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A comparison has been made between the extreme ultraviolet (XUV) solar images obtained since 1963 by the Naval Research Laboratory (NRL), and the corresponding Ca-K spectroheliograms photographed by the McMath-Hulbert Observatory, giving special attention to the centers of activity and the corona. One rocket-borne instrument is a spectroheliograph, that produces a spectrum of monochromatic solar images, covering λ 171 - 650 Å. Although there is much overlapping, the images in certain important lines are sufficiently separated to permit distinguishing between centers of activity. These lines are He II 304 Å, O IV 554 Å, O V 630 Å, Ne VII 465 Å, Mg IX 368 Å, Fe XV 284 Å and Fe XVI 335, 361 Å; arranged in this order they come from higher and higher levels in the solar atmosphere; therefore, viewed in these lines, the change in form and intensity of a center of activity can be followed through the chromosphere into the corona. The resonance lines of Fe IX - XIV between 171 Å and 274 Å are also present, with great intensity; but

they lie so close together that the solar images are not well separated.

A second type of instrument, called an XUV heliograph, was first flown on 27 July 1966. This uses a paraboloidal mirror and three aluminum filters in series to form a broad-band XUV solar image, including all emissions from 171 Å to about 500 Å. The image has great intensity; with 30 sec exposures XUV coronal emission extending to 3 $R_\odot$ has been recorded (Purcell, Tousey and Koomen, 1967).

Table I lists the dates on which spectroheliograms and heliograms have been obtained by NRL, and describes briefly the solar activity and the nature of the photographic results. For the purpose of making intensity correlations between the XUV and Ca-K plages, an arbitrary intensity scale was set up, similar to the one which is used for Ca-K plages at the McMath-Hulbert Observatory. Plages were selected no farther than approximately 70° from the central longitude. The photographic density of each active region in He II 304 Å was estimated relative to the average disk background on a scale rated: 1 = just detectable, to 5 = extremely bright. This was also done for the XUV heliograms.

When the He II 304 Å intensity values were plotted against the McMath-Hulbert values for the same regions in Ca-K, a linear relationship was observed with a scatter of ± half a scale unit, excluding the exceptional cases to be discussed. The intensity estimates of the plages, as recorded by the broad-band XUV heliograph, also correlated well with Ca-K. The plages in He II 304 Å are more intense, relative to the quiet background than in Ca-K, as was found for H-Lyman-α (Purcell and Tousey, 1961). For the higher ionization lines such as Mg IX 368 Å, Fe XV 284 Å and Fe XVI 335, 361 Å there was no background against which to make a comparison; however, with a few exceptions, the plage intensities in the different lines increased or decreased together.

There were a few cases of plages not close to the limb that were clearly different in the XUV than in Ca-K. The most notable example is shown in Figure 1, where two of the best He II 304 Å images obtained as yet, with 10″ spatial resolution, are compared with images in Ca-K and H-α. The activity on 28 April 1966 lay in a belt in the north. The plage at 9° E, 28° N is strong in Ca-K but is just

detectable in He II; in H-α this feature is small and weak, and is surrounded by a ray-like absorption structure. This plage received no McMath-Hulbert number, but was the western extension of plage #8278. Its position was about halfway between the two longitude zones of maximum activity.

Great differences between the XUV and the Ca-K images are observed for regions near and on the limb. For example, in Figure 2 two exposures with the XUV heliograph on 27 July 1966 are compared with Ca-K and H-α. Over most of the disc the same plages are present, with similar shapes and intensities. Within one or two minutes of the limb and beyond the limb, however, the images show much more emission in the XUV than in Ca-K. The intense XUV emission in the NW is the most striking example; it is not present at all in Ca-K and H-α. This activity is the coronal extension above a plage complex that was two to three days over the limb.

The bright, partial ring present in Figure 2 is a characteristic of all XUV heliograms and is much the same in images produced by x-rays of $\lambda < 100$ Å. It is composed of two parts, which cannot be fully separated without greater spatial resolution. One is just the corona above the quiet regions; the emitting layer is optically thin and is

much more intense when viewed edge-on. The second contribution is from the corona above the active regions on or within a few days of limb passage. The ring is especially pronounced in all of the XUV images obtained by NRL because, for every flight date except 20 September 1963, both zones A and B of maximum solar activity (H. Dodson-Prince and E. R. Hedeman, 1967) lay close to the limb, and the disc as a whole showed a relatively "empty center". Therefore, enhancements in the emission ring were prominent; for each enhancement an active center that appeared to account for it was found either on the limb or within one to five days of limb passage.

