COMPARATIVE STUDY OF THE DUST POLARIMETRIC PROPERTIES IN SPLIT AND NORMAL COMETS

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Abstract. Our polarimetric database contains six comets, C/1975 V1 (West), 16P/Brooks 2, C/1988 A1 (Liller), D/1996 Q1 (Tabur), C/1999 S4 (LINEAR), and C/2001 A2 (LINEAR), which can be related to the group of split comets. Comets West, S4 (LINEAR) and A2 (LINEAR) were observed during splitting. We compare the polarimetric measurements of the dust particles in these comets, sometimes together with available photometric and colorimetric data, with those in normal comets. We conclude that there is no significant evidence for differences of polarization between tidally split comets (e.g., Brooks 2), dissipating comets (e.g., Tabur), non-tidally split comets (e.g., West) and normal comets. The total disintegration of Comet S4 (LINEAR), however, did produce significant changes in the observed properties of dust.

Keywords: Comets, dust, polarization, split comets

1. Introduction

For several years, we have carried out polarimetric observations of comets which disintegrated to a different degree: C/1975 V1 (West), 16P/Brooks 2, D/1996 Q1 (Tabur), C/1988 A1 (Liller), C/1999 S4 (LINEAR), and C/2001 A2 (LINEAR). Our data set contains also the results of polarimetric observations of many comets, which do not belong to the group of split comets. Most of these "normal" comets are dusty comets. Their individual curves of polarization are very similar. The phase dependence of polarization of this group of dusty comets can be represented by a single synthetic curve, which is well described by the following trigonometric fit (Lumme and Muinonen, 1993)

$$P(\alpha) = b(\sin\alpha)^{c1}(\cos\alpha/2)^{c2}\sin(\alpha - \alpha_o), \qquad (1)$$

where the coefficients b, $c1$, $c2$, α_o are the free parameters. For the fit the dusty comets 67P/Churuymov–Gerasimenko, 22P/Kopff, P/1983 V1 (Hartley–IRAS), 27P/Giacobini–Zinner, 1P/Halley, C/1987 P1 (Bradfield), C/1990 K1 (Levy),

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TABLE I

Coefficients of the trigonometric fit for the blue and red continuum filters

λ [nm]	b	$c1$	$c2$	α_o
484/6	26.832	0.740	0.260	20.9
684/9	31.130	0.797	0.357	21.1

4P/Faye, C/1991 T2 (Shoemaker–Levy), C/1996 B2 (Hyakutake), and C/1999 U1 (LINEAR) were used in the continuum filters λ484/6 nm, λ684/9 nm and close to them (Chernova et al., 1993, 1994; Kiselev and Velichko, 1998; Kiselev et al., 2000a). The coefficients of the trigonometric fit for the blue and red continuum region are given in Table I.

Comet Hyakutake, which is accounted above as "normal" comets, may actually belong to the group of split comets. On March 26.2, 1996, two trailing condensations were observed at distances of about 1700 km and 3500 km from the nucleus by Harris et al. (1997). Both condensations moved along the tail with a velocity of about 19 m/sec. Therefore, they were included in our diaphragm (6622 km) during the polarimetric observations on March 25.0 and 26.0 (Kiselev and Velichko, 1998). Nevertheless, there were no significant variations in polarization of the comet at that time. A similar fragment was seen in the polarimetric image by Jockers on March 30, 1996. However, the brightness of the fragment was too weak to measure its degree of polarization. Polarimetric observations of comets near the maximum of polarization are still rare. Therefore, we have included the polarization measurements of Comet Hyakutake into the synthetic phase dependence of polarization for normal dusty comets. Using the trigonometric fit the polarization degree of split comets can be compared with the synthetic curve for normal comets. In this way we can draw conclusions on a possible difference in their dust properties.

2. Comet C/1975 V1 (West)

During February 19.1–March 6.5, 1976, close to the perihelion passage (Sekanina, 1976, 1982), the nucleus of Comet West broke up into four fragments A, B, C, D.

