FINAL REPORT

H RESOLUTION STUDY OF THE SOLAR ATMOSPHERE

!-695791 May 1970

Lockheed

MISSILES & SPACE COMPANY

A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

SUNNYVALE, CALIFORNIA

FINAL REPORT

HIGH RESOLUTION STUDY OF THE SOLAR ATMOSPHERE

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Lockheed Solar Observatory

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Section 1

INTRODUCTION

The work under Contract NASW-1890 falls into two main caregories.

1) Final design and procurement of a large solar spar for use in high-resolution solar studies for NASA.

2) Implementation of a new program involving high-resolution time-lapse photography of the sun in the D_3 line of neutral helium.

The following sections describe results in these two areas of work. The final section briefly describes steps which have been taken at LMSC expense to prepare instrumentation for use on the new NASA spar when funding becomes available for continuation of that research program.

Section 2

THE NEW SOLAR SPAR

Solar research at the Lockheed Solar Observatory has emphasized those problems which require superior spatial and time resolution. This emphasis reflects the qualities of our observing site as well as the interests and talents of our staff. Early successes and scientific contributions in this work (Ref., Solar Filtergrams of the Lockheed Solar Observatory by Nolan, Smith and Ramsey) indicated the need for a solar spar telescope designed specifically for expanded large-scale studies of the solar atmosphere. The preliminary design of the spar was worked out on the basis of a solar research program involving the use of a multiple-slit filtered spectrograph and related large-scale solar filtergraphs. This program was proposed to NASA in 1968 and Contract NASW-1890, to provide for the first phase of this work, was signed in 1969. This final report summarizes completion of work under that contract.

On 31 March 1970 the completed solar spar, fabricated by Thomas Tool & Die Company, Sun Valley, California was installed at Lockheed Rye Canyon Research Center, Saugus, California (Figure 1).

The solar spar is similar to the previous Lockheed spar consisting of four quadrants, each capable of holding one or more systems. The spar is enclosed in a 3 foot tube and is 14 feet long. The polar axis and yoke hold the center of the spar 9-1/2 feet above the base plate. The base plate is an 8' x 8' x 1" steel plate which was flush mounted in the 25' x 35' concrete slab (Figure 2).

All four spar quadrants have complete access to any part of the eight optical mounting surfaces through double-folding doors. These doors are recessed into locking lips with over-center spring catches for secure weather seal of interior components. The spar has been provided with a fitted, zippered, heavy-duty cover for weather protection.