The high spatial resolution spectroheliograms of 28 April 1966 show several interesting limb features. In Figure 3 the range 240 - 340 Å is reproduced, and in Figure 4 four particular images are brought together for comparison.

In Fe XV 284 Å and Fe XVI 335 Å there is coronal emission in the NW that extends to about 65° apparent latitude and reaches 5′ beyond the limb. This emission is present also in He II 304 Å, but in this case there is a possibility that it may be caused by Si XI 304 Å instead of He II (Smith, 1967). This coronal emission is believed to originate from a large active complex between latitudes 15° and 35°, and lying

30° to 60°, heliocentric, over the limb; this was the great particle-emitting region of March 1966. The complex was assigned plage numbers 8262 and 8275 and had total area 7100 and intensity 3.5 during the preceding half-period; it was given numbers 8294, 8299, 8300 during the succeeding half-period. Therefore the XUV emission region, seen in projection above the NW limb, was at a height above the photosphere of at least 3.5×10^5 km ($0.5\ R_\odot$) and may have been observed to 10^6 km ($1.5\ R_\odot$).

Close to east limb passage on 28 April 1966 there were two centers of activity; plage #8284 at 24°N latitude crossed the limb one day earlier; plage #8285 at 18° N latitude crossed two days later. The difference in XUV emission from them is easily observable in Figures 1, 3, and 4. Plage #8284, on the visible side of the sun, is observable in all lines, including, of course Ca-K, H-α, and He II. In O V, however, its area is very small and its intensity is great. Coronal emission above plage #8285 on the back side cannot be seen in H-α, Ca-K, He II, O IV, O V, and probably not in Ne VII. It is conspicuous, however, in Mg IX, Si XII, Fe XV, and Fe XVI. It is most diffuse in Mg IX, and appears to have the steepest gradient in Fe XVI. Because plage #8284 lies closer

to the limb than #8285, and has twice the area (3900 vs 1900), it would be expected to show as much or more emission above the limb, but none was detected. A possible explanation is that the extensions into the corona are not radial, but are strongly tilted under the influence of the local magnetic field. Another possibility is that the two plages were really different in character. Actually #8285 was new, and was recorded with intensity 3, and sunspot classification A; plage #8284, on the other hand, was the return of #8240, and its intensity was only 2.5; it was class J. This suggests that emission extends higher into the corona above a new and intense plage than above one that is old, more diffuse, and less intense.

In order to make a comparison between the XUV images and the white light corona, a flight was scheduled for 12 November 1966, the day of the total eclipse in So. America. Figure 5 shows Newkirk's (1967) beautiful eclipse photograph, but with the center removed and an XUV image introduced to scale. Below, is another XUV image that was exposed for a longer time. Close to the limb the XUV emission matches very well the detail in the white light corona. This is to be expected, because collisional excitation of the XUV resonance

lines follows n_e^2, and optical excitation follows n_e. Farther out, however, the two types of corona are less similar; the long XUV exposure shows no structure or streamers, but only a diffuse emission, correlating in an approximate fashion with the white light corona.

The XUV spectroheliograms and heliograms contain a great deal of information about the structure of the chromosphere and corona. But to make use of them a day to day series is required. The spatial resolution should be the greatest that can be attained. An instrument to accomplish this with about 1′ resolution is nearing completion at NRL, and will be flown in an Orbiting Solar Observatory (OSO-F) in 1968. This will be followed, one to two years later, by a photographic spectroheliograph with very high spatial resolution, that will be included in the Astronomical Telescope Mount of the Apollo Applications Program, and will operate over one to two solar rotations.

We wish to express our sincere appreciation to Dr. Helen Dodson-Prince and to Miss Ruth Hedeman of the McMath-Hulbert Observatory for making available their solar data and much helpful advice.

