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Fundamental Spectrophotometry
of the Major Planets

A PROGRESS REPORT

25 February 1971

Department of Physics and Astronomy
THE UNIVERSITY OF IOWA

Iowa City, Iowa

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John S. Neff

John S. Neff, Principal Investigator
NASA Grant NGR 16-001-094

PROGRESS REPORT

I. INTRODUCTION

This report covers the time interval between 1 June 1970 and 1 February 1971. During this time our efforts were devoted to planetary filter photometry, instrumentation, data reduction, and related theoretical work.

II. PERSONNEL

The following persons were either full time or part time employees on this subject, supported either by National Aeronautics and Space Administration grants NGR 16-001-094 to Dr. J. S. Neff and NGL 16-001-002 to Dr. J. A. Van Allen or by state funds.

Dr. J. S. Neff, Associate Professor of Astronomy
Dr. J. D. Fix, Assistant Professor of Astronomy
Dr. A. A. Lacis, Part Time Research Associate
Dr. D. C. Enemark, Electronics Consultant
K. Knight, Research Assistant
D. Bangston, G. Clements, M. Gaffey, Larry Kelsey,
F. J. Vrba, and W. Ward, Research Aides

Machinists and electronics technicians also worked part time on this project.

III. PLANETARY FILTER PHOTOMETRY

A filter photometer employing a blue filter was modified by J. S. Neff to automatically switch between planet and sky. The data were automatically logged on paper tape for processing in the manner described earlier [Neff, 1968]. This instrument was used to observe Pluto, Uranus, and Neptune as well as Titan, Vesta, and the Jovian satellites.

The observations of Pluto were obtained as part of a continuing program to improve the light curve of Pluto so that the analysis of Lacis and Fix [1970] of Hardie's light curve can be extended. The observations of Uranus and Neptune were obtained as part of a continuing program to search for rotational modulation of their light curves in order to obtain improved values for their rotational periods. The other objects were observed to obtain improved light curves so they could be analyzed by the method developed by Lacis and Fix.

Lacis and Fix are presently inverting published light curves of asteroids and will report on their method and results at the Asteroid Conference at Tucson.

Further filter photometry of planets will be obtained during late spring and early summer of 1971.

IV. INSTRUMENTATION

The following improvements were made to the scanner. A new slit mask was installed to permit automatic switching between light source plus sky and sky alone; the wavelength drive was rebuilt to permit rapid scanning. The automatic switching between source and background will greatly increase efficiency of observation and will improve our ability to observe faint objects such as Pluto.

The offset guider was modified to permit observations to be made of an incandescent lamp which serves as a secondary standard of spectral irradiance. The incandescent lamp can be replaced by a set of arc lamps to facilitate calibration of the wavelength scale. We have a standard current source so that amplifier calibrations are easily made. Thus, it is now possible to do a complete set of calibrations in about ten minutes. Previously, calibrations took several hours to complete.

A new solar attenuator was constructed for the 24-inch telescope. This device consists of four sky baffles and four diffusers coated with barium sulfate paint. The diffusers are followed by more baffles at right angles to the first set. The device is fastened to the top of the 24-inch telescope. Tests of this attenuator are now in progress.

A solar attenuator to be used independently of the 24-inch telescope was constructed by K. Knight. This device automatically compares integrated monochromatic flux from the sun with the flux from two standard lamps. This is accomplished by scanning in right ascension with a declination equal to that of the sun and at a fixed wavelength, the sky, sun, dark, lamp 1, dark, lamp 2, and dark in a continuous sequence. The wavelength is then incremented and the declination scan is repeated. The advantage of the procedure is that all necessary observations at one wavelength are made within thirty seconds, thus variations in sensitivity between a solar observation and calibration observation are reduced. The observed solar flux corrected for sky and normalized to the average flux from the lamps is then plotted against air mass to determine the solar flux incident at the top of the terrestrial atmosphere. This instrument has not as yet yielded satisfactory results. Work is continuing to determine the source of the problem.

The rapid scanner has been tested extensively in the laboratory and on several occasions on the telescope. The old data logging system is not fast enough to keep up with the rapid scanner. Thus testing was carried out with a borrowed multichannel scaler. We have designed and are presently testing a faster data logging system that employs a digital tone system for recording data on an inexpensive stereo tape recorder at the observatory (see Figure 1). The data is played back four times as fast through a decoder into a multichannel scaler at the Physics Research Center (see Figure 2).

