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PRELIMINARY SOLAR FLARE OBSERVATIONS WITH A SOFT X-RAY SPECTROMETER ON THE ORBITING SOLAR OBSERVATORY

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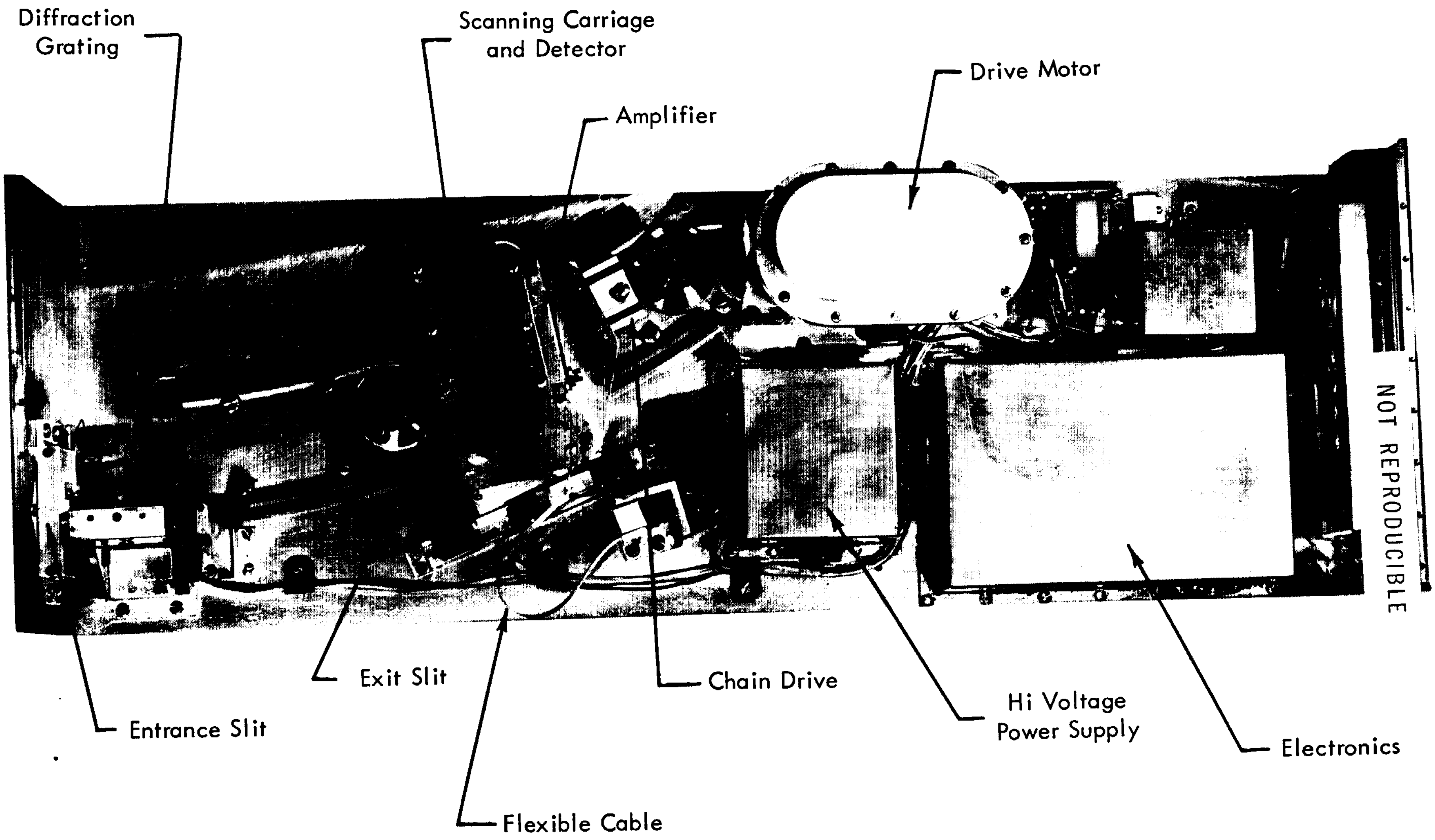
INTRODUCTION:

The prime experiment flown on the first Orbiting Solar Observatory was a soft x-ray spectrometer designed specifically to make satellite measurements of the solar spectrum from wavelengths of 10 to 400 Angstroms. As a result of the successful launch of the satellite into a near circular earth orbit, 550 km perigee and 600 km apogee, and the subsequent successful operation of the experiment, the first long term measurements of the soft x-ray solar spectrum have been obtained. Our purpose in this paper is to describe briefly the instrument, to illustrate its performance with data obtained from a rocket launch and to present some very preliminary satellite data obtained before and during the solar flare of 13 March 1962.