Figure 1. Installation of the NASA Solar Spar at Rye Canyon Research Center

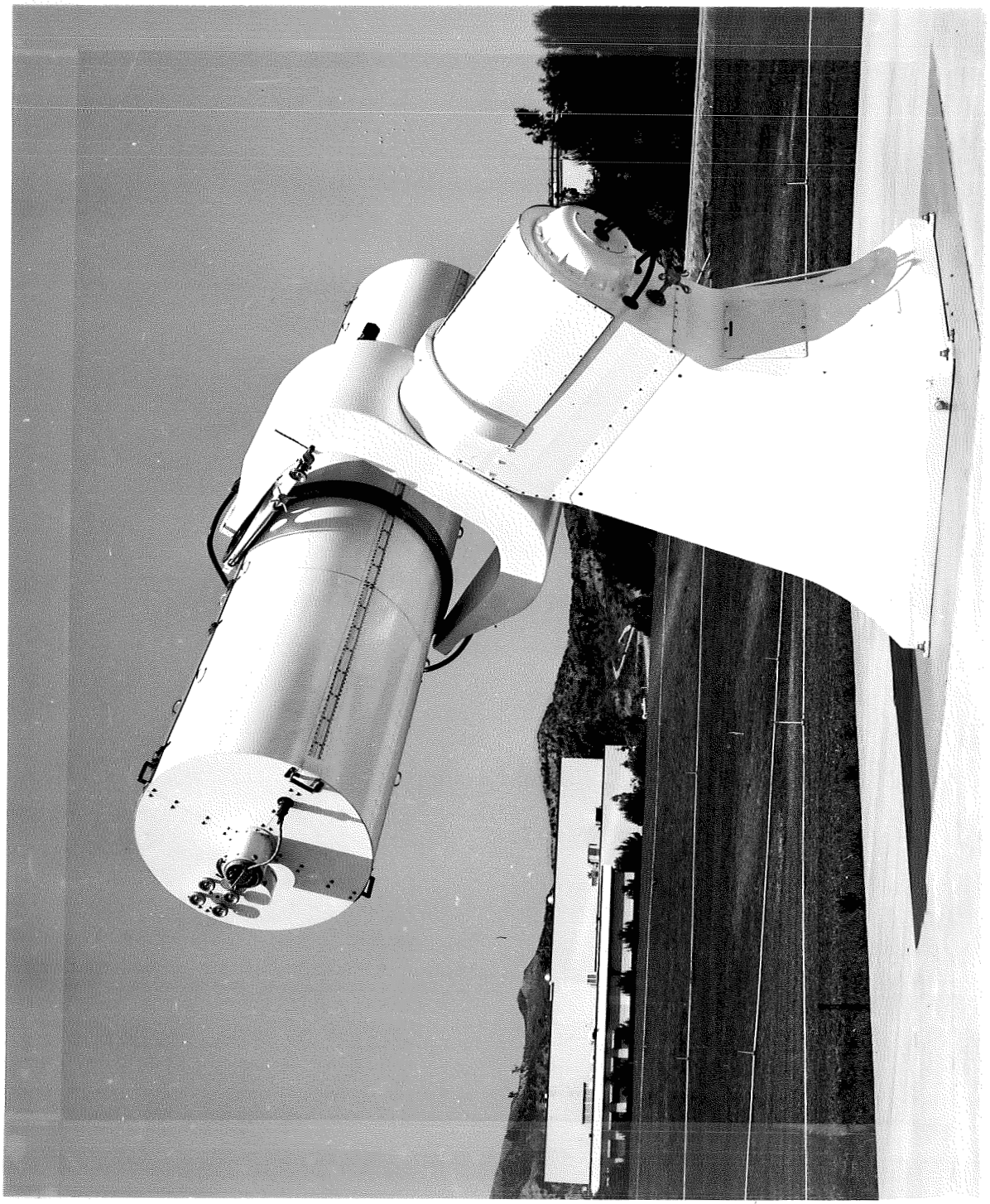


Figure 2. The 14-Foot X 3-Foot Diameter NASA 4 Quadrant Solar Spar

The solar spar has a four photo cell solid state guider using plug-in circuit boards, automatic threshold control, visible meter monitoring of guider action and exposure meter. Simple and precise control of solar image size and focus at the guider heads is provided by two controls located on the back of the spar. Simple and precise control of the spar pointing to any portion of the solar disk or limb is provided by two additional controls also located on the back of the spar.

Initial testing of the spar tracking capability showed improper action of the hour angle drive mechanism. This was traced to flexure in a universal coupling in the drive train. Thomas Tool and Die responded to the problem replacing the coupling with one using tapered threaded pins. The trouble has been successfully corrected and the spar now appears to be mechanically sound.

The solar guider exhibited initial difficulties, showing a tendency to over-run in correction. The guider boards were modified resulting in satisfactory guider performance. Critical evaluation of the solar guider performance will require mounting a large scale telescope system on the spar and assessment of time-lapse films and/or video monitoring.

With the exception of the two problems described above which have now been corrected, the solar spar drive mechanism, guider, pointing mechanism, and guider image size and focus control have been tested, and functions properly.