The use of the MCS is a temporary stage in the development of the system since we hope to build an interface that will permit us to send the decoded data directly to the Computer Center via a telephone line from our decoder.

We have obtained a real time display at the observatory by driving the X axis of an oscilloscope in the dome with the output of a wavelength encoder (i.e., a potentiometer that is gear-driven by the digital wavelength drive) while the dc voltage from the photomultiplier amplifier is displayed on the Y axis. The oscilloscope in the dome has a long persistence phosphor so that the observer can monitor the spectral energy distribution of the source. A photographic record of the observation is obtained on a second oscilloscope downstairs in the laboratory.

Normal observational procedure will be to scan the source plus background in the foreward direction and background only in the reverse direction. Since a typical scan takes from 10-20 seconds the observer can check the guiding during the reverse scan several times a minute which should make accurate guiding very easy.

We intend to rebuild the filter photometer to make it into an area scanner. It is intended that this instrument will be used to construct monochromatic maps of planets and other extended objects as well as for planetary photometry. G. Clements, for an undergraduate honors project, has designed an area scanner that scans in declination with a linear scan rate of 40 arcsec/sec. He has worked out a scheme for gating our variable rate telescope drive during the dwell time of the cam to obtain a raster scan pattern. We believe it is possible to obtain a display of the monochromatic map on an oscilloscope in either the form of an isometric plot or as intensity versus position.

V. DATA REDUCTION

All the data has been transferred to a disk pack and most programs are in final form with the exception of the programs to analyze the filter photometry. We have been working with the best data on several small projects. F. J. Vrba has been studying the temporal variations of the energy distribution and the equivalent widths of the strongest lines of δ Cephei. Neff and Fix [1971] have reported on the spectrum of Nova Serpentis 1970. Neff and Lacis are starting to systematically process the best data on stars and planets to obtain absolute flux distributions.

VI. RELATED THEORETICAL WORK

The nature of the brightness variation of Pluto is being studied from two opposite points of view. An analysis of the light curve of Pluto has been performed to determine whether the light curve can be understood in terms of a simple two component surface model. (This model has also been applied to the analysis of the light curves of asteroids.) The possibility that the brightness variations might be due to a phase change of surface material is being investigated using numerical heat flow experiments involving materials which could conceivably constitute the surface of Pluto.

VII. REFERENCES

Lacis, A. A., and J. D. Fix, An Analysis of the Light Curve of Pluto, B.A.A.S., 2, 327, 1970.

Neff, J. S., Automatic Photoelectric Spectrophotometry, Astron. J., 73, S194, 1968.

Neff, J. S., and J. D. Fix, Photoelectric Spectrophotometry of Nova Serpentis, B.A.A.S., 3, 13-14, 1971.

