A COMPARISON OF SURFACE BRIGHTNESS MEASUREMENTS FROM OAO-2 AND OSO-6

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ABSTRACT

A comparison of surface brightness measurements of the night sky from the OAO-2 and OSO-6 satellites with ground observations shows good agreement between the space experiments but a systematic error in the zero point of the ground observations, indicating an additional atmospheric source of radiation.

I. INTRODUCTION

Ground-based measurements of the surface brightness of the night sky are complicated by extinction and scattering by the troposphere and airglow emissions from the ionosphere. Observations from space vehicles avoid these difficulties but may, in turn, be complicated by sunlight scattered into the instrument and by a time-dependent radiation-belt induced dark current.

In this paper we compare surface brightness measurement of the same sky regions obtained from space with the Wisconsin Experiment on OAO-2 and the Rutgers Experiment on OSO-6. Such a comparison serves as a check on the performance and calibration of each instrument, and, by virtue of the independence of the readings, adds confidence in the combined result.

This preliminary study is based on a few such measurements near the galactic center.

II. INSTRUMENTATION

The two instruments and the spacecraft which support them vary greatly both in design and mode of operation. Their one common feature is the ability to record the surface brightness of the sky background from above the earth's atmosphere. Their characteristics are summarized in Table 1.

Table 1. Summary of Experiment Characteristics

Characteristic	OAO-2	OSO-6
Orbital Information		
Launch Date	December 7, 1968	August 9, 1969
Mean Altitude	776 km	528 km
Period	100.13 min	95.1 min
Eccentricity	0.00073	0.00475
Instrument		
Angular Field	10 arc min	2 degrees
Field Area	0.0218 sq. deg	3.14 sq. deg
Filters	12 in interval 4250-1050 Å	4000, 5000, 6100 Å (±200 Å)
Polarization Measurement	No	Yes
Measurements Made	During satellite night	During satellite day

The Wisconsin experiment (Code et al. 1970) was designed for the photometry of bright stars at twelve wavelengths in the 1000-4000 Å spectral region. It is carried by the OAO-2 spacecraft which is stabilized in three-axes and can be pointed to a discrete region of the sky with an accuracy of ±1 arc minute. The OAO has no capability for continuous sweeps across the sky.

The Rutgers experiment was designed for precise polarimetry of the zodiacal light at 4000, 5000 and 6000 Å. It is located in the wheel section of the OSO-6 spacecraft which is spin-stabilized at 30 rpm with its axis of rotation nearly perpendicular to the ecliptic plane. As the wheel turns, the sky brightness is measured at five degree intervals from 180° to

±10° solar elongation. In the course of a year, a band of sky along the ecliptic several degrees wide is swept by the OSO photometer.

The two instruments complement each other in the sense that one scans the sky continuously in a narrow band around the sky while the other obtains single point measurements over the entire sky. The instruments have a bandpass in common at 4000 Å and, for sky regions which both have observed, provide continuous wavelength coverage from 1050 to 6300 Å.

III. OBSERVATIONS

a) The OAO-2 Photometer

The observing program for the Wisconsin experiment is controlled by an astronomer on the ground who selects discrete objects for study and programs the spacecraft to obtain the appropriate measurements. Most of the observing time has been devoted to spectrophotometry and multi-color photometry of stars, planets and galaxies. Surface brightness measurements have been made (1) as off-sets from the stars to determine the sky background correction, (2) by observations of the Kaptyen Selected Areas and (3) by observations of particular regions of the sky such as the ecliptic and galactic poles.

A typical observing sequence with one of the four stellar photometers consists of nine measurements: two dark readings, a calibration reading and two measurements with each of the photometer's three interference filters. The sequence requires from 24 to 32 minutes depending on the integration times used and takes up a complete spacecraft night.

b) The OSO-6 Photometer

The Rutgers photometer is automatically programmed to make a sequence of readings from which the brightness, degree of polarization, plane of polarization and degree of ellipticity of the sky background light can be determined at 4000, 5000 and 6100 Å. During a given rotation of the satellite wheel sky readings are made for a given arrangement of filter and analyzer wheels at three solar elongations (i.e., -195°, -190°, -185°). After five rotations the analyzer-filter combination is changed and another set of readings is obtained. Ninety wheel rotations or about three minutes are required to record data for all 18 combinations of filter and analyzer settings (three filter and six analyzer positions). This procedure is then repeated for three new elongations (i.e., -180°, -175°, -170°). For elongations ±60° to ±10° the filter-analyzer combination is changed every rotation. The photometer continues to make observations all around the orbit, as long as the satellite is in daylight. In one orbit a total of 5256 sky readings are made. To date more than 11,000 orbits have produced about 58 million sky observations. In this report we concentrate on some 950 individual readings from 95 orbits selected for the purpose of effecting a general comparison between the OSO and OAO instruments.

