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PREFACE

The Sun is a main-sequence dwarf star typical of many million other stars that populate the spiral arms of our galaxy, yet it is unique in that it is the only star in the universe whose surface can actually be seen. This circumstance, which is dependent on the relative proximity of the Sun to the Earth, 92,900,000 miles, that is, 1 astronomical unit (a.u.) as compared with a distance of 271,000 a.u. to the nearest known star Alpha Centauri, provides us with the opportunity to observe phenomena which, in the case of other stellar bodies, are completely beyond the reach of observation.

Study of the Sun does not stand alone as an activity but contributes at a fundamental level to stellar astronomy, to many branches of pure physics, to investigations of the solar system and to fundamental problems concerned with man's ability to function, according to his aspirations, in the geo-environment.

The possibility of contributing significantly to so many other disciplines is for the solar physicist exciting and lends to his work the dimension of forming part of a concerted scientific advance in human knowledge. Yet, it is the intrinsic fascination of the subject itself that provides the fundamental intellectual challenge. The Sun is to the investigator an inexhaustible source of interest, ever changing, ever new, and among the features it displays none is more spectacular and intriguing than an 'active solar region'. Here, within a well-defined section of the atmosphere, are formed such diverse structures as spots, plages, filaments and coronal condensations. Here too, on occasions, impulsive enhancements of electromagnetic radiation occur over a spectral range extending from decametre radio-waves to $\gamma$-rays. In association with such major events, powerful mass motions and shock waves may, in addition, be produced, and particles be associatively accelerated up to relativistic energies and ejected into interplanetary space.

Through the courtesy of the staff of the McMath Hulbert Observatory, I have been accorded the privilege of studying high quality H$\alpha$ and calcium records obtained at Michigan during the disk transit of an exceptionally active solar region. These optical data were supplemented by a wealth of background material, drawn from many sources, concerning associated ionizing, radio and particle emissions, and there were also available daily white light pictures of the relevant sunspot group together with a number of magnetographic charts.

The sheer magnitude and variety of the material provided for analysis has indeed almost proved overwhelming, and many problems were experienced in bringing meaningfully together records obtained using so many basically different experimental procedures. The various phenomena resultingly detected at different levels within the active solar region did not, however, occur in isolation. They were individually born of the interaction between solar magnetic fields and motions of the solar plasma and continued to be influenced by regional magnetic fields throughout their respective lifetimes. Apparently disparate events were thus interconnected by virtue of their shared magnetic background, and it was with the aim of elucidating the fundamental interplay between different types of phenomena that the present analysis has been attempted.

It is hoped that such an in-depth examination of the observations, facts and data of region 59Q may lead to a somewhat clearer general realization of what is happening in a great center of activity during its main phase of development and provide background information for those planning to embark on a study of those especially active regions currently emerging during solar cycle 21.

# CHAPTER 1

## ACTIVE SOLAR REGIONS DURING THEIR MAIN PHASE OF DEVELOPMENT - PREVIOUS AND PRESENT INVESTIGATIONS

A brief description is given of the birth, main phase and decay of active solar regions and a list of references to important studies previously carried out on such regions during their 'main phase' of development provided. The exceptional 'main phase' activity displayed by the region chosen for the present study, HAO-59Q, in the context of previous solar history, is then outlined.

### 1.1 The First Phase of Development of an Active Region

The first observable sign of the birth of an active region is the occurrence in the photosphere and chromosphere of 'patches' of magnetic field which are generally referred to as Magnetic Plages, Christiansen et al. (1960). In association with this emergence of flux, corresponding areas in the photosphere and chromosphere brighten and these enhanced regions are referred to either as faculae or plages, Leighton (1959), Martres et al. (1966a and 1966b).

In calcium light, plages are seen to appear at the boundaries of adjacent supergranulation cells; that is, in regions of concentration of magnetic flux. The new emission spreads initially along network cell boundaries, then gradually expands to fill in some of the cells themselves, Bumba and Howard (1965a, 1965c), Bumba et al. (1968a), and Bappu et al. (1968). In some cases, formation of a plage represents the peak of the anomalous activity, and 'normal' solar conditions are quickly restored after hours or days. In instances of more profound disturbance one or more sunspots are also formed.

Prior to the outbreak of spots, the brightness difference of photospheric levels increases in the sense that the intergranular space becomes darker, de Jager (1968). Magnetic measurements indicate that, at such times, longitudinal fields may have different polarities on opposite sides of a single supergranular cell and polarity differences may also sometimes exist in juxtaposition within the compass of a single boundary region, Simon and Leighton (1964), Bruzek (1972).

If only one sunspot is born in the intercellular space, it disappears rapidly, perhaps within hours. A bipolar group is more stable and survives many days. The development of bipolar fields is asymmetric in that the follower part (in the sense of solar surface rotation) tends to appear and develop earlier than does the corresponding "leader part'. If the level of disturbance is very great, many sunspots form and comprise an association that may be followed through several solar rotations. The gross configuration of the resulting field is bipolar with large regions of opposite longitudinal field divided by a line of magnetic inversion, the so-called 'neutral line'. On a small scale, the field configuration may be very complex with many inversions, inclusions and magnetic hills, de Jager (1959), Bruzek (1972), Tandberg-Hanssen (1973).

The appearance and development of active regions is not an independent process. Evidence exists that they originate at 'favoured' longitudes situated about 180$^{o}$ apart and in locations that already contain weak residual magnetic fields left over from 'old' active centres. These latter magnetic patterns are not associatively disturbed, so it appears that an emerging centre is not formed by the reorganisation or concentration of existing surface fields but rather by the emergence of new magnetic flux from below the photosphere. This new flux tends to appear at the borders of existing regions, and long-lived 'families' of activity are consequently produced. The complexity achieved by any individual group appears considerably influenced by age and positioning of neighbouring older regions. This is in the sense that the complexity developed is increased the younger is the previously present region and the more closely the 'old' and the new regions are superimposed, Bumba and Howard (1965b), Dodson and Hedeman (1968), Martres (1968, 1970).

## 1.2 The Main Phase of Development of Active Solar Regions and Typical Manifestations of Flares Produced During This Period

After the formation of sunspots, the bright photospheric and chromospheric plages expand dramatically in area, and this growth is deemed to define the main phase of a region's development. It is associated with the production of intense chromospheric and coronal activity and, in particular, by the appearance of solar flares, de Jager (1968).

A striking manifestation of these latter phenomena, when they are energetically important, is the rapid enhancement that takes place in optical EUV, X-ray, Y-ray and radio frequency radiation, Ellison (1963), Smith & Smith (1963), Zirin (1966), Bruzek (1969a), Zirin (1974), Švestka (1975). Shock waves may also be associatively produced and particles accelerated and ejected from the sun with energies extending up into the relativistic range.

A number of different experimental techniques have been developed to detect these various effects. At optical wavelengths, monochromatic spectroheliographic data have traditionally supplied important positional and developmental information concerning individual flares. Information concerning certain flare related short-wave electromagnetic emissions may, on the other hand, be derived through monitoring changes in the ionosphere. This is due to the production in the sunlit hemisphere at flare times of strong D-layer ionization, leading to such effects as fade-outs in short wave radio signals, and sudden enhancements of very long radio waves (the latter being reflected from the base of the D-layer). 'Crochets' or short lived changes in the components of the earth's magnetic field are also sometimes produced due to the associated production of impulsive increases in the conductivity of one or more layers of the ionosphere, Ellison (1950), Mitra (1974), Švestka (1976). Spacecraft observations, largely pioneered by the successful series of OSO (Orbiting Solar Observatory) missions, together with observations made from the SKYLAB manned orbiting laboratory (1973-1974), provide direct information concerning a wide spectral range of flare produced short wave emissions.

In the case of particle expulsion, high resolution cimematography, multislit spectroscopy and tunable and broad-band filters have been used to study the passage of various kinds of flare ejecta through the chromosphere. Moving emanations, often referred to as Moreton waves, which propagate outwards across the chromosphere at speeds of $\sim$1,000 $kms^{-1}$ and up to distances of $\sim 1R_{\odot}$ have also been recorded by these methods and such events are interpreted theoretically by Uchida et al. (1973a) to comprise purely MHD wave phenomena. Work by McKenna-Lawlor and Martin (1979) has more recently suggested that this description should be re-examined to consider whether such phenomena might rather represent the traces of fast-moving particles.

The continual outward passage to higher layers of the solar atmosphere of flare produced disturbances may be conveniently tracked through monitoring those radio emissions associatively produced (centimeter waves are generated at, or just above the solar chromosphere, and metre-decimeter waves in the corona at heights of up to 2-3 solar radii).

Dynamic flare associated bursts recorded by means of radio heliography are typically of several characteristic types.* Among these may be mentioned Type II bursts which show a slow, 1 $MHzs^{-1}$, drift in the frequency of maximum intensity from high to low frequencies, and are generally accepted to indicate the outward propagation from flare sites of MHD shock waves. Type III bursts, which correspondingly show a relatively rapid frequency drift of $\sim$20 $MHzs^{-1}$, are deemed, on the other hand, related to plasma oscillations excited by the passage outwards, through decreasingly dense layers of the solar atmosphere, of flare accelerated electrons having energies in the range 10-100 keV, Wild et al. (1963), Wild and Smerd (1972).

The designation spectral Type IV is generally taken to refer to a "long period continuum event in any part of the radio spectrum which follows a flare". By continuum is meant "persistent smooth (often featureless) emission over a broad band of frequencies. Slow variations in intensity may occur and it is not necessary that the emission be entirely free of bursts. Often, numerous individual suggestions of fast frequency drift are present", Wild (1963). Components in the metre-wave, decimetre-wave and micro-wave bands are individually referred to as IVm {subdivided into two components called IVmA (moving type) and IVmB (stationary type)}; IVdm (the component between the metric range and microwaves); and IVμ (the well known 'microwave early burst' corresponding to that part of IV which correlates closely with hard X-rays).

The trajectories of moving sources of Type IV emission are tracked through the corona from Culgoora by recording, at suitable metre wavelengths, a rapid (1s) sequence of two dimensional images of such events in both senses of circular polarization. These observations have revealed cases where flare associated radio radiation originates in expanding arch shaped flux tubes rooted in active

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*Type I denotes a "noise storm" (i.e., a disturbed period of hours or days duration which consists of a long series of bursts called 'storm bursts' superposed on a weak background continuum. The evidence for the association of Type I storm activity with flares is currently conflicting, see the detailed treatment in Chapter 5.

regions. As the expansion proceeds, such an arch is seen to comprise three discrete sources; one unpolarized and located at the apex, which may be attributed to synchroton radiation from relativistic electrons, and a pair of oppositely polarized sources located near the arch 'feet' deemed due to plasma radiation excited by superthermal electrons. The data also show that different centres of activity on the solar disk are connected by magnetic field lines which can conduct a disturbance from one distant site to another. Correlated radio bursts can thus occur above centres which, on optical records, appear to be quite separate, Wild (1970, 1974), McKenna-Lawlor and Smerd (in press).

Recent theoretical interpretations and associated controversy concerning several aspects of Type IV emission are discussed by Smerd (1977) in a general review paper concerning research activity in solar radio astronomy, 1975-1977.

Finally, Type V emission consists of wide-band emission at metric wavelengths of considerable intensity ($\sim 10^{-18}$ Watts per square cm per cycle per second near 100 MHz) and short duration (between about 0.5-5.0 minutes). Originally interpreted as representing synchrotron radiation from a stream of electrons trapped in the corona, Wild et al. (1959a), such bursts have been recently suggested by Robinson (1977) to comprise plasma radiation from steadily lengthening electron streams injected into open, but curved and rapidly diverging, magnetic field lines.

Flare associated disturbances in the low and intermediate corona can also be followed by photographing the sun in specific wavelength bands in the X-ray spectrum, using equipment flown aboard rockets and satellites. Such pictures show that the 'quiet' corona is composed almost entirely of closed loop structures that appear to map the positions of magnetic tubes of force extending upwards above the photosphere. Observations in the FeXIV line show the whip like opening of individual coronal arches in response to transient flare disturbances while, in the yellow Ca XV line, the presence of hot regions at the tops of flare loops may be detected. White light observations reveal attendant electron density changes and blobs of material traversing the corona at speeds of up to 400 km/s are frequently seen, Altschuler (1975).

The characteristic gamma ray emission of heavy hydrogen at 2.23 Mev and other gamma ray lines at 0.51 Mev (from positron anihilation), 4.43 and 6.14 Mev (due to $^{12}C$ and $^{16}O$ nuclei deexcitation) confirms that, under favourable conditions, flare processes can impart high energies to solar particles, Chupp et al. (1973), Ramaty et al. (1974), Talon et al. (1975).

Records of responses evoked at various celestial objects by travelling solar disturbances (as provided for example by in situ spacecraft measurements of shocks in the solar wind or by observations of the scintillation of distant radio sources) permit shock waves and plasma clouds to be tracked outwards from the sun to considerable distances in the interplanetary medium. For many years the earth's own atmosphere has been used as a detector of solar particles since those of lowest energy (<1 Mev) are associated with the production of magnetic storms and auroral displays; those of intermediate energy (10-400 Mev) produce at the poles strong D-layer ionization which results in the absorption and consequent blackout of incoming cosmic noise in the VHF band; also, high energy (>1 Bev) protons produce secondary cosmic ray events at ground level, Ellison (1963).

Recent direct measurements of solar particle fluxes from satellites and space probes now extends our knowledge down to ~0.3 Mev for protons besides distinguishing different particle species (particles, heavier nuclei, protons and electrons) and these data indicate, since the number of low energy 'satellite-sensed' events exceeds by many times the number of proton events detectable by ground-based equipment, Švestka and Simon (1975), that particle production in flares is a very common occurrence.

## 1.3 The Decay Phase of an Active Region

After an active phase that may endure up to several weeks, spots, flares and associated phenomena disappear. The facular field decreases in brightness becoming more and more patchy and long quiescent filaments form which later migrate polewards, de Jager (1968).

This so called 'decay phase' is a very slow process which takes place in a period of the order of 3-5 months although sometimes individual regions may survive for considerably longer intervals. Since the decay of a plage and of its associated magnetic field occurs through continued expansion and fragmentation until its identity becomes effectively lost against a background of newly emerging regions, the 'true' end of such a feature is very poorly defined optically. A somewhat broader view is provided by radio frequency flux measurements and by those emissions observed in the extreme ultra-violet and X-ray spectral ranges. However, in complex solar situations where several active regions are simultaneously present on the disk, it is difficult to unambiguously deduce the contribution of each individual centre to such radiation, Sawyer (1968a).

## 1.4 Previous Studies of Solar Active Regions During Their Main Phase of Development

Because of the spectacular and diverse nature of phenomena associatively displayed, the main phase of development of solar active regions has formed a special focus for research. Twenty-four-hour coverage of the sun cannot, however, be obtained at any one observing site and many investigations have tended to concentrate on single phenomena such as outstanding flares recorded at particular observatories. More extended studies have necessitated elaborate co-operations between differently sited teams of observers. These co-operations take three main forms. One involves the pooling at one observatory of international records of a particular solar feature. The temporally comprehensive data are synthesized at this location and the results published with suitable references to the several original observers. The second procedure involves a decision of workers in different countries to collect complimentary solar data within an agreed time interval. The material obtained is then analysed at the stations of origin and the results jointly published, together with a general evaluation and summary prepared by senior co-ordinators of the programme. A third method involves the flying by different research groups of a variety of solar instruments within a single satellite or space station, perhaps in co-ordination with ground based 'back up' experiments. The equipment concerned makes simultaneous observations of a variety of solar phenomena and the results obtained tend to appear in the literature either as isolated contributions or as part of the published proceedings of special symposia.

References to eight important co-operative studies of the main phase of solar active regions (which fall into one or other of the above categories) appear in the literature as follows:

(a) "Detailed study of the development of an active solar region, 1954, August 20-27", Dodson & Hedeman (1956).

(b) "A study of a solar-active region using combined optical and ratio techniques", Christiansen et al. (1960).

(c) "Detailed analysis of flares, magnetic fields and activity in the sunspot group of September 13-26, 1963", Zirin & Werner (1967). See also Moreton and Severny (1968).

(d) "The proton flare project (May 01-September 30, 1966)". Švestka (1966 and 1968b). Also, results obtained by individual groups of investigators involved in this project are published in Annals of the IQSY, Volume 3, (MIT Press) - together with an overall summary of these various results compiled by Simon and Švestka (1969). Research papers concerning outstanding solar events occurring on August 28 and September 02 appear in a variety of journals and are comprehensively discussed, with references to all previous publications, by Švestka and Simon (1969).

(e) "The flares of August, 1972", Zirin and Tanaka (1973) and Tanaka and Zirin (1973).

(f) "The campaign for integrated observations of solar flares (CINOF) 5-29 June, 1972", Shea and Smart (1974, 1975) and de Jager (1975).

(g) "The Appolo Telescope Mount (ATM) solar experiment aboard Skylab, 28 May 1973-February 08, 1974". Research papers concerning the flares observed during this mission appear in many journals but a comprehensive account of the results obtained is contained in "Solar Flares. Proceedings of the Second Skylab Workshop" Ed. P. S. Sturrock (in press).

(h) "The flare build-up study (FBS)", Švestka (1974b), de Feiter (1975).

## 1.5 The Present Investigation of the July Disk Transit of Outstanding Active Region HAO-59Q

The present work comprises a study of the entire disk transit of an active solar region during its main phase of development. In addition to high quality multi-wavelength records of this centre, obtained during the sunlit hours at the McMath Hulbert Observatory, the available optical material was extended to provide effective twenty-four-hour coverage of the sun through the unique circumstance of the existence, for the relevant interval, of a continuous solar movie, compiled from world-wide Hα records by Smith (1963). The usual elaborate liaison between observing sites to obtain temporally comprehensive optical material was thus not necessary for this investigation. Also, by a happy coincidence, disk passage occurred during an interval of International Geophysical

Co-operation (IGC., 1959), so that abundant background material concerning ionizing, radio and particle radiation was readily accessible for correlation purposes. A set of white light pictures of the spot groups, which in some cases included several pictures taken on individual days, was additionally available for the entire period of transit as were also magnetographic charts of the region obtained on five consecutive days at the Crimean Astrophysical Observatory.

Of the several investigations of active regions mentioned in Section 1.4 perhaps the closest comparable study was that listed under (e). However, this latter analysis was concerned with solar material that showed many radical differences from that herein described and its treatment took quite another form.

The specific centre of activity presently treated crossed the central meridian of the sun at latitude N 15$^{o}$ on July 14, 1959. Then on its fifth passage across the solar disk, the region was, during this period, undergoing its 'Main Phase' of development. It is identified in solar activity summary HAO-49 as Region 59Q, Trotter and Roberts (1960) but is often referred to in the literature as McMath plage 5265. Examination of original drawings made on a number of occasions at the McMath telescope reveals however, that, at times, of high activity, flaring in McMath plage 5265 spread into McMath plage 5270. It was thus considered expedient here to refer to the active centre in general as region 59Q.

The flare activity associated with the July transit of this region was outstanding. It was a prolific producer of subflares and, even when viewed against the background of its presence during Solar Cycle 19 {(which of the 20 solar cycles since 1755 showed the highest smoothed monthly relative sunspot number, Waldmeier (1961)}, represents one of only 5 "unusual" solar regions identified by Dodson et al. (1973) as developing during the cycle at least four "major" flares with Comprehensive Indices $\geqslant$11. The statistics for the Comprehensive Flare Index were limited to flares that were "major" in the sense that at least one of the following circumstances was satisfied: SID $\geqslant 3$, H$\alpha$ imp. $\geqslant 3$, 10 cm flux $\geqslant 500 \times 10^{-22} Wm^{-2} (Hz)^{-1}$, Type II burst, Type IV radio emission, duration >10 minutes, Dodson and Hedeman (1971).

Among the 5 'unusual' solar regions thus defined only one other generated somewhat comparable particle radiation. Indeed, although cosmic rays have been recorded continuously with ground based detectors for almost forty years, only one cosmic ray storm*, the record breaking event associated with the transit of McMath Plage 11976 in August 1972, ever exceeded in magnitude that recorded during July 1959, Pomerantz and Duggal (1973). It is noteworthy that, in contrast with the July 1959 event which occurred during the early part of the descending branch of cycle 19 when the level of activity was still very high, the August 1972 storm occurred close to the minimum of unspectacular cycle 20.

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*A cosmic ray storm comprises a superposition of Forbush decreases, that is, a series of sudden reductions in the intensity of the galactic cosmic radiation.

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## CHAPTER 2

## SOURCES AND KINDS OF SOLAR DATA ANALYSED IN THE PRESENT STUDY

An account is given of the various McMath-Hulbert optical records used in studying active region 59Q and of the instruments employed in obtaining them. The 'Continuous Solar Movie' is also described and those additional sources of flare data contained in world wide published lists itemized. Also listed are the sources of white light, magnetographic, radio ionizing and particle records which provided correlative data.

### 2.1 Monochromatic Spectroheliograms

The monochromatic data used in this study were based primarily on spectroheliograms secured by the staff of the McMath Hulbert Observatory, the University of Michigan, during the sunlit hours July 7-21, 1959. These records were of two main types: (a) Hα spectroheliograms obtained with the McMath SECASI* telescope for the international flare patrol (solar diameter 1.45 cm) and (b) concomitant swept wavelength observations centered on Hα and on the K-line of $Ca^+$ obtained with the Observatory Tower Telescope at focal lengths of 6.09 cm and 12.192 m (solar diameters 5.59 and 11.18 cm respectively).

The monochromatic SECASI* telescope incorporated a Lyot filter of standard design, Dolfus (1956). It was built up of eight birefringent plates of quartz and others of calcite with intermediate 'Polaroids' all contained inside a cylindrical block of aluminum. The temperature of the block was thermostatically controlled so that, at the working temperature of the filter (44.2°C), the band pass of 0.5Å was maintained precisely fixed upon the centre of the Hα line (6562.8Å). The duration between exposures was pre-selected for intervals of 30 sec. By the operation of a uni-selector switch, every eleventh frame received an exposure five times normal. This had the effect of over exposing the disk and these long exposure records proved particularly useful in allowing the profile of region 59Q to be studied as it transited the east and west limbs.

The Tower Telescope records comprised numerous sweeps or series of seventeen spectroheliograms recorded with systematic changes of wavelength from 3Å or more on the violet to 3Å or more on the red side of the Hα line and corresponding sweeps to 1.5Å or more on either side of the K-line of $Ca^+$. For details of the spectroheliograph see McMath et al. (1960). Observations at Hα were made with slit widths corresponding to a spectral band 0.36Å wide. Observations at the Ca 11, K-line were made with the spectral band 0.18Å wide. Each series required 2 to 4 minutes of observing time.

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*This acronym refers to the firm Société d'Études et de Construction d'Appareillages Scientifiques et Industriels (S.E.C.A.S.I.) of Bordeaux which put the instrument into commercial production.

In addition to the Michigan data, Hα spectroheliograms taken at one minute intervals over the period July 06-20, 1959 were available, contained in a copy of the Continuous Solar Movie. This latter film was compiled from world wide Lyot heliographic records by Dr. Henry Smith of the Sacramento Peak Observatory, Smith (1963), and it provides an approximately 80% complete time coverage of the Sun over this 15-day interval. Table 2.1a (see below) lists the observatories whose records were used in preparing this composite movie.

Inevitably, a certain amount of detail was lost from the original photographic records on standardizing them into a homogeneous integrated movie. Through the courtesy of the staff of Sacramento Peak Observatory, however, the copy of the film supplied for the present study was of specially improved contrast.

Table 2.1a

Contributions to the Continuous Solar Movie as Listed

by Smith (1963)

| Station | Scenes | Coverage | | Percentage blank |
|---|---|---|---|---|
| | | h | m | |
| Abastumani (USSR) | 5 | 11 | 54 | 13.8 |
| Capetown-Dunsink (S. Africa, Eire) | 10 | 53 | 32 | 12.8 |
| Climax (USA) | 1 | 9 | 05 | 0.0 |
| Greenwich (UK) | 1 | 1 | 54 | 0.0 |
| Lockheed (USA) | 14 | 113 | 11 | 1.8 |
| McMath Hulbert (USA) | 7 | 25 | 04 | 0.8 |
| Meudon (France) | 7 | 24 | 01 | 3.5 |
| Mitaka (Japan) | 6 | 17 | 56 | 3.8 |
| Sacramento Peak (USA) | 5 | 14 | 50 | 4.3 |
| Sydney (Australia) | 9 | 23 | 24 | 10.7 |
| Tashkent (USSR) | 5 | 10 | 27 | 0.0 |
| Gaps. | 31 | 55 | 40 | - |

## 2.2 Published Lists of Flares

The optical records in region 59Q were supplemented by data contained in world wide published lists of flares tables in three separate volumes: (a) "The McMath Hulbert Observatory Working Lists of Flares and Daily Flare Index for

IGC-1959", Dodson and Hedeman (1961); (b) "Standardized Solar Flare Data 1959 through 1961", Warwick (1966a); (c) "List of Sub-Flares Reported to World Data Center A", Lincoln (private communication).

## 2.3 White Light Data

White light pictures of the sunspot group were kindly provided for days July 8-20, 1959 by Mrs. Ogir (Crimean Astrophysical Observatory, Russia), for days July 9-15 by Dr. R. Howard (Mt. Wilson Observatory, U.S.A.), and for days July 9-10 and July 13-14 by W. M. Baxter (Private Observatory, Acton, England).

## 2.4 Magnetographic Data

Magnetographic charts of region 59Q for days July 14-18, 1959 were originally obtained by the staff of the Crimean Astrophysical Observatory, U.S.S.R. They were rephotographed for the present study, with authorial permission, from a publication by Howard and Severny, Howard and Severny (1963a) and reproduced, for comparison with the optical data, to the scale of the McMath 12.19 m records. Relevant polarities and field strengths were taken from measurements made at the Mt. Wilson and Palomar Observatories, the Crimean Astrophysical Observatory and at the Potsdam Astrophysical Observatory.

## 2.5 Single and Swept Frequency Radio Data

Details of single-frequency radio bursts occurring during the period July 7-21, 1959 inclusive were taken from the "Quarterly Bulletin of Solar Activity" (Zürich, 1959). These internationally reported emissions covered a wide range of individual frequencies varying from 23 MHz to 19,000 MHz.

Spectrum observations of emissions of Types I, II, III, and IV, occurring within the same period, were taken from the "Solar Burst Spectrum Observations of the University of Michigan" (Ann Arbor, 1959) and from the "Quarterly Bulletin of Solar Activity" (Zürich, 1959). These data comprised observations made at the University of Michigan Radio Astronomy Station, Ann Arbor and at the Harvard Radio Astronomy Station, Fort Davis, Texas (both covering the range 25-580 MHz)* and at the Division of Radiophysics, CSIRO, Sydney, Australia (covering the range 25-210 MHz). Swept frequency observations were only available over the periods listed in column 4 of Table 4.3a, p. 36.

## 2.6 Ionospheric Data

Details of Short Wave Fade Outs (SWFs) and Sudden Enhancements of Atmospherics (SEAs) July 7-21, 1959 were taken from the confirmed lists contained in the "Central Radio Propagation Laboratory Ionospheric Data Report CRPL-Part B" (Solar Geophysical Data, 1959).

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*The Harvard radio frequency range although quoted in the Quarterly Bulletin to extend during 1959 from only 100-580 MHz was actually changed in January of that year to include 25-100 MHz, cf. Maxwell et al. (1963).

## 2.7 Solar Corpuscular Data

Details of the arrival at the earth in July 1959 of high and intermediate energy protons deemed associated with flaring in region 59Q were taken from (a) "Solar Manual", McDonald (1963); (b) "Catalog of the Principal PCA Events 1952-1963", Bailey (1964); (c) "Catalog of High Energy Solar Particle Events 1957-1961", Cummings (1965); and (d) "Catalog of Solar Particle Events 1955-1969", Ed. by Švestka and Simon (1975). These various catalogs are based on careful evaluations of primary reports and contain references to the original sources of data.

Details concerning the corresponding arrival at the Earth of Magnetic Storm Particles were taken from a list contained in the "Catalog of Solar Activity during 1959", Jonah, Dodson and Hedeman (1965). This list is also based on the evaluation of data reported by individual observatories and includes references to the original reports.

A useful supplementary source of information concerning relevant solar particle emissions was provided by the Proceedings of the Helsinki "Symposium on the July 1959 events and associated phenomena" (Institut. Géographique National, 1960).

## CHAPTER 3

## COMPARISON BETWEEN NUMBERS OF OBSERVED AND REPORTED FLARES IN REGION 59Q. IDENTIFICATION OF ESPECIALLY FLARE ACTIVE LOCATIONS IN THE REGION

Practical considerations confining the counting of impulsive flare brightenings in region 59Q to selected portions of the McMath SECASI record are described. Differentiation is made between the occurrence of impulsive brightenings in this flare active region and the gradual lateral spread there of diffuse bright flaring along the locus of chains of the chromospheric network. A comparison is made between the number of impulsive brightenings actually observed to commence in region 59Q and the corresponding number of flares reported internationally to occur in this centre. The relative times of occurrence of the observed and reported events are investigated, having special reference to the importance class of the reported flares. It is shown that certain locations within region 59Q were outstandingly flare productive.

### 3.1 Restrictions Imposed on the Use of the Available Observational Material in Identifying and Counting Individual Impulsive Brightenings in Region 59Q

It was at first projected in the present study to examine separately, on a minute by minute basis, every individual transient localized brightening recorded in region 59Q during its July disk passage - using as observational data both the McMath SECASI and the Continuous Solar Movie Hα spectroheliograms. This would have the effect of subjecting to detailed analysis each impulsive component of every flare event recorded. Unfortunately, although the coverage provided by the Continuous Solar Movie (CSM) for the period July 7-20, 1959 inclusive is approximately 80% complete, this film proved unsuitable for making identifications of localized impulsive brightenings in region 59Q. This was due to the fact that the CSM essentially comprises a composite of films from eleven observatories and serious problems inherent in making a continuous movie from photographic originals which varied widely in contrast, density and size have necessitated the production by the makers of a projection positive six generations removed from the original negatives.

A considerable amount of detail is consequently missing from the resulting pictures and a preliminary comparison between sections of the high quality McMath SECASI record and corresponding sections of this film indicated that variations in density and contrast between individual film frames often tended to obliterate minor solar brightenings and at other times to erroneously indicate that flare brightenings had taken place. It was thus decided to limit the counting of individual localized flare events to those time intervals covered by the McMath SECASI records alone.

Column (2) of Table 3.1a comprises a list of those periods within which Hα observations were obtained with the McMath SECASI telescope, i.e., on days July 7-17 and July 19-21, 1959 inclusive.

TABLE 3.1a

List of Observing Times Covered by the McMath SECASI Telescope on Days July 7-17 and July 19-21, 1959, Inclusive Together with Corresponding Periods Within Which Individual Impulsive Hα Brightenings in Region 59Q Were Counted on This Record

| Date 1959 | Overall observing times of McMath SECASI telescope (U.T.) | Periods within which impulsive Hα brightenings were counted in 59Q using the McMath SECASI record (U.T.) |
|---|---|---|
| July 7 | 1040-2311 | 1040-2311 |
| July 8 | 1044-2009, 2134-2316 | 1044-2009, 2134-2316 |
| July 9 | 1810-2330 | 1810-2109 |
| July 10 | 1050-2319 | 1050-2319 |
| July 11 | 1219-2318 | 1219-2318 |
| July 12 | 1134-2245 | 1134-2245* |
| July 13 | 1050-2303 | 1050-2303 |
| July 14 | 1056-1755, 2145-2309 | 1056-1755, 2145-2309 |
| July 15 | 1105-2256 | 1105-2256 |
| July 16 | 1123-2317 | 1123-2120 |
| July 17 | 1143-1431, 1915-2139 | 1143-1431, 1915-2139 |
| July 19 | 1241-2145 | 1241-2145 |
| July 20 | 1319-1427, 1821-2311 | 1319-1427, 1821-2311 |
| July 21 | 1105-2259 | 1105-2259 |

*The gradual spread from $<22^h\ 12^m$ - $>22^h\ 45^m$ U.T. on July 12 of extensive flaring along chromospheric chains II and III (see Fig. 3.1e) is not included in the total of impulsive localized brightenings counted in region 59Q on this day.

Assuming only that a flare consists of a sudden transient localized brightening recorded on a Hα spectroheliogram, the McMath films were carefully searched for records of individual impulsive brightenings occurring throughout the extent of region 59Q.

It was then found that impulsive flare activity in this region tended to occur recurrently in favoured locations that could be recognized unambiguously from day to day. Many of these flare sensitive areas were located above the position of the main magnetic complex Mt. Wilson group 14284. (See detailed account in Section 7.4.) For convenience it was at first attempted to designate such individual flare sensitive areas by the letters a-z and to compute the number of Hα brightenings occurring within each. However, because of the limited number of such letters (26) and the large number of individual areas observed to flare (over 100) it was later found appropriate to add roman subscripts and superscripts to individual letters in differentiating between areas that flared in close proximity to one another. The positions of the various 'flare sensitive' areas thus identified are indicated in Figures 3.1a-3.1j, pages 25-34. These figures individually comprise composite drawings showing the relative positions in 59Q on different days of sunspot umbrae and penumbrae, flare sensitive areas, bright structures in the calcium network, well defined elevated dark filaments and elevated diffuse dark material.

At times of high activity, diffuse bright flaring was sometimes seen to spread gradually along the locus of chains of the chromospheric network to form bright 'arms' extending far from the main centre of flaring. This gradual spread of excitation appeared to differ in nature from the impulsive brightenings occurring in well defined areas close to the main spot group and it was decided to consider this aspect of flaring separately in conjunction with special studies of particularly complex solar events (see Appendix A).

In consequence, those portions of the McMath SECASI record taken between $21^h\ 09^m$ - $23^h\ 30^m$ U.T. on July 09 and between $21^h\ 20^m$ - $23^h\ 17^m$ U.T. on July 16 when major flares showing such gradually spreading excitation were respectively in progress, were not included among those records from which counts of impulsive Hα brightenings in 59Q were made on July 09 and July 16, respectively.

Column 3 of Table 3.1a lists the periods within which impulsive Hα brightenings were in fact counted on each individual day from July 7-17 and July 19-21, inclusive*. In addition, the gradual spread of flaring from $<22^h\ 12^m$ - $>22^h\ 45^m$ U.T. on July 12 along chromospheric chains designated in Fig. 3.1e by the Roman numerals II and III is not included in the total of impulsive brightenings counted in region 59Q on this day (cf. footnote, Table 3.1a).

## 3.2 Number of Impulsive Optical Brightenings Observed in Region 59Q Using Selected Portions of the McMath SECASI Record and the Number of Flares Reported in World Wide Literature To Have Occurred in the Region Over a Corresponding Period

Over 136.1 hours covered by those portions of the McMath SECASI record selected for study, 1006 separate impulsive brightenings were observed to occur in region 59Q. A summary of the total numbers of impulsive brightenings counted in region 59Q on each individual day of these observations is contained in Table 3.2a.

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*That is over 37.8% of the total transit time.

TABLE 3.2a

Number of Impulsive Optical Brightenings Observed in Region 59Q on Successive Days Using the McMath SECASI Record*

| Date | No. of hours covered by the McMath SECASI record* | No. of impulsive brightenings observed in region 59Q |
|---|---|---|
| 7 | 12.53 | 5 |
| 8 | 11.15 | 76 |
| 9 | 3.00 | 51 |
| 10 | 12.50 | 19 |
| 11 | 11.00 | 62 |
| 12 | 11.20 | 82** |
| 13 | 12.23 | 158 |
| 14 | 8.42 | 109 |
| 15 | 11.87 | 119 |
| 16 | 9.97 | 169 |
| 17 | 5.23 | 43 |
| 19 | 9.08 | 50 |
| 20 | 6.00 | 19 |
| 21 | 11.92 | 44 |

*These times cover the periods listed in column (3) of Table 3.1a.

**See footnote to Table 3.1a.

This total of 1006 brightenings is by no means complete for the period since (a) passing cloud and intervals of poor seeing introduced minor breaks in the film during which flare activity was unavoidably missed; (b) occasionally, particularly during periods of high activity, certain of the flaring areas became so overexposed that no further intensity fluctuations could be detected within them over extended time intervals; (c) reference has already been made (cf. Section 3.1) to the exclusion from the overall counts of diffuse flaring along extensive chains of the chromospheric network from $<22^h\ 12^m$ - $>22^h\ 45^m$ U.T. on July 12. Again, on days July 9 and 16, respectively, a bias is introduced in the 'observed' number of brightenings counted by excluding from the total those enhancements that occurred during the 'spreading phase' of the major flares.

The list of "Standardized Solar Flare Data 1959 through 1961" compiled by Warwick (1966a), from world wide flare reports, contains details of 87 flare events attested to have occurred in region 59Q over those periods of the McMath SECASI observations listed in column (3) of Table 3.1a. These reported events were classified in optical importance by Warwick according to a scheme originally presented by Ellison (1957), and disposed among the various importance classes according to the distribution shown in Table 3.2b.

TABLE 3.2b

Distribution Among the Various Importance Classes* of Those Flare Events Reported in "Standardized Solar Flare Data 1959 through 1961" Warwick (1966a) To Have Occurred in Region 59Q over the Period of the McMath SECASI Observations**

| Importance class | Number of flares |
|---|---|
| (1-) | 57 |
| (1 ) | 20 |
| (1+) | 5 |
| (2-) | 1 |
| (2 ) | 2 |
| (2+) | 1 |
| (3 ) | 1 |
| Total | 87 |

*See Ellison (1957).
**As listed in column (3) of Table 3.1a.

The difference between the observed (1006) and reported (87) number of flares counted in the region reflects the fact that published flare lists represent a practical simplification of complex solar circumstances and no attempt is made in such lists to describe the detailed behaviour of complex outbreaks of emission.

## 3.3 Comparison Between the Times of Flares Reported in World Wide Literature To Have Occurred in Region 59Q over the Selected Period of the McMath SECASI Observations and the Corresponding Times of Those Impulsive Brightenings Actually Observed to Occur Using the Optical Record

Warwick (1966a) lists for each catalogued flare an "earliest reported" beginning and a "last reported" end time based on all available world wide records in addition to a "mean" beginning and ending time estimated from these various data. For most purposes, the estimated "mean" values are taken as being representative of reported flares. However, lack of agreement in flare times quoted by different observers can mask important information concerning the complexity of the flare which has occurred and it was decided, for the purpose of comparing the times of 'reported' with actually 'observed' flare brightenings in region 59Q, to choose to use the 'earliest reported' beginning and latest ending times rather than the more subjective 'estimated' values.

Comparisons between the "earliest reported" beginning and "last reported" end times of the 87 flares reported to have occurred in 59Q over the period of the McMath observations and the commencement times of those impulsive brightenings actually observed to have occurred in this region using the McMath record reveals that 337 brightenings (i.e. 33.5% of all observed events) occurred in the interim periods between reported flares and the remaining 669 events (66.5% of the total) during reported flare times.

The number of observed Hα brightenings occurring during the rise and decay times of reported flares are listed in Table 3.3a.

TABLE 3.3a

Number, and Total Percentage, of Observed Hα Brightenings Occurring During the Rise and Decay Times of Reported Flares

| No. of observed Hα bri. | Corresponding % of total no. of Hα bri. observed | Time of occurrence of observed bri. relative to rise and decay times of reported flares* |
|---|---|---|
| 235 | 23.3 | During 'decay times' |
| 328** | 32.7** | During 'decay times' |
| 106 | 10.5+ | Uncertain |

*Brightenings observed to occur within $1^m$ of the reported first beginning or last reported end time of a listed flare were deemed associated with that particular flare.

**These include 8 brightenings which occurred coincidentally with the reported starting times of flares for which no 'maximum time was reported'.

+These events occurred after the commencement times of flares for which no time of maximum was reported.

These figures show that, in addition to the 33.5% of observed events occurring in the interim periods between reported flares, 23.3% of these events occurred during the reported 'decay times' of flares.

The number of brightenings that took place during the rise times of reported flares is grossly underestimated due to such factors as the inability at times of high activity to detect further intensity fluctuations on already over exposed film records. In the case of the importance 3 flare of $21^h\ 14^m$ U.T. on July 16 alone, because of the extreme complexity of the optical event, only those individual brightenings observed during the early part of the flash phase from $21^h\ 14^m$ - $21^h\ 20^m$ U.T. were included among the events 'observed' prior to flare maximum. The inclusion in the counts of those brightenings actually occurring during the remaining eight minutes until reported maximum at $21^h\ 28^m$ U.T. would obviously, could these have been meaningfully estimated, make in themselves a significant difference to the figures. However, despite such difficulties, we can conclude from the comparisons that major flares in 59Q represent, not so much isolated outbursts, as temporal enhancements within a general background of flare activity.

### 3.4 Number of Optical Brightenings Observed to Occur During the Rise Times of Flares of Different Importance Classes

Events reported to be subflares (according to the classification of Ellison, 1957) were not necessarily characterized by the excitation of only a single brightening during the reported duration of their 'rise times', (although this was the most common case). Table 3.4a, p. 21, lists in detail the frequencies with which various numbers of multiple brightenings were observed to occur in region 59Q during the reported rise times of flares of different importance classes, July 7-17 and July 19-21, 1959*. It is seen from the table that, allowing for the fact that the total number of brightenings exhibited by major flares is in considerable doubt, there was a rapid increase in the number of individual brightenings occurring during the 'rise times' of flares of ascending importance.

The majority of reported importance 1-flares was characterized by the excitation of only one impulsive brightening. However, a significant number of such events showed instead multiple brightenings. The highest number of brightenings counted during the rise time of an importance 1-event was 15**.

It should be noted that the importance classification given by Warwick cannot be transferred to the new system of classification introduced from January 1, 1966 by Commission 10 of the International Astronomical Union ("Solar Flares in Hα. Amendments to IQSY Instruction Manual for Solar Activity" 1965). This latter system is based on both area and maximum brightness in Hα and no information is listed by Warwick concerning the Hα intensities of the various flares reported to have occurred in region 59Q during its transit.

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*Note that 8 impulsive brightenings that occurred coincidentally with the reported starting times of flares for which no 'maximum time' was reported together with 106 further brightenings which occurred after the starting times of such flares are excluded from the present counts (although they are included in the analysis of Section 3.3) since the number of Hα brightenings occurring during the 'rise times' of such events cannot be estimated.

**This comprised an importance 1-flare on July 16, located at N15, W33. Beg. $11^h\ 49^m$ U.T. Max. $12^h\ 05^m$ U.T., End $12^h\ 30^m$ U.T. Mean corrected apparent area 0.6 square degrees.

## 3.5 Identification of Those Areas in 59Q Associated with the Occurrence of Single and Multiple Impulsive Brightenings

Over the $136.1^h$ covered by the McMath SECASI observations, 104 separate areas in region 59Q were observed to show impulsive brightenings*. Of this total of flare active areas, cf. Table 3.5a, 77.9% showed 10 or fewer brightenings and only 1.9% had more than 50 individual brightenings.

TABLE 3.5a

Percentage of Flare Active Areas in Region 59Q Associated with the Production of a Single or Recurrent Brightenings over the Time Intervals Covered by the McMath SECASI Records July 7-17 and July 19-21, 1959*

| Number 'n' of individual impulsive brightenings counted | Percentage of flare active areas showing 'n' impulsive brightenings |
|---|---|
| { 1 | { 19.2 |
| { >1 - <10 | { 58.7 |
| >10 - <25 | 13.5 |
| >25 - <50 | 6.7 |
| >50 - <100 | 1.9 |

*These time intervals are listed in column 3 of Table 3.1a.

Table 3.5b** lists the frequencies with which individual flare sensitive areas in region 59Q were observed to show single or multiple brightenings. These figures indicate that, over the McMath sunlit hours, the observed frequencies of flare brightenings ranged from 1 per flare sensitive area (20 cases) to 89 per flare sensitive area (1 case). Further, of the 104 flare sensitive areas identified in region 59Q (see Figs. 3.1a-3.1j), the two single most flare active areas were $d^1$ (showing 61 recurrent brightenings) and d (showing 89 recurrent brightenings).

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*Cf. also Chapter 7 where the special characteristics of these flare active areas are discussed in detail.

**Cf. p. 22.

TABLE 3.4a

Frequencies with Which Various Numbers of Multiple Brightenings Were Observed to Occur, Using McMath SECASI Records, During the Reported Rise Times of Flares of Different Importance Classes in Region 59Q, July 7-17 and July 19-21, 1959 Inclusive

| No. of observed brightenings | Importance class | | | | | | |
|---|---|---|---|---|---|---|---|
| | (1-) | (1) | (1+) | (2-) | (2) | (2+) | (3) |
| 1 | 10 | 3 | | | | | |
| 2 | 6 | 2 | | | | | |
| 3 | 5 | | | | | | |
| 4 | 3 | 2 | | | | | |
| 5 | 2 | 1 | | | | | |
| 7 | | 1 | | | | | |
| 8 | 1 | 1 | | | | 1* | |
| 9 | | 1 | | | | | |
| 11 | | | | 1 | | | |
| 12 | | | 1 | | | | |
| 13 | 1 | 2 | | | | | |
| 14 | | | 2 | | | | |
| 15 | 1 | | | | | | |
| 16 | | | | | | | 1** |
| 18 | | 1 | | | (1)+ | | |
| 20 | | | | | 1x | | |
| 24 | | | 1 | | | | |
| Total no. of brightenings | 95 | 88 | 64 | 11 | 38 | 8 | 16 |

*Refers to importance 2+ flare of $16^h\ 04^m$ U.T. July 16. The exclusion of 11 further brightenings recorded at $16^h\ 17^m$ U.T. from the total of 8 is purely arbitrary and according to the convention of adopting the time of maximum $16^h\ 15^m$ U.T., given by Warwick (1966a) as 'true' maximum.

**Refers to importance 3 flare of $21^h\ 14^m$ U.T. July 16. Only brightenings occurring during the early part of the flash phase from $21^h\ 14^m$ - $21^h\ 20^m$ U.T., are included in the count of 16 (cf. Section 3.1 and Section 3.3).

+Refers to importance 2 flare of $21^h\ 34^m$ U.T., July 12. Flaring spreading gradually along extensive chains of the chromospheric network from $<22^h\ 12^m$ U.T. is not included in the overall count of 18 impulsive brightenings listed for the event (cf. Section 3.1).

xRefers to importance 2 flare of $19^h\ 30^m$ U.T., July 9, Warwick (1966a), a 'latest end' time for this event of $>23^h\ 20^m$ U.T., and an estimated end time of $22^h\ 09^m$ U.T. Three further importance 1 flares were reported to commence in the region of $<21^h\ 15^m$ U.T., $21^h\ 55^m$ U.T. and $22^h\ 26^m$ U.T., respectively. Because of the complexity of the event which includes both impulsive flaring and gradually spreading excitation, those portions of the McMath SECASI record taken between $21^h\ 09^m$ - $23^h\ 30^m$ U.T. are excluded from the present analysis (cf. Section 3.1).

TABLE 3.5b

Distribution Between Areas a-z of 1006 Impulsive Brightenings Observed in Region 59Q During Its July Transit Using the McMath SECASI Record Alone*

| No. of impulsive brightenings 'n' observed in each flare sensitive area | Individual flare sensitive areas showing 'n' impulsive brightenings | Total no. 't' of flare sensitive areas showing 'n' brightenings | Total no. of impulsive brightenings observed t x n |
|---|---|---|---|
| 1 | $a^{I}$, $c_{I}$, $d_{I}$, $e^{II}$, $e^{III}$, $i^{I}$, $o^{II}$, $t_{I}$, $u^{III}$, $u^{IV}$, $v^{II}$, $v^{III}$, $v^{IV}$, $w^{I}$ $x^{I}$, $x^{II}$, $x^{VIII}$, $x^{IX}$, $y^{II}$, $z^{I}$ | 20 | 20 |
| 2 | $c^{I}_{I}$, $i^{I}_{I}$, $k^{VI}$, $s^{IV}$, u, $u^{I}$, $u^{II}$, x, $x^{III}$, $y^{VI}$ | 10 | 20 |
| 3 | $e^{IV}$, j, $k^{V}$, p, $q^{IV}$, $q^{VI}$, $t^{III}$ $v^{I}$ | 8 | 24 |
| 4 | $d^{VIII}$, $e^{I}_{I}$, $m^{II}$, $m^{IV}$, $o^{I}$, $q^{VII}$ $s^{III}$, w, $x^{VII}$ | 9 | 36 |
| 5 | $d^{II}$, $d^{VI}$, $n^{I}$, $w^{II}$, $x^{V}$, $x^{VI}$ | 6 | 30 |
| 6 | $d^{III}$, $i^{II}$, n, o, $q^{II}$, r, $r^{I}$ | 7 | 42 |
| 7 | h, $m^{I}$, $m^{III}$, $s_{I}$, $s^{II}$, $x^{IV}$ | 6 | 42 |
| 8 | $l^{I}$, $o^{III}$, $y^{I}$ | 3 | 24 |
| 9 | i, q, $q^{I}$, $q^{V}$, $s^{I}$, t, $t^{II}$ | 7 | 63 |
| 10 | $d^{IV}_{I}$, $d^{V}$, l, $t^{I}$, v | 5 | 50 |
| 14 | $c^{I}$, $d^{VII}$, s | 3 | 42 |
| 15 | $k^{IV}$ | 1 | 15 |

*Periods within which impulsive Hα brightenings were counted in 59Q are listed in column 3 of Table 3.1a.

TABLE 3.5b - Concluded

| No. of impulsive brightenings 'n' observed in each flare sensitive area | Individual flare sensitive areas showing 'n' impulsive brightenings | Total no. 't' of flare sensitive areas showing 'n' brightenings | Total no. of impulsive brightenings observed t x n |
|---|---|---|---|
| 18 | f | 1 | 18 |
| 19 | e, $k^{I}$ | 2 | 38 |
| 21 | b, y, $y^{V}$ | 3 | 63 |
| 23 | g | 1 | 23 |
| 24 | $d^{IV}$ | 1 | 24 |
| 25 | a, m | 2 | 50 |
| 26 | $y^{IV}$ | 1 | 26 |
| 31 | $y^{III}$ | 1 | 31 |
| 32 | k | 1 | 32 |
| 34 | $k^{II}$ | 1 | 34 |
| 35 | $e^{I}$ | 1 | 35 |
| 37 | c, $k^{III}$ | 2 | 74 |
| 61 | $d^{I}$ | 1 | 61 |
| 89 | d | 1 | 89 |
| Total | 104 | 104 | 1006 |

## Legend to Figs. 3.1a-3.1j

Series of composite drawings made from McMath 40' Hα and K spectroheliograms showing spot groups, chromospheric chains, flare sensitive areas and dark absorption material in region 59Q on days July 08-17, 1959 inclusive.*

Spot umbrae are shown in black and penumbral borders are indicated by a 'fringed' continuous line.

Regions of bright emission in the chromospheric network are shown enclosed within a continuous line interspersed with black circles. Individual lengths of the network referred to in the text are designated by roman numerals.

The positions of individual flare sensitive areas are indicated by the letters a-z with, on occasions, added roman subscripts and/or superscripts.

Faint dark filaments are shown enclosed within a continuous line. Well defined dark filaments are shown enclosed within a continuous line and stippled. Amorphous dark material is hachured diagonally.

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*Spot groups and regions of bright emission in the chromospheric network are drawn as they appeared on K spectroheliograms. Filamentary material was generally more clearly visible on Hα than on K spectroheliograms and is thus drawn as it appeared on such pictures.

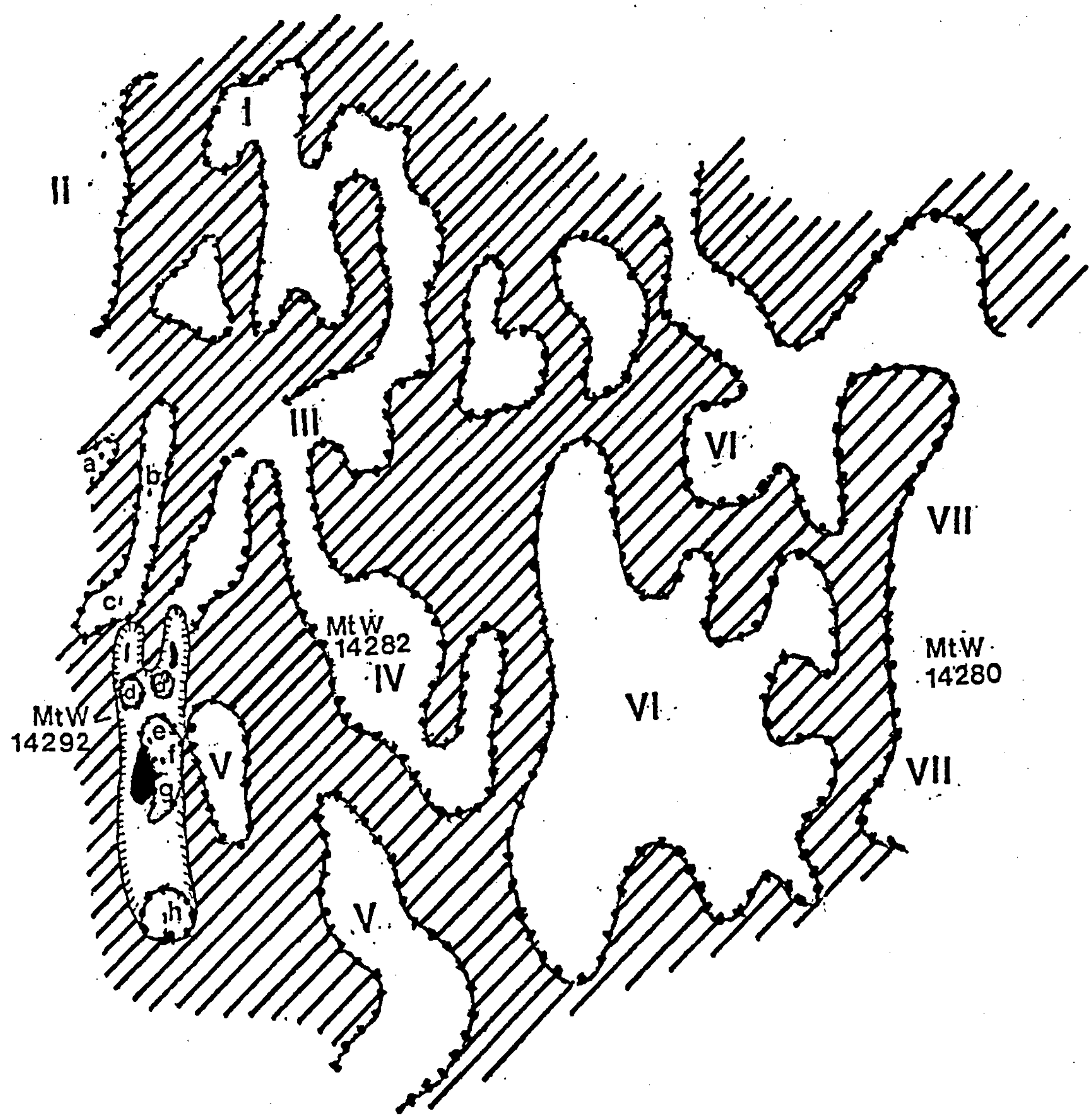


Fig. 3.1a. Composite drawing made from McMath 40' spectroheliograms showing spot groups, chromospheric chains, flare sensitive areas and dark absorption material in region 59Q, July 08, 1959.

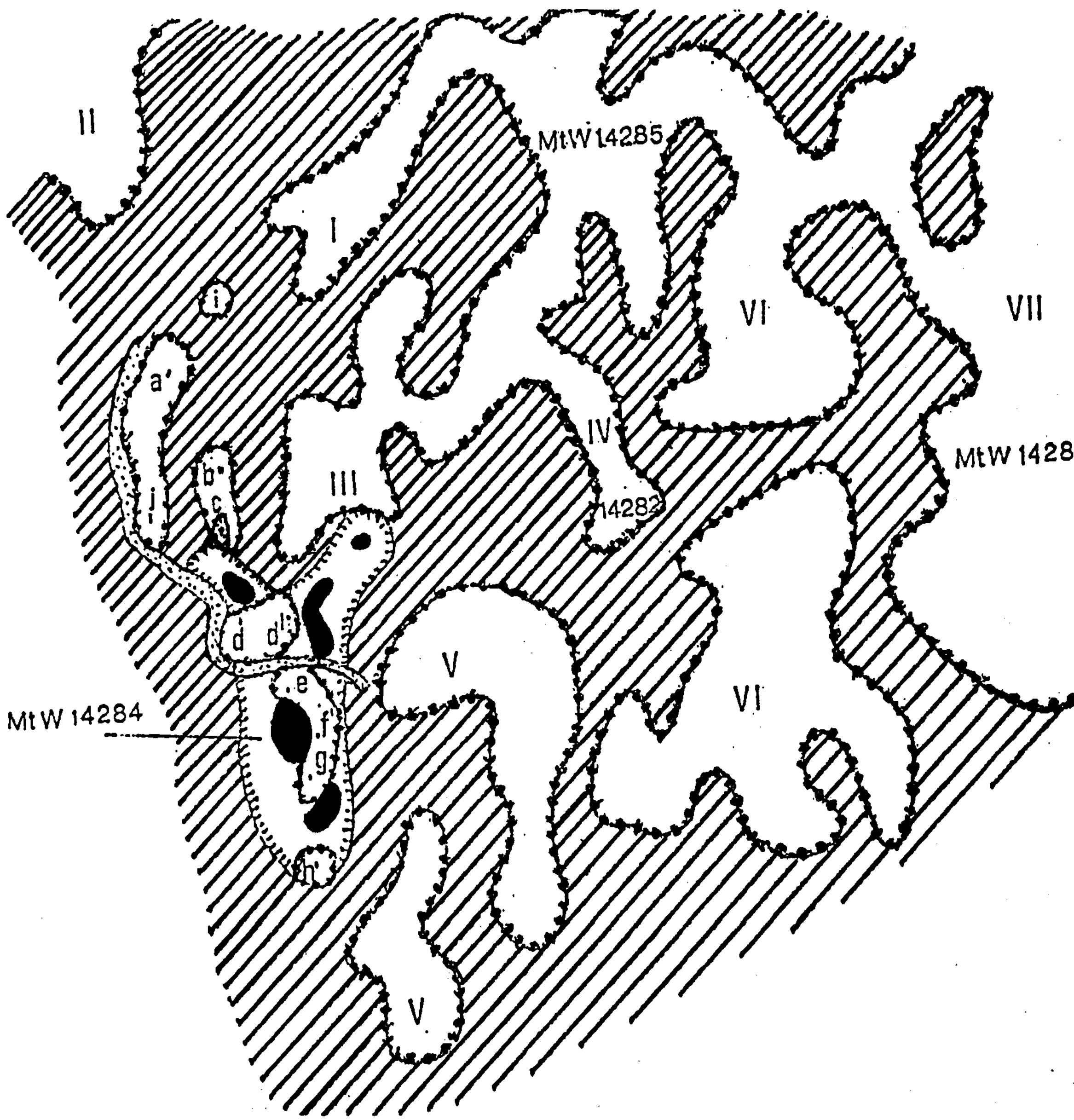


Fig. 3.1b. Composite drawing made from McMath 40' spectroheliograms showing spot groups, chromospheric chains, flare sensitive areas and dark absorption material in region 59Q, July 09, 1959.

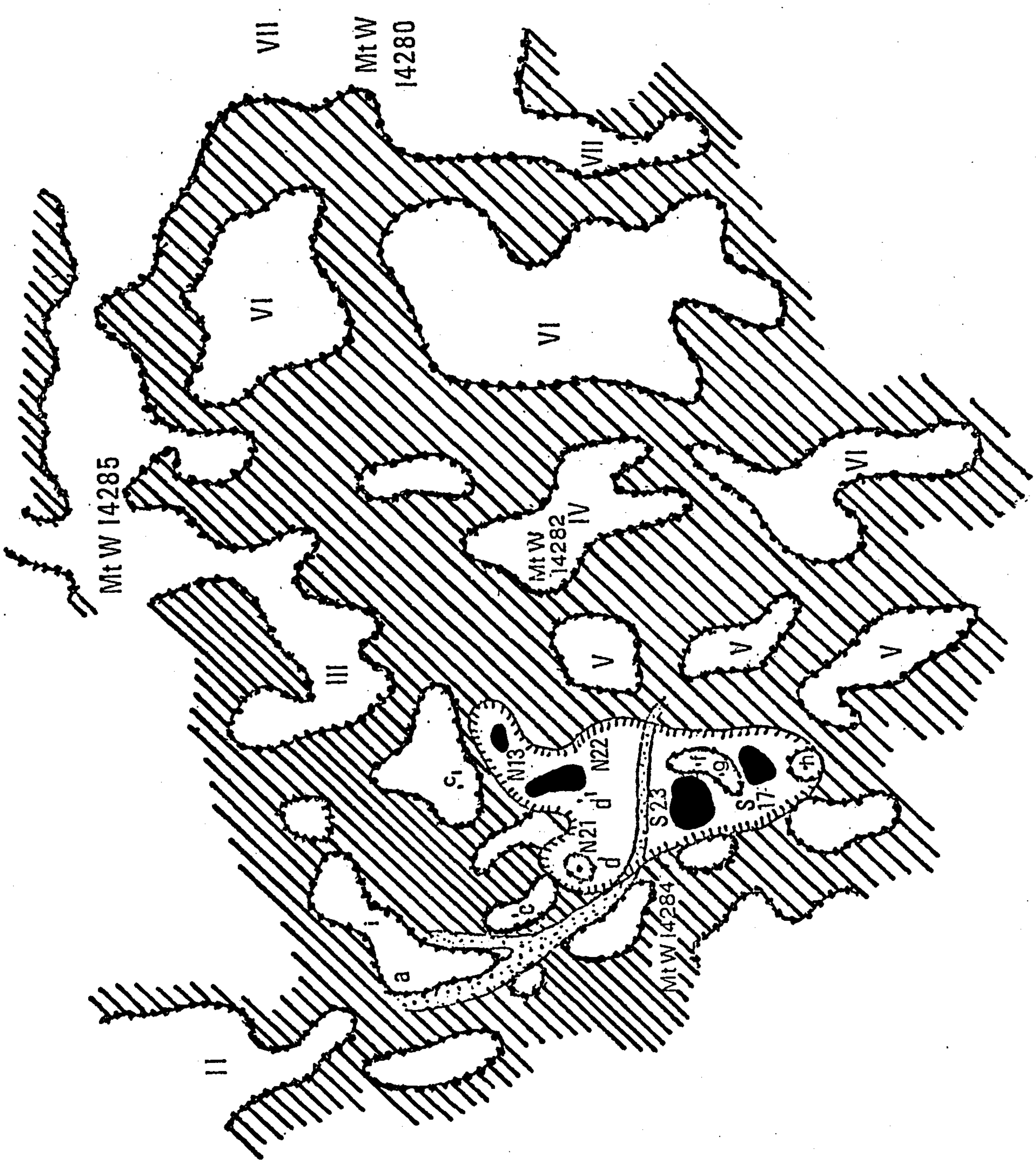


Fig. 3.1c. Composite drawing made from McMath 40' spectroheliograms showing spot groups, chromospheric chains, flare sensitive areas and dark absorption material in region 59Q, July 10, 1959.

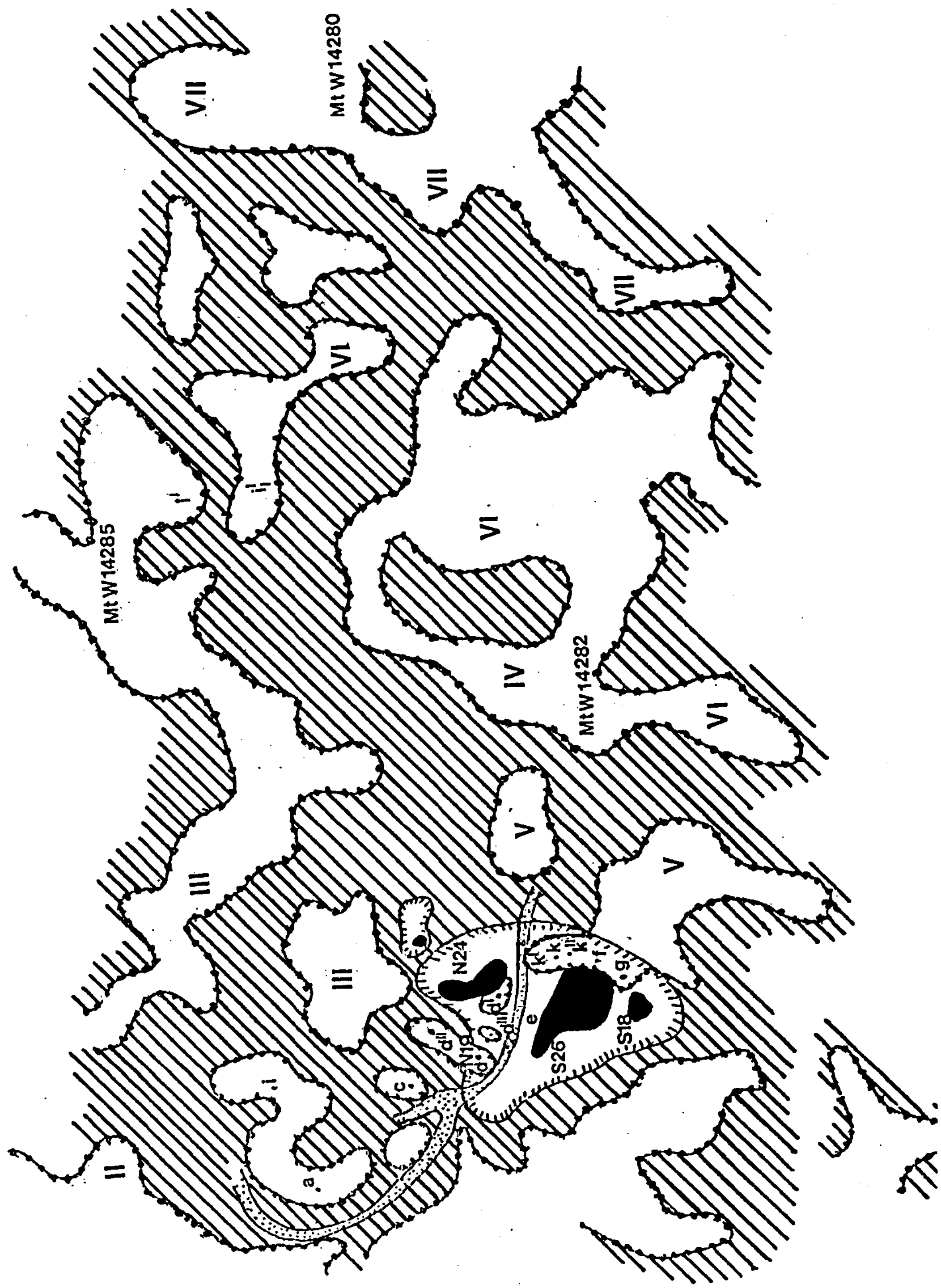


Fig. 3.1d. Composite drawing made from McMath 40' spectroheliograms showing spot groups, chromospheric chains, flare sensitive areas and dark absorption material in region 59Q, July 11, 1959.

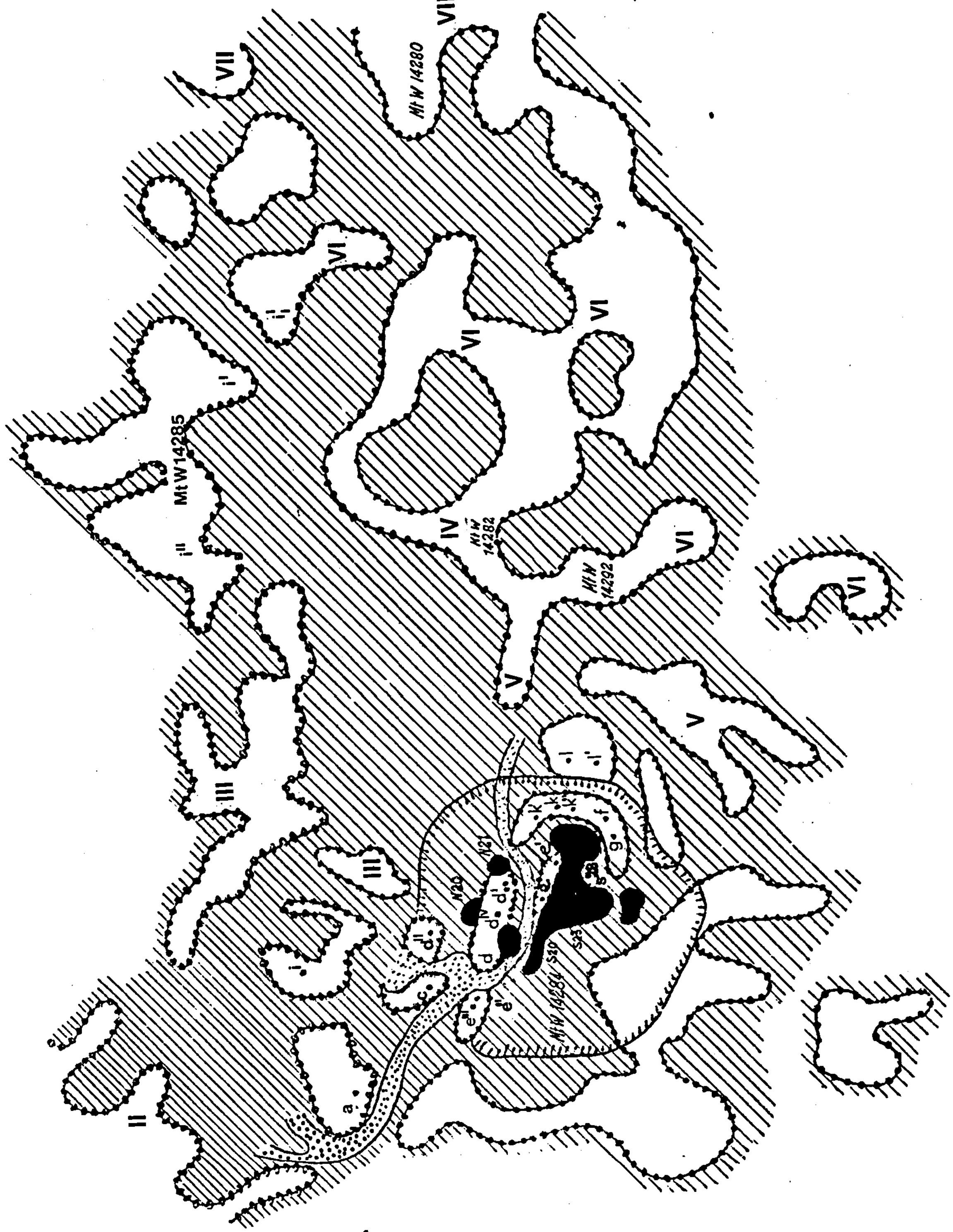

Fig. 3.1e. Composite drawing made from McMath 40' spectroheliograms showing spot groups, chromospheric chains, flare sensitive areas and dark absorption material in region 59Q, July 12, 1959.

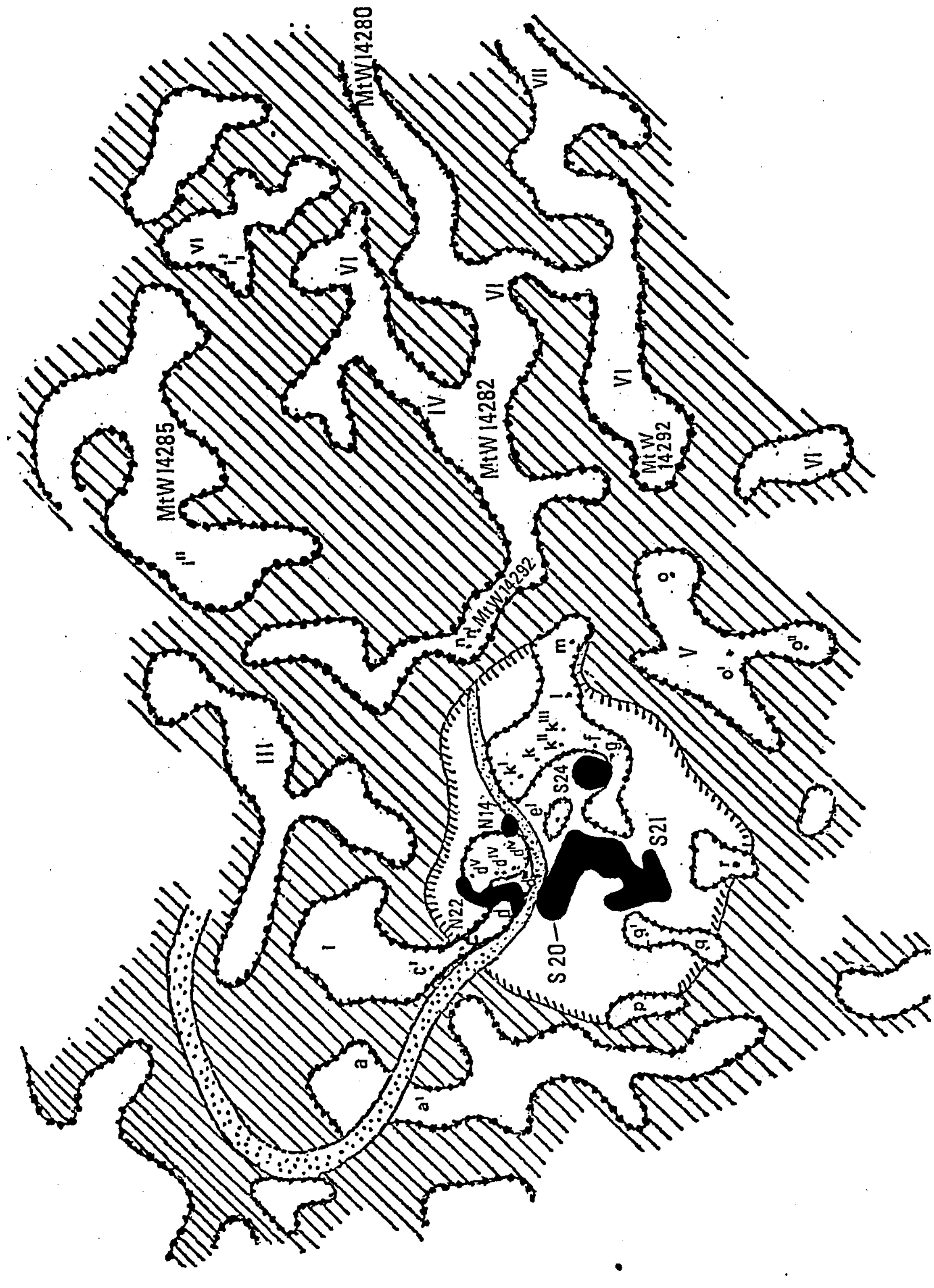

Fig. 3.1f. Composite drawing made from McMath 40' spectroheliograms showing spot groups, chromospheric chains, flare sensitive areas and dark absorption material in region 59Q, July 13, 1959.

