THE LPSP INSTRUMENT ON OSO 8. II. IN-FLIGHT PERFORMANCE AND PRELIMINARY RESULTS

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ABSTRACT

The in-flight performance for the first 18 months of operation of the French, pointed instrument on board OSO 8 are described. The angular and spectral resolution, the scattered light level, and various other instrumental parameters are evaluated from the observed data and shown to correspond mostly to nominal design values. The properties of the instrument are discussed, together with their evolution with time. The distribution of the first 8363 orbits between various observing programs is given. Preliminary results are also described. They include studies of the chromospheric network, sunspots and active regions, prominences, oscillations in the chromosphere, chromosphere-corona transition lines, and aeronomy.

Subject headings: instruments — Sun: chromosphere — Sun: prominences — Sun: spectra — Sun: sunspots — ultraviolet: spectra

I. INTRODUCTION

One of the major goals of solar physics is to understand the nature, origin, and evolution of the various features present in the solar atmosphere. Some, like the granulation, represent dynamical responses to the convection zone. Others, like spots or the more dispersed magnetic flux tubes (e.g., network fragments), represent symptoms of a magnetic process. Any advance in our understanding of such interior processes must come from high angular and spectral resolution observations of the line profiles of such features.

The NASA orbiting solar satellite OSO 8, launched on 1975 June 21, carried in its pointed section two instruments designed for the highest angular and spectral resolution achieved by spacecraft to date. One of these instruments was the responsibility of the Laboratoire for Atmospheric and Space Physics (LASP) of the University of Colorado, the other was that of the Laboratoire de Physique Stellaire et Planétaire (LPSP) of the Centre National de la Recherche Scientifique (France).

In this paper, we describe the performance achieved in orbit and outline the main results obtained with the LPSP instrument after 18 months of successful operation. Most of these results are in a preliminary state. A complete description of the instrumentation has been given in Artzner et al. (1977), hereafter referred to as Paper I.

II. SUMMARY OF THE INSTRUMENT CAPABILITIES

Because of the limitations imposed by the size of the spacecraft (although considerably larger than the previous OSOs), the LPSP telescope was a Cassegrainian with a diameter of 16 cm. Consequently we limited our observations to the most intense chromospheric lines. Because the chromosphere is of limited depth, the spectrometer was designed so as to simultaneously observe six lines:

- Ca II H (396.9 nm) and K (393.4 nm);
- Mg II h (280.3 nm) and k (279.6 nm);
- H I λ 1 (121.6 nm) and λ 2 (102.5 nm).

A very rapid and versatile spectral scanner made it possible to also study the lines of O VI (103.2 nm) and Si III (120.6 nm) nearly simultaneously with those listed above and enabled us to study propagation effects and to obtain height resolution from the upper photosphere to the lower corona. Table I summarizes the main characteristics of the spectrometer, which operates with two different spectral resolutions.

Two methods were available to make spectroheliograms. One was by means of spacecraft rasters: two image sizes were available, 44' x 40' and 275' x 275' (nominal). The reader is referred to Paper I (Table 2) for more details on these rasters. In addition, the LPSP telescope had an articulated secondary mirror which was moved by a two-axis stepping mechanism. Accordingly the solar image could be moved step by step. Each step was 1" on the solar surface while the maximum area covered was 64" x 64".

A slit wheel mechanism, at the focus of the telescope, was used to select various slit sizes ranging...
TABLE 1

<p>| Design Characteristics of the OSO 8 LPSP Six-Channel High-Resolution Spectrometer |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th><strong>CENTRAL LINE</strong></th>
<th><strong>Spectral Resolution (nominal)</strong></th>
<th><strong>Low Mode</strong> (nm)</th>
<th><strong>High Mode</strong> (nm)</th>
<th><strong>Maximum Spectral Range per Grating Step</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca II H</td>
<td>396.9</td>
<td>0.1</td>
<td>0.0020</td>
<td>395.164-398.244</td>
</tr>
<tr>
<td>Ca II K</td>
<td>393.4</td>
<td>0.02</td>
<td>0.0025</td>
<td>391.444-394.942</td>
</tr>
<tr>
<td>Mg II h</td>
<td>280.3</td>
<td>0.1</td>
<td>0.0005</td>
<td>277.739-282.264</td>
</tr>
<tr>
<td>Mg II k</td>
<td>279.6</td>
<td>0.02</td>
<td>0.0025</td>
<td>277.005-281.551</td>
</tr>
<tr>
<td>H I Lα</td>
<td>121.6</td>
<td>0.02</td>
<td>0.0020</td>
<td>120.569-122.291</td>
</tr>
<tr>
<td>H I Lβ</td>
<td>102.5</td>
<td>0.1</td>
<td>0.0060</td>
<td>101.686-103.229</td>
</tr>
</tbody>
</table>

Note.—Wavelength units are nanometers (nm).

III. IN-FLIGHT PERFORMANCE

Prior to launch, the instrument was submitted to numerous tests and calibrations, the results of which are given in Paper I. Here we present the actual performance measured in flight.

a) Angular Resolution

The ground tests of the telescope led us to expect an instrumental profile with a full width at half-maximum (FWHM) of 2'. Two methods have been used to estimate the angular resolution in orbit:

i) Images of Limb Shape

Repeated scans of the solar limb, as observed with a 1" × 1" aperture using the internal raster mode in the

![Graph](image-url)
far wings of the Ca II line, show a limb darkening with a 50% decrease over an angular distance of 2°.

However, this method does not separate the resolution of the telescope from the jitter of the pointing system. Rapid, one-dimensional scan of the solar limb as well as other methods allowed us to estimate the amplitude of the rms jitter as 0.5".

ii) Partial Solar Eclipses

On 1976 April 29 and October 23, two partial eclipses of the Sun were visible from OSO 8. Figure 1a represents spatial scans laterally across the lunar limb measured in relative intensity units. The actual profile as given in Figure 1b. The fit using the profile of Figure 1b represents a good approximation. We therefore conclude that the instrumental profile has a FWHM of 2.7 ± 0.5.

b) Spectral Resolution

i) Lα and Lβ Channels

For these we take advantage of the narrow absorption line due to geocoronal hydrogen. By applying a method developed for the study of interstellar absorption lines (Vidal-Madjar et al. 1977), we obtain a spectral resolution in flight of 0.002 ± 0.0005 nm at Lα, and 0.006 ± 0.001 nm at Lβ.

ii) Calcium and Magnesium Channels

We compare the solar spectra obtained by our instrument with ground based (Ca II channels) and balloon- or rocket-borne observations (Mg II channels).

