INFRARED OBSERVATIONS OF COMET 1965f*

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ABSTRACT

Infrared photometric measurements of Comet 1965f were made on 19 days during October and November, 1965. Absolute intensities as a function of the comet's distance to the Sun were measured in a region centered on the cometary nucleus at wavelengths near 1.65, 2.2, 3.4, and 10 μ . On three days the intensity in the tail was measured.

Color temperatures were calculated in both the head and tail region from these absolute intensities. From the color temperatures the nature of the emissivity of the emitting particles is derived and the nature of some possible materials is discussed.

INTRODUCTION

On September 18, 1965, K. Ikeya and T. Seki independently discovered a cometary object of about eight magnitude. Early observations indicated that this comet, 1965f, was a member of the 1882 II family of Sun-grazing comets and might well become visible in daylight as it neared the Sun on October 21.

Infrared measurements were started October 6 with the 24-inch reflector at Mount Wilson. This comet was successfully observed on ten days before and on nine days after perihelion in wavelength windows centered at 1.65, 2.2, 3.4, and 10 μ . The last observation was obtained on November 1. The comet-Earth distance varied less than 10 per cent from the mean value of 1 a.u. during the full observing period. During the first and last parts of these periods, the measurements were taken before sunrise, while from October 16 until October 26 the data were obtained in daylight near transit of the comet.

THE EQUIPMENT

Infrared measurements were made with two separate photometers mounted on opposite arms of the 24-inch reflector at Mount Wilson. This telescope, an f-16 bent cassegrainian, has hollow declination axes and a rotatable flat mirror which allows equipment to be mounted on each arm of the fork mounting and to be illuminated by a simple rotation of the "bending" flat. On those days when the comet was nearest the Sun it was necessary to mask the eastern half of the telescope tube to prevent sunlight from illuminating the primary mirror.

The photometer and detector used for the 10- μ measurements were similar to those described by Westphal, Murray, and Martz (1963). The photometer used for the 1.6-, 2.2-, and 3.4- μ measurements is optically similar, though physically rather different. The detectors used in the shorter wavelengths were PbS cells cooled with liquid nitrogen. Each detector was mounted in a separate Dewar with a cooled band-pass filter to isolate the appropriate atmospheric window. Observations were made in windows at 1.5–1.8 μ , 2.0–2.4 μ , 3.0–3.8 μ , and 8.4–13.5 μ .

THE OBSERVATIONS

Table 1 is a record of the usable observations obtained from 1965f. Standard stars (Johnson 1964; Low and Johnson 1964) were observed to obtain absolute flux calibra-

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tions in all wavelength regions. Extinction was measured by observing stars or, with a diaphragmed telescope, the Sun at various hour angles. The total extinction correction was less than 40 per cent for even the most extreme hour angles.

Figures 1-4 illustrate the observed absolute intensities in each wavelength region with respect to distance R from the Sun. These intensities were observed in a 40''-diameter circular area located on the head of the comet to yield maximum flux. During twilight observations this area was observed to be well centered on the starlike nucleus. The size of the error bars is, in most cases, due to uncertainty in the extinction correction.

The flux from the tail was observable for several days near perihelion. Figures 5 and 6 illustrate the normalized flux from the tail on two days for two and three wavelengths. These data resulted from scanning westward in right ascension from the nucleus with the 40'' diaphragm. Figure 7 shows the tail at 3.4 μ on October 16 and 23. Flux profiles for various declination scans across the tail are also shown. The signal-to-noise ratio of these scans always exceeded 10:1; thus the sharp differences shown are real and not instrumental.

TABLE 1
PERIHELION, OCTOBER 20.2

Date (U.T.)	1 65 μ	2 2 μ	3 4 μ	10 μ
October:				
6 . .	. .	X	..	
7	. .	X		
8	. .	X		
9	. .	X	X	X
10		X	X	
12	X	X	X	X
14	X	X	X	X
16	X	X	X	
17	. .	X	X	X
18		X	X	X
23	X	X	X	X
24	X	X	X	X
25		X	X	X
26 . . .	X		X	X
27	X	X	X	X
28	X	X	X	X
29	X	X	X	X
30	X	X	. .	
November:				
1	X	X		

Figures 8 and 9 show the data plotted with respect to wavelength for each observed solar distance. The relative solar spectrum has been plotted, normalized to the 1.65- μ data at $R = 0.45$ a.u., to illustrate the relative reflected component of the observed intensities. The dashed lines connecting each day's data are only to clarify the graph and should not be used as an interpolation of the data.

