STUDY OF LUNAR EARTHSHINE BY PHOTOELECTRIC PHOTOMETRY

Grant NGR 09-015-025

Final Report

For the Period 1 November 1965 to 30 September 1967

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Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

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1. INTRODUCTION

The project for which this final report marks a culmination had a two-
fold purpose: 1) to provide accurate photoelectric photometry of the earthlit
portion of the moon, primarily to establish an albedo for the earth; and 2) to
investigate the various instrumental and observational constraints that such
a type of measurement imposes. In particular, we wished to know whether
small, semiportable instruments could be used at a number of field stations
to monitor via earthshine measurements possible changes in the earth's
albedo. In the Attachment to this report, we present an account, already
published (Franklin, 1967), centering on the first purpose. The observations
reported are two-color photoelectric measures obtained with a 16-inch
instrument on 14 nights at the Boyden Observatory in South Africa. They
are in close accord with the visual observations of Danjon (1954) and present
new photometric parameters for the earth in the blue. In Sections 2 and 3,
we discuss the result of the second purpose: the design, construction, and
operation of a 5-inch field instrument. Section 4 gives the photometric
results obtained by that instrument at the Smithsonian astrophysical observing
station at Organ Pass, New Mexico.

Certain aspects of this study grew from a project initiated in 1957 by
F. L. Whipple. This earlier work (Bakos, 1964) emphasized a technique
pioneered by Danjon (1954), that is, use of the so-called cat's eye photometer,
to obtain visual measurements of the earthshine from six stations at widely
different latitudes and longitudes. The results of that earlier study were
somewhat disappointing. Although it was indeed possible to derive visual

albedos for the earth, averaged both over the period of a year and over all latitudes and longitudes involved, the large scatter in these observations prevented a more refined analysis. We refer the reader to Bakos (1964) for details, and we echo here his conclusion: that data much more homogeneous and accurate were required before fluctuations in the earth's albedo due to seasonal or meteorological changes could be reliably determined. We shall stress here that we did not address ourselves to this problem in this study. Our primary aim was to develop techniques to obtain data of sufficient observational accuracy so that a search for fluctuations would be a meaningful problem. We feel that we do have a small number of such observations, but they are too few to represent more than a reconnaissance.

2. CONSTRUCTION OF THE INSTRUMENT

The instrument used in this study was intended to measure photoelectrically the intensity of the earthlight reflected from areas of the lunar surface directly in terms of adjacent standard stars of known brightness. Since our interest was ultimately to make these measurements from stations widely distributed in latitude and longitude, we wished to develop an instrument that would involve only a small initial investment for construction and that, while incorporating ruggedness with low operating cost, would be capable of measuring the earthshine with the highest precision possible. To this end, we suggested a 5-inch instrument.

The optical arrangement of the resulting instrument is shown in Figure 1. Light from the object under investigation entered the 5-inch diameter F/5 Achromat (1) and formed an image on a front-surfaced aperture plate (3). The position of the image on the aperture plate could be controlled by an observer looking through a guiding eyepiece (9) at the aperture plate by means of a beam-splitter (2) fixed at a 45-degree angle in the path of the light from the 5-inch lens. The image could then be centered so it fell through a hole 8 arcmin in diameter in the aperture plate. The light next passed through interchangeable B (Corning 5030 + 2 mm Schott GG13) and V (Corning 3384) filters (4), interchangeable clear and opaque neutral-density filters (5), a field lens (6), windows on the cold box (7), and onto the photomultiplier tube (8).