III. THE SKY REGION UNDER STUDY

The problem of the intercomparison of the two sets of observations is illustrated in Figure 1. The solid line represents the ecliptic in galactic coordinates in the general vicinity of the galactic center (galactic latitude, $b_{II} = 0$; galactic longitude, $l_{II} = 0$). OSO-6 observations are made along the ecliptic (at an elongation of 180°) as the sun moves approximately one degree per day and, since, further, there are about 15 orbits per day, there are 150 individual readings between the 10-day markers in Figure 1. The parallel dashed lines represent the region raked over by four other solar elongations during 1970. We note that elongation 175° involves an observational sweep across the galactic center direction.

The circles on Figure 1 indicate regions of the sky which have been included in the OAO program, usually as sky background measurements near planets. On the scale of the figure, the OAO field (1/6°) is approximately equal to the thickness of the ecliptic line; the OSO field is about twice the size of the circles.

Figure 2 illustrates the nature of the seasonal variation in surface brightness along the ecliptic for observations made in the anti-solar (gegenschein) direction. The gegenschein itself may be considered as a constant background superimposed on which is the highly variable contribution from the integrated starlight. The plot was made on the basis of published ground observations, omitting any contribution from airglow. During May, June and July (orbits 4000 to 5500 for OSO-6 during 1970) the bright region of the Milky Way in the vicinity of the galactic center is traversed. Thus a natural photometric band of variable brightness is at our disposal for comparing (a) the separate experimental results against the published ground data and (b) the two experimental results against each other.

IV. A COMPARISON OF GROUND AND SPACE OBSERVATIONS

The relationship between pairs of some ground observations of sky brightness and space observations of the same regions are shown in Figure 3. In the upper diagram the 5000 Å data from OSO-6 has been compared with the expected sky brightness due to the zodiacal light (Smith <u>et al</u>. 1965) plus integrated

