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CCD Imaging Photometry of Comet 9P/Tempel 1

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Abstract.

We present results of our photometric monitoring campaign of comet 9P/Tempel 1. The observations started on February 7, 2005, and lasted until July 11, 2005. Images of the comet were obtained in R- and B-filters, with a CCD camera attached to the Schmidt telescope of the National Astronomical Observatory, Rozhen. The calibration of the images is based on standard stars from the USNO-A V2.0 catalogue. We describe the instrumentation, the process of data reduction, and the derived photometric parameters. The results are presented in form of maps of the surface brightness of the comet, and curves of its total brightness against the heliocentric distance. We discuss possible correlations between variations of the integral brightness and morphological changes in the coma.

1 Introduction

Comet 9P/Tempel 1 was the target of the Deep Impact mission. The primary science objective of the mission was to create a crater on the surface of the nucleus of comet Tempel 1. Analysis of the crater formation and of the excavated material yields valuable information on the physical structure of comets, on the chemical composition several meters below the cometary surface, where the material is pristine and contains important information on the formation of the Solar System. The Deep Impact spacecraft encountered comet 9P/Tempel 1 on July 4th, 2005.

During several months before and after the encounter regular observations of the comet have been conducted at the National Astronomical Observatory, Rozhen. Photometry of the comet before the impact was important for two purposes: (1) to derive the physical properties of the comet, and (2) to establish a reference for analysis of the observational features resulting from the impact.

2 Instrumentation, Observations and Data Reduction

The observations were conducted with the Schmidt telescope of the National Astronomical Observatory, Rozhen. The focal length of the telescope is 172 cm. The detector was a ST8 CCD camera. This imaging CCD has a full frame resolution of 1530×1020 pixels at 9 micrometers square, which yields a scale of 1.08 arcsec/px. Images were obtained with Bessel B and R filters.

The results presented in this paper are based on the R images only. A total of 217 images were obtained in several observational campagnes, covering the period from 2005, Feb 7 to 2005, Jul 11.Here we present a subset of 20 images, one representative image for each observational night. Detailed information on the selected images is presented in table 1.

Table 1. Observation data for comet 9P/Tempel 1.

Date, UT (1)	Days (2)	Exp (3)	mag (4)	r (5)	Δ (6)	STO (7)	PsA (8)	PlA (9)
05/02/08.08233	147.1	300	15.50	2.052	1.335	23.63	282.1	-7.3
05/02/09.12071	146.1	300	15.02	2.046	1.320	23.48	281.6	-7.4
05/02/10.13344	145.1	300	14.87	2.040	1.306	23.31	281.2	-7.5
05/03/12.88525	114.3	180	13.00	1.869	0.943	15.59	256.3	-10.8
05/03/15.07183	112.1	300	12.72	1.858	0.923	14.91	252.9	-10.9
05/03/17.05914	110.1	300	12.65	1.847	0.905	14.30	249.5	-11.0
05/03/17.89148	109.3	300	12.63	1.843	0.898	14.04	248.0	-11.1
05/04/10.83299	85.4	300	11.52	1.725	0.753	12.20	177.5	-10.4
05/04/12.83354	83.4	120	11.67	1.716	0.745	12.80	171.5	-10.2
05/04/13.79866	82.4	180	11.53	1.711	0.742	13.11	168.9	-10.0
05/05/02.03167	64.2	300	10.94	1.636	0.711	21.41	136.6	-6.8
05/05/02.77355	63.4	300	10.90	1.633	0.711	21.79	135.8	-6.6
05/05/03.89347	62.3	300	10.86	1.629	0.711	22.35	134.6	-6.4
05/05/05.93686	60.3	180	11.01	1.621	0.711	23.37	132.7	-5.9
05/05/08.81154	57.4	180	11.16	1.611	0.713	24.78	130.2	-5.2
05/05/10.00713	56.2	300	11.02	1.607	0.714	25.36	129.2	-4.9
05/06/04.86859	30.3	300	11.12	1.537	0.768	35.50	116.9	1.3
05/06/11.82490	23.4	180	11.46	1.524	0.793	37.35	115.2	2.8
05/07/07.83562	-2.5	300	11.30	1.506	0.913	41.21	110.9	7.0
05/07/10.85887	-5.6	60	12.93	1.507	0.929	41.39	110.5	7.3