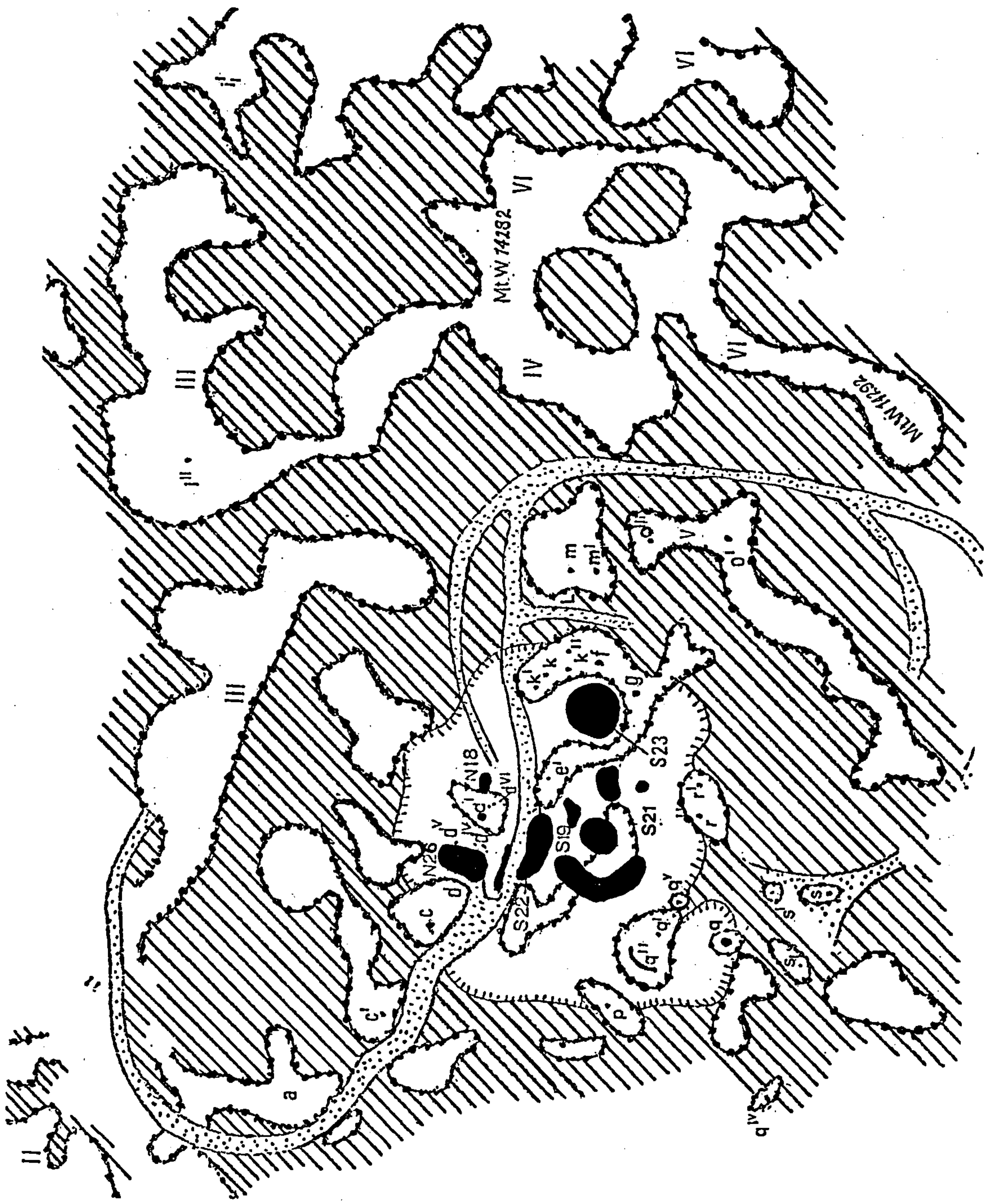


Fig. 3.1g. Composite drawing made from McMath 40' spectroheliograms showing spot groups, chromospheric chains, flare sensitive areas and dark absorption material in region 59Q, July 14, 1959.


Fig. 3.1h. Composite drawing made from McMath 40' spectroheliograms showing spot groups, chromospheric chains, flare sensitive areas and dark absorption material in region 590, July 15, 1959.

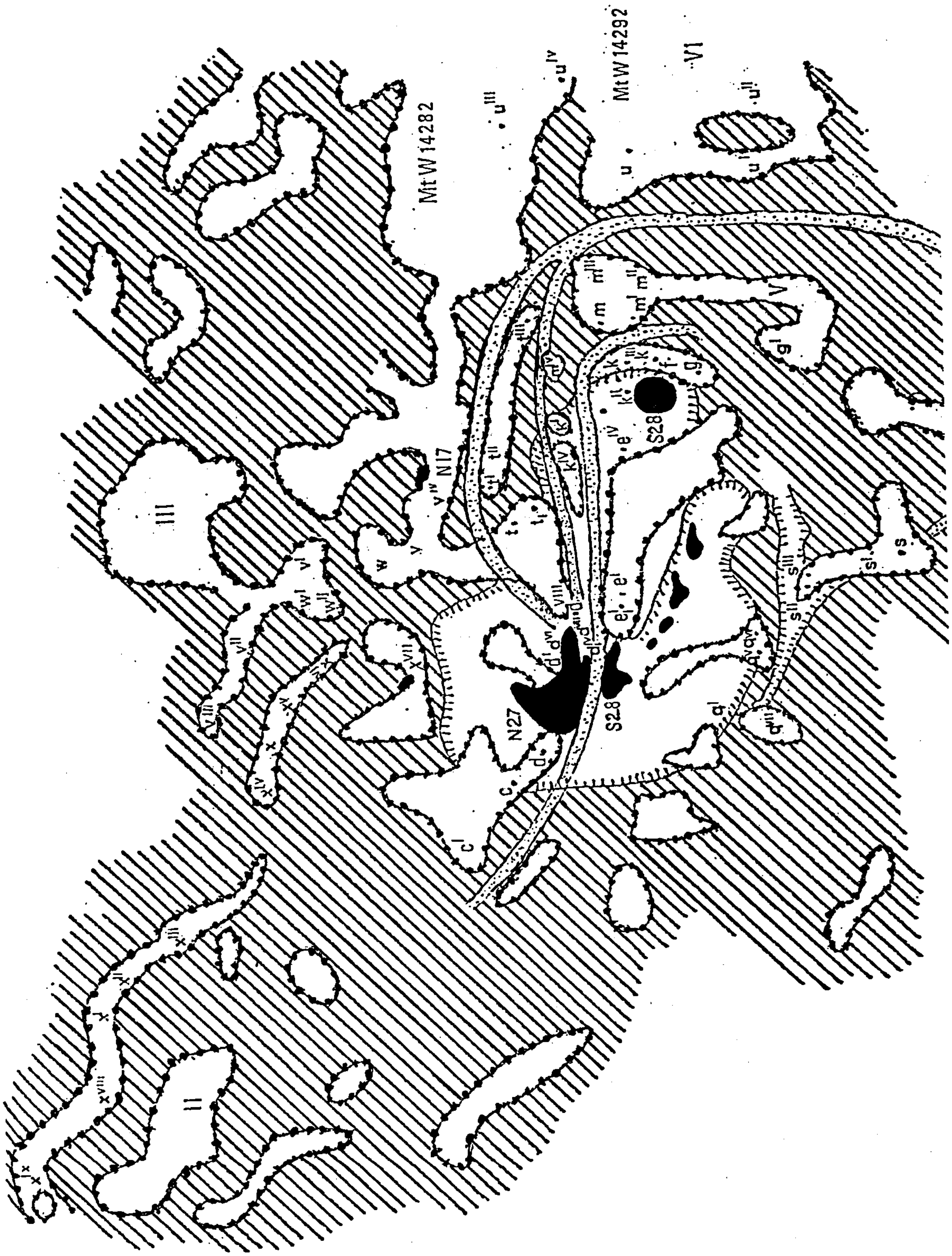


Fig. 3.1i. Composite drawing made from McMath 40' spectroheliograms showing spot groups, chromospheric chains, flare sensitive areas and dark absorption material in region 59Q, July 16, 1959.

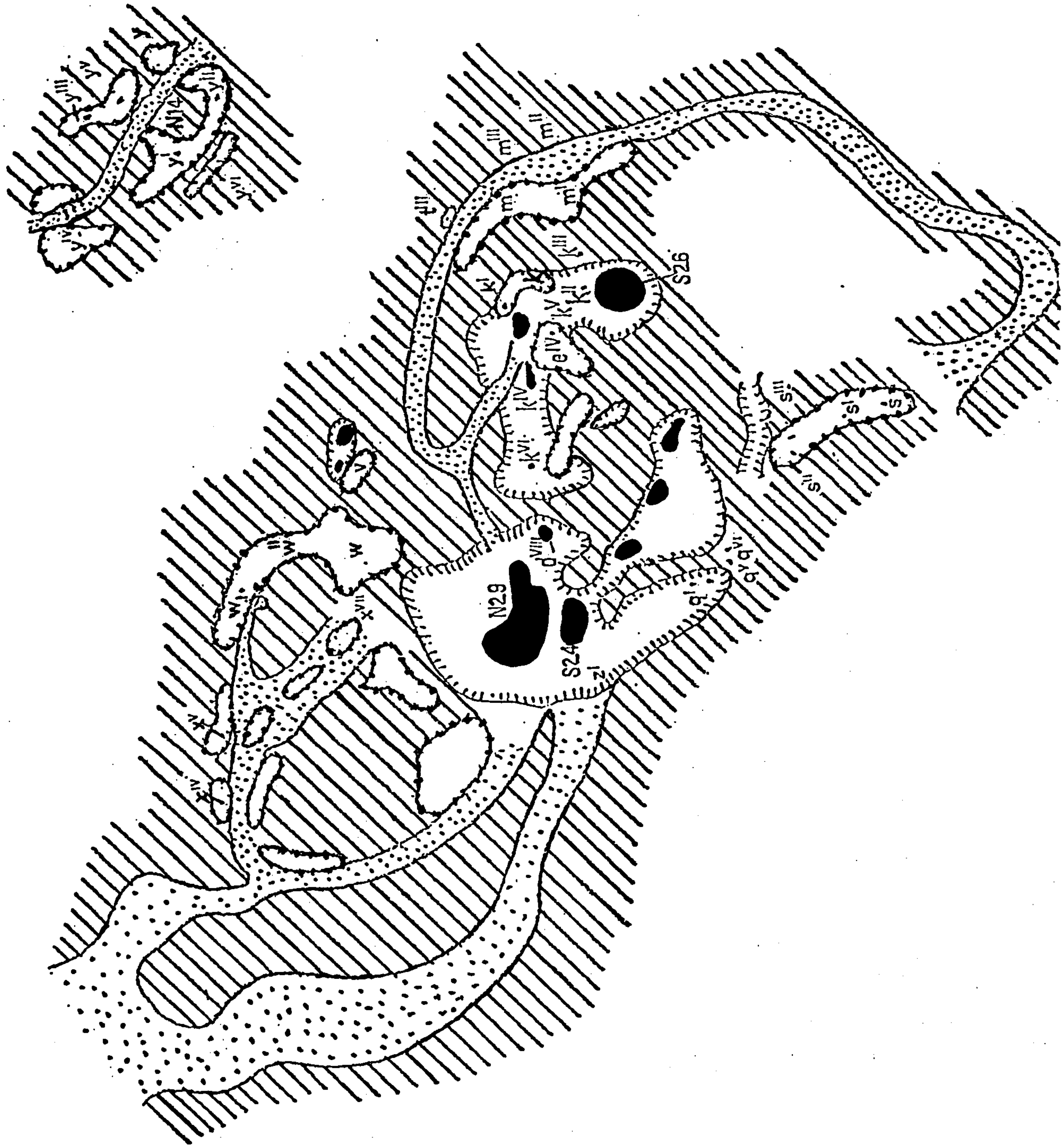

Fig. 3.1j. Composite drawing made from McMath 40' spectroheliograms showing spot groups, chromospheric chains, flare sensitive areas and dark absorption material in region 59Q, July 17, 1959.

# CHAPTER 4

# THE ASSOCIATION OF TYPE III BURSTS WITH MANIFESTATIONS OF ACTIVITY IN REGION 59Q

Criteria for correlating Type III burst activity with impulsive optical flaring in 59Q under different observational conditions are devised. Due to the high expected number of chance associations in the sample however, those observed correlations between the swept frequency and optical data are of low statistical significance. Nonetheless, 59Q possessed characteristics which distinguish it as a more likely progenitor of Type III bursts than any other simultaneously transiting centre. In particular, it may have been situated at the base of a dense overlying coronal structure. It is noted that all the identified Type III burst associated flares in 59Q showed a special spatial relationship with active dark material.

## 4.1 The Association Between Type III Bursts and Solar Flares

The association between Type III bursts and flaring has already been investigated by many authors and the results of these studies indicate that many Type III bursts are closely associated with the flash phase of flares. A detailed study by Malville (1961) using high-speed H$\alpha$ patrol films of the Lockheed Solar Observatory indicates that 69% of Type III bursts occur between $1^m$ before the onset of the flare flash phase and $\frac{1}{2}^m$ after it. The percentage of bursts found by this author to occur within $\pm 2^m$ of the flash phase, of the start and of the maximum of flares were 97%, 50% and 36%, respectively. See also studies by Wild et al. (1954), Loughead et al. (1957), Swarup et al. (1960), Rabben (1960), Malville (1962), Erickson (1962), Wild et al. (1963), Zirin and Werner (1967) and Lin (1970a, 1970b)*.

Recent papers by Kane (1972), Vorpahl and Zirin (1972) and Kuiper and Pasachoff (1973) indicate that the occurrence of Type III bursts is often closely related in time with those kinds of impulsive brightenings accompanied by the generation of X-ray and microwave bursts.

## 4.2 The Association Between Type III Bursts and Flares in Region 59Q

In a preliminary investigation of the association between optical flaring in 59Q and Type III burst activity, McKenna (1966), the starting times of radio events reported to have occurred during the period of the sunlit hours of the McMath SECASI telescope July 8-11, 1959 inclusive, were compared with the times of commencement of those impulsive optical brightenings recorded on simultaneous McMath spectroheliograms. These comparisons indicated the onset of a specific,

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*Note that the references quoted throughout this section are not intended to provide a comprehensive review of all papers concerning the various kinds of radio burst discussed but rather to indicate general lines of research.

although perhaps only a minor, impulsive brightening on the solar disk within ±$1^m$ of the start of at least 96%, and most probably 100%, of all the radio frequency events examined. This suggested, in harmony with the results quoted in Section 4.1, that the time basis for statistical correlation between optical and radio frequency phenomena should not exceed this interval.

In attempting to apply this criterion here to correlations between optical and burst activity over the total transit period July 7-21, 1959 of region 59Q, the implied requirement of high quality optical records spaced at intervals apart of not less than half a minute, can only be met with during the observation times of the McMath SECASI telescope. These observing times are listed in Table 3.1a. In view of the relatively restricted period covered by these records and the fact that the percentage of flare brightenings in 59Q accompanied by the emission of radio radiation was found in a preliminary survey to be relatively few, it was decided to also investigate the possibility of including in the comparisons those optical brightenings recorded on the relatively poor quality spectroheliograms of the Continuous Solar Movie - individually spaced at intervals apart of one minute. It was then found that, although variations in density and contrast millitated (cf. Section 3.1) against the use of this film in identifying all of the optical brightenings to occur in region 59Q within a specific time interval, it was generally feasible, using this composite record, to identify a brightening which occurred at a specific time in association with a known radio burst. The spectroheliograms of the CSM were thus included with the SECASI records in the analysis of the association between impulsive flaring and radio burst activity.

## 4.3 Criteria Adopted in Defining Impulsive Flaring and Radio Burst Activity as 'Time Associated' Under Different Observational Circumstances

Table 4.3a lists the times of radio spectrograph observations taken at the University of Michigan Radio Astronomy Station, Ann Arbor, at the Harvard Radio Astronomy Station, Fort Davis, and at the Division of Radio Physics, CSIRO, Sydney.

TABLE 4.3a

| Date 1959 (1) | Station (2) | Range MHz (3) | Swept-frequency observations U.T. (4) | Simultaneous McMath SECASI and swept-frequency observations U.T. (5) |
|---|---|---|---|---|
| July 7 | Harvard | 100-580 | 0000-0150 | |
| | Sydney | 25-210 | 0000-0608 | |
| | Harvard | 100-580 | 1215-1557, 1601-1621, 1627-1632, 1650-2400 | 1215-1557, 1601-1621, 1627-1632, 1650-2311 |
| | Sydney | 25-210 | 2259-2400 | 2259-2311 |

TABLE 4.3a Continued

| Date 1959 (1) | Station (2) | Range MHz (3) | Swept-frequency observations U.T. (4) | Simultaneous McMath SECASI and swept-frequency observations U.T. (5) |
|---|---|---|---|---|
| July 8 | Harvard | 100-580 | 0000-0150 | |
| | Sydney | 25-210 | 0000-0625 | |
| | Harvard | 100-580 | 1227-1532 | 1227-1532 |
| | Ann Arbor | 100-580 | 1430-2400 | 1430-2009, 2134-2316 |
| | Harvard | 100-580 | 1910-2400 | 1910-2009, 2134-2316 |
| | Sydney | 25-210 | 2258-2400 | 2258-2316 |
| July 9 | Ann Arbor | 100-580 | 0000-0110 | |
| | Harvard | 100-580 | 0000-0150 | |
| | Sydney | 25-210 | 0000-0625 | |
| | Ann Arbor | 100-580 | 1000-2015 | |
| | Harvard | 100-580 | 1230-2230 | 1810-2230 |
| | Ann Arbor | 100-580 | 2203-2400 | 2203-2330 |
| | Harvard | 100-580 | 2235-2400 | 2235-2330 |
| | Sydney | 25-210 | 2259-2400 | 2259-2330 |
| July 10 | Ann Arbor | 100-580 | 0000-0109 | |
| | Harvard | 100-580 | 0000-0150 | |
| | Sydney | 100-580 | 0000-0539 | |
| | Harvard | 100-580 | 1230-2400 | 1230-2319 |
| | Ann Arbor | 100-580 | 1615-1725 | 1615-1725 |
| July 11 | Harvard | 100-580 | 0000-0150 | |
| | Ann Arbor | 100-580 | 1000-1450 | 1219-1450 |
| | Harvard | 100-580 | 1300-2400 | 1300-2318 |
| | Ann Arbor | 100-580 | 1945-2400 | 1945-2318 |
| July 12 | Ann Arbor | 100-580 | 0000-0110 | |
| | Harvard | 100-580 | 0000-0150 | |
| | Ann Arbor | 100-580 | 1000-2400 | 1134-2245 |
| | Harvard | 100-580 | 1230-2400 | 1230-2245 |
| | Sydney | 25-210 | 2315-2400 | |
| July 13 | Ann Arbor | 100-580 | 0000-0109 | |
| | Harvard | 100-580 | 0000-0150 | |
| | Sydney | 25-210 | 0000-0008 | |
| | Ann Arbor | 100-580 | 1000-2400 | 1050-2303 |
| | Harvard | 100-580 | 1235-1540, 1542-2400 | 1235-1540, 1542-2303 |
| | Sydney | 25-210 | 2313-2400 | |
| July 14 | Ann Arbor | 100-580 | 0000-0109 | |
| | Harvard | 100-580 | 0000-0150 | |
| | Sydney | 25-210 | 0000-0610 | |

TABLE 4.3a Concluded

| Date 1959 (1) | Station (2) | Range MHz (3) | Swept-frequency observations U.T. (4) | Simultaneous McMath SECASI and swept-frequency observations U.T. (5) |
|---|---|---|---|---|
| July 14 (Cont) | Ann Arbor | 100-580 | 1000-2400 | 1056-1755, 2145-2309 |
| | Harvard | 100-580 | 1230-2400 | 1230-1755, 2145-2309 |
| | Sydney | 25-210 | 2329-2400 | |
| July 15 | Ann Arbor | 100-580 | 0000-0109 | |
| | Harvard | 100-580 | 0000-0150 | |
| | Sydney | 25-210 | 0000-0650 | |
| | Ann Arbor | 100-580 | 1000-2400 | 1105-2256 |
| | Harvard | 100-580 | 1230-2400 | 1239-2256 |
| | Sydney | 25-210 | 2257-2400 | |
| July 16 | Ann Arbor | 100-580 | 0000-0109 | |
| | Harvard | 100-580 | 0000-0150 | |
| | Sydney | 25-210 | 0000-0627 | |
| | Ann Arbor | 100-580 | 1000-2400 | 1123-2317 |
| | Harvard | 100-580 | 1230-2400 | 1230-2317 |
| | Sydney | 25-210 | 2241-2400 | 2241-2317 |
| July 17 | Ann Arbor | 100-580 | 0000-0130 | |
| | Harvard | 100-580 | 0000-0150 | |
| | Sydney | 25-210 | 0000-0620 | |
| | Ann Arbor | 100-580 | 1000-2029 | 1143-1431, 1915-2029 |
| | Harvard | 100-580 | 1230-2400 | 1230-1431, 1915-2139 |
| | Ann Arbor | 100-580 | 2033-2400 | 2033-2139 |
| July 18 | Ann Arbor | 100-580 | 0000-0114 | |
| | Harvard | 100-580 | 0000-0150, 1230-2400 | |
| | Ann Arbor | 100-580 | 1020-2249 | |
| July 19 | Harvard | 100-530 | 0000-0150, 1230-2400 | 1241-2145 |
| | Ann Arbor | 100-580 | 1900-2400 | 1900-2145 |
| | Sydney | 25-210 | 2326-2400 | |
| July 20 | Ann Arbor | 100-580 | 0000-0109 | |
| | Harvard | 100-580 | 0000-0150 | |
| | Sydney | 25-210 | 0000-0609 | |
| | Ann Arbor | 100-580 | 1000-2400 | 1319-1427, 1821-2311 |
| | Harvard | 100-580 | 1230-2400 | 1821-2311 |
| | Sydney | 25-210 | 2304-2400 | 2304-2311 |
| July 21 | Ann Arbor | 100-580 | 0000-0109 | |
| | Harvard | 100-580 | 0000-0150 | |
| | Sydney | 25-210 | 0000-0608 | |
| | Ann Arbor | 100-580 | 1000-2400 | 1105-2259 |
| | Harvard | 100-580 | 1230-2400 | |

Flaring on the solar disk and Type III burst activity were deemed time associated under several different observational circumstances. These different kinds of association were classified for convenience as 'Unambiguous', 'Shared', 'Inferred' and 'Reported' associations, respectively.

'Unambiguous' associations*

A radio burst was considered to be time associated with an optical event if it occurred within $\pm 1^m$ of an optical brightening recorded on a McMath or within $\pm 1.5^m$ of a brightening recorded on a Continuous Solar Movie spectroheliogram. Such coincidences may be assumed for the purposes of a preliminary analysis to indicate the simultaneous emission on these occasions from specific solar regions of optical and radio radiation (see however Section 4.6, p. 42).

'Shared' associations

In cases when simultaneous brightenings in region 59Q and in other centres on the solar disk occurred within $\pm 1^m$ of a single radio burst, the probability that the radio burst was associated with region 59Q alone was taken to be 1/n (where n = the total number of centres to have brightened). Such estimated associations were individually classified as 'Shared'.

'Inferred' associations

Bursts were 'Inferred' to have been associated with flaring in region 59Q under four separate circumstances: (1) When in the absence of other disk activity, one or more flaring areas in this centre were so brilliant as to be over-exposed at the time of the radio event. In this situation, no further specific intensity fluctuation could be detected in the flare active area at the time of the burst although the association between optical and burst activity appeared to be obvious. (2) When, although records of flaring in region 59Q were missing within specifically $\pm 1^m - 1.5^m$ of the radio burst, the available data indicated that the burst was associated with a particular outstanding optical event in this centre**. (3) When 59Q showed simultaneous extensive flaring so that the burst could not be associated with intensity changes occurring within any specific active area**. (4) When radio bursts were associated with the commencement of impulsive brightenings in other active disk regions at times when part of region 59Q was already so over-exposed that no (possibly) accompanying

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*'Unambiguous' in this context implies that no other optical brightening on the disk could be time associated with the relevant radio event. It does not preclude the possibility of chance associations, cf. Section 4.6, p. 42 or correlations with motions of dark absorbing material, cf. p. 47.

**If active centres other than 59Q were additionally already brilliant at the time of commencement of the burst so that no intensity fluctuation could be detected within them in association with the radio event, the probability that the burst was associated with region 59Q alone was estimated to be only 1/n (where n = the total number of active centres involved).

intensity fluctuation could be detected within it, then the probability that the burst might in fact have been associated with region 59Q was estimated to be 1/n (where n = the total number of active centres involved).

Reported associations

Bursts which occurred during the rise times of flares in region 59Q which, although not recorded on either the McMath SECASI or CSM spectroheliograms due to minor cloud breaks were reported in the international flare catalogs listed in Section 2.3, were classified as constituting 'Reported' associations. In cases where a radio burst was associated with the rise times of separate reported flares, the probability that the burst was associated with region 59Q alone was taken to be 1/n.

Probable associations

The level of confidence in accepting a radio burst as time associated with flaring in region 59Q is somewhat less in the case of those events falling within the categories of 'Shared', 'Inferred' and 'Reported' associations than pertains when a burst occurred within specifically $\pm 1^m - 1.5^m$ of an observed single or multiple brightening in this particular active centre. Accordingly, in contrast to the so-called 'Unambiguous' cases, such time associations will hereafter be collectively referred to as 'Probable' and the three sub-classes covered by this designation will no longer be mentioned.

### 4.4 Number of Radio Bursts Deemed, Within the Limitations of the Association Criteria Adopted, To Have Been Time Associated With Flaring in Region 59Q During Its July Disk Passage

Some 76 Type III bursts may be recognised according to the association criteria explained in Section 4.3 as 'time associated' with flaring in 59Q. (48 'unambiguous' and $23^5/6$ 'probable' associations.)

These events included:

(a) 60 Type III events occurring alone or in association with single frequency radio bursts (38 'Unambiguous' and 19 'Probable' associations).

(b) 16 Type III events which occurred simultaneously with reported Type I events either in the presence or absence of single frequency radio bursts (10 'Unambiguous' and $4^5/6$ 'Probable' associations).

### 4.5 Estimation of the Expected Level of Chance Associations Between Type III Bursts and Flares in Region 59Q

Clearly, not all of the observed time associations between Type III bursts and impulsive brightenings may be statistically significant. During its July transit, region 59Q was by no means alone on the solar disk but formed one of several centres contributing to the maintenance of a high overall level of flaring and, in this experimental circumstance of sustainedly high activity, the number of chance associations between flares and Type III bursts is expected to be high.

An effort to compute the number of chance associations present in the data was made following the well known method originally designed by Smith and McIntosh (1962) to determine the number of chance associations between flares and noise storms within an interval covered by the IGY. Unfortunately, not all of the 76 Type III events mentioned in Section 4.4 can be included in this statistical analysis. Firstly, meaningful estimates of the number of chance coincidences may only be made over those periods of radio spectrograph observations for which simultaneous McMath SECASI spectroheliograms are available (cf. column 5 of Table 4.3a). During intervals covered only by the composite CSM observations, inherent variations in density and contrast on the spectroheliograms render attempted counts of the number of flare brightenings occurring in 59Q too unreliable for use. Further, because of the complex nature of the flaring occurring in 59Q between $21^h\ 09^m$ - $23^h\ 30^m$ U.T. on July 9 and $21^h\ 20^m$ - $23^h\ 17^m$ U.T. on July 16, no reliable counts can be made, even using the available high quality McMath records, of the total number of impulsive H$\alpha$ brightenings occurring within these intervals.

As a result of these considerations only $7211^m$ of simultaneous radio and optical observations may be selected from the data for analysis. Following the method of Smith and McIntosh (1962) calling this total observing time 't', then $T = t/2$ represents the number of individual $2^m$ intervals contained within the period. (A Type III burst was deemed flare associated if it occurred within $\pm 1^m$ of an impulsive intensity increase recorded on a McMath spectroheliogram.) If now F is taken to represent the number of impulsive brightenings in 59Q and B the number of Type III bursts observed in time 't' the number of chance associations expected to be present in the sample $N_c$ is given by

$$N_c = FB/T$$

The strendth of the association between flaring in region 59Q and the onsets of Type III bursts may further be expressed in terms of the coefficient of association Q defined by Kendall (1952).

$$Q = \frac{N_o\ (T-F-B+N_o) - (F-N_o)\ (B-N_o)}{N_o\ (T-F-B+N_o) + (F-N_o)\ (B-N_o)}$$

where

$N_o$ is the number of observed associations.

$(T-F-B+N_o)$ represents the number of $2^m$ intervals during which no Type II burst or flare occurred in the region, assuming that both flares and Type III bursts are randomly distributed in time.

$(F-N_o)$ represents the number of unassociated impulsive flares.

$(B-N_o)$ represents the number of unassociated Type III bursts.

Q ranges from +1 for complete association through 0 for independence of the two parameters to -1 (negative values provide an indication of uncertainty in the statistics).

Within the $7211^m$ of selected simultaneous radio and optical records, 997 impulsive brightenings were accepted to have occurred in region 59Q. Within this same interval, 55 bursts were deemed time associated with flaring in 59Q (39 'Unambiguous' and 13.83 'Probable' associations). It is assumed that no one of 20 Type III bursts occurring during intervals of poor seeing was actually associated with region 59Q. According to these figures, the number of chance associations in the data is given by $N_O$ = FB/T = 27.10 and the coefficient of association Q between flares and Type III bursts is Q = 0.52.

## 4.6 Discussion of the Statistical Results

Since only 52.83 radio bursts were estimated to have been time associated with flaring in region 59Q over the selected period of joint optical and radio observations, it appears from the value $N_c$ determined above ($N_c$ = 27.10) that over half of these associations can be attributed to chance. However, this result can only be taken as a very tentative one since there are serious inherent uncertainties in the statistical treatment. These uncertainties include: (1) That the total number of brightenings counted in 59Q over the period of the joint optical and radio observations is seriously too low due to such effects as minor gaps in the record and over exposure of the film at times of important flaring. (2) It is implicit in the calculation of $N_c$ that both flares and Type III bursts were uniformly distributed in time. In this connection, examination of the day to day frequencies of occurrence of Type III bursts over the period July 7-21, 1959 indicates that in fact some flares in 59Q were succeeded by a marked reduction in the level of Type III burst activity (for example over periods immediately following the importance 3+ flares of July 10 and July 14). Particularly relevant to this observation is the statement by Švestka (1974a) that "there may be a large well developed active region on the Sun which does not produce any Type III bursts at all (then) another region, also inactive in Type III bursts, suddenly starts to produce Type III bursts in large quantity, maybe several tens per day, and this production again suddenly stops after $20^h$ or one or two days". In the special case of 59Q, evidence will be presented in the text (cf. Chapter 7) that the level of flaring and burst association appeared to depend on transient periods of instability within the underlying spot group. (3) It is assumed in the calculation that none of the 20 Type III bursts which could not, due to observational difficulties, be correlated with the optical records was in fact associated with region 59Q. However, as will be indicated in Sections 4.8, 4.9, this centre displayed certain characteristics which render it more likely to have been a producer of Type III bursts than any other active region simultaneously present on the solar disk. (4) It was assumed, in estimating the number of bursts associated with 59Q, that a radio event coincident with flaring in 'n' active centres had a probability 1/n of being associated with any one of them. If region 59Q was indeed more burst active than other centres this procedure would not be justified.

## 4.7 Characteristics of Active Regions Indicating Them To Have Been Probably Associated With the Production of Type III Bursts

The inherent difficulty of applying statistical techniques such as that described in Section 4.2 directly to complex solar situations suggests the necessity of trying to determine if certain active regions display characteristics which distinguish them as likely progenitors of Type III brusts.

At the present time there is no consensus of opinion as to what makes one region rather than another particularly burst productive. However, consideration of the literature (cf. below) indicates that it is probably typical (a) that such regions be associated with a complex sunspot group and (b) that they be overlaid by a dense coronal structure.

(a) The association of burst active regions with complex photospheric magnetic fields

A statistical investigation by Kleczek et al. (1968) indicates that burst activity increases rapidly with the growth of active regions and decreases again with their decay. It becomes noticeable for those centres of activity with spot groups of, later than, Type C*. In this connection the authors specially underline the importance of strong complex magnetic fields in providing conditions suitable for the occurrence of instabilities leading to the production of radio bursts. Burst activity may also depend on the phase of the solar cycle since the productivity of a given type of spot group was found to be considerably higher in association with 1966 groups that was the case with groups occurring during the previous years of solar minimum.

These results complement observations by Fokker (1957) that noise storms are mainly emitted by regions containing D,E,F or G Type spots and reports of a general increase (see p. 44) in the percentage of flares associated with Type III bursts when a stationary noise storm overlies a flare active region. Also, relevant to this is the condition that the ability of a spot group to be associated with a noise storm is not so much associated with the area of the group as a whole, as with the area of the largest spot present, Payne-Scott and Little (1951). In this connection Dodson and Hedeman (1957) showed that enhanced 200 MHz radiation is emitted from regions with spot areas $\geqslant 170 \times 10^{-6}$ of the visible hemisphere while great storms occur if the largest spot has an area exceeding 400-500 $\times 10^{-6}$ of the disk. For sunspots of still larger area the probability of noise storm association increases with magnetic field strength.

(b) The association of burst active regions with dense overlying coronal structure

According to the plasma hypothesis, Wild (1950), the systematic frequency drift in Type III bursts may be interpreted as a rapid outward motion of a disturbance which excites plasma oscillations in the surrounding coronal gas. The greater the height of the disturbance, the lower is the electron density surrounding it and hence the lower the frequency emitted. The systematic variation of position with frequency predicted by this hypothesis has been confirmed by interferometric measurement, Wild et al. (1959a). The regions of origin of Type III bursts are, however, consistently found to be at much greater heights than would be expected on the basis of conventional models of coronal electron density (as inferred from K-coronagraphs). Thus, many authors consider that Type III bursts are propagated along the axes of coronal streamers where the

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*Various stages in the development of spot groups may be designated by the letters A......H, Waldmeier (1938).

densities are considerably higher than is the case in the ambient corona, see Newkirk (1959, 1961, 1967), Shain and Higgins (1959), Morimoto and Kai (1961), Hughes and Harkness (1963), Erickson (1963), Morimoto (1963, 1964), Malitson and Erickson (1966), and Fainberg and Stone (1971).

A recent model of Type III production by Wild and Smerd (1972), based on an accumulation of observational and theoretical evidence, envisions sudden electron acceleration and ejection to take place in an unstable region above an active centre which contains opposing lines of force. Some of the ejected electrons have access to open field lines around neutral planes (supposed to delineate coronal streamers), and these, in their passage outwards through the solar atmosphere, give rise to Type III bursts. Confirmation that those particles generating Type III bursts are indeed electrons rather than protons has been provided by satellite observations, e.g., Van Allen and Krimigis (1965), Anderson and Lin (1966), Lin and Anderson (1967a), Lin (1970a, 1970b, 1973a, 1973b), Lin et al. (1973), Lin (1974a, 1974b).

Work by Riddle (1972) and Leblanc (1973) on the other hand shows that, since scattering can account for most of the discrepancy between electron densities derived from radio and optical observations, it is not actually necessary to invoke a model of Type III bursts being propagated along coronal streamers. Further, Smith and Pneuman (1972) deduced theoretically that Type III bursts cannot in general, because of the presence of strong transverse magnetic fields, escape along the axes of such streamers. In contradiction Priest and Smith (1972) suggest that these supposed transverse magnetic fields may in fact be significantly smaller than was at first estimated. Some experimental evidence in favour of the theoretically deduced 'non axial' propagation of Type III events may be provided by observations recorded between 20 and 65 MHz by Kuiper (1973) and Leblanc et al. (1974) who report that "most of the Type III bursts observed ---------- are propagated at the edge of a dense structure." However, these latter results have been criticized by Stewart (1974) who declares them "inconclusive".

Although the question as to whether Type III bursts are channelled along neutral sheets or follow open field lines at the edge of, or within the body of, a coronal streamer is currently an open one, the actual presence of such a density anomaly in the solar atmosphere appears to be a general feature of both theory and observation. Thus, the occurrence of such a structure may be symptomatic that a particular region is in a sufficiently active condition to produce burst associated flares. In this connection, both Malville (1961, 1962) and Simon (1962) have found that the percentage of flares to be associated with Type III bursts is greatly increased when a stationary noise storm overlies a flare active region. Such Type I storm activity is typically generated in coronal condensations located within the 'legs' of large scale magnetic arches overlying an active centre, Gaigne et al. (1971). Further, Simon (1962) found that the percentage of flares to be associated with Type III bursts increases markedly when a Type IV burst is associated with the relevant active centre. This observation probably reflects the fact that Type IV events of different subclasses are generated by particles trapped within magnetic flux loops above active centres where, on occasions, stationary Type IV bursts can even degenerate into noise storms, Pick-Gutmann (1961), Bioschot and Pick (1962), Wild (1970, 1971), and Kai and Sekiguchi (1973)*.

## 4.8 The Association of Region 59Q With Complex Photospheric Magnetic Fields

Region 59Q possessed all of the magnetic characteristics mentioned by the various authors quoted in Section 4.7, as typical of burst active regions: (1) Among the aggregate of spot groups of which it was composed (including Mt. Wilson Nos. 14280, 14282, 14284, 14285, 14292 and 14297)**, principal group Mt. Wilson No. 14284 was of Zürich classification E+ and its associated magnetic field strength on July 18 was 2700 Gauss. (2) The corrected mean area of the aggregate of spots was $1412 \times 10^{-6}$ of the solar disk⁰. (3) The July disk transit of 59Q occurred in the early post maximum phase of a solar cycle (since the maximum of relevant cycle 19 took place in the previous year during March 1958).

These several relationships indicate that the strong complex photospheric fields underlying 59Q probably were such that the region was in a condition favourable to the production of those instabilities that lead to high levels of noise storm and Type III burst production.

## 4.9 The Association of Region 59Q With a Dense Overlying Coronal Structure

No direct information is available concerning the presence of a coronal streamer above region 59Q. However, optical swept wavelength records reveal that, at the chromospheric level, the region was spanned during its disk transit by a well defined dark filament whose boundaries were dependent on the positions of underlying spot umbrae.

As already indicated in Section 4.7, it is generally accepted that Type IV and Type I radiation is generated by charged particles trapped at different heights along magnetic field lines which loop upwards into the corona and Wild (1971) further significantly suggests that these magnetic loops may be the coronal counterpart of Hα loop prominences. This view is in line with models

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*Several authors report that the probability that a particular flare will be accompanied by a Type III burst increase considerably when that flare is already accompanied by a surge. Further to this, Giovanelli (1959) suggests that it may in fact be flare puffs, as defined by Giovanelli and McCabe (1958), which are associated with Type III bursts rather than the surges themselves. Since 'puffs' are not easily observed on ordinary flare-patrol films because of their short durations and small dimensions, this special line of investigation will not be followed in the present study.

**See details in Section 7.1.

+Great bipolar group; many small spots; length >10°, Waldmeier (1938).

⁰Magnetic information taken from Jonah et al. (1965). See also Chapter 7.

by Kuperus and Tandberg-Hanssen (1967), by Sturrock and Smith (1968), and by Pneuman (1968, 1969) who deduce theoretically that streamers develop along the neutral lines separating regions of opposite polarity. It also agrees with the observation by Newkirk (1971), that "coronal density enhancements appear over plages where the field strengths are higher than normal". See also a report by Axisa et al. (1971) that "coronal streamers are closely related to a magnetic neutral sheet and their cross section at 169 NHz essentially reflects the configuration of the underlying filament".

According to this model, Type IV (continuum) bursts associated on three occasions* during its July passage with major flaring in 59Q may provide evidence for the upward extension through the corona of that dark absorption feature seen on successive days overlying the region at the chromospheric level. It may be noted that the major flaring associated with Type IV radiation was of a kind designated by McKenna-Lawlor (1968) and in Section 6.1 as Prominence Flaring and involved the excitation of impulsive brightenings within lengths of the suspended dark material itself.

The Type IV radiation was in each case accompanied by strong prolonged noise storm activity. There is some doubt, cf. Sections 5.1; 5.3, as to the precise nature of the association between noise storms and flaring. However, the available data indicate that a high overall level of fluctuating noise storm activity, the latter possibly associated with internal motions within the dark bridge of absorption material overlying the active centre, was a persistent feature of the radio radiation associated with transiting region 59Q. The radio radiation was also probably generated within elevated levels of the dense dark structure seen on the optical records.

If it is accepted that the composite optical and radio observations indicate the presence above region 59Q of a density anomaly extending to great heights in the solar corona, then the very presence of such a dense structure may be indicative, cf. Section 4.7, that the region was in a sufficiently disturbed condition to be a frequent progenitor of Type III burst events.

### 4.10 The Association of Other Centres Traversing the Disk July 07-21, 1959, With Dense Overlying Coronal Structures and With Complex Magnetic Fields

No information is available concerning the presence of dense elevated coronal structures above the various other active centres transiting the disk July 7-21, 1959. However, it may be significant that: (1) The transit of region 59Q over the west limb on July 21 was accompanied by a dramatic cessation in Type I storm activity. This clearly indicates that the strong fluctuating noise storm reported on preceding days was specifically generated above this active centre rather than above any other. (b) Over the entire period of its disk passage, only region 59Q was characterized by the generation of flare associated Type IV radiation.

*Possibly four occasions, cf. Section 6.6, p. 69 and Table 6.6a, p. 88.

Table 4.10a (p. 47) lists comparative magnetic data concerning all simultaneously transiting sunspot groups. It is seen that, at these, Mt. Wilson $\gamma$ group 14284 was magnetically by far the most important.

These data indicate that, among the several active centres traversing the disk between July 7-21, 1959, region 59Q was the most likely to have been an efficient producer of radio bursts. Accordingly, under conditions when impulsive flaring in 59Q and in some other of these regions occurred simultaneously in time association with a particular Type III event, the likelihood is somewhat greater that the radio burst was specifically associated with region 59Q. Such probabilities are, however, too qualitative to be introduced into the calculations of Section 4.5.

## 4.11 The Association Between Type III Bursts and Motions of Dark Absorbing Material

Although most authors accept the idea that Type III bursts are often generated during the flash phase of flares, not all observed Type III bursts appear to be flare associated. Malville (1962) suggested a flare-burst association of the order of about 70 percent. However, there is currently no general agreement as to the percentage of bursts that may be meaningfully associated with other kinds of transient solar phenomena.

Associations between Type III bursts and dark filament activations have been discussed by several authors including Talmicha and Takakura (1963), McLean (1969, 1970), Palmer and Lin (1972), Martres et al. (1972), Axisa et al. (1973a, 1973b), Mercier (1973, 1974), Kane et al. (1974), and Priest and Heyvaerts (1974). Of special interest are the observations of Martres et al. and Axisa et al. who deduce that Type III bursts essentially occur in association with motions of absorbing material observed at ±0.75Å away from the Hα core. These motions are interpreted to take place in rather dense and cool material in the chromosphere or in the low corona, part of which moved downward and part upward. Type III events are thought to be more closely associated with the downward motion. It is suggested that, in relation with the moving feature, a stream of fast electrons is accelerated which, under suitable conditions, triggers both flare and Type III emission. In other instances Type III bursts alone are produced. This is in accord with the general observation that not all Type III bursts are flare associated.

## 4.12 The Association Between Type III Bursts and Motions of Absorbing Material in Region 59Q

In order to investigate if motions of absorbing material accompanied any of the Type III events deemed time associated with flaring in region 59Q, the available swept wavelength records were carefully searched for evidence of such burst associated motions. According to the observations of Axisa et al. (1973a, 1973b) the relevant absorbing feature should (a) lie along an inversion line of the longitudinal photospheric magnetic field ($H_{II}$ = 0 line) and (b) should be located at the border of an active centre, such that a portion of it lies inside the facula between a well-developed spot and a region of particular polarity. The external part lies outside the facula; hence in a region where the magnetic fields are weaker and more dispersed.

It was found that all of the 76 Type III associated flares identified in region 59Q occurred along the borders of active dark absorbing material obeying the 'Axisa criteria'. However, this material showed almost continuous internal activity on flare active days and these motions could not be unambiguously distinguished from transient perturbations of the special kind noted by Axisa et al. (1973a, 1973b). No case was identified of a Type III burst occurring in association with perturbations of active dark material in region 59Q in the absence of flaring. However, over the period July 7-21, 1959, some 63 Type III bursts occurred which could not, either because of the unreliable nature of the available time associated optical observations or in the complete absence of optical observations, be time correlated with activity in any disk region. It is possible that members of this relatively large group might have included Type III bursts which were not specifically flare associated.

TABLE 4.10a

Comparative Data Concerning Important Sunspot Groups Transiting the Solar Disk from July 7-21, 1959

| Mt.Wilson number | Days seen | McMath plage number | Mt. Wilson magnetic class | Days from July 7-21 when Zürich class was > Type C | | Corrected mean area of whole spots |
|---|---|---|---|---|---|---|
| | | | | Days | Zürich class | Millionths of solar disk |
| 14263 | June 29-July 10 | 5244 | dβ pl | July 07 | E | 355 |
| | | | | 08 | D | |
| 14269 | June 29-July 11 | 5244 | dβ 1 | July 07-10 | E | 609 |
| 14284 | July 08-July 21 | 5265 | 1γ 1 | July 09-16 | H | 1412 |
| | | | | 17-20 | E | |
| 14287 | July 10-July 14 | 5271 | dβ pl | July 12 | D | 326 |
| | | | | 13 | E | |
| 14288 | July 11-July 17 | 5264 | dβ pl | July 12-14 | E | 460 |
| | | | | 15-17 | G | |
| 14290 | July 11-July 17 | 5273 | 1α d | July 11-12 | J | 32 |
| 14296 | July 13-July 26 | 5280 | 1α pl | July 14-15 | H | 392 |
| | | | | 21 | H | |

## CHAPTER 5

# THE ASSOCIATION OF NOISE STORM ACTIVITY WITH OPTICAL EVENTS IN REGION 59Q

The association of centimetre burst associated flaring in 59Q with noise storm activity is investigated and it is suggested that, excluding events of Type IVc and a sudden storm cessation, such close time associations between the data as exist either represent consequences of special solar circumstances that simultaneously support both, potentially independent, manifestiations of activity or they are alternatively due only to chance. It is cautioned that the adoption of statistical procedures in correlating storm events with flaring should only be attempted when the observational data available is very complete and unambiguous. Reported storm activity was especially time associated with periods when strong internal motions were present in prominence material overlying 59Q. It is expected that variations in the configurations of elevated magnetic fields, evoked by changing conditions in the photosphere, should, whether they play an initiating role or not, modulate the conditions under which flares and noise storms can be produced at particular times.

## 5.1 The Association Between Noise Storms and Solar Flares

Noise storm radiation consists of a background continuum with superimposed bursts of short duration and fine structure. The bursts associated with noise storms were classified as Type I by Wild and McReady (1950) and they are also known as "storm bursts". (There is some controversy as to whether the storm bursts should be considered as phenomena which are fundamentally distinct from the background continuum, although both appear to originate from the same source.) Again, Wild, Smerd and Weiss (1963) define Type I noise storms to consist of long series of bursts, sometimes accompanied by continuum radiation, recorded at metre wavelengths. Noise storms are associated with large sunspots of high magnetic field strengths, Payne-Scott and Little (1951). The size of the order of 1.2' - 4.5' at 169 MHz, Daigne (1968). Also, Kai (1970) and McLean and Sheridan (1972) indicate that they frequently contain double, multiple or bipolar structure at 80 and at 160 MHz. Type I sources are not usually situated radially above an active region but are rather displaced by a few minutes of arc, Le Squeren (1963). The locations of separated sources of Type I activity have been used to infer the presence above active regions of large scale magnetic loops within the 'legs' of which the Type I activity is generated. In some instances the arched field lines may form connections between active centres which appear 'separated' on the disk. See Daigne et al. (1971), Newkirk (1971), Trotter and Newkirk (1971), and Dulk and Nelson (1973).

The evidence for the association of noise storm activity with flares is conflicting. Dodson et al. (1953) and Dodson (1958) found some evidence that flares coincide with or precede noise storms observed at 200 MHz. Swarup, Stone and Maxwell (1960) however criticized these results on the basis that they are not statistically significant. They point out that, since noise storms may last for several days with considerable intensity fluctuations, chance associations will be numerous with Dodson's time base of the flare life time plus 30 min, at either end.

The same criticism should apply to a report by Maligne (1960) that about 92% of noise storms are preceded within 2 hours by a flare.

Fokker (1960) investigated noise storms recorded over the period 1956-1959 on 200 MHz at the Nera Observatory. He concluded that, while some of these events were preceded within only a few minutes by flares and were apparently caused by these flares, others occurred without any previous flare activity. Some of the flares considered to give rise to a storm were optically important but others were quite minor.

A distinction may be made between noise storms and prolonged flare-associated enhancements at metre wavelengths. These latter, according to Pick (1961) constitute a third phase of Type IV emission (Type IVc), especially characterized by their directivity of emission. The flux density on 169 MHz can reach values greater than $10^{-19} W\ m^{-2} Hz^{-1}$ although there may sometimes be wide variations in this flux which are not apparently flare associated. Gradually, Type I bursts start to occur and ultimately the emission becomes 'ordinary noise storm' - Pick (1961), Boischot and Pick (1962), Wild (1970, 1971), and Kai and Sekiguchi (1973)*.

The probability of occurrence of Type IVc was shown by Pick (1961) to depend largely on the energy radiated at centimetre wavelengths in the early part of the flare (say on a wavelength of 10 centimetres). When this energy is greater than $50 \times 10^{-17} Jm^{-2} Hz^{-1}$ the probability of observing Type IVc is greater than 70%. Further, the flares associated with this emission are of greater importance (about 60% of importance 3 and 3+) than those occurring without it. It seems likely that many of the phenomena which were considered by Dodson (1958) as flare associated noise storms had the nature of these Type IVc radio events.

Smith and McIntosh (1962) defined a noise storm as a Type I noise burst or continuum and considered such a radio event to be associated with a specific flare if it started or increased in intensity within $15\text{-}17^m$ of the start of that flare. Using a statistical technique, based on the assumption that both flares and bursts are randomly distributed in time, they showed that when subflares are included, the association between flares and noise storms is not statistically significant although "the association improves with increasing flare importance and more especially with increasing flare brightness". A revision of these data by Smith (1962), such that Type V events were excluded from the counts, indicates that Type I activity is statistically associated with flares of importance 1 and greater but only slightly so. According to these figures, the percentage association of flares of importance ⩾1 with Type I events is between 2-4% and the corresponding association with flares of importance ⩾2 is between 7-10%.

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*See also Section 4.7.

5.2 <u>The Association of Centimetre Burst Associated Flaring in 59Q With Noise Storm Activity Occurring up to ~$30^m$ Later</u>

In the present study, not all impulsive brightenings in 59Q but specifically those identified, using the Criteria of Section 4.3, as closely 'time associated' with the generation of centimetre wave radiation were examined to see if they might have been followed within ~$30^m$ by the onset of noise storm activity.* Such a relationship would correspond with an average velocity of the order of 150 km/s for a flare associated perturbation to travel from the chromosphere to the corona at the place of origin of 169 MHz noise storms, Kundu (1965).

Within the period July 7-21, 1959, 53 centimetre wave bursts were found to be time associated with flaring in region 59Q. (31 'Unambiguous' and $18^1/3$ 'Probable' associations.) This total includes centimetre wave bursts occurring in the presence and in the absence of various kinds of reported swept frequency events as well as broad band bursts extending to decimetre or metre wavelengths.

Of these 53, one was characterized by the apparently time associated cessation of a strong Type I noise storm**; 18 events were followed within $\leqslant 32^m$ by a storm event and 3 further centimetre bursts occurred directly within certain of these $32^m$ intervals; 13 bursts were not followed within $\leqslant 32^m$ by an impulsive storm event and 18 bursts could not be correlated over so long a time base with the available data. The 18 centimetre wave bursts found to be followed within $\leqslant 32^m$ by noise storm activity are listed in Table 5.2a, p. 55+ with five other events which individually either occurred during intervals of poor seeing or

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*In this context, the special relationship noted in Section 4.10 between noise storm activity and region 59Q is recalled.

**A cm-m wave burst accompanying the importance 3+ flare of $02^h05^m$ U.T. on July 10; noise storm cessation from $02^h\ 09^m$ U.T.

+A tentative attempt is made in Table 5.2a to determine if any of the succeeding storm events might have comprised members in long lived series of related fluctuations. In this connection, a noise storm event is arbitrarily deemed to form a member of a 'group' if it occurred within Ih of that noise storm immediately preceding it. Although at least 10 separate sequences of storm events are resultingly "identified" as possibly initiated by preceding centimetre burst associated flaring in 59Q, it is felt that no real reliance can be placed on the method since (1) days on which sequences of related events are "identified" were days on which the level of noise storm activity was already so high that the influence of particular flares in modulating it is highly suspect; (2) when the Sun is highly active, there are multiple ways in which particular fluctuations might be considered associated with preceding flaring and the specific choice of any one of them is a subjective matter; (3) within the compass of the relatively long time base adopted, pertaining solar circumstances suggest that there should be many chance coincidences; and (4) in the absence of positional information, it is not certain that all events "counted" as associated with 59Q really occurred above this region.

were associated with flaring in regions other than 59Q. Of these, at least those events associated with the generation of long duration continuum radiation on July 9, 14, and 16 appear to have been events of the kind defined by Pick (1961) as Type IVc (cf. Section 5.1 and compare Table 5.2a with Table 6.6a, p. 88).

Within that same interval when 18 storm events were observed to occur within $\leqslant 32^{m}$ of centimetre burst associated flaring in 59Q, 75 storm events (well distributed over the period July 07-21) occurred which were not preceded within $\leqslant 32^{m}$ by a centimetre wave burst, or even by members of any obvious series of Type I storms plausibly initiated by such a burst.*

It is feasible then, excluding events of Type IVc and also the noise storm cessation of $02^{h}$ $09^{m}$ U.T., July 10, that such correlations between Type I storms and centimetre burst associated flaring as do exist either represent consequences of special solar circumstances that anomalously support, at the same time, both potentially independent manifestations of activity or they are alternatively due only to chance.**

Further to these possibilities, investigation of the individual intervals between the commencements of reported Type I storms and the corresponding beginnings of preceding centimetre wave associated brightenings (column 5, Table 5.2a, pp. 55-56), reveals that, on several occasions, storm onsets succeeded ratio important flaring by only a few minutes.

Such close time associations would suggest the ability, under certain circumstances, of the solar atmosphere to generate a Type I noise storm practically simultaneously with centimetre burst associated flaring. The observations do not however constitute definite evidence of this. (It should be specially noted that the radio events relevant to these close time associations did not include the most energetic centimetre wave bursts in the sample.)

It is associatively recalled that several members of that group of noise storms previously reported by Fokker (1960) as "convincingly flare associated" (using five years of data obtained at Nera Observatory) also followed their corresponding flares within only a few minutes while, in addition, the relevant flares were optically quite minor and not necessarily associated with the generation of centimetre wave bursts.

As noted by Elgarφv (1977), other characteristics than flare importance may be critical in determining whether, in a particular instance, a noise storm is triggered or not and "it seems very reasonable to assume that the structure of the corona and the magnetic field strength above the active region must be taken into account in this connection". See Wild and Zirin (1956) who demonstrated that there is a close connection between the ordering of the coronal material by those solar magnetic fields producing loops and streamers and the production of radio noise storms.

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*See the footnote to page 51.

**A meaningful statistical analysis of the results cannot be attempted in the absence of sufficiently complete experimental data. See also Section 5.3.

## 5.3 The Statistical Association Between Type I Storms and Flaring in Region 59Q

An attempt was made to determine the statistical association between Type I storms and flares in 59Q following Smith and McIntosh (1962) - using a selected interval of 7045 m covered by simultaneous optical and radio spectroheliograph observations (the observing times covered by the Ann Arbor instrument were excluded since no Type I storms were associatively reported during the transit of 59Q). Within the selected period, 88 individual Type I storms occurred of which 33 could be closely time associated with impulsive flaring in 59Q. At other times, minor gaps in the record due to cloud and simultaneous activity in different parts of the disk compounded those uncertainties already existing in correlating the data due to lack of positional observations of the relevant noise storm sources.

Also, it could not be assumed* that flares and noise storms were uniformly distributed in time since, at least following the importance 3+ flare of July 10, there was an abrupt and apparently flare associated cessation in a strong Type I noise storm (cf. footnote p. 51) from which condition "recovery" took something of the order of two days - while an associated drop in flaring in 59Q was reversed much more rapidly.

In the light of these uncertainties and in the situation that fluctuating storm activity generally already preceded those several intensity enhancements seen to be closely time associated with particular storm events, a statistical treatment was deemed an unsuitable vehicle for finding meaningful correlations. It is cautioned that the adoption of such procedures should only be attempted when the available observational material is very complete and unambiguous.

## 5.4 The Association Between Type I Storm and Filament Activity in 59Q

Examination of the swept wavelength records indicates that a high level of storm activity was characteristically associated with those occasions when a 'bridge' or filament of dark absorbing material traversing region 59Q showed strong internal motions. No special storm activity was correspondingly reported on 'quiet days'.

Although filament activation and filament ascent often directly precede an outbreak of flaring, filamentary activity can endure for long periods in the complete absence of such flaring. Filament activations provide in themselves a sensitive indicator of magnetic instabilities within an active centre and it is significant that in the present case the emergence and disappearance of underlying umbrae characterised those days when filamentary motions and reported storm activity was particularly marked (cf. Chapter 7).

It is possible to envisage a situation where filamentary activation at the chromospheric level and noise storm radiation generated at a high level within the same dense overlying structure might represent different manifestations of a transient instability within the active centre. In certain circumstances optical flaring might additionally be associatively or independently produced.

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*As required by the Smith and McIntosh method.

It cannot presently be inferred what special characteristics might pertain to disturbances producing (a) noise storm onsets or cessations associated with the commencement of impulsive flaring, (b) storm events unassociated with optical flaring, or (c) impulsive flaring unaccompanied by the initiation or discontinuation of storm activity. However, it appears at least a prerequisite that a dome of magnetic loops, rooted in strong underlying sunspot fields, should be present above an active region within which these various phenomena can be produced. It is expected that variations in the configurations of these elevated fields, evoked by changing conditions in the photosphere, should, whether they also play an initiating role or not, provide in individual circumstances suitable environmental conditions within which these various phenomenological events can be produced.

TABLE 5.2a

Possible Association of 'Series' of Type I Storms with Preceding Flare Associated Radio Bursts on Centimetre Wavelengths July 7-21, 1959*

| Date 1959 | Radio burst on centimetre wavelengths assoc. with impulsive flaring | | | First Type I event succeeding the cm burst in $\leq 32^m$ | | | | Further Type I events, possibly* representing members of a series associated with the original cm wave burst | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Freq.**, MHz | Beg. U.T. | End. U.T. | Int. | Period** covered U.T. | Duration, mins. | Interval from commencement of cm burst to commencement of Type I event, mins. | Int. | Period** covered U.T. | Duration, mins. | |
| 9 | 9400 | 1440.8 | 1446.1 | 1 | (1504-1505) | 2 | 23.2 | | | | Type V event at $14^h$ $41^m$ U.T. Simultaneous Type III. Reported Type I of greater duration than a typical Type V burst*. |
| | 2800 | 1810 | 2410 | 1 | 1812-1822 | 11 | 2.0 | | | | |
| | | | | | | | | 1 | 1910 | 1 | |
| | | | | | | | | 2 | 1917-1919 | 3 | |
| | | | | | | | | 1 | 1940-1948 | 9 | |
| | | | | | | | | 2 | 1948-1953 | 6 | |
| | | | | | | | | 1 | 2001-2017 | 17 | Type V event at $20^h$ $19^m$ U.T. |
| | | | | | | | | 1 | 2028-2038 | 11 | |
| | 2800 | 2042 | 2102 | 1 | (2054-2118)$^x$ | 25 | 12.0 | | | | Type V event at U.T. |
| | (2000) | <2150 | >2205 | 2 | (2204-2205) | 2 | 14.0 | | | | |
| | 2800 | 2218 | 2236 | 1 | (2240-2257) | 18 | 22.0 | | | | |
| | | | | | | | | 2 | (2313) | 1 | |
| | | | | | | | | 2 | (2348-0142) | 115 | |
| 10 | | | | | | | | 2 | (<0000-0209) | >130 | |
| 12 | 2800 | 2008 | 2020 | 1 | (2028-2048) | 21 | 20.0 | | | | High level of Type I activity previous to $20^h$ $08^m$ U.T. |
| | | | | | | | | 1 | (2102-2132)$^x$ | 31 | |
| | | | | | | | | 1 | 2157-2210 | 14 | |
| | 2800 | 2207 | 2407 | 1 | 2211-2226 | 16 | 4.0 | | | | Type I in progress with possibly superposed Type V in association with a cm burst at $22^h$ $24^m$ U.T. |
| | (2800)$^x$ | 2248 | 2253 | 1 | (2302-0039) | 98 | 14.0 | 1 | (<2315-0026) | >72 | |
| 13 | | | | | | | | 1 | (0040-0054) | 15 | |
| | | | | | | | | 1 | (0110-0144) | 35 | |
| | | | | | | | | 1 | (0219-0233) | 15 | |
| 14 | 9400 | 0330 | 0349 | 3 | 0401-0610 | 130 | 31.0 | | | | Type V event at $17^h$ $33^m$ U.T. Simultaneous Type III at $17^h$ $48^m$ U.T. The reported Type I is of greater duration than a typical Type V burst. |
| | (2800)$^x$ | 1443 | 1513 | 1 | (1515-1609)$^x$ | 55 | 32.0 | | | | |
| | 2800 | 1734 | 1744 | 1 | 1747-1832 | 46 | 13.0 | | | | |
| | | | | | | | | 1 | (1924-2018) | 55 | |
| | | | | | | | | 1 | (2040-2108) | 29 | |
| | | | | | | | | 1 | 2131 | 1 | |
| | | | | | | | | 1 | (2151-2155) | 5 | |
| | | | | | | | | 1 | 2217-2223 | 7 | |
| | 9400 | 2223 | 2229 | 1 | 2241-2259 | 19 | 18.0 | | | | Reported Type I event with possibly superposed Type V burst endures from $22^h$ $23^m$ - $22^h$ $33^m$ U.T. |
| | | | | | | | | 2 | (2259-2302) | 4 | |
| | | | | | | | | 1 | 2305-2342 | 38 | |
| | | | | | | | | 1 | (2343-2348) | 6 | |

*A Type I storm is arbitrarily deemed to form a member of a related group if it occurred within $1^h$ of that Type I preceding it.

**Events listed in brackets occurred during periods of poor seeing and were not associated in Chapter 4 with any specific region. Events listed in brackets with the superscript x were previously deemed, according to the criteria of Section 4.1, associated with flaring in regions other than 59Q.

TABLE 5.2a - Concluded

| Date 1959 | Radio burst on centimetre wavelengths assoc. with impulsive flaring | | | First Type I event succeeding the cm burst in $\leq 32^m$ | | | | Further Type I events, possibly* representing members of a series associated with the original cm wave burst | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Freq.**, MHz | Beg. U.T. | End. U.T. | Int. | Period** covered U.T. | Duration, mins. | Interval from commencement of cm burst to commencement of Type I event, mins. | Int. | Period** covered U.T. | Duration, mins. | |
| 15 | 9400 | 1257 | 1339.6 | 2 | 1255-1300 | 6 | -2.0 | 1 | (0017-0111) | 55 | Possibly the reported commencement time of one of these bursts is in error. |
| | 2800 | 1327.5 | 1330 | 1 | 1331 | 1 | 3.5 | | | | Event at $13^h$ $31^m$ U.T. might rather have been associated with a cm burst at $13^h$ $00^m$ U.T. |
| | | | | | | | | 1 | 1348-1430 | 43 | |
| | | | | | | | | 1 | (1445-1457) | 13 | |
| | | | | | | | | 1 | (1512-1521) | 10 | |
| | | | | | | | | 1 | (1549-1558) | 10 | |
| | 9400 | 2240 | 2250 | 1 | 2243-2303 | 21 | 3.0 | | | | Type V events at $23^h$ $28^m$ U.T. and at $23^h$ $38^m$ U.T. |
| 16 | | | | | | | | 1 | 0019-0127 | 9 | Type V events at $00^h$ $00^m$ U.T. and at $00^h$ $59^m$ U.T. |
| | 2800 | 1351 | 1441 | 1 | 1404-1415 | 11 | 13.0 | | | | |
| | | | | | | | | 1 | 1454 | 1 | |
| | | | | | | | | 1 | 1535-1622 | 48 | |
| | 2800 | 1613 | 1622 | 2 | 1622-1631 | 10 | 9.0 | | | | Event at $16^h$ $22^m$ U.T. might rather have been associated with cm bursts of $16^h$ $06^m$ U.T. or $16^h$ $10^m$ U.T. |
| | | | | | | | | 1 | 1640-1654 | 15 | |
| | | | | | | | | 1 | 1658-1702 | 5 | |
| | | | | | | | | 1 | $(1716-1725)^x$ | 10 | |
| | | | | | | | | 1 | (1736-1755) | 20 | |
| | | | | | | | | 1 | (1810-1813) | 4 | |
| | | | | | | | | 1 | 1909-1916 | 8 | |
| | | | | | | | | 1 | 1939-2010 | 32 | |
| | | | | | | | | 1 | (2011-2024) | 14 | |
| | | | | | | | | 1 | (2100-2101) | 2 | |
| | 2800 | 2118 | 2418 | 1 | <2241-0440 | >360 | <83.0 | | | | |
| 17 | 9400 | 0041 | 0042 | 1 | (0113-0124) | 12 | 32.0 | | | | |
| | 2800 | 1340 | 1423 | 2 | 1343 | 1 | 3.0 | | | | |
| | (9500) | 2117 | >2227 | 1 | (2148-2158) | 11 | 31.0 | | | | |
| | | | | | | | | 1 | 2223 | 1 | Identity of associated flare uncertain. |
| 18 | 2800 | 1811 | 1814 | 1 | (1841-1842) | 2 | 30.0 | | | | |
| | | | | | | | | 1 | 1922-1931 | 10 | |
| | | | | | | | | 1 | (1954-2212) | 139 | |
| | | | | | | | | 1 | (2230) | 1 | |
| 19 | $(1000)^x$ | 0053 | 0058 | 1 | (0123-0127) | 5 | 30.0 | | | | Type V event at $00^h$ $54^m$ U.T. |
| Totals: | $18+(2)+(3)^x$ | | | | $12+(9)+(2)^x$ | | | | $19+(23)+(2)^x$ | | |

*A Type I storm is arbitrarily deemed to form a member of a related group if it occurred within $1^h$ of that type I preceding it.

**Events listed in brackets occurred during periods of poor seeing and were not associated in Chapter 4 with any specific region. Events listed in brackets with the superscript x were previously deemed, according to the criteria of Section 4.1, associated with flaring in regions other than 59Q.

CHAPTER 6

# IDENTIFICATION OF DIFFERENT KINDS OF FLARING IN REGION 59Q, THE OPTICAL CHARACTERISTICS OF THESE PHENOMENA AND THEIR RESPECTIVE ASSOCIATIONS WITH THE GENERATION OF RADIO, IONIZING AND PROTON RADIATION

Two apparently different types of optical flare are identified in 59Q and described as Prominence Flares and Plage Flares, respectively. Prominence Flares are shown to be of three varieties individually named 'Stationary', 'Moving' and 'Impact' Prominence Flares. These phenomena are compared on the basis of their optical characteristics and of their association with the production of radio, ionizing and proton radiation. An attempt is made to determine the relative frequency of occurrence within the active region of Plage and Prominence Flares.

## 6.1 General Optical Characteristics of Prominence and Plage Flares

Smith and Smith (1963) defined a solar flare to consist of "a sudden, short-lived brightening of a localized area of the chromosphere, seen in monochromatic radiation, usually Hα or Ca II K". These authors point out that it is difficult to make a clear distinction between flares and very active, bright, short-lived prominences. Since some prominences at the limb are called flares on the basis of their brightness in Hα, Menzel (1960, 1961) has suggested that certain events identified in the literature as "disk" flares may really have been bright loop prominences. McKenna-Lawlor (1968), assuming only that a flare consists of a sudden, transient, localized brightening recorded on an Hα or K spectroheliogram, distinguishes between two types of event termed Prominence Flares and Plage Flares, respectively.

Prominence Flares consist of impulsive brightenings within lengths of absorbing material (prominence material in projection on the disk) which do not appear to be coincident with the plage network. In some cases the bright prominence material maintains its spatial position relative to features within the underlying plage network, thus exhibiting the condition defined by McKenna Lawlor as 'Stationary Prominence Flaring'. At other times the flaring prominence material changes its spatial position relative to the plage network in the course of the observed activity to constitute the phenomenon termed 'Moving Prominence Flaring'. A further kind of brightening within dark prominence material not previously described by McKenna Lawlor will be designated here by the term 'Impact Prominence Flaring'. The special optical characteristics of these three varieties of Prominence Flare, together with those of Plage Flares, will now be discussed separately.

## Stationary Prominence Flares

Stationary Prominence Flares appear to show a flash phase as defined by Ellison (1949) and (1963), that is a period during the early (pre-maximum) part of the event in which there is a rapid increase in Hα line width. At periods of high activity and under solar circumstances when long chromospheric chains* are aligned in a simple manner along regions of opposite longitudinal magnetic fields, flare excitation is seen to spread horizontally along the magnetic inversion line from the site within the prominence of the initiating disturbance. This very rapid expansion of flare borders corresponds with the explosive phase defined by Moreton (1964). Excitation which spreads in this way tends to be bright and diffuse. Localized intensity increases showing line width variations are sometimes observed to occur within diffuse bright material at locations overlying flare active areas within the plage network. These events can, in particular circumstances, either represent cases where Plage Flaring is seen through amorphous superposed Prominence Flaring or indicate localized enhancements within the flaring prominence material itself.

## Moving Prominence Flares

In certain instances when, according to the process described above, the spread of excitation on either side of the magnetic inversion line had resulted in the formation of two bright 'ribbons' within suspended prominence material, these flaring elements are seen to gradually separate with velocities of up to about 10 km/sec. The velocity of recession in particular instances appears to be dependent on the strength of the magnetic field in the flare region. Sometimes only one bright filament of the pair moves, thus constituting the phenomenon described by McKenna Lawlor as a 'One Arm Moving Prominence Flare'. When both filaments move the event is termed a 'Two Arm Moving Prominence Flare'. The position away from which the filaments drift is the magnetic 'neutral line'.

## Impact Prominence Flares

Several authors including Dodson and Hedeman (1952), Roberts and Billings (1955), Kleczek (1963), Jeffries and Orrall (1964), Sturrock and Coppi (1965), Hyder (1967a, 1967b, 1968, 1973), Bruzek (1969b), Nakagawa and Hyder (1969), Dodson et al. (1973), Nakagawa et al. (1973), Michalitsanos and Kupferman (1973), Rust and Bar (1973), Tandberg-Hansen (1973), Zirin (1974), and de Jager (1975) have considered the relationship between falling material and the occurrence of transient brightenings in Hα at the apparent place of impact.

At present the physical processes involved in producing such emission is in some dispute. In particular, Hyder's well known 'infall-inpact' mechanism, described in Hyder (1967a), has been criticized by Michalitsanos and Kupferman (1973), Rust and Bar (1973), and Zirin (1974). It may however, be inferred, in

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*Components of the bright chromospheric network of the plage in region 59Q tended to align themselves in chains.

view of the many reported cases, that the relationship between falling material and the production of at least sub-flare brightenings in the chromosphere is probably 'real' although details of the actual processes involved are as yet not fully understood.

On the McMath swept wavelength records, falling material is typically seen to traverse curvilinear trajectories which apparently follow magnetic field lines rooted in underlying spot umbrae. Sometimes, a number of well defined brightenings (of sub-flare intensity) occur in diffuse dark prominence material, appearing in projection to lie across the paths of the descending streams. Such brightenings appear to be situated directly above the positions of those umbrae towards which the falling material is travelling. At other times, an extensive length of the intercepting material goes into general diffuse emission. When viewed in profile at the limb, excitation associated with falling material is sometimes seen to spread laterally to form a supernatent layer on a previously present dark prominence structure*. On the premise that minor brightenings in prominence material situated along the tracks of descending jets of matter are interrelated, such events will hereafter be referred to in the text as Impact Prominence Flares.

### Plage Flares

In contrast to the various kinds of Prominence Flares described above, Plage Flares, as originally defined by McKenna Lawlor (1968), comprise brightenings within part of the plage network composing active centres. During such events, an area of this network showing sharp well-defined edges will brighten impulsively and it is characteristic of such flare sensitive areas that they retain their positions relative to other features within the plage for the duration of the activity.

Some of them recur and can be recognized on successive days. Plage Flares that appear simultaneously in close proximity to one another in the same active centre often show emissions of quite different line widths in Hα and also in K.

## 6.2 Stationary, Moving and Impact Prominence Flaring Observed in Region 59Q

One of the most striking characteristics of region 59Q during its disk transit, July 7-21, 1959, was its ability to eject prominence material. These ejecta were visible on July 7 and 21 respectively in profile against the sky and on other days they appeared as absorption features projected against the disk. Although much of the ejected material was observed on limb pictures and on swept wavelength records to fall back towards the chromosphere, a considerable portion of it apparently remained trapped in the strong magnetic fields above the region. This trapped material appeared as a diffuse dark cloud within which well-defined slender filaments of absorption material were embedded. When region 59Q was near the east limb, only one well-defined dark filament was

*This may be analogous to the disk observation already described. See also Appendix C1, p. 187 and Fig. C1-c, p. 204.

visible spanning the spot group. This structure terminated to the north and south of the active centre in well-defined prominences. With time, as the effects of spot motion and differential solar rotation deformed the region in a roughly east west direction, the suspended bridge of dark absorbing material became similarly aligned and more internally complex.

Fig. Bl-b, p. 203, shows the absorbing material as it appeared on July 16. Well-defined slender filaments visible on this day within the general diffuse dark matrix are shown stippled. Intercomparison of this drawing with the magnetic data in the study of Howard and Severny (1963a), shows that the filamentary material between the large spots of north and south polarity (N 27 and S 28) lay close to the neutral line of the longitudinal magnetic field. To the east, individual widely separated filamentary loops curved first northward, then back towards a position near the centre of the region where minor umbrae were located. To the west, the filamentary structures extended southward, with one strand curving inward towards a minor spot group separated from the main magnetic complex. Thus the boundaries of the dark material were dependent on the positions of minor umbrae.

This suspended prominence evidently formed a relatively dense sheet of matter supported in the solar atmosphere by the photospheric magnetic fields. In common with prominence material observed at the limb, its detailed internal structure appeared to consist of a system of arches, the individual 'feet' of which were deduced, from a comparison of spectroheliograms taken in the red and blue wings of the Hα and calcium lines, to pass through components of the bright chromospheric network of the plage.

## Stationary Prominence Flaring in 59Q*

On the occasions of Stationary Prominence Flaring in 59Q, part of the suspended dark prominence material went into bright emission. This emission tended to commence within the "shoulder" of a dark arch, the lower extension of which passed through a flare active area of the underlying chromospheric network. The simplest case observed comprised an impulsive brightening on one side only of a dark arch. Such an event may be called a 'single site' Stationary Prominence Flare. Similarly 'double site' and 'multiple site' Stationary Prominence Flares occurred and it may be noted that such events occurred either on the same side or on opposite sides of the neutral line passing through the crest of the overall system of dark arches. In the latter case, individual flare sites were not necessarily connected by common flux tubes.

On the occasions of more optically important events, bright emission was seen to spread very rapidly along the "shoulders" of adjacent prominence arches from those positions within the dark material at which brightenings first occurred. The resulting flares thus presented the appearance of bright, and sometimes approximately parallel 'ribbons' traversing the active centre. {This is in line with observations from Skylab which indicate that "the two Hα ribbons

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*This account is based on a careful study of all Stationary Prominence Flares identified in the region.

of a flare represent rows of 'foot-points' of magnetic loops extending into the corona" (Švestka, 1976), although it is envisioned here that the "ribbons" represent the locus of flaring at a particular stratum within a set of adjacent loops, the legs of which extend on downwards through the chromospheric network into the underlying photosphere.} On the occasions of particularly spectacular flares, the crests as well as the 'shoulders' of the suspended prominence arches went into brilliant emission, thus presenting the condition of flaring above the magnetic 'neutral line'.

Since, with the exception of that emission generated in the crests of the suspended arches, Stationary Prominence Flaring was superposed over flare active chains of the chromospheric network, it was generally necessary to consult the large scale, swept wavelength pictures from the McMath Tower Telescope in order to determine unequivocably if Prominence rather than Plage Flaring was present at any particular time. The most difficult case for identification was the 'single site' Stationary Prominence Flare which could only be distinguished optically from Plage Flaring by its irregular shape and diffuse appearance. The simplest case to identify was flaring in the crests of prominence arches which could readily be identified on the swept wavelength records going in and out of emission.

