THE ASTRONOMICAL JOURNAL VOLUME 85, NUMBER 2 FEBRUARY 1980

THE 1.5–2.5 μM SPECTRUM OF PLUTO

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Received 22 August 1979; revised 31 October 1979

ABSTRACT

New spectrophotometric observations of Pluto from 1.5–2.5 μm with a resolution of $\Delta\lambda/\lambda \sim 0.05$ are reported. The new observations confirm the presence of methane frost on the surface of Pluto.

I. INTRODUCTION

In recent years new understanding of the surface composition of the satellites of the outer planets has been derived from near-infrared spectral observations. These observations are particularly sensitive to the ice constituents of planetary surfaces since the major ices—H_2O, NH_3, and CH_4—all have characteristic reflection spectra in the near infrared. In this paper new low resolution spectral observations of Pluto from 1.5–2.5 μm are reported. These observations confirm the presence of methane ice previously reported (Cruikshank, Pilcher, and Morrison 1976; Lebofsky, Rieke, and Lebofsky 1979) as a major constituent of the surface of Pluto.

II. OBSERVATIONS

Observations of the entire disk of Pluto were obtained with a liquid/solid nitrogen cooled continuously variable interference filter spectrometer with a spectral resolution of $\Delta\lambda/\lambda \sim 0.05$. The observations were made with the 5 m Hale telescope on 1979 March 12 UT. The data were reduced to flux densities by observing the A3V star ζ Vir whose flux density at 2.2 μm was taken as 37×10^{-26} W m^{-2} Hz^{-1} and whose spectrum was assumed to follow a Rayleigh-Jeans spectrum. The observed flux densities, including those obtained from broadband measurements at 1.25, 1.65 and 2.20 μm, are given in Table I.

The spectrum of Pluto was reduced to normalized reflectance as a function of wavelength by dividing the observed spectrum by that of the solar spectrum (Labs and Neckel 1970), and normalizing to unity at 1.46 μm. The resultant quotient was normalized to the geometric albedo at 2.0 μm which was obtained using the solar flux at 2.0 μm as taken from Arvesen, Griffin, and Pearson (1969). The Pluto-Sun-Earth Geometry was taken from the American Ephemeris and Nautical Almanac (1979) and the diameter of Pluto was taken to be 3600 km (Arnold, Boksenberg, and Sargent 1979). The resulting geometric albedo of Pluto is plotted in Figure 1.

The flux densities shown in Table I agree with the data of Lebofsky *et al.* to ± 10% for the observations in the 2.2 μm window, while the results in the 1.65 μm window disagree with those of Lebofsky *et al.* by as much as 60%. The broadband data obtained at the same time as the narrowband data are consistent with the narrowband observations, and give relative reflectances of a (1.65 μm) = 0.78 ± 0.08 and a (2.2 μm) = 0.52 ± 0.05; a (1.2 μm) is taken as 1.0. These results are consistent with those of Cruikshank, Pilcher, and Morrison (1977), who found a (1.65 μm) = 0.94 ± 0.08 and a (2.2 μm) = 0.57 ± 0.08. While we do not understand the discrepancy with the data of Lebofsky *et al.*, the consistency with the data of Cruikshank *et al.* (1977) and the agreement with the methane frost spectrum lends confidence to the present results. Since the measurements were made at different times this may reflect a distribution in the surface composition of Pluto.

TABLE I. Observed flux densities of Pluto.

λ(μm)	Δλ(μm)[a]	Flux Density[b] (10^{-29} W m^{-2} Hz^{-1})
1.25	0.24	15.7 ± 1.6
1.46		14.9 ± 0.3
1.50		14.2 ± 0.3
1.54		12.8 ± 0.5
1.58		11.2 ± 0.2
1.62		9.1 ± 0.2
1.65	0.30	10.0 ± 0.8
1.66		8.3 ± 0.3
1.70		7.9 ± 0.2
1.74		7.8 ± 0.3
1.78		7.0 ± 0.5
1.82		7.5 ± 0.7
1.95		8.3 ± 0.7
2.00		8.5 ± 0.4
2.05		7.1 ± 0.5
2.10		6.3 ± 0.4
2.15		4.6 ± 0.2
2.20		3.6 ± 0.1
2.20	0.41	4.5 ± 0.4
2.25		2.7 ± 0.4
2.30		2.4 ± 0.2
2.35		2.2 ± 0.4
2.40		3.3 ± 0.3
2.45		2.6 ± 0.5
2.50		4.3 ± 1.0

[a] Unless otherwise indicated $\Delta\lambda = 0.05 \times \lambda$.
[b] For broadband observations at 1.25, 1.65, and 2.2 μm the flux error includes an estimated error for the absolute calibration. For all other wavelengths the error is purely statistical.

