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A Comparison of the Continuum Spectra of Four Comets[1]

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The continuum spectra of comets carry information concerning the physical and chemical properties of solid coma grains. Although it is not feasible to use the continuum spectra to uniquely characterize the solid grains, variations among the continua of different comets may reveal subtle differences in their respective grain populations. We have taken and reduced optical spectra of four comets in the wavelength range 3700–7300 Å using a single observing system and reduction procedure. The continua all appear reddened with respect to the solar spectrum. The amount of reddening is consistent with a prevalence of ~2-μm-sized grains in all four comets, if the refractive indices of the grains are approximately equal to those of terrestrial rocks. Significant color differences were measured among the comets. Different intrinsic grain properties are suggested since the scattering geometries were very similar. The amount of reddening does not appear to be correlated with the amount of dust in the coma. © 1985 Academic Press, Inc.

1. INTRODUCTION

The optical spectra of comets consist of emission lines and bands (due to excited gas) and continua (due to sunlight scattered from solid grains). Most previous spectral studies pertain to comets at small heliocentric distances, $R < 2$ AU. In these spectra the emission features tend to be strong and are often sufficiently broad and numerous as to obscure the true nature of the underlying continuum. Consequently, while there are many published studies of cometary emission features, there are relatively few reliable observations of cometary continua.

The problem of distinguishing the continuum from the molecular band emission can be reduced by observing at high spectral resolution and by observing comets at $R > 2$ AU, where the emission features tend to become faint relative to the continua. The spectra of several distant comets have been measured using spectrophotometric techniques by Gebel (1970), Spinrad *et al.* (1979), Cochran and McCall (1980), Cochran *et al.* (1980), P. E. Johnson *et al.* (1981), A'Hearn *et al.* (1984), Myers and Nordsieck (1984), J. R. Johnson *et al.* (1984), and others. In all of these cases the cometary continua appeared either neutral or slightly reddened when compared to the solar continuum. Corresponding observations through narrowband filters (e.g., Newburn *et al.* 1981) give qualitatively similar results, although A'Hearn *et al.* (1979) have reported blue continua in some comets having low dust/gas ratios.

Precise measurements of the scattering from cometary grains are potentially of great value, since together with measurements of the grain polarization and thermal emission they constitute the only directly observable grain properties. Since the shape of the cometary continuum depends upon the shape, size distribution, and composition of the grains, it is possible that systematic measurements of the continuum at a range of phase angles and wavelengths may illuminate the physical and chemical natures of the grains.

[1] Observations were taken at McGraw–Hill Observatory, which is operated by a consortium including the University of Michigan, Dartmouth College and MIT.

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It seems prudent to study the continuum spectra with concurrent knowledge of the intrinsic cometary brightness and the apparent dust/gas mass ratio in the coma. The latter quantities are highly variable, both among comets and in individual specimens; many of the spectral continuum observations of comets (references above) were undertaken during outbursts, which are poorly understood.

There are several systematic uncertainties affecting the intercomparison of cometary continua and their relation to the incident solar spectrum. Different spectral reduction techniques have been used by various authors. More seriously, there are significant doubts as to the quality of numerous proposed "solar analog" stars sometimes used to define the solar spectrum (Taylor, 1984).

With these difficulties in mind, we undertook a limited study of the continua of the three distant comets, IRAS 1983k (R = 4.2 AU), IRAS 1983o (R = 2.6 AU), and P/Smirnova–Chernykh (R = 3.6 AU), and a near-Sun comet, P/Crommelin (R = 1.0 AU). The use of a single spectrograph and data-reduction procedure largely eliminates systematic errors between comet observations and makes this study of particular value for the detection of small differences between the cometary continua. In the following sections we describe our observing and reduction procedures and discuss the interpretations of the measured spectra.

2. OBSERVATIONS AND DATA REDUCTION

The observations were taken in March/April 1984 using the 1.3-m telescope at McGraw–Hill Observatory on Kitt Peak. The Mark II spectrograph and a 2048-channel intensified Reticon detector (Shectman and Hiltner, 1976) were used at the $f/7.5$ Cassegrain focus. A 300-line-mm^{-1} grating was used, giving a dispersion of 2.3 Å per channel. The effective resolution in the 3700 to 7300-Å wavelength range was 15 Å.

