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Polarization studies of comet C/2000 WM1 (LINEAR)

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Abstract. Linear polarization observations were carried out on comet C/2000 WM1 with the 1.2 m telescope at Mt. Abu Observatory during November 2001 and March 2002. The observations in November were at low phase angle (<22°) when the polarization is negative and where the data for most of the comets are rather meager. The observations during March were made when the phase angle was ~47°. Observations were conducted through the *IHW* narrow band and *BVR* broad band filters. Based on these polarization observations we infer that the comet C/2000 WM1 belongs to high polarization class i.e. the dusty comet family.

Key words. comets: individual: C/2000 WM1 (LINEAR)

1. Introduction

The polarized radiation received from cometary grains contains vital information which has proved to be very useful in our understanding of the origin of solar system. There are two main mechanisms which contribute to the cometary polarized radiation: (i) sunlight scattered by the cometary dust particles, and (ii) fluorescence emission by the cometary molecules. Linear and circular polarization measurements have been made by several investigators in the past for many comets. Most of these studies are aimed at understanding the nature of polarization which occurs due to the scattering of the sunlight by cometary dust particles. The first major efforts for detailed polarization observations were made for the Comet P/Halley by many groups (Bastien et al. 1986; Brooke et al. 1987; Dollfus & Suchail 1987; Kikuchi et al. 1987; Lamy et al. 1987; Le Borgne et al. 1987; Metz & Haefner 1987; Sen et al. 1988). There were other bright comets after P/Halley such as Austin, Hyakutake, and Hale-Bopp and polarization observations were reported for these comets by several groups (e.g. Sen et al. 1991; Eaton et al. 1992; Joshi et al. 1997; Ganesh et al. 1998; Furusho et al. 1999; Manset & Bastien 2000).

A study of the variation of polarization with phase angle (α), defined as the sun-comet-earth angle, and the wavelength dependence of polarization allows inferences to be drawn about the size distribution and composition of the scatterers. Based on the data obtained by various researchers, Dollfus et al. (1988) established a phase curve describing the variation of the degree of linear polarization with the phase angle. The study of the dust grains in comets has been an active area of investigation for quite some time but the exact nature and composition of the cometary grains are still not well understood. Dollfus (1989) pointed out the possibility of the grains giving rise to the polarization being large, rough and dark, resembling fluffy aggregates such as Brownlee particles.The space mission to Comet Halley made some in-situ measurements and have contributed new information on the nature of grains in that comet (Kissel et al. 1986; Mazets et al. 1986; Levasseur-Regourd et al. 1986). However, ground based observations have indicated that the detailed behaviour of grains differs in different comets. Until more in-situ measurements are carried out on other comets, the information about dust grains in the comets has to come mainly from the ground based observations in conjunction with theoretical models (Krishna Swamy 1986; Xing & Hanner 1997; Jockers 1999; Petrova et al. 2001a; Petrova et al. 2001b).

On the basis of the polarization behaviour of 13 comets, Chernova (1993) pointed out the existence of two types of comets: gassy and dusty. Subsequently Levasseur-Regourd et al. (1996) and Hadamcik et al. (1999) expanded this work by studying the polarization phase curve for a large number of comets. It is seen that all the polarization phase curves show similar behaviour at low phase angles i.e. small negative values of polarization for phase angle $\alpha < 22°$, increasing nearly linearly in the range $30 < \alpha < 70°$ and reaching a maximum value of 10–30% in the phase angle range 90–110°. However, for $\alpha >$ 30° comets follow two distinct distributions in the polarization-phase angle diagram which led Levasseur-Regourd et al. (1996) to propose two classes of comets: low polarization and high polarization comets. It is clear now that high polarization comets are dusty while low polarization comets are gassy. The maximum value of polarization reaches about 15% and 25% for the gassy and the dusty comet classes respectively. In fact the degree of polarization is found higher for Hale-Bopp than for any other comet previously observed so much so that Hadamcik et al. (2002) proposed to add one more class (Hale-Bopp class) to the classification of comets.