Section 3

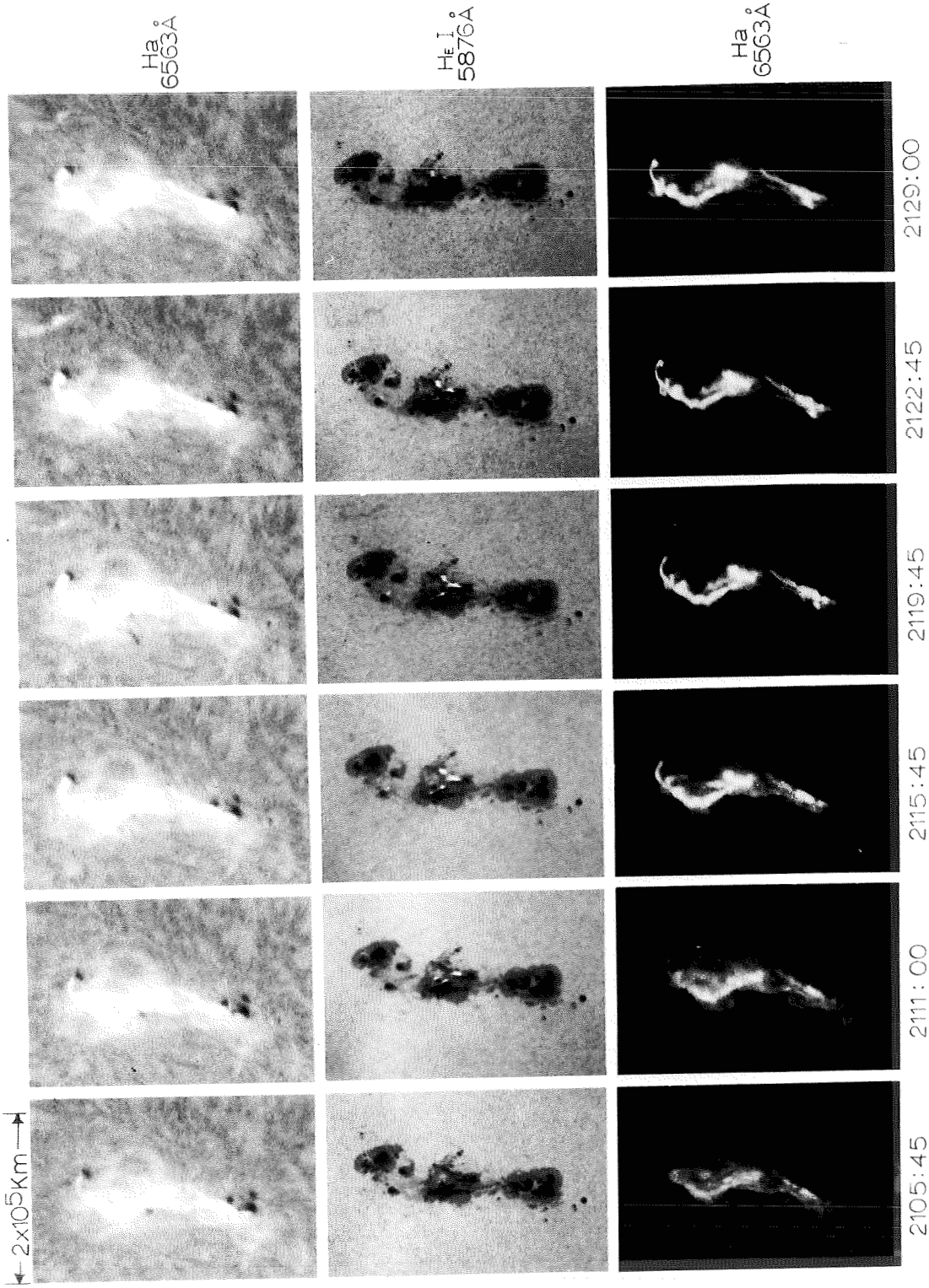
HIGH RESOLUTION STUDIES OF THE SOLAR ATMOSPHERE

In preparation for utilization of the new spar, several technical improvements in solar filter photography have been investigated. These have included extensive testing of Fabry-Perot filters of various types, tandem Fabry-Perot and birefringent filters, as well as birefringent filters in a variety of configurations. This work was supported by the Lockheed Independent Research Program as well as this contract.

