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Imaging polarimetry of comet 73P/Schwassmann–Wachmann 3 main fragments during its 2006 apparition ☆

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ABSTRACT

We have observed the dust ejected by parts of the nucleus (so-called fragments or components) of comet 73 P/Schwassmann–Wachmann 3 during seven consecutive nights from 2006, April 27 to May 3 by imaging polarimetry using the 0.8 m telescope at OHP (Observatoire de Haute-Provence, France). Three fragments were observed, B and C main fragments on all nights and G fragment on two nights at 24 h interval. Fragment C, which almost behaves as a normal comet, presents some night-to-night evolution on polarization maps together with some sunward-jets morphology. Fragment B, as noticed by numerous observers, continues to fragment, with clues to the presence of large secondary fragments, tailward on the intensity images; an increase of activity is noticed on May 2. Jets and fans are observed sunward, with a larger extension in fragment C than in B. Fragment G is fainter and, as fragment B, it continues to fragment. A short sunward jet is detected on the rotational gradient image together with an important tailward structure. The integrated polarization for the two main fragments is typical of polarization of high-P_{max} comets. An important evolution is observed from night-to-night on the polarization maps. Fragment C presents, in two nights at 48 h interval, a lower polarization in the inner coma, neither observed in the intermediate night nor later. A high polarization is also observed on the two sides of the lower polarization regions. In fragment B, the regions around the secondary fragments have a higher polarization than the surrounding coma, They are easily detected in the treated intensity images. As usually, the polarization increases when the phase angle increases. Numerous observers have found similar chemical compositions for the two main fragments together with differences in their optical properties, suggesting heterogeneities in the physical properties during the aggregation of the original nucleus and/or changes after the ejection of dust particles.

1. Introduction

Comet 73 P/Schwassmann–Wachmann 3 (hereafter SW3) passed close to Earth (perigee on May 12 at 0.079 au) in April–May 2006, allowing a high spatial resolution imaging and numerous remote observations. It is a very active Jupiter-Family Comet (JFC) with an orbital period of 5.36 years and an orbit inclination of 11.39°. Its increasing activity in 1995 was detected by radio observations (Crovisier et al., 1995). The existence of at least four fragments (named A, B, C, and D) was revealed in December 1995 by photometry in the red wavelength domain and thermal observations (Boehnhardt et al., 1995). In 2001, the recovered fragments B and C and a new fragment E appeared well separated (Boehnhardt et al., 2002). Altogether, more than 60 fragments were detected in 2006, although evidence for none of them was found around the main fragment C, which was the primary component (Toth et al., 2006). Dello Russo et al. (2007) studying the volatile composition of fragments B and C found similar compositions, qualified as carbon-chain depleted (DiSanti et al., 2007).

The linear polarization of the solar light scattered by dust around main fragments (B and C) was also studied in the visible and the near Infrared (Bonev et al., 2008; Jones et al., 2008; Kiselev et al., 2008). Linear polarization studies, which are independent of the number of particles in the field of view (for optically thin media), provide complementary clues on the optical and physical properties of dust inside a coma (see e.g. Levasseur-Regourd (1999)). Polarization values depend not only on the dust properties, but also on the phase angle and the wavelength of observations. Using all the available data in the literature, in wavelength ranges as free as possible of gaseous emission contaminations, a classification of comets by their polarization at large phase angles and large apertures was built with two classes called high-P_{max} comets and low-P_{max} comets (Levasseur-Regourd et al., 1996).

☆Based on observations made at observatoire de Haute-Provence (CNRS), France.
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Both laboratory simulations (see e.g. Hadamcik et al. (2007a, 2011)) and numerical simulations (e.g. Kimura et al., 2006; Lasue et al., 2009; Kolokolova and Kimura, 2010) provide realistic interpretations of the observations. They are confirmed by correlations with results obtained by other observational techniques such spectroscopy (with silicate infrared emission features). The high polarization values for high-P_{max} comets are usually interpreted by the presence of sub-micron sized grains, which can be parts of fluffy aggregates (Hadamcik and Levasseur-Regourd, 2003a). Low-P_{max} comets may present no jet activity at all or just a few jets in a limited region of the inner coma, with an important decrease in polarization as the aperture increases, as for 9 P/Tempel 1 before Deep Impact (Hadamcik et al., 2007b). This high polarization in the inner part can be interpreted by large dark particles, which move slowly. Some comets with an important seasonal effect, as comet 67P/Churyumov–Gerasimenko, may behave like low-P_{max} comets before perihelion and present more jets (with smaller grains) at perihelion or after it (Hadamcik et al., 2010). The presence of large particles (100 µm or more) before 2015 perihelion has been confirmed by the first results from COSIMA and GIADA experiments onboard Rosetta spacecraft (e.g. Schulz et al., 2015; Rotundi et al., 2015).

In the present paper, after a description of our observations and data reduction method, the results are presented with emphasis on particular structures or events. The intensity images allow to follow the morphologies. Differences in optical properties are underlined in the linear polarization maps. Comparisons with other comets establish that the two main fragments belong to the high-P_{max} class comets and have similar optical properties than other splitting comets.

