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Polarimetric study of comets from Mt. Abu observatory

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Abstract. The sunlight is scattered by the dust grains present in the coma and tail of comets which makes it visible. The scattered sunlight is characteristically polarized with degree of polarization generally depending upon the phase angle, wavelength of the incident light, shape and size distribution of the scattering particles and refractive indices of the particles. High precision photopolarimetric observations at several wavebands and phase angles were made on several bright comets during the last decade using the facilities at Mt. Abu observatory with the aim to study the characteristics of the dust grains in the comets. All these comets were bright comets and found to belong to high polarization class of comets. At low phase angles comets show significant negative polarization indicating the grains to be regolith consisting of monomers of sub micron size.

Keywords : comet-dust grains-comet coma-polarization

1. Introduction

The study of comets has proved to be very useful in understanding the origin of solar system. Comets stay away from the Sun for most part of their lives and hence face minimal weathering. They, therefore, act as fossils in revealing the primitive composition of the solar system. The early phase of accumulation of grain and ice with other volatile elements produced first proto cometary nucleus, in which the solid grains remained embedded in ice. Information regarding the physical and chemical conditions at the time of formation of solar nebula is imprinted on the dust grains and the ices. At times these cold bodies get deflected to wards the Sun. On reaching closer to the Sun, the temperature of the

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outer layer of comet increases and ices close to the surface sublimate releasing the gas and dust into space, often violently. The grains which are ejected from the interior are pristine and those blown out from the crust may have been reworked. Dust particles in comet's coma and tail scatter sun light creating a fascinating sight. The scattered sunlight is characteristically polarized with degree of polarization generally depending upon the phase angle, wavelength of the incident light, shape and size distribution and refractive indices of the scattering particles and hence study of the polarization phase curve and wavelength dependence of polarization allows inferences to be made 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. 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 study of dust grains in comets has been an active area of investigation for quite some time but the exact nature and composition of cometary grains are still an enigma. The space mission to Comet Halley made some in-situ measurements and have contributed important information on the nature of grains in comet P/Halley(Kissel et al., 1986; Mazets et al., Mazets 1986; Levasseur-Regourd et al., 1986). However, ground based observations have indicated that the detailed behavior of grains differ in different comets. Until more in-situ measurement are carried out on other comets, the information about dust grains in comets has to come mainly from the ground based observations in conjunction with theoretical models (Krishnaswamy, 1986; Xing & Hanner, 1997; Jocker et al., 1999; Petrova et al., 2001a; Petrova et al., 2001b).

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 effort for detailed polarization observations was in the case of Comet P/Halley by many groups (eg. 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, Hale-Bopp, C/2000 WM1(LINEAR), C/2001 Q4(NEAT). Polarization observations were made on these comets by several groups including our group (eg. Joshi et al. 1997; Sen et al., 1991; Ganesh et al., 1998). Some of the results are presented here.

2. Polarimetric observations of comets from Mt Abu observatory

During the past decade photopolarimetric observations of some bright comets (eg comet Hyakutake, Hale-Bopp, C/2000 WM1 (LINEAR) and C/2001 Q4(NEAT)) were carried out from the 1.2 m telescope of Mt. Abu Observatory operated by Physical Research

Laboratory, Ahmedabad, equipped with a two channel photopolarimeter (Deshpande et al., 1985). The polarimeter, one of the most successful back-end instrument, developed in-house works on the principle of rapid modulation. A combination of rapidly rotating super achromatic half wave plate and a Wollaston prism modulates the incoming light beam. Figure 1 shows the schematic diagram and a picture of the polarimeter mounted on the telescope. The polarimeter was equipped with the IAU/IHW filters. Observations were made through IHW filters (see Obsborn et al., 1990) in continuum bands 3650/80 (UC), 4845/65 (BC),6840/90(RC). IHW filters were acquired about two decades ago for comet P/Halley campaign and were carefully preserved in a dry atmosphere. However, to be sure of their characteristics, we determined their transmission curves before the start of the observations for each case and found that except for the CO^+ (4260 Å) filter, transmission curves for all other filters compared very well with the transmission characteristics supplied by the manufacturers without any significant deterioration. Though some of these continuum filters are slightly contaminated by molecular emission (Schleicher, private communication), the degree of polarization and position angle are not significantly affected. Also the observations with these filters facilitate comparison with comets observed earlier with the same set of filters, hence their continued use is justified.

