Compilation of

SCIENTIFIC OBJECTIVE portions

of Ames Research Center study contracts on a Solar Probe and a short report on "Particle and Fields Experiments for a Solar Probe."

submitted to Solar Physics
Subcommittee members Nov. 1-2, 1963

"PARTICLE AND FIELDS EXPERIMENTS
FOR A SOLAR PROBE"

By Dr. E. N. Parker

N65-29515

Particle and Fields Experiments for a Solar Probe

It is to be expected that the next few years will yield a fairly broad and quantitative description of the behavior of particles and fields in the vicinity of the orbit of Earth from times of minimum solar activity to maximum. Such quantitative observational information should go a long way toward providing a picture of what is going on in space near the annual path of Earth. It will be possible to go much further than at present in constructing a quantitative model of the expanding solar corona, which supplies the solar wind, and of the extended solar magnetic field, which provides the interplanetary magnetic field along which energetic particles tend to propagate.

In spite of this quantitative progress, however, there will remain outstanding several qualitative questions which can be answered only by observations of particles and fields far inside and/or outside the orbit of Earth, and far from the plane of the ecliptic. The most fundamental questions will be got at by observations to some relatively small fraction of an astronomical unit from the sun. This is not to say that observations out of the plane of the ecliptic, or to some distance such as 3 AU outward from the sun, would not be extremely interesting and provide much important information concerning the polar corona, the evolution of the magnetic fields in the solar wind beyond Earth, and the effect on galactic cosmic rays and energetic solar particles. But the more basic questions of the structure of the solar corona and the origin of its energy supply, the development of the blast waves that produce magnetic activity and often trap energetic solar particles, the origin and development of the turbulence indicated by the interplanetary field fluctuations at 1 AU etc. are to be pursued by a vehicle traveling inward toward the sun.

To elaborate these questions and illustrate the kinds of experiments that should be carried out on a solar probe, consider the structure of the corona. There are a number of observational results which suggest that the solar corona may perhaps consist of a large number of fine streamers and filaments instead of being a more or less smooth and homogeneous atmosphere. If such fine streamers exist, they would be expected to preserve their identity out to perhaps half an astronomical unit into space. Indeed, the radio observations of Hewish give direct indication of some kind of radial structure in the corona out at least to 0.4 AU. Thus there is every reason to expect that if the corona is principally a collection of fine streamers, a solar probe to, say, 0.3 AU should find direct evidence in the behavior of the plasma and magnetic fields. Calculations suggest that fine streamers may lead to a large amount of disorder in the interplanetary magnetic field when they break up at larger distance from the sun and lose their identity. The break up of any fine streamers in the corona must be complete by 0.7 AU, since Mariner II found no direct evidence for individual fine streamers in the solar wind.

A question that is a little more subtle but hardly less important to a complete understanding of coronal heating and expansion is whether the solar corona is heated actively by the dissipation of waves to some very large distance into space. The alternative is that the corona is heated actively to 10^6°K only in a relatively thin region at its base, with thermal conduction transporting the energy outward from there. Recent calculation by Scarf and Noble show that it is not unreasonable to assume the latter, i.e., the Mariner data on the solar wind can be fitted with a pure conduction model of the corona. But on the other hand the observations of temperature and density are nowhere so precise as to rule out active heating by wave dissipation to some very large distance into space.

The development of the blast waves, and their attendant magnetic field configurations, responsible for magnetic storms, cosmic ray decreases, trapping of energetic solar particles etc., is presently known only from the most idealized calculations. Direct observation from a position close to the sun is essential to an understanding of the origin of these blasts. We presently do not know at what elevation in the corona, 0.01 - or $2.R_{\odot}$, the waves originate. Until the elevation is determined, the energy supply responsible for the explosion remains a matter of conjecture. The energy supply is of particular importance to the theory of the solar flare, since the blast wave seems to carry away the major portion of the energy associated with the flare phenomenon. Close observation of the blast wave and its field configuration in space should help to clarify some of the questions of the origin of the waves.

Finally, we note that the propagation of energetic solar particles outward, and around, the sun is an interesting phenomenon in itself, besides giving a large amount of information on the general configuration of the interplanetary magnetic field. For instance it is not known whether the particles produced in association with a solar flare come out into space along a narrow cone of field, and subsequently spread out when their radial progress is impeded at distances of 1 AU or more, or whether they are broadly released with considerable time delay from the sun.

Now a solar probe to 0.3 AU carrying a suitable plasma detector should go a long way toward answering these qualitative questions, besides providing, of course, a wealth of quantitative data that is otherwise unavailable. The plasma detector should give directional information, for the study of blast waves, as well as the density and mean bulk velocity of the plasma. If at all possible the plasma detector should provide quantitative information on the rms velocity of the plasma ions in the frame of reference of the bulk motion. It would be extremely valuable if one could measure the electron temperature of the plasma, but no method has yet been devised.

The magnetometer should measure vector fields with a sensitivity of 0.2×10^{-5} gauss and an absolute accuracy of 0.5×10^{-5} gauss.

The energetic particle detectors should observe protons, alpha particles, and electrons over as much of the range of 1 - 1000 Mev as possible, but in any case protons and alphas in 50 - 500 Mev.

Telemetering limitations at the large distances involved will mean that only an extremely small fraction of the time resolved data available from the experiments can be used. Since part of the importance of the experiments is to look for small scale (i.e., rapid fluctuation) effects, some provision should be provided for data storage for a rapid sampling mode of operation. Such a mode would be used only occasionally unless the information gained should be so startling as to suggest otherwise.

The data obtained while the solar probe was around toward the other side of the sun may be as valuable an aspect of the probe in exploring the propagation of energetic particles as its close approach to the sun.

The question naturally arises as to the closeness of approach to the sun to make a solar probe of scientific value. It is obvious, of course, that for a given set of instruments the closer to the sun, the more decisive and comprehensive will be the information from the probe. On the other hand, the technical difficulties (i.e., dollars, delay, and failure) of the more advanced rocket systems, heat shields, and power supplies needed for approach to 0.1 AU argue strongly against attempting a very close approach right away. Thus, just as we believe there is no justification for launching a solar probe at all until the experiments carried by the probe have been carried out, and conditions fully measured, near the orbit of Earth, so also do we believe that there is no justification for going beyond present technical capabilities of about 0.3 AU until conditions in to 0.3 AU have been fully explored.

E. N. Parker
6 August 1963

N65-29516

GENERAL ELECTRIC COMPANY

MISSILE AND SPACE DIVISION

VALLEY FORGE SPACE TECHNOLOGY CENTER

VALLEY FORGE, PENNSYLVANIA

3.1 INTRODUCTION

The sun, a typical star, dominates the interplanetary environment throughout its solar system. Besides the fact that it comprises most of the material of the solar system and serves as the principal energy source, it affects the spatial and temporal distribution of the interplanetary medium, and indeed serves as a continuous but highly variable source of plasma which expands throughout the solar system. The distribution of the interplanetary dust is to a large extent determined by the solar gravitational and electromagnetic radiation fields. The ionization of neutral interplanetary gas occurs due to solar ultraviolet radiation and possibly from charge exchange from the solar plasma wind.

Close to the sun, the solar magnetic field controls the motion of charged particles. Energetic particles accelerated in chromospheric flares may be temporarily trapped before being released into the outer weak field regions. Plasma streams emitted from active regions may be strongly affected. Temperatures and densities in the solar corona serve as the boundary conditions for the interplanetary plasma, which in this region is just beginning its expansion. Proceeding out from the near neighborhood of the sun, the solar magnetic field weakens, and is carried by the plasma wind to the outer reaches of the solar system. Some systematic average structure of the distant solar field must be discernible which serves to modulate galactic cosmic ray intensities and to guide energetic solar particles accelerated in the chromosphere.

The impingement of solar particles upon the earth can give rise to geomagnetic disturbances, auroral displays, certain types of disturbances to radio communications, and almost certainly to terrestrial weather effects.

A study of the solar magnetic field would, in addition to helping us understand the interplanetary medium and charged particle propagation, offer a distinct possibility for adding to knowledge of the sun itself. A recent theory due to H. W. Babcock[1] describes the 22 year solar cycle in terms of differential solar rotation and the consequent release from sunspot pairs of internal solar magnetic fields into the interplanetary space. This theory predicts a consequent weakening of the general external solar magnetic field throughout the period of increasing sunspot number, leading to ultimate reversal of the external field. Measurements of the external solar magnetic field as close as possible to the sun throughout a period of solar activity would be important for checking this theory. An understanding of the structure of the solar magnetic field nearer the sun would aid in an understanding of the corona and its change in structure with the solar cycle. A search could be made for evidence of detachment of field lines. Improved measurements of electron densities through the corona, achievable by radio propagation experiments, would also extend knowledge of this important region, at the beginning of the expansion of the interplanetary plasma.

The distribution of meteoroid streams through the solar system is known almost exclusively from observations of those which intersect the earth's orbit. Recent data from the Soviet Mars I vehicle[1] revealed a swarm which may not be observable from earth and there are undoubtedly many more. Any knowledge of the variation of micrometeoroid populations as a function of heliocentric distance would be an aid in distinguishing between details of theories concerning the possible origin of these objects from asteroidal collision processes or from the comets. Improved estimates of meteoroid collision probabilities for future space vehicles would be obtained.

Data from Mariner II showed large peaks in plasma current lasting for one or two days with a recurrence in the solar rotational period. These peaks are strongly correlated with terrestrial magnetic disturbances[2] and thus also, apparently, with central solar meridian passage of active solar regions[3]. A theory exists[4] for the expansion of the solar plasma along a tube of flow, but the theory cannot account for the change in cross-section of the tube or its overall shape with distance from the sun. Nevertheless, using reasonable assumptions, the theory provides conclusions for the variation with heliocentric distance of the plasma velocity and density. It would be highly desirable to test, in particular, the theoretical conclusion that the variation of velocity with distance is relatively slight until one approaches the sun closer than one or two tenths of an astronomical unit. The widths of the plasma beams as a function of distance from the sun could also be studied on a statistical basis.

That the solar magnetic field strongly affects the penetration of galactic particles into the inner solar system is known from the 11 year intensity modulation of galactic cosmic rays. Recent evidence[5] indicates that during a period when solar activity was declining and the high energy cosmic ray flux was approaching its maximum value, the flux of low energy cosmic rays was declining. This argues for a solar source for the low energy component. The steadiness of this low energy component requires either its continual emission by the sun, or a storage mechanism for solar flare particles with a storage time on the order of a month. The important question as to the origin of these particles could be resolved by measurements taken as a function of heliocentric distance.

The strong tendency for streams of high energy solar protons to reach the earth from flares close to the western solar limb as opposed to the eastern limb indicates that the paths of these solar particles outward from the sun, and hence the shape of magnetic field lines, are portions of a spiral with considerable curvature. The curvature is probably different for plasma clouds previously ejected from solar flares of different intensities. The overall direction of the magnetic field should be controlled largely by the plasma flow, but the manner in which the field lines connect to the sun is not understood. It would be highly instructive to throw further light into this area by making measurements close to the sun of energetic particles, plasma streams, and magnetic fields which might allow a more detailed picture of the propagation paths and overall field configuration to emerge.

The relatively low frequency of major solar proton events arising in flares has retarded progress in understanding this important phenomenon. Space vehicles with energetic particle monitors located at widely different heliocentric longitudes would add to the number of these events for which definitive information is available. It would be desirable to have vehicles whose heliocentric anomalies depart from the earth at a rapid enough rate so as to attain a large difference in heliocentric anomaly in a time short compared to the vehicle lifetime. Such a rapid rate of departure is associated with an orbit whose semi-major axis is considerably less than one astronomical unit. Another aspect of such an orbit is the possibility for providing means for making a crude measurement of the position on the solar disc of the larger flares. Measurements of this sort taken of the solar hemisphere invisible from the earth would allow an increase in the number of flare events for which correlations could be made with the subsequent arrival of energetic particles.

Measurements of the interplanetary plasma, magnetic fields, energetic particles, and interplanetary dust particles are presently under way in various programs of the Office of Space Sciences and the NASA centers. These measurements, which will be made mostly at heliocentric distances approximating one astronomical unit, will add to the scientific understanding of the interplanetary particles and fields, particularly in the case of the Venus and Mars probes which have made or may make a few measurements in the region 0.7 to 1.6 Astronomical Units (AU). It would be beneficial to the understanding of the fields and particles in interplanetary space to include some measurements taken at distances closer to the sun over a considerable period of time. This is particularly true of the plasma and magnetic field measurements, which have a pronounced effect on the other phenomena. A vehicle in a heliocentric orbit with a perihelion within approximately one-third AU of the sun would have the further advantage of giving an instrument package a large change in heliocentric anomaly in a relatively short time, which would allow for more complete longitude coverage of short lifetime events and for radio propagation experiments through large regions of the solar system and through the solar corona.

The Solar Probe vehicle presented in this report has been designed to range over heliocentric distances between 1.0 and 1/3 AU with a corresponding orbital period of approximately six months and to provide scientific measurements contributing to the following scientific objectives.

- Understand the flow of the solar wind, particularly in regions closer to the sun.
- Study the dimensions of large plasma clouds ejected from active regions and paths followed through observations at widely different heliocentric longitudes to the sun.
- Study the structure of the interplanetary magnetic field as close as possible.
- Search for evidence of possible solar magnetic field line detachments.
- Hopefully, obtain data for better understanding of the solar cycle.
- Study energetic solar particles and galactic cosmic rays -- search for steady solar source or possible solar system storage mechanisms.
- Study paths of propagation of solar flare particles by obtaining simultaneous data at different heliocentric longitudes to study path widths.
- Obtain data on more solar flare events by seeing flares on the back side of sun.
- Study distribution of electron density over long paths through the inner solar system via radio phase shifts.
- Obtain coronal electron densities as a function of depth and time.
- Search for new micrometeoroid showers as an aid to theories as to their origins.
- Study the micrometeoroid size distribution as a function of heliocentric distance to learn more about energy loss mechanisms.

These experiments generally determined the features of the spacecraft design and the mission profile, within the limitations of present space probe technology. The following sections describe the vehicle, the mission, and a representative experimental package which would yield a greatly improved understanding of interplanetary particles, fields, and their propagation. In addition to the principal experiments upon which the spacecraft design was based, a number of others should be considered for inclusion on one or more of the spacecraft.

These experiments are described in a separate section below. In only a few cases would these experiments require a modification of the spacecraft, and in most cases the modifications would be relatively minor. Among these other experiments would be ultraviolet or visible facsimile photography of active regions on the invisible solar hemisphere for correlation with the particle and field events observed and for possible aid in solar flare prediction, a study of the neutral hydrogen distribution at various distances, studies of the zodiacal light at perihelion, a search for VLF radio energy near the local critical plasma frequency at perihelion, a search for evaporation neutrons from spallation reactions originating in chromospheric flares, and an improved determination of the astronomical unit.

It is understood, of course, that final selection of the instrument package for such a space probe would be made by the NASA following detailed consideration of proposals submitted by various universities and government laboratories. During the course of this study, helpful advice was obtained from scientists in various university and government laboratories too numerous to mention. This help is gratefully acknowledged.

3.1.1 REFERENCES FOR SECTION 3.1

1. H. W. Babcock "The Solar Magnetic Cycle" - Symposium on Plasma Space Science, Catholic University, June 11 - 14.
2. T. N. Nazarova, "Meteoric Matter Along the Trajectory of the Mars 1 Probe Flight" 1963 COSPAR Symposium, Warsaw, Poland.
3. C. Snyder, "Direct Measurements of Solar Plasma", Symposium on Plasma Space Science, Catholic University, June 11 - 14.
4. G. Kuiper, "The Sun" University of Chicago Press, p 3.
5. E. N. Parker, Astrophys. J. 128, 664 (1958).
6. P. Meyer and R. Vogt, Phys. Rev. 129, 5, 2275 (1963).

3.3 PRIME EXPERIMENTS

In this section we shall review those interplanetary phenomena our understanding of which would be very greatly increased by measurements which could be made by the launching of one or more Solar Probe vehicles carrying instruments which are presently available or under nearly completed development. In order to provide a basis for design of the Solar Probe vehicle, a nominal instrument package was chosen consisting of five prime experiments involving seven separate instruments with an estimated total weight of 36 pounds and a data requirement of 395 data words.

These experiments are believed to be of such unquestionable value that they (or similar experiments) are very likely to be selected in any final choice made by NASA on recommendation by the Space Sciences Steering Committee. In addition, a number of other instruments were identified which are likely candidates for inclusion in one or more Solar Probe instrument packages. These additional experiments and instruments are described in Section 3.6 of this volume. Because of the large number of these additional experiments, and because in some cases the feasibility or priority of the experiment cannot be definitely established at this time, no selection within this group has been attempted. Instead, ten additional pounds and eleven additional data words were allocated to these priority "B" experiments.

The specification of some definite form of instrument package was required in order to examine the types of constraints imposed upon the vehicle and mission. Considerable flexibility, however, exists with respect to the details of the instruments carried.

The spacecraft design constraints deriving from the nominal instrument package (priority "A" experiments) are discussed in Section 3.4. Most of the experiments considered on the "B" list would require at most minor vehicle design changes. It is highly probable that some varying mix of instruments would be adopted for successive Solar Probe vehicles.

3.3.1 REFERENCE DESIGN INSTRUMENT PACKAGE

The following is the list of instruments and their gross characteristics assumed for the Solar Probe design reference instrument package:

	Weight (lbs.)	Power (watts)	Data Words
1A Plasma Experiments			
2 @ narrow angle electrostatic analyzers, 4 directions each	8.0	3.0	256
1 @ wide angle Faraday cup instrument	5.0	1.5*	90
2A Magnetic Field Experiment Triaxial Fluxgate Magnetometer	4.5	0.5	3
3A High Energy Charged Particle Experiment			
@ 1 ea. E_{total} x (dE/dx) telescope	7.5	1.0	15
@ 1 ea. charged particle telescope	2.0	0.5	5
4A Integrated Electron Density Radio Propagation Experiment			
@ 3 ea. Radio Receivers (50 mc, 400 mc, 2000 mc)	5.0	2.0	7
5A Micrometeoroid Experiment Acoustic Sensor	4.0	1.0	1
Priority "B" Experiments	10.0	5.5	11
	46.0	15.0	388

*10 watt peaks 30 ms duration

A more detailed discussion of each experiment and the corresponding phenomenon to be studied follows.

3.3.2 SOLAR WIND (INTERPLANETARY PLASMA)

The presence of an interplanetary plasma streaming outward from the sun has been detected recently by instruments aboard Luniks II and III[1], Explorer 10[2] and most recently by Mariner II (1962). The presence of this solar wind had been inferred earlier from a variety of indirect evidence, including the airglow and aurorae, geomagnetic fluctuations, Forbush events and the appearance of certain types of comet tails.

Based on the data which are available and the most widely accepted theory of the solar wind, it is believed that the solar wind is an extension of the Sun's corona which is expanding hydrodynamically into interplanetary space. The plasma consists mainly of fully ionized hydrogen with a measurable fraction of helium nuclei. It is considered likely that traces of other elements (fully or perhaps partially ionized) are present in the plasma, but their detection awaits more sensitive experiments than have been flown to date.

Because of the high electrical conductivity of the plasma, magnetic lines of flux present in the corona tend to be effectively frozen into the plasma. Since the kinetic energy density of the plasma is greater than the magnetic energy at distances greater than a few hundredths of an AU, the magnetic field is carried along by the plasma as it expands into interplanetary space. Thus the structure of the interplanetary magnetic field is intimately connected with the presence of the solar wind.

The recurrence of magnetic disturbances with successive passages of active regions across the face of the solar disc suggests that more intense beams of plasma flow in certain directions and that these rotate with the sun. The Mariner II plasma instrument gave the first direct measurement of these beams, and showed that during the time of observation, the plasma current in the beams was an order of magnitude higher than the average plasma current. A strong correlation was found between the time of occurrence of peak plasma current and the time of peak disturbance in the geomagnetic field, with allowance for the difference in heliocentric longitude of the probe and earth.

The occurrence of a Forbush decrease in galactic cosmic ray intensity in conjunction with intense magnetic storms is interpreted as due to the deflection of the cosmic ray particles by large scale magnetic field systems associated with unusually dense plasma clouds which reach the vicinity of the earth. The Pioneer V experiments showed that the Forbush decrease is indeed associated with large scale increases in the interplanetary field, but the spatial extent needs investigating. Since the magnetic fields carried by these plasma clouds act to guide solar cosmic rays, as discussed below, the shapes of the clouds and the manner of their connection to the sun requires further study in regions as close as possible to the sun.

The present experimental situation relating to the solar wind leaves open a large number of questions; nevertheless, the Mariner II experiment has provided several fundamental facts about the solar wind. The plasma instrument was a narrow angle device which was always pointed directly towards the sun; at all times during the flight measurable, although at times rapidly fluctuating, plasma current was detected. The current is believed to move out approximately radially from the sun, although it is not certain that the Mariner instrument was viewing the direction of the stream. Indeed, Biermann's comet tail work indicates that the plasma moves out in slightly curved paths which make angles with the radial direction of between 6° and 16°. Thus a possibility exists that the plasma flux and density, as determined by the Mariner experiment, might have occasionally been on the low side. It would therefore be desirable to examine the interplanetary plasma with a wide angle instrument to obtain a better measure of the total plasma density. To study plasma direction, complementary narrow angle instruments are indicated. The density measured by the Mariner II instrument was of the order of 4 ions/cm^3 at $\sim$ 1 AU.

The Mariner II instrument measured a spectrum each telemetry frame from which a measure of the mass motion velocity and temperature of the ionic component of the plasma was determined. The mass transport velocity varied considerably (314 to 1250 km/sec) but had an average value of about 500 km/sec. The ion temperature can be estimated to be about 10^5 to 10^6 °K, the specific value depending on the particular spectrum analyzed. At times during the flight rapid changes in the plasma spectrum were detected; at least one of these can be ascribed to the passage of a plasma shock front. The sampling rate of the spectrum was too slow however, (3.7 minutes) to study the energy turbulence in the shock front.

A Solar Probe should carry plasma instruments capable of looking in several directions about the sun-probe line to determine plasma stream directions. A wide angle instrument should also be provided to obtain a better measurement of the total plasma density. The coarseness of the Mariner energy spectra makes temperature determinations and observation of helium ions subject to considerable uncertainty. Therefore, more energy resolution should be provided than was available for Mariner II.

Thus far no mention has been made of the electron component of the plasma. The kinetic energy of electrons due to the plasma mass transport velocity is expected to be much lower than that of the ions due to their small mass. On the other hand, approximate equipartition of random thermal energy would be expected between ions and electrons. Based on plasma temperatures deduced from the Mariner II experiments, the random thermal electron velocity is expected to be much greater than the plasma mass transport velocity so that the electrons should have a nearly isotropic distribution. Since the average electron energy is expected to be only of the order of tens of volts, based on the ion temperatures measured by Mariner II, the vehicle electrostatic potential may act as a serious perturbation on any measurements of plasma electron spectra, since plasma currents and photoelectric effect could easily result in a vehicle potential on the order of ten volts which cannot easily be measured. Since there are other difficult technical problems associated with measuring the electron portion of the solar wind, we have not specifically considered any instruments designed to measure their spectrum.

One of the most important missions for a solar probe to 0.3 AU will be to examine the relationship between the solar wind and the magnetic fields as a function of heliocentric distance.

3.3.2.1 PLASMA EXPERIMENTS

The requirements for the interplanetary plasma experiments in order to furnish a quantitative understanding of the flow outward from the sun, the dimensions and propagation of intense beams originating in active solar regions, and interplay with the interplanetary magnetic field, are the following:

1. Instruments capable of determining the direction of the main plasma stream with an angular resolution of the order of 5° to 10°.
2. Based on the Mariner II spectrum measurements, the plasma analyzer should cover the range of plasma ion mass velocities from about 200 km/sec to perhaps as high as 2500 km/sec in about 30 energy steps.
3. Although the electron component of the plasma is of considerable interest, the problems of making clear cut measurements of the electrons do not appear to be solved at present. Therefore, a separate electron plasma probe need not be provided.
4. One of the unique sets of data to be gathered by the solar probe is the plasma density as a function of heliocentric distance. A wide angle instrument should be employed to insure a good measurement of the density.
5. The most valuable spectrum data would be a series of snapshot-like spectra. A spectrum gathered in a time of the order of a few seconds would be desirable.
6. Due to the fact that the solar probe orbital velocity will be of the order of 60 km/sec at perihelion which is roughly 12% of the average mass motion velocity measured by Mariner II, consideration of this aberration effect should be taken into account when the pointing directions for the plasma probes are selected.

The above requirements can be satisfied by combining narrow angle and wide angle instruments. Narrow angle instruments have been developed which can examine plasma currents in a number of directions lying near a given plane by utilizing hemispherical electrostatic deflection plates and multiple collectors. Two such instruments can be used to examine the angular direction of plasma flow near the plane of the ecliptic and near another plane perpendicular to the ecliptic and containing the direction towards the sun (see Figure 3.3.2-1). Since vehicle aberration effects will be different for ions of widely different velocities, the maximum current directions are not expected to be the same for widely different energy channels.

The large aperture available in the wide-angle plasma instrument will give a sensitive measurement of weak plasma currents. The importance of the plasma measurements justifies a certain amount of redundancy in the plasma instrumention.

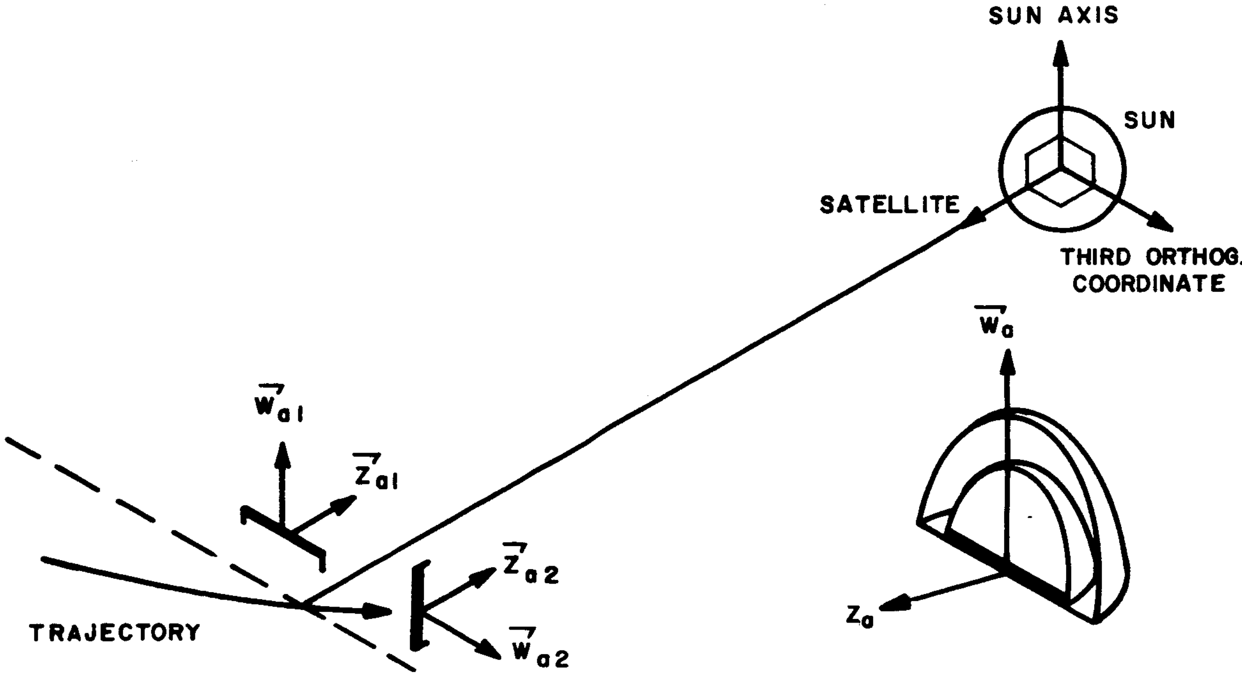


Figure 3.3.2-1. Possible Orientation of Plasma Electron Analyzers

3.3.2.2 REFERENCES FOR SECTION 3.3.2

1. K.I. Gringauz et al. Proc. of 3rd International Space Science Symposium, Washington, D.C. 1962.

2. H.A. Bridge et al. J. Phys. Soc. Japan 17 Supple. A2, 553 (1962).

3.3.3 INTERPLANETARY MAGNETIC FIELD

A considerable body of evidence regarding the nature of the interplanetary magnetic field is available from observations of the following phenomena:

1. Appearance of filaments in the solar corona
2. Modulation of galactic cosmic radiation, including Forbush events
3. Terrestrial magnetic disturbances and ionospheric absorption events resulting from arrival of low energy solar cosmic rays
4. Observation of energetic solar particles originating in flares.

Recently, preliminary measurements in situ, notably on the Pioneer V spacecraft, have become available. The Pioneer V data indicated the presence of a rather steady field of approximately 4 γ, with occasional increases by an order of magnitude. This probe measured the component of the field perpendicular to its spin axis, which lay generally along the line towards the sun. A report on the experiment[1] indicates that the results are difficult to reconcile with many theories of the interplanetary magnetic field. More recent measurements aboard the Mariner II spacecraft showed variations in the interplanetary magnetic field over heliocentric distances from 1.0 to 0.7 AU with a period of the same order as the solar rotational period, but a lack of zero calibration and suspected vehicle induced fields prevented the attainment of a picture of the interplanetary field at these distances. Considerable fluctuations were observed and the data were consistent with an interplanetary field whose radial direction near the ecliptic does not change, except possibly over regions extending on the order of half way around the sun.

Coronal filaments which appear to outline magnetic field lines show evidence for a rather ordered field in the immediate neighborhood of the sun's poles. An overall dipole field is excluded by the fact that the Pioneer V and Mariner II data would, if extrapolated in this manner to the surface of the sun, give field strengths far in excess of those obtained by measurements of Zeeman splitting of optical lines.[2] A comparison of plasma particle energy densities and magnetic field energy densities deduced at a heliocentric distance near unity shows that any systematic intergalactic field penetrating through the solar system should be swept out by the plasma wind.

At latitudes corresponding to those containing most solar surface activity, the coronal streamers show evidence of closing at distances not exceeding a solar radius or so, while lines emanating from the less active polar regions appear to extend to great distances from the sun. It has been pointed out[3] that this general structure is consistent with the expectation that clouds of plasma ejected from active regions would sweep away the magnetic fields at small and intermediate latitudes, and that ultimate detachment of the corresponding field lines from the solar surface must occur through dissipative processes. The magnetic pressures available in the coronal regions should be completely inadequate to prevent the expansion of such relatively dense and energetic clouds of highly conducting plasma.

That systems of magnetic field lines carried out to the earth's orbit must in many cases retain a high degree of attachment to the solar surface is indicated by the high degree of correlation between observations of the Forbush decrease and the frequency and intensity of solar proton events observed at the earth from chromospheric flares. Pioneer V served to prove that the Forbush decrease was not a geocentric phenomenon but is connected with large scale magnetic field increases in the interplanetary space. The magnetic field strengths observed during disturbed times were of the order of 40 γ, which are known to be adequate to cause a Forbush type decrease if the regions involved extend over distances of the order of an astronomical unit. The high degree of probability of occurrence of geomagnetic disturbances from large disturbed regions of the solar surface indicates that, at least in many cases, the plasma clouds presumably giving rise to increases in the interplanetary magnetic field must extend over extremely large regions.

The fact that geomagnetic disturbances can occur periodically with successive solar disc passage of M regions and the recent direct observations aboard Mariner II of plasma current peaks with the periodicity of the solar rotation suggests that magnetic lines swept out by the plasma may retain a high degree of attachment to the sun. A high degree of overall order to the interplanetary field may therefore exist despite the dominance of magnetic field pressure by plasma particle pressure, but this field structure must be considerably more complicated than, for example, the geomagnetic field.

Evidence from solar energetic particle events[4] indicates that, following the expulsion of large plasma clouds from active solar regions, the interplanetary magnetic field between the earth and sun tends to lie near the plane of the solar equator. Analysis of two solar cosmic ray events indicated that the direction of the field near the earth's orbit must have made an angle of approximately 60° from the earth-sun line. Analysis of the relative frequency of occurrence of solar flares resulting in energetic particle arrival at earth shows that particle arrival is most probable for events occurring near the western solar limb. The fact that, for the events analyzed, rise times for energetic particle fluxes are much more rapid for flare events occurring near the western limb, while flares near the central solar meridian give slow rise times, strongly indicates that during these disturbed times, magnetic lines of force connect the earth with the western portions of the sun. The difference in rise times of the energetic particle fluxes is understandable, from this hypothesis, since particles from flares near the western limb can reach the earth quickly by spiralling along field lines, while those originating from flares near the center of the solar disc must diffuse across magnetic field lines in order to reach earth. This interpretation is further confirmed by the fact that for the latter type of events, the delay times are longer for the particles with lower energies.

The hydrodynamical expansion theory of the solar plasma[5] and evidence from the orientation of comet tails[6] indicates that the plasma motion in the vicinity of the inner planets should be principally in the radial direction. The plasma currents measured by the narrow angle Mariner II instrument, which was pointed at the sun, appear to give some confirmation of this expectation. On the other hand, if there is the expected correlation between the direction of the plasma flow and the direction of field lines swept out by it, the large deviations of the apparent field direction from the radial direction, deduced as mentioned above from solar energetic particle events on two occasions need to be explained. It is of course possible that the pitch angle of the outward spiral described by the plasma flow and the field lines changes radically during solar disturbances. The mean plasma velocity (500 km/sec) measured by Mariner II corresponds to arrival at the earth at a time when the responsible active region would be near the western limb but the shorter transit times sometimes observed from geophysical evidence indicates that the tightness of the spiral paths may be highly variable.

The importance of the overall structure of the interplanetary field and its time variations indicates the desirability of performing in situ magnetometer measurements at various distances from the sun which can complement and perhaps reconcile the evidence based on other types of studies. In particular, it is desirable to make measurements as close as possible to the sun in order to observe the transition to a more ordered field and to search for possible field detachment processes.

As mentioned in the introduction, a recent theory[7] for the sunspot cycle which seeks to explain the periodic reversal of polarity of the leading spot in groups in northern and southern hemispheres could be tested by measurements of the ordered solar field. Magnetometer measurements aboard a Solar Probe might thus have far reaching implications for solar physics as well as for the field and particle physics of interplanetary space.

For the measurement of the interplanetary magnetic field, the most suitable instrument appears to be the saturable core flux gate magnetometer. This instrument has adequate sensitivity (to 0.12 γ), adequate range, and has proven itself in other space probe experiments. The magnitude of the field fluctuations already observed in interplanetary space indicates that the greater sensitivity of the gas-type magnetometer, such as the rubidium vapour device (sensitivity 0.01 γ) would not be warranted. Neither do the temperature limitations of the sensing element (40° - 55°C) appear suitable for boom mounting in an environment in which the solar heating flux will be highly variable over the orbit.

For purposes of Solar Probe vehicle design, an instrument similar to one recently developed by the Schoenstedt Instrument Company for measurement of small fields was assumed. This would be a three axis instrument which would cover the range between instrument noise level (0.12 γ) and 500 or 1000γ. For periodic zero calibration, it is necessary to mechanically reverse the direction of each separate sensor axis. Two axes can be reversed simultaneously by a rotation about the third axis, but the third sensor must be mounted separately with its own reversing mechanism. Two reversing mechanisms are assumed in the vehicle design. Operation of the reversing mechanism will be provided by an on board clock several times per day. Override capability may be provided by radio command so that possible development of periodic instrument zero drifts can be distinguished from fluctuations in field direction or strength.

Great care must be exercised in the entire vehicle design in order to insure that the weak interplanetary field is not seriously perturbed by fields generated by the vehicle. Quality control for all vehicle parts, components, and systems will include rigid specifications for maximum induced magnetic fields.

3.3.3.1 REFERENCES FOR SECTION 3.3.3

1. Coleman, Davis, Sonett, Phys. Rev. Letter 5 (1960) 43
2. H. W. Babcock, Astrophysics, U., 118, 387 (1953)
3. T. Gold Proc. of the 2nd International Space Science Symposium, Florence, 1961, p. 828
4. K. G. McCracken, Proc. of the 2nd International Space Science Symposium, Florence, 1961, p. 815
5. E.N. Parker loc. cit.
6. L. Bierman, Symposium on Plasma Space Science, Catholic U, June 1963
7. H. W. Babcock, loc. cit., Symposium on Plasma Space Science Catholic U, June 1963

3.3.4 ENERGETIC CHARGED PARTICLES

Our understanding of solar and galactic cosmic radiation has greatly increased over the last few decades. However the number of questions which have been answered is only a small fraction of the number of new questions that have been raised. Since the discovery was made by Forbush and Lang in 1942 that high-energy charged particles of solar origin bombard the Earth, much emphasis has been placed on studying the nature of these particles and speculating on the mechanisms which produce them and the manner in which these particles propagate through interplanetary space. Although much work remains to be done in the vicinity of 1 AU, the need to study the solar particle radiation as a function of heliocentric distance is becoming more clear.

