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Thermal infrared and optical photometry of Asteroidal Comet C/2002 CE_{10}

Tomohiko Sekiguchi[a,*], Seidai Miyasaka[b], Budi Dermawan[c], Thomas Mueller[d], Naruhisa Takato[e,f], Junichi Watanabe[e], Hermann Boehnhardt[g]

[a] Hokkaido University of Education, 9 Hokumon, Asahikawa, Japan
[b] Tokyo Metropolitan Government, 2-8-1, Nishishinjuku, Shinjuku, Tokyo, Japan
[c] Department of Astronomy, Bandung Institute of Technology, Bandung 40132, Indonesia
[d] Max-Planck-Institute for Extraterrestrial Physics, Giessenbachstrasse, 85748 Garching, Germany
[e] National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo, Japan
[f] Subaru Telescope, 650 North A'ohoku Pl., Hilo, HI, USA
[g] Max-Planck-Institute for Solar System Research, Justus-von-Liebig-Weg 3, Göttingen 37077, Germany

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ABSTRACT

C/2002 CE_{10} is an object in a retrograde elliptical orbit with Tisserand parameter −0.853 indicating a likely origin in the Oort Cloud. It appears to be a rather inactive comet since no coma and only a very weak tail was detected during the past perihelion passage. We present multi-color optical photometry, lightcurve and thermal mid-IR observations of the asteroidal comet. With the photometric analysis in *BVRI*, the surface color is found to be redder than asteroids, corresponding to cometary nuclei and TNOs/Centaurs. The time-resolved differential photometry supports a rotation period of 8.19 ± 0.05 h. The effective diameter and the geometric albedo are 17.9 ± 0.9 km and 0.03 ± 0.01, respectively, indicating a very dark reflectance of the surface. The dark and redder surface color of C/2002 CE_{10} may be attribute to devolatilized material by surface aging suffered from the irradiation by cosmic rays or from impact by dust particles in the Oort Cloud. Alternatively, C/2002 CE_{10} was formed of very dark refractory material originally like a rocky planetesimal. In both cases, this object lacks ices (on the surface at least). The dynamical and known physical characteristics of C/2002 CE_{10} are best compatible with those of the Damocloids population in the Solar System, that appear to be exhaust cometary nucleus in Halley-type orbits. The study of physical properties of rocky Oort cloud objects may give us a key for the formation of the Oort cloud and the solar system.

1. Introduction

On February 2, 2002, the LINEAR project of the MIT Lincoln Laboratory in Socorro, USA, discovered an object approaching the Sun at about Jupiter's distance. Although of asteroidal appearance without sign of activity, it was classified as cometary object, C/2002 CE_{10}, based upon its retrograde comet-like orbit (see Table 1). Deep imaging of the object, obtained with the Subaru telescope around the period of closest approach to Earth, revealed a short faint tail of C/2002 CE_{10} (Takato et al., 2003). The faint tail may either be caused by very weak or by temporal cometary activity (sublimation of gas and release of embedded dust), or it may be due to a recent impact event of low, but non-zero occurrence probability. Since cometary coma activity in C/2002 CE_{10} has not been reported so far despite deep imaging attempts using the Subaru telescope's Prime Focus Camera: Suprime-Cam, and despite the object passed through perihelion well within the water sublimation limit, C/2002 CE_{10} may represent a transitional object between the population classes of comets and asteroids. This paper primarily presents an analysis of the nucleus properties of this object and the properties of dust tail with the Finson–Probstein analysis and no coma activity will be analyzed in a future paper.

The criteria for classification a minor body as asteroid or as comet are appearance (coma and tail versus point-like) and orbit parameters, namely the Tisserand parameter; T_J. The parameter T_J characterizing the dynamical link of minor bodies to the gravitational disturbance by planet Jupiter (Carusi et al., 1995) is used to differentiate the Halley-type comets ($T_J < 2$) from the Jupiter-family comets ($3 > T_J > 2$) and objects with $T_J > 3$ are generally considered to be dynamically asteroidal. It is given by $T_J =$

* Corresponding author.
E-mail address: sekiguchi.tomohiko@a.hokkyodai.ac.jp (T. Sekiguchi).

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Table 1
Orbital information of C/2002 CE_{10} (orbital elements taken from M.P.E.C. 2003-R41.

a: Semimajor axis	9.815 (au)
q: Perihelion distance	2.047 (au)
Q: Aphelion distance	17.585 (au)
e: Eccentricity	0.7915
i: Inclination	145.46 (°)
ω: Argument of perihelion	126.19 (°)
Ω: Longitude of the ascending node	147.44 (°)
M: Mean anomaly	0.0609 (°)
n: Mean motion	0.0320 (°/d)
Perihelion passage	2003, June 22.10 TT
Earth approach	2003, Sept 04.90 TT ($\Delta = 1.231$ au)
P: Orbital period	30.75 (years)
T_J: Jupiter Tisserand parameter	−0.853