Careful observations suggest that, among 1,006 separate brightenings observed in 59Q over $136.1^h$ of selected McMath observations (cf. Section 3.2) 199 constituted intensity increases within suspended prominence material. This number includes 6 brightenings in suspended Prominence Material deemed to constitute components of Impact Prominence Flares. The relevant flaring material remained stationary relative to underlying features of the chromospheric network throughout the duration of the observed activity. Since Stationary Prominence Flares tended in general to be long lived events showing multiple intensity increases, some of the brightenings counted comprised enhancements within already flaring material. This draws attention to a difficulty. In many instances, parts of the film record were overexposed for long periods (sometimes up to several hours) during prominence flaring, and many additional enhancements potentially occurring during these extended time intervals could not accordingly be detected.

This must render counts of such brightenings as can be recorded of doubtful inventorial value. It is therefore deemed hereafter expedient to choose to consider intensity fluctuations occurring within already flaring material as forming part of earlier events rather than to count individual brightenings separately.

In circumstances when region 59Q was already highly active, this procedure involves some subjectivity in deciding what comprised an enhancement and what a separate flare. With this difficulty in mind, however, a total of 10 composite Stationary Prominence Flares, some of them showing complex changes, can be identified in region 59Q over the period of the McMath observations.

In view of the fact that Stationary Prominence Flares are often spectacular long lived events, the Continuous Solar Movie (despite its variable minute to minute quality) is in general quite suitable for use in detecting these phenomena. A search of these additional records then over the full period

July 7-21, 1959, enables a total of 30 composite Stationary Prominence Flares to be identified in region 59Q during its disk transit. The starting times of these events are listed in Table 6.2a, p. 75* and the more optically important of these flares are described in Appendices A-B. Only one 'composite' Moving Prominence Flare, also listed in Table 6.2a, was detected in 59Q during its July transit. This event was, according to the terminology of McKenna Lawlor (1968), a 'Two Arm Moving Prominence Flare'.

## Impact Prominence Flaring in Region 59Q

Transient optical brightenings apparently associated with falling material and referred to by the term Impact Prominence Flares were identified in 59Q under two conditions: (a) when in profile against the limb and (b) on swept wavelength records.

Clearly limb observations were only relevant while the region was at very high solar longitudes. On intermediate days, while the McMath swept wavelength records were excellent for the purpose of identifying brightenings associated with falling material, they were only available for 23% of the McMath sunlit hours (i.e. 9% of the total transit time). It is thus very possible that many examples of Impact Flaring in the region cannot be identified in the absence of suitable swept wavelength pictures.

In estimating the total number of Impact Prominence Flares present in the available data, it was decided (a) to consider multiple brightenings occurring along part of a well defined 'column' of falling material as constituting components of a single composite event and (b) to consider brightenings apparently produced by flare associated ejections from other parts of the active region as events in their own right. In this way, 8 Impact Prominence Flares were identified in region 59Q during its July disk passage. Of these, 3 events were observed at the limb; 3 were associated with dark material falling within loop prominence systems during the post maximum phases of major flares and 2 were identified on the disk using swept wavelength pictures. Cf. Appendix C and Table 6.2b, p. 76.

## Plage Flaring in Region 59Q

Over the period of the July transit of region 59Q, plage flaring was often seen to commence either simultaneously or in close association at a number of

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*No distinction is made ascribing a letter to a flaring area (as individually illustrated in Figs. 3.1a-3.1j, pp. 25-34), between brightenings occurring in the plage itself and those brightenings occurring in superposed prominence material. In Tables 6.2a and 6.2c, however, on the basis of either direct comparisons between the McMath SECASI and swept wavelength observations or of identifications made as a result of prolonged experience in recognising the individual characteristics of these separate flare types on the film, a differentiation may be made between Prominence and Plage events.

different locations within the active centre. It is thus necessary to decide whether to count such events separately or to consider them to comprise 'composite' events.

Swept wavelength records show that plage brightenings which appear simultaneously in close proximity to one another often show emissions of quite different line widths in Hα and also in K. On the other hand, simultaneous brightenings occurring in widely separated areas of the plage can show on occasions very similar line widths. Although it well may be that at least a fraction of the simultaneous plage brightenings observed in 59Q constituted related responses to 'primary' solar disturbances within this active centre, a decision as to which events might and might not have been 'truly' associated at any particular time is a prey to fallibility of judgement. In contrast then to the procedure adopted in counting Stationary and Moving Prominence Flares it seems less subjective to count all individual plage brightenings observed as separate events.

Of 1,006 impulsive brightenings observed in region 59Q during $136.1^h$ of selected McMath SECASI observations, 807 events, individually listed in Table 6.2c are deemed by this method to have been Plage Flares (cf. p. 77).*

## Association of Plage Flares With Surges

Due to the handicap of a fixed pass band, the SECASI records are not ideal for use in a search for surges on the disk. Nevertheless, because of their high time resolution, a number of surges were observed on these spectroheliograms and they appeared to be typically associated with Plage rather than with Prominence Flares. This observation is in agreement with Gopasyuk and Ogir (1963) who found that, in the main, surges occur in association with small flares and report "if there are other flaring regions at all in the same active region the surge and 'its' flare may be rather independent: they may be isolated and occur often, during or after the 'main' flare".

Because of the difficulty in detecting surges on centre of the line pictures and the very limited coverage provided by the swept frequency observations (see above) no meaningful estimate can be made of the frequency with which such events were associated with Plage Flares.

An impression is gained however from the SECASI records that, in 59Q, flares associated with such ejections occurred particularly above transient umbrae which had just been 'born' within the active centre (cf. Chapter 7). Thus the frequency of surge associated Plage Flares may have depended on a particular phase in the development of underlying solar magnetic fields.

## 6.3 The Association of Prominence Flaring in Region 59Q With the Generation of Centimetre Wave Radiation

Optical brightenings occurring in active region 59Q may be classified, according to the characteristics of their time associated emission at radio

*Cf. footnote to page 62.

frequencies, as events associated with 'Very Strong', 'Strong', 'Moderate', 'Moderate-Weak' and 'Weak' radio bursts, respectively.

The classifications adopted are as follows:

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|---|---|
| 'Very Strong' radio bursts | Brightenings accompanied by very broad band (>9000 MHz) bursts in the centimetre-metre range, smoothed peak flux density at centimetre wavelengths >1000 units*, duration $>1^h$. |
| 'Strong' radio bursts | Brightenings accompanied by broad band (>1000 MHz) bursts in the centimetre-metre range, smoothed peak flux density at centimetre wavelengths <1000 units*, duration $\leqslant 1^h$. |
| 'Moderate' radio bursts | Brightenings accompanied by broad band ($\geqslant$1000 MHz) or by single frequency bursts in the centimetre range only, smoothed peak flux density at centimetre wavelengths <1000 units*, duration $\leqslant 1^h$. |
| 'Moderate-Weak' radio bursts | Brightenings accompanied by Type III bursts. |
| 'Weak' radio bursts | Brightenings unaccompanied by reported ratio bursts. |

It may be noted that the category 'Weak' has been included, in order to cover those cases where either (a) a radio burst occurred but was not detectable by the available single swept frequency radio receivers or (b) a radio burst was recorded but fell below the threshold value adopted by the radio observers in compiling their published lists of events. Such cases cannot be distinguished from those in which no radio burst actually occurred.

## Stationary and Moving Prominence Flaring in 59Q and the Generation of Centimetre Wave Bursts

Of the 30 composite 'Stationary' and 1 composite Moving Prominence Flares identified in region 59Q during its July transit** all but 2, namely Stationary Prominence events at approximate longitudes E88° and E71°, were associated at their commencement times with bursts of centimetre wave radiation.

In considering the two exceptions it may be recalled, following Kakinuna et al. (1969), that the intensity of bursts at frequencies between 9.4 - 1 GHz associated with flares located at central meridian distances ~75°, is only of the order of half that associated with flares occurring near the centre of the disk. Thus it may be that the absence of centimetre wave radiation at the commencement times of the two east limb flares mentioned above was due either to

*Solar flux unit (sfu) = $10^{-22}$ Wm$^{-2}$ Hz$^{-1}$.

**See Table 6.2a, p. 75 and also p. 62, and the time association criteria of Section 4.3.

anisotropic emission by the source itself and/or due to attenuation of the radio emission by an absorbing layer located above the source.

Impulsive centimetre wave radiation (some bursts extending to decimetre or metre wavelengths) was associated with the 30 (cf. Table 6.3a) Stationary Prominence Flares identified in 59Q on at least 38 occasions (30 'Unambiguous' and 5-1/2 'Probable' associations). Of these, 28 bursts were associated with the actual commencement times of flares and 10 bursts with intensity enhancements within flaring prominence material. The optical records suggest that the "estimated probability" of association with 59Q may in fact be under-rated and that each of the 38 bursts concerned was associated specifically with Stationary Prominence Flaring in this region. A centimetre-metre wave burst was associated with the commencement and 5 centimetre wave bursts with later important activity within the single Moving Prominence Flare identified in region 59Q.

On 39 occasions impulsive centimetre wave radiation was associated specifically with either Stationary or Moving Prominence Flaring in 59Q while, on 5 occasions, concomitant Stationary Prominence and Plage Flaring was in progress. In another instance a centimetre wave burst with estimated probability of association with plage flaring in 59Q = 1/2 was suggested by the optical data to have been more probably associated with important Stationary Prominence Flaring at N08$^{o}$, W70$^{o}$ than with the (very minor) plage flaring in region 59Q itself. In no case was a centimetre wave burst associated with Plage Flaring alone on any part of the disk. It appears likely then that the generation of centimetre wave radiation is especially characteristic of important activity associated with Stationary and Moving Prominence Flares.

Of the 44 centimetre wave bursts associated specifically with Stationary and Moving Prominence Flaring in region 59Q, 31 were 'Moderate', 10 'Strong' and 3 'Very Strong' radio events (according to the classification system given in Section 6.3, pp. 63-65).

This indicates that in approximately 70% of all cases examined, the outstanding radio emissions associated with these kinds of Prominence Flaring were centimetre wave bursts with no decimetre or metre wave component. Such radiation would be generated relatively low down within the suspended prominence material*. In the remaining 30% of cases the associated generation of metre and/or decimetre wave bursts evidently corresponded with the occurrence of disturbances which propagated to higher levels within the suspended prominence**.

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*The altitude of microwave radiation, based on observations of behind-the-limb flares, is relieved to be $\sim 2 \times 10^4$ km, cf. Covington and Harvey (1961b), Bruzek (1964c), Kundu (1965) and Enome and Tanaka (1971).

**The height of at least the long duration stationary metric wave events accompanying major flares is estimated to be of the order of 0.2-1.0$R_{\odot}$, increasing with wavelength, Wild et al. (1963). Moving radio sources can of course be followed out to much greater distances in the corona, Wild and Smerd (1972).

## 6.4 The Association of Prominence Flaring in Region 59Q With the Generation of Ionizing Radiation

Some 30 ionospheric disturbances were confirmed in the CRPL Bulletin to have occurred during the disk transit of region 59Q, July 7-21, 1959, inclusive*. In relating these various phenomena with flaring it was generally required that the earliest reported start of an ionospheric event should have occurred within times of the order of $\pm 2^m$ of the commencement of an impulsive optical brightening.

Out of the total of 30 separate occurrences, 16 were time associated with observed flaring in region 59Q alone; 4 occurred at times when simultaneous brightenings in 59Q and in other active disk regions were associated with a single ionizing event; 2 occurred during the rise times of flares reported to occur in 59Q but for which no optical records were available; 6 were associated with either observed or reported flaring in active regions other than 59Q; 2 were not associated with any obvious disk activity.

Among the 16 ionospheric events mentioned above as time associated with flaring in 59Q <u>alone</u>, some 13 were associated with the commencement and 2 with the enhancement of Stationary Prominence Flaring within this region. The remaining ionospheric disturbance was detected at the commencement of the single Moving Prominence Flaring identified in this active centre.*

Of those 4 ionizing events occurring at the times of simultaneous flaring in 59Q and in other active regions, the optical data strongly suggest that 3 were associated with important Stationary Prominence Flaring in 59Q rather than with minor concomitant plage activity in other regions; the fourth event appeared more likely to have been associated with Stationary Prominence Flaring in progress at N08, W70 than with minor Plage Flaring in 59Q itself.

Among the overall 18 ionospheric events deemed associated with <u>Stationary</u> Prominence Flaring in 59Q, some 15 occurred at the commencements and 3 at times of intensity enhancements within such flares. These latter three apparently represented fluctuations within a single primary ionospheric event.

### The Special Association of Ionizing Radiation With Stationary and Moving Prominence Flares

If we review again those 20 cases in which ionospheric events were associated with the onset or enhancement of observed flaring in region 59Q, it is found that 16 of these were associated with either Stationary or Moving Prominence Flares in the region and 4 were associated with simultaneous Stationary Prominence and Plage Flaring in 59Q and in other active disk regions. In no case was an ionospheric event associated with Plage Flaring in 59Q alone. It thus appears that the generation of ionizing radiation was characteristic of important activity associated with certain Stationary and Moving Prominence Flares.

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*Cf. Table 6.3a, pp. 80-85.

Percentage of Stationary and Moving Prominence Flares in 59Q Associated With the Generation of Ionizing Bursts

If we relate the 15 'composite' ionospheric events deemed associated with Stationary Prominence Flaring in 59Q with the 30 composite Stationary Prominence Flares counted in the region during its July disk passage, then at least 50% of such flares were associated with the generation of ionizing radiation. This percentage, however, probably only represents a lower limit to the 'true' figure since, in addition to inherent limitations in the available data, a variety of effects including low altitude of the ionizing source*, the presence of special absorption effects close to the solar limb and the disruption of the ionosphere during severe geomagnetic storms, millitate against the successful detection at the Earth of ionizing bursts.

As already noted, the single Moving Prominence Flare identified in 59Q was associated with the generation of an important ionospheric event.

Association Between the Generation of Broad Band Centimetre Wave Radiation and the Detection of Ionospheric Effects

Despite some lacunae due to lack of observations, the data indicate that there was a significantly higher success rate in recording an ionospheric event, when the associated flare in 59Q was sufficiently energetic to generate radio radiation at high levels within the suspended prominence than when only centimetre wave radiation was produced.

Ralationship Between the Earliest Reported Commencements or Enhancements of Ionospheric Events and the Corresponding Times of Commencement of Stationary and Moving Prominence Flaring

Comparisons between the earliest reported commencement times of ionospheric disturbances and the corresponding times of commencement of Prominence Flaring indicates that ionizing bursts can begin early relative to optical flares, although there is considerable variation from event to event (the intervals between those starting times observed varied between $-6^m$ and $+3^m$), cf. Table 6.4a, p. 86.

These observations are in agreement with satellite data which indicate that there is a tendency for soft solar X-rays to begin their increase earlier than the beginning of their associated Hα flares, cf. Donnelly (1968) and Teske

*Information concerning the altitude of the ionizing source is inferred from published material concerning behind-the-limb flares; e.g., Warwick (1955) finds that a minimum height of only 15,000 km is necessary for the production of an S.I.D. and this is consistent with altitude determinations by Frost and Dennis (1971) and McKenzie and Peterson (1973). Study of OSO-5 X-ray spectroheliograms by René-Roy and Datlowe (1974) suggest that "the scale height of soft X-ray emission in the energy range 5-10 keV is similar to that found by Catalano and Van Allen (1973), 11,000 km for X-ray emission primarily in the range 1-3 keV".

and Thomas (1969). In particular, Thomas and Teske (1971) report that such X-ray bursts begin about $2^m$ before the start of the Hα event, reach peak flux about $3^m$ after maximum Hα intensity and end several minutes after the optical flare is no longer visible. It is however stressed by these authors that the figures quoted are based on statistical averages and that the great dispersion observed in individual values is undoubtedly responsible for the conflicting results provided by other timing studies such as those of Landini et al. (1965) and Falciani et al. (1968).

The Suggested Source in 59Q of Those Bursts of Ionizing Radiation Produced During the July Disk Passage of This Region

The fact that soft-ray bursts can be emitted before the commencement of time associated Stationary and Moving Prominence Flaring, introduces some undertainty in relating the source of this short wage radiation too closely with the suspended prominence above 59Q. However, general observations from above the Earth's atmosphere indicate that soft X-ray emissions may find their origin within a bridge like structure. Vaiana and Giacconi (1969) and Beigman et al. (1959) demonstrated that the sources of soft X-ray emission appear as long filamentary structures and the former authors in particular describe a case where "although there were considerable similarities between the shape of the Hα flare and the X-ray distribution, there was in addition a bridge of X-ray emission between the two Hα emission centres on opposite sides of the magnetic neutral line". Further, indirect evidence for a bridge like structure emitting soft X-rays as well as Hα radiation has been presented by Zirin et al. (1969) and X-ray features associated with points of high field gradient along the longitudinal magnetic 'neutral line' have been reported by Krieger et al. (1971). An arch like feature observed at wavelengths near 1.9Å, at an estimated height of about 35,000 km above an Hα flare, has also been described by Neupert et al. (1974) who suggests that the arch would have its footpoints in or above those portions of bright Hα emission located nearest to the underlying magnetic 'neutral line'. Also, Skylab instruments have recorded a pre-flare enhancement of soft X-ray emission in an activated filament on 05 September 1973, spanning two centres that later went into emission, Webb (1979).

These data suggest then that the various soft X-ray emissions, inferred from the evidence of the ionospheric events studied to be generated in region 59Q during its July disk passage, may indeed have been produced within elevated parts of that dark prominence material seen on Hα spectroheliograms to go into associated bright emission.

## 6.5 The Association of Prominence Flaring in Region 59Q With the Generation of Type II Bursts

Seven Type II events were recorded during the July transit of 59Q.* Of these, 4 were associated with known Stationary Prominence Flares in this region and 1 with what appears to have been an additional Stationary Prominence Flare occurring while 59Q was still behind the east solar limb on July 7. Excluding

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*Cf. Table 6.5a, p. 87.

from consideration the event of July 7 which is of uncertain origin, only ~13% of known composite Stationary Prominence Flares in 59Q was associated with the generation of Type II radiation.

Two separate Type II bursts appear to have been associated with the single Moving Prominence Flare identified in region 59Q.

## 6.6 The Association of Prominence Flaring in Region 59Q With the Generation of Type IV Radiation

Only 3 confirmed Type IV events (cf. Table 6.6a, p. 88) occurred during the disk transit of 59Q. Two of these, occurring on July 9 and 14, respectively, were associated with Stationary Prominence Flaring in this region. The remaining reported event was associated with the corresponding Moving Prominence Flare of July 16. It is probable that an additional unchronicled Type IV accompanied further Stationary Prominence Flaring in 59Q (see below) on July 10.

Only the Sydney station, recording in the range 25-210 MHz, was in operation at the time of commencement of the important Prominence Flare of $02^h\ 05^m$ U.T., on July 10 and, although the Australian observers did not report Type IV continuum radiation in association with this event, Jonah et al. (1965), in an analysis of the time associated radio radiation, deem it likely that "some form of Type IV emission occurred".

## 6.7 The Association of Prominence Flaring in Region 59Q With Particle Radiation

Only Icosmic ray event at ground level was reported during the disk transit of 59Q on July 16 (cf. Table 6.7a, p. 89). One 'probable' PCA was reported on July 09 and 3 confirmed PCA events on July 10, 14 and 16, respectively (cf. Table 6.7b, p. 90). Three sudden commencement geomagnetic storms were individually reported to commence on July 11, 15 and 17 (cf. Table 6.7a, p. 89) and each of these events was accompanied by a marked Forbush Decrease.

Stationary Prominence Flares in 59Q with flash phases at $18^h\ 10^m$ U.T. on July 09, at $02^h\ 05^m$ U.T. on July 10 and at $<03^h\ 33^m$ U.T. on July 14 plus a Moving Prominence Flare with a flash phase at $21^h\ 18^m$ U.T. on July 16 displayed properties generally deemed characteristic of proton producing events: (a) they comprised 2 roughly parallel flare filaments individually superposed on the largest underlying umbrae of north and south polarity*; (b) they showed the highest solar index of all flares occurring in the $12^h$ period prior to particle commencement**; (c) loop prominence systems dominated at least the post maximum phases of the flares of July 10, 14 and 16+; and (d) as is characteristic of

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*Dodson and Hedeman (1960, 1961b), Ellison et al. (1961a), Avignon et al. (1963), Martres and Pick (1962).

**Thompson and Maxwell (1960), Kundu (1962), Warwick and Haurwitz (1962), Bell (1963).

+Bruzek (1962, 1964a, 1964b).

great geomagnetic storm producing flares, the optical events of July 09, 10, 14 and 16 were each associated with the generation of combined Type II-Type IV ratio bursts*.

On the basis of this various evidence (and in accordance with identifications listed in the catalogues quoted in Section 2.7) it appears legitimate to identify the source of all the Ground Level and PCA protons as well as of the magnetic storm particles recorded from July 7-21, 1959, with important flaring in region 59Q.

Non-relativistic electrons from flares tend to arrive at the Earth at the same time or before energetic flare protons and relativistic flare electrons, see Lin and Anderson (1967a) and Simnet (1971). It is consequently suggested by Lin (1974a) that non-relativistic flare electrons are injected into the interplanetary medium more than $10^{m}$ prior to the injection of the relativistic particles. This effect is variously suggested to be due either to a special delay in the ejection from the Sun of relativistic protons and electrons which is not experienced by the non-relativistic particles, or to differential propagation effects in the Sun-Earth space. Alternatively, two entirely separate acceleration mechanisms may be operating such that, during the flash phase, non-relativistic electrons are accelerated and, sometime later, the relativistic electrons, protons and heavier nucleii, Wild et al. (1963), de Jager (1969), Forst and Dennis (1971), Lin (1974a) and Švestka (1974a). Whichever interpretation is accepted, if the proton acceleration occurred at or after the commencements of the 'Strong' and 'Very Strong' radio bursts accompanying the flash phases of the flares of July 9, 10, 14 and 16, as indeed appears likely considering the correlation between radio-important events and the subsequent detection at the Earth of particle radiation, then the acceleration was associated on each occasion with the condition of Stationary or Moving Prominence Flaring in region 59Q, rather than with any preliminary brightenings within the plage.

## 6.8 The Association Between Centimetre Wave and Type III Bursts Accompanying Stationary and Moving Prominence Flaring in Region 59Q

Radio spectrograph observations were available at the commencement times of 30 out of 38 centimetre bursts (some extending out to decimetre and metre wavelengths) known to be associated with impulsive Stationary Prominence Flaring in 59Q and at the onsets of 6 corresponding broad or narrow band centimetre wave bursts accompanying Moving Prominence Flaring in this region.

Consideration of these data indicates that the correlation between impulsive centimetre wave radiation and the production of Type III bursts is at best a loose one. However, there is a higher probability that a Type III burst would occur in association with broad band than with pure microwave radiation. In cases where impulsive centimetre wave radiation and Type III bursts together accompanied Stationary or Moving Prominence Flaring in region 59Q, there was a tendency for the centimetre wave commencements to precede the Type III bursts, cf. Table 6.8a, pp. 92-93.

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*Kundu (1962, 1965), Bell (1963).

This is in agreement with a detailed study by Daene and Kruger (1966) of the association between Type III events and microwave bursts. According to these authors, microwave emission starts at the same moment as the associated Type III, or somewhat earlier, and the origin of the Type III event lies at a level below the one which corresponds with the frequency where the burst first shows up in the spectrum. See also the supporting review paper by de Groot (1974).

## 6.9 The Association Between Ionizing Events and Type III Bursts Accompanying Prominence Flaring in Region 59Q

Reliable swept frequency observations were available at the commencement times of 11 of those 16 composite ionizing events deemed in Section 6.4 to be associated with Stationary and Moving Prominence Flaring in region 59Q during its July disk transit.

Column 9 of Table 6.8a, p. 92, lists, where these data are known, the interval between the earliest reported commencement or enhancement of an ionizing event and the time of commencement of a closely associated Type III burst. Here, a negative sign indicates that the ionizing event occurred in advance of the Type IV burst and it is seen that the available figures show a considerable scatter with perhaps some tendency towards negative values.

The lack of close correlation between ionizing and Type III radiation is not unexpected. Kane (1972) has already shown that impulsive hard X-ray and Type III bursts are essentially simultaneous and it seems likely that soft X-ray emissions should rather tend to correlate with the 'early' thermal phase of flares. However, despite recent studies by Hudson et al. (1969), Teske et al. (1971) and Khaler (1972), the relationship between soft X-ray bursts and non-thermal flare electrons is not at present fully understood.

## 6.10 The Association of Type III Bursts With Plage Flaring in Region 59Q

In all, 76 Type III bursts were associated with flaring in 59Q:* 15 in association with the onset or enhancement of centimetre burst accompanied Stationary or Moving Prominence Flares; 21 when either Stationary or Moving Prominence Flaring was in progress - but in the absence of accompanying impulsive centimetre wave bursts; 35 in association with impulsive Flage Flaring. Due to the lack of suitable optical observations, 5 events could not be associated with any particular kind of flaring.

It is possible that, in addition to the 35 events actually counted, certain additional Type III bursts in the sample may have been correlated with Plage Flaring in 59Q which occurred at a time of complex overlying Prominence Flaring.

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*See however Section 4.12, p. 47.

## 6.11 Comparison of the Overall Properties of Prominence and Plage Flares Observed in Region 59Q

Impact Prominence Flares in 59Q were apparently low energy events since in no case were they found to be associated with the generation of either radio, ionizing or proton radiation.

Plage flares were also apparently of low energy but accompanied in <3% of cases by Type III bursts. These Type III bursts indicate the associated passage through the solar corona of energetic electrons in the approximate energy range 10-100 KeV.

Stationary Prominence Flares were associated in the most simple cases with the generation of ionizing radiation and/or centimetre wave bursts. In more complex cases they were accompanied by a whole range of phenomena including ionizing radiation, centimetre-metre wave bursts, Type II, Type III and Type IV bursts, Polar Cap Absorption events and geomagnetic storms. The only Moving Prominence Flare identified in the region was, in addition to all of the various other phenomena mentioned above, associated with the production of a ground level cosmic ray event. It appears from these observations that particles were accelerated during various Stationary and Moving Prominence Flares in 59Q over a range of energies extending from ≤10 KeV in the case of electrons producing soft X-ray emissions to >1 GeV in the case of those protons producing ground level effects.

## 6.12 Investigation of the Association Between Prominence and Plage Flaring in 59Q and the Areas of Flares Reported to Occur in the Region at Corresponding Times

It is of improtance to investigate if the apparent association between Prominence Flaring and impulsive centimetre wave bursts, SIDs and proton emissions might in fact represent a correlation between the magnitudes of the flares involved and the generation of such phenomena. Table 6.12a, p. 94, then comprises a comparison between the times of commencement of the one Moving and 30 Stationary Prominence Flares identified in region 59Q during its July disk transit (cf. Table 6.2a) and details of the importance classes and areas of those flares which were reported by Warwick (1966a) to occur in the region at corresponding times.

Examination of the Table reveals that the Prominence Flares identified in 59Q can be associated with reported flares on 26 out of 31 occasions. As shown in column 9, the mean corrected apparent areas of the 30 flares varied over a wide range, extending from 0.4-31.6 sq degrees, and the comparative data suggest that the generation of (at least) impulsive radio and ionizing radiation is more closely associated with the involvement of prominence material in flaring than it is with flare magnitude. Given the presence of flaring prominence material, there appears however to be a relationship between the optical importance and area of reported flares and their association with the generation of increasingly energetic electromagnetic and proton radiation. For example, the three flares of highest importance class and area observed in the region (namely the importance 3-3+ events of July 10, 14 and 16) were not only Prominence Flares and very extensive, but they also were the only flares in

59Q to be associated with the generation of 'Very Strong' centimetre wave and confirmed proton radiation.

Table 6.12b, p. 95, comprises a comparison between the times of commencement of 807 plage brightenings deemed to occur in region 59Q over $136.1^h$ of selected McMath observations (cf. Table 6.2e) and corresponding flare data from the Warwick catalog*. In this table, a plage brightening is counted as associated with a reported flare if it occurred within an interval defined by $-1^m$ of the first reported beginning and $+1^m$ of the last reported end time of the event - as estimated by Warwick (1966a).

Examination of the data reveals that the plage brightenings in 59Q primarily consisted of sub-flares occurring either in association with, or in the interim periods between, reported flares**. Sometimes also, Plage Flaring occurred in association with Prominence Flaring.

A comparison between Tables 6.12a and 6.12b indicates that, although major flares do tend to be associated with extensive Prominence Flaring, reported area measurements cannot in themselves provide an indication of the presence on the Sun of Plage rather than Prominence Flaring since (1) certain quite small events can constitute a Prominence Flare, cf. for example the event of $14^h38^m$ U.T. July 09 of reported mean corrected apparent area 0.7 sq. degrees which was accompanied by a 'Strong' radio burst; (2) an aggregation of individual small plage brightenings occurring simultaneously may be reported as a single event having quite a high composite area (compare for example the importance 1 multiple Plage event of $14^h50^m$ U.T. July 13 mean corrected apparent area 2.7 sq. degrees, with the multiple site importance 1 Prominence event of $17^h30^m$ U.T. July 14, mean corrected apparent area 2.2 sq. degrees, which later was accompanied at its onset by a 'Strong' radio burst); (3) in the case of composite Stationary or Moving Prominence Flares, part of the reported area may include a Plage component (cf. for example, in addition to the several instances included in Table 6.12b, an outstanding case described in Appendix A1, when, in the course of protracted Stationary Prominence Flaring from $18^h10^m$ U.T. on July 09, long lengths of chromospheric chains 1 and 11 went into associated emission).

For comparison, Table 6.12c, p. 100, shows the total numbers of individual Plage and Prominence brightenings counted in 59Q over $136.1^h$ of selected McMath SECASI observations, plus the total numbers of composite Prominence Flares identified in this region during its complete July transit, which individually fell during periods covered by those flares of different importance classes reported by Warwick (1966a) to be associated with 59Q over the same time intervals*. These figures clearly indicate that Plage brightenings were preferentially associated with reported subflares while Stationary Prominence brightenings were particularly associated with reported flares of importance classes between 1 and 2+.

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*Based on world-wide flare patrol data.

**Exclusively Plage Flares seldom become very large phenomena.

## 6.13 Determination of the Relative Frequency of Occurrence of Plage and Prominence Flaring in Region 59Q

Plage Flares in 59Q were often very minor events with time scales of the order of minutes. They were thus dependent for their detection on the cadence and quality of all the film frames and many such brightenings were probably missed during intervals of poor seeing.

Stationary and Moving Prominence Flares in 59Q tended to be spectacular events which caused the film record to remain overexposed for long periods, sometimes amounting to several hours. Thus any intensity enhancements occurring in the prominence material within these long time intervals would be missed.

Impact Flares in 59Q required rather stringent observation conditions for their detection and it is expected that many such events were either missed or misidentified due to lack of coverage by the Tower Telescopes.

It cannot always be determined from the records if impulsive brightenings apparently occurring within flaring prominence material suspended above 59Q represented in individual cases intensity enhancements within the already flaring prominence or Plage Flares viewed through overlying bright prominence material.

In view of these difficulties, despite the interest of trying to determine the relative frequency of occurrence of Plage and Prominence Flaring in 59Q, such a determination cannot be meaningfully made on a 'brightening for brightening' basis.

An attempt to compare the incidence of Plage and Prominence Flaring in 59Q over the period of the McMath SECASI observations may however be made by comparing the total number of impulsive brightenings identified within the plage during this interval with the corresponding number of intensity increases within the overlying prominence which were associated with the simultaneous generation of impulsive centimetre wave radiation. In this way it was found that Plage Flaring occurred approximately 18 times more frequently than did impulsive centimetre wave associated prominence flaring.

TABLE 6.2a

Starting Times of 30 Stationary Prominence Flares and 1 Moving Prominence Flare Identified in Region 59Q During Its July Disk Transit and the Flare Sensitive Areas Involved in Each Case in the Initiation of Flaring

| Date 1959 | Time of commencement of Stationary or Moving Prominence Flaring, U.T. | Flare sensitive area/s first seen to brighten in 59Q | Flare sensitive area/s associated with the early part of the flash phase |
|---|---|---|---|
| July 08 | 1330 | $d^{I}$,e | $d^{I}$,e |
| | 1846 | d | d |
| 09 | 0818 | d | d |
| | 1438-1440 | b | a,b,c,d |
| | 1810 | b | (**) |
| 10 | 0205 | c,d | a,b,c,d,$d^{I}$,e,f,g,h |
| 11 | 0133 | d,$d^{II}$ | d,$d^{II}$ |
| | 0232 | d,$d^{II}$ | d,$d^{II}$ |
| | 0449 | d | d |
| | 2313-2314 | $i^{I}_{I}$ | (+) |
| 12 | 0425 | d,$d^{I}$,$d^{IV}$ | d,$d^{I}$,$d^{IV}$ |
| | 0628-0629 | d | d |
| | 1314 | d | d |
| | 1405 | d | d(‡) |
| | 2207 | $d^{I}$,i,$i^{I}$ | (X) |
| 13 | 0609 | d | d |
| 14 | <0333 | c,d | $c^{I}$,c,d,$d^{IV}$,$e^{I}$,$o^{I}$ |
| | 1145-1147 | $q^{II}$,$s_{I}$ | $q^{II}$,$s_{I}$,q,$q^{I}$ |
| | 1734-1736 | p,q | p,q,$q^{I}$,$r^{I}$,$q^{IV}$ |
| | 2224 | $q^{I}$,$q^{II}$,s,$s^{I}$ | $q^{I}$,$q^{II}$,s,$s^{I}$ |
| 15 | 1255 | d,$d^{IV}$,$d^{VII}$ | (XX) |
| | 1606 | $d^{VII}$,$k^{IV}$ | $d^{VII}$,$k^{IV}$ |
| | 1925 | (O) | s,$s_{I}$,$s^{I}$,$s^{II}$,$s^{III}$,$s^{IV}$,$q^{V}$,$q^{VI}$,$q^{VII}$,u |
| | 2240 | $d^{IV}_{I}$ | $d^{IV}_{I}$,t,$t^{I}$,$t^{II}$,$d^{I}$,$d^{IV}$,$d^{V}$,$d^{VI}$,$d^{VII}$,m,$m^{I}$ |
| 16 | 0637 | $d^{I}$ | $d^{I}$,d,$d^{IV}$ |
| | 1351 | c,d | c,d,$v^{I}$,$x^{I}$,$x^{III}$,$x^{VI}$,$x^{II}$,$x^{IV}$,$x^{V}$ |
| | 1604 | s,$s^{II}$ | s,$s^{II}$,$q^{I}$,$q^{V}$,$q^{VI}$,s,$s^{II}$,$s^{III}$ |
| | 2118* | (*) | $c^{I}$,c,d,$d^{IV}$,$d^{I}$,$e^{I}_{I}$,$e^{I}$,$k^{III}$,$x^{VII}$,k,$k^{II}$,f |
| 17 | 1339-1340 | s,$s^{I}$,$s^{II}$,$s^{III}$ | s,$s^{I}$,$s^{II}$,$s^{III}$,$q^{V}$,$q^{VI}$ |
| 18 | 1048 | y | y |
| | <1754 | (ǥ) | (ǥ) |

*See Appendix B for a detailed account of this Moving Prominence Flaring which began from $21^{h}$ $14^{m}$ - $21^{h}$ $16^{m}$ U.T. with brightenings in the plage at locations $d^{IV}$,d,$e^{I}$ and $e^{I}_{I}$.

**Complex Stationary Prominence Flaring thereafter, see details in Appendix A1.

+Prominence material in emission at this time between chromospheric chains III and VI at a position immediately to the north of area $i^{I}_{I}$.

‡Very poor seeing. Flaring spreads in chromospheric chain III from <$14^{h}$ $19^{m}$ U.T.

XGradual associated spread of Prominence Flaring along chromospheric chains II and III. Important impulsive flash from $22^{h}$ $24^{m}$ - $23^{h}$ $28^{m}$ U.T. in prominence material located above areas $e^{I}$,k,l,m,$k^{II}$,f and g.

XXSee Appendix A5 for details of this complex flare.

OA preliminary brightening occurred in plage area s at $19^{h}$ $23^{m}$ U.T., previous to the important flash in suspended prominence material which occurred at $19^{h}$ $25^{m}$ U.T.

ǥThis brightening occurred within a length of already flaring prominence material, then extended southwards towards area s.

TABLE 6.2b

Impact Prominence Flares Identified in Region 59Q During Its 1959 July Disk Transit*

| Date 1959 | Time of commencement of the flare U.T. | Associated impulsive radiation | | | Remarks |
|---|---|---|---|---|---|
| | | (Radio) | (Ionizing) | (Proton) | |
| July 07 | {1108 (area b)<br>1114 (area d) | None reported | No reported ionospheric event | None | Brightenings above 'b' and 'd' seen in projection against the sky at the east limb. |
| 08 | {1745 (area a)<br>1747 (area b) | 18 MHz burst of $2^m$ duration at $17^h 44^m$ U.T. | No reported ionospheric event | None | |
| 09 | {1816<br>1852 | 'Strong' ratio burst in progress from $18^h 10^m$ U.T. | S.W.F. in progress from $18^h 12^m$ U.T. | Time of accel. of P.C.A. protons unknown | Suspended prominence material to the north of 59Q brightened in association with falling material at $18^h 16^m$ U.T. This brightening increased in area and spread at $18^h 52^m$ U.T. Stationary Prominence Flaring already in progress above part of the main magnetic complex from $18^h 10^m$ U.T. |
| {10<br>14<br>15 | {>0236+<br>>0356+<br>>2128+ | Complex radio events in decline | Ionospheric events in decline | Time of accel. of associated proton radiation unknown | The post maximum phases of 3 major proton producing flares were each dominated by the formation of loop prominences. Material poured down the sides of these loops into underlying bright flare filaments. |
| 15 | ~1441 (Chain VI) | None reported | No reported ionospheric event | Proton event of July 14 in decline | Several intensity increases of subflare brightness in chromospheric Chain VI in association with falling material possibly one of a sequence of Impact Flares (cf. Appendix C). |
| 15 | {<1713 (area v)<br>1800 (area v) | None reported | No reported ionospheric event | Proton event of July 14 in decline | Brightening above 'v' in line centre seen on swept wavelength records to be associated with falling material. |
| Total | 8 | | | | |

*Multiple brightenings occurring in association with a well defined column of falling material are considered to comprise components of a composite event.

+These times represent the respective maxima reported by Warwick (1966a) of three major flare events in 59Q with individual flash phases at $02^h 05^m$ U.T. July 10, $<03^h 33^m$ U.T. July 14 and $21^h 18^m$ U.T. July 16.

TABLE 6.2c

Times of Commencement and Locations of 307 Plage Flares Deemed To Have Occurred in Region 59Q over $136.1^h$ of Selected McMath SECASI Observations*

| Date 1959 | Time of start of brightening, U.T. | Associated flare sensitive areas |
|---|---|---|
| July 07 | 1256 | g |
| | 1301 | f |
| | 1404 | a |
| July 08 | 1109 | d |
| | 1110 | c |
| | 1120 | d |
| | 1132 | d,e |
| | 1138 | c |
| | 1143 | d |
| | 1203 | c,d |
| | 1224 | e |
| | 1225 | $d^{I}$ |
| | 1228 | c |
| | 1239 | d |
| | 1256 | $d^{I}$,e |
| | 1309 | e |
| | 1310 | $d^{I}$ |
| | 1321 | $d^{I}$ |
| | 1322 | e |
| | 1335 | a |
| | 1337 | c |
| | 1339 | $d^{I}$ |
| | 1355 | e |
| | 1408 | c |
| | 1410 | d |
| | 1413 | d |
| | 1428 | $d^{I}$ |
| | 1436 | $d^{I}$,e |
| | 1442 | b |
| | 1455 | $d^{I}$ |
| | 1517 | e |
| | 1530 | c,e |
| | 1548 | e |
| | 1619 | d |
| | 1625 | d,$d^{I}$ |
| | 1626 | c |
| | 1627 | a |
| | 1647 | g |
| | 1658 | h |
| | 1711 | d |
| | 1723 | $d^{I}$ |
| | 1729 | a |
| | 1742 | $d^{I}$ |
| | 1754 | $d^{I}$ |
| | 1802 | $d^{I}$ |
| | 1818 | $d^{I}$ |
| | 1851 | g |
| | 1856 | h |
| | 1857 | c |
| | 1913 | d |
| | 1915 | g,h |
| | 1927 | c |
| | 1933 | b |
| | <2004 | g |
| | 2008 | d |
| | <2134 | b |
| | 2137 | d |
| | 2144 | g,h |
| | 2156 | b |
| | 2221 | b |
| | 2235 | g |
| July 08 (Cont.) | 2241 | b,f |
| | 2253 | $d^{I}$ |
| | 2303 | b |
| July 10 | 1201 | h |
| | 1209 | $d^{I}$;f,g |
| | 1210 | h |
| | 1247 | $d^{I}$,f |
| | 1317 | $d^{I}$,f |
| | 1449 | $d^{I}$ |
| | 1556 | $c_{I}$ |
| | 1621 | g |
| | 1655 | c,d |
| | 1732 | c,d |
| | 1854 | g |
| | 1938 | g |
| | <2110 | d |
| July 11 | <1224 | d |
| | 1230 | g |
| | <1239 | d |
| | 1243 | $d^{III}$ |
| | 1255 | k,$k^{I}$ |
| | 1301 | d |
| | 1306 | k,$k^{II}$ |
| | 1307 | c |
| | 1311 | $k^{II}$ |
| | 1321 | d |
| | 1339 | d,$k^{II}$ |
| | 1344 | k |
| | 1346 | $d^{III}$ |
| | 1414 | k |
| | 1416 | d |
| | 1507 | d |
| | 1508 | e |
| | 1509 | i |
| | 1510 | a |
| | <1520 | $d^{III}$,k |
| | <1545 | $d^{II}$ |
| | 1553 | $d^{I}$ |
| | 1627 | d |
| | <1634 | a,i |
| | <1640 | e |
| | <1657 | a,$d^{I}$ |
| | <1721 | d |
| | 1814 | $d^{I}$ |
| | 1816 | d |
| | <1845 | $k^{II}$ |
| | <1908 | d |
| | 1920 | d,$d^{II}$ |
| | <1948 | $d^{I}$ |
| | 2007 | $d^{I}$,$k^{I}$ |
| | 2059 | a,d,k,$k^{I}$ |
| | 2102 | $d^{III}$ |
| | 2104 | i |
| | 2107 | $d^{II}$,k,$k^{I}$ |
| | 2141 | d |
| | 2147 | d,$d^{II}$ |
| | 2207 | $d^{I}$,$k^{I}$ |
| | 2215 | d |
| | 2219 | $d^{III}$,$k^{I}$ |
| | 2240 | $d^{III}$ |
| | <2315 | $i^{I}$ |
| July 12 | 1216 | d |
| | <1226 | d |
| | 1227 | $d^{IV}$ |
| | 1228 | $k^{I}$,l |
| | 1252 | $e^{I}$ |
| | 1253 | c |
| | 1255 | d |
| | 1256 | e,$e^{I}$ |
| | 1258 | $k^{I}$,l |
| | 1300 | $l^{I}$ |
| | 1303 | $d^{I}$ |
| | 1310 | $d^{IV}$ |
| | 1316 | $l^{I}$ |
| | 1322 | c |
| | 1326 | d |
| | 1337 | $l^{I}$ |
| | 1352 | $l^{I}$ |
| | 1356 | $d^{IV}$ |
| | 1357 | $k^{I}$ |
| | 1440 | $k^{II}$ |
| | 1448 | d,$d^{I}$ |
| | 1459 | d |
| | 1631 | k |
| | 1632 | $d^{I}$ |
| | 1651 | e |
| | 1657 | d |
| | 1743 | a,c |
| | 1744 | $e^{III}$ |
| | 1748 | $d^{I}$ |
| | 1751 | d |
| | 1848 | l |
| | <1940 | d,k |
| | 1959 | $l^{I}$ |
| | 2017 | k |
| | <2050 | c,d,k |
| | 2122 | $d^{I}$ |
| | 2127 | c,d |
| | <2136 | $d^{IV}$,e |
| | 2137 | k |
| | <2153 | a |
| | 2153 | $d^{I}$,i,$i^{II}$ |
| July 13 | <1050 | a,d,$d^{IV}$,l,m |
| | 1053 | $d^{I}$,$d^{IV}$,$d_{I}^{IV}$ |
| | 1055 | k |
| | 1107 | $d_{I}^{IV}$ |
| | 1116 | l,m,$k^{II}$,$k^{III}$ |
| | 1118 | k |
| | 1121 | o |
| | 1132 | $d^{I}$,$d^{IV}$ |
| | 1141 | $d^{I}$,n |
| | 1142 | $n^{I}$,o |
| | 1147 | $d^{I}$ |
| | 1151 | $d_{I}^{IV}$ |
| | 1153 | $k^{II}$,$k^{III}$ |
| | 1157 | $d^{I}$ |
| | 1159 | $d_{I}^{IV}$ |
| | 1206 | k |
| | 1207 | $d^{I}$,$d^{IV}$,$d_{I}^{IV}$,r |
| | 1214 | $k^{II}$ |
| | 1217 | $d^{I}$,$d_{I}^{IV}$ |
| | 1232 | $k^{II}$ |
| | 1235 | m |

*Details concerning the selection procedure involved are contained in Section 3.1.

TABLE 6.2c - Continued

| Date 1959 | Time of start of brightening, U.T. | Associated flare sensitive areas | Date 1959 | Time of start of brightening, U.T. | Associated flare sensitive areas | Date 1959 | Time of start of brightening, U.T. | Associated flare sensitive areas |
|---|---|---|---|---|---|---|---|---|
| July 13 (Cont.) | 1244 | $d^{I}$ | July 14 | <1056 | $i^{II},r,r^{I}$ | July 15 (Cont.) | 1230 | $c^{I}$ |
| | 1301 | $k,k^{I},k^{II},m$ | | 1103 | $o^{III}$ | | 1234 | $d^{IV},d^{V}$ |
| | 1302 | $a,c^{I},d$ | | 1115 | $i^{II}$ | | 1235 | $d^{VII}$ |
| | 1303 | $i,l,m$ | | 1118 | $o^{III}$ | | 1241 | $q^{V}$ |
| | 1305 | $n,n^{I}$ | | 1141 | $q,q^{II},s_{I}$ | | 1245 | $s$ |
| | 1308 | $n$ | | 1152 | $r^{I}$ | | 1246 | $k^{III}$ |
| | 1314 | $k^{III},m$ | | 1154 | $m$ | | 1250 | $d^{IV},d^{VII}$ |
| | <1345 | $d^{V},o$ | | 1206 | $c,d,k,k^{III}$ | | 1251 | $k^{III},m$ |
| | 1348 | $d^{I},d^{IV}$ | | 1220 | $d$ | | 1343 | $v$ |
| | 1403 | $e^{I},k,m$ | | 1226 | $e^{I}$ | | 1353 | $d,k^{III}$ |
| | 1408 | $n,n^{I},o,o^{I}$ | | 1229 | $m$ | | 1358 | $c^{I},r,s^{I},s^{II}$ |
| | 1429 | $k^{II},k^{III}$ | | 1231 | $d,g,r^{I}$ | | 1359 | $k^{III},q^{V}$ |
| | 1451 | $m$ | | 1232 | $m,m^{I},o^{III}$ | | 1401 | $s^{I},v$ |
| | 1453 | $o^{I}$ | | 1236 | $r$ | | 1404 | $t^{I},t^{II}$ |
| | 1456 | $m$ | | 1239 | $o^{III}$ | | 1405 | $s,s^{I},t$ |
| | 1457 | $o^{II}$ | | 1243 | $o^{III}$ | | 1407 | $c^{I},d,q^{I}$ |
| | 1501 | $k,k^{III}$ | | 1244 | $g,r$ | | 1409 | $m^{II}$ |
| | 1507 | $k^{II},k^{III}$ | | 1249 | $i^{II}$ | | 1412 | $t^{I}$ |
| | 1508 | $d^{IV},l,m,n,n^{I}$ | | 1251 | $o^{III}$ | | 1413 | $q^{VII}$ |
| | 1524 | $o$ | | 1252 | $r^{I}$ | | 1415 | $s$ |
| | <1530 | $a$ | | 1307 | $d,e^{I},k,k^{III},l$ | | 1417 | $c^{I},d$ |
| | 1538 | $e^{I}$ | | 1324 | $k^{III}$ | | 1425 | $d^{VII},k^{IV}$ |
| | 1545 | $e^{I}$ | | 1332 | $k^{III}$ | | 1430 | $d^{V}$ |
| | <1630 | $c,c^{I},d$ | | 1333 | $k,k^{I}$ | | 1431 | $k^{IV}$ |
| | 1632 | $e^{I}$ | | 1334 | $d,d^{I}$ | | 1437 | $d^{IV},d^{V},d^{VII}$ |
| | 1655 | $d,d^{I},d^{IV}$ | | <1431 | $i^{II}$ | | 1440 | $e^{I}$ |
| | 1656 | $c,c^{I}$ | | <1506 | $m$ | | 1507 | $d^{VII},k^{IV}$ |
| | 1715 | $k^{III}$ | | 1523 | $q$ | | 1654 | $e^{I}$ |
| | 1724 | $k^{II},k^{III}$ | | 1526 | $k$ | | 1655 | $t^{I}$ |
| | 1725 | $o$ | | 1530 | $r$ | | 1704 | $d^{I}$ |
| | 1727 | $f,o^{I}$ | | 1532 | $k^{III}$ | | <1732 | $d^{I},d^{VI},d^{VII},k^{IV}$ |
| | 1728 | $d,d^{V}$ | | 1533 | $m$ | | <1818 | $s,s^{I}$ |
| | 1729 | $c,c^{I}$ | | 1537 | $c^{I}$ | | <1857 | $v$ |
| | 1731 | $g$ | | 1538 | $d^{I},d^{VI}$ | | <2009 | $d$ |
| | 1732 | $n$ | | 1540 | $c$ | | <2042 | $d^{I},d^{VII},k^{IV}$ |
| | 1733 | $n^{I}$ | | 1546 | $k^{I}$ | | <2119 | $v$ |
| | 1736 | $e^{I},k^{III},q,q^{I}$ | | <1610 | $d^{I},d^{VI}$ | | 2147 | $d^{I}$ |
| | 1751 | $k^{III}$ | | 1618 | $s_{I}$ | | <2158 | $v$ |
| | 1802 | $f$ | | 1622 | $c^{I}$ | | 2201 | $d^{IV}$ |
| | 1824 | $k^{II},k^{III}$ | | 1630 | $d^{I},d^{VI}$ | | 2202 | $d^{IV},d^{VII}$ |
| | 1825 | $f$ | | 1633 | $r^{I}$ | | 2233 | $v$ |
| | <1845 | $d^{V}$ | | 1634 | $i^{I}$ | | 2237 | $t,t^{I}$ |
| | 1905 | $e^{I}$ | | <1702 | $k^{III}$ | July 16 | 1143 | $k^{I},t$ |
| | 1906 | $d^{I},d^{IV},d^{V}$ | | 1704 | $k^{I},k^{II},s_{I}$ | | 1148 | $k^{IV},t$ |
| | 1944 | $i,k^{II},k^{III}$ | | 1712 | $o^{III}$ | | 1149 | $k,t^{I},t^{II}$ |
| | 1955 | $d$ | | 1717 | $k,k^{I},k^{II},k^{III}$ | | 1150 | $k^{III},m^{I}$ |
| | 1959 | $f,k^{II},k^{III}$ | | 1726 | $m$ | | 1151 | $m^{III}$ |
| | 2011 | $c^{I}$ | | 1727 | $o^{I},o^{III}$ | | 1152 | $t^{III}$ |
| | 2014 | $d$ | | 1731 | $q^{II},s_{I}$ | | 1157 | $x^{IV}$ |
| | 2048 | $k^{III}$ | | 1736 | $r^{I}$ | | 1158 | $m^{III}$ |
| | 2101 | $f,k^{II},k^{III}$ | | <2145 | $e^{I}$ | | 1159 | $t^{I}$ |
| | <2112 | $c,c^{I},d$ | | 2204 | $e^{I},q^{V}$ | | 1200 | $t^{II}$ |
| | 2114 | $d^{V}$ | | 2210 | $q^{IV}$ | | 1203 | $v,v^{IV}$ |
| | <2141 | $k,q^{I}$ | | 2211 | $q$ | | 1207 | $x^{VI}$ |
| | 2145 | $c^{I}$ | | 2212 | $p$ | | 1212 | $m^{III}$ |
| | <2200 | $c,d,f,k^{II},k^{III}$ | | 2216 | $q$ | | 1219 | $m^{II}$ |
| | 2211 | $m$ | | 2221 | $q^{V}$ | | 1220 | $m^{II},m^{III}$ |
| | 2222 | $e^{I}$ | | 2251 | $e^{I}$ | | 1230 | $k^{I},k^{IV}$ |
| | 2227 | $c^{I}$ | | 2300 | $q^{I},q^{II}$ | | 1236 | $k^{IV}$ |
| | 2230 | $c^{I}$ | | 2303 | $q$ | | <1309 | $f,k$ |
| | 2231 | $c,d$ | | | | | <1337 | $w^{II},x^{VI}$ |
| | 2232 | $a^{I}$ | July 15 | 1123 | $d$ | | 1342 | $w^{II},x^{VI}$ |
| | 2236 | $a$ | | 1124 | $d^{IV}$ | | 1344 | $v^{I},w,x^{V}$ |
| | 2252 | $d^{V}$ | | 1140 | $d^{IV},d^{VII},e^{I}$ | | 1345 | $x^{VII}$ |
| | 2254 | $f,g,k^{III}$ | | 1150 | $e^{I}$ | | 1347 | $x^{IV},x^{VII}$ |
| | 2255 | $c^{I}$ | | 1227 | $d_{I}$ | | 1402 | $k^{IV},t_{I}$ |

TABLE 6.2c - Concluded

| Date 1959 | Time of start of brightening, U.T. | Associated flare sensitive areas |
|---|---|---|
| July 16 (Cont.) | <1405 | $d^{VIII}$,$k^{I}$ |
| | <1420 | $q^{V}$,$q^{VII}$,s,$s^{II}$,$s^{III}$ |
| | 1427 | t |
| | <1437 | $d^{I}$,$e^{I}$ |
| | 1443 | $t^{I}$,$t^{II}$ |
| | 1444 | $m^{III}$,t |
| | 1446 | $t^{III}$ |
| | 1454 | $t^{II}$ |
| | 1511 | m,$m^{I}$ |
| | 1515 | $e^{I}$ |
| | 1516 | c,d |
| | 1518 | $d^{I}$ |
| | 1523 | $k^{III}$ |
| | <1528 | k,$k^{III}$ |
| | <1531 | $s^{II}$ |
| | 1541 | f,k,m,$m^{I}$ |
| | 1545 | $e^{I}$ |
| | 1549 | $d^{I}$ |
| | 1550 | $d^{VII}$ |
| | <1555 | $k^{I}$,$k^{IV}$,$m^{IV}$ |
| | 1557 | $e^{I}$,$e^{I}_{I}$,$t^{II}$ |
| | 1600 | t |
| | <1617 | m,$m^{I}$,$m^{III}$ |
| | 1702 | d |
| | 1709 | k,$k^{II}$,$k^{III}$,$m^{IV}$,$t^{I}$,$t^{II}$ |
| | 1712 | $e^{I}$ |
| | 1713 | d |
| | <1726 | $w^{II}$,$x^{IV}$,$x^{VI}$ |
| | 1733 | d |
| | 1740 | $e^{I}$,$e^{I}_{I}$ |
| | 1747 | $k^{II}$,$m^{IV}$,$t^{II}$ |
| | <1828 | $v^{I}$,$w^{II}$,$x^{IV}$,$x^{V}$ |
| | <1847 | m,$m^{IV}$ |
| | <1938 | k,$k^{II}$,$k^{IV}$,x,$x^{III}$ |
| | 1939 | d |
| | <1946 | $d^{I}$,$e^{I}$,$e^{IV}$,$k^{I}$ |
| | 1948 | $k^{IV}$ |
| | 1958 | d |
| | 2006 | $k^{II}$ |
| | <2111 | $d^{IV}$,$d^{VIII}$,t,$t^{I}$ |
| | 2114 | $d^{IV}$ |
| | 2115 | d |
| | 2116 | $e^{I}$,$e^{I}_{I}$ |
| July 17 | 1143 | $k^{II}$,$k^{III}$ |
| | 1146 | w,$x^{VII}$ |
| | 1143 | v |
| | 1152 | $k^{II}$,$k^{III}$,$k^{V}$ |
| | 1153 | $e^{IV}$ |
| | 1200 | $k^{II}$ |
| | 1209 | $k^{V}$ |
| | <1239 | $e^{IV}$,$k^{II}$,w,$x^{IV}$,$x^{V}$,y |
| | 1326 | $d^{VIII}$,$k^{II}$,$k^{III}$ |
| | <1341 | $k^{IV}$,$t^{III}$,y |
| | 1344 | $m^{II}$,$m^{III}$ |
| | 1345 | $k^{II}$,$k^{VI}$ |
| | 1355 | $k^{II}$ |
| | <1411 | $d^{VIII}$ |
| | <1427 | w |
| | <1946 | $w^{I}$,$w^{II}$,$x^{IV}$,$x^{V}$ |
| | <2039 | $k^{V}$ |
| | <2124 | $k^{VI}$,$s^{I}$ |
| July 19 | <1241 | $y^{III}$,$y^{V}$ |
| | 1300 | $y^{III}$ |
| | <1327 | $y^{IV}$,$y^{V}$ |
| | <1333 | $y^{V}$ |
| July 19 (Cont.) | 1350 | $y^{V}$ |
| | 1401 | $y^{IV}$ |
| | 1406 | $y^{V}$ |
| | <1417 | $y^{III}$ |
| | 1421 | $y^{IV}$ |
| | <1433 | $y^{I}$ |
| | 1450 | $y^{IV}$ |
| | <1503 | $y^{III}$ |
| | 1514 | $y^{IV}$ |
| | <1530 | $y^{II}$ |
| | 1539 | $y^{III}$ |
| | 1555 | $y^{V}$ |
| | 1558 | $y^{III}$ |
| | <1615 | $y^{III}$ |
| | 1626 | $y^{III}$,$y^{V}$ |
| | 1627 | y |
| | 1642 | $y^{V}$ |
| | 1644 | $y^{III}$ |
| | 1704 | $y^{IV}$ |
| | 1712 | $y^{III}$ |
| | 1718 | y |
| | <1735 | y |
| | 1743 | y,$z^{I}$ |
| | <1755 | $y^{IV}$,$y^{V}$ |
| | 1757 | y |
| | 1802 | y |
| | 1807 | $y^{IV}$ |
| | 1828 | $y^{III}$ |
| | 1836 | $y^{IV}$ |
| | 1843 | $y^{IV}$ |
| | <1856 | $y^{III}$ |
| | <1907 | $y^{V}$ |
| | 1917 | y,$y^{IV}$ |
| | 1925 | $y^{III}$ |
| | <1931 | $y^{I}$ |
| | 1937 | $y^{III}$,$y^{V}$ |
| | 2015 | $y^{III}$ |
| | <2104 | $y^{III}$ |
| | 2136 | $y^{V}$ |
| July 20 | <1326 | $y^{V}$ |
| | <1835 | $y^{IV}$ |
| | <1840 | $y^{III}$ |
| | 1845 | s,$y^{V}$ |
| | <1929 | $y^{I}$,$y^{V}$ |
| | 1942 | y |
| | 2041 | $y^{V}$ |
| | 2051 | $y^{V}$ |
| | <2102 | $y^{III}$ |
| | 2125 | $y^{IV}$ |
| | <2130 | y |
| | <2142 | $y^{I}$ |
| | <2222 | $y^{III}$,$y^{IV}$ |
| | <2238 | $y^{I}$,$y^{V}$ |
| | 2255 | s |
| July 21 | <1105 | $y^{IV}$,$y^{V}$ |
| | <1120 | y |
| | 1125 | $y^{I}$ |
| | 1126 | $y^{III}$ |
| | 1136 | y,$y^{I}$ |
| | 1137 | $y^{III}$,$y^{IV}$,$y^{V}$ |
| | <1146 | s |
| | <1212 | y |
| | <1228 | $y^{I}$,$y^{III}$ |
| | 1231 | $y^{IV}$ |
| July 21 (Cont.) | 1243 | y |
| | 1250 | $y^{III}$ |
| | 1253 | y |
| | 1311 | $y^{IV}$ |
| | <1320 | y,$y^{III}$ |
| | 1326 | y,$y^{III}$,$y^{IV}$ |
| | <1348 | $y^{III}$ |
| | <1353 | $y^{IV}$ |
| | <1408 | y |
| | 1410 | $y^{III}$ |
| | 1429 | $y^{IV}$ |
| | <1447 | $y^{III}$ |
| | <1458 | $y^{IV}$ |
| | <1521 | y |
| | <1550 | y,$y^{VI}$ |
| | 1552 | $y^{V}$ |
| | <1600 | $y^{IV}$ |
| | 1646 | $y^{IV}$ |
| | <1733 | $y^{III}$ |
| | <1816 | $y^{III}$,$y^{VI}$ |
| | <1833 | $y^{III}$,$y^{IV}$ |
| | <2024 | $y^{IV}$ |
| | 2035 | s |

TABLE

Times of Commencement or Enhancement of 30 Stationary Prominence and the Associated Commencement Times of Centimetre Wave Bursts,

| Date 1959, July | Prominence Flaring in region 59Q | | | Associated centimetre wave radiation | | |
|---|---|---|---|---|---|---|
| | Time of commencement or enhancement of Prominence Flaring U.T. | Type of Prominence Flare | Flare sensitive areas involved in flash phase | Association category | Class of radio event,* | Earliest reported centimetre wave burst U.T. |
| 08 | 1330 | Double site | $d^{I}$,e | Unambiguous | Strong | 1329 |
| 08 | 1846 | Single site | d | - | Weak or none | - |
| 09 | 0818 | Single site | d | - | Weak or none | - |
| 09 | 1438-1440 | Multiple site | a,b,c,d | Unambiguous | Strong | 1440.8 |
| 09 | 1810 | Single site | b | Unambiguous | Strong | 1810 |
| 09 | 1941 | Single site | b | - | - | In progress |
| 09 | 2033 | Single site | g | - | - | In progress |
| | 2036 | Single site | b | - | - | In progress |
| | 2041-2043 | Multiple site | b,c,g | Unambiguous | Moderate | 2042 |
| 09 | Gradual spread of Prominence Flaring along chromospheric chains I and II in progress at 2112 U.T. | Multiple site | Extensive complex flaring | Inferred | Moderate | 2112 |
| 09 | 2217 | Single site | b | Unambiguous | Moderate | 2218 |
| 09 | Brilliant Prominence Flare in progress in b at 2224 U.T. | Single site | b | - | - | In progress |
| 10 | 0205-<0209 | Multiple site | a,b,c,d,$d^{I}$,e,f,g,h | Unambiguous | Very strong | 0208 |
| 11 | 0133 | Double site | d,$d^{II}$ | Unambiguous | Moderate | 0132.8 |
| 11 | 0232 | Double site | i,$d^{II}$ | Unambiguous | Moderate | 0233 |
| 11 | 0449 | Single site | d | Unambiguous | Moderate | 0449 |
| 11 | 2313-2314 | Multiple site | $i^{I}$,$i^{I}_{I}$ areas a-l and d bright and active | Unambiguous | Moderate | 2314 |
| 12 | 0425 | Multiple site | d,$d^{I}$,$d^{IV}$ | Unambiguous | Moderate | 0423 |
| 12 | 0628-0629 | Single site | d | Unambiguous | Moderate | 0630 |
| 12 | 1314 | Single site | d | Shared | Moderate | 1313 |
| 12 | 1405 | Multiple site | d (see Remarks) | Unambiguous | Moderate | 1406 |
| 12 | 2207 (gradual assoc. spread of Prominence Flaring along chromospheric chains II and III) | Multiple site | $d^{I}$,i,$i^{I}$ appear generally bright and active | Shared | Moderate | 2207 |
| 12 | 2224-2228 | Multiple site | $e^{I}$,k,l,m,$k^{II}$,f,g | Unambiguous | Moderate | 2224 |

*According to the convention adopted in Section 6.3.

6.3a

Flares and 1 Moving Prominence Flare Identified in Region 59Q

Type III Bursts, Ionospheric Events and Particle Radiation

| Type III bursts | Associated ionospheric events | | | Associated particle radiation | | Remarks |
|---|---|---|---|---|---|---|
| Start-Type III burst U.T. | Ionospheric event no. | Recorded effect | Time of start U.T. | Recorded effect | Time of start, day/U.T. | |
| 1328g | - | - | - | - | - | |
| Ann Arbor | 2 | S.W.F.<br>S.C.N.A.<br>S.E.A. | 1848<br>1849<br>1849 | - | - | Region 59Q located at N16, E88. |
| No obvs. | 3 | S.W.F. | 0820 | - | - | Region 59Q located at N16, E71. |
| 1442g | - | - | - | - | - | |
| 1810g | 4 | S.W.F. | 1812 | - | - | |
| None | 5 | S.W.F.<br>S.C.N.A.<br>S.E.A. | 1940<br>1947<br>1947 | | | Plage Flare from 1940 U.T. at N10, W72. Type I event at 1940 U.T. |
| None<br>None<br>2042b | 6 | S.E.A.<br>S.W.F. | 2035<br>2038<br>2040 | | | |
| None | 6 | S.E.A. | In progress | | | |
| None | - | - | - | - | - | |
| None | 7 | S.E.A. | 2225 | | | |
| 0210-0212g | 8 | S.W.F.<br>S.F.A.<br>S.C.N.A. | 0200<br>0205<br><0215 | P.C.A.<br>Mag. S.<br>F. Dec. | 10/0400<br>11/1625<br>11/1715 | |
| None | - | - | - | - | - | |
| No obvs. | - | - | - | - | - | |
| No obvs. | - | - | - | - | - | |
| None | - | - | - | - | - | Prominence material goes into emission between chromospheric chains III and VI at a position immediately to the north of area $i_I^I$ (cf. Fig. 3.1d). |
| No obvs. | 11 | S.W.F. | 0420 | - | - | 0425 U.T. is earliest time at which Prominence Flaring was definitely identified. Poor seeing but part of 59Q especially bright at 0419 U.T. |
| No obvs. | 12 | S.W.F. | 0630 | - | - | |
| None | - | - | - | - | - | Concomitant Plage Flaring from 1314 U.T. at S26, E65. |
| None | - | - | - | - | - | Flaring spreads in chain III from <1419 U.T., very poor seeing. |
| 2209b | - | - | - | - | - | Importance 2 flare in progress in 59Q with multiple brightenings Imp. 1 - Plage Flare at S14°, W07° from 2210 U.T. fading by 2217 U.T. Earliest time at which Prominence Flaring positively identified in 59Q is 2207 U.T. |
| 2227b | 14 | S.E.A.<br>S.W.F. | 2218<br>2220 | -<br>- | -<br>- | |

TABLE 6.3a -

| Date 1959, July | Prominence Flaring in region 59Q | | | Associated centimetre wave radiation | | |
|---|---|---|---|---|---|---|
| | Time of commencement or enhancement of Prominence Flaring U.T. | Type of Prominence Flare | Flare sensitive areas involved in flash phase | Association category | Class of radio event* | Earliest reported centimetre wave burst U.T. |
| 13 | 0609 | Single site | d | Unambiguous | Moderate | 0610 |
| 14 | <0333 | Multiple site | $c^{I}_{I}$, c, d, $d^{IV}$, $e^{I}$ $o^{I}$ | Unambiguous | Very strong | 0330 |
| 14 | 1145-1147 | Multiple site | q, $q^{I}$, $q^{II}$, $s_{I}$ | Unambiguous | Moderate | 1146.5 |
| 14 | 1734-1736 | Multiple site | p, q, $q^{I}$, $r^{I}$, $q^{IV}$ | Unambiguous | Strong | 1734 |
| 14 | 2224 | Multiple site | $q^{I}$, $q^{II}$, s, $s^{I}$ | Unambiguous | Strong | 2223 |
| 15 | 1255-1256 | Multiple site | d, $d^{IV}$, $d^{VII}$ | Unambiguous | Moderate | 1257 |
| 15 | 1300-1301 | Multiple site | m, $m^{I}$, d, $d^{IV}$, $d^{VII}$ | Umambiguous | Moderate | 1300 |
| 15 | 1327-1329 | Multiple site | a, d, $d^{IV}$, $c^{I}$, $c^{I}_{I}$ | Unambiguous | Strong | 1327.5 |
| 15 | 1606-1607 | Double site | $d^{VII}$, $k^{IV}$ | Unambiguous | Moderate | 1606.9 |
| 15 | 1925 | Multiple site | s, $s_{I}$, $s^{I}$, $s^{II}$, $s^{III}$ $s^{IV}$, $q^{V}$, $q^{VI}$, $q^{VII}$, u | Unambiguous | Strong | 1925 |
| 15 | 2240-2242 | Multiple site | $d^{IV}$, t, $t^{I}$, $t^{II}$, $d^{I}$ $d^{IV}$, $d^{V}$, $d^{VI}$, $d^{VII}$, m, $m^{I}$ | Unambiguous | Moderate | 2240 |
| 16 | 0637-0633 | Multiple site | d, $d^{I}$, $d^{IV}$ | Unambiguous | Moderate | 0636 |
| 16 | Flare in progress in 59Q at 0708 U.T. | Multiple site | Prominence Flaring began in 59Q at 0637 U.T. | Inferred | Moderate | 0708.2 |
| 16 | 1351-1352 | Multiple site | c, d, $v^{I}$, $x^{I}$, $x^{II}$, $x^{III}$, $x^{IV}$, $x^{V}$, $x^{VI}$ | Shared | Moderate | 1351 |
| 16 | 1604 | Double site | s, $s^{II}$ | Unambiguous | Moderate | 1605 |
| 16 | 1610 | Multiple site | $q^{I}$, $q^{V}$, $q^{VI}$, s, $s^{II}$, $s^{III}$ | Unambiguous | Moderate | 1610 |
| 16 | Prominence Flaring in progress at 1613 U.T. | Multiple site | No optical record. Prominence Flaring from 1610 U.T. in $q^{I}$, $q^{V}$, $q^{VI}$, s, $s^{II}$, $s^{III}$ | Inferred | Strong | 1613 |

*According to the convention adopted in Section 6.3.

Continued

| Type III bursts | Associated ionospheric events | | | Associated particle radiation | | Remarks |
|---|---|---|---|---|---|---|
| Start-Type III burst U.T. | Ionospheric event no. | Recorded effect | Time of start U.T. | Recorded effect | Time of start, day/U.T. | |
| No obs. | - | - | - | - | - | |
| None | 19 | S.W.F.<br>S.E.A. | 0328<br>0328 | P.C.A.<br>Mag. S.<br>F. Dec. | 14/0445<br>15/0803<br>15/0830 | 0333 U.T. is earliest time at which Prominence Flaring could be definitely identified but uncategorized flare activity seen in progress from <0327 U.T. and reported from 0319 U.T. |
| Ann Arbor | - | - | - | - | - | |
| 1735-1736G<br>1736-1737G<br>1737.6-1738 | 21 | S.W.F. | 1735 | - | - | |
| 2223g<br>2224-2228G | 22 | S.E.A.<br>S.C.N.A. | 2225<br>2229 | - | - | |
| None | 23 | S.W.F. | 1258 | - | - | |
| None | 23 | S.E.A. | 1301 | - | - | |
| None | 23 | S.E.A. | In progress | - | - | |
| None | - | - | - | - | - | |
| 1926-1928G | 24 | S.W.F.<br>S.C.N.A. | 1922<br>1924 | - | - | |
| None | - | - | - | - | - | |
| No obs. | - | - | - | - | - | |
| No obs. | 25 | S.W.F. | 0705 | - | - | Plage at S07°, W65° bright and active at this time but seeing not sufficiently good to determine if it showed an intensity increase. No reported flare in this region. |
| None | - | - | - | - | - | Minor Plage Flare from 1360 U.T. at S07°, W65°. |
| None | - | - | - | - | - | |
| 1610g | 26 | S.W.F. | 1610 | - | - | |
| 1614.4-1615.2g<br>1615g | 26 | S.W.F.<br>S.C.N.A.<br>S.E.A. | In progress<br>1613<br>1614 | - | - | Gap in optical record 1611-1616 U.T. |

TABLE 6.3a -

| Date 1959, July | Prominence Flaring in region 59Q | | | Associated centimetre wave radiation | | |
|---|---|---|---|---|---|---|
| | Time of commencement or enhancement of Prominence Flaring U.T. | Type of Prominence Flare | Flare sensitive areas involved in flash phase | Association category | Class of radio event* | Earliest reported centimetre wave burst U.T. |
| 16 | 2113-2120+ | Multiple site | $c^{I}, c, d, d^{IV}, d^{I}, e^{I}$ $e^{I}_{I}, k^{III}, x^{VII}, k, k^{II}, f$ | Unambiguous | Very strong | 2118 |
| 16 | Prominence Flare in progress at 2313 U.T. | Multiple site | Extensive complex flaring | Inferred | Moderate | 2313 |
| 16 | Prominence Flare in progress at 2346 U.T. | Multiple site | Extensive complex flaring | Inferred | Moderate | 2346 |
| 17 | Prominence Flare in progress at 0024 U.T. | Multiple site | Extensive flaring | Inferred | Moderate | 0024x |
| 17 | Prominence Flare in progress at 0032 U.T. | Multiple site | Extensive flaring | Inferred | Moderate | 0032x |
| 17 | Prominence Flare in progress at 0041 U.T. | Multiple site | Extensive flaring | Inferred | Moderate | 0041x |
| 17 | 1339-1340 | Multiple site | $s, s^{I}, s^{II}, s^{III}, q^{V}, k^{IV}$ | Unambiguous | Moderate | 1340 |
| 18 | 1048 | Single site | y | Unambiguous | Strong | 1047.6 |
| 18 | 1754 (Brightening seen in part of already brilliant flaring prominence material).** | Multiple site | Bright prominence material expanding southward towards area s | Inferred | Strong | 1754.5 |
| 18 | Prominence flare in progress at 1811 U.T. | Multiple site | Bright prominence material expanding southward towards area s | Inferred | Moderate | 1811 |

*According to the convention adopted in Section 6.3.

**This flare probably commenced at $17^{h}$ $50^{m}$ U.T. in association with a 'Moderate' centimetre wave burst but, due to poor seeing, the precise time of commencement of the flare cannot be determined. The event of $17^{h}$ $54^{m}$ U.T. comprised a brightening within a length of already flaring prominence material which was then extended southwards towards area s. Due to the effects of over exposure it is uncertain how much of the prominence material went into enhanced emission at this time.

+$21^{h}$ $18^{m}$ U.T. defined the start of the flash phase of a Moving Prominence Flare in 59Q. (Cf. Section 6.2 and Appendix B.)