Polarimetric observations of this comet were carried out by Kiselev and Chernova (1978) from March 6.0 to July 4.8, 1976. Before March 21, 1976, all four fragments of the nucleus of Comet West were observed in the 88 arcsec diaphragm of the polarimeter. After this date, only fragments A and D were centered in the diaphragm. Polarimetry of the single fragments A, B, and D in the V filter was made by Narizhnaia et al. (1977). Michalsky (1981) measured the polarization

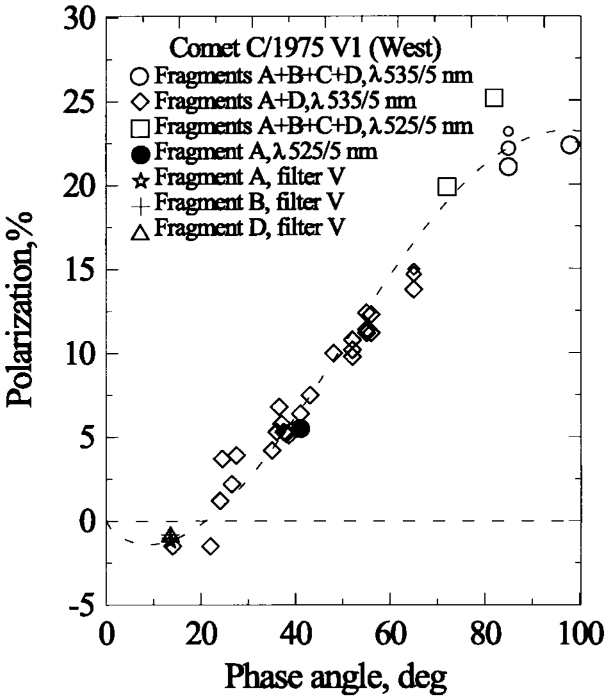

Figure 1. The phase-angle dependence of polarization for fragments of Comet West in comparison with the trigonometric fit to the phase curve for normal comets (blue continuum filter λ484/6 nm).

of Comet West with an aperture of 27 arcsec, in which nucleus A and D were observed. All above-mentioned polarimetric data for Comet West are presented in Figure 1. The employed filters are indicated.

In Figure 1 the data points of polarization degree of Comet West measured in different diaphragms scatter significantly. This is not related to the location of the fragments in the diaphragms of different size. A dependence of polarization on the size of the diaphragm was observed for different dusty comets and was explained by an evolution of dust particle properties after their release from the cometary nucleus (Kolokolova et al., 2001). Therefore one can conclude that there is no difference in polarization of different fragments of the Comet West nucleus and other dusty comets within the accuracy of the polarization measurements. On the other hand, Rosenbush (1986) have found spectral differences in fragments A and D. Tarashchuk (1980) has noted a difference of the color indexes B–V and U–B of fragments A, B, and D. According to these authors the spectral and color distinctions were caused by the difference in gas production of the fragments but not by intrinsic properties of their dust. Thus, neither spectrophotometric nor polarimetric data have revealed significant differences in the dust properties of individual fragments of Comet West as compared to normal dusty comets.

