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CCD Photometry of Comet 73P/Schwassmann-Wachmann 3 during Its 2006 Apparition Observed from the Bosscha Observatory

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Abstract

On 9-10 May 2006 UT comet 73P/Schwassmann-Wachmann 3 (73P/SW3) passed 0.093 AU from the Earth, being slightly farther away than its discovery on 1930. Interestingly, it has been reported since 1995 that the comet has been breaking up to many components during its trajectory orbiting the Sun with a period of 5.4 years. Here we report our CCD photometric observations of major components B and C during its 2006 apparition. Successful observations were done on 12-14 May 2006 UT at the Bosscha Observatory, Lembang. Since comet is a moving object, we carried out stacking techniques to combine our images in order to strengthen the signal-to-noise ratio. Our investigations to their surface brightness show that the coma of 73P/SW3 was not in a steady state. Under assumption of a steady state coma, the dust production rate of the component is found to be 24.7 cm and the mass-loss rate of 4.94 kg s^{-1}.

Keywords: *Comets; Photometric observations.*

1. Introduction

More than 40 comets have been experienced splitting of the nuclei for over the past 150 years[1)]. It is estimated that statistically the lower limit of the splitting rate is 0.01 per year per comet[2)]. The comet 73P/SW3 has a relatively short orbital period of 5.4 years with a low inclination of 11°. It is classified as a Jupiter-family comet.

In 1995 the comet nucleus firstly reported to split into five components (A to E) after a major outburst event, at which the nucleus activity was increased by a factor of 20[3)]. It was first confirmed that the actual fragmentation was occurred on 12 and 13 December 1995[4)]. Only three components (B, C, E) were still visible in the 2001 return.

In 2006 return, it was reported that seven components were initially observed and more were discovered subsequently[5)]. The continuing disintegration of the component B was reported in April of 2006. Mini components were detected trailing behind the main component observed by the Hubble Space Telescope (HST) on 28 April 2006[6)]. Meanwhile the component C is now considered to be the principal one, because of its maximum brightness[7)].

The radius of the comet before break-up was estimated ranging from 0.68 – 1.3 km[8)]. However, recently it is regarded that the upper limit of the comet radius is 1.1 km[9)]. If the dynamical lifetime of short periodic comets is a few × 10^5 yr[10)], nucleus splitting may occur up to a thousand of times. However, the detailed mechanism of the 73P/SW3 splitting is still unknown.

The 2006 apparition was the best moment to photometrically investigate the comet in detail. Here we report our CCD observations of this comet to derive some principal physical parameters.

Table 1. Observing geometries of components B (upper tab) and C (lower tab).

Obs Time (UT)	α J2000 (h m)	δ (° ′)	*r* (AU)	Δ (AU)	Solar Phase (°)	Motion (′/h)	Airmass
12 May ~22h	20 17	+36 53	1.002	0.68	85.5	12.6	1.4
13 May ~22h	20 50	+34 19	0.998	0.67	90.2	12.1	1.3
14 May ~22h	21 21	+31 12	0.993	0.67	94.8	11.3	1.3

Obs Time (UT)	α J2000 (h m)	δ (° ′)	*r* (AU)	Δ (AU)	Solar Phase (°)	Motion (′/h)	Airmass
12 May ~22h	21 00	+25 22	1.002	0.68	89.3	12.6	1.2
13 May ~22h	21 24	+22 46	0.998	0.67	93.1	12.1	1.2
14 May ~22h	21 48	+20 02	0.993	0.67	96.6	11.3	1.2

r and Δ are the heliocentric and the geocentric distances, respectively.

Table 2. Observing circumstances.

Obs Time (UT)	CCD	FOV (′)	Scale (″/pix)	Filter	Exp (s)
12 May ~22h	ST-8XE	24 × 16	0.9 × 0.9	V, R	30, 60
13 May ~22h	ST-7XE	12 × 8	0.9 × 0.9	R	30
14 May ~22h	ST-8XE	24 × 16	0.9 × 0.9	V, R	30

2. Observations and Data Reduction

The major components B and C of comet 73P/SW3 were observed on 12-14 May 2006 UT at the Bosscha Observatory using a Celestron NexStar GPS 8-inch portable telescope equipped with ST-8/XME and ST-7/XME CCD cameras. Tables 1 and 2 shows the observing geometry and circumstances, respectively.