The comets were located and centered using a wide-field TV guider. Each comet appeared as a marginally extended image (2–3 arcsec full width), and the identifications were ensured by observing motions in the predicted directions and at the predicted rates. Guiding errors were estimated to be less than 2 arcsec. The seeing on each of the five photometric nights was estimated to be about 2 arcsec FWHM. Both the seeing and the guiding uncertainties were small in comparison with the 8-arcsec-diameter circular diaphragm employed for all observations.

Night sky subtraction was achieved by chopping the diaphragm to a position 40 arcsec west of the comet position. The comet and night sky positions were alternately sampled several times per minute. Additional night sky observations were taken at positions several degrees from each comet in order to check for extended coma contamination in the 40-arcsec offset sky positions. No such contamination was seen in Comets IRAS 1983o, IRAS 1983k, or P/Smirnova–Chernykh. However, emission bands were seen more than 120 arcsec from the nucleus of Comet P/Crommelin, and sky subtraction in that case was performed using positions 2 degrees away from the comet center.

Spectrophotometric calibration was obtained through observations of the standard stars EG42, EG79, and EG119 (Oke, 1974; Stone, 1977). The comets and standard stars were observed through similar air masses (see Table I) to minimize the potential error in assuming the Kitt Peak mean extinction curve. The instrumental response functions obtained from observations of these flux standards were intercompared; the differences were found to be insignificant.

To compare the comet spectra with the solar spectrum we define the spectral reflectivity, $S(\lambda)$, as the ratio of the comet flux density to the solar flux density at 1.0 AU. To obtain the proper spectral resolution for the solar spectrum we observed the solar analog star 16 Cyg A (Taylor, 1984). Potential differences between the contin-

TABLE I

JOURNAL OF OBSERVATIONS

Comet	UT[a] (1984)	Integration[b] (sec)	Air mass	Standard star air mass	R (AU)	Δ (AU)	Phase angle (°)
IRAS 1983k	Mar 29.29	1200/1200	1.34	1.01	4.208	3.234	3.45
	Apr 02.24	2400/2400	1.36	1.12	4.238	3.278	4.31
P/Smirnova-Chernykh	Mar 29.23	3000/1500	1.10	1.01	3.559	2.614	6.09
	Apr 01.27	3600/1800	1.06	1.06	3.560	2.629	6.84
IRAS 1983o	Mar 30.25	1800/900	1.20	1.04	2.649	1.716	9.61
	Mar 31.34	3000/1500	1.02	1.02	2.655	1.724	9.71
P/Crommelin	Mar 29.14	900/600	2.31	2.18	1.018	0.795	65.53
	Mar 30.13	900/600	2.21	2.39	1.034	0.798	64.60
	Mar 31.14	600/600	2.19	2.17	1.051	0.801	63.62
	Mar 01.14	600/600	2.69	2.51	1.068	0.805	62.70

[a] Time (UT) of the comet observation.
[b] Seconds integrating on comet and sky/seconds integrating on sky.

uum shapes of the solar analog stars and the continuum shape of the Sun, as discussed by Taylor, were eliminated by forcing the 16 Cyg A spectrum to match the continuum shape of the Arvesen *et al.* (1969) solar spectrum at low resolution. We divided the solar spectrum by the instrumental spectrum (counts/Å) of 16 Cyg A and smoothed the result. The subsequent flux calibration applied to 16 Cyg A produced a solar-type spectrum having both the desired instrumental spectral resolution and the precise continuum flux density of the Sun as defined by Arvesen *et al.* (1969).

A journal of observations is given in Table I.

3. RESULTS

Continuum Spectra

The continuum shapes of each comet were found to be constant from night to night. The following discussions concern the averaged spectra of each comet; these averages are shown in Fig. 1. It may be seen from Fig. 1 that the distant Comets IRAS 1983o, IRAS 1983k, and P/Smirnova–Chernykh exhibit pure continuum spectra whereas the spectrum of Comet P/Crommelin is dominated by emission lines and bands (some of the lines and bands *did* vary from night to night, unlike the continuum).