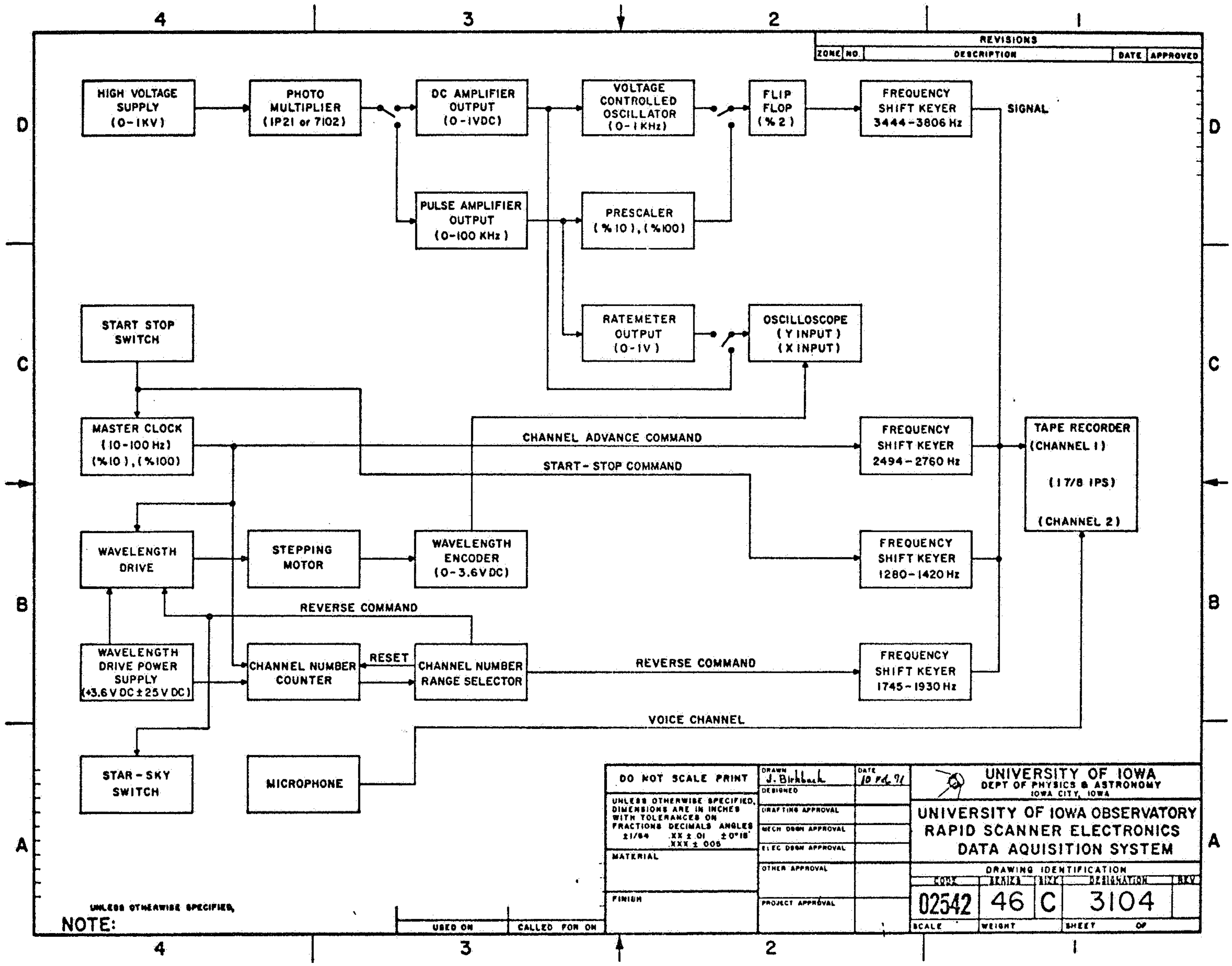

FIGURE 1. Block diagram of new data acquisition system of the University of Iowa Observatory.

