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SOLAR SATELLITE PROJECT

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CALIBRATION CHANGES IN EUV SOLAR SATELLITE INSTRUMENTS

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ABSTRACT

This paper reviews the problem of absolute photometric calibration in the extreme ultraviolet range with particular reference to a solar satellite instrument. EUV transfer standards, the use of predispersing spectrometers, and polarization effects at near normal incidence are discussed. Changes in preflight calibration associated with the general problems of contamination are given as the background to the main discussion relating to changes in photometric calibration during orbital operation. Conclusions relating to adequate photometric measurements in orbit are drawn, with a short list of the "best" solar flux measurements for reference. Finally, the importance of rocket flights for photometric calibration of satellite instruments is indicated.

I. INTRODUCTION

A precise knowledge of absolute photometric calibration in the extreme ultraviolet (EUV) spectral range is vital for the detailed interpretation of measurements of plasma diagnostic parameters in solar, stellar, and laboratory light sources. A special need arises in the case of sounding rockets and satellites, because of the infrequency and cost of observations. For our purposes we here refer to the EUV range as that extending upwards from approximately 300 Å, determined by the lower limit cut-off of normal-incidence optical systems, to approximately 1300 - 1400 Å, which overlaps the lower limit of regions accessible with transmitting optics and enclosed photomultipliers. The general problem of photometric calibration for solar rocket or satellite instruments divides logically into two parts. Firstly, a knowledge of the absolute response of the instrument, consisting usually of mirrors, gratings, detectors, and geometrical parameters. The second problem is to maintain the precision of the absolute response through periods of instrument storage and test, launch and stabilization in orbit. We shall discuss these two phases of activity primarily in relation to the Harvard College Observatory spectrometer carried on OSO-IV, launched October 18, 1967, compare the calibration changes to analogous changes under laboratory conditions, and discuss the relevant conclusions.

II. GENERAL BACKGROUND

In the EUV wavelength range, solar instrumentation divides into two main divisions, namely normal incidence optical systems characterized by angles of incidence generally less than 10°, and grazing incidence optical systems where the glancing angles are used to increase the efficiency of the system at the lowest wavelengths. The latter geometry has been used down to 20 Å, while the former has been limited to a lower wavelength characterized by Fe XV (284 Å) because of the high rate at which reflectance in normal incidence systems falls as the wavelength is decreased below 500 Å. The problems of in-orbit calibration changes in these two types of systems are markedly different.

Several grazing incidence spectrometers have been flown for solar observations. These are characterized by the instruments on Orbiting Solar Observatories, particularly OSO-III and -IV. Of special interest are two experiments which viewed the sun continuously during the daylight portion of the orbit, and were provided by H. Hinteregger[1] and by W. Neupert et al[2]. Both instruments and results have been described in more detail elsewhere.

These two instruments both used Bendix magnetic electron multipliers (different types) and a grating as the single optical element. The Air Force Cambridge Research Laboratory instrument "unfortunately...suffered from a slow but progressive deterioration of absolute efficiency, the exact time-dependence and wavelength dependence of which could be assessed only approximately."[3] This steady decrease can readily be explained in terms of a steady loss of the gain of the electron multiplier which would cause the pulse light distribution of emergent pulses to shift and submerge below the fixed threshold of the amplification and counting system. An order of magnitude drop in sensitivity was observed over a period of several months, but no change could be specifically attributed to changes in the grating efficiency in this trend[4]. By itself this latter comment would be inconclusive. However, the Goddard Space Flight Center grazing incidence spectrometer on the same spacecraft experienced no change in either grating efficiency or overall sensitivity and after a year was "functioning without deterioration"[2]. A similar long term maintenance of sensitivity has been observed by the University College London grazing incidence monochromator in the wheel portion of OSO-IV. A single Bendix magnetic electron multiplier accommodates the positions of He II (λ 304) and L_α (λ 1216) and records the integrated solar disc intensity every few seconds. Rocket flights were used to assess the maintenance of sensitivity[5].

From the in-flight performance of these instruments it appears that optical systems at grazing incidence can maintain a stable efficiency over long periods of time in an ambient vacuum of 10^{-9} Torr, providing the gain of the electron multiplier and amplification systems remains high enough to detect the major fraction of the photomultiplier pulses.

Normal incidence optical systems for solar EUV observations have shown significant variations of sensitivity during prolonged periods of laboratory storage and in-orbit operation. Instrumentation is here characterized by the Harvard College Observatory spectrometer-spectroheliometer (to be described in greater detail in the next section) and the Naval Research Laboratory instrument of Dr. R. Tousey and his collaborators on OSO-V. The NRL instrument consisted of an objective grating with a series of six Mullard channel multipliers spanning the wavelength range 284 Å to 1216 Å. The instrument carried a β-source to check the sensitivity of the detectors separately from the efficiency of the grating. All of the detection systems showed changes in sensitivity of a factor of 2 or more in about five months[6] which can be attributed to a combination of changes in grating efficiency and a time-dependent gain of the electron multipliers. The sensitivity changes were different for each of the six wavelengths which makes it impossible to separate the optical and electronic effects. The separation of the optical and electronic effects can be observed in the Harvard OSO-IV experiment data since stable electronic sensitivity was achieved in the presence of large changes in optical efficiency. Since these optical changes are the main subject of the present discussion, the instrument data will be presented in some detail.