The flux densities plotted in Fig. 1 have been converted to spectral reflectivities by dividing by the solar spectrum as described in Section 2. Figure 2 exhibits the plots of reflectivity, $S(\lambda)$, versus wavelength, λ. The continuum reflectivities are seen to be smooth and nearly linear functions of wavelength. The enhanced noise at $\lambda < 4000$ Å is a result of reduced instrumental sensitivity at these wavelengths. Note that the solar absorption lines have been effectively removed by the calculation of reflectivity. The reflectivities of the comets have been represented by polynomial approximations, determined by the method of least squares. The coefficients of the relation

$$S(\lambda) = A + B(\lambda - \lambda_0) + C(\lambda - \lambda_0)^2 \quad (1)$$

were computed for linear ($C \equiv 0$) and quadratic polynomial fits. The wavelength zero point was chosen to be $\lambda_0 = 3700$ Å. The constant term A is proportional to the total grain cross section present in the projected observing diaphragm. The linear slope of the reflectivity is given by B, while the curvature is given by $2C$. The reflectivity of

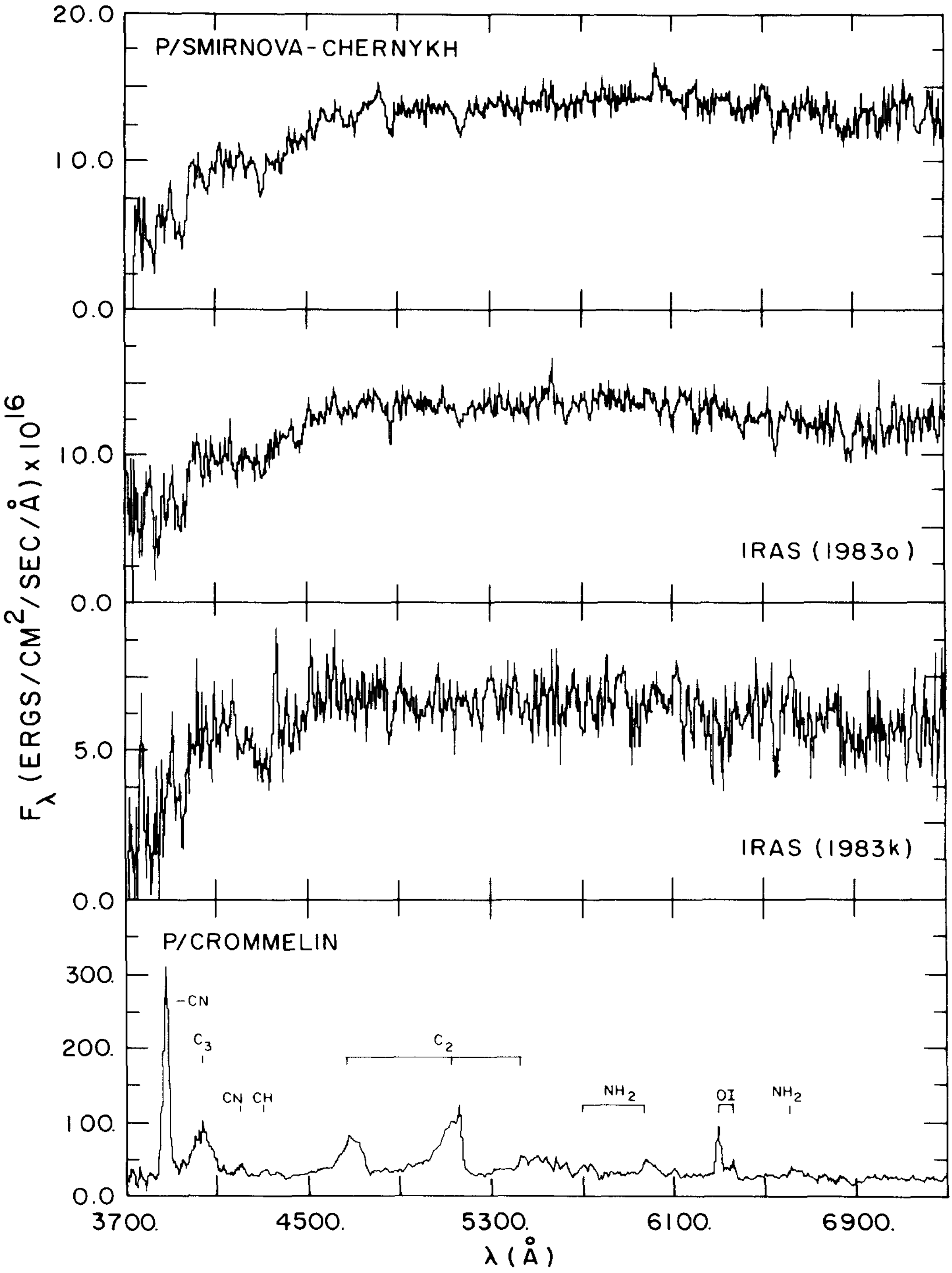

FIG. 1. The flux density in each comet is plotted as a function of the wavelength. These are the means of the spectra described in Tables I and II. The quantity plotted along the ordinate is 10^{16} times the measured flux density. Increased noise at wavelengths <4000 Å is due to reduced Reticon efficiency at short wavelengths. Conspicuous gaseous features are identified in the spectrum of Comet P/Crommelin.