During the observations we faced some difficulties in telescope tracking, annoying significantly for longer exposure time of more than 60 s. Thus some data were useless and neglected prior to the reduction steps. However, a number of appropriate data were good enough for photometry measurements. Standard data reduction[11] and photometry[12] were performed using the IRAF (Image Reduction Analysis Facility). To strengthen the signal-to-noise ratio, the well-known stacking technique was used to finally provide total integration times of 60-120 s.

Samples of the stacked images are shown in Figure 1. The comet motion was close to some rather bright field stars. Directions to the North, East, and the Sun are labelled, respectively, by N, E, and ⊙.

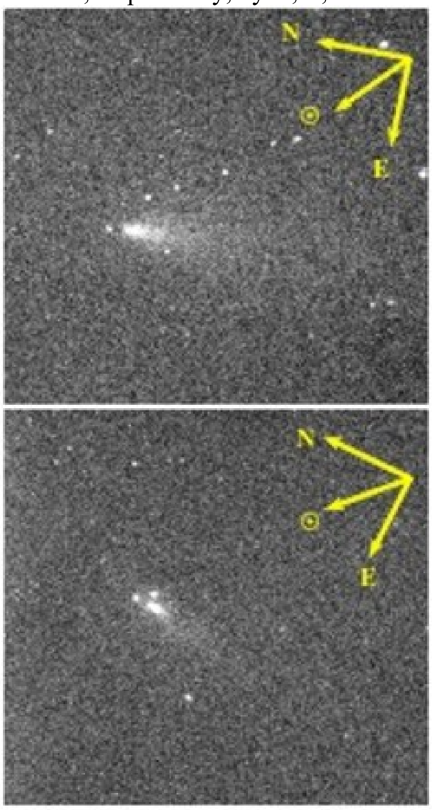

Figure 1. Components B (upper) and C (lower) of comet 73P/SW3. FOV of the stacked images is 16' × 16'.

3. Results and Discussion

When the reduction steps were conducting we found an inconsistency of ephemerides generated by the two established institutions, i.e. JPL-Horizon and the Minor Planet Center. In order to solve this problem, we carefully generate the ephemerides based on the specific component and checked them with the field stars taken on the data. This problem was also previously happened and noticed[7]. Since the comet has experienced close encounters and continuing fragmentations, the orbit of the comet changes significantly. Thus the ephemerides should be accurately generated again if new observation data become available. The ephemerides is strongly dependent to the new observation data, causing the above inconsistency.

We made use of daily stacked images to measure surface brightness profiles of components B and C, and also the associated field stars. Surface brightnesses of the comet components are measured radially from its center for about 20 arcsec when available. Figures 2 and 3 show the normalized R-band surface brightness profiles of the components B and C, respectively. The normalization was taken with respect to the brightness of the nucleus at the center. Filled circles (with broken lines show the slope) in both figures are denoted brightnesses of the components, while the associated field star by empty circles.

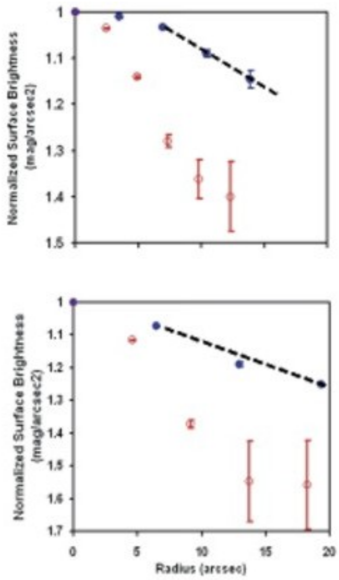

Figure 2. Daily normalized surface brightnesses of component B (filled circles with a broken-line slope) on 13 May (top) and 14 May 2006 (bottom). Empty circles are those for an associated field star.