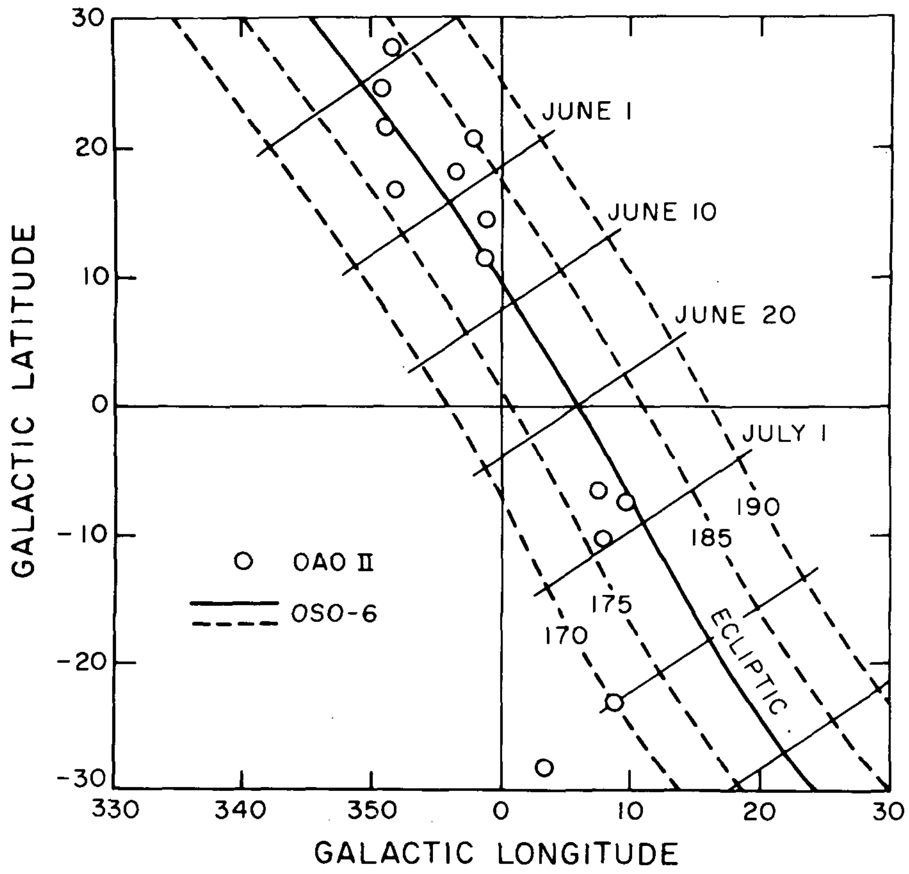

Figure 1.—The sky regions observed by OSO-6 and OAO-2 in galactic latitude and longitude.

starlight (Roach and Megill 1961) at 5300 Å. In the lower diagram the 4250 Å data has been compared with the sky brightness predicted by the zodiacal light observations of Smith, assuming $S_{10}(B) = S_{10}(V)/1.69$ (Roach and Smith 1964) and the GR 43 star counts for the Kapteyn Selected Areas (Van Rhijn 1925), assuming $S_{10}(B) = 0.903\ S_{10}(pg)$.

An examination of the data reveals a linear relationship between the ground and space observations with a scatter which probably represents real fluctuations in the star background intensity. The slopes of the lines provide a check on the instrumental calibration. For both instruments the slope is in excellent agreement with that predicted from star observations and the nominal field of view.

In both cases the intercept is such that ground-based photometry shows a residual sky brightness when the satellite measurements go to zero. This is consistent with previous