Recent evidence obtained by Meyer and Vogt indicates the existence of a significant continuous flux of energetic particles, their measurements covering the range from 80 to 350 Mev. They further observe that this flux of particles decreases with the declining level of solar activity while the galactic cosmic-ray flux increases. It is therefore suggested that these particles are of solar origin. A probe travelling toward the Sun could establish their origin unambiguously since if they were of solar origin the flux would increase with diminishing heliocentric distance, whereas if they were of galactic origin the flux would diminish due to the increased shielding against cosmic rays provided by the increasing magnetic fields. An alternative explanation requires the trapping or storage of the solar cosmic rays emitted from a flare in a field which would hold them with a characteristic time of about 30 or more days.

It would also be of extremely great interest to examine events following major solar flares occurring during the flight of a solar probe. One of the questions which could be answered if the probe was in an appropriate position would be whether or not the dispersion in onset times of first arriving energetic solar flare particles is a consequence of diffusion through the general solar magnetic field. This field has been assumed by some investigators to have an effect out to 50 - 100 solar radii (0.25 AU to 0.5 AU).

Of great interest to the astrophysicist is the abundance of nuclei other than protons or alpha-particles in flare events. From the meager data which are currently available, it appears that the relative abundance of Li nuclei in solar flare events is about 10^{-5} the abundance of Li in galactic cosmic rays. Appropriate instrumentation aboard a solar probe could investigate this matter which has considerable cosmological significance. Current thinking is that flares may provide a part of the source of galactic cosmic rays, that is, flares on other stars similar to our Sun. Since the flare spectrum is not similar to the galactic spectrum, the hypothesis has been forwarded that flare particles leak out of the stellar magnetic fields and are further accelerated in interstellar or intergalactic space.

To explain the change in angular distribution of flare particles with time, i.e., the change from collimated beams to isotropic beams, it has been suggested that in addition to diffusion across magnetic lines of flux in the inner solar system (distances less than 1 AU from the Sun), one might consider the possibility of particles being scattered back from the expanding plasma shock front. By observing the various time delays associated with solar flare particle fluxes as a function of heliocentric distance such mechanisms might be investigated.

High energy galactic cosmic rays would not profitably be studied on a solar probe to 0.3 AU. The differences between the high energy flux at 0.3 AU and 1.0 AU would not be sufficient for the types of instruments which could feasibly be carried on the solar probe. The low energy galactic cosmic rays which could experience a significant modulation difference between 1.0 AU and 0.3 AU would be studied as a matter of course along with the solar cosmic rays fluxes. Therefore an additional experiment at high energies need not be planned at this time.

A great deal of information on the above types of phenomena could be gotten from an experiment consisting of a pair of coincidence telescopes oriented in different directions. At least one of the telescopes should be capable of measuring specific ionization as well as total energy in order to discriminate between particles of different mass. The telescope elements would be thin semiconductor wafers, except that the last telescope element might be a scintillator crystal. This instrument places no special requirements upon the spacecraft design except that unobstructed viewing directions should be provided. A number of possible viewing directions can be considered; their selection should depend upon the provisional state of knowledge which is available at the time the detailed experiment proposals are submitted. Two interesting directions might be the direction towards the sun and a direction normal to this lying in the ecliptic plane. Such an arrangement would give two components for proton currents moving away from the sun in the ecliptic plane, whose presence has been deduced by McCracken. On the other hand, a search for and measurement of time delay for solar particles reflected backwards from magnetic inhomogeneities lying beyond the spacecraft would be a great interest for distinguishing between different models for the propagation and trapping of these particles. The viewing directions illustrated in the spacecraft drawings of Volume II were chosen as being perpendicular to the ecliptic plane and in the direction away from the sun, as suggested by one investigator currently active in this field. Reliability of the semiconductor detectors is enhanced by a relatively temperate environment in the spacecraft interior in which the instruments are to be mounted.

Less elaborate energetic particle detectors, such as Geiger tubes, will almost certainly be proposed as well for the Solar Probe vehicle. Such a detector might have considerable merit for the purpose of providing comparisons in data with data obtained with similar instruments flown on other interplanetary space probes. Similar data might also be provided by the singles rate of the first element of a coincidence telescope.

3.3.5 MEASUREMENTS OF INTERPLANETARY AND CORONAL ELECTRON DENSITY

Because of the complex spatial and temporal distributions of the interplanetary plasma, and because the measurements aboard a space probe are restricted to single points of space, it is highly desirable to complement these point measurements with integral measurements over large regions of space. The discussions above have mentioned some of the wealth of information regarding overall-interplanetary distributions of plasma and fields derived from studies of their effects upon the trajectories of charged particles. An even more direct method for studying large scale plasma density distributions is by means of variations in phase of electromagnetic signals of properly chosen frequency. Techniques for studies of plasma densities through microwave probe techniques are well established in the laboratory. The corresponding technique applied to the low density interplanetary plasma requires the use of suitably lower frequencies. Plans are being made by the Stanford Center for Radio Astronomy for the measurement of line integrals of electron densities along radio propagation paths between earth and the Pioneer probe by comparing the phase of modulation envelopes applied to two carrier signals of widely different frequencies. For a study of the interplanetary electron densities expected for path lengths of the order of 1/2 AU at a mean distance from the sun of 1.0 AU, frequencies of 50 mc and 400 mc are suitable. Correction for the phase shifts from earth ionosphere are quite important and accurate simultaneous ionospheric measurements will be used for this purpose.

For measurements along propagation paths lying on the average at closer heliocentric distances, which will be available in the Solar Probe mission, the ionospheric correction will become less important. On the other hand, rapid fluctuations in overall phase of the received signal on board the spacecraft may require greater receiver bandwidth so that phase lock can still be maintained even if large scale changes in plasma density occur due to rapidly moving plasma clouds ejected from active solar regions.

Perhaps the most attractive potential of such an experiment is the possibility for measuring the overall change in the integral electron density as the path moves progressively deeper into the outer reaches of the solar corona. In this region the phase shift would be primarily due to the relatively short portion of the path lying deepest in the corona, so a relatively good picture of the variation of coronal electron density with depth would be achieved. It would be desirable to choose an orbit so that the propagation path ultimately grazed the limb of the sun. On the other hand, telemetry reception from the probe will be lost when the probe-earth-solar limb angle decreases below 2 or 4 degrees. Since it is also desirable to obtain measurements as a function of time of the densities at a given depth in the corona, an orbit has been chosen which gives a relatively long dwell time for probe-earth-sun angles just beyond the telemetry blackout limit (see Figure 3.2.2-4). When the probe finally passes behind the limb of the sun, the earth-probe-sun angle is changing rapidly enough that telemetry blackout is minimized.

Because of the possibility of losing phase lock between receiver and transmitter in the phase measurement loop due to rapid changes in coronal electron density, comparison of two higher frequency propagation phases should be made when the propagation path passes deep in the corona. Preliminary considerations indicate that a third receiver on 2 kmc should be provided and the relative phase shifts in the 400 mc and 2 kmc modulated carrier measured.

The transmitter will be the 150 foot Stanford dish. Recent increases in transmitter power available at this installation indicate that the experiment can be performed with adequate signal to noise ratio over propagation distances as great as 2.0 astronomical units using omnidirectional receiving antennas aboard the vehicle. The measurement will be made by comparing the phase of a 10 kc modulation envelope applied to the carriers at different frequencies; the 400 mc and 2000 mc signals being compared when the propagation path contains high electron density regions near the sun and the 50 mc and 400 mc signals being compared at other times.

Equipment for this experiment has already been developed with the exception of the 2000 mc receiver, which is currently under development. The antennas required are as follows:

50 mc:	1/4 wave stub mounted perpendicular to the orbit plane (perpendicular to the direction to earth)
400 mc:	1/4 wave stubs. In the design illustrated two were found to be required in order to provide a continuous clear view of earth.
2000 mc:	use TM dish by diplexing from TM waveguide

In this way Faraday rotations along paths through the deep corona might be detected. For paths through interplanetary space, it might be possible to detect a rotation of the plane of polarization due to a relativistic effect arising from the ordered motion of the electrons in the solar wind. In the reference instrument package, provision for the polarization measurements has not been shown. Such provisions might be added later in the event that such measurements prove successful in the Pioneer experiments.

3.3.6 INTERPLANETARY DUST

The zodiacal light, a phenomenon observed for the past three centuries, has at various times been attributed to the scattering of sunlight by dust particles whose radius lies in the range .2 to 100 microns, free electrons with a number density in the order of 600 cm^{-3} at 1 AU. from the sun, and a combination of both. Before 1953 it was generally accepted that interplanetary dust was the principal scattering agent. Behr and Siedentopf[1] performed a series of polarization measurements from which they concluded (assuming that the degree of polarization produced by light scattered from dust particles is near zero) that half of the observed surface brightness of the zodiacal light near elongation 35° was due to the scattering of sunlight by free electrons in interplanetary space. Their assumption that the coefficient of scattering is unity for micron size particles has been disputed by a number of investigations.[2] Evidence that interplanetary dust may also scatter highly polarized light has been introduced by van de Hulst.[3] Recently Blackwell and Ingham[4] using the facilities at Chacaltaya have carried out an extensive optical measurements program in an effort to more accurately define the constitutive make up of the zodiacal light. While far from being conclusive, it is apparent that both dust and free electron components exist. Furthermore, it is generally now believed that the zodiacal light can be regarded as the outer part of the solar corona in which there exists a K - (free electron) and F - (dust particle) component. Additional observations made at Chacaltaya also report a fluctuation in the surface brightness of the zodiacal light at times of increased solar activity.

Recent in situ measurements from satellite probes conducted primarily by McCracken, Alexander and Dubin[5] in the vicinity of the earth yield higher spatial densities than those obtainable from the zodiacal measurements. This has led Wipple[6] to postulate a geocentric "dust belt" around the earth. The results of Mariner II, on the other hand, lead to a much lower value than expected, recording only one or two impacts during the flight with no impacts recorded in the vicinity of Venus. This is four orders of magnitude less than that recorded in the vicinity of the earth by the Explorer VIII satellite.

Therefore, to resolve some of these problems it is proposed that the dust component in interplanetary space lying in the region $.3 < r < 1.0$ AU. from the sun be monitored for the dust as well as the free electron component, and that in the event of a strong solar flare be correlated, if possible, with any brightness fluctuations in the zodiacal light. (The latter would be recorded via earth based observations.) Since an understanding of the nature, origin and dynamics of this dust component may be an important clue to our understanding of the origin and evolution of the solar system, the importance of such an experiment cannot be overestimated.

The proposed experiment is designed to measure the flux and momentum of cosmic dust particles (momentum range 2.5×10^{-4} to 2.5×10^{-1} dyne-sec) in interplanetary space. These measurements are to be obtained as a function of the distance from the sun. The latter aspect of the measurements are of particular importance and have not been flown before since the majority of similar experiments have been centered around the earth with only a few probes extending out as far as the orbit of Venus. The experiment is directed toward providing direct observational data to aid in a separation of the zodiacal light source into a dust and an electron component. The solar probe provides the only vehicle to date that allows direct sampling of one of these, the dust component near the sun. The radio propagation experiment on board the solar probe is designed to measure the electron component.

The parameters of the cosmic dust environment requiring investigation are size, mass, structure, chemical composition, speed and direction of motion, number density, and distribution in space. Present non-recovery techniques measure only size and the combination of mass and velocity (i.e., momentum and/or energy).

The instruments developed to date together with the quantity that they measure are given below.

Type	Measurement
(a) Crystal Microphone	number density - momentum*
(b) Wire Grid	number density - size
(c) Flash Detector	number density - energy
(d) Thin Film	number density - size
1. photosensitive	
2. pressure	

The crystal microphone detector will probably be most suitable for the solar probe design reference package primarily for its reliable past performance, its simplicity,

*Note - The response characteristics of the microphone detector have been the subject of numerous debates with regard to just what quantity is being measured. The arguments run from mv to $mv^{4/3}$ to mv^2. We consider it here to be an mv detector, the commonly accepted view held by the majority of investigators active in this field.

and its inherent long life. The latter characteristic is not found in the the wire grid and thin film types of instruments.

Two units are employed in an effort to record the momentum spectra of those particles overtaking the probe and those being overtaken by the probe. This arrangement will help define the number densities and momenta for particles having direct and retrograde orbital motions. This latter point is of interest in cosmological studies.

A conventional crystal microphone of small size and appropriate sensitivity is directly mounted against a sounding plate which is acoustically isolated from the remainder of the vehicle by rubber, polyethylene, or other suitable grommets. Additional acoustical isolation can be provided by tuning the crystal to provide a maximum signal at ultrasonic frequencies high with respect to vehicle vibrational frequencies in the order of 100 KC.

A conventional 120 db gain voltage sensitive amplifier with a passband of ± 10 kc centered at 100 kc receives the signal from the microphone. The pulse rate from this amplifier is recorded by four counters of two binaries each fed from amplifier taps separated by 30 db in gain. Thus, a crude momentum spectrum is obtained.

3.3.6.1 REFERENCES FOR SECTION 3.3.6

1. A. Behr and H. Siedentopf, Zeits. f. Astrophys., 32, 19, 1953
2. E. J. Opik, Zeits. f. Astrophys, 35, 43, 1954
3. H. C. van de Hulst, Les Particles Solides dans les Astres, Liege, pg. 89, 1955
4. D. E. Blackwell and M. F. Ingham, M. N. 122, 114, 1962
5. C.W. McCracken, W.M. Alexander and M. Dubin, NASA TN D-1174, Dec. 1961
6. F. L. Whipple, "The Dust Cloud About the Earth" Nature 189 (4259) 127-128, Jan. 1961

3.6 ALTERNATE EXPERIMENTS

The purpose of this section is to describe other experiments which could contribute new information regarding the interplanetary physics in the region near the sun if incorporated into a solar probe vehicle with a perihelion of approximately 0. 3 AU. As stated in Section 3. 3, the scientific instrument package assumed for vehicle design purposes contains a weight, power, and data word allocation sufficient for some experiments in addition to those described in Section 3. 3, of which the vehicle design takes explicit account. The alternate experiments which will be discussed are the following:

		Lbs.	Watts
1.	Ionization Chamber X-Ray Experiment	3. 0	1. 0
2.	Intermediate Energy Particles-Semiconductor Detector	2. 0	0. 5
3.	Lyman Alpha Experiment-UV Photometer	7. 0	3. 0
4.	Zodiacal Light Experiment-White Light Photometer/scanner	5. 0	1. 0
5.	VLF Radio Noise Experiment (requires VLF antenna)	8. 0	0. 5
6.	TV Facsimile Experiment	10. 0	12. 0*
7.	VLF Antenna Impedance Measurement to Determine Electron Density	2. 0	1. 0
8.	Neutron Experiment (requires boom)	20. 0	1. 0
9.	Energetic Electron Detector-Coincidence telescope	2. 0	0. 5
10.	Experiment to Determine Surface-Charge Generating Voltmeter	4. 0	2. 0
11.	High Energy Cosmic Ray Experiment-Coincidence telescope	7. 0	1. 0
12.	RF Mass Spectrometer	5. 0	5. 0
13.	Improved Determination of the Astronomical Unit	0	0

*For 2 seconds per picture

3.6.1 IONIZATION CHAMBER FOR DETECTION OF SOLAR X-RAYS

In order to detect large solar flares on the solar hemisphere invisible from earth, means for their observation should be provided aboard a Solar Probe. The simplest means of detection might be an ion chamber to detect soft X-rays. Work done with the SR 3[1] satellite showed that large increases in X-rays in the 8 to 16 Angstrom band occurred in conjunction with a class 3^+ solar flare and it is likely that this association is quite general. Various degrees of sophistication can be considered in the design of a detector of active solar regions. It has been proposed[1] that a coarse matrix of photodiodes with a simple optical system could detect hot solar regions by ultraviolet light and give a rough indication of their location on the solar disc. A more elaborate system for optical examination of the back side of the sun utilizing a vidicon system is described in detail in another item below. Here we will confine our attention to the simplest flare detector, which is probably just a thin walled, gas filled ionization chamber. Flare detection by radio noise is another possibility.

The relative infrequency of large solar proton events indicates that a serious effort should be made to obtain as much data as possible from those which will occur during the next increase in solar activity. Instruments to study the energetic particles are recommended in Section 3.3 above. For those events originating from flares on the invisible solar hemisphere, it would be highly desirable to have an indication of the time of occurrence and some measure of the intensity of the event so that information regarding propagation times for particles of various energies would be obtained. When further information is available regarding the intensities of solar X-rays generated in flares of different importance, the flare X-rays might be used to trigger a high sampling rate mode for the energetic particle detectors, so that accurate propagation time and rise time information could be obtained despite the relatively slow average sampling frame rates available on an interplanetary space vehicle. If a TV facsimile experiment is also provided on board the vehicle, it might be desirable to trigger its picture taking by means of the same flare detector. By this means an actual photograph showing the location of the flare would be obtained. Such knowledge of the flare location would be useful in obtaining information regarding propagation paths and widths of the proton beams for more of these rare events than would be possible otherwise.

A suitable ionization chamber would have a volume of several cubic inches and would be shielded from ionizing radiation in directions other than the sun direction. It would be provided with a thin window whose thickness would be several mg/cm^2 of aluminum and be filled with nitrogen to the order of one atmosphere pressure. Because of the relatively large aperture required for the window, such an instrument would cause an unduly large variable heat source to enter the instrument compartment if the aperture were provided in the vehicle heat shield. For this reason an external mounting similar to that chosen for the Faraday cup instrument should be provided so that the ion chamber can dissipate the solar heat received via radiation from its back side with relatively short heat conduction paths. Such a location is illustrated in the vehicle drawings in Volume II of this report.

3.6.1.1 REFERENCE FOR SECTION 3.6.1

1. Action & Chubb, JGR 68, 3335, (1963)
2. J. A. Simpson, private communication

3.6.2 INTERMEDIATE ENERGY PARTICLES

It is believed that the energetic solar particles are accelerated in local regions surrounding flares. The low energy plasma represents a more or less steady expansion of the solar corona with continuous beams having their roots in the most active solar regions with occasional intense clouds ejected from the regions of flares. A clean cut distinction between these two types of particles may not, however, be possible. On the one hand it is believed that polar cap ionospheric absorption events are caused mainly by protons whose energy is of the order of 10 Mev, which impinge on the ionosphere when unusually intense clouds of plasma arrive from the sun. Whether these energetic particles originate in the sun or are accelerated from the interplanetary medium by the action of a plasma shock front is not known. On the other hand, a weak source of low energy cosmic rays, whose intensity declines with solar activity, has been mentioned above in Section 3.3. These particles must either be continuously emitted by the sun, or if their origin is in flare events, an interplanetary storage mechanism must be postulated. It would be highly desirable to perform experiments which would close the energy gap between the lowest which can be measured by energetic particle techniques (5 to 10 Mev) and the highest which can be measured by plasma probe techniques (perhaps tens of kilovolts). Such measurements would doubtlessly aid in understanding the phenomena discussed above.

The importance of a measurement of proton fluxes in the range of tens of kilovolts to several Mev is such that it would deserve a place in a Solar Probe instrument package provided suitable experimental equipment can be developed. Several groups are currently active in developing windowless solid state particle detection techniques which might be ready in time. Outstanding problems at present are detector and preamplifier noise and detector stability.

3.6.3 LYMAN ALPHA ABSORPTION CORE EXPERIMENT

3.6.3.1 OBSERVATION OF ABSORPTION CORE

The solar Lyman alpha line has been shown to exhibit an absorption feature[1] when viewed with a high dispersion spectrograph flown above the earth's atmosphere. This feature is composed of two components, a broad weak reversal and a deep narrow central absorption core. A microphotometer tracing of the line is shown in Figure 3.6.3-1.

The broad reversal is believed to originate in the solar atmosphere whereas the absorption core is attributed to neutral hydrogen lying above the E-layer of the earth's atmosphere but outside the sun's atmosphere. The emission line itself arises in the chromosphere of the sun. The kinetic temperature required to form the line is in the order of 60,000 - 100,000°K whereas the temperature characterizing the emergent radiation averaged over the disk of the sun is about 7200°K.

To define the spatial distribution of the neutral hydrogen cloud as a function of solar distance is of great interest and is determined by recording the depth of the absorption core as the solar probe vehicle approaches the sun. By observing the change in the equivalent width of the core it will be possible to calculate the number of atoms $/cm^2$ in a column lying between the probe and the sun. The total as seen from the earth's vicinity has been computed to be in the order of 2×10^{12} atoms$/cm^2$.

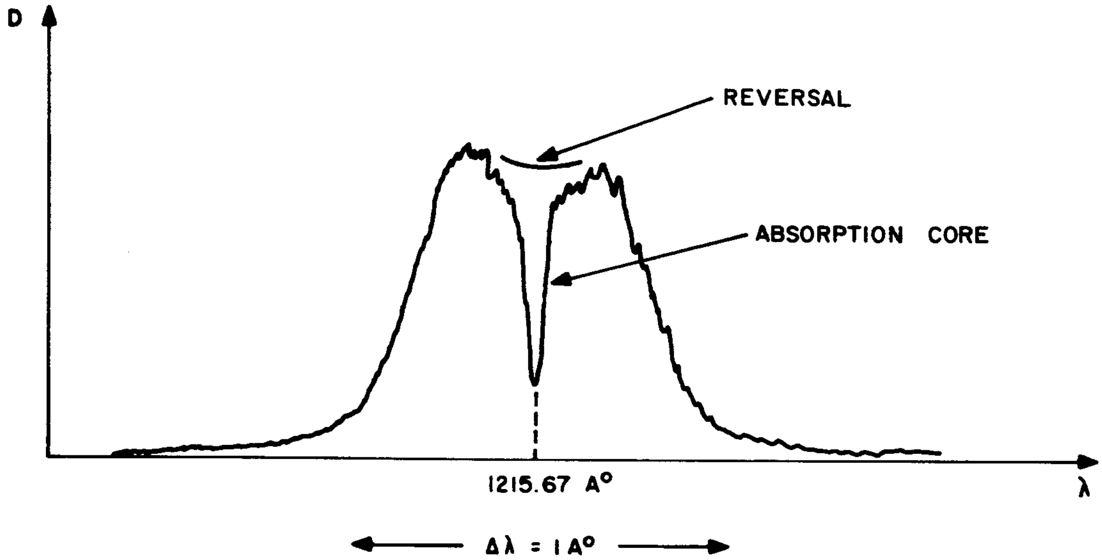


Figure 3. 6. 3-1. Solar Lyman Alpha Curve

Since the Lyman alpha line is quite intense (6 erg/cm^2 sec), from which the narrow core removes approximately . 1 erg/cm^2, detection problems are minimal. Thus a diffraction grating spectrometer of the type used by Purcell and Tousey appears adequate for this experiment.

3. 6. 3. 1. 1 Detector — The detector is a photodetector using a tungsten cathode and LiF window. This combination has a spectral passband 1050A° $<\lambda<$ 1800A°. The rejection of the scattered near-U. V. and visible radiation within the spectrometer is an important aspect of this combination of filter and photocathode. Operation at a pressure of 10^{-5} mm is required. This may be achieved either by evacuation of the entire spectrographic system which allows the use of a windowless phototube and a LiF filter (not recommended) or to use the LiF as part of the glass envelope around the phototube with evacuation being limited to the phototube itself (recommended operation).

3.6.3.1.2 Spectrometer — The spectrometer similar to the NRL instrument will use a 50 cm, 1200 line/mm diffraction grating in the 13th order operation in a Rowland mount with a predispersive grating ahead of the entrance slit mechanically deformed so that the spectra appearing at the exit slit will be stigmatic over the entire length.

The dispersion from such a system will be in the order of 2. 6°A/mm with the exit slit scanning across the line having an effective width of . 01°A. Thus the entire line which is 1°A wide and the core which is 0. 04 to 0. 05°A wide at the half maximum point will be resolved in enough detail to trace the disappearance of the core as the vehicle approaches the sun. The exit slit will scan through an arc of 1 mm in length along the Rowland circle thus covering 2. 6°A in wavelength centered at 1216°A. This will insure complete coverage of the line plus a portion of the continuum on either side of the line required for a reference comparison.

While it is not necessary to vacuum seal the entire spectrograph, it is necessary to keep dirt away from the slits and thus clean assembly practices will have to be followed. Slit widths are in the order of 10 - 15 micron. The gratings are coated with fresh aluminum overlaid with magnesium floride in order to ensure sufficient light efficiency.

In Figure 3. 6. 3-2 the angles of incidence and diffraction are exaggerated.

3.6.3.2 OBSERVATION IN EMISSION

Examination of the distribution of neutral hydrogen in the solar system could also be made by an experiment sensitive to resonance fluorescence or de-excitation of gas atoms at considerable elongations from the sun. This experiment could be performed by photoionization chambers which look alternately perpendicular to the ecliptic plane or in the ecliptic plane normal to the direction to the sun. Information regarding the spatial distribution of neutral hydrogen in the solar system could be obtained by comparing the way in which the absolute and relative intensities of the Lyman alpha light from the two directions changed as a function of heliocentric distance.

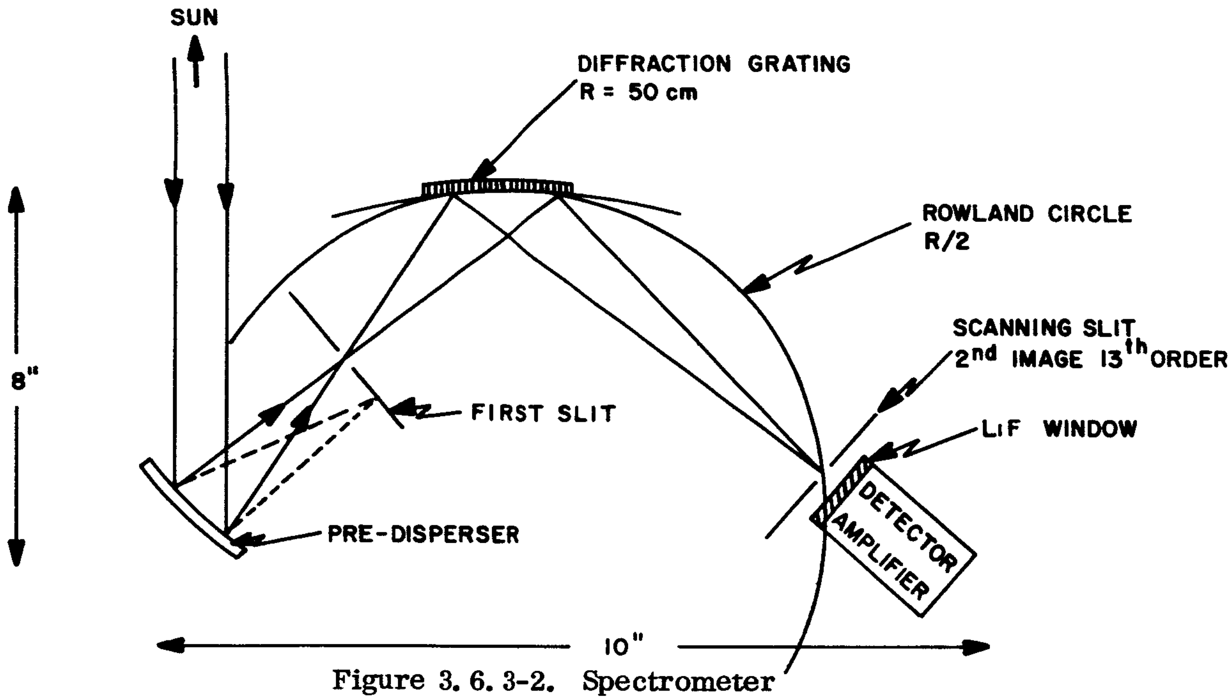


Figure 3. 6. 3-2. Spectrometer

Significant instrumental characteristics of this experiment follow.

3.6.3.2.1 Detector — The detector is a photoionization chamber which consists of a ceramic shell, gold plated on the inside, fitted with a highly polished central collecting wire electrode, and incorporating a window of suitable transmission properties. The filling gas and window material for the present experiments are given below.

Filling Gas	Gas Press	Filter	Filter Thickness	Quant. Eff.	Spect. Range
CS_2	15 mm Hg	LiF	1 mm	50-60%	1050-1240 A°
NO	20 mm Hg	CaF_2	1 mm	20-30%	1230-1350 A°

Note that the CS_2 detector covers the L α range. The NO detector is required to provide a calibration level outside the L α range. Relative as well as absolute intensities are obtained.

Operation of these detectors for weak signals of the order of 10^{-5} ergs/cm^2/sec require gas gains on the order of 200 to 300. This is provided by raising the collector voltage. The exact amount depends upon the gas. For our purposes voltages in the order of from 500 - 700 volts are likely to be required.

These detectors average 1.4 inches in diameter, 1.5 inches in length, and have a window opening of 0.4 inch diameter.

3.6.3.2.2 Photometer — Each photometer consists of a pair of detectors, one NO and one CS_2, for which a single optical system is provided for the pair in which the detectors are mounted side by side and equally displaced from the optical axis. This is possible since quality imaging is not required.

The primary collector can be a five inch diameter spherical mirror providing a 1 degree field of view for each detector. The detectors are mounted at the prime focal surface and the effective aperture is approximately 4.5 inches.

A sketch of this arrangement is shown in Figure 3.6.3-3.

It is to be noted that each detector does not look exactly at the same 1° field of view. For this experiment this is of little importance.

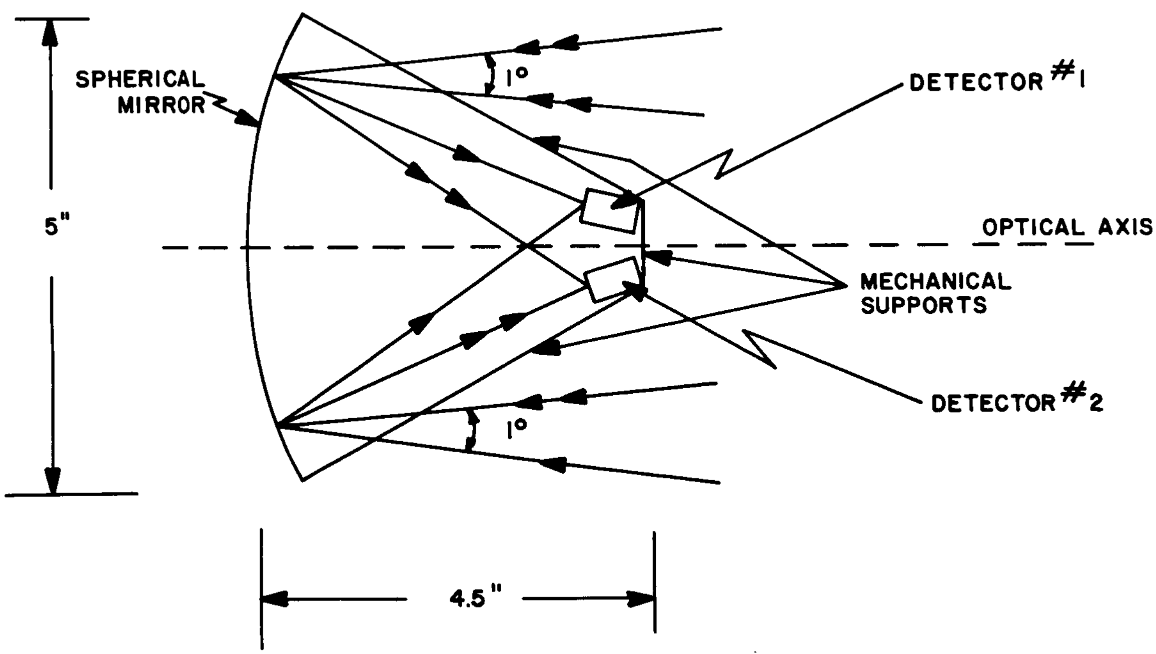


Figure 3.6.3-3. Photometer

A conventional linear electrometer amplifier with a sensitivity of the order of 10^{-12} amperes per telemetered volt is required for each detector.

Since the strength of the expected signal is quite uncertain, possibility of saturation exists. For this reason provisions may be required to remove the signal by a mechanical shutter or by electrical de-activation of the instrument.

3.6.3.3 REFERENCES FOR SECTION 3.6.3

1. I. D. Purell and R. Tousey, Proc. of the First International Symposium on Space Science, Nice, (1960) p. 550.

3.6.4 ZODIACAL LIGHT EXPERIMENT

A brief discussion of the zodiacal light was given in Section 3.4.4 and the extent to which the interplanetary dust contribution to its source could be studied by in situ measurements using acoustic sensors was noted. The brightness of the zodiacal light has been measured[1] from the corona out to an elongation of 75°. Considerable information could be deduced regarding the distribution of the source of this light in the space about the sun by performing a similar experiment at a distance of approximately one-third astronomical unit from the sun. Alternate color filters should be used ahead of the photometer detectors in order to be able to detect the degree to which scatter light agrees in color with sunlight. In this way a separation can be effected between the electron and Mie scattering and the Rayleight scattered components. Polarization measurements would also be of assistance here. The degree to which the relative intensity of these components changes at various elongation angles would indicate possible differences in heliocentric distributions of the respective sources.

The rapid removal of the dust component from the solar system by energy loss via energy transfer to electrons, assisted by the Poynting-Robertson effect, requires a large source of dust for its continual replenishment. Analysis of the heliocentric distribution of this dust might distinguish between alternate postulated sources of this dust, such as debris from asteroidal collisions or from comets.

The zodiacal light experiment consists of optical filters, sensitive photometers and an optical system capable of scanning. This experiment has been chosen for illustration in the drawings of Volume II as a part of one of the alternate experiment packages and is also shown in Figure 3.6.4-1 below. In this illustration, a scanning mirror with only a single degree of freedom scans in elongation from the outer corona to elongations of perhaps 75°. The nodding of the space vehicle about the roll axis, due to the Canopus tracker orientation system described in Volume II, gives scans which lie at various angles between -15° and +15° of the ecliptic plane at different positions in the vehicle orbit. Because of the relatively high intensity of light from the brighter stars, correction for starlight should be made at the higher elongations. For this purpose telemetering of the position of the scanning mirror as well as the photometer readings would be required. The nod position of the space vehicle would be known from the orbit position.

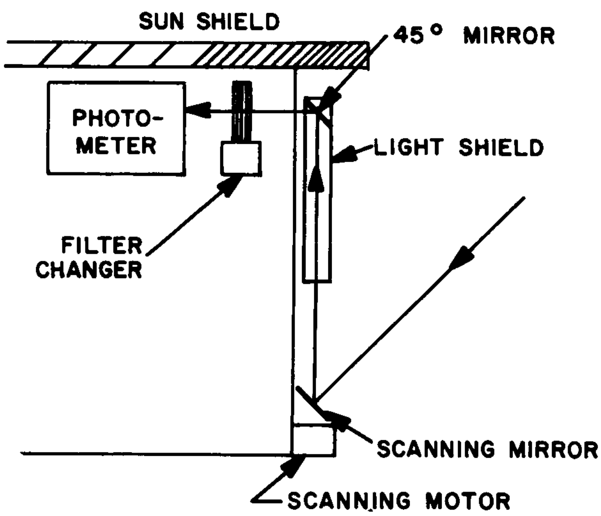


Figure 3.6.4.1. Zodiacal Light Experimental Optical System

The principal problem imposed in performing this experiment aboard the Solar Probe is to prevent scattered sunlight from the solar paddles from entering the photometer through the 45° fixed mirror illustrated. This can be accomplished by surrounding the optical path between the two mirrors by a tubular light shield which prevents the

45° mirror from seeing the solar paddles. Both mirrors are shaded from direct sunlight by the projecting edge of the vehicle sun shield. Light scattered from the solar sails can be prevented from entering the tubular light shield after second scattering from the scanning mirror by using a mirror somewhat larger than the diameter of the tube which would then block the paths of such light rays.

3.6.5 VLF RADIO NOISE EXPERIMENT

Two radio astronomy laboratories which were contacted during the course of this study indicated an interest in VLF radio noise measurements aboard any space vehicle which might be planned for flight in beyond the orbit of Mercury. The existence of large amounts of RF energy trapped in cavities formed by plasma clouds characterized by higher plasma frequencies cannot be excluded. If such phenomena existed, it would be of extreme importance for understanding of acceleration of charge particles in interplanetary space. The mean ion density of 4 cm^{-2} measured by Mariner 2 indicates an average plasma frequency of 18 kc, but this plasma density was observed to be highly variable. Based on Parker's calculations that the plasma velocity changes little between earth's orbit and a heliocentric distance of one-third AU, one would expect average plasma frequencies on the order of 60 kc at Solar Probe perihelion.