An interesting feature of the instrument was the cold box used to refrigerate the detector for reduction of dark current. The box was a Research Model TE-101TS thermoelectric unit, which was capable of cooling the detector face from ambient temperature to ±0.25°C of any selected temperature between -10°C and 20°C. Excellent contact between the walls of the tube chamber and the detector was afforded for uniform cooling of the tube. In addition, the box employed a double-pane insulating window that

reduced the effects of blackbody radiational heating of the detector cathode and that prevented dewing of the detector face and the window surfaces.
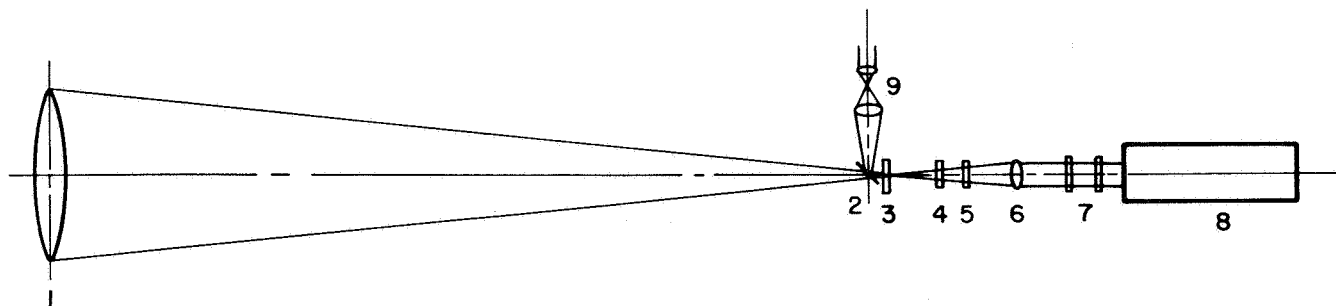
1. 5-inch diameter achromatic objective lens
2. 10/90 beam splitter
3. Field stop
4. Neutral density filters #1, 2, and 3
5. B, V filters
6. Collimating lens
7. Condensation inhibiting windows
8. EMI 9558 photomultiplier
9. Guide eyepiece

Figure 1. Optical components of albedo photometer.

The detector was an EMI 9558 11-stage photomultiplier with an S-20 photocathode. The tube was selected for its high sensitivity and high quantum efficiency.

Our electronic equipment, block diagrammed in Figure 2, included a Northeast Scientific DC power supply to drive the detector. A General Radio electrometer Model 1250 was used as the DC amplifier. This was followed by a divider circuit designed to provide signal attenuations in one-half magnitude steps and a Honeywell Model 15* strip chart recorder.

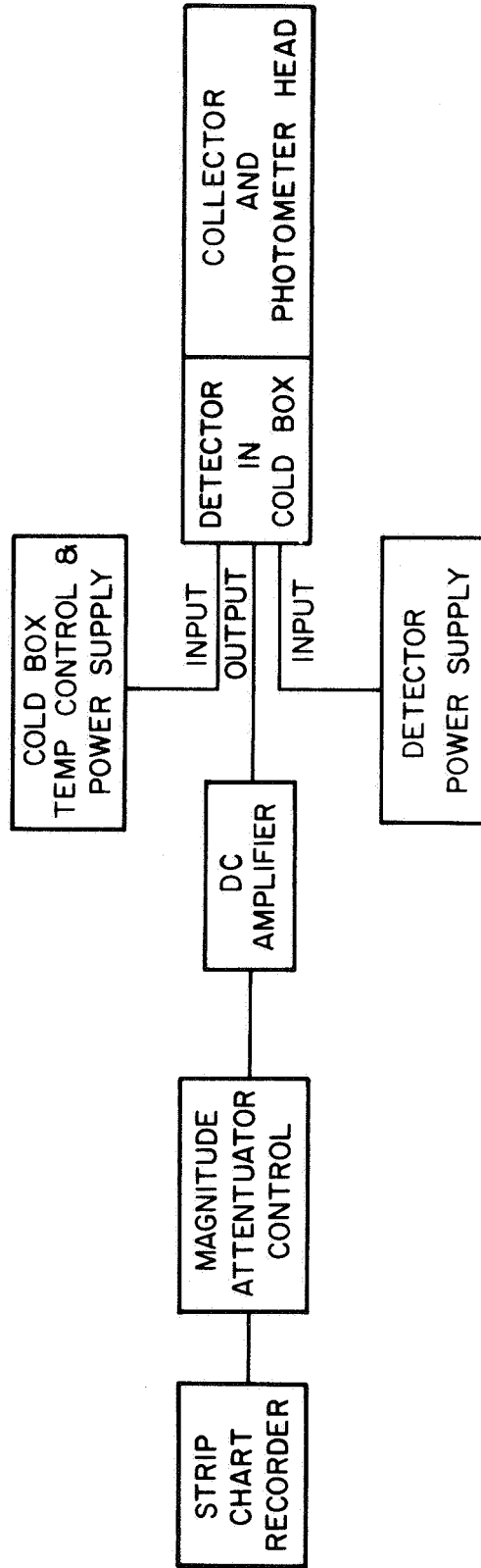Figures 3, 4, and 5 are photographs of the albedo equipment.