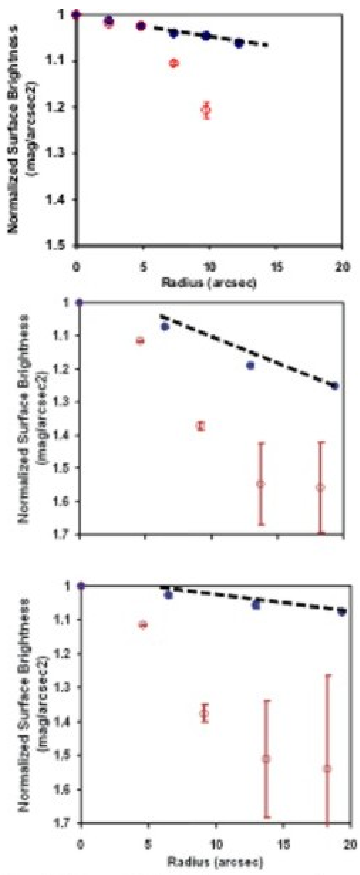

Figure 3. Same as Fig. 2 but for component C on 12 May (top), 13 May (middle), and 14 May 2006 (bottom).

In general surface brightness profiles of the components are shallower than those of the field stars. This indicates that nuclei of the components are indeed active. The flux from the nucleus dominated the inner coma, with the majority of the dust confined in a jet. The magnitude of the coma is estimated to be ~10%[13,14], contaminating the nucleus magnitude. Notice that the seeing condition influences the slope of surface brightness profile of the associated field star. The steeper the slope, the better the seeing condition.

It is evidence that the daily slope of the profile for each component of 73P/SW3 was not fairly stable, slightly vary from 12 to 14 May 2006. This qualitative inspection implies that the comas of 73P/SW3 components may not be in a steady state.

It is reasonable that non steady state brightness of the comas of 73P/SW3 can be explained by the fact that the components are actually fragments of a larger body. Moreover, it is generally known that comets belong to high porous object. The dust was ejected rather sporadically regarding its shape and rotation, while the fragmentation was indeed in progress[5]. For short time-span compared to its orbital period of 5.4 years, such as during our three days observation, it can be assumed that the brightness of each component was roughly stable about its mean value. By this assumption, principal parameters of dust production and mass-loss rates can be obtained.

Following a standard cometary model[15], dust production rate can be estimated using the well-known the $Af\rho$ formalism:

$$Af\rho\,(\alpha) = (4r^2\Delta^2/\rho)(F_{dust}/F_{solar}), \qquad (1)$$

where A is the wavelength-dependent albedo of the dust grains, f is the ratio of the cross section of the dust grains to the total field of view, ρ is the projected radius of the photometric aperture in cm. α is the solar phase angle. Thus, the quantity $Af\rho$ is the dust production rate. F_{dust}/F_{solar} is flux ratio between the emitting dust coma and the incoming one from the Sun.

We evaluated from the photometric calibration that the sky brightness near the comet was 15.4 mag/arcsec^2. If we adopt a ρ-value of 1.15 cm[16], hence regarding the heliocentric and geocentric distances given in Table 1, dust production rate of this comet can be obtained using Equation 1, that is about 24.7 cm. This value is appropriately consistent with 31.6 cm given recently[5], and one order of magnitude smaller than that of the upper limit of comet C/NEAT (2001 T_4)[17].

Dust production rate can then be used to estimate mass-loss rate Q_{dust} if the coma is about a steady state. Current models[14,17] provide the expression:

$$Q_{dust} = Af\rho\,(4a_{dust}v_{ej}\sigma)/(3p), \qquad (2)$$

where a mean dust grains radius a_{dust} of 1 μm, dust albedo p of 0.04, grain density σ of 1 g cm^{-3}, and ejection velocity (v_{ej}) consistent with water sublimation of $600\sqrt{r}$ m s^{-1}. Thus, we obtain the mass-loss rate of components of 73P/SW3, using Equation 2, was about 4.94 kg s^{-1}. This value stays close to the upper limit of the mass-loss rate of comet C/NEAT (2001 T_4)[17].