It has been pointed out by a number of workers that impedance measurements of VLF antennas can in principle yield the electron density in the vicinity of the antenna; such measurements could be made a natural part of a radio noise experiment, in which antenna impedance mismatch is needed in any event to obtain absolute effective noise temperatures. Such electron density measurements would complement any such measurements which might be made by electrostatic analyzers or Faraday cup collectors.

The difficulties of measurement of changes in antenna impedance under practical conditions where the uncompensated antenna reactance in vacuum might be rather extreme due to antenna size limitations, and the logical case for first adequately performing such experiments in the neighborhood of earth's orbit has led us to consider this experiment only as one which might be proposed at some time in the future.

3.6.6 TV FACSIMILE OF SOLAR SURFACE FEATURES

It has been speculated that in time there might be developed a means for predicting major solar flares which result in intense energetic particle fluxes in interplanetary space. Since early attempts[1] to derive criteria for predicting periods free from major solar flares based on observation of sunspot penumbras, there has been some renewal of interest in flare prediction based on observation of characteristics of calcium plage regions.[2] Improved scientific understanding of these complex phenomena might conceivably lead to useful prediction schemes, in which event observation of activity on the invisible solar hemisphere could become crucial to the manned space flight programs.

For prediction of solar proton events in the earth-moon space, the following qualification must be stated regarding the potential value of observing solar activity invisible from the earth. As summarized briefly in the sections above on High Energy Charged Particles and Interplanetary Magnetic fields, energetic particles reach the vicinity of the earth preferentially from flares on the western solar limb. It is unlikely that flares that have rotated beyond the western limb by more than a few days contribute to the events observed at earth, although in one case[3] riometer measurements indicated an intense flux of energetic particles incident on the upper atmosphere at a time when no class 3 flare was observed from earth. Thus, for possible schemes which might be developed to predict large flares several days ahead, the observations on which the predictions were based would have to be made at a time when the relevant solar region was visible from earth. Regions which had not yet rotated into sight around the eastern limb several days ahead of the flare would not yet be in a position to propagate any energetic particles to the vicinity of the earth.

In the event that a useful flare prediction scheme can be developed with a prediction time of the order of a week or more, then the observation of the relevant activity development behind the sun would be required, since in one week or more, active regions not yet brought by rotation around the eastern solar limb would arrive near the central solar meridian or beyond at the time of the postulated flare, which would then be likely to be connected to the earth moon system with magnetic field configurations favorable to the propagation of energetic particles.

In order to obtain an estimate of the complexity of a system for observation of solar activity in conjunction with a hypothetical prediction scheme with a prediction time exceeding one week, studies were made of solar photographs viewed with a digital TV system. Positive transparencies of the solar disc taken in white light, H_{α}, and CaK were scanned with various degrees of brightness quantization and raster resolution. The white light and CaK data have relevance to the prediction schemes based upon observation of sunspot penumbra and calcium plage regions. Recent speculations[4] on the mechanism of acceleration of energetic particles in flares indicates that magnetic null points may be involved. The presence of the appropriate magnetic field configurations could possibly be deduced from observation of solar magnetograms, but an experiment to examine magnetograms was not considered due to its complexity and the as yet unverified nature of the theoretical speculations.

As mentioned previously, such a TV facsimile experiment would also have the capability of transmitting photographs of the locations of large flares invisible from the earth, if a UV-sensitive vidicon were used. This data would be extremely useful in connection with the study of the interplanetary propagation of energetic solar cosmic rays.

The results of the study of a digital TV system, with figures obtained from the white light pictures are given in the following pages. This work was kindly contributed by the Electro-Mechanical Research Corporation and was performed by them on a solicited, unfunded basis.

3.6.6.1 SYSTEM REQUIREMENTS

The function of the proposed television system is to produce pictures of the sun having sufficient resolution and dynamic range to show the location and size of typical sun spots and flares. For obvious reasons, the size, weight, and power requirements of the system must be held to a minimum. It is equally important that the required data be transmitted to earth with as few information bits as possible. Additional problems which must be considered in the system design are the inaccuracies in the spacecraft pointing vector and the variations in the distance to the sun during the mission.

3.6.6.2 PRELIMINARY DESIGN CONSIDERATIONS

The requirement of minimum size, weight, and complexity conflicts with the requirement of obtaining maximum picture detail per transmitted bit. Several typical sun pictures were analyzed on the EMR EDITS (Experimental Digital Television System) equipment to determine which trade-offs between complexity and picture quality were most advantageous. The variable parameters in these tests were resolution and number of quantizing levels.

Figures 3.6.6-1 and 3.6.6-2 are reproductions of the original white light photographs, and figures 3.6.6-3 and 3.6.6-4 are representative of the pictures obtained using 256 scanning lines and three bit quantization to reproduce the white light sun photographs.

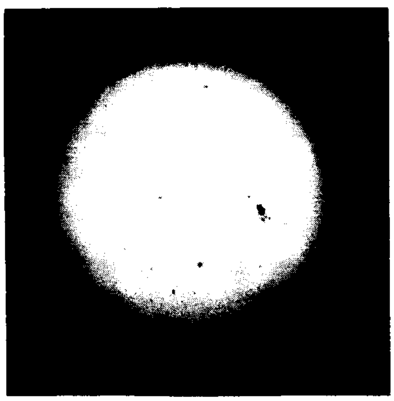


Figure 3.6.6-1. Reproduction No. 233 of Original White-Light Photograph

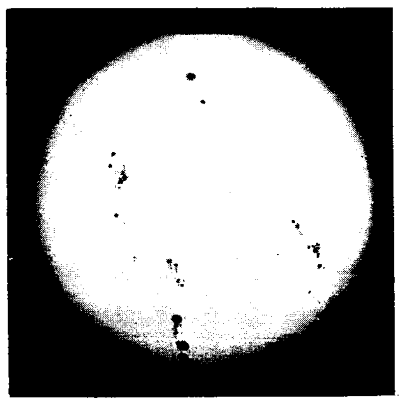


Figure 3.6.6-2. Reproduction No. 240 of Original White-Light Photograph

Courtesy of the Mount Wilson and Palomar Observatories

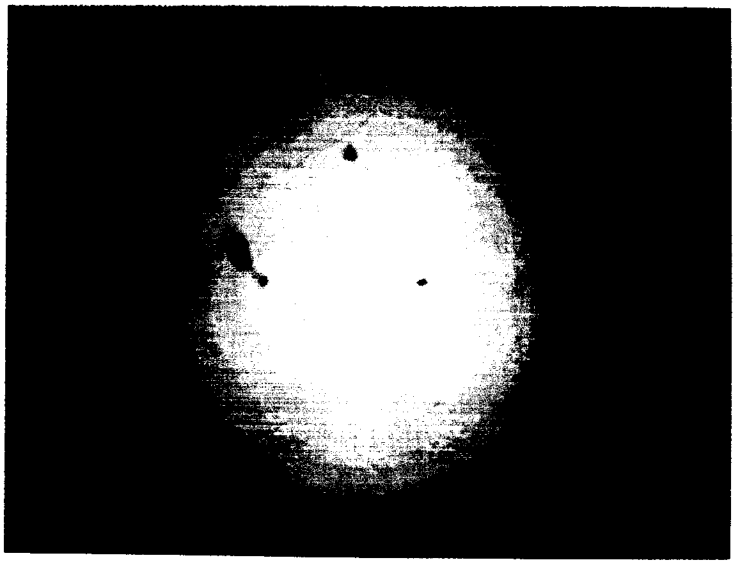


Figure 3.6.6-3. Transparency No. 233A, 256 Lines, 3 Bits

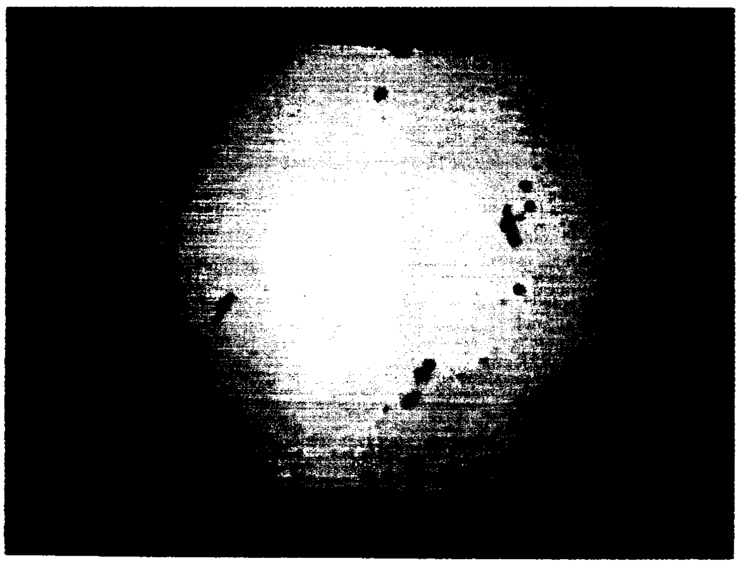


Figure 3.6.6-4. Transparency No. 240, 256 Lines, 3 Bits

These two reproductions retain essentially all of the pertinent information contained in the originals. Figures 3.6.6-5 and 3.6.6-6 were made from the same transparencies but with only 128 scanning lines and again, three bit quantization. Although the qualitative inferiority of Figures 3.6.6-5 and 3.6.6-6 is obvious, a close comparison of these with Figures 3.6.6-3 and 3.6.6-4 suggests that very little actual information is lost by using the coarser scan.

Additional experiments were conducted with EDITS to determine whether or not sufficient data compression could be achieved to make the use of 256 line pictures feasible, on a data rate basis. The optimum compression technique for the "white light" pictures is "run length coding"; analysis of the picture statistics indicates a compression ratio of approximately 5:1. By using "run length coding", each 256 line picture would require only 40,000 bits as compared to 50,000 bits for an uncompressed 128 line picture.

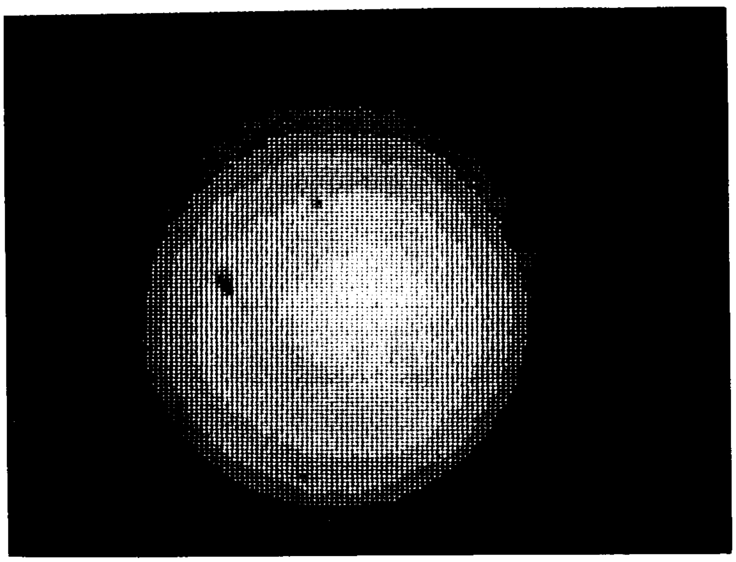


Figure 3.6.6-5. Transparency No. 233A, 128 Lines, 3 Bits

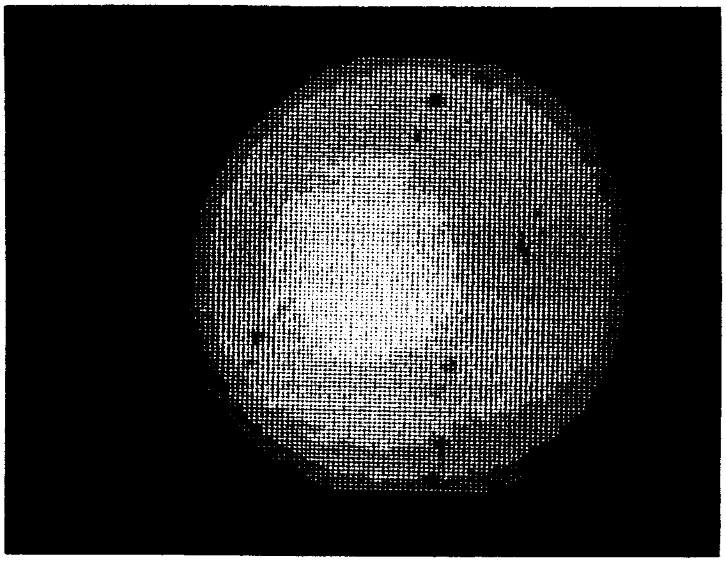


Figure 3.6.6-6. Transparency No. 240, 128 Lines, 3 Bits

On this basis, it would obviously be desirable to use the high resolution compressed system provided that the penalty in system complexity and size is not too large. Unfortunately, a preliminary system design and parts estimate indicates that the compression equipment would add approximately seven pounds to the payload weight; this is judged to be too severe a penalty to pay for the expected gain in system performance. Another point against the compressed system is that the compression ratios for the H_{α} and C_{ak} pictures studied would be as low as 2:1 or 3:1 because of their greater detail; thus, the improvement realized by the added complexity is partly offset by an increase in the required bits per picture.

3.6.6.3 SYSTEM DESCRIPTION - OPTICAL SYSTEM

Figure 3.6.6-7 is a functional block diagram of the major system components. The vidicon objective lens provides a fixed field of view of 1.5° on the vidicon target.

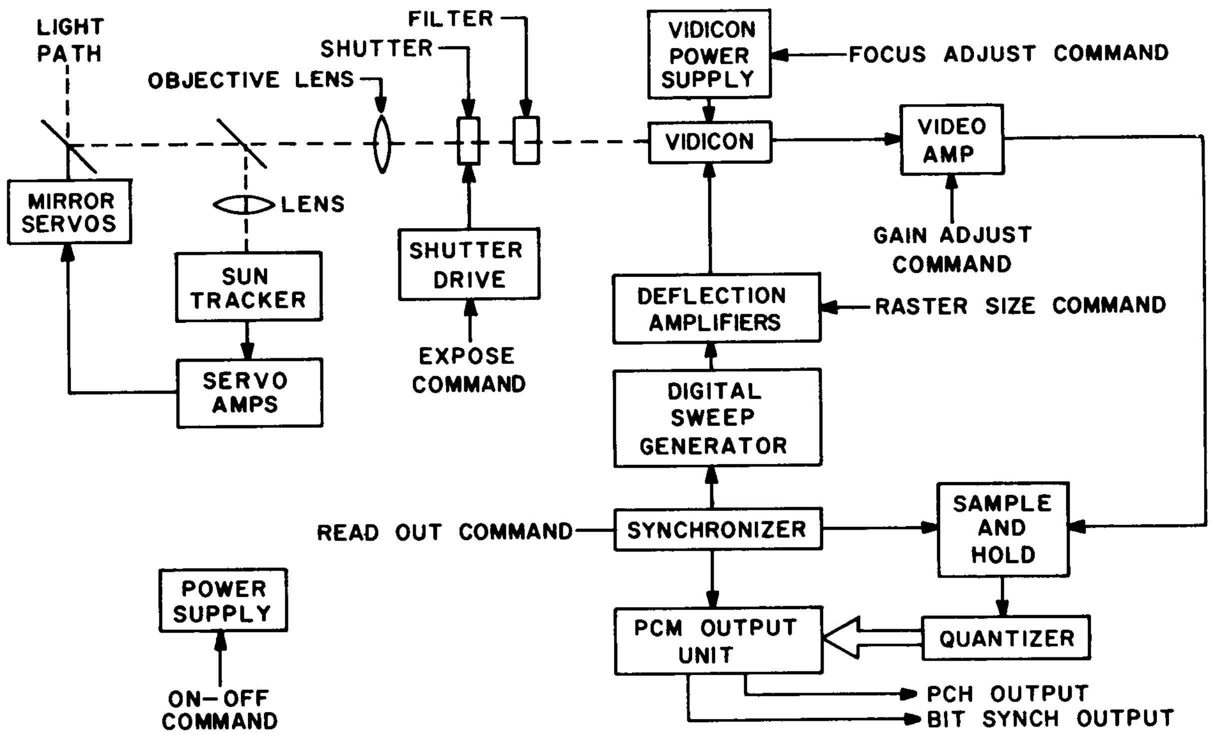


Figure 3.6.6-7. Solar Probe TV System Block Diagram

With this field of view, the diameter of the sun's image varies from 0.95 D_T to 0.33 D_T (D_T = length of side of useful square target area), at perihelion and aphelion, respectively. The vidicon can resolve 500 lines across the full target and 500 X 0.33 = 165 lines for the minimum size sun image; thus the system resolution of 128 lines is not degraded by using the fixed focal length optical system.

The beam splitter directs a portion of the total incident light to a silicon radiation tracking transducer; the sun tracker field of view is approximately 5°. The X and Y error signals from the tracker drive the mirror servos to center the sun's image on the vidicon target. Centering the image on the vidicon serves two purposes. First, it assures that the total image is included in the vidicon field of view in spite of the spacecraft pointing vector inaccuracies. Second, since the image position is known, the size of the scanning raster can be adjusted in accordance with the varying image size, to maintain the full 128 line resolution across the image. Figure 3.3.6-8 shows the relative image and raster sizes at the extremes of the solar orbit. A total of six intermediate raster sizes will provide adequate scan utilization throughout the orbit. The raster

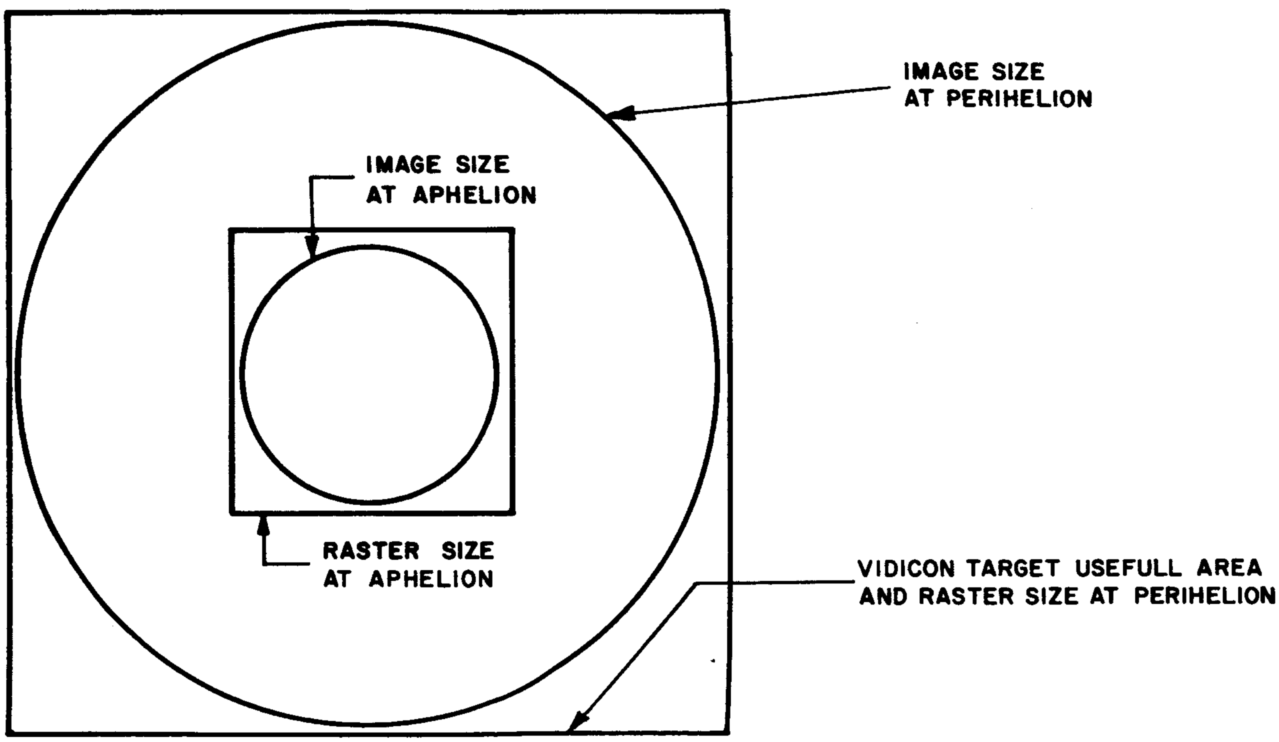


Figure 3.6.6-8. Relative Image and Raster Sizes at Aphelion and Perihelion

size changes can be accomplished by transmitting a three bit code word each time a new size is required; the interval between size changes will be days, near aphelion, and weeks near perihelion.

Optimum vidicon exposure is achieved by using a ten millisecond shutter in conjunction with a neutral density filter having a density of approximately 3.0; the objective aperture is approximately 14 millimeters. In the event that H_α or C_{ak} pictures are required, additional filters and a positioning mechanism, operated by command signals, would be required and a longer exposure time would be used.

3.6.6.4 CAMERA ELECTRONICS

The camera tube is a slow scan, electrostatic vidicon capable of storing images for several minutes before readout, with negligible deterioration. The vidicon power supply generates regulated voltages for all the vidicon elements including the heater; provision is also made for an eight step focus voltage adjustment which is set, if required, by a 3 bit command word. Vidicon beam current is regulated to obviate the necessity of commanded adjustments. Target voltage need not be adjustable, since the light levels to be encountered are well known and remain constant.

The vidicon deflection amplifiers contain simple logic circuits to vary the digital raster size in eight steps; a single 3 bit command word is required to set the size adjustment.

The video amplifier unit provides for a 3 bit command gain adjustment to match its output level to the sample and hold unit; this is a precaution against possible build up of long term drifts in vidicon sensitivity, sample and hold circuit gain and quantizer threshold.

3.6.6.5 DIGITAL CIRCUITS

The synchronizer generates all timing waveforms required in the system. It supplies sweep advance pulses to the digital sweep generator at the element rate of 133 pulses per second.

The quantizer provides a 3 bit parallel output for each element sample to the PCM output unit. The PCM pulse train to the vehicle storage is at a 400 pulse per second rate. Horizontal synchronizing code words are inserted at the end of each line by the PCM output unit. Each picture requires 50,000 bits, yielding a frame readout time of 125 seconds at a PCM rate of 400 pulses per second.

3.6.6.6 SYSTEM IMPLEMENTATION

The entire electronic portion of the system, with the exception of the mirror servos, can be implemented with circuits already designed and proven for Project Celescope. This approach is definitely recommended because of the similar reliability requirements of the two equipments. The Celescope equipment makes use of micropower, quad-redundant circuit modules to achieve a life expectancy of 10,000 hours in orbit, after 10,000 hour storage. The life expectancy of the Solar Probe Television System will be even longer because of its relative simplicity and the fact that far fewer components are required.

Detailed block diagrams of the proposed system were used to establish an electronic part count, and size and power estimates were made. The estimates for the system, including optics, are as follows:

Weight :	154 ounces
Volume :	175 cubic inches
Power Consumption:	12 watts (only when actually making a picture, otherwise negligible).

3.6.6.7 REFERENCES FOR SECTION 3.6.6

1. K. A. Anderson, NASA TN D 700, Mar. 1961
2. J. B. Weddell, Paper P5 Bull. APS 1963 Summer Meeting, Alberta, Canada
3. G. C. Reid & H Leinbach, Geophys. Res. 64, 11, 1801, (1959)
4. J. E. Dungey, "Null Point in Space Plasmas" Symposium on Plasma Space Physics, Catholic U., June 1963

3.6.7 VLF ANTENNA IMPEDANCE MEASUREMENT TO DETERMINE ELECTRON DENSITY

Discussed in Paragraph 3.6.5, above.

3.6.8 SOLAR NEUTRONS

The possibility of detecting neutrons from the Sun has been discussed by Biermann, Haxel, and Schlüter[1] as early as 1951. Attempts to detect such neutrons by means of instruments located near the Earth have so far given either negative or inconclusive results.[2] A more extensive attempt to detect solar neutrons during quiet Sun has been made recently by Haymes in balloon flights from Texas; the results are not yet available.[3]

Here we will not discuss the mechanism of neutron production on the surface of the Sun, nor make any estimate of the production rate of such neutrons. The phenomena on the solar surface are not sufficiently understood to justify such a detailed discussion in the present context. Suffice it to note however that neutrons are undoubtedly produced in nuclear reactions taking place on the solar surface, especially in active regions and during solar flares. These neutron-producing reactions will involve the more abundant light nuclei (i.e., He, C, N, O) found both in the solar surface material and in the solar-cosmic-ray beam accelerated in flares. It is reasonable to assume that the energy of these neutrons at the time of production are on the order of 1 Mev if they are evaporation neutrons, from "stationary" nuclei and on the order of 10 to 100 Mev if they are from direct processes, or from evaporation by nuclei moving at high velocity. There must also be solar neutrons of still higher energy, but these must be very rare compared with neutrons of lower energy. Some of the neutrons will be moderated by the hydrogen in the solar surface, but these slow neutrons have practically no chance of being detected as will be shown.

As far as solar neutron studies are concerned, the advantages of a solar probe (at 1/3 AU) over an Earth satellite (at 1 AU) arise from the following three considerations: (1) The shorter distance the neutron must travel between source and detector increases markedly the probability of survival against decay; (2) The inverse square law favors the solar probe by a factor of nine; (3) The solar probe is not subject to the background due to atmospheric albedo neutrons. We now discuss the first two points more quantitatively.

We know that the neutron at rest decays into a proton, an electron, and a neutrino, with a mean life of about 1,000 seconds. If a neutron is moving with a velocity approaching that of light, its mean life is appreciably increased as prescribed by special relativity. Suppose a collimated beam of solar neutrons is emitted in the direction of a detector located at a distance R from the Sun. For an Earth satellite $R_e = 1$ AU = 1.5×10^{13} cm. For the solar probe, R = 1/3 AU = 0.5×10^{13} cm. The fraction f (E) of the emitted neutrons of kinetic energy E surviving to the detector is, on the average,

$$f(E) = e^{\frac{-R/v(E)}{\tau_o \gamma(E)}} \quad (1)$$

where v (E) is the velocity of a neutron of kinetic energy E, τ_o is the mean life of neutron at rest $\approx$ 1000 sec., $\gamma \equiv \frac{1}{\sqrt{1-\beta^2}}$ and $\beta \equiv \frac{v}{c}$, and $c = 3 \times 10^{10}$ cm/sec = velocity of light.

Eq. (1) can be written as

$$f(E) = e^{\frac{-R/c}{\tau_o \beta(E)\gamma(E)}}$$

$$= e^{\frac{-R/c}{\tau_o \sqrt{\gamma^2 - 1}}} \quad (2)$$

For $\nu \ll c$, Eq. (2) reduces to

$$f(E) = e^{\frac{-R/c}{\tau_o \beta(E)}} \quad (2)^1$$

Table 3.6.8-1 gives f_e and f_p for the cases R_e = 1 A.U. and R_p = 1/3 AU, respectively, as a function of neutron energy. Also given in Table 3.6.8-1 are the quantities

$$g_e = \frac{fe}{4 \pi R_e}$$

$$g_p = \frac{fp}{4 \pi R_p}$$

g is the average number of solar neutrons reaching a detector surface of 1 cm^2 located at a distance R from the Sun, per solar neutron emitted isotropically from the Sun. The assumption of isotropy at emission is probably justifiable considering the complex orientations of the charged particles in solar active regions.

The quantity of interest in Table 3.6.8-1 is g_p/g_e. For example, it is seen that detection at 1/3 AU. is some 10^4 times as efficient in detecting 1-Mev solar netrons as one located at 1 AU. That f_p/f_e is about a factor of 10 smaller than g_p/g_e is expected since f_p/f_e does not take the solid-angle advantage of the solar probe into account.

Obviously, the lower the neutron energy, the greater the advantage of the solar probe over the Earth satellite. For neutrons below 0.1-Mev, detection is perhaps hopeless anywhere except for detectors very close to the inner corona. For neutrons above 100 MeV, the advantage of the solar probe is not remarkable. Since the neutrons of greatest interest are in the 0.1 to 100 Mev range, and since no conclusive detection of solar neutron has yet been made from the Earth's vicinity it is desirable to search for solar neutrons in the proposed solar probe. The considerable flux advantage of the solar probe ensures that the merit of such an experiment will not be greatly diminished should solar neutrons be already detected in Earth satellites when the solar probe becomes ready.

One of the problems that will arise is that of the choice of design of neutron detectors. The difficulty stems from the need to discriminate against charged particles and photons from the Sun as well as the neutrons produced in the spacecraft structure and in

TABLE 3.6.8-1. CALCULATED VALUES FOR VARIOUS E(eV)

E (ev)	10^2	10^4 (10 Kev)	10^5 (0.1 Mev)	10^6 (1 Mev)	10^7 (10 Mev)	10^8 (100 Mev)
β			0.0146	0.046	0.146	0.43
γ			1.0001	1.001	1.0108	1.106
f_e			1.4×10^{-15}	1.7×10^{-5}	0.033	0.35
f_p			1.1×10^{-5}	2.7×10^{-2}	0.32	0.71
f_p/f_e			0.8×10^{10}	1.6×10^{3}	10	2
g_e (cm^{-2} per neutron)			5×10^{-43}	6×10^{-33}	1.2×10^{-29}	1.2×10^{-28}
g_p (cm^{-2} per neutron)			3.6×10^{-32}	8.7×10^{-29}	1×10^{-27}	2.2×10^{-27}
g_p/g_e			0.7×10^{11}	1.5×10^{4}	100	20
Transit time T_e (sec)			34,300	11,000	3,430	1,160
Transit time T_p (sec)			11,400	3,700	1,140	380

the detector itself. A particularly favorable position for solar neutron detection is when the detector is on the same side of the Sun as the flare but is not magnetically coupled to the flare. In this position, the detector is in the neutron flux but not in the full charged-particle flux. Such a situation arises when the flare is near the central meridian (as seen from the detector) or to the east of it. The neutrons produced in the spacecraft structure can be eliminated by placing the detector on the end of a boom or a cord extended from the main spacecraft. Neutrons produced in the detector material as well as charged particles and photons from the Sun can be discriminated against by means of various biasing and anti-coincidence arrangements. Perhaps the most successful of such detectors at present is that of Mendell and Korff[4] which detects fast neutrons mainly in the range 1 to 10 Mev. In its present form, it weighs some 70 lbs., and is obviously too heavy for the earlier solar probes. It is not at present clear whether the weight of this detector can be greatly reduced. It is, however, to be expected that during the years before the first solar probe is ready, fast-neutron detection technology will be much improved (e. g. solid-state neutron detectors).

3.6.8.1 REFERENCES FOR SECTION 3.6.8

1. L. Biermann, O. Haxel, & A Schluter, 2 Naherforschung 6a, 47 (1951)
2. M. Swetnick, H.A.C. Neuburg, and S.A. Korff, Phys. Rev. 86, 589 (A) (1952), and T. A. Bergstralk & C.A. Schroeder, Phys, Rev. 81, 244 (1951)
3. R.C. Haymes. Phys. Rev. 116, 1231 (1959) and private communicate (1963)
4. R.B. Mendell & S.A. Korff, preprint (1963)

3.6.9 ENERGETIC ELECTRON DETECTOR

Following large solar flares, solar radio emissions are observed which appear to be characteristic of synchrotron radiation from relativistic electrons. It is reasonable to assume that the flare acceleration mechanisms which give rise to energetic proton fluxes observed in the vicinity of earth would also be capable of accelerating electrons to high energies. On the other hand, energetic electrons have not been observed in interplanetary space during solar proton events. To some extent this may be related to the difficulty of discriminating a weak flux of minimum ionizing electrons in the presence of an intense flux of heavily ionizing particles. On the other hand, radiation loss and greater inhibition to diffusion across magnetic field lines might greatly weaken the flux of electrons as compared to protons. It would be interesting to search for energetic electrons at closer distances to the sun. Measurements of the spectrum of electrons accelerated in flares and comparison with the spectrum of heavier particles might give clues as to the nature of the acceleration processes.

Recent developments in thin wafer solid state detectors indicate that minimum ionizing electrons can be discriminated in the presence of intense backgrounds of more heavily ionizing particles. It is desirable, however, that more effort be expended upon performing such an experiment in the vicinity of the earth's orbit before it is designed for and flown on a solar probe mission.

3.6.10 EXPERIMENT TO DETERMINE VEHICLE SURFACE CHARGE

As mentioned in Section 3.3.2, measurement of the spectrum of the electron component of the interplanetary plasma is expected to be considerably complicated by the presence of a vehicle electrostatic potential, in the event that this is appreciable compared to the mean energy of the electrons. The plasma temperatures deduced from the widths of the ion energy distributions measured aboard Mariner II appeared to lie in the range 10^5 to 10^6 °K, corresponding to energies in the range of tens of electron volts. The vehicle potential due to photo effect and electron bombardment could easily be important for the lower temperatures, assuming the electrons are in thermal equilibrium with the ions. In order to interpret the electron's measurements in such a case, some attempt should be made to derive the value of the vehicle potential relative to space. This might be done by measuring the vehicle surface charge, which gives the value of the normal component of the electric field, and comparing with theoretical computations to obtain the vehicle potential. The following discussion is intended to indicate a possible manner in which this might be done.

It is important to note that the escape of photoelectrons is not necessarily limited by the space vehicle potential but by the potential drop to a possible potential minimum within the sheath structure.[1] In that case there will be a double layer of space charge outside the surface, negative near the surface and positive further out. The electric field at the surface can, therefore, be reduced to a small value or even reversed. Thus on the sunward side of the vehicle there may be a complicated sheath structure because there the current flow is a combination (1) of the ion current which consists only of those ions swept from the plasma by the relative gross motions of the vehicle and plasma wind, (2) of the plasma electron current which is almost wholly accounted for by thermal motion, and (3) of the photoelectric emission current. In contrast, on the shaded side the only non-negligible current is that of the electrons whose space charge effect in the absence of ions will be negligible. There will be no double sheath, so that the surface field will be an accurate indication of a satellite potential different from zero. These considerations are of utmost importance for the placement of the relevant experiments. They tell us that if the vehicle potential relative to space is to be found by neasuring surface charge, the surface used must be on the shady side of the vehicle. An ideal position would be in the middle of the back surface of the vehicle. This region would be well shielded from the sunward side double layer and the density of surface charge would bear a fixed relation to the vehicle potential.

The surface charge yields a field strength, but a distance is needed in addition, in order to find a potential. This, the Debye length, can be estimated from the plasma temperature and density. Using the mean values deduced from Mariner II, we obtain a Debye length of about 20 vehicle radii in the vicinity of the earth's orbit, so that there the "ground" against which the vehicle potential exists can be taken as infinity.

The device to measure surface charge can be conceived as a generating voltmeter. An insulated portion of the satellite surface is alternately exposed to space and covered by a shutter which is grounded to the vehicle skin. The charging current is a direct measure of the surface electric field, but there is, in addition, a particle current because of the local unbalance of current to the collector. Electronically analyzing the composite current, the charging component can be separated out, since the time dependence of the two components is considerably different.

The generating voltmeter can be calibrated using a scaled-down model which can duplicate the particular geometries which can occur.

3.6.10.1 REFERENCES FOR SECTION 3.6.10

1. Collected works of I. Langmuir Vol 5, p. 140

3.6.11 HIGH ENERGY COSMIC RAY EXPERIMENT

As discussed in Section 3.3.4, the principal new experiment in the field of energetic particles which could be contributed by a Solar Probe vehicle would be aimed at separating the lower energy particles into those originating from the sun and those entering from outside the solar system. The frequency of occurrence and delay times for various energies and directions observed during solar events could add greatly to knowledge of propagation and possible trapping of these particles. Because of the range of energies observed from solar flares and because the solar modulation of galactic cosmic rays is expected to be greatest at the lower energies, primary attention should be focussed on the range below several hundred Mev, as discussed previously. For this reason, a cosmic ray experiment aimed at examining higher energies, say to 1 Gev, is here delegated to the alternate experiment list. In the event that future interest indicated the desirability of performing an experiment at such higher energies, other equipment than that indicated in Section 3.3.4 is indicated—Cherenkov detectors for example. In any event, it is unlikely that such an experiment would fly on the earlier Solar Probes.

3.6.12 RF MASS SPECTROMETER

Considerable interest hinges upon the measurement of the exact chemical composition of the gases in interplanetary space. The Mariner II plasma detectors gave evidence on some occasions of doubly ionized helium gas components participating in the general mass motion of the more abundant ionized hydrogen. More detailed energy spectra with improved instruments should add materially to these observations. A reasonably precise measurement of the abundance ratio of hydrogen and helium in the solar wind would give clues as to the abundance of these gases on the surface of the sun, which would be helpful for the astrophysical calculations which use surface composition as a boundary value for the internal composition problem.