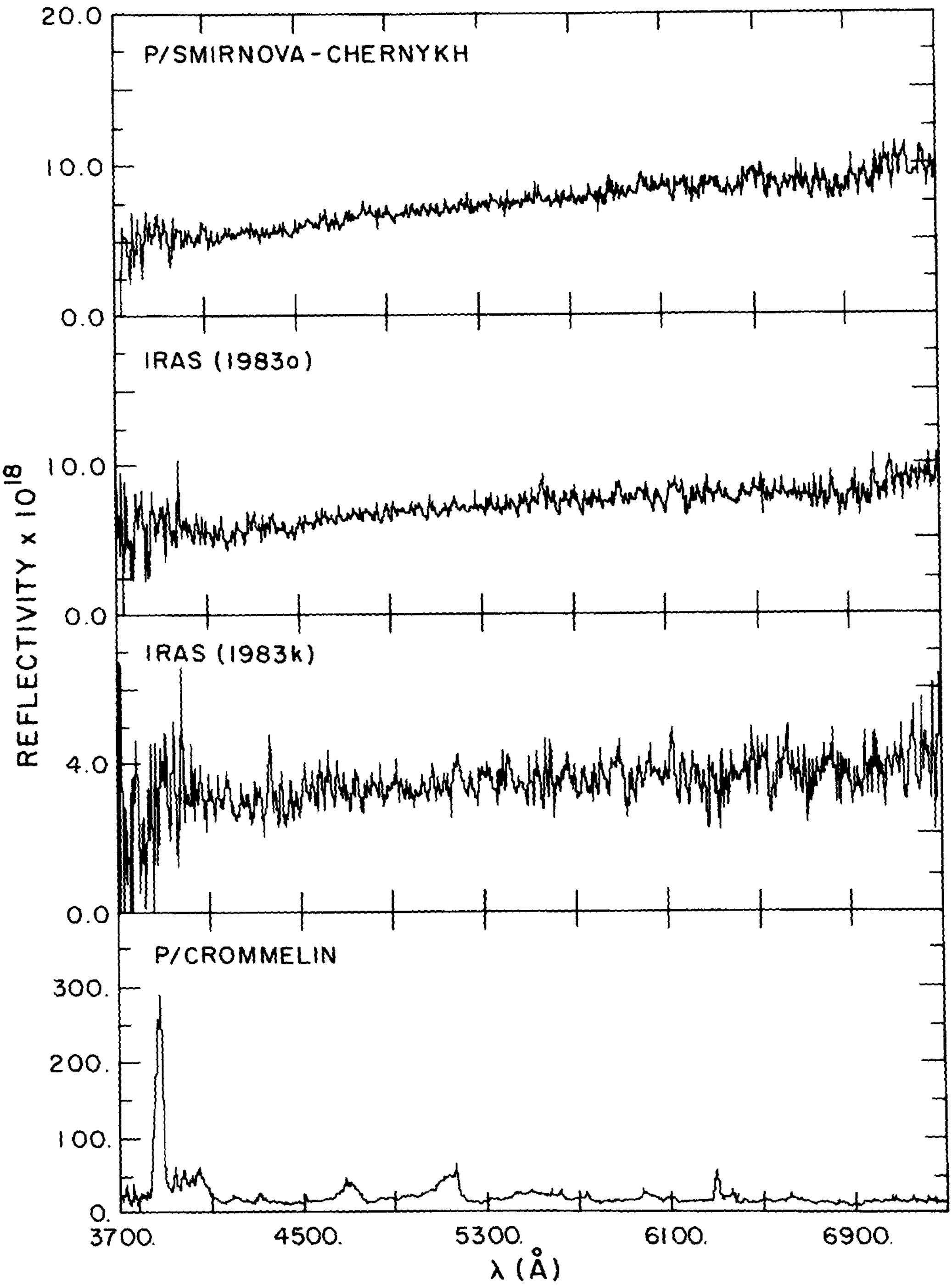

FIG. 2. The spectral reflectivity of each comet is plotted as a function of the wavelength. Reflectivities of Comets P/Smirnova–Chernykh, IRAS 1983o, and IRAS 1983k are seen to be approximately linear and these comets are redder than sunlight. The dust continuum of Comet P/Crommelin is strongly contaminated by gaseous emission bands.

TABLE II

PARAMETERS OF THE SPECTRA

Comet	UT (1984)	V[a]	B–V[a]	Cross section[b] σ_c (10^{10} cm^2)	$\overline{dS/d\lambda}$[c]	B	C	Apparent M_D/M_G
IRAS 1983k	Mar 29.29	16.90 ± 0.07	0.72 ± 0.03	440 ± 30	7.8 ± 0.9	26.6 ± 1.1	−1.63 ± 1.02	>8
	Apr 02.24	16.81 ± 0.05	0.80 ± 0.03	480 ± 24	9.2 ± 0.6			
P/Smirnova-Chernyk	Mar 29.23	16.08 ± 0.04	0.86 ± 0.02	450 ± 20	15.7 ± 0.6	23.5 ± 0.7	−0.48 ± 0.64	>21
	Apr 01.27	16.03 ± 0.04	0.93 ± 0.02	450 ± 20	17.6 ± 0.6			
IRAS 1983o	Mar 30.25	15.94 ± 0.04	0.83 ± 0.02	118 ± 5	10.2 ± 0.6	23.9 ± 0.6	−1.13 ± 0.50	>35
	Mar 31.34	16.24 ± 0.04	0.86 ± 0.02	89 ± 4	12.4 ± 0.6			
P/Crommelin	Mar 29.14	14.72 ± 0.04	0.54 ± 0.03	7.8 ± 0.3	6.0 ± 1.7	15.3 ± 27.5	−0.58 ± 4.08	0.3
	Mar 30.13	14.82 ± 0.04	0.50 ± 0.03	7.5 ± 0.3	8.6 ± 2.2			
	Mar 31.14	14.81 ± 0.04	0.52 ± 0.03	8.3 ± 0.3	9.6 ± 2.3			
	Apr 01.14	15.00 ± 0.04	0.61 ± 0.03	7.1 ± 0.3	9.9 ± 2.9			

[a] Photometric magnitudes are calculated from the spectra by integrating the comet flux densities over the B and V filter bandpasses given by Allen (1976). The errors listed include consideration of photon statistics and the analysis of fluctuations for other stars that were observed on these nights. The V magnitude is more sensitive to light loss at the diaphragm than is B–V.