Concluded

| Type III bursts | Associated ionospheric events | | | Associated particle radiation | | Remarks |
|---|---|---|---|---|---|---|
| Start-Type III burst U.T. | Ionospheric event no. | Recorded effect | Time of start U.T. | Recorded effect | Time of start, day/U.T. | |
| 2120-2121g<br>2122g | 27 | S.W.F.<br>S.C.N.A.<br><br>S.E.A. | 2118<br>2117<br><br>2115 | P.C.A.<br>Mag. S.<br><br>F. Dec. | 16/2250<br>17/1624<br>or 1938<br>17/1930 | What was probably Plage Flaring seen in progress from 2114 U.T. |
| None | 27 | S.W.F.<br>S.C.N.A.<br>S.E.A. | In progress<br>In progress<br>In progress | | | Part of proton flare of 2114 U.T. |
| None | 27 | S.W.F.<br>S.C.N.A. | In progress<br>In progress | | | |
| None | 27 | S.C.N.A. | In progress | | | These events associate with the declining phase of the proton flare of 2114 U.T.; July 16. |
| None | 27 | S.C.N.A. | In progress | | | |
| None | 27 | S.C.N.A. | In progress | | | |
| None | | - | - | - | - | |
| 1047.8-1049 | - | - | - | - | - | |
| None | 28 | S.E.A.<br>S.C.N.A. | 1750<br>1754 | - | - | Seeing too poor at 1750 U.T. to detect intensity fluctuations. |
| None | 28 | S.E.A. | Declining | - | - | Minor Plage Flare at N17°, E20° from 1810 U.T. |

TABLE 6.4a

**Times of Commencement or Enhancement of 31 Prominence Flares Identified in Region 59Q and the Earliest Reported Commencement and Enhancement Times of Associated Centimetre Wave Bursts and Ionospheric Events**

| Date 1959 | Time of commencement of Prominence Flaring in region 59Q U.T. | Time of centimetre wave and/or ionizing burst assoc. enhancement of Prominence Flaring in 59Q U.T. | Centimetre wave radiation: Time of earliest reported commenc. or enhancement of centimetre wave radiation U.T. | Centimetre wave radiation: Class of* earliest reported cm. radio burst | Ionospheric events: Earliest reported time of commenc. or enhancement of ionospheric events U.T. | Ionospheric events: Ionospheric+ event no. | Ionospheric events: Interval between‡ first reported commenc. or enhancement of an ionospheric event and the time of commenc. of impulsive Prom. Flaring, mins. |
|---|---|---|---|---|---|---|---|
| July 08 | 1330 | - | 1329 | Strong | None | - | - |
| 08 | 1846 | - | None | W. or N.ˣ | 1848 | 2 | +2 |
| 09 | 0818 | - | None | W. or N.ˣ | 0820 | 3 | +2 |
| 09 | (1438-1440) | - | 1440.8 | Strong | None | - | - |
| 09 | 1810 | {1941 | {1810 | {Strong | {1812,1940 | {4,5 | +2 |
| | | (2033,2036,2041) | 2042 | Moderate | (2035,2038,2040) | 6 | |
| | | 2217 | 2112 | Moderate | 2225 | 7 | |
| | | | 2218 | Moderate | | | |
| 10 | 0205 | Complex flaring | 0206 | V. Strong | 0200 | 8 | -5 |
| 11 | 0133 | - | 0132.8 | Moderate | None | - | - |
| 11 | 0232 | - | 0233 | Moderate | None | - | - |
| 11 | 0449 | - | 0449 | Moderate | None | - | - |
| 11 | (2313-2314) | - | 2314 | Moderate | None | - | - |
| 12 | 0425 | - | 0423 | Moderate | 0420 | 11 | -5 |
| 12 | (0628-0629) | - | 0630 | Moderate | 0630 | 12 | +2 |
| 12 | 1314 | - | 1313 | Moderate | None | - | - |
| 12 | 1405 | - | 1406 | Moderate | None | - | - |
| 12 | 2207 | | {2207 | {Moderate | {- | {- | {- |
| | | (2224-2228) | 2224 | Moderate | 2218 | 14 | -6 |
| 13 | 0609 | - | 0610 | Moderate | None | - | - |
| 14 | <0333 | Extensive flaring | 0330 | V. Strong | 0328 | 19 | <-5 |
| 14 | (1145-1147) | - | 1146.5 | Moderate | None | - | - |
| 14 | (1734-1736) | - | 1734 | Strong | 1735 | 21 | +1 |
| 14 | 2224 | - | 2223 | Strong | 2225 | 22 | +1 |
| 15 | (1255-1256) | {(1300-1301) | {1257 | {Moderate | | | |
| | | | 1300 | Moderate | 1258 | 23 | (+3) - (-2) |
| | | (1327-1329) | 1327.5 | Strongˣˣ | | | |
| 15 | (1606-1607) | - | 1606.9 | Moderate | None | - | - |
| 15 | 1925 | - | 1925 | Strong | 1922 | 24 | -3 |
| 15 | (2240-2242) | - | 2240 | Moderate | None | - | - |
| 16 | (0637-0638) | - | {0636 | {Moderate | { | | |
| | | Bright flare in progress | 0708.2 | Moderate | 0705 | 25 | [-3.2]° |
| 16 | (1351-1352) | - | 1351 | Moderate | None | - | - |
| 16 | 1604 | 1610 | {1605 | Moderate | | | |
| | | (No optical obs. at 1610) | 1610 | Moderate | 1610 | 26 | -0 |
| | | | 1613 | Strong | | | |
| 16 | 2118 | Extensive flaring | {2118 | {V. Strong | 2115 | 27 | -3 |
| | | | 2313 | Moderate | | | |
| | | | 2346 | Moderate | | | |
| | | | 0024 | Moderate | | | |
| | | | 0032 | Moderate | | | |
| | | | 0041 | Moderate | | | |
| 17 | (1339-1340) | - | 1340 | Moderate | None | - | - |
| 18 | 1048 | - | 1047.6 | Strong | None | - | - |
| 18 | [<1754]§ | 1754§ | {1754.5 | {Strong | | | |
| | | | 1811 | Moderate | 1750 | 28 | 0 - (-4)§ |
| Total | 30 + 1§ | | 28 commencements<br>16 enhancements§ | 3 V. Strong<br>10 Strong<br>31 Moderate<br>2 W. or N. | 16 commencements<br>3 enhancements | | |

*According to the classification system adopted in Section 6.3.

+Ionospheric event numbers as assigned in column 2 of Table 6.3a.

‡A negative value indicates that the reported earliest commencement of the ionospheric event precedes the observed commencement of the Prominence Flare.

ˣW or N signifies radio class 'Weak' or 'None', cf. Section 6.3.

°The flare is already too overexposed by $07^h\ 05^m$ U.T. to detect any intensity fluctuation but, if such a change did occur in association with the 'Moderate' centimetre wave burst of $07^h\ 08.2^m$ U.T., then the relevant delay time between the onset of the ionospheric event and this enhancement would be $-3.2^m$.

§This flare probably commenced at $17^h\ 50^m$ U.T. in association with a 'Moderate' centimetre wave burst but the seeing was too poor at this time to detect any intensity fluctuation on the disk. The observed event of $17^h\ 54^m$ U.T. comprised a brightening within what appeared to be part of an already brilliant length of flaring prominence material. However, due to the effects of overexposure, it cannot be decided how much of the prominence brightened at this time in association with the centimetre wave burst.

TABLE 6.5a

Association of Prominence Flaring in Region 59Q With the Generation of Type II Bursts

| Date, July 1959 | Radio spectograph observations | | Time of Type II event U.T. | Time of commencement of flash phase of parent flare U.T. | Type of parent flare | Class of associated radio burst | Remarks |
|---|---|---|---|---|---|---|---|
| | Station | Freq. range, MHz | | | | | |
| 7 | Sydney | ( 25-210) | 0343.5 -0345 | ~0337 | Unknown | Unknown | Flare occurs at N $19^{o}$, E 93$^{o}$ in region 59Q. An unconfirmed S.W.F. reported by 1 station. Optical event was probably a low lying Prominence Flare. |
| 9 | Sydney | ( 25-210) | <2259 -2400 | Several intensity fluctuations in already flaring Prominence material previous to 2259 U.T. | Stationary Prominence Flare in progress. | 'Moderate' if associated with radio burst of 2218 U.T. This latter event is itself a late enhancement of a 'Strong' radio burst which began at 1810 U.T.* | Observations began at Sydney at 2259 U.T. at which time there is reported a 'possible' Type II in progress and continuum emission < 2259-0139 U.T. |
| 10 | Sydney | ( 25-210) | 0222 -0306 | ~0205 | Stationary Prominence Flare | 'Very Strong'* | Proton event. |
| 14 | Sydney | ( 25-210) | <u>0338</u> <u>-0412</u> | <0333 | Stationary Prominence Flare | 'Very Strong'* | Proton event. |
| 16 | Harvard<br>Ann Arbor | ( 25-260)<br>(100-580) | 1616 -1623<br>1616 -1622 | May have been either 1604, 1610, or 1613. | Stationary Prominence Flare | 'Moderate' if associated with impulsive events at 1604 U.T. or 1610 U.T. 'Strong' if associated with event of 1613 U.T. | Event associated with a major ejection. |
| {16<br>{17 | Ann Arbor<br>Sydney | (100-580)<br>( 25-210) | 2120.7 -2300<br>0602 -0606 | 2118 | Moving Prominence Flare | 'Very Strong'* | Proton event. No S.W.F. or 10 cm burst reported at 0602 U.T. during the declining phase of the above flare. |

*See also Table 6.6a for details of associated long duration continuum radiation.

TABLE 6.6a

Association of Prominence Flaring in Region 59Q With the Generation of Long Duration Continuum Radio Radiation

| Date, July 1959 | Radio spectograph observations | | | Time of commencement of flash phase of parent flare in 59Q U.T. | Type of parent flare in 59Q | Class of associated radio radiation | Remarks |
|---|---|---|---|---|---|---|---|
| | Station | Frequency range, MHz | Recorded start of continuun radiation U.T. | | | | |
| 9 | Harvard | ( 25-580) | 2044-2105-2110-2114-2257-2330-2400 (IV) | 2041 This event represents an intensity enhancement in an extensive Prominence Flare which began at 1810 U.T. | Stationary Prominence Flare | 'Moderate' radio event at 2042 U.T. represents an enhancement of the microwave component of a 'Strong' radio event which began at 1810 U.T. | 2045-2046 U.T. an unclassified burst/Int. 3. From 2114-2257 structure in the continuum. |
| | Ann Arbor | (100-580) | <2203-2245 2345-2400 | | | | |
| | Sydney | ( 25-210) | <2259-2326-2346-2400 | | | | |
| 10 | Sydney | ( 25-210) | 0000-0018-0033-0048-0102-0139 | See above | Stationary Prominence Flare | See above | The major proton producing Prominence Flare of 0205 U.T., July 10 was probably associated with Type IV radiation, see text. |
| 13 | Harvard | (100-580) | 1937-1943-2005 (IV) | - | - | - | Dropped from catalogue of Maxwell et al. (1963). Prob. assoc. with extensive flaring at S15°,E45°. Also concomitant flaring at N10°, W85° and at S25°,E50°. |
| 14 | Sydney | ( 25-210) | 0401-0535-0610 (IV) | <0333 | Stationary Prominence Flare | 'Very Strong' | |
| 16 | Harvard | ( 25-580) | 2121-2250-2256-2302 2313-2322 2348-2354 2400 | 2118 | Moving Prominence Flare | 'Very Strong' | 2121-2250 U.T. structure in the continuum over a range of 25-580 MHz consisting of fast drift burst with positive and negative slopes. |
| | Ann Arbor | (100-580) | 2120.7-2300 | | | | |
| | Sydney | ( 25-210) | <2241->2400 (IV) | | | | |
| 17 | Harvard | ( 25-580) | <0000-0143 (IV) | See above | See above | See above | Declining aspect of the event of July 16. |

TABLE 6.7a

Cosmic Ray Increases Detected at Ground Level by Various Stations and Their Association With Moving Prominence Flaring in 59Q on July 16, 1969

| Cosmic ray event at ground level (G.L.E.) | | | | | | Associated flare | | |
|---|---|---|---|---|---|---|---|---|
| Date 1959 | Station | Cut-off rigidity*, Bev | Max. amplitude of increase, % | C.ray start (U.T.) | C.ray max. (U.T.) | Time start flash phase (U.T.) | Imp. | Type |
| July 16 | Churchill | 0.11 | 7.8 ± 0.5+ | 2250x | ~0500 on July 17 | 2118 | 3 | Moving Prominence Flare |
| | Mawson | 0.75 | 6.1 ± 0.5 | | | | | |
| | Ottawa | 0.96 | 4.7 ± 0.5 | | | | | |
| | Deep River | 0.97 | 4.4 ± 0.6 | | | | | |
| | Sulphur Mt. | 0.98 | 10.0 ± 0.6 | | | | | |
| | Mt. Washington | 1.03 | 4.1 ± 0.6 | | | | | |
| | Ellsworth | 1.13 | 4.9 ± 0.5 | | | | | |
| | Chicago | 1.54 | 3.3 ± 0.5 | | | | | |
| | Climax | 2.71 | 3.0 ± 0.5 | | | | | |

*Values derived by Quenby and Webber (1959).

+Standard deviation.

xGiven by McCracken et al. (1960).

TABLE 6.7b

Subcosmic Ray Events July 7-21, 1959, and Their Association With Prominence Flaring in Region 590*

| Polar cap absorption events | | | | | | Direct particle+ observations | Associated flare event | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date 1959 | Onset time (U.T.) | Rise time (hours) | Duration (hours) | Max.riom. obs. (db) | References | References | Day (July) | Time start (U.T.) | Imp. | Type | Start of flash phase (U.T.) |
| July 09 | 2000$^{x}$ | - | 312 | - | "Catalogue of Solar Particle Events 1955-1969" (1975) | Akasofu and Chapman (1961) | 09 | 1930 | 2 | Stationary Prominence Flare | See footnote o |
| July 10 | 0400<br>0700<br>1100 | -<br>29<br>- | >96<br>360+<br>96 | >15<br>20<br>- | Bailey (1962)<br>Bailey (1964)<br>Brown et al. (1959)<br>Collins et al. (1961)<br>Kahle (1962)<br>Lockwood (1960)<br>Maeda et al. (1962)<br>Malitson (1963)<br>Ortner et al. (1960)<br>Reid et al. (1959)<br>Shapley et al. (1960)<br>Sinno (1961)<br>Warwick et al. (1962) | Biswas (1961)<br>Brown et al. (1959)<br>Brown et al. (1961a)<br>Brown et al. (1961b)<br>Earl (1961)<br>Ehmert et al. (1960)<br>May (1961)<br>Winckler (1959)<br>Winckler et al. (1961) | 10 | 0205 | 3+ | Stationary Prominence Flare | 0205 |
| July 14 | 0445<br>0730 | -<br>20 | >72<br>72+ | 20<br>23.7 | Bailey (1962)<br>Bailey (1964)<br>Brown et al. (1959)<br>Collins et al. (1961)<br>Kahle (1962)<br>Lockwood (1960)<br>Malitson (1963)<br>Ortner et al. (1960)<br>Reid et al. (1959) | Brown et al. (1959)<br>Ehmert et al. (1960)<br>Meyer (1960)<br>Winckler (1959)<br>Winckler et al. (1961) | 14 | 0319 | 3+ | Stationary Prominence Flare | <0333 |
| July 16<br>17<br>17 | 2250<br>0000<br>0300 | -<br>10<br>- | 120<br>67<br>120 | 15<br>21.2<br>- | Anderson et al. (1960)<br>Bailey (1962)<br>Bailey (1964)<br>Brown et al. (1959)<br>Carmichael et al. (1961)<br>Collins et al. (1961)<br>Ghielmetti (1961)<br>Kahle (1962)<br>Lockwood (1960)<br>Malitson (1963)<br>McCracken et al. (1960)<br>Ortner et al. (1960)<br>Reid et al. (1959)<br>Sinno (1961)<br>Warwick et al. (1962) | Anderson et al. (1960)<br>Earl (1961)<br>Ehmert et al. (1960)<br>Meyer (1960)<br>Winckler (1959)<br>Winckler et al. (1961) | 16 | 2114 | 3 | Moving Prominence Flare | 2118 |

*Protons with energies in the range 10-400 Mev were called 'subcosmic rays' by Ellison (1963).

+Particles directly observed during balloon flights using either Geiger counters, Scintillation counters, Ionization chambers or emulsion packs.

$^{x}$This is an unconfirmed event reported by Akasofu and Chapman (1961), cf. Section 6.7.

$^{o}$This reported importance 2 flare formed part of a Stationary Prominence Flare deemed to begin at $18^{h}$ $10^{m}$ U.T. and which thereafter showed several centimetre and ionizing burst associated intensity enhancements, cf. Table 6.3a.

TABLE 6.7c

Magnetic Storm Events July 7-21, 1959, and Their Association With Prominence Flaring in Region 59Q

| Day 1959 | Forbush decrease | | | | Geomagnetic storm | | | | | | Associated flare event | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Onset time (U.T.) | Mag. of decrease (%) | Duration of decrease phase (hours) | References | Onset time (U.T.) | End time (day/U.T.) | Type | Max. intensity* | Max. $K_p$ | References | Day 1959 | Time start (U.T.) | Imp. | Type |
| July 11 | 1715 | 9.9 | 12 | Lockwood (1960)<br>Maeda et al. (1962) | 1625 | 12/03xx | sc | ms | 7 - | De Feiter (1960)<br>Dvoryashin et al. (1961)<br>Haurwitz (1962)<br>Lockwood (1960)<br>Maeda et al. (1962)<br>Malitson (1963)<br>Obayashi et al. (1960)<br>Ortner et al. (1962)<br>Sinno (1961) | July 10 | 0205 | $3^+$ | Stationary Prominence Flare |
| July 15 | 0830 | 14.5 | 10 | Kahle (1961)<br>Lockwood (1960)<br>Maeda et al. (1962)<br>Shapley et al. (1962) | 0803 | 16/09xx | sc | s | 9 o | De Feiter (1960)<br>Dvoryashin et al. (1961)<br>Haurwitz (1962)<br>Lockwood (1960)<br>Maeda et al. (1962)<br>Malitson (1963)<br>Maxwell et al. (1963)<br>Obayashi et al. (1960)<br>Pisharoty et al. (1962)<br>Sinno (1961) | July 14 | 0319 | $3^+$ | Stationary Prominence Flare |
| July 17 | 1930 | 13.5 | 7 | Kahle (1961)<br>Lockwood (1960)<br>Maeda et al. (1962)<br>Shapley et al. (1962) | 1624<br>1938 | 19/18xx | sc | s | 9 - | De Feiter (1960)<br>Dvoryashin et al. (1961)<br>Haurwitz (1962)<br>Lockwood (1960)<br>Maeda et al. (1962)<br>Malitson (1963)<br>Obayashi et al. (1960)<br>Ortner et al. (1962)<br>Sinno (1961) | July 16 | 2114 | 3 | Moving Prominence Flare |

*Symbols: ms - moderately severe ($K_p$ = 6 or 7)
s - severe ($K_p$ = 8 or 9)

TABLE 6.8a

Time Intervals Between the Earliest Reported Commencements and Enhancements of Centimetre Wave Bursts and Ionospheric Events Associated With Prominence Flaring in Region 59Q and the Corresponding Times of Commencement of Type III Bursts

| Date 1959 | Prominence Flaring: Time of commencement and centimetre wave and/or ionizing burst assoc. enhancement of Prominence Flaring, U.T. | Centimetre wave radiation: Time of earliest rept. commenc. & enhancement of cm wave radiation, U.T. | Centimetre wave radiation: * Class of earliest reported radio burst | Ionospheric events: Time of earliest reported commenc. and enhancement of ionospheric events, U.T. | Type III bursts: Type of commenc. of centimetre wave associated Type III bursts, U.T. | Type III bursts: Interval between earliest[+] reported commenc. or enhancement of centimetre wave radiation and the time of commenc. of Type III bursts, mins. | Type III bursts: Interval between earliest[++] reported commenc. or enhancement of an ionospheric event and the time of commenc. of closely assoc. Type III bursts, mins. |
|---|---|---|---|---|---|---|---|
| July 10 | 0205 (Extensive flaring) | 0206 | V. strong | 0200 | 0210-0212G | -4 | -10 |
| 14 | <0333 (Extensive flaring) | 0330 | V. strong | 0328 | None | - | - |
| 16 | 2118 (Extensive flaring) | 2118 | V. strong | 2115 | 2120-2121g,2122g | -2 | -5,-7 |
| | | 2313 | Moderate | | None | | |
| | | 2346 | Moderate | | None | | |
| | | 0024 | Moderate | | None | | |
| | | 0032 | Moderate | | None | | |
| | | 0041 | Moderate | | None | | |
| 08 | 1330 | 1329 | Strong | None | 1328g | +1 | - |
| 09 | (1438-1440) | 1440.8 | Strong | None | 1442g | -1.2 | - |
| 09 | 1810,1941, | 1810 | Strong | 1812,1940 | 1810g | 0 | +2 |
| | (2033,2036,2041,2046 | 2042 | Moderate | (2035,2038,2040) | 2042b,2045-2046g | 0 | -7 |
| | | 2112 | Moderate | | None | | - |
| | 2217 | 2218 | Moderate | 2225 | None | | - |
| 14 | (1734-1736) | 1734 | Strong | 1735 | 1735-1736G | -1 | 0 |
| 14 | 2224 | 2223 | Strong | 2225 | 2233g | 0 | +2 |
| 15 | 1925 | 1925 | Strong | 1922 | 1926-1928G | -1 | +4 |
| 18 | 1048 | 1047.6 | Strong | None | 1047.8-1049 | -0.2 | - |
| 18 | x | 1754.5[x] | Strong | 1750 | None | - | - |
| | | 1811 | Moderate | | None | - | - |
| 11 | 0133 | 0132.8 | Moderate | None | None | - | - |
| 11 | 0232 | 0233 | Moderate | None | No obs. | - | - |
| 11 | 0449 | 0449 | Moderate | None | No obs. | - | - |
| 11 | (2313-2314) | 2314 | Moderate | None | None | - | - |
| 12 | 0425 | 0423 | Moderate | 0420 | No obs. | - | - |
| 12 | (0628-0629) | 0630 | Moderate | 0630 | No obs. | - | - |
| 12 | 1314 | 1313 | Moderate | None | None | - | - |
| 12 | 1405 | 1406 | Moderate | None | None | - | - |
| 12 | 2207 | 2207 | Moderate | Decaying SEA | 2209b | -2 | +9 |
| | (2224-2228) | 2224 | Moderate | 2218 | 2227b | -3 | -9 |
| 13 | 0609 | 0610 | Moderate | None | No obs. | - | - |
| 14 | (1145-1147) | 1146.5 | Moderate | None | Ann Arbor | - | - |
| 15 | (1255-1256) | 1257 | Moderate | | None | - | - |
| | (1300-1301) | 1300 | Moderate | 1258 | None | - | - |
| | (1327-1329) | 1327.5# | Strong | | None | - | - |
| 15 | (1606-1607) | 1606.9 | Moderate | None | None | - | - |
| 15 | (2240-2242) | 2240 | Moderate | None | None | - | - |
| 16 | (0637-0638) | 0636 | Moderate | None | No obs. | - | - |
| | | 0708.2 | Moderate | 0705 | No obs. | - | - |
| 16 | (1351-1352) | 1351 | Moderate | None | None | - | - |
| 16 | 1604 | 1605 | Moderate | 1610 | 1610g | -5 | 0 |
| | 1610 | 1610 | Moderate | | None | - | - |
| | No optical obs. at 1613 | 1613 | Strong | | 1614.4-1615g | -1.4 | -4.4 |
| 17 | (1339-1340) | 1340 | Moderate | None | None | - | - |
| 08 | 1846 | None | Weak or None | 1848 | Ann Arbor | - | - |
| 09 | 0818 | None | " " | 0820 | No obs. | - | - |
| Total | 31 | 28 commenc. +16 enhancements | 3 V.strong<br>10 Strong<br>31 Moderate<br>2 W. or N. | 16 commenc.<br>3 enhancements | 11 commenc.<br>4 enhancements | | |

Footnotes are listed on following page 93.

Footnotes to Table 6.8a

*According to the classification system adopted in Section 6.3.

+A negative value indicates that the reported earliest commencement or enhancement of the ionospheric event precedes the start of the Type III burst.

++A negative value indicates that the reported earliest commencement or enhancement of the ionospheric event precedes the start of the Type III burst.

xThis flare probably commenced at $17^h$ $50^m$ U.T. in association with a 'Moderate' centimetre wave burst but the seeing was too poor at this time to detect any intensity fluctuation on the disk. The observed event of $17^h$ $54^m$ U.T. comprised a brightening within what appeared to be part of an already brilliant length of flaring prominence material. However, due to the effects of over exposure, it cannot be decided how much of the prominence brightened at this time in association with the centimetre wave burst.

§The radio burst at $13^h$ $27.5^m$ U.T. was only $2.5^m$ in duration at centimetre wavelengths; smoothed peak flux density 9 solar flux units.

TABLE 6.12a

Comparison Between the Characteristics of Stationary and Moving Prominence Flares in 59Q Deduced From the Present Data and the Parameters of Flares Reported by Warwick (1966a) to Occur in the Region at Corresponding Times on the Basis of World Wide Patrol Data

| Date 1959 | Time of onset or enhancement U.T. of Stationary and Moving Prominence flares in 59Q | Time of onset U.T. and class of accompanying centimetre wave burst* | Presence of an ionizing event | Standardized solar flare data | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Beg. U.T. | Max. U.T. | End. U.T. | Mean corrected importance | Mean corrected apparent area, sq. deg. |
| July 08 | 1330 | 1329 (Strong) | None reported | | None reported | | | |
| 08 | 1846 | - (Weak or None) | Yes | | None reported | | | |
| 09 | 0818 | - (Weak or None) | Yes | 0707 | 0714 | 0921 | 1+ | 2.3 |
| 09 | 1438-1440 | 1440.8 (Strong) | None reported | 1413 | - | 1443 | 1 | 0.7 |
| 09 | 1810, 1941, 2033, 2036, 2041-2043, 2112, 2217 | 1810 (Strong), 2042, 2112, 2218 (Moderate) | Yes | 1810 | 1815 | 1830 | 1 | 2.0 |
| 10 | 0205-<0209 | 0206 (Very Strong) | Yes | 0206 | 0236 | 0851 | 3+ | 21.6 |
| 11 | 0133 | 0132.8 (Moderate) | None reported | | None reported | | | |
| 11 | 0232 | 0233 (Moderate) | None reported | | No reported patrol | | | |
| 11 | 0449 | 0449 (Moderate) | None reported | 0440 | 0451 | 0516 | 1- | 1.0 |
| 11 | 2313-2314 | 2314 (Moderate) | None reported | 2311 | - | 2318 | 1- | 0.4 |
| 12 | 0425 | 0423 (Moderate) | Yes | 0424 | 0432 | 0538 | 1 | 2.5 |
| 12 | 0628-0629 | 0630 (Moderate) | Yes | 0628 | 0637 | 0654 | 1 | 2.8 |
| 12 | 1314 | 1313 (Moderate) | None reported | 1200 | - | 1340 | 1- | 2.3 |
| 12 | 1405 | 1406 (Moderate) | None reported | <1410 | 1425 | 1515 | 2- | 6.5 |
| 12 | 2207, 2224 | 2207, 2224 (Moderate) | Yes | 2155 | 2230 | 2339 | 2 | 13.1 |
| 13 | 0609 | 0610 (Moderate) | None reported | 0609 | - | 0618 | 1- | - |
| 14 | <0333 | 0330 (Very Strong) | Yes | 0319 | 0356 | 0907 | 3+ | 21.3 |
| 14 | 1145-1147 | 1146.5 (Moderate) | None reported | 1140 | 1152 | 1204 | 1- | 1.4 |
| 14 | 1734-1736 | 1734 (Strong) | Yes | 1730 | 1737 | 1756 | 1 | 2.2 |
| 14 | 2224 | 2223 (Strong) | Yes | 2204 | 2229 | 2255 | 1 | 3.8 |
| 15 | 1255-1256, 1300-1301, 1327-1329 | 1257, 1300 (Moderate), 1327.5 (Strong) | Yes | 1255 | 1311 | 1404 | 1+ | 4.5 |
| 15 | 1606-1607 | 1606.9 (Moderate) | None reported | 1607 | 1608 | 1620 | 1- | 0.9 |
| 15 | 1925 | 1925 (Strong) | Yes | 1923 | 1927 | 1951 | 1+ | 5.0 |
| 15 | 2240-2242 | 2240 (Moderate) | None reported | 2237 | 2244 | 2253 | 1+ | 4.6 |
| 16 | 0637-0638, 0708 (in prog) | 0636, 0768.2 (Moderate) | Yes | 0637 | - | 0758 | 1+ | 5.2 |
| 16 | 1351-1352 | 1351 (Moderate) | None reported | 1347 | 1358 | 1424 | 1+ | 5.7 |
| 16 | 1604, 1610, 1613 (in prog) | 1605, 1610 (Moderate), 1613 (Strong) | Yes | 1606 | 1615 | 1658 | 2+ | 9.0 |
| 16 | 2118-2120, 2313, 2346, 0024 0032, 0041 (in prog) | 2118 (Very Strong), 2313, 2346, 0024x, 0032x, 0041x (Moderate) | Yes | 2116 | 2128 | 2430 | 3+ | 31.6 |
| 17 | 1339-1340 | 1340 (Moderate) | None reported | 1340 | 1345 | 1406 | 1 | 2.3 |
| 18 | 1048 | 1047.6 (Strong) | None reported | | None reported | | | |
| 18 | 1754, 1811 | 1754.5 (Strong), 1811 (Moderate) | Yes | 1754 | 1759 | 1842 | 1- | 2.0 |

*See the classification system given in Section 6.3.

TABLE 6.12b

Comparison Between the Times of Commencement and Locations of Plage Flares Observed in Region 59Q During 136.1$^h$ of Selected McMath SECASI Observations and the Parameters of Flares Reported by Warwick (1966a) to Occur in the Region at Corresponding Times on the Basis of World Wide Patrol Data

| Date 1959 | Times of commencement (U.T.) and locations of Plage Flares observed in region 59Q during the McMath SECASI observations | Standardized solar flare data | | | | | Remarks |
|---|---|---|---|---|---|---|---|
| | | Beg. U.T. | Max. U.T. | End. U.T. | Mean corrected importance | Mean corrected apparent area, sq deg | |
| July 07 | 1256(g), 1301(f) | 1256 | - | 1318 | 1- | 1.0 | |
| | 1404(a) | | | None reported | | | |
| 08 | 1109(d), 1110(c) | 1106 | - | 1115 | 1- | - | |
| | 1126(d) | | | None reported | | | |
| | 1132(d,e), 1138(c), 1143(d) | 1131 | 1145 | 1150 | 1- | - | |
| | {1203(c,d), 1224(e), 1225($d^{I}$), 1228(c)*, 1239(d), 1256($d^{I}$,e), 1309(e), | | | None reported | | | |
| | 1310($d^{I}$), 1321($d^{I}$)*, 1322(e), 1335(a), 1337(c), 1339($d^{I}$)*, 1355(e), 1408(c)} | | | | | | |
| | 1410(d), 1413(d) | 1411 | 1412 | 1415 | 1- | - | |
| | 1428($d^{I}$)*, 1436($d^{I}$,e) | | | None reported | | | |
| | 1442(b)* | 1442 | 1446 | 1453 | 1- | 0.5 | |
| | 1455($d^{I}$), 1517(e), 1530(c,e) | | | None reported | | | |
| | 1548(c) | 1546 | 1550 | 1609 | 1- | 0.7 | |
| | 1619(d)* | | | None reported | | | |
| | 1625(d,$d^{I}$), 1626(c), 1627(a) | 1624 | 1626 | 1630 | 1- | 0.8 | |
| | 1647(g), 1658(h), 1711(d), 1723($d^{I}$), 1729(a), 1742($d^{I}$) | | | None reported | | | |
| | 1754($d^{I}$), 1802($d^{I}$), 1818($d^{I}$) | 1747 | 1754 | 1820 | 1- | 0.1 | Impact Prominence brightening at 1747 U.T. in b. |
| | 1851(g), 1856(h), 1857(c) | 1849 | 1850 | >1906 | 1- | 0.2 | |
| | 1913(c), 1915(g,h) | <1906 | - | 1914 | 1 | 1.1 | |
| | 1927(c) | 1927 | 1928 | 1935 | 1- | 0.6 | |
| | 1938(b)*, <2004(g), 2008(d) | | | None reported | | | |
| | <2134(b), 2137(d), 2144(g,h) | 2121 | 2124 | 2145 | 1- | 0.3 | |
| | 2156(b), 2221(b) | | | None reported | | | |
| | 2235(g), 2241(b,f) | <2232 | - | >2250 | 1- | 0.1 | |
| | 2253($d^{I}$), 2303(b) | | | None reported | | | |
| 10 | 1201(h), 1209($d^{I}$,f,g), 1210(h) | <1049 | 1204 | 1220 | 1 | 1.8 | |
| | 1247($d^{I}$,f) | 1246 | 1248 | 1253 | 1- | 0.2 | |
| | 1317($d^{I}$,f) | <1316 | 1317 | >1329 | 1- | 0.3 | |
| | 1449($d^{I}$) | <1446 | - | >1459 | 1- | - | |
| | 1556($c_{I}$), 1621(g), 1655(c,d) | | | None reported | | | |
| | 1732(c,d) | <1730 | - | >1800 | 1- | 0.5 | |
| | 1854(g), 1938(g), <2110(d) | | | None reported | | | |
| 11 | <1224(d), 1230(g) | | | None reported | | | |
| | <1239(d), 1243($d^{III}$), 1255(k,$k^{I}$), 1301(d), 1306(k,$k^{II}$), 1307(c), | <1240 | - | >1320 | 1- | 1.0 | |
| | 1311($k^{II}$), 1321(d)* | | | | | | |
| | 1339(d,$k^{II}$), 1344(k), 1346($d^{III}$), 1414(k), 1416(d) | | | None reported | | | |
| | 1507(d), 1508(e), 1509(i), 1510(a), <1520($d^{III}$,k), <1545($d^{II}$) | 1507 | - | >1550 | 1- | 0.7 | |
| | 1563($d^{I}$), 1627(d)* | | | None reported | | | |
| | <1634(a,i), <1640(e), <1657(a,$d^{I}$), <1721(d) | 1630 | 1702 | >1730 | 1 | 2.0 | |
| | 1814($d^{I}$), 1816(d), <1845($k^{II}$), <1908(d), 1920(d,$d^{II}$)*, <1948($d^{I}$), 2007($d^{I}$,$k^{I}$) | | | None reported | | | |
| | 2059(a,d,k,$k^{I}$), 2102($d^{III}$), 2104(i), 2107($d^{II}$,k,$k^{I}$), 2141(d), 2147(d,$d^{II}$) | 2058 | 2108 | >2150 | 1 | 3.4 | |
| | 2207($d^{I}$,$k^{I}$), 2215(d), 2219($d^{III}$,$k^{I}$), 2240($d^{III}$) | 2206 | 2208 | 2255 | 1 | 3.1 | |
| | <2315($i^{I}$) | <2311 | - | >2318 | 1- | 0.4 | Stationary Prominence Flaring at <2315 U.T. in $i^{I}_{I}$ and in prominence material between chains III and VI 'Moderate' burst at 2314 U.T. |

*Brightenings marked with an asterisk were accompanied by impulsive Type III bursts.

Table 6.12b - Continued

| Date 1959 | Times of commencement (U.T.) and locations of Plage Flares observed in region 59Q during the McMath SECASI observations | Standardized solar flare data: Beg. U.T. | Max. U.T. | End. U.T. | Mean corrected importance | Mean corrected apparent area, sq deg | Remarks |
|---|---|---|---|---|---|---|---|
| July 12 | 1216(d), <1226(d), 1227($d^{IV}$), 1228 ($k^{I}$,l), 1252($e^{I}$), 1253(c), 1255(d),<br>1256(e,$e^{I}$), 1258($k^{I}$,l), 1300($i^{I}$), 1303($d^{I}$), 1310($d^{IV}$), 1316($l^{I}$),<br>1322(c), 1326(d), 1337($l^{I}$) | <1148 | - | >1340 | 1- | 2.3 | Stationary Prominence Flaring at 1314 U.T. in d accompanied by a 'Moderate' burst. |
| | 1352($l^{I}$), 1356($d^{IV}$), 1357($k^{I}$) | | | None reported | | | |
| | 1440($k^{II}$), 1448(d,$d^{I}$), 1459(d) | <1410 | 1425 | 1515 | 2- | 6.5 | Multiple site Stationary Prominence Flaring from 1405 U.T. accompanied by a 'Moderate' burst. |
| | 1631(k), 1632($d^{I}$) | | | None reported | | | |
| | 1651(e) | <1642 | - | >1654 | 1- | - | |
| | 1657(d) | | | None reported | | | |
| | 1743(a,c), 1744($e^{III}$), 1748($d^{I}$), 1751(d) | 1742 | 1747 | 1815 | 1- | 1.1 | |
| | 1848(l), <1940(d,k), 1959($l^{I}$), 2017(k), <2050(c,d,k), 2122($d^{I}$), 2127(c,d) | | | None reported | | | |
| | <2136($d^{IV}$,e), 2137(k), <2153(a), 2158($d^{I}$,i,$i^{II}$) | 2134 | 2230 | 2419 | 2 | 13.1 | Multiple site Stationary Prominence Flaring from 2207 U.T. 'Moderate' bursts at 2207 U.T. and 2224 U.T. |
| 13 | <1050(a,d,$d^{IV}$,l,m), 1053($d^{I}$,$d^{IV}$,$d^{IV}$), 1055(k), 1107($d_{I}^{IV}$), 1116(l,m,$k^{II}$,$k^{III}$),<br>1118(k), 1121(o), 1132($d^{I}$,$d^{IV}$), 1141($d^{I}$,n), 1142($n^{I}$,o), 1147($d^{I}$), 1151($d_{I}^{IV}$),<br>1153($k^{II}$,$k^{III}$), 1157($d^{I}$), 1159($d_{I}^{IV}$), 1206(k), 1207($d^{I}$,$d^{IV}$,$d_{I}^{IV}$,r), 1214($k^{II}$),<br>1217($d^{I}$,$d_{I}^{IV}$) | <1035 | - | 1230 | 1 | 2.5 | |
| | 1232($k^{II}$),1235(m), 1244($d^{I}$) | | | None reported | | | |
| | 1301(k,$k^{I}$,$k^{II}$,m), 1302(a,$c^{I}$,o), 1303(i,l,m), 1305(n,$o^{I}$), 1308(n),<br>1314($k^{III}$,m), <1345($d^{V}$,o), 1348($d^{I}$,$d^{IV}$), 1403($e^{I}$,k,m), 1408(n,$n^{I}$,o,$o^{I}$),<br>1429($k^{II}$,$k^{III}$) | <1255 | 1309 | 1430 | 1- | 2.8 | |
| | 1451(m), 1453($o^{I}$), 1456(m), 1457($o^{II}$), 1501(k,$k^{III}$), 1507($k^{II}$,$k^{III}$),<br>1503($d^{IV}$,l,m,n,$n^{I}$), 1524(o), <1530(a), 1538($e^{I}$), 1545($e^{I}$) | 1450 | 1510 | 1550 | 1 | 2.7 | |
| | <1630(c,$c^{I}$,d), 1632($e^{I}$), 1655(d,$d^{I}$,$d^{IV}$), 1656(c,$c^{I}$), 1715($k^{III}$),<br>1724($k^{II}$,$k^{III}$), 1725(o), 1727(f,$o^{I}$), 1728(d,$d^{V}$), 1729(c,$c^{I}$), 1731(g),<br>1732(n), 1733($n^{I}$), 1736($e^{I}$,$k^{III}$,q,$q^{I}$), 1751($k^{III}$), 1802(f), 1824($k^{II}$,$k^{III}$),<br>1825(f), <1845($d^{V}$) | | | None reported | | | |
| | 1905($e^{I}$), 1906($d^{I}$,$d^{IV}$,$d^{V}$) | 1904 | 1910 | 1912 | 1- | 1.7 | |
| | 1944(f,$k^{II}$,$k^{III}$), 1955(d), 1959(f,$k^{II}$,$k^{III}$), 2011($c^{I}$), 2014(d),<br>2048($k^{III}$), 2101(f,$k^{II}$,$k^{III}$) | | | None reported | | | |
| | <2112(c,$c^{I}$,d), 2114($d^{V}$), <2141(k,$q^{I}$), 2145($c^{I}$), 2200(c,d,f,$k^{II}$,$k^{III}$),<br>2211(m), 2222($e^{I}$)* | | | | | | |
| | 2227($c^{I}$), 2230($c^{I}$), 2231(c,d), 2232($a^{I}$),<br>2236(a), 2252($d^{V}$), 2254(f,g,$k^{III}$), 2255($e^{I}$) | 2225 | 2232 | 2303 | 1- | 1.4 | |
| 14 | <1056($i^{II}$,r,$r^{I}$), 1103($o^{III}$), 1115($i^{II}$), 1118($o^{III}$) | <1056 | - | >1300 | 1 | 1.7 | |
| | 1141(q,$q^{II}$,$s_{I}$), 1152($r^{I}$), 1154(m), 1206(c,d,k,$k^{III}$) | 1140 | 1152 | 1215 | 1- | 1.4 | Multiple site Stationary Prominence Flaring from 1145 U.T. accompanied by a 'Moderate' burst. |
| | 1220(d), 1226($e^{I}$) | | | None reported | | | |
| | 1229($r_{I}$), 1231(d,g,$r^{I}$), 1232(m,$m^{I}$,$o^{III}$), 1236(r), 1239($e^{III}$), 1243($o^{III}$),<br>1244(g,r), 1249($i^{II}$), 1251($o^{III}$), 1252($r^{I}$)*, 1307(d,$e^{I}$,k,$k^{III}$,l) | 1230 | 1236 | 1320 | 1 | 2.7 | |
| | 1324($k^{III}$) | | | None reported | | | |
| | 1332($k^{III}$), 1333(k,$k^{I}$), 1334(d,$d^{I}$)* | 1330 | 1334 | 1340 | 1- | 0.4 | |
| | <1431($i^{II}$), <1506(m), 1523(q), 1526(k), 1530(r), 1532($k^{III}$), 1533(m),<br>1537($c^{I}$), 1538($d^{I}$,$d^{VI}$), 1540(c), 1546($k^{I}$) | | | None reported | | | |

*Brightenings marked with an asterisk were accompanied by impulsive Type III bursts.

Table 6.12b - Continued

| Date 1959 | Times of commencement (U.T.) and locations of Plage Flares observed in region 59Q during the McMath SECASI observations | Standardized solar flare data: Beg. U.T. | Max. U.T. | End. U.T. | Mean corrected importance | Mean corrected apparent area, sq deg | Remarks |
|---|---|---|---|---|---|---|---|
| July 14 | <1610($d^{I},d^{VI}$)* | 1558 | 1602 | 1614 | 1- | 1.6 | |
| | 1618($s_{I}$) | | | None reported | | | |
| | 1622($c^{I}$(, 1630($d^{I},d^{VI}$), 1633($r^{I}$), 1634($i^{I}$)* | 1623 | 1624 | 1640 | 1- | 0.6 | |
| | <1702($k^{III}$), 1704($k^{I},k^{II},s_{I}$), 1712($o^{III}$), 1717($k,k^{I},k^{II},k^{III}$), 1726(m), | | | None reported | | | |
| | 1727($o^{I},o^{III}$) | | | | | | |
| | 1731($q^{II},s_{I}$), 1736($r^{I}$) | 1730 | 1757 | 1757 | 1 | 2.2 | Multiple site Stationary Prominence Flaring from 1734 U.T. accompanied by a 'Strong' burst. |
| | <2145($e^{I}$) | | | None reported | | | |
| | 2204($e^{I},q^{V}$), 2210($q^{IV}$), 2211(q), 2212(p), 2216(q), 2221($q^{V}$), 2251($e^{I}$) | 2203 | 2229 | 2256 | 1 | 3.8 | Multiple site Stationary Prominence Flaring from 2224 U.T. accompanied by a 'Strong' burst. |
| | 2300($q^{I},q^{II}$), 2303(q) | | | None reported | | | |
| 15 | 1123(d), 1124($d^{IV}$) | 1019 | 1024 | >1130 | 1 | 3.4 | |
| | 1140($d^{IV},d^{VII},e^{I}$), 1156($e^{I}$), 1227(d), 1230($c_{I}^{I}$), 1234($d^{IV},d^{V}$), 1235($d^{VII}$) | | | None reported | | | |
| | 1241($q^{V}$)*, 1245(s), 1246($k^{III}$) | | | | | | |
| | 1250($d^{IV},d^{VII}$), 1251($k^{III}$,m), 1343(v), 1353($d,k^{III}$), 1358($e^{I},r,s^{I},s^{II}$), | 1251 | 1311 | >1404 | 1+ | 4.5 | Multiple site Stationary Prominence Flaring from 1255 U.T. accompanied by 'Moderate' bursts at 1257 and 1300 U.T. and by a 'Strong' burst at 1327.5 U.T. |
| | 1359($k^{III},q^{V}$), 1401($s^{I}$,v), 1404($t^{I},t^{II}$), 1405($s,s^{I},t$), 1407($c^{I},d,q^{V}$) | | | | | | |
| | 1409($m^{II}$), 1412($t^{I}$), 1413($q^{VII}$), 1415(s)*, 1417($c^{I}$,d), 1425($d^{VII},k^{IV}$) | <1409 | - | 1425 | 1- | 1.4 | |
| | 1430($d^{V}$), 1431($k^{IV}$), 1437($d^{IV},d^{V},d^{VII}$) | | | None reported | | | |
| | 1440($e^{I}$), 1507($d^{VII},k^{IV}$), 1654($e^{I}$), 1655($t^{I}$), 1704($d^{I}$)* | | | | | | |
| | <1732($d^{I},d^{VI},d^{VII},k^{IV}$) | 1730 | 1733 | 1743 | 1- | 1.1 | |
| | <1818($s,s^{I}$) | 1756 | 1801 | 1835 | 1- | 1.9 | Impact Prominence Flaring at 1800 U.T. in v |
| | <1857(v) | | | None reported | | | |
| | <2009(d) | | | None reported | | | |
| | <2042($d^{I},d^{VII},k^{IV}$) | 2042 | 2051 | 2106 | 1- | 1.1 | |
| | <2119(v) | | | None reported | | | |
| | 2147($d^{I}$), <2158(v), 2201($d^{IV}$), 2202($d^{IV},d^{VII}$) | <2135 | 2144 | >2220 | 1 | 4.2 | |
| | 2233(v), 2237($t,t^{I}$) | 2234 | 2244 | 2256 | 1+ | 4.6 | Multiple site Stationary Prominence Flaring from 2240 U.T. accompanied by a 'Moderate' burst. |
| 16 | 1143($k^{I}$,t) | | | None reported | | | |
| | 1148($k^{IV}$,t), 1149($k,t^{I},t^{II}$), 1150($k^{III},m^{I}$), 1151($m^{III}$), 1152($t^{III}$), 1157($x^{IV}$) | 1149 | 1205 | 1230 | 1- | 0.6 | |
| | 1158($m^{III}$), 1159($t^{I}$), 1200($t^{I}$), 1203($v,v^{IV}$), 1207($x^{VI}$), 1212($m^{III}$), 1219($m^{II}$) | | | | | | |
| | 1229($m^{II},m^{III}$), 1230($k^{I},k^{IV}$) | | | | | | |
| | 1236($k^{IV}$)* | | | None reported | | | |

*Brightenings marked with an asterisk were accompanied by impulsive Type III bursts.

Table 6.12b - Continued

| Date 1959 | Times of commencement (U.T.) and locations of Plage Flares observed in region 59Q during the McMath SECASI observations | Standardized solar flare data: Beg. U.T. | Max. U.T. | End. U.T. | Mean corrected importance | Mean corrected apparent area, sq deg | Remarks |
|---|---|---|---|---|---|---|---|
| July 16 | <1309(f,k) | <1300 | 1314 | >1324 | 1 | 3.3 | |
| | <1337($w^{II},x^{VI}$), 1342($w^{II},x^{VI}$), 1344($v^{I},w,x^{V}$), 1345($x^{VII}$), 1347($x^{IV},x^{VII}$) 1402($k^{IV},t_{I}$), <1405($d^{VIII},k^{I}$), <1420($q^{V},q^{VII},s,s^{II},s^{III}$), 1427(t), <1437($d^{I},e^{I}$), 1443($t^{I},t^{II}$), 1444($m^{III}$,t), 1446($t^{III}$), 1454($t^{II}$), 1511($m,m^{I}$), 1515($e^{I}$), 1516(c,d), 1518($d^{I}$) | 1336 | 1358 | 1519 | 1+ | 5.7 | Multiple site Stationary Prominence Flaring from 1351 U.T. accompanied by a 'Moderate' burst. |
| | 1523($k^{III}$) | | | None reported | | | |
| | <1528($k,k^{III}$), <1531($s^{II}$), 1541($f,k,m,m^{I}$), 1545($e^{I}$), 1549($d^{I}$), 1550($d^{VII}$), 1557($t^{II}$), 1600(t) | 1525 | 1601 | >1622 | 1+ | 7.3 | Multiple site Prom. Flaring from 1604 U.T. accompanied by 'Moderate' bursts at 1605 and 1610 U.T. and by a 'Strong' burst at 1613 U.T. |
| | <1555($k^{I},k^{IV},m^{IV}$), 1557($e^{I},e_{I}^{I}$) | 1552 | 1556 | 1604 | 1- | - | |
| | <1617($m,m^{I},m^{III}$), 1702(d), 1709($k,k^{II},k^{III},m^{IV},t^{I},t^{II}$), 1712($e^{I}$), 1713(d) | 1604 | 1615 | 1800 | 2+ | 9.0 | |
| | <1726($w^{II},x^{IV},x^{VI}$), 1733(d), 1740($e^{I},e^{I}$), 1747($k^{II},m^{IV},t^{II}$) | 1721 | 1723 | >1750 | 1- | 0.3 | |
| | <1828($v^{I},w^{II},x^{IV},x^{V}$) | | | None reported | | | |
| | <1847($m,m^{IV}$) | 1834 | 1842 | 1904 | 1- | 0.8 | |
| | <1938($k,k^{II},k^{IV},x,x^{III}$), 1939(d), <1946($d^{I},e^{I},e^{IV},k^{I}$), 1948($k^{IV}$), 1958(d), 2006($k^{II}$), <2111($d^{IV},d^{VIII},t,t^{I}$) | | | None reported | | | |
| | 2114($d^{IV}$), 2115(d), 2116($e^{I},e_{I}^{I}$) | 2114 | 2128 | 2430 | 3 | 31.6 | Multiple site Moving Prominence Flaring from 2118 U.T. accompanied by 'Moderate' bursts at 2313, 2346, 0024, 0032 and 0041 U.T. |
| 17 | 1143($k^{II},k^{III}$), 1146($w,x^{VII}$), 1148(v), 1152($k^{II},k^{III},k^{V}$), 1153($e^{IV}$), 1200($k^{II}$) | <1138 | - | >1200 | 1- | 1.5 | |
| | 1209($k^{V}$) | | | None reported | | | |
| | <1239($e^{IV},k^{II},w,x^{IV},x^{V},y$), 1326($d^{VIII},k^{II},k^{III}$) | 1221 | 1225 | >1330 | 1- | 1.4 | |
| | <1341($k^{IV},t^{III},y$), 1344($m^{II},m^{III}$), 1345($k^{II},k^{VI}$), 1355($k^{II}$), <1411($d^{VIII}$) | 1339 | 1345 | 1415 | 1 | 2.3 | Multiple site Stationary Prominence Flaring from 1339 U.T. accompanied by a 'Moderate' burst. |
| | <1427(w) | | | None reported | | | |
| | <1946($w^{I},w^{II},x^{IV},x^{V}$) | 1939 | 1948 | 2005 | 1 | 2.0 | |
| | <2039($k^{V}$) | 2036 | 2039 | 2044 | 1- | 0.6 | |
| | <2124($k^{VI},s^{I}$) | | | None reported | | | |
| 19 | <1241($y^{III},y^{V}$)*, 1300($y^{III}$) | | | None reported | | | |
| | <1327($y^{IV},y^{V}$), <1333($y^{V}$) | 1325 | 1328 | 1345 | 1- | 0.6 | |
| | 1350($y^{V}$), 1401($y^{IV}$), 1406($y^{V}$), <1417($y^{III}$), 1421($y^{IV}$), <1433($y^{I}$), 1450($y^{IV}$), <1503($y^{III}$), 1514($y^{IV}$), <1530($y^{II}$), 1539($y^{III}$), 1555($y^{V}$), 1558($y^{III}$), <1615($y^{III}$), 1626($y^{III},y^{V}$), 1627(y), 1642($y^{V}$), 1644($y^{III}$), 1704($y^{IV}$), 1712($y^{III}$), 1718(y) | | | None reported | | | |
| | <1735(y), <1743($y,z^{I}$)*, <1755($y^{IV},y^{V}$), 1757(y), 1802(y), 1807($y^{IV}$), 1828($y^{III}$), 1836($y^{IV}$), 1843($y^{IV}$), <1856($y^{III}$), <1907($y^{V}$), 1917($y,y^{IV}$), 1925($y^{III}$), <1931($y^{I}$), 1937($y^{III},y^{V}$) | | | | | | |
| | 2015($y^{III}$) | 2015 | - | 2030 | 1- | - | |

*Brightenings marked with an asterisk were accompanied by impulsive Type III bursts.

Table 6.12b - Concluded

| Time 1959 | Times of commencement (U.T.) and locations of Plage Flares observed in region 59Q during the McMath SECASI observations | Standardized solar flare data | | | | | Remarks |
|---|---|---|---|---|---|---|---|
| | | Beg. U.T. | Max. U.T. | End. U.T. | Mean corrected importance | Mean corrected apparent area, sq deg | |
| July 19 | <2104($y^{III}$) | | | None reported | | | |
| | 2136($y^{V}$) | 2136 | 2142 | 2146 | 1 | 0.4 | |
| 20 | <1326($y^{V}$) | | | None reported | | | |
| | <1836($y^{IV}$), <1840($y^{III}$), 1845(s,$y^{V}$), 1929($y^{I}$,$y^{V}$), 1942(y), 2041($y^{V}$) | | | None reported | | | |
| | 2051($y^{V}$), <2102($y^{III}$) | 2052 | 2057 | 2402 | 1- | - | |
| | 2125($y^{IV}$), <2130(y), <2142($y^{I}$) | | | None reported | | | |
| | <2222($y^{III}$,$y^{IV}$), <2238($y^{I}$,$y^{V}$) | 2221 | 2226 | 2242 | 1- | 0.6 | |
| | 2255(s) | 2255 | 2256 | 2258 | 1- | 0.2 | |
| 21 | <1105($y^{IV}$,$y^{V}$), <1120(y), 1125($y^{I}$), 1126($y^{III}$), 1136(y,$y^{I}$), 1137($y^{III}$,$y^{IV}$,$y^{V}$),<br><1146(s), <1212(y), <1228($y^{I}$,$y^{III}$), 1231($y^{IV}$), 1243(y), 1250($y^{III}$), 1253(y),<br>1311($y^{IV}$), <1320(y,$y^{III}$), 1326(y,$y^{III}$,$y^{IV}$), <1348($y^{III}$), <1353($y^{IV}$),<br><1406(y), 1410($y^{III}$), 1429($y^{IV}$), <1447($y^{III}$), <1458($y^{IV}$), <1521(y) | | | None reported | | | |
| | <1550(y,$y^{VI}$), 1552($y^{V}$) | 1548 | 1552 | 1554 | 1- | 0.3 | |
| | <1600($y^{IV}$), 1646($y^{IV}$), <1733($y^{III}$), <1816($y^{III}$,$y^{VI}$), <1833($y^{III}$,$y^{IV}$),<br><2024($y^{IV}$), 2035(s) | | | None reported | | | |

*Brightenings marked with an asterisk were accompanied by impulsive Type III bursts.

Table 6.12c

Numbers of Individual Plage and Prominence Brightenings Observed in 59Q Over 136.1$^h$ of Selected McMath SECASI Observations and Numbers of Composite Prominence Flares Identified in This Region Over Its Entire July Transit, Which Respectively Fell During Periods Covered by Those Flares of Different Importance Classes Reported by Warwick (1966a) To Be Associated With 59Q Over the Same Time Intervals

| Individual impulsive brightenings observed in 59Q over 136.1$^h$ of selected McMath observations and composite Prominence Flares identified in 59Q over its entire July disk transit | No. of brightenings occurring with a flare was not previously reported | No. of brightenings occurring while flares of importance class (1-) were in progress | No. of brightenings occurring while flares of importance class (1- 1+) were in progress | No. of brightenings occurring while flares of importance class (-2-2+) were in progress | No. of brightenings occurring while flares of importance class (-3-3+) were in progress | Total |
|---|---|---|---|---|---|---|
| Plage Brightenings+ | 330 | 233 | 217 | 23 | 4 | 807 |
| Impact Prominence Brightenings | 2 | 4 | 0 | 0 | 0 | 6 |
| Stationary Prominence Brightenings | 5 | 8 | 88 | 80 | 0 | 181 |
| Moving* Prominence Brightenings | 0 | 0 | 0 | 0 | 12 | 12 |
| Composite Impact Prominence Flares | 1 | 3 | 1 | 0 | 3 | 8 |
| Composite Stationary Prominence Flares | 6 | 7 | 13 | 2 | 2 | 30 |
| Composite Moving Prominence Flares | 0 | 0 | 0 | 0 | 1 | 1 |

*An individual brightening or a composite flare is deemed associated with one of Warwick's reported events if it occurred within $-1^m$ of its earliest reported beginning time and within $+1^m$ of its latest reported end time.

+Due to problems associated with the contrast on the CSM no estimate is available of the number of Plage Brightenings occurring in 59Q outside the times of the selected McMath observations, cf. Sections 3.1 and 6.2.

CHAPTER 7

# THE ASSOCIATION OF FLARING IN REGION 59Q WITH CHANGING FEATURES IN THE UNDERLYING PHOTOSPHERIC MAGNETIC FIELD

Region 59Q is shown to have consisted of an aggregate of groups of sunspots of different magnetic classes, one group of which possessed all the attributes typically displayed by regions associated with the production of flares. Flare active sites tended to be located along the borders of lengths of dark prominence material suspended above these individual spot groups. Certain sites displayed outstanding capacities for producing burst associated flaring. Individual active areas were located above minor umbrae aligned along or within 10" of a locus of zero longitudinal magnetic field. Prominence Flaring appeared to be triggered directly above positions where magnetic changes took place within intervals closely bridging the optical events. The observed presence of localized active dark material indicates that magnetic instability was already in progress either prior to or at the very onsets of many (perhaps all) of the associated Prominence Flares concerned. Plage Flares were not confined to intervals spanning obviously important change but were sited above positions with a 'history' of magnetic instability.

## 7.1 Details of the Individual Spot Groups Associated With Active Region 59Q During Its July Disk Passage

When region 59Q is observed on white light pictures, it is found to consist of an aggregate of groups of sunspots. Certain of these groups have been assigned numbers by Mt. Wilson and Table 7.1a (see p. 102) summarizes information concerning their respective magnetic classes, field strengths and lifetimes. Drawings made at Mt. Wilson of these various spot groups are shown in Fig. 7.1a, p. 126.

The principal complex group in the region, Mt. Wilson No. 14284, was a return of $\gamma$ group Mt. Wilson No. 14211 (identified in McMath Plage 5204 during a previous passage, C.M.P. 17 June 1959). This in turn was a return of $\beta p$ group Mt. Wilson No. 14139 in McMath Plage 5157 (which developed on the disk on May 17, C.M.P. May 20, 1959). As seen during early July, magnetically complex Mt. Wilson No. 14284 consisted of multiple umbrae of north polarity, separated from a large region of south polarity, all contained with the same penumbra. Umbrae of opposite polarity were separated by less than $1^{\circ}$ and the group thus formed a $\delta$ configuration according to the criterion of Künzel (1960).

In addition to the magnetic features listed in Table 7.1a, a minor group, not specially designated by a Mt. Wilson number, and which appeared directly to the south of the southern penumbral border of Mt. Wilson 14284 on July 13-14, 1959, should be specially mentioned.

TABLE 7.1a

The Magnetic Classes, Field Strengths and Life Times of Sunspot Groups Identified at the Mt. Wilson Observatory in Region 59Q During Its July 1959 Disk Passage

| Mt. Wilson No. | Mag.* class | Intensity+ 100 Gauss | Days seen |
|---|---|---|---|
| 14280 | dβ d | (7) | 07-14 |
| 14282 | dα pd | (2) | 08-14 |
| 14284 | lγ l | 27 | 08-20 |
| 14285 | dβ pl | 13 | 09-20 |
| 14292 | dα d | (2) | 12-16 |
| 14297 | dx d | (2) | 14-15 |

*Mount Wilson sunspot classification and notation as given by Hale and Nicholson (1938).

[α]Denotes unipolar groups and β bipolar groups.

[γ]Denotes groups with mixed polarities; complex polarities.

[αp]Denotes a unipolar group with polarities of the 'preceding' component (leader) of a normal bipolar group.

[βp]Denotes a bipolar group where the preceding component is stronger.

[x]Denotes a group observed but for which no polarities were measured.

[l]When a group came over the limb the magnetic classification is preceded by the leter 'l'. Similarly if the group disappeared over the western limb a letter 'l' follows the magnetic classification.

[d]If the group was born on the visible disk a letter 'd' precedes the magnetic classification; if it disappeared on the disk the letter 'd' follows the magnetic classification.

[+]Field strength in units of 100 gauss. A bracket indicates an estimated value.

This magnetic feature will hereafter be called for reference Spot group A*. Also, a scatter of umbrae which appeared immediately to the north of the northern penumbral border of Mt. Wilson 14284 on July 14-15 will be called Spot group B in the present text*. The constituents of groups A and B were considered included with the umbrae of aggregate 14284 by the Mt. Wilson observers.

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*The relevant umbrae are thus designated in the white light drawings of 59Q comprising Fig. 7.1 (July 16), p. 128.

## 7.2 Characteristics of an Active Region Indicating It to be Especially Likely to Generate Important Flares

Flare activity in a given spot group is very strongly dependent on the stage of development of that group, being greatest when it is passing through Zürich classes, D, E, and F, Waldmeier (1955). According to Waldmeier, the largest flares produced within a region also develop while the group is passing through such stages and this latter result is confirmed by Kleczek (1953) and Künzel (1960). Further, flare activity depends on the magnetic classification and increases dramatically as the parent group evolves from being simple unipolar $\alpha$ type, through bipolar $\beta$ and $\beta\gamma$ types to complex $\gamma$ type, Giovanelli (1939), Bell and Glazer (1959), Martres et al. (1966a) and Smith and Howard (1968).

Especially flare active regions are also frequently reported to be characterized by steep gradients in the longitudinal component of the magnetic field close to the 'neutral line'* and they tend to show 'polarity inversion', Ellison et al. (1960a), Sakurai (1967, 1972), Zirin (1970, 1974) and Prata (1971). Sudden increases in the rate of flare activity are correlated by Bumba et al. (1968b) with specific periods of growth and renewal within the life of an active region when reorganization of the magnetic field into more complex structures takes place. A magnetic configuration that is especially favourable for the production of major flaring is that in which closely spaced umbrae of opposite polarity are enclosed within a single penumbra. This is the so-called $\partial$ configuration defined by Künzel (1960). Practically all proton flares occur in $\partial$ groups, Warwick (1966b), Sakurai (1967, 1969, 1960).

It was first recognised by Ellison et al. (1964a) that flares emitting GLE protons appear as twin bright filaments arrayed above two close rows of sunspots of opposite polarities. These filaments cover partially or completely those underlying umbrae of highest field strengths. From a study of the flares associated with PCA events, Dodson and Hedeman (1961b) concluded that the extension of a flare to cover at least one umbra was significant in its association with protons. Avignon et al. (1963, 1964a, 1964b, 1965) describe two configurations of PCA flares which are closely related to the geometry of the underlying spot group. The first (configuration A) corresponds with that already described by Ellison et al. where flaring occurs above two sets of spots of opposite polarity separated by a small distance. The second (configuration A'), which is produced above a region displaying a plage filament pointing towards two closely spaced spots of opposite polarities, is such that part of the flare is above one of the sunspots and part extends along the plage filament.

Sunspot groups that produce proton flares often rotate counter-clockwise (clockwise) in the norther (southern) hemisphere for several days before proton events are produced, Sakurai (1967, 1969). Sawyer and Smith (1970), Vrabec (1971). On examining this rotating motion McIntosh (1969, 1970) found that the relevant spot groups were accompanied by counter-clockwise and clockwise rotating motion in the northern and southern hemispheres, respectively. A further

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*See however Section 7.21, p. 125.

characteristic of proton producing spot groups may be the presence in the solar neighbourhood, up to distances of several tens of degrees, of 'satellite spot groups', Kopecký and Křivský (1966), Kleczek and Olmr (1967) and Křivský and Obridko (1969).

## 7.3 Characteristics of Region 59Q Indicating Its Special Potential to Produce Important Flares

Region 59Q possessed all of the attributes ascribed by the various authors quoted in Section 7.2 as pertaining to especially flare active regions. Among the aggregate of spot groups of which it was composed, principal group Mt. Wilson 14284 was of Zürich classification E, it showed reversed polarity and the gradient of the longitudinal component of the magnetic field near the 'neutral line' was high. Also, 59Q showed during its July transit that overall increase in the complexity of its magnetic structure that characterizes the development of enhanced levels of flaring (cf. Section 7.2). These changes could be ascribed to several processes including (a) the growth, diminution and disappearance of previously present umbrae and penumbrae, (b) splitting of spot umbrae, (c) the birth of new spots, (d) the proper motion of spots leading to either the merging or separation of individual magnetic features and to the consequent creation of strong magnetic shears, (e) the overall westward distension of the region due to the effects of solar rotation, and (f) counter-clockwise rotation of the magnetic axis of the group.

Properties of group 14284 indicating its potential to produce proton flares included (a) the presence of a $\partial$ configuration, (b) the presence of an A configuration, (c) the counter-clockwise rotation of the group axis, and (d) the presence of neighbouring 'satellite sunspot groups'*.

## 7.4 The Association of Impulsive Flaring in 59Q With Individual Spot Groups in the Region

It is of interest to try to determine the frequencies with which impulsive brightenings occurred above individual spot groups in region 59Q during at least part of its July disk passage. As already indicated in Section 3.2, some 1006 separate impulsive intensity increases were observed in 59Q over $136.1^h$ of McMath SECASI observations. In Table 7.4a, p. 130, details of the locations of these individual brightenings relative to the positions of underlying spot groups are given on a day-to-day basis. These daily data are summarized for convenience in Table 7.4b, p. 131.

Of the total of 1006 individual brightenings observed in 59Q, 767 occurred above Mt. Wilson group 14284; 119 above Mt. Wilson group 14285; 49 above Spot group B; 46 above Spot group A; 19 above Mt. Wilson group 14292, and 6 above Mt. Wilson group 14297.

These figures are expressed again in Table 7.4c** as percentages of the total number of impulsive brightenings counted in 59Q above 6 different spot

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*These 'satellite groups' included Mt. Wilson Nos. 14280, 14282, 14285, 14292 and 14297; cf. details in Table 7.1a, p. 102.

**See page 105.

groups. It is clear from these data that the overwhelming majority, namely 76.24% of flare events, occurred above Mt. Wilson 14284 (magnetic class γ); 11.83% above Mt. Wilson 14285 (magnetic class β); 4.87% above Spot group B (magnetic class unknown); 4.57% above Spot group A (magnetic class unknown); 1.89% above Mr. Wilson 14292 (magnetic class α) and 0.60% above Mt. Wilson 14297 (reported magnetic class x). Those minor features designated here as groups A and B were not originally accorded special numbers by Mt. Wilson but considered rather to form part of group 14284. If this view is also adopted here, it raises the percentage association of impulsive brightenings with the γ complex to 85.68%. This special relationship with the group is in agreement with reports by Bell and Glazer (1959), Künzel (1960), Wolbach (1963) and Martres et al. (1966a) who note that flares most frequently occur in association with large spot groups displaying strong complex magnetic fields.

TABLE 7.4c

Individual Percentages of 1006 Impulsive Brightenings Observed in 59Q Occurring Above Spot Groups of Different Magnetic Classes

| Spot group in 59Q | Class of spot group | Percentage of total no. of impulsive brightenings occurring above individual Spot groups |
|---|---|---|
| Mt. Wilson 14284 | 1γ 1 | 76.24 |
| Group B | * | 4.87 |
| Group A | * | 4.57 |
| Mt. Wilson 14285 | dβ pl | 11.83 |
| Mt. Wilson 14292 | dα d | 1.89 |
| Mt. Wilson 14297 | d x d | 0.60 |

*These constituted minor magnetic features that were not accorded a special group number by Mt. Wilson but were rather deemed included in aggregate 14284.

## 7.5 Procedure for Identifying Flare-Sensitive Areas in 59Q Which Were Particularly Associated With the Production of Radio Bursts

Flare sensitive areas in 59Q which were particularly associated with the production of radio bursts may be identified by a four-step process - (1) by determining, according to the technique of Section 4.3, if a particular radio burst was 'Unambiguously' or 'Probably' associated with flaring in region 59Q; (2) by calculating the probability that a burst associated with flaring in 59Q was associated with a particular flare active area within that region. This may be estimated as 1/mm where n = the total number of active centres on the disk to show simultaneous flaring and m = total number of flare active areas to have brightened within 59Q itself*; (3) by adding together all the individual estimated probabilities that radio bursts were associated with in particular flare active areas in 59Q during its transit July 07-21, 1959; and (4) by comparing the individual frequencies with which various locations were thus estimated to have been associated with the generation of radio bursts.

## 7.6 Identification of Areas in 59Q Deemed Particularly Associated With the Generation of Type III Bursts

Over the period of its July passage, 76 Type III bursts were deemed, in the presence or absence of reported accompanying single frequency and/or swept frequency radiation, to be time associated (according to the criteria of Section 4.3).

Of these 76, only 56 bursts (46 'Unambiguous' and 7-1/3 'Probable' associations) were associated with actually observed, sometimes multiple, intensity increases in identifiable parts of region 59Q (see an important footnote to p. 39 concerning the terminology used).

Table 7.6a, col. 3, p. 132, lists the total probabilities, estimated according to the procedure of Section 7.5, that those 56 Type III bursts mentioned above were associated with individual areas in region 59Q from July 07-21, 1959, inclusive. It is seen from the table that 42 different areas in 59Q can be time associated with Type III burst production, that is ~40% of those 106 areas within the region known to have exhibited flare activity**. The single three most burst active areas appear from the data to have been b, d, and $d^1$, respectively.

Since the figures continued in column 3 of Table 7.6a include even very minor probabilities of flare burst association, it is interesting to compare them with the data in column 2, which lists the sums of those individual occasions when Type III bursts occurred within $\pm 1^m$ of brightenings in <u>individual areas</u> in region 59Q. Only 11 areas could be thus closely associated with Type III burst activity (that is ~10% of those 106 areas within the region known to show flare activity)** and of these areas b, d and $d^1$ again stand out as having been particularly burst active.

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*Calculation of a probability based on the total number of flare areas to have brightened on the disk is impracticable since it presupposes a detailed knowledge of flaring patterns in each of the several active centres appearing on the Sun from July 07-21, 1959, inclusive.

**Table 3.5b, p. 22, lists 104 individual flare sensitive areas identified in 59Q using the McMath SECASI record alone. Two further areas, described here as $y^{VII}$ and z were seen on the CSM to brighten in 59Q on July 17 at $09^h\ 12^m$ U.T. and $23^h\ 38^m$ U.T., respectively, in time association with radio burst onsets.

## 7.7 The Locations of Areas in 59Q Deemed Particularly Associated With the Generation of Type III Bursts Relative to Individual Spot Groups and to Suspended Prominence Material

The locations relative to individual spot groups and to suspended prominence material of those 42 areas deemed in Section 7.6 to be 'Unambiguously' and 'Probably' associated with the generation of Type III bursts, are discussed in detail below and summarized in Table 7.7a, p. 133.

Note that it is not possible to represent the relationships between flare active areas and suspended prominence material, discussed here and in succeeding sections, on any one diagram. Firstly, not all of the flare active areas forming a 'sequence' were present on individual days. Also, the visibility within lengths of diffuse dark material of well-defined filamentary strands close to a 'neutral line', was a 'time function' of the level of activity present within specific parts of the region. As a result, only segments of individual strands tended to be visible at any one time although by scanning forward and back between film frames and building up composite drawings, the overall outlines of particular features could be traced day by day (allowing for the effects of differential solar rotation and filament ascent). It is possible to follow at least the gross features of the relationships thus carefully derived by intercomparing the drawings of Figs. 3.1a-j. It must, however, be emphasized that, due to difficulties of representation, there is no substitute for a close examination of the original films.

Areas a, b, c, d, $d^{I}$, $d^{VI}$ and $d^{VII}$ formed a well-defined sequence of adjacent burst associated locations, appearing in projection to lie along the northern edge of a well-defined dark filament traversing Mt. Wilson group 14284 (cf. Figs. 3.1a-j). Locations j, $z^{I}$, e and $e^{I}$ formed a similar sequence lying along the southern boundary of this same filament. These data indicate that areas a-$d^{VII}$ and j-$e^{I}$ formed sequences of 'complimentary' burst active sites lying along opposite side of the main filament traversing group 14284.

Comparisons between the data listed in column 2 of Table 7.7a indicate that, among those areas to the south of the latter filament, location e showed the highest total probability of association with Type III burst production. However (compare with the data of Table 7.6a), in no case was a Type III burst associated with a simultaneous brightening in area e alone. Locations b, d and $d^{I}$ on the other hand to the north of the filament repeatedly showed a 'one to one' relationship between impulsive flaring and Type III burst activity. Indeed area d displayed the highest overall probability of burst association exhibited by any location within 59Q.

Again, areas $k^{IV}$, $k^{I}$, $k^{II}$, f, g and h formed a sequence of adjacent burst associated areas which appeared in projection to lie along the eastern edge of a strand of dark absorption material extending southward from the main filament traversing group 14284. Areas l, m and $o^{III}$ in chromospheric chain V were in turn located along the western boundary of this same filamentary strand, cf. Fig. 3.1g, p. 31.

Of the various areas mentioned, only $k^{IV}$ and h, which individually showed the highest estimated probabilities of Type III burst association in this part of the active region, were 'Unambiguously' associated, each on a single occasion, with Type III burst activity.

Area $d^{II}$ was situated above the northern penumbral boundary of Mt. Wilson 14284 and along the western edge of a filamentary strand which extended north-eastwards from the main filament traversing the spot group, cf. Fig. 3.1e, p. 29. On no occasion was a Type III burst associated 'Unambiguously' with this flare active area.

Areas q and $q^{VII}$ lay above the southern perimeter of a peninsular extension to the southeastern penumbral border surrounding Mt. Wilson 14284. This feature first developed between July 13-14. Areas p, $q^{II}$, $q^{I}$, $q^{V}$, $q^{VI}$ and $r^{I}$ formed a sequence of burst active areas which developed above adjacent penumbral material from around the same time. Burst associated areas $q^{IV}$, $s_{I}$, $s^{IV}$, $s^{II}$, $s^{III}$, $s^{I}$ and s were individually situated above Spot group A immediately to the south of Mt. Wilson 14284.

It may be noted that Spot group A was located near the terminus of a branch of the main absorption filament that traversed Mt. Wilson group 14284. This well-defined extension appeared in projection to pass southwards between chromospheric chains V and VI (cf. Fig. 3.1h, p. 32), then to curl around north-westwards towards Spot group A with an extension, which showed complex changes, passing between this group and the boundary of 14284. Only area $q^{V}$ to the north and area s to the south of the filamentary material between groups 14284 and A were 'Unambiguously' associated, each on a single occasion, with the generation of Type III radiation.

Area $i^{I}_{I}$ above, Mt. Wilson group 14285 was seen to flare once only using the McMath SECASI records. On this occasion ($16^{h}$ $34^{m}$ U.T., July 14) either $i^{I}_{I}$ or contemporaneously flaring area $r^{I}$ (which was seen to brighten above 59Q 6 times in all) may have been associated with the generation of a Type III burst. Area $i^{I}_{I}$ was located in a part of chain VI lying along the eastern boundary of dark absorption material traversing Mt. Wilson 14285, cf. Fig. 3.1f, p. 30. A marked upsurge in activity above this spot group occurred from July 17 and areas y, $y^{V}$ and $y^{III}$ associatively formed a sequence of burst associated locations lying along the western boundary of this same dark filament, cf. Fig. 3.1j, p. 34.

Area u above Mt. Wilson group 14292 formed one of 10 flare active areas that went into emission at $19^{h}$ $25^{m}$ U.T. on July 15 in association with the generation of simultaneous centimetre wave, Type V and Type III bursts. On this occasion, Mt. Wilson group 14292 and Spot group A were respectively located at the western and eastern termini of a large dark prominence which was suspended between them. The remaining 9 areas to simultaneously brighten (which included $q^{V}$ and s, see above) were located above Spot group A.

## 7.8 Identification of Areas in 59Q Particularly Associated With the Generation of Centimetre Wave Bursts of All Classes

Over the period of its July passage, 38 bursts confined to centimetre wavelengths only and 15 broad band bursts extending out to decimetre or to metre wavelengths, were time associated with flaring in 59Q (according to the criteria of Section 4.1). Of these, only 34 bursts (31 'Unambiguous' and 1-1/2 'Probable' associations) were correlated with actually observed, sometimes multiple, impulsive intensity increases in 59Q.