Details on the observations and results can be found in the literature: comets Hyakutake (Joshi et al., 1997), Hale-Bopp (Ganesh et al., 1998) and C/2000 WM1 LINEAR (Joshi et al., 2002, 2003). Recently (May-June 2004), we have carried out polarimetric observations of Comet NEAT (C/2002 Q4). Some of the results are discussed here.

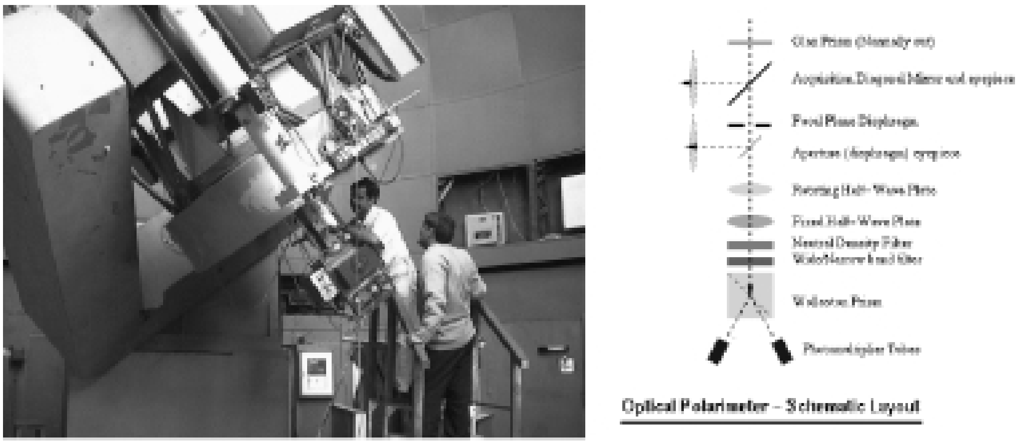

Figure 1. Picture of the polarimeter mounted on the telescope and the schematic diagram.

3. Results and discussions

As mentioned above, degree of polarization mainly depends upon incident wavelength(λ), refractive indices of the scatterer, phase angle(ϕ) and particle size distribution:

$$P = f(\lambda, n - ik, \phi, n(a)).$$

As there are several unknown parameters to fit-in in the observed data, it may be difficult to get a unique solution. The only parameters where an observer has some control are: λ and to some extent ϕ. To achieve the best possible results, attempts were made to cover the maximum possible phase angle at three continuum wavelengths.

Comet Hale-Bopp was observed during October 1996- May 1997 in three IHW continuum bands(3650, 4845, 6849Å) covering wide phase angle 17.1 - 47.4 deg. Comet C/2000 WM1 was Observed during Nov 23-26 2001 when the phase angle ranged between 15-22 deg degree. However, the C/2000 WM1 was relatively faint during the observing run, and it turned out to be difficult to achieve good S/N ratio even for the integration time as long as 20 min. The presence of the moon also played havoc in the early part of the observing run when the comet was up in the sky and we had to wait till the moon was set. The sky remained very good (photometric sky all through), during the whole observing run. After the moon was set, the comet was already very low in the sky and little time was left for the observations and therefore we reverted to the observations with broad bands - BVR of Johnson and Morgan system. For comparison purpose we made a few observations through IHW filter 4845/65 (BC). Fortunately we succeeded in obtaining data through the broad band filters - BVR and IHW filter BC. The second round of polarization observations on C/2000 WM1 was conducted in March 2002 when the phase angle was near 47 deg. Observations covering low to high phase angle are important to give better insight on the behavior of polarization with phase angle.

In figure 2 we combine polarization vs phase curve for comets Hale-Bopp and C/2000 WM1. Comparison of the polarization phase curves of comet hale-Bopp and comet C/2000 WM1 with the composite polarization phase curve for several comets by Levasseur-Regourd et al.(1996) show that both the comet belong to high polarization comets ie to dusty comets. From the figure we also note that the degree of polarization for Hale-Bopp is higher than for the comet WM1 at larger phage angle (ϕ) (ie near 47 deg). During May-June 2004, we have carried out polarimetric observations of Comet C/2002 Q4 (NEAT). Due to the limitation on the page numbers, we have avoided the detailed results on this comet in this communication. However, we would like to mention here that comet C/2002 Q4(NEAT) was also found to belong to the high polarization class ie dusty comet. It has been found that the polarization of comet Hale-Bopp is higher than any other comet studied so far for polarization. Some authors even preferred to assign another class (ie class III) to comet Hale-Bopp (Hadamcik, 2000). Comet belongs to high polarization class (dusty comet), inferred to have aggregate grains with monomer size comparable to wavelength of incident light.