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Initially the detection of negative polarization at low phase angle ($\alpha < 22°$) in comets was received with a surprise as the negative polarization was considered more associated with atmosphere-less solar system objects having a surface made of fluffy layers of small grains, such as Mercury, the Moon, the asteroids (Dollfus & Auriere 1974; Gehrels et al. 1987; Zellner & Gradie 1976; Dollfus & Zellner 1979). The objects quite different in nature – dark and bright satellites of the planets, Mercury, asteroids and cometary comae demonstrate similar negative polarization below phase angle 22°. This phenomenon is observed in a wide spectral range from UV to IR and the polarization appears to be almost wavelength independent. Also the cross over angle ($\alpha_{\rm inv}$), slope at the cross over point and polarization minimum ($P_{\rm min}$) do not show significant wavelength dependence in most of the cases. However, some faint comets, like 29P/Schwassmann-Wachmann (Kiselev & Chernova 1979) or 47P/Ashbrook-Jackson (Kiselev & Chernova 1981) are reported to have shown significant variation of polarization with wavelength for $\alpha < 25°$. These day-to-day variations detected at a given phase angle were thought to be related to the activity in comets. Though the high precision polarimetric observations of comets covering a large phase angle range are important to fully characterize the grains, such data are lacking for the negative branch of the polarization phase curve. High S/N observations at low phase angles are relatively difficult due to the comets being faint, as in general comets are at large distances from the Sun when α is low. The complete information on the polarization phase curve for a large number of comets would be helpful to understand their formation and evolution and their relation to other solar system bodies.

The apparition of comet C/2000 WM1 provided a good opportunity to make polarimetric observations at low phase angles. During its pre-perihelion approach the comet was conveniently located in the sky and was bright enough to achieve a reasonably good S/N ratio at low phase angles. On 22.67 January 2002 the comet was at a perihelion distance of 0.55 AU. We carried out linear polarization observations on this comet during November 23–26, 2001 when the phase angle, α, was $<22°$ and later in March when α was $\approx 47°$. The preliminary results from these observations were reported by Joshi et al. (2002). In this communication, the results are discussed in detail and compared with the results for other comets.

2. Observations and analysis

Photopolarimetric observations of comet C/2000 WM1 were made with a two channel photopolarimeter (Deshpande et al. 1985; Joshi et al. 1987) mounted on the 1.2 m telescope of Mt. Abu Observatory operated by Physical Research Laboratory, Ahmedabad (PRL). The PRL photopolarimeter modulates the polarized component of the incident light at 41.67 Hz with a rotating super-achromatic half-wave plate in front of a Wollaston prism. It is equipped with IAU/IHW filters (see Osborn et al. 1990) and *BVR* broad band filters. The IAU/IHW filters were acquired about a decade ago for observations of comet Halley. Since then these were used for observations of several other comets (Ganesh et al. 1998; Sen et al. 1991; Joshi et al. 1987). The filters are carefully stored in dry atmospheric conditions to preserve their transmission characteristics. However, to be sure of their characteristics, their transmission curves were obtained in the laboratory and compared with the original curves supplied by the manufacturer. We found that except for the CO^+ filter (4260 Å), characteristics for all other filters compare very well with the original transmission characteristics. It is to be noted that the observations made with the same set of filters facilitate comparison with other comets observed earlier, hence their continued use is justified.

Observations were made during November 23–26, 2001 when phase angle ranged from 14–22° and then during March 16–18 ($\alpha \approx 47°$). We attempted observations through *IHW* filters in continuum bands 3650/80, 4845/65 and 6840/90. However, the comet was too faint to achieve good S/N ratios with these narrow band filters even for an integration time as long as 10 min. Also, during the November observing run the presence of the Moon in the early part of the night hampered the polarimetric observations of the comet. In the presence of the Moon, not only the sky background was bright but also highly polarized and even a minute variation in the sky resulted in large error in the measured polarization. At low phase angle the degree of polarization being low ($P \sim 1$ to 2%), the S/N ratio deteriorates in presence of highly polarized Moon light. Therefore the polarimetric observations were made after the Moon had set and the sky was dark albeit at the cost of available observing time. To achieve a good S/N in a limited available observing time, we switched over to observations with the broad band – *BVR* filters of the Johnson and Morgan system. The Sun-comet distance during the November observing run was about 1.3 AU. In general comets start showing activity at such a distance and therefore observations in broad band filters are usually expected to be contaminated by molecular emission. However, as discussed in the next section, the magnitudes in all the bands, normalized with respect to 4845 Å band, do not show any variation throughout the observing run in November, indicating that the molecular emission remained weak and steady during the observing run and hence the use of *BVR* filters is justified. To allow for comparison, we made a few observations through the *IHW* filter 4845/65 (cf. Table 2).