In Figure 2 we show the full range Ca II K and Mg II spectrograms. The variation with wavelength of the sensitivity of the instrument has been corrected for, and the spectra are deconvoluted from the instrumental profile. The comparison with the spectrum of the Kitt Peak Preliminary Solar Atlas (Brault and Testerman 1972), which has a spectral resolution of 0.0024 nm, shows that our resolution in orbit is better than this value. In the case of the Mg II channels, comparison with the spectra of Lemaire and Skumanich (1973) and Kohl and Parkinson (1976) yields a resolution of 0.0025 ± 0.00025 nm. This value is equal to the nominal design value (cf. Table 1).

c) Dispersion and Grating Mechanism

(Spectral Scanner) Stability

The dispersion law of the spectrometer was determined in orbit by measuring the position, in units of a grating step, of 11 solar absorption lines of known wavelengths in the Ca II and Mg II channels. For the Lβ channel we used the O I lines at 130.48 and 130.6 nm and N I at 119.9 nm (which appear in the 11th and 12th orders of diffraction).

Because of the lack of lines in the Lα channel, we deduce the dispersion law from that at Lβ. The absorption line of geocoronal hydrogen provides an absolute reference. This proved to be valuable due to the appearance of positioning uncertainties (±1 grating step) in the movable Lα, Lβ exit slit mechanism. The dispersion law was measured repeatedly to check for long-term variations. Over 1 year we found that the correspondence between absolute wavelength and grating step number varied by no more than ±3 grating steps (cf. last column of Table 1).

To check the mechanism stability over one orbit, we measured the position of the photospheric line 391.52 nm in the wings of Ca II K. Any departure from the orbital Doppler effect could be attributed to photospheric Doppler shifts and/or changes in the spectrometer. The result is shown on Figure 3. One can easily recognize the 300 s photospheric Doppler oscillations after removal of the orbital Doppler shift, measured for the first time from space. The amplitude of the residual noise on this curve amounts to ±30 m s⁻¹. The stability of the mechanism over a full orbit day is better than one grating step and exceeds our design expectations. We are able to easily and accurately measure Doppler shifts of photospheric and chromospheric lines (see § Vc below).

d) Scattered Light Background and Dark Current

The level of scattered light in the telescope plus spectrometer was determined from partial eclipses of the Sun. From Figure 1 we see that at 11° from the lunar limb this level amounts to 2% of the intensity of the disk in the calcium channels. For Mg II it is 4%. For Lα and Lβ these figures become 10% and 20%, respectively, which indicates that the scattered light level may vary with wavelength, roughly as 1/λ².

No simple and unambiguous method was available to measure separately and give an absolute value for the amount of scattered light in the spectrometer due to wavelengths well away and near the wavelength of interest.

In the case of the Ca II and Mg II channels, we could compare the performance of our spectrometer with those of other ground-based or rocket-borne instruments. The result of this comparison appears in Table 2, where we give the ratio of intensities at Ca II H, K, Mg II h, and k, relative to those of the Ca II and Mg II line wings. We note that our performance is excellent for the Ca II channels, for which these ratios are smaller than those deduced from the Utrecht (Minnaert, Mulders, and Houtgast 1940) and the Air Force (Beckers, Bridges, and Gilliam 1976) atlases. We also compare our values with those of Linsky (1970) and of White and Suemoto (1968) who used particularly good optical systems. The Utrecht Atlas was used to evaluate the ratio of the H₃ and K₃ intensities relative to that of the continuum at 400.0 nm. The results are:

\[
\frac{I_{H3}}{I_{400.0}} = 0.053, \quad \frac{I_{K3}}{I_{400.0}} = 0.065, \quad \text{for OSO 8},
\]

while White and Suemoto (1968) find 0.071 ± 0.0015 and 0.061 ± 0.001, respectively, and Linsky (1970)
Fig. 2.—Full range spectral scans in the Ca II K and Mg II k channels using a 1" × 3" entrance slit. The ordinates are counts per gate. Instrumental sensitivity variations over the wavelength range have been corrected for. Notice the reversed asymmetries in the Mg II h and k lines. It takes approximately 50 s to go from Mg II k to h, and the asymmetries reflect time variations in the line profiles over 50 s.
Fig. 3.—Relative velocity of the 391.52 nm photospheric line observed in the Ca II K channel. The 300 s oscillation is easily evidenced. The spacecraft Doppler shift has been removed. Spikes are identified as telemetry noise. The vertical scale is in m s$^{-1}$; the horizontal scale is in units of 10 s.
TABLE 2
RATIO OF INTENSITIES AT THE λ POSITIONS Ks, Hs, hs, and ks TO INTENSITIES MEASURED IN THE WINGS OF Ca ii AND Mg ii LINES IN THE OSO 8 CHANNELS

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca ii H</td>
<td>I(395.18)/I(Hs)</td>
<td>0.084</td>
<td>0.085</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>I(398.13)/I(Hs)</td>
<td>0.077</td>
<td>0.090</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Ca ii K</td>
<td>I(391.47)/I(Ks)</td>
<td>0.078</td>
<td>0.088</td>
<td>0.087</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>I(394.83)/I(Ks)</td>
<td>0.083</td>
<td>0.096</td>
<td>0.095</td>
<td>...</td>
</tr>
<tr>
<td>Mg ii h</td>
<td>I(ks)/I(277.73)</td>
<td>0.079</td>
<td>...</td>
<td>...</td>
<td>0.048</td>
</tr>
<tr>
<td></td>
<td>I(hs)/I(282.01)</td>
<td>0.063</td>
<td>...</td>
<td>...</td>
<td>0.045</td>
</tr>
<tr>
<td>Mg ii k</td>
<td>I(ks)/I(277.73)</td>
<td>0.048</td>
<td>...</td>
<td>...</td>
<td>0.048</td>
</tr>
<tr>
<td></td>
<td>I(hs)/I(282.01)</td>
<td>0.037</td>
<td>...</td>
<td>...</td>
<td>0.028†</td>
</tr>
</tbody>
</table>

Note.—The results are compared with the same ratios evaluated from Solar Atlases or available published data. r and v referred to the red and the blue part of the lines.
* We are indebted to Dr. J. Kohl for providing original records of his spectra.
† These values are probably uncertain due to the difficulty of measuring the solar intensity at Ks.