III. INSTRUMENT DESCRIPTION

The Harvard instrument has been described elsewhere[7,8], together with some preliminary results. A first surface concave mirror with platinum coating forms an image of the sun at the entrance slit of the spectrometer which selects a region of 1 arc minute. The light from this region passes to the diffraction grating, an original Bausch and Lomb 1800 line/mm grating ruled in gold with a first order blaze at 800 Å. The dispersed radiation passes through an exit slit to a tungsten photocathode Bendix magnetic electron multiplier Output pulses from the multiplier are amplified and counted in a binary mode for transmission to the ground in real time or storage on board the spacecraft tape recorders for later transmission. The spectrum at the center of the sun could be scanned by moving the diffraction grating in rotational increments (in an off-Rowland circle mounting) in units corresponding to 0.1 Å at the exit slit over the range 300 to 1400 Å. The capability was also provided to stop the motion of the diffraction grating at any point in the scan to allow a desired wavelength to be positioned on the exit slit. The sail portion of the spacecraft was then commanded into a raster mode to construct spectroheliograms within a field of view of 36.5 arc minutes centered on the sun.

Figure 1 shows a spectral scan of the center of the sun from 300 to 1400 Å with the more prominent lines identified. The upper portion of the picture displays simulated image representations of the data for four lines at different heights in the solar atmosphere from the Lyman continuum at a temperature of approximately 10,000°, through the transition region, illustrated by O VI 1032 Å at a temperature of 300,000° and into the corona, with Mg X 625 Å at 1.4 million degrees and Si XII 499 Å at a temperature of 2.5 million degrees.

IV. PHOTOMETRIC CALIBRATION

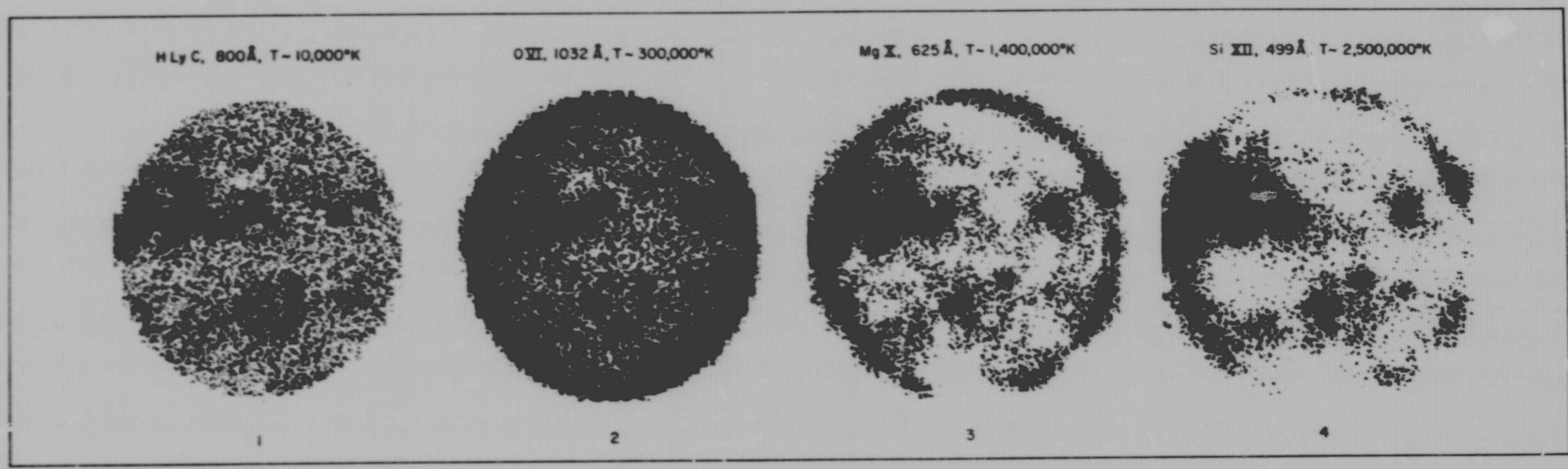
To calibrate the Harvard experiment the reflectance of the primary mirror and certain geometrical parameters were first measured in separate experiments over the wavelength range 300 - 1600 Å. The reflective coating was a semi-transparent platinum coating on the quartz substrate, kindly provided by Dr. G. Haas and Mr. W. Hunter at Fort Belvoir and the Naval Research Laboratories, Washington, D.C. A one-inch platinum-coated reference flat, coated at the same time as the primary mirror, was carried within the instrument at all stages of handling on the ground prior to launch. The mirror was removed and measured at intervals to assess any changes in the photometric efficiency during the period between instrument delivery and launch. Only a relatively small amount of optical contamination was observed over several months (See Section V.).

