INFRARED OBSERVATIONS OF FAINT COMETS

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Abstract

Infrared observations of the periodic comets Encke, Stephan-Oterma and Chernykh indicate that the dusty component in this class of comets is not radically different from the dusty component found in nonperiodic comets. The differences in the infrared behavior among these three comets suggests that a range of behaviors rather than a single behavior typifies the cometary activity. The range in albedo (0.02 to 0.10) of the dust calculated for the periodic comets is similar to the range in albedos seen among the asteroids.

I. Introduction

Most infrared observations of comets have been directed at bright, active, easily observable nonperiodic comets that have been close to the sun. These observations have been, for the most part, exploratory in nature although several systematic studies over a range of infrared wavelength and heliocentric distances of Comet Kohoutek (cf., Rieke and Lee, 1974), Comet West (cf., Ney and Merrill, 1976) and Comet Bradfield (Ney, 1974) have been completed.

Infrared photometry has been applied only sparingly to comets in the past and generally limited to commonly available broad band and relatively narrow band filters from 1 to 30 microns. This situation is not surprising since (1) bright, easily observable comets are generally nonperiodic hence unpredictable in occurrence and observability which precludes systematic observing programs, and (2) physically meaningful interpretations of any observations are at best difficult since so little is currently known about comets themselves, i.e., it is difficult to know what features to expect and how to best detect them.

In spite of the problems associated with comet observations several studies have been completed. Infrared photometry was first applied to Comet Ikeya-Seki (1965 VIII) by Becklin and Westphal (1966). This study demonstrated that the particles in the comet tail and head are similar, that these particles respond primarily to solar heating but reach temperatures higher than would a black body, and that the particles are small with low infrared emissivities. Maas, Ney and Woolf (1970) demonstrated that the sharp emission peak observed near 10 microns that was superposed on the blackbody-like continuum was due to silicate grains. The higher than blackbody equilibrium temperature was interpreted to be caused by the presence of opaque particles smaller than the wavelength of the thermal emission, i.e., micron-sized particles composed of iron or carbon, but the silicate feature was interpreted to be caused by a population of silicate particles. O'Dell (1971) interpreted the infrared characteristics as being caused by submicron (0.1 micron) particles with an albedo about 0.3.

The most extensively observed comet in the infrared is Kohoutek (1973f) since a major campaign was organized to monitor cometary activity both pre- and post-perihelion out to heliocentric distances of 2 AU. A dependence of the 10 micron silicate emission feature with heliocentric distance and an increase in grain temperature with decreasing heliocentric distance were clearly demonstrated. The albedo of the dust grains in Kohoutek (1973f) estimated to be about 0.2 (Rieke and Lee, 1974) has been recalculated to be 0.15.

Only Comet West (1975n) has been studied as extensively as Kohoutek (1973f). Ney and Merrill (1976) used an extended series of visual and infrared photometric measurements to infer that the scattering phase function of the cometary dust is strongly peaked in the forward direction. Oishi et al. (1978) used infrared photometric and infrared polarimetric observations of Comet West (1975n) to construct a cometary dust model which requires the dust to be a mixture of metallic (graphite or iron) grains and dielectric (silicate) grains.

Measurements on several other comets are available but are generally more limited in scope or completeness. Observations of Comet Bennett (1969i) and Comet Bradfield (1974b) by Ney (1974) demonstrated that there are large differences in dust activity among comets.

The objective of previous infrared observations of comets has been to understand the thermal emission from the dust coma and dust tail. Very little attention has been given to direct studies of the nucleus itself because the flux from the nucleus is generally masked by the flux from the surrounding dust grains. Hence, the majority of observations have concentrated on the monitoring of the form and change in the thermal spectrum of the dust to obtain information about the physical properties of the dust.