0.0409 ± 0.0022 and 0.0434 ± 0.0011 for the same ratios. Our results are intermediate between these two, confirming the very good performance of the Ca ii channels.

For Mg ii we have used the spectrum of Kohl and Parkinson for comparison. Excellent agreement is obtained in the k channel, our spectra indicating nearly exactly the same amount of scattered light as in the comparison spectrum. The agreement is, however, poor in the case of the h channel. Both the h and k lines can be observed in this channel together with the reference wavelength at 277.73 nm, allowing direct comparison between the two channels. As a result, we notice that the h channel has a much higher level of scattered light. This might be the result of degraded spectral resolution, due to a defective adjustment of the common coma and astigmatism corrector used in the Mg ii channels whose delicate adjustment was nearly exactly the same amount of scattered light as in the comparison spectrum. The agreement is, how-

Dark-current measurements were performed systematically each orbit during the first year and every 2 or 3 days in the second year. The dark current was found to be stable, with nearly no change during 18 months. The values are respectively 1.3, 1.1, and 0.1 counts s⁻¹ for Mg ii, Lα, and Lβ, respectively.

The calcium channel dark current was typically 200 counts s⁻¹. This comparatively bad performance is due to a leak in the enclosure system (skin).

e) Photometric Standardization

Photometric sensitivities have been measured regularly in orbit relatively to their values at launch. Such measurements are made every day or two with the 1" x 10" entrance slit at disk center quiet Sun, in the high spectral resolution mode for Ca ii and Mg ii and low resolution mode for Lα and Lβ. The number of counts at certain standard wavelengths (see below) measures the relative efficiency, whose variation as a function of time is shown in Figure 4.

The interpretation of these curves may be of interest to those who plan to utilize similar instruments in space. The telescope mirrors, the collimator, the grating, and all surfaces in the Lα, Lβ, and Mg ii channels were coated at the Goddard Space Flight Center, with Al + LiF (Bradford et al. 1969). Elaborate precautions were taken in the storing and handling of the collimator. In that case, a special 300 square meter facility was built with air cleanliness and with temperature carefully controlled and humidity always kept below 30% (Salvetat 1975). A loss of sensitivity such as the one reported here is very unlikely due to a contamination in the instrument before the launch and should rather be regarded as caused by the outgassing of the spacecraft and the instrument once placed in the space vacuum. In that case, the greater the number of reflections, the larger the degradation. The presence of steps which appear at nearly the same time on all the curves of Figure 4 is probably the signature of sudden outgassing periods. The significant differences noticeable between the individual curves, however, are indicative of causes of degradation proper to each channel, affecting either the mirrors, the filters, or the detectors.

The two Lyman channels show nearly the same behavior, with the larger loss at Lα attributed to the larger number of reflections in this channel (seven at Lα versus five at Lβ). At day 540, i.e., 18 months after launch, the sensitivity at Lα and Lβ was 10⁻³ and 5.10⁻³ respectively, of the value at launch. Assuming that each reflection is affected equally by the contamination (which is certainly a crude approximation), these numbers indicate that each reflection has reached 35% at Lα and 37% at Lβ of its value at launch.

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Fig. 4.—Variations of the instrument sensitivity relative to its value at launch. Time is in days after launch.
day zero. Such results are not particularly dramatic when compared with the photometric behavior of other solar space instruments (Huber et al. 1973).

However, the combined effect of outgassing and the baking of the secondary mirror surface by a flux of more than 18 "solar constants" is likely to be responsible in a large proportion for the sensitivity loss. A simulation made a few weeks prior to launch at NASA on Al+LiF coated samples illuminated by 17 "solar constants" and placed in a normally outgassing environment showed a decay in efficiency from 63% to 58%, and from 67% to 55% at La and Lβ, respectively, only 52 hours after pumpdown.

Obvious solutions, such as closing a shutter in front of the telescope during the first orbits when outgassing is high, were unfortunately not possible and would have delayed the launch several months.

Assuming, arbitrarily, that the secondary mirror is responsible for a loss of a factor 10 at both La and Lβ, each surface would have reached an efficiency of 46% of its value at launch, which is more or less normal.

Totally unexpected and more striking is the behavior of the Mg and Ca channels. Although of yet unknown origin, outgassing might also be responsible for the degradation observed in these channels, at least until day 160 when the sensitivity reaches 1/40 and 1/20, respectively, of the value at launch. This corresponds to an average loss per reflection of 48% and 55%. After day 160 the sensitivity in the two Ca channels rises again. At the same time a faster decay is observed in the Mg channels. This peculiar behavior is attributed to interference phenomena, probably complementary, in Ca and Mg within thin films of contaminant(s) deposited on any one of the optical surfaces. Deteriorations of the interference filters which are used in all these channels may also contribute. In the case of the Mg channel it is also very likely that the detector itself is responsible for the loss of sensitivity. This is apparently not the case for the two Ca channels since their sensitivity follows nearly the same variation with time, which more likely reflects a variation in the optics used in common.

The overall loss of sensitivity compromised certain aspects of the observing program. However, the versatility of the instrument made it possible to obtain scientific data of high quality and value throughout the mission.

f) Absolute Calibration

The calcium channels were calibrated by comparison with the data of Linsky (1970) and Livingston and White (1978) which represent average quiet Sun conditions. The absolute intensity at our standard wavelengths Hα and Kα were taken as 0.0751 and 0.0687, respectively, in units of the continuum intensity at 400 nm.

For the magnesium channels we attempted to improve Bonnet's 1967 results (Bonnet 1968) and designed a high spectral resolution instrument calibrated against a blackbody constructed by R. Peyturaux at the Institut d'Astrophysique de Paris. This instrument was launched twice on the LASP rockets number 21029 on 1975 July 28, and 21030 on 1976 February 18, but because of malfunctions in the electronics it did not give reliable results. We prefer therefore to rely on other recent measurements—e.g., those of Kohl and Parkinson (1976). The absolute intensity at the standard wavelengths Hα and Kα, were taken as 8 and $6 \times 10^{-12}$ ergs cm$^{-2}$ s$^{-1}$ sr$^{-1}$ cm$^{-2}$, respectively.