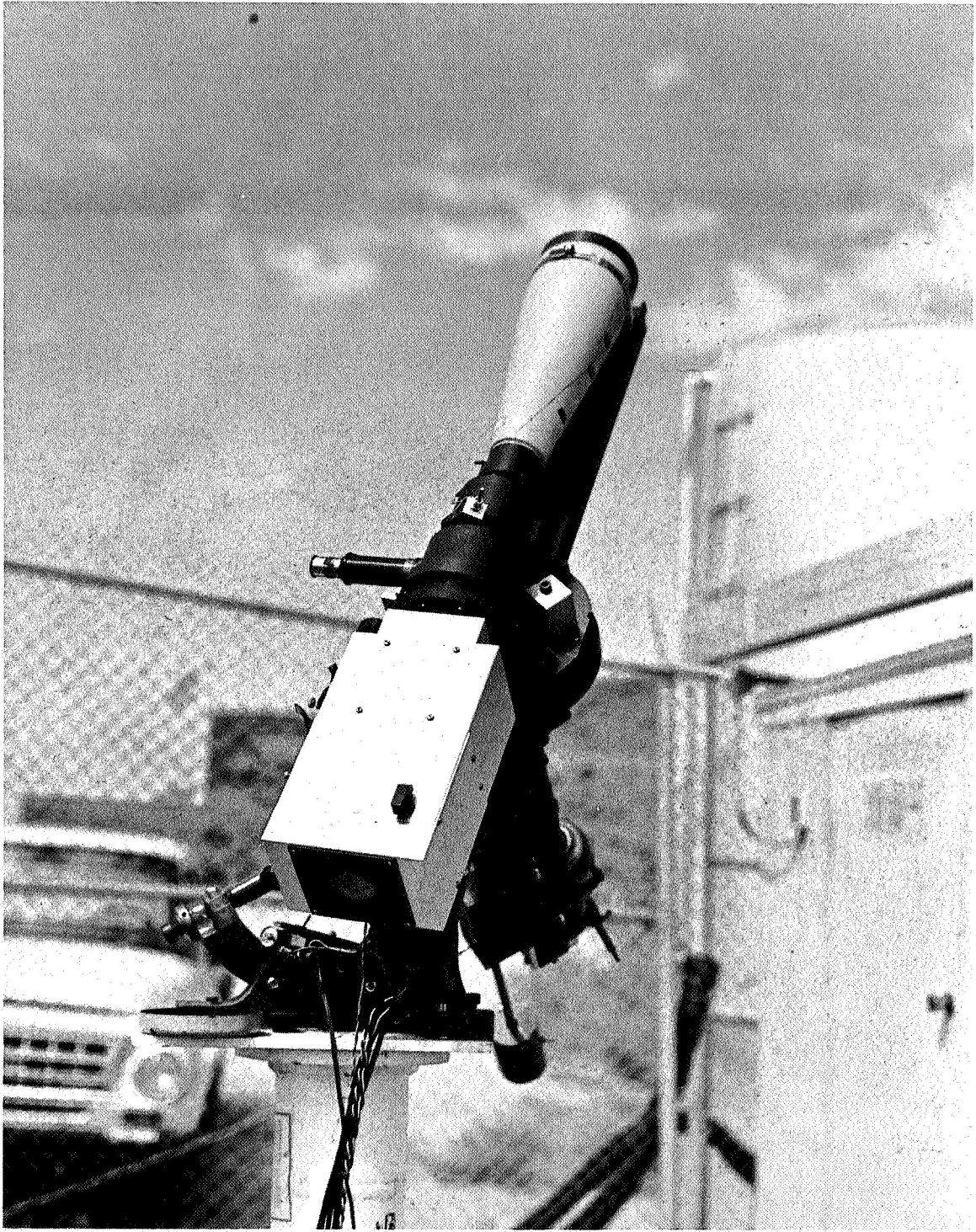Figure 2. Block diagram of albedo photometer instrumentation.