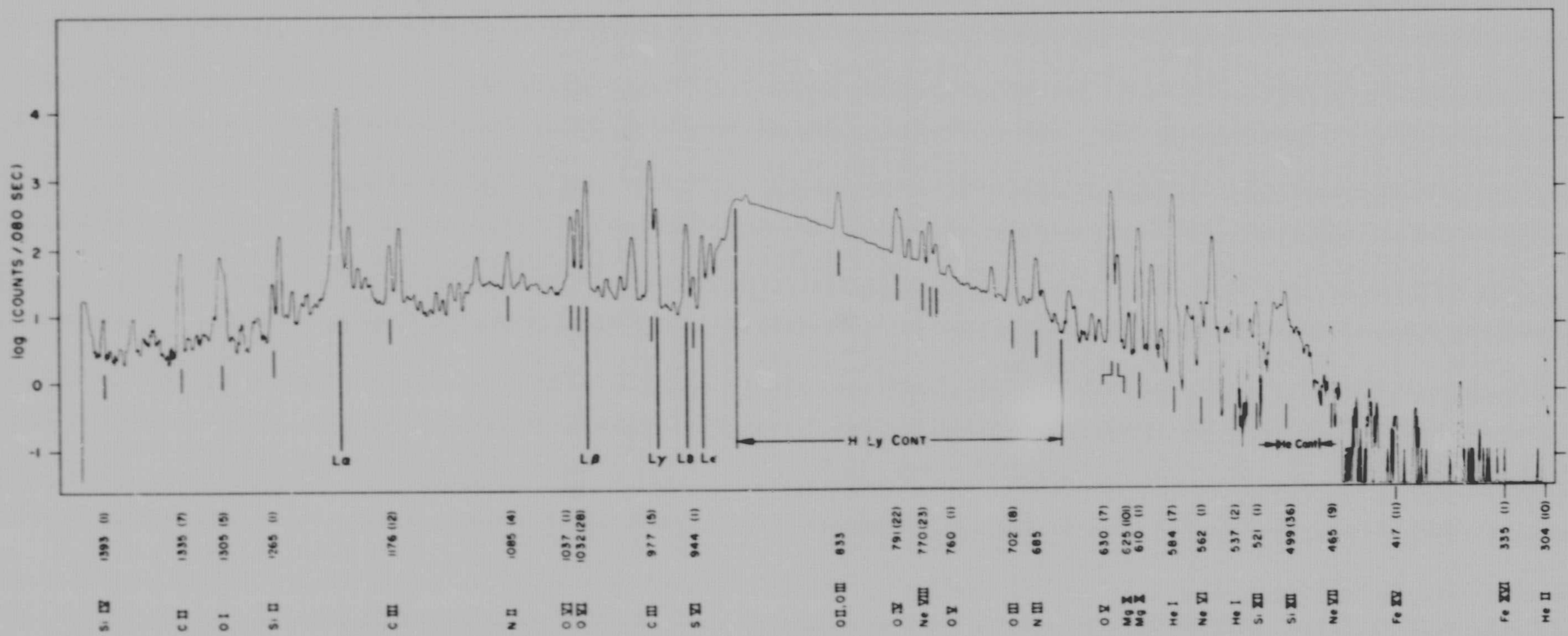
The spectrometer portion of the instrument, consisting of the grating, photomultiplier, amplifier, counter, etc., was then calibrated by illuminating the entrance slit (with the telescope removed) with a monochromatic beam and measuring the intensity of the light which passed through the entrance slit, by means of a tungsten photodiode. The detection system and calibration are discussed in greater detail elsewhere[9]. As in the calibration of other EUV spectrometers the use of a tungsten photodiode constitutes the main transfer standard for photometric

Figure 1

Lower Portion: A spectral scan from 300 - 1400 Å at the center of the sun on a compressed scale. Intensities on the ordinate scale are in recorded detection systems counts per counting interval.

Upper Portion: Four simulated solar images in lines formed at selected heights in the solar atmosphere (see text).


H Ly C, 800Å, T~10,000°K
O VI, 1032 Å, T~300,000°K
Mg X, 625 Å, T~1,400,000°K
Si XII, 499 Å, T~2,500,000°K
1
2
3
4


log (COUNTS / .080 SEC)
Lα
Lβ
Lγ
Lδ
Lε
H Ly CONT
He Cont
Si IV 1393 (1)
C II 1335 (7)
O I 1305 (5)
Si II 1265 (1)
C III 1176 (12)
N II 1085 (4)
O VI 1037 (1)
O VI 1032 (28)
C III 977 (5)
S VI 944 (1)
O II, O III 833
O IV 791 (22)
Ne VIII 770 (23)
O V 760 (1)
O III 702 (8)
N III 685
O V 630 (7)
Mg X 625 (10)
Mg X 610 (1)
He I 584 (7)
Ne VI 562 (1)
He I 537 (2)
Si XII 521 (1)
Si XII 499 (36)
Ne VII 465 (9)
Fe XV 417 (11)
Fe XVI 335 (1)
He II 304 (10)

calibration. The response of the diode was here measured with a gas absorption chamber up to 1000 Å and with a sodium salicylated photomultiplier to 1400 Å by Dr. James A. Sampson of the Geophysics Corporation of America. Dr. R.P. Madden and his colleagues kindly provided measurements of the photoelectric yield of the tungsten diode made by comparison with a thermopile at selected wavelengths. The agreement between these independent methods was quite good.

In the photometric calibration of all normal incidence grating spectrometers it is particularly important to consider with great care the effects of spatial inhomogeneity in gratings. In general, the emergent beam from a grating is not spatially uniform and, furthermore, the nonuniformities are a function of wavelength. This nonuniformity results from the change in shape of the groove structure over the surface and the change in diffraction properties as the angles of incidence and diffraction are changed with wavelength. Uniform illumination of a monochromator predispersing grating by a light source can usually be achieved without much difficulty. However, the instrument grating to be evaluated also has a nonuniform emergent response characteristic when illuminated with a uniform beam of radiation. This response characteristic is the parameter to be determined, since in orbit a telescope mirror will produce a spatially uniform illumination of the instrument grating. Unfortunately, during laboratory calibration the inherently nonuniform beam that results from a predispersing monochromator is usually used to feed the instrument grating, and the resulting response is the product of the true instrument grating efficiency in uniform illumination and the convolution of the nonuniform effects of the beams. The second aspect can be large and is extremely difficult to assess. A minimized effect can be achieved if we use the property that the efficiency along the length of the grating groove is less variable than that at right angles to the direction of the groove. For this instrument the predisperser and instrument gratings were used in cross dispersion. The focus, as well as angular settings in two mutually perpendicular directions, could be remotely controlled for the predispersing grating. Calibration effects of a factor of two or greater have been measured when the spatial properties of the two gratings were incompatible, either by having their dispersions co-planar or by using a grating with marked spatial non-uniformities.