Comets Hale-Bopp and C/2000 WM1(LINEAR) have been Observed when the phase angle was below 20 degree. Both the comets show negative polarization when the phase angle is less than 20 deg. Observing comets at low phase angle is difficult because at

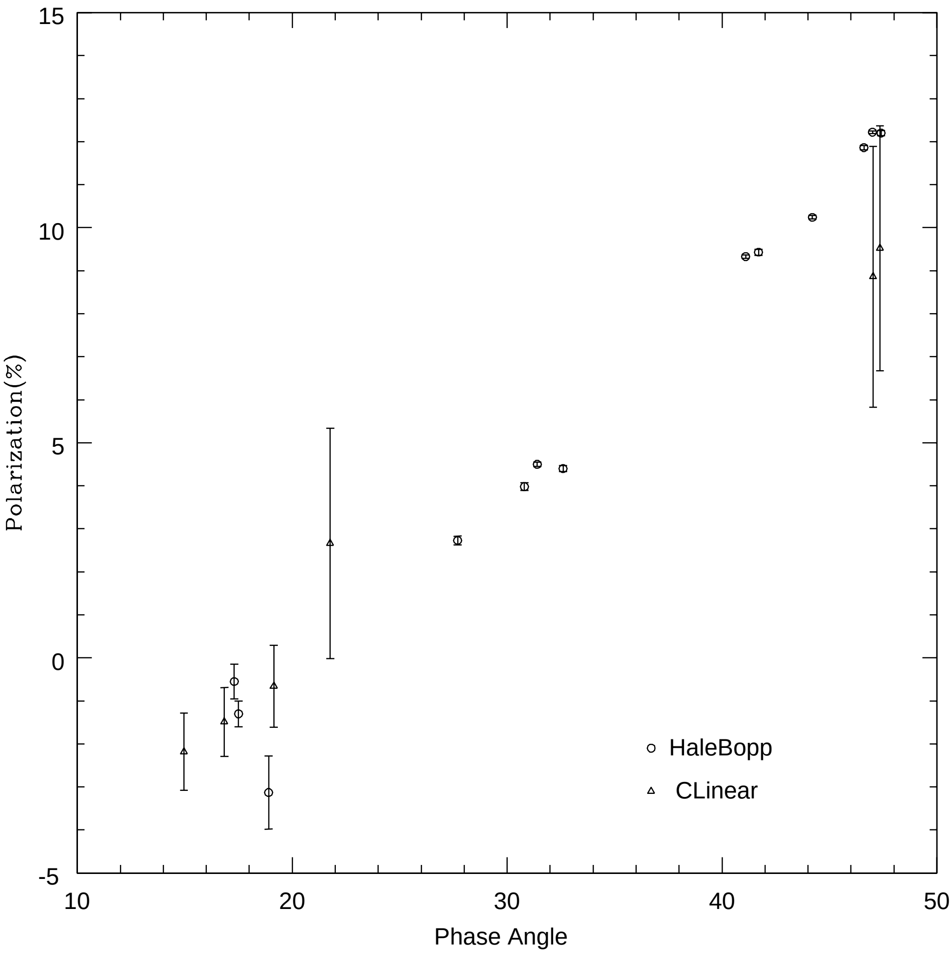

Figure 2. The phase dependence of polarization of comet Hale-Bopp and C/2000 WM1 (LINEAR) for blue wave bands centred at 485nm.

low phase angle comets are expected to be far off in the sky and appear faint. Also the duration for which comets are accessible in the sky at low ϕ is short. However we succeeded in getting good data at low ϕ. The significance of observing negative polarization observed in comet Hale-Bopp and C/2000 WM1 and the detailed results are discussed by Joshi et al.(2002, 2003). It is to be noted that moon and asteroid also show negative polarization at low phase angle (eg Coyne and Pellicori 1970).

For the negative polarization branch of the curve, particles with sizes more or equal to wavelength of incident light are required. Such branch in the phase curve is typical for regolith-like surfaces(cohesive fluffy surface). This highly porous texture is common property of all lunar samples returned to Earth. The negative branch of polarization-phase curve is produced by the effect of multiple scattering and mutual shadowing between grains of a complex texture, eg absorbing grains like those obtained on finely pulverized basalt. Such an interpretation is confirmed by lunar returned samples. The small size particles are known to produce only positive polarization.

From the polarization study of the comets, it appears that cometary grains are either fluffy with monomers size particles or there may be bimodal distribution of the grains small grains (sub micron size) and large grains (micron size or larger). The small grains may be responsible for positive polarization and large grains with fluffy surface structure responsible for the negative polarization.

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