The observations were taken with an aperture size of 26.5 arcsec centered on the photocentre of the comet. We took several measurements of shorter integrations (30 to 50 s) per filter which were later averaged. The errors associated with these observations are estimated as follows. As described by Joshi et al. (1987), a least squares fit to the data provides the degree of polarization and the position angle. The error in the fit gives the error in the degree of polarization while the errors in the position angle are obtained using the Eq. (8.5.4) given in Serkowski (1974). To take care of sky polarization, observations were made alternately on the photocentre of the comet and on the region of the sky more than 30 arcmin away from the Sun-comet line. Polarization standard stars ϕ Cas and 9 Gem were observed to calibrate the observed position angle. Instrumental polarization was much smaller (0.03%) than the errors in observations and therefore is neglected. The journal of the observations along with other informations like phase angle of the comet, UT, moon set time at Mt. Abu etc is shown in Table 1. Heliocentric and geocentric distances

Table 1. Observation log and comet parameters. Final column (Ap.) is the linear size of the aperture projected on the comet.

Date & time (UT)	*r* AU	Δ AU	*Phase* deg	Moon-set (UT)	Ap. kms
23/11/2001					
20:00	1.3458	0.3758	14.91	19:38	7242
20:30	1.3455	0.3756	14.94		7238
24/11/2001					
21:00	1.3291	0.3630	16.80	20:30	6995
21:30	1.3287	0.3627	16.84		6990
25/11/2001					
21:30	1.3126	0.3517	19.08	21:20	6778
22:00	1.3123	0.3515	19.13		6774
26/11/2001					
22:00	1.2962	0.3418	21.73	22:12	6587
22:30	1.2958	0.3416	21.79		6583
16/03/2002					
23:30	1.2401	1.2375	47.36	15:24	23848
17/03/2002					
00:00	1.2404	1.2374	47.35	16:14	23846
23:30	1.2563	1.2374	47.03		23846
18/03/2002					
00:00	1.2567	1.2374	47.03	17:08	23846

and the aperture projected on the comet at the time of observations are also listed. Table 2 lists the observed values of polarization in *BVR* bands along with some observations made through *IHW* filters. There are four observing runs in November 2001 (before perihelion passage) and two in March 2002 (after the perihelion passage). In addition to the polarization values we also report the normalised magnitudes in different filter bands. Instrumental magnitudes were first corrected for the atmospheric extinction and the values thus obtained were normalised with respect to the magnitude in the continuum band at 4845 Å (Table 2). On 17th March 2002, the observations were made when the elevation of the comet was low. Hence, photometric errors being large, the magnitude values are not considered. The polarization phase curves are plotted in Figs. 1 and 2 and wavelength dependence of polarization is shown in Fig. 3.

3. Discussion

During the November observing run, the Sun-comet distance changed only by about 5% while the Earth-comet distance changed by about 10% resulting in a variation of ≈20% in the sampled area on the comet. This might cause some change in the degree of polarization provided the sampled region is heterogeneous. The inner coma region of comets has been found to be quite heterogeneous in the spatial distribution of dust, which in turn is responsible for the spatial variation of polarization in the inner region (Renard & Hadamcik 1996; Eaton et al. 1988, 1991; Dollfus & Suchail 1987; Jockers et al. 1999; Furusho et al. 1999; Kolokolova et al. 2001). In the case of Comet Halley a fair degree of agreement is seen among the observations made by different groups with different aperture sizes as long as the polarization is estimated over the whole coma with a large aperture centered on the nucleus which averages out the effect of heterogeneity. In the case of comet Hale Bopp no significant difference was found in the polarization observed through two apertures, 26.5 and 52.4 arcsec, corresponding to linear scales of 14 318 km and 28 313 km respectively (Ganesh et al. 1998). Similar results are reported for Hale-Bopp by Manset & Bastien (2000). In the present case the radius of the area sampled on the coma is relatively large (6500 km to 7200 km in diameter, much larger than the inner coma) and the inhomogeneities in the coma are expected to be averaged out. The observed data (Table 2) support this view. We also note that the overall polarization characteristics of the comet WM1 are similar to comet Halley and Hale-Bopp as is discussed later. Therefore, the comparison of the polarimetric observations on different dates for comet C/2000 WM1 is meaningful.