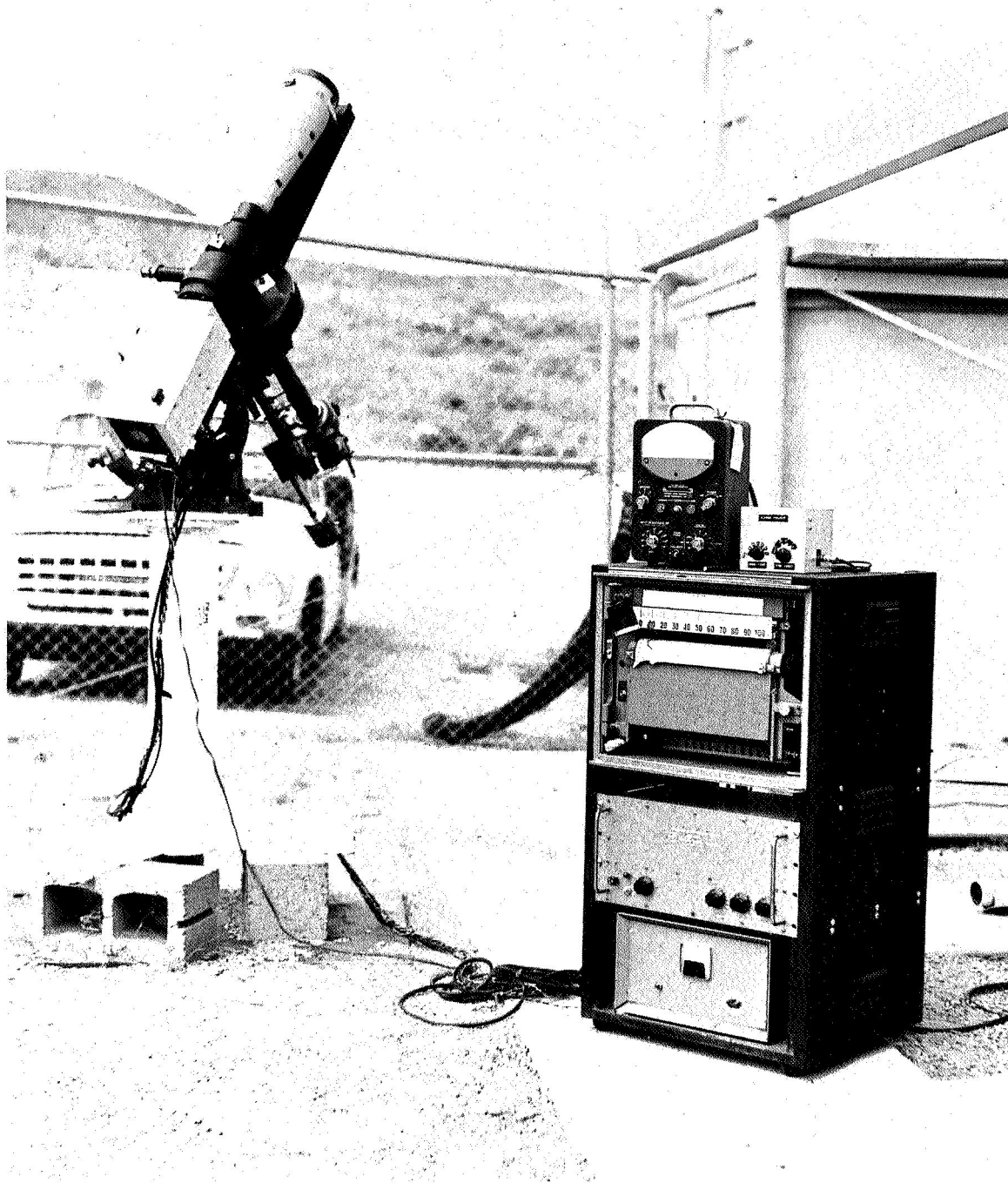Figure 3. The albedo photometer and telescope.