For the Lyman channels we also used the above rocket program to carry packages consisting of $\frac{1}{2}$ m Ebert-Fastie spectrometers, measuring the integrated solar disk to calibrate the LASP and LPSP instruments separately. Only the second flight yielded good calibration data. The results are given in Table 3 and are compared there with other measurements. The LPSP values are somewhat high; however, they are in the direction suggested by geophysicists (Levasseur et al. 1976). To use these integrated intensities in La and Lβ, we use quiet Sun average profiles computed for the whole disk (Fig. 5). We have taken into account the center-to-limb variation in an approximate way that will ultimately be improved upon by means of entire Sun raster-generated profiles (i.e., profiles constructed from spectrophotograms), when these become available from the data tapes. The absolute flux at the standard wavelength (core of the line) used to monitor the La relative sensitivity was taken to be $3 \times 10^{10}$ photons cm$^{-2}$ s$^{-1}$ nm$^{-1}$.

IV. REAL TIME OPERATION AND PROBLEMS

The various modes of operation of the instrument have been described in Paper I. Here we discuss the "real-time" operation mode which allowed one, for

| TABLE 3 |
| INTEGRATED SOLAR FLUX MEASUREMENTS OBTAINED WITH CALIBRATION ROCKETS AT LA AND Lβ |

<table>
<thead>
<tr>
<th>CALIBRATION ROCKETS</th>
<th>1975 July 28</th>
<th>1976 Feb. 18</th>
<th>1976 Feb. 18</th>
<th>OSO 5†</th>
<th>AE/C†</th>
</tr>
</thead>
<tbody>
<tr>
<td>CALIBRATED FLUX</td>
<td>LASP*</td>
<td>LSP*</td>
<td>LASP*</td>
<td>Aug. 8</td>
<td>Apr. 11</td>
</tr>
<tr>
<td>F(10.7 cm) (10$^{-22}$ W m$^{-2}$ Hz$^{-1}$)</td>
<td>75.5</td>
<td>70.1</td>
<td>70.1</td>
<td>70</td>
<td>none</td>
</tr>
<tr>
<td>F(Lα) (ergs cm$^{-2}$ s$^{-1}$)</td>
<td>4.02</td>
<td>5.46 ± 20%</td>
<td>4.05 ± 20%</td>
<td>4.25</td>
<td>0.050</td>
</tr>
<tr>
<td>F(Lβ) (ergs cm$^{-2}$ s$^{-1}$)</td>
<td>none</td>
<td>0.078 ± 20%</td>
<td>none</td>
<td>none</td>
<td>none</td>
</tr>
</tbody>
</table>

* Rottman 1977.
† Vidal-Madjar 1977.
‡ Hinteregger 1976.
the first time, to point from an orbiting observatory with an absolute accuracy of nearly 1". The LPSP and LASP instruments were both operated from LASP (Boulder, Colorado) with "resident" LPSP scientists and guest investigators involved in the daily operations. Target selection alternated daily between LPSP and LASP until 1976 April and then weekly. For a more complete description of the operations command generation and quick-look facilities, see Jouchoux and Hansen (1978).

a) Pointing System Problems

The pointing system of the "sail" section of OSO 8 uses either one of two Sun sensors (SEAS), designed by Hughes Aircraft Company, mounted on each instrument. These devices coalign the SEAS pointing axis with the optical axis of the associated telescope. This corrects for drifts of the optical axis with respect to the mechanical structure of the instruments.

Because of an electronic problem, the SEAS on the LPSP instrument failed after 56 days in orbit and all subsequent operations made use of the other SEAS. Consequently thermal and other drifts between the LPSP axis and the LASP axis had to be known. To determine these, we measure relative positions ($\pm X, \pm Y$) of the solar limb (in the $X$-$Y$ frame of the satellite) during one orbit using images from the internal raster mode. We corrected for these drifts by programming the secondary mirror when it was necessary to stay within 1" of the target.

Variations in the SEAS scale factor and zero point (Sun-center line of sight) proved to be more troublesome. A weekly determination of the absolute four positions of the solar limb in the $X$-$Y$ frame of the satellite was necessary. Using such data, from spacecraft and internal rasters, an extrapolated scale and zero point could be found for the particular day of observation. This proved to be successful, and we were able to position targets at the very center of our field of view, often without the need for corrections. Finally, the repeatability of the pointing system at the limb was found to be within 1" or 2", but with occasional jumps of 5".

b) Target Acquisition

Nearly 80% of the orbits under LPSP control were dedicated to studies of selected targets, often as small as a few seconds of arc. This mode of observation from an unmanned observatory involves a fairly complex procedure which requires considerable care and dispatch from the observer. We illustrate this in Figure 6 and describe the acquisition of the core of a sunspot.
Fig. 6.—Block diagram showing the circuitry of telemetry and telecommand data between Boulder and NASA and illustrating "real-time" acquisition of a solar target ($t_0$ is the execution time).
As soon as a spot is visible on either a Hα picture (taken daily by NOAA/NBS in Boulder) or the Ca ii K picture transmitted by telephone from Sacramento Peak Observatory, we determine its Stonyhurst coordinates for the time of the photograph. These coordinates are then transformed and oriented into the satellite spin frame of reference for the projected time of observation. Finally the scale distortion of the pointing system is corrected for. The instrument commands and associated pointing commands are generated and sent to NASA on the day before the date of observation. During the day of observation an internal image of the spot, 64° × 64°, is executed in the far wings of Ca ii or Mg ii during a real-time pass of the satellite over a ground station. These real-time data are received by telephone via GSFC on the PDP 11 computer at Boulder, where they are subsequently decoded and displayed as an image. Any corrections to the position of the spot are determined from the image and are sent by telephone to NASA who uplink the corrections to the spacecraft. The time delay between the real-time pass and execution of pointing corrections can be as short as the time interval between two successive ground station passes, namely, 1/4 hours. This apparently straightforward operation is made more difficult because of the need to extrapolate the scale distortion parameters and to correct for the drifts of the line of sight already mentioned.

c) La Modulation

The La signal was discovered to be occasionally modulated with an amplitude which may reach 10% of the signal at precisely the rotation period of the spacecraft wheel except during the first 2 minutes after sunrise when sometimes a period distinctly shorter than the wheel period was found.