3.1. Polarization phase curve

The polarization behavior of the comet C/2000 WM1 is displayed in Fig. 1 which shows the degree of polarization for different spectral bands (*BVR* and *IHW* filters: 4845 and 6840) as a function of phase angle in the range 14–47°. There is a good coverage of phase angle between 14 and 22°. It should be noted that the data are very rare in the important range of low phase angles. The polarization behavior in this phase angle range provides clues to the refractory nature of the grains. Observations were largely made through the broad-band filters to achieve good S/N ratio. However, some observations were made through narrow-band *IHW* filters which also help to compare with the observations made through broad-band filters. The normalized magnitudes do not show variation during the observing run in November (see Table 2), indicating a weak and steady cometary activity. This means that molecular emission was too weak to have any significant influence on continuum polarization. We find from the figure that the polarization values observed through *BVR* filters and the narrow band filters compare very well. In Fig. 2, we have plotted a magnified view of the polarization-phase-curve for phase angle <22°. As seen in this figure, polarization behaviour near $P_{\min}$ appears, within the errors of measurement, to be independent of wavelength.

Near the cross-over phase angle, the degree of polarization is close to zero and hence the position angle is ill-defined. Looking at Table 2 we notice that on November 26 the position angle in different spectral bands deviates from perpendicular or parallel to the scattering plane when the phase angle is near 22°. The errors associated with the position angle measurements are large. Therefore no meaningful conclusions can be drawn from the position angle.

Table 2. Polarization observations of comet C/2000 WM1 (LINEAR). Listed entries are date and time (UT), total integration time (IT) in seconds, filter, degree of polarization (P%) , error in polarization (Ep%), position angle (θ) in equatorial plane, magnitude (normalized with respect to magnitude at 4845 band), and phase angle (α) at the time of observations. Magnitude values are not listed for 17th March 2002 as the photometric errors were larger than 10%.

Date	Time(UT)	IT	Filter	P%	ϵ_p%	θ	ϵ_θ	Mag	Phase
23/11/2001	19 58 50	200	*R*	1.27	0.19	102	4	−3.24	14.90
23/11/2001	20 07 10	200	*V*	1.18	0.19	108	5	−3.34	14.91
23/11/2001	20 13 30	200	*B*	1.57	0.25	103	4	−2.80	14.92
23/11/2001	20 35 00	400	7000	2.72	0.80	104	8	−0.17	14.94
23/11/2001	20 46 40	450	4845	2.18	0.90	110	12	0.0	14.96
24/11/2001	20 45 30	200	*R*	1.01	0.18	94	5	−3.22	16.78
24/11/2001	20 53 30	250	*V*	1.03	0.21	102	6	−3.31	16.79
24/11/2001	21 04 10	450	*B*	0.75	0.30	90	11	−2.82	16.80
24/11/2001	21 16 00	500	7000	2.40	0.75	72	9	−0.16	16.82
24/11/2001	21 30 30	600	4845	1.49	0.80	93	15	0.0	16.84
25/11/2001	21 26 40	200	*R*	0.73	0.19	67	7	−3.24	19.07
25/11/2001	21 32 30	200	*V*	0.64	0.21	87	9	−3.34	19.08
25/11/2001	21 38 50	250	*B*	0.56	0.41	84	20	−2.95	19.09
25/11/2001	21 47 40	450	7000	1.30	0.86	83	19	−0.16	19.10
25/11/2001	22 08 30	600	4845	0.66	0.95	74	52	0.0	19.14
26/11/2001	22 11 30	200	*B*	0.39	0.85	177	52	−2.87	21.75
26/11/2001	22 15 50	150	7000	1.9	1.6	140	52	−0.26	21.76
26/11/2001	22 21 00	250	4845	2.7	2.7	148	52	0.0	21.77
26/11/2001	22 28 00	200	*V*	0.66	0.34	161	15	−3.5	21.78
26/11/2001	22 35 30	200	*R*	0.04	0.35	106	52	−3.27	21.79
16/03/2002	23 28 53	180	*R*	8.68	0.66	6	2	−3.21	47.36
16/03/2002	23 34 55	180	*V*	7.52	0.55	1	2	−3.55	47.36
16/03/2002	23 42 40	180	*B*	7.85	0.98	3	3	−2.95	47.35
16/03/2002	23 50 30	360	6840	10.8	2.2	172	6	−0.16	47.35
16/03/2002	23 59 59	300	4845	9.5	2.8	170	8	0.0	47.35
17/03/2002	00 11 50	300	5140	9.2	1.4	7	4	−0.83	47.35
17/03/2002	23 47 22	100	4845	13.3	3.5	3	10		47.03
17/03/2002	23 53 21	100	6840	12.3	3.5	19	8		47.03
18/03/2002	00 02 51	100	*B*	9.34	0.68	0	2		47.03
18/03/2002	00 08 00	60	*V*	6.88	0.57	7	2		47.03
18/03/2002	00 12 22	60	*R*	10.68	0.51	15	1		47.03
18/03/2002	00 16 31	60	5140	7.9	1.5	0	5		47.03