THE SPECTROMETER:

The angular aperture of the spectrometer is approximately 1.2 by 2.2 degrees. Hence, with moderately accurate pointing (within plus or minus a few minutes of the center of the solar disc), the spectrometer responds to the total light intensity emitted by the sun. The orientation of the spectrometer is such that the sunlight falls perpendicularly on the front face of the instrument (Figure 1.), passes through the entrance slit and strikes a concave grating mounted in grazing incidence, the angle of incidence being 88 degrees. The grating is an original which has been



OSO SPECTROMETER

FIG I

lightly ruled in a special glass by the Nobel Institute in Stockholm at 576 lines per mm on a one-meter radius of curvature blank. No reflecting coatings of any kind were used on this grating. The diffracted rays continue to the exit slit in front of the detector. The detector is mounted on a carriage, which moves on a circular rail so that the exit slit follows along the Rowland circle where the spectrum is in focus. The plane of the exit slit stays approximately perpendicular to the diffracted ray at all positions along the rail, thereby keeping the spectral passband nearly constant for all angles of diffraction. The 50 micron entrance and exit slits provide a spectral passband of 1.7A and permit resolution of lines 0.85A apart.

The detector used was an open window multiplier phototube developed by the Bendix Corporation specifically for use in this spectrometer and designated the M-306. Photoelectrons from the tungsten cathode move along cycloidal paths in crossed electric and magnetic fields between two glass strips, each coated with a semi-conducting secondary-emitting oxide layer. One of the glass strips serves as a continuous dynode. Each photoelectron is multiplied into a pulse of approximately 10^6 electrons at the anode. These electrical pulses are amplified and after coding to compress bandwidth are recorded on a tape recorder for later transmission to a ground station.

The spectrometer uses about 1.3 watts supplied by the satellite at 18 volts D.C. About one watt of this goes to the oscillator powering the three-phase synchronous motor which requires about 300 mw at 137 cps to yield 100 mw of mechanical output power. The remainder of the power is used in the multiplier and pulse handling circuitry.

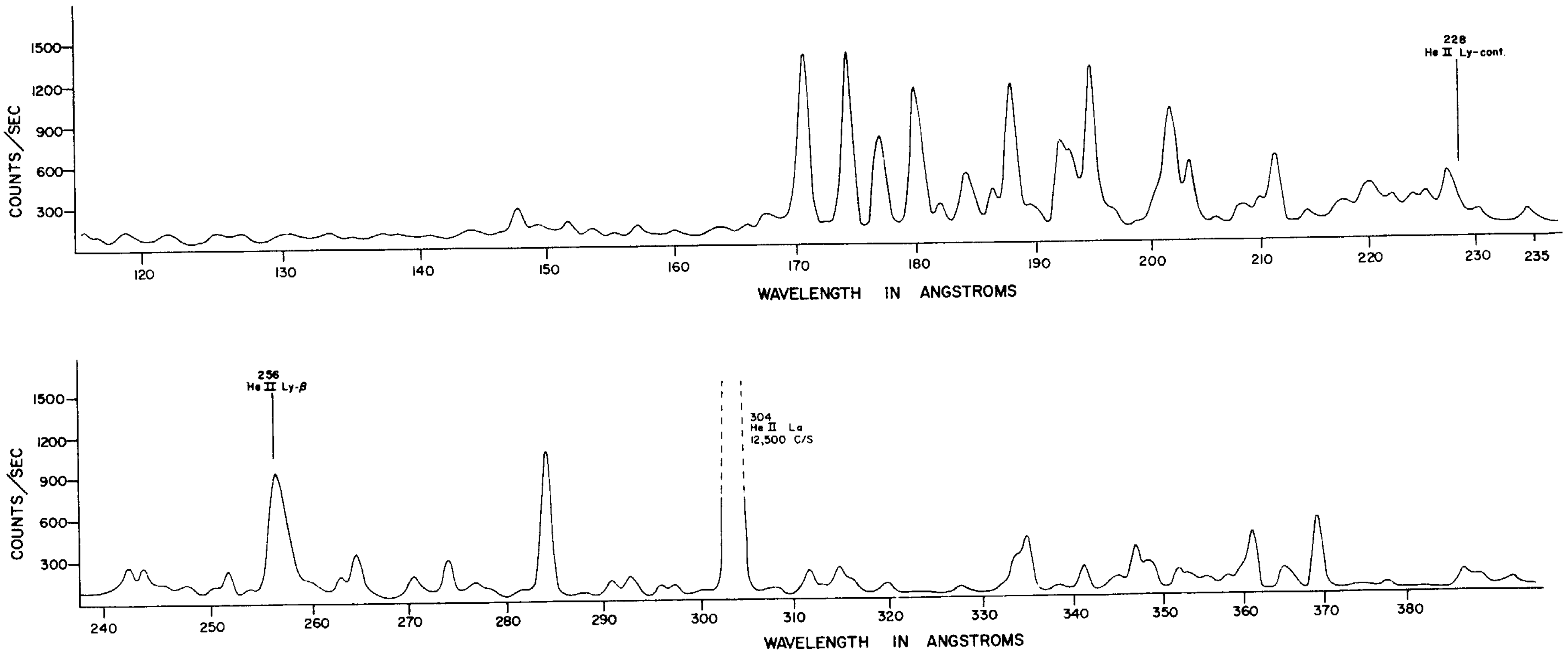
All of the materials exposed inside the spectrometer were tested at a pressure of about 10^{-6} mm of Hg to eliminate any material which had a high vapor pressure. Because the electronic circuits were potted in a compound having a high vapor pressure, they were enclosed in sealed boxes which were vented to the outside through holes in the spectrometer base plate. During assembly all the parts exposed to the interior were carefully cleaned to be free of oil, grease, and other contaminants.