Table 7.8a, p. 134, lists the total probabilities, estimated according to the procedure described in Section 7.5, that these 34 centimetre bursts were associated with individual flare active areas in 59Q. The figures in column 9 represent the individual probabilities with which each area was compositely associated with 'Very Strong' + 'Strong' + 'Moderate' radio bursts in 59Q. The figures in columns 2-7 are broken down to illustrate the individual probabilities with which each area was associated, with 'Very Strong', with 'Strong' and with 'Moderate' radio bursts, respectively. It is seen from the data that 57, that is, ~54% of known flare active areas in 59Q can be thus associated with centimetre burst production. Of these, areas d, b and $d^{I}$ showed the highest total estimated probabilities of burst association. These figures include even very minor probabilities and it is interesting (as in the case of the Type III bursts) to compare them with the numbers of occasions when centimetre wave bursts occurred 'Unambiguously' within $\pm 1^{m}$ of brightenings in individual areas of 59Q (cf. columns 2, 4, 6 and 8 of Table 7.8a). It is then found that only 3 areas in 59Q could be thus closely associated with the onset of centimetre burst activity*, namely area d, which was associated on 4 occasions with the onsets of 'Moderate' radio bursts; area b which was associated on 1 occasion with the onset of a 'Moderate' and on another occasion with the onset of a 'Strong' radio burst; and area y which was associated on 1 occasion with the onset of a 'Strong' radio burst.

## 7.9 Interrelation Between the Various Burst Active Locations in 59Q

Careful examination of the available data indicates that there were at least 6 general locations in 59Q, each characterized by the presence of active dark prominence material and underlying spot umbrae, that were associated with centimetre burst accompanied flaring. These positions will be individually referred to hereafter as Locations 1-6.

### Location 1

Centimetre bursts of all classes were generated in association with flare active areas lying along the northern (length $a$-$d^{I}$) and southern (length e-g) boundaries of the dark filament that passed, first between the main north and south polar umbrae of Mt. Wilson 14284, then extended westwards around separating S23.

'Moderate' bursts alone were generated in association not only with a somewhat longer length ($a$-$d^{VII}$) of the northern boundary of the main dark filament and with areas ($l$-$m^{I}$) along its western and (e-g) along its southern edge, but also in association with a further branch of this dark material extending first north-westwards between $d^{VII}$ and $k^{IV}$, then nearly westwards between v and t and

*i.e. <3% of known flare areas.

finally southwards between $m^{II}$ and chromospheric chain IV. The additional flare active areas thus involved with 'Moderate' burst activity included $k^{IV}$, $t, t^{I}, t^{II}$. The various centimetre burst associated sites identified in association with the ramifications of filamentary material traversing Mt. Wilson 14284 are here defined to be situated at Location 1 region 59Q.

There are persuasive indications that among the several burst active areas recognized at Location 1, d, $d^{I}$ and b to the north of the main dark filament, repeatedly constituted 'trigger points' both for burst unaccompanied and for radio important optical events: (a) these areas showed outstanding capacities for producing impulsive flaring, (b) they collectively displayed the three highest estimated probabilities of association with Type III burst and with centimetre burst production, (c) 15 out of 17 'Moderate' and 4 out of 4 'Strong' radio bursts associated with identifiable brightenings at Location 1 were accompanied by impulsive flaring in at least 1 of these areas and (d) 3 out of 3 'Very Strong' bursts associated with flaring at Location 1 were accompanied by impulsive brightenings which included area d.

## Location 2

Centimetre wave bursts of classes 'Strong' and 'Moderate' were generated in association with flare active areas bordering prominence material extending between the southern penumbral border of Mt. Wilson 14284 and Spot group A (see Fig. 7.1g, p. 128). Among the burst active sites identified at this so called Location 2, area s apparently repeatedly constituted a "trigger point" for burst unaccompanied and for radio important events since, of the various areas in this part of the region; (a) s showed the highest capacity for impulsive flaring, (b) it showed the highest estimated probability of association with Type III bursts and with centimetre wave production and (c) 4 out of 5 'Moerate' and 4 out of 5 'Strong' radio bursts associated with flaring at Location 2 were accompanied by brightenings which either included s or occurred in prominence material expanding southwards towards s.

## Location 3

Flare active areas bordering a length of dark prominence material traversing Mt. Wilson 14285 were associated with the generation of one 'Strong', one 'Moderate' and with several Type III burst events. The area showing the highest level of impulsive flaring at this so called Location 3 was $y^{III}$, cf. Fig. 3.1j, p. 34.

## Location 4

On July 16 a 'Moderate' burst was associated with simultaneous brightenings in c and d at Location 1, with multiple site Prominence Flaring above Mt. Wilson 14297 and with Prominence Flaring to the north and south of active dark material traversing Spot group B. This latter part of 59Q (cf. Fig. 7.1) is referred to as Location 4 and was characterized by the occurrence of many other brightenings apparently unaccompanied by centimetre wave or by Type III burst activity.

## Location 5

As already indicated above, on July 16 a 'Moderate' burst was associated with simultaneous brightenings in c and d at Location 1, with extensive Prominence Flaring at Location 4 and with multiple site Prominence Flaring above Mt. Wilson 14297. This latter part of 59Q will hereafter be referred to as Location 5. Although flaring spread towards the position of group 14297 during the course of a number of important flares in 59Q, this was the only occasion when the onset of a centimetre wave burst could be correlated with an actual outbreak of flaring there.

## Location 6

Chromospheric material above Spot group A appeared on the spectroheliograms to be directly linked with chromospheric chain VI by means of a bridge of dark prominence material, cf. Fig. C2-a, p. 205. 'Strong' centimetre wave and Type III burst flaring above Spot group A on July 15, and possibly also on July 16, was accompanied by what appeared to be related flaring in chromospheric chain VI. This latter position at the western terminus of the suspended dark prominence is referred to as Location 6.

## 7.10 Flare Active Areas in 59Q and the Positions of Individual Underlying Umbrae

Detailed information concerning the relationship between flare active areas in 59Q and the positions of individual umbrae in underlying spot groups may be obtained by comparing the McMath SECASI records with spot data contained in (a) the McMath λ-swept spectroheliograms and (b) in white light pictures of the spot group obtained at various observatories.

Such comparisons between the various McMath and white light records indicate that at least 91 out of 104 individual areas seen to flare in 59Q were located directly above minor umbrae. In the remaining 13 cases, the available data were not sufficiently good to determine unambiguously if minor umbrae were or were not located beneath the various flare active areas concerned. Such a positioning however is strongly indicated by the available records.

Columns 4-5 of Table 7.10a, p. 135, list the intervals within which those umbrae underlying the various flare active areas in 59Q 'appeared' and 'disappeared' on the solar disk. The times quoted have reference to the presence or absence of particular umbrae on individual white light pictures of the region and as such depend (a) on the cadence and (b) on the relative contrasts of the pictures compared. An attempt is made to eliminate errors due to the latter effect by choosing in certain instances to compare pictures which were not necessarily the most closely separated in time of those available (cf. list in Table 7.10b, p. 139).

If we collate the intervals within which impulsive brightenings occurred in individual areas in 59Q with the times within which directly underlying spot umbrae were known to be present on the disk, it is found that, in at least 62 instances, no impulsive brightenings occurred previous to the interval within which the relevant underlying umbra appeared and when it had correspondingly vanished impulsive activity ceased. The umbra concerned was usually too small to be clearly visible on the λ-sweep records although it could be easily identified on the white light pictures.

In 29 instances, either because the flare sensitive area concerned was too close to the east or to the west solar limb or because the contrast on the available pictures was not sufficiently good to determine when the umbra concerned actually appeared or disappeared on the disk, it is not possible to determine if an underlying umbra was present over the entire interval defined by impulsive flaring. However, in each of these cases an umbra was at least present over that portion of the life time of the flare active areas for which reliable white light records were available.

In 13 cases (as already stated) the available data were not sufficiently good to determine if minor umbrae were ever present beneath the various flare active areas concerned although the indications are that they were indeed so positioned.

Those minor umbrae above which the various flare active areas in 59Q were situated, appeared in projection to either directly border lengths of dark absorption material traversing individual spot groups in the region, that is to lie along the locus of zero or of very low values (see below) of the longitudinal magnetic field, or to be positioned at the perimeters of major spots and within 10" of a magnetic 'neutral line'. It may be recalled that "small localized enhancements of magnetic field of both polarities around the perimeter of a sunspot" are defined by Smith (1971) to comprise "satellite spots". This definition does not quite correspond with that given by Rust (1968) who describes satellite spots as "polarity reversals in $B_{11}$ near the edges of large spot penumbrae". In the case of region 59Q, because of the relatively low resolution of the only available (Crimean) magnetic measurements, it is not possible to determine if those minor umbrae observed at the boundaries of major spots displayed contrasting polarities or not. They can hereafter then be only referred to as 'satellite spots' in the sense defined by Smith.

## Positions of spot umbrae at Location 1

The circumstances that minor umbrae appeared in projection primarily situated at Location 1 bordering the 'tracks' of filamentary material traversing Mt. Wilson 14284 resulted in the presence within this group of chains of 'complementary' minor spots. Close to, and within the channel separating the major north and south polar umbrae, individual members of the chains underlying flare active areas d, $d^{I}$ and e constituted in themselves "satellite spots" which bounded the magnetic 'neutral line'. To the west of the main north polar umbra, the suspended dark material split into several well-defined strands which appeared in projection to pass between 'avenues' of minor spots. One strand, which was first extended northwards along a track defined by umbrae underlying $d^{VII}$ and $k^{IV}$, followed the locus of zero longitudinal magnetic field in the group. Another, extending westwards around separating S23, passed through a milieu where, as shown by magnetograms obtained at the Crimean Astrophysical Observatory, Howard and Severny (1963a)* very low values of the magnetic field

*See also the discussion in Section 7.14.

pertained. Any flare associated umbra (such as for example that underlying $d^V$) not appearing to directly border part of the branched dark filament traversing 14284, comprising a satellite spot at the perimeter of a major umbra in the group and was situated within at least 10" of the magnetic 'neutral line'.

Positions of spot umbrae at Location 2

All of the flare active areas identified at Location 2 were positioned above minor umbrae. Those umbrae underlying areas $p-r^I$ and q were situated either within a rapidly changing penumbral extension to, or directly along the southern penumbral border of, Mt. Wilson group 14284. Areas $s_I-s^{IV}$ were located above the components of Spot group A. Comparison of the white light and spectroheliographic records with the Crimean magnetograms reveals that those umbrae to the north of the filamentary material separating the southern part of Mt. Wilson 14284 from Spot group A were of southern polarity and individually situated along a magnetic 'neutral line'. The umbrae of Spot group A on the other hand were disposed on July 16 in a cluster, which corresponded on this day to an oyster shaped 'hill' of north magnetic polarity (as seen on the Crimean magnetograms)*.

Positions of spot umbrae at Locations 3-6

Due to poor contrast on the available white light pictures, minor umbrae underlying flare active areas in Mt. Wilson 14285 (Location 3) could not be unambiguously identified during the early part of the transit of 59Q. From July 17-18, however, a marked increase in activity at this location was characterized by the appearance there of well-defined umbrae and these emerging features could be seen to border active dark material traversing the evolving spot group.

Flare active areas identified at Location 4 were positioned directly above individual constituents of Spot group B.

Due to the inadequacies in the available records, it cannot be unambiguously decided if flare active areas at Location 5 were positioned directly above constituent umbrae of Mt. Wilson group 14297, although the available data strongly suggest that this was the case.

Again, due to inadequacies in the available observational data, only 2 out of 7 flare active areas at Location 6 can be definitely identified as situated above minor umbrae in Mt. Wilson group 14292.

## 7.11 The Association of Major Flaring With Changes in the Total Areas of Underlying Spot Groups

The total areas of several spot groups in which proton flares occurred were noted by Howard (1963) to show a marked, and presumably associated, decrease within one day after each major flare. These results were later challenged by

*See also the discussion in Section 7.14.

Sivaraman (1969) and it is suggested by Sawyer (1968b) that, while there are many exceptions, isolated cases exist where the decline of sunspot area sets in suddenly and immediately after flaring. See also McIntosh and Sawyer (1969).

### 7.12 The Association of Major Flaring in Region 59Q With Changes in the Overall Area of Its Underlying Spot Group

Proton flares in 59Q on July 10 and July 14 respectively took place within a period characterized by the overall growth of parent spot group Mt. Wilson 14284. This growth was occasioned not alone by the emergence of new flux, but also by the proper motions of certain south polar umbrae combined with the effect of differential solar rotation, which acted together to impose a westward distension on the group.

In the case of the July 16 event, as already noted by Sawyer (1968b), the sunspot group reached its maximum area within a day after the GLE flare, declining thereafter.

### 7.13 Magnetographic Records of (Possibly) Flare Associated Magnetic Field Changes

A number of reports in the literature, based on magnetographic observations, indicate that the longitudinal component of the photospheric magnetic field changes in association with major flaring. Examples include Michard et al. (1961), Severny (1969a, 1969b)*, Rust (1968, 1972, 1973, 1975), Malville and Tandberg-Hanssen (1969b), Zvereva and Severny (1970), Mayfield (1971), Janssens (1972), Tanaka and Nakagawa (1973), Livingston (1974) and Rust and Roy (1975), Zvereva and Severny (1970) note that those degradations in field which they found to be associated with major flaring quickly disappear so that the preflare magnetic state is again restored. This is relevant to the potential of a region to produce 'Homologous Flares'. Observations by Severny (1964, 1968, 1969) indicate that if the structure of the transverse field is compared before and after certain important flares, a rotation of $H_1$ by $90^o$ may be seen to have occurred within part of the active region.

In contrast, several other reports indicate that photospheric field changes do not accompany flaring, see for example papers by Harvey et al. (1971), Wiehr (1972) and Michalitsanos and Kupferman (1973). Rust (1975) criticises the latter results on the basis of their inherent lack of sensitivity and time resolution and concludes that, while many reported cases of flare associated changes in spot fields can rather be attributed to those variations associated with the 'normal' growth and decay rates of the spot fields concerned, some evidence does exist for the occurrence of magnetic changes in association with certain major flares.

Two magnetographic studies have been made of region 59Q during its July transit, one at the Mt. Wilson Observatory by Howard and Babcock (1960) and the other at the Crimean Astrophysical Observatory by Howard and Severny (1963a).

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*See also earlier studies by Severny.

In the first study, fourteen "fine scan" magnetograms of region 59Q were obtained at Mt. Wilson between $21^h\ 19^m$ U.T. July 16 and $01^h\ 07^m$ U.T. July 17, that is over an interval spanning the development of the importance 3 Moving Prominence Flare of July 16, with flash phase at $21^h\ 18^m$ U.T.*. Each magnetogram obtained required $15^m$ to complete and the resolving power of the instrument was 7500 km. Incremental brightenings of the trace occurred at levels of approximately 5, 10, 20 and 40 gauss and the latter figure represented the highest field strength distinguishable in the course of the observations. A published analysis of the fourteen records obtained, Howard and Babcock (1960), indicates that no changes with time in the strength or configuration of the measured magnetic fields, other than certain minor effects attributable to seeing and imperfections in scanning, occurred during the course of the observations.

Ten magnetic maps of region 59Q were made in the interval July 14-18, 1959, with the magnetograph of the Crimean Astrophysical Observatory. Each magnetogram required $45^m$ to record and the resolving power of the instrument was 7,000 km. Isogauss lines were plotted only for the stronger (50-100 gauss) magnetic fields on the maps and these lines referred almost entirely to magnetic fields within sunspots. A published investigation of the records by Howard and Severny (1963a) indicates that, with an interval between $15^h\ 00^m$ U.T. July 16 - $06^h\ 00^m$ U.T. July 17, that is spanning the importance 3 Moving Prominence Flare of July 16, the higher magnetic fields near and inside certain associated sunspots decreased by nearly a factor of 3. The resulting loss of magnetic energy amounted to about $10^{32}$ ergs. It is noted by Howard (1964) with reference to this observation that "the central field strength of the spots as measured photographically or visually did not show an appreciable change but the spot group did decrease in area from the day before to the day after the flare**. The 7,000 km resolution of the Crimean Observatory would show as a result a decrease in the strength of the measured spot fields". It may be mentioned that the magnetic measurements described above which were obtained at Mt. Wilson would not have shown changes in fields which always remained greater than 40 gauss. Thus, the Mt. Wilson observers could not have recorded those changes in the spot fields in 59Q which were detected at the Crimea. Magnetic changes preceding or occurring during the opening minutes of the flare in the 5-40 gauss fields would also have been missed at Mt. Wilson.

## 7.14 Methods of Investigating the Relationship Between Flaring in 59Q and Time Associated Changes in Directly Underlying Umbrae and Penumbrae Using Magnetographic Data and Spot Data

Publication by Howard and Severny (1963a) of six of their magnetograms taken at various times (listed in Table 7.14a, p. 140) between July 14-18, inclusive, has rendered possible the direct comparison of the available optical records for these days with the magnetic charts. The positions of various flare-sensitive areas in 59Q with respect to the umbrae and penumbrae of underlying spots were first determined through careful intercomparisons between sweep

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*See account in Appendix B.

**See however Section 7.12 and the report by Sawyer (1968b).

spectroheliograms taken in both Hα and calcium light with the McMath Tower Telescope and with white light pictures of the region provided by various observatories. Then, with the aid of these composite records, the optical observations were brought into apparently close agreement with the Crimean magnetograms. The great difficulty of bringing together data from different telescopes and the inherent uncertainties in magnetographic data discussed by Howard, Bumba and Smith (1967) were borne constantly in mind during this procedure.

Careful intercomparisons between the various records reveals that changes in the magnetic maps from day-to-day closely reflected local daily changes in spot size and location. These changes appeared to show some correlation with those positions at which 'radio important' prominence flares such as the July 16 event were initiated. Using magnetographic records which were so few and so separated in time as those six published by Howard and Severny however (cf. col. 2, Table 7.14a, p. 140), it was not possible to determine unequivocally if the changes observed were 'sudden' and 'flare associated' or if they rather represented progressive variations produced by the gradual comings and goings of spots. Thus it is deemed that the possible role of flares in contributing to or producing changes in the magnetic field in 59Q cannot really be deduced unambiguously from the available magnetographic records.

Information concerning the relationship between the positions in 59Q at which flares were triggered and changes in underlying umbral and penumbral features can be examined on a closer time scale by comparing the McMath 'in line' spectroheliograms with (a) spot data contained in corresponding pictures taken in the wings of the Hα and K lines and (b) with those white light pictures of the region listed in Table 7.10b, p. 139.

The resulting comparisons are, in their detail, unwieldly. It was thus decided to confine chronological descriptions of them to an Appendix (Appendix D), see also McKenna-Lawlor (1979b), and to present here only an account of those relationships that can be deduced between the positions of onset of (a) prominence flares accompanied by centimetre wave bursts of different classes and (b) plage flares accompanied and unaccompanied by Type III burst radiation, and time associated changes in underlying magnetic features.

## 7.15 The Relationship Between Prominence Flares Accompanied by 'Very Strong' Radio Bursts and Time Associated Changes in Spot Umbrae

Three prominence flares occurred in 59Q which were accompanied by the generation of 'Very Strong' radio bursts (cf. Table 7.15a)*. These events, with individual flash phases at $02^h\ 05^m$ U.T. July 10, $<03^h\ 33^m$ U.T. July 14 and $21^h\ 18^m$ U.T. July 16 each began above γ group Mt. Wilson 14284 and in that part of the active region described in Section 7.9, as Location 1.

*See details of the development of these three individual events in Appendices A and B.

Each flare was associated at its onset with a brightening in d. Area d was situated above a satellite spot flanking a north polar umbra of field strength >2000 gauss. The polarity of the satellite umbra is not known.

In one instance (July 10) the large north polar umbra flanking d disappeared* and in two instances (July 14 and 16) the corresponding, newly waxed, umbra was significantly reduced in area within the compass of time intervals that included the flash phase of each parent flare. These time intervals individually never exceeded $10^h$, which represents an upper limit, determined by the availability of white light pictures of the region.

Within the $8.4^h$ time interval pertinent to the flare of July 10, changes also took place among the south polar umbrae. An impression is given, either that certain south polar umbrae disappeared, or else that they moved southwards and merged. In either instance, those south polar umbrae present on July 10 following the major flare appeared to be further apart than were those present prior to flare onset (thus indicating that a change had taken place in the magnetic gradient in this part of the spot group).**

On July 14 and 16, in addition to magnetic changes produced by a general separation between south polar umbrae within the group, superposed magnetic variations due to the waning and/or waxing of certain umbrae between the main fragmenting south polar spots were introduced.**

In each of the three instances discussed, the flash phase of the major flare took place above those positions within the spot group where magnetic changes occurred within $<10^h$ intervals bridging the optical events. This resulted in the development of each flare so that it crossed and obscured those umbrae of high field strength within the group which showed magnetic change.

The subsequent development of 'flare arms' extending outside Mt. Wilson 14284 did not take place at random but was strongly influenced by circumstances relating to previously existing magnetic features. Firstly, these flare arms extended only along the loci of chains of the chromospheric network. A close correlation is known to exist between the K plage and longitudinal fields of 20-200 gauss, see Howard (1967) and Bumba and Godoli (1968), while Hα plages are identified as regions where the photospheric field strength is >80 gauss, Nakagawa et al. (1974b). It consequently appears that the spread of extensive flaring was intimately associated with the underlying presence of such 'moderate' solar magnetic fields. Also, individual flare arms extended only towards the positions of outlying 'satellite' sunspot groups.

The 3 major flares appeared to occur at times when these outlying satellite groups were changing. This may indicate that the flare events were associated with large scale subphotospheric disturbances in 59Q. However, in no instance

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*Compare Fig. 3.1b with Fig. 3.1c. See also Appendix D, pp. 207-216, and Plate 1 McKenna-Lawlor (1979).

**See details in Table 7.15a, p. 141.

did emission spread from an outlying group towards the position of Mt. Wilson 14284 during the course of flaring although activity could take place alone in a distant group without apparently involving 14284 itself.

Careful comparisons between the McMath spectroheliograms, the Crimean magnetograms and the Mt. Wilson sunspot drawings of Fig. 7.1 reveals that, when diffuse bright flaring spread along the locus of a chain of the chromospheric network towards the position of an outlying spot group, it did so such that the excitation spread from above the position of an umbra of a particular polarity to a location above an umbra of the same polarity.

Emission appeared to spread during each flare to the positions of distant spot groups according to the following sequence, group 14284 (initial flash), group 14285, group 14297, umbrae underlying chain V and group 14292. These three events seem then to have been "Homologous" as defined by Ellison et al. (1960b). Due to cloud gaps in the relevant records, it is not possible to establish if the times required to carry out the sequence were similar in each case.

On July 10, following the proton flare, there was a conspicuous drop in activity above parent group Mt. Wilson 14284, that is to say above that group from which the umbra referred to disappeared. Recovery on July 11 appeared to be associated with the emergence in the region of new magnetic flux. Similarly, on July 14 there was, following the proton flare, a depression in activity directly above parent group 14284, that is above that group where a spot had (see above) suffered a rapid diminution in area. The fact that important flaring meanwhile took place in association with a changing magnetic situation along the 'distant' southern border of group 14284 and in Spot group A (cf. Appendix D, p. 207) meant that the overall reported level of activity in 59Q remained high on this day. Following the catastrophic proton event of July 16 there was no further significant flaring above group 14284, that is to say above that group where a spot had (see above) once again suffered a rapid diminution in area. During the remainder of the July transit (up until July 21) the bulk of activity observed in 59Q rather took place above newly active group 14285.

These observations suggest that there was an exhaustion of the energy supply in group 14284 after each major event and a period of recovery was required before another 'Homologous' flare could be produced. Conditions favourable for triggering such events were reestablished between July 10-14 in $\sim 97^h\ 28^m$ and between July 14-16 in $\sim 65^h\ 45^m$. The marked difference in time scale may have been associated with the fact that the magnitude of the magnetic change associated with the flare of July 10 (disappearance of a major north polar umbra) was much greater than that associated with the flare of July 14 (partial disappearance of such an umbra). Following the three-fold decrease in umbral field strength in the group associated with the July 16 event, as reported by Howard and Severny (1963a), no further 'Homologous' flare was produced before 59Q transited the west limb on July 21, that is for $>122^h$.

7.16 <u>The Relationship Between Prominence Flares Accompanied by 'Strong' Radio Bursts and Time Associated Changes in Spot Umbrae</u>

There were 10 occasions when prominence flares in 59Q were associated at their commencements or enhancements with the generation of 'Strong' radio bursts (see details Table 7.16a, p. 142). Four of these events took place too close to either the east or west solar limb to enable possibly associated magnetic changes to be detected in underlying spot groups. Of the six remaining events, four occurred at Location 2 and two at Location 1 (cf. Section 7.09 and also Appendix B).

The four events occurring at Location 2 (at $17^h\ 34^m$ July 14, $22^h\ 24^m$ July 14, $19^h\ 25^m$ July 15 and $16^h\ 13^m$ July 16, respectively) were associated with flaring occurring on either side of the magnetic 'neutral line' separating Mt. Wilson 14284 from Spot group A. Summarizing the magnetic conditions pertaining to each case then: (a) The component flare areas were situated above umbrae which waxed or waned within intervals that included each flares flash phase and which in no case exceeded $12.7^h$, this interval represents an upper limit set by the availability of white light pictures. (b) All of the transient umbrae underlying the several flare active areas were small; none comprised a satellite to a large spot and their individual field strengths, although not measured at Mt. Wilson or Potsdam, must have been somewhere above that threshold value for development of 1,100 gauss calculated by Steshenko (1967). (c) With time, the centre of flaring at Location 2 shifted laterally westward on both sides of the magnetic 'neutral line'. This trend followed a decline to the east, and progressive emergence at positions shifting ever further to the west, of umbrae and ambient penumbral material. (d) This trend took place in a direction running roughly parallel with the direction of change exhibited by the main disintegrating south polar chain in group 14284. (e) Two of the flares at Location 2 (at $19^h\ 25^m$ U.T. July 15 and at $16^h\ 13^m$ U.T. July 16, respectively) were accompanied by flaring at Location 6, i.e., at the opposite terminal of a large dark prominence suspended between these separated parts of 59Q; it is not known if related magnetic changes took place in Mt. Wilson 14292 underlying Location 6.

Of two 'Strong' burst associated flares at Location 1, that at $13^h\ 27^m$ U.T. July 15 occurred within an $8.5^h$ period defining the merging of the several north polar umbrae in group 14284 with N28; the south polar umbrae in the group meanwhile moved further apart; this burst associated event was specially characterized by brightenings at d and $d^{IV}$ above umbrae flanking N28.

The remaining 'Strong' burst associated brightening at Location 1 occurred in b at $18^h\ 10^m$, July 09, and formed part of a long lived flare preceding the 'Very Strong' burst associated event of $02^h\ 05^m$ July 10. A minor umbra and ambient penumbral structure underlying area b certainly disappeared between $18^h\ 00^m$ July 09 - $06^h\ 02^m$ July 10, that is within $8.4^h$. Since minor umbrae are difficult to identify unambiguously on the swept wave length records, it is not certain if the umbra underlying b was still present on spectroheliograms of the region available up to $21^h\ 38^m$ on July 09. Thus, the disappearance of this umbra cannot be related with the flare of July 09 rather than with that of July 10. It may be noted however that conspicuous dark filament activity seen in the neighbourhood of b on the McMath swept wavelength pictures provided an indication that magnetic instability was at least present in Location 1 on July 09 although it cannot be deduced if this culminated in the disappearance of the umbra by $21^h$ $38^m$ U.T.

## 7.17 The Relationship Between Prominence Flares Accompanied by 'Moderate' Radio Bursts and Time Associated Changes in Spot Umbrae

There were 31 occasions, see details in Table 7.17a, p. 143, when Prominence Flares in 59Q were associated at their commencements or enhancements with the generation of 'Moderate' radio bursts and, of these, only 17 occurred under circumstances that enabled their magnetic characteristics to be investigated. Of these latter, 13 occurred in circumstances characterized by the gradual emergence of magnetic flux in an environment where closely associated magnetic fields were meanwhile declining (events of category 1). Two further displayed simultaneous flaring above several spot groups within the active region, at least one of which groups is known to have shown time-related magnetic variations (events of category 2).

The remaining two occurred in association with the 'splitting off' from the γ group of large umbrae accompanied by minor spots that were individually positioned close to a magnetic 'neutral line' (events of category 3).

Of 13 events falling into category 1, 10 showed brightenings which included area d. This area was located above a satellite spot on the eastern perimeter of an evolving north polar umbra. The latter feature increased due to (a) its 'natural' development and (b) its afinity for merging with other north polar umbrae. On one occasion a north polar umbra adjacent to the agrandizing feature was sub-dividing; in the 9 remaining instances, adjacent south polar umbrae within the group were fragmenting. Two further 'Moderate' burst events were associated with minor umbrae waxing on July 15 to the north and south of the magnetic 'neutral line' in group 14284. The emergence of new magnetic flux and the influence of the oppositely evolving major umbrae resulted in general change in the orientation of part of this 'neutral line' between July 14-15. The last 'Moderate' burst event in category 1 was associated with the emergence of flux along the southern border of group 14284 and in Spot group A, while the main south polar chain in 14284 meanwhile slowly disintegrated.

The two 'Moderate' events in category 2 were each associated with flaring above the changing umbrae of group 14284. One was characterized by the spread of flaring towards groups 14285 and 14297; the other was accompanied by flaring in 14297 and in Spot group B. Of the distant groups concerned, only B was clearly visible on the available white light pictures and this feature was in course of showing complex magnetic changes.

Among two events in category 3, one was associated with flaring above a crescent of satellite spots surrounding S23 within a $14.3^h$ interval within which this feature and its satellite separated from 14284. The other event on July 17 was associated with flaring at $q^V$ to the north and in multiple areas to the south of the 'neutral line' at Location 2. Over an approximately $24^h$ interval spanning this event, a pair of large umbrae, together with ambient penumbra enveloping that minor umbra underlying $q^V$ (which was situated close to the 'neutral line'), separated from 14284. The constituent umbrae in group A meanwhile declined. The time intervals quoted represent upper limits set by the availability of white light pictures.

## 7.18 The Relationship Between Plage Flares Accompanied and Unaccompanied by Type III Burst Radiation and Time Associated Changes in Spot Umbrae

Over the $136.1^h$ covered by the McMath SECASI observations 807 impulsive Plage Flares were identified in region 59Q. Table 7.18a, p. 146, describes in detail the positions, relative to spots and to active dark material, of the 89 different areas involved in the production of these Plage Flares. Examination of the data reveals (a) that with the exception of Location 5 above Mt. Wilson 14297*, Plage Flaring occurred in the same general locations in 59Q previously shown to be associated with Prominence Flaring; 583 Plage Flares were observed at Location 1; 14 at Location 2; 10 at Location 3; 12 at Location 4 and 2 at Location 6; (b) each flare active area was positioned at the bounding edge of a length of suspended prominence material; (c) in at least 86 (and possibly all 89) cases, the plage active areas were situated above minor umbrae; and (d) the areas most frequently associated with Plage Flaring (d and $d^I$) were individually located above satellite spots bordering the eastern perimeters of the two major north polar umbrae in group 14284.

Table 7.18b, p. 148, details, on a day-to-day basis, the frequency of Plage Flaring in individual areas of 59Q as determined during the McMath sunlit hours of its 1959 July transit. This table also outlines the magnetic situation pertaining in various underlying spot groups involved. Consideration of the data suggests that (a) Plage Flaring occurred above minor umbrae which in many cases were also involved in the initiation of those Prominence Flares associated with the generation of centimetre burst activity, (b) Plage Flaring was not confined to intervals spanning important magnetic changes in underlying spot groups but appeared to both precede and follow such events and (c) within the limitations of the available data it appears that a minor umbra was always present directly underlying each active area before Plage Flaring commenced and when this magnetic feature had vanished Plage Flaring ceased.

Plage Flares may be expected to be characterized by more subtle magnetic changes than those accompanying centimetre burst associated Prominence Flares since in principle they should be more easily initiated than such energetically important events. It is thus understandable that such phenomena should (a) not have been confined to intervals defined by dramatic change while still remaining associated with positions of special magnetic instability; (b) that they should have occurred approximately 18 times more frequently than did centimetre burst associated Prominence Flares (cf. Section 6.13) and (c) that they should never have spread to cover major changing spot umbrae.

There were in all 35 occasions when Type III burst activity was time associated with Plage Flaring, distributed over a total of 23 different areas in 59Q. Among these areas, only b, c, d, $d^I$, $k^{IV}$, $q^V$, s and $y^V$ were 'Unambiguously' associated with the generation of Type III bursts. These latter areas were located above specially unstable magnetic environments and the pertinent under-

*Where Plage Flaring was not identified.

lying conditions can be summarized to have individually comprised (a) umbral and penumbral material in a mainfestly disturbed mileu preceding the local disolution of magnetic structure; (b) satellite spots bordering the eastern perimeters of magnetically variable major north polar umbrae and individually situated close to the magnetic 'neutral line'; (c) a minor umbra embedded in what appeared to be strongly sheared penumbral material in course of disjunction; and (d) well defined umbrae which, by emerging within the precincts of individual members of that aggregate of magnetic groups comprising 59Q, notably disturbed the magnetic circumstances already prevailing at these special sites.

It may be recalled (see Section 4.12) that, not only those 35 Type III events discussed above, but indeed all 76 Type III events deemed to accompany flaring in 59Q, were characterized by their association with brightenings occurring along the borders of active dark absorbing material. Such activity probably constituted a symptom of an inherently unstable situation made further manifest, under special solar circumstances, by the generation of Type III radiation. It is interesting to note that, while flare active areas along that length of filamentary material traversing the major umbrae in group 14284 and extending around separating S23 were Type III burst associated, corresponding areas along a further strand of this material extending northwestwards between $d^{VII}$ and $k^{IV}$ and remote from large spots showed no probability of association with Type III burst activity*.

## 7.19 Significance of the Time Association Between Flaring in 59Q and Changes in Underlying Spot Umbrae

Although it has been shown in the foregoing sections that there was a close association between positions showing magnetic change in 59Q and those several sites where radio important flares were triggered in the active region, the time resolution (which ranged between $7.4^h$ and approximately 1 day in individual cases**) was not sufficiently good to provide evidence for abrupt changes in the photospheric field at flare times. It might thus be alternatively suggested, despite the close spatial associations demonstrated, that the changes observed were not particularly flare associated but represented rather variations produced by the 'normal' comings and goings of spots.

It is well known, however, that chromospheric structures+ frequently show localized field changes in association with flares. For example, there are many

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*This is in agreement with a report by Zirin and Werner (1967) on corresponding selectivity associated with the Sunspot Group of September 13-26, 1963.

**See column 7 of Tables 7.15a, 7.16a, and 7.17a.

+Observations by Bruzek and Demastus (1970) indicate that pre-flare filament activations are complimented at the coronal level by the appearance of expanding green line arches. These structures may disrupt at the moment when a flare appears at their base. Other such transient and probably flare-associated coronal events have been described by de Mastus et al. (1972) and by Hansen et al. (1972). Valdez and Altschuler (1970) and Altschuler (1974, 1975) note that, after proton flares, the surrounding coronal magnetic field tends to decrease in flux and to change from a closed loop (arcade) structure to an open or diverging field. No coronal observations are available for study in association with flaring in 59Q.

reported cases of preflare filament activation and ascent as well as of filament eruption at flare onset which are indicative of an associated disruption of the magnetic fields supporting these structures, cf. Smith and Ramsey (1964), Hyder (1967a, 1967b), Martin and Ramsey (1972), McKenna-Lawlor (1978). Distinct changes in field dependent chromospheric fine structure in the surroundings of flares have also on occasions been detected. These changes, which are of several kinds, include the formation of a flare 'nimbus' - that is to say of a dark 'halo' that first begins to surround certain major flares some minutes after the attainment of Hα maximum, Ellison et al. (1960a, 1960c, 1961b, 1962), Bruzek (1968). The latter phenomenon is interpreted by Reid (1963) to represent fading of the brighter parts of the ambient chromospheric striation pattern due to the flare associated extraction of magnetic energy from regions in its immediate vicinity.

Investigation of the available swept wavelength records associated with 59Q indicated (although the correlations are incomplete due to lack of telescopic coverage) that there was a close association between filament activation and flaring in this region. It is interesting to note that, like the flaring itself, these filament activations tended to be strongly localized (see for example Fig. A4-a, p. 195, which shows the presence on July 14 of active dark material in close association with optically important flaring at Location 2). The presence of such localized active dark material in association with impulsive flaring in 59Q provides an indication that those parts of the active region within which magnetic changes occurred over intervals spanning optically important flares, were already in a state of instability either prior to, or at the onsets, of many, and perhaps even all, of the flares concerned.

Only the proton event of July 16 was seen to be accompanied by the formation of a flare nimbus. This made its first appearance at $21^h\ 34^m$ U.T. (that is $2^m$ after the estimated time of flare maximum) and was deemed to be most conspicuous at $22^h\ 11^m$ U.T., cf. Ellison et al. (1961b). Its dimensions, at this latter time were of the order of $3 \times 10^5$ km. The phenomenon thereafter endured until $23^h\ 00^m$ U.T. If Reids' explanation is tentatively accepted, then this effect may indicate the extraction of magnetic energy from 59Q at the time of the flare itself.

If a nimbus (which is an effect at once rare and difficult to detect) was not in fact associated with any other flare in 59Q during its July transit*, it may be significant that this was also the only flare in the region of sufficient energy to have produced a cosmic ray event at ground level**. It also marked the "end" of major flare activity in the region.

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*In the case of the proton events of July 10 and 14, the contrast on the CSM is certainly not sufficiently good to determine if a nimbus was present or not. However, no such effect was reported by the original recorders of these flares at Sydney and Meudon.

**The more easterly disk location of other confirmed PCA flares occurring in 59Q (on July 10 and 14, respectively) militated however against their producing a GLE.

It is possible to infer from the sunspot observations that the release of magnetic instabilities at specific locations in 59Q may have been responsible for producing those various electromagnetic and particle phenomena detected at flare times. On the specific occasions of the proton events of July 10, 14 and 16, the loss of large amounts of magnetic energy associated with the destruction or change of certain underlying spot umbrae would, according to this view, have supported the several energetic phenomena deemed to accompany these events. However, changes in magnetic structure and those sudden releases of energy occurring at flare times may rather have represented individual responses to some fundamental type of subphotospheric disturbance, which is as yet not understood.

## 7.20 Positions Within an Active Region Especially Associated With the Occurrence of Flaring

The properties of flare localization in connection with inversion lines have been specially discussed by many authors including Severny (1958, 1960), Bruzek (1958), Bumba (1958), Michard et al. (1961), Martres et al. (1966b), Smith and Ramsey (1967), Rust (1968), and Michard (1971). In summary, these various observations indicate: (a) That the initial Hα brightenings tend to occur in regions of high field gradient and close (within ~10") to the $H_{II} = 0$ inversion line, rather than directly on it. In the case of flares showing more than one bright knot, these are located above umbrae of different polarities on either side of the inversion line and, when bright elongated features develop, they do so along the sides of the line. (b) In a perturbed bipolar structure having a main 'abnormal inversion line', this latter abnormality is the preferred seat of flares. 'Abnormal' lines may exist for example around single polarities (parasite or satellite spots) embedded in an opposite field*.

Also, a law of evolution of magnetic patterns associated with the production of minor flaring was derived by Martres et al. (1968a, 1968b) and confirmed by Ribes (1969). These authors divide each complex pattern of longitudinal field into a number of 'Evolving Magnetic Features' (EMF) and show that individual flares involve at least two adjacent EMF's of opposite polarities. These have opposite senses of evolution in the period of flare occurrence, one increasing, the other decreasing. If two adjacent EMF's of opposite polarity have the same sense of variation, no flare can connect them.

---

*Relative to the field $H_I$, it was found in the course of observations by Moreton and Severny (1966, 1968) and Severny (1969a, 1969b) that flares tend to occur in regions of complication - such as places of apparent crossings of transverse magnetic fields (bifurcations). Also, they occur at places of close contact of oppositely directed vectors $H_I$. It is concluded that flaring is produced at places where strong electric currents exist (strong is to say $>2 \times 10^{11}$ Amp in a region $5000 \times 5000$ km$^2$). No traverse magnetic field observations are available for study in association with flaring in region 59Q.

## 7.21 General Comments Concerning Positions Within 59Q Especially Associated With the Occurrence of Flaring

In accordance with the general 'localization patterns' outlined in Section 7.20 as typical, flaring above Mt. Wilson tended to commence in regions of high gradient and close to the $H_{II} = 0$ inversion line. The particular observation that impulsive Prominence Flaring did not commence at positions far from the magnetic 'neutral line' may have been a consequence of the fact that 'distant' positions would in fact have lain outside the compass of that bridge of suspended dark material within which such flares were produced.

Portions of this suspended material may have condensed from the corona. However, it appears from the evidence of the swept wavelength pictures that material ejected from the underlying region made an important contribution to the building up of this feature. If this is correct, then the capability of an active region to eject and trap dark material may constitute a necessary attribute of solar regions that develop the potential to produce 'Prominence' and by extension (cf. Section 6.7, p. 69) proton producing flares.

Strong fields and steep gradients in the magnetic field, although pertaining in group 14284, did not seem to be generally necessary for the production of optically important flaring in 59Q. For example, changes in quite minor umbrae supporting either side of a branch of the main dark absorption filament passing between the southern boundary of group 14284 and Spot group A, appeared to result on several occasions in the production of extensive Prominence Flaring (see the account of activity at Location 2 contained in Appendix B). Similar examples may be quoted concerning Prominence Flaring above other Locations in the region. These observations are relevant to a report by Dodson and Hedeman (1970) that approximately 7% of flares of importance 2 take place above regions which are either spotless or contain only very small spots with areas of the order of 100 millionth of the solar hemisphere.

The most flare active sites in 59Q (d and $d^I$) were situated above satellite spots along the 'neutral line' traversing Mt. Wilson 14284. It is not known if these magnetic features represented polarity inclusions.

In accordance with the law of Evolving Magnetic Features derived by Martres et al. (1968a, 1968b), flaring in 59Q appeared especially associated with situations where underlying umbrae of one polarity were merging and/or waxing while umbrae of the opposite polarity were declining and/or fragmenting, cf. details in Appendix B and in column 5 of Tables 7.15a, 7.16a, and 7.17a.

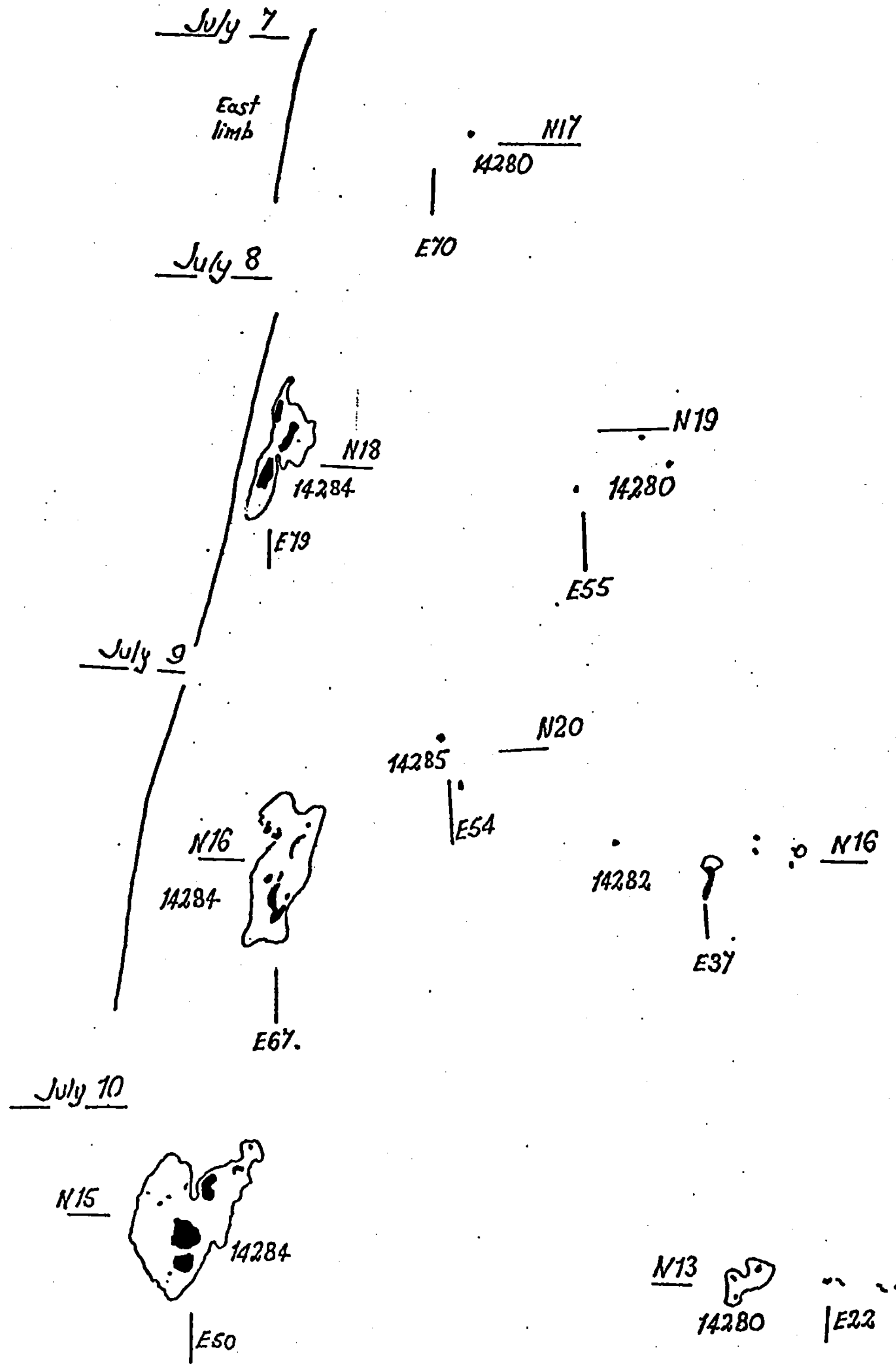


Fig. 7.1a. Sequence of drawings of region 59Q made in white light at the Mt. Wilson Observatory, July 07-July 20 inclusive (communicated to the author through the kindness of Dr. R. Howard).

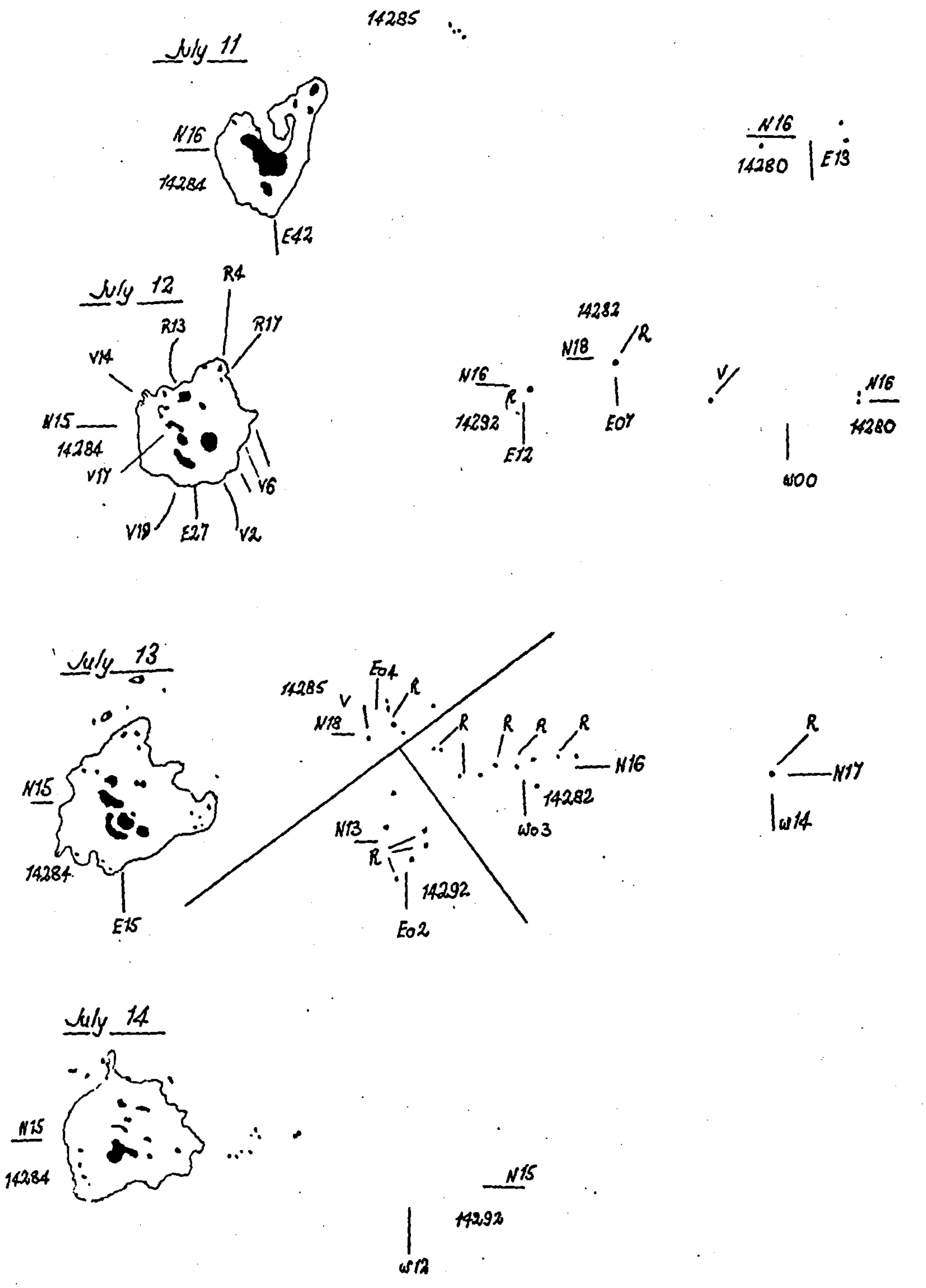


Fig. 7.1a - Continued.

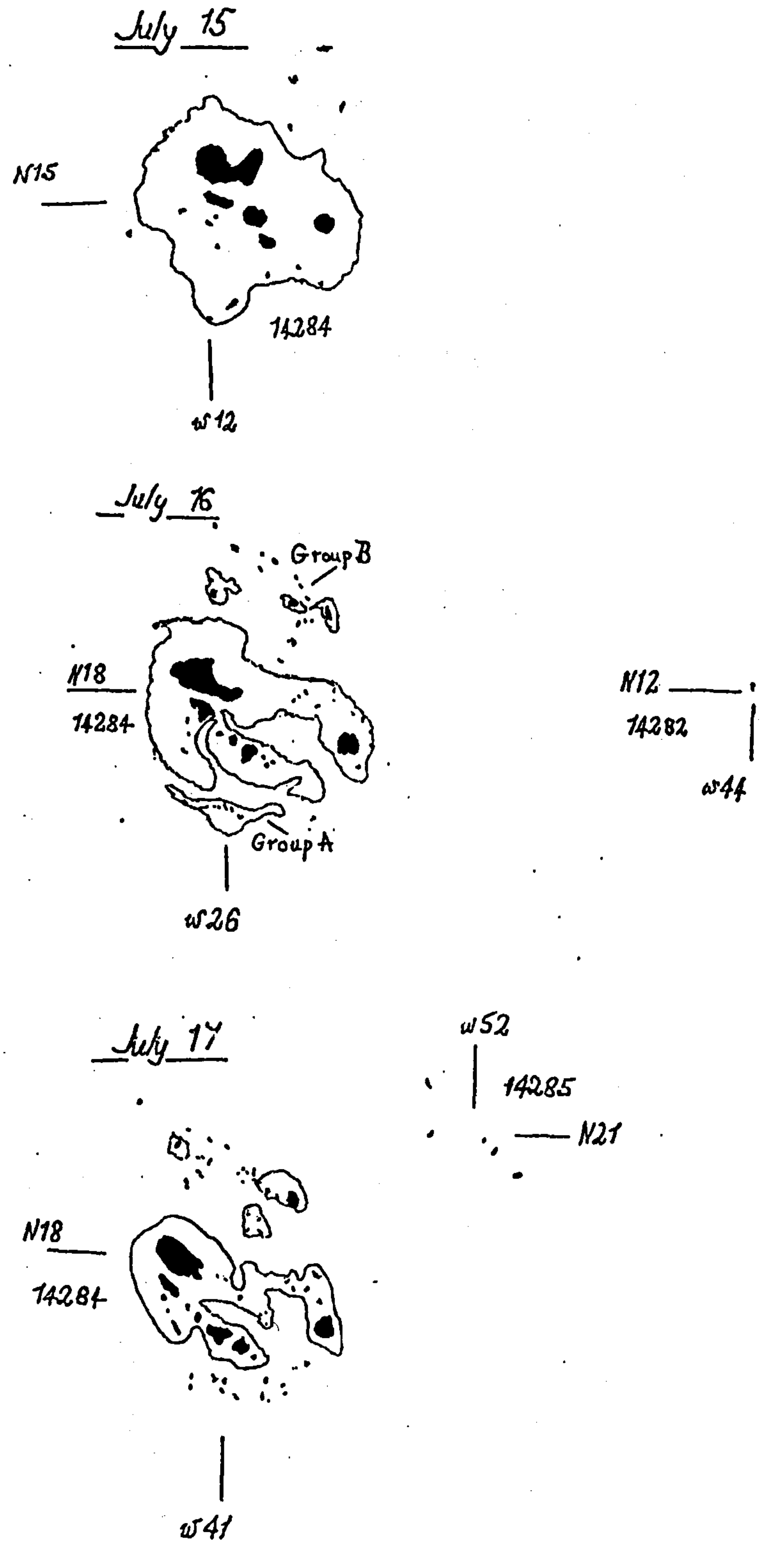


Fig. 7.1a - Continued.

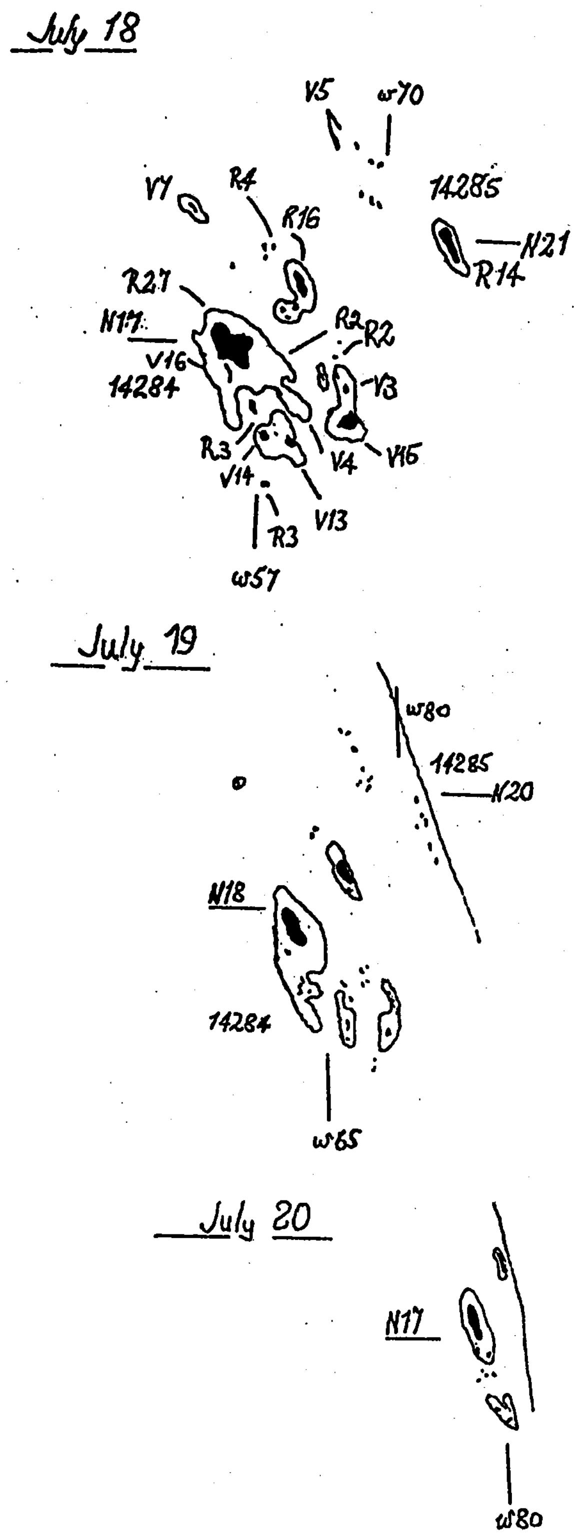


Fig. 7.1a - Concluded.

TABLE 7.4a

Association Between the Locations of Impulsive Flare Brightenings in Region 59Q July 07-21, 1959, and the Positions of Underlying Spot Groups

| Date 1959 | Period covered by McMath SECASI observations | Areas observed to flare in 59Q using the McMath records and the number of impulsive brightenings counted in each one of them<br>Area (No. individual brightenings) | Spot group underlying the flare active areas |
|---|---|---|---|
| July 07 | 1040-2311 | a(1), b(1), d(1), f(1), g(1) | Mt. Wilson 14284 |
| 08 | 1044-2099, 2134-2316 | a(4), b(8), c(10), d(15), $d^{I}$(17), e(11), f(1), g(6), h(4) | Mt. Wilson 14284 |
| 09 | 1810-2109 | a(7), b(12), c(7), d(7), $d^{I}$(2), e(3), f(1), g(6), h(1), i(2) j(3) | Mt. Wilson 14284 |
| 10 | 1050-2319 | c(2), $c_{I}$(1), d(3), $d^{I}$(4), f(3), g(4), h(2) | Mt. Wilson 14284 |
| 11 | 1219-2318 | a(4), c(1), d(16), $d^{I}$(6), $d^{II}$(4), $d^{III}$(6), e(2), g(1), i(3), k(7), $k^{I}$(6), $k^{II}$(4) | Mt. Wilson 14284 |
| | | $i^{I}$(1), $i_{I}^{I}$(1) | Mt. Wilson 14285 |
| 12 | 1134-2245 | a(4), c(6), d(15), $d^{I}$(7), $d^{II}$(1), $d^{IV}$(5), e(3), $e^{I}$(7), $e^{II}$(1), $e^{III}$(1), f(1), g(1), i(3), k(6), $k^{I}$(3), $k^{II}$(2), l(5), $l^{I}$(8), m(1) | Mt. Wilson 14284 |
| | | $i^{I}$(2) | Mt. Wilson 14285 |
| 13 | 1050-2303 | a(4), $a^{I}$(1), c(6), $c^{I}$(8), d(10), $d^{I}$(11), $d^{IV}$(6), $d_{I}^{IV}$(8), $d^{V}$(6), $e^{I}$(9), f(8), g(2), i(1), k(7), $k^{I}$(1), $k^{II}$(13), $k^{III}$(17), l(4), m(11), o(6), $o^{I}$(3), $o^{II}$(1), q(1), $q^{I}$(2), r(1), | Mt. Wilson 14285 |
| | | n(6), $n^{I}$(5) | Mt. Wilson 14292 |
| 14 | 1056-1755, 2145-2309 | c(2), $c^{I}$(2), d(5), $d^{I}$(4), $d^{VI}$(3), $e^{I}$(5), g(2), k(5), $k^{I}$(4) $k^{II}$(2), $k^{III}$(7), l(1), m(6), $m^{I}$(1), $o^{I}$(1), $o^{III}$(8), p(3), q(8), $q^{I}$(5), $q^{II}$(6), $q^{V}$(3), r(4), $r^{I}$(6) | Mt. Wilson 14284 |
| | | $i^{II}$(4), $i_{I}^{I}$(1) | Mt. Wilson 14285 |
| | | $q^{IV}$(3), s(1), $s_{I}$(6), $s^{I}$(1) | Group A |
| 15 | 1105-2256 | a(1), $c^{I}$(3), $c_{I}^{I}$(2), d(8), $d_{I}$(1), $d^{I}$(5), $d^{IV}$(10), $d_{I}^{IV}$(2), $d^{V}$(4), $d^{VI}$(2), $d^{VII}$(13), $e^{I}$(5), $k^{II}$(1), $k^{III}$(5), $k^{IV}$(7), m(3), $m^{I}$(2), $m^{II}$(1), $q^{I}$(1), $q^{V}$(3), $q^{VI}$(1), $q^{VII}$(2), r(1), t(3), $t^{I}$(5), $t^{II}$(2) | Mt. Wilson 14284 |
| | | u(1), $u^{I}$(1), $u^{II}$(1) | Mt. Wilson 14292 |
| | | s(5), s(1), $s^{I}$(5), $s^{II}$(2), $s^{III}$(1), $s^{IV}$(1) | Group A |
| | | v(8) | Group B |
| 16 | 1123-2120 | c(3), $c^{I}$(1), d(9), $d^{I}$(5), $d^{IV}$(3), $d^{VII}$(1), $d^{VIII}$(2), $e^{I}$(9), $e_{I}^{I}$(4), $e^{IV}$(1), f(3), k(7), $k^{I}$(5), $k^{II}$(5), $k^{III}$(5), $k^{IV}$(7), m(4), $m^{I}$(4), $m^{II}$(2), $m^{III}$(6), $m^{IV}$(4), $q^{I}$(1), $q^{V}$(2), $q^{VI}$(1), $q^{VII}$(2), t(6), $t_{I}$(1), $t^{I}$(5), $t^{II}$(7), $t^{III}$(2) | Mt. Wilson 14284 |
| | | u(1), $u^{I}$(1), $u^{II}$(1), $u^{III}$(1), $u^{IV}$(1) | Mt. Wilson 14292 |
| | | s(3), $s^{I}$(1), $s^{II}$(4), $s^{III}$(2), $s^{IV}$(1) | Group A |
| | | v(1), $v^{I}$(3), $v^{II}$(1), $v^{III}$(1), $v^{IV}$(1), w(1), $w^{II}$(4), x(2) $x^{IV}$(5), $x^{V}$(3), $x^{VI}$(5), $x^{VII}$(3) | Group B |
| | | $x^{I}$(1), $x^{II}$(1), $x^{III}$(2), $x^{VIII}$(1), $x^{IX}$(1) | Mt. Wilson 14297 |
| 17 | 1143-1431, 1915-2139 | $d^{VIII}$(2), $e^{IV}$(2), $k^{II}$(7), $k^{III}$(3), $k^{IV}$(1), $k^{V}$(3), $k^{VI}$(2) $m^{II}$(1), $m^{III}$(1), $q^{V}$(1), $q^{VI}$(1), $t^{III}$(1) | Mt. Wilson 14284 |
| | | y(2) | Mt. Wilson 14285 |
| | | s(1), $s^{I}$(2), $s^{II}$(1), $s^{III}$(1) | Group A |
| | | v(1), w(3), $w^{I}$(1), $w^{II}$(1), $x^{IV}$(2), $x^{V}$(2), $x^{VII}$(1) | Group B |
| 19 | 1241-3145 | $x^{I}$(1) | Mt. Wilson 14284 |
| | | y(7), $y^{I}$(2), $y^{II}$(1), $y^{III}$(16), $y^{IV}$(11), $y^{V}$(12) | Mt. Wilson 14285 |
| 20 | 1319-1427, 1821-2311 | y(2), $y^{I}$(3), $y^{III}$(3), $y^{IV}$(3), $y^{V}$(6) | Mt. Wilson 14285 |
| | | s(2) | Group A |
| 21 | 1105-2259 | y(10), $y^{I}$(3), $y^{III}$(12), $y^{IV}$(12), $y^{V}$(3), $y^{VI}$(2) | Mt. Wilson 14285 |
| | | s(2) | Group A |

TABLE 7.4b

Numbers of Impulsive Brightenings Observed Above Different Spot Groups in Region 59Q Over the Period of the McMath SECASI Observations

| Date 1959 | No. of hours covered by McMath SECASI record | No. of impulsive brightenings observed above different spot groups in 59Q over the period of the McMath SECASI observations | | | | | |
|---|---|---|---|---|---|---|---|
| | | Mt. Wilson No. 14284 | Mt. Wilson No. 14285 | Mt. Wilson No. 14292 | Group A | Group B | Mt. Wilson No. 14297 |
| July 07 | 12.53 | 5 | | | | | |
| 08 | 11.15 | 76 | | | | | |
| 09 | 3.00 | 51 | | | | | |
| 10 | 12.50 | 19 | | | | | |
| 11 | 11.00 | 60 | 2 | | | | |
| 12 | 11.20 | 80 | 2 | | | | |
| 13 | 12.23 | 147 | | 11 | | | |
| 14 | 8.42 | 93 | 5 | | 11 | | |
| 15 | 11.87 | 93 | | 3 | 15 | 8 | |
| 16 | 9.97 | 117 | | 5 | 11 | 30 | 6 |
| 17 | 5.23 | 25 | 2 | | 5 | 11 | |
| 19 | 9.08 | 1 | 49 | | | | |
| 20 | 6.00 | | 17 | | 2 | | |
| 21 | 11.92 | | 42 | | 2 | | |
| Total | 136.10 | 767 | 119 | 19 | 46 | 49 | 6 |

TABLE 7.6a

Identification of Areas in 59Q Particularly Associated With the Generation of Type III Bursts, Based on the Total Estimated Probabilities That 56 Type III Bursts Were Associated With These Areas Over the Period July 07-21, 1959, Inclusive*

| Flare active are in 59Q | Total estimated probabilities that Type III bursts were associated with flaring in specific areas of 59Q during its July transit* | |
|---|---|---|
| | Total 'Unambiguous' assoc. with specific areas in region 59Q | Total estimated assoc. with specific areas in region 59Q |
| b | 7.0 | 10.666 |
| d | 5.0 | 7.875 |
| $d^{I}$ | 4.0 | 6.792 |
| a | 2.0 | 4.166 |
| c | 1.0 | 3.833 |
| s | 1.0 | 1.517 |
| $k^{IV}$ | 1.0 | 1.500 |
| y | 1.0 | 1.500 |
| $q^{V}$ | 1.0 | 1.267 |
| e | | 1.167 |
| h | 1.0 | 1.000 |
| $y^{III}$ | | 1.000 |
| $y^{V}$ | 1.0 | 1.000 |
| $r^{I}$ | | 0.950 |
| g | | 0.893 |
| $d^{II}$ | | 0.667 |
| $e^{I}$ | | 0.643 |
| $q^{I}$ | | 0.617 |
| $d^{VI}$ | | 0.500 |
| $d^{VII}$ | | 0.500 |
| $i^{I}_{I}$ | | 0.500 |
| j | | 0.500 |
| $z^{I}$ | | 0.500 |
| $s^{I}$ | | 0.350 |
| f | | 0.310 |
| k | | 0.268 |
| $q^{VI}$ | | 0.267 |
| $s^{II}$ | | 0.267 |
| $s^{III}$ | | 0.267 |
| $o^{III}$ | | 0.250 |
| $q^{II}$ | | 0.250 |
| p | | 0.199 |
| q | | 0.199 |
| $q^{IV}$ | | 0.199 |
| $k^{II}$ | | 0.143 |
| l | | 0.143 |
| m | | 0.143 |
| $k^{I}$ | | 0.125 |
| $q^{VII}$ | | 0.100 |
| $s_{I}$ | | 0.100 |
| $s^{IV}$ | | 0.100 |
| u | | 0.100 |
| Total 42 | 25.0 | 53.333 |

*Estimated according to the procedure described in Section 7.5.

TABLE 7.7a

Location of Areas in 59Q Deemed Associated With the Generation of Type III Bursts Relative to Individual Spot Groups in Region 59Q and Suspended Dark Material

| Mt. Wilson Group No. 14284 | | | Group A | | | Mt. Wilson Group No. 14285 | | | Mt. Wilson Group No. 14292 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Flare active area in 59Q | Total est. prob. of Type III burst assoc. | Remarks | Flare active area in 59Q | Total est. prob. of Type III burst assoc. | Remarks | Flare active area in 59Q | Total est. prob. of Type III burst assoc. | Remarks | Flare active area in 59Q | Total est. prob. of Type III burst assoc. | Remarks |
| a | 4.166 | Areas closely bounding the northern edge of the filament traversing Mt. Wilson group 14284. | $q^{IV}$ | 0.199 | Areas located near the southern edge of a branch of the main dark filament where it was aligned between the southern boundary of Mt. Wilson 14284 and Spot group A. | $i^{I}_{I}$ | 0.500 | Area $i^{I}_{I}$ was located along the eastern and y, $y^{V}$ and $y^{III}$ along the western boundary of a dark filament traversing Mt. Wilson 14285. | u | 0.100 | Area u was located at the western terminus of a dark prominence suspended between Mt. Wilson 14292 and Spot group A. |
| b | 10.666 | | $s_{I}$ | 0.100 | | y | 1.500 | | | | |
| c | 3.833 | | $s^{IV}$ | 0.100 | | $y^{V}$ | 1.000 | | | | |
| d | 7.875 | | $s^{II}$ | 0.267 | | $y^{III}$ | 1.000 | | | | |
| $d^{I}$ | 6.792 | | $s^{III}$ | 0.267 | | | | | | | |
| $d^{VI}$ | 0.500 | | $s^{I}$ | 0.350 | | | | | | | |
| $d^{VII}$ | 0.500 | | s | 1.517 | | | | | | | |
| j | 0.500 | Areas closely bounding the corresponding southern edge of the main dark filament. | | | | | | | | | |
| $z^{I}$ | 0.500 | | | | | | | | | | |
| e | 1.107 | | | | | | | | | | |
| $c^{I}$ | 0.643 | | | | | | | | | | |
| $k^{IV}$ | 1.500 | Areas lying along the eastern edge of a strand of absorption material extending southwards from the main dark filament. | | | | | | | | | |
| $k^{I}$ | 0.125 | | | | | | | | | | |
| k | 0.268 | | | | | | | | | | |
| $k^{II}$ | 0.143 | | | | | | | | | | |
| f | 0.310 | | | | | | | | | | |
| g | 0.893 | | | | | | | | | | |
| h | 1.000 | | | | | | | | | | |
| l | 0.143 | Areas lying along the corresponding western edge of this filamentary strand. | | | | | | | | | |
| m | 0.143 | | | | | | | | | | |
| $o^{III}$ | 0.250 | | | | | | | | | | |
| $d^{II}$ | 0.667 | Area lying adjacent to a strand of absorption material extending north eastwards from the main dark filament. | | | | | | | | | |
| p | 0.199 | Areas lying near the northern edge of a further branch of the main dark filament where it was aligned between the southern boundary of Mt. Wilson 14284 and Spot group A. | | | | | | | | | |
| $q^{II}$ | 0.250 | | | | | | | | | | |
| $q^{I}$ | 0.617 | | | | | | | | | | |
| $q^{V}$ | 1.267 | | | | | | | | | | |
| $q^{VI}$ | 0.267 | | | | | | | | | | |
| $r^{I}$ | 0.950 | | | | | | | | | | |
| q | 0.199 | | | | | | | | | | |
| $q^{VII}$ | 0.100 | | | | | | | | | | |
| Total 30 | | | 7 | | | 4 | | | 1 | | |

*Individual flare active areas are illustrated in the drawings of Fig. 3.1a, pp. 25-34.

The locations of filamentary and amorphous dark material are also shown on these drawings.

The characteristics of individual sunspot groups are described in detail in Section 7.1a, p. 101.

White light drawings of 59Q, showing the positions within the active region of each of these groups, are presented in Fig. 7.1a, pp. 126-129.

TABLE 7.8a

Identification of Flare Active Areas in 59Q Particularly Associated With the Generation of Centimetre Wave Bursts, Based on Composite Estimated Probabilities That 34 Centimetre Bursts of Various Classes Were Associated With Flaring in These Areas Over the Period July 7-21, 1959, Inclusive*

| Flare active area in 59Q | Total probabilities that different kinds of centimetre burst were associated with flaring in specific areas of 59Q during its July transit** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Moderate bursts | | 'Strong' bursts | | 'Very Strong' bursts | | 'Moderate' + 'Strong' + 'Very Strong' bursts | |
| | Unambig. assoc. | Overall assoc. | Unambig. assoc. | Overall assoc. | Unambig. assoc. | Overall assoc. | Total unambig. assoc. | Total overall assoc. |
| d | 4 | 6.759 | | 0.450 | | 0.337 | 4 | 7.546 |
| b | 1 | 1.333 | 1 | 1.250 | | 0.111 | 2 | 2.694 |
| $d^{I}$ | | 1.257 | | 0.500 | | 0.337 | | 2.094 |
| $d^{IV}$ | | 1.290 | | 0.200 | | 0.227 | | 1.717 |
| s | | 0.834 | | 0.350 | | | | 1.184 |
| $d^{VII}$ | | 1.124 | | | | | | 1.124 |
| $d^{II}$ | | 1.000 | | | | | | 1.000 |
| y | | | 1 | 1.000 | | | 1 | 1.000 |
| c | | 0.388 | | 0.250 | | 0.337 | | 0.975 |
| $s^{II}$ | | 0.834 | | 0.100 | | | | 0.934 |
| $q^{I}$ | | 0.417 | | 0.450 | | | | 0.367 |
| $k^{IV}$ | | 0.667 | | | | | | 0.667 |
| e | | | | 0.500 | | 0.111 | | 0.611 |
| g | | 0.476 | | | | 0.111 | | 0.587 |
| a | | | | 0.450 | | 0.111 | | 0.561 |
| $a^{I}$ | | 0.166 | | 0.350 | | | | 0.516 |
| $i^{I}$ | | 0.500 | | | | | | 0.500 |
| $i^{I}_{I}$ | | 0.500 | | | | | | 0.500 |
| $q^{II}$ | | 0.250 | | 0.250 | | | | 0.500 |
| q | | 0.250 | | 0.200 | | | | 0.450 |
| $q^{V}$ | | 0.334 | | 0.100 | | | | 0.434 |
| $s^{III}$ | | 0.334 | | 0.100 | | | | 0.434 |
| m | | 0.434 | | | | | | 0.434 |
| $c^{I}$ | | | | 0.200 | | 0.227 | | 0.427 |
| $e^{I}$ | | 0.143 | | | | 0.227 | | 0.370 |
| $e_{I}$ | | 0.250 | | 0.100 | | | | 0.356 |
| f | | 0.143 | | | | 0.195 | | 0.338 |
| $m^{I}$ | | 0.291 | | | | | | 0.291 |
| $q^{VI}$ | | 0.166 | | 0.100 | | | | 0.266 |
| k | | 0.143 | | | | 0.083 | | 0.226 |
| $k^{II}$ | | 0.143 | | | | 0.083 | | 0.226 |
| $c^{I}_{I}$ | | | | 0.200 | | | | 0.200 |
| p | | | | 0.200 | | | | 0.200 |
| $q^{IV}$ | | | | 0.200 | | | | 0.200 |
| $r^{I}$ | | | | 0.200 | | | | 0.200 |
| $o^{I}$ | | | | | | 0.143 | | 0.143 |
| f | | 0.143 | | | | | | 0.143 |
| h | | | | | | 0.111 | | 0.111 |
| $q^{VII}$ | | | | 0.100 | | | | 0.100 |
| $s^{IV}$ | | | | 0.100 | | | | 0.100 |
| u | | | | 0.100 | | | | 0.100 |
| $d^{IV}_{I}$ | | 0.091 | | | | | | 0.091 |
| $d^{V}$ | | 0.091 | | | | | | 0.091 |
| $d^{VI}$ | | 0.091 | | | | | | 0.091 |
| t | | 0.091 | | | | | | 0.091 |
| $t^{I}$ | | 0.091 | | | | | | 0.091 |
| $t^{II}$ | | 0.091 | | | | | | 0.091 |
| $e^{I}_{I}$ | | | | | | 0.083 | | 0.083 |
| $k^{III}$ | | | | | | 0.083 | | 0.083 |
| $x^{VII}$ | | | | | | 0.083 | | 0.083 |
| $v^{I}$ | | 0.055 | | | | | | 0.055 |
| $x^{I}$ | | 0.055 | | | | | | 0.055 |
| $x^{II}$ | | 0.055 | | | | | | 0.055 |
| $x^{III}$ | | 0.055 | | | | | | 0.055 |
| $x^{IV}$ | | 0.055 | | | | | | 0.055 |
| $x^{V}$ | | 0.055 | | | | | | 0.055 |
| $x^{VI}$ | | 0.055 | | | | | | 0.055 |
| Total 57 | 5 | 21.500 | 2 | 8.000 | | 3.000 | 7 | 32.500 |

*Based on the data contained in Table 7.6a.