The plasma detectors discussed in Section 3.3.2 should have sufficient energy channels to give important information on relative abundances of charged ions of different masses. Information on the neutral gas distribution will not be obtained; on the other hand most of the interplanetary gas is expected to be ionized, particularly in the vicinity of the solar probe perihelion. For this reason, it is considered that more work should be done to detect the neutral gas component of the interplanetary medium before such an experiment be considered for inclusion on a solar probe mission.

3.6.13 IMPROVED DETERMINATION OF THE ASTRONOMICAL UNIT

In the construction of planetary ephemerides the unit of distance is the astronomical unit, the unit of mass the solar mass, and the gravitational constant, the Gaussian constant. This system of units accurately defines the relative scale of the solar system since the distance at any time between any two bodies in the solar system for which the motions are adequately known can be expressed in these units. Conversely if the distance between any two bodies in the solar system can be measured in a physical system of units, say the MKS system, always assuming that the orbits are adequately known, such a measurement will yield the value of the astronomical unit in meters. Thus the scale of the solar system can be expressed in terms of an absolute rather than a relative set of physical parameters.

The objective of this experiment is to provide a means for more accurately determining the absolute value of the astronomical unit. Consider, therefore, the earth to be one body, the solar probe the other, both in orbit around the sun. The orbital motion of the earth is precisely known. From the launch and near earth tracking conditions the orbit of the solar probe can be computed and an ephemeris compiled in the relative system of units. (This computation should include the gravitational perturbations due to the other planets in the solar system as well as the earth and sun.) By tracking the probe we may continually compare the observed and computed trajectory parameters. But since the tracking data is in a physical system of units the comparison can only be made by the introduction of a proportionality constant, viz the numerical value of the A. U. expressed in meters. By computing a least squares fit of the observed and computed values of the observables along the entire orbit this constant will be continually refined and a more accurate value determined.

For the solar probe the observable is the Doppler shift in the probe's transmitter frequency corresponding to the relative radial velocity difference between the probe and the earth based tracking stations. By removing the effects of the earth's rotation and revolution the absolute radial velocity of the probe in an inertial reference frame can be obtained.

Such an experiment has been conducted in tracking the Pioneer V and the Mariner Venus fly by, but unfortunately both of these probes lost contact with the earth after having traveled only approximately 1/3 of one revolution in their orbits around the sun. Thus the fit was over this limited portion of the orbit and the precision with which the A. U. could be determined was only to the order of older determinations by other methods (Rabe 1950). With the solar probe it is expected that a more accurate determination will be made since Doppler tracking will be available over at least one full orbit.

The solar probe should employ for this experiment a phase-locked transponder that upon interrogation from the earth emits an R. F. signal in the 2 gc range with a frequency known to an accuracy of one part in 10^{10} of the transmitted frequency. This signal should be unmodulated and of a duration of at least 30 seconds once phase-lock has been achieved. The Doppler shift in the carrier retransmitted from the vehicle should be monitored and integrated during the periods when the DSIF is being used to interrogate the Solar Probe. Sampling along the orbit should be as frequent as possible during an entire vehicle orbit. It appears that the equipment necessary to perform this experiment will be available in the form of the DSIF - Solar Probe telemetry link and that no additional experimental equipment will be needed.

3.6.13.1 REFERENCES FOR SECTION 3.6.1.13

1. G. deVaucouleurs "The Astronomical Unit of Distance," Jan. 1961, AD248633
2. D. Brouwer "An Assessment of the Present Accuracy of the Value of the Astronomical Unit," Navigation, Vol. 9, No. 3, 1962
3. McGuire, et al, Sky and Telescope, XX6, 337, 1960
4. E. Rabe, A.J. 55, 112-116, 1950
5. E. Rabe, A.J. 59, 409-411, 1954

N65-29517

MARTIN COMPANY

SPACE PROGRAMS DIVISION

BALTIMORE, MARYLAND

Volume II

Scientific Objectives

Dr. Joseph P. Martin
Research Institute for Advanced Studies (RIAS)
Martin Company

CONTENTS

		Page
	Summary and Conclusions	vii
I.	Model of the Solar Atmosphere	1
	A. Solar Surface	1
	B. Solar Wind	4
	C. Solar Flares	7
	D. Interplanetary Region	9
II.	Scientific Experiments	13
	A. Solar Wind	13
	B. Magnetic Fields	15
	C. Energetic Charged Particles	16
	D. Neutrons	19
	E. Coronal Electron Density	20
	F. Other Electromagnetic Observations	25
	G. Micrometeoroid Measurements	26
III.	Specific Missions	27
	A. Suitable Orbits	27
	B. Launch Schedules	27
	C. Minimum Payload for Solar Approach	27
	D. Lightweight Payload for Solar Approach	28
	E. Typical Full Payload for Solar Approach	28
	F. Mission Away from Sun	30

SUMMARY AND CONCLUSIONS

The present level of knowledge of the sun and its atmosphere is based on the traditional combination of theory and experiment. However, experimental investigations have been limited by the difficulty of simulating the sun and its atmosphere in the laboratory and by the presence of the earth's atmosphere and magnetosphere. In the last decade strides have been made in experimental investigation by the use of rockets, earth orbiting satellites (e.g., OSO) and the first interplanetary probe, Mariner II. A survey of the present knowledge of the solar atmosphere is presented, describing both the solar surface and the interplanetary medium.

Even with the tremendous accumulation of experimental data since 1950, there is no certainty as to which, if any, of the many concepts of the dynamic corona is correct. While some of these concepts differ only in detail, others such as Parker's and Mustel's disagree fundamentally. These latter are discussed at length in order to point out the areas of disagreement and the experimental evidence supporting areas of each. Scientific measurements are discussed that would permit us to evaluate the degree of validity of the various concepts in the development of a broad concept of a dynamic corona, as well as to measure the solar atmosphere at the particular time of flight. This discussion is limited to experiments which are uniquely suited to a Solar Probe mission and which give information that cannot be obtained by observations from the earth or earth satellites. These experiments revolve mostly around measurements of the solar wind properties, the magnetic fields and the energetic charged particles of solar and galactic origin. The special requirements for these experiments are discussed, such as magnetic cleanliness in the vehicle and interference to the particle detectors by a radioisotope power supply. It is seen that a plasma probe and charged particle detector gain in usefulness by being mounted on a rotating platform. On the other hand the magnetometer and neutron

detector need to be on a 25-foot boom. A discussion of a VHF transmission experiment describes how one can get electron density information in the outer corona by observing the dispersive doppler shift of a VHF signal transmitted from earth to the spacecraft. The importance of having magnetic field, plasma (solar wind) and energetic charged particle detection for study of solar flare phenomena is stressed. It is also seen that a single solar flare X-ray scanner can increase the usefulness of other flare data by identifying the location of flares which produces data onboard but cannot be seen from the earth.

It is concluded that a solar approach in the vicinity of 0.2 to 0.4 AU will satisfy most of the scientific objectives proposed. A launch schedule is proposed with a first launch during the quiet sun in 1967 and then successive launches at eight-month intervals starting in 1969 so that two spacecraft are in flight during the period of maximum solar activity. In this way simultaneous measurements can be made by two Solar Probes at different positions in the solar atmosphere and correlated with measurements from earth orbiting satellites (OSO) and earth based observations.

A bare minimum payload is presented to illustrate what instruments would be considered absolutely essential to making the Solar Probe worthwhile. These include magnetometer, plasma probe and charged particle telescopes. A lightweight payload of 30 pounds is also suggested. This adds two experiments to the minimum payload, the VHF experiment and the flare scanner. An Atlas/Agena/X-259 launch vehicle can inject this payload to a perihelion of 0.3 AU to be consistent with a 200-pound spacecraft. A more complete experimental payload is presented to be consistent with a 400-pound spacecraft that the Atlas/Centaur/X-259 launch vehicle can inject to a 0.3 AU perihelion. This complement of experiments weighs 60 pounds; it includes, in addition to the above, a neutron detector, a white light corona meter, a rubidium vapor magnetometer and a mass spectrometer.

A payload which would be typical for a mission going away from the sun is also given. This includes a magnetometer plasma probe, charged particle telescope and a large surface area micrometeoroid detector.

I. MODEL OF THE SOLAR ATMOSPHERE

A. THE SOLAR SURFACE

1. Photosphere

Optical observations have yielded a great deal of knowledge about the surface of the sun. The visible disk of the sun, referred to as the photosphere, has a black body temperature of about 6000° K, although the uppermost portion of the photosphere appears to be as low as 4500° K. The photosphere is decorated with brightened granules having lifetimes of the order of three minutes and diameters of approximately 1000 km. At any one time there are about a million visible on the photosphere covering about a third of the visible area. Structures formed of this granulation have recently been found and given the name supergranulation. This structure takes the form of small rings of more intense granulation surrounding the normal granulation.

On this surface one sees the development of centers of activity. These appear in general to be bipolar magnetic regions which are thought to be due to twisted irregular magnetic field strands, which were initially submerged below the solar surface and became twisted as a result of the differential velocities of solar rotation. (The solar equator is seen to rotate with a period of 25 days. The period lengthens at successively higher latitudes, reaching 30 days at the poles.) Having come to the surface, these centers of activity, referred to as photospheric faculae, contain a number of sunspots--darker regions which have magnetic fields with strengths estimated at several thousand gauss. The darkness indicates a lower temperature, evidently due to restricted motion in the large magnetic field. The magnetic fields in the facular region surrounding the sunspots appear to be less than 100 gauss. The sunspot groups evolve in about a week from the appearance of the first spots to the maximum development and then decay again over a period of several weeks. The gas density at the photospheric surface is deduced from the light intensity to be about 10^{-8} gm/cm^3.

2. Chromosphere

The boundaries of the chromosphere are defined in terms of optical diameter of the photosphere at one extreme, and in terms of temperature and density of neutral hydrogen atoms at the other extreme. Just above the photosphere, the chromospheric temperature begins a rapid rise to an estimated ~50,000° K at 1000 km and then to ~1 million °K at a height of about 3500 km. While the height of the chromosphere-corona interface varies in both time and space, the 3500 km represents an average height of this interface above the photosphere.

Photospheric faculae, which contain the sunspots, have chromospheric faculae (plages) above them which are particularly bright in the K line of singly ionized calcium and extend to dimensions of 10^5 km around the sunspots. The material in the chromosphere shows definite upward and downward motions although the relative amounts of each are a matter of considerable uncertainty. The vertical velocities seem to be of the order of 15 km/sec, although on the plages they appear to be about half this value due to the stronger magnetic fields in the plages estimated between 20 and 100 Gauss. On looking more closely at the chromosphere, one sees many fine spicules or columns rising in the chromosphere with many of them rising well up into the corona. The plage areas are seen to be simply a denser packing of spicules. It is also quite suggestive that energy transfer through the spicules accounts for the great heating of the upper chromosphere and the corona. The supergranulation on the photosphere appears to be the base of the spicules whereas no spicules appear to arise from the normal granulation (Fig. 1). This chromospheric network of spicules is topographically identical with a magnetic network with a field strength comparable to plage field strengths. Thus the spicules, observed as a fine mottling of the chromosphere, are the seats of the chromospheric magnetic network.

3. Corona

The region beyond the chromosphere starting at ~3500 km above the photosphere is called the corona. The outer boundary of the corona has often been described as the outer part of the "visible" corona seen in eclipse photographs although it is probably more realistic to describe the entire interplanetary space as part of the corona. The activity in the corona is evidently very dependent on the situation in the chromosphere below it. The coronal regions above plages seem to have an increased density. A density ratio of a factor of 10 higher than the surrounding corona has been seen above plages at a height of 10^5 km. The temperature in this condensation is somewhat higher than the surrounding corona (~twice) and the magnetic field is about 2 to 6 Gauss at 10^5 cm. The high temperature of the corona results most probably from a flux of acoustic energy rising through the chromosphere in the spicules. Calculations have shown that the flux of acoustic energy from a region with a magnetic field of about 50 Gauss is about five to 10 times greater than the flux from the quiet parts of the sun. The acoustic energy transforms into a shock wave, dissipating its energy in the upper parts of the chromosphere and causing the increased density and heating in the corona above it.

Coronal temperatures are usually deduced from radio observations, emission line intensities, and emission line profiles. The line emission observed is produced by ions in high stages of ionization. The radio observations and line intensities yield electron temperatures, whereas the line profiles give ion temperatures. Although all of these

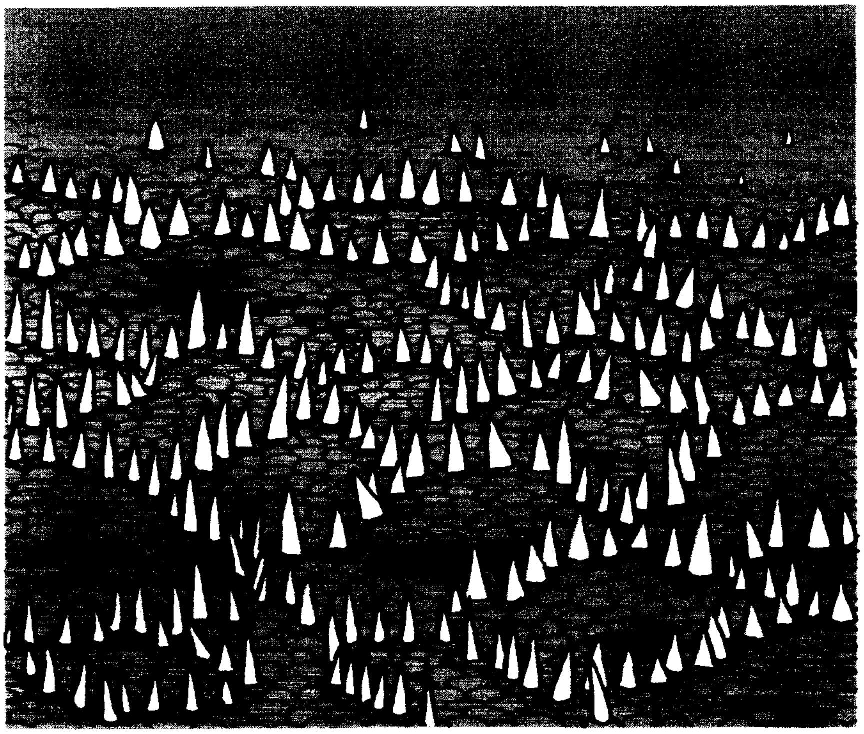


Fig. 1. Chromospheric Spicules Rooted to Supergranulation of Photosphere

temperatures seem to be of the same order of magnitude ($\sim 10^6$ deg), the electron temperatures derived from line intensities rarely agree with the ion temperatures derived from profiles of the same lines. Thus, the determination of details of the thermal structure of the corona is still an important problem of current research. In fact, any heating mechanism will have to account for such a structure once it becomes known.

B. SOLAR WIND

Evidence from many sources has pointed to the existence of a high velocity stream of particles being emitted from the sun. Bierman pointed out 12 years ago that the acceleration and the excitation and ionization of type-I comet tails can be explained only by a continual high speed streaming of particles from the sun. His analysis showed that this corpuscular radiation is more intense during periods of enhanced solar activity, but there is no indication that this radiation ever ceases even during extended quiet periods. This view is consistent with ascribing the quiet day aurora and continual agitation of the polar geomagnetic field to incidence of solar corpuscular radiation. With this picture of a "solar wind" there can be no static interplanetary medium since all interplanetary gas would experience the same acceleration as do the comet tails.

Plasma probes aboard the Russian Luniks and aboard Explorer X satellite measured such particle fluxes intermittently. The Mariner II plasma probe, directed toward the sun, detected a solar wind during the entire four months of its flight path from Earth to Venus with velocities between 300 and 800 km/sec and fluxes of about 1.2×10^8 particles/(cm^2 sec).

A number of models of a dynamic solar corona have been developed, with differences in models varying from the fundamental to mere subtleties. Two concepts which are both comprehensive and fundamentally different are those of Parker and Mustel. These are discussed below not only to point out the differences in concepts, but to define the scientific measurements that would not only permit definition of the solar atmosphere at the time of flight, but would permit evaluation of the degree of validity of each concept in development of a broad concept of a dynamic solar corona. It should be noted that the same types of measurements would be needed to verify or disprove any of the other concepts currently under consideration.

1. Parker's Model of Solar Wind

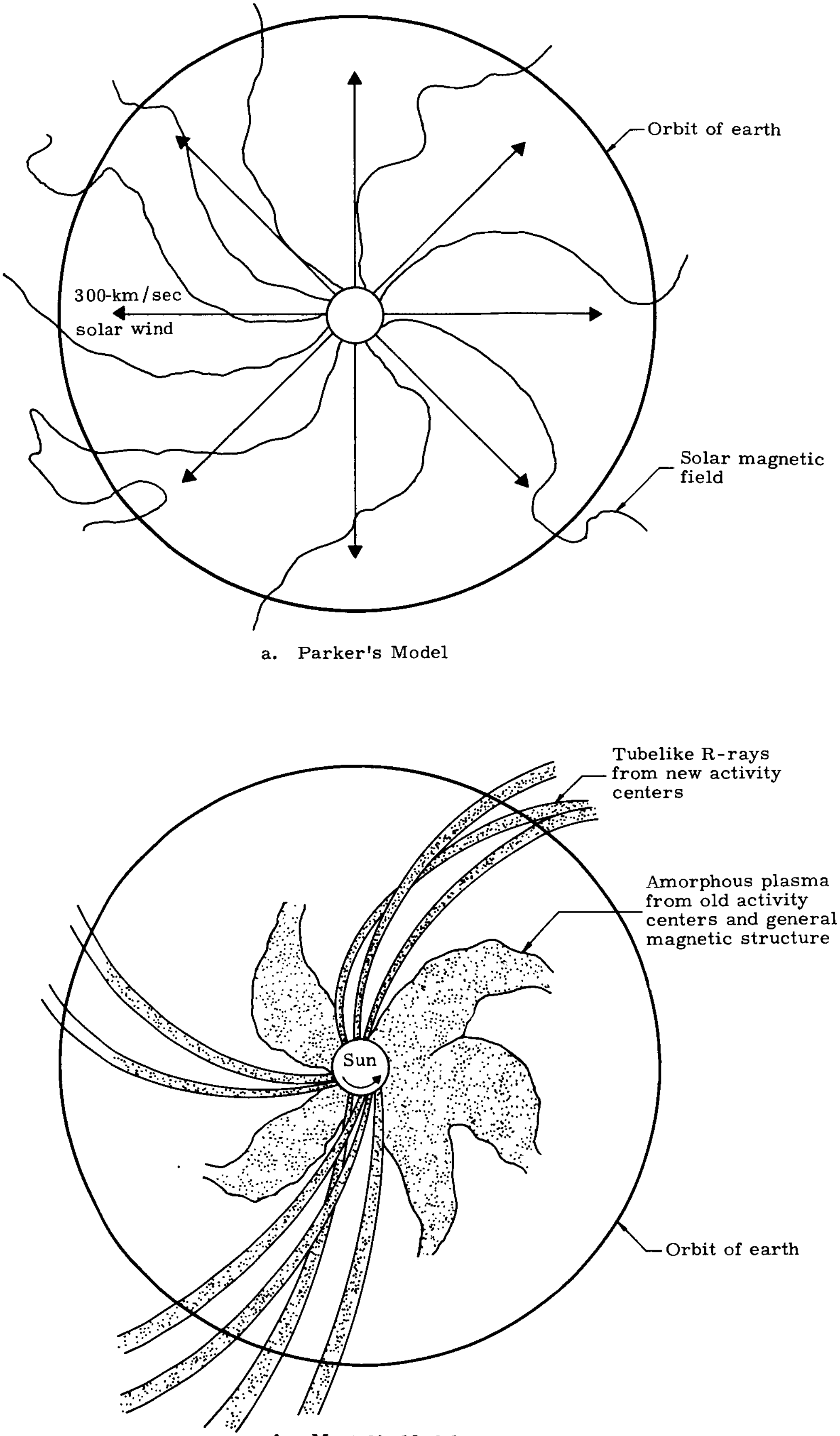
Parker has shown (Fig. 2a) that starting with the generally accepted coronal temperature of about $10^{6\circ}$ K, which extends out to several solar radii by thermal conduction and/or active thermal heating, and if one treats the corona as a hydrodynamic system tightly bound by the solar gravitational field, then one is led to conclude the existence of a continual hydrodynamic expansion of the outer corona into space. The velocity obtained for this outward blowing solar wind actually increases with distance from the sun (Fig. 3). This is because the outward pressure due to high temperature of the corona would not decrease as fast with distance as the gravitational potential of the sun.

The energy necessary to maintain the coronal temperature in the face of the energy blown off in this solar wind is considerably larger (~100 X) than the estimates usually associated with radiation and conduction to the corona. Parker shows that hydromagnetic waves propagating outward through the solar corona would convert all but a small portion of their energy into suprathermal particles by a Fermi type of acceleration, suggesting that this is the source of the large energy necessary to maintain the temperature of the corona with its continued expansion into the solar wind.

Parker's model of the solar wind consists, in its idealized form, of an isotropic flow of gas radially outward from the sun. The general solar magnetic fields are dragged out by the outblowing solar wind. However, due to the rotation of the sun these magnetic field lines describe an Archimedes spiral. Further, on the basis of cosmic ray modulation data, he expects that the magnetic spiral becomes highly disordered somewhere beyond 1 AU. Admittedly there are a number of qualifications which must be appended to this model, although the fundamental aspects are still the same. For example, there seems to be evidence that the gas outflow becomes less with increasing solar latitude. Furthermore, there is evidence for a rather inhomogeneous solar wind even in the equatorial plane.

2. Mustel's Model of Solar Wind

Mustel describes a rather different concept of the coronal expansion. He envisions the expansion in terms of the continuous ejection of isolated clouds of plasma with their frozen-in magnetic fields oriented at random (Fig. 2b). Mustel argues that such a random character of the magnetic fields of the solar wind is consistent with the observed radial and continuous motions from the sun of ionized gases in comet tails.



a. Parker's Model

b. Mustel's Model

Fig. 2. Solar Atmosphere Models

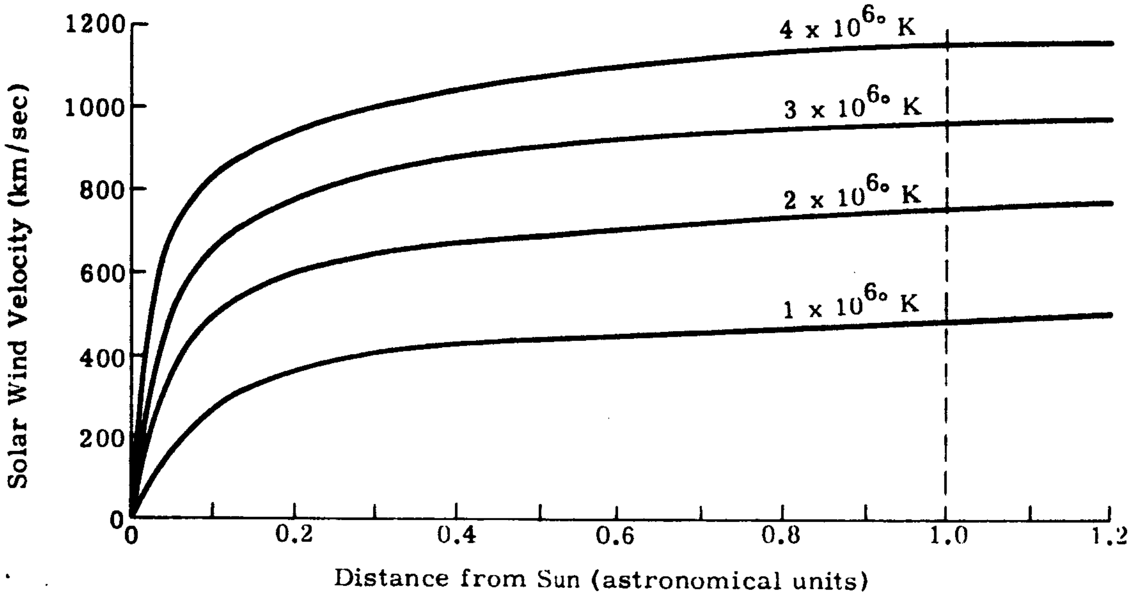


Fig. 3. Solar Wind Velocity Versus Coronal Temperature and Distance from Sun

The enhanced coronal density and elevated temperature above the magnetic structure in the spicules of the chromosphere are seen as the sources of gas outflow from the sun. Very slight increases in coronal temperature cause a great increase in mass flow. The greatest mass flow would come from the coronal condensations above the plages, since the temperatures and densities are a little higher here than above the spicules in the general chromospheric magnetic network. The gas which thus escapes from the magnetic regions of the chromosphere carries with it the magnetic field of the region. Thus the outflow of gas is seen as a conglomeration of individual gas clouds, each carrying a magnetic field. The large variations seen in the coronal occultation of radio stars are cited as evidence of this emission of elongated plasma clouds. These plasma clouds end up forming a rather amorphous group of "classical streamers," which would extend out to only 0.15 to 0.25 AU.

Mustel also describes plasma emissions from faculae or young activity centers as being of a more filamentary nature. These R-rays, as he calls them, which move radially out, and tend to be wound up spiral-like at greater distances to the sun, consist of many thinner threads which do not expand outward, presumably kept together by the magnetic fields they carry with them. These magnetic fields are probably much stronger than those carried by the "classical streamers," since they originate in the facular regions where the chromospheric magnetic fields are stronger. These R-rays can extend up to great distances from the sun and have been postulated as identified largely with the streams of particles responsible for the 27-day recurrent geomagnetic storms. The sources of these streams were introduced as M-regions by Bartels in 1932 to explain the recurrent storms. Thus

Mustel identifies new centers of activity as the M-regions whereas Waldmeir has shown statistically that the recurrent storms can also be connected with the activity regions from which the sunspots have since disappeared.

C. SOLAR FLARES

Once in a while a sudden brightening is seen to occur in the vicinity of a center of activity on the sun. This brightening, or flare, is observed to occur in the upper chromosphere or lower corona. The essential feature of the flare is that it has a great and suddenly acquired density (10^3 to 10^5 times greater than the surrounding region). It appears as many thin knots and threads having thicknesses of about 10 km. The flare seems to arise when two bipolar spot groups approach each other. The magnetic energy density due to these groups in the high chromospheric region far exceeds the kinetic energy of the plasma, so that the approaching magnetic fields greatly condense the plasma. This eventually reaches a point where instabilities occur, causing some sort of sudden collapse of the plasma and the subsequent optical flare. The mechanism of energy emission is not well understood. Numerical estimates based on the observed size and compression ratios tend to rule out (1) cooling of coronal gas which condensed in the flare, (2) kinetic energy of the two approaching masses of gas and (3) release of magnetic energy. Nuclear transmutations seem to be the most likely source of energy release; this seems partially substantiated by the tritium found in a recovered satellite nose cone which was in orbit during a 3+ flare.

Local electric fields can develop during the early phase, reaching field strengths of 10^5 to 10^6 volts with dimensions probably not exceeding 100 meters. These would accelerate electrons in many directions, some of which would go downwards where they would interact with the denser matter in the photosphere to produce X-ray Bremsstrahlung which has been observed in the 1 to 0.1 Å region during a number of flares. Some would accelerate upwards into the chromosphere where they would excite plasma oscillations in the corona. These have been observed as the Type III radio bursts which are of a few seconds duration. In this time the radio noise changes in frequency at a rate of about -20 mc/sec/sec. This decrease in frequency corresponds to the decrease in the plasma frequency of the region of the disturbance as the electrons move upward with a velocity of ~150,000 km/sec (8×10^4 ev).

The compression characteristics of the flare produce a hydromagnetic shock wave. Matter propagates outward behind the shock front with a speed of ~1500 km/sec. The upward speed of this disturbance is characteristic of a change in plasma frequency which is seen in the slower frequency shift (-1 mc/sec/sec) of the narrow band Type II radio emission observed in subsequent minutes of flare development. The flow of matter which accompanies this shock wave is probably the same flux of plasma which causes the sudden commencement of magnetic storms at the earth's magnetosphere.

The combining magnetic fields of two approaching spot groups can produce a field configuration capable of trapping electrons which would gyrate in the field emitting synchrotron radiation which is observed as the Type IV solar radio noise continuum. The oppositely directed magnetic fields of the two approaching groups would ultimately cancel each other, causing a sudden collapse of the magnetic field. This would induce electric fields in a linear accelerator manner which from numerical estimates based on the magnetic field strength, size, and lifetime of the flare could accelerate particles to Bev energies. Such particles, protons, nuclei of helium and carbons, for example, have been observed at the earth. The arrival of particles at the earth is highly correlated with the observation of Type IV radio bursts from flares. All proton events have had the long duration broad frequency Type IV emission. Some 80% of the occurrences of Type IV emission in the cm wavelengths have been associated with proton events seen at the earth. The acceleration of particles could very likely be downward as well as upward, in which case a large number of neturons would be emitted from nuclear reactions between the accelerated particles and the denser matter in the photosphere.

D. INTERPLANETARY REGION

The behavior of the sun certainly strongly influences the interplanetary region surrounding it as was shown in the discussion of the solar wind.

It is evident that if the visible corona co-rotates with the sun, any magnetic structure from the sun extending out this far most certainly must co-rotate with the sun. However, there are difficulties in assuming that the fields as far as earth are connected to the sun and co-rotate with it. It has been estimated by Lüst that a breakoff point exists at about 0.25 to 0.40 AU.

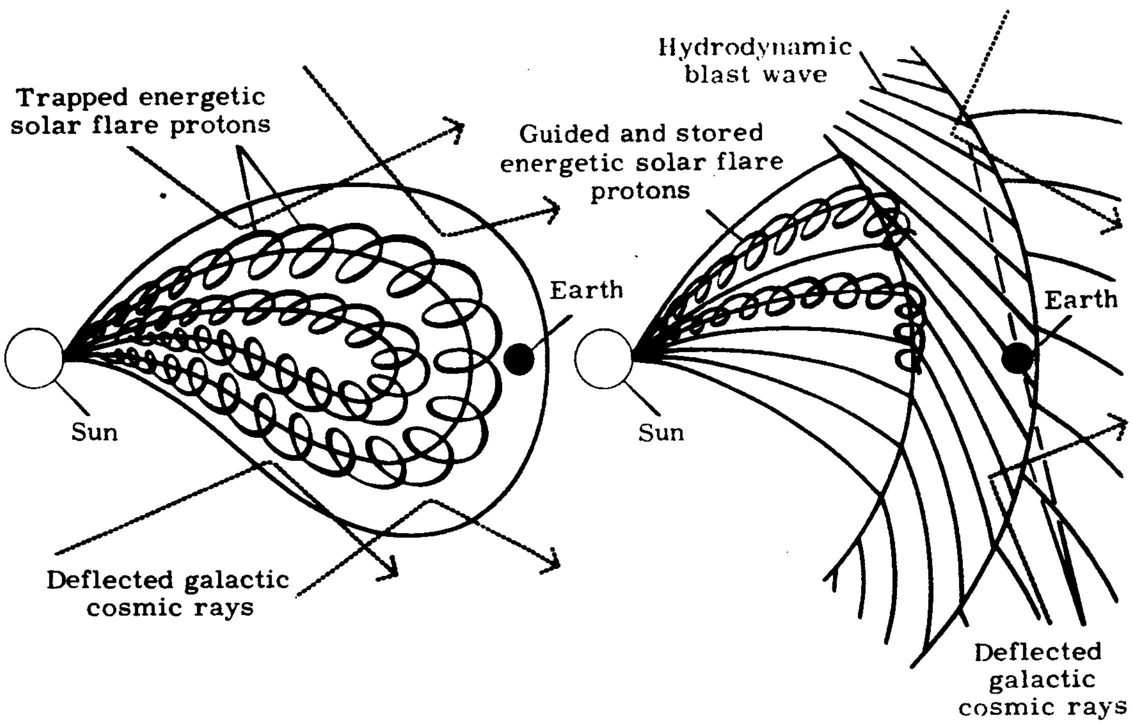
The condition of the interplanetary region has a decided influence on the cosmic radiation which can enter the region from interstellar space. This has been inferred from the observed modulation in cosmic radiation through the 11-year solar cycle. (Cosmic radiation levels during solar minimum are about double those during solar maximum.) The changes through the solar cycle of protons and α's have been seen to vary with magnetic rigidity in exactly the same way as they do during a Forbush decrease. The Forbush decrease, moreover, has been shown to be associated with a direct modulation by the solar magnetic field rather than indirectly by a change in the earth's field caused by a geomagnetic storm. This was shown by the existence of the Forbush decrease in cosmic ray counters on Pioneer V which was well away from the earth's magnetosphere. The magnetic field interface between the solar field and the interstellar field would have a profound influence on the modulating mechanism as well as would the shape of the field within the solar region.

According to Parker's model of an ordered magnetic field inside of 1 AU and a disordered field somewhere beyond 1 AU, one would expect the disordered fields to act as a barrier keeping much of the lower energy part of the galactic cosmic ray spectrum away from the earth and the inner solar system. Thus, one would expect an increase in cosmic rays as one moves outside of 1 AU but no appreciable change in going closer than 1 AU.

The propagation of particles emitted from the sun during a solar flare is also greatly influenced by the state of the interplanetary field. The mechanisms involved have been subject to a large number of interpretations. The prompt arrival of particles from west limb flares and late or nonarrival of particles from east limb flares has been interpreted as being due to the guiding effect of "garden hose" spiraling magnetic lines of force. The exceptions have been explained by the existence of a steady state magnetic field modified by the plasma cloud from a previous flare. The exceptions could also be explained by the existence of a cutoff in the co-rotation of the solar magnetic field discussed above. Thus, the existence of a spiral field within a sphere somewhere inside of 1 AU would tend to give an increased probability to the prompt arrival of particles from west limb flares but, at least during certain periods, there would be no magnetic connection between earth and sun.

Gold has described the concept of a "magnetic tongue" type of plasma cloud emission (Fig. 4a) from a solar flare to explain the various flare effects seen at the earth; namely, Forbush decrease in cosmic ray intensity, geomagnetic storm, and free access of solar protons to the earth. The enhanced magnetic field forming the boundary of the tongue causes the geomagnetic storm and also the interference with the arrival of galactic cosmic rays. The magnetic connection which exists between the sun and the earth once the tongue has engulfed the earth allows free access of solar flare energetic protons from the sun to the earth. The tongue also serves as a magnetic storage mechanism which would account for the observed flux of solar flare protons long after the flare has ended.

Parker explains that the solar flare data is consistent with his picture of a hydrodynamic blast wave which propagates outward from a flare (Fig. 4b). The observed temperature in the corona at the time of a flare eruption is about $4 \times 10^{6\circ}$ K. According to Fig. 3, this would produce an explosive expansion of plasma moving with a velocity in excess of 1000 km/sec. The resultant blast wave profile is shown in Fig. 4b where the front of the blast wave (R_1) is a compression of the slow moving (300 km/sec) quiet sun plasma which existed in the interplanetary region before the flare. The material emitted by the sun at the time of the flare is behind the rear (R_2) of the blast wave profile. The blast wave produces twisting and pinching of the quiet day magnetic field lines--a serious impediment to passage of cosmic ray particles. Thus, the blast wave will store energetic flare protons behind it and push galactic cosmic rays ahead of it, consistent with cosmic ray observations following a flare.



a. Gold's Magnetic Tongue

b. Parker's Blast Wave

Fig. 4. Solar Flare Models

Parker's disagreement with Gold's magnetic tongue concept is based on the lack of an observed delay between the onset of geomagnetic activity and the Forbush decrease of the galactic cosmic radiation. The tongue, which then is supposed to impede the galactic cosmic rays causing the Forbush decrease, could not possibly arrive sooner than six hours after the blast wave. Yet the cosmic ray decrease is usually observed with the first onset of geomagnetic activity. The constriction and twisting of the existing magnetic field lines by the blast wave could, on the other hand, produce the cosmic ray decrease concurrent with the geomagnetic storm.

A much clearer picture of the propagation mechanisms should be possible with observations closer to the sun since diffusion effects and propagation time differences would be significantly reduced. The conclusions about the magnetic field structure resulting from interpretation of the arrival of solar flare particles are of course always subject to the fact that this describes the field at a time when it is probably disturbed.

The fate of some of the high energy electrons accelerated outward is not entirely clear. They lose energy, of course, in producing the various radio emissions, but some small flux (~2% of proton flux) of electrons with energy above 100 Mev has been observed at the earth by Meyer and Vogt.

The fate of possible solar flare produced neutrons is also not well known. Some search for these has been made on OSO-1, but no very large flares have occurred during the time. The experiment was hampered also by a background of albedo neutrons from the earth and by secondaries produced in the vehicle. Moreover the short lifetime of neutrons (~12 min) causes a large decrease in reaching the earth, especially for the lower energies. A given flux of 3 Mev neutrons which might be seen at 0.3 AU would be down by a factor of 900 at 1 AU.