The temperature of the instrument is controlled by the radiation balance. Most of the outer case was polished. The central section was painted black in order to tie the temperature closely to that of the satellite.

Alignment of the spectrometer was accomplished using only visible light by means of a fixture with a radius rod pivoted at the center of the Rowland circle. The procedure was developed on the basis of the method described by Rathenau and Peerlkamp. (Reference 1). Alignment tests were performed using a source of carbon K radiation. A separate Bendix photomultiplier was used to provide a monitor on the stability of this source. The response to scattered hydrogen Lyman-alpha radiation was checked using a closed hydrogen discharge lamp. The grating used was selected by means of comparative tests performed on several gratings by Professor Tomboulian at Cornell University.

THE ROCKET FLIGHT:

Figure 2 shows the solar spectrum obtained with a similar instrument during an Aerobee rocket flight using a Ball Brothers rocket pointing control. In this spectrum the wavelength regions of 120A to 170A and 220A to 240A represent the average of data taken in three different scans in an attempt



SOLAR SPECTRUM
SEPT 30 1961

TIME 14:33 (GMT) ALT. 201 TO 216 KM

FIG 2

to improve the reliability of faint lines and to provide continuity in the region originally containing wavelength marker pulses. In the region below 100A evidence of spectral lines is inconclusive. Comparison of the observed counting rates with laboratory scattered light measurements indicates that for the rocket flight the signal attributable to the first order spectrum becomes lost in the scattered light below about 60A.

An attempt has been made to identify the resonance lines of highly ionized atoms of the heavier elements. Lines produced by several stages of ionization of C, N, O, and also by Mg, Si, Ne and Fe have already been found at longer wavelengths. The extension of isoelectronic sequences to heavier elements leads to resonance lines with wavelengths below 400A. The wavelengths of some of the strong lines observed are shown in Table I, along with tentative identifications of their origin. The tabulation of emissions compiled by Varsavsky (Reference 2), was used in this work.

Criteria for making assignments were: (1) agreement with theoretically extrapolated values of the spacing and relative intensities of members of a multiplet, assuming, for the intensities, an optically thin corona, (2) approximate agreement in wavelength with theory for lines not yet observed under laboratory conditions, and (3) observation of more than one stage of ionization.