TABLE I

DATE	INSTRUMENT	IMAGE SIZE	SPATIAL RESOLUTION	SOLAR CONDITIONS
10 May 1963	Spectroheliograph 170-400 Å	1.8 mm	1′	Numerous old cycle regions of moderate activity.
28 June 1963	Spectroheliograph 170-400 Å	1.8 mm	1′	The data covered zone A. The principal centers of activity were on the back side.
20 September 1963	Spectroheliograph 170-400 Å	1.8 mm	40″	The flare-rich proton region was near the "center", but the flight occurred 8 hrs. before the great proton flare.
20 October 1965	Spectroheliograph 170-700 Å	4.6 mm	20″	Only small plages present on front side. The big spot and radio region of Oct. was on the back side.
1 February 1966	Spectroheliograph 170-700 Å	4.6 mm	1′	An "empty center." The major regions (January cluster) on the back side marked the first distinctive rise in activity in the new cycle. The features near the east limb were ancestors of the great April region
28 April 1966	Spectroheliograph 170-700 Å	4.6 mm	10″	Region #8279 (NE) was the return of the great April region. The back side was the site of the great proton region of March

TABLE I (contd)

DATE	INSTRUMENT	IMAGE SIZE	SPATIAL RESOLUTION	SOLAR CONDITIONS
27 July 1966	Heliograph 171-400 Å	4.6 mm	1′.5	Zones A and B were on the limbs. The north member of the double group in the east was the return of the 7 July proton flare and was the site of a flare on 28 July. The region just south and to the east of it was the site of proton flares on 28 Aug. and 2 Sept.
12 November 1966	Heliograph 171-500 Å	2.3 mm	30″	Plage #8573 dominated the "center" and contained a spot of long duration (six rotations) that formed in Aug., and radiated strongly at radio frequencies. The strong region in the NW was new.
9 May 1967	Spectroheliograph 170-370 Å; 550-700 Å	4.6 mm	15″	The only big region on the sun was on the opposite hemisphere. Zones A and B were again at the limb.
	Heliograph 171-500 Å	2.3 mm	30″	

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Newkirk, G. Jr.: 1967, Sky and Telescope 33, 136.

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Smith, T. S.: 1967, discussion at the meeting of the Am. Astron. Soc., Boulder, Colo., Oct. 3, 1966.

FIGURE CAPTIONS

Fig. 1 Two He II 304 Å spectroheliograms obtained on 28 April 1966, compared with Ca-K from Mt. Wilson and H-α from Sacramento Peak. The Fe XV 284 Å image, whose position is shown, produces the plages that appear at the center of the He II image, and others that are in the west; several prominences are present in He II, but Fe XVI 335 Å accounts for the large limb feature in the NE.

Fig. 2 Medium and long exposures with the XUV heliograph (171 - 500 Å) on 27 July 1966, compared with Ca-K and H-α from the Mt. Wilson Observatory. The grid pattern was caused by the mesh on which one of the aluminum filters was supported.

Fig. 3 The section, 250 - 340 Å, of the spectroheliogram of longest exposure on 28 April 1966, printed so as to reproduce the coronal emission in the NW, associated with Fe XVI 335 Å, Fe XV 284 Å, He II and Si XI 304 Å, and faintly with Fe XIV.

Fig. 4 Sections of the 28 April 1966 spectroheliogram covering O IV 554 Å, O V 630 Å, Ne VII 465 Å, and Mg IX 368 Å. Also present are a small part of the He I 584 Å image, and half of the second-order image of He II 304 Å. The east limb features discussed in the test are indicated.

Fig. 5 The white light corona, photographed during the 12 November 1966 eclipse by the Bolivian Expedition of the High Altitude Observatory and The Johns Hopkins University, with the center replaced by an XUV heliogram obtained on the same date by the Naval Research Laboratory. The second heliogram, of long exposure, shows the extension of XUV emission into the corona. North is at the top and east to the left.