TABLE 1. Summary of the infrared observations*

Comet	Date(UT)	r (A.U.)	Δ (A.U.)	J	H	K	N	(10.4/N)
Chernykh	10/13/77	2.76	1.77	--	--	--	5.76 ±0.51	0.36 ±0.07
	10/15/77	2.76	1.77	--	13.65 ±0.04	13.65 ±0.10	5.82 ±0.51	--
Encke	10/10/80	1.23	0.45	--	15.20 ±0.16	--	--	--
	10/12/80	1.20	0.43	--	--	--	3.71 ±0.10	--
Stephan-Oterma	10/10/80	1.73	0.96	12.80 ±0.06	12.65 ±0.06	12.51 ±0.01	--	--
	10/12/80	1.72	0.94	--	--	--	3.63 ±0.06	0.39 ±0.03

*Effective wavelengths of the filters: J, λ_{eff} = 1.25 μm; H, λ_{eff} = 1.6 μm; K, λ_{eff} = 2.2 μm; N, λ_{eff} = 10.6 μm, FWHM = 5.1; 10.4 narrow band, λ_{eff} = 10.4 μm, FWHM = 1.3 μm.

The grains in the dust coma seem to be sub-micron sized particles composed of a mixture of at least two materials: a metallic-like grain (either iron or graphite) to account for the thermal continuum and a silicate component to explain the silicate emission features at 10 and 20 microns.

The silicate component is identifiable from the emission feature at 10 microns but these particles must be very small (< 5 micron; Hanner, 1980) to remain optically thin at these wavelengths. These small silicate grains cannot contribute significantly to the dominant component of the black-body-like spectrum. Iron or graphite particles with low infrared emissivities are necessary to explain the overall thermal properties of the dust. Oishi et al. (1978) demonstrate that these metallic-like grains can explain the polarization and scattering functions of Comet West (1975n).

In spite of the identification of the silicate component in cometary dust, the nature of the silicate material is still unknown. Day (1974) has produced amorphous silicates in the laboratory that may be suitable analogs. Friedman et al. (1979) point out that phyllosilicates such as those found in some carbonaceous meteorites are close matches to the spectra of some interstellar and circumstellar grains and, therefore, should be considered as a possible silicate composition. Identification of a phyllosilicate composition for the silicate component would have important implications to our understanding of the origins of the cometary nuclei.

Infrared and visual studies of comets have shown each comet to be unique in one way or another. It is difficult to draw firm conclusions about the nature of cometary dust and the nucleus since it is not clear whether the differences in amount of dust, composition of the dust, thermal evolution, etc., are the result of true differences among the nuclei of various comets or are the result of the number of perihelion passages. Without complete sets of systematically obtained observations, the physical properties of the comet nucleus will remain in question, or at least until the nucleus can be observed directly.

II. Observations

The short period comets seem to have been neglected in comparison to the long period and nonperiodic comets. This situation is undoubtedly due to the faintness of the short period comets and their subsequent unglamorous perihelion passages. Until now, the only short period comet known to have its thermal spectrum measured is P/Encke (Ney, 1974). An attempt to measure the N magnitude of short period comet P/Arend-Rigeaux was unsuccessful.

A systematic infrared study of three period comets has been initiated at the University of Arizona with the J, H, K, N and 10.4 μm passbands. The observations of Comets P/Encke, P/Stephan-Oterma and P/Chernykh, summarized in Table I, were obtained with the Catalina 154 cm telescope using the infrared observational techniques and calibration described by Low and Rieke (1974). These observations represent the first nearly simultaneous observations of the thermal and reflected part of the spectrum of any periodic comet.

The H-K colors for both P/Stephan-Oterma (H-K = +0.14) and P/Chernykh (H-K = 0.00) are slightly redder than solar colors (J-H = +0.30 and H-K = -0.05; Johnson et al., 1975), and are similar to observations of the reflected light from the dust of non-periodic comets. The J-H color for p/Stephan-Oterma (J-H = +0.15) is slightly bluer than solar colors and is noticeably lower than values measured by others (A'Hearn, 1981). The majority of the dust particles in these two periodic comets probably is not smaller than about 0.1 μm since there is little evidence for large amounts of Rayleigh scattering by the dust. The JHK colors are not atypical of the JHK colors of asteroids and meteorites reported by Leake et al. (1978).