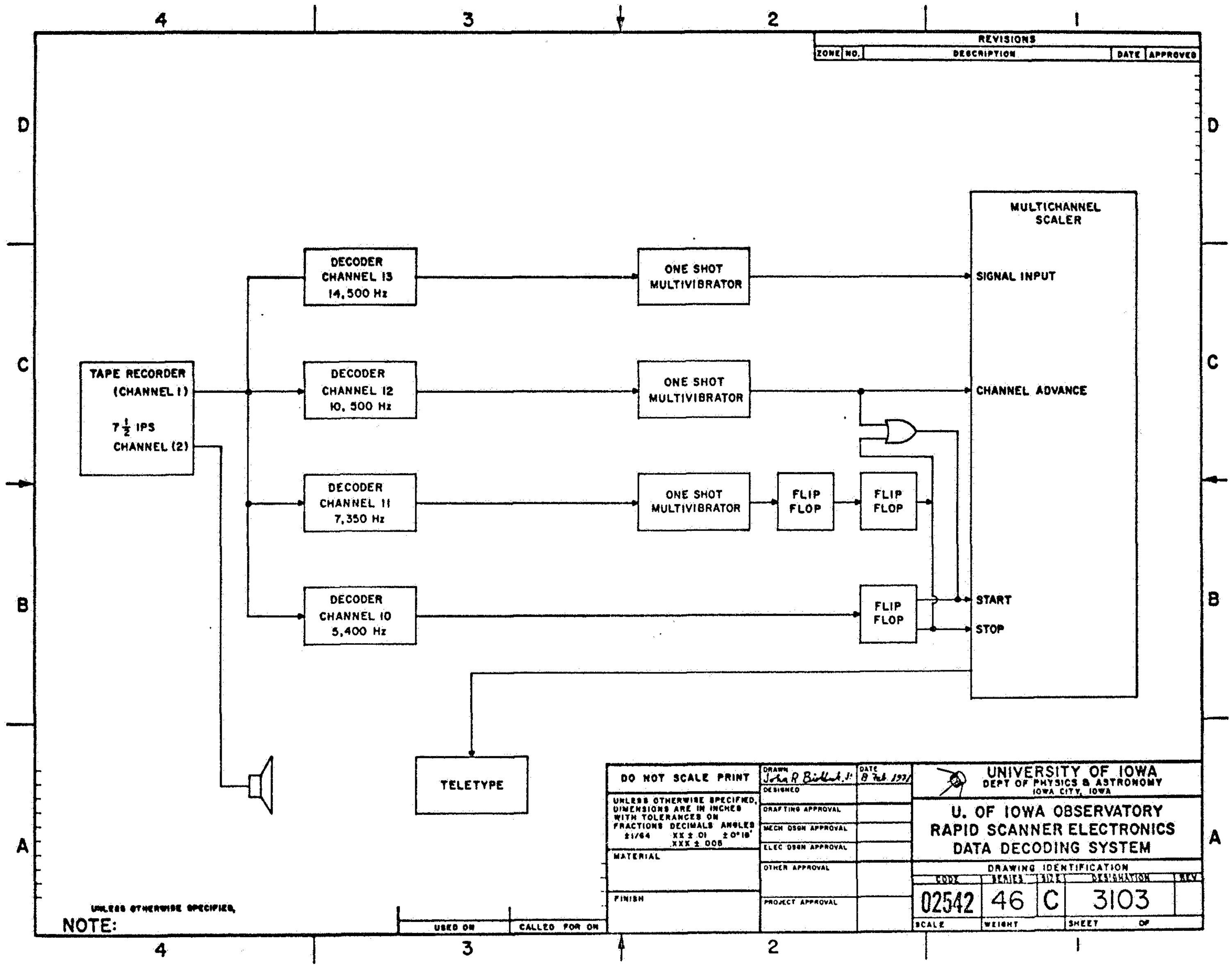

FIGURE 2. Block diagram of the new data decoding system of the University of Iowa Observatory.

Astron. J., 73, S194-S195 [1968]

Automatic Photoelectric Spectrophotometry. J. S. NEFF, *University of Iowa.*—A photoelectric spectrophotometer with automatic data logging and wavelength scanning has been developed at the University of Iowa. The scanner has an Ebert Fastie $f/16$ optical system, and a linear wavelength drive that is driven by a stepping motor. Interchangeable detectors and diffraction gratings permit observation in the 0.31–0.95 μ region of the spectrum. This instrument can also be used for low-dispersion spectroscopy by inserting a mirror in the dispersed beam to reflect light into a camera. Normally the instrument is used as a scanner or narrow-bandpass photometer. The bandpass can be varied from 2–375 Å.

Automatic control of wavelength and data logging was achieved by adding control circuits and interlocks to a semi-automatic digital data logging system for an integrating digital photometer. This unit is fast enough to drive a magnetic tape unit, a 1000 line/min printer, or a small computer, but output speed is presently limited to nine 44 character records/min by a flexowriter.

The modified control unit will drive the stepping motor wavelength drive and log the data for each wavelength. For an integration time of 8 sec/wavelength, the system will observe and log the data for 100 wavelength intervals in 15 min. The punched paper tape output is presently converted to magnetic tape with the departmental Univac 418 computer, and the magnetic tape processed on the university computer center IBM 360/65 computer. An observation of 100 wavelength intervals can be processed and plotted on the printer in less than 4 sec.

A description of the construction and operation of the instrument and the associated data reduction programs are given. Sample data for stars and planets in 3100–6200 Å spectral region are discussed. Photoelectric measurements of the strength of Hγ are also discussed.

It is a pleasure to acknowledge that undergraduate and graduate students in astronomy and engineering assisted with the design, construction and testing of this instrument. Thanks are due to NSF, NASA, and ONR for supporting portions of this work and to the State of Iowa for the bulk of the financial assistance.