II. SCIENTIFIC EXPERIMENTS

The preceding discussions serve to suggest some of the areas of knowledge about the sun and the surrounding interplanetary medium which are still quite uncertain. The following discussion will present ways in which a Solar Probe spacecraft would be uniquely suited to filling some of these gaps in our knowledge. The discussion is summarized in Fig. 5.

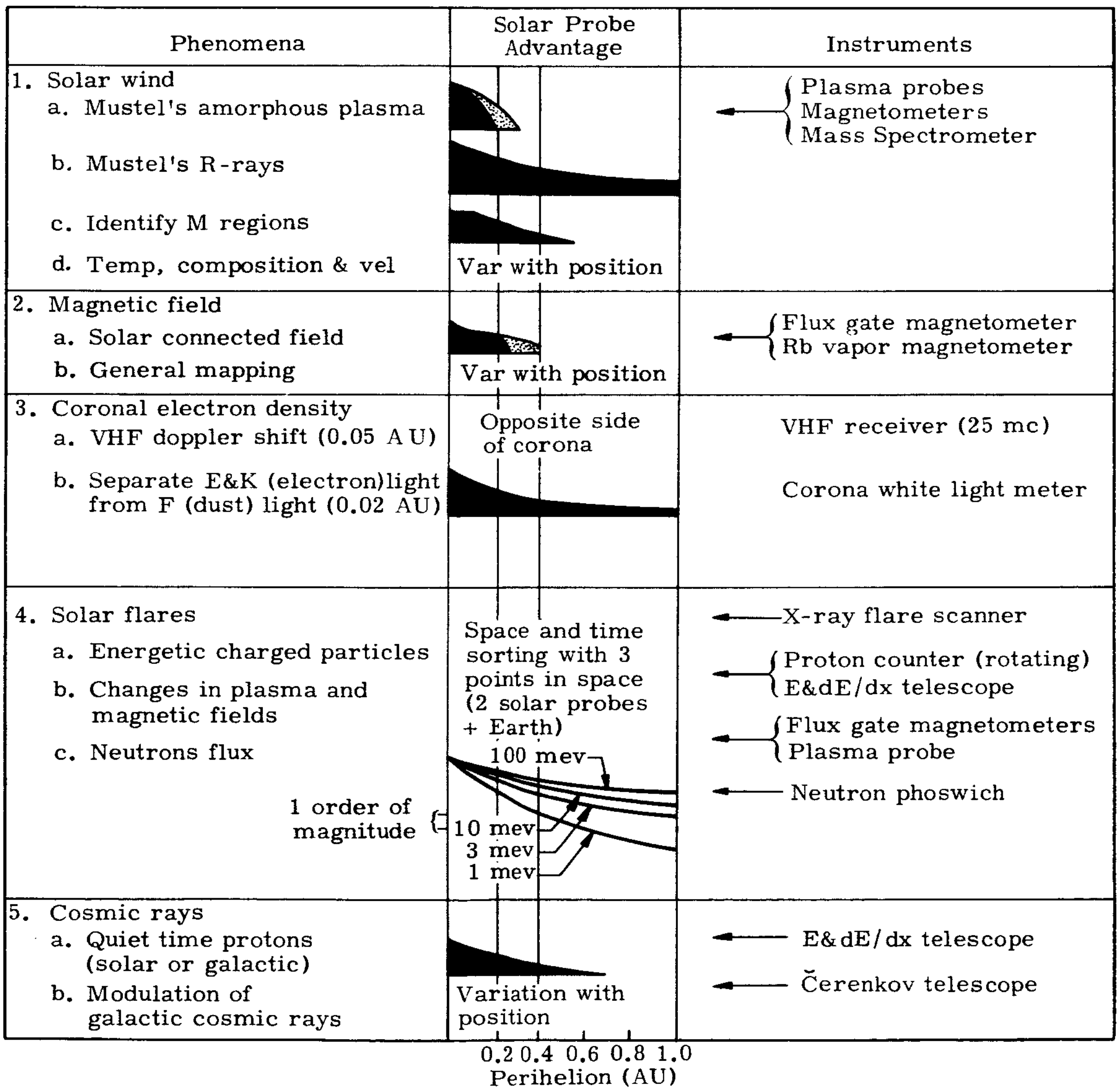


Fig. 5. Scientific Objectives and Experiments

A. SOLAR WIND

There is apparently quite a variance between Parker's and Mustel's concepts of the structure of the solar wind. According to Mustel's model, one should see intense R-rays sweeping past a spacecraft as the sun rotates. Then as the craft reaches ~0.3 AU, one should begin to see the amorphous plasma which he describes as arising from the general magnetic structure of the chromosphere. The probability of intercepting the narrow R-rays should increase with approach to the sun. Parker's picture shows a much more uniform wind, which decreases in velocity with approach to the sun. The Mariner plasma data tends to favor Parker's picture, but actually appears to be somewhat of a compromise between the two. However, the Mariner data could be equally well fitted with a model solar atmosphere that is heated isothermally to the earth or by one which is heated only at the base of the corona. In order to disentangle these ambiguities, the mean velocity, average density and temperature of the solar wind must be known as a function of distance from the sun. The intensity and direction of magnetic field as a function of distance from the sun is also vital, since this acts as a memory for the distortions and variations in the solar wind. Since these quantities need to be measured as a function of distance from the sun, a spacecraft which covers 2/3 of that distance would go a long way toward providing the answers.

Thus, if a spacecraft is to provide data for a firm model of the solar wind and entrapped magnetic fields, it is most important that it carry both a plasma probe and a magnetometer. In order to adequately measure the temperature of the solar wind, the energy spectrum and the angular distribution of the plasma need to be known. The energy spectrum can be obtained by varying the potential on 1) a grid of a Faraday cup as on Explorer X, or 2) the curved plates of an electrostatic analyzer as on Mariner II. By using a narrow angle plasma probe which rotates in a plane which includes the sun, one can measure both the angular distribution and the average direction of arrival of the plasma. The folded-in measurement of energy spectrum, divided by velocity, of course yields the particle density of the plasma.

An alternative to the rotating plasma probe would be a fixed, electrostatically scanned plasma probe which would essentially work as a reverse cathode-ray tube. Such a device is being explored by the MIT group. A great number of difficulties are involved in this type of device due to the necessity for very accurate geometrical alignment.

The ion composition of the plasma is very important to understanding what sources in the sun are responsible for particles in the solar wind. If one is to assume that all the solar wind ions are blowing out at the same velocity (which is not unreasonable since streams of different velocities are incompatible with the hydrodynamic picture of the solar wind), then the composition should be identifiable from observation of 15 separate energy peaks. In such a way the Mariner II plasma probe suspected an α-particle peak during measurements of an enhanced plasma. A mass spectrometer suited to the high velocity solar wind would provide a much less ambiguous determination of compositions. This would be especially true as one approaches the sun, where the resolution of the peaks would get worse because the temperature would be higher and the bulk velocity smaller.

B. MAGNETIC FIELDS

The magnetic fields along the path of the spacecraft can be measured in both direction and intensity quite accurately by using a combination of a rubidium vapor magnetometer for an accurate absolute scalar field measurement and a triaxial flux gate magnetometer for accurate directional measurements.

The necessity of maintaining the vicinity of the magnetometers free of locally produced fields is probably one of the most stringent conditions imposed by the experiments on the spacecraft. Every attempt to eliminate and minimize the use of permeable materials must be made by all the spacecraft subsystems as well as by the other experiments. Also, self-canceling currents must be used to fullest advantage, especially in the solar cell panels. The largest single spacecraft magnetic field most probably would be from the permanent magnet on the communications transmitter. A typical 20-watt TWT tube provides magnetic fields with a maximum strength of 60 γ at two feet from the center of the tube. Above all this, it is simply necessary to remove the magnetometer from the near vicinity of the spacecraft by putting it on a long boom. A reasonable upper limit for total allowable spacecraft fields would be 200 γ at 3.5 feet from the spacecraft center. This would produce a field of $1/2$ γ at the end of a 25-foot boom, which would enable micropulsations in the solar field to be detected above the spacecraft field.

By allowing the spacecraft to continue spinning slowly before final stabilization as was done on Mariner II, the contribution of the spacecraft field to two axes of the triaxial flux gate magnetometer can be subtracted out. Also the contribution to all three axes can be obtained by making measurements with both the triaxial magnetometers and the Rb-vapor magnetometer during a slow deployment of the magnetometer boom. A simple extrapolation to $1/r = 0$ would give a fairly accurate measure of the residual contribution of the spacecraft field in the fully deployed position. The flux gate magnetometers have a problem in that their zero level tends to drift. This problem can be avoided by periodically rotating the triaxial flux gate magnetometer through 180 degrees. This reverses two of the axes, making it possible to subtract out the zero drift in these two axes. The zero drift in the third axis can be subtracted out by comparing the sum of the squares of the three-axis readings with the square of the Rb-vapor magnetometer reading.

It was mentioned above that the magnetic field serves as a historical record for the plasma variations. It is therefore quite important to measure this in as many parts of the solar system as possible. Magnetic field measurements during the onset of solar flare effects, along with plasma and energetic particle measurements, can go a long way toward deciding between the Gold type of magnetic tongue and the Parker blast wave. This is especially true if two Solar Probe vehicles are at different parts of the solar system at the same time.

An interesting possibility for determining the direction of the magnetic front would be to add simple flux gate magnetometers on the solar trim stabilization booms. By measuring the relative times at which the magnetic disturbance arrives at the various magnetometers, one can reconstruct a profile of the motion of the front. For a front moving at 1000 km/sec and a spacing between magnetometers of 10 meters, one gets a difference of 10 μsec, which is easily measurable.

Magnetic field measurements as one approaches the sun should be compared with those taken beyond the orbit of earth. Parker predicts that somewhere beyond the orbit of earth, perhaps as far as 1.4 AU, the magnetic field configuration breaks up into a disordered field, which is believed to act as a shield keeping out the lower end of the galactic cosmic ray energy spectrum.

The approach to the sun is necessary to determine if the magnetic fields break off at 0.25 to 0.4 AU as predicted by Lüst.

C. ENERGETIC CHARGED PARTICLES

The galactic cosmic radiation consists of protons, heavier nuclei and a small flux of electrons (about 3% of total) as observed near the earth. These particles, which enter the solar system from somewhere outside, are potentially useful probes for identifying the solar magnetic fields. However, when we can observe them from only one spot in the solar system, their usefulness is very limited since they are thus too ambiguous to read. It would be very desirable in this sense to observe the cosmic radiation particularly from vantage points well outside the orbit of earth. In particular one would look for electrons and the low energy protons (< 100 Mev) and other nuclei which are thought by Parker to be impeded from entering the inner solar system by disordered magnetic fields just beyond the orbit of earth.

In looking at the low energy (< 100 Mev) part of the cosmic radiation, Meyer saw a peculiar phenomenon which led him to suspect that protons in this energy range are emitted by the quiet sun, at least during the active part of the solar cycle. His data (Fig. 6) taken in 1960 and 1961 showed the normal increase in galactic cosmic radiation as the 11-year solar cycle approaches minimum. Thus the protons with E > 100 Mev show an increase between 1960 and 1961. On the other hand the protons with E < 100 Mev show a decrease from 1960 to 1961 as though these were in reality of solar origin and would therefore be expected to decrease with the decreasing solar activity. It would be possible to really decide whether such protons are actually of solar origin by approaching the sun. At 0.3 AU, if they are of solar origin they should increase by a factor of ten. If not, they should either decrease or remain constant. The observations from Mariner were not really able to distinguish this effect. The approach to 0.72 AU only allowed a factor of two increase, which could easily be missed with the broad energy range allowed by the detectors. This would amount to a change of only about 10% in these detectors.

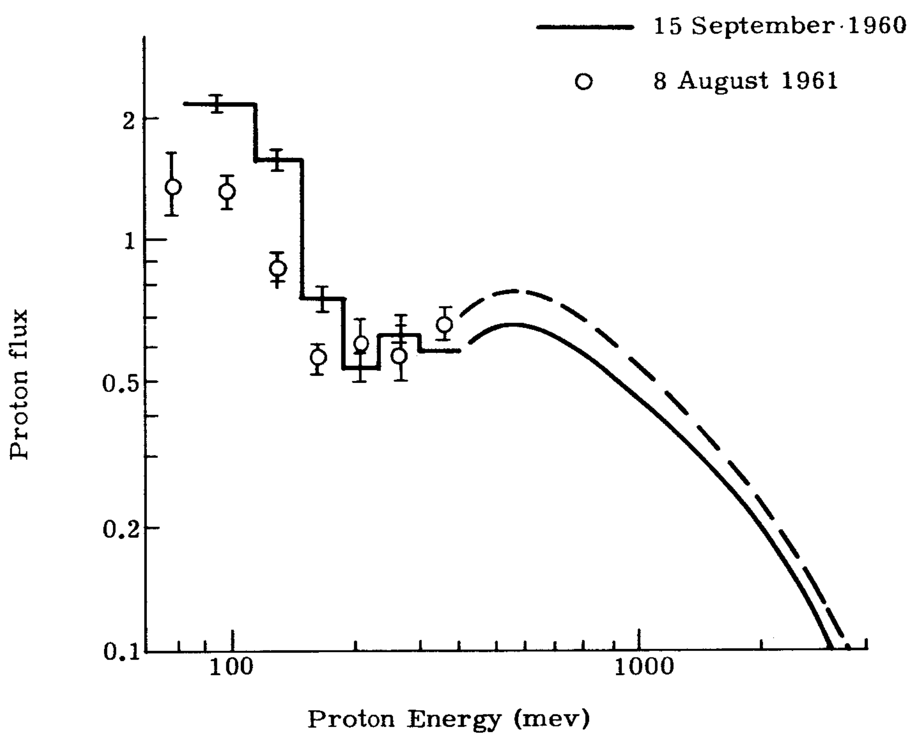


Fig. 6. Proton Cosmic Ray Spectra Variation with Solar Cycle Variation

The energy spectrum and particle composition of charged particles both from the sun and from the galaxy form a vital part of the studies which are uniquely suited to spacecraft flights ranging over a distance from ~0.3 AU to ~3 AU

It is very important to the understanding of solar flares to know something about the particle composition and energy spectrum of the particles emitted. These factors are very largely beclouded in measurements at 1 AU by the poorly understood propagation history of the particles. Measurements made simultaneously from two Solar Probes at different approaches to the sun, along with measurements made from one of the EGO, IMP or Pioneer vehicles, would go a long way toward obtaining an understanding of the propagation mechanisms as well as the source spectrum and composition. Since one cannot, of course, predict when a solar flare will occur, it would make no sense to talk about detailed planning of relative positions of Solar Probe vehicles for most significant observation of flare phenomena. It makes sense only to plan to the point of having two vehicles in transit at any one time in significantly different portions of the solar system.

A telescope to measure loss rate (dE/dX) and total energy (E), similar to those used by MacDonald at Goddard and by Simpson at the University of Chicago, is a very attractive device for determining both energy and composition of the charged particles emitted from flares as well as for the low energy portion of the cosmic radiation. The use of such a telescope would require the readout of a 15-bit word for each particle detected or the use of a two-dimensional multichannel pulse height storage.

If a solid-state detector four-element telescope similar to Simpson's is used, the count rate of galactic particles would be of the order of 0.3 cts/sec so that the 15 bit readout for each particle would amount to an average bit rate of 4.5 bps. Thus this scheme would be about adequate for the galactic radiation. However, the greatly increased flux from solar flares (up to four orders of magnitude) would prohibit the use of this scheme. For solar flare measurements, either the counting rates must be determined on the basis of microseconds of observation, or a large storage unit must be designed into the data handling system. Either approach will keep the bit rates within reasonable limits. Spectral information can be obtained from counting rates for various coincidence combinations of several elements of the scintillation telescope such as used on Explorer X. This information would not be limited by the bit rate.

A device which would be quite useful for determining the electron versus proton composition would be an organic crystal such as stilbene or the liquid scintillators which exhibit different pulse shapes for electrons and protons. Connected to a photomultiplier tube and proper pulse shape differentiating circuitry, it could be used with two simple multichannel analyzers to obtain energy spectra for both. This would involve a total of 2 x 64 x 10 = 1280 bits for a 10-bit (1024-count) memory in each channel. At a readout rate of 1.05 bps this could be read out in 20 minutes.

D. NEUTRONS

There is good reason to believe that fast neutrons are emitted from a solar flare as discussed by Hess and by Chubb. Hess and Schrader looked for them on OSO-1 and did not find any. However, these experiments were plagued with albedo neutrons from the earth and secondary neutrons from the spacecraft. An even more serious limitation in performing such an experiment on an earth satellite is the loss of neutrons due to β-decay on the way between the sun and earth. Thus a given flux of 3-Mev neutrons which might exist at 0.3 AU would be down by a factor of 900 at 1 AU. Therefore an approach to 0.3 AU would be a great help in determining whether neutons are emitted from flares.

The electron-proton device described above can be modified further to detect neutrons by adding a thin shell of scintillator plastic around the outside of the stilbene but optically separated from it. Another photomultiplier tube looking at the scintillator shell is used for anticoincidence or coincidence. If a pulse occurs in both scintillators it was caused by the entrance of a charged particle. But if only the stilbene scintillator registors a pulse, then it was produced by a neutron (the knock-on proton in the stilbene makes the pulse) or a gamma ray (the scattered electron makes the pulse). The pulse shape discrimination of the stilbene can then separate out the proton from electron pulses (identified by the scintillator anticoincidence).

Due to the ever present problem of local production of secondary neutrons in the spacecraft by solar flare protons, it is imperative that a neutron detector be placed on a boom extending well away from the spacecraft. A 25-foot boom would be adequate to keep the secondary neutron flux from most flares below 0.01 neutron/cm^2sec.

Consideration has been given to the use of a radioisotope power supply in lieu of solar cells. This appears to cause considerable background difficulty in the neutron detector and in the charged particle detectors. The solid-state diodes in a Simpson-type particle telescope would see a count for every 250 neutrons/cm^2 having an energy greater than 1.6 Mev. Its counting rate of galactic cosmic rays is of the order of 0.3 count/sec so that the neutrons from the radioisotope source should be reduced to at least this rate; i.e., to 75 neutrons/cm^2sec. A scintillator detector such as MacDonald's telescope will be considerably more sensitive to neutrons At the neutron detector the flux of neutrons with $E > 0.5$ Mev must be kept down to about 0.1 neutron/cm^2sec.

E. CORONAL ELECTRON DENSITY

A knowledge of the coronal electron densities is very important to the development and understanding of the various models of the solar atmosphere. There are several ways in which a Solar Probe can make a very significant contribution to this knowledge.

1. VHF Transmission in the Solar Corona

By virtue of the fact that a Solar Probe spacecraft will pass behind the solar corona, it is in a unique position to provide a platform for receiving a coherent signal through the corona. Thus, by transmitting a VHF signal to the Solar Probe along with the UHF tracking signal, one can measure the dispersive doppler shift of the VHF caused by the motion of the spacecraft.

In a fully ionized gas, the phase delay of a signal of frequency ω in a region of plasma frequency $\omega_p = 2\pi (8.97 \times 10^3 N^{1/2})$, is given by

$$\beta = \frac{\omega}{c} \left[1 - \left(\frac{\omega_p}{\omega} \right)^2 \right]^{1/2}$$

For the purpose of experimental planning, it is assumed that, in the outer corona, the density is

$$N = \frac{2}{r^3}$$

where r is the distance from the center of the sun measured in astronomical units. This form puts the optically measured density of $\sim 2 \times 10^3$ at 0.1 AU in fairly good agreement with measured densities at 1 AU.

Method of measurement. In this experiment, a sinusoidal signal of about 25 mc is transmitted from the ground to the Solar Probe vehicle when the vehicle is in such a position that the path of propagation will pass through the corona with a closest approach to the sun of about 0.05 AU. Assuming the transmitted wave will have the form

$$X_T(t) \sim \cos \omega t$$

the received wave will have the form

$$X_R(t) \sim \cos (\omega t + \theta_d + \theta_s)$$

where θ_d is the phase delay due to the "free space" distance traveled neglecting plasma effects, and θ_s is the additional phase delay due to the plasma.

The phase shift due to the plasma alone is

$$\beta' = \pi\left(\frac{f_p}{f_0}\right)^2 \text{ per free space wave length.}$$

Since $f_p = 8.97 \times 10^3 N(r)^{1/2}$ is not constant over the entire path, the total phase delay due to the plasma

$$\theta_s = \frac{\pi}{\lambda f_0^2}(8.97 \times 10^3)^2 \int_s N(r)\,ds \qquad \text{for path } s$$

or

$$\theta_s = \frac{\pi}{\lambda f_0^2}(8.97 \times 10^3)^2 N(r(0))L$$

where r(0) is the distance of nearest approach to the sun and L is an effective length for this path. The effective frequency shift is therefore

$$\omega_s = \frac{d\theta_s}{dt} = \frac{\pi}{f_0^2}\frac{L}{\lambda}(8.97 \times 10^3)^2 \frac{dN(r(0))}{dr(0)}\frac{dr(0)}{dt}$$

At any r(0), $\frac{dN(r(0))}{dr(0)}$ may be calculated from the assumed density contour and

$\frac{dr(0)}{dt}$ from the trajectory.

For a perihelion of 0.3 AU it is found that ω_s will be about 7 cycles/sec. Frequencies of this magnitude can be readily measured. A method of measurement appropriate to the Solar Probe vehicle is described below.

Method of data reduction. If it is assumed that the density has the form

$$N = N_0 \, r(0)^{-\gamma}$$

where γ is a parameter, then it is seen that

$$\ell n \omega_s = \ell n \left[\frac{\pi}{f_0^2} \frac{L}{\lambda} (8.97 \times 10^3)^2 \right] + \ell n \frac{dr(0)}{dt} + \ell n(-N_0) - \gamma \, \ell n \, r(0)$$

In this equation, the term on the left is a known function of a measured value, the first term on the right is a constant, the second term on the right is a function of r_0 known to the extent that the trajectory is known, and the third term is an unknown constant as is γ in the last term.

Hence it may be seen that

$$Y = \ell n(-\gamma N_0) - \gamma \, \ell n \, r(0)$$

This is obviously a linear equation in $\ell n \, r(0)$. If several measurements are taken at each of several values of $r(0)$, values for N_0 and γ can be determined by regression analysis.

Since regression analysis yields a measure of "goodness of fit" for any given formulation, the same data can be used to compare several different formulations.

This experiment will include a group of measurements of the coronal density at a range of radii about 0.05 AU and a density profile is empirically derived from this data. The choice of this radius interval is related to the choice of the 25-mc frequency. If, with this frequency, measurements are made at much smaller radii, plasma attenuation will cause almost complete degradation of signal detectability. Also refraction effects, which are virtually absent within the prescribed range, would make the data virtually uninterpretable. To extend the range to larger radii does not appear feasible because the frequency shift effect would become immeasurably small.

Another frequency, of course, could have been chosen. Had it been a much higher frequency, its effective range of observation would have been much closer to the sun. Such observations would be of less value since observations of the inner portions of the corona have already been made during eclipses. Had the frequency been much lower, impractically large antennas would have been necessary.

Method of implementation. It was shown above that the density profile can be obtained by measuring a frequency shift in addition to the regular doppler shift. To do this, it is necessary to have a knowledge of the transmitted frequency and of the "free-space" doppler shift, or of the sum of the two frequencies. The latter is accomplished by utilizing the center frequency (carrier) of the Solar Probe communications link since, in the radial range of interest, an S-band signal is unaffected by the plasma.

The communications carrier frequency, 2113-5/16 mc is obtained by frequency multiplication of a crystal-generated sine wave. In the "turnaround transponder," in the Solar Probe vehicle (see Vol. IV), it is processed as shown in Fig. 7a.

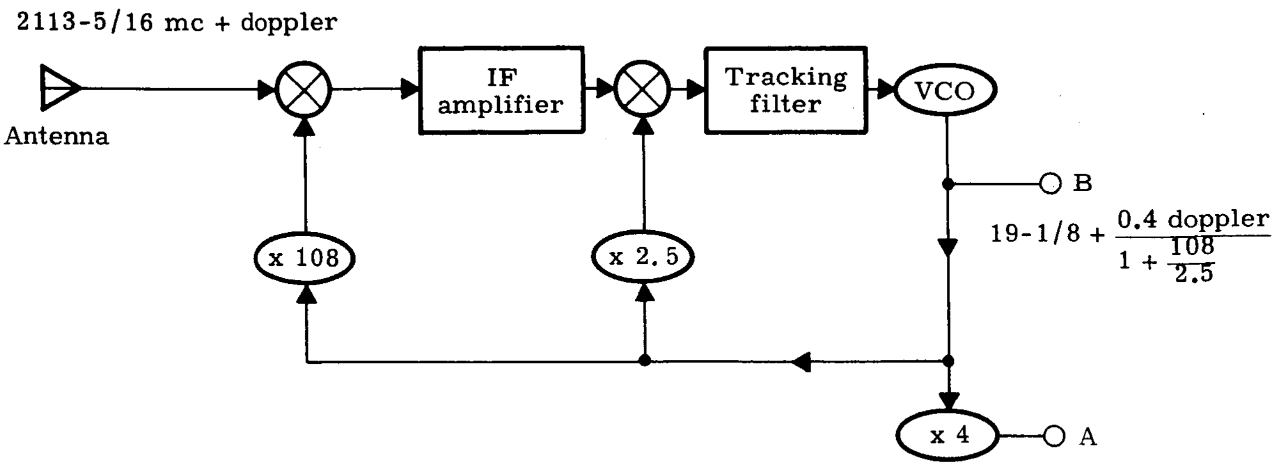
The experimental frequency (about 25 mc) is also derived from the same crystal oscillator (assume it is 28-11/16 mc). The exact frequency must be dictated by the FCC. Figure 7b indicates the processing of this received signal.

If the signals at Point B, Fig. 7a, and Point B', Fig. 7b, are multiplied, the output of the multiplier will be a signal with a beat-note at $0.4 \times \omega_s$. The final step, therefore, in measuring ω_s is a beat counting process.

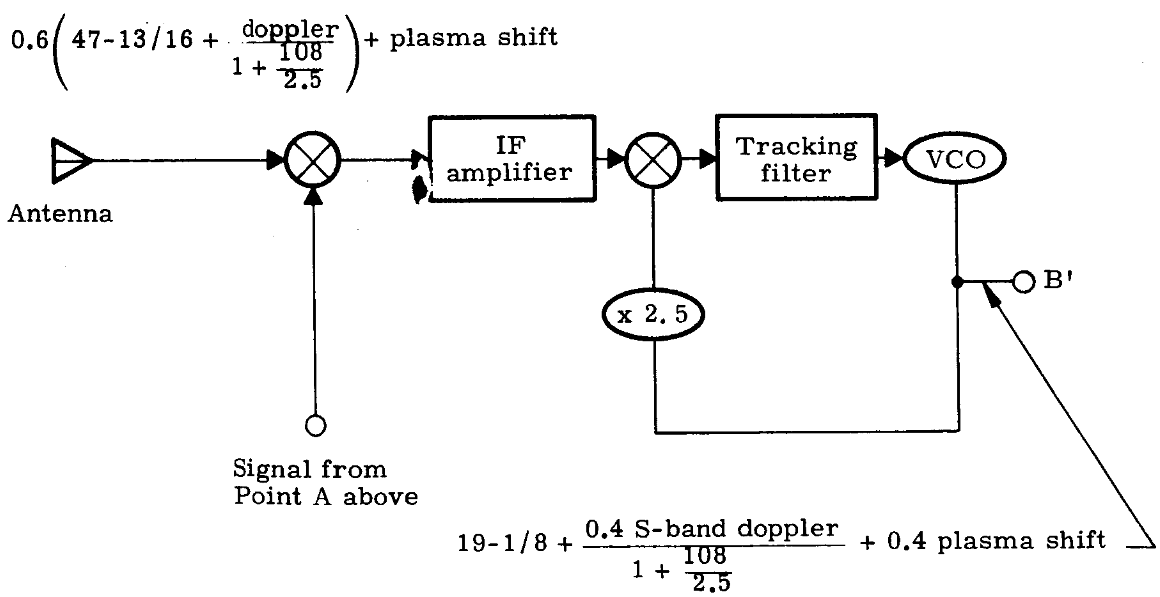
The onboard implementation other than this circuit is quite simple, including a simple dipole antenna.

The ground system parallels, but is simpler than, the communication system and can be made entirely compatible with DSIF. The ground power required during operation will be between 10^4 and 10^5 watts depending on the available antenna size. An antenna in the 50-foot range would require a signal with power near the maximum.

Conclusion. This discussion indicates that, using a single frequency in the VHF portion of the spectrum, the mean electron density in a finite range of distances from the center of the sun can be measured quite accurately under quiescent conditions. Furthermore, a formulation consistent with these results can be determined to extrapolate outside this range.



a. S-band receiver



b. VHF receiver

Fig. 7. VHF Transmission Experiment

If data is desired outside this range, it can be acquired by using several frequencies. This would necessitate a more versatile antenna and more complex circuitry.

Data can be gathered on both sides of the sun in order to test the symmetry of the sun's atmosphere, or, if approximate symmetry is assumed, to justify the assumption that a quiescent state exists.

Finally, it may be concluded that these measurements will not seriously interfere with any other function of the vehicle mission.

2. Separation of K corona from F corona

The K part of the coronal light is that part which is due to scattering of sunlight from coronal electrons, while the F part is that due to scattering of sunlight from dust particles. The K light intensity gives a measure of the electron density in the part of the corona from which the light is being observed. The zodiacal light is light scattered from dust particles further away from the sun. The F and K portions are generally separated in the measurements by observing the depth of the Fraunhaufer absorption lines in the solar spectrum. The F light shows absorption lines characteristic of the dust particles. These tend to be filled in by the white K light scattered from the hot electrons. The K light, moreover, is polarized. Following the electron density gradient the K light falls off rapidly with distance from the sun. It becomes very difficult to measure the K light from the outer parts of the corona, since the signal-to-noise (F light from the intervening interplanetary dust) ratio becomes very bad. Thus if one were to take the same measurements from close up to the coronal region under investigation, then this signal-to-noise ratio would improve by at least the factor shown in Fig. 5, which assumes a uniform distribution of dust in the interplanetary space. The device necessary would be a white light meter with a polarizer to separate the polarized K light from the unpolarized F light. This device would be mounted on a rotating platform so that it would scan through the corona and on out to observe the zodiacal light as well. This would provide valuable new data about the spatial distribution of the zodiacal light scattering particles.

F. OTHER ELECTROMAGNETIC OBSERVATIONS

The majority of observations of the sun in the electromagnetic spectrum can be made quite adequately from an earth satellite. Because of the much higher payload weights and communication bit rates, they can generally be done much better on an earth satellite than on a deep space probe.

1. Solar Flare Scanning

There would be considerable value to having some sort of device to identify the location on the solar disk of a flare when it occurs. This is because about half of the flares which will produce charged particles observable from the spacecraft during its lifetime will not be on the part of the disk which is visible from the earth. The charged particle and neutron data obtained then would be relatively useless since there would be no flare to identify with these data.

Such a device would also be quite useful in following the development of a center of activity as it moves across the back side of the sun. This would have some value in manned space flight protection since activity centers which have produced flares tend to be the ones which will produce more flares. Hence, when a center of activity is observed to be generating several flares on the back side of the sun it can serve as an early warning.

This scanner would probably take the form of an X-ray detector which has a thin vertical slit and is mounted on the rotating platform. Thus the phase of the rotating platform when flare X-rays are observed would identify the longitude of the flare. The latitude would be integrated out by the vertical slit since this information is not necessary.

2. Lyman α Detection for Interplanetary Neutral Hydrogen

An experiment which would scan the sky for the Lyman-α light in search of solar Lyman-α light scattered by interplanetary neutral hydrogen would be well suited to a spacecraft going out beyond 1 AU. The distribution of neutral hydrogen in the solar system is vital to an understanding of the fate of the solar wind and the connection between interplanetary and interstellar space.

G. MICROMETEOROID MEASUREMENTS

The results of Mariner II micrometeoroid experiment do not argue for much emphasis on such an experiment aboard a spacecraft approaching the sun. However a mission going to 2.4 AU would be well into the asteroid belt and should certainly have some micrometeoroid detection on board.

III. SPECIFIC MISSIONS

A. SUITABLE ORBITS

In weighing the various advantages of approach to the sun as illustrated in Fig. 5, we can conclude that most of the scientific objectives could be reasonably satisfied with a perihelion of 0.2 to 0.4 AU.

In a mission directed out away from the orbit of earth, a minimum requirement at 1.4 AU would be required to look for Parker's disordered fields. The micrometeoroid experiments would want to go out to the asteroid belt which begins at about 2.1 AU and extends to about 3.5 AU.

Orbits out of the plane of the ecliptic would probably be best delayed until a little bit more has been learned in the ecliptic in order to refine the models. The principal reason for this is that for any real significance one should go at least 30 degrees out of the ecliptic. This already becomes quite expensive in launch energy.

B. LAUNCH SCHEDULES

It would be very worthwhile to launch a first Solar Probe as early as reasonable, probably in 1967, to gain base line information about the solar atmosphere during the more quiet part of the solar cycle. Following this date, there certainly would be a desire to make changes in the experiments and perhaps in the spacecraft on the basis of what is learned in the first mission. A 1 to 1-1/2 year lead time to the next launch would provide this opportunity. Then successive launches at perhaps six or eight month intervals would be made in 1969, 1970 and 1971 in order to have 2 Solar Probes in space simultaneously during most of the time of maximum solar activity. More detailed discussion of this possibility is presented in Vol. III, Mission Analysis and Flight Operations.

C. MINIMUM PAYLOAD FOR SOLAR APPROACH

What is the minimum payload the Solar Probe can carry and still achieve worthwhile scientific objectives? The answer depends to a large extent on who is answering the question. Avoiding the truism that anything is better than nothing, we can nevertheless come to a reasonable estimate of what would be considered a minimum payload. Certainly of prime importance are the quiet solar atmosphere and the solar flare phenomena. Thus a triaxial magnetometer and a plasma probe would be certainly necessary. The plasma probe could be a split plate Faraday cup with variable voltage grid as proposed by the

MIT group for Pioneer. A charged particle detector similar to Simpson's depletion layer detector telescope would then be able to give a crude spectral identification of the solar flare charged particles. These three instruments would therefore be considered absolutely minimal for a scientifically meaningful mission.

(1) Triaxial flux gate magnetometer on boom.

(2) Split plate Faraday cup plasma probe.

(3) Depletion layer charged particle telescope.

D. LIGHTWEIGHT PAYLOAD FOR SOLAR APPROACH

Considering now a payload which allows somewhat more than the minimum, we would gain very much by the addition of two more experiments. These would be 1) the VHF propagation experiment to determine the electron density profile and 2) the X-ray solar flare scanner to double the probability of getting significant data from the solar flare effects on the other detectors. This payload would thus consist of

(1) Triaxial flux gate magnetometer on boom.

(2) Split plate Faraday cup plasma probe.

(3) Depletion layer charged particle telescope.

(4) VHF transmission experiment.

(5) Solar flare X-ray scanner.

Weights and bits rates have been derived for this complement of experiments (Vol. IV, Chapter I) and have been included in a 200-pound vehicle (Vol. V, Chapter I) design that the Atlas/Agena/X-259 launch vehicle can inject to a 0.3 AU perihelion.

E. FULL PAYLOAD FOR SOLAR APPROACH

To make the best use of a Solar Probe mission, we have indicated that a trajectory with a perihelion in the vicinity of 0.2 to 0.4 AU would be very significant scientifically. As has been discussed in the section on Scientific Experiments, several experiments can use the Solar Probe vehicle to distinct advantage in addition to those listed for the lightweight payload. A typical payload has been defined which could be carried to full advantage by a 400-pound Solar Probe (Vol. V, Chapter I) that the Atlas/Centaur/X-259 launch vehicle can inject to a 0.30 AU perihelion. This increased vehicle weight permits the distinct advantage of putting some of the instruments on a rotating platform. The plasma probe is the first candidate for this platform since the angular distribution of the plasma would give us the complete picture of the plasma temperature and record momentary changes in the plasma direction. The charged particle telescope has also been added to the platform to look for the anisotropies in the solar flare particles, which are seen even at the earth during the onset of the flare storm. The solar flare X-ray scanner can be made more simply if it scans the solar longitudes by virtue of the platform rotation.

Four additional experiments have been added above those listed for the lightweight payload. They are 1) a neutron detector to search for solar flare neutrons, 2) a rubidium vapor magnetometer to greatly improve the accuracy of magnetic field measurements, 3) a mass spectrometer to determine the composition of the solar wind as a function of solar activity and of position and 4) a white light corona meter for measuring the coronal electron density and interplanetary dust distribution.