The effects of polarization in normal incidence satellite instruments has not previously been reported. Measurements were made on a similar flight instrument at wavelengths between 500 and 1300 Å and were found to be less than 3%. These measurements were made by introducing a three-plate polarizer into the entrance beam of the predisperser grating, remotely rotating the polarizer through 90°, and measuring the combined response of the predisperser and instrument gratings. Since it is unlikely that the effect of two gratings in crossed dispersions will be such as to cancel the polarization effects at three widely separated wavelengths, the response to polarization can be safely assumed to be negligible at these near normal incidences (less than 5°). If a large response to polarization of the monochromator illuminating beam had been observed, then clearly it would have been impossible to assign a polarization effect to the flight instrument proper. Three-plate polarizers in both the entrance and exit beams of the predisperser grating would allow such a determination, although in the wavelength range below 1200 Å reflectances quickly reduce signal levels when multiple optical elements are employed.

The simple expedient often reported in the literature for measuring the polarization effects in an instrument, namely to rotate one instrument through 90° in the emergent beam of a similar instrument, can lead to invalid results, since the effects of the non-uniform beam profiles can greatly outweigh the polarization effects. Such effects were observed in the early stages of the calibration of the Harvard instrument.

V. CALIBRATION CHANGES PRIOR TO LAUNCH

Although a specific effort is always made to reduce the effects of optical contamination in rocket and satellite instruments during the long periods of instrument integration and test prior to launch, some changes in calibration are frequently observed. A long series of laboratory experiments has shown that the reflectance of mirrors at normal incidence in the wavelength range 300 to 1600 Å is particularly sensitive to small amounts of contamination on the surface. The contamination can usually be removed by chemical cleaning in the early stages, but in later stages, the reflectance change is non-recoverable. A decrease by a factor of two or more can be observed in the most sensitive region, around 1200 Å. The monitoring of mirror reflectance at a single wavelength between 1100 and 1300 Å, commonly simplest at Lα 1216 Å or Krypton I 1236 - 1243 Å, can be used to assess the degree of optical contamination of mirrors of this type. Since the reflectance changes are a strong function of the wavelength, which probably differs for differing types of contamination, no single wavelength can be used to determine precisely the change in reflectance over a wide wavelength range.

Contamination of optical surfaces has been the subject of many discussions, including those at a recent conference, Optical Contamination in Space, held at Aspen, Colorado, in

August 1969. Major areas of concern are: (1) particulate contamination; (2) vapor contamination in vacuum systems; (3) vapor contamination from instrument materials; (4) vapor contamination from external sources such as other parts of the spacecraft or spacecraft systems in orbit.

Particulate contamination can be reduced by the common procedures of clean-rooms and proper handling. This type of contamination is particularly important for coronagraph experiments and less important for ultraviolet spectrometers, except for the physical blocking of spectrometer slits which frequently are of the order of 10 - 100 microns or even less. Nevertheless, careful attention to normal clean-room procedures produces a significant byproduct, namely, ensuring a general level of care and respect for the environment in which the instrument is placed as well as achieving the principal objective of reducing the number of residual particles.

Contamination of optical surfaces in vacuum systems has also been studied in the visible and ultraviolet portions of the spectrum. With proper attention to monitor mirrors throughout the vacuum system, the monitoring of the vacuum properties with residual gas analyzers, and proper vacuum system design through careful attention to back-streaming, the contamination of optical surfaces in vacuum systems can be reduced to an acceptable level.

The selection of material for the fabrication of satellite instrument is well discussed in NASA publications and many studies have been done on "acceptable" materials.

Unfortunately, the common criterion for acceptability of materials for space applications is weight loss as a function of time. From the standpoint of optical contamination the parameter of weight loss is rather gross, since reflectance losses result from monolayers of material on the mirror surface, and even the "acceptable" materials exhibit some weight loss with time. Selection of materials, potting procedures, surface treatment of metals, trapped gas, lubricants in moving parts, etc., have been variously considered in individual studies. A good rule-of-thumb for optical space instruments is to place the maximum amount of electronics, etc., outside of the optical cavity so that any outgassing products cannot migrate in a direction towards the optical system, but preferably are directed away from the instrument entirely.

In the category of external contamination sources in orbit, the problem of normal spacecraft outgassing contaminations, which can under some circumstances drift into the optical instrument, is compounded by the use of reaction jets to control spacecraft orientation and, in the case of manned experiments planned for the near future, by waste disposal in orbit. With a proper choice of gases for reaction jets and care in their location, and planned procecures of human waste disposal, these orbital effects can undoubtedly be reduced. Experiments are planned in the Apollo program to evaluate these residual effects through the flight and recovery of mirror samples.