As a result of this work, we have been successful in assembling a very satisfactory 1/8 Å filter for magnetic studies utilizing the 5324Å line of neutral iron. We have also assembled a clean 1Å filter for solar active region and flare studies using the 5876Å line of neutral helium.

An observational program utilizing the 5324Å filter and directed toward the study of rapid, small-scale, changes in the photospheric magnetic field is currently underway. It is too early to comment on potential results of this effort.

The 5876Å filter is being employed in a systematic study of the so-called "D_3" ($2^3P - 3^3D$) line of neutral helium. This line is of interest because it may appear either in absorption or emission against the photosphere during flares. Present theory indicates that the strength of the D_3 line relative to the continuum may be used to infer the electron density of the emitting volume. It is found that, in general, the D_3 observations will refer to parts of the flare with densities of the order of 10^{13} cm^{-3}. For comparable temperatures the H-alpha line becomes so optically thick at these densities that the spatial information on these portions of the flares is essentially unavailable (Figure 3). For this reason, the D_3 observations have the potential of providing significant new information on dense flare centers.



11 Feb 1970

Figure 3. HeI (5876) in Emission Occurs in Small Concentrated Points, the Brightest Remaining Visible for About Fifteen Minutes.

Our initial interest in HeI was generated in private communication with Dr. Richard Dunn (SPO) and Dr. Richard White (HAO). Dunn expressed interest in the possible correlation of D_3 emission with proton flares and, together with Lew Gilliam at SPO, has initiated a program of D-3 spectroheliograms of major flares. White's spectrographic observations of the D_3 chromosphere at the solar limb, showing D_3 occurring as a shell concentrated ~ 2 seconds of arc above the photospheric limb and invariably associated with active centers, further emphasized the need for a program of high resolution filtergrams (1963).

At Lockheed we have interest in D_3 as a candidate for future studies with the new multiple-slit monochromatic spectrograph. The optical transparency of the D_3 chromosphere against the solar disk should make interpretation of spectral features occurring with flares much simpler than those observed in H-α against a background of varying and high optical density. Prior to converting the multiple-slit spectrograph to D_3 from H-α (a change of narrow-band pre-filters and polarizing beam-splitters) and committing the instrument to an extended observational program, it seemed prudent to make an extended survey of D_3 with the simpler time-lapse filtergrams.

For technical reasons D_3 at 5876 was chosen over other HeI lines in the visible and near infrared spectrum. The HeI at 10,830Å has obvious merit but is not available for simple photographic recording. HeI at 5876 can easily be spectrally isolated with a 1Å filter, and polarizing materials will work efficiently at its wavelength. Other HeI lines in the visible spectrum do not meet these requisites. There is a faint telluric line at the same wavelength as D_3, however, it does not appear to present any difficulty in observation or interpretation.

After construction of a 1Å filter and spectral centering using a Helium lamp source for calibration, the filter was installed in one of the 7" aperture large scale systems of the Lockheed spar. A 3" diameter solar image was photographed by the 35mm time-lapse camera providing a 10 x 8 arc-minute

field of view. The program of photographic and visual assessment of D_3 activity commenced on 17 December 1969 and is presently being continued.

3.1 Preliminary Results from HeI (5876) Filtergram Observations

To provide preliminary results for this report, films and visual data for the period 17 December 1969 to 18 May 1970 were examined. The data included a total of 60 H-α flares occurring in the regions monitored by D_3. Of the 60 H-α flares, 54 were classed as sub-flares, 5 as Importance I, and one as Importance II. This data sample obviously contains too few major flares to consider their observed D_3 characteristics as typical.

The following table summarizes the D_3 visibility of either absorption or emission features associated with the small sample of flares observed in H-α. Note that any one flare may be visible in several of the four ways listed.