2. Observations and data reduction method

The observations have been performed with an imaging polarimetric technique with the Cassegrain 0.8 m telescope at Observatoire de Haute-Provence (OHP) in France. Four polaroid filters are mounted on a rotating wheel, with their fast axis oriented at 45° from one another. During each night, polarized and unpolarized standard stars are observed to control the non-polarization of the instrument and to determine the origin of the instrumental reference system (θ_0 corresponding to the position angle (PA) of the polarization of one polarized filter). The intensity, the measured polarization degree P (which has not sign), the measured position angle θ, the position angle of the polarization plane and finally the values of the polarization Pr (which can be positive or negative), and the position angle θ_r in the coordinate system referring to the scattering plane are calculated by the following expressions:

$$I = I_0 + I_{90} = I_{45} + I_{135} \quad (1)$$

$$P = 200\frac{\sqrt{(I_0 - I_{90})^2 + (I_{45} - I_{135})^2}}{I_0 + I_{90} + I_{45} + I_{135}} \quad (2)$$

$$\theta = 0.5\arctan\frac{I_{45} - I_{135}}{I_0 - I_{90}} \quad (3)$$

$$\theta_r = \theta - \theta_0 - (\phi \pm 90) \quad (4)$$

The polarized intensities are measured in the instrumental reference system. $\theta_r = (\theta - \theta_0)$ is the position angle of the polarization plane in the equatorial reference system. The position angle of the scattering plane (ϕ) is known at each date. For symmetry reason it is defined between 0° and 180° and can be deduced from the value of the Sun-comet radius vector position angle (Sun-C PA in Table 1). The sign between the parentheses, in Eq. 4, is chosen to ensure the condition $0° < (\phi \pm 90°) < 180°$. θ_r is generally of about 90° for comets observed at phase angles larger than 25° (Levasseur-Regourd et al., 1996). A more detailed description of the instrument and method can be found in Hadamcik et al. (2007b).

Table 1
Log of the observations. Dates correspond to the beginning of each night e.g. April 27 = 27–28 night. R_h = heliocentric distance, Δ = geocentric distance, m_{vis} = visual magnitude, α (°) = phase angle, Sun-C PA = extended Sun-comet radius vector position angle (JPL Horizons ephemeris); Exposure time = total exposure time for each polarized component.

Dates, 2006	R_h(au)	Δ(au)	m_{vis}	α (°)	Sun-C PA (°)	Exposure time (s)
Fragment C						
April 27	1.110	0.155	9.6	45.0	215.4	1020
April 28	1.103	0.147	9.4	46.4	216.1	840 + 180
April 29	1.095	0.140	9.3	47.9	217.1	720
April 30	1.088	0.133	9.1	49.5	218.1	1200
May 1	1.081	0.126	9.0	51.3	219.4	1200
May 2	1.074	0.119	8.9	53.3	211.1	620
May 3	1.068	0.113	8.7	55.5	215.2	900
Fragment B						
April 27	1.110	0.155	11.8	43.3	205.6	1260
April 28	1.103	0.147	11.7	44.6	205.8	840 + 180
April 29	1.095	0.140	11.5	45.9	206.2	1320
April 30	1.088	0.133	11.4	47.4	206.9	960
May 1	1.081	0.126	11.3	49.0	207.7	360
May 2	1.074	0.119	11.0	50.7	208.9	1260
May 3	1.068	0.113	10.8	52.6	210.3	900 + 600
Fragment G						
April 29	1.095	0.140	13.2	45.7	204. 3	540
April 30	1.088	0.133	13.1	47.1	204.8	240 partly cloudy

The exposure time for each polarized image was short (10–60 s) to avoid any tracking problem. Numerous images were recorded to build the polarized components for the different fragments and finally the intensity and polarization maps. The log of the observations is presented in Table 1. The weather and sky conditions were remarkably clear, except during some hours with faint clouds and/or wind. These periods are not used in the data. The region blurred by seeing remained smaller than 200 km radius (and often than 120 km) on the comet. To reduce the contaminations by the gaseous emissions, a Thuan-Gunn 'r' filter has been used (655 nm, $\Delta\lambda = 90$ nm; Thuan and Gunn, 1976). Results obtained with this filter were validated during previous studies of different comets e.g. comet 103 P/Hartley 2 which is a low-P_{max} comet; comparisons with results obtained through ESA cometary continuum narrow band filters (684 nm, $\Delta\lambda = 9$ nm and 443 nm, $\Delta\lambda = 4$ nm) have shown the absence of any major contamination when using the broad Thuan-Gunn filter (Hadamcik et al., 2013; 2014). Nevertheless, the continuum may be contaminated by the O1D band at 630 nm and in a lower ratio at 633.4 nm, NH_2 bands (0,8,0) at 633.5 nm, (0,7,0) at 665 nm and (0,5,0) at 695 nm. In the spectrum (unfortunately limited to 650 nm), published by Kanda Yu-I et al. (2008) for observations on 2016/05/02), gas emission bands may be present, but with a relatively small contribution as compared to the continuum. This will be discussed with the polarization results and comparison with other observations.

A center gravity algorithm is used to find the position of the optocenter of the comet on each polarized image. To avoid artifacts in the polarization maps, the polarized components are centered with a precision of 0.1 pixel before any addition or calculation. The sky background estimated in a region outside the coma (in the solar direction at more than 2 arc min) is subtracted from each image and controlled. The fluxes through apertures of 12 and 24 pixels diameters are measured for each polarized component, and the stability of intensity values is controlled for the whole series. If a difference greater than 2% is detected, the image is rejected. For some of the observations a median sum is applied to series of six