Bulletin, American Astronomical Society
Volume 2, p. 314 [1970]

Spectrophotometry of Pluto. JOHN D. FIX AND JOHN S. NEFF, *Univ. of Iowa, Iowa City.*—Spectrophotometric observations of Pluto were carried out on the evenings of 3, 5, 6, and 8 May 1970, using the 24-inch reflector at the University of Iowa Observatory at Hills. Measurements were made at 21 equally spaced wavelengths between 3400 and 5900 Å using a triangular instrumental profile having a full-width at half-maximum of 128 Å. The 23 best scans were used in the determination of the average spectral distribution of Pluto. In the intermediate-wavelength range, the probable errors of the relative brightness of Pluto were between 6% and 10%.

The wavelength dependence of the relative albedo of Pluto was found by dividing the Pluto spectrum by the normalized solar spectrum having the same resolution. The resulting albedo curve for Pluto generally increases toward the red and is in good agreement with the published values of the intrinsic $(B-V)$ index of the planet. The albedo appears to increase somewhat below about 3800 Å and there seems to be a shallow depression in the curve in the vicinity of 4900 Å. The slope of the curve appears to decrease slightly above 4500 Å.

Bulletin, American Astronomical Society
Volume 2, p. 327 [1970]

An Analysis of the Light Curve of Pluto. A. A. LACIS AND J. D. FIX, *University of Iowa, Iowa City.* —The light curve of Pluto is analyzed in terms of a geometrical model consisting of bright and dark areas which are assumed to exhibit either a Lambert law or a geometrical type of reflectivity. Two independent methods, a Fourier analysis and a least-squares type, have been developed for inverting the observed light curve to obtain the longitudinal distribution of the light and dark areas for any combination of albedos selected for the two types of terrain.

The optimum values of the bright and dark area albedos are then selected from the physically possible distributions which give the best agreement with the observed light curve. Although the solution is not unique, the exactness to which the possible values of the albedos can be determined depends on the accuracy of the observed light curve, i.e., the number of Fourier terms which are considered to be significant.

The analysis indicates that the light curve of Pluto can be readily understood in terms of a spotted surface consisting of bright and dark areas. However, on the basis of the present data, the existence or absence of limb darkening (as a result of the Lambert law reflectivity) can not be definitely established.

Bulletin, American Astronomical Society
Volume 3, pp. 13-14 [1971]

15.8.6 Photoelectric Spectrophotometry of Nova Serpentis. J. S. NEFF and J. D. FIX, Univ. of Iowa. - Observations of Nova Serpentis were made in February and March of 1970 at the University of Iowa Observatory using an automatic photoelectric spectrophotometer mounted at the Cassegrain focus of a 24 inch reflecting telescope. The entrance and exit slits were set to give a triangular instrumental profile with a full width at half maximum response of 16A. Measurements of the nova's spectrum were made at 200 consecutive wavelengths between λ3148A and λ6263A. These data were subsequently reduced to obtain the run of absolute monochromatic flux from the nova with wavelength. The absolute calibration of E. Lamla (1969 Theory and Observation of Normal Stellar Atmospheres, Ed. O. Gingerich, MIT Press, Cambridge, Chapter 8), altered for $\lambda <$ 4600A to produce closer agreement with D. Hayes et al. (1968 Astrophys. J. 152, 871) was adopted for the standard star α Lyrae. The spectra of the nova obtained in this manner were used to determine the continuous energy distribution of the nova and to determine color temperature as a function of wavelength and time. The line strengths of emission and absorption lines were determined, and unblended lines were used to estimate electron temperatures and densities in the nova shell. We wish to thank Mr. and Mrs. L. Kelsey and Mr. W. Ward for their assistance in obtaining and reducing these data.

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Spectrophotometry of Pluto

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The relative brightness of Pluto has been measured at 21 equally spaced wavelengths between 3400 and 5900 Å. Using these measurements and the normalized solar spectrum we have determined the relative albedo of Pluto at each of the wavelengths. The albedo of Pluto generally increases toward the red. The diagram of albedo versus wavelength shows indications of a peak below 3800 Å, a depression at about 4900 Å, and a decrease of slope at about 4500 Å.

SPECTROPHOTOMETRIC observations of Pluto were carried out on the evenings of 3, 5, 6, and 8 May 1970, using the 24-inch reflector at the University of Iowa Observatory at Hills. The spectrophotometer was adjusted to produce a triangular instrumental profile with a full-width at half-maximum of 128 Å. Measurements were made at 21 equally spaced wavelengths between 3400 and 5900 Å.