(2) days to perihelion; (3) exposure time in sec
(5) heliocentric distance; (6) geocentric distance
(7) object phase angle as seen from observer's location (Sun-Object-Observer)
(8) the position angle of the extended Sun-object radius-vector
(9) angle between observer and object orbital plane

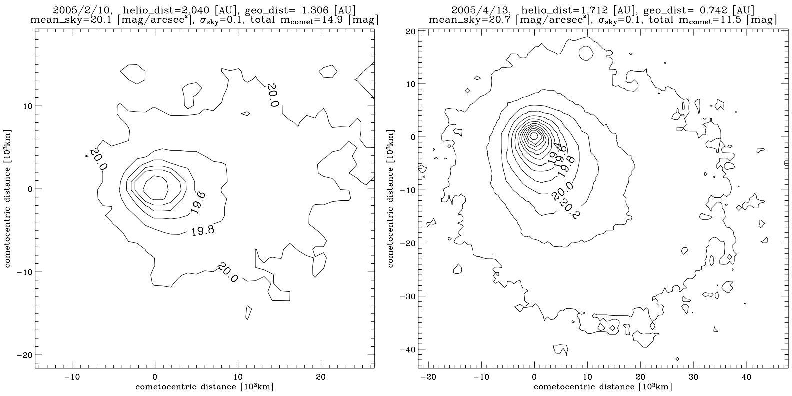

Figure 1. Surface brightness distribution of comet 9P/Tempel 1 derived from R-band images, obtained on Feb 10, and Apr 13, 2005. The labels at the contours show the brightness in magnitudes/arcsec^2 The value of the outermost isophote is $1 \times \sigma$ above the sky background. The origin of the coordinates is at the comet's photocenter. North is up, East to the left.

The calibration of the images was performed relative to the field stars. Photometric data for these stars were taken from the USNO-A V2.0 catalogue. The photometric accuracy of this catalogue is rather poor, about 0.4 magnitudes, but it's usage has the advantage to offer a large number of stars in the field of view, spread over a great magnitude range. Thus, an increase of the accuracy of our photometric calibration is reached by using a large number of standard stars. The number of standard stars is different for the different images, having a mean value of more than 100.

3 Results and Discussion

3.1 Surface brightness

Figures 1 and 2 show contour maps of comet 9P/Tempel 1, created from 4 calibrated R-band images. The tailward extension of the comet increase from about $20\,10^3$ km on Feb 10 to about $60\,10^3$ km on May 2, 2005. Over the same time interval the distance to the outermost contours in sunward direction increases from below $10\,10^3$ km to more than $20\,10^3$ km. The right panel in Figure 2 shows the surface brightness of the comet on July 7, three days after the impact. No indications for morphological changes can be seen in the brightness distribution which could be related to the impact. The results of the coordinated ground based observations show that several days after the impact the comet returns to its pre-impact state [4]. The elongated shape of the coma in our post-impact image is due to the greater phase angle as compared to the pre-impact images presented in this paper.

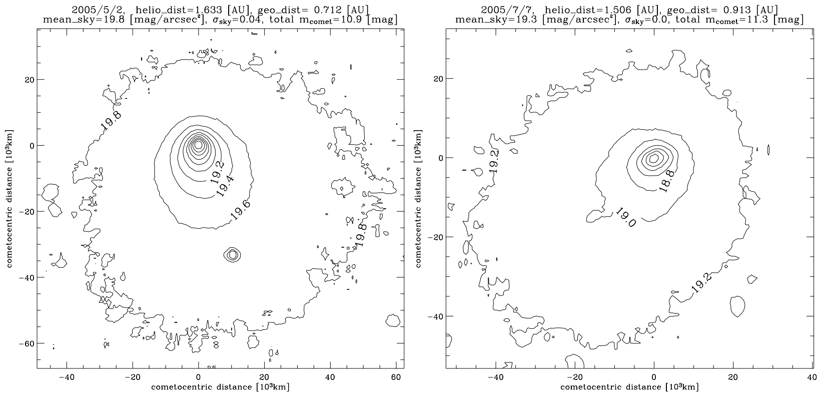

Figure 2. Same as in figure1 but for images of the comet obtained on May 2, and Jul 7, 2005.