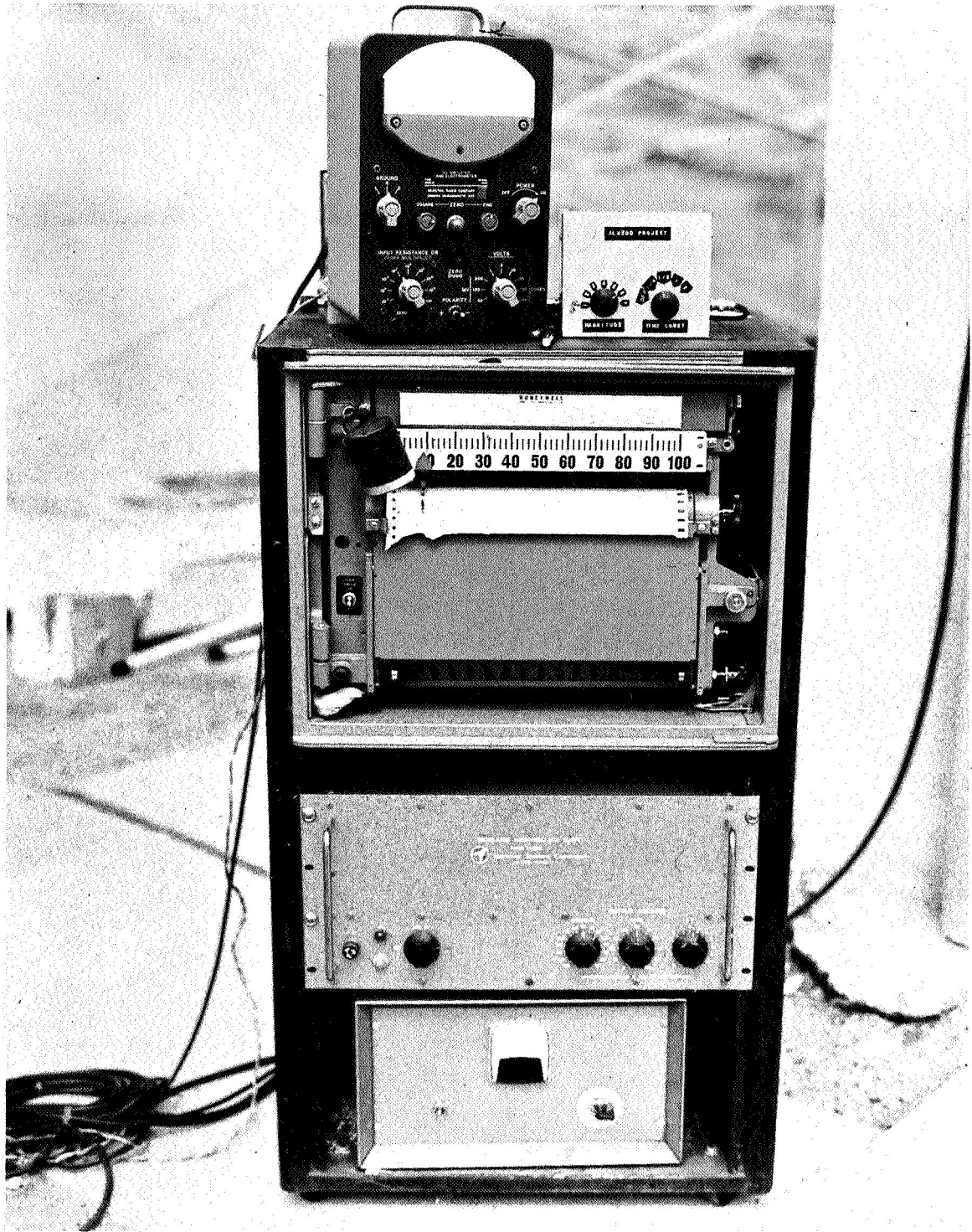Figure 4. The telescope and electronic equipment.