**Estimated according to the procedure described in Section 7.5.

TABLE 7.10a

Association Between Intervals Within Which Individual Areas in 59Q Were Observed to Flare and the Intervals Within Which Spot Umbrae Were Seen on White Light Pictures Directly Underlying the Positions of These Active Areas

| Flare sensitive areas in 59Q | First flare observed in the area using the McMath SECASI records | Last flare observed in the area using the McMath SECASI records | Intervals within which directly underlying umbrae appeared and disappeared | |
|---|---|---|---|---|
| | | | Umbra appeared | Umbra disappeared |
| a | 1404 July 07 | 1327 July 15 | <0601 July 09* | >1617 July 15 |
| $a^{I}$ | 2232 July 13 | 2232 July 13 | 1447 July 11-0617 July 12 | 0732 July 14-1641 July 14 |
| b | 1108 July 07 | 2041 July 09 | <0601 July 09* | 2133 July 09-0602 July 10 |
| c | 1110 July 08 | 2118 July 16 | <0601 July 09* | 1617 July 15-0442 July 17 |
| $c_{I}$ | 1556 July 10 | 1556 July 10 | 0608 July 10-1558 July 10 | 1558 July 10-0617 July 11 |
| $c^{I}_{I}$ | 1230 July 15 | 1329 July 15 | 1550 July 13-0514 July 14 | 1617 July 15-0442 July 17 |
| $c^{I}$ | 1302 July 13 | 2118 July 16 | 1449 July 12-0830 July 13 | 0501 July 16-0442 July 17 |
| d | 1114 July 07 | 2118 July 16 | <0601 July 09* | 0501 July 16-0447 July 18 |
| $d_{I}$ | 1227 July 15 | 1227 July 15 | 1641 July 14-0440 July 15 | 0501 July 16-0447 July 18 |
| $d^{I}$ | 1225 July 08 | 2118 July 16 | <0601 July 09* | Reduction of composite umbra containing $d^{I}$ from 0501 July 16-0442 July 17 |
| $d^{II}$ | <1545 July 11 | <1421 July 12 | 0602 July 10-0517 July 11 | 1449 July 12-0503 July 13 |
| $d^{III}$ | 1243 July 11 | 2240 July 11 | 1558 July 10-0617 July 11 | 0503 July 13-1550 July 13 |
| $d^{IV}$ | 1227 July 12 | 2118 July 16 | 1447 July 11-0511 July 12 | Reduction of composite umbra containing $d^{IV}$ from 0301 July 16-0442 July 17 |
| $d^{IV}_{I}$ | <1050 July 13 | 2240 July 15 | 1449 July 12-0712 July 13 | Reduction of composite umbra containing $d^{IV}_{I}$ from 0501 July 16-0442 July 17 |
| $d^{V}$ | <1345 July 12 | 2242 July 15 | 1447 July 11-0617 July 12 | 1900 July 16-0442 July 17 |
| $d^{VI}$ | 1538 July 14 | 2242 July 15 | 0503 July 13-1550 July 13 | Reduction of composite umbra containing $d^{VI}$ from 0501 July 16-0442 July 17 |
| $d^{VII}$ | 1140 July 15 | 1550 July 16 | 0503 July 13-1550 July 13 | Reduction of composite umbra containing $d^{VII}$ from 0501 July 16-0442 July 17 |
| $d^{VIII}$ | <1405 July 16 | <1411 July 17 | 1617 July 15-0501 July 16 | >0511 July 19 |
| c | 1132 July 08 | <2136 July 12 | <0601 July 09* | 0503 July 13-1550 July 13 |
| $e^{I}$ | 1252 July 12 | 2118 July 16 | 1447 July 11-0511 July 12 | >0511 July 19 |
| $e^{I}_{I}$ | 1557 July 16 | 2118 July 16 | 1617 July 15-0501 July 16 | >0511 July 19 |
| $e^{II}$ | <2212 July 12 | <2212 July 12 | 1447 July 11-0511 July 12 | 1449 July 12-0712 July 13 |
| $e^{III}$ | 1744 July 12 | 1744 July 12 | 1447 July 11-0511 July 12 | 0503 July 13-0712 July 13 |
| $e^{IV}$ | <1946 July 16 | <1239 July 17 | 1617 July 15-0501 July 16 | 0501 July 16-0447 July 18 |
| f | 1301 July 07 | 2120 July 16 | <0601 July 09* | 0447 July 18-0511 July 19 |
| g | 1256 July 07 | 1244 July 14 | <0601 July 09* | 0447 July 18-0511 July 19 |
| h | 1658 July 08 | 1210 July 10 | <0601 July 09* | 1558 July 10-1447 July 11 |

*In the case of areas a, b, c, d, $d^{I}$, e, f, g, and h, the spot group was too close to the east limb to enable underlying umbrae to be identified on white light pictures in association with flaring from $<06^{h}\ 01^{m}$ U.T. July 09. Similarly, in the case of areas s, y, $y^{I}$, $y^{II}$, $y^{III}$, $y^{IV}$, $y^{V}$, and $y^{VI}$ the spot group was too close to the west limb to enable underlying umbrae to be identified in association with flaring from $>05^{h}\ 11^{m}$ U.T. July 19.

TABLE 7.10a - Continued

| Flare sensitive areas in 59Q | First flare observed in the area using the McMath SECASI records | Last flare observed in the area using the McMath SECASI records | Intervals within which directly underlying umbrae appeared and disappeared | |
|---|---|---|---|---|
| | | | Umbra appeared | Umbra disappeared |
| i | 1948 July 09 | 1303 July 13 | <1998 July 10+ | 1590 U.T. July 13-0782 July 14 |
| $i_{I}^{I}$ | <2315 July 11 | 1634 July 14 | Group 14285 reported by Mt. Wilson from July 09** | Uncertain |
| $i^{I}$ | <2315 July 11 | 2158 July 12 | Group 14285 reported by Mt. Wilson from July 09** | Uncertain |
| $i^{II}$ | <1056 July 14 | <1431 July 14 | Group 14285 reported by Mt. Wilson from July 09** | Uncertain |
| j | 1946 July 09 | 2016 July 09 | <0601 July 09 | 2138 July 09-0602 July 10 |
| k | 1255 July 11 | 2120 July 16 | 0517 July 11-1447 July 11 | 0501 July 16-0442 July 17 |
| $k^{I}$ | 1255 July 11 | <1946 July 16 | 0517 July 11-1447 July 11 | 0501 July 16-0442 July 17 |
| $k^{II}$ | 1306 July 11 | 1355 July 17 | 0517 July 11-1447 July 11 | >0447 July 18 |
| $k^{III}$ | 1116 July 13 | 1326 July 17 | 1447 July 11-0511 July 12 | 0442 July 17-0447 July 18 |
| $k^{IV}$ | 1320 July 15 | <1341 July 17 | 1641 July 14-0440 July 15 | >0511 July 19 |
| $k^{V}$ | 1152 July 17 | <2039 July 17 | 1617 July 15-0501 July 16 | 0447 July 18-0511 July 19 |
| $k^{VI}$ | 1345 July 17 | <2124 July 17 | 1617 July 15-0501 July 16 | 0442 July 17-0447 July 18 |
| l | 1228 July 12 | 1307 July 14 | 1447 July 11-0617 July 12 | 0732 July 14-1641 July 14 |
| $l^{I}$ | 1300 July 12 | <2231 July 12 | 0511 July 12-1449 July 12 | 0503 July 13-1550 July 13 |
| m | 2225 July 12 | <1847 July 16 | 1447 July 11-0617 July 12 | >1617 July 15+ |
| $m^{I}$ | 1232 July 14 | <1617 July 16 | 0503 July 13-1305 July 13 | >1617 July 15+ |
| $m^{II}$ | 1409 July 15 | 1344 July 17 | 1550 July 13-0732 July 14 | Uncertain+ |
| $m^{III}$ | 1151 July 16 | 1344 July 17 | 1550 July 13-0732 July 14 | Uncertain+ |
| $m^{IV}$ | <1555 July 16 | <1847 July 16 | 1550 July 13-0732 July 14 | 0442 July 17-0447 July 13 |
| n | 1141 July 13 | 1732 July 13 | 1449 July 12-0503 July 13 | 1550 July 13-0514 July 14 |
| $n^{I}$ | 1142 July 13 | 1733 July 13 | 1449 July 12-0503 July 13 | 1550 July 13-0514 July 14 |
| o | 1121 July 13 | 1725 July 13 | <0712 July 13 | Uncertain+ |
| $o^{I}$ | 1408 July 13 | 1727 July 13 | <0712 July 13 | Uncertain+ |
| $o^{II}$ | 1457 July 13 | 1457 July 13 | <0712 July 13 | Uncertain+ |
| $o^{III}$ | 1103 July 14 | 1727 July 14 | <0712 July 13 | Uncertain+ |
| p | 1734 July 14 | 2227 July 14 | 0514 July 14-1641 July 14 | 1641 July 14-1617 July 15 |
| q | 1736 July 13 | 2303 July 14 | 1550 July 13-0514 July 14 | 1641 July 14-0440 July 15 |
| $q^{I}$ | 1736 July 13 | 1610 July 16 | 1550 July 13-0514 July 14 | 0501 July 16-0442 July 17 |
| $q^{II}$ | 1141 July 14 | 2300 July 14 | 1550 July 13-0732 July 14 | 1617 July 15-0601 July 16 |
| $q^{IV}$ | 1736 July 14 | 2229 July 14 | 1550 July 13-1641 July 14 | Uncertain+ |
| $q^{V}$ | 2204 July 14 | <1341 July 17 | 1641 July 14-0440 July 15 | 0447 July 18-0511 July 19 |
| $q^{VI}$ | <1929 July 15 | <1343 July 17 | 1641 July 14-0440 July 15 | 0447 July 18-0511 July 19 |
| $q^{VII}$ | 1413 July 15 | <1617 July 16 | 1641 July 14-0440 July 15 | 1900 July 16-0442 July 17 |

**In the case of $i_{I}^{I}$, $i^{I}$, $i^{II}$, $i^{III}$, u, $u^{I}$, $u^{II}$, $u^{III}$, $u^{IV}$, $x^{I}$, $x^{II}$, $x^{III}$, $x^{VIII}$ and $x^{IX}$, the available data are not sufficiently good to determine if minor umbrae were present directly underlying these various areas or not.

+In the case of area i the contrast on the available pictures was not sufficiently good to determine when the relevant umbra appeared and in the case of areas m, $m^{I}$, $m^{II}$, $m^{III}$, o, $o^{I}$, $o^{II}$, $o^{III}$, $q^{IV}$, t, and $t_{I}$ when it disappeared from the solar disk.

TABLE 7.10a - Continued

| Flare sensitive areas in 59Q | First flare observed in the area using the McMath SECASI records | Last flare observed in the area using the McMath SECASI records | Intervals within which directly underlying umbrae appeared and disappeared | |
|---|---|---|---|---|
| | | | Umbra appeared | Umbra disappeared |
| r | 1207 July 13 | 1358 July 15 | 1449 July 12-0712 July 13 | 0501 July 16-0442 July 17 |
| $r^{I}$ | <1056 July 14 | 1736 July 14 | 1449 July 12-0712 July 13 | 0501 July 16-0442 July 17 |
| s | 2324 July 14 | 2035 July 21 | 1641 July 14-0440 July 15 | >0511 July 19* |
| $s_{I}$ | 1141 July 14 | <1929 July 15 | 1550 July 13-0514 July 14 | 1617 July 15-0501 July 16 |
| $s^{I}$ | 2224 July 14 | <2124 July 17 | 1641 July 14-0440 July 15 | 0442 July 17-0447 July 15 |
| $s^{II}$ | 1358 July 15 | <1341 July 17 | 1641 July 14-0440 July 15 | 0447 July 18-0511 July 19 |
| $s^{III}$ | <1929 July 15 | <1341 July 17 | 1641 July 14-0440 July 15 | 0447 July 18-0511 July 19 |
| $s^{IV}$ | <1929 July 15 | <1617 July 16 | 0440 July 15-1617 July 15 | 0501 July 16-0442 July 17 |
| t | 1405 July 15 | <2111 July 16 | 1641 July 14-0440 July 15 | Uncertain+ |
| $t_{I}$ | 1402 July 16 | 1402 July 16 | 1641 July 14-0440 July 15 | Uncertain+ |
| $t^{I}$ | 1404 July 15 | <2111 July 16 | 1641 July 14-0440 July 15 | 0501 July 16-0442 July 17 |
| $t^{II}$ | 1404 July 15 | 1747 July 16 | 1641 July 14-0440 July 15 | 0501 July 16-0442 July 17 |
| $t^{III}$ | 1152 July 16 | <1341 July 17 | 1641 July 14-0440 July 15 | 0442 July 17-0447 July 13 |
| u | <1929 July 15 | <1617 July 16 | Group 14292 reported by Mt. Wilson from July 12** | Uncertain |
| $u^{I}$ | <1929 July 15 | <1617 July 16 | Group 14292 reported by Mt. Wilson from July 12** | Uncertain |
| $u^{II}$ | <1929 July 15 | <1617 July 16 | Group 14292 reported by Mt. Wilson from July 12** | Uncertain |
| $u^{III}$ | <1617 July 16 | <1617 July 16 | Group 14292 reported by Mt. Wilson from July 12** | Uncertain |
| $u^{IV}$ | <1617 July 16 | <1617 July 16 | Group 14292 reported by Mt. Wilson from July 12** | Uncertain |
| v | 1343 July 15 | 1148 July 17 | 0440 July 15-1617 July 15 | >0511 July 19 |
| $v^{I}$ | 1344 July 16 | <1828 July 16 | 0440 July 15-1617 July 15 | >0447 July 18 |
| $v^{II}$ | 1353 July 16 | 1353 July 16 | 0440 July 15-1617 July 15 | >0447 July 18 |
| $v^{III}$ | 1356 July 16 | 1356 July 16 | 0440 July 15-1617 July 15 | >0447 July 18 |
| $v^{IV}$ | 1203 July 16 | 1203 July 16 | 0440 July 15-1617 July 15 | >0523 July 20 |
| w | 1344 July 16 | 1427 July 17 | 0440 July 15-1617 July 15 | >0447 July 18 |
| $w^{I}$ | <1946 July 17 | <1946 July 17 | 0440 July 15-1617 July 15 | >0447 July 18 |
| $w^{II}$ | <1337 July 16 | <1946 July 17 | 0440 July 15-1617 July 15 | >0447 July 18 |
| x | 1353 July 16 | <1938 July 16 | 1641 July 14-0440 July 15 | >0511 July 19 |

*In the case of areas a, b, c, d, $d^{I}$, e, f, g, and h, the spot group was too close to the east limb to enable underlying umbrae to be identified on white light pictures in association with flaring from $<06^{h}\ 01^{m}$ U.T. July 09. Similarly, in the case of areas s, y, $y^{I}$, $y^{II}$, $y^{III}$, $y^{IV}$, $y^{V}$, and $y^{VI}$ the spot group was too close to the west limb to enable underlying umbrae to be identified in association with flaring from $>05^{h}\ 11^{m}$ U.T. July 19.

**In the case of $i_{I}^{I}$, $i^{I}$, $i^{II}$, $i^{III}$, u, $u^{I}$, $u^{II}$, $u^{III}$, $u^{IV}$, $x^{I}$, $x^{II}$, $x^{III}$, $x^{VIII}$ and $x^{IX}$, the available data are not sufficiently good to determine if minor umbrae were present directly underlying these various areas or not.

+In the case of area i the contrast on the available pictures was not sufficiently good to determine when the relevant umbra appeared and in the case of areas m, $m^{I}$, $m^{II}$, $m^{III}$, o, $o^{I}$, $o^{II}$, $o^{III}$, $q^{IV}$, t, and $t_{I}$ when it disappeared from the solar disk.

TABLE 7.10a - Concluded

| Flare sensitive areas in 59Q | First flare observed in the area using the McMath SECASI records | Last flare observed in the area using the McMath SECASI records | Intervals within which directly underlying umbrae appeared and disappeared | |
|---|---|---|---|---|
| | | | Umbra appeared | Umbra disappeared |
| $x^{I}$ | 1351 July 16 | 1351 July 16 | Group 14297 reported by Mt. Wilson from July 14** | Uncertain |
| $x^{II}$ | 1352 July 16 | 1352 July 16 | Group 14297 reported Mt. Wilson from July 14** | Uncertain |
| $x^{III}$ | 1351 July 16 | <1938 July 16 | Group 14297 reported by Mt. Wilson from July 14** | Uncertain |
| $x^{IV}$ | 1157 July 16 | <1946 July 17 | 1641 July 14-0440 July 15 | >0511 July 19 |
| $x^{V}$ | 1344 July 16 | <1946 July 17 | 0440 July 15-1617 July 15 | >0511 July 19 |
| $x^{VI}$ | 1207 July 16 | <1726 July 16 | 0440 July 15-1617 July 15 | >0511 July 19 |
| $x^{VII}$ | 1345 July 16 | 1146 July 17 | 0440 July 15-1617 July 15 | >0511 July 19 |
| $x^{VIII}$ | 1353 July 16 | 1353 July 16 | Group 14297 reported by Mt. Wilson from July 14** | Uncertain |
| $x^{IX}$ | 1357 July 16 | 1357 July 16 | Group 14297 reported by Mt. Wilson from July 14** | Uncertain |
| y | <1239 July 17 | <1550 July 21 | 0501 July 16-0447 July 18 | >0511 July 19* |
| $y^{I}$ | <1433 July 19 | <1228 July 21 | 0501 July 16-0447 July 18 | >0511 July 19* |
| $y^{II}$ | <1530 July 19 | <1530 July 19 | 0501 July 16-0447 July 18 | >0511 July 19* |
| $y^{III}$ | <1241 July 19 | <1833 July 21 | 0501 July 16-0447 July 18 | >0511 July 19* |
| $y^{IV}$ | <1327 July 19 | <2024 July 21 | 0501 July 16-0447 July 18 | >0511 July 19* |
| $y^{V}$ | <1241 July 19 | 1552 July 21 | 0501 July 16-0447 July 18 | >0511 July 19* |
| $y^{VI}$ | <1550 July 21 | <1816 July 21 | 0501 July 16-0447 July 18 | >0511 July 19* |
| $z^{I}$ | 1743 July 19 | 1743 July 19 | 0501 July 16-0442 July 17 | 0511 July 19-0523 July 20 |

*In the case of areas a, b, c, d, $d^{I}$, e, f, g, and h, the spot group was too close to the east limb to enable underlying umbrae to be identified on white light pictures in association with flaring from $<06^h\ 01^m$ U.T. July 09. Similarly, in the case of areas s, y, $y^{I}$, $y^{II}$, $y^{III}$, $y^{IV}$, $y^{V}$, and $y^{VI}$ the spot group was too close to the west limb to enable underlying umbrae to be identified in association with flaring from $>05^h\ 11^m$ U.T. July 19.

**In the case of $i^{I}_{I}$, $i^{I}$, $i^{II}$, $i^{III}$, u, $u^{I}$, $u^{II}$, $u^{III}$, $u^{IV}$, $x^{I}$, $x^{II}$, $x^{III}$, $x^{VIII}$ and $x^{IX}$, the available data are not sufficiently good to determine if minor umbrae were present directly underlying these various areas or not.

TABLE 7.10b

List of Dates and Times at Which Those White Light Pictures of Region 59Q Available for Study Were Taken at the Crimean, Potsdam, Acton and Mount Wilson Observatories Respectively

| Date 1959 | Crimean Astrophysical Observatory U.T. | Potsdam Astrophysical Observatory | Acton Observatory | Mount Wilson Observatory |
|---|---|---|---|---|
| July 09 | $06^h01^m$ | $06^h13^m$ | 0915 | $18^h00^m$ |
| 10 | $06^h02^m$ | $06^h08^m$ | 0945 | $15^h33^m$ |
| 11 | $05^h17^m$ | $06^h17^m$ | | $14^h47^m$ |
| 12 | $05^h11^m$ | $06^h17^m$ | | $14^h49^m$ |
| 13 | $05^h03^m$ | $07^h12^m$ | 0830 | $15^h50^m$ |
| 14 | $05^h14^m$ | $07^h32^m$ | 0945 | $16^h41^m$ |
| 15 | $04^h40^m$ | $07^h47^m$ | | $16^h17^m$ |
| 16 | $05^h01^m$ | | | $17^h11^m$ |
| 17 | $04^h42^m$ | | | |
| 18 | $04^h47^m$ | | | |
| 19 | $05^h11^m$ | | | |
| 20 | $05^h23^m$ | | | |

TABLE 7.14a

Comparison Between the Starting Times of Magnetographic Records of 59Q Obtained at the Crimean Astrophysical Observatory and the Times of Onset or Enhancement of Centimetre Burst Associated Prominence Flaring Occurring Between the Taking of These Records*

| Date 1959 | Starting times of magnetograms of region 59Q U.T. | Times of onset or enhancement of centimetre burst associated Prominence Flaring occurring in 59Q between the taking of each individual magnetogram U.T. | Class of each flare associated centimetre wave burst** |
|---|---|---|---|
| July 14 | 0856 | | |
| | | 1145-1147 | Moderate |
| | | 1734-1736 | Strong |
| | | 2224 | Strong |
| 15 | | 1255-1256 | Moderate |
| | | 1300-1301 | Moderate |
| | 1310 | | |
| | | 1327-1329 | Strong |
| | | 1606-1607 | Moderate |
| | | 1925 | Strong |
| | | 2240-2242 | Moderate |
| 16 | | 0637-0638 | Moderate |
| | | 0708 | Moderate |
| | 1135 | | |
| | | 1351-1352 | Moderate |
| | 1500 | | |
| | | 1604 | Moderate |
| | | 1610 | Moderate |
| | | 1613 | Strong |
| | | 2118-2120 | Very Strong |
| | | 2313 | Moderate |
| | | 2346 | Moderate |
| 17 | | 0024x | Moderate |
| | | 0032x | Moderate |
| | | 0041x | Moderate |
| | 0800 | | |
| | | 1340 | Moderate |
| 18 | 0847 | | |
| | | 1048 | Strong |

*These magnetographic charts were published in Howard and Severny (1963a).

**For details of this classification system see Section 6.3.

TABLE 7.15a

Relationship Between the Occurrence of Flaring in 59Q Associated With the Generation of 'Very Strong' Radio Bursts and Changes in Underlying Spot Groups

| Date 1959 | Time of onset (U.T.) and type of flaring | Flare sensitive areas involved in flash phase | Time of onset (U.T.) of 'Very Strong' radio burst | Changes in underlying spot group | Interval within which magnetic change occurred | No. of hours within which magnetic change occurred |
|---|---|---|---|---|---|---|
| July 10 | $02^h05^m$ (Prominence)<br>$02^h06^m$ (Prominence)<br>$<02^h09^m$ (Prominence) | c,d<br>a-b-c-d-$d_I^I$<br>a-b-c-d-d-e-f-g-h | $02^h06^m$ | Disappearance of N21 between c and d and possibly of minor umbrae and penumbral structure underlying b and c*, apparent merging and southward motion of umbrae underlying f and g, distension westwards of western penumbral boundary. | $21^h38^m$ July 09-$06^h02^m$ July 10 | <8.4 |
| 14 | $<03^h27^m$ (Plage)<br>$<03^h33^m$ (Prominence) | c,d<br>$c^I$-c-d-$d^{UV}$<br>$e^I$,$o^I$ | $03^h30^m$ | Umbra N26 between d and $d^{IV}$ shows a reduction in area; separation of south polar umbrae and growth of a new umbra between S23 and fragmenting main group. | $19^h14^m$ July 13-$05^h14^m$ July 14 | <10.0 |
| 16 | $21^h14^m$-$21^h16^m$ (Plage)<br>$21^h18^m$ (Prominence) | d,$d^{IV}$,$e^I$-$e_I^I$<br>(d,$d^{IV}$) ($e^I$-$e_I^I$) ($k^{III}$)<br>$c^I$-c-d-$d^{IV}$-$d^I$<br>$e^I$-$e_I^I$<br>$k^{III}$-k-$k^{II}$-f<br>$x^{VII}$ | $21^h18^m$ | Umbra N28 between d and $d^{IV}$ shows a reduction in area - also umbrae located immediately to the north and south of S28 disappeared and those underlying $e^I$ and $e_I^I$ faded.<br>Two minor umbrae waxed somewhat to the west of this latter pair. A large island of penumbra containing S28 as well as a waxing south polar umbra underlying $k^{IV}$ separated from the main body of group 14284. | $21^h20^m$ July 16-$04^h42^m$ July 17 | <7.4 |

*Minor umbrae and ambient penumbral structure underlying b and c certainly disappeared between $18^h00^m$ July 09-$06^h02^m$ July 10. Since minor umbrae are difficult to identify unambiguously on the swept wavelength records it is not certain if these magnetic features were present on the spectroheliogram of $21^h38^m$ July 09 when umbra N21 was still clearly visible.

**TABLE 7.16a**

**Relationship Between the Commencement or Enhancement of Prominence Flaring in 59Q Associated With the Generation of 'Strong' Radio Bursts in Underlying Spot Groups**

| Date 1959 | Time of onset or enhancement (U.T.) of Prominence Flaring in 59Q | Flare sensitive area/s involved | Time of onset (U.T.) of 'Strong' radio burst | Changes in underlying spot group | Interval within which magnetic change occurred | No. of hours within which magnetic change occurred |
|---|---|---|---|---|---|---|
| July 02 | $13^h30^m$ | $d^I$,e | $13^h29^m$ | Region too close to east limb to detect possible associated magnetic changes. | | |
| 09 | $14^h38^m$-$14^h40^m$ | a,b,c,d | $14^h40.8^m$ | Contrast on pictures not sufficiently good $06^h01^m$-$18^h00^m$ U.T. to detect possible assoc. magnetic change. | | |
| 09 | $18^h10^m$ | b | $18^h10^m$ | Disappearance of minor umbra underlying b and ambient penumbral structure. | $18^h00^m$ July 09-$06^h02^m$ July 10* | ~12.0* |
| 14<br>14 | $17^h34^m$-$17^h36^m$<br>$22^h24^m$ | p,q,$q^I$,$r^I$,$q^{IV}$<br>$q^I$,$q^{II}$,s,$s^I$ | $17^h34^m$<br>$22^h23^m$ | Virtual disappearance of an umbra underlying q with its ambient penumbra while an umbra underlying p is greatly reduced. Appearance of minor umbrae underlying s,$s^I$,$s^{II}$,$s^{III}$ with assoc. enveloping penumbra. | $16^h41^m$ July 14-$04^h40^m$ July 15 | ~12.0 |
| 15 | $13^h27^m$-$13^h29^m$ | a,d,$d^{IV}$,$c^I$,$c^I_I$ | $13^h27.5^m$ | A sliver of umbra underlying $d^{IV}$ merging with consolidating north polar umbrae. Close south polar umbrae disintegrating. | $07^h47^m$ July 15-$16^h17^m$ July 15 | ~8.5 |
| 15 | $19^h25^m$ | $s_I$,$s^I$,$s^{II}$,$s^{III}$,$s^{IV}$ $q^V$,$q^{VI}$,$q^{VII}$,u | $19^h25^m$ | Penumbral material enveloping umbrae beneath s,$s^I$,$s^{II}$,$s^{III}$ becomes internally structured rather than diffuse; material flanking umbrae below $q^V$ and $q^{VI}$ disappears. Umbrae fading to east and waxing to west of position of $q^V$ and $q^{VI}$. | $16^h17^m$ July 15-$05^h01^m$ July 16 | ~12.7 |
| 16 | $16^h13^m$ | Gap in record. Flaring at <$16^h17^m$ U.T. above $q^V$,$q^{VI}$,$q^{VII}$,s,$s^I$,$s^{II}$, $s^{III}$,$s^{IV}$ and above Mt. Wilson 14292. | $16^h13^m$ | Reduction in umbrae underlying s and $s^I$; umbrae waxing to south of S28 on the other side of the 'neutral line'. | $05^h01^m$ July 16-$17^h11^m$ July 16 | ~12.2 |
| 18 | $10^h48^m$ | y | $10^h47.6^m$ | Region too close to west limb to detect possible assoc. magnetic changes. | | |
| 18 | $17^h54^m$ | Flaring in progress in prominence material extending towards s. | $17^h54.5^m$ | Region too close to west limb to detect possible assoc. magnetic changes. | | |

*Minor umbrae and ambient penumbral structure underlying b and c certainly disappeared between $18^h00^m$ July 09-$06^h02^m$ July 10. Since minor umbra are difficult to identify unambiguously on the swept wavelength records it is not certain if these magnetic features were present on the spectroheliogram of $21^h33^m$ July 09 when umbra N21 was still clearly visible.

TABLE 7.17a

Relationship Between the Commencement of Prominence Flaring in 59Q Associated With the Generation of 'Moderate' Radio Bursts and Changes in Underlying Spot Groups

| Date 1959 | Time of onset or enhancement (U.T.) of Prominence Flaring | Flare sensitive areas involved | Time of onset (U.T.) of 'Moderate' radio burst | Changes in underlying spot group | Interval within which magnetic change occurred | No. of hours within which magnetic change occurred |
|---|---|---|---|---|---|---|
| July 09 | $20^h41^m$–$20^h43^m$<br>$21^h12^m$ | b,c,g<br>Extensive flaring spreads from above Mt. Wilson 14284 to Mt. Wilson 14285 and the inferred position of Mt. Wilson 14297. | $20^h42^m$<br>$21^h12^m$ | Disappearance of minor umbrae underlying b and c and ambient penumbral structure; apparent merging and southward motion of umbrae underlying f and g. | $18^h00^m$ July 09-$06^h02^m$ July 10*. Interval covers a 'Very Strong' burst associated Prominence Flare with onset at $02^h05^m$ July 10. | ~12.0 |
| | $22^h17^m$ | b | $22^h18^m$ | | | |
| 11 | $01^h33^m$<br>$02^h32^m$<br>$04^h49^m$ | d,$d^{II}$<br>d,$d^{II}$<br>d,$d^{II}$ | $01^h32.8^m$<br>$02^h33^m$<br>$04^h49^m$ | Waxing of satellite underlying d and adjacent to N19; separation of N24 into two parts, one of which then migrates towards N19; the penumbral border immediately to the north containing minor umbra underlying $d^{II}$ shows associated developmental changes. | $05^h17^m$ July 11-$14^h47^m$ July 11. Interval covers the splitting of N24. | 9.5 |
| 11 | $23^h13^m$-$23^h14^m$ | $i^I$,$i_I^I$ | $23^h14^m$ | Contrast on available white light pictures not sufficiently good to detect possible assoc. magnetic change at Mt. Wilson 14285. | | |
| 12 | $04^h25^m$<br>$06^h28^m$-$06^h29^m$<br>$13^h14^m$<br>$14^h05^m$ | d,$d^I$,$d^{IV}$<br>d<br>d<br>d | $04^h23^m$<br>$06^h30^m$<br>$13^h13^m$<br>$14^h06^m$ | Migrating fragment of N21 gradually merging with umbra N25 which was itself waxing and developing new satellite umbrae. South polar umbrae meanwhile start to separate. | <$05^h11^m$ July 12-$14^h49^m$ July 12 (merging of umbrae in progress). | >9.6 |
| | $22^h07^m$ | Flaring spreads from above Mt. Wilson 14284 to Mt. Wilson 14285 and the inferred position of Mt. Wilson 14297. | $22^h07^m$ | Contrast on white light pictures not sufficiently good to detect possible associated magnetic change at Mt. Wilson 14285 and 14297. | | |

*Minor umbrae and ambient penumbral structure underlying b and c certainly disappeared between $18^h00^m$ July 09-$06^h02^m$ July 10. Since minor umbrae are difficult to identify unambiguously on the swept wavelength records it is not certain if these features were present on the spectroheliogram of $21^h38^m$ July 09 when umbra N21 was still clearly visible.

TABLE 7.17a - Continued

| Date 1959 | Time of onset or enhancement (U.T.) of Prominence Flaring | Flare sensitive areas involved | Time of onset (U.T.) of 'Moderate' radio burst | Changes in underlying spot group | Interval within which magnetic change occurred | No. of hours within which magnetic change occurred |
|---|---|---|---|---|---|---|
| July 12 | $22^h24^m$-$22^h28^m$ | $e^I$,k,l,m,$k^{II}$,f,g | $22^h24^m$ | Separation from main complex and subsequent westward migration of S23 with its crescent satellite umbrae underlying $e^I$,k,$k^{II}$,f,g and the preceding minor umbra underlying l. Concomitant agrandizment of umbra N25. | $14^h49^m$ July 12-$05^h03^m$ July 13. | 14.3 |
| 13 | $06^h09^m$ | d | $06^h10^m$ | Umbra N22 still growing and developing satellite umbrae; south polar umbrae growing gradually further apart. | | |
| 14 | $11^h45^m$-$11^h47^m$ | q,$q^I$,$q^{II}$,$s_I$ | $11^h46.5^m$ | As the main south polar umbrae break up and migrate westwards minor umbrae underlying these flare active areas are waxing in a newly developed penumbral extension to Mt. Wilson 14284 and in Spot group A. | | |
| 15 | $12^h55^m$-$12^h56^m$<br>$13^h00^m$-$13^h01^m$ | d,$d^{IV}$,$d^{VII}$<br>m,$m^I$,d,$d^{IV}$,$d^{VII}$ | $12^h57^m$<br>$13^h00^m$ | N28, N25 and a sliver of umbra underlying $d^{IV}$ merging together; close south polar umbrae meanwhile separating. | $07^h47^m$ July 15-$16^h17^m$ July 15. Interval covers a 'Strong'burst assoc. flare at $13^h27^m$ U.T. in the same general location. | 8.5 |
| 15 | $16^h06^m$-$16^h07^m$ | $d^{VII}$,$k^{IV}$ | $16^h06.9^m$ | Umbrae underlying $d^{VII}$ and $k^{IV}$ waxing on either side of magmetic 'neutral line'. That underlying $k^{IV}$ later grows relatively large. | | |
| 15 | $22^h40^m$-$22^h42^m$ | $d^{IV}$,t,$t^I$,$t^{II}$,$d^I$,<br>$d^{IV}$,$d^V$,$d^{VI}$,$d^{VII}$<br>m,$m^I$ | $22^h40^m$ | As minor polar umbrae consolidate, minor umbra underlying $d^{VII}$ waxing main south polar umbrae still separating while minor umbrae underlying $k^{IV}$,t,$t_I$,$t^I$,$t^{II}$,$t^{III}$ are developing south of the magnetic 'neutral line'. | | |
| 16 | $06^h37^m$-$06^h38^m$<br>$07^h08^m$ | d,$d^I$,$d^{IV}$<br>Flaring in progress above Mt. Wilson 14282. | $06^h36^m$<br>$07^h08.2^m$ | Composite north polar umbrae still changing with growth of an umbra underlying $d^{VIII}$, main south polar umbrae still fragmenting and separating. | | |

TABLE 7.17a - Concluded

| Date 1959 | Time of onset or enhancement (U.T.) of Prominence Flaring | Flare sensitive areas involved | Time of onset (U.T.) of 'Moderate' radio burst | Changes in underlying spot group | Interval within which magnetic change occurred | No. of hours within which magnetic change occurred |
|---|---|---|---|---|---|---|
| July 16 | $13^h51^m$-$13^h52^m$ | c,d,$v^{I}$,$x^{I}$,$x^{II}$, $x^{III}$,$x^{IV}$,$x^{V}$,$x^{VI}$ | $13^h51^m$ | North polar umbrae still changing as above. Umbrae underlying $x^{I}$, $x^{II}$ and $x^{III}$ were components of Mt. Wilson 14297; those underlying $v^{I}$,$x^{IV}$,$x^{V}$ and $x^{VI}$ were components of Spot group B. Contrast on white light pictures not sufficiently good to detect possible assoc. magnetic changes at Mt. Wilson 14297. Complex changes in Spot group B on this day with various umbrae waxing and waning. | | |
| 16 | $16^h04^m$<br>$16^h10^m$ | s,$s^{II}$<br>$q^{I}$,$q^{V}$,$q^{VI}$,s,$s^{II}$,$s^{III}$ | $16^h05^m$<br>$16^h10^m$ | Reduction in umbrae underlying s and $s^{I}$; umbrae waxing to south of S28 on the other side of the magnetic 'neutral line'. | $05^h01^m$ July 16-$17^h11^m$ July 16. Interval covers a "Very Strong' burst assoc. flare at $16^h13^m$ U.T. in the same general location. | ~12.2 |
| 16 | $23^h13^m$<br>$23^h46^m$<br>$00^h24^m$<br>$00^h32^m$<br>$00^h41^m$ | Extensive importance 3 Prominence Flare, with onset at $21^h18^m$ July 16, still in progress. | $23^h13^m$<br>$23^h46^m$<br>$00^h24^m$ x<br>$00^h32^m$ x<br>$00^h41^m$ x | Umbra N28 between d and $d^{IV}$ shows a reduction in area; separation of main south polar umbrae and disappearance of minor umbrae to north and south of S28. Fading of minor umbrae underlying $e^{I}$ and $e_{I}^{I}$. A waxing pair somewhat to the west of them. | $21^h20^m$ July 16-$04^h42^m$ July 17. Interval covers a 'Very Strong' burst assoc. Prominence Flare which began above Mt. Wilson 14284 at $21^h18^m$ July 16. | <7.4 |
| July 17 | $13^h39^m$-$13^h40^m$ | s,$s^{I}$,$s^{II}$,$s^{III}$,$q^{V}$,$k^{IV}$ | $13^h40^m$ | A pair of large umbrae together with ambient penumbral material containing a minor umbra underlying $q^{V}$ separated from group 14284 to migrate westwards as a unit; material decline in the appearance of Spot group A and of the umbra underlying $k^{IV}$. | $04^h42^m$ July 17-$04^h47^m$ July 18. | ~24.1 |
| 18 | $18^h11^m$ | Flaring in progress in prominence material extending towards s. | $18^h11^m$ | Region too close to west limb to detect possible associated magnetic changes. | | |

TABLE 7.18a

The Positions, Relative to Underlying Spots and to Active Dark Material of Those Areas in 59Q Involved in the Production of Impulsive Plage Flaring

| Location in 59Q | Active area in 59Q and number of times it was seen to show Plage Flaring over the period of the McMath observations | Position of flare areas relative to spots and to active dark material | Active area in 59Q and number of times it was seen to show Plage Flaring over the period of the McMath observations | Position of flare areas relative to spots and to active dark material |
|---|---|---|---|---|
| 1 | $a$ (14)<br>$i$ ( 5)<br>$b$ ( 7)<br>$c_I$ ( 1)<br>$c^I$ (12)<br>$c$ (27)<br>$d$ (71)<br>$d_I$ ( 1)<br>$d^V$ ( 9)<br>$d^{IV}$ (18)<br>$d_I^{IV}$ ( 9)<br>$d^{III}$ ( 6)<br>$d^I$ (54)<br>$d^{VI}$ ( 4)<br>$d^{VII}$ (10)<br>$d^{VIII}$ ( 4) | Areas either situated above minor spots closely bordering the northern edge of the dark filament traversing 14284 or positioned above satellite spots within 10" of the magnetic 'neutral line'. | $a_I^I$ ( 1)<br>$c_I$ ( 1)<br>$e^{III}$ ( 1)<br>$z_I^I$ ( 1)<br>$e_I$ ( 3)<br>$e_I$ (15)<br>$e_{IV}$ (29)<br>$e_{II}$ ( 3) | Areas situated above minor spots closely bordering the southern edge of the dark filament traversing 14284 and extending westwards through a south polar milieu towards separating S23. |
| | | | $d^{II}$ ( 4) | Situated above a minor spot along the western edge of a strand of dark absorption material extending northwards from the filament traversing 14284. |
| | $k^I$ (19)<br>$k_{II}$ (30)<br>$k_{III}$ (31)<br>$k$ (35)<br>$f$ (15)<br>$g$ (16)<br>$h$ ( 6) | Areas situated above minor umbrae forming a crescent about S23 and bordering the eastern edge of a strand of absorption material extending southwards from the filament traversing 14284. | $k^{VI}$ ( 2)<br>$k^{IV}$ (13)<br>$k^V$ ( 3)<br>$i$ ( 8)<br>$i^I$ ( 5)<br>$m_I$ (22)<br>$m_{III}$ ( 5)<br>$o_I$ ( 8)<br>$o$ ( 4) | Areas $k^{VI}$-$k^V$ situated above spots bordering the northern edge of the dark filament described above. Areas 1-$o^I$ situated above minor umbrae along the western edge of filamentary material extending southwards with those umbrae underlying $k^I$-h along its eastern edge. |
| | $t_I$ ( 1)<br>$t_I$ ( 8)<br>$t_{II}$ ( 9)<br>$t_{III}$ ( 8)<br>$t$ ( 3) | Areas situated above minor umbrae bordering the southern edge of a branch of the dark filament traversing 14284 where it extended north westwards between $t^I$ and $v^{IV}$. | $m^{IV}$ ( 4)<br>$m^{III}$ ( 7)<br>$m^{II}$ ( 4)<br>$o_{II}$ ( 6)<br>$o$ ( 1) | Areas situated above minor umbrae bordering the western edge of a strand of that material described to the left (in column 3) where it curled southwards to ultimately extend towards Spot group A. |

TABLE 7.18a - Concluded

| Location in 59Q | Active area in 59Q and number of times it was seen to show Plage Flaring over the period of the McMath observations | Position of flare areas relative to spots and to active dark material | Active area in 59Q and number of times it was seen to show Plage Flaring over the period of the McMath observations | Position of flare areas relative to spots and to active dark material |
|---|---|---|---|---|
| 2 | $p_{II}$ ( 1)<br>$q$ ( 3)<br>$q^{I}$ ( 4)<br>$q^{V}$ ( 5)<br>$r$ ( 6)<br>$r^{I}$ ( 6)<br>$q_{VII}$ ( 6)<br>$q$ ( 2) | Areas situated above minor umbrae within a rapidly changing penumbral extension to, or directly along the southern border of, group 14284. These umbrae bordered the northern edge of a length of dark absorption material originally curling southwards between group 14284 and 14292 then turning north eastwards with a strand aligned between the southern boundary of 14284 and Spot group A. | $q^{IV}$ ( 1)<br>$s_{I}$ ( 4)<br>$s^{II}$ ( 3)<br>$s^{III}$ ( 1)<br>$s^{I}$ ( 5)<br>$s$ ( 9) | Areas situated above minor umbrae in Spot group A and near the terminus of that length of dark absorption material described to the left in column 3. |
| 3 | $i^{I}$ ( 2)<br>$i^{II}$ ( 4)<br>$i_{I}^{I}$ ( 1) | Areas $i^{I}$-$i_{I}^{I}$ identified above group 14285 between July 11-13 near the terminus of a branch of the main dark filament traversing 14284 which then extended north westwards towards this position**. | | |
| | $y_{I}^{IV}$ (26)<br>$y_{VI}$ ( 8)<br>$y_{II}$ ( 2)<br>$y$ ( 1) | Areas $y^{IV}$-$y^{II}$ situated above umbrae along the eastern border of active dark material traversing Spot group B. | $y^{III}$ (31)<br>$y^{V}$ (21)<br>$y$ (21) | Areas situated above umbrae along the western border of active dark material traversing 14285. |
| 4 | $y^{IV}$ ( 1)<br>$y$ ( 8)<br>$w_{II}$ ( 4)<br>$w_{I}$ ( 5)<br>$v_{I}$ ( 2)<br>$w_{VII}$ ( 1)<br>$x$ ( 3) | Areas situated above umbrae to the north west of active dark material traversing Spot group B. | $x^{VI}$ ( 4)<br>$x^{V}$ ( 4)<br>$x_{IV}$ ( 1)<br>$x_{III}$ ( 6)<br>$x$ ( 1) | Areas situated above umbrae to the south east of active dark material traversing Spot group B. |
| 6 | $n$ ( 6)<br>$n^{I}$ ( 5) | Areas situated above minor umbrae in group 14292 and along the western edge of a length of absorption material between groups 14284 and 14292. | | |

*Based on data contained in Table 6.2c.

**The white light data are not sufficiently good to determine if $i^{I}$, $i_{I}^{I}$ and $i^{II}$ were positioned directly above individual umbrae in Mt. Wilson 14285.

TABLE 7.18b

The Frequency of Plage Flaring in Individual Areas of 59Q as Observed on Successive Days of Its July Transit Using the McMath SECASI Records.

Outline of Magnetic Situation Pertaining in the Various Underlying Spot Groups Involved

| Date 1959 | Period covered by McMath SECASI observation | Flare sensitive areas in 59Q and the number of times per day they were individually observed to display impulsive Plage Flaring | General location in 59Q at which Plage Flaring occurred | The magnetic situation pertaining in those spot groups underlying individual locations at which Plage Flaring occurred |
|---|---|---|---|---|
| July 07 | 1040-2311 | a(1), f(1), g(1) | Location 1 | Mt. Wilson 14284 too close to east limb on July 07-08 to allow magnetic variations to be detected but changes in dark material suspended above the group were visible in profile against the sky on these days. |
| 08 | 1044-2009<br>2134-2315 | a(3), b(7), c(10), d(14), $d^{I}$(15)<br>e(10), f(1), g(6), h(4) | Location 1 | |
| 10 | 1050-2319 | $c_I$(1), c(2), d(3), $d^{I}$(4), f(3), g(4), h(2) | Location 1 | With the exception of a brightening above a newly emerged umbra underlying $c_I$, flare activity was associated with those umbrae involved in the magnetic changes which occurred between $21^h38^m$ July 09-$06^h02^m$ July 10 (cf. Table 7.15a). |
| 11 | 1219-2318 | a(4), i(3), c(1), d(16), $d^{II}$(4), $d^{III}$(6), $d^{I}$(6) | Location 1 | One north polar umbra N19 waxing on this day, the other N24 split between $05^h17^m$ July 11-$14^h47^m$ July 11. |
| | | e(2), g(1), k(7), $k^{I}$(6), $k^{II}$(4) | | Development of a crescent of minor spots surrounding separation S28. |
| | | $i^{I}$(1) | Location 3 | Area situated above general position of Mt. Wilson 14285. |
| 12 | 1134-2249 | a(2), i(1), c(5), d(11), $d^{IV}$(4), $d^{I}$(6) | Location 1 | North polar umbrae in group 14284 waxing and merging between $14^h49^m$ July 12-$05^h03^m$ July 13. |
| | | $e^{III}$(1), e(3), $e^{I}$(2), k(5), $k^{I}$(3)<br>$k^{II}$(1), l(3), $l^{I}$(5) | | S28 and its enveloping crescent of minor umbrae separated from the main body of the group and migrated westwards preceded by several minor umbrae underlying l and $l^{I}$. |
| | | $i^{I}$(1) | Location 3 | Area situated above general position of Mt. Wilson 14284. |
| 13 | 1050-2303 | a(4), i(1), $c^{I}$(8), c(6), d(10), $d^{IV}$(6) | Location 1 | North polar umbrae in group 14284 waxing and growing together. |
| | | $d^{IV}$(8), $d^{V}$(6), $d^{I}$(11)<br>$a^{I}$(1), $e^{I}$(9), $k^{I}$(1), k(7), $k^{II}$(13), $k^{III}$(17)<br>f(8), g(2), l(4), m(11), o(6), $o^{I}$(3), $o^{II}$(1) | | S24 migrating further westwards from the fragmenting main group preceded by essentially two outlying crescents of minor umbrae. |
| | | q(1), $q^{I}$(2), r(1) | Location 2 | Development of umbral and penumbral material along southern border of 14284 between $15^h50^m$ July 13-$05^h14^m$ July 14. |
| | | n(6), $n^{I}$(5) | Location 6 | Minor umbrae developing at position of Mt. Wilson 14292. |
| 14 | 1056-1755<br>2145-2309 | $c^{I}$(2), c(2), d(5), $d^{I}$(4), $d^{VI}$(3)<br>$e^{I}$(5), $k^{I}$(4), k(5), $k^{II}$(2), $k^{III}$(7)<br>g(2), l(1), m(6), $m^{I}$(1), $o^{III}$(8), $o^{I}$(1) | Location 1 | Activity associated primarily with those umbrae in group 14284 involved in the magnetic changes that occurred between $19^h14^m$ July 13-$05^h14^m$ July 14 (cf. Table 7.15a). |
| | | p(1), $q^{II}$(3), $q^{I}$(1), $q^{V}$(2), r(4), $r^{I}$(6), q(5)<br>$q^{IV}$(1), $s_I$(4) | Location 2 | Umbral and penumbral changes along the southern boundary of Mt. Wilson 14284 and in spot group A particularly between $15^h41^m$ July 14-$04^h40^m$ July 15 (cf. Table 7.16a). |
| | | $i^{II}$(4), $i^{I}_{I}$(1) | Location 3 | Areas situated above general position of Mt. Wilson 14285. |

TABLE 7.18b - Concluded

| Date 1959 | Period covered by McMath SECASI observation | Flare sensitive areas in 59Q and the number of times per day they were individually observed to display impulsive Plage Flaring | General location in 59Q at which Plage Flaring occurred | The magnetic situation pertaining in those spot groups underlying individual locations at which Plage Flaring occurred |
|---|---|---|---|---|
| July 15 | 1105-2256 | $c^{I}(2)$, $d(5)$, $d_{I}(1)$, $d_{I}^{IV}(1)$, $d^{IV}(6)$ $d^{V}(3)$, $d^{I}(4)$, $d^{VI}(1)$, $d^{VII}(9)$, $c_{I}^{I}(1)$, $e^{I}(5)$, $k^{IV}(5)$, $k^{III}(4)$ $m(1)$, $t(2)$, $t^{I}(4)$, $t^{II}(1)$, $m^{II}(1)$ | Location 1 | Merging of north polar umbrae in group 14284 between $07^{h}47^{m}$ July 15-$16^{h}17^{m}$ July 15. Main south polar umbrae are separating but there is a marked development of new minor umbrae to the south of the magnetic 'neutral line'. |
| | | $q^{I}(1)$, $q^{V}(2)$, $r(1)$, $q^{VII}(1)$ $s^{I}(4)$, $s^{II}(1)$, $s(4)$ | Location 2 | Changes along the southern magnetic border of Mt. Wilson 14284 and in Spot group A particularly between $16^{h}17^{m}$ July 15-$05^{h}01^{m}$ July 16. |
| | | $v(6)$ | Location 4 | Emergence of many components of Spot group B. |
| 16 | 1123-2120 | $c(1)$, $d(7)$, $d^{IV}(2)$, $d^{I}(4)$, $d^{VII}(1)$, $d^{VIII}(2)$ $e^{I}(8)$, $e_{I}^{I}(3)$, $e^{IV}(1)$, $k^{IV}(7)$, $k(6)$, $k^{I}(5)$, $k^{II}(4)$, $k^{III}(4)$, $f(2)$, $m(4)$, $m^{I}(4)$ $t_{I}(1)$, $t(6)$, $t^{I}(5)$, $t^{II}(7)$, $t^{III}(2)$ $m^{IV}(4)$, $m^{III}(6)$, $m^{II}(2)$ | Location 1 | Merging north polar and separating south polar umbrae in Mt. Wilson 14284. Emergence of several minor umbrae in this group. |
| | | $q^{V}(1)$, $q^{VII}(1)$, $s^{II}(2)$, $s^{III}(1)$, $s(1)$ | Location 2 | Changes along southern magnetic border of Mt. Wilson 14284 and in Spot group A particularly between $05^{h}01^{m}$ July 16-$17^{h}11^{m}$ July 16 (cf. Table 7.16a). |
| | | $v^{IV}(1)$, $v(1)$, $w(1)$, $w^{II}(4)$, $v^{I}(2)$, $x^{VII}(2)$ $x^{VI}(4)$, $x^{V}(2)$, $x(1)$, $x^{IV}(4)$, $x^{III}(1)$ | Location 4 | Spot group B developing on this day. |
| 17 | 1143-1431 1915-2139 | $d^{VIII}(2)$, $e^{IV}(2)$, $k^{VI}(2)$, $k^{IV}(1)$, $k^{V}(3)$ $k^{II}(7)$, $k^{III}(3)$ $t^{III}(1)$, $m^{III}(1)$, $m^{II}(1)$ | Location 1 | Flaring primarily associated with the umbrae contained in an 'island' of penumbral material enveloping S28 which separated from the main body of group 14284 during a period of magnetic change between $21^{h}20^{m}$ July 16-$04^{h}42^{m}$ July 17 (cf. Table 7.15a). |
| | | $s^{I}(1)$ | Location 2 | Spot group A in decline. |
| | | $y(2)$ | Location 3 | Mt. Wilson group 14285 waxing on this day. |
| | | $v(1)$, $w(3)$, $w^{II}(1)$, $w^{I}(1)$, $x^{VII}(1)$ $x^{V}(2)$, $x^{IV}(2)$ | Location 4 | Spot group B showing marked changes. |
| 19 | 1241-2145 | $z^{I}(1)$ | Location 1 | Region 59Q too close to west limb from July 10 to enable magnetic changes in individual spot groups to be clearly followed. |
| | | $y^{IV}(11)$, $y^{I}(2)$, $y^{II}(1)$, $y^{III}(16)$, $y^{V}(12)$, $y(7)$ | Location 3 | |
| 20 | 1319-1427 | $s(2)$ | Location 2 | See above. |
| | 1821-2311 | $y^{IV}(3)$, $y^{I}(3)$, $y^{III}(3)$, $y^{V}(6)$, $y(2)$ | Location 3 | |
| 21 | 1105-2259 | $s(2)$ | Location 2 | See above. |
| | | $y^{IV}(12)$, $y^{I}(3)$, $y^{VI}(2)$, $y^{III}(12)$, $y^{V}(3)$, $y(10)$ | Location 3 | |

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## BIBLIOGRAPHY


Akasofu, S. I., and Chapman, S., 1960, Proc. Helsinki Symp. on "The July 1959 Events and Associated Phenomena," Publ. Union Géodesique et Géophysique Internationale Monographie No. 7 (Imprimé par l' Institut Géographique National, Paris), p. 93.

Akasofu, S. I., and Chapman, S., 1961, Geophys. Inst. Univ. Alaska, Sci. Report No. 7, U.A.G. - R112.

Allen, C. W., 1947, M. Not. Roy. Astron. Soc. 107, 386.

Altschuler, M. D., 1974, Proc. IAU Symp. No. 57 on "Coronal Disturbances" (in press).

Altschuler, M. D., 1975, Proc. IAFE Flare Conference, Buenos Aires, Argentina (in press).

Anderson, K. A., and Enemark, D. C., 1960, J. Geophys. Res., 65, 2657.

Anderson, K. A., and Lin, R. P., 1966, Phys. Rev. Ltrs., 16, 1121.

Annals of the IQSY, 3, 1969, "The Proton Flare Project (The July 1966 Event)", Ed. A. C. Strickland (Publ., The MIT Press, Cambridge, Mass. and London, England).

Athay, R. G., 1961, Proc. 2nd Internat. Space Sci. Symp., "Space Research II," Ed. H. C. van de Hulst, C. de Jager and A. F. Moore (Publ., North-Holland Publ. Co., Amsterdam), p. 837.

Athay, R. G., and Moreton, G. E., 1961, Astrophys. J., 133, 935.

Avignon, Y., Caroubalos, C., Martres-Tropé, M. J., and Pick, M., 1964a, Proc. "AAS-NASA Symposium on the Physics of Solar Flares," NASA SP-50, Ed., W. N. Hess (Publ., National Aeronautics and Space Administration, Washington, D.C.), p. 25.

Avignon, Y., Caroubalos, C., Martres, M. J., and Pick, M., 1965, Proc. IAU Symp. No. 22 on "Stellar and Solar Magnetic Fields," Ed. R. Lust. (Publ., North-Holland Publ. Co., Amsterdam), p. 373.

Avignon, Y., Martres-Tropé, M. J., and Pick-Gutmann, M., 1963, Compt. Rend., 256, 2112.

Avignon, Y., Martres, M. J., and Pick, M., 1964b, Ann. d'Astrophys., 27, No. 1, p. 23.

Avignon, Y., and Pick-Gutmann, M., 1959, Compt. Rend., 24, 2276.

Axisa, F., Avignon, Y., Martres, M. J., Pick, M., and Simon, P., 1971, Solar Phys., 19, 110.

Axisa, F., Martres, M. J., Pick, M., and Soru-Escaut, I., 1973a, Solar Phys., 29, 163.

Axisa, F., Martres, M. J., Pick, M., and Soru-Escaut, I., 1973b, Proc. of the "Symposium on High Energy Phenomena on the Sun," NASA SP-342 (Publ. National Aeronautics and Space Administration, Washington, D.C.), p. 615.

Bappu, M. K. V., Grigorjev, V. M., and Stepanov, V. E., 1968, Solar Phys., 4, 409.

Bailey, D. K., 1962, J. Phys. Soc. Japan, 17, A-1, 106.

Bailey, D. K., 1964, Planet. Space Sci., 12, 495.

Bell, B., 1963, Smithsonian Contrib. Astrophys., 8, 119.

Bell, B., and Glazer, H., 1959, Smithsonian Contrib. Astrophys., 3, 25.

Beigman, I. L., Grineva, Yu. I., Mandel'stam, S. L., Vainstein, L. A., and Zhitnik, I. A., 1969, Solar Phys., 9, 160.

Biswas, S., 1961, J. Geophys. Res., 66, 2653.

Boischot, A., 1957, Compt. Rend., 244, 1326.

Boischot, A., and Pick, M., 1962, J. Phys. Soc. Japan, 17, Suppl. A-II, 203.

Brown, R. R., and D'Arcy, R. G., 1959, Phys. Rev. Ltrs., 3, 390.

Brown, R. R., and D'Arcy, R. G., 1961a, Arkiv for Geofysik., Bd. 3, Nr. 21, 443.

Brown, R. R., and D'Arcy, R. G., 1961b, J. Geophys. Res., 66, 2516.

Brown, R. R., and Weir, R. A., 1961, Arkiv for Geofysik., Bd. 3, Nr. 21, 523.

Bruzek, A., 1958, Z. Astrophys., 44, 183.

Bruzek, A., 1962, Z. Astrophys., 54, 225.

Bruzek, A., 1964a, J. Geophys. Res., 69, 2386.

Bruzek, A., 1964b, Astrophys. J., 140, 746.

Bruzek, A., 1964c, Proc. "AAS-NASA Symposium on the Physics of Solar Flares," Ed. W. N. Hess, NASA SP-50 (Publ., National Aeronautics and Space Administration, Washington, D.C.), p. 301.

Bruzek, A., 1968, Proc. Nobel Symp. IX on "Mass Motions in Solar Flares and Related Phenomena," Ed. Y. Öhman (Publ., J. Wiley & Sons, New York), p. 67.

Bruzek, A., 1969a, Proc. COSPAR Symposium on "Solar Flares and Space Research," Ed. C. de Jager and Z. Švestka (Publ., North-Holland Publ., Co., Amsterdam), p. 61.

Bruzek, A., 1969b, Proc. Conference on "Plasma Instabilities in Astrophysics," (Publ. Gordon and Breach Science Publishers, New York), p. 71.

Bruzek, A., 1972, "Solar Terrestrial Physics/1970," Part 1, Gen. Ed. E. R. Dyer (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 49.

Bruzek, A., and de Mastus, H., 1970, Solar Phys., 12, 447.

Bumba, V., 1958, Isv. Krymsk, Astrofiz. Obs., 19, 105.

Bumba, V., 1960, Publ. Crim. Astrophys. Obs., 23, 212.

Bumba, V., 1962, Bull. Astr. Inst. Czech., 13, 48.

Bumba, V., 1972, "Solar Terrestrial Physics/1970," Part I, Gen. Ed. E. R. Dyer (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 21.

Bumba, V., and Godoli, G., 1968, Proc. IAU Symp. No. 35 on "Structure and Development of Solar Active Regions," Ed. K. O. Kiepenheuer (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 338.

Bumba, V., and Howard, R., 1965a, Astrophys. J., 141, 1492.

Bumba, V., and Howard, R., 1965b, Astrophys. J., 141, 1502.

Bumba, V., and Howard, R., 1965c, Astrophys. J., 142, 796.

Bumba, V., Howard, R., Martres, M. J., and Soru-Iscovici, I., 1968a, Proc. IAU Symp., No. 35 on the "Structure and Development of Solar Active Regions," Ed. K. O. Kiepenheuer (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 13.

Bumba, V., Křivský, L., Martres, M. J., and Soru-Isovici, I., 1968b, Proc. IAU Symp. No. 35 on the "Structure and Development of Solar Active Regions," Ed. K. O. Kiepenheuer (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 311.

Castelli, J. P., and Guidice, D. A., 1972, "On the Classification, Distribution and Interpretation of Solar Microwave Burst Spectra and Related Topics," AFCRL-72-0049 (Publ., L. G. Hanscom Field, Bedford, Mass., USA).

Catalano, C. P., and Van Allen, J. A., 1973, Astrophys. U., 185, 335.

Carmichael, H., Steljes, J. F., Rose, D. C., and Wilson, E. G., 1961, Phys. Rev. Ltrs., 6, 49.

"Catalog of Solar Particle Events 1955-1969," 1975, Ed. Z. Švestka and P. Simon, Astrophysics and Space Science Library, Vol. 49 (Publ., D. Reidel, Dordrecht-Holland).

Charakhachian, A. N., Tulinov, V. F., and Charakchian, T. N., 1960, Proc. First International Space Sci. Symp. at Nice on "Space Research," (Publ., North-Holland Publ. Co., Amsterdam), p. 649.

Christiansen, W. N., Mathewson, D. S., Pawsey, J. L., Smerd, S. F., Boischot, A., Denisse, J. F., Simon, P., Kakinuma, T., Dodson-Prince, H., and Firor, J., 1960, Annales d'Astrophys., 23, 75.

Chupp, E. L., Forrest, D. L., and Suri, A. N., 1973, "Symp. on High Energy Phenomena on the Sun," NASA SP-342 (Publ., National Aeronautics and Space Administration, Washington, D.C.), p. 285.

Collins, C., Jelly, D. H., and Matthews, A. G., 1961, Canad. J. Phys., 39, 35.

Covington, A. E., and Harvey, G. A., 1961a, Nature, 192, No. 4798, 152.

Covington, A. W., and Harvey, G. A., 1961b, Phys. Rev. Ltrs., 6, 51.

Croom, D. L., 1973, Proc. of the Symp. on "High Energy Solar Phenomena on the Sun," NASA SP-342 (Publ., National Aeronautics and Space Administration, Washington, D.C.), p. 114.

Cummings, P., 1965, "Catalog of High Energy Solar Particle Events 1957-1961," AFCRL-66-140, Scientific Report No. 7 (Publ., Harvard University, Fort Davis, Texas).

Daene, H., and Krüger, A., 1966, Astron. Nachr., 289, 117.

Daigne, G., 1968, Nature, 220, 567.

Daigne, G., Lantos-Jarry, M. F., and Pick, M., 1971, Proc. IAU Symp. No. 43 on "Solar Magnetic Fields," (Publ., D. Reidel, Dordrecht-Holland), p. 609.

Davies, R. D., 1954, Mon. Not. Roy. Astron. Soc., 114, 74.

d'Azambuja, L., 1953, L'Astronomie, 67, 430.

de Feiter, L. D., 1960, Planet. Space Sci., 2, 223.

de Feiter, L. D., 1975, Space Science Revs., 17, 181.

de Feiter, L. D., and de Jager, C., 1973, Solar Phys., 28, 183.

de Groot, T., 1974, "Type III Bursts," Review by the Solar Radio Group, Utrecht, Correspondent: de Groot, Space Sci. Revs., 16, 45.

de Jager, C., 1959, "Encyclopedia of Physics," Vol. LII, Astrophys. III, The Solar System, Ed. S. Flügge (Publ., Springer-Verlag, Berlin), Sect. 46, p. 183.

de Jager, C., 1961, "Vistas in Astronomy, 4, Ed. A. Beer (Publ., Pergamon Press, London), p. 143.

de Jager, C., 1968, Proc. IAU Symp. No. 35 on "Structure and Development of Solar Active Regions," Ed. K. O. Kiepenheuer (Publ., R. Reidel, Dordrecht-Holland), p. 602.

de Jager, C., 1969, COSPAR Symp. on "Solar Flares and Space Research," Ed. C. de Jager and Z. Švestka (Publ., North Holland Publ. C., Amsterdam), p. 1.

de Jager, C., 1975, Solar Phys., 40, 133.

de Mastus, H. L., Wagner, W., and Robinson, R. D., 1972, Proc. of the Conference on "Flare Produced Shock Waves in the Corona" (in press).

Dezsö, L., Gerlei, O., Kovács, Á., 1968, Proc. IAU Symposium No. 35 on the "Structure and Development of Solar Active Regions," Ed. K. O. Kiepenheuer (Publ., D. Reidel Co., Dordrecht-Holland), p. 70.

Dodson, H. W., 1958, Proc. IRE, 46, No. 1, 149.

Dodson, H. W., 1961, Proc. Nat. Acad. of Sci., 47, No. 7, 901.

Dodson, H. W., 1969, 1QSY 3, paper 21, p. 154.

Dodson, H. W., and Hedeman, E. R., 1952, "The Observatory," 72, 30.

Dodson, H. W., and Hedeman, E. R., 1956, Mon. Not. Roy. Astron. Soc., 116, No. 4, 428.

Dodson, H. W., and Hedeman, E. R., 1957, Astrophys. J., 125, 827.

Dodson, H. W., and Hedeman, E. R., 1960, Astron. J., 65, 51.

Dodson, H. W., and Hedeman, E. R., 1961a, "McMath Observatory Working Lists of Flares and Daily Flare Index for IGY-1959," IGY Solar Activity Report Series No. 15, HAO (Publ., Boulder, Colorado).

Dodson, H. W., and Hedeman, E. R., 1961b, Arkiv Geofysik., 3, 469.

Dodson, H. W., and Hedeman, E. R., 1964, Proc. "AAS-NASA Symposium on the Physics of Solar Flares," Ed. W. N. Hess, NASA SP-50 (Publ., National Aeronautics and Space Administration, Washington, D.C.), p. 15.

Dodson, H. W., and Hedeman, E. R., 1968, Proc. of IAU Symp. No. 35 on the "Structure and Development of Solar Active Regions," Ed. K. O. Kiepenheuer (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 56.

Dodson, H. W., and Hedeman, E. R., 1970, Solar Phys., 13, 401.

Dodson, H. W., and Hedeman, E. R., 1971, "An Experimental Comprehensive Flare Index and Its Derivation for 'Major' Flares. 1955-1969," Report UAG-14, Solar World Data Centre A (Publ., NOAA, Boulder, Colorado).

Dodson, H. W., Hedeman, E. R., and de Miceli, M. R., 1972, Solar Phys., 23, 360.

Dodson, H. W., Hedeman, E. R., and Mohler, O. C., 1973, "Comparison of Activity in Solar Cycles 18, 19 and 20." Invited paper presented at Symposium on Solar-Terrestrial Phenomena for Cycles 18-20, AGU Fall Annual Meeting, December 12, 1973 (private communication).

Dodson, H. W., Hedeman, E. R., and Owren, L., 1953, Astrophys. J., 118, 169.

Dolfus, A., 1956, Rev. d'Optique, 35, 539.

Donnelly, R. F., 1968, "Early Detection of a Solar Flare: A Study of X-Ray, Extreme Ultraviolet, Hα and Solar Radio Emission from Solar Flares," ESSA Technical Report ERL 81-SDL, 2, July (U.S. Govt. Printing Office, Washington, D.C.).

Dulk, G. A., and Nelson, G. J., 1973, Proc. Astron. Soc. Australia, 2, No. 4, p. 211.

Dvoryashin, A. S., Levitskii, L. S., Pankratov, A. K., 1961, Soviet Astron., 5, p. 311.

Earl, J. A., 1961, J. Geophys. Res., 66, 3095.

Ehmert, A. H. E., Pfotzer, G., Enger, C. D., and Brown, R. R., 1960, J. Geophys. Res., 65, 2685.

Elgarøy, Ø., 1977, "Solar Noise Storms," Internat. Series in Natural Philosophy, Vol. 90 (Publ., Pergamon Press).

Ellison, M. A., 1949, Mon. Not. Roy. Astron. Soc., 109, 3.

Ellison, M. A., 1950, Publ. Roy. Observatory Edinburgh, Vol. I, No. 4, 53.

Ellison, M. A., 1957, Trans. Internat. Ast. Union, 9, 146.

Ellison, M. A., 1963, Planet. Space Sci., II, 597.

Ellison, M. A., McKenna, S. M. P., and Reid, J. H., 1960a, The Observatory, 80, 149.

Ellison, M. A., McKenna, S. M. P., and Reid, J. H., 1960b, "Light Curves of 30 Solar Flares in Relation to Sudden Ionospheric Disturbances," Dunsink Observatory Publications, 1, No. 1, p. 3.

Ellison, M. A., McKenna, S. M. P., and Reid, J. H., 1960c, "The 3+Flare of 1960 June 1 and Its Influence on the Hα Striation Pattern," Dunsink Observatory Publications, 1, No. 2, p. 39.

Ellison, M. A., McKenna, S. M. P., and Reid, J. H., 1961a, "Cosmic Ray Flares," Dunsink Observatory Publications, 1, No. 3, p. 54.

Ellison, M. A., McKenna, S. M. P., and Reid, J. H., 1961b, Mon. Not. Roy. Ast. Soc., 122, 491.

Ellison, M. A., McKenna, S. M. P., and Reid, J. H., 1962, Mon. Not. Roy. Ast. Soc., 124, 263.

Enome, S., and Tanaka, H., 1971, Proc. of IAU Symposium 43 on "Solar Magnetic Fields" (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 413.

Erickson, W. C., 1962, General Dynamics/Astrophysics Report, ERR-AN.233.

Erickson, W. C., 1963, J. Geophys. Res., 68, 3169.

Fainberg, J., and Stone, R. G., 1971, Solar Phys., 17, 392.

Falciani, R., Landini, M., Righini, A., and Rigutti, M., 1968, Proc. IAU Symp. No. 35 on the "Structure and Development of Solar Active Regions," Ed. K. O. Kiepenheuer (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 451.

Fokker, A. D., 1957, Document for Comm. 5, URSI Meeting, Boulder.

Fokker, A., 1960, Doctoral Thesis, University of Leiden.

Fokker, A. D., 1961, Rendiconti SIF., 12, 385.

Fokker, A. D., 1963, Space Sci., Rev., 2, 70.

Fokker, A. D., and Roosen, J., 1961, Bull. Astron. Inst. Netherl., 16, 86.

Frost, K. J., and Dennis, B. R., 1971, Astrophys. J., 165, 655.

Ghielmetti, H. S., 1961, J. Geophys. Res., 66, 1611.

Giovanelli, R. G., 1939, Astrophys. J., 89, 555.

Giovanelli, R. G., 1958, Australian J. Phys., 11, 350.

Giovanelli, R. G., 1959, Proc. of the Paris Symposium on "Radio Astronomy," Ed. R. N. Bracewell (Publ., Stanford University Press, Stanford), p. 214.

Giovanelli, R. G., and McCabe, M. K., 1958, Australian J. Phys., 11, 191.

Gopasyuk, S. I., and Ogir, M. G., 1963, Izv. Krim. Astrophys. Obs., 30, 185.

Gopasyuk, S. I., Ogir, M. B., Severny, A. B., and Shaposhnikova, E. F., 1963, Publ. Crim. Astrophys. Obs., 30, 15.

Guidice, D. A., and Castelli, J. P., 1973, Proc. of the Symposium on "High Energy Solar Phenomena on the Sun," NASA SP-342 (Publ., National Aeronautics and Space Administration, Washington, D.C.), p. 87.

Hale, G. E., and Nicholson, S. B., 1938, Carnegie Inst., Wash., Publ. No. 498.

Hakura, Y., and Goh, T., 1961, Proc. 2nd. Internat. Space Sci. Symp. "Space Research II," Ed. H. C. van de Hulst, C. de Jager and A. F. Moore (Publ., North Holland Publ. Co., Amsterdam), p. 803.

Hansen, R. T., Hansen, S. F., and Garcia, C., 1972, Proc. of the Conf. of "Flare-Produced Shock Waves in the Corona" (in press).

Harvey, K. L., Livingston, W. D., Harvey, J. W., and Slaughter, C. D., 1971, Proc. IAU Symp. No. 43 on "Solar Magnetic Fields," Ed. R. Howard (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 422.

Hatanaka, T., and Moriyama, F., 1952, Rep. Ionosph. Res., Japan, 6, 99.

Haurwitz, M. W., 1962, J. Geophys. Res., 67, 2979.

Hey, J. S., 1955, Mon. Not. Roy. Astron. Soc., 115, 605.

Hey, J. S., Parsons, S. J., and Phillips, J. W., 1948, Mon. Not. Roy. Astron. Soc., 108, 354.

Howard, R., 1963, Astrophys. J., 138, 1312.

Howard, R., 1964, Proc. "ASSA-NASA Symp. on the Physics of Solar Flares," Ed. W. N. Hess (Publ., National Aeronautics and Space Administration, Washington, D.C.), p. 89.

Howard, R., 1967, Ann. Rev. Astron. Astrophys., 5, 1.

Howard, R., and Babcock, H. W., 1960, Astrophys. J., 132, 218.

Howard, R., Bumba, V., and Smith, S. F., 1967, "Atlas of Solar Magnetic Fields," Carnegie Institution of Washington Publications 626, Washington, D.C., p. 8.

Howard, R., Cragg, T., and Babcock, H. W., 1959, Nature, 184, 351.

Howard, R., and Severny, A., 1963a, Astrophys. J., 137, 1242.

Howard, R., and Severny, A., 1963b, Astrophys. J., 153, 367.

Hudson, H. S., Peterson, L. E., and Schwartz, D. A., 1969, Astrophys. J., 157, 389.

Hughes, M. P., and Harkness, R. L., 1963, Astrophys. J., 138, 239.

Hyder, C. L., 1967a, Solar Phys., 2, 49.

Hyder, C. L., 1967b, Solar Phys., 2, 267.

Hyder, C. L., 1968, Proc. Nobel Symp. No. IX on "Mass Motions in Solar Flares and Related Phenomena," Ed. Y. Öhman (Publ., John Wiley & Sons, Inc., New York), p. 57.

Hyder, C. L., 1973, Proc. of Symp. on "High Energy Phenomena on the Sun," NASA SP-342 (Publ. National Aeronautics and Space Administration, Washington, D.C.), p. 19.

Janssens, T. J., 1972, Solar Phys., 27, 149.

Jefferies, J. T., and Orrall, F. Q., 1964, Proc. "AAS-NASA Symp. on the Physics of Solar Flares," NASA SP-50, Ed. W. N. Hess (Publ., National Aeronautics and Space Administration, Washington, D.C.), p. 71.

Jefferies, J. T., and Orrall, F. Q., 1965, Astrophys. J., 141, 519.

Jonah, F. C., Dodson, H. W., and Hedeman, E. R., 1965, "Solar Activity Catalogue, Vol. 4, Catalogue of Solar Activity During 1959," Rept. No. 00650, LTV (Publ., Aerospace Corporation, Dallas, Texas).

Kahle, A. B., 1961, Univ. of Alaska, Geophys. Rep., R-127.

Kahle, A. B., 1962, Univ. of Alaska, Geophys. Inst. Sci. Report No. 2.

Kahler, S. W., 1972, Solar Phys., 25, 435.

Kai, K., 1970, Solar Phys., 11, 456.

Kai, K., and Sekiguchi, H., 1973, Proc. Ast. Soc. Australia, 2, 217.

Kakinuma, T., Yamashita, T., and Enome, S., 1969, Proc. Res. Inst. Atm., Hagoya Univ., Japan, 16, 127.

Kane, S. R., 1972, Solar Phys., 27, 174.

Kane, S. R., Kreplin, R. W., Martres, M. J., Pick, M., and Soru-Escaut, I., 1974, Solar Phys., 38, 483.

Kendall, M. G., 1952, "The Advanced Theory of Statistics," C. Griffin & Co., Ltd., London, Ch. 13.

Kiepenheuer, K. O., 1968, Proc. IAU Symp. No. 35 on the "Structure and Development of Solar Active Regions," Ed. K. O. Kiepenheuer (Publ., D. Reidel, Dordrecht-Holland), p. 3.