COLOR TEMPERATURES

Figure 10 shows the color temperatures of the cometary head derived from the 2.2- and 3.4- μ data, corrected for solar reflection, assuming that all of the flux at 1.65 μ is reflected sunlight. The emitting material is assumed gray. Also plotted is the equilibrium temperature for a black or gray conducting sphere assuming solar heating. Figure 11 illustrates a similar set of data derived from the 3.4- and 10- μ fluxes. The color temperature 1' from the nucleus along the tail on October 18 was essentially the same as that

FIG 1

FIG. 2

FIG. 1.—Intensity at 1.65μ , measured in an area $40''$ in diameter centered on the head of comet 1965f, displayed with respect to $\log_{10}$ of the comet-Sun distance. The distance from Earth to the comet was essentially constant.

FIG. 2.—Same as Fig. 1 with intensity at 2.2μ .

FIG 3

FIG 4

FIG. 3.—Same as Fig. 1 with intensity at 3.4μ .

FIG. 4.—Intensity at 10μ , measured in an area $30''$ in diameter centered on the head of comet 1965f, displayed with respect to $\log_{10}$ of the comet-Sun distance. The distance from Earth to the comet was essentially constant. The intensity values have been corrected to those that would have been measured in a $40''$ area by use of Fig. 15.

FIG 5

FIG 6

FIG. 5—Fluxes measured in the tail of comet 1965f at 0.195 a.u. from the Sun as the comet approached perihelion. The flux has been normalized at the head for each profile. The equivalent optical density, assuming clean iron particles, is shown on the right scale.

FIG. 6—Fluxes measured in the tail of comet 1965f at 0.195 a.u. as the comet receded from the Sun. The flux has been normalized at the head for each profile. The equivalent optical density, assuming clean iron particles, is shown on the right scale.

FIG. 7.—The 34- μ flux from the tail of comet 1965f shown in the lower graph as the comet approached the Sun on October 16, 1965, at a solar distance of 0.295 a.u. and in the upper graph on October 23, 1965, at a solar distance of 0.195 a.u. as the comet receded from the Sun. The normalized flux along a right ascension profile is shown on the left, the declination profiles with the same flux scale at each of several locations along the tail with the declination scale on the right.

FIG 8

FIG 9

FIG. 8.—Intensities measured about the head of comet 1965f displayed for each wavelength at various comet-Sun distances as the comet approaches the Sun. The slope of the solar spectrum is shown by the solid line on the left.

FIG. 9.—Intensities measured about the head of comet 1965f displayed for each wavelength at various comet-Sun distances as the comet receded from the Sun. The slope of the solar spectrum is shown by the solid line on the left.

FIG. 10

FIG 11

FIG. 10.—The color temperatures calculated from the 2.2- and 3.4- μ intensities assuming a constant emissivity. The solid line shows the temperature reached by a black (or gray) conducting sphere due to solar heating.

FIG. 11.—The color temperatures calculated from the 3.4- and 10- μ intensities assuming a constant emissivity. The solid line shows the temperature reached by a black (or gray) conducting sphere due to solar heating.

measured on the head. The effect of line emission or absorption on the above color temperatures can be estimated in the 2.2- μ region from spectra obtained on October 11 and 19, 1965 (D. McCammon and G. Neugebauer, private communication). The results show that line emission or absorption is less than 10 per cent of the continuum. The observed continuous spectrum in this region has a distribution which is consistent with the above color temperature.

DISCUSSION

The color temperature derived from both the 2.2–3.4- μ and 3.4–10- μ observations indicate a temperature higher than that which would be reached by a solar-heated gray body. However, the solar equilibrium temperature will agree with the color temperatures if it is assumed that the emissivity at 0.5 μ is about 4 times larger than the average emissivity from 2 to 10 μ . If the emissivities in the infrared decrease with increasing wavelength, as they do for those natural materials which have low-infrared emissivities, then the emissivities at 2.2, 3.4, and 10 μ must be in a ratio of about 2:1:1.

Of the materials observed to be present in this comet at perihelion (Dufay, Swings, and Fehrenback 1965), iron has approximately the above emissivity ratios. The emissivity of iron is given in Table 2. Figures 12 and 13 illustrate the 2.2–3.4- μ and 3.4–10- μ

TABLE 2
EMISSION OF IRON (AFTER COBLENTZ 1906)

λ (μ)	ϵ	λ (μ)	ϵ	λ (μ)	ϵ
0.55	0.45	3.0	0.15	8.0 . . .	0.06
1.0	.35	4.0 . . .	.10	10.0 . . .	.05
1.5 . . .	.28	5.0 . . .	.08	12.0 . .	.04
2.0	0.22	6.0	0.07	14.0 . .	0.04

color temperatures with the assumption that the radiating material is clean iron in particle sizes large enough to radiate as bulk iron. The equivalent equilibrium temperatures are also plotted. The 3.4–10- μ temperatures in Figure 13 appear somewhat low, suggesting that the emissivity at 10 μ is somewhat higher than that of clean iron. A small coating of oxide or other “black” material would selectively increase the apparent emissivity at longer wavelengths.