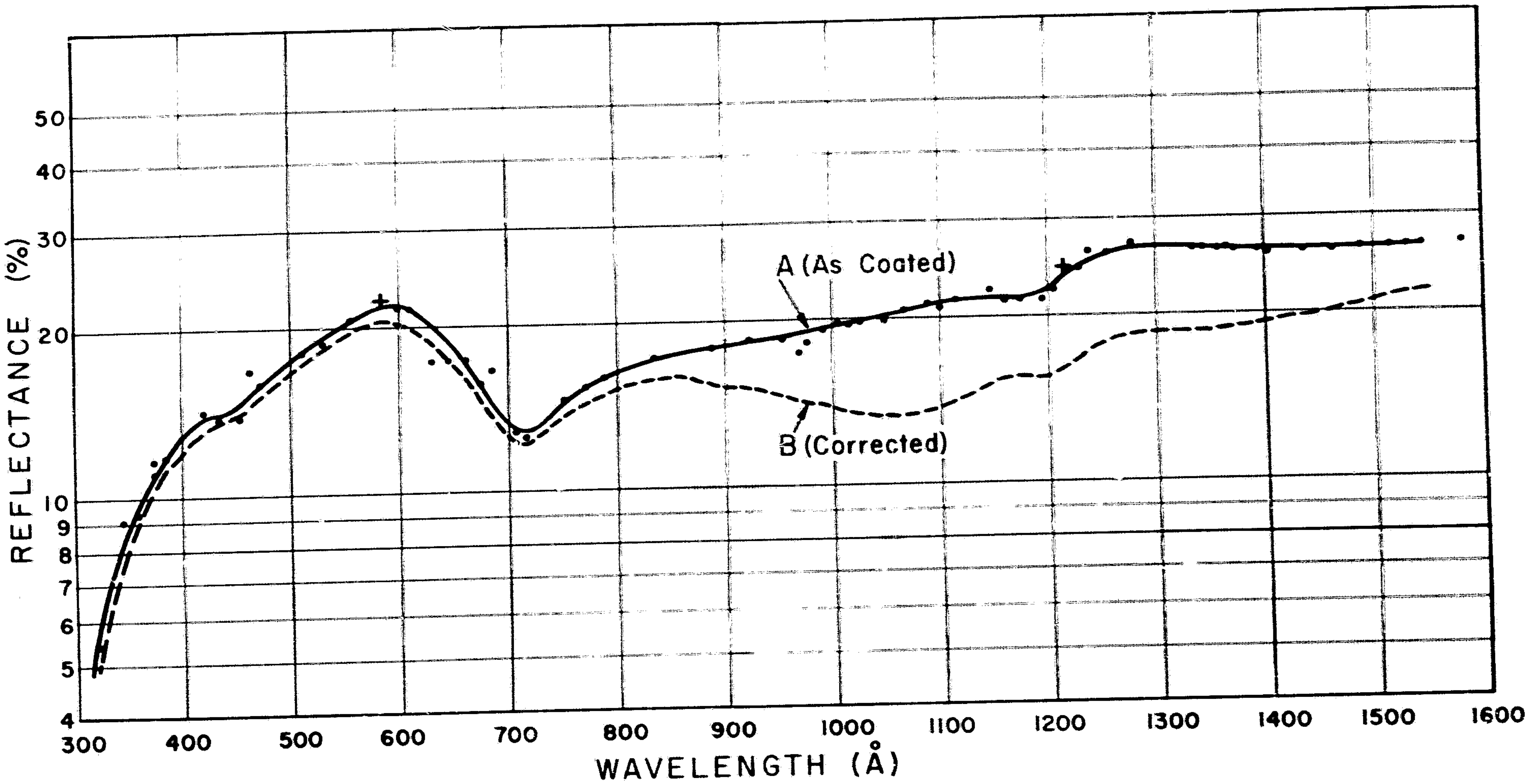
Figure 2 shows the reflectance of a platinum coated telescope mirror from the OSO-IV instrument as a function of wavelength. Curve A shows the reflectance soon after the mirror was coated, and the crosses show the reflectance determined from the monitor mirrors used to assess contamination during pre-launch testing by changes in reflectance. Curve B of Figure 2 shows the estimated reflectance after correction for the accumulated contamination. Figure 3 shows the ratio of the monitor mirror reflectance at instrument delivery to the reflectance of the mirror just after it was removed from the instrument on the launch tower, only hours prior to launch, as a function of wavelength, and thus indicates the accumulated reflectance change during the pre-launch test and storage period. The resultant change is consistent with experience in laboratory experiments on optical contamination.

Figure 2

Reflectance of the platinum-coated telescope mirror.

Curve A: The reflectance measured soon after the mirror was received. The two crosses (+) indicate independent measurements on a reference flat coated in the same operation.

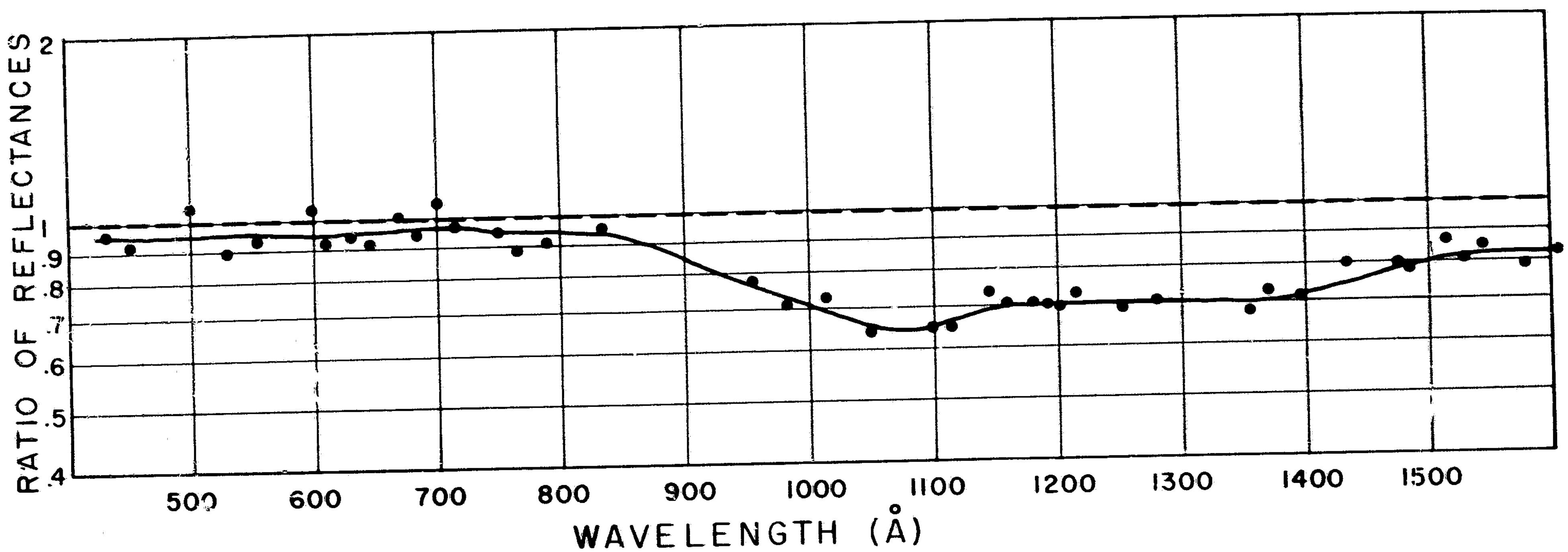
Curve B: The reflectance estimated for the time of launch from changes observed in a separate monitor mirror (Figure 3).