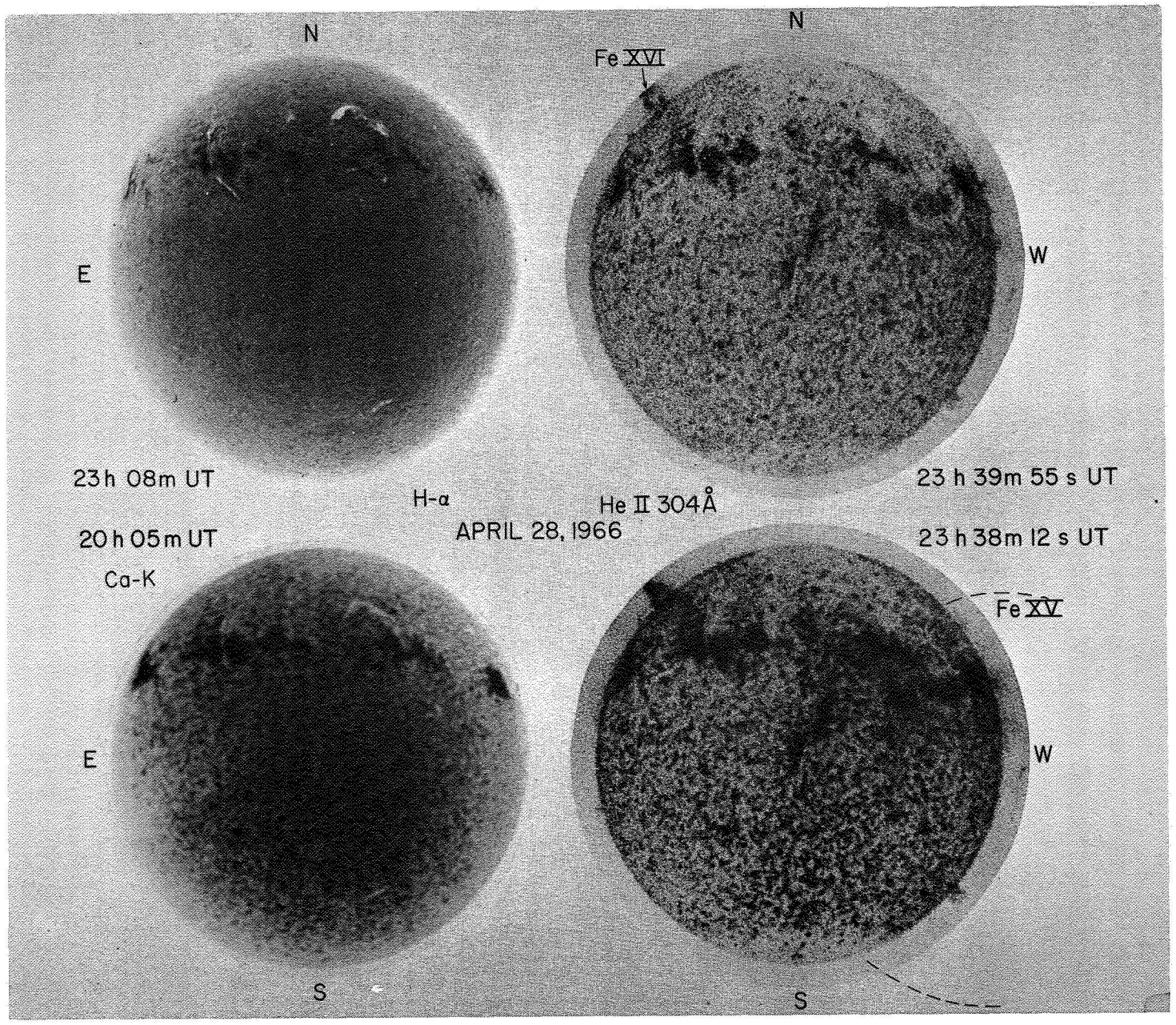

N
E
23h 08m UT
H-α
N
Fe XVI
W
23 h 39m 55 s UT
He II 304Å
APRIL 28, 1966
20 h 05m UT
Ca-K
E
S
23 h 38m 12 s UT
Fe XV
W
S