III. DISCUSSION

Cruikshank *et al.* (1976) concluded from their photometric broadband observations in the near infrared

[a] Operated jointly by the Carnegie Institution of Washington and the California Institute of Technology

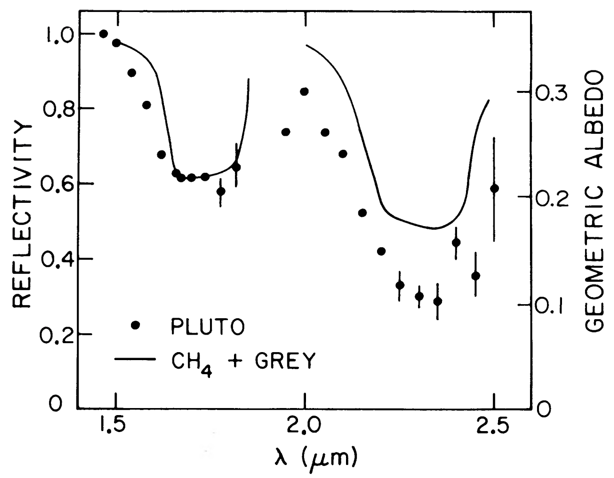

FIG. 1. The geometric albedo of the surface of Pluto plotted from 1.5–2.5 μm. The spectral resolution of the data are $\Delta\lambda/\lambda \sim 0.05$. The solid curve is a sum of a grey and methane frost reflectivities (see text).

that methane frost covers the surface of Pluto. Lebofsky *et al.* (1979) confirmed these conclusions with narrow-band photometry with discrete filters ($\Delta\lambda/\lambda \sim 0.05$–$0.3$) in the 1.65 μm and 2.2 and 3.5 μm atmospheric windows, but they note that their observations of Pluto do not match in detail the near-infrared reflectivity of methane frost.

The solid curve in Figure 1 shows a model fit to the present observations based on the laboratory reflectance of methane frost (Smythe 1975). The fit was derived by summing equal fractions of methane frost reflectivity as given by Smythe and grey reflectivity at 2.0 μm; the laboratory data have been degraded to the resolution of the observations. This model matches the general features of the Pluto reflectivity spectrum from 1.5–2.5 μm. In particular the sharp drops in reflectivity of methane ice at ~1.62 and 2.15 μm are both seen in the observed spectrum as is the increasing reflectivity beyond 2.35 μm. A better fit to the data could be achieved by summing a reflectivity that increases to shorter wavelengths with the methane reflectivity, but the major features are shown by the simple model. The agreement between the observed reflectivity and the major features of the methane reflectivity is excellent, and we believe the data show conclusively that methane frost is a major constituent of the surface layers of Pluto. While the agreement between the methane frost spectrum and the observed reflectivity of Pluto is good, a contribution from gaseous methane cannot be ruled out. The short wavelength side of the observed 2 μm absorption occurs at a shorter wavelength, 2.15 μm, than that of methane gas, 2.25 μm (Pierson, Fletcher, and St. Clair Gantz 1956); however, the laboratory spectrum was obtained under higher temperature and pressure conditions than are appropriate to the environment of Pluto, and the effect of this difference might be significant. As pointed out by Benner, Fink, and Cromwell (1978), high resolution spectra of the 2 μm absorption should be able to distinguish between gas and solid phase. Unfortunately, the present observations do not have sufficient resolution to resolve the question, and Pluto is sufficiently faint that present infrared instrumentation cannot make such measurements.

The observed geometric albedo at 2.0 μm is 0.30 ± 0.03 while the reflectivity of methane frost at 2.0 μm is 0.4 (Smythe 1975). This suggests that a significant fraction of the surface is covered with methane frost that is in a relatively clean state. If this is the case, the decrease in strength of the bands at 1.7 and 2.2 μm over that reported by Smythe (1975) must be due to a surface granularity size effect. Such effects are expected in water frost (Pollack *et al.* 1978), and so it is not surprising that such effects should exist for methane frost.

While these observations confirm the existence of methane on Pluto the problem of explaining its existence remains. Lebofsky (1975) has shown that methane frost is highly unstable at the orbit of Pluto. Lebofsky (private communication) has pointed out that these calculations did not include effects of the gravitational field and low temperature of Pluto on the retention of methane. Clearly a more detailed analysis of this problem is appropriate.

We thank Juan Carrasco for assistance with these observations and L. Lebofsky for a careful reading of the manuscript. This work was supported by NASA grants NGL 05-002-207 and NGL 05-002-140 and NSF grant AST 77-20516.

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