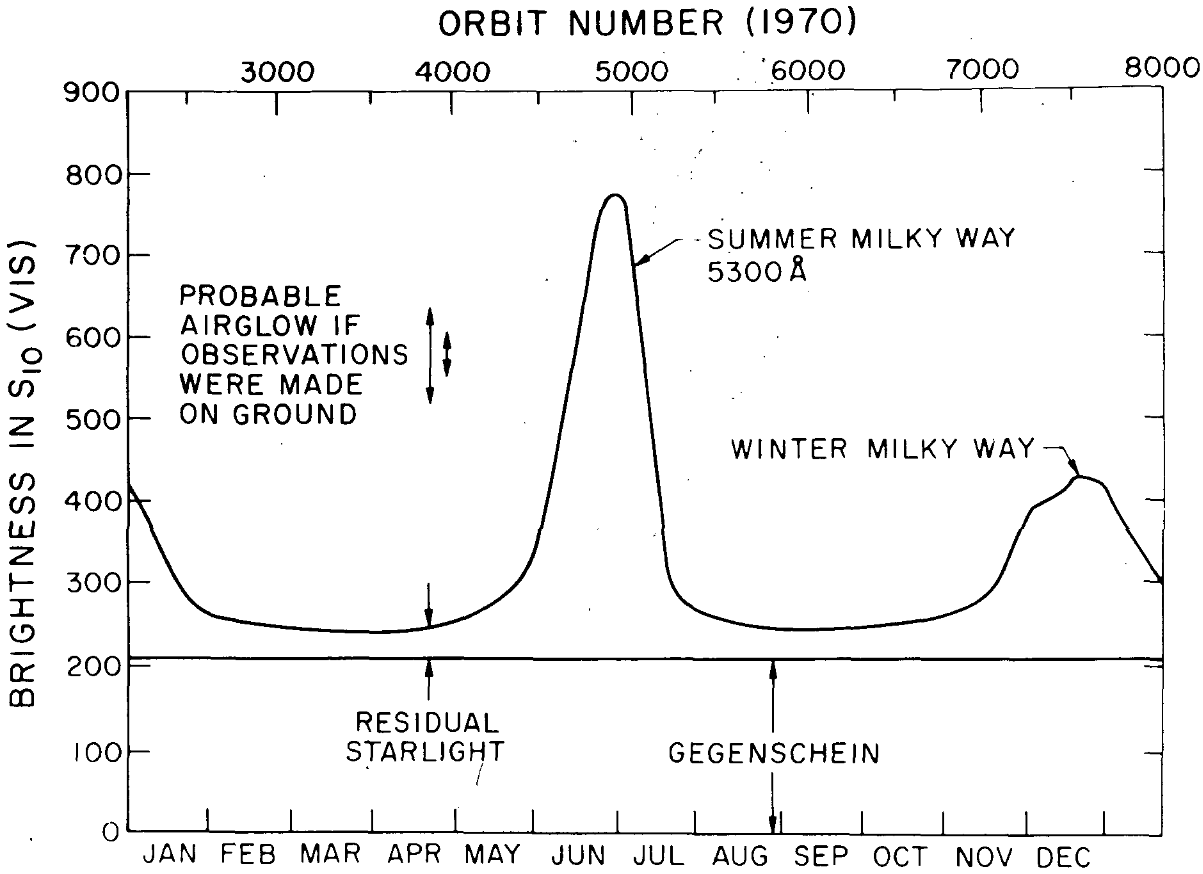

Figure 2.—The brightness of the night sky due to starlight and zodiacal light in the anti-solar direction as a function of time.

rocket and satellite measurements of the sky brightness (Lillie 1969), (Sparrow and Ney 1968) which indicate ground-based observations suffer from a systematic error, perhaps from scattering in the earth's atmosphere. Also, there is no suggestion of scattered light in the OAO or OSO data.

V. COMPARISON OF OBSERVATIONS FROM THE TWO SPACE EXPERIMENTS

A comparison of OAO-2 and OSO-6 results for the region of the galactic center is shown in Figure 4. In this diagram we plot the sky brightness at 4000 Å in the anti-solar direction as measured by OSO-6 versus time, orbit number and galactic latitude. (This is the scan path labeled "ecliptic" in Figure 1.) The data is for the time span May 3 to July 26, 1970 (orbital span 4050 to 5325 and galactic latitude span +39° to

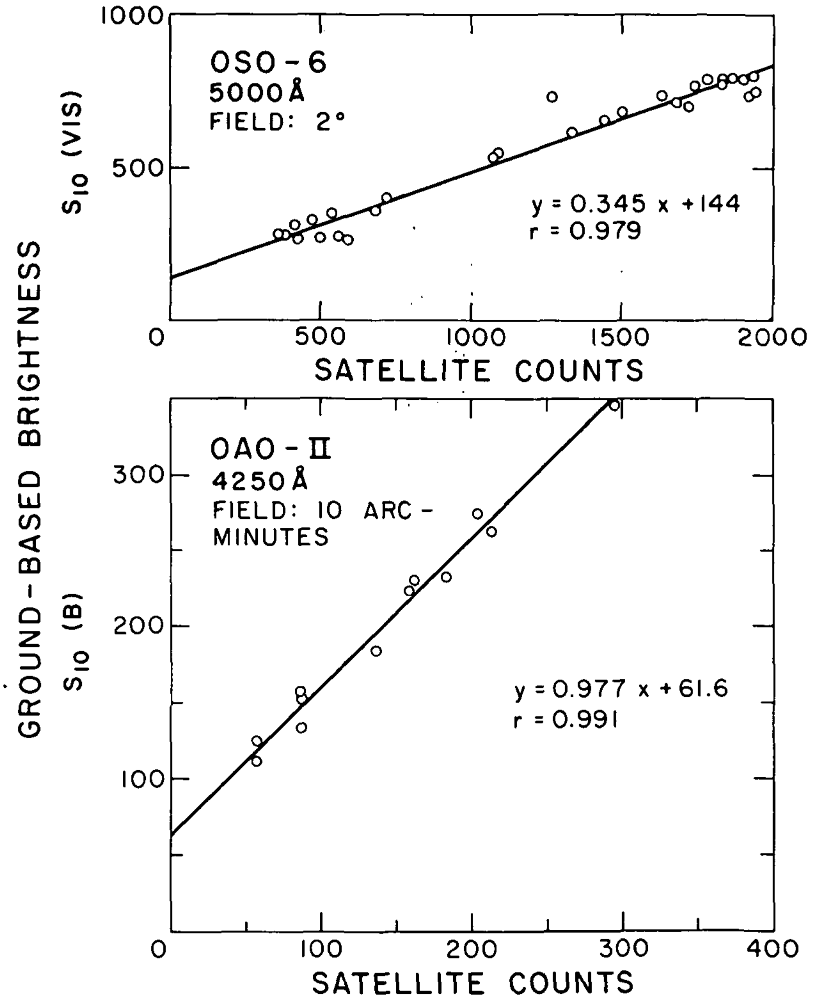

Figure 3. A comparison of the OAO-2 and OSO-6 observations with sky brightness due to starlight and zodiacal light from ground-based observations.