Figure 1

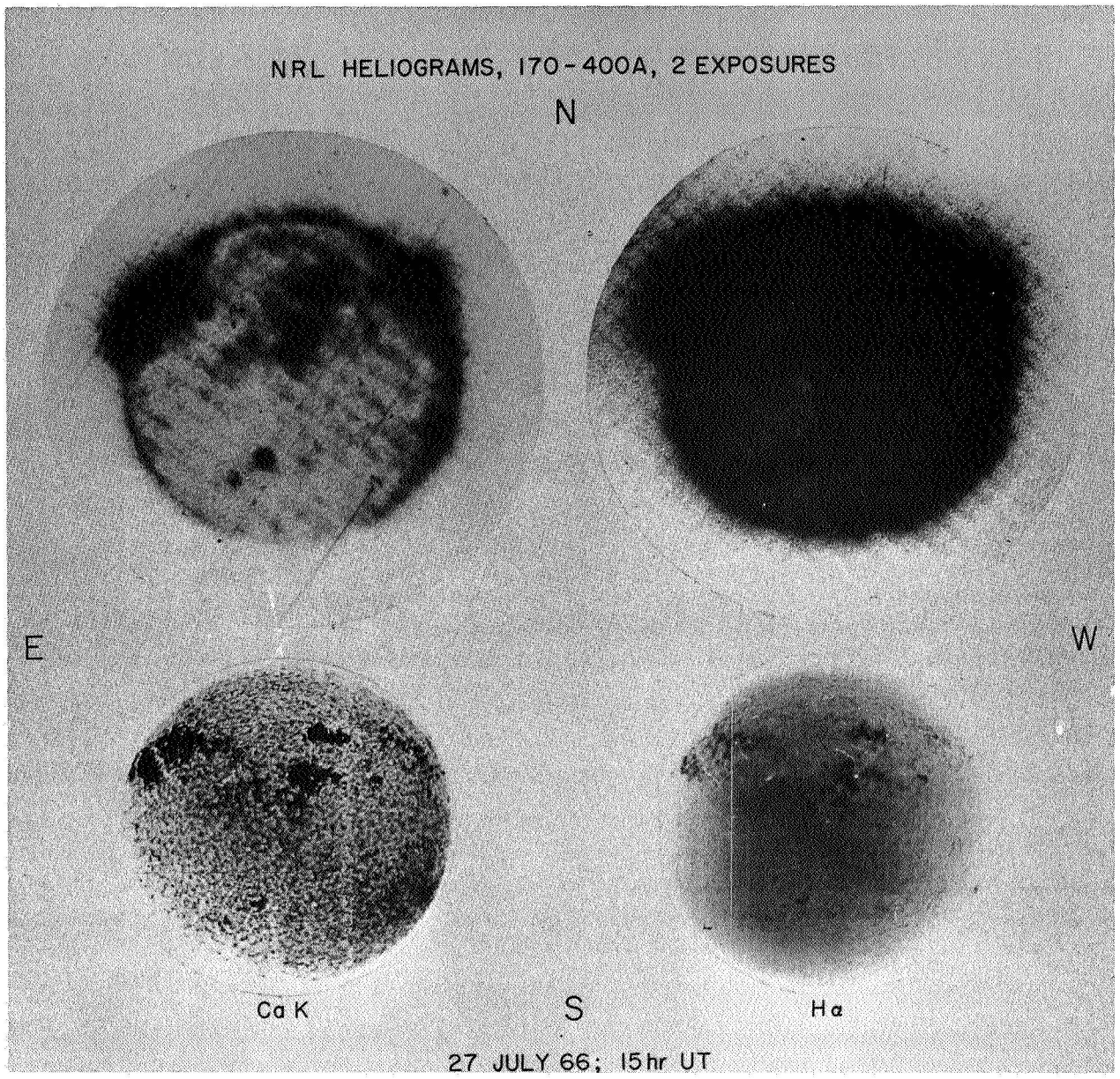

NRL HELIOGRAMS, 170-400A, 2 EXPOSURES
N
E
W
Ca K
S
Hα
27 JULY 66; 15hr UT

Figure 2

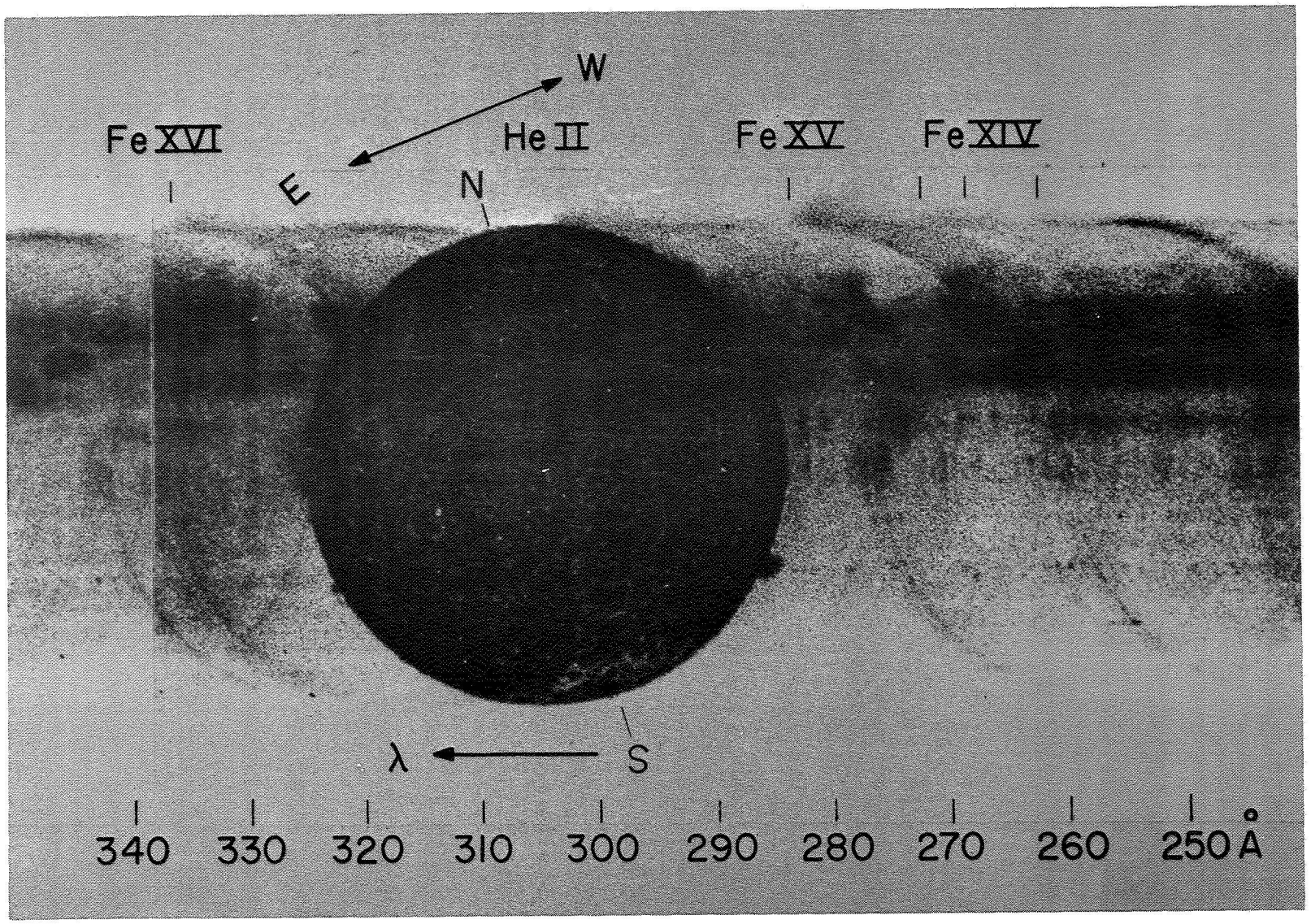

W