Since the effective emissivity of an electrically conducting particle is a function of the particle size to emitted wavelength ratio, the derived emissivity ratios might also be explained by assuming a distribution of particle sizes.

Of course it is not possible to rule out an internal heat source, although it would have to operate in each particle separately for the color temperature to remain the same in the tail where the density is about ten times lower than in the head.

Figure 14 shows the mean optical density τ_R in a region centered on the comet head as a function of distance R from the Sun. If $\tau_R \ll 1$ we have

$$\tau_R = \frac{I_{3.4}(R)}{\epsilon_{3.4} B_{3.4} T(R)},$$

where $I_{3.4}$ is the measured intensity, $\epsilon_{3.4}$ is the emissivity of iron, and $B_{3.4}[T(R)]$ is the Planck function at a temperature determined by the 2.2- and 3.4- μ intensities (see Fig. 12).

The optical density may also be calculated from the reflected sunlight observed at 1.65 μ , if one assumes that the particles have albedos similar to iron, are large with respect to the scattered wavelength, and scatter like a Lambert surface. The optical density

FIG 12

FIG 13

FIG. 12.—The color temperatures calculated from the 2.2- and 3.4- μ intensities assuming an emissivity like iron. The solid line shows the temperature reached by an iron sphere due to solar heating.

FIG. 13.—The color temperatures calculated from the 3.4- and 10- μ intensities assuming an emissivity like iron. The solid line shows the temperature reached by an iron sphere due to solar heating.

FIG 14

FIG. 15

FIG. 14.—The optical density of a 40'' area around the head of comet 1965f, assuming iron emissivities

FIG. 15.—The relationship of flux and observing aperture size at 2.2 μ on October 9, 1965.

calculated from the $1.65\text{-}\mu$ data under these assumptions and that derived from the thermal data agree within experimental error.

The agreement of these independent measurements of optical density depends strongly on the use of the above emissivity ratios. For example, a gray material with an $\epsilon = 0.8$ results in a disagreement in optical density of more than a factor of 10.

It should be noted that the functional relationship between the optical density and the distance to the Sun is about the same for both the approaching and the receding cases. This is consistent with the following assumptions about the processes taking place in the comet: (1) The measured thermal energy was coming from particles which were eroded off of a "solid" nucleus. (2) Over the period of observations the loss of material was small compared to the total material in the nucleus. (3) The velocity of the particles away from the nucleus was large enough so that the mean instantaneous optical density in the region of observation was determined by the instantaneous "boiling" rate. Each of these assumptions can be looked at more closely in terms of other information we have about the comet.

Figure 15 shows the measured flux from the head at $2.2\text{ }\mu$ as a function of aperture diameter on October 8, 1965. The flux is seen to be proportional to aperture diameter within experimental error. If the particles are being generated uniformly and escaping with a uniform velocity distribution, then the calculated integrated particle density would be linear with radius from the nucleus.

The optical density data displayed in Figure 14 show that in passing within $1 R_{\odot}$ of the Sun the nucleus lost only about $\frac{1}{2}$ of its surface area. This suggests that when the comet is farther from the Sun the material lost is small compared to the total material in the nucleus.

A minimum velocity of the particles away from the nucleus can easily be calculated under the third assumption. The particle velocity must be large enough so that in the time between observations the particles will travel at least the distance to the edge of the aperture. If we take the time $\sim 5 \times 10^4$ sec and projected aperture $\sim 1.5 \times 10^4$ km, then the velocity of expansion must be of the order of or greater than 0.3 km/sec. This can be compared to the following known velocities. (1) The development of the tail shown in Figure 6 after perihelion requires a velocity at least 3 km/sec. (2) Spherical halos from the nucleus of Halley's comet in 1910 had expansion velocities less than 1 km/sec (Bobrovnikoff 1931). (3) The two parts of this comet observed after perihelion were separating at about 0.03 km/sec (Pohn 1965).

It is interesting to note that, from the calculated optical density two days before and two days after conjunction with the Sun, it may be concluded that the surface of the nucleus was reduced by a factor of about 2. This implies that the physical radius was reduced by about 30 per cent and the mass was reduced by about 65 per cent.

SUMMARY

Observations in the infrared of Comet 1965f have shown that the color temperature changes with distance to the Sun in about the way expected from solar heating. For solar-heated particles, the ratio of emissivities between the visible and the infrared must be about 4.

The color temperature measured in the tail is essentially the same as that measured in the head.

If one assumes that the emissivity decreases smoothly with increasing wavelength then the emissivity ratio from 2.2 to $3.4\text{ }\mu$ is about 2:1 and that from 3.4 to $10\text{ }\mu$ is about 1:1.

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