-27°). The ordinate is in units of stars of brightness B = $10^{m}.0$ per square degree [S_{10}(B)].

(Note that Figure 2 and the upper part of Figure 3 are in S_{10}(vis) units which are numerically about twice the S_{10}(blue) values.)

The circles in the figure are 4250 Å observations made with the OAO-2 photometer in twelve specific regions near the ecliptic plane. As shown in Figure 1, the OAO observations were not always at points within the OSO field of view and they have been plotted for the orbit of "nearest approach" to the OSO scan path. The OAO observations have been given the

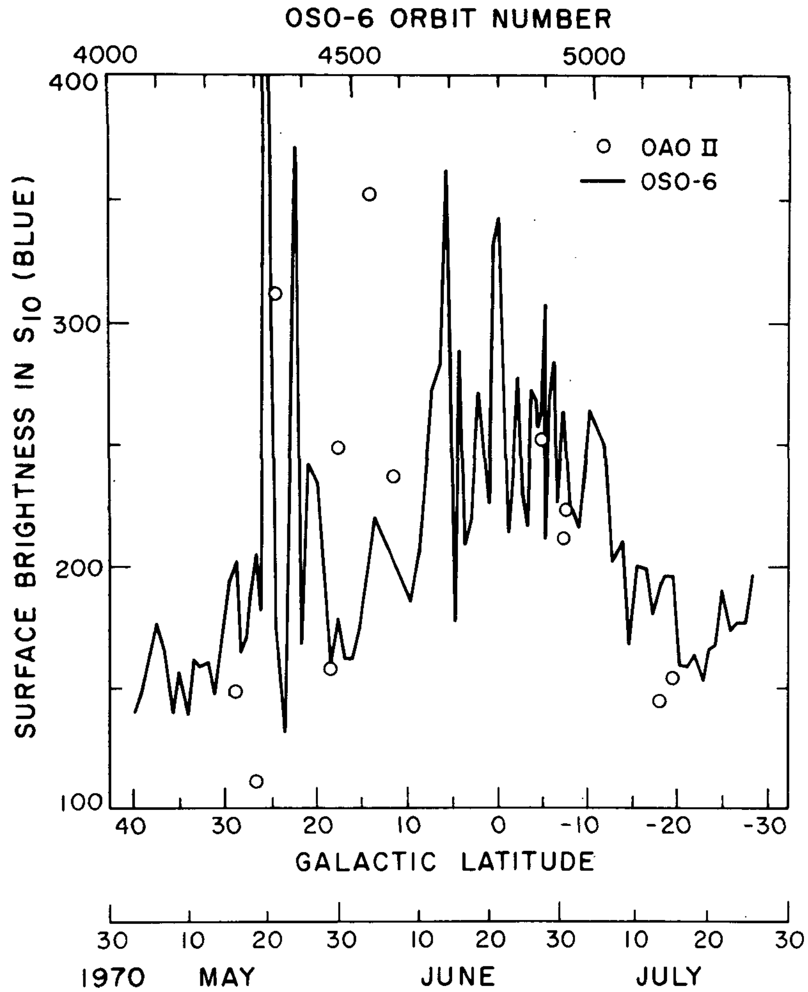

Figure 4.—A comparison of observations from the two space experiments in the region of the galactic center.

gegenschein zodiacal light intensity by first removing the contribution of the measured signal due to zodiacal light (Lillie 1970) and then adding 100 S_{10}(B), which is close to the value of the gegenschein brightness found by Lillie (1969) in a rocket experiment.

Examining Figure 4, we note the following:

a) there is a pronounced maximum in the OSO observations at 0° galactic latitude;

b) there is pronounced scatter in the OSO observations;

c) the general level of the two independent sets of observations is similar; and

d) the scatter of the OAO results is consistent with the scatter in the OSO observations and with the probability that one or more stars of magnitude 10 or fainter may have been in the field of view.

VI. SUMMARY

In this paper we have compared sky brightness measurements from two independent space experiments with each other and with ground-based observations. We find good agreement between the space experiments, considering the difference in their fields of view.

We agree with ground observations as far as variations in sky brightness are concerned but disagree with the zero point. The ground observations are systematically too bright at both 4250 Å and 5000 Å, suggesting a light source in the earth's atmosphere for which the ground observations are not being corrected.

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