Fe XVI
He II
Fe XV
Fe XIV
E
N
λ
S
340
330
320
310
300
290
280
270
260
250 Å

Figure 3

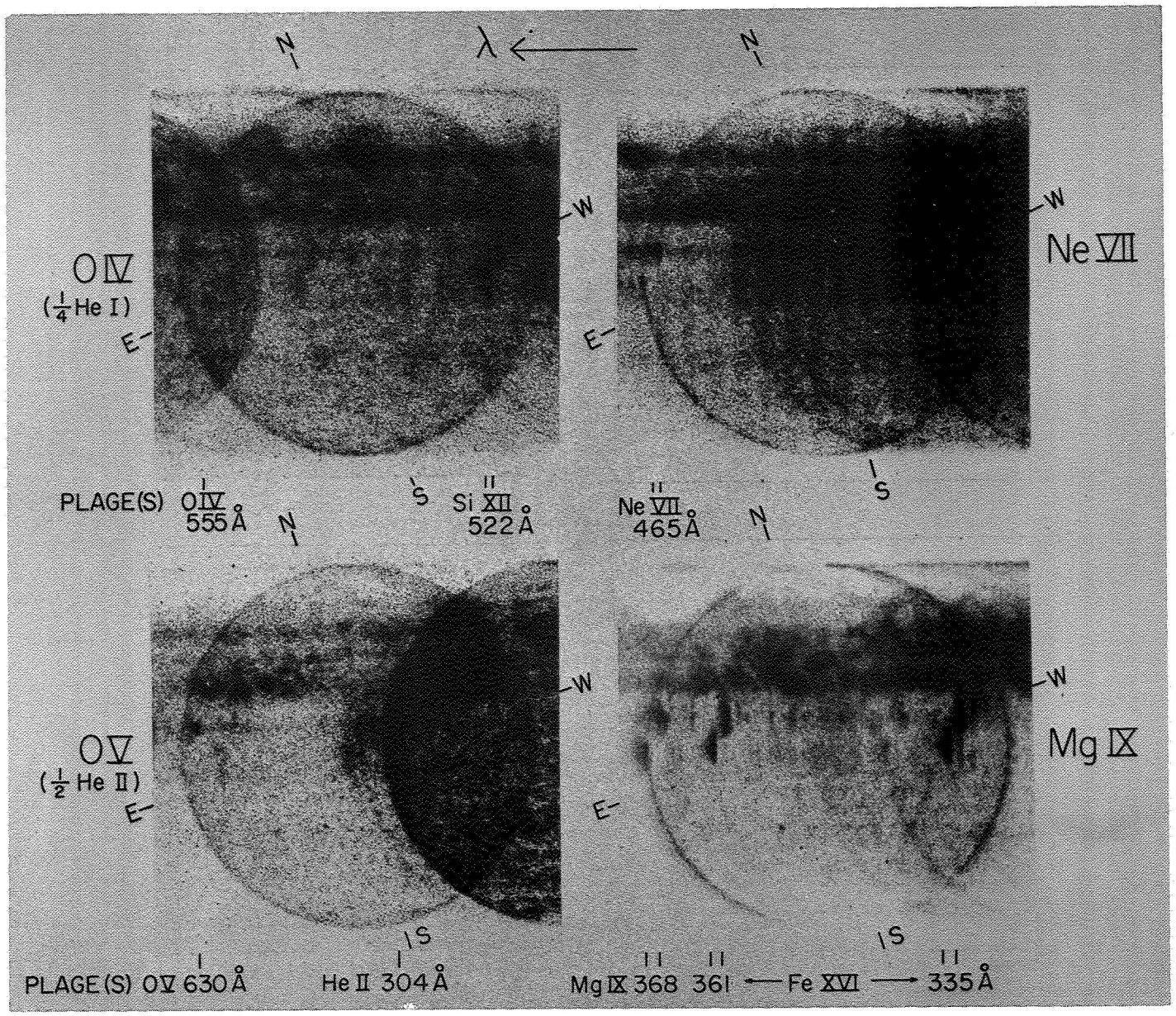
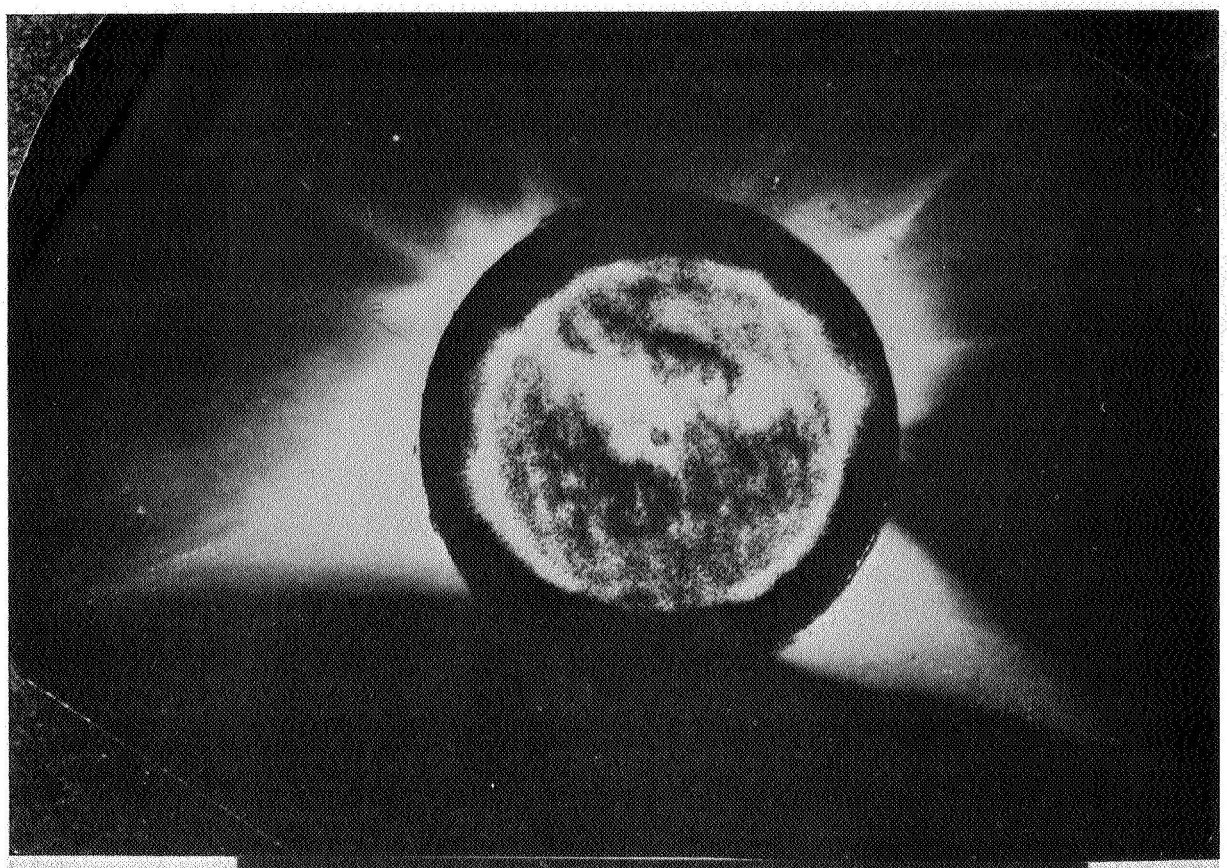