3.2. Wavelength dependence of polarization

Figure 3 displays degree of polarization against the mean wavelength for the comet when its phase is about 47°. The *IHW* and *BVR* filters are indicated in the figure. The figure shows that the degree of polarization increases with the wavelength though the errors are large for *IHW* filters. In general the values of polarization for broad band filters are lower compared to the *IHW* filters as one would expect. On March 17/18, 2002 when the comet phase was 47.03°, the polarization values indicate an increase over the values of the previous night when the phase was at 47.35°. The observations also indicate a tendency for the polarization colour to be redder compared to the previous night which might be due to the increased comet activity releasing more small grains. However, since the errors are relatively large, the above statement is to be taken with caution.

We notice that the polarization observed through the *V*-band on March 17/18 is lower than what was observed on the previous night, though the polarization in the *R* band shows an increase. The reason is that the *R* band polarization is less influenced by molecular emission compared to the *V* band.

3.3. Classification of WM1 based on polarization data

Based on the extent of polarization at various phase angles, comets are classified in two classes, high polarization and low polarization class (Levasseur-Regourd et al. 1996; Hadamcik et al. 1999). We compare the polarization values for comet C/2000 WM1 in Table 2 with the values from combined polarization phase curve as given by Levasseur-Regourd et al. (1996). At the 47° phase angle the expected value of

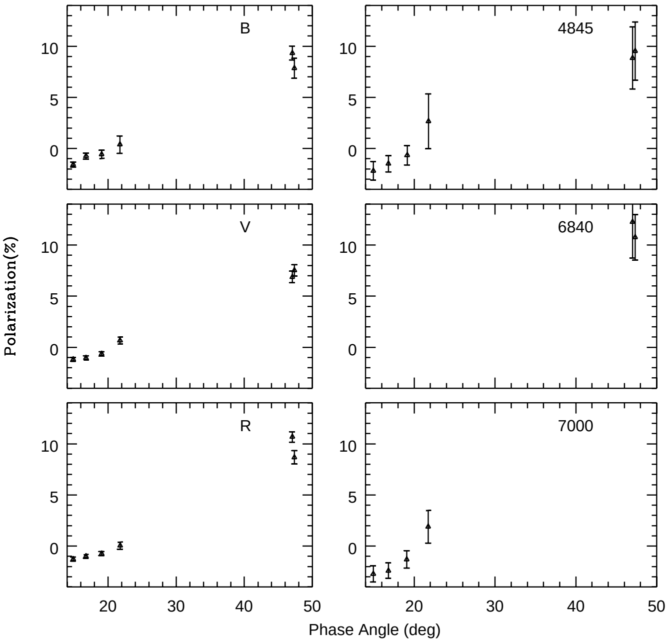

Fig. 1. The phase dependence of polarization in *BVR* broad bands and IAU/IHW filter bands for the comet C/2000 WM1.

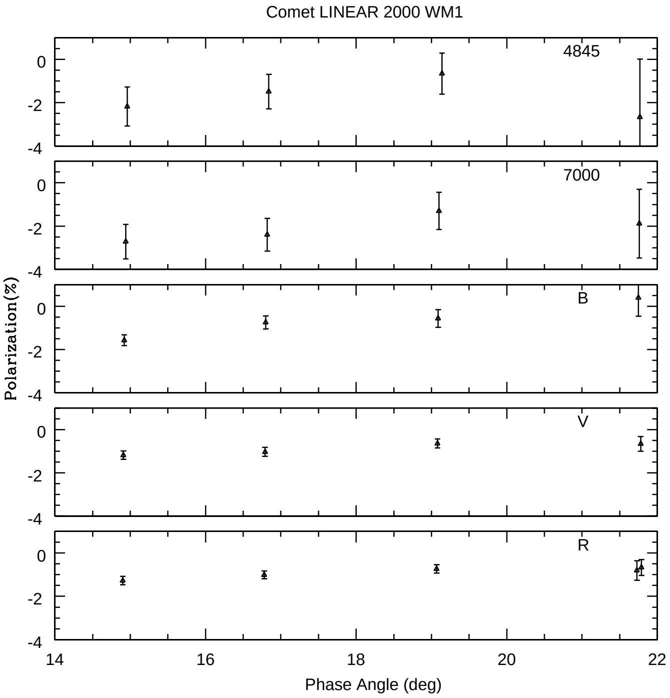

Fig. 2. Enlarged version of the phase dependence of polarization of Comet C/2000 WM1 for lower phase angle.