The existence of a 10 μm silicate emission feature can generally be ascertained by comparing the 10.4 μm narrow-band flux with the broadband N or 10 μm flux (cf., Lebofsky and Rieke, 1979). A value of 0.35 for the ratio 10.4/N is expected for a featureless thermal spectrum. No positive identification of a silicate emission feature was made for either P/Chernykh or P/Stephan-Oterma. The lack of an emission feature is not surprising in the case of P/Chernykh since Rieke and Lee (1974) have shown this feature to be dependent upon heliocentric distance and have found the feature to have disappeared in Comet Kohoutek at similar heliocentric distances. A weak feature cannot be ruled out in the case of P/Stephan-Oterma. Observations of P/Stephan-Oterma by Tedesco and Gradie (1981) show the presence of a weak emission feature at 1.61 a.u. several months later.

The Bond albedo of the dust in each comet was calculated according to the expression derived by O'Dell (1971). However, the phase angle dependence of the albedo was corrected by using the scattering phase function obtained for Comet West (1975n) by Ney and Merrill (1976). The albedos and phase angles are given in Table II.

TABLE II. A comparison of the Bond albedo of the dust and the dust parameters T and D among various comets

Comet	r (A.U.)	Albedo	Scattering Angle	T	D
P/Chernykh	2.76	0.05	180°	2.7×10^{-5}	2.8×10^{-5}
P/Encke	1.21	0.02	131°	1.3×10^{-5}	1.3×10^{-5}
P/Stephan-Oterma	1.72	0.10	151°	2.8×10^{-5}	3.1×10^{-5}
Kohoutek* (1973f)	1.25	0.10	145°	6.5×10^{-5}	7.6×10^{-5}
Kohoutek* (1973f)	1.75	0.15	156°	2.9×10^{-5}	1.9×10^{-5}

*From Rieke and Lee (1974).

The relative amount of dust can be estimated from the albedo and the quantity T which is defined as the ratio of the thermal surface brightness of the comet to the surface brightness of a solid blackbody at the same distances from the earth and sun. T is proportional to the amount of dust observed and to ($1-A_B$) where A_B is the bolometric Bond albedo. Dividing the T values in Table II by ($1-A_B$) for each comet gives a quantity proportional to the amount of dust, D. The D values for the three periodic comets are compared with values determined for Comet Kohoutek (1973f) at 1.2 and 1.7 a.u.

Although the D values in Table II are very model dependent, some qualitative statements can be made about the amounts of dust found in each comet. As expected, the amount of dust is dependent upon heliocentric distance--the amount of dust in Kohoutek dropped by a factor of 4 between 1.25 and 1.75 a.u. P/Chernykh appears to be extremely dusty, even at 2.76 a.u.

The lower value of D for P/Encke may not be significant but it does appear that Encke has less dust than other comets, however, it cannot be considered extremely dust poor. It should be noted that the albedo of the dust calculated for P/Encke (A_B = 0.02) is the lowest encountered so far. Although this low albedo may be an artifact of the application of the scattering function determined for Comet West on the Encke observations, it cannot be ruled out that the albedo of the dust is indeed very low. The range in albedo between P/Stephan-Oterma and P/Encke is similar to the range in albedo known to exist for the asteroids. If the low albedo for dust in P/Encke is confirmed, then it may be that the silicate material in comet nuclei is as varied as is found for the asteroids including the very low albedo, kerogen-rich material suggested by Gradie and Veverka (1980) to compose some of the Trojan asteroids.

III. Suggestions for Future Observations of Faint Comets

Infrared studies can provide some of the parameters needed for understanding the physical nature of the cometary dust and comet nucleus. Two schemes are envisioned: (1) a systematic study of each nonperiodic comet during its single observable passage through the inner solar system and (2) a systematic study of the short period comets over the course of several perihelion passages.

Nonperiodic Comets: The study of the long period and nonperiodic comets has obvious advantages: the objects are generally bright and easily observable. For example, the wide range in phase angles gives leverage for the determination of the scattering function of the dust grains.

Unfortunately, the unpredictability of the occurrence and observability of the nonperiodic comets limits the preparation time for observation. In addition, the individuality that comets seem to display during their one time occurrence may confuse the issue as to what typifies a comet.