A (As Coated)
B (Corrected)
REFLECTANCE (%)
50
40
30
20
10
9
8
7
6
5
4
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
WAVELENGTH (Å)

Figure 3

Change in reflectance during the two month period between final mirror installation and launch. The ordinate gives the ratio of the measured reflectance of the monitor mirror removed from the instrument just prior to launch to the reflectance when the monitor and telescope mirrors were installed.


RATIO OF REFLECTANCES
2
1
.9
.8
.7
.6
.5
.4
500
600
700
800
900
1000
1100
1200
1300
1400
1500
WAVELENGTH (Å)

VI. OPTICAL EFFICIENCY CHANGES IN ORBIT

The Harvard OSO-IV instrument was launched October 18, 1967, and operated successfully for six weeks. During this time marked changes were observed in the intensities of solar spectral lines, attributed to changes in the optical efficiency of the instrument in orbit. The experiment was in orbit for approximately one week before the high voltage detection system was fully operational. Therefore, the instrument had experienced the launch process and a week's immersion in an orbital vacuum of approximately 10^{-9} Torr with full ultraviolet solar illumination.

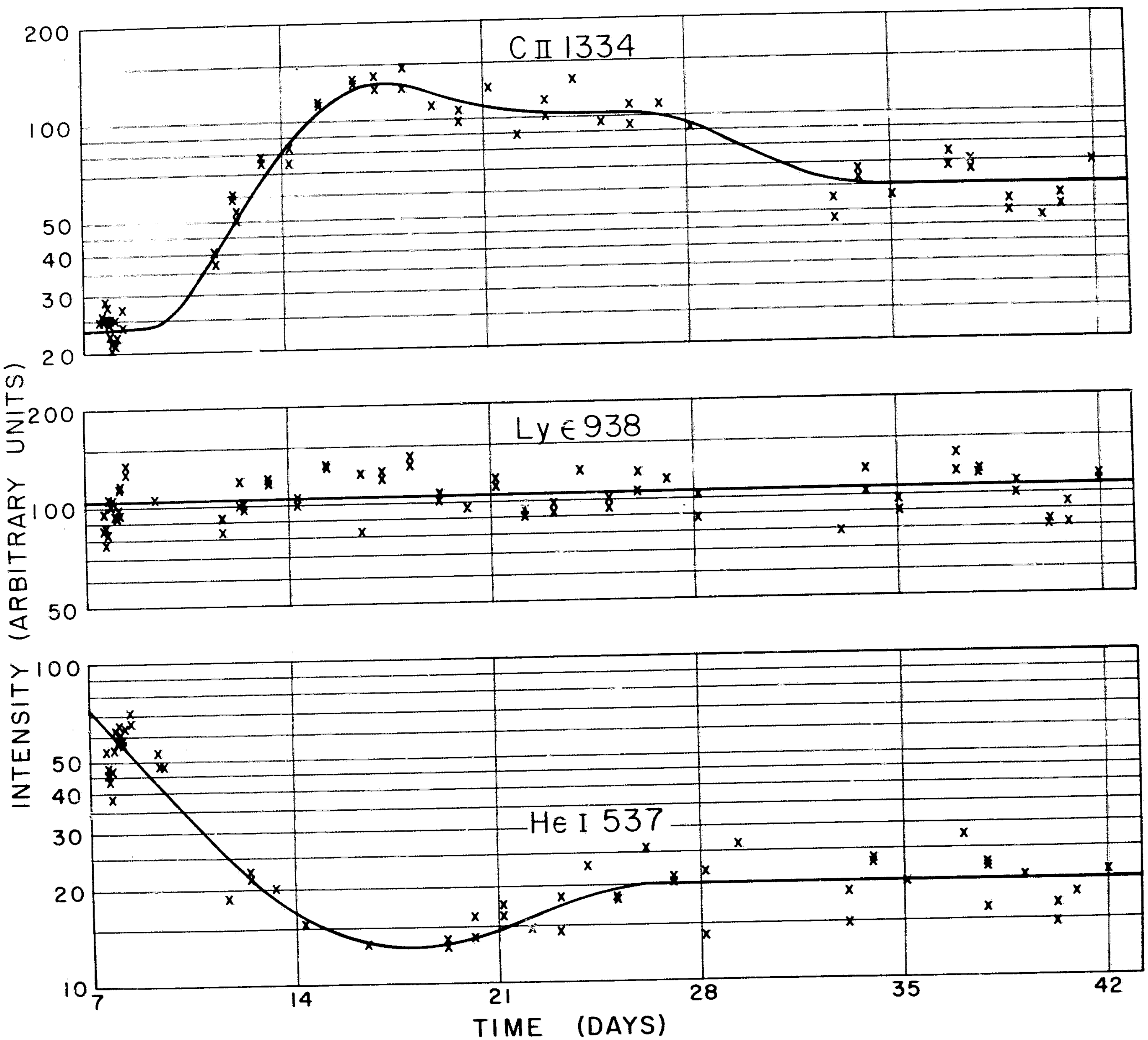
Two methods were used to assess the relative change in orbital calibration. Firstly, large raster spectroheliograms including the entire solar disk were constructed in solar emission lines of relatively low ionization energy at frequent intervals during the instrument lifetime. The radiation from low stages of ionization averaged over the entire disk is not sensitive to large fluctuations with solar conditions, particularly over the short interval of six weeks and in the absence of solar flares.[3,5] Solar activity primarily affects ions of quite high stages of excitation[2], such as Si XII, and Fe XV, XVI, producing very strong enhancements locally over active regions (Figure 1).