[b] The scattering cross section is calculated from the continuum reflectivity assuming a geometric albedo of 0.1 and a phase function of 1.0. The result for Comet P/Crommelin significantly underestimates the total grain cross section since much of the light falls outside of the projected spectrograph diaphragm in that case.

[c] The reflectivity spectra were fit by a linear function, giving $\overline{dS/d\lambda}$, and by a second order polynomial, giving B and C. The linear slopes are expressed in % per thousand Å, to facilitate comparisons among the comets.

Comet P/Crommelin has physical significance only for the continuum wavelengths. It is difficult to define the continuum of Comet P/Crommelin since the emission line and band contamination is so extensive. The parameters of the continuum of Comet P/Crommelin were judged from the wavelength intervals 4390–4450 Å, 5760–5820 Å, 6380–6500 Å, and 7060–7180 Å, these regions being the only ones apparently free of gaseous emission features.

The quadratic fits are not significantly better than the linear fits. The polynomial coefficients are given in Table II, and they are expressed in percent per 1000 Å for comparison with other studies. Table II also contains values of the apparent V magnitude and B–V color index for each comet, determined by integrating the cometary flux densities over the standard B and V filter bandpasses (Allen, 1976).

It can be seen from Table II that

(i) the slopes, B, are positive in every comet (i.e., the comets are redder than the Sun),

(ii) the slopes of the continua of Comets 1983o, 1983k, and P/Smirnova–Chernykh are significantly different, although the phase angles are very similar, and

(iii) the reflectivity curvatures, $2C$, are insignificant within the formal uncertainties of measurement.