(1) Triaxial flux gate magnetometer on boom.

(2) Narrow angle rotating plasma probe.

(3) Rotating charged particle telescope.

(4) VHF transmission experiment.

(5) Rotating X-ray flare scanner.

(6) Neutron scintillator on boom.

(7) Rubidium vapor magnetometer on boom.

(8) Mass spectrometer.

(9) White light corona meter with polarizer (rotating).

This complement of experiments is by no means unique. For example, it might well be argued that an additional charged particle telescope designed for larger energy range flexibility would be preferable to the mass spectrometer. Also the additional magnetometers on the solar stabilization booms discussed above could well be added to detect the angle of approach of magnetic fronts. The particular complement of experiments listed above was chosen to ensure that the vehicle design is compatible with a wide variety of possible experiments, rather than to define the scientifically optimum grouping.

F. MISSION AWAY FROM THE SUN

The main objectives to be achieved in sending a spacecraft out beyond the orbit of earth are involved in looking for the fate of the solar atmosphere as it proceeds outward beyond the orbit of earth and in learning more about the true galactic cosmic radiation. Experiments recommended for such a mission would therefore still involve the magnetic field and plasma measurements and charged particle detector. The micrometeoroid detector would also be added. Thus, we could have the following complement of experiments:

(1) Triaxial flux gate magnetometer on boom.

(2) Split plate Faraday cup plasma probe.

(3) Charged particle telescopes (two energy ranges).

(4) Micrometeoroid detector.

These experiments do not require any new or unusual instruments. The primary requirements over instruments already flying are protection against increased thermal environment and--if a radioisotope is used--shielding of the particle detectors against neutrons.

PHILCO

WESTERN DEVELOPMENT LABORATORIES

PALO ALTO, CALIFORNIA

N65-29518

CHAPTER II
SCIENTIFIC OBJECTIVES

1. SUMMARY

Any space probe leaving the influence of the Earth will have opportunities for conducting experiments to advance the state of solar-interplanetary physics. The solar probe will not only provide a carrier for scientific instrumentation, but will also have a capability for exploring regions of interplanetary space heretofore untouched by other space programs. Because there are innumerable possible experiments and objectives which can be accomplished by the solar probe, the basic task of the scientific objectives study has been to optimize the choice of experiments to achieve maximum scientific utility with each probe and with the entire series.

The scientific objectives task involves iteration of four basic steps, along with interfaces with mission analysis and spacecraft design efforts. The first step is the selection of provisional scientific objectives for the solar probe series, based on guidelines which permit the focus on select, and presumably the most important, objectives from the ensemble of possibilities. The second step is the identification of sets of experiments which best fulfill these objectives. Next is the determination of measurements required to conduct the experiments. The final step is the selection of instruments to accomplish the measurements. In a basic sense, then, the selection process yields a set of instruments which perform the measurements needed to fulfill the scientific objectives of the solar probe.

The method chosen to establish the objectives was to view the solar probe as part of the total program of deep-space experiments and to derive the objectives which should most logically be associated with it. Objectives proposed on the basis of the guidelines were evaluated in terms of implementation capability to insure that the best selection had indeed been made.

Results of the study are presented in the following paragraphs and enumerated in Figures 1 and 2.

2. GENERAL OBJECTIVES OF THE SOLAR PROBE

Observational solar astronomy became possible with the invention of the telescope in 1608; however, it has only been within the past 150 years that real progress is solar physics has been made. During this time, the spectrograph, the spectrohelioscope, the coronagraph, and other instrumental techniques which made possible the observation of the solar spectrum were invented and employed in investigations of the physical and chemical conditions in the solar atmosphere.

As a result, a great body of knowledge about the sun has been acquired, the bulk of which is the result of observation of its electromagnetic radiation spectrum in the two principal windows of frequencies that pass through the earth's atmosphere. One is the range between ionospheric critical frequencies and frequencies absorbed by oxygen and uncondensed water vapor in the troposphere (about 10 to 10,000 Mc/s). The other is the combined optical and infra-red ranges (about 10^6 to 10^9 Mc/s).

In recent years, balloons, high-altitude rockets, and earth-orbiting observatories have provided the means for extending the observations to the ultraviolet, X-ray, and gamma ray parts of the spectrum and also to radio frequencies between the ionospheric and interplanetary plasma frequencies that is, between about 10 Mc/s and 10 kc/s.

Present interpretations of solar phenomena are in many cases founded on too narrow a basis of observations. It is important to realize, therefore, that future progress is solar physics must be based on the availability of a large quantity of observational data. To produce as much as possible of this data would be the major scientific objective of the solar probe.

Diagramatic Representation of the Approach Taken in Establishing Scientific Objectives and Experiments for the Solar Probe

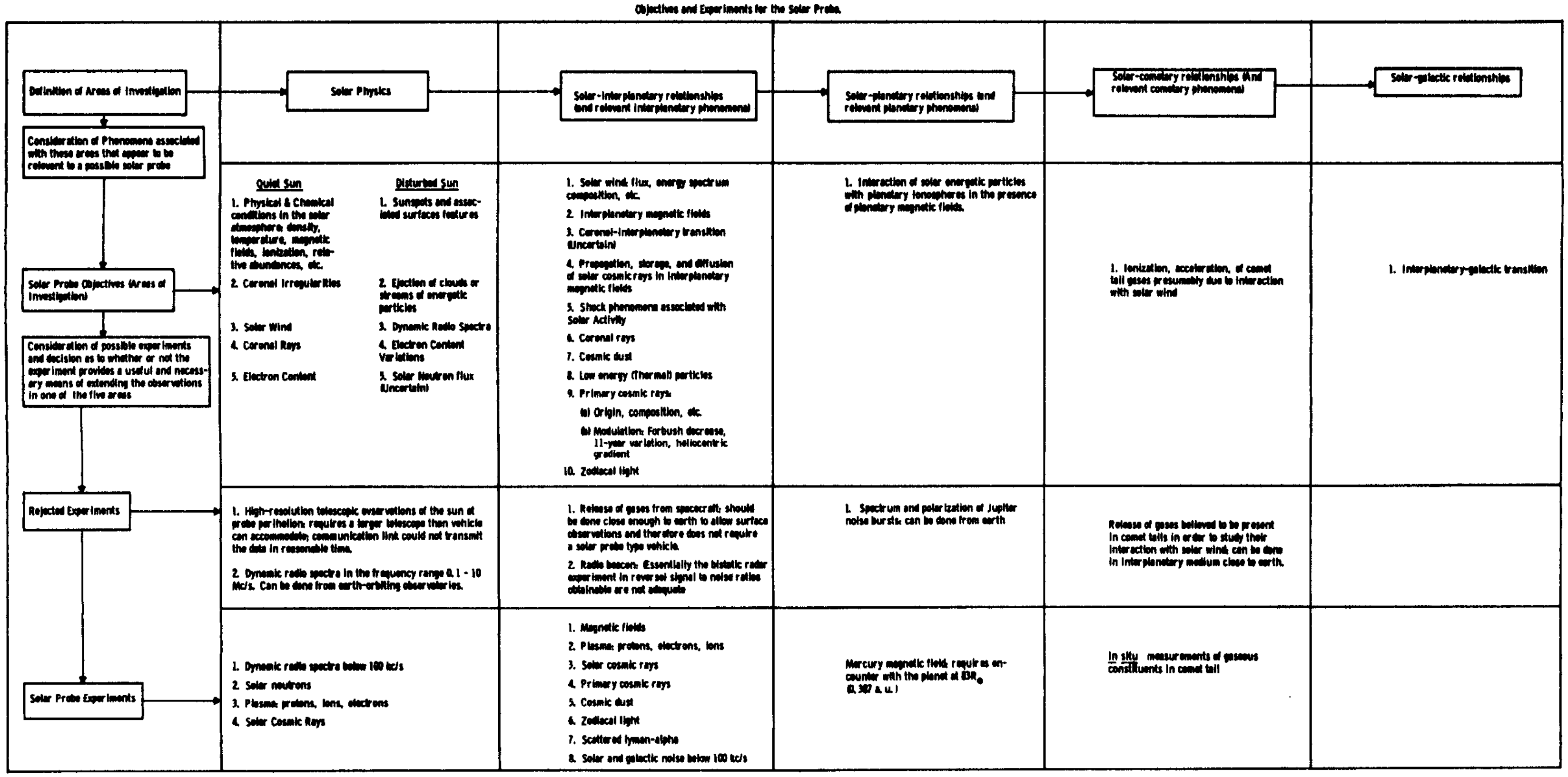


Figure 1. Diagramatic Representation of the Approach Taken in Establishing Scientific Objectives and Experiments for the Solar Probe

A Family of Possible Experiments for the Solar Probe

EXPERIMENT	OBJECTIVE	TECHNIQUE	INSTRUMENT	DESIRED TRAJECTORY	REMARKS
<u>In Situ Measurements</u> 1. Magnetic fields	To investigate the nature, structure and dynamics of the magnetic fields in interplanetary space.	Direct measurement of the intensity and direction of the interplanetary magnetic field	Magnetometer: Search coil, (Pioneer V) Triaxial, fluxgate (Mariner II) Proton precession Rubidium vapor (Explorer X) Helium (Under development)	Measurements should be performed over as wide a-range of heliocentric distance and latitude as possible	
2. Plasma	To monitor spatial and temporal variations in the solar wind. To investigate the interaction of the solar wind with the interplanetary magnetic field.	Direct measurement by collection of particles of the flux energy spectrum, and direction of flux of solar wind protons (and electrons where instrument sensitivity allows) arriving from the general direction of the sun	Curved plate electrostatic analyzer, Protons 240-8400 ev (Mariner II) Curved plate electrostatic analyzer, Protons 200-20,000 ev (EGO) Faraday cup plasma probe 10-10,000 ev (EGO) Planar trap ion-electron detector 0-10 ev (IMP)		
3. Ions	To determine the density distribution of positive ions in the interplanetary space	Direct measurement of the ambient ion composition	RF ion mass spectrometer (EGO) 1-50 AMU; 10 to 10^5 cm^{-3}		The ion densities in interplanetary space are somewhat below the lower limit of detectability of this instrument
4. Electron	Measure distribution of election density and temperature	Direct measurement of ambient electron density	Swept voltage electron (Langmuir) probe 10^3 to 4×10^6 cm^{-3} (Atmospheric Structure Satellite)		Instrument sensitivity too low. The value $N = 10^3$ cm^{-3} corresponds to a heliocentric distance of 20 or 30 solar radii (≈0.1 a. u.)
		Direct measurement of flux	Planar trap ion-electron detector 0 - 10 ev (IMP)		
		Measure the intensity of the incident cosmic radio noise below 100 kc/s	Sweep-frequency receiver Long erectable antenna: 100-300 ft. Receiver gain calibration system		Similar instrumentation scheduled on EGO-I, except 2-4 Mc/s frequency range
5. Primary cosmic rays	To investigate the sources and acceleration processes associated with cosmic rays. To investigate the modulation mechanism of cosmic radiation and also the magnetic field configuration in regions of space not accessible to direct measurement by measurements of heliocentric gradients (and possibly Forbush decreases, if they occur)	Direct measurement of the energy spectrum and charged-particle composition of cosmic ray particles in interplanetary space	Integrating ion chamber (Mariner II) GM Tube (Mariner II)		
6. Solar cosmic rays	To measure solar cosmic ray protons to assist in studying emissions from solar flares and propagation to the earth. To investigate the possible trapping of energetic electrons in solar magnetic fields				
7. Cosmic dust	To determine the spatial distribution and flux of dust particles in interplanetary space	Direct measurement of the flux, momentum, and mass of impinging dust particles	Combined electrostatic piezoelectric microphone detector (Mariner II)		
8. Solar neutrons	To detect the presence or confirm the absence of neutrons in the interplanetary space following a major solar flare To investigate the kinetic temperature in the source region by observations of the neutron energy spectrum, which is markedly dependent on source temperature (Petukhov, 1955)	Direct measurement of the energy spectrum of neutrons arriving from the direction of the sun following the flare.		Minimum possible perihelion distance	The maximum distance at which solar neutrons could be observed is unknown, since flux data is unavailable. Provided solar neutrons are produced, their flux would decrease roughly exponentially with increasing distance from the sun. Experiment should be performed at sunspot maximum.
<u>Electromagnetic Radiation Measurements</u> 1. Zodiacal light	To determine the intensity and degree of polarization of zodiacal light at discrete wavelengths	Measurement of the distribution and spectral characteristics of zodiacal light. Scan the celestial sphere including sweep across the ecliptic.	Photomultipliers with polaroid filters to give intensity and polarization data. (OSO B)	Inclined, so that measurements can be made both in and out of ecliptic plane	
2. Scattered Lyman alpha	To determine the distribution of neutral hydrogen in the interplanetary medium	Ion chambers mounted to look in various directions and measure the scattering of Lyman-α radiation (1216Å) from the sun due to neutral hydrogen	Ion-chambers Lyman - α photometer (EGO)	Inclined, for same reason as zodiacal light measurements	Whether or not the neutral hydrogen density is large enough to produce a measureable effect has not been determined
<u>Radio Wave Measurements</u> 1. VLF Radio	1. To monitor the ambient electron density along the probes trajectory by means of critical frequency measurements 2. To measure the dynamic radio spectra of solar bursts and the cosmic noise intensity at frequencies near the interplanetary cut-off frequency (10 - 100 kc/s, depending on heliocentric distance)	Sweep-frequency receiver measurements of the intensity of the incident radiation	Sweep-frequency receiver Erectable antenna (100-300 FL) Receiver gain calibration system	Measurements should be performed over as wide a range of heliocentric distance and latitude as possible	The solar data gives information about the electron density gradients and optical depths in the corona. The cosmic noise data gives information about these same quantities, but in the intervening interplanetary medium.
2. Bistatic Radar	To monitor the electron content of the interplanetary medium and the solar corona during quiet, non-storm conditions and variations in this quantity during disturbed conditions. To investigate the nature of the sun's radio occulting disk	Measurement in the spacecraft of the relative phase shift of carriers on harmonically related frequencies (50 and 400 Mc/s, for example), which gives variations in the integrated electron content. Measurement of the relative phase shift of the modulation which gives the integrated electron content.	Phase-locked receiver	Trajectory not critical for trajectories in or inclined < 1.5 deg. to ecliptic For inclined orbit: perihelion should be at 0.528 a. u. in order to ensure the occurrence of an occultation. For the same reason, probes traveling away from the sun in an inclined orbit: aphelion should be at 2.17 a. u.	
	To study the nature of electrons in the energetic particle streams ejected by the sun at the time of a solar flare	Measurement of the direction of polarization of the incident wave, which, according to theory (Lusignan, 1963), is shifted by the streaming motion of electrons.			

Figure 2. A Family of Possible Experiments for the Solar Probe

At the outset, it would seem advisable to define the region in space that might logically be regarded as the domain of a solar probe (disregarding for the moment the problem of placing a vehicle in a given trajectory about the sun and the fact that only four probes are being considered for the first mission). It seems reasonable to define the boundaries of the region as those encompassing the volume of space under the direct influence of the various solar electromagnetic and particle emissions.

It is well known that the various processes that take place within this region are largely controlled by the magnetic fields and plasma, or highly-ionized, conducting gas, which evidently have their origin on the sun. Further, as the recent plasma experiments performed on Mariner II have shown, the plasma energy density is much greater than the energy density of the magnetic field. It is known from magneto-hydrodynamical theory that in this case the solar magnetic field is carried along by the solar wind into interplanetary space and, moreover, the existing interplanetary magnetic fields give little or no hinderance to the plasma flow, but rather are carried along more or less radially by the flow. Further, the interplanetary fields influence the propagation of the primary and solar cosmic rays; that is, the relativistic particles that arrive at the solar system continuously from all directions in the galaxy and those that occasionally are ejected at the time of a chromospheric flare and travel outward through the corona. Although the energy of individual cosmic ray particles is quite high, the particle flux is low so that the cosmic ray energy density is small compared with that of the magnetic field. As a result, the particles have little effect on the magnetic field, but are confined to spiral paths along the field lines.

It is clear from considering this one aspect alone that the processes taking place on the sun and in the interplanetary space form such a system of complex and interrelated phenomena that what is observed is usually the total intricate picture and it is often difficult to distinguish individual features. The hazard consists not in putting all these things together and treating them as one great complex bundle, but in thinking that we presently know how to disentangle them and treat them separately, rather than as aspects of an overall picture. The point here is that many of the so-called interplanetary phenomena are essential aspects of solar physics.

It seems reasonable to conclude at this point that the contributions to the long-range, broad investigation of solar phenomena by means of deep-space probe must ultimately involve phenomena taking place not only in the outer layers of the solar atmosphere itself, but also in the remainder of the interplanetary cavity, including the region out of the ecliptic and the transition to the galactic medium.

The interplanetary cavity is obviously not the exclusive domain of the Solar Probe, since it is occupied by the planets and their satellites, comets, asteroids, etc. It is not the region in space alone, but rather the region together with the specific objectives that distinguishes one mission from another. The problem then is to sort out from the broad objectives of deep-space investigation those that are directly related to the sun.

Existing knowledge about the sun and awareness of the many questions that have arisen in attempting to explain the various observations made on earth and elsewhere are essential elements in establishing objectives for the Solar Probe mission. (In this connection much of the material in the appendix serves as a necessary background for the present discussion.) From such considerations, it has become increasingly evident that many questions about the sun, especially those concerned with the nature, structure, and extent of its outer atmosphere, can never be fully answered without the aid of direct measurements in space. Full advantage should be taken of the seemingly unlimited possibilities afforded by the deep space probe. A Solar Probe is clearly a necessary step for the continuing advancement of solar astronomy.

3. SELECTION OF OBJECTIVES

On the basis of what is presently known, it would appear that a solar probe can be most effectively employed in the following areas of investigation:

a. Investigation of the nature of fields and particles in the interplanetary medium by direct measurements along the probe's trajectory

b. Monitoring of the interplanetary and coronal electron content by radiowave methods

c. Extension of the observations of solar and cosmic electromagnetic radiation to the low-frequency spectral regions near the interplanetary cutoff, which heretofore have been inaccessible to observation

d. Special encounters with other objects in the solar system.

The classes of experiments for the solar probe program may be grouped in the categories of particles and fields, physics observations, and special encounters. In general, both particle and field measurements and also special encounters are extensions of observations which have been or can be made from satellites, sounding rockets, balloons, or Earth observatories. Hence, this class of experiments appears justified only if their inclusion in the solar probe leads to a significant improvement in capability or if a correlative measurement is desired.

Examination of desired experiments leads to the interesting conclusion that an optimum choice of controlling objectives in the interests of scientific diversity is possible. In particular, most of the special encounters and physics observations are categorized as singular observations whose required locales are within the regions also required for investigation of particles and fields. The sole exception is the class of observations concerned with defining solar topography. Hence, the solar probe program could be totally oriented by requirements of particles and fields objectives if it is acceptable to obviate this topography class. Assessments, presented in the Appendix, clearly indicate that the class requires payload weights, technology and communication capabilities far in excess of reasonable capability of a Solar Probe, and/or exclusive devotion of the vehicle to this single experiment which appears undesirable. Thus the choice of controlling objectives of the solar probe leads to the following question:

> Can a payload be specified which yields maximum scientific diversity for any phenomenological measurements when its orbits and trajectories (i. e., locales) are constrained to those required for logical development of understanding of particles and fields for phenomana?

It follows that an affirmative answer to this question establishes an optimum choice of controlling scientific objectives for the Solar Probe. Examination of Figure 2 strongly suggests that from the viewpoint of experiments per se, an affirmative answer is indeed suggested. To confirm this requires examination of the logical development of a particles and fields program.

Among the most demanding theories of the interplanetary medium are those relating to the configuration of the interplanetary medium which accounts for Forbush decreases and associated phenomenological observations (Parker, Gold and others). It appears reasonable to assume that provision of capability to effectively evaluate such theories could serve as basic evidence of substantiation. This requires integration of both observation and data retrieval capability as shown in the Appendix. These studies, which involve statistical sampling considerations, appear to confirm the validity of the Solar Probe for such application. They can logically be generalized to suggest that given a basic measuring instrument (e. g., magnetometer, particle telescope), the Solar Probe offers the basic capability of defining structure, form and composition in a manner which is totally consistent with a major advance in interplanetary medium understanding.

Also of concern to assessing logical development would be required sequence of flights. It appears obvious that the Solar Probe should first be concerned with examining phenomena in the ecliptic plane since the bulk of our scientific knowledge and theories stem from a base of such knowledge. Once this critical link is established, the interest should shift to out of ecliptic observations to indicate the validity of derived conclusions. Within the framework of our present knowledge, the coverage provided by mutually compatible trajectories appears totally adequate for initial examination of planets and comets. Since there are a large number of opportunities for such encounters, there appears to be no penalty involved in permitting somewhat limited examination as a means of determining if a more intensive exploration is warranted.

In summary then, it appears that almost total compatibility with all potentially desirable experiments exists within the framework of a controlling set of scientific objectives derived from particles and fields considerations. It is recognized, however, that this condition may not continue to exist with further accumulation of scientific knowledge, particularly from initial launches of the Solar Probe itself.

4. CONSIDERATIONS OF EXPERIMENTS

It is not the intent here to present an exhaustive list of experiments, but rather to discuss a representative few, either quantitatively where detailed calculations have been carried out, or qualitatively where no precise numerical conclusions can be drawn. It is hoped that what follows illustrates the type of problem involved in the various categories of experimental techniques.

4.1 GENERAL

A primary class of experiments that should be considered are those involving transmission of radio signals through the interplanetary medium. The basic reason for this choice is that such experiments effectively portray the characteristics of large spatial areas and serve to markedly enhance the coverage regions of the solar probe. Included in this category are solar cosmic emission and bistatic radar experiments.

Figure 3 illustrates optimum regions of the solar system for performing several of the electromagnetic experiments under consideration. The VLF galactic noise experiments is seen to be unique in that the low frequency cut-off of the interplanetary plasma decreases in frequency with increasing distance. The bistatic radar experiment is of interest at all distances from the sun, as are the Lyman-α and zodicacal light experiments.

4.1.1 Solar and Cosmic Emission

Much additional knowledge about the production and acceleration of solar cosmic ray particles and other chromospheric flare effects might be obtained by extending the observations of solar dynamic emission spectra to frequencies below the F-layer cut off at about 10-20 Mc/s. Such emission might be found to extend to frequencies as low as the critical frequency of the interplanetary gas, roughly 10-20 kc/s.

At the same time, the observation of cosmic radio emission at frequencies near the interplanetary critical frequency would be of great value is studying the properties of the interplanetary plasma. It is expected that at these frequencies the optical depth of the medium is fairly large and a significant refractive bending of radio ray paths occurs. Thus both refractive and absorptive effects, combined with those due to the magnetic field and to the continuous changes in the medium brought about by the streaming solar plasma will have a marked influence on the observed

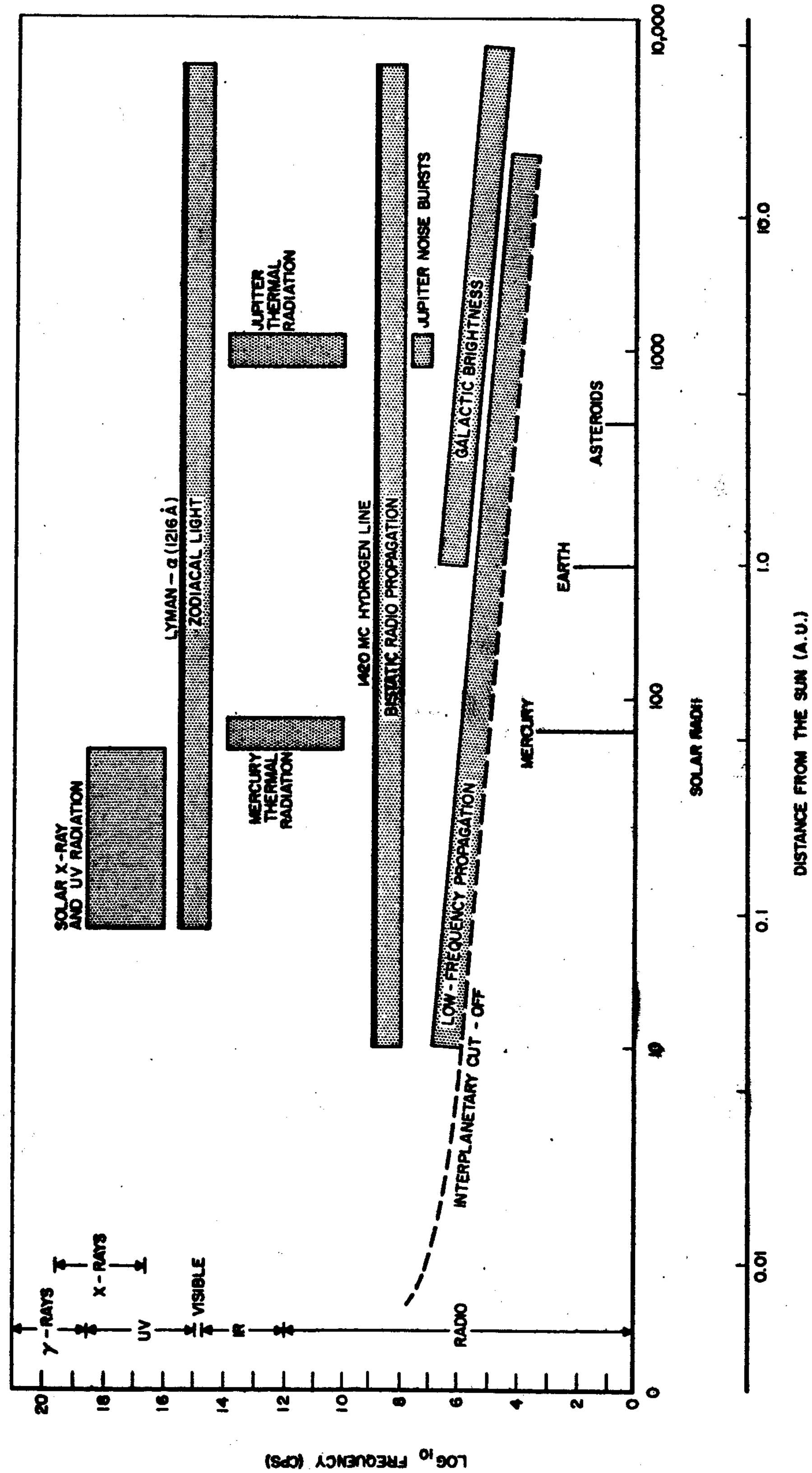


Figure 3 Favorable Regions for Electromagnetic Radiation and Propagation Measurements

cosmic radio emission spectrum. The observations of the cosmic radio emission can only be extended to very low frequencies, of the order of 20 kc/s, by sending the spacecraft to a point well away from the dense parts of the solar system, possibly even into the galactic medium itself.

Although at frequencies near the critical frequency, the radio propagation characteristics of the interplanetary medium may complicate the measurement of the cosmic emission spectrum, use may be made of this phenomenon to study certain features of the medium, such as the electron density in the vicinity of the vehicle. In such an experiment a VLF receiver tuned to say 20 kc/s would be carried in the spacecraft whose trajectory passes through the level at which 20 kc/s is the local critical frequency. As the spacecraft crosses this level, the reception cone would shrink completely, resulting in a sharp decrease in the received emission. Thus, by recording the received noise level as a function of time, the electron density along the spacecraft trajectory could be studied. However, owing to the expected variation in the critical frequency of the medium and for other reasons, it would be desirable to sweep the receiver over a band of frequencies, say 10 – 100 kc/s. Such an experiment would also provide data on the solar radio bursts that might occur in this frequency range during solar active periods.

4.1.2 Bistatic Radar Astronomy Experiments

A bistatic radar system is one in which the transmitter and receiver are at different locations, in contrast to the usual (monostatic) radar in which their location is the same. This approach allows very large antennas and high power transmitters to be employed on the ground and only lightweight receiving equipment in the spacecraft.

The usual method of investigating the properties of a thin, highly ionized gas, such as the solar corona, which is not accessible to direct observation is to observe the effects impressed upon the wave during transit of the intervening medium. By employing this technique it would be possible to make some deductions about physical conditions in the corona. The observable effects might include alteration of the frequency, polarization, amplitude and also the phase and group delay of the received signals from the values that would have been observed in the absence of the solar medium.

Although many types of radio experiments are possible, probably the easiest one to implement involves the differential Doppler frequency shift. In this method two harmonically related frequencies are radiated by the ground based transmitter and received at the vehicle. The refractive index of the ionized gas is different for the two frequencies and thereby affects the Doppler shifts differently. Consequently, the received frequencies are not precise harmonics, and if the highest received frequency is divided by the integer ratio of the two transmitted frequencies and compared with the lower frequency, there is a beat between the two which is a measure of the integrated electron density along the propagation path.

Although the physical principles involved are basically the same in all applications of the technique, there are certain unique aspects in employing it in investigating the solar corona. For example, because the Doppler shift is proportional to the relative velocity component in the direction of the departing ray at the transmitter and since there are two ray paths connecting the Earth and probe, a direct ray and a refracted ray, there is a different Doppler shift associated with each of the two ray paths.

As the probe approaches superior conjunction with the Sun, the refracted ray moves away from the Sun while the direct ray moves toward the Sun. The two rays eventually merge and disappear as the probe passes behind the radio occulting disc of the Sun. As these events occur, the two Doppler frequencies would also be observed to approach each other and finally merge into a single frequency just as the signal disappears at occultation. The duration of the occultation period depends on a variety of factors; at a frequency of 100 Mc/s it would likely be of the order of a week. At the end of this period, the probe emerges from behind the Sun's occulting disc and the events described above are repeated in reverse order.

In the presence of a magnetic field the radio signals will be split into ordinary and extraordinary propagation modes. Thus, there would be associated with both the direct and refracted rays two components of different delay, polarization, and frequency shift. In this case there will be four independent Doppler modes. Furthermore, radio waves propagated through a turbulent, irregular medium would be affected by both the spatial distribution of refractive index and by its variation with time. For example, random fluctuations in the phase path between the probe and Earth would give rise to a corresponding fluctuation in the Doppler frequency shift.

Rather than discrete frequencies, a broadened spectrum would therefore be expected. Careful measurements of these effects might be used to determine the magnitude of the coronal magnetic field, velocity of random motion of inhomogeneities, and drift velocity of plasma clouds.

4.2 SOLAR PLASMA

In considering the plasma measurements that can be made from an interplanetary space probe, much use can be made of the data already obtained from previous flights. The principal value of the preliminary measurements obtained along the Mariner II trajectory, for example, is that of establishing the dynamic range, sampling rate, sensitivity, and other characteristics of various instruments for more detailed measurements of the various phenomena observed.

It is clear that both small and large scale structure in the plasma-magnetic field distribution will be found under various conditions of solar activity. For example, the requirement for fast time response is pointed up by the Mariner II data (Neugebauer and Snyder, 1962) in which the magnetic storm of 7 October was observed. It was desired, but not possible, to analyze the structure of the shock wave, which apparently passed the spacecraft at a velocity of 504 km/sec, because the time resolution was not fine enough.

The Mariner II results together with observations of the disturbance in the Earth's magnetic field, the variation of the galactic cosmic ray flux, and other phenomena reveal characteristic periods of the plasma and magnetic field variations ranging from a few seconds to a few days. Ideally, continuous measurements should be made for the duration of the flight, but practical considerations rule against this procedure. It would, however, be desirable to have a sampling rate and measurement period that would allow detailed study of the small-scale structure of the medium and the magnetohydro-dynamic shock waves which give rise to rapid time variations in the medium.

The study of free electrons in the solar atmosphere and the interplanetary medium is an important aspect of solar research. Except for the more energetic electrons which are counted along with cosmic ray protons by the high-energy particle detectors that have been flown on various spacecraft, there have been no direct measurements of electrons in space. In particular, there have been no direct measurements of the relatively low-energy electrons in the solar wind. There are probably present, but below the level of detectability of the plasma spectrometers that have been employed to study the proton component of the solar wind.

Most of the observational data on various aspects of solar phenomena involves the region of space within a few solar radii of the sun; that is, in the chromosphere and corona; and it is in this region, where correlation with other types of data would be possible, that electron density measurement would be of greatest value.

4.3 MAGNETIC FIELDS

Any magnetometer measurements of the vector magnetic field along the Solar Probe trajectory would be performed as a part of the broad scientific investigations of the physical processes causing the magnetic fields of the sun, the planets, and the interplanetary space. The major objectives of these experiments would be (1) to study the interplanetary magnetic field and its fluctuations, which presumably result from interaction with plasma clouds ejected from the sun; (2) to investigate the nature of the magnetic field in the transition region between the solar corona and the interplanetary medium, which, if, such a region exists, may occur where the coronal streamers are observed to end at about 30 to 50 solar radii (0.14 to 0.23 AU) from the sun; (3) to study the nature and extent of coronal rays, which are evidently magnetic tubes of force stretching out, presumarly from the M-regions on the surface, to perhaps 300 solar radii (1.5 AU) or more; (4) to determine the extent of the interplanetary magnetic field and the nature of the transition to the galactic magnetic field; (5) to determine the extent of solid-body rotation of coronal structure and, possibly (6) to study magnetic fields of planets (Mercury, for example), provided a trajectory could be found that would not only provide an encounter with the planet but would be compatible with the primary experiments. Clearly, not all of these would be amenable to investigation by the same vehicle since totally different trajectories would be required in many cases.

4.4 SOLAR NEUTRONS

The question of whether or not solar neutrons are produced in the active region at the time of a solar flare has important implications regarding the processes taking place. The question might be settled by an experiment that would detect the presence or confirm the absence of solar neutrons in the interplanetary medium following a large flare.

In dealing with the problem of ascribing an optimum trajectory for the solar neutron experiment one encounters the nearly complete lack of basic quantitative data regarding the expected flux levels as a function of heliocentric distance, which would be needed to make such a judgement. About all that is known with any degree of certainty is the half-life of the neutron decay process, which seems to be about 15 minutes. It is quite clear, therefore, that any attempts to detect the presence or confirm the absence of solar netrons in the interplanetary space following a major solar flare should be made as close as possible to the sun as the flux is expected to drop in an exponential manner with increasing heliocentric distance.

5. ON THE SELECTION OF TRAJECTORIES

It is natural to inquire where in space the first probe should be sent, when it should be sent, in what sequence the others should follows, and whether or not the trajectory should be the same in each case. There are numerous factors that must be taken into account in attempting to answer such questions. For one thing, virtually all of our present knowledge about the sun and the interplanetary medium is based on observations made either in or relatively close to the ecliptic plane, and, with one or two notable exceptions, is limited primarily to conditions in the region between the sun and the earth. Consequently, it would appear that for the first probe there is much to be said for a trajectory that is in or only slightly inclined to the ecliptic and which takes the probe in as close as possible to the sun. Perhaps in this way our present knowledge could be best employed as a basis for interpretation of the data that would be obtained.

It is clear that observations should also be made out of the ecliptic. There are several reasons why an orbit that is inclined at an angle of between say 15 and 90 degrees with respect to the ecliptic would be desirable for, say, the second probe. For one thing, the variation with heliocentric latitude of various features of the interplanetary medium is of great scientific interest. For example, is there any anisotropy associated with the solar wind, or does it stream from the sun more or less uniformly from equator to pole? For another, the spacecraft would be out of the zodiacal dust cloud, which is confined approximately to the ecliptic (actually the plane of Jupiter's orbit). As pointed out by Goldberg (1962), one of the inherent limitations to observation from observatories traveling in the ecliptic plane is the background brightness produced by the scattering of sunlight by the interplanetary dust. This limitation could be removed by orbiting the observatory about the sun in a plane highly inclined to the ecliptic.

If the bistatic radar experiment is included in the family of experiments, there is another factor that should be taken into account in the selection of trajectories. In order to take full advantage of the unique opportunities afforded by the bistatic radar measurements to obtain information about electron densities in regions close to the sun there are certain constraints imposed on the trajectory. If the plane of the probe's trajectory is only slightly inclined (that is, less than about two degrees) to the ecliptic, there are no special requirements. For launches in the ecliptic any perihelion (or aphelion) distance is suitable for this experiment. On the other hand, if the trajectory is inclined to the ecliptic, then there are only certain orbital periods that allow the greatest amount of information to be derived from this experiment. If the probe's orbital period is in synchronism with that of the earth, then regardless of the inclination, when the spacecraft arrives at one of the nodes of its orbit, it will be in superior conjunction with the sun as viewed from earth. This particular configuration guarantees that the probe will pass behind the sun's radio occulting disk and therefore that the maximum amount of information will be derived from the experiment. There is an endless number of such synchronous orbits; however, only three achieve superior conjunction in one year or less. The three are as follows:

a. Perihelion at 0.260 AU., equipment lifetime six months

b. Perihelion at 0.528 AU., equipment lifetime one year

c. Aphelion at 2.17 AU, equipment lifetime one year.