A second method for assessing changes in orbital calibration stemmed from an observing program in which the spectrum from the center of the solar disk was scanned at frequent intervals, normally at least once per calendar day. In the present solar cycle the two near-equatorial belts of activity are separated from the center of the disk, the northerly belt being the more active. Hence, except at periods when solar active regions are drifting across the sun and produce enhancements at the geometrical center, the center of the sun can be used as a "quiet sun" standard of calibration. This assumption of a quiet sun center must not be pushed too far, since we have found that fluctuations of a factor of 2 in the intensities of even low stages of ionization are observed in quiet regions in day-to-day spectral scans. Approximately 10 readings of the total integrated intensity under individual lines were used for each spectral scan to determine the intensity of the quiet sun. However, from day to day these intensities, which showed statistical fluctuations within a given single wavelength scan, varied by factors of 2, as presumably the pointing selected different locations within the "quiet" solar regions. However, since a great many complete wavelength scans were obtained, a smooth curve could be drawn through the scattering of points to produce a resultant calibration change. Approximately 45 wavelengths over the instrument range 300 - 1400 Å were used to follow the calibration changes in orbit.

After the instrument had been approximately six weeks in orbit the calibration at all wavelengths was observed to have stabilized. Figure 4 shows the intensity changes

Figure 4

Changes in instrument sensitivity with time in orbit for three selected wavelengths, 1334 Å, 938 Å, and 537 Å. The ordinate is the measured signal from the quiet center of the solar disc plotted against days after launch.


C II 1334
Ly ε 938
He I 537
200
100
50
40
30
20
200
100
50
100
50
40
30
20
10
7
14
21
28
35
42
TIME (DAYS)
INTENSITY (ARBITRARY UNITS)

recorded from spectral scans at the center of the sun as a function of time for three selected wavelengths, C II 1334 Å, L_ϵ 938 Å, and He I 537 Å. These lines represent three different types of wavelength effect observed over the instrument range. Each plotted point of Figure 4 is the average of at least 10 readings of the total integrated intensity under the solar emission lines, and on given orbits two spectral scans frequently are obtained. The ratio of the intensity at each orbit to the final stabilized intensity was plotted as a function of time for 31 wavelengths over the spectral range 300 to 1400 Å. Again, lines of relatively low stages of ionization were used, and quite variant shapes were observed in the curves, although a relatively smooth progression in shape change could be followed. To follow the wavelength-dependent calibration changes accurately with time, it is necessary to follow "standard" wavelengths at least at 100 Å intervals, and preferably at 50 Å intervals. The use of a very few wavelengths, such as result from certain standard light sources would not have been adequate to follow the observed changes. Since no appreciable time-dependent change in signal could be determined for wavelengths between 850 Å and 970 Å, we take this to be a valid indication that the sensitivity of the electronic system, including photomultiplier gain, counter efficiency, and electronic noise, must have remained stable. The derived internal calibration changes were estimated to be internally consistent and valid to approximately $\pm$ 20% in the wavelength interval λ525 to λ1350 and to ≤50% outside this interval.

The changes in sensitivity at wavelengths longer than 970 Å and shorter than 850 Å were observed to have an opposite sense. That is, while the instrument sensitivity is increasing at the longer wavelengths, it is frequently decreasing at the shorter wavelengths. For the shortest wavelengths, below 500 Å, the changes become complex indeed, showing several reversals. A particularly strong change in character of variation was observed between 465 Å and 304 Å, a relatively short wavelength increment.

VII. INTERPRETATION OF ORBITAL CALIBRATION CHANGES

In the satellite instrument, the changes in photometric response must be a combination of changes in the optical efficiencies of the mirrors and grating and the photoelectric yield changes of the tungsten photocathode. Madden[10] has shown that for tungsten photocathodes cleaned and in ultrahigh vacuum, the photoelectric yield changes strongly, even when monolayers of such pure gases as nitrogen and oxygen are added. Moreover, the sense of the change is a function of wavelength over our instrument range 300 - 1400 Å. For the purposes of these discussions, we must consider that the instrument reflectance and tungsten photoelectric efficiency at the time of instrument calibration were not those of "clean" surfaces as expected, but were rather in a stable contaminated condition resulting from chemical cleaning. For mirrors this state is very close to the reflectance measured <u>in situ</u> immediately after coating and before contamination can occur. For the photocathode, on the other hand, Madden's measurements have shown that heating a tungsten photodiode to moderate temperatures of several hundred degrees in vacua of 10^{-6} Torr produces large changes in the photoelectric yield, with a decreasing sense near 580 Å for most metals. A similar "cleaning" effect would be expected from subjecting a sample to ultra-high vacua such as occur in orbit for extended periods of time. We have already determined from laboratory experiments that cleaning of optical surfaces can be accomplished in this manner. Madden's experiments, showing the changes in photoelectric yield after the addition of gas layers, demonstrates that nitrogen and oxygen have different effects. Presumably different curves would result for other "contaminating species". Since the satellite instrument must contain a host of different contaminants in varying amounts predicting the observed effects in terms of specific contaminants would be unjustified.