polarization in the case of the high polarization class (dusty comets) is ~11% whereas for the low polarization class the expected value is ~5.5%. The observed polarization value for comet C/2000 WM1 at this phase angle is around 10%. The polarization values as observed on March 16 and 17 differ by a small amount which cannot be due only to the very small change in phase angle but the main contribution could be from increased cometary activity. The observed values of the polarization on both the above dates are close to the mean value of 11% as obtained from the common phase curve for the dusty comets. Therefore the comet C/2000 WM1 belongs to the high polarization class i.e. to the class of dusty comets.

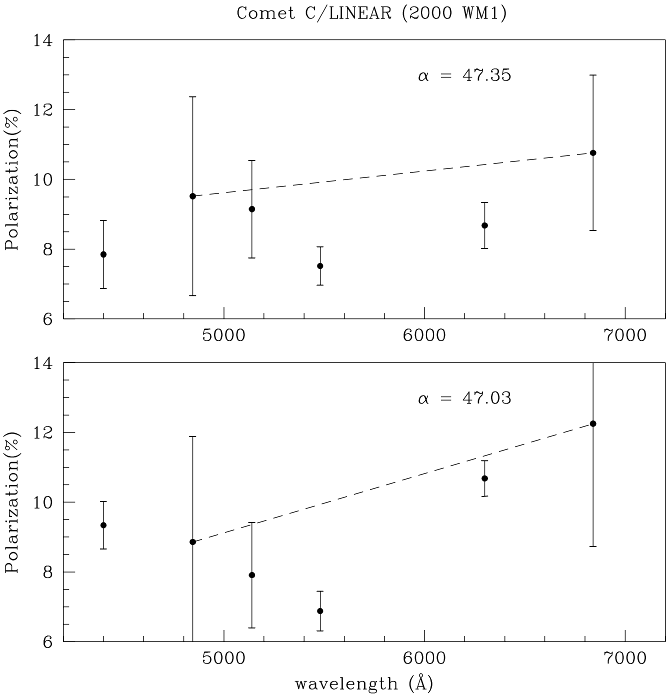

Fig. 3. Wavelength dependence of the degree of polarization for the comet C/2000 WM1. The polarization values at the continuum bands 4845 and 6840 Å are joined by the dashed line.

3.4. On the nature of the grains

Figure 2 shows a magnified version of P vs. α curve for $\alpha < 22°$. The polarization phase curve of comet C/2000 WM1 (Figs. 1 and 2) is very similar to other bright dusty comets like comet P/Halley and Hale-Bopp, indicating that the dust particles have similar characteristics in all these comets. In the present study the polarization phase curve is well covered for low phase angle where the polarization is negative. The negative branch of the polarization phase curve in comets is still not well understood as similar behaviour is observed in other atmosphere-less solar system bodies such as Mercury, the Moon and asteroids (Dollfus & Auriere 1974; Gehrels et al. 1987; Zellner & Gradie 1976; Dollfus & Zellner 1979). The similarity in the polarization behaviour of the cometary grains and these types of scattering surfaces was noted by several researchers (Kiselev & Chernova 1981; Myer 1985; Bastien et al. 1986; Steigmann & Dodsworth 1987). It should be noted that while the cometary coma is optically thin, atmosphere-less solar system bodies are regolith surfaces and are treated as optically thick systems. Therefore, the objects, which are quite different in nature (e.g. asteroids, planet Mercury, cometary coma) but show similar negative branch of polarization, supposedly have an aggregate structure of dust grains (Brownlee 1985a,b; West & Smith 1991; Petrova et al. 2001a; Petrova et al. 2001b). From the above facts one can infer that negative polarization of light at small phase angle is a collective effect of light scattering from particles and not a manifestation of their individual physical properties. Shkuratov and his colleagues showed that the negative branch of polarization appears if the particles of the scattering surface or their structural irregularities are comparable to the wavelength of radiation (Shkuratov 1994; Shkuratov et al. 1994). Theoretical modeling of the properties of aggregate particles confirms that the collective effect of monomers significantly changes the single scattering characteristics of clusters as compared to those of the independent particles, and negative polarization can be produced with parameters (aggregate size, monomer size, wavelength, refractive index) close to those for the particles observed in cometary coma (West & Smith 1991; Xing & Hanner 1997; Petrova et al. 2001b).