All attempts made to detect a similar phenomenon in the other channels have failed, suggesting that it is not caused by a pointing problem. Indeed we have sometimes observed oscillations in the pointing axis with periods equal to that of the wheel rotation and an amplitude of 0.5, but these affect all channels at the same time.

The phenomenon has to be taken into account when analyzing time series and profiles of the La line. As described in Paper I, the duration of every individual measurement is the product of 0.16 s gate time by a power of 2, and the most commonly used values are 10.24 s (64 grating steps) and 20.48 s (128 grating steps). The period of rotation of the wheel of the spacecraft varies from 10.7 to 9.5 s and for spectral scans with a time base equal to or larger than 10.24 s, the modulation induces a "beat" of period ranging from infinity to 131 s.

Figure 7 plots the raw data for the first moment of the wavelength of the line versus time. A strong 800 s period is evident. If the individual data points are corrected for the modulation with a period equal to that of the wheel and the first moment is recomputed, then the circles in Figure 7 show that the 800 s oscillation is suppressed.

This proves without ambiguity that the phenomenon is purely instrumental and that the possibility of its solar origin, should be definitely disregarded.

V. PRELIMINARY RESULTS

Spacecraft (playback) data are sent by NASA to Boulder by telephone line and recorded there on magnetic tapes. Mass production tapes of this data are prepared by NASA and mailed to the Centre National d'Etudes Spatiales (CNES) (Toulouse, France), which is in charge of the processing and distribution of the final data tapes to the LPSP investigators and guest investigators. The results presented below have been obtained mostly from playback data at Boulder.

a) Observational Program

Table 4 presents a summary of the various types of observations that were programmed during the first 8363 orbits. No distinction is made in the table with regard to pointing control. Orbits with problems in either the instrument, the spacecraft, or the command system represent only 2% of the total.

The column headings in the table describe the modes of operation of the instrument while the rows indicate the scientific question or the solar feature under study.

Orbits labeled "Line Profiles" usually correspond to spectral scans ranging from 64 to 512 grating steps centered at either the six chromospheric lines or the O vi line at 103.2 nm. The "Others" columns indicate studies in either the wings of the Ca ii and Mg ii lines or the O v and Si iii lines at 121.8 nm, 120.6 nm, respectively. Other lines such as O i, N i, etc., were observed in the L/3 channel by making use of the different grating orders. During these orbits the satellite was in the pointed mode.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>LINE PROFILES</th>
<th>SPECTROHELIOMGRAMS</th>
<th>VELOCITY FIELDS AND OSCILLATIONS</th>
<th>LARGE $\lambda$ SCANS</th>
<th>GUEST OBSERVER ORBITS</th>
</tr>
</thead>
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<tr>
<td></td>
<td>6 Lines</td>
<td>O vi 103.2</td>
<td>Others</td>
<td>Transients</td>
<td>Scans</td>
</tr>
<tr>
<td>Quiet Sun:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chromospheric network</td>
<td>554</td>
<td>194</td>
<td>...</td>
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<td>87</td>
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<td>3</td>
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<td></td>
<td></td>
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<td>High resolution (20°)</td>
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<td>R 128f</td>
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<td>Low resolution (40°)</td>
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<td>miscellaneous</td>
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<td>...</td>
<td>...</td>
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</tbody>
</table>

Note.—Numbers represent full day orbits.
Under "Spectroheliograms" we classify orbits for which most of the time is spent rastering, using either the internal or the satellite raster mode. Morphology and long-term variability studies of solar features were of interest here.

During orbits labeled "Velocity Fields and Oscillations" we spent most of the time in the pointed mode studying rather small areas of the disk, not more than 64° x 1°. Here, special spectral scans were made. For example, short-period waves (T < 40 s) were searched for by scanning rapidly through the line profiles using wavelength position separated by 16 grating steps.

Under "Transients" are grouped orbits observed with the fast, low-resolution satellite rasters. The short time constant of such modes allows one to observe rapidly propagating shocks and any other rapid phenomena.

"Large A Scans" represent the full scanning capability of the grating and were performed either to study lines in the low orders of the Lβ channel or to standardize the Mg II and Ca II line cores with respect to their far wings.

For most orbits, sunset and sunrise experiments were performed in order to measure atmospheric extinction at various wavelengths of interest (see § Vg below). "Chromospheric Network Studies" include not only morphology and time evolution but also line profiles for center-to-limb and cell-network comparisons. "Limb Studies" include orbits dedicated to the shape of the limb, spicules, and the vertical extension of the solar atmosphere in various lines.

"Photometric Calibration" has already been described in § III; for these orbits the satellite is pointed at disk center in a quiet region.

The last five rows of Table 4 include scientific as well as instrument or satellite calibration orbits. Also included are orbits devoted to eclipse observations, to studies of the geocoronal hydrogen line, and to the search for lines such as Fe XIII 121.64 nm and He II 102.5 nm.

**b) Quiet Sun and Chromospheric Studies**

Figure 8 (Plate 21) represents an example of our study of the network and the quiet Sun. Such internal raster images along with associated profiles will permit an intercomparison of cell and network properties.

Figure 9 compares profiles obtained at the center of a cell and in a network fragment. One can notice the strong variation in intensity, particularly in Mg II k and Lα, between the two regions. This is due partly to a decreasing line background contribution as well as differential temperature sensitivity. The asymmetry of Lα is always much less pronounced than in the case of Mg II h and k, presumably because of smaller velocity gradients at the Lα height of formation.

Figure 10 shows average quiet Sun profiles of Lα and Lβ taken with a 6° x 2° slit at disk center and near the limb (μ = 0.14). Notice the two lines of O I at 130.48 and 130.59 nm in the wings of Lβ (observed in the 11th order). By the insertion into the light beam of a MgF2 filter one can block out all photons below 115 nm and observe only the two O I lines. Differenting permits one to reconstruct the Lβ profile. The result of this procedure is shown on Figure 11. The remaining slight anomaly at grating step 180, might be due to the Hβ line of He II (102.53 nm). Center-to-limb measurements at the corresponding wavelength show appreciable limb brightening. Investigations are under way to confirm this observation.