Figure 5. The electronic equipment.

3. METHOD OF OBSERVATION

Our intention was to look for a net change in the intensity of the earth-shine after the observations had been corrected for the effects of aureole, atmospheric extinction, and average phase variation of the earth. Then, any change in brightness, assuming these contributions could be accurately dealt with, would represent changes in the albedo of the earth due to changes on the earth's surface or in the atmosphere. The problem was to measure the extinction and the aureole effects with sufficient precision to permit residual brightness effects to be detected.

To eliminate atmospheric extinction, we used a simple technique that involved making B-V observations of a standard star near the moon in eleva-tion and azimuth each time lunar readings were taken. Thus, assuming that the reading for the lunar aureole was properly made, a comparison between the measured brightness for the star corrected for the effects of sky back-ground and the measured brightness of the earthshine would eliminate the effects of extinction.

Correcting for the aureole in the earthshine readings was a more difficult proposition, since any measurement of the earthlight also measures light scattered from the bright crescent onto the darker portion of the moon. We decided that a method for measuring the aureole suggested by Dr. Franklin and employed in some earlier work would be fruitful (see Attachment). It involved determining isophotes, or contours of equal brightness, for the scattered light from the crescent moon. The contours were intended to provide the shape of rather than quantitative values for the aureole. First, we measured the intensity of the scattered light around the moon at various phases by permitting the moon to drift across the diaphragm of the photometer. The intensity curves resulting from the drifts were then plotted around a map of the moon, and contours were drawn through the points of equal bright-ness on the drift curves. For phases to 1st quarter and after 3rd quarter,

the contours near the dark limb showed a tendency to lie parallel to the terminator at points slightly to either side of the line passing through the center of symmetry of the crescent. This parallelism to the terminator held for points just off the dark limb as well.

A typical observing session with the instrument proceeded approximately as follows: we took earthshine readings in B and V by setting the photometer near the dark limb, slightly below the line of symmetry of the crescent (point A on Figure 6). Next, we set the photometer at a point just off the lunar limb on the sky (point B on Figure 6), along the contour passing through point A, and took measurements of the sky background brightness in two colors. Setting of the photometer at points A and B was made possible through the use of a special graduated reticle in the guiding eyepiece.
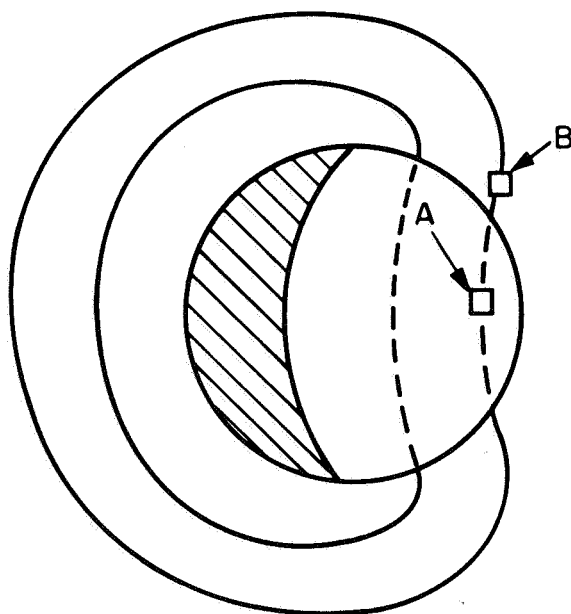

Figure 6. Observed isophotes around lunar crescent.