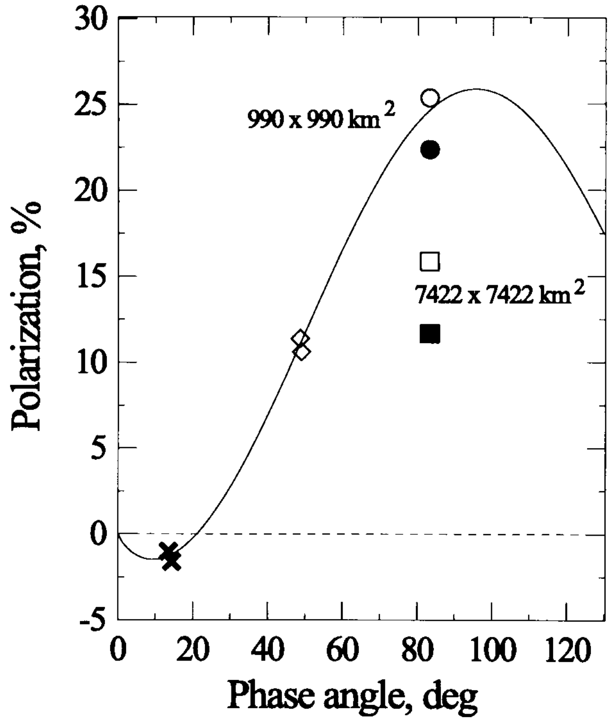

Figure 2. Polarization degree of Comet Brooks 2 (crosses), gas-rich Comet Tabur (circles) and dusty Comet Liller (diamonds) in comparison with trigonometric fit for dusty comets in the red continuum filter λ684/9 nm (solid line). Open and filled circles and squares denote the corrected (Kiselev et al., 2001a) and observed (Jockers, 1997) polarization of Comet Tabur, respectively, in different diaphragms: 990 × 990 km^2 and 7422 × 7422 km^2. For Comet Liller, the aperture used corresponds to the coma area of 39875 km.

3. Comet 16P/Brooks 2

Comet Brooks 2 belongs to the group of tidally split comets (Sekanina, 1997). After a close approach to Jupiter in July 1886, the comet broke up into several components, from which only the brightest fragment was observed in 1889. Since 1896 only the principal nucleus A has been visible and is still surviving today. Unique polarimetric observations of Comet Brooks 2 were carried out by Jockers and Chernova (unpublished data) at the 1.23-m telescope of the Calar Alto Observatory on December 3 and 5, 1994 at phase angles 13.5° and 14.4°, respectively. The focal reducer of the Max Planck Institute for Aeronomy with the four-beam Wollaston prism assembly and the wideband red filter λ694/79 nm was used for the observations (Jockers et al., 2001b). Comparison of the polarization degree of Comet Brooks 2 with the trigonometric fit for dusty comets is shown in Figure 2. One can see that there is no difference between the polarization of Comet Brooks 2 and normal comets.

4. Comets D/1996 Q1 (Tabur) and C/1988 A1 (Liller)

The similarity of orbital parameters of comets D/1996 Q1 (Tabur) and C/1988 A1 (Liller) suggests that these comets were fragments of a common parent body. However, these fragments were very different according to their gas-to-dust ratio (Kawakita et al., 1997). Comet Tabur was a gas-rich comet, while Comet Liller was a dusty one. In this respect a comparison of polarization for both comets is very important for the study of the diversity of secondary nuclei of the split parent body. Comet Tabur belongs to the so-called dissipating comets (Sekanina, 1997). Its brightness decreased catastrophically in late October 1996. Since neither outbursts nor disruption of the nucleus were observed, one can assume that the sharp decrease of comet brightness could be caused by a deactivation of the nucleus (Kiselev et al., 2001a). According to Fulle et al. (1998) the deactivation of the cometary nucleus was caused by seasonal effects, or by the complete end of the nucleus surface activity (possibly caused either by nucleus mantling or by exhaustion of the ice reservoirs).

Polarimetric observations of Comet Tabur were carried out on October 10, 1996, just before the dissipation of the comet (Jockers, 1997). A comparison of polarization degree of comets Tabur and Liller with normal dusty comets is shown in Figure 2. One can see that the polarization of Comet Tabur strongly depends on aperture size. The polarization in the near nucleus region corrected for the NH_2 contamination is similar to that for dusty comets, including Comet Liller. This may imply that the dust particles freshly emitted by the nucleus of a gas-rich comet have the same polarimetric properties as the dust particles in a dusty comet. It is necessary to emphasize that in the large aperture even the corrected polarization remains still small. The possible reasons of this are discussed by (Kiselev et al., 2001a; Rosenbush et al., 2002).

5. Comet C/1999 S4 (LINEAR)

This comet fragmented several times, as manifested by a series of sporadic outbursts in June and July before the complete disintegration of the nucleus around July 23, 2000. In Figure 3 we present the results of aperture polarimetry of Comet S4 in the green continuum filter $\lambda 526/5$ nm (Kiselev et al., 2000b). The polarization values are considerably larger than those for normal comets in the continuum filter $\lambda 484/6$ nm (dashed line). However, they are in a good agreement with the fit obtained for the red filter $\lambda 684/9$ nm of the normal comets (solid line). For most of the comets the polarization of dust usually is higher in the red spectral region as compared to the blue one. The spectral dependence of polarization of Comet S4 was very unusual. Most of the time the degree of polarization in the red filter was lower than in the green and the blue spectral range (Kiselev et al., 2001b).