The variation of the distance between peaks of the Lα and Lβ lines from center to limb is apparent together with the variation of the ratio of the peak to core intensities (see Table 5). The values in Table 5 at μ = 0.14 are close to those calculated by Vernazza (1972).

One noticeable feature is the reversed intensity asymmetry between the Lα and Lβ shortward and longward peaks at the disk center. In Lα the shortward peak is generally higher than the longward peak while the reverse holds in Lβ. At the limb, both Lα and Lβ profiles become symmetrical. It is possible that this effect may not be intrinsic but is either an instrumental effect or the effect of unresolved lines at Lβ. The matter is under study.

To study the morphology of network fragments and their evolution in time, monochromatic images have been obtained simultaneously in the six lines alternately with broad-band images in O VI (103.2 nm) for a number of observing sequences (Fig. 12). Preliminary analysis of a 20 hr sequence shows that significant evolutionary changes can occur over a 12 hr period. The larger size K, fragments are easily identified in the Lα + Lβ (= H Lyman) and O VI images where they do not appear as extended as indicated by the ATM data (Reeves 1976). This is supported by an analysis of the Lα brightness distribution. Applying the method of Skumanich, Smythe, and Frazier (1975) to both present OSO 8 sequence and ATM data, one finds a fractional Lα network area of 37% and 41%, respectively. The ratio of mean network to mean cell brightness proved to be 1.9 and 2.1, respectively. For comparison the OSO 8 Ca II distribution yielded a fractional area of 27% and brightness ratio of 1.3.

**c) Quiet Chromospheric Oscillation and Transients**

We have already mentioned in § IIIc (cf. Fig. 3) our successful detection of the 300 s oscillation of photospheric lines in the wings of Ca II H and K.

**TABLE 5**

<table>
<thead>
<tr>
<th>LINE</th>
<th>SEPARATION OF PEAKS (nm)</th>
<th>I&lt;sub&gt;peak&lt;/sub&gt;/I&lt;sub&gt;core&lt;/sub&gt;</th>
<th>μ = 1.0 μ = 0.14</th>
<th>μ = 1.0 μ = 0.14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lα</td>
<td>0.043 0.05</td>
<td>1.3 ± 50% 2.2</td>
<td>μ = 1.0 μ = 0.14</td>
<td></td>
</tr>
<tr>
<td>Lβ</td>
<td>0.027 0.031</td>
<td>1.4 ± 50% 1.5</td>
<td>μ = 1.0 μ = 0.14</td>
<td></td>
</tr>
</tbody>
</table>

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The Mg II k and Ca II K lines (Fig. 13) show oscillations of ~200 s period. We parametrize the profile of Mg II k as a difference of two Gaussians:

\[ I(\lambda) = E_1 \exp \left( \frac{\lambda - E_2}{E_3} \right)^2 \left[ 1 - A_1 \exp \left( \frac{-A_2}{A_3} \right)^2 \right] \]

where \( E_1 \) and \( A_1 \) represent the intensities of the emission and absorption components of the profile, respectively, and \( E_2 \) and \( A_2 \) the average wavelength position (or "first moment of the wavelength") of the emission and absorption components. We should point out that no physical meaning is to be attached to this parametrization. The time behavior of these various parameters is shown on Figure 14.

The oscillation of the parameter \( E_2 \) or average emission position covers a range of \( \pm 0.00186 \) nm or \( \pm 2 \) km s\(^{-1}\). For \( A_2 \) or average absorption position, this value is doubled. This clear difference might be interpreted as the amplification, with increasing height in the atmosphere, of a wave, if one assumes, as usual, that the core of Mg II k is formed at a higher altitude than the wings. The average "bluer" position of \( E_2 \) (emission) compared to \( A_2 \) (absorption) reflects the
Fig. 10.—$\lambda$ and $\lambda\beta$ profiles at the center and at the limb of the Sun obtained with a $6' \times 2'$ resolution. The two lines in the wings of $\lambda\beta$ are O i 130.48 nm and 130.59 nm appearing in the 11th order of diffraction. Wavelengths increase to the left. The abscissae are grating step numbers. For conversion in $\lambda$ units, see Table 1.
Fig. 12.—Evolution with time of network fragments, observed with 64" x 64" internal rasters in O vi, Ls, and Ca ii lines.
Fig. 13.—Oscillations of the center of symmetry of the Ca II (upper curve) and Mg II (lower curve) emission components. Horizontal units are multiples of 10 s.
In Figure 16 we see the variation over 40 s of the Mg II and Ca II K profiles observed simultaneously. The Mg II lines exhibit the same periods as the Ca II lines. We have a broad set of observations which contain wave trains lasting in general no longer than a few cycles with periods ranging from 250 s down to 130 s. A search for shorter periods was undertaken, in particular by guest observers, but no clear evidence has yet emerged from these investigations at this early stage of data analysis.

The good results obtained in Mg II encouraged us to search for a possible oscillation of La. The large contribution function of the line, which tends to smooth out the effects of any wave on the profile, together with the low photon count in this channel made this observation a particularly difficult one. We first tried to detect intensity fluctuations by integrating the number of photons over ± 0.025 nm from line center. We did not find any obvious evidence of variations, other than random, a result in accord with the previous attempts made from studies of Skylab results (Vernazza et al. 1975).

To overcome the low photon statistics problem, we tried to correlate the shape of La with that of Mg II k profiles. We definitely see evidence for a correlation, the bluer k profiles corresponding to redshifted La profiles. The amplitude of the shift is of the order of 2 grating steps (3 km s⁻¹). More work is under way, but we may state at this stage that the oscillations seen in Mg II k have an influence higher in the chromosphere, at the altitudes where La is formed (Artzner et al. 1978).