The positive slopes are in accord with the few published spectrophotometric results mentioned in Section 1. Differences between the continuum slopes of the four comets are highly significant in view of the systematic observing and reduction procedures applied to all data. The continua become increasingly reddened in the order IRAS 1983k, P/Crommelin, IRAS 1983o, and P/Smirnova–Chernykh. The relative color differences were easily seen by computing ratios of the comet spectra. This dispersion of the cometary colors apparently shows no correlation with heliocentric distance or phase angle. It should be noted that the B–V color index of Comet IRAS 1983o remained constant (to within 3%) even as the total brightness of the comet decreased by 30% (from March 30.25 to March 31.34).

Mie Scattering Calculations

We have attempted to reproduce the observed linear, red reflectivities by calculating Mie scattering intensities as a function of wavelength for a variety of distributions of spherical homogeneous particles. We used the code from Hansen and Travis (1974). Log-normal functions were used to simulate the cometary grain size distributions. Broad distributions were needed to avoid resonance features and sharp slopes, neither of which were observed. The distribution width parameter was $b = 0.7$, and the distribution was limited to particle sizes between 0.2 and $5.0a$, where a is the most probable particle size. The chosen real and imaginary indices of refraction were $N_R = 1.5$ and $N_I = 10^{-3}$, respectively, and the calculations covered the spectral range 3700–7300 Å in 100 wavelength steps. These indices are qualitatively similar to values measured in terrestrial rocks (Pollack *et al.*, 1973).

A series of Mie scattering spectra were calculated by slowly incrementing the size parameter, a. Broad distributions with $a \geq 2.0$ μm produced scattering spectra basically similar to the continuum reflectivity spectra of the comets. At small phase angles ($\theta = 5°$) the calculated Mie spectra changed monotonically from blue to red as the value of the size parameter reached $a \sim 1.2$ μm. This result was only marginally sensitive to small changes in N_R (1.3 and 1.7), N_I (0 and 3×10^{-3}), and θ (0 and 10°). However, the result was not applicable to the larger phase angle of P/Crommelin ($\theta \sim 63°$), where Mie reddening occurs over a large range in the size parameter, a. Furthermore, if the grains are composed of more absorbing material ($N_I \geq 0.01$), then the Mie spectra will remain red for smaller grain sizes, and the observations will no longer constrain the size parameter.

The grain size obtained above ($a \geq 2.0$ μm) is consistent with the results obtained from dynamical studies of dust tails in other comets (Finson and Probstein, 1968). However, it must be recognized that the models of the dust grain continua using Mie theory do not provide a unique fit, and the similarity between the grains and terrestrial rocks cannot be proven. Also, we can provide no compelling justification for the assumption of Mie theory, since the cometary grains are likely to be nonspherical aggregates similar to the Brownlee particles and quite unlike the idealized spherical, homogeneous Mie particles.

Coma Brightness and Dust/Gas Ratios

We aim to deduce the intrinsic brightness and the *apparent* dust/gas ratios of the comae, since these quantities provide some insight regarding the conditions in the comae when the continuum reflectivities are measured. As mentioned in the introduction, these quantities relate to the evolution and the variability of the cometary comae. We emphasize that the apparent dust/gas ratio is not equivalent to the intrinsic dust/gas ratio of the comet's nucleus. This issue is discussed further in Section 4.

The number of solid grains contained within the projected spectrometer diaphragm can be estimated from the magnitude of the continuum reflectivity, $S(\lambda)$. The sum of the cross sections of the grains, in cm^2, is

$$\sigma_c = 2.24 \times 10^{26}\ \pi\ S(\lambda) R^2\ \Delta^2/(\alpha\phi), \quad (2)$$

where α is the geometric albedo of the grains at wavelength λ, ϕ is the grain phase coefficient, and R and Δ are the heliocentric and geocentric comet distances, in AU, respectively. In Table II we have listed the grain cross sections, σ_c, assuming $\alpha = 0.1$ and $\phi = 1$ and using the average value of $S(\lambda)$ in the wavelength range 3700–7300 Å.

The total mass of grains within the projected spectrometer diaphragm is simply the product of the total number of grains with the mass of a single grain,

$$M_d = \tfrac{4}{3}\rho a \sigma_c \quad (3)$$

where ρ and a are the grain density and the mean grain radius.