The observations show that the negative polarization is almost independent of the wavelength, which means that dust particle characteristics, i.e. the mean size and composition, do not play an important role in generating the negative branch of the phase curve. However, careful examination of the polarization data of several comets show some minor difference in polarization behaviour at smaller phase angle as is seen in the Table 2 of Dollfus (1989). For example, comets Ashbrook-Jackson (1977g) and Chernykh (1977e) show deeper polarization minima compared to the other comets listed in their table. The crossover angle also differs from comet to comet, though this variation is small and depends weakly on the wavelength of observation. In the present case the observations show that the shorter the wavelength, the smaller is the crossover angle i.e. $\alpha_{\rm inv}$ is smaller for *B*-band compared to that for the *V*- and the *R*-bands. This indicates that the grains in this comet consist of a silicate core and organic mantle as discussed below.

A model of single scattering of light is quite appropriate for comets since the density of the dust in cometary coma is too low for multiple scattering to take place. Therefore, the negative polarization observed in comets at small α can only be explained by an aggregate structure of dust particles. An aggregate of random structure composed of monomers with size parameter close to 1.5 and refractive index close to (1.65 + i0.05) displays polarization properties (Petrova 2001b) similar to those observed in comets such as P/Halley, Hale-Bopp, and the present case of C/2000 WM1. These properties include negative polarization at small α, weak dependence of inversion angle $\alpha_{\rm inv}$ on wavelength, red colour of cometary dust and the degree of polarization independent of λ at low phase angles.

Petrova et al. (2001b) have shown that a composite structure of aggregate particles resulting in the interaction of monomers in the light scattering process is responsible for the negative polarization at small phase angles if the monomer size is comparable to the wavelength of radiation. Comparison of the model calculations of Petrova et al. (2001b) with the present observations indicates that the random structure composed of monomers of size parameter close to 1.5 and the refractive index close to (1.65 + i0.05) fits the observed polarization curve of WM1. Therefore the dust grains appear to be a mixture of silicate and organics. The model also predicts an increase in the degree of linear polarization with wavelength at the larger phase angles. This is what we noticed during the observing run in March 16–17, 2002 when the phase angle was approximately 47°. We also note that $\alpha_{\rm inv}$ weakly depends on λ, being smaller for shorter wavelength. If the imaginary part of the refractive index decreases with λ, the negative branch of polarization and the inversion angle slightly depend on λ (Petrova et al. 2001b), characteristics of organic material. This study suggests that grains with a silicate core and organic mantle represent a realistic model. Fluffy aggregate of such monomers can explain the negative polarization and other characteristics of the observed negative branch of the *P* vs. α curve.

4. Conclusions

This work reported linear polarization observations of comet C/2000 WM1 (LINEAR) for the low phase angle where the data are rather rare and also at a phase angle near 47°. Our study based on the polarization observations leads to the following conclusions:

1. Comet C/2000 WM1 belongs to the high polarization class i.e. the dusty comet family.
2. The negative branch of polarization is explained to be due to the scattering of light by the aggregate grains with monomer size comparable to the wavelength of radiation. The mutual influence of the monomers composing aggregate particles produces the negative polarization. The present observations are explained if the monomer size parameter is close to 1.5 and refractive index close to (1.65 + i0.05). Possibly, the dust grains are composed of a silicate core and organic mantle.
3. The observations on March 17, 2002 indicate enhanced cometary activity.

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References

Bastien, P., Menard, F., & Nadeau, R. 1986, MNRAS, 223, 87
Brooke, T. Y., Knacke, R. F., & Joyce, R. R. 1987, A&A, 187, 621
Brownlee, D. E. 1985a, BAAS, 17Q, 685
Brownlee, D. E. 1985b, AREPS, 13, 147
Chernova, G. P., Kiselev, N. N., & Jockers, K. 1993, Icarus, 103, 144
Deshpande, M. R., Joshi, U. C., Kulshrestha, A. K., et al. 1985, Bull. Astron. Soc. India, 13, 157
Dollfus, A., & Auriere, M. 1974, Icarus, 23, 465
Dollfus, A., & Zellner, B. 1979, in Asteroids, ed. T. Gehrels (Univ. Arizona Press), 170
Dollfus, A., & Suchail, J. L. 1987, A&A, 187, 669
Dollfus, A., Bastien, P., Le Borgne, J.-F., Levasseur-Regourd, A. C., & Mukai, T. 1988, A&A, 206, 348
Dollfus, A. 1989, A&A, 213, 469
Eaton, N., Scarrott, S. M., & Warren-Smith, R. F. 1988, Icarus, 76, 270
Eaton, N., Scarrott, S. M., & Wolstencroft, R. D. 1991, MNRAS, 250, 654
Eaton, N., Scarrott, S. M., & Gledhill, T. M. 1992, MNRAS, 258, 384