Kelczek, J., 1953, Bull. Astron. Inst., Czech., 4, 9.

Kleczek, J., 1963, "The Solar Corona," Ed. J. Evans (Publ., Academic Press, New York), p. 155.

Kleczek, J., and Olmr, J., 1967, Bull. Astron. Inst. Czech., 18, 68.

Kleczek, J., Olmr, J., and Krüger, A., 1968, Proc. IAU Symp. No. 35 on the "Structure and Development of Solar Active Regions," Ed. K. O. Kiepenheuer (Publ., D. Reidel, Dordrecht-Holland), p. 594.

Kopecký, M., and Krivský, L., 1966, Bull. Astron. Inst. Czech., 17, 360.

Krieger, A. S., Vaiana, G. S., and Van Speybroeck, L. P., 1971, Proc. of IAU Symp. No. 43 on "Solar Magnetic Fields" (Publ., D. Reidel, Dordrecht-Holland), p. 397.

Křivský, L., and Obridko, V., 1969, Solar Phys., 6, 418.

Kuiper, T. B. H., 1973, Proc. of the Symp. on "High Energy Phenomena on the Sun," NASA SP-342 (Publ., National Aeronautics and Space Administration, Washington, D.C.), p. 540.

Kuiper, T. B. H., and Pasachoff, J. M., 1973, Solar Phys., 28, 187.

Kundu, M., 1962, J. Phys. Soc., Japan, 17-AII, 259.

Kundu, M. R., 1965, "Solar Radio Astronomy," Vol. 2, The University of Michigan Radio Astronomy Observatory Report No. 64-4 (Publ., Interscience, New York), p. 661.

Kundu, M. R., 1973, Proc. of the Symp. on "High Energy Phenomena on the Sun," NASA SP-342 (Publ., National Aeronautics and Space Administration, Washington, D.C.), p. 104.

Künzel, H., 1960, Astron. Nachr., 285, 271.

Kuperus, M., and Tandberg-Hanssen, E., 1967, Solar Phys., 2, 39.

Landini, M., Russo, D., and Tagliaferri, G. L., 1965, Space Res., 6, 1041.

Leblanc, Y., 1973, Astrophys. Ltrs., 14, 41.

Leblanc, Y., Kuiper, T. B. H., and Hansen, S., 1974, "Coronal Density Structures in Regions of Type III Activity," Proc. of IAU Symp. No. 57, on "Coronal Disturbances" held at Surfer's Paradise, Australia, September 1973 (in press).

Leighton, R. B., 1959, Astrophys. J., 130, 366.

Le Squeren, A. M., 1963, Ann Astrophys., 26, 97.

Leinbach, H., and Reid, G. C., 1960, Proc. Helsinki Symp. on "The July 1959 Events and Assoc. Phenomena," Publ., Union Géodesique et Géophysique Internationale Monographie No. 7 (Imprimé par l'Institut Géographique National, Paris), p. 145.

Lin, R. P., 1970a, Solar Phys., 12, 209.

Lin, R. P., 1970b, Solar Phys., 12, 266.

Lin, R. P., 1973a, Space Sciences Lab., Series 14, Issue 42.

Lin, R. P., 1973b, Proc. of the Symp. on "High Energy Phenomena on the Sun," NASA SP-342 (Publ., National Aeronautics and Space Administration, Washington, D.C.), p. 439.

Lin, R. P., 1974a, Space Sci. Rev., 16, 189.

Lin, R. P., 1974b, "Fast Electrons in Small Solar Flares," Proc. IAU (COSPAR), Symp. No. 68, "Solar X, $\gamma$ and EUV Radiation" held in Buenos Aires, Argentina, June, 1974 (in press).

Lin, R. P., and Anderson, K. A., 1967a, Solar Phys., 1, 446.

Lin, R. P., and Anderson, K. A., 1967b, Solar Phys., 4, 33.

Lin, R. P., Evans, L. G., and Fainberg, J., 1973, Astrophys. Ltrs., 14, 191.

Lincoln, V., "List of Sub-Flares Reported to World Data Centre A (private communication).

Livingston, W. C., 1974, "Flare Related Magnetic Field Dynamics," Ed. Y. Nakagawa and D. M. Rust (Publ., Natl. Ctr. Atmos. Res., Boulder, Colorado).

Lockwood, J. A., 1960, J. Geophys. Res., 65, 3859.

Loughhead, R. E., Roberts, J. A., and McCabe, M. K., 1957, Australia J. Phys., 10, 483.

Maeda, H., Sakurai, K., Ondoh, T., and Yamamoto, M., 1962, Ann. Geophys., 18, 305.

Maligne, A. M., 1960, Ann. d'Astrophys., 23, 574.

Maligne, A. M., 1963, Ann. D'Astrophys., 26, 97.

Malitson, H., 1963, "Solar Proton Manual," Ed. F. B. McDonald, NASA Technical Report R-169, 109.

Malitson, H. H., and Erickson, W. C., 1966, Astrophys. J., 144, 337.

Malville, J. M., 1961, "Studies of Fast-Drift Radio Bursts and Related Phenomena," Doctoral Thesis, University of Colorado.

Malville, J. M., 1962, Astrophys. J., 135, 834.

Malville, J. M., and Tandberg-Hanssen, E., 1969, Solar Phys., 6, 278.

Martin, S. F., and Ramsey, H. E., 1972, "Solar Activity Observations and Predictions," Ed. P. S. McIntosh and M. Dryer (Publ., MIT Press, Cambridge, Mass.), p. 371.

Martres, M. J., 1968, Proc. IAU Symp. No. 35 on the "Structure and Development of Solar Active Regions," Ed. K. O. Kiepenheuer (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 25.

Martres, M. J., 1970, Solar Phys., 11, 258.

Martres, M. J., Michard, R., and Soru-Iscovici, I., 1966a, Ann d'Astrophys., 29, 245.

Martres, M. J., Michard, R., and Soru-Iscovici, I., 1966b, Ann d'Astrophys., 29, 249.

Martres, M. J., Michard, R., Soru-Iscovici, I., and Tsap, T., 1968a, Proc. IAU Symp. No. 35 on the "Structure and Development of Solar Active Regions," Ed. K. O. Kipenheuer (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 318.

Martres, M. J., Michard, R., Soru-Iscovici, I., and Tsap, T., 1968b, Solar Phys., 5, 187.

Martres, M. J., and Pick, M., 1962, Ann d'Astrophys., 25, 293.

Martres, M. J., Pick, M., Soru-Escuat, I., and Axisa, F., 1972, Nature (Physical Science), 236, 63, p. 25.

Matsuura, O. T., and Nave, M. F. F., 1971, Solar Phys., 16, 417.

Maxwell, A., Howard, III, W. E., and Garmire, G., 1959, "Solar Radio Interference at 125, 200, 425, 550 Mc/s," USAF Rome Air Development Centre, Scientific Report No. 14, AF 19(604)-1394.

Maxwell, A., Hughes, M. P., and Thompson, A. R., 1963, J. Geophys. Res., 68, 1347.

May, T. C., 1961, Tech. Report CR-36, Univ. of Minnesota (April).

Mayfield, E. B., 1971, Proc. IAU Symp. No. 43 on "Solar Magnetic Fields," Ed. R. Howard (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 376.

Melrose, D. B., 1973, Proc. Astronom. Soc., Australia, 2, 208.

Menzel, D. H., 1960, Astron. J., 65, 494.

Menzel, D. H., 1961, Publ. Astron. Soc., Pacific, 73, 194.

Meyer, P., 1960, J. Geophys. Res., 65, 3881.

Mercier, C., 1973, Solar Phys., 33, 177.

Mercier, C., 1974, Solar Phys., 39, 193.

Michalitsanos, A. G., and Kupferman, P., 1973, Pre-print BBSO No. 0138 (Publ., Big Bear Solar Observatory, Calif. Inst. Techn.).

Michard, R., 1971, Proc. IAU Symp. on "Solar Magnetic Fields," Ed. R. Howard (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 359.

Michard, R., Mouradian, Z., and Semel, M., 1961, Ann d'Astrophys., 24, 54.

Mitra, A. P., 1974, "Ionospheric Effects of Solar Flares," Astrophys. and Space Sci. Library, Vol. 46 (Publ., D. Reidel - Holland/Boston).

Moreton, G. E., 1960, Astrophys. J., 65, 494.

Moreton, G. E., 1964, Proc. "AAS-NASA Symp. on the Physics of Solar Flares," NASA SP-50, Ed. W. N. Hess (Publ., National Aeronautics and Space Administration, Washington, D.C.), p. 209.

Moreton, G. E., and Severny, A. B., 1966, Astron. J., 71, 172.

Moreton, G. E., and Severny, A. B., 1968, Solar Phys., 3, 282.

Morimoto, M., 1963, Ann Tokyo Astron. Obs., 8, 125.

Morimoto, M., 1964, Publ. Astron. Soc., Japan, 16, 163.

Morimoto, M., and Kai, K., 1961, Publ. Astron. Soc., Japan, 13, 294.

McCracken, K. G., and Palmeira, R. A. R., 1960, J. Geophys. Res., 65, 2673.

McDonald, F. B., 1963, "Solar Proton Manual," NASA TRR-169, Ed. F. B. McDonald (Publ., National Aeronautics and Space Adminsitration, Washington, D.C.).

McIntosh, P. S., 1969, World Data Centre A., Report UAG-5 (Publ., ESSA, Boulder, Colorado), p. 14.

McIntosh, P. S., 1970, World Data Centre A, Report UAG-8, Part I (Publ., ESSA, Boulder, Colorado), p. 22.

McIntosh, P. S., and Sawyer, C., 1969, Annals of the IQSY, 3 (Publ., MIT Press), p. 169.

McKenna, S. M. P., 1965, Astrophys. J., 70, 684.

McKenna, S. M. P., 1966, The Observatory, 86, No. 954, 207.

McKenna, S. M. P., 1967, Astrophys. J., 150, 1087.

McKenna-Lawlor, S. M. P., 1968, Astrophys. J., 153, 367.

McKenna-Lawlor, S. M. P., 1970, Astrophys. J., 159, 51.

McKenna-Lawlor, S. M. P., 1977, Irish Astron. J., Vol. 13, No. 3/4, p. 77.

McKenna-Lawlor, S. M. P., 1978, "Mass Ejections Accompanying the Flare of September 05, 1973," Report to the Second Skylab Workshop.

McKenna-Lawlor, S. M. P., 1979, Proc. Conference on Solar-Terrestrial Predictions," Ed. R. F. Donnelly (in press).

McKenna-Lawlor, S. M. P., and Martin, S. F., 1979, "Solar Flares: Proc. Second Skylab Workshop," Ed. P. Sturrock (Publ., Colorado University Press, Boulder), Appendix B (in press).

McKenna-Lawlor, S. M. P., and Smerd, S. (in press).

McKenzie, D. L., and Peterson, L. E., 1973, Bull. AAS, 3, 340.

McLean, D. J., 1969, Proc. Astron. Soc., Australia, 1, 188.

McLean, D. J., 1970, Proc. Astron. Soc., Australia, 1, 315.

McLean, D. J., and Sheridan, K. V., 1972, Solar Phys., 26, 176.

McMath, R. R., Mohler, O. C., and Dodson, H. W., 1960, Proc. Nat. Acad. Sci., 46, 165.

Nagata, T., Hakura, Y., and Goh, T., 1960, "Symp. on the July 1959 Events and Associated Phenomena," Helsinki, Union Géodesique et Géophysique Internationale, Monographie No. 7 (Imprimé par l'Institut Géographique National, Paris), p. 135.

Nagata, T., and Kodoma, M., 1960, "Symp. on the July 1959 Events and Assoc. Phenomena," Helsinki, Union Géodesique et Géophysique Internationale, Monographie No. 7 (Imprimé par l'Institut Géographique National, Paris), p. 28.

Nakagawa, Y., and Hyder, C. L., 1969, Environ. Res. Paper 320, AFCRL-70-0273 (Publ., Air Force Cambridge Res. Centre, Bedford, Mass., USA).

Nakagawa, Y., Wu, S. T., and Han, S. M., 1973a, Solar Phys., 30, 111.

Nakagawa, Y., Raadu, M. A., and Harvey, J. W., 1973b, Solar Phys., 30, 321.

Neupert, W. M., 1969, Ann. Rev. Astron. Astrophys., 7, 121.

Neupert, W. M., Thomas, R. J., and Chapman, R. D., 1974, Solar Phys., 34, 349.

Newkirk, G., 1969, Proc. of Symp. on "Radio Astronomy," Ed. R. N. Bracewell (Publ., Stanford Univ. Press, Stanford, USA), p. 149.

Newkirk, G., 1961, Astrophys. J., 133, 983.

Newkirk, G., 1967, Ann. Rev. Astron. Astrophys., 5, 213.

Newkirk, G., 1971, Proc. IAU Symp. No. 43 on "Solar Magnetic Fields," Ed. R. Howard (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 547.

Neylan, A. A.; 1959, Australian, J. Phys., 12, 399.

Obayashi, T., and Hakura, Y., 1960, Rep. Ionoph. Space Res., Japan, 14, 1.

Ortner, J., Egeland, A., and Hultqvist, B., 1960 Trans. Inst. Radio Eng. AP-8, 621.

Ortner, J., Hultqvist, B., Brown, R. R., Hartz, T. R., Hold, O., Landmark, B., Hook, J. L., and Leinbach, H., 1962, J. Geophys. Res., 67, 4169.

Palmer, I. D., and Lin, R. P., 1972, Proc. Astronom. Soc. Aust., 2, 101.

Payne-Scott, R., and Little, A. G., 1951, Aust. J. Phys., A4, 508.

Payne-Scott, R., and Little, A. G., 1952, Aust. J. Sci. Res., A5, 32.

Pick, M., 1961, Ann d'Astrophys., 24, 183.

Pisharoty, P. R., and Srivastava, B. J., 1962, J. Geophys. Res., 67, 2189.

Pneuman, G. W., 1968, Solar Phys., 3, 578.

Pneuman, G. W., 1969, Solar Phys., 6, 255.

Pomerantz, M. A., and Duggal, S. P., 1973, Nature, 241, 331.

Pomerantz, M. A., and Duggal, S. P., 1974a, J. Geophys. Res., 79, 913.

Pomerantz, M. A., and Duggal, S. P., 1974b, Rev. Geophys. and Space Phys., 12, 343.

Prata, S. W., 1971, Solar Phys., 19, 92.

Priest, E. R., and Heyvaerts, J., 1974, Solar Phys., 36, 433.

Priest, E. R., and Smith, D. F., 1972, Astrophys. Ltrs., 12, 25.

Proceedings of the "Helsinki Symp. on the July 1959 Events and Assoc. Phenomena," 1960, Union Géodesique et Géophysique Internationale, Monographie No. 7 (Imprimé par l'Institut Géographique National, Paris).

Quarterly Bulletin of "Solar Activity" (Publ., Zürich, 1959).

Quenby, J. J., and Webber, W. R., 1959, Phil. Mag., 4, 90.

Rabben, H. H., 1960, Zs. f. Ap. 49, 95.

Ramaty, R., Kozlovsky, B., and Lingenfelter, R. E., 1974, X-660-74-368, GSFC Preprint.

Ramsey, H. E., and Smith, S. F., 1965, Astrophys. J., 70, 688.

Reid, J. H., 1963, "A Study of Regions Where Important Solar Flares Occur," Dunsink Observatory Publ. I, No. 4, p. 91.

Reid, G. C., and Leinbach, H., 1959, J. Geophys. Res., 64, 1801.

René-Roy, J., and Datlowe, D. W., 1974, Big Bear Solar Observatory, Preprint No. BBSO-0143 (Publ., Calif. Inst. Technology).

Report entitled "Hα Flare Classification" of the Working Committee on the Improvement in Assignment of Hα Flare Importance, submitted for consideration by Commission 10 at the XII General Assembly of the IAU, Hamburg 1964 (approved at General Assembly and circulated on behalf of the IAU).

Ribes, E., 1969, Astron. Astrophys., 2, 316.

Riddle, A. C., 1972, Proc. Astron. Soc. Aust., 2, 148.

Roberts, W., and Billings, D., 1955, Astron. J., 60, 176.

Robinson, R. D., 1977, "A Study of Metre-Wavelength Continuum Radiation from the Sun," Ph.D. Thesis, University of Colorado.

Rust, D. M., 1968, Proc. IAU Symp. No. 35 on the "Structure and Development of Solar Active Regions," Ed. K. O. Kiepenheuer (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 77.

Rust, D. M., 1972, Solar Phys., 25, 141.

Rust, D. M., 1973, Solar Phys., 33, 105.

Rust, D. M., 1975, "An Active Role for Magnetic Fields in Solar Flares," AS & E Report ASE-3788 (Publ., American Sci. and Engineering, Inc., Cambridge, Mass.).

Rust, D. M., 1976, "Proceedings of the Flare Build-up Study Workshop," Solar Phys. (in press).

Rust, D. M., and Bar, V., 1973, Solar Phys., 33, 445.

Rust, D. M., and Roy, J. R., 1975, "The Late June 1972 'CINOF' Flares," AFCRL-TR-75-0437, Special Reports, No. 193 (Publ., Air Force Cambridge Research Laboratories, Hanscom AFB, Mass.), p. 61.

Sakurai, K., 1967, Rep. Ionos. Space Res., Japan, 21, 113.

Sakurai, K., 1969, J. Geomag. Geoel., 21, 463.

Sakurai, K., 1970, Planetary Space Sci., 18, 33.

Sakurai, K., 1972, Solar Phys., 23, 142.

Sawyer, C., 1968a, Annual Review Astronom. and Astrophys., 6, 115.

Sawyer, C., 1968b, Proc. IAU Symp. No. 35 on "Structure and Development of Solar Active Regions," Ed. K. O. Kiepenheuer (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 543.

Sawyer, C., and Smith, S. F., 1970, World Data Centre A, Report UAG-9 (Publ., ESSA, Boulder, Colorado), p. 9.

Severny, A. B., 1958, Izv. Krymsk. Astrofiz. Obs., 20, 22.

Severny, A. B., 1960, Izv. Krym. Astrofiz. Obs., 22, 12.

Severny, A. B., 1964, Izv. Krym. Astrofiz. Obs., 31, 199.

Severny, A. B., 1969a, Proc. COSPAR Symp. on "Solar Flares and Space Research," Ed. C. de Jager and Z. Švestka (Publ., North Holland Publ. Co., Amsterdam), p. 38.

Severny, A. B., 1969b, Annals of the IQSY, Vol. 3 (Publ., MIT Press), p. 11.

Severny, A. B., and Steshenko, N. V., 1972, Proc. Internat. Symp. on Solar Terrestrial Physics held in Leningrad, USSR, May 1970, Gen. Ed. E. R. Dyer (Publ., D. Reidel Publ. Co., Dordrecht-Holland), Part 1, "The Sun," p. 173.

Shain, C. A., and Higgins, C. S., 1959, Australian J. Phys., 12, 357.

Shapley, A. H., and Lincoln, J. V., 1962, Annals of IGY, 16-3, 201.

Shapley, A. H., and Trotter, D., 1960, Proc. Helsinki Symp. on "The July 1959 Events and Associated Phenomena," Publ. Union Géodesique et Géophysique Internationale, Monographie No. 7 (Imprimé par l'Institut Géographique National, Paris), p. 72.

Shea, M. A., and Smart, D. F., Eds., 1974, Air Force Cambridge Research Laboratories Special Reports No. 177, AFCRL-TR-74-0271.

Shea, M. A., and Smart, D. F., 1975, Air Force Cambridge Research Laboratories Special Reports, AFCRL-TR-75-0437.

Simnett, G. M., 1971, Solar Phys., 20, 448.

Simon, P., 1962, Ann d'Astrophys., 25, 12.

Simon, G., and Leighton, R. B., 1964, Astrophys. J., 140, 1120.

Simon, P., and Švestka, Z., 1969, Annals of the IQSY, Vol. 3 (Publ., MIT Press), p. 469.

Sinno, K., 1961, J. Geomag. Geoelec., 13, 1.

Sivaraman, K. R., 1969, Solar Phys., 6, 152.

Smerd, S., 1977, "Research Activities in Radio Astronomy 1975-1977," Report prepared for Internat. Sci. Radio Union (Distributed by CSIRO Div. of Radiophysics).

Smith, D. F., and Pneuman, G. W., 1972, Solar Phys., 25, 461.

Smith, E. v P., 1962, J. Geophys. Res., 67, No. 10, 3797.

Smith, E. v P., and McIntosh, P. S., 1962, J. Geophys. Res., 67, No. 3, 1013.

Smith, H. J., 1963, Sky and Telescope, Vol. XXV, No. 1.

Smith, H. J., and Smith, E. v P., 1963, "Solar Flares" (Publ., Macmillan Co., New York).

Smith, S. F., 1971, Proc. IAU Symp. No. 43 on "Solar Magnetic Fields," Ed. R. Howard (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 323.

Smith, S. F., and Howard, R., 1968, Proc. IAU Symp. No. 35 on "Structure and Development of Solar Active Regions," Ed. K. O. Kiepenheuer (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 33.

Smith, S. F., and Ramsey, H. E., 1964, Z. Astrophys., 60, 1.

Smith, S. F., and Ramsey, H. E., 1967, Solar Phys., 2, 158.

"Solar Flares"; Proceedings of the Second Skylab Workshop, Ed. P. S. Sturrock, Colorado University Press, Boulder (in press).

"Solar Flares in Hα; New Scheme of Classification and Report to WDC (starting January 1, 1966) Amendments to IQSY Instruction Manual for Solar Activity," 1965, Distributed by IAU Commission 10.

Steshenko, N. V., 1967, Izv. Krym. Astrofiz. Obs., 37, 21.

Stewart, R. T., 1974, "Ground-Based Observations of Type III Bursts," Proc. of IAU Symp. No. 57 on "Coronal Disturbances" held at Surfer's Paradise, Australia, Sept., 1973 (in press).

Sturrock, P., and Coppi, A., 1965, Astrophys. J., 143, 3.

Sturrock, P. A., and Smith, S. M., 1968, Solar Phys., 5, 87.

Švestka, Z., 1962, Bull. Ast. Inst. Czech., 13, 190.

Švestka, Z., 1965, Advances in Astronomy and Astrophysics (Publ., Academic Press, New York), p. 318.

Švestka, Z., 1966, Bull. Astr. Inst. Czech., 17, 262.

Švestka, Z., 1968a, Proc. of IAU Symp. No. 35 on "Structure and Development of Solar Active Regions," Ed. K. O. Kiepenheuer (Publ., D. Reidel Publ. Co., Dordrecht-Hollant), p. 287.

Švestka, Z., 1968b, Proc. IAU Symp. No. 35 on "Structure and Development of Solar Active Regions," Ed. K. O. Kiepenheuer (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 513.

Švestka, Z., 1974a, Proc. of the IAU/COSPAR Conf. on "Solar X, γ and EUV Radiation" held at Buenos Aires, Argentina, June, 1974 (in press).

Švestka, Z., 1974b, "Report of the Working Group of the IAU Commission 10 on the Flare Build-Up Study" submitted to the Symp. on Solar-Terrestrial Physics, Sao Paulo, Brazil (private communication).

Švestka, Z., 1976, Reports on Astronomy Commission 10, Solar Activity (9. Solar Flares), Trans. IAU Vol. XVIA-2 (Publ., D. Reidel, Dordrecht-Holland), p. 30.

Švestka, Z., and Simon, P., 1969, Solar Phys., 10, 3.

Swarup, G., Stone, P. H., and Maxwell, A., 1960, Astrophys. J., 131, 725.

Takakaura, T., 1960a, Publ., Astron. Soc., Japan, 12, 55.

Takakura, T., 1960b, Publ., Astron. Soc., Japan, 12, 352.

Takakura, T., 1967, Solar Phys., 1, 304.

Takakura, T., 1969, Proc. of Symp. on "Solar Flares and Space Research," Ed. C. de Jager and Z. Švestka (Publ., North Holland Publ. Co., Amsterdam), p. 165.

Talmicha, A., and Takakura, T., 1963, Nature, 200, 999.

Talon, R., Vendrenne, G., Melioransky, A. S., Pissarenko, N. F., Shamolin, V. M., and Linkin, O. B., 1975, Proc. IAU Symp. No. 68 on "Solar X, Gamma and EUV-Radiation," Ed. S. R. Kane, R. P. Lin, and J. Sahade (Publ., D. Reidel, Dordrecht-Holland), p. 315.

Tanaka, K., and Nakagawa, Y., 1973, Solar Phys., 33, 187.

Tanaka, K., and Zirin, H., 1973, Proc. of the Symp. on "High Energy Phenomena on the Sun," NASA SP-342 (Publ., National Aeronautics and Space Administration, Washington, D.C.), p. 26.

Tandberg-Hanssen, E., 1973a, Earth and Extraterrestrial Sci., 2, 89.

Tandberg-Hanssen, E., 1973b, Revs. Geophys. and Space Phys., Vol. II, No. 2, p. 469.

Teske, R. G., Astron. J., 1967, 72, 832.

Teske, R. G., and Thomas, R. J., 1969, Solar Phys., 8, 348.

Teske, R. G., Soyumer, T., and Hudson, H. S., 1971, Astrophys. J., 165, 615.

Thomas, R. J., and Teske, R. G., 1971, Solar Phys., 16, 431.

Thompson, A. R., and Maxwell, A., 1960, Nature, 185, 89.

Thompson, A. R., and Maxwell, A., 1962, Astrophys. J., 136, 546.

Trotter, D. E., and Newkirk, G., 1971, Solar Phys., 20, 372.

Trotter, D. E., and Roberts, W. O., 1960, "Solar Activity Summary III," High Altitude Obs. Rept. No. 49, p. 5.

Uchida, Y., 1973, Proc. Symp. on "High Energy Phenomena on the Sun," NASA SP-342 (Publ., National Aeronautics and Space Administration, Washington, D.C.), p. 577.

Uchida, Y., Altschuler, M. D., and Newkirk, G., 1973a, Solar Phys., 28, 495.

Vaiana, G. S., and Giacconi, R., 1969, "Plasma Instabilities in Astrophysics," Ed. D. A. Tidman and D. G. Wentzel (Publ., Gordon and Breach, New York), p. 91.

Vaiana, G. S., Reidy, W. P., Zehnpfenning, I., Van Speybreech, L., and Giacconi, R., 1968, Science, 161, 564.

Vaiana, G. S., Kreiger, A. S., and Timothy, A. F., 1973, Solar Phys., 32, 81.

Valdez, J., and Altschuler, M. D., 1970, Solar Phys., 15, 446.

Van Allen, J. A., and Krimigis, S. M., 1965, J. Geophys. Res., 70, 5737.

Vorpahl, J. A., 1972, Solar Phys., 26, 397.

Vorpahl, J. A., 1973, Proc. of the Symp. on "High Energy Phenomena on the Sun," NASA SP-342 (Publ., National Aeronautics and Space Administration, Washington, D.C.), p. 221.

Vorpahl, J. A., and Zirin, H., 1972, Big Bear Solar Observatory Rep. 114.

Vrabec, D., 1971, Proc. IAU Symp. on "Solar Magnetic Fields," Ed. R. Howard (Publ., D. Reidel Publ. Co., Dordrecht-Holland), p. 329.

Waldmeier, M., 1938, Z. Astrophys., 16, 285.

Waldmeier, M., 1955, "Ergebnisse und Probleme der Sonnenforschung," 2nd Edit., Leipzig, Geest u. Portig.

Waldmeier, M., 1961, "The Sunspot-Activity in the Years 1910-1960" (Publ., Zürich Schulthess and Co. AG).

Warwick, C. S., 1955a, Astrophys. J., 121, 385.

Warwick, C. S., 1955b, Astrophys. J., 165, 655.

Warwick, C. S., 1966a, "Standardized Solar Flare Data 1959 through 1961," IGY Solar Activity Report Series No. 33, HAO, Boulder, Colorado.

Warwick, C. S., 1966b, Astrophys. J., 145, 215.

Warwick, C. S., and Haurwitz, M. W., 1962, J. Geophys. Res., 67, 1317.

Webb, D., 1979, "Solar Flares: Proc. of the Second Skylab Workshop," Ed. P. Sturrock (Publ., Colorado Univ. Press, Boulder), Appendix B (in press).

Weiss, A. A., 1965, Aust. J. Phys., 18, 167.

Weiss, A. A., and Stewart, R. T., 1965, Aust. J. Phys., 18, 143.

Whitfield, G. R., 1957, Mon. Not. Roy. Astron. Soc., 117, 680.

Wiehr, E., 1972, Solar Phys., 24, 129.

Wild, J. P., 1950, Aust. J. Sci. Res., A3, 541.

Wild, J. P., 1962, J. Phys. Soc., Japan, 17, Suppl. A-II, 249.

Wild, J. P., 1970, Proc. Astr. Soc. Austr., 1, 365.

Wild, J. P., 1971, Radiophysics Publications of CSIRO (RRP-1540). Reprinted from "Invited and Rapporteur Papers to 12th Internat. Conf. on Cosmic Rays, Hobart, Univ. Tasmania," p. 29.

Wild, J. P., 1974, "Highlights of Astronomy," Ed. G. Contopulos, IAU Copyright, p. 3.

Wild, J. P., and McReady, L. L., 1950, Aust. J. Sci. Res., A3, 387.

Wild, J. P., Roberts, J. A., and Murray, J. D., 1954, Nature, 173, 532.

Wild, J. P., Sheridan, K. V., and Neylan, A. A., 1959a, Aust. J. Phys., 12, 369.

Wild, J. P., Sheridan, K. V., and Trent, G. H., 1959b, Proc. Paris Symp. on "Radio Astronomy," Ed. R. N. Bracewell (Publ., Stanford Univ. Press, Stanford, USA), p. 176.

Wild, J. P., Smerd, S. F., and Weiss, A. A., 1963, Ann Rev. Ast. and Astrophys., Vol. I, 291.

Wild, J. P., and Smerd, S. F., 1972, Ann Rev. Astron. and Astrophys., 10, 159.

Wild, J. P., and Zirin, H., 1956, Aust. J. Phys., 9, 315.

Williams, S. E., 1948, J. R. Soc. W. Australia, 34, 17.

Winckler, J. R., 1959, "Balloon Flight Record Status Report as of 31 December 1959," Publ. School of Physics, Univ. of Minnesota.

Winckler, J. R. Bhavsar, P. D., and Peterson, L. E., 1961, J. Geophys. Res., 66, 995.

Wolbach, J. G., 1963, Smithsonian Contrib. Astrophys., 8, No. 2, 101.

Zvereva, A. M., and Severny, A. B., 1970, Izv. Krymsk. Astrofiz. Obs., 41, 97.

Zirin, H., 1966, "The Solar Atmosphere" (Publ., Blaisdell Publ. Co., London).

Zirin, H., 1970, Solar Phys., 14, 328.

Zirin, H., 1974, Vistas in Astronomy, Vol. 16, Ed. A. Beer (Publ., Pergamon Press, Oxford and New York), p. 1.

Zirin, H., Ingham, W., Hudson, H., and McKenzie, D., 1969, Solar Phys., 9, 269.

Zirin, H., and Tanaka, K., 1973, Solar Phys., 32, 173.

Zirin, H., and Werner, S., 1967, Solar Phys., 1, 66.

APPENDIX A

IMPORTANT STATIONARY PROMINENCE FLARES IN 59Q

## A1 Flaring in 59Q and Associated Activity from $18^h\ 10^m$ U.T., July 09, 1959

The Catalog of Standardized Solar Flare Data, Warwick (1966a), describes flaring in region 59Q from $18^h\ 10^m$ U.T. on July 09 to consist of one Importance 2 and five Importance 1 events. The consecutive flares are listed in Table A1-a. It is chosen in the present text to consider this protracted activity 'in toto' as a single Stationary Prominence Flare.

TABLE A1-a

Flares Reported in the "Catalog of Standardized Solar Flare Data," Warwick (1966a), to Occur in Region 59Q on July 09 from $18^h\ 10^m$ U.T.

| Date 1959 | Earliest reported beg. time U.T. | Mean beg. time U.T. | Mean max. time U.T. | Mean end. time U.T. | Latest reported end. time U.T. | Mean values of Lat.CMD | Mean corrected importance |
|---|---|---|---|---|---|---|---|
| July 09 | (1810) | 1810 | 1815 | 1830 | (>1830) | N14°,E67° | 1 |
| | (1840) | 1840 | 1856 | 1930 | (>1930) | N14°,E67° | 1 |
| | (1930) | 1931 | 1959 | 2209 | (>2320) | N18°,E67° | 2 |
| | (<2115) | 2115 | 2130 | 2155 | (>2155) | N19°,E48° | 1 |
| | (2155) | 2155 | 2230 | 2320 | (>2320) | N21°,E55° | 1 |
| | (2226) | 2226 | 2228 | 2232 | (2232) | N16°,E66° | 1 |

On disk spectroheliograms 59Q was seen on July 09 to be traversed by a diffuse cloud of absorption which terminated far to the north and south of the active region in well-defined prominences. From <$18^h\ 10^m$ U.T., a length of this suspended material stretching from flare sensitive area a to h was seen to be in emission although the brightness achieved was only of subflare intensity.

At $18^h\ 10^m$ U.T. a brilliant impulsive intensity enhancement occurred in prominence material suspended above flare sensitive area b. This brightening was accompanied by the generation of a Strong* radio burst and by simultaneous Type III and Type I events. A sudden SWF of importance class 2 began at $18^h\ 12^m$ U.T. A calcium sweep taken from $18^h\ 08^m$ - $18^h\ 12^m$ U.T. showed no special emission at b or in any other part of the active centre. Four minutes later material at b was faintly bright in calcium light.

*See the radio classification adopted in Section 6.3, p. 63.

Type III bursts were associated with brightenings in prominence material above d and g at $18^h\ 16^m$ U.T., above b alone at <$18^h\ 39^m$ U.T. and above areas b and d at $18^h\ 53^m$ U.T. A calcium sweep made from $18^h\ 50^m$ - $18^h\ 54^m$ U.T. also shows a bright 'point' in the red wing of the line immediately to the north of the main spot group at $18^h\ 53^m$ U.T. of Fig. A-1a, p. 192.

From at least $19^h\ 05^m$ U.T. (that is for approximately half an hour previous to the reported Importance 2 flare of $19^h\ 30^m$ U.T.) dark material was seen rising along the eastern edge of the bright plage containing flare sensitive areas a and j. Various minor brightenings occurred in 59Q within this same interval against a general background of centimetre wave radiation and fluctuating Type I activity. A calcium sweep taken from $19^h\ 19^m$ - $19^h\ 22^m$ U.T. shows that bright diffuse prominence material located above area d was wide in the wings of the line.

Type III associated brightenings seen above a and c at $19^h\ 33^m$ U.T. in Hα were followed at $19^h\ 36^m$ U.T. by a further Type III associated flash which included material above areas c, d, $d^I$, e, f and g. Material above b brightened at $19^h\ 38^m$ U.T. and again at $19^h\ 41^m$ U.T. A calcium sweep from $19^h\ 37^m$ - $19^h\ 40^m$ U.T. shows that flaring prominence material suspended above flare sensitive areas d-g was particularly bright and wide in the wings of the K line, see Fig. A1-a, p. 192.

By $19^h\ 42^m$ U.T. this emission had waned considerably in intensity and line-width. Note that part of this bright prominence material was apparently suspended above the position of the 'neutral line'. This is reminiscent of the various reports quoted in Section 6.4, pp. 66-68 of the generation of soft X-ray radiation within similarly located arch like structures.

CRPL reported the start of a sudden SWF at $19^h\ 43^m$ U.T. Examination of the McMath ionospheric record shows however that this event was already in progress as early at $19^h\ 40^m$ U.T. Since the start of the ionospheric event is not accurately known it cannot be determined if it ought to be associated with activity in area b alone rather than with the optically important flash at $19^h\ 36^m$.

By at least $19^h\ 44^m$ U.T., portions of dark prominence material located between two hitherto non-flaring sections of the chromospheric network within the plage gradually became relatively bright, indicating the gradual spread northward of Prominence Flaring. Specifically those parts of the prominence appearing in projection to lie directly adjacent to two bright chromospheric chains (designated in Fig. A1-a, p. 192, by the Roman Numerals I and II) achieved subflare brightness. This material, which did not appear to traverse any preexisting bright plage structure, formed two long extensions to the diffuse flaring envelope superposed above the main active region. These two extensions, hereafter called Arms 1 and 2, are shown in Fig. A1-a, p. 192, as they appeared at $20^h\ 44^m$ U.T. They were first clearly visible on spectroheliograms taken in the red wing of the calcium line. Later they became prominent in observations made at line centre. This gradual spread of activity was accompanied by Type III associated impulsive brightenings above c and j at $19^h\ 46^m$ U.T. and above a at $19^h\ 57^m$ U.T.

On a calcium sweep taken from $20^h\ 01^m$ - $20^h\ 04^m$ U.T., what was possibly a bright 'point' was visible on the blue and red sides of the line somewhat to the west of the main south polar umbra. A more conspicuous feature, however, was a length of prominence material, partly located above area b, which showed brightenings at $20^h\ 00^m$ U.T. and at $20^h\ 03^m$ U.T., the latter event associated with a Type III burst. This material comprised a well-defined brilliant feature in the red wing of the K line but at line centre was immersed in a matrix of bright emission extending northwards above the active region. Material above area e which was seen to flare in Hα at $20^h\ 00^m$ U.T. was wide in the blue wing of the calcium line but not especially conspicuous at line centre. Brightenings above a and c from $20^h\ 18^m$ - $20^h\ 19^m$ U.T. were associated with the reported onset of Type III and Type I events. (It is possible that the latter reported Type I event might in fact have been a Type V burst.)

A further possible Type III-Type V event was associated with centimetre burst associated brightenings in prominence material above areas b, c and g at $20^h\ 41^m$ - $20^h\ 43^m$ U.T. Bright material traversing b additionally extended for a considerable distance along the western boundary of that part of the suspended prominence which had previously been of only subflare brightness. This tract of material also appeared bright and wide in the blue wing of the Hα line. CRPL reported a sudden SWF of importance class 1+ from $20^h\ 40^m$ U.T. However, the McMath record shows that this commencement time is suspect since the WWV signal was still greatly depressed from the former event of $19^h\ 40^m$ U.T. Fort Belvoir observers state the starting time to be as early as $20^h\ 38^m$ and an SEA of importance class 2+ was reported to begin at $20^h\ 35^m$ U.T. Although brightenings above g and b at $20^h\ 33^m$ U.T. and at $20^h\ 36^m$ U.T., respectively, might have been associated with such 'early' ionospheric activity it is probably significant that no radio frequency emissions were associated with these events. It is plausible that the start of the ionospheric enhancement was associated with the 'Moderate' centimetre wave event of $20^h\ 42^m$ U.T.

Observers at Harvard reported a great burst of Type IV radiation from $20^h\ 44^m$ - >$24^h\ 00^m$ U.T., in the frequency range <25 - >580 MHz. A Type III event and an unclassified burst of intensity 3 from $20^h\ 45^m$ - $20^h\ 46^m$ U.T. were associated with an impulsive brightening above area h.

From about $21^h\ 09^m$ U.T., swept wavelength pictures showed that a length of chromospheric Chain 1 adjacent to the flaring prominence material comprising Arm 1 began to increase slowly in intensity until it achieved flare brightness while Arm 1 itself gradually began to fade.

The flaring observed in chromospheric Chain 1 was so spatially close to Arm 1 that a cursory examination of the small scale flare patrol records would give the erroneous impression that Arm 1 had either expanded somewhat or drifted to the position of Chain 1 before achieving flare brightness. The large scale 40' focal length calcium records however make it clear that this was not the case and that these structures were fundamentally different, comprising Stationary Prominence Flaring and Plage Flaring, respectively. In a short time, part of chromospheric Chain II bordering Arm 2 similarly brightened to flare intensity while Arm II itself gradually faded.

Minor flaring was observed above spot group 14282 from $<21^h\ 15^m$ U.T. Structure was observed in the continuum from $21^h\ 14^m$ - $22^h\ 57^m$ U.T. on the Harvard record spectrograph record. Flaring was also observed above spot group 14285 from $21^h\ 55^m$ U.T. (cf. Fig. 3.1b, p. 26). This latter activity was still conspicuous at $22^h\ 17^m$ U.T. when prominence material above area b, already bright since $<22^h\ 07^m$ U.T., exhibited several intensity fluctuations, appearing particularly brilliant circa $22^h\ 27^m$ U.T. These events may have been associated with a centimetre wave burst reported to begin on 2800 MHz at $22^h\ 18^m$ U.T., with maximum at $22^h\ 27^m$ U.T.

The McMath observations ceased at $23^h\ 30^m$ U.T. when Prominence Flaring was still in progress. Type IV radiation reported by observers at Ann Arbor from $< 22^h\ 03^m$ - $22^h\ 45^m$ U.T. and from $23^h\ 45^m$ - $24^h\ 00^m$ U.T. was also still in progress at this time. Observers at Sydney reported a 'possible' Type event in progress at $<22^h\ 59^m$ U.T. (cf. Table 6.5a, p. 87) as well as continuum radiation from $<22^h\ 59^m$ - $01^h\ 39^m$ U.T. This latter observation may be an indication that the Type IV event endured until $01^h\ 39^m$ U.T.

That part of the flare activity defined by Warwick (1966a) as an importance 2 event commencing at $19^h\ 30^m$ U.T. is associated in the "Catalog of Solar Particle Events" (1975) with an unconfirmed P.C.A. having onset at $20^h\ 00^m$ U.T. (cf. Section 6.7 and Table 6.7b, p. 90).

## A2 Stationary Prominence Flaring in 59Q from $02^h\ 05^m$ U.T., July 10, 1959

The "Catalog of Standardized Solar Flare Data," Warwick (1966a), reports an importance 3+ flare to begin in 59Q at $02^h\ 06^m$ U.T., and to show maximum at $02^h\ 36^m$ U.T. The mean ending time is given as $08^h\ 51^m$ U.T. and the latest reported ending time as $10^h\ 00^m$ U.T.

No McMath observations are available of this event but the CSM contains records obtained at the Sydney and Meudon Observatories. The flare was seen on the Sydney record to begin at $02^h\ 05^m$ U.T. with a sudden and very outstanding flash in intensity above locations c and d$^*$. By $02^h\ 06^m$ U.T. flaring was occurring above areas a-$d^I$ and by $02^h\ 09^m$ U.T., a bright band of emission appeared to stretch from area a to area h. As in the case of the Prominence Flare of the previous day, this emission traversed the underlying magnetic 'neutral line', compare Figs. 3.1c, p. 27 and A2-a, p. 193.

Type IV continuum emission was not reported in association with this event although, see the discussion in Section 6.6, p. 69, it seems likely, because of the strong single frequency radio events recorded, that some kind of Type IV emission occurred. A great 10 cm burst at $02^h\ 06^m$ U.T., duplicated at other centimetre wavelengths, coincided with the early flash phase of the Prominence

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$^*$Careful correlations made between the CSM spectroheliograms showing the development of this flare and swept wavelength records made at the McMath Tower Telescope on July 9 and 10 indicate that these brightenings took place within suspended prominence material.

Flare. A slow SWF of importance class 3+ was reported to begin at $02^h\ 00^m$ U.T. If this represents a case of an ionizing burst beginning early relative to the Hα flare (see Section 6.4, p. 66) this would associate it with the early flash phase of the flare.

From $02^h\ 08^m$ U.T. emission began to spread north westward within prominence material adjacent to chromospheric chain III. From $02^h\ 17^m$ U.T., emission also spread along chromospheric chain II. Part of the dark prominence material extending southward to terminate in a hedgerow like structure seen at the east limb on the previous day (cf. Fig. C1-c, p. 204) but projected against the disk on July 10, then became gradually relatively bright. This heralded the occurrence from $02^h\ 29^m$ U.T., of adjacently located flare emission above chromospheric chain V. A continuous band of flare brightness was not formed but the general outline of the adjacent semibright material was followed. At $02^h\ 22^m$ U.T. curved features of flare intensity developed along the eastern boundary of the main flare region and these altered greatly in appearance with time. Major bursts at decimetre and metre wavelengths, a group of Type IIIs with continuum at $02^h\ 10^m$ U.T. and a Type II event reported by Sydney in the range 22-210 MHz at $02^h\ 22^m$ U.T. occurred during this gradual development.

There was a gap in the available optical records from $05^h\ 04^m$ - $09^h\ 44^m$ U.T. Bruzek (1964b) however describes a system of loop type prominences seen in absorption from $05^h\ 04^m$ - $09^h\ 00^m$ U.T. which in the main were rooted on the one side in chromospheric emission above chain II and at the other in emission above the main south polar umbrae in group 14284. These loops were visible out to +6A° (cf. Fig. 4 of Bruzek's paper).

By $09^h\ 44^m$ U.T., the flare was nearly over but part of chromospheric chain VI had flared in the interim and formed a conspicuous bright feature that faded slowly. It is uncertain if this latter brightening represented Plage or Prominence Flaring.

As indicated in Section 6.7, this complex importance 3+ flare was associated with the confirmed ejection of solar protons. Full details of the various particle emissions detected are summarized in tables 6.7 (a-c), pp. 88-91.

## A3 Stationary Prominence Flaring in 59Q from <$03^h\ 33^m$ U.T. on July 14, 1959

The catalog of Standardized Solar Flare Data, Warwick (1966a), reports an importance 3+ flare to begin in 59Q at $03^h\ 19^m$ U.T. and to show maximum at $03^h\ 56^m$ U.T. The mean ending time is given as $09^h\ 07^m$ U.T., and the latest reported ending time as >$11^h\ 45^m$ U.T.

No McMath observations are available of this event but the CSM includes a spectroheliogram obtained at Sydney at $03^h\ 27^m$ U.T. which shows that by this time plage areas c and d had brightened. A cloud gap followed immediately but, by $03^h\ 33^m$ U.T., bright diffuse emission, interpreted to represent Stationary Prominence Flaring, was seen to extend from at least areas $c^I$-$d^I$ to the north and as far as S23 to the south of the magnetic 'neutral line'. Compare Fig. 3.1g, p. 31, with Fig. A3-a, p. 194.

Thereafter Prominence Flaring spread gradually along part of chromospheric chains III and V. At $03^h\ 39^m$ U.T. material above area a brightened and extended westwards. There was another cloud gap from $03^h\ 47^m$ - $04^h\ 13^m$ U.T. By this latter time, prominence material above chromospheric chains II and IV could be identified in emission and also material immediately to the north of the more westerly extension to chromospheric chain III. As in the case of the previously described flares of July 09 and July 10, Stationary Prominence Flaring was located above the position of the 'neutral line' in Mt. Wilson group 14284.

At centimetre wavelengths, burst activity commenced at about $03^h\ 30^m$ U.T. and a sudden SWF began at $03^h\ 28^m$ U.T. These events appeared to be associated with the early flash phase of the flare. Bursts at decimetre and metre wavelengths at $03^h\ 37^m$ U.T. occurred during the developing part of the flare, nearly coincidently with the start of a Type II burst recorded from $03^h\ 38^m$ U.T. at Sydney (cf. Table 6.5a, p. 87). Type IV emission was reported from $04^h\ 01^m$ U.T.

There was another gap in the optical record from $04^h\ 15^m$ - $07^h\ 09^m$ U.T. Bruzek (1964b), however, reports a system of loop type prominences seen in absorption from $<05^h\ 30^m$ - $09^h\ 00^m$ U.T. These loops were rooted in flare emission above chromospheric chains III and IV on the one side and in flare emission above Mt. Wilson group 14284 on the other. They would be observed out to at least +6A in Hα (cf. Fig. 3 of Bruzek's paper). The dark loops were also recorded on McMath spectroheliograms taken from $07^h\ 10^m$ U.T., where they were seen to occupy a position previously covered by bright flaring material, compare drawings of Fig. A3-a. The major flare thereafter faded gradually but Type IV radiation was still in progress, although it was somewhat reduced in intensity, when observations ceased at Sydney at $06^h\ 10^m$ U.T.

This importance 3+ flare was also associated with the confirmed ejection of solar protons and details of the particle emissions detected are summarized in Tables 6.7 (a-c), pp. 89-91.

### A4 <u>Stationary Prominence Flaring in 59Q at $11^h\ 45^m$ U.T., at $17^h\ 34^m$ U.T., and at $22^h\ 24^m$ U.T., July 14, 1959</u>

A feature of July 14 was important flaring, associated concomitantly with minor umbrae in a penumbral extension to the southeast of Mt. Wilson group 14284, and with other minor umbrae located immediately to the south of this magnetic feature but on the other side of the 'neutral line' (see details in Section 7).

Three Stationary Prominence Flares were identified on this day within this part of the active region. Prominence flaring commenced on these individual occasions at $11^h\ 45^m$ U.T., at $17^h\ 34^m$ U.T. and at $22^h\ 24^m$ U.T., respectively (cf. Table 6.3a, p. 80). Unfortunately, swept wavelength observations are only available during the second of these events. Reports concerning these various flares which appeared in the Catalog of Standardized Solar Flare Data, Warwick (1966a), are contained in Table A4-a.

Table A4-a

Flares Reported to Occur in 59Q on July 14, 1959, by Warwick (1966a)
Which Formed Part of 3 Stationary Prominence Flares Identified in 59Q
to the South of Mt. Wilson Group 14284

| Date 1959 | Earliest reported beg. time U.T. | Mean beg. time U.T. | Mean max. time U.T. | Mean end. time U.T. | Latest reported end. time U.T. | Mean values of Lat.CMD | Mean corrected importance |
|---|---|---|---|---|---|---|---|
| July 14 | 1140 | 1140 | 1152 | 1204 | 1215 | N12°,E06° | 1- |
| | 1730 | 1730 | 1737 | 1756 | 1757 | N13°,E02° | 1 |
| | 2203 | 2204 | 2229 | 2255 | 2256 | N13°,W02° | 1 |

The first of these flares was seen, using the McMath SECASI record, to commence at $11^h\ 41^m$ U.T. with minor brightenings on either side of the neutral line at q, $q^{II}$ and $s_I$, respectively. Only the radio spectrograph at Ann Arbor was in operation at this time. No swept frequency event was reported but at 808 MHz a burst lasting $6^m$ was recorded at $11^h\ 41.5^m$.

At $11^h\ 45^m$ U.T. impulsive intensity increases on either side of the 'neutral' line at $q^{II}$ and $s_I$, followed by further brightenings in q and $q^I$ at $11^h\ 47^m$ U.T., were bright and diffuse and appeared to be located within suspended prominence material. These latter brightenings were accompanied at centimetre wavelengths by a centimetre wave burst lasting $3^m$ only. No ionospheric event was reported in association with this flare.

Swept wavelength observations in Hα were available from $13^h\ 03^m$ U.T. A series taken at this latter time from $13^h\ 03^m$ - $13^h\ 06^m$ U.T. shows dark material rising and falling immediately to the east of flare sensitive area $s_I$. By $13^h\ 57^m$ U.T. dark material was also seen falling at the location of flare sensitive area q. Further swept wavelength series in Hα taken between $16^h\ 04^m$ U.T. and $16^h\ 25^m$ U.T. show a general increase in prominence activity to the south of the active region with material rising and falling in several areas simultaneously (cf. Figs. 3.1g, p. 31, and A4-a, p. 195).

At $17^h\ 31^m$ U.T. minor brightenings in $q^{II}$ and $s_I$ prefaced the start of the Prominence Flare. This commenced at $17^h\ 34^m$ U.T. with brightenings in prominence material above p and q, followed by $17^h\ 35^m$ U.T. by a brightening above $q^I$ and at $17^h\ 36^m$ U.T. by brightenings above $q^{IV}$ and $r^I$. A swept wavelength series in calcium taken from $17^h\ 39^m$ - $17^h\ 42^m$ U.T. shows that a length of prominence material located directly to the south of area q and above the magnetic 'neutral line' was broad in the red wing of the line. Other material, broad in the red wing of calcium, was located above p,$q^I$ and $q^{II}$.

A 'Strong' radio burst as well as Type III and Type I emissions (the latter probably constituting a Type V burst) began between $17^h\ 33^m$ - $17^h\ 35^m$. A sudden SWF was also reported from $17^h\ 35^m$ U.T.

At line centre, a clearly defined funnel shaped absorption feature (cf. Fig. A4-a) defined a trajectory along which dark material was seen to be ejected on several occasions throughout the day from the vicinity of the flare active region. From about $22^h 10^m$ U.T. this absorption feature became suddenly darker as such an ejection took place along its 'stem'. At this time various minor brightenings were occurring, probably in the plage, above minor umbrae to the south of group 14284. At $22^h 24^m$ U.T. however, in addition to such minor intensity increases at $q^I$, $q^{II}$ and $s^I$, a sudden brightening occurred directly within the dark cone of suspended prominence material above an area designated on succeeding days by the letter s, cf. Fig. A-4a. This event was followed by the sudden disappearance of the ambient dark absorption. At $22^h 27^m$ U.T. a bright extensive flash took place in prominence material located above p, q, $q^I$, $q^{II}$ and $q^V$ on the other side of the magnetic 'neutral line'. From $22^h 28^m$ - $22^h 29^m$ U.T. further prominence material brightened above $s_I$ and $q^{IV}$, respectively. Flaring within suspended material at p, q, $q^I$, $q^{II}$ and $s^I$ endured long after $22^h 28^m$ U.T. when emission had faded above area s itself. No swept wavelength records are available of this brightening.

Strong radio bursts and Type III and Type I events (the latter probably being associated with the generation of a Type V burst) began simultaneously at $22^h 23^m$ U.T. These radio commencements and the start of an importance class 1 SEA from $22^h 25^m$ U.T. were probably associated with the start of prominence flaring and the disparition brusque at location s.

## A5 Stationary Prominence Flaring in 59Q at $12^h 55^m$ U.T., July 15, 1959

The "Catalog of Standardized Solar Flare Data," Warwick (1966a) reports an importance 1+ flare to commence in 59Q between $12^h 51^m$ U.T. (earliest reported beginning time) and $12^h 55^m$ U.T. (mean beginning time). The mean maximum time was estimated to be $13^h 11^m$ U.T., mean ending time at $14^h 04^m$ U.T. and the latest reported ending time was $14^h 45^m$ U.T.

On the McMath SECASI record, minor brightenings, probably located in the plage, were seen in $d^{IV}$ and $d^{VII}$ at $12^h 50^m$ U.T. and in m and $k^{III}$ at $12^h 51^m$ U.T. Between $12^h 55^m$ - $12^h 56^m$ U.T. a bright flash occurred in prominence material suspended above d, $d^{IV}$ and $d^{VII}$. This was followed between $13^h 00^m$ - $13^h 01^m$ by brightenings in prominence material above m, $m^I$, and above d, $d^{IV}$ and $d^{VII}$. Then between $13^h 02^m$ - $13^h 04^m$ U.T. by brightenings above $k^{II}$ and $k^{III}$. Swept wavelength records are available from $12^h 44^m$ U.T. On a calcium sweep, taken early in the prominence flare from $12^h 53^m$ - $12^h 57^m$ U.T., it was found, cf. Fig. A5-a, p. 197, that part of the prominence material located directly between umbrae N28-N25 and S27 in Mt. Wilson group 14284 was bright and wide in the blue and faintly bright in the red wing of the K line. It was not however in emission at line centre. Faint emission in the wings of the K line was also visible within prominence material suspended somewhat to the north east of group 14284.

A further calcium sweep taken two minutes later from $12^h 59^m$ - $13^h 03^m$ U.T. shows brilliant emission in line centre at those various locations within the prominence already mentioned above as going into emission in H$\alpha$ light within this same time interval. These several brightenings appeared broad and brilliant in the red and blue wings of the K line. Bursts of centimetre wave radiation were recorded at $12^h\ 57^m$ U.T. and $13^h\ 00^m$ U.T. on 9400 and 1500 MHz, respectively, in association with the developing prominence flare. A sudden SWF also commenced at $12^h\ 58^m$ U.T.

By $13^h\ 27^m$ - $13^h\ 31^m$ U.T., when another calcium sweep was taken, emission in that segment of the prominence material suspended directly between the main north and south polar umbrae was still bright out of wavelength as were also several other sections of its north easterly extension, cf. Fig. A5-a, p. 197. In line centre itself, prominence material above areas a, d, $d^{IV}$, $c^I$ and $c^I_I$ showed impulsive brightenings from $13^h\ 27^m$ - $13^h\ 29^m$ U.T. in association with a centimetre-decimetre wave burst. Lengths of emission of subflare brightness were also visible around this time extending westwards from a location above area a. This latter emission appeared on an Hα sweep taken from $13^h\ 33^m$ - $13^h\ 36^m$ U.T. to be associated with falling dark material, cf. Figs. A-5a (centre) with A-5a (red). This sweep also showed a considerable quantity of active dark material rising and falling within that part of the active prominence already seen to be bright out of wavelength in calcium. This was the declining stage of the flare which thereafter gradually faded.

## A6 Stationary Prominence Flaring in 59Q from $13^h\ 51^m$ U.T., July 16, 1959

The "Catalog of Standardized Flare Data," Warwick (1966a), reports an importance 1+ flare to commence in 59Q between $13^h\ 36^m$ U.T. (earliest reported beginning time) and $13^h\ 47^m$ U.T. (mean beginning time). The mean maximum time was estimated to be $13^h\ 58^m$ U.T., mean ending time at $14^h\ 24^m$ U.T., and the latest reported ending time was $15^h\ 19^m$ U.T.

From $<13^h\ 37^m$ U.T. a number of minor brightenings were observed to occur within a developing part of chromospheric chain III to the north of group 14284. Between $13^h\ 51^m$ - $13^h\ 52^m$ U.T., in addition to brightenings at c and d, prominence material above locations $v^I$, $x^I$, $x^{II}$, $x^{III}$, $x^{IV}$, $x^V$ and $x^{VI}$ in chromospheric chain III as well as in material located near the apex of a great prominence loop suspended to the north east of the active region (and seen in projection against the disk) went into flare emission simultaneously (cf. Fig. A6-a, p. 199). These brightenings were accompanied by a Moderate radio burst at centimetre wavelengths. Swept wavelength observations in Hα were available from $13^h\ 54^m$ - $13^h\ 57^m$ U.T. and these show that emission was broad in the wings of the line above segments of chromospheric chain III and in the flaring part of the suspended dark loop.

By the time of a further Hα sweep from $14^h\ 02^m$ - $14^h\ 21^m$ U.T., bright emission in part of the flaring prominence material suspended above x, $x^V$ and $w^{II}$ in chromospheric chain III had changed to absorption at line centre and formed an integral part of a dark loop that appeared particularly well defined in the red wing of the line.

## A7 Stationary Prominence Flaring in 59Q from $16^h\ 04^m$ U.T., July 16, 1959

The "Catalog of Standardized Flare Data," Warwick (1966a), reports an importance 2+ flare to commence in 59Q between $16^h\ 04^m$ U.T. (earliest reported beginning time) and $16^h\ 06^m$ U.T. (mean beginning time). The mean maximum time was estimated to be $16^h\ 15^m$ U.T., mean ending time at $16^h\ 58^m$ U.T. and the latest reported ending time was $18^h\ 00^m$ U.T.

The SECASI record shows a brightening in s, $s^{II}$ at $16^h\ 04^m$ U.T., which was accompanied by a Moderate radio burst on 9400 MHz. These brightenings appeared to take place within suspended prominence material. At $16^h\ 10^m$ U.T. a spectacular flash occurred in prominence material suspended above locations s, $s^{II}$, $s^{III}$, $q^I$, $q^V$, and $q^{VI}$, cf. Fig. A6-a. A Moderate 2800 MHz burst, a Type III event and an importance class 2- SWF also began at $16^h\ 10^m$ U.T. There is a gap in the SECASI record from $16^h\ 11^m$ - $16^h\ 16^m$ U.T., that is over a period within which at $16^h\ 13^m$ U.T., a Strong radio burst and further Type III activity occurred. From $16^h\ 16^m$ U.T. a Type II event was observed in the dynamic spectrum at Harvard over a frequency range from $<25\text{-}>260$ MHz.

Although seeing was very poor at the start of this flare due to cloud, the beginning of an H$\alpha$ series taken from $16^h\ 18^m$ - $17^h\ 05^m$ U.T., shows a major ejection in progress from a location between the main flaring segments to the south of group 14284. Prominence material above an extensive part of distant chromospheric chain VI was also in emission by this time. The latter flaring took place at what appeared in projection to be the western terminus of a large dark prominence suspended between the two separated flare sites (cf. Section C2, p. 188). Thereafter, the event slowly declined.

APPENDIX B

# MOVING PROMINENCE FLARING IN 59Q

## B1 Important Prominence Flaring in 59Q from $21^h$ $18^m$ U.T., July 16, 1959

The "Catalog of Standardized Solar Flare Data," Warwick (1966a), reports an importance 3 flare to begin between $21^h$ $14^m$ U.T. (earliest reported commencement time) and $21^h$ $16^m$ U.T. (mean beginning time). It is estimated to have shown a maximum at $21^h$ $28^m$ U.T. The mean ending time and the last reported ending time are both given as $24^h$ $30^m$ U.T.

On the McMath SECASI record the event was observed to begin at $21^h$ $14^m$ U.T. with a brightening in chromospheric area $d^{IV}$ bordering the neutral line and apparently superposed directly on large umbra N27, cf. B1-a, p. 201. This enhancement was followed at $21^h$ $15^m$ U.T. by the brightening of area d within the same chromospheric chain. Areas $e^I$ - $e^I_I$ which were situated on the other side of the neutral line in a chromospheric chain that crossed large umbra S28 brightened at $21^h$ $16^m$ U.T. These intensity increases individually constituted Plage Flares. A burst on 545 MHz lasting $165^m$ commenced at $21^h$ $14^m$ U.T. The earliest reported ionospheric event was an importance 3+SEA that commenced at $21^h$ $15^m$ U.T.

At $21^h$ $18^m$ U.T. areas d and $d^{IV}$ increased markedly in optical importance to form a single bright segment which rapidly extended northeastward. Areas $e^I$ - $e^I_I$ showed a simultaneous intensity increase. Concomitantly, bright emission appeared at $k^{III}$ to the north of distant spot umbra S28 in the western part of the region. At $21^h$ $20^m$ this latter emission extended until the large umbra was practically osbcured. This sequence of phenomena beginning at $21^h$ $18^m$ defined the start of the flash phase of the flare and was marked on 2800 MHz by the onset of a 'Very Strong' radio burst. The times of beginning of bursts in the range 9400-3750 MHz is not known. Type IV radiation was reported from $21^h$ $21^m$ U.T. by dynamic spectrum observers at Harvard and Ann Arbor. A Type II burst at $21^h$ $21^m$ U.T. was reported by the Michigan observers but not by those at Harvard. The latter however reported structure in the continuum between $21^h$ $21^m$ - $22^h$ $50^m$ U.T. comprising fast drift bursts with positive and negative slopes.

Large scale, centre of Hα pictures taken with the Tower Telescope were obtained from $21^h$ $20^m$ - $23^h$ $11^m$ U.T. Careful comparison of these pictures with previous Hα and Ca II records reveals that at this time, part of the absorption material suspended above flaring plage areas d, $d^{IV}$ and $e^I$ - $e^I_I$ were in emission such that Stationary Prominence Flaring was superposed on Plage Flaring. Unfortunately the $21^h$ $20^m$ - $21^h$ $23^m$ U.T. Hα series is incomplete and pictures to the redward side of the line are missing. On the next series from $21^h$ $24^m$ - $21^h$ $26^m$ U.T., however, it was seen that the brightest parts of the flare showed in emission over the full 6Å range of the λ sweeps.*

*The spectral lines of Ca II, Na, He and H were additionally reported to be in emission at this time by Howard et al. (1959).

## Ejections During the Rise to Maximum Intensity

The swept wavelength records provide evidence for several ejections during the rise to maximum intensity. Two of these injections marked A and B, respectively, in Fig. Bl-a, p. 201,were visible from $21^h\ 24^m$ U.T. at the eastern and western extremities of the two bright flare segments then developing on either side of the magnetic 'neutral line'. As noted by Dodson and Hedeman (1964) they apparently emerged from those portions of the flare showing maximum curvature on centre-of-Hα images. Their velocities were individually ⩾200 km/sec, the observational limit.

The $21^h\ 24^m$ - $21^h\ 26^m$ U.T. sweep also shows that well-defined filaments of absorption material visible to the northwest of the main spot group were active in the red, and especially in the blue wing of the Hα line at this time. Subsequent series indicate that ejection B may possibly in its passage have swept part of this suspended material westwards (cf. Fig. Bl-a, blue). It is interesting to note that a well-defined segment of the southern extension of this 'disturbed' filament* disappeared from line centre in Hα at $21^h\ 25^m\ 54^s$ U.T. but (cf. Dodson and Hedeman (1964)) "appeared apparently intact on the redward side of Hα with Doppler displacements of the order of 1Å. Three minutes later the filament segment, still intact, showed a similar displacement but at this time to the violet side of Hα."

On a sweep taken from $21^h\ 35^m$ - $21^h\ 38^m$ U.T. another length of the same dark filament, this time suspended somewhat to the southwest of the main spot group, appeared active in the blue wing of the Hα line. This activity was not visible on a series taken $5^m$ earlier. From $21^h\ 40^m$ - $21^h\ 43^m$ U.T. this active material was seen to be in the path of a further ejection, designated in Fig. Bl-a, by the letter C, and which was then travelling westward with a velocity ⩾200 km/sec. That segment of the southern extension of this dark filament previously seen to 'wink' was again displaced from approximately $21^h\ 32^m$ U.T. to the redward side of Hα and it executed a complete down-up motion before becoming relatively stable at $21^h\ 40^m$ U.T.

The earliest Hα sweep taken during the major flare from $21^h\ 20^m$ - $21^h\ 23^m$ U.T. shows what appears to be two bright globules above the position of flare sensitive area $d^{IV}$. On succeeding sweeps these two features, which were broad and bright in both wings of the line, appeared in projection to progress at about 10 km/sec from a location near the base of umbra N27 along trajectories defining the bounding edges of an umbral 'spur' projecting northwards. This behaviour is illustrated in Fig. B-la. The identity of these globules is in some doubt. They may have constituted part of an ejection which was Doppler shifted in the main outside the Hα centered transmission band covered by the Tower Telescopes. However, since they apparently moved within and at the same rate as the drifting bright flare filament against which they were seen (cf. below) it is possibly that they merely represented two particularly bright features within this structure.

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*Not all of this filament was visible on the 40' spectroheliogram used in preparing Fig. Bl-a. However, the drawing of Fig. C2-a, p. 205, made from a 20' image photographed on the previous day, clearly shows the complete extent of the filament.

Development of Two Bright Flare Ribbons

Between $21^h$ $18^m$ U.T. and $21^h$ $26^m$ U.T., flare excitation spread rapidly. That portion of the event comprising Prominence Flaring above chromospheric region $e^I$ - $e^I_I$ spread initially to prominence material immediately to the south of it and then both eastward and westward within extensive lengths of the previously present dark filament. Compare Figures Bl-b(A) and Bl-b(B), p. 203. That part of the excitation spreading westward joined with flare emission already present in dynamically changing prominence material associated with the far western spot S28, while its northeastern extension reached points far removed from any visible spot. At $21^h$ $26^m$ U.T., the large S shaped flare filament thus formed had a total length of 280,000 km and lay within and along the northern boundary of the large similarly placed dark filament shown in Figure Bl-b(A).

During the same time interval, excitation spread northeastward from that part of the prominence material flaring above chromospheric areas d and $d^{IV}$. By $21^h$ $26^m$ U.T., the two "parallel" bright flare ribbons so characteristic of certain large flares were resultingly present (see Figure Bl-b(B)). The two segments had formed through the spreading and coalescence of separate flare elements and not from the bifurcation of a single flare filament.

After $21^h$ $26^m$ U.T., the two bright flare ribbons appeared to separate rather than to elongate. This process is followed in detail in Figure Bl-a and effectively summarized in Figure Bl-b. It is possible that the apparent separation was an effect of an ascending and expanding phenomenon through the superposed amorphous absorption that overlay the region and which is indicated in Figure Bl-b by parallel black lines.

At about $21^h$ $40^m$ the apparent displacement of the southern branch of the flare stopped. By this time, flare excitation had spread to the southern border of the amorphous absorption above the spot group and of the great dark loop extending northeastwards. At about this same time, the width of Hα emission decreased rapidly. The position of the southern flare filament did not change further between $21^h$ $40^m$ U.T. and $22^h$ $25^m$ U.T. Compare Figures Bl-b(c) and Bl-b(D).

The northern flare ribbon developed over a longer time. Between $21^h$ $26^m$ U.T. and > $22^h$ $25^m$ U.T., excitation within prominence material associated with regions d and $d^{IV}$ spread at first northward, then westward until it reached spot N17. Thereafter, from about $21^h$ $40^m$ U.T., flare emission extended to form a bright ribbon within the northern boundary of the previously existing absorption features. Compare the four drawings of Figure Bl-b. This latter prominence flaring was superposed on a chromospheric chain extending eastward from spot N17 within which the northern boundary of the dark filament was rooted.

According to these records, the positions of both the northern and southern ribbons of the fully developed flare were influenced strongly by circumstances relating to previously existing filaments.

At $21^h\ 40^m$ U.T. a loop of subflare brightness appeared within the central absorption feature at a position lying approximately between umbra N27 and S28 (see Figures Bl-a and Bl-b, C). Hα emission in this feature was approximately 0.75Å wide. Other similar bright structures gradually appeared within the absorption band and comprised individually the crests of what were probably developing loop-type prominences. Possibly as early as $21^h\ 53^m$ U.T., and certainly by $22^h\ 06^m$ U.T., dark curvilinear features, already interpreted by Dodson (1961) and Dodson and Hedeman (1964) as systems of loop-type prominences in projection against the disk, were visible within the active region. The exclusively redward Doppler shifts to 0.5Å or more from the centre of Hα displayed by these dark features indicated that material was pouring downward through the loops into the underlying bands of bright emission (cf. Fig. Bl-b,D). Material was still descending along these loops when observations ended at $23^h\ 11^m$ U.T. The descending dark material of the loop-type prominences late in the flare occurred in the general location of the previously existing amorphous absorption shown in Figure Bl-b,A and the loops had their 'feet' in the bright flare ribbons.

This importance 3 flare was the last during the July transit of 59Q to be associated with the confirmed ejection of solar protons. Details of the particle emissions detected are summarized in Tables 6.7(a-c), pp. 89-91.

APPENDIX C

# IMPACT PROMINENCE FLARES IN 59Q

## C1 Impact Flares Seen at the Limb

On July 07 at the east limb, numerous active prominences preceded the appearance of the principal plage and spots in region 59Q. Long exposure frames taken every 5 minutes with the McMath SECASI instrument proved particularly useful in allowing the profile of these features to be studied and this activity is described in detail in McKenna (1967).

On July 07, as early as $10^h\ 41^m$ U.T., a large structured prominence could be seen to the north of 59Q, part of which was projected against the disk and part of which still lay behind the limb. By $17^h\ 55^m$ U.T., a hedgerow-like prominence could also be seen coming around the limb well to the south of the main plage area, compare Figures C-1a, 1 and 4, p. 204. These prominences formed the terminals of an ever growing concentration of absorbing material traversing the active region and already described in Section 6.2. The northern and southern terminals of this material are designated on the drawings by the letters N and S, respectively. In addition to these features an isolated column of elevated material was visible against the sky from at least $10^h\ 41^m$ U.T. The location of the foot or base of this column which repeatedly ejected material was somewhat to the north of bright flare active area 'a'.

From $11^h\ 03^m$ U.T., the top of the active columnar prominence was seen to extend toward and to precipitate into flare active area 'b'. From $11^h\ 08^m$ U.T., a flare brightening at b seen in projection against the sky appeared to be associated with this descending material. Spatially close flare area 'd' was also seen to go into emission by $11^h\ 14^m$ U.T. However, areas b and d are not differentiated in Figures C1-a, 2. No radio burst or ionospheric event was reported in association with these brightenings. It may be noted that from $11^h\ 08^m$ U.T., prominence N altered greatly in appearance extending further northward to form a bright streamer lying close to the limb. It later gradually vanished but reappeared on a reduced scale several times throughout the day.

On July 08 the features at the limb were essentially similar to those observed on the previous day. Prominence N was at $10^h\ 45^m$ U.T., represented by a structured but rather faint feature while S, previously just visible on July 07, had rotated well into view. This latter structure remained quiescent until approximately $15^h\ 26^m$ U.T., when it began to show internal changes. Activity became dramatic at $17^h\ 11^m$ U.T., when a bright arch formed (cf. Figs. C1-b, 2, p. 204. A section of the changing prominence was later ejected and, having travelled northward in a graceful curving trajectory, commenced to pour partly into flare active area 'a' and partly into N. Possibly due to the influence of this descending material, diffuse prominence material of subflare brightness seen on normal exposures overlying area 'a' went into brilliant emission at $17^h\ 45^m$ U.T. and material above adjacent area 'b' flared at $17^h\ 47^m$ U.T. Only an 18 MHz burst lasting for $2^m$ was reported at $17^h\ 44^m$ U.T. No ionospheric event was recorded. Following this activity S appeared reduced to a number of small tufts while N, having gained a considerable amount of material, spread out to form a large mound like structure.

By July 09, region 59Q had rotated well onto the disk. Only a portion of the hedgerow-like prominence S was on this day still visible above the limb of the Sun. Material belonging to N was, however, still traversing the limb and formed an imposing feature against the sky, cf. Fig. Cl-c. This structure remained reasonably quiescent from at least $11^h\ 47^m$ - $18^h\ 07^m$ U.T., but, after this latter time, material ejected along a trajectory from still further north appeared to be falling, at least partly, into the main bulk of the prominence. From approximately $18^h\ 16^m$ U.T., the point at which this material appeared to be descending showed a marked increase in brightness while still remaining detached from the limb, cf. Fig. Cl-c,2, p. 204. A further ejection was in progress at $18^h\ 52^m$ U.T., and, as the additional matter later fell back into the prominence, the flare-like brightening increased in area and extended southward, cf. sketches 3 and 4 of the Figure. Viewed from above against the disk, this elevated, temporarily bright prominence would probably have appeared like a typical bright flare filament. It may be noted that Staionary Prominence Flaring associated with the generation of centimetre wave and ionizing radiation was detected directly above active region 59Q from $18^h\ 10^m$ U.T. No radio bursts or ionospheric effects were reported in time association with the earlier Impact Prominence Flare at the limb. The time of acceleration of protons producing an unconfirmed P.C.A. event from $20^h\ 00^m$ U.T. cannot be deduced.

C2 <u>Impact Flares Observed on the Disk and Related Activity</u>

The late stages of three of the major flares observed in region 59Q during its July disk passage, namely the Stationary Prominence Flares with flash phases at $02^h\ 05^m$ U.T., July 10 and $<03^h\ 33^m$ U.T., July 14 (cf. Sections A4 and A5) and the Moving Prominence Flare with flash phase at $21^h\ 18^m$ U.T., July 16 (cf. Section Cl) were dominated by the formation of great systems of loop-type prominences. These loop like structures had their 'feet' in underlying bright flare ribbons into which material, streaming down the sides of the loops, appeared to pour; Bruzek (1964b) estimates that matter descends in such 'loop legs' at velocities of the order of 100 km/sec. It is plausible that at least a contribution to the emission of the underlying flare filaments may have been made by the downflowing material (cf., however, de Jager (1975)). Note that these loop type prominences were seen in the post maximum phases of their respective flares at times when the energetic radio and ionizing events accompanying the flash phase were in a state of overall decline. It is not known when the fast protons detected in association with these flares received their respective accelerations.

It is possible that a <u>sequence</u> of Impact Prominence Flares occurred in region 59Q over the internal July 15-16. In the absence of necessary supportive observations this cannot be confirmed, and only one event namely that of $\sim 14^h\ 41^m$ U.T. July 15 (see below), can be identified with any confidence. However, in view of the interest of the possibility either (a) that material ejected from Prominence Flaring in one part of an active region may produce Impact Prominence Flaring at a distant site within the same centre or (b) that disturbances channelled along a connecting filament may produce associated flaring at its two widely separated terminals, the relevant observations will be given in detail.