The ratio of dust to gas components can be estimated from the strengths of (or upper limits to) the gaseous emission features. Note that the computed dust/gas ratio is physically quite different from the ratio of the dust/gas production rates. The strongest emission feature in the observed spectral range is the CN 0–0 transition at 3883 Å. The CN emission is prominent in the P/Crommelin spectrum, but is absent from the spectra of 1983o, 1983k, and P/Smirnova–Chernykh (see Figs. 1 and 2). The observed flux in the CN band may be used to constrain the column density of CN radicals contained within the projected diaphragm at each comet. This number is

$$N_{\mathrm{CN}} = \frac{F_{\mathrm{CN}}}{\Omega g_{\mathrm{T}}} \quad (4)$$

where F_{CN} (erg sec^{-1} cm^{-2}) is the emission flux within the CN band, $\Omega = 1.18 \times 10^{-9}$ sr is the observed solid angle, and g_{T} (erg sec^{-1} cm^{-2} sr^{-1}/cm^{-2}) is the ratio of surface brightness to column density for the CN 3883-Å transition, taking into account the Swings effect. Values of g_{T} have been tabulated as a function of heliocentric distance, R, and radial heliocentric velocity, dR/dt, by Tatum and Gillespie (1977) and Tatum (1984). We have employed the latter work.

The F_{CN} values (or upper limits) are obtained by calculating the product of the reflectivity value above the local continuum with the solar flux at that wavelength, and integrating over the wavelength interval of the CN band (3830 to 3890 Å). In the case of P/Crommelin we have measured $F_{\mathrm{CN}} = 8.65 \times 10^{-13}$ erg s^{-1} cm^{-2} in the 8 arcsec diaphragm. This implies [Eq. (4)] a CN column density of 2.42×10^{10} cm^{-2}, which is typical for a comet at 1 AU (Newburn and Spinrad, 1984). For Comets 1983k, Smirnova-Chernykh, and 1983o, we measure 3σ upper limits to the CN band fluxes of 1.1×10^{-14}, 7.1×10^{-15}, and 6.3×10^{-15} erg sec^{-1} cm^{-2}, respectively. The corresponding upper limits to the CN column densities are 4.6×10^{9}, 2.7×10^{9}, and 8.6×10^{8} cm^{-2}, respectively.

A'Hearn (1982) estimates the CN mixing ratio as $f_{\mathrm{CN}} = 1.3 \times 10^{-3}$. This mixing ratio applies to the entire coma. For the observation of P/Crommelin we use $f_{\mathrm{CN}} = 8.45 \times 10^{-4}$; this value includes a spatial distribution factor calculated from the Haser model (M. F. A'Hearn, 1985, private communication) to estimate a correction for the relatively small projection of the spectrograph diaphragm on the nearby comet. The mass of gas within the projected diaphragm is then

$$M_{\mathrm{g}} = 2.24 \times 10^{26}\, \mu m_{\mathrm{H}} N_{\mathrm{CN}} \Omega\, \Delta^2 / f_{\mathrm{CN}} \quad (5)$$

in which $m_{\mathrm{H}} = 1.67 \times 10^{-24}$ g is the mass of the hydrogen atom and $\mu = 18$ is the adopted mean atomic weight of the gas.

The apparent dust grain/gas mass ratio within the projected aperture is obtained from Eqs. (2)–(5) (all cgs units except R in AU)

$$M_{\mathrm{d}}/M_{\mathrm{g}} = 2.51 \times 10^{24} \frac{\rho a f_{\mathrm{CN}}}{\alpha \phi \mu} \frac{g_{\mathrm{T}} \bar{S} R^2}{F_{\mathrm{CN}}}. \quad (6)$$

The grain/gas mass ratios are evaluated in Table II for $a = 2.0 \times 10^{-4}$ cm, $\rho = 2$ g cm^{-3}, $\alpha = 0.1$, $\phi = 1$, and $\mu = 18$. Although the absolute values of the apparent grain/gas mass ratio are uncertain, the relative magnitudes are probably quite well determined by Eq. (6). The obvious difference between CN band fluxes exhibited in the spectrum of P/Crommelin and in each of the others requires much more than an order of magnitude difference in the apparent dust/gas ratios of the comet comae.