Time resolution is important on both the long and short scales. Long term changes are expected to be the result of changes in heliocentric distances so that observing intervals of several days to weeks are necessary. Observations of the appearance and evolution of the 10 and 20 micron silicate features are essential for our understanding of the evolution of the dust grains under solar isolation. As demonstrated by Lebofsky and Rieke (1979), the 10 micron feature can be most easily monitored by a comparison of a narrow band filter centered at 10.4 microns with the broad band N filter at 10 microns.

The nucleus of a nonperiodic comet may remain unobservable in the infrared because of the masking effect of the thermal emission from the surrounding dust coma. However, monitoring the comet to large (greater than 2 a.u.) heliocentric distances may allow us to see that point where the obscuring dust disappears and the thermal emission is mostly from the nucleus. Comet Bradfield (1974b) apparently shed its dust coma at about 0.84 a.u. (Ney, 1974). Ney calculated a nuclear diameter of about 5 km using the observed visual magnitude ($\sim 10^m$–$10\overset{m}{.}5$) and an albedo of about unity. However, since the observation was at $\sim 75^o$ phase and the albedo is probably less than unity, the actual diameter may be larger.

Periodic Comets: The periodic comets may provide the most fruitful opportunities for studies of the nucleus as well as the dust coma. In particular the short period comets may be the best targets for several reasons: (1) they are not as active compared to the nonperiodic comets, (2) their frequency of perihelion passage is large enough to allow repeated observations of the same coma over several perihelion passages, (3) their orbits are generally known well enough that their positions can be accurately calculated while extremely faint and (4) some short period comets can be observable over longer periods of time than can the nonperiodic comets. One problem with the short period comets is their extreme faintness: perihelion passage generally occurs further from the sun than for the bright nonperiodic comets hence they are generally less active. Perihelion magnitudes rarely reach less than 6th magnitude in the visible and most are generally fainter than 10th magnitude. However, the predictability of their orbits is an advantage when planning for observing with large aperture telescopes.

There is no a priori reason to believe that the dust in a short period comet is compositionally different from that in a nonperiodic comet. In fact, our observations suggest that the differences in dust content may not be very large. Several projects can be envisioned: (a) monitoring the quantity of dust as a function of heliocentric distance, (b) monitoring the temperature of the dust as a function of heliocentric distance, (c) monitoring the presence or absence of silicate emission features.

Continuous monitoring of the dust coma of a short period comet may shed light on the fluctuations in the infrared spectrum observed for some long-period comets and the unusual periodic comet p/Schwassmann- Wachmann I. These observations would be useful in distinguishing between an "onionskin" model of the nucleus where successive layers peel off and the "volatile pocket" model where pockets of volatiles in a matrix of a more resilient material. It is entirely possible that each model may apply to different comets. P/Schwassmann-Wachmann I may be an example of the extreme "volatile pocket" model whereas the quieter short period comets may be examples of the extreme case of the "onionskin" model.

Photometric observations in the near-infrared between 1 micron and the longest wavelength not affected by thermal emission can be used to determine the scattering function of the dust particles and, if infrared polarimetric observations are obtained simultaneously at a large variety of phase angles the scattering properties of the dust can be examined in detail as described by Oishi et al. (1978). Simultaneous photometric and polarimetric observations can be used to provide constraints on the composition of the dust (cf., Oishi et al.). However, in the case of short period comets, the range of phase angles, hence scattering angles, is generally restricted.

The discovery of water of hydration on the asteroid Ceres (Lebofsky, 1979) from narrowband spectrophometry in the 2.8-3.6 micron region should provide the impetus for the search for H_2O features in the comet nucleus and dust. A study by Oishi et al. (1978a) of Comet West (1975n) showed no trace of an ice feature in the dust coma. Sekanina (1975) has concluded that the Type II tails of comets at large heliocentric distances are probably due to grains of clathrate hydrates which have very long lifetimes beyond 4 a.u. but may be unstable closer than 2 a.u. It is possible that attempts to observe the water-frost bands in comets have failed thus far simply because the comets were too close to the sun. However, the search should be continued.

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