3.2 Total brightness

The total magnitude of the comet is derived by integrating the brightness of the comet between $3 \times \sigma$ over the sky background and the peak value at the comet's photocenter. The results of this integration are presented in Figure 3. The left panel in this figure shows the variations of the total brightness of the comet as a function of the time to perihelion. The most remarkable feature in this light curve is the maximum of the comet activity about 50 days before perihelion. This is consistent with the results of narrowband photometry and spectral measurements reported by [1]. These authors show that the production rates of H_2O, CN and dust (Afρ) exhibit clear seasonal variations, with the peak production occurring about two months before perihelion [1]. A peak in activity of this comet, 80 to 60 days before perihelion, was found by [2], also. In previous apparitions this comet exhibits a sharp rise in brightness even at greater time intervals pre-perihelion [3]. The right panel in Figure 3 shows the total brightness dependence on the heliocentric distance. If we ignore the variations caused by phase changes, the total magnitude of a comet is given by [5]:

$$m = m(1,1) + 5\ \lg(\Delta) + 2.5\,n\ \lg(r), \qquad (1)$$

where m(1,1) is the magnitude of a comet at $r = \Delta = 1$ AU, and n is the photometric parameter giving the variation of the comet's activity with heliocentric distance. From a linear fit to the data presented in the right panel of Figure 3 we obtain following photometric parameters for comet 9P/Tempel 1: m(1,1) = 7.9, and n = 7.9 (=19.7/2.5). The found value for n is in the upper range of values reported for other comets [5]. This rather high value is consistent with the mean variation of the dust production on heliocentric distance derived for comet 9P/Tempel 1 by [2].

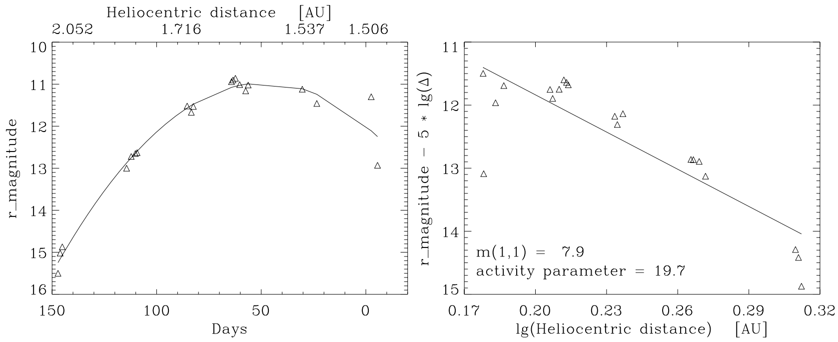

Figure 3. Left: R magnitudes versus time to perihelion (days to 2005-Jul-05). The light curve exhibits a maximum about 60 days before perihelion. Right: R magnitudes versus heliocentric distance. The R magnitudes are corrected for the geocentric distance of the comet. The parameter of activity, shown in the figure, indicates the slope of the brightness increase with decreasing heliocentric distance (see text for a discussion).

4 Conclusions

- R-band CCD images of comet 9P/Tempel 1 were obtained in the period Feb–Jul 2005. The calibrated images are presented in form of maps of surface brightness.
- The total magnitude of the comet and its photometric parameters are derived: m(1,1) = 7.9, and n = 7.9.
- The brightness of comet 9P/Tempel 1 exhibits a peak about 2 months before perihelion. This distinguished feature of the comet persists for the last several perihelion passages of the comet.
- The post-impact images do not show any morphological changes which could be caused by the impact.

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