Several orbits were devoted to the study of oscillations in the O I, Si III, and O VI lines, but have not yet been analyzed. Transient and short time phenomena have been observed. Numerous tachograms dedicated

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**Fig. 15.**—Mg II k profiles observed at the maxima and minima of the oscillations of the line center of gravity, showing obvious occurrence of asymmetrical blue peaked profiles at maxima and symmetrical or slightly asymmetrical red peaked profiles at minima. Wavelengths increase to the left.
d) Study of Sunspots and Active Regions

Sequences of high-resolution images and spectra taken 1° apart show the evolution of spot morphology and profiles in space and time. Umbrales have been observed as well as oscillations. Nearly simultaneous observations of lines from the photosphere to the transition region and above have been made. This is the case both for some unipolar single spots as well as multipolar spot groups. However, we do find circumstances when single spots show the transition region “plume” directly over the spot as reported by Foukal et al. (1974).

Figure 17 shows this phenomenon, where isophotes are represented in photospheric light, $L_0$, and $\Omega$ $\omega$.

We have also found examples of step-like changes in the distribution of the enhanced $\Omega$ $\omega$ emission (Fig. 18). If we assume that the enhanced $\Omega$ $\omega$ emission is associated with a specific magnetic field connectivity, then our results imply “step” changes in field connectivity. The general $\Omega$ $\omega$ emission in the active region was found to be approximately 10 times brighter, with strongly enhanced features approximately 100 times brighter, than the average quiet Sun. Simultaneous observations in $L_\alpha$, $L_\beta$, Mg II, and Ca II also show the general active-region enhanced emission as well as strongly enhanced features. The $L_\alpha$ and $L_\beta$ features are identical, but show systematic horizontal displacement with respect to the Ca II and Mg II emission features. Little or no correlation is found with the $\Omega$ $\omega$ structures. With regard to the profiles of the resonance lines, the self-reversal is weak or absent above regions as shown on Figure 19. Presumably the line-forming region has reduced opacity.

e) Studies of Prominences

Temporal evolution of, and velocity field in, prominences were studied with consecutive monochromatic spacecraft rasters. Figure 20 shows, at the top, Ca II images at wavelengths ranging from $-0.012$ nm to $+0.03$ nm from line center. The main loop is clearly visible only at line center; this is confirmed by spectra constructed from the different monochromatic images of the prominence which show a single emission peak with a FWHM of $0.020$ nm which is typical of quiescent prominences (Engvold and Livingston 1971). This is consistent with a mean turbulent velocity of $9$ km s$^{-1}$ and a temperature $T_e = 8500$ K. At the bottom of Figure 20 are two simultaneous $L_\alpha$ and $L_\beta$ images.

Several observations were made to study the thermal structure and evolution of active and eruptive prominences. Figure 21 shows an internal raster performed with a slit of $1'' \times 1''$ above active region McMath No. 14127.

The first three simultaneous images in $L_\alpha$, $L_\beta$, and Ca II $K_{\alpha}$ show a loop system with a rather faint contrast in $K_{\alpha}$ as compared to the plage at the limb, but a higher contrast in $L_\alpha$ (and $L_\beta$). The next three images are separated by 11 minutes (raster repetition rate) and are made in O $\omega$ 103.2 nm. They trace out the high-temperature evolution of the region (O $\omega$ being formed at approximately 350,000 K). The first O $\omega$ image shows a faint high loop, the second some residual brightness around the foot of the loop, and the third an important enhancement at this same point. Then within 20 min the loop disappeared, as can be seen on the next three images in $L_\alpha$, $L_\beta$, and Ca II $K$.

Many images and spectra have been obtained that will allow the study of temperature, density, and velocity variations during loop evolution (Vial et al. 1978).
Fig. 17. The variation with wavelength in the shape of a spot: the superposition of O vi and Ly α and "white light" isophotes evidence a deformation with height in the solar atmosphere.
Fig. 18.—Illustration of step changes in field connectivity of spot evolution. The two upper pictures are satellite rasters made in the wings of Mg II $\lambda$. The two lower pictures are taken simultaneously in O vi. The evolution of the sunspot group is continuous when observed in white light and discontinuous in O vi.
Figure 22 represents observations of an active region at the limb on 1975 July 7. The slit was parallel to the limb and probably intersected it slightly, as indicated by the presence of scattered light in the wings of the Ca II profiles. On the left portion of Figure 22, full and dotted lines correspond to profiles taken at positions separated by only 1". The emission maxima in Ca II and Mg II are displaced shortward with an amplitude corresponding to about 20 and 15 km s\(^{-1}\), respectively. These maxima may in fact correspond to an amplitude of 20 and 15 km s\(^{-1}\), and, if they are corrected for, a shift to the longward is still found for Ca II and Mg II with an amplitude of 5 km s\(^{-1}\). Moreover, Ca II and Mg II lines have essentially the same intensity while La has increased by a factor of 2.

f) Chromosphere-Corona Transition Lines

The two lines Si III 120.65 nm (3s\(^1\)S–3p\(^1\)P\(^0\)) and O VI 103.19 nm (2s\(^2\)P\(^2\)–2p\(^2\)P\(^0\)) are formed in the chromosphere-corona transition region at 40,000 K and 350,000 K, respectively (Jordan 1969). They are observed with the LPSP instrument with a spectral resolution of 0.002 and 0.006 nm, respectively.

The shape of transition-region line profiles may indicate whether there is any propagation of either acoustic or magnetohydrodynamic waves (McWhirter 1977). The presence of such waves may be symptomatic of coronal heating mechanisms.

Figure 23 shows an average (single orbit) Si III profile at the center of the disk (quiet Sun) observed with a resolution of 1" × 40". The FWHM is 0.015 nm and, if we assume that the line is optically thin, the rms (line-of-sight) nonthermal velocity is 22 km s\(^{-1}\). This value is 4 km s\(^{-1}\) higher than the values obtained by Nicolas et al. (1976) for the Si III lines at 128.9 and 130.3 nm. Quiet and active Sun profiles of the O VI line at the center of the disk are given on Figures 24a and 24b. This line is optically thin, and the FWHM is 0.021 nm nearly identical for both quiet and active Sun; the rms line-of-sight nonthermal velocity is 30 km s\(^{-1}\). A departure from a purely Gaussian profile can be noticed in both profiles. The line appears asymmetric and may indicate the effect of a velocity structure in the region of formation of the line.

Figure 24c shows a quiet limb O VI profile, averaged over several positions above the limb (+2° + 6°). The FWHM is now 0.026 nm, equivalent to a rms line-of-sight nonthermal velocity of 38 km s\(^{-1}\). This is larger by 11 km s\(^{-1}\) than the value previously quoted by Moes and Nicolas (1977).