Furusho, R., Suzuki, B., Yamamoto, N., et al. 1999, PASJ, 51, 367
Ganesh, S., Joshi, U. C., Baliyan, K. S., & Deshpande, M. R. 1998, A&AS, 129, 489
Gehrels, T., Landau, R., & Coyne, G. V. 1987, Icarus, 71, 386
Giese, R. H., Weiss, K., Zerull, R. H., & Ono, T. 1978, A&A, 65, 265
Hadamcik, E., Levasseur-Regourd, A. C., & Renard, J. B. 1999, EM&P, 78, 365
Hadamcik, E. 2002, IAU Coll., 186 (presentation made in the Coll.)
Jockers, K. 1999, EM&P, 79, 221
Jockers, K., Rosenbush, V. K., Bonev, T., & Credner, T. 1999, EM&P, 78, 373
Joshi, U. C., Deshpande, M. R., Sen, A. K., & Kulshrestha, A. 1987, A&A, 181, 31
Joshi, U. C., Baliyan, K. S., Ganesh, S., et al. 1997, A&A, 319, 694
Joshi, U. C., Baliyan, K. S., & Ganesh, S. 2002, EM&P, 90, 413
Kikuchi, S., Mikami, Y., Mukai, T., & Hough, J. H. 1987, A&A, 187, 689
Kiselev, N. N., & Chernova, G. P. 1979, SvAL, 5, 156
Kiselev, N. N., & Chernova, G. P. 1981, Icarus, 48, 473
Kissel, J., Brownlee, D. E., Buchler, K., et al. 1986, Nature, 321, 336
Kolokolova, L., Jockers, K., Gustafson, Bo, Å. S., & Lichtenberg, G. 2001, JGR, 106, 10113
Krishna Swamy, K. S. 1986, Physics of Comets (Singapore: World Scientific)
Lamy, P. L., Grum, E., & Perrin, J. M. 1987, A&A, 187, 767
Le Borgne, J. F., Leroy, J. L., & Arnaud, J. 1987, A&A, 187, 52
Levasseur-Regourd, A. C., Bertaux, J. L., Dumont, R., et al. 1986, Nature, 321, 341
Levasseur-Regourd, A. C., Hadamcik, E., & Renard, J. B. 1996, A&A, 313, 327
Manset, N., & Bastien, P. 2000, Icarus, 145, 203
Mazets, E. P., Aptekar, R. L., Golenetskii, S. V., et al. 1986, Nature, 321, 276
Metz, K., & Haefner, R. 1987, A&A, 187, 539
Myer, J. H. 1985, SPIE, 513, 321
Osborn, W. H., A'Hearn, M. F., Carsenty, U., et al. 1990, Icarus, 88, 228
Petrova, E. V., Jockers, K., Kiselev, N. N., & Nikolai, N. 2000, Icarus, 148, 526
Petrova, E. V., Jockers, K., & Kiselev, N. N. 2001a, SoSyR, 35, 57
Petrova, E. V., Jockers, K., & Kiselev, N. N. 2001b, SoSyR, 35, 390
Renard, J.-B., Hadamcik, E., & Levasseur-Regourd, A.-C. 1996, A&A, 316, 263
Sen, A. K., Joshi, U. C., Deshpande, M. R., Babu, G. S. D., & Kulshrestha, A. K. 1988, A&A, 204, 317
Sen, A. K., Joshi, U. C., & Deshpande, M. R. 1991, MNRAS, 253, 738
Serkowski, K. 1974, Methods in Experimental Physics, 12A (Academic Press), 391
Shkuratov, Yu. G. 1994, AVest, 28, 23
Shkuratov, Yu. G., Muinonen, K., Bowell, E., et al. 1994, EM&P, 65, 201
Steigmann, G. A., & Dodsworth, M. B. 1987, Obs, 107, 263
West, R. A., & Smith, P. H. 1991, Icarus, 90, 330
Xing, Z., & Hanner, M. S. 1997, A&A, 324, 805
Zellner, B., & Gradie, J. 1976, AJ, 81, 262