It does not seem to be possible to disentangle the changes in reflectance and efficiency of the telescope mirrors and grating from the changes in the photoelectric yield, as this would require a knowledge of more parameters than those available. Since other satellite experiments using tungsten photocathodes and magnetic multipliers have shown no similar sensitivity changes at the lower wavelength region in common (namely He II λ 304) we are inclined to attribute the observed changes in the greater part to reflectance and efficiency changes in the optical system.

In passing, reference should be made to the use of radioactive sources as a means of assessing any changes in the efficiency of the photomultiplier as a whole. Since the released energy and number of photoelectrons is different for the very energetic β-rays than for the much less energetic photons (which also varies and the wavelength changes by a factor of four), the response of the multiplier as a whole will be different in the two cases. The response of these Bendix magnetic multipliers is very dependent on the energy of the first photoelectron[9]. It is probably valid to use a β-source to assess the multiplier gain stability (particularly at shorter wavelengths) but the results should not be applied to the photometric efficiency of the entire photomultiplier (particularly at longer wavelengths).

VIII. ABSOLUTE PHOTOMETRIC CALIBRATION IN ORBIT

Experience with rocket experiments at the Harvard College Observatory and elsewhere has shown that absolute photometric calibration over extended wavelength ranges can be maintained for the short duration of a rocket preparation and flight. The results of the previous section show that the periods of changes resulting from in-flight high vacuum cleaning are much longer than the several minutes involved in a ballistic rocket experiment. We have concluded that a reliable photometric calibration in orbit can be achieved by integrating the intensity from the entire solar disc in lines of low stages of ionization and then normalizing these to data from rocket flights. An equally valid approach would be to use the "quiet" areas on the solar disc as a reference. However, the rocket measurements made to date, primarily by Hinteregger, employ light from the whole solar disc and the effects of limb darkening, limb brightening, and active regions can play an important role in the integrated intensities of certain solar emission lines and continua. Our own evaluation of the "best values" from published[11,12,13,14] and unpublished[15] results is shown in Table 1. We are indebted to Drs. Hinteregger and Hall of Air Force Cambridge Labs for making their unpublished data available to us. It is generally agreed that absolute calibration in this wavelength range is probably not accurate to better than within a factor of 2 to 3. Hence, one might naively assume that the observed orbital calibration changes are perhaps insignificant. However,

TABLE I

ABSOLUTE FLUXES USED FOR IN-FLIGHT CALIBRATION

Line	Ident.	Flux $\times 10^{-9}$ (ph cm^{-2} s^{-1})
Cont.	1400*	0.44
Si IV	1394	2.1
C II	1334	6.9
C III	1176	2.4
O VI	1032	2.5
L_β	1026	3.5
C III	977	4.9
L_∞	897*	0.48
L_∞	800*	0.061
O IV	791	0.26
O III	702	0.24
O V	630	1.1
He I	584	0.89
O IV	553	0.31
He_∞	504*	0.12
He II	304	7.5

*integrated over 3.16 Å continuum

the uncertainty of absolute calibration in this wavelength range must be reduced to 10 or 20% for proper interpretation for ultraviolet results in terms of solar structure and mechanisms. This problem is certainly aggravated by ths use of normal incidence optical systems as witnessed by the present data and those of the Naval Research Laboratory[6]. However, achieving spatial resolution on the solar disc is quite difficult with grazing incidence optical systems in the EUV where gratings are required to achieve spectral resolution of about 1 Å or better necessary to isolate lines from different regions of the chromosphere and corona, or to separate closely spaced lines of differing stages of ionization. An experiment of the latter type is first scheduled to fly on OSO-H in 1970/1971, prepared by Dr. Neupert of Goddard Space Flight Center.

The spectral lines of the chromosphere and transition zone fall mainly in the spectral region most conveniently accessible with normal incidence systems, i.e., about 280 - 1400 Å. Normal incidence systems provide a reasonable insensitivity to problems arising from multiple overlapping grating orders leading to loss of spectral purity in the image. To achieve a precise and reliable photometric calibration over prolonged periods with any EUV satellite instrument is a necessary objective. To achieve this objective instruments must either be free of long term calibration changes or the calibration changes tracked at frequent wavelength intervals with normalization to an absolute standard. At the present time, available standard sources are neither sufficiently reliable nor contain sufficiently well spaced wavelengths to serve as an absolute standard to the desired accuracy. It would appear, however, that the goal can be achieved by launching a series of rockets, probably using grazing incidence systems, during the lifetime of an orbiting satellite instrument to achieve points of absolute calibration by observing the quiet sun or the entire solar disc. This approach will be attempted in later experiments.

ACKNOWLEDGEMENTS

The work reported here represents a part of the data from the Harvard instrument on OSO-VI, the accumulation and reduction of which has been the result of the combined efforts of many people. We particularly wish to acknowledge Drs. G.L. Withbroe and R.W. Noyes, and the programming and compilation assistance of Mrs. J. Flagg and Mrs. E. Levin.* The engineers and technicians of the Solar Satellite Project merit special commendation for their years of effort in preparing this instrument for launch. Mssrs. N.L. Hazen, F. Kazynski, J. Rechavi, S. Diamond, and J. Crawford are among those who deserve special mention. We also acknowledge the cooperation of Dr. Hinteregger of the Air Force Cambridge Research Laboratory, Dr. Timothy of University College London, and Dr. Tousey of the Naval Research Laboratory

*Dr. M.C.E. Huber made the measurements on polarization.

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