The chromosphere and transition region height distribution is shown on Figure 25 as derived from internal raster scans simultaneously in the wing of Mg II h, Mg II h, O VI 121.8 nm, and N I 119.95 nm.

As is apparent from the figure, the h\(_c\) chromosphere appears to have an additional contribution, which may likely be due to spicules that appear to peak at about the same height as the O VI component. Separate measurements of O VI (and for the far wing of Mg II h) show a similar behavior as O VI. These results would argue for an inhomogeneous transition between chromosphere and corona (cf. Doschek, Feldman, and Tousey 1975).

g) Aeronomy Investigations

At orbital sunsets and sunrises, the solar UV light is absorbed by successively denser layers of the Earth's atmosphere. Vertical distribution of number densities of several components may be studied by this technique as indicated in Table 6. The light in the Ca channels is not attenuated and provides a pointing reference.

The measurement of the width and depth of the hydrogen geocoronal absorption was undertaken during several orbit days. This is a new and very promising observational technique to measure simultaneously the exospheric temperature at each point of the orbit and the atomic hydrogen density at the exobase, which may solve the question of what mechanism(s) control(s) the hydrogen distribution at the exobase. The preliminary results of aeronomy investigation have been published in Vidal-Madjar et al. (1976).

VI. CONCLUSION

We have described here the actual performance of one of the most complex solar physics instruments launched into space and the main results obtained with the first high-resolution multichannel UV and visible spectrometer placed in orbit by OSO 8. For the first time, an absolute pointing accuracy of nearly 1" could be achieved in orbit with real time operations. It undoubtedly represents the largest and most complex experiment of the French space program in solar physics. Although the bulk of the data has not yet been assessed, the results obtained are quite promising for the future.
been examined in detail, preliminary analyses show that the performance of the instrument was nominal and at times beyond nominal expectations. The results presented here are only isolated samples of what has been obtained in the first 18 months. The instrument continues to perform nominally and has begun its third year of operation. This will allow us to obtain more data on active regions and particularly on flares which were very rare during the first 18 months. Indeed, only one flare, that of 1977 April 19, has been observed so far (Jouchoux et al. 1977).

The operation of the instrument has been very exhausting, and we have benefited from the assistance of many people. Our experience with regard to the remote management of an entirely automated complex instrument is, we feel, of great value for similar experiments in the future.

The accomplishment of this experiment would not have been possible without the support of CNES and particularly of Dr. A. Lebeau, former Director of Programs and Plans, and Professor M. Levy, former President. We would like to thank collectively the NASA and CNES engineers who have contributed to this experiment.

The operations of the instrument from Boulder would not have been possible without the kind hospitality of LASP, in particular of its Director, Professor C. Barth. We also thank the LASP OSO 8 staff for their contributions. We are indebted to NASA and LASP for access to space on the American calibration rockets. The excellent spirit of cooperation and the dedicated service of the OSO 8 Control Center at the Goddard Space Flight Center was certainly a key to the success of real time acquisition and of the daily programming of observations in general. The observations of sunspots, active regions, and flaring regions could not have been done without the generous assistance of NOAA, Big Bear Solar Observatory, Meudon Observatory, Sacramento Peak Observatory, and Lockheed Research Laboratory. We wish to express our warmest acknowledgements to these numerous and often anonymous people who played such an important although thankless role in the daily work required by the continuous observation of the Sun during several years. Highly appreciated were the contribution of Drs. P. Bruston and M. Malinovsky of LPSP in the preparation and checkout of observing programs. Invaluable and continuous support in the daily operations was provided by M. Bruston (Mrs.) and N. Dionnau of LPSP. We also thank J. Borsenberger (Institut d'Astrophysique de Paris) and B. Phissamay (LPSP) for their important contribution.

Last but not the least, all of the Guest Investigators who have assisted our team in the operation and
Fig. 20.—Series of satellite raster negative images, taken at different positions in the Ca K line ranging from $-0.012$ nm to $+0.03$ nm from line center. At the bottom are two simultaneous images of the loop prominence in Lα and Lβ. Image size is $2'3 \times 2'7$, repetition rate 82 s, resolution $10'' \times 10''$.


The contribution, calibration, and operation of this instrument were funded under CNES contracts 70-220, 71-202, 73-202, 74-202, 75-202, 76-202, and 77-202. Special funding was provided by CNRS for the salaries of the seven LPSP scientists and programmers in charge of the operations at Boulder. The Guest Investigator Program was funded in the USA under NASA grant NSG 7130.

Additional acknowledgement must go to G. Sharmer for his extensive and supportive contributions which far exceeded his role as Guest Investigator.
Fig. 21.—Development and evolution of an eruptive prominence associated with Active Region 14127 (McMath number) when it crossed the west limb.
Fig. 22.—Profiles taken over an active region visible at the limb on 1975 July 7. The set of profiles on the left (solid and dashed lines) correspond to two points 1° apart. On the right, solid and dashed profiles correspond to profiles taken 22 min apart, in time.
Fig. 23.—Profile of the Si III 120.6 nm line observed at Sun center with a resolution of 1" x 40". Wavelengths increase to the left. For conversion into λ units, see Table 1. Counts represent an average over one orbit.

Fig. 24.—(a) Quiet and (b) active Sun profiles of O vi at Sun center. Each profile is an average of 20 individual profiles. The full lines represent the observations; the dashed line, a best Gaussian fit. The resolution is 1" x 40". Wavelengths increase to the left. For conversion into λ units, see Table 1. Profile (c) refers to the limb; it is also an average, but the individual profiles were observed at another orbit, and the units cannot be compared with those of profiles (a) and (b).
LPSP INSTRUMENT ON OSO 8

Fig. 25.—Limb “darkening” profiles, in Mg ii h3, the far wing of Mg ii k, N i 119.95 nm, and O v 121.83 nm. Distance is measured in arcsec (arbitrary origin).

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Fig. 8.—Internal raster images of the quiet Sun chromospheric network in Ca II K and H, Mg II h and κ, Lα, and Lβ. The field is 64′′ × 64′′, the slit size 1″ × 1″.

Bonnet et al. (see page 1044)