A preliminary analysis of the spectrum was made for ions known to exist in the solar atmosphere. These are ions of Fe, Ni, and, with lesser abundances, Ca and A. Identification of iron multiplets on the basis of one observation is made difficult by the presence of strong second order lines as well as the superposition of the multiplets themselves. Only the Fe XV line has been calculated with accuracy by Edlen (Reference 3), and has been

TABLE I

IDENTIFICATION	WAVELENGTH (Angstroms)	IDENTIFICATION	WAVELENGTH (Angstroms)
Fe XIV, Fe XII	370	He II, Ni XVII	256
Fe X	366	A XIV	250
	365	He II	244
Fe XVI	361		243
Fe XII	360	He II	234
Ni XV, Fe X	347	Ca XV	227
Fe XIV	345	S IX	220
	341		211
Fe XVI	335		204
Ni XV	333		202
	320		195
Ni XV	316		193
	315		192
	312	A XI	188
He II	304	A XI	186
	293	Cl IX	184
Fe XV	284		182
Cu XIX	274	Cl IX	180
	271		177
S X	264		174
A XIV	263		171

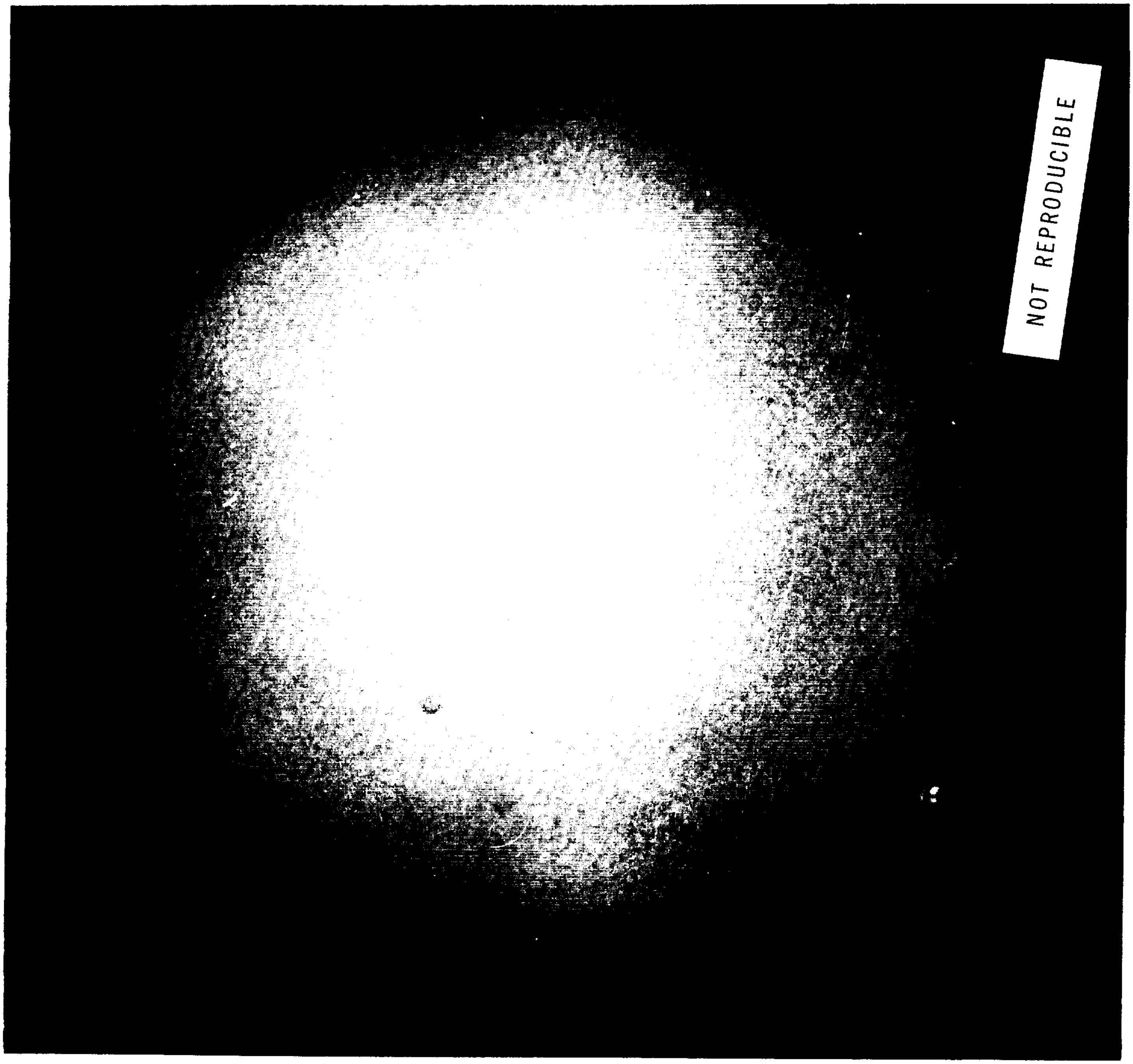
identified with a strong line at 284A. The resonance lines of Ca XII and Ca XIII (two ions observed in the visible coronal spectrum), cannot be associated with any of the emissions in the far ultraviolet spectrum. Neither is a correlation observed, although it is expected, for A X.