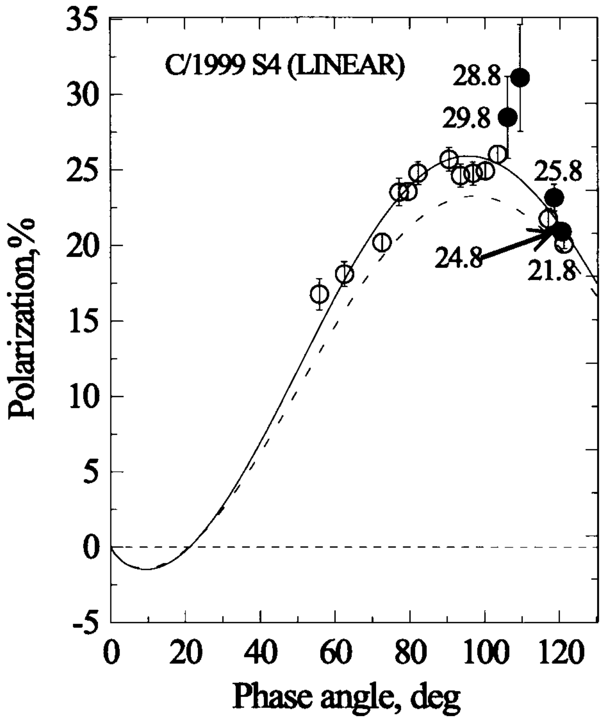

Figure 3. Polarization degree of Comet S4 (LINEAR) versus phase angle. The polarization of the comet measured in the green continuum filter λ526/5 nm (open circles) is in a good agreement with trigonometric fit for normal dusty comets in the filter λ684/9 nm (solid line). The trigonometric fit for normal comets in the filter λ484/6 nm is shown (dashed line). After the final fragmentation, the degree of polarization of the comet became significantly higher (filled circles).

This anomalous spectral dependence of polarization was also detected in Comet 21P/Giacobini–Zinner (Kiselev et al., 2000a). One more feature of S4 is that this comet as well as Giacobini–Zinner belongs to the taxonomic class of carbon chain-depleted comets (Farnham et al., 2001). Moreover, Comet S4 had a strong continuum with very high color gradient, greater than 20% per 100 nm (T. Bonev et al., private communication).

As it is seen in Figure 3, there were no features in the polarization curve before the total disintegration of the comet. After its final fragmentation, however, a dramatic increase in polarization was observed The cometary coma faded rapidly between July 25 and 28. At this time the degree of polarization increased up to 31.1% on July 28.8 and up to 29.5% on July 29.8.

We suggest that during the final disintegration of the comet the properties of the dust particles changed. In particular, fresh dust in the form of small particles could have been ejected and this may have resulted in a considerable increase of polarization (Jockers et al., 2001a).

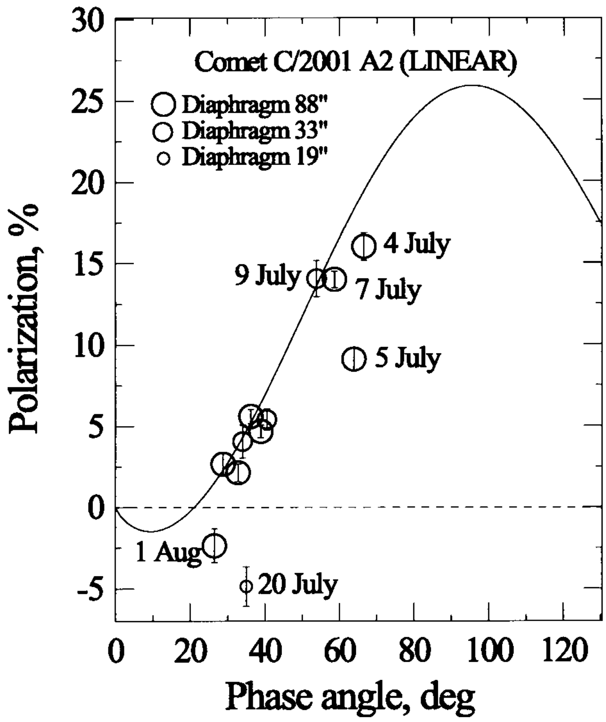

Figure 4. Polarization degree of Comet A2 (LINEAR) versus phase angle. Polarization measured in the red continuum filter λ713/6 nm as compared with the trigonometric fit for normal comets in the filter λ684/9 nm (solid line).