Of the 34 scans obtained, 23 were judged to be of good quality and were used in the determination of the average spectral distribution of Pluto. It should be noted that because the period of Pluto is about 6.4 days (Walker and Hardie 1955) our observations, which covered a period of five days, include data from several different configurations of the planet. Although the spectral distribution of Pluto might thus have varied from night to night during the course of our observations, we have made no attempt to look for nightly differences in the spectral distributions but rather have combined the data from all four nights. In any case, the time variations in the spectral distribution of Pluto are probably not very large since the total light variation of the planet is only about 10%.

The relative brightness of Pluto in the 21 wavelength bands observed is shown in Fig. 1. The error bars represent probable errors. In the intermediate-wavelength region, the probable error is usually between 6% and 10%.

Of more interest than the brightness spectrum of the planet is its wavelength-dependent albedo. This is found by dividing the relative spectrum of Pluto by the normalized solar spectrum having the same resolution. At the present time, there still appears to be a fair degree of uncertainty in the determination of the solar spectrum. This uncertainty seems to be of the order of 5% in some wavelength regions. We have used both the recent NASA determination of the solar spectrum (Thekaekara *et al.* 1969) and the older determination by Johnson (1954) to find the wavelength dependence of Pluto's albedo. At our resolution, the two solar determinations result in very similar looking curves for Pluto. The relative albedo of Pluto is also shown against wavelength in Fig. 1. In obtaining this curve we have used the Johnson determination of the solar spectrum since it resulted in slightly better agreement with the observed $(B-V)$ index of Pluto normalized to the sun. Since the radius of Pluto is somewhat uncertain, only the relative albedo of the planet can be determined.

Figure 1 shows that the albedo of Pluto generally increases toward the red. The normalized $(B-V)$ index derived from our curve is about $+0.18$, in good agreement with the observed value of $+0.17$ reported by Harris (1961). As the probable errors indicate, our results become less reliable as the ultraviolet and infrared parts of the spectrum are approached. Never-

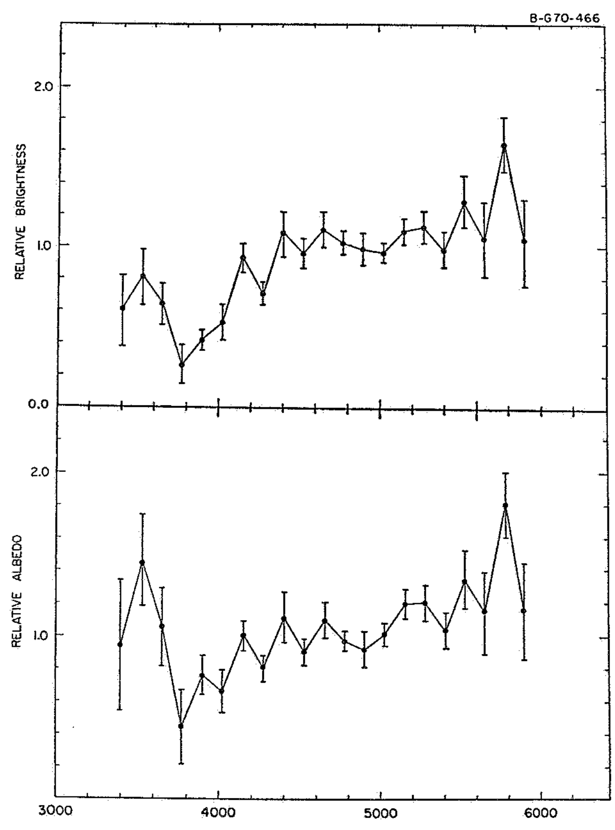

FIG. 1. The wavelength dependence of the relative brightness and the wavelength dependence of the relative albedo of Pluto.

theless, it appears that there is a genuine peak or upward trend below about 3800 Å. The most definite evidence of structure in the curve occurs at about 4900 Å, where there appears to be a real but shallow depression. There also appears to be a decrease in the slope of the curve at a wavelength of about 4500 Å.

ACKNOWLEDGMENTS

We wish to thank Mrs. L. J. Kelsey and Messrs. G. L. Clements, K. L. Knight, and F. J. Vrba for their help in making the observations.

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