As already indicated in Section A4, on July 14 a well-defined funnel shaped absorption feature defined a trajectory along which dark material was intermittently ejected eastwards from the general vicinity of a group of minor umbrae located to the south of Mt. Wilson group 14284. By July 15, a large dark prominence encompassed this feature and its western terminal appeared to be rooted in distant chromospheric chain VI, cf. Fig. C2-a, p. 205.

On a calcium sweep taken from $14^h\ 46^m$ - $14^h\ 49^m$ U.T., July 15, a dark absorption feature was seen on the red side of the line apparently traversing part of the western 'leg' of the superposed prominence and falling into chromospheric chain VI (cf. Fig. C2-a). By $15^h\ 08^m$ U.T. this material was no longer visible. It may have either constituted part of a jet of absorption material seen to be ejected from the vicinity of area s as early as $13^h\ 58^m$ U.T., part of a similar undetected jet ejected from the same location somewhat later or just material falling along the western leg of the prominence due to some internal disturbance. In any case, the event was associated with the occurrence in chromospheric chain VI, from ~$14^h\ 41^m$ U.T., of several intensity increases of subflare brightness which possibly may be classed as Impact Prominence Flares. No associated impulsive radio or ionospheric event was recorded.

A spectacular ejection from the vicinity of area s, seen on an Hα sweep from <$18^h\ 21^m$ U.T., followed the same trajectory towards chromospheric chain VI. However, the seeing on succeeding swept wavelength pictures was not sufficiently good to determine if its arrival was associated with the occurrence of impact flaring.

At $19^h\ 25^m$ U.T., on July 15, a bright flash in prominence material near the eastern terminal of the great dark prominence occurred above s, $s_I$, $s^I$, $s^{II}$, $s^{III}$ and $s^{IV}$ on the one side and above $q^V$, $q^{VI}$ and $q^{VII}$ on the other side of that magnetic 'neutral line', immediately to the south of group 14284. These events were accompanied by a simultaneous bright flash at the western terminal of the prominence*. Unfortunately no swept wavelength observations are available so that it is not known if falling material was associated with these events. On band observations in Hα show the 'winking' at $19^h\ 28^m$ U.T. of part of a large strand of prominence material suspended somewhat further to the south of the main active region, cf. Fig. C2-a, p. 205. A centimetre-metre wave burst and a Type III and reported Type I (the latter probably a Type V event) began at $19^h\ 25^m$ U.T., in association with the flash phase of the flare. A sudden SWF was reported from $19^h\ 22^m$ U.T.

The centimetre wave associated Prominence Flare which began at $16^h\ 04^m$ U.T. on July 16 above s, $s^{II}$, at the general location of the eastern terminal of the dark prominence of July 15, is already described in detail in Section A7. A centimetre wave and ionizing burst associated flash occurred in material located above s, $s^{II}$, $s^{III}$ on the one side and above $q^I$,$q^V$ and $q^{VI}$ on the other side of

*It is not clear from the data if this latter flash took place in the prominence itself or in chromospheric chain VI.

the 'neutral line' at $16^h\ 10^m$ U.T. Following a gap in the optical record from $16^h\ 11^m$ - $16^h\ 16^m$ U.T., during which a 'Strong' radio burst and further Type III activity occurred, part of chromospheric chain VI was seen to have gone into bright emission in the interim. An Hα series taken from $16^h\ 18^m$ - $17^h\ 05^m$ U.T. shows a major ejection in progress at the beginning of the series from a location between the main flaring segments. This material was travelling in a general southwesterly direction but unfortunately the exposures on the red side of the line were too dense to determine if part of this material was falling into chromospheric chain VI.

It cannot be decided if the brightenings of $19^h\ 25^m$ U.T., July 15, and $<16^h\ 17^m$ U.T., July 16, in chromospheric chain VI were associated with falling material or with disturbances channelled within the associated prominence along the magnetic field lines*.

A flare brightening was seen at line centre above area v from $<16^h\ 50^m$ U.T., on July 15. An Hα series taken from $17^h\ 13^m$ - $17^h\ 16^m$ U.T. shows a streamer of dark material with velocity $\geqslant$ 200 km/sec (the observational limit) pouring into this location, cf. Fig. C2-a. The dark material was not well defined at line centre. A calcium sweep taken from $17^h\ 26^m$ - $17^h\ 39^m$ U.T. shows a small feature located at the base of the dark streamer which was bright in both wings of the K line**. At $18^h\ 00^m$ U.T., a further impulsive brightening occurred in Hα above v. A calcium sweep was taken from $18^h\ 00^m$ - $18^h\ 21^m$ U.T., but, due to cloud, the red wing of the K line hardly showed. However, the base of the streamer was seen to be broad and bright in the blue wing of the line. Another Hα series taken from $18^h\ 21^m$ - $18^h\ 24^m$ U.T. shows flaring at v to be still in progress with high velocity dark material continuing to descend into it. No associated impulsive radio or ionospheric event was recorded.

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*No further possible members of this series were observed.

**A further feature somewhat to the eastward which was simultaneously bright in the wings of the Ca line but not in either centre line Ca or Hα was located above the site of an umbra which had appeared at $x^{VII}$ by July 16.

## Legend to Figs. Ala-C2a

Series of composite drawings of various Stationary, Moving and Impact Prominence Flares in 59Q, made from swept wavelength records taken in Hα and Calcium light with the Tower Telescopes of the McMath Hulbert Observatory and from Hα line centre records contained in the Continuous Solar Movie.

Spot umbrae are shown in black and penumbral borders are indicated by a 'fringed' continuous line.

Regions of bright emission in the chromospheric network are shown enclosed within a continuous line interspersed with black circles. Individual lengths of the network referred to in the text are designated by Roman numerals.

Well-defined dark filaments are shown enclosed within a continuous line and stippled.

The positions of certain of those individual flare sensitive areas described in Section 3.1 are indicated by the letters a-z with, on occasions, added Roman subscripts and/or superscripts. Lengths of flaring prominence material that appeared bright at line centre in Hα or in Calcium light are cross hatched*.

Prominence material that appeared bright in (a) the blue and (b) the red wing of the Hα or Calcium lines is indicated on the drawings by vertical and by horizontal hachuring, respectively. Dark prominence material seen (a) rising and (b) falling in the wings of these lines is similarly indicated on the drawings by rows of either vertical or horizontal dots joined by continuous lines.

The times (U.T.) at which those individual features depicted presented the appearance shown in Hα or Calcium light, is indicated at the appropriate position on each figure. The time chosen for a drawing was not necessarily that at which some particular feature referred to in the text and illustrated first appeared, but depended rather on its being then well developed and present on a good quality spectroheliogram. By including many scenes on individual drawings made in the centre and in the blue and red wings of the Hα and Calcium lines, variations in the level of prominence and flare activity on individual days can be compositely followed.

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*See however the special convention applicable to Fig. Bl-b, which is described on p. 203.

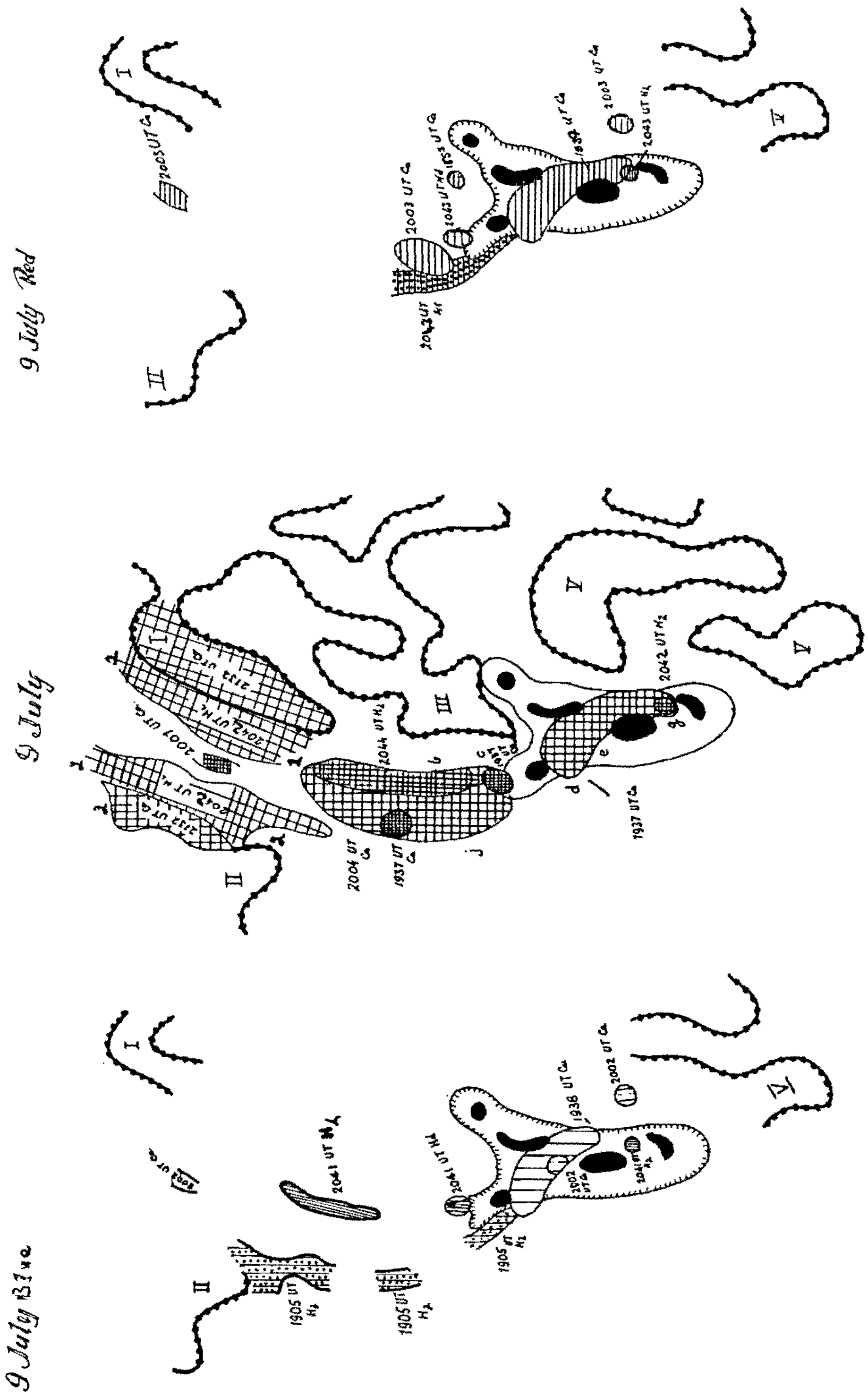



Fig. Al-a. Composite drawings made from swept wavelength Hα and Calcium McMath 40' spectroheliograms, showing variations in the level of prominence and flare activity in 59Q, July 09, 1959.

July 10

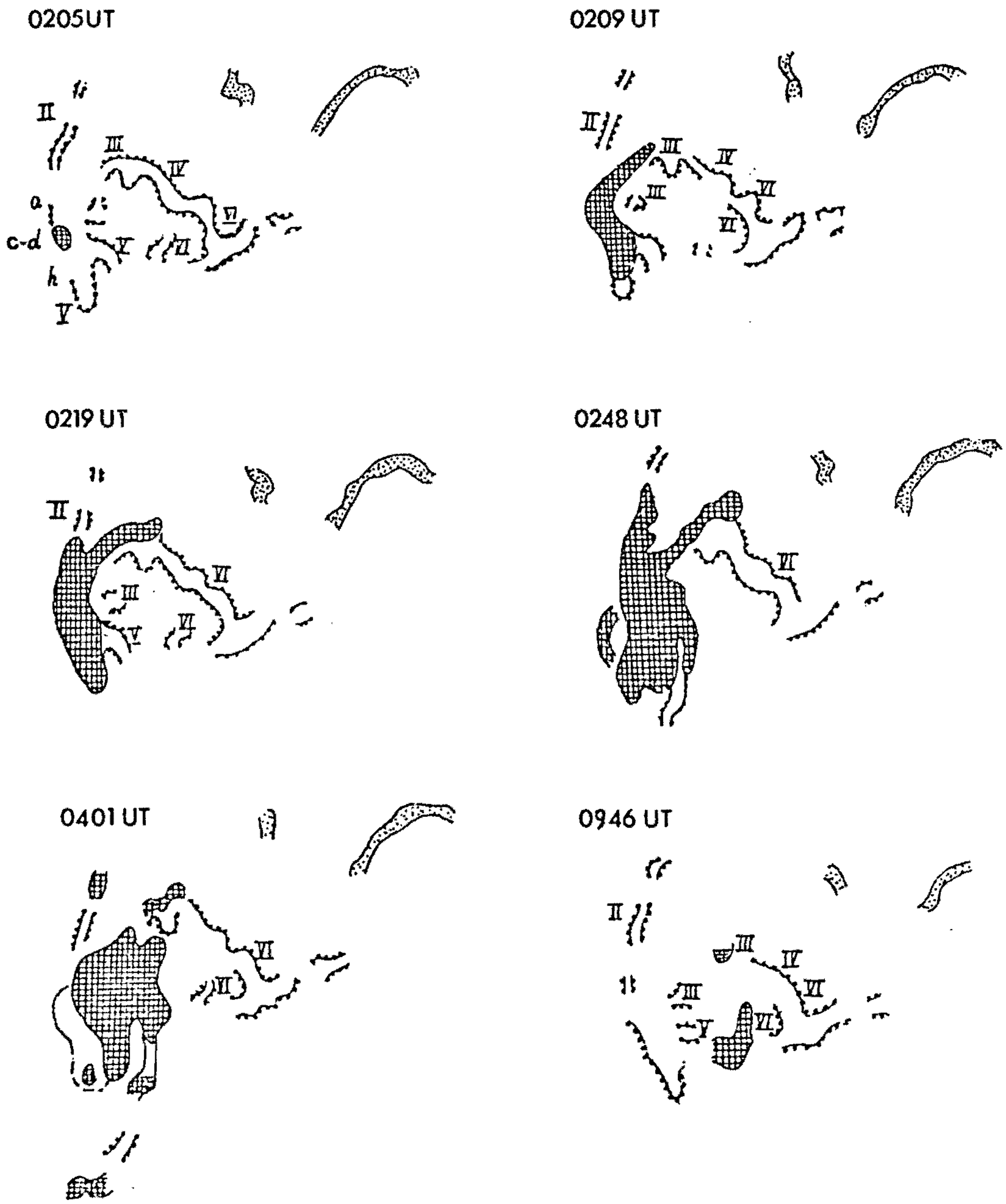



Fig. A2-a. Sequence of drawings made from spectroheliograms of the Continuous Solar Movie, showing the development of the Stationary Prominence Flare of $02^h\ 05^m$ U.T., July 10, 1959.

July 14

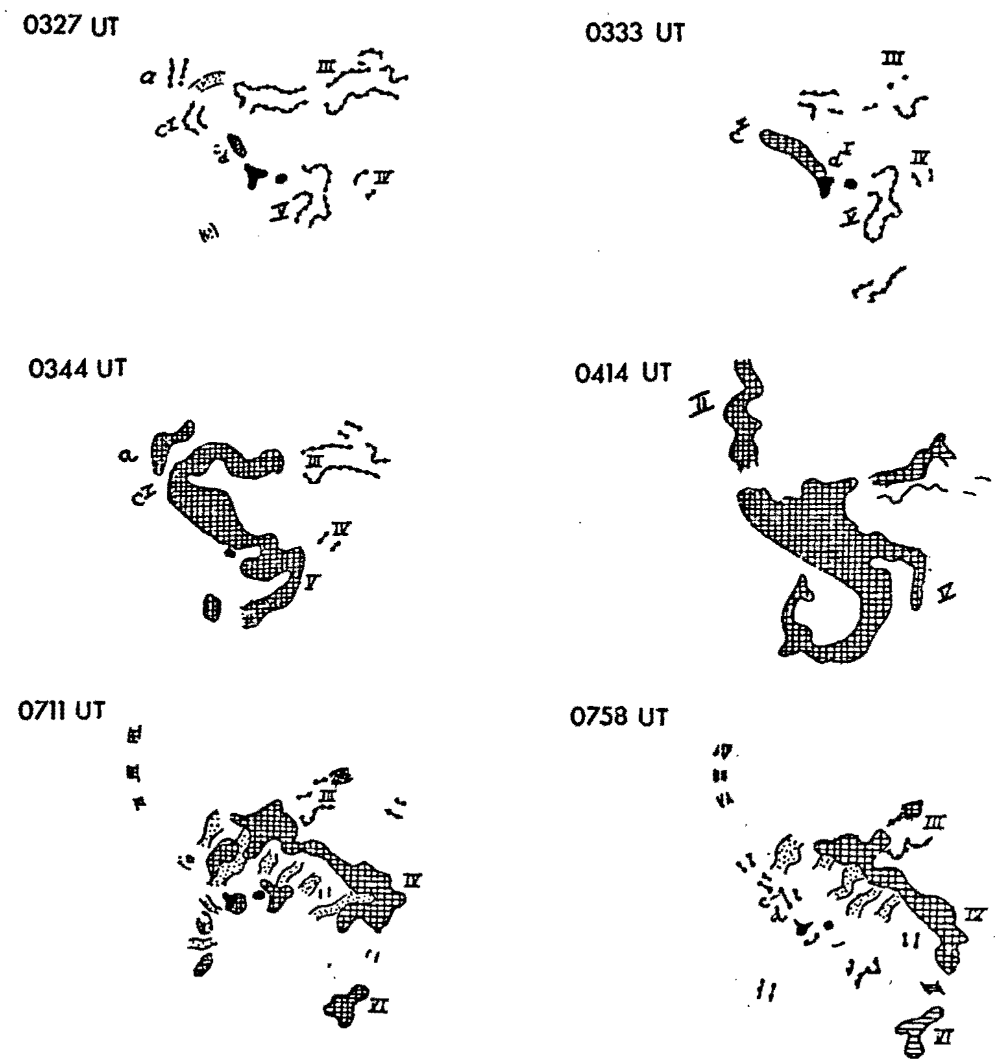



Fig. A3-a. Sequence of drawings made from spectroheliograms of the Continuous Solar Movie showing the development of the Stationary Prominence Flare of <$03^h$ $33^m$ U.T., July 14, 1949.

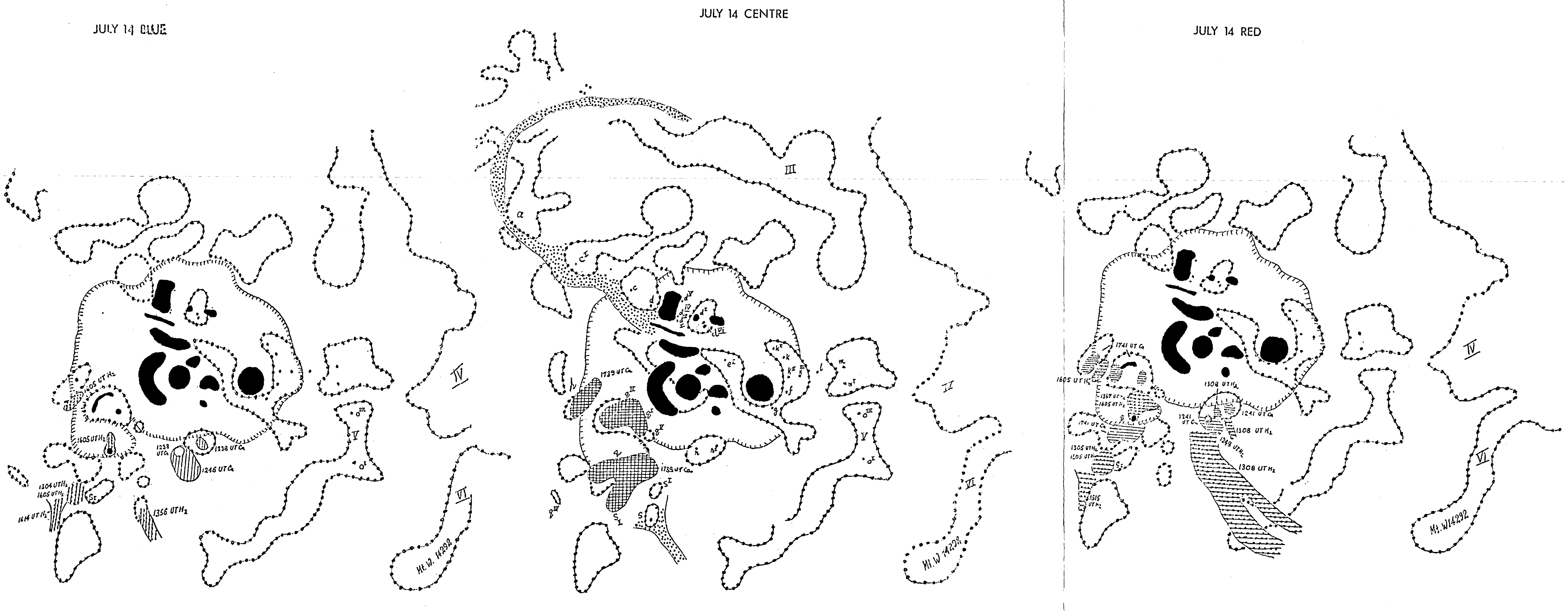



Fig. A4-a. Composite drawings made from swept wavelength Hα and Calcium McMath 40' spectroheliograms, showing variations in the level of prominence and flare activity in 59Q, July 14, 1959.

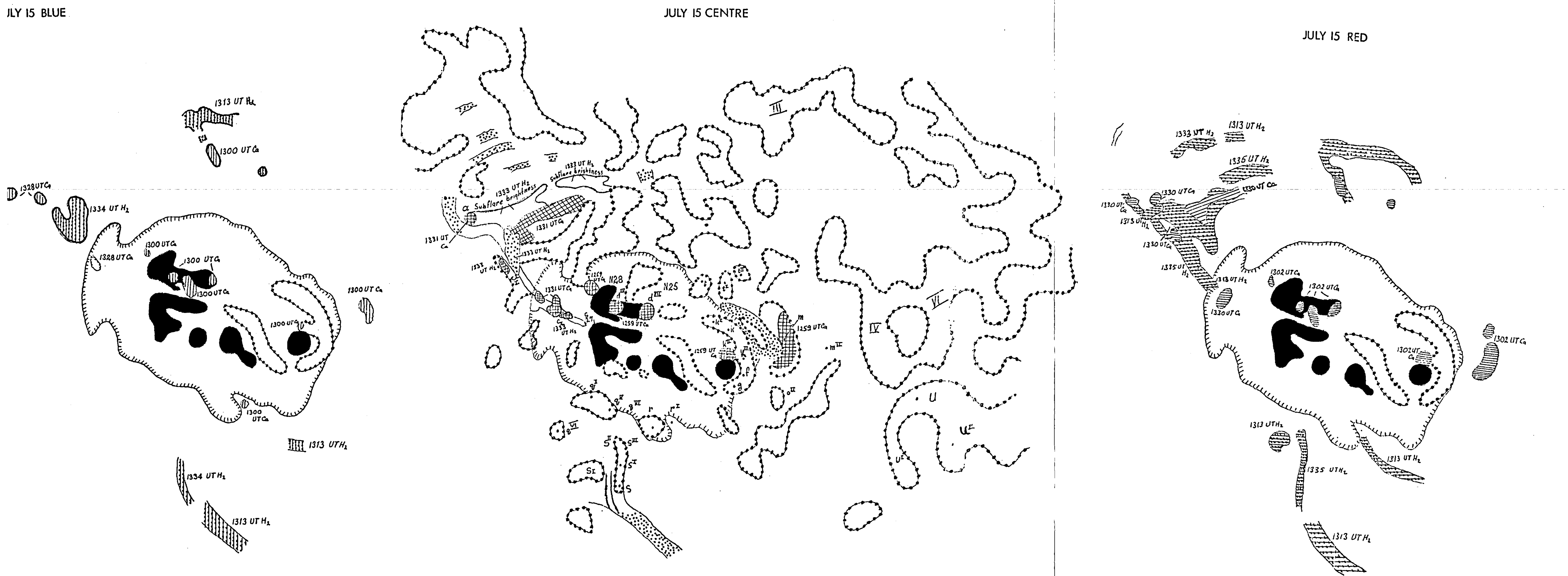



Fig. A5-a. Composite drawings made from swept wavelength Hα and Calcium McMath 40' spectroheliograms, showing variations in the level of prominence and flare activity in 59Q, July 15, 1959.

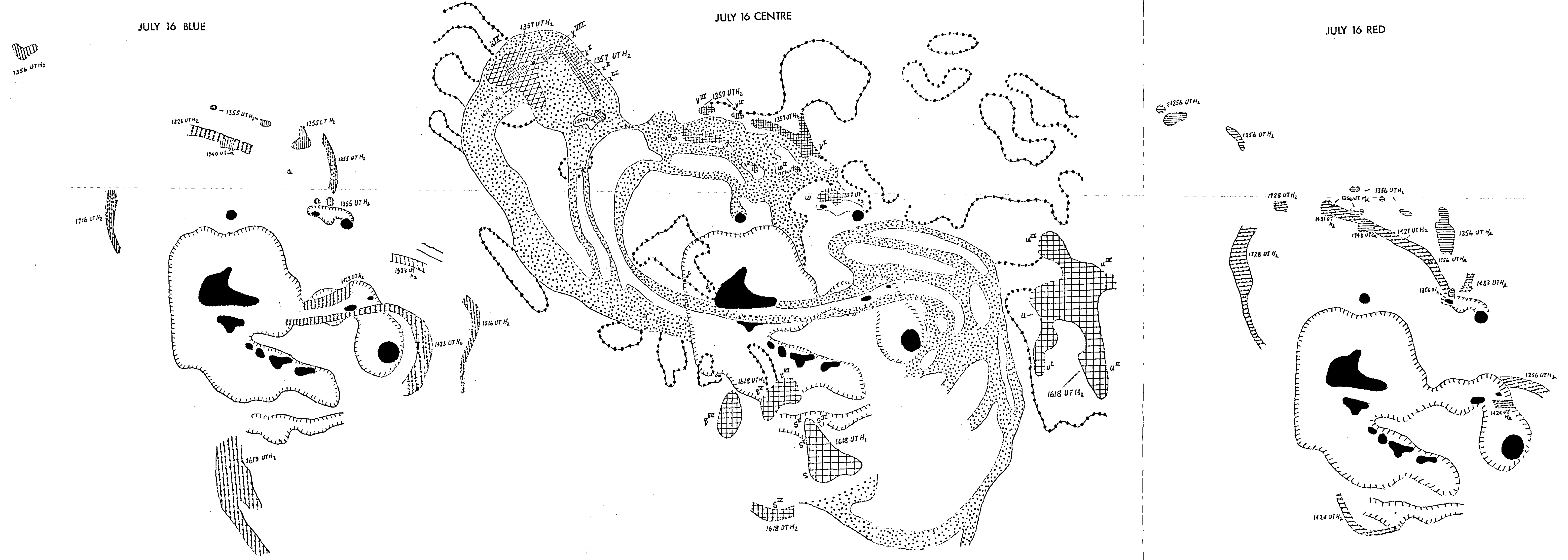



Fig. A6-a. Composite drawings made from swept wavelength Hα and Calcium McMath 40' spectroheliograms, showing variations in the level of prominence and flare activity in 59Q, <21$^{h}$ 14$^{m}$ U.T., July 16, 1959.

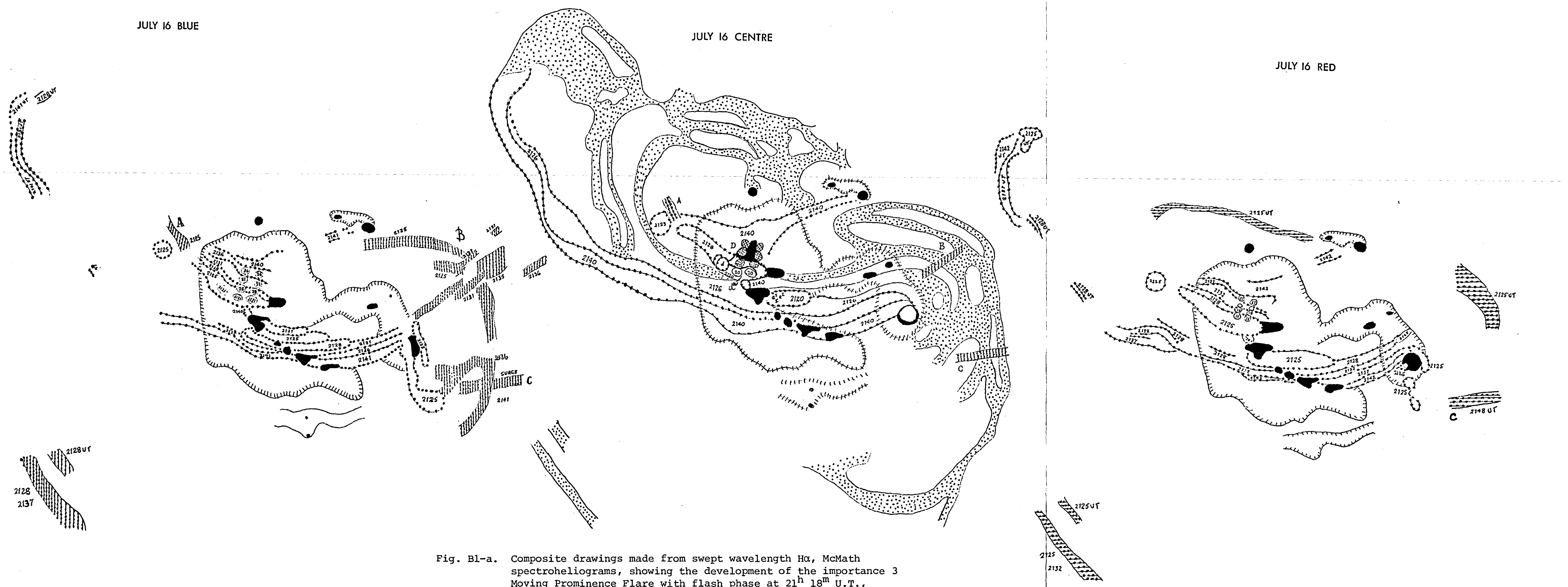
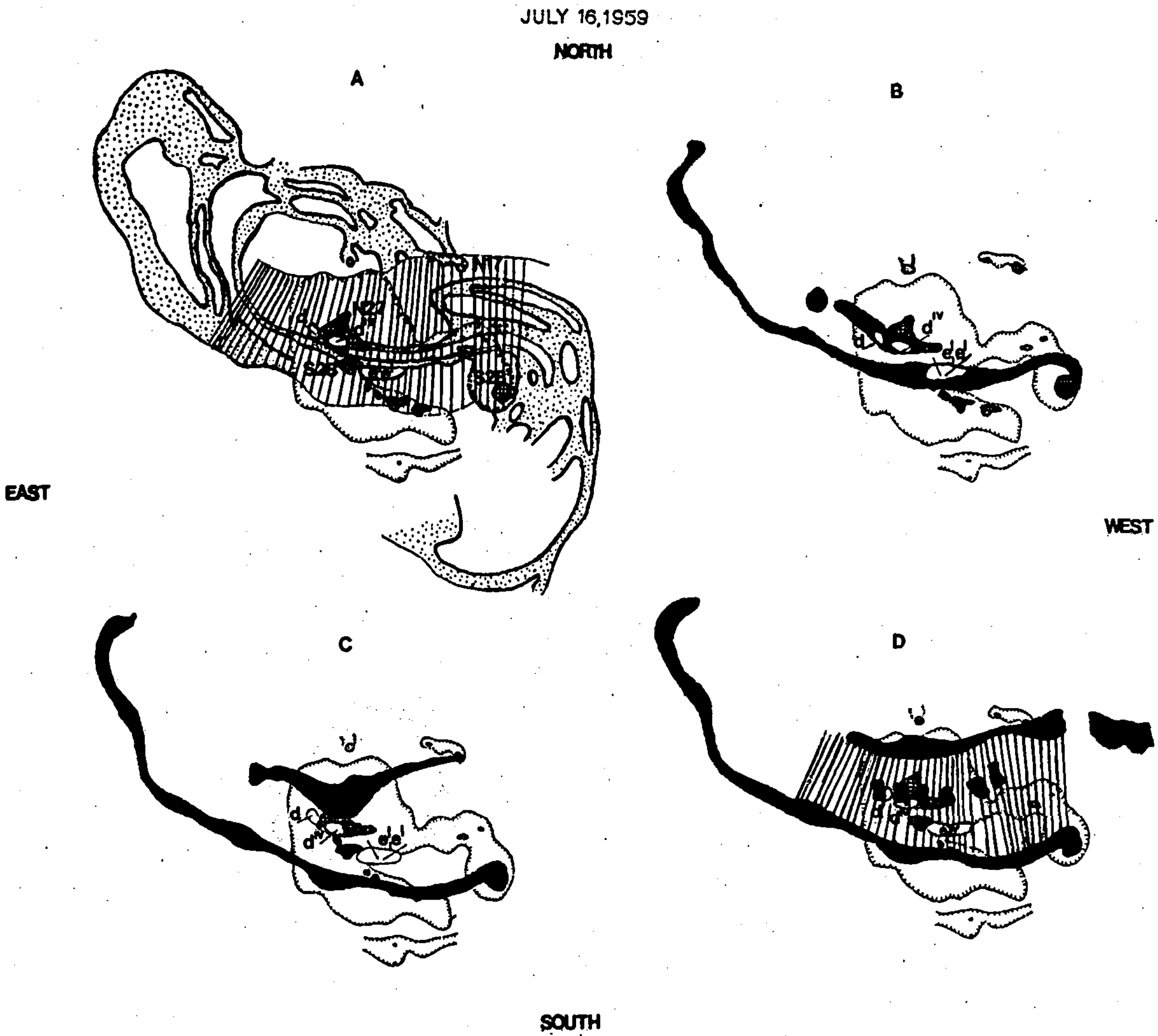



Fig. B1-a. Composite drawings made from swept wavelength Hα, McMath spectroheliograms, showing the development of the importance 3 Moving Prominence Flare with flash phase at $21^h\ 18^m$ U.T., July 16, 1959.




'ig. Bl-b. Composite drawings made from swept wavelength Hα McMath spectroheliograms before, during the development of, and during the declining stages of the importance 3 Moving Prominence Flare, with flash phase of $21^h\ 18^m$ U.T., July 16, 1959.

A Composite drawings of the region during those hours prior to the outbreak of the flare. A well-defined 'bridge' of diffuse dark material, visible at line centre, is hachured vertically.

B Scene during the developing flare at $21^h\ 26^m$ U.T., flare emission is shown in black.

C Scene during the developing flare at $21^h\ 40^m$ U.T., flare emission is shown in black.

D Scene during the declining flare at $22^h\ 25^m$ U.T., flare emission is shown in black. Descending dark material recorded to be redward of Hα is hachured vertically and appears in the general location of the previously existing amorphous absorption shown, similarly hachured, in drawing A.

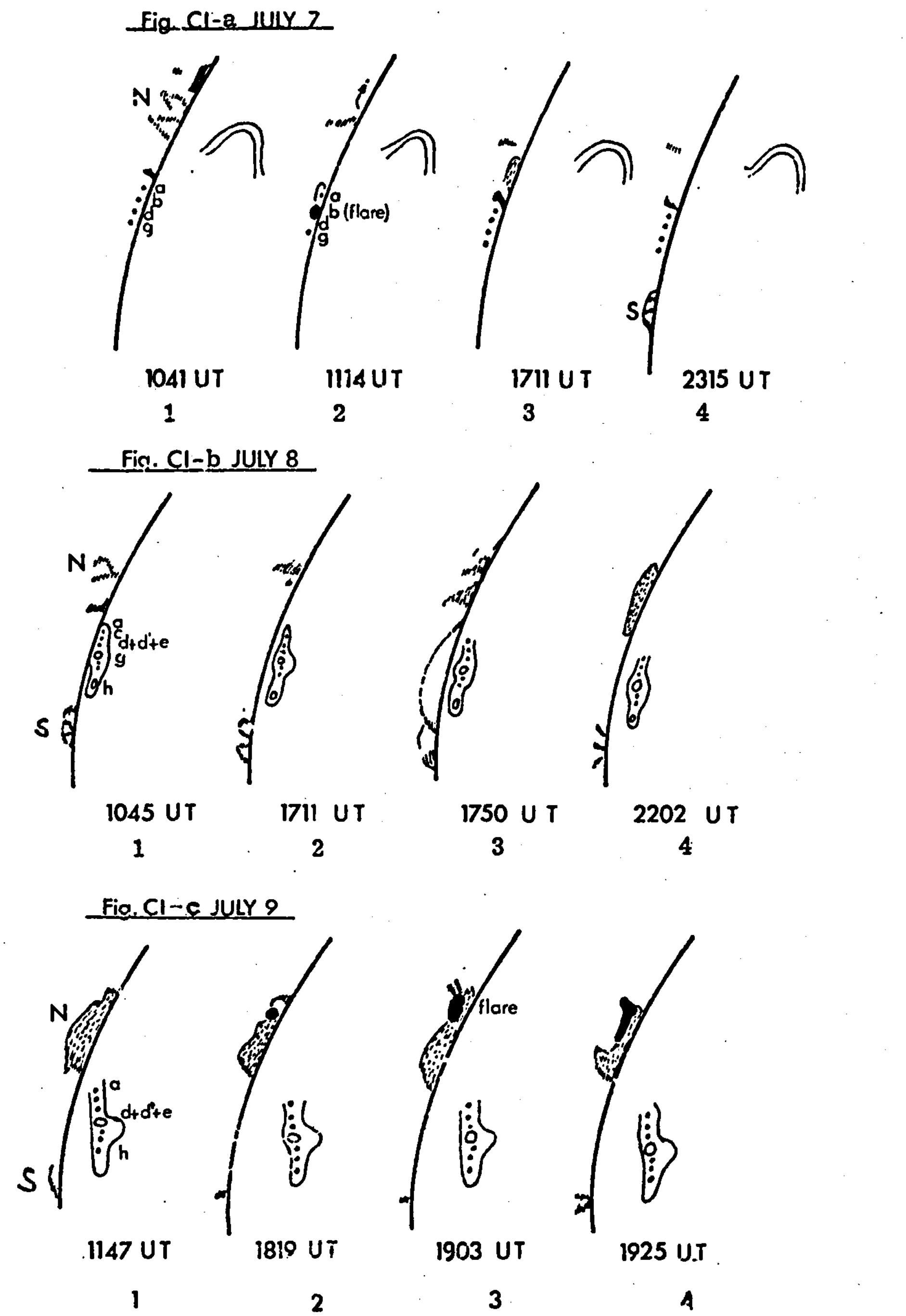



Fig. C1-(a-c). Prominence and flare activity seen at the east limb on July 07, 08 and 09, 1959. The letters a-h indicate repeatedly flaring areas and S and N refer to southern and northern prominences that formed the terminals of a growing accumulation of suspended absorbing material.

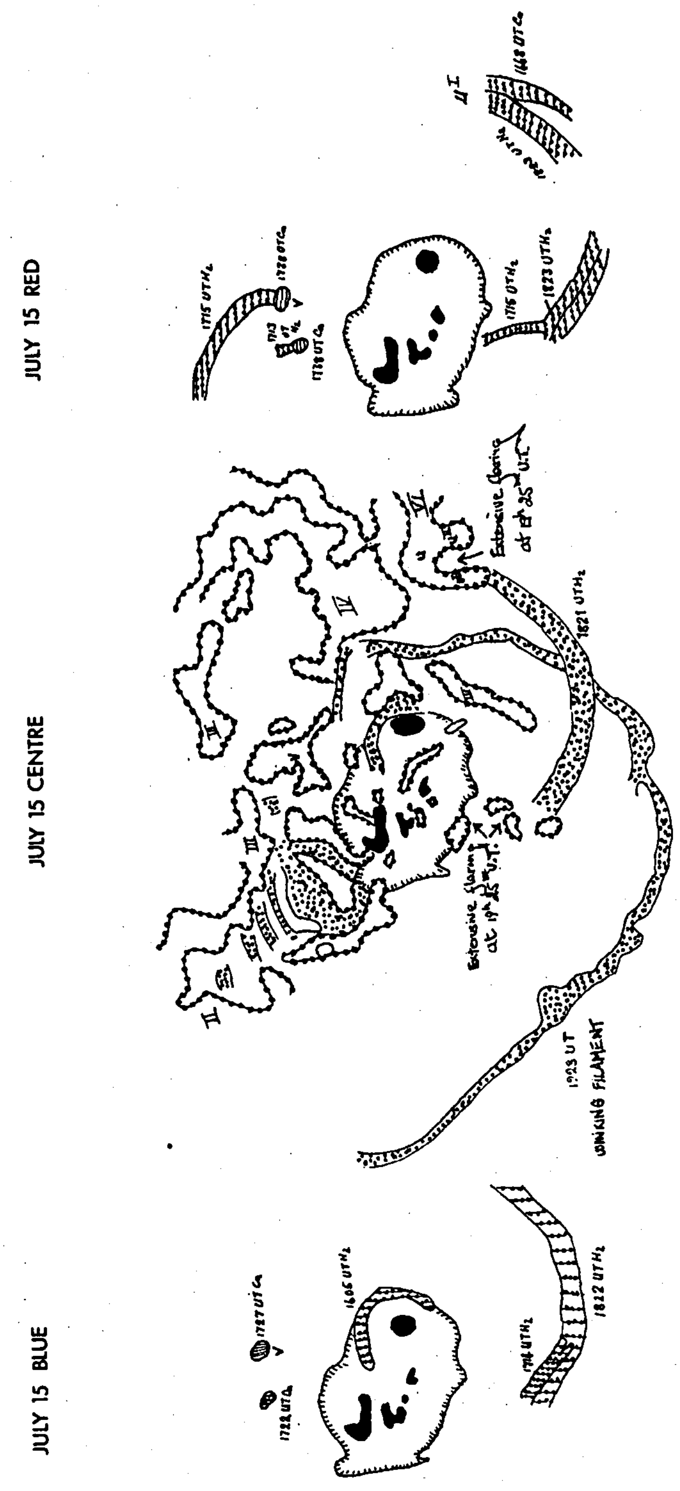



Fig. C2-a. Composite drawings made from swept wavelength Hα and Calcium McMath 20' spectroheliograms, showing variations in the level of prominence and flare activity in 59Q, July 15, 1959.

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## APPENDIX D

### DAY-TO-DAY RELATIONSHIP BETWEEN FLARING IN REGION 59Q AND CHANGES IN UNDERLYING UMBRAE AND PENUMBRAE

#### July 07

On July 07 at the east limb, numerous active prominences preceded the appearance of the principal plage and spots in region 59Q. Mt. Wilson Spot group 14280, magnetic class β in the leading portion of the region appeared on the disk on this day. However, the only material observed over the period of the McMath observations occurred above Mt. Wilaon 14284. This group was still behind the limb on July 07 but its location and spatial relation to flare activity could be deduced from the altitudes of the various elevated brightenings observed.

#### July 08

By July 08, principal magnetic region Mt. Wilson 14284, magnetic class γ had rotated onto the disk and Mt. Wilson 14282, magnetic class α had formed (cf. Table 7.1a, p. 102).

All of the brightenings observed in 59Q on this day using the McMath record occurred above Mt. Wilson 14284. At $13^h\ 30^m$ U.T. a 'Strong' radio burst was associated with the commencement of a Stationary Prominence Flare in areas $d^I$ and e. The active region was still too close to the east limb at this time to determine if associated changes occurred in those umbrae directly underlying the relevant flare active areas. However, this was clearly a day when the pattern of magnetic fields associated with 59Q was showing substantial changes.

#### July 09

On July 09, Mt. Wilson 14285 magnetic class β formed on the disk. The first 'Strong' radio burst of the day occurred at $14^h\ 40.8^m$ U.T. and accompanied the onset of Stationary Prominence Flaring at a, b, c and d directly to the north of the magnetic 'neutral line' in Mt. Wilson 14284. At $18^h\ 10^m$ U.T. a further 'Strong' radio burst accompanied the brightening of prominence material at area b.

Over that period of the McMath observations from $18^h\ 10^m - 21^h\ 09^m$ U.T. some 51 individual impulsive brightenings were observed to occur in diffuse prominence material suspended above group 14284. It was noted that, from $\sim 19^h\ 44^m$ U.T., flaring spread gradually northwards along two 'arms', one oriented north westward and extending towards the position of waxing group 14285, the other oriented north north-eastwards and extending towards a position where Mt. Wilson first identified umbrae (Mt. Wilson group 14297) some five days later on July 14*.

Figure AI-a** shows those areas in 59Q that were bright out of wavelength in the course of this long lived flare. It is seen that a length of prominence material extending roughly from d-g, as well as material above c and b, appeared particularly bright out of wavelength in the wings of the calcium line during flare development. These various bright areas were located directly above Mt. Wilson 14284.

Minor flaring was observed above group 14282 from <$21^h$ $15^m$ U.T. and above group 14285 from $21^h$ $55^m$ U.T. Prominence Flaring was still in progress above group 14284 when the McMath observations ceased at $23^h$ $30^m$ U.T. The whole complex event, which was accompanied (cf. Table 6.3a and also Appendia A1) by fluctuating centimetre wave and Type IV radiation, may be regarded as a 'forerunner' to the importance 3+ proton flare of the following day.

## July 10

The proton flare began at $02^h$ $05^m$ U.T. July 10 with a sudden flash in intensity in c and d accompanied from $02^h$ $06^m$ U.T. by a 'Very Strong' radio burst. Flare excitation spread rapidly so that by $02^h$ $09^m$ U.T. a bright band of emission appeared to stretch above Mt. Wilson 14284 from area a to area h (cf. Fig. A2-a and also Appendix A2).

From $02^h$ $08^m$ U.T. emission began to spread north westwards towards the position of Mt. Wilson 14285; from $02^h$ $17^m$ U.T. emission spread towards the 'inferred' position of Mt. Wilson 14297 (cf. footnote to page 207). From $02^h$ $17^m$ U.T., part of a dark prominence traversing group 14284, and extending southward to terminate in a hedgegrow-like structure, became relatively bright. From $02^h$ $29^m$ U.T. adjacently located flare emission in chromospheric chain V, at a position overlying several minor umbrae, outlined part of the semi-bright material (cf. Fig. A2-a, p. 193). There was a gap in the optical record from $05^h$ $04^m$ - $09^h$ $44^m$ U.T. At the latter time, part of chromospheric chain VI traversing Mt. Wilson 14282 was in emission. It appears from these data that the shape and extent of the major flare was influenced strongly by circumstances relating to previously existing magnetic features.

Between $21^h$ $38^m$ U.T. July 09 - $06^h$ $02^m$ U.T. July 10, that is within an $8.4^h$ interval spanning the flare, the more easterly of the north polar umbrae in Mt. Wilson 14284, namely N21, substantially disappeared. (Compare Fig. 3.1b with 3.1c. See also plate I, McKenna-Lawlor (1979).)

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*The tendency for excitation to extend north-eastwards during this and other important flare events prior to July 14 indicates that elements of group 14297 were already present on the disk as early as July 09.

**See page 192.

Umbra N21 was situated between flare active areas c and d, that is between those positions at which the radio important flare was initiated.*

Another variation in the appearance of the spot group occurred within the same time interval. Several minor umbrae arrayed along the western boundary of the main south polar umbra at a location underlying flare active areas f and g apparently either disappeared or moved southward to form a single large umbra at the southern extremity of the group. Part of the western boundary of the penumbral material surrounding the south polar umbrae had meanwhile become substantially distended westwards (again compare Fig. 3.1b with Fig. 3.1c). It may be noted that not only was this part of Mt. Wilson 14284 covered by brilliant flaring during the early flash phase of the event of $02^h$ $05^m$ U.T. July 10, but areas b, c, d, e, f and g also appeared brilliant and wide in the wings of the line during the preceding long flare of July 09. It seems likely that this latter activity constituted an optical response to magnetic changes taking place in group 14284 as early as $18^h$ $10^m$ U.T. July 09.

Following the disappearance of part of group 14284 there was a considerable diminution in the level of flaring in 59Q as compared with that prevailing on the previous day (19 impulsive brightenings were observed to occur over $\sim 12.5^h$ of McMath observations on July 10 as compared with 51 observed during $\sim 3^h$ of observations on July 09). All of these brightenings occurred above group 14284.

## July 11

On July 11 a north polar umbra, N19, which later developed into a major magnetic feature, was waxing within the eastern penumbra of Mt. Wilson 14284. A relatively minor umbra underlying area d, which constituted on succeeding days a 'satellite umbra' bordering the eastern perimeter of the incipiently large spot, was also becoming well defined on this day. Between the site of the developing umbra and N24, two minor umbrae underlying flare sensitive areas $d^{I}$ and $d^{III}$ were clearly visible.

Over the interval $05^h$ $17^m$ - $14^h$ $47^m$ U.T. July 11, the northern part of N24 was seen to be in course of detaching itself from its 'parent' umbra and the separated portion later migrated southeastwards to ultimately merge with the newly developing 'major' spot. Immediately to the north of this changing feature, the penumbral border, which contained a minor umbra underlying $d^{II}$, showed associated developmental changes.

It is probably significant that brightenings located above the changing magnetic situation at d and $d^{II}$ were associated at $01^h$ $33^m$ U.T. and at $02^h$ $32^m$ U.T., respectively, by the generation of 'Moderate' radio bursts. A further

*Minor umbrae and ambient penumbral structure underlying b and c disappeared between $18^h$ $00^m$ July 09 - $06^h$ $02^m$ July 10. Since minor umbrae are difficult to identify unambiguously on the swept wavelength records it is not certain if these magnetic features were present on the spectroheliogram of $21^h$ $38^m$ U.T. when umbra N21 was still clearly visible.

'Moderate' radio burst at $04^h\ 49^m$ U.T. was associated with a brightening in area d alone.

The last 'Moderate' burst of the day at $23^h\ 14^m$ U.T. was associated with flaring above Mt. Wilson 14285. The contrast on the available white light pictures at this location was not sufficiently good on July 11-12 to determine if associated magnetic changes took place within the spot group.

Another feature of July 11 was the development of a 'crescent' of minor umbrae surrounding the western perimeter of S28 (cf. Fig. 3.1d, p. 28). These minor umbrae were located beneath areas k, $k^I$ and $k^{II}$ which had become flare active since the previous day.

## July 12

Between $14^h\ 47^m$ U.T. July 11 - $05^h\ 11^m$ U.T. July 12, the important north polar umbra described as 'waxing' on July 11 enveloped that minor umbra underlying area $d^{III}$. A fragment of N24 seen separating from its parent spot on July 11, appeared to merge with the still growing umbra between $< 05^h\ 11^m$ - $14^h\ 49^m$ U.T. July 12. Further, newly born satellite umbrae underlying $d^{IV}$ and $d^V$ were visible along the eastern perimeter of the developing spot.

Mt. Wilson reported the appearance of group 14292, magnetic class $\alpha$ on this day but no associated flaring was detected above its component spots during the period of the McMath observations.

The changing magnetic situation on July 12, occasioned by the merging and growth of the various umbrae described above, was marked by the initiation, at this general location, of several Prominence Flares accompanied by 'Moderate' burst activity. The first such event at $04^h\ 25^m$ U.T. began with simultaneous brightenings in d, $d^I$ and $d^{IV}$. Three succeeding events at $06^h\ 28^m$ U.T., at $13^h\ 14^m$ U.T. and at $14^h\ 05^m$ U.T. commenced with the brightening of area d alone. In the case of the latter event, flaring spread from $< 14^h\ 19^m$ U.T. along chromospheric chain III towards the position of Mt. Wilson 14285. A further 'Moderate' burst, accompanying Prominence Flaring at $22^h\ 07^m$ U.T. above group 14284, was associated with a subsequent spread of excitation towards Mr. Wilson 14285 as well as towards the inferred position of Mt. Wilson 14297 (cf. footnote to page 208). The seeing on the white light pictures for July 12-13 was not sufficiently good at the positions of these latter groups to determine if associated magnetic changes took place there or not.

A significant magnetic feature on July 12 was that the leading edge of the main umbra of south polarity S28 began to protrude westwards on this day. As a result, between $14^h\ 49^m$ July 12 - $05^h\ 03^m$ July 13, a 'daughter' umbra separated from the main complex and started to migrate westwards, still surrounded (cf. notes for July 11) by a crescent of minor umbrae. Further minor umbrae were meanwhile developing immediately to the west of this separating feature, that is underlying newly flare active areas l, $l^I$ and m. It is possible that the multiple site Prominence Flare of $22^h\ 24^m$ U.T. which involved $e^I$, k, $k^{II}$, f, g, l, and m, that is areas above sites surrounding and preceding the separating south polar umbra, was associated with the actual separation of this magnetic feature from the main group. It may be noted that area $e^{I}$, which was positioned above a minor umbra located at the 'break point', appeared to be outstandingly brilliant.*

## July 13

On July 13, the bulk of impulsive flaring appeared to be associated with satellite umbra d (to the east) and satellite umbrae $d^{IV}$, $d^{IV}_{I}$ and $d^{V}$ to the west of the still developing major umbra N22 in group 14284. There was also a high level of flaring above an umbra underlying $d^{I}$ situated along the eastern boundary of N14. Only one 'Moderate' burst, accompanying a brightening in prominence material at d, was associated with flaring in 59Q on this day.

South polar umbra S24 migrated further westwards on July 13 with minor umbrae underlying flare active areas $k^{I}$, k, $k^{II}$, $k^{III}$, f and g forming a well defined 'crescent' about its leading edge. Those minor umbrae underlying l, $l^{I}$, m, $m^{I}$, $o^{III}$ and $o^{I}$ formed a configuration which, by < $16^{h}$ $41^{m}$ U.T., July 14 when the components at l and $l^{I}$ had faded, essentially comprises a second 'crescent' of umbrae preceding S24.

Between $15^{h}$ $50^{m}$ U.T. July 13 - $05^{h}$ $14^{m}$ U.T. July 14, a 'penumbral arm' containing several minor umbrae developed at the southeastern extremity of group 14284. Minor flaring occurred at q and $q^{I}$ above the positions of two of these umbrae by at least $17^{h}$ $36^{m}$ U.T. on July 13. Also, on this day minor impulsive activity was observed above umbrae in Mt. Wilson 14292.

## July 14

On July 14 Mt. Wilson first identified group 14297 on the disk and designated it to be of class x, since no polarities were associatively measured. Within the interval $15^{h}$ $50^{m}$ July 13 - $05^{h}$ $14^{m}$ July 14, in addition to a 'penumbral arm' already mentioned as having developed along the southern border of Mt. Wilson 14284, the first members of an aggregation of minor umbrae (described in Section 7.1 as Spot group A) emerged to the south of this magnetic complex. These spots were not assigned a special group number by the Mt. Wilson observers and were presumably included by them with the umbrae of group 14284. The magnetograms, however, show that these spots were located on the southern side of a magnetic 'neutral line' arrayed along the southern border of the major group and that the several umbrae concerned collectively displayed 'north' polarity.

July 14 was marked by the occurrence of an importance 3+ Stationary Prominence Flare accompanied by the generation of a 'Very Strong' radio burst.

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*An observation taken at Mt. Wilson on July 18, cf. Fig. 7.1a, p. 126, indicates that S28 was in fact moving away from the position of a north polar umbra 'nested' among the south polar spots.

The first areas to brighten in the course of this complex event were c and d at <$03^h$ $27^m$ U.T. By <$03^h$ $33^m$ U.T. related excitation extended from $c^I$ to $d^I$ to the north and as far as separating S23 to the south of the magnetic 'neutral line'. Thereafter, as in the case of the importance 3+ event of July 10, excitation did not spread at random but rather followed the locus of chromospheric chains towards the sites of groups 14285, 14297, 14282 and Spot group A (cf. development pattern illustrated in Fig. A3-a, p. 194). Thus the shape and extent of the major flare appeared to be influenced by circumstances relating to previously existing magnetic features.

Between $19^h$ $14^m$ July 13 - $05^h$ $14^m$ July 14, that is over a $10^h$ interval spanning the major flare, umbra N26 between areas d and $d^{IV}$ showed a marked diminution in area. The records generally convey the impression that a 'sliver' along the southern extremity of this north polar umbra had become separated from its parent and was lying in the 'gap' between N26 and S22 (cf. Fig. A4-a). The south polar part of the group was meanwhile gradually breaking up. A new umbra between S23 and the fragmenting umbrae of the main south polar group formed a rapidly growing feature during this day. Emission at <$13^h$ $33^m$ U.T., three minutes after the onset of the 'Very Strong' burst accompanying the major flare, extended from $c^I$ as far westwards as S23, thus including in the early flash phase those positions within which magnetic changes were known to occur.

Following the importance 3+ event there was a general drop in the level of flaring above this part of the group and no further centimetre burst associated flares occurred there during July 14. Instead, centimetre burst associated activity appeared to accompany flaring lying on either side of the magnetic 'neutral line' separating the southern penumbral boundary of group 14284 from developing Spot group A.

Multiple site brightenings in this part of the region at $11^h$ $45^m$ U.T. and $17^h$ $34^m$ U.T. were accompanied by 'Moderate' and by 'Strong' bursts, respectively. The only areas common to these two flares were q and $q^I$ to the north of the magnetic 'neutral line'. A further 'Strong' radio burst at $22^h$ $24^m$ U.T. accompanied brightenings in $q^I$, $q^{II}$, s and $s^I$. The brightenings at s occurred within an ambient dark cone of absorption material and was accompanied by the sudden disappearance of this cone. At $22^h$ $27^m$ U.T. an extensive flash took place in prominence material suspended above p, q, $q^I$, $q^{II}$ and $q^V$ to the north of the magnetic 'neutral line', followed from $22^h$ $28^m$ - $22^h$ $29^m$ U.T. by brightenings above $s_I$ and $q^{IV}$ to the south of this line. This extensive prominence event endured long after emission had faded above area s.

Over an interval spanning the 'Strong' burst associated flares, that is, between $16^h$ $41^m$ July 14 - $04^h$ $40^m$ July 15, the umbra underlying area q together with its ambient penumbra substantially disappeared while a further umbra underlying area p became greatly reduced. Meanwhile, a minor umbra emerged beneath area s within penumbral material which also contained 'new' umbrae underlying $s^I$, $s^{II}$ and $s^{III}$.

## July 15

On July 15, the several north polar umbrae in group 14284 appeared to be merging together over the interval $07^h\ 47^m$ - $16^h\ 17^m$ U.T. to form a single composite umbra. The south polar umbrae were meanwhile migrating further apart. Minor umbrae underlying $k^{IV}$, t, tI, $t^I$, $t^{II}$, $t^{III}$ to the south of the 'stretching' magnetic 'neutral line' were waxing on this day as was also an umbra underlying $d^{VII}$ on the northern side of this line. There were also changes during the day in the penumbra immediately to the north of S25 where several minor umbrae started to develop, underlying $k^V$ and $k^{VI}$, between $16^h\ 17^m$ U.T., July 15 - $05^h\ 01^m$ U.T., July 16.

Area $d^{IV}$, which was situated above that position where the sliver of umbra seen to be definitely separate from N26 on the previous day was now gradually merging with the large umbra, appeared particularly flare active on this day. So also did areas $d^{VII}$ and $k^{IV}$.

A long lived, multiple site, Stationary Prominence Flare with accompanying 'Moderate' bursts at $12^h\ 57^m$ U.T. and $13^h\ 00^m$ U.T. and a 'Strong' burst at $13^h\ 27.5^m$ U.T. appeared bright in the wings of the K line above d, $d^{IV}$, $d^{VII}$, m and $k^{II}$ at $12^h\ 59^m$ U.T. (cf. Fig. A5-a, p. 197) (note that $k^{II}$ was situated above a minor umbra immediately to the north of S25). The drawing also shows that part of the prominence material located directly between umbrae N28-25 and S27 was bright in the wings of the K line at $12^h\ 59^m$ U.T. although it was not in emission at line centre.

A further 'Moderate' burst at $16^h\ 06.9^m$ U.T. was associated with brightenings in $d^{VII}$ and $k^{IV}$ to the north and south, respectively, of the same magnetic 'neutral line'. A more spectacular, multiple site, event involving flaring above the composite north polar umbra to the north, as well as above newly developed south polar umbrae to the south, of this 'neutral line', began in association with yet another 'Moderate' burst at $22^h\ 40^m$ U.T.

On July 15 at $06^h\ 44^m$ U.T., a 'Strong' radio burst was associated with the rise time of a 'reported' importance 1 flare in 59Q. No film record is available of this event. However, a drawing of the flare at $07^h\ 05^m$ U.T., obtained from the University of Istanbul, indicates that, at that time, activity was in progress in the vicinity of $q^I$ and $q^{II}$, to the north, and of s, $s^I$, $s^{II}$ and $s^{III}$ to the south of a magnetic 'neutral line' separating Mt. Wilson 14284 from Spot group A. Within the interval $04^h\ 40^m$ - $16^h\ 17^m$ July 15 those umbrae underlying $q^I$ and $q^{II}$ had greatly diminished.

A further 'Strong' radio burst accompanying brightenings in $q^V$, $q^{VI}$, to the north, and in $q^{VIII}$, s, $s_I$, s, $s^I$, $s^{II}$, $s^{III}$, $s^{IV}$ to the south of the same 'neutral line' occurred at $19^h\ 25^m$ U.T. There was also a simultaneous flash above chromospheric chain VI at the western terminus of a dark filament suspended between Spot group A and the umbrae of Mt. Wilson 14292.* July 15 was a day of change along the southern penumbral boundary of group 14284 and in Spot

*Cf. footnote to p. 189.

group A. In addition to the fading of umbrae at $q^{I}$ and $q^{II}$ already mentioned, umbrae were waxing at $q^{V}$ and $q^{VI}$ along the southern border of group 14284. On the other side of the 'neutral line' an umbra at $q^{VII}$ was also waxing.

Between $16^{h}\ 17^{m}$ July 15 - $05^{h}\ 01^{m}$ July 16 penumbral material enveloping s, $s^{I}$, $s^{II}$ and $s^{III}$ became internally structured rather than diffuse while material adjacent to $q^{V}$ and $q^{VI}$ disappeared. Further westwards, umbrae along the border of group 14284 appeared to be situated in penumbral material which was in course of separating from the main group, while a separate 'island' of penumbra containing several new south polar umbrae formed to the south of S25.

The contrast is not sufficiently good on the white light pictures to determine if magnetic changes were taking place in the umbrae of Mt. Wilson 14292 underlying chromospheric chain VI.

A feature of July 15 was the emergence to the north of Mt. Wilson 14284 of a scatter of umbrae which were not assigned any special number by Mt. Wilson but are referred to in the present text as Spot group B (cf. description of the designation in Section 7.1). Area v, overlying one of these emerging umbrae, showed a high level of impulsive flaring over the period of the McMath observations but none of the recorded brightenings appeared to be associated with the generation of radio burst activity.

## July 16

On July 16, the north polar umbrae continued to consolidate while the south polar umbrae continued to gradually grow further apart. Spot group B now contained several quite large umbrae, one of which was determined at Mt. Wilson to be of polarity and field strength N17. As already indicated, several umbrae waxed in size along the southern extremity of group 14284 and to the south of S25 between July 15-16, while Spot group A appeared enveloped in a more structured penumbra.

Two 'Moderate' bursts were associated with a Prominence Flare which began at $06^{h}\ 37^{m}$ U.T. with brightenings in d, $d^{I}$ and $d^{IV}$. At $13^{h}\ 51^{m}$ U.T. a further 'Moderate' burst was associated with flaring in prominence material suspended above umbrae in Spot group B and in Mt. Wilson 14297. Part of this flaring material appeared bright and conspicuous out of wavelength. The umbrae in Spot group B showed considerable changes between $05^{h}\ 01^{m}$ July 16 - $04^{h}\ 42^{m}$ July 17. The contrast at the position of Mt. Wilson 14297 was not sufficiently good to determine if associated magnetic changes took place there or not.

The most important flare of the day was an importance 3 event accompanied by a 'Very Strong' radio burst. This began between $21^{h}\ 14^{m}$ - $21^{h}\ 16^{m}$ U.T. with brightenings in the plage at $d^{IV}$, d and $e^{I}$-$e^{I}_{I}$. At $21^{h}\ 18^{m}$ U.T. a flash occurred in prominence material suspended above d and $d^{IV}$ and a bright segment quickly formed extending from $c^{I}$-$d^{I}$. Simultaneously, Prominence Flaring began at $e^{I}$-$e^{I}_{I}$ and at $k^{III}$. It may be noted that $e^{I}_{I}$ was located above a minor umbra which appeared within the interval $16^{h}\ 17^{m}$ July 15 - $05^{h}\ 01^{m}$ July 16. Emission spread eastwards and westwards from above this general location to form a long bright flare filament (cf. details in Appendix B). Meanwhile, emission above $k^{III}$ spread rapidly across S28 towards the position of those newly formed umbrae immediately to the south of it (which were previously mentioned). Later, flaring spreading westwards from $e^I$ united with that flaring taking place in the vicinity of S28.

The subsequent development of the optical event was such that excitation spread north-eastwards to umbra N17 in Spot group B and then further westwards towards the position of the umbrae of Mt. Wilson 14282. Excitation also extended north-eastwards towards the position of Mt. Wilson 14297. The development of the flare (cf. Fig. B1-b, p. 203) did not thus take place at random but was influenced by previously present magnetic features. (See below, July 17, for an account of changes in underlying spot umbrae.)

The only other radio important event which occurred in 59Q on this day was a Stationary Prominence Flare which began in areas s and $s^{II}$ at $16^h\ 04^m$ U.T. in time association with a 'Moderate' radio burst. Brightenings in $q^I$, $q^V$ and $q^{VI}$ along the penumbral border of group 14284, and in s, $s^{II}$ and $s^{III}$ above the umbrae of Spot group A, took place at $16^h\ 10^m$ U.T. at the time of yet another 'Moderate' burst. During the same flare, a 'Strong' radio burst occurred at $16^h\ 13^m$ U.T. that is, during a cloud gap on the SECASI record. At $16^h\ 17^m$ U.T. extensive flaring was not only seen to be in progress to the north and south of the 'neutral line' separating group 14284 from group A but also (cf. Fig. A6-a, p. 199) above certain of the umbrae of group 14292. (See below for an account of changes in underlying spot umbrae.)

## July 17

Between $21^h\ 20^m$ July 16 - $04^h\ 42^m$ July 17, that is, over a $7.4^h$ period spanning the proton flare, there was a diminution in the area of the composite north polar umbra located between d and $d^{IV}$. Also, umbrae located immediately to the north and south of S28 disappeared and those underlying areas $e^I$ and $e^I_I$ faded substantially. Two minor umbrae meanwhile waxed a little to the west of the latter faded pair. All of the magnetic changes described took place beneath positions seen to go into emission during the opening minutes of the flash phase of the major optical event. It may be noted that between July 16-17 a large "island" of penumbra containing westward migrating umbra S28, a waxing south polar umbra underlying area $k^{IV}$ and an adjacent small north polar umbra separated from group 14284. Thereafter this magnetic entity continued to remain separate from the main complex.

The umbrae of Spot group A also appeared greatly reduced between $05^h\ 01^m$ July 16 - $04^h\ 42^m$ July 17. This change had already taken place in the neighbourhood of the umbrae underlying s and $s^I$ between $05^h\ 01^m$ - $17^h\ 11^m$ July 16. However, seeing on the latter picture is not sufficiently good to be certain if there was also a reduction in those umbrae underlying $s^{II}$ and $s^{III}$.

The further decline of the magnetic fields at Location 2 was marked on July 17 by the onset there of a multiple site Prominence Flare at $13^h\ 39^m$ - $13^h\ 40^m$ U.T. This event, which was accompanied by a 'Moderate' radio burst, occurred at $q^V$ to the north and in several areas to the south of the 'neutral line' dividing Mt. Wilson 14284 from Spot group A. To the north of this line and over the interval $04^h\ 42^m$ July 17 - $04^h\ 47^m$ July 18, two large south polar umbrae with their ambient penumbra, including the minor umbra underlying $q^V$, separated from the main body of Mt. Wilson 14284 to form a separate magnetic "island" migrating westwards*. There was also a marked decline in the appearance of Spot group A within the same period.

Over the sunlit hours at the McMath Observatory on July 17, the bulk of impulsive flaring occurred either in the vicinity of S26 or in association with the scatter of umbrae comprising Spot group B. There was also a vestige of a revival of activity in Mt. Wilson group 14285.

## July 18

No McMath observations were available on July 18. However, using the CSM, impulsive flaring was observed on a number of occasions above Mt. Wilson 14285 in association with metre burst activity. Also, one such brightening at $10^h\ 48^m$ U.T. was associated with the onset of a 'Strong' radio burst. On this day, region 59Q was too close to the western solar limb to determine if associated umbral changes occurred.

Two additional radio bursts, one 'Strong' at $17^h\ 54.5^m$ U.T., the other 'Moderate' at $18^h\ 11^m$ U.T., occurred in prominence material extending southwards towards area s in Spot group A. Again, the region was too close to the west limb on July 17 to determine if associated umbral changes occurred.

## July 19-21

With the exception of minor activity in s above Spot group A, the bulk of flaring in 59Q on days July 19-21 was located above Mt. Wilson 14285. July 21 marked the day when region 59Q transited the west solar limb.

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*This cleavage occurred immediately to the west of north polar umbra R3, cf. Fig. 7.1a, p. 126.

## SYNOPSIS

Region 59Q comprised an anomaly in the solar atmosphere which was studied during its entire disk transit July 07-21, 1959 (C.M.P. N 15$^\circ$ on July 14).

At the photospheric level it consisted of an aggregate of groups of sunspots of which one group, Mt. Wilson 14284, displayed in its complexity and behaviour all of the attributes known to be typical of solar regions associated with the production of major flares.

A special characteristic of 59Q was its capability to eject dark material. Part of this material remained trapped in the strong magnetic fields above group 14284. Here it formed a 'nested' system of interrelated arches, the legs of which, it was deduced, passed through components of the bright chromospheric network of the plage and were rooted in underlying umbrae. In that channel separating the major umbrae of north and south polarity, the 'feet' of the innermost arch were rooted in minor spots, some of which were satellites to major umbrae. Further to the west within the group, the suspended material was characterized, after CMP, by the presence of several well-defined slender filaments which individually represented components of a system of tunnelled arches spanning 'avenues' of minor spots. A diffuse surrounding matrix of trapped material represented part of the superposed 'crest' of this related system. The suspended dark prominence extended to the east and west of group 14284 in well-defined filamentary 'arms' the termini of which were rooted in members of the various surrounding 'satellite' sunspot groups composing the composite active region.

Two apparently different types of optical flare were identified in 59Q, namely Plage Flares, which comprised brightenings within part of the chromospheric network, and Prominence Flares which comprised brightenings within suspended dark prominence material. Some 807 brightenings within the plage were identified in 59Q over 136.1$^h$ of McMath SECASI observations. Prominence Flares were of three varieties classified as Impact, Stationary and Moving Prominence Flares, respectively. Many Prominence Flares tended to be long lived events showing multiple intensity increases, some of which comprised enhancements within already flaring material. It was decided to consider intensity fluctuations within already flaring material as part of earlier complex events rather than to count individual brightenings separately. In this way a total of 8 composite Impact Prominence Flares, 10 composite Stationary Prominence Flares and 1 composite Moving Prominence Flare were identified in 59Q during its July disk passage.

Plage Flares appeared to be low energy events accompanied in <3% of cases by the generation of Type III bursts. Impact Prominence Flares were apparently unaccompanied by the production of energetic electromagnetic or proton radiation. Stationary and Moving Prominence Flares were variously associated at their times of onset or enhancement with the production of different kinds of single and swept frequency radio bursts, ionizing events, geomagnetic storms and PCA and GLE protons. The generation of at least impulsive radio and ionizing radiation is apparently more closely associated with the involvement of absorbing material in flaring than it is with flare magnitude. Given the presence of flaring absorbing material, however, there appears to be a relationship between increasing optical importance and area of reported flares and the associated generation of progressively more energetic electromagnetic and proton radiation.

At least 87.5%, and probably all of the impulsive brightenings observed in 59Q, began directly above minor spots, many of which were satellites to major umbrae. These magnetic features were aligned in chains along the locii of zero or of very low values of the longitudinal magnetic field (that is bordering long lengths of suspended filamentary material). Alternatively, impulsive brightenings commenced above satellite spots situated within 10" of such positions.

Stationary and Miving Prominence Flares were triggered at sites beneath which magnetic variations occurred within time intervals which included the flash phase of each event identified. These 'bridging' intervals never exceeded approximately 1 day and showed in at least one case a duration of less than 7.4 hours. The magnetic variations observed included disappearing magnetic structure, emerging magnetic flux and disjunctions within magnetic material. There is some evidence that local magnetic changes were already in progress either prior to or at the onsets of many of the flares concerned.

The data convey the impression that magnetic variations in a minor umbra at the 'foot' of a prominence arch were associated with the triggering of Prominence Flaring. If the magnetic change was not very great, flaring remained confined to the 'overhead' position. In cases of more profound disturbance, as when an adjacent major umbra either disappeared or showed a marked diminution in area, Prominence Flaring spread rapidly to also cover the large changing umbra. Three such events (proton flares on July 10, 14 and 16) commenced above Mt. Wilson group 14284. Emission thereafter spread only along the loci of chains of the chromospheric network (that is in association with their component 'moderate' magnetic fields) towards the positions of outlying satellite spot groups.

Strong fields and steep gradients in the underlying magnetic field did not appear to be generally necessary for the production of optically important Prominence Flaring but there appeared to be a correlation between the magnitude of the magnetic change taking place and the 'energy importance' of the Prominence Flare produced.

Plage Flares were not confined to intervals defined by identifiable variations in magnetic structure but they none the less occurred above positions having a 'history' of magnetic instability. They were produced approximately 18 times more frequently than were centimetre burst associated Prominence Flares and were never observed to spread to cover major umbrae.

Although the release of magnetic instabilities at specific locations in 59Q might have been responsible for producing those various electromagnetic and particle phenomena detected at flare times, it is possible than changes in magnetic structure and the sudden releases of energy occurring at flare times may have represented individual responses to some fundamental type of subphotospheric disturbance which is as yet not understood.

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15. SUPPLEMENTARY NOTES

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16. ABSTRACT


A comprehensive investigation was made of phenomena attending the disk passage, July 07-21, 1959, of active solar center HAO-59Q. At the photospheric level this comprised an aggregate of groups of sunspots of which one group, Mt. Wilson 14284, showed all the attributes deemed typical of solar regions associated with the production of major flares.

A special characteristic of 59Q was its capability to eject dark material. Part of this material remained trapped in the strong magnetic fields above group 14284 where it formed a system of interrelated arches, the legs of which passed through components of the bright chromospheric network of the plage and were rooted in various underlying umbrae.

Two apparently different kinds of flare were identified in 59Q; namely, Prominence Flares (which comprised brightenings within part of the suspended dark prominence) and Plage Flares (which comprised brightenings within part of the chromospheric network). Prominence Flares were of three varieties described as 'Impact', 'Stationary' and 'Moving' Prominence Flares respectively. Impact Prominence Flares were apparently low energy events of subflare brightness, unassociated with the generation of either radio, ionizing or proton radiation. On the other hand, Stationary and Moving Prominence Flares were variously associated at their times of onset or enhancement with the production of different kinds of single and swept frequency radio bursts, ionizing events, geomagnetic storms and PCA and GLE protons. The observations indicate that, within the compass of the sample studied, flare particles were accelerated over a range of energies extending from $\leq$ 10 keV in the case of those electrons producing soft X-ray emissions to > 1 GeV in the case of those protons producing ground level effects. Plage Flares were accompanied in < 3 percent of cases by Type III bursts. These latter radio events indicate the associated passage through the corona of energetic electrons in the approximate energy range 10-100 keV.

At least 87.5 percent, and probably all, impulsive brightenings in 59Q began directly above minor spots, many of which were satellites to major umbrae. Stationary and Moving Prominence Flares were individually triggered at sites beneath which magnetic changes occurred within intervals which included each flare's flash phase. The relevant 'flare bridging' intervals are known to have never exceeded ∿ 1 day, and in at least one case had a duration of < 7.4 h. There appeared to be a correlation between the magnitude of the magnetic change taking place and the energy importance of the flare produced. There is some evidence that local magnetic instability was already present either prior to, or at the time of onset of, many of the Prominence Flares concerned. Plage Flares, although not confined to intervals spanning identifiable change, took place above sites with a 'history' of magnetic instability.


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