6. Comet C/2001 A2 (LINEAR)

Comet C/2001 A2 (LINEAR) showed considerable variability during its approach to the Sun. This was caused by a partial fragmentation of the nucleus. The breakup of the nucleus into the fragments A and B took place on March 29.9, 2001. A separation of additional components C, D, E, and F from nucleus B occurred on May 11, June 3.5, June 9.5, and June 11.3, respectively (Hergenrother et al., 2001; Broughton, 2001; Jehin et al., 2001; Schuetz et al., 2001; Sekanina, 2001).

We observed the brightest fragment of the comet – nucleus B (Rosenbush et al., 2002). The dust-equivalent A(α)fρ production rates and the color of the dust were calculated according to Farnham et al. (2000). The gas-to-dust ratio expressed by the equivalent width of the C_2 emission was large, $W(C_2) \approx 1000$ Å, for a coma size of 20400–33800 km. Therefore, Comet A2 (LINEAR) was a gas-rich comet. The dust in the comet was blue relative to the Sun in the wavelength range λ345–526 nm (UC–GC: −25% per 100 nm) and red in the wavelength rangeλ526–713 nm (GC–RC: 22% per 100 nm). The blue color of dust is more often observed for gas–rich comets. However, this effect can be due to the gas contamination in the UC continuum filter (A'Hearn et al., 1995). Therefore the different colors of Comet

A2 (LINEAR) in the blue and red wavelength regions can be due to the differential gas contamination in the continuum filters. A procedure developed by Farnham et al. (2000) allows to remove the contamination caused by the main emissions, such as C_2 and C_3. However, according to Arpigny (1995), there are a lot of weak unidentified lines in high resolution spectra of comets. For gas-rich comets such unidentified emissions will look as pseudo-continuum. Therefore the observed color as well as polarization of gas-rich comets may be significantly distorted. It is important to note that comet C/A2 was more dusty ($W(C_2) = 562$ Å) for the smaller diaphragm (area of coma 7700 km) (Rosenbush et al., 2002). In the smaller diaphragm the UC–GC color is redder (UC–GC = -8.4% per 100 nm), while the GC–RC color did not change with respect to the value in the large diaphragm. It is possible that the gas contribution was incompletely removed in Comet A2 (LINEAR), in particular in the UC filter. In such a case the manifestation of the gas contamination should be larger in the larger aperture. However, the intrinsic properties of dust may also change with distance from the nucleus (Kolokolova et al., 2001). Therefore, the origin of the blue colors of the gas-rich comets still remains unknown.

The comparison of polarization of Comet A2 in the filter λ713/6 nm with the trigonometric fit for dusty comets observed in the red continuum filter λ684/9 nm is shown in Figure 4. As in the case of Comet Tabur, the polarization degree of A2 strongly depended on the aperture size. Nevertheless, the polarization measured in the narrow-band filter and the near nucleus region of the coma was similar to that for the normal comets.

Along with this, an unexpected change of the polarization plane was observed in Comet A2 on July 19.9 and 30.9 at phase angles 35° and 26.5°, respectively. Usually, the position angle of the polarization plane is perpendicular to the scattering plane (the polarization is positive) for phase angles larger than 22°. We cannot explain these results by observational errors and a change of dust properties in Comet A2 (LINEAR) during its splitting cannot be ruled out as an explanation for this observation.

7. Conclusions

We have compared the observed properties of dust in several comets, which disintegrated to a different degree. The process of partial fragmentation of comets, such as West, Brooks 2, Liller, Tabur, and A2 (LINEAR), not always causes changes in polarization. Disintegration of Comet S4 (LINEAR) represents an example of an extreme disintegration of a comet. In this case significant changes of the scattering properties of dust particles were found.

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