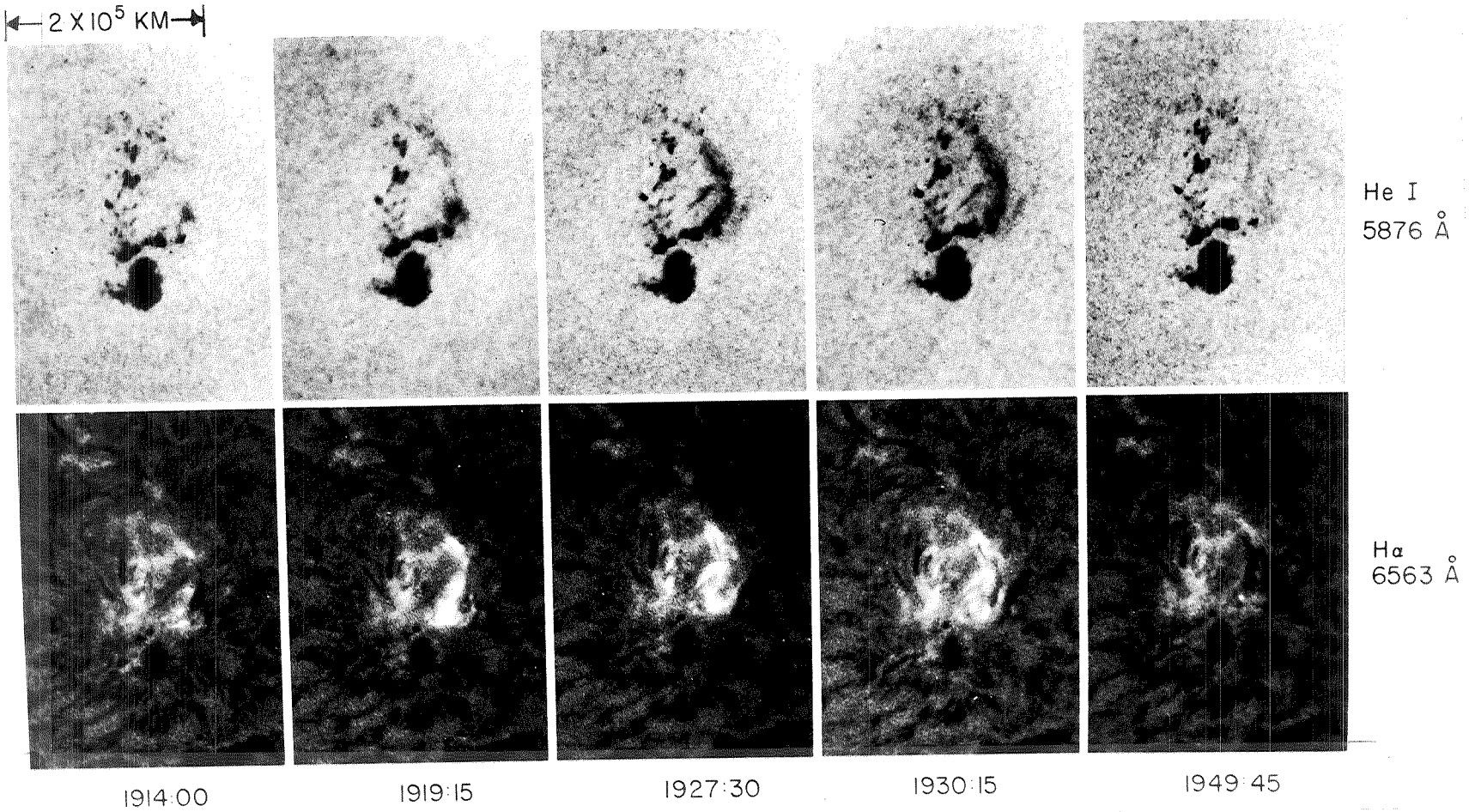
Flare Importance	Total No. Hα Flares	No Visible D_3 Activity	Faint Absorp. Features	Dark Absorp. Features	Faint Emission Features	Bright Emission Features
0	54	50	4	0	2	0
I	5	2	3	1	2	1
II	1	0	1	0	1	1

As we can see from the table, sub-flares are generally not detectable in D_3 with a 1Å filter for any portion of their H-α life-time. A small percentage show low contrast absorption features and more rarely short-lived faint emission. D_3 visibility increased with flare importance, with increased incidence of faint absorption and emission. Bright D_3 emission was observed in only two cases, once with an Importance I flare (visually) and most visibly with the Importance II flare of February 11, 1970, shown in Figure 3.