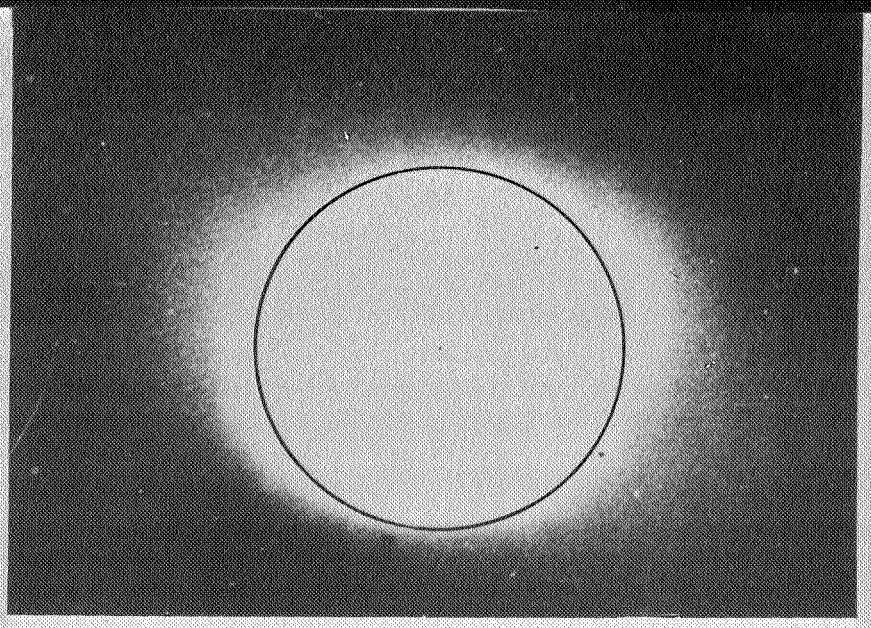

λ
N
W
E
S
O IV
(¼ He I)
PLAGE(S) O IV 555 Å
Si XII 522 Å
Ne VII
Ne VII 465 Å
O V
(½ He II)
PLAGE(S) O V 630 Å
He II 304 Å
Mg IX
Mg IX 368 361 ← Fe XVI → 335 Å

Figure 4





12 NOV. 66 1620 UT

TOP: CENTER, XUV SOLAR DISK 170-400Å NRL
OUTSIDE, WHITE-LIGHT CORONA NEWKIRK H A O

BOTTOM: XUV SOLAR DISK 170-400Å LONG EXPOSURE NRL

Figure 5