4. Conclusion

CCD photometry of major components B and C of comet 73P/SW3 have been conducted on 12 to 14 May 2006. Some principal physical parameters of the components have been derived. The surface brightness profiles play as important role for deriving magnitude of the background sky. By using the profiles, dust production ($Af\rho$) and mass-loss (Q_{dust}) rates of comet 73P/SW3 can be estimated. $Af\rho$ and Q_{dust} of comet 73P/SW3 was about 24.7 cm and 4.94 kg s^{-1}, respectively.

References

1. H. Boehnhardt, Split Comets, in *Comets II*, ed. M. C. Festou, H. U. Keller, & H. A. Weaver (Tucson: Univ. Arizona Press), 301, 2004.
2. J. Chen and D. C. Jewitt, On the Rate at which Comets Split, *Icarus*, **108**, 265, 1994.

3. J. Crovisier *et al.,* What Happened to Comet 73P/Schwassman-Wachmann 3?, *Astron. & Astrophys.*, **310**, L17, 1996.
4. H. Boehnhardt and H. U. Kaüfl, Comet 73P/Schwassmann-Wachmann 3, *IAU Circ*., **6274**, 1995.
5. D. G. Schleicher *et al.,* The Composition of the Interior of Comet 73P/Schwassmann-Wachmann 3: Results from Narrowband Photometry of Multiple Components, *Bull. Amer. Astron. Soc.*, **38**, 485, 2006.
6. H. A. Weaver *et al.,* Hubble Space Telescope Investigation of the Disintegration of 73P/Schwassmann-Wachmann 3, AAS/Division for Planetary Sciences Meeting Abstracts, **38**, 06.02, 2006.
7. T. Fuse *et al.,* Observations of Fragments Split from Nucleus B of Comet 73P/Schwassmann-Wachmann 3 with Subaru Telescope, *Publ. Astron. Soc. Japan*, **59**, 381, 2007.
8. P. L. Lamy *et al.,* The Sizes, Shapes, Albedos, and Colors of Cometary Nuclei, in *Comets II*, ed. M. C. Festou, H. U. Keller, & H. A. Weaver (Tucson: Univ. Arizona Press), 223, 2004.
9. T.-M. Ho *et al.,* 73P/Schwassmann-Wachmann 3-B Observed from the Optical Ground Station, *Astron. & Astrophys.*, **477**, 299, 2008.
10. M. Duncan *et al.,* Dynamical Evolution of Ecliptic Comets, in *Comets II*, ed. M. C. Festou, H. U. Keller, & H. A. Weaver (Tucson: Univ. Arizona Press), 193, 2004.
11. P. Massey, A User's Guide to CCD Reductions with IRAF, NOAO, Arizona, Tucson, 1997.
12. L. E. Davis, A Reference Guide to the IRAF/APPHOT Package, NOAO, Arizona, Tucson, 1989.
13. J. X. Luu and D. C. Jewitt, Near-Aphelion CCD Photometry of Comet P/Schwassmann-Wachmann 2, *Astron. Journal*, **104**, 2243, 1992.
14. M. D. Hicks and J. M. Bauer, P/2006 HR_{30} (Siding Spring): A Low Activity Comet in Near-Earth Space, *Astrophys. Journal*, **662**, L47, 2007.
15. M. F. A'Hearn *et al.,* Comet Bowell 1980b, *Astron. Journal*, **89**, 579, 1984.
16. S. C. Lowry *et al.,* CCD Photometry of Distant Comets, *Astron. & Astrophys*., **349**, 649, 1999.
17. J. M. Bauer *et al.,* An Optical Survey of the Active Centaur C/NEAT (2001 T_4), *Publ. Astron. Soc. Pacific*, **115**, 981, 2003.