Case b. above would appear to be the optimum choice for the first-generation solar probes that include the bistatic radar experiment.

Interpretation of the data that would be obtained on the first one or two flights should permit the drawing of at least some conclusions to guide subsequent efforts. It is conceivable, for example, that unexpected ranges of measured quantities may be encountered, and it may in this or some other way become necessary to adapt the techniques employed to different requirements.

The objective of missions involving a single probe should probably be regarded as primarily that of gathering temporal data on the various phenomena. However, spatial variations exist and effects would certainly be present in the data, but it would be difficult to interpret any data obtained along a single trajectory in space terms of these spatial variations. In some cases the earth can provide a second point of observation, but, as a rule, its strong magnetic field and atmosphere substantially influence or totally shield the phenomena that otherwise might be observed. Moreover, for trajectories such as that envisioned for the Solar Probe the distance between the earth and probe would probably be too great to provide synoptic data for much of the flight.

Nevertheless, knowledge of the spatial component could lead to a better understanding of the structural features associated with certain phenomena and perhaps shed some light on the solar processes involved. It seems worthwhile, therefore, to consider the possibilities of obtaining such information. An obvious way, would be to launch two spacecraft in rather quick succession, say one or two months apart, on trajectories that would allow simultaneous measurements to be made along a double path through space. Another method would be to launch the remaining probes within one or two months of Mariner or Voyager launches, since some of their instrumentation will be capable of making interplanetary measurements. Clearly, there is much to be said for sending the remaining two probes along such trajectories.

REFERENCES

1. V.A. Petukhov, Solar Neutron Ejection as the Cause of Aurorae and Magnetic Storms, in The Airflow and the Aurorae, E.B. Armstrong and A. Dalgarno (eds.), Pergamon Press, New York, 1955.

2. C.F. Hall, G.J. Northwang and H. Hornby, "A Feasibility Study of Solar Probes," Presented at the IAS 30th Annual Meeting, New York, New York, January 22-24, 1962.

3. J.R. Miles, Sr., Problems in the Design of Unmanned Spacecraft for Planetary and Interplanetary Exploration, Presented at the IAS 31st Annual Meeting, New York, New York, January 21-23, 1963.

4. D.W. Dugan, A Preliminary Study of a Solar Probe Mission, NASA TN D-783, 1961.

5. M. Neugebauer and C.W. Snyder, Solar Plasma Experiment, The Mission of Mariner II: Preliminary Observations, Science, Vol. 138, pp 1095 – 1100, 1962.

6. B. B. Lusignan, Detection of Solar Particle Streams Using High Frequency Radio Waves, Sci. Rep. 2, Contract AF 19(604)-7994, Stanford Electronics Laboratories, Stanford, California, 1963.

7. L. Goldberg, Stellar and Interstellar Observations, in Space Age Astronomy, A. J. Deutsch and W.B. Klemperer, eds., Academic Press, New York, 1962.

N65-29519

UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH

BOULDER, COLORADO

This is a report of suggested experiments oriented principally to solar physics for a close-in solar probe. Report authors:

R. Grant Athay
Lewis L. House

High Altitude Observatory
Boulder, Colorado

I. OUTLINE OF THIS STUDY

A scientifically instrumented space vehicle capable of approaching significantly closer to the sun than orbiting Earth satellites appears feasible from a technological point of view at the present time. The rapid growth of the space sciences and the construction of larger and larger booster rockets lends promise that both the feasibility and desirability of such vehicles will evolve considerably in the next few years. For these reasons, it seems useful to think seriously about desirable experiments that possibly might be carried out aboard such a space craft. We have initiated, with support from Ames Research Center, NASA, such a study with particular emphasis on experiments relative to electromagnetic radiation from the sun and the nature of the interplanetary medium. We have not considered in detail the many interesting experiments relative to particles and fields measurements near the sun. This choice was made with the understanding that other groups were considering the particles and fields experiments and does not reflect either lack of interest on our part or a feeling that these experiments are less useful. Indeed, it seems immediately evident that many of the more interesting experiments aboard such a space craft will involve particles and fields measurements.

This report is the outgrowth of informal discussions along the lines mentioned above with various scientists in the Boulder, Colorado, community interested in solar, interplanetary and terrestrial atmospheric phenomena. Some of the discussions were of a seminar type with strong audience participation and others were private. We have not attempted to label all ideas expressed nor criticisms of ideas with the names of particular individuals. Thus, this report has been influenced by many people, even though, in most cases, they are unnamed. The responsibility for accurate reporting and detailed comments, however, lies solely with the authors.

The nature of our discussions can be summarized by the following questions indicative of our general approach to the subject: (1) What experiments would be useful to carry out from a space vehicle approaching the sun from Earth? (2) What is the specific scientific purpose of these experiments? (3) At what maximum distance from the sun do these experiments offer enough improvement over similar experiments carried aboard orbiting Earth satellites to justify the added technical difficulties of approaching near to the sun? (4) What are the general requirements of the space craft for pointing accuracy and control?

The first question led to a rather uncritical listing of experiments, some of which could be immediately discarded when challenged by questions (2) and (3). We have retained some of these easily discarded experiments in this report for the sake of completeness and future reference. In doing so, we do not wish to imply that our list is complete in any sense. The list represents simply those experiments that were of interest to some member of the discussion group. The second question asks essentially for a scientific justification of a proposed experiment in order to distinguish the meritorious experiments from those that are suggested simply because they become possible under the particular circumstances. The third question is difficult to answer in many cases and involves some knowledge of the technical difficulties of performing such experiments. We have considered these difficulties only in crude terms, and because of this limitation we have set the maximum distances in equally crude terms. The fourth question is similarly involved in technology. We have included it because it is relatively easy to answer without knowing details of instrument design, etc., and because it is helpful in the planning of a solar probe vehicle. We have specifically avoided detailed considerations of weight, power and telemetry requirements.

The discussion that follows is not intended in any way as a proposal for support of specific space experiments. It is intended only as a guide to those who subsequently may wish to propose experiments.

II. General Considerations

The scientists' wish to observe the sun and its space environment from vantage points nearer to the sun than the orbit of Earth is prompted by a desire to gain better physical understanding of the sun and its environment. An observing station nearer the sun would experience a greater density of radiant flux from the sun and would view a sun of large angular diameter. As a result, small features on the sun and faint emissions would be relatively easier to detect. Furthermore, the nature of solar phenomena is such that we cannot safely assume that an observer at Earth is capable of detecting all that transpires on or near the sun. In particular, magnetic field configurations near the sun may change markedly with little or no detectable change at the orbit of Earth; and clouds of solar plasma may be ejected from the sun in association with many flares, or other solar phenomena, without ever producing an observed effect at the orbit of Earth. Finally, an observer at Earth can acquire only very restricted observations of such phenomena as zodiacal light, the F-corona and the solar wind. Observations at closer approaches to the sun offer hope for great improvements in the quality and quantity of data available for the study of such phenomena.

The sun is an extended source rather than a point source, and the advantages to be gained by a close approach must be carefully considered. A given focussing lens will intercept radiant flux in proportion to r^{-2}, where r is the distance from the lens to the sun. The image formed, however, increases in area in proportion to r^{-2} with the result that the surface intensity in the image is constant. Thus, a spectrograph, for example, with a given imaging system and a fixed slit that is smaller than the solar image will not experience any increase in the flux passing through the slit as r is changed. The ratio of image area to slit area, however, will increase in proportion to r^{-2}, and the spectrograph will gain in spatial resolution of the solar image. On the other hand, if the gain in spatial resolution is sacrificed by enlarging the entrance slit of the spectrograph the flux received will increase in proportion to r^{-2}.

Linear resolution on the sun increases in proportion to r^{-1} as r is decreased. At a fixed distance from the sun, the theoretical linear resolution is proportional to the diameter of the objective flux collector. Thus, an approach to 0.1 A.U. is equivalent to increasing the diameter of the flux collector at 1 A.U. by a factor of 10, or increasing the flux collecting power by a factor of 10^2.

We have arbitrarily adopted an increase in theoretical linear resolution of a factor of 10 as the marginal value for studies aimed at increased spatial resolution, i.e., the increased resolution becomes a compelling factor when $r \lesssim 0.1$ A.U.

Since the total flux received by a collector increases in proportion to r^{-2}, a theoretical increase in useful flux of a factor 10^2 is achieved at 0.1 A.U. In many cases, however, this total increase cannot be utilized because of design problems. Again, we have set 0.1 A.U. as the general marginal condition for studies requiring greater flux levels. Some notable exceptions to this arbitrary condition will arise, however.

In setting the above limits, we recognize that current technology makes it far more difficult to reach 0.1 A.U. than to reach 0.3 A.U., and that this alone may offset the advantages gained by shorter distance from the sun. We have not taken this into consideration. Instead, we have proceeded under the assumption that the difficulty of achieving a major reduction in r is roughly comparable to increasing either flux collecting power or the sensitivity of flux detection by a factor of 10^2. A solar probe at 0.3 A.U. would very definitely present strong advantages in increased spatial resolution on the sun and minimum observable intensities. However, it seems to us to be more realistic to attempt to achieve this same gain by increasing the flux gathering and detecting power of instruments aboard Earth satellites by a factor of 10.

A further advantage of a close solar probe over an Earth satellite is in the required accuracy and stability of pointing. For example, a solar feature such as a spicule or granule with 1" of arc angular size at the orbit of Earth subtends 3.3" of arc at 0.3 A.U. and 10" of arc at 0.1 A.U. The pointing accuracy and stability of the space vehicle required to observe such features is therefore substantially less than at 1 A.U.

Again, the relative expense of this gain must be weighed in terms of the engineering difficulties, which we do not feel competent to judge. For this reason, we have excluded from our study any consideration of experiments designed primarily for achieving high spatial resolution. We have included some experiments where merely "better" resolution is desired, however.

III. SUMMARY OF SUGGESTED EXPERIMENTS

A. - Lyman-α; Interplanetary Absorption. (Suggested by J. W. Warwick and E. P. Todd)

The purpose of this experiment is to determine the distribution of neutral hydrogen in interplanetary space by searching for a narrow absorption feature in the solar spectrum near Lyman-α. For a stationary hydrogen gas, the absorption core in Lyman-α would have a Doppler width of about .04 to .13 Angstroms, corresponding to assumed temperatures of 10^4 and 10^5 °K, respectively. The depth of the absorption feature will depend upon the number of neutral hydrogen atoms between the probe and the sun. A depression by about 0.1 would occur if there were 3×10^{12} neutral hydrogen atoms in the optical path from probe to sun. At a probe distance of 1 A.U. this would correspond to an average neutral hydrogen density in interplanetary space of about .2 per cm^3. (The absorption coefficient at line center for Lyman-α is 0.56×10^{-13} for a temperature of 10^4 °K and 0.19×10^{-13} for a temperature of 10^5 °K.)

This experiment would involve crude pointing towards the sun and a spectral resolution of about .1 Å. This would not give an accurate profile for the absorption component, but would be sufficient to give the total absorption. A resolution of 0.01 is required for studies of the absorption profile, which would provide valuable new data.

If the interplanetary neutral hydrogen is moving outwards from the sun with an average radial velocity of, say, 500 km/sec, the absorption line would be shifted 2Å to the violet of the normal Lyman-α line, and would be difficult to observe as an absorption line.

The density of neutral hydrogen atoms in interplanetary space can be estimated from data obtained by Explorer X and from more general considerations (see appendix). On the basis of the observed solar wind flux alone, there would not be enough neutral hydrogen within the orbit of Earth to detect by this technique. A relatively small change in the wind flux, however, could result in detectable amounts of neutral hydrogen.

In view of the uncertainty in the amount of interplanetary hydrogen, experiments to detect it should be flown aboard orbiting Earth satellites or space probes going beyond the geo-corona. In the event that these preliminary experiments successfully detect interplanetary neutral hydrogen a solar probe experiment to determine the radial distribution of the neutral hydrogen between 1 and 0.5 A.U. would be of great value. An experiment capable of resolving the profile of the absorption core in Lyman-α would enhance the value of the experiment.

B. - <u>Lyman-α; Interplanetary Scattering</u>. (Suggested by R. G. Athay)

The purpose of this experiment, again, is to determine the distribution of neutral hydrogen in interplanetary space by searching for Lyman-α emission produced by scattering from neutral hydrogen atoms.

If we assume, for convenience, that neutral hydrogen is uniformly distributed in interplanetary space, the Lyman-α photon flux arising at a 90° angle to the sun-probe line is (see appendix)

$$8.3 \times 10^{9}\ n_h\ R/r,\ cm^{-2}\ sec^{-1}\ , \qquad (1)$$

and the flux arising from a point opposite the sun

$$5.3 \times 10^{9}\ n_h\ R/r,\ cm^{-2}\ sec^{-1}\ , \qquad (2)$$

where n_h is the number of scattering atoms in a cubic centimeter, r is the probe-sun distance and R is the Earth-sun distance. A Lyman-α photon counter capable of detecting 1×10^{9} photons per sec, would therefore be able to detect at 1 A.U. an average $n_h \geq .12$ looking at 90° to the sun-probe line and an average $n_h \geq .2$ looking directly away from the sun.

If n_h is proportional to r^{-1}, the numerical coefficients in equations (1) and (2) are reduced by factors of about 2 and 4, respectively, and n_h is redefined as the ambient n_h in the vicinity of the probe (see appendix). Obviously, n_h cannot continue to increase towards the sun and the approximation that $n_h \propto r^{-1}$ is intended only in the vicinity of the probe and at greater distances from the sun.

If there is enough neutral hydrogen in interplanetary space to be observed in this way, changes in the emission with orientation of the instrument and with distance from the sun should provide the necessary data to determine concentrations and gradients of neutral hydrogen. The observations need only record total flux in Lyman-α and preferably should scan across the plane of the ecliptic.

Measurements of Lyman-α emission scattered by interplanetary neutral hydrogen appear to be somewhat simpler to carry out than measurements of the central absorption core in direct solar Lyman-α radiation and would provide essentially the same data. In principle, this technique is capable of detecting much smaller concentrations of neutral hydrogen than is the absorption experiment. Since the feasibility of this experiment depends directly upon the sensitivity of the Lyman-α photon counters employed, we will not attempt to predict its success or failure. Again, studies of the line profile would substantially increase the value of the data. The profile of the scattered Lyman-α line would be essentially the same as the profile of the central absorption core.

As in the preceding experiment, preliminary observations from orbiting Earth satellites or space probes should precede the close solar probe. A solar probe experiment, if initiated, should approach within 0.5 A.U. of the sun.

C. - Lyman-α; Coronal Electron Scattering. (Suggested by I. Öhman)

Electrons in the solar corona will scatter the chromospheric Lyman-α line, and, because of the high velocity of the elect[illegible], the line profile of the scattered light will be considerably broader than in the normal solar spectrum. The purpose of this experiment is to provide a unique and accurate measure of the coronal electron temperature by measuring the profile of the scattered Lyman-α line. The mean Doppler velocity of coronal electrons (assuming 1×10^6 °K) is 5500 km/sec, which produces a Doppler width in the profile of the scattered Lyman-α line of 22Å. A spectrograph with 1Å resolution would give a sufficiently accurate profile.

The flux of Lyman-α photons at the orbit of Earth due to coronal scattering is of the order of 1.4×10^6 cm^{-2} sec^{-1}. In order to obtain profile information, this flux must be divided into about 10 bands, leaving an average flux of 1.4×10^5 cm^{-2} sec^{-1} at the orbit of Earth.

The coronal flux may be much less than the total flux due to interplanetary scattering. However, if the corona is imaged on a photon counter the counter can be shielded from all interplanetary flux except that arising in the solid angle subtended by the corona. This latter flux is comparable to the coronal flux if the probe is at 1 A.U. and $n_H \approx 0.1$. If the probe is at 0.3 A.U., presumably the interplanetary flux decreases markedly and the coronal flux increases by a factor of about 10. At 0.1 A.U. the coronal flux increases by a factor of 10^2 compared to the flux at 1 A.U. and the interplanetary flux decreases still further. Since the profile of the coronal scattered Lyman-α is about 22A wide whereas the profile of the interplanetary scattered Lyman-α is about 0.1A wide, the two components could be separated with rather crude spectroscopic resolution.

This would be a valuable experiment to carry out. The advantage of a close approach to the sun, however, must be weighed in terms of instrumental capabilities and the distribution and density of interplanetary neutral hydrogen. If it turns out that interplanetary scattering of Lyman-α is as weak as predicted by the presence of the solar wind, there is little to be gained in this experiment by a close approach to the sun.

D. - Separation of F and K-Corona. (Suggested by R. G. Athay)

The true solar corona (K-corona) at all solar latitudes at sunspot maximum or near the solar equator at sunspot minimum merges at about one radius above the solar limb with a false F-corona produced by forward scattering by interplanetary dust. It is likely that the interplanetary dust is very tenuous near the sun and relatively denser at greater distances. A solar probe at 0.3 A.U. would see an F-corona with its intensity reduced by at least a factor of 3.3 and possibly by over a factor of 10. A reduction by a factor of 3.3 in the brightness of the F-corona would make it comparable with the brightness of the K-corona (at the times and position indicated) at about two radii above the solar limb, and a reduction in the F-corona brightness by a factor of 10 would make the two comparable in brightness at distances varying from 3-10 radii above the solar limb. Direct observations of the corona at 0.3 A.U. could, therefore, show much more of the structural detail of the true K-corona than will observations at 1 A.U.

Interpretation of much coronal data in terms of the spatial and thermodynamic properties of the corona depends quite heavily on our ability to separate accurately the F and K components of the corona. Hence, this experiment could be of considerable value. Observations could be made in white light and would require either imaging or scanning of the corona.

E. - <u>3-D Corona</u>.

One of the major unsolved problems of the solar atmosphere is the nature of the spatial irregularities in density and temperature. The structure is complex, and the proper interpretation of spectroscopic data depends quite critically on the precision with which the geometry can be specified. The effective path length through which emergent coronal radiation originates is long compared to individual features in the corona. As a result, many of these features are obscurred by chance superposition and over-lapping with other features.

The great distance of the sun from Earth makes interpretation of the spatial configuration of any observed coronal structures difficult. For example, it is not known whether the long equatorial streamers of the corona at sunspot minimum form a continuous disk encircling the sun or whether they are discrete features like spokes radiating from a central hub.

If we assume that a given streamer is a spoke-like structure we cannot tell where it is anchored in relation to features on the solar disk without forming a three dimensional coronal picture.

Simultaneous pictures of the corona made from two points which subtend an angle of about 10° or greater when viewed from the sun could be used to construct three dimensional models of the corona that are considerably superior to models currently available. The success of such a program depends substantially on the spatial resolution of the pictures and on the angular separation of the observing points.

One picture of a pair, of course, could be obtained from a white light coronagraph aboard an orbiting Earth satellite or from the ground at a total solar eclipse. A similar instrument aboard a space probe could provide a good second picture. Since the primary requirement is to get adequate angular separation of the two observing points there is no particular reason for a close approach to the sun.

F. - Zodiacal Light and F-Corona. (Suggested by G. N. Newkirk)

From the intensity and polarization of the zodiacal light and the variation of these quantities with elongation angle from the sun it is possible, in principle, to determine the size distribution of particles in the interplanetary medium. The interpretation of such observations is greatly complicated by the fact that not only the size distribution but also the spatial distribution of the scattering particles must be inferred from the observations. With so many parameters required to describe the interplanetary dust it is not surprising that the observations lead to ambiguous results. Observations of the zodiacal light or the F-corona from a "Close-In Solar Observatory" as it slowly approached the sun would be of inestimable value since the parameters of the spatial distribution could be inferred directly from the observations.

Also by performing such an experiment we might well be able to answer the question of how large a sphere of particle-free space the sun has carved out of the interplanetary medium. Several authors have estimated that the solar system within the orbit of Venus is essentially free of interplanetary particles. Such measurements could not only answer the direct question of what is the distribution of interplanetary material in the inner solar system, but would also shed light on the rather intriguing problems of the dynamics of the interplanetary particles.

The instrumentation required to observe the intensity, the polarization, and the direction of polarization of the zodiacal light at representative angles covering nearly the entire sky would be relatively simple. The cone of approximately 20° half-angle centered on the sun would be excluded from measurement in order to keep the optical system of the photometer to the simplest possible form. The sun shield of the satellite could be used as a rather large occulting disk to prevent direct photospheric light from striking any portion of the zodiacal light photometer, which would be on the anti-solar side of the vehicle. The exact program by which the zodiacal light photometer would scan the sky would, of course, depend upon the type of satellite stabilization.

The accuracy with which the observations would be required would be approximately one percent in relative intensity. To accomplish this stability most simply it would be necessary to calibrate the photometer on the attenuated radiation of the direct solar disk seen through the axis of the satellite.

We make the, admittedly inexperienced, guess that a zodiacal light photometer-polarimeter of approximately 2 or 3 inch aperture and its associated electronics would weigh approximately five to ten pounds. Assuming that the photometer were to examine the zodiacal light in 10° by 10° samples we find that approximately 500 sampling positions in the sky would be required. With 3 pieces of data to an accuracy of one percent from each sampling position we should need approximately 1.5×10^5 pieces of information while the satellite is in a given position in the solar system. Under the additional assumption that data is desired from at least ten different locations in the solar system from 1 A.U. to 0.3 A.U. approximately 2×10^6 pieces of information would be required during the entire operation of the experiment.

The slightly different form of zodiacal light photometry involved in observing the F-corona requires a more sophisticated piece of equipment but would also promise more information about the size and spatial distribution of the zodiacal light particles. This experiment would involve an externally occulted coronagraph capable of examining the zodiacal light and F-corona from approximately 2° from the center of the sun out to approximately 50° from the center of the sun. Such data have an inherent simplicity of interpretation because the scattering functions from very small particles are generally single valued within a scattering angle of 20° or 30° and the ambiguity present in zodiacal light measurements at larger scattering angles is removed. The information handling facility required for this experiment would be approximately an order of magnitude smaller than that required for the zodiacal light photometry.

G. - <u>White Light Detection of Plasma Clouds</u>. (Suggested by R. G. Athay)

A plasma cloud ejected from the sun may contain enough electrons to give the cloud appreciable brightness in the visual spectrum arising from scattering of sunlight. At an angular distance of 10° from the sun, a plasma cloud in which the product of electron density, n_e, and cloud diameter, L, is 10^{15} cm^{-2} would have about the same brightness as the zodiacal light at the same elongation angle. This value of n_eL is arrived at by extrapolation from the coronal brightness. At 0.5 radii beyond the solar limb, (n_eL) corona $\approx 10^{17}$ cm^{-2}. At 10° from the limb the flux density of photospheric radiation is reduced by about 10^{-2} and a cloud with $n_eL \approx 10^{15}$ cm^{-2} could be about 10^{-4} as bright as the corona at 0.5 radii. This is comparable to the brightness of the zodiacal light.

A zodiacal light photometer scanning across the plane of the ecliptic near the sun would be capable of detecting such clouds. In this case there is not so much advantage in a close approach to the sun. On the other hand, a zodiacal light or F-corona photometer would almost automatically detect these clouds if properly programmed.

H. - <u>Solar Neutrons</u>. (Suggested by E. P. Todd)

It is probable that the outer regions of the sun's atmosphere may, at times, produce energetic neutrons capable of escaping the gravitational field of the sun. At times of solar activity, protons with energies of a few Mev up to hundreds of Mev are observed to emanate from the sun. Such protons will almost certainly undergo interactions with nuclei, causing charge exchange scattering and producing fast neutrons. Other possible interactions are nuclear disintegrations and evaporations (star-formation). Star production in the solar corona then can lead to neutrons of at least 10 Mev energy. A mechanism such as this indicates a strong dependence of neutron production upon the eleven-year solar cycle. It should also be pointed out that neutrons produced at depths greater than 150 g/cm^2 will have a large probability of absorption within the sun. A knowledge of the energy spectrum of neutrons produced in energetic solar events would be of great value in understanding both the nature of these events and the nature of the surrounding solar atmosphere.

Several attempts to measure solar neutrons have been made with negative or ambiguous results and it is clear that at a distance of one astronomical unit the number of such neutrons cannot be large compared to the number of neutrons in the earth's outer atmosphere arising from primary cosmic rays and from albedo processes.[1-6] In the experiments thus far accomplished, the neutrons produced in the atmosphere by cosmic rays and by albedo processes undoubtedly mask the presence of solar neutrons. It should further be pointed out that in the production processes mentioned above the neutron spectrum produced should be expected to be a power law spectrum with appreciable production only at energies lower than, say, 200 Mev and probably with the production concentrated primarily at energies of a few tens of Mev and less.

A solar probe traveling towards the sun presents an excellent opportunity for an experiment designed to detect and monitor the solar neutron spectrum. Since the likelihood is that the neutron production is appreciable only at the lower energies, an enhancement in the counting rate obtained on such a satellite, in addition to the simple $1/R^2$ variation which would enhance the solar neutron counting rate at 0.3 A.U. by a factor of about 10, would be encountered due to the increased survival probability of the lower energy solar neutrons. The enhanced counting rate due to increased survival probability alone for a few selected energies for a satellite at 0.3 A.U. is shown in Table I. Additionally the background of neutrons in the outer atmospheres of the earth which have plagued earlier attempts to detect solar neutrons will be attenuated.

Neutrons in interplanetary space which belong to the primary cosmic ray flux will probably be small in number and also of exceedingly high energy so that they will be of no importance as a background to the experiment to detect solar neutrons. However, cosmic radiation will produce low energy neutrons within the space craft itself, which will enhance the background noise. Also, the sun itself will produce cosmic ray albedo neutrons in great quantity. Since these neutrons are not of direct interest in connection with neutrons produced by discrete solar events, the solar albedo neutrons must be regarded as part of the noise background. Thus, while it is important to escape the terrestrial neutrons and to move closer to the sun, a close approach to the sun may be detremental.

In essence, the problem of detecting solar neutrons produced locally in the sun is just the problem of trying to separate out these neutrons from those produced by the solar cosmic ray albedo. Since the locally produced neutrons are supposedly produced by solar particles of near cosmic ray energies the energy spectrum of these neutrons may be quite similar to that of the albedo neutrons. Thus, one would be looking for an increase in solar neutron flux produced by a local "hot spot" on the sun. In this sense, the only advantage of going close to the sun is to increase the total solar neutron flux to countable levels.

If the neutrons produced locally in the solar atmosphere by solar activity have a softer energy spectrum than the albedo neutrons, an approach to something like 0.3 A.U. would be valuable. Otherwise, there would appear to be relatively little advantage in a close approach to the sun, so long as the space craft is far enough away from the earth to escape the terrestrial neutron albedo. This achievement alone will greatly reduce the noise background.

In spite of the increased signal to background advantage to be enjoyed by a neutron detector well removed from terrestrial neutrons, it would be desirable to make the detector directional and to arrange for it to point away from the sun at least once in a while in order to demonstrate definitely that neutrons are coming from the sun. The directionality required of the detector for this purpose is of a crude nature only and pointing could be correspondingly crude.

Table I

Neutron Survival Probability at 0.3 A.U. Relative to that at 1.0 A.U. (T = 13 minutes)

Neutron Energy (Mev)	Relative Survival Probability
0.1	2.2×10^{13}
1.0	1.5×10^{4}
10	24.5
30	4.9
100	2.9
1000	1.6

I. - U. V. and X-Ray.

Ultraviolet and X-ray data for the sun are still seriously lacking in spatial resolution on the solar disk and in the detection of faint flumes. Both of these problems could be substantially helped by a solar probe at 0.1 A.U. or closer. At the present, however, it seems more advantageous to concentrate on the perfection of detectors and image forming devices than to expend our energy in a close solar probe.

J. - Backside Solar Activity.

From time to time it is suggested that activity on the opposite side of the sun can result in energetic solar particles observed at Earth. While such suggestions are not rare, they tend to become rarer, for a given phenomena, as more data are accumulated. Nevertheless, it would be of interest for some applications to monitor activity on the side of the sun opposite Earth. There does not seem to be any compelling reason for a close approach to the sun however.

K. - Radar Sounding of Corona.

Study of the solar corona and solar activity by means of reflected radar signals holds promise of yielding significant new information that will aid in understanding these phenomena. Even at distances of .3 A.U. the power requirements for a transmitter/receiver system mounted on a solar probe are large and probably eliminate this experiment at present.

However, a new technique of space radar astronomy has been described recently, principally by V. R. Eshleman. The technique is called "bi-static radar astronomy". In a bi-static system the experiment involves three locations: the Earth as a platform for a powerful radar transmitter and a large tracking antenna; the object of study, in this case the solar corona; and a receiver on a space probe near the sun. Radar pulses travel from the transmitter to the receiver on the probe by the direct path and also by a path reflected from the corona. Several frequencies could be transmitted simultaneously to measure the dispersion and other physical properties of the propagating medium. The combination of signals following the two paths and their reception at the probe, together with the possible multiplicity of frequencies provide unique opportunities for: (1) self-calibration of the measurements, since the instrumental delay times and delays imposed on both signals by the interplanetary medium would be canceled out; (2) the detection of effects that depend on the angle of incidence; and, (3) occultation phenomena. Occultations of radio stars by the solar corona have, of course, been observed frequently but the small angular diameter and time delay measurement possibilities of the bi-static radar approach would give considerably more information than can be derived from the radio star measurements.

For this experiment, a close approach to the sun is highly desirable.

L. - Faraday Rotation and Doppler Shift. (Suggested by D. E. Billings and C. G. Little)

The reception of a radio signal of known initial polarization from a transmitter on a solar probe would yield information on the magnetic field and electron density of the intervening medium. The Doppler shift of the signal, produced by phase shifts in local irregularities, in a similar manner would indicate the extent of motions along the path of the signal. In effect one would measure the integral of the magnetic field, density distribution, or ordered motions over the path of the signal. Superimposed upon this would be intrinsic time variation in these parameters. In fact, the local time variation may be short compared to the progress of the probe in orbit. At best it is likely to be a difficult experiment to interpret. One further difficulty in the measurement of the Faraday rotation is introduced by the unknown contribution to the polarization of the signal in traversing the ionosphere. It is well established that there are frequent local variations of short periods in the ionosphere which alter the polarization. Thus, a probe experiment designed to measure Faraday rotation in interplanetary space would require simultaneous measurements of Faraday rotation in the ionosphere along the same ray trajectory.

The object of this experiment is to monitor the space environment between the probe and Earth. A close approach to the sun is therefore desirable.

M. - Excitation of Plasma Oscillation. (Suggested by C. G. Little)

The electron density in the vicinity of a probe presumably could be determined by the excitation of local plasma oscillations. A swept low-frequency radio signal transmitted from the probe would produce oscillations of the electrons irradiated by the signal. At the local plasma frequency a resonant oscillation would occur and could be detected by suitable circuitry. This technique provides a relatively simple means of determining electron densities in the vicinity of the probe, but not so close as to be influenced by the vehicle itself.

There are, of course, detectors capable of measuring directly the local ion density near a space probe. This technique is both simpler to carry out and simpler to interpret than the plasma oscillation experiment. Since there is, at present, no good reason to believe that the electron density differs locally from the ion density in free space, it appears that the plasma oscillation experiment would not add to the direct detection of the local ion density.

N. - Solar VLF Emission.

The possible existence of VLF emission in the solar atmosphere is of importance in solar physics and offers a possible additional means of studying the solar atmosphere. A close solar probe, for example, might detect "whistler" type phenomena in the form of VLF emission trapped in the sun's general magnetic field. This and other phenomena associated with VLF emission would give valuable information on the over-all structure of the solar atmosphere and the solar magnetic field. Such an experiment would require a very close approach to the sun, within 0.1 A.U. at least.

O. - Radio Spectrum Gradient. (Suggested by D. Lund)

The purpose of this experiment is to provide clues to the emission mechanism(s) for radio emission in the solar corona. This information is necessary in order to be able to write correct source functions for the radiative transfer problem.

The known emission mechanisms produce radically different spectral "signatures." These spectra may be distinguished by the slope of the spectral power density with frequency. It is proposed to sample these slopes at a number of discrete low frequencies down to the plasma frequency corresponding to known electron densities in the region between sun and Earth.

Directional information is necessary to isolate any observed emission as being of solar origin. Since the frequency consideration introduced above requires antenna structures which are small compared to the wavelength, directional information must be derived from antenna response minima, rather than maxima. Improvement of the signal-to-noise ratio by placing the experiment close to the sun is clearly desirable, but the experiment could be carried out at the orbit of Earth.

F. - Fields, Particles and Plasmas.

While we have not given detailed consideration to the many fields, particles and plasma experiments that are suggested by a close solar probe, we submit the following general remarks. Solar events resulting in an ejection of plasma clouds with embedded magnetic fields that penetrate at least as far as the orbit of Earth are not infrequent. It seems very probable that at distances from the sun of the order of 0.3 - 0.1 A.U. such plasma-magnetic field events will be considerably more frequent than at 1 A.U.

The solar mechanism leading to the expulsion of energetic particles and photons is not understood. Part of the difficulty in attempting to interpret available data in terms of physical mechanism is that events that are otherwise very similar sometimes produce energetic particles and sometimes do not. This forces us to conclude that we have not yet discovered a really satisfactory link between the production of particles of either high or low energy and other specific characteristics of related solar events. Many specific optical and radio characteristics of flares have been proposed as being closely related to polar proton events. It must be admitted, however, that none of these proposed relationships purport to answer the basic question of just how the energetic particles are accelerated and what specific relationship the acceleration mechanism has to the production of the related optical or radio event. These questions must be answered, but they cannot be until we know much more concerning the total flare event, both in the electromagnetic and particle spectrum.

Particles, fields and plasma cloud observations near the sun at the times of solar flares hold promise of increasing greatly our knowledge of the flare phenomenon, No one can predict with certainty just how much we stand to gain by such observations, but certainly this is a promising space experiment with great potential reward.

For these experiments, an approach to about 0.3 A.U. from the sun would be very valuable. An approach to 0.1 A.U. would be considerably more valuable, however.

In the same vein, the study of solar wind particles as a function of radial distance from the sun would add much to our understanding of this important phenomena and, hence, to our understanding of the corona. For this purpose, one needs closely spaced, or simultaneous, observations of the magnetic field vectors, velocities and densities of particles and kinetic temperatures as defined by particle motions in each of the three coordinates r, θ and ϕ.

Unless the solar probe approaches within 0.05 A.U., the solar wind data will not add greatly to data obtained at the orbit of Earth. An approach this close would be valuable for studying solar rotation at these distances and would further enhance the value of the active sun experiments mentioned in the foregoing.

Q. - Gravitational Red Shift. (Suggested by P. Bender)

A further experiment to be considered for a low perigee solar satellite is a measurement of the slowing down of light going by the sun. One version of the experiment would be to put a frequency standard and a pulsed low threshold laser aboard the satellite. With a 10^{-4} radian beam aimed at the Earth and a 0.1 joule output this gives about 10^{3} photons/meter^{2} of collector in 10^{-7} sec and in less than a 1Å bandwidth. This should be compared with fluctuations in scattered sunlight near the limb in a roughly 10^{-8} sterradian solid angle for a comparable time. Since the solar disk gives about 5×10^{6} photons/meter^{2}, in 1Å, 10^{-8} sterradians, and 10^{-7} sec, the fluctuations about 0.1 solar radius from the limb should be small. The laser would flash perhaps every few minutes at times controlled by the satellite frequency standards and the received pulses could be timed with respect to frequency standards on the Earth to better than 10^{-7} sec. Since the experiment would take of the order of a day and a frequency standard uncertainty of one part in 10^{11} would give a 10^{-6} sec per day time uncertainty, the major uncertainties would probably be in the satellite frequency standard and in the knowledge of the satellite orbit.

For a satellite passing behind the sun, the predicted time delay due to light passing through the sun's gravitational field is given by the general theory of relativity (J. Weber, private communication) as

$$\Delta t = \frac{GM}{c^3} \; (\ell n\, r + R - 2\ell n\, D) \; , \qquad (3)$$

where r and R are the distances of the satellite and Earth from the sun and D is distance of closest approach of the earth-satellite line to the center of the sun. The maximum rate of change of Δt occurs at the limb and is

$$\frac{d}{dt}\,(\Delta t) = -\,\frac{2GM}{c^3} \cdot \frac{1}{R_\odot}\;\frac{dD}{dt} \; , \qquad (4)$$

where $R_\odot$ is the solar radius. For a 0.3 A.U. perigee orbit, the result is about 10^{-5} sec per day on the first pass about 4 months after launch and about 2×10^{-5} sec per day on another pass about 9 months after launch.

Another version of the experiment would be to have a transponder aboard the satellite and measure the time directly. However, 10^{-7} sec timing over more than 1 A.U. using conventional microwave communications systems seems difficult. Whether a laser transponder would be simpler than a frequency standard aboard is hard to guess.

