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Study of some comets through imaging polarimetry

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ABSTRACT

Comets C/2007 N3 (Lulin), C/2011 L4 (PANSTARRS) and 290P/Jager were observed at phase angles <40○; between 2009 and 2014; with the 0.8 m Telescope at Haute-Provence Observatory (OHP) in France. The observations were polarimetric and mainly carried out in the red and near infra-red wavelength domains to reduce gaseous contaminations. The overall shape of the coma of comet Lulin is about circular without evident jet structure. The coma of comet C/2011 L4 is enlarged in the antisolar direction. Jets in a fan-like structure have been noticed between position angles 135°–245° in the treated intensity images. A correlated higher polarization region is noted on the corresponding polarization map. The shape of the coma of 290P/Jager is slightly elongated in the antisolar direction. Deeper negative polarization is found in the inner coma. The whole coma polarization values of these three comets correspond to the synthetic phase curve for comets at similar phase angles and wavelength.

1. Introduction

Imaging polarimetry is a nice technique to investigate the optical and physical properties of dust grains ejected by comets when they approach the sun. Previous works by the polarimetric imaging method have revealed that different regions inside coma show some differences in polarization suggesting differences in physical properties of the dust particles. Jets, fan-like structures usually show a higher polarization than the background. In some comets, regions close to the nucleus are marked with a smaller positive value at phase-angles larger than the inversion angle and a deeper negative polarization at small phase angles. (e.g. Dollfus and Suchail, 1987; Sen et al., 1990; Hadamcik et al., 2003a,b, 2010, 2013, 2014). In the present work, three comets are studied. C/2007 N3 (Lulin), Comet C/2011 L4 (PANSTARRS), 290P/Jager were observed polarimetrically with the 0.8 m telescope of Haute-Provence Observatory (OHP) in France.

Comet C/2007 N3 (Lulin) was discovered by Ye Quanzhi and Lin Chi-Sheng on 11 July 2007 using the 41-cm (16 in) Ritchey-Chretien at Lulin Observatory, Nantou, Taiwan as a part of the Lulin Sky Survey project. Two months after its last perihelion (10 January 2009), the comet was observed during the period 17–20 March 2009 at a geocentric distance 0.9 au, while the phase angle varied between 35.7° and 36.7°.

Comet C/2011 L4 (PANSTARRS) was discovered by Richard Wainscoat (Institute for Astronomy, University of Hawaii) on 6 June 2011 with the 1.8-m "Pan-STARRS 1 Ritchey-Chretien telescope" at Haleakala, HI, USA. For our study, the comet was observed on 6 and 7 May 2013, two months after the perihelion (on 10 March 2013) at a geocentric distance 1.5 au and phase angle 38°.

Comet 290P/Jager (or 1998 U3 or 2013 N1) was discovered by Michael Jager with a 0.25-m, f/2.8 Schmidt camera. From OHP, it was observed on 27 & 28 January 2014 at a geocentric distance 1.3 au, when phase angle was 14°–15°.

2. Observations and data reductions

The observation log and data reduction procedure are discussed below.

2.1. Instruments

The observations were carried out with the 0.8 m Cassegrain telescope of the Observatory of Haute-Provence, "OHP" situated near Marseille, France (Observatory reference: 511).

Details on the instruments can be found in Hadamcik et al. (2010, 2013). In brief, the telescope has a focal ratio f/15; the field

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of view for polarization imaging is 7 arcmin. The CCD camera has 2048×2048 pixels, back-illuminated, of 13.5 μm each. The resolution by pixel is thus 0.21 arcsec; the pixels are binned 4×4 giving a final resolution of 0.84 arcsec. There are four polarizing filters mounted on a rotating wheel. The direction of polarization axis of first one is called direction '00'. The polarization axes of the three others are oriented at 45° from one another. For each orientation, a polarized intensity image is recorded and they are called respectively I_{00}, I_{45}, I_{90}, I_{135}. To avoid tracking problems short exposures were used; as the comets were faint, the final polarized images were built by adding the 10–15 individual images for each position of the polarization axis. In this way signal-to-noise ratio is increased.

The intensity (I), the measured polarization (P), and polarization angle (θ) are calculated by the following expressions:

$$I = I_0 + I_{90} = I_{45} + I_{135} \tag{1}$$

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

$$\theta = 0.5 \arctan\left[\frac{I_{45} - I_{135}}{I_0 - I_{90}}\right] \tag{3}$$

2.2. Log of observations

The log of observations is presented below (Table 1), α=phase angle, PA=sun–comet radius vector position angle, Δ=distance of the comet from the earth, R=distance of the comet from the sun. The filters used are Thuan-Gunn red R_{OHP} 655 nm, $\Delta\lambda$ 90 nm and I_{OHP} 810 nm, $\Delta\lambda$ 150 nm.