All of the foregoing assignments must be regarded as tentative and are presented as "work in progress." It is expected that application of satellite observations and further theoretical analyses can be combined to achieve more reliable identifications.

Long term observations from the satellite will permit additional conditions to be applied: (1) constancy in time of the ratio of intensities of members of a multiplet, assuming no change in the opacity of the corona with time, (2) regularity in the variations of intensity over the observed stages of ionizations; and (3) for each stage of ionization, agreement in variations of intensity with corresponding variations in visual coronal lines.

PRELIMINARY SATELLITE OBSERVATIONS:

The Orbiting Solar Observatory was launched at 1606 UT, 7 March 1962. The sun was unusually quiet until 13 March when a small flare occurred. The Hα flare (Figure 3), shows sun in Hα at 15:43:22), was classified as a 2+ by Wendelstein, the onset being recorded under very poor observing conditions at 1448 UT with the duration observed as 73 minutes. The heliographic coordinates were recorded as E66, N06. Climax first observed the flare in progress at 1502 UT, estimating the importance as 1+ and recorded



PHOTOGRAPH OF
HYDROGEN ALPHA FLARE
AT 1543:22
COURTESY OF HIGH ALTITUDE
OBSERVATORY: BOULDER, COLO.

FIG 3

the ending at 1615 UT. The heliographic coordinates were recorded as E63, N03. A typical S-SWF(short wave fadeout) was recorded at NERA at 1448 UT with importance 2 (scale 1-3+, somewhat like that for flares). HAO gives 1455-1634 UT for the duration and 3 for the importance. Type III radio bursts were recorded by HAO on 22-41 MC from 1519 to 1550 UT. Major radio bursts occurred on 108 MC from 1450 to 1510 UT and on 200 MC from 1450 to 1505. There was no evidence of energetic particle fluxes.

In the time available, it has been possible to reduce only partially the satellite data for the six orbits that surrounded the beginning of the visual flare. Three spectral lines were chosen for analysis: He II Lyman Alpha at 303.8 Angstroms, 284 Angstroms (tentatively identified as an Fe XV line), and 171 Angstroms of unknown origin. These data are shown in Figure 4, from which we observe:

1. Increased emission conciding with or preceeding visual observations or other indicators.
2. Continued enhancement after cessation of other indicators.

Using average values for these three lines before the onset of the flare and during the flare, we find the percentage enhancements for the lines were as follows: 304A, 10%; 283A, 34%; 171A, 35%. Typical error flags are shown with the data. Practically all of the error is statistical, and is due to the relatively small number of photons counted. The changes in the observed line intensities are larger than the expected errors, and are believed to represent real changes associated with the flare.