The importance of a fairly small perigee comes from the resulting faster passage behind the sun and thus lower stability requirements on the frequency standard. Also, if the perigee is near the orbit of Venus or further out it will take two years or more for the vehicle to make its first pass behind the sun. Two easy-to-analyze orbits are those with periods 1.5 and 2.5 times shorter than the earth's. These put the satellite at perigee one year after launch at solar distances of 0.53 and

0.09 A.U. and give rates of change for the time delay of about 25 microsec/day and 150 microsec/day. The 0.53 A.U. perigee orbit would not be quite as suitable for the experiment as a closer orbit because of the smaller number of passes per year but would be usable. If orbit uncertainties are small enough the predicted change in delay could be checked to 5% or better.

IV. Condensed Summary of Experiments and Evaluation

The following table contains a rough classification for each of the foregoing suggestions in terms of their scientific merit. We also include an indication of the desirable maximum distance from the sun, and a general indication of required pointing. In making the classification and indicating maximum distances, we have paid little or no attention to either the difficulty of attaining a close approach or the difficulties involved in carrying out the suggested experiment given the necessary vehicle.

Table II

Summary of Experiments

Suggested Experiment	Scientific Merit	Maximum Sun-Probe Distance	Pointing and Direction	Scan
A - Lyman-α absorption*	I	.5	sun $\pm$ 5°	none
B - Lyman-α emission*	I	.5	90°	180° altitude sweep
C - Lyman-α corona	I	1	sun $\pm$ ½°	none
D - F and K corona	I	.3	sun $\pm$ ½°	none
E - 3-D corona	II	1	sun $\pm$ ½°	none
F - Zodiacal light	I	.3	within 10° of sun	sweep alt. and az.
G - White light plasma clouds	II	1	same as F	
H - Neutrons	I	1	sun $\pm$ 10°	none
I - U.V. and X-ray	II	.1	sun $\pm$ ½°	none
J - Backside activity	III	1	none	
K - Radar sounding	II	.3	----	
L - Faraday and Doppler	III	.3	----	
M - Plasma oscillation	III	.3	----	
N - Solar VLF	II	.1	----	
O - Radio spectrum	II	1	----	
P - Fields and Particles	I	.3-.05	----	
Q - Gravitational Red Shift	II	.3	----	

*Assumes that previous experiments succeed in detecting interplanetary neutral hydrogen by these techniques.

V. Appendix - Added Notes on Suggested Experiments

A. The Absorption Core of Solar Lyman-α Produced in a Neutral Component of Interplanetary Hydrogen Gas.

Some of the physical properties of the interplanetary gas follow fairly directly from general geophysical and astrophysical circumstances. For example, the range in density values lies between 1 cm^{-3} and 10^3 cm^{-3} proton-electron pairs. The former value is the over-all density of matter in interstellar space, and the latter, the Chapman value from magnetic storm data. Explorer X data give a proton density of about 10 per cm^3 for protons with energies near 500 ev. A plausible density of neutral plus ionized gas is then, say, 30 cm^{-3} at the Earth's distance from the sun. If the gas originates at the sun, with a velocity exceeding the escape velocity (e.g. the solar wind), and moves at substantially constant speed $\underline{v}$ at the Earth's orbit, say at 300 km/sec, then the flux of atoms at distance $\underline{r}$ is $nv\, 4\pi r^2 = Q$, where $\underline{n}$ is number density and Q is a constant. Taking $n = 30$ and $v = 300$ $km \cdot sec^{-1}$ at 1 A.U., $Q = 2.5 \times 10^{36}$ sec^{-1}, or 4×10^{12} $grams \cdot sec^{-1}$.

With this simple model of the interplanetary gas, we can formulate the problem of the absorption, by the neutral component of the gas, of central regions of the chromospheric Lyman-α line. The optical depth τ_o, at line center of the interplanetary line, is

$$\tau_o = \int_{R_\odot}^{r} n_1 \alpha_o \, dr \quad . \tag{5}$$

If the gas flows at an average velocity of 250 $km \cdot sec^{-1}$, the Lyman-α line absorption (or emission) will be shifted 1Å to the blue of the chromospheric line. Since the chromospheric line is only about 1Å wide we could observe the gas perhaps most easily by observing the inter-planetary emission in the Lyman-α line rather than its absorption against the background solar radiation.

On the other hand, if we assume that the density is constant (at say $n = 10^2$), and the gas is stationary, we can find the way in which reversal of Lyman-α would build up in the planetary system as one observes the sun from different distances.

The absorption rate of Lyman-continuum photons by a neutral hydrogen atom moving with velocities less than about 10^4 km/sec with respect to the sun is given by $\alpha_\nu P_c$ where α_ν is the absorption coefficient in the Lyman-continuum and P_c is the Lyman-continuum photon flux. Over the first 100Å of the Lyman-continuum, $\bar{\alpha}_\nu \approx 5 \times 10^{-18}$ cm^2 and $P_c \approx 6 \times 10^9$ cm^{-2} sec^{-1} at the orbit of the Earth. Thus, the absorption rate is 3×10^{-8} sec^{-1}.

The collisional ionization rate for a neutral hydrogen atom depends upon electron density and temperature. The collision rates are:

temperature	2×10^4	5×10^4	1×10^5
collisional ionization rate sec^{-1}	$7 \times 10^{-12}\ n_e$	$1 \times 10^{-9}\ n_e$	$2 \times 10^{-7}\ n_e$

Near the orbit of Earth we expect $T \leq 5 \times 10^4$ and $n_e \lesssim 10^2$, so that photoelectric ionizations probably predominate somewhat over collisional ionizations.

As we approach the sun, electron density, temperature and Lyman-continuum flux density all increase. The Lyman-continuum flux density increases in proportion to r^{-2}, and electron density obeys essentially the same law[7] up to about 0.1 A.U. Within 0.1 A.U. the electron density increases faster than r^{-2} and collisions will predominate due to this effect alone. Also, the increase in temperature nearer the sun will greatly increase the collisional ionization rate.

At 0.3 A.U., the temperature may be as high as 5×10^4 to 1×10^5 °K, in which case collisional ionization rates probably exceed photoionization rates by factors of about 10-10^3 respectively.

If, in addition to static or thermal interplanetary hydrogen, there are solar wind protons of density n_p^*, charge exchange collisions will play an important role in the ionization equilibrium. At proton energies of 500 ev, the charge exchange cross-section for the 1 - 1 transition is about 10^{-15} cm^2, and the ionization rate of thermal hydrogen atoms by solar wind protons will be about 3×10^{-8} n_p^*. For $n_p^* = 10$ cm^{-3}, this gives an ionization rate ten times as large as the photoionization rate.

The total number of neutral hydrogen atoms is not changed by this reaction. In effect, the neutral hydrogen acquires a velocity equal to that of the solar wind, which it retains for a time $3 \times 10^7/n_p$ sec. If we take n_p of the order of 20 and an average wind velocity of 100 km sec^{-1}, the hydrogen atom created by the charge exchange reaction is carried a distance of the order of 1 A.U. before it re-exchanges its electron with a thermal proton. Hence, each charge exchange reaction removes a neutral hydrogen atom from the region between the sun and Earth, and must be considered along with the ionization processes.

The ratio of neutral, hydrogen atoms to protons in the interplanetary medium is given by

$$\frac{n_H}{n_p} = \frac{\text{ionization time}}{\text{recombination time}} \quad . \tag{6}$$

In the presence of the solar wind, the ionization time at 1 A.U. is about $3 \times 10^7/n_p^*$ sec, and in the absence of solar wind it is of the order of 3×10^7 sec. The recombination time is $2 \times 10^{12}/n_e$ sec at 10^4 °K and $1.2 \times 10^{13}/n_e$ sec at 10^5 °K. Near 1 A.U. we expect the electron temperature to be of the order of 10^4 °K. This gives

$$\frac{n_H}{n_p} = 1.5 \times 10^{-5} \quad n_e/n_p^* \tag{7}$$

in the presence of the solar wind and

$$\frac{n_H}{n_p} = 1.5 \times 10^{-5} \; n_e \tag{8}$$

if the solar wind is unimportant. As an upper limit, we set $n_e \approx 10^2$ and $n_e/n_p^* \approx 10$ at 1 A.U. This gives $n_H < 1.5 \times 10^{-2}$ in the presence of the solar wind and $n_H < .15$ in the absence of the solar wind.

At 0.3 A.U., we take $n_e = n_p \approx 10^3$ and $T_e \approx 10^5$ °K. The recombination time is therefore 1.2×10^{10} sec and the collisional ionization time is of the order of 5×10^3, which probably exceeds the charge exchange ionization rate. Thus, we expect $n_H/n_p \approx 4 \times 10^{-7}$ and $n_H \approx 4 \times 10^{-4}$. If we take the larger value of n_H estimated at 1 A.U., the total number of neutral hydrogen atoms in a column of 1 cm^2 cross-section extending from 1 A.U. to 0.3 A.U. is about 10^{12}, and the optical thickness at the center of the Lyman-α line is about 0.06. This is near the margin of detectability for absorption core studies. In the presence of a solar wind of flux 10^9 protons cm^{-2} sec^{-1}, the expected amount of neutral hydrogen would be at most 10^{11} in a 1 cm^2 column and an absorption core in Lyman-α would be very difficult to detect against the background solar radiation.

The detectability of interplanetary hydrogen by scattering of Lyman-α radiation is discussed in the next section.

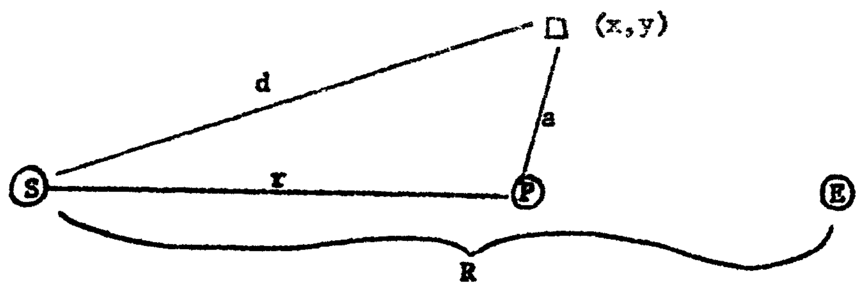
The foregoing calculations assume that there is no neutral hydrogen feeding into the interplanetary system. This is known to be erroneous, however. Solar prominences of the eruptive, spray and surge types all feed neutral hydrogen into the space surrounding the sun. A single large prominence ejected from the sun may supply a total of 10^{39} neutral hydrogen atoms plus protons into interplanetary space. Of these, about 10^{35} will be neutral. A comparable ratio of neutral to ionized atoms may persist for times of the order of 10^5 - 10^6 sec, which is comparable to the frequency of such events when the sun is active.

Other possible evidence for a supply of neutral matter feeding into interplanetary space is given by the presence of the dust grains producing the zodiacal light and the F-corona. These particles could not persist indefinitely in the presence of the solar wind without either being swept out of the solar system or disintegrated. Their continuous presence in interplanetary space implies that they are either continuously replenished or that the solar wind is intermittent. The flux of particles in the solar wind depends heavily on the temperature structure of the outer corona. It is therefore quite plausible that the solar wind intensity diminishes strongly near sunspot minimum.

We conclude then, that although the likelihood of there being enough neutral hydrogen in interplanetary space to detect by either Lyman-α absorption or emission experiments is rather small, we should not completely dismiss these experiments from the list of interesting and profitable ones to be carried out aboard a close solar probe.

B. Lyman-α Scattering by Interplanetary Hydrogen.

Lyman-α emission scattered by interplanetary hydrogen is illustrated by the following geometry:



If the photon flux density from the sun is $\ell_\odot$, the flux scattered into a 1 cm^2 aperture at the probe by a volume $2\pi a^2 \sin\alpha \, d\alpha \, da$ is

$$2\pi a^2 \sin\alpha \, d\alpha \, da \; n_H \frac{\cos\alpha}{4\pi a^2} \int \alpha_\nu \, \ell_\odot \, d\nu \, , \qquad (9)$$

where α is the angle between the direction to the scattering volume and the normal to the aperture and n_H is the density of neutral hydrogen. For the case under consideration, we may assume that $\ell_\odot$ is uniformly distributed over a bandwidth of 1Å, which is wide compared to the effective width of α_ν. We further assume that α_ν is Gaussian and obtain

$$\int \alpha_\nu \, \ell_\odot \, d\nu = \sqrt{\pi} \, \Delta \nu_o \, \alpha_o \, \ell_\odot = \sqrt{\pi} \, \Delta \lambda_D \frac{\lambda^2}{c} \, \alpha_o \, \ell_\odot = 5 \times 10^{-15} \, \ell_\odot \qquad (10)$$

The solar photon flux $\ell_\odot$ may be written

$$\ell_\odot = L_\oplus \frac{R^2}{d} \qquad (11)$$

where $L_\oplus = 2.7 \times 10^{11}\ cm^{-2}\ sec^{-1}$ is the flux density at the orbit of Earth. Thus, the total scattered flux, L_p, passing through the 1 cm^2 aperture at p is

$$L_p = 1.4 \times 10^{-3} R^2 \int_o^\infty \int_o^{\pi/2} n_H \frac{\sin\alpha \cos\alpha}{2\, d^2}\ d\alpha\, da \qquad (12)$$

$$= 3.5 \times 10^{-4} R^2 \int_o^\infty \frac{n_H}{d^2}\ da$$

At 90° to the probe-sun line, $d^2 = r^2 + a^2$ in a direction opposite the sun $d = r + a$ and in the direction of the sun $d = r - a$. If we take n_H = constant, we obtain

$$L_p(90°) = 5.5 \times 10^{-4}\ n_H \frac{R^2}{r} = 8.3 \times 10^9\ n_H \frac{R}{r}, \qquad (13)$$

$$L_p(180°) = 3.5 \times 10^{-4}\ n_H \frac{R^2}{r} = 5.3 \times 10^9\ n_H \frac{R}{r}, \qquad (14)$$

and

$$L_p(0°) = 8 \times 10^{-4}\ n_H \frac{R^2}{r} = 1.2 \times 10^{10}\ n_H \frac{R}{r}. \qquad (15)$$

The latter case $L_p(0°)$ assumes that $n_H = 0$ inside 0.5 A.U.

If we take $n_H \propto d^{-1}$, we obtain

$$L_p(90°) = 5.3 \times 10^9\ n_H' \frac{R}{r}, \qquad (16)$$

$$L_p(180°) = 2.7 \times 10^9\ n_H' \frac{R}{r}, \qquad (17)$$

and

$$L_p(0°) = 2.65 \times 10^{10}\ n_H' \frac{R}{r}. \qquad (18)$$

where n_H' is the ambient density near the probe. Again $L_p(0°)$ assumes $n_H = 0$ inside 0.3 A.U.

C. Coronal Electron Scattering of Lyman-α.

A cubic centimeter of the lower corona "sees" a Lyman-α photon flux of about $2\pi\ (R/R_\odot)^2\ L_E \approx 7.5 \times 10^{16}\ cm^{-2}\ sec^{-1}$, where L_E is the photon flux per cm^2 and per sec at Earth. The Thompson scattering cross-section is $6.6 \times 10^{-25}\ cm^2$ and the coronal electron density is about 3×10^8. Thus, the photon flux scattered by $1\ cm^3$ is about 15 per sec.

The effective path length for a tangential ray through the inner corona is approximately $(2\ R_\odot H)^{1/2} \approx 6 \times 10^{10}$, where H is the vertical scale height. Hence a $1\ cm^2$ tangential column scatters about 10^{12} photons per sec. Of these scattered photons, a fraction 3.6×10^{-28}, or 3.6×10^{-16} photons per sec, will pass through a $1\ cm^2$ aperture at the orbit of Earth. The flux of scattered Lyman-α photons from the entire corona at the orbit of Earth is $1.4 \times 10^6\ cm^{-2}\ sec^{-1}$. The flux at 0.1 A.U. is $1.4 \times 10^8\ cm^{-2}\ sec^{-1}$.

The coronal scattered Lyman-α flux must be compared with the interplanetary scattering from the same solid angle. The solid angle subtended by the corona out to $2R_\odot$ is 3×10^{-4} sterradians and the preceding expressions for $L_p(0°)$ must be corrected by a factor 1.2×10^{-3}. Thus, at 1 A.U. we obtain

$$L_p(0°) = 1.4 \times 10^7\ n_H \qquad (19)$$

for n_H = constant

$$L_p(0°) = 3.1 \times 10^7\ n_H \qquad (20)$$

for $n_H \propto d^{-1}$ for $d \geq 0.3$ A.U. and $n_H = 0$ $d < 0.3$ A.U. If $n_H > 0.1$, the interplanetary scattering from the direction of the sun would be comparable to the coronal scattering observed at 1 A.U. At 0.3 A.U. the coronal scattering would increase by a factor 10 and the interplanetary scattering would presumably disappear.

The mean Doppler velocity of coronal electrons (assuming 10^6°K) is 5500 km/sec, and the Doppler width of the scattered Lyman-α line will be about 22Å. A spectrograph with 5Å resolution would give reliable information on the line profile and would permit a determination of the electron temperature.

The profile of the interplanetary scattered Lyman-α will presumably have a Doppler width of about 0.04 - 0.13Å due to thermal broadening at a temperature of 10^4 - 10^5°K.

This report was prepared under a grant from the Ames Research Center, National Aeronautics and Space Administration. The authors are indebted to E. N. Parker for some of the ideas expressed concerning different suggested experiments.

Participants in Informal Discussion:

R. G. Athay

P. Bender

D. E. Billings

J. W. Firor

R. T. Hansen

L. L. House

C. G. Little

D. Lund

G. Newkirk

W. Rense

J. Rush

E. Smith

H. Smith

E. Tandberg-Hanssen

E. P. Todd

H. Zirin

References

1. Haymes, R. C., "High Altitude Neutron Intensity Diurnal Variation." Technical Report on Contract Nonr-285(21), New York University, 15 March, 1959.
2. Yuan, L.C.L., Phys. Rev., 81, 175 (1951).
3. Simpson, J. A., Phys. Rev., 83, 1175 (1951).
4. Soberman, R. K., Phys. Rev., 102, 1399 (1956).
5. Gatbe, J. O., Phys. Rev., 112, 497 (1958).
6. Bergstralk, T. A., and C. A. Schroeder, Phys. Rev., 81, 244 (1951).
7. Parker, E. N., Ap.J., 132, 821 (1960).

not in file

N65-29518

SOLAR PROBE REPORT

ERRATA SHEETS

Chapter 1, p. 1.6, Table 1, change spacecraft weight from "290.5" to "300.5" for both launches.

Chapter 2, **Mission Analysis**
p. 2-7, line 17, change to read "special encounters are unique, whereas solar physics measurements are extensions of observations which have been or can..."

Chapter 3, p. 3-19, Figure 8, lower curve, change title to "Atlas/Agena/X-259".

p. 3-21, Figure 10, first line of title, change to read "Atlas/Agena D/Antares".

Chapter 7. Communications

Page 5-115	Line 4, change "order diversions" "to size".
Page 5-120	Item (a) under Frequency Modulation with Feedback, change "FMFM" to "FMFB".
Page 5-125	Paragraph 7.6.3.3, line 1, change to read "The Frame Register..."
Page 5-126	Second paragraph, line 2, change "$M-\frac{1}{2}$ to" $\mu -\frac{1}{2}$".
Page 5-128	Third paragraph, last line, change "n=15" to "m=15".
Page 5-141	Figure 10, statement should read "The tolerance is interpreted as the number..."
Page 5-148	Second paragraph, line 8, add asterisk (for footnote) to last word "measurements". Last line, change "excessive" to "successive".
Page 5-149	Second paragraph, line 5, change "improving" to "defining".

Rpt 27683

ERRATA _ WDL-TR2133

Chapter 9 - Program Development

Page 9-9	Figure 1-2, sixth major heading from top, change "Spacecraft Subsystem" to "Spacecraft System".
Page 9-30	Figure, "Component Assembly and Acceptance Test Plan", add figure number "1-4".
Page 9-31	Figure 1-5, figure in top left corner, add title "Component Screening Test Schedule". Figure in bottom left corner, add title "Component Acceptance Test Schedule". Figure on right side, add title "Component Qualification Test Schedule".
Page 9-40	"Figure 4-1", change to "Figure 2-1".

Appendix A

Page	Item
A1.1-12	Line 15 should be "Mean Distance from Earth, ρ_e
A1.1-13	Line 2 "After Smith [1960]" should be "After Smith [16]". Type IV burst should read "Following after a large flare" and "circular".
A1.1-14	Reference 9 should be "pp 161-168, 1958".
A1.1-17	Line 3 "BM (b. polar magnetic)" should be "BM (bipolar magnetic)".
A1.2-2	Line 2 "scattering or" should be "scattering of".
A1.2-7	Line 8 "radium" should be "radius".
A1.2-12	Equation 7, the integral should be $\int \frac{N^2 A_1(2)\, dp}{T^{3/2}\sqrt{1 - \frac{e^2 n}{\pi m f^2} - \frac{a^2}{p^2}}}$
A1.2-16	Line 12, "about Kc/s" should be "about 8 Kc/s".
A1.2-18	Line 18, "expression for"" should be "expression for σ".
A1.2-19	Equation 14 left side should read "$\left(\frac{\sin\beta\cos\gamma}{q}\frac{d\beta}{dq}\right)_{q=0}$"
A1.2-20	Line 2, "at q-o" should be "at q=o". Line 5, "(1) in Sec. I and eq. (7) in Sec. 2" should be "(1) in Sec. 3 and eq. (7) in Sec. 7".
A1.3-2 & A1.3.3	Page numbers should be reversed.
A1.3-5	Line 12, "NDS" should be "$\int$Nds".
A1.3-9	Line after eq. 5, "distances" should be "distances, R_p and R_A, eq. 8 should be $T_o = l_m \pi / \|(n_p - n_e)\|$.
A13-13	Line 2, change "9" to "3".
A1.3-16	Line 6, "2 x 10^{10}/" should be "2 x $10^{10}/(8.7)^2$". Line 7, "$(8.7)^2$ = 2.64 x 10^8" should be "= 2.64 x 10^8".
A1.3-22	Line 2, "relativeistic" should be "relativistic".
A1.3-30	Delete
A1.3-31	Delete
A1.3-32	Change Table "1" to "3".
	Add after page A1.3-32, "Figure 3" enclosed.

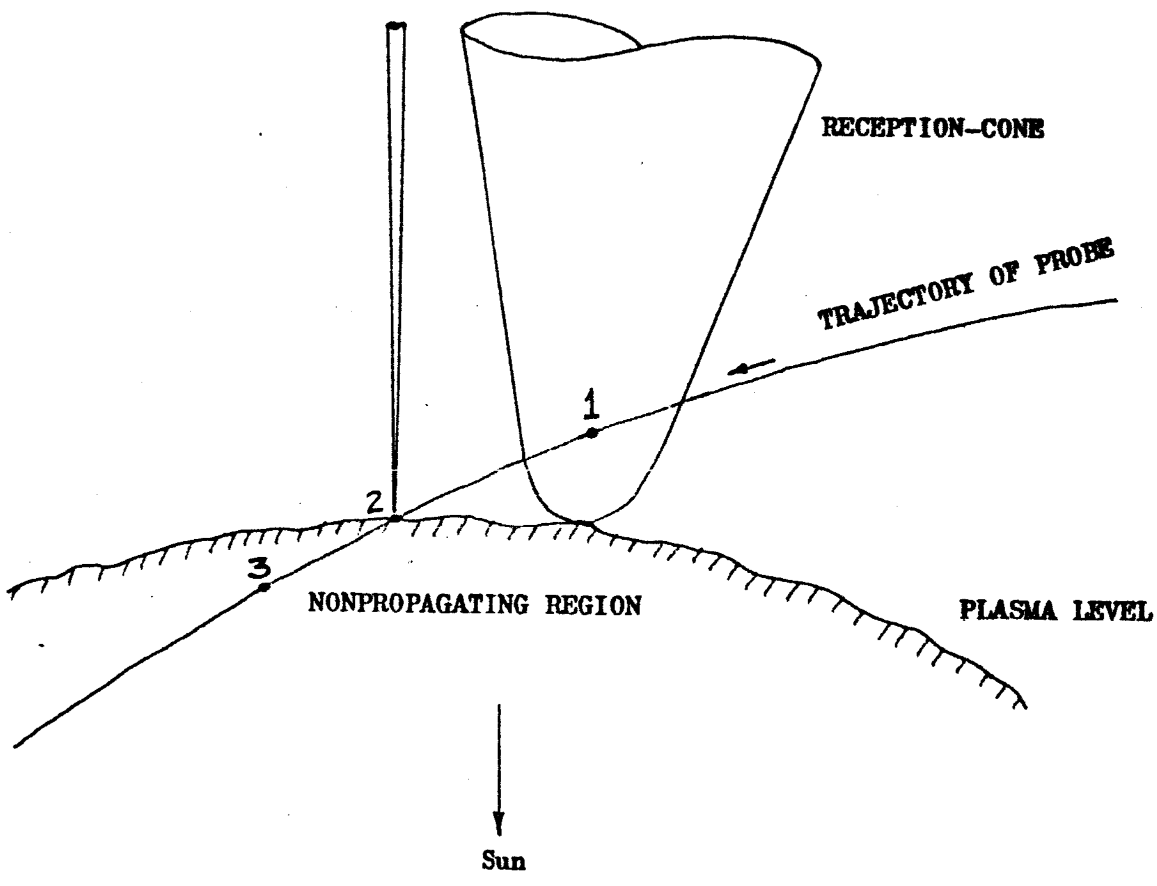


Fig 3. Variations in the reception-cone of cosmic radio emission for a particular wave frequency.

ERRATA - WDL-TR2133

Appendix A1.5

A1.5-10 Third paragraph, line 2, change "Figure 2" to "Figure 5".

Third paragraph, line 3, add "zero and" to end of sentence.

End of third paragraph, add text from page A1.5-14, third paragraph, starting with "From Figure...", and continuring to the end of the first paragraph on p. A1.5-15, with the sentence "....at the same thickness".

A1.5-12 Second paragraph, line 6, change "dish" to "disc" and all subsequent occurances on this page.

A1.5-16 Line 4, "$P_1 V_1 = P_2 V_2$".

ERRATA - WDL-TR2133

Appendix A-1
WDL-TR-E320

Page	Item
2-1	In line 7 of Section 2.2, the frequency "3000" should read "9400".
2-3	Delete Figure 2-2.
2-10	The label "OUTBURSTS (TYPE II)" identifies the dashed curve (after Coutrez) that begins in the upper left-hand corner of Figure 2-6 as well as the burst data indicated by x's in the upper right-hand corner. The solid curve in the lower right-hand portion of the figure should be labelled "SVC (AFTER KAKINUMA and SWARUP)".
3-5	In the first paragraph under Section 3.2.1, line 4 should read "for the 60-foot, 85-foot and 210-foot reflectors...". In line 5, delete "60-foot".
3-7	At the beginning of line 4, add "For the 'min' conditions,".
3-17	In Section 3.2.2.2 lines 3 to 6 should read as follows: "and will be identical in general for the same diameter-frequency product. For example, the 30-foot/1200 Mc antenna temperature curve in Figure 3-5 and the 60-foot/600 Mc curve in Figure 3-6 exhibit maxima and minima at the same angles."
3-33	At the end of line 7, add "at vertical polarization."
4-3	In Figure 4-1 the second G_T in the numerator of the equation for C/N should read "G_R".

ERRATA - WDL-TR2133

Appendix B - 1 & 2

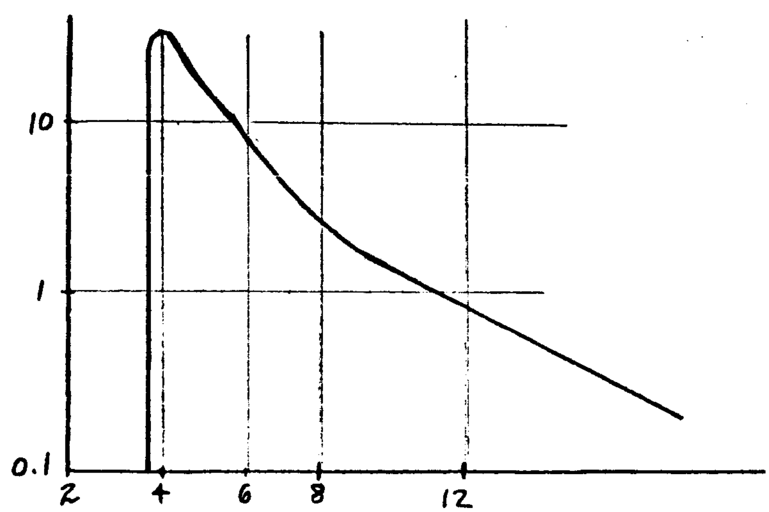
Page B1.1-4 Table II, change exponential as shown below:

Z	N	E_T
1	$4000\ E_T^{-1.15}$	2-20

Page B1.1-9 Line 10 should read, "for $t \leq 29.5$ hours".

Line 16 should read, "$N = 3.77 \times 10^5$".

Page B1.1-16 Figure 4 is incomplete, curve should appear as below:



Page B1.1-20 Figure 8, add titles under the two cross sections shown:

top a. Spherical Model

bottom b. Disc Model

ERRATA - WDL-TR2133

Appendix B-3

B1.3.6.1-3	Configuration: Add -
	First Column heading: θ
	Second Column heading: $\frac{ds}{\epsilon}$
	Third Column heading: #
	Fourth Column heading: X Inches
	Fifth Column heading: Y Inches
	Item VI Super Insulation:
	First Column heading: Eff
	Second Column heading: $\frac{ds}{\epsilon}$
	Under 0.3 A.U., change "10" to "510".
B1.3.6.1-4	Line 27, add after 8 watts/ft^2 "except at relative large separation distances".

Appendix B-4

B4.1-4	Equation (1)	$= I \frac{"I"}{H_B}$
B4.3-2	Line 16,	4.3.2 - "A", B . . .
B4.4-2	Line 17,	Change "H" to "$\bar{H}$".

ERRATA - WDL-TR2133

Book B, Appendix 5 - Communications

Page ii	Section B-5.5, add title "Data Bandwidth Compression", add page "B5.5-1". Delete last line.
B5.1-3	Line 9, change "B_u" to "B_n".
B5.1-4	First equation, change "t_o" to "To".
B5.1-5	Equation (1), "$G_{RV} - L_g$".
B5.1-6	Middle of page, add " = 2 (approx.)" after equation for $\frac{\partial}{\partial_o}$.
B5.1-8	Line 12, change 198.4 to 201. Last line, after "Section", add "5.3".
B5.1-10	Last line, change "range" to "usage".
B5.1-12	Second line, change "1.5" to "1.8". Item No. 6, R = "2" A.U. Item No. 13, change "L" to "K".
B5.1-13	Second line, change "1.5" to "1.8". Item 25, ($A\phi$ = .55). Item 31, ($A\phi$ = .46). Item 33, ($2B_{LO}$ = 1 cps).
B5.1-14	Second line, change "1.5" to "1.8". Item 25, ($A\phi$ = .55). Item 31, ($A\phi$ = .46).
B5.1-15	Item 6, R = "2" A.U.
B5.1-16	Item 25, ($A\phi$ = .55). Item 31, ($A\phi$ = .46).
B5.1-17	Line 2, change "point 2" to "part B".
B5.1-18	Line 4, change "0228.6" to "-228.6". Line 7, change "203.6" to "-203.6". Line 17, equation 7, change "(± 1)" to "($\pm {0 \atop 1}$)".
B5.1-21	Line 6, Section "B5.6". Line 14, change "A.M." to "A.U.".
B5.1-25	Delete dotted line in lower part of Figure 3.
B5.1-26	Second paragraph, line 5, change "8t" to "85".

Book B, Appendix 5 - Communications - (Cont. from pp. 10)

B5.1-28	Equation 9, change "118.7" to "-118.7".
B5.2-13	Line 4, "could be saved if ....". Line 10, change "prevents" to "permits".
B5.2-20	Table III, MPSK-PM & MPSK-FM, change "$2_B - B_K > 50$" to "$2_B \sin \frac{\phi}{2} > 50$". Add to the table: "MASK-PM & MASK-FM, $p = 0$, $B_2 - B_K > 50$, ref. 10".
B5.2-24	Add title, "Figure 1 - Area Under Gaussion Curve.
B5.3-2	Lines 8 and 9, change "S/N" to "ST/N/B".
B5.4-17	Line 13, middle term of equation should read "$(X^5 + X^4 + X^3 + X^2 + 1)$."
B5.4-20	At the input, a connection should be added from the first binary adder to the first flip-flop.
B5.4-26	Equation 3, $P_{n,k}$ = "1" $- g^n$ ....
B5.4-27	Should be numbered "B5.4-34". The next page in text sequence after B5.4-26 will be B5.4-28. Third paragraph, line 1, last word, add "λ_o". Fourth paragraph, line 4, add "λ_o" after "fixed".
B5.4-31	Third line, change "channes" to "channel".
B5.4-32	Equation 11, change "K r-1" to "K r - 1".
B5.4-39	Line 3, change "Dinit" to "Binit".
B5.4-46	Title, change "Infinitive" to "Infinite Length".
B5.4-47	Title, change "Infinitive" to "Infinite Length".
B5.8	Figures 2.4, 2.11, 2.13, 3.3, delete.
B5.11-1	Change Section "5.11" to "5.5" and page numbers 5.11-1 through 5.11-19 to 5.5-1 through 5.5-19.
B5.11-4	Fourth paragraph, line 5, change "$y = a\Delta X$" to "$\Delta y = a\Delta X$".

ERRATA - WDL-TR2133

Book B, Appendix 6 - Power

B1.1-2 Refer to page B1.1-36 for Table 1A.

B1.1-7 Refer to page B1.1-34 for Table 1.

B1.1-10 Paragraph 3.3.2, change equation from $\frac{\text{"7.8 hr"}}{\beta^-, \gamma}$ to $\frac{\text{"7.8 hr"} \rightarrow}{\beta^-, \gamma}$ and from $\frac{\text{"1.9 yr"}}{\beta^-, \gamma}$ to $\frac{\text{"1.9 yr"} \rightarrow}{\beta^-, \gamma}$.

B1.1-18 Third paragraph, line 2, change "thermionic" to "thermoelectric".

B1.1-36 Table 1.A, change "Curium 144" to "Cerium 144".

B1.2-1 Last line, change "leads" to "loads".

B1.2-5 Change Figure references as indicated below. Figures 12, 13, 14, 14, 16 and 17 should be changed to Figures 10, 11, 12, 13, 14 and 15, respectively.

B1.2-7 P_0 equation near bottom of page, change to read:

$$P_0 = P[\exp \frac{0.693\ tm}{T_{\frac{1}{2}}}]$$

B1.2-9 Paragraph 1.2.1.5, change "Figure 18" to "Figure 16".

B1.2-10 Third line, change "Figure 19" to "Figure 17".

B1.2-22 Paragraph 1.2.2.5, line 2, Section "1.2.1.5".

B1.2-25 Delete entire page.

B1.2-27 Paragraph 1.2.3.1, second paragraph, line 1, change "drypton" to "Krypton".

B1.4-7 Delete.

B1.4-8 Delete.

B1.5-19 Change Figure number from "19" to "20".

B1.5-20 Change Figure number from "20" to "19".

Book B, Appendix 6 - Power - (Cont. from pp. 12)

B1.5-27 to B1.5-30 Figures 27 through 30. Values for Power ($P_{max.}$) and current (I) are divided by Electronsmittance (η_D) of the associated filters. Values of η_D are as follows:

Figure 27, $\eta_D = 0.65$
Figure 28, $\eta_D = 0.83$
Figure 29, $\eta_D = 0.69$
Figure 30, $\eta_D = 0.5$

B1.5-33 "Relative Spectral Response of G_A A_S Solar Cell" should refer to curve labeled "Spectral Solar Irradiance in Space" and vice versa.

Book C, Appendix 1 - Data Handling

C1.1-1 Paragraph 1.1, line 3, add Section "B-5-6".

C1.1-4 Last line, Sections "B-5.6 and B-5.1".

C1.1-5 Middle of page, delete "Section", add "Chapter 6 of the main text".

C1.1-7 Line 9, delete "Section", add "Chapters 1 & 2 of the main text".

C1.1-9 Footnote, change "33-38" to "33-83".

C1.1-12 Last paragraph, line 2, add "Section 7.7, Chapter 5 of the main text".

C1.1-13 Third paragraph, line 3, add Section "B-5".

C1.1-14 Paragraph 4.2, change "Figure 4.2-1" to "Figure 4.1-2".

C1.1-16 Change "Table 2.1-1" to "Table 5.0-1". Footnote, change "33-38" to "33-83".

C1.1-17 Footnote, change "See AMR" to "See Appendix C-1.2", add to end of sentence "AMR".