2.3. Data reduction

Bias subtraction and flat field correction to all cometary images were applied. After that, centering of optocenter with a precision of 0.1 pixel was done with gravity center algorithm. The sky background was estimated from a region outside the coma and free of faint stars and was subtracted from each polarized image. For each set of four images, the stability of fluxes at different apertures of polarized components (I_0, I_{45}, I_{90}, I_{135}) is controlled by measuring fluxes of each individual polarized components at apertures of diameter 5, 10, 15 pixels. If a difference greater than 1% is detected between the fluxes ($I_0 + I_{90}$ and $I_{45} + I_{135}$) for 15 pixels on the successive images, the image is rejected because in less than ten minutes interval between the successive images, they have to be same. As mentioned in Section 2.1, the final polarized images are built by adding the 10–15 individual images for each position of the polarization axis and thus intensity I, Eq. (1) is calculated for the whole series.

3. Results

Azimuthally integrated radial profiles of intensity and profiles of decrease in intensity along solar and anti-solar directions are presented first in this section. Coma morphologies (obtained from intensity images) followed by aperture linear polarization and polarization maps are presented subsequently. The variation in polarization values is studied with increase in aperture and the polarization maps are obtained to detect variation in polarization in different regions inside the coma and declare any decisive relation with different structures.

3.1. Intensity images

Intensity images are obtained by adding two mutually orthogonal polarized components. The components are either (I_0, I_{90}) or (I_{45}, I_{135}). The successive intensity images thus obtained for a particular set are further added (I_0, I_{90}) or (I_{45}, I_{135}) to build the final intensity images.

3.1.1. Intensity radial profile

Decrease in intensity as a function of optocentric distance is measured for all the comets from the intensity images. It is done by calculating the intensity in one pixel thickness annulus and then dividing by the number of pixels in that annulus. The log of the intensity values as a function of log of radial distance (in km) from optocenter is called azimuthally averaged radial intensity log–log profile (Fig. 1).

For Lulin, the slope of decrease on the radial profile is found to be about −1 for radial distance larger than 1080 km from the optocentre. It is around −1.16 between 540 and 1080 km and −0.9 within the radial distance 540 km. The slope along anti-solar direction is −1.06 between 1080 and 1750 km and that between 400 and 1080 km is about −1.2. Along solar direction, the slope is −1.2 between 540 and 1080 km and −1 after 1080 km.

In case of C/2011 L4, for optocentric distance larger than 4700 km, the slope of radial profile is around −1.17. From 1170 to 4700 km, the slope is about −1.19; between 700 and 1170 km it is about −0.81 and within 700 km, it is about −0.6. Along solar direction, the slope is −1.05 between 700 and 1170 km and −0.98 between 1170 and 5870 km. Along anti-solar direction, it is −0.94 from 940 km to 1880 km; and −1.04 from 3050 km to 5870 km.

For Jager, the slope is around −1(−0.98) for optocentric distance larger than 1560 km. In a region from 780 km to 1560 km, it is about −1.09 and before 780 km, the slope is nearly −0.88. Along the solar direction, the slope changes from −1.64 between 780 and 1560 km to −1.02 between 1560 and 2530 km. That along anti-solar direction is −0.83 between 580 and 970 km and −1.03 between 970 and 1560 km.

Table 1
Log of observations.

The comet	Date of observation	α°	PA°	Δ (au)	R (au)	Resolution (km/pixel)	Filter, exposure time (sec) × number of images used
C/2007 N3	17.03.2009						R_{OHP},20 × 15;I_{OHP},20 × 15
(Lulin)	18.03.2009	35.7	97	0.9	1.5	135	R_{OHP},10 × 18;I_{OHP},20 × 12
	19.03.2009	−36.7	−96				R_{OHP},10 × 20
	20.03.2009						R_{OHP},20 × 12
C/2011 L4	06.05.2013	38	310	1.5	1.3	235	R_{OHP},30 × 15
(PANSTARRS)	07.05.2013		−309				R_{OHP},30 × 15;I_{OHP},30 × 12
290P/Jager	27.01.2014	14–15	104	1.3	2.1	195	R_{OHP},120 × 5
	28.01.2014		−103				I_{OHP},120 × 4