4. DISCUSSION

The reddening of sunlight by dust grains in the comae of comets is apparently a common phenomenon. The results given here confirm and quantify the large variations reported in the scattering properties of different comets (A'Hearn, 1982). Our study demonstrates significant differences in the amount of reddening in the three comets that were observed at very similar phase angles (3.4–9.7°). These variations imply that there are intrinsic differences in grain compositions or grain size distributions between the comets, since the observing geometries were quite similar.

We do not see blue continua of the type reported by A'Hearn *et al.* (1979). This may be because of insufficient sampling (we examined *only* four comets). However, it seems likely that some of the "continuum" filters used by A'Hearn *et al.* may be contaminated by emission bands. Specifically, their continuum filters at 3930 ± 30, 4120 ± 35, and (to a lesser extent) 5240 ± 70 Å would all admit substantial proportions of gaseous emission, relative to grain continuum, in Comet P/Crommelin. The confirmation of blue continua in active comets must await further spectrophotometric observations.

We find no obvious correlation between the amount of reddening ($\overline{dS/d\lambda}$) and the total grain cross section (σ_c) among these comets (see also Myers and Nordsieck, 1984; J. R. Johnson *et al.* 1984). Since dynamical studies indicate that outbursting comets show increased mean particle sizes (Finson and Probstein, 1968), this lack of correlation at nearly constant phase angle suggests that the intrinsic differences in grain properties are more significant than the changes related to the amount of dust in the coma. A similar conclusion can be drawn from the comparison of dynamical studies of several comets (see Delsemme, 1982).

The measured range of cometary grain colors (8–17% per 10^3 Å) may be compared with the color of the grains in the zodiacal light. The latter appear reddened with respect to the Sun and have optical reflectivity gradients of about 10 ± 3% per 10^3 Å near elongation 90° (Leinert *et al.*, 1981). The reddening decreases with increasing elongation such that the B–V color is nearly neutral in backscattering. Hence, it appears that the cometary grains are slightly redder than the zodiacal light grains, when viewed near backscatter. An assessment of the magnitude of the color difference should consider the reddening measurements of a large number of comets. Although the zodiacal light grains are thought to be produced by comets, the probable optical color difference is not a cause for alarm but may indicate that the grain size distribution evolves after the dust is deposited in the interplanetary cloud.

The great range of the fluxes in the CN 3883-Å emission line relative to the fluxes in the continua suggests that the *apparent* dust/gas ratio in the coma can increase by much more than an order of magnitude as a comet travels from 1.0 to 3.0 AU. This difference may be explained, at least in part, as a consequence of less efficient gas/grain coupling due to the reduced total sublimation rate at larger heliocentric distances (see Delsemme, 1982). Spectrophotometry might be used to determine whether the reddening properties of comet grains are correlated with the *intrinsic* dust/gas ratio, but only if a sample of comets is measured at both small and large heliocentric distances, with each distance extreme observed at common phase angles.

The observations of P/Crommelin were taken when the comet was at a heliocentric distance of ~1 AU, where the gas production rate is high and gas/grain coupling is expected to be strong. The apparent dust/gas ratio is expected to equal the intrinsic ratio in this case. The ratio (~0.3) is similar to the ratios obtained for other comets (Delsemme, 1982), but the accuracy is limited by the assumptions given to evaluate Eq. (6).

5. CONCLUSIONS

Systematic spectral observations of four comets reveal dust grain continua which are all slightly reddened with respect to the solar continuum.

The degree of reddening is different for different comets and shows no obvious correlation with phase angle, heliocentric distance, or total dust cross section. The lack of correlation suggests that the color differences may be due to intrinsic differences between the grain properties of the observed comets.

The observed continua are all consistent with an origin by scattering of sunlight from broad distributions of spherical dielectric grains of mean radius $a \geq 2$ μm, if the grains possess refractive properties similar to those of terrestrial rocks. Smaller grains tend to produce either neutral or slightly blue continua which are not consistent with the observed continua.

Based on our observations of Comet P/Crommelin, we caution against the general use of filters for continuum studies. In that comet, all but a few narrow spectral windows were clearly contaminated by molecular emission features. The continuum filters used by A'Hearn *et al.* (1979), and those advocated by the International Halley Watch, for instance, would almost certainly be contaminated by emission features in Comet P/Crommelin.

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