Examination of the D_3 emission compared to the H-α in Figure 3 shows D_3 occurring in small concentrated points the brightest remaining visible for about 15 minutes. They correlate nicely with the brightest H-α centers and appear analogous to the H-α flare points best observed in the red wing of H-α (LMSC Report 681495). In cine-projection there is an apparent short-lived flow of faint D_3 emission out from center in the direction of the largest H-α flare filament. All flare points observed thus far in D_3 occur in close proximity to sunspots.

Figure 4 shows our best example of D_3 in absorption compared to the Importance I H-α flare of 3 January 1970. In this case the D_3 dark features compare favorably in "size" and location with the H-α emission centers. This is not a typical H-α flare however, in that the H-α emission centers are short-lived and rapidly changing in the same way as the D_3 dark features. This type of fast changing short-lived H-α emission is observed most frequently in the H-α "flare-surge" events with an obvious outward ejection of visible material into the corona.

Careful visual examination of the D_3 chromosphere at the limb confirmed the results of White's analysis of D_3 limb spectra. The D_3 chromosphere is elevated one or two seconds of arc above the photospheric limb. Under the best conditions it is faintly visible around the entire disk, but obviously strongly concentrated above active centers. Almost all limb prominences showed faintly with active prominences frequently becoming strongly visible. (On the disk, only the very dark active filaments were visible in D_3 absorption). Photographic studies of the D_3 limb will require an eclipsing telescope and faster photographic emulsions than those we presently use. We favor some additional effort in this direction, in particular to photograph the D_3 chromosphere at the limb in high resolution, and also to photograph active D_3 prominences. Eruptive prominences which display a significant brightening in H-α as they acquire high radial velocities are of interest to observe to see if they also display a similar brightening in D_3. The H-α brightening



3 Jan 1970

Figure 4. HeI (5876) Dark Features Compare Favorably in Size and Location with the H-α Flare Emission Centers.

is presently attributed to the effective removal of the dense absorbing chromosphere below by Doppler shift of the outward moving material. A similar mechanism cannot apply in D_3 with an optically transparent chromosphere.

The most obvious conclusions reached after limited observations with a narrow-band D_3 filter, are as follows:

1. Less than 10% of all H-α flares display readily visible activity in D_3, and this is limited to the largest and brightest H-α flares.

2. D_3 activity when observed appears partially analogous to H-α flares observed with broad-band filters, and as such may provide a more realistic optical measure of the geophysical significance of flares.

3. D_3 emission occurs in small concentrated centers closely associated with sunspots, offering the potential of more precise spatial correlation with photospheric magnetic fields.

4. The low optical density of D_3 offers more effective studies of active centers as they traverse the limb, with high resolution eclipsing telescopes.

Section 4

PREPARATIONS FOR NASA SOLAR SPAR USAGE

At LMSC expense, the following steps have been taken to prepare instrumentation for mounting in the new NASA spar, for use in high resolution studies of solar activity.

The detailed design of the multiple-slit, filtered spectrograph is essentiallly complete. This includes dimensional design with specifications of all components, including objective lens, secondary lenses, diffraction grating, polarizing beam-splitters, slits, and narrow-band filters.

Detailed drawings are completed for the 10" lens mount, Littrow lens mount, diffraction gratings mount and tilt mechanism, 2 frame 35mm time-lapse camera, and holders for small lenses, polarizing beam-splitters, narrow-band filters, and multiple-slits.

The following major components of the spectrograph have been ordered:

10" objective lens
Diffraction gratings
2 narrow-band pre-filters
2-frame time-lapse 35mm camera

REFERENCE

White, Oran R., "A He(D_3) Emission Shell in the Solar Chromosphere?" Astro. Phy. Jnl., Vol. 138, No. 4, Nov. 1963