After a series of earthshine-sky background measurements had been made, we took B and V readings on a standard star that was of spectral type similar to that of the sun and that was at nearly the same zenith angle as

the moon. We repeated the lunar and star readings either until the moon was too low in the evening sky for reliable measurements to be obtained or until, in the morning, the sky became as bright as the comparison star.

4. RESULTS WITH THE 5-INCH INSTRUMENT

Both the observing and the data-handling techniques outlined in the Attachment and used for the data supplied by the 15-inch instrument, have also served, with the one exception noted below, to gather data with the 5-inch instrument and reduce them. Because the 5-inch program as it has recently been executed should be regarded as a feasibility study rather than as an established research effort, we have used one alternate procedure. In order to avoid determing the B, V transformation coefficients for this instrument, we have used stars of nearly solar spectral class as comparison objects for lunar photometry.

Measurements were obtained at Organ Pass, New Mexico, on eight nights during the summer of 1967. Table 1 gives details of observations on the five best nights only.

Table 1.

Lunar photometry with a 5-inch telescope.

Date	Lunar phase	V per arcsec^2	B	(V_E-V_S)	(B_E-B_S)
Aug. 28.4	88°	14.22	14.82	10.65	10.42
29.4	75	14.33	15.02	10.76	10.62
30.4	63	14.04	14.92	10.47	10.52
Sept. 9.1	63	14.56	15.22	10.99	10.82
30.4	47	14.47	15.06	10.90	10.66

Each V or B entry results from 3 to 7 separate settings on the moon. Measurements are reproducible to an accuracy of ~0.2 mag. Guiding and setting uncertainties proved the major source of error.

A comparison of this table with the one that presented results for the 15-inch instrument (Table 1 in Attachment) are in general agreement. We do feel, however, that one point needs to be stressed. Although, as Table 1 of this report suggests, a small instrument is capable of providing mean values of the brightness of the earthshine, it cannot achieve sufficient accuracy to permit measurement of small fluctuations (~ 0.1 mag) probably associated with meteorlogically induced changes in the earth's reflectivity. We feel that this statement is aptly demonstrated by Table 1 for phase angles > 45°. Weather conditions never permitted observations at smaller phase angles so that observations at phase angles < 45° with an accuracy of 0.1 mag remain at best a dubious possibility.

5. CONCLUSIONS OF THE SMALL-INSTRUMENT STUDY

Our work with the 5-inch instrument has permitted us to draw the following conclusions about its usefulness in monitoring possible changes in the earth's albedo by means of earthshine measurements.

1. The 5-inch instrument can, in the hands of a skillful observer, give individual measures of the earthshine to an accuracy of about 0.2 mag. Thus, it provides an average value of the earth's brightness, but not of fluctuations about the mean.

2. The 5-inch instrument could be improved for performance superior to that investigated here by (a) a smaller diaphragm, perhaps 2 to 3 arcmin in diameter rather than 8, and (b) better guiding and setting arrangements. In connection with (b), our observations made clear that unless it is possible to see features in the earthshine part of the moon (and with our instrument it was not), repeatable setting of the photometer cannot be made. This lack of setting repeatability made it impossible for us to judge if the night-to-night fluctuations of the measured earthshine intensity were due to setting of the photometer on lunar areas, such as maria and mountains, having different reflecting characteristics, or to other causes.

3. Any project specifically designed to look for changes in the earth's reflectivity would do well to employ an instrument substantially larger than a 5-inch one.

4. A compromise is very likely possible wherein an instrument as small as a 5-inch is used at phase angles < 45°, thus providing a series of measurements during those 4 to 5 days of the lunar cycle when the earthshine is brightest.

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