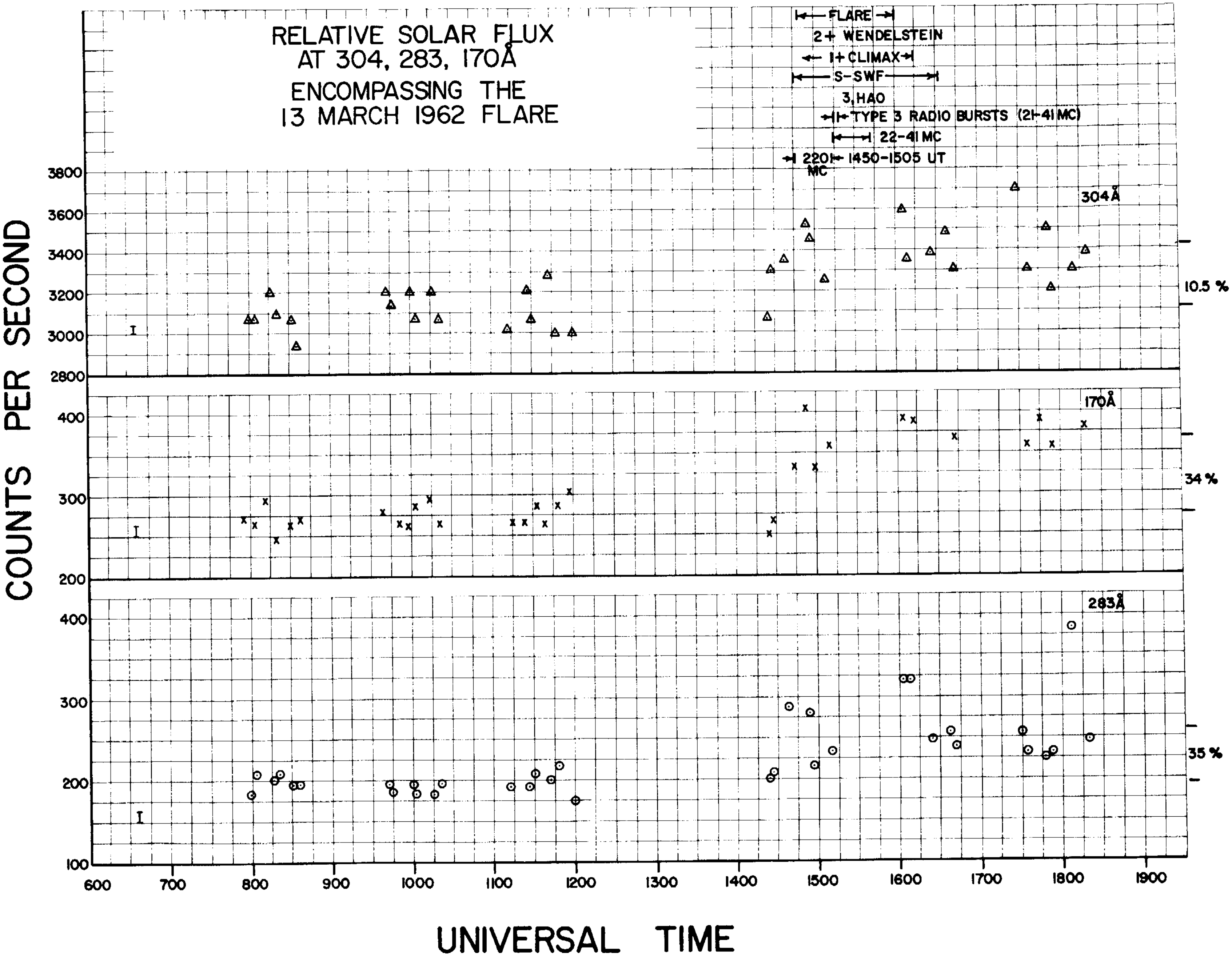

RELATIVE SOLAR FLUX
AT 304, 283, 170Å
ENCOMPASSING THE
13 MARCH 1962 FLARE
FLARE
2+ WENDELSTEIN
1+ CLIMAX
S-SWF
3 HAO
TYPE 3 RADIO BURSTS (21-41 MC)
22-41 MC
2201 MC
1450-1505 UT
304Å
170Å
283Å
10.5 %
34 %
35 %
COUNTS PER SECOND
3800
3600
3400
3200
3000
2800
400
300
200
400
300
200
100
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
UNIVERSAL TIME

FIG. 4

As of 13 April the Orbiting Solar Observatory had made approximately 550 orbits around the earth with the result that some 3500 spectra of the sun in the 10-400A region have been collected. During this time fourteen flares of varying importance occurred; the largest a Class 3 on March 22. We believe these data will:

1. Aid in identifying the spectral lines.
2. Allow limits to be placed on the continua in this wavelength region, for a quiet sun as well as during solar activity.
3. Allow quiet sun line intensity measurements with some certainty. From our preliminary measurements, it can be seen that a rocket-borne instrument would have encountered enhancement several hours after the visual flare was over.
4. Determine line intensity enhancement, if any, before and during, and following visual flare activity.
5. Determine enhancement, if any, associated with other solar activity, i.e., plage areas. & spot groups.
6. Determine short time fluctuations in line intensities not associated with other easily observable phenomena.

Analysis and interpretation of these results should throw light on the energy transport in the corona and the relaxation time of the corona as well as form the basis for a more complete model of the chromosphere.

ACKNOWLEDGEMENTS:

So many people played an important part in the development of this spectrometer that it is not possible to mention all of them. However, the authors would like to especially thank Professor D. H. Tomboulian of Cornell University, who developed and carried out the tests of the gratings on the basis of which the flight gratings were selected. He also gave us the benefit of his counsel and his great knowledge of instruments and phenomena in the soft x-ray and vacuum ultraviolet regions. We are indebted also to Mr. Kennard Saffer and Mr. Paul Kraft of the Naval Weapons Plant in Washington, D. C., for executing the design and supervising the construction of the spectrometer. We thank Mr. W. A. Nichols of the Solar Physics Branch, who carried out the modifications required for the rocket spectrometer.

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