$\frac{a_J}{a} + 2\{\frac{a}{a_J}(1-e^2)\}^{\frac{1}{2}}\cos(i)$, where a_J and a are the semi-major axis of Jupiter and the object (asteroid, comet or others) respectively, i and e are the object's inclination and eccentricity, respectively. Recently, this classification approach is challenged by the discovery of objects of cometary appearance in asteroid-like orbits, the so called "Main Belt Comets" (MBCs), and of objects of point-like appearance in cometary orbits. Jewitt (2005) assigned Halley-type orbit asteroids and inactive comets into a new group, the "Damocloids", named after asteroid (5335) Damocles. Meech et al. (2016) reported that Oort cloud comet C/2014 S3 (PANSTARRS) shows a very weak level of cometary activity and S-type asteroid spectra with a silicate absorption feature around 1 μm wavelength, indicating that the comet may be physically similar to an inner main belt rocky S-type asteroid.

The T_J-value of C/2002 CE_{10} is −0.853 (Table 1), indicating in object in an Halley-type orbit. This result together with no coma appearance (Takato et al., 2003) suggests that C/2002 CE_{10} might be either an extinct comet or a quasi-inert object that has been eject from the Oort Cloud, giving us a good opportunity to investigate basic physical characteristics of an Oort Cloud object. Furthermore, the results may provide insights in the surface aging of minor bodies and the link between asteroids and comets. After an outline of the observations and data reduction performed, we present results on physical properties of C/2002 CE_{10}: rotation period, axis ratio, dimension, albedo and color taxonomy. In the final section of the paper we discuss, based upon our findings, the relation of C/2002 CE_{10} with other minor body populations in the solar system.

2. Observations and data reduction

C/2002 CE_{10} was observed in September and October 2003 in the visible and thermal infrared wavelength ranges.

2.1. Optical observations

The *BVRI* observations of C/2002 CE_{10} were carried out on a photometric night, 2003-Oct-3, using the 1.05 m Schmidt telescope at the Kiso observatory, Japan. The CCD camera used has 2048 × 2048 pixels with pixel size of 24 μm and covers a field of view (fov) of 50′ × 50′. It is well-suited for time-resolved observations of Solar System objects using an adequate number of reference stars in the fov for differential photometry of moving targets. *B* and *V* exposures were taken through Johnson-type filters, *R* and *I* exposures through Cron-Cousins-type filters. The multi-color photometric observations were embedded in the series of *I*-band exposures for lightcurve sampling (i.e. –*I*–*I*–*B*–*I*–*V*–*I*–*R*–*I*–*I*– sequence) in order to follow and compensate for brightness variations due to non-spherical shape or albedo in combination with the rotation motion of the object. The photometric parameters of the telescope-instrument combination and of the atmosphere were determined by measuring various standard star fields at different airmasses Lightcurve observations were performed between 2003-Oct-2 and 2003-Oct-8, occasionally with thin clouds. In order to minimize the fluctuation of sky conditions and scattering of lunar light by thin cloud, *I*-band filter was used. The standard calibration frames (CCD bias and flatfield exposures) were also obtained as needed. Table 2 summarizes the observing geometry, exposures types and sky conditions for the C/2002 CE_{10} observations.

Differential photometry between C/2002 CE_{10} and comparison stars in the fov is applied. In order to reduce the influence of possible variable stars on the photometric results, to gain a high signal-to-noise ratio, and to ensure the confidence of the measurements and a good coverage for the lightcurve analysis, we selected comparison stars according to the following criteria: (1) as many as possible, (2) as bright as possible, (3) with maximum exposure level below 40,000 ADU to stay well inside the linearity range of the CCD detector, (4) visible and measurable in the whole set of images of a single night. Daily extinction and zero-point parameters were derived from the exposures of the Landolt standard star fields and by measuring the comparison stars in the object fov. Magnitudes of comparison stars are derived per night series using photometric data of the standard stars at the same airmasses.

2.2. Thermal mid-IR observations

Thermal observations of C/2002 CE_{10} were carried out on 2003-Sep-6. *N*-band images were taken in service mode with the 3.6 m telescope and the TIMMI2 instrument at the La Silla site of the European Southern Observatory ESO in Chile. TIMMI2, the Thermal Infrared Multi-Mode Instrument 2 (Käufl et al., 2003) has a 240 × 320 pixel SiAs detector, and it is operated at 6.5–7.5 K. The image scale used for our observations was 0.″202 pixel^{-1} which offers a field of view of 64″ × 48″ on the sky. The *N*1-filter of the TIMMI2 instrument (with effective central wavelength of 8.6 μm) was chosen because of an expected advantageous sensitivity for the observations of C/2002 CE_{10}. The individual TIMMI2 detector integration time (DIT) was set to 20.8 milliseconds. The observations were performed as a series of 4 exposures using secondary mirror chopping and telescope nodding as follows: On target position 3 DIT readouts were taken at two chopping positions offset in North-South direction by 10″. This chopping-integration cycle was repeated 60 times. Thereafter, the telescope was moved 10″ in East-West direction and 80 chopping-integrations were repeated as before. An exposure series of C/2002 CE_{10} were made with a total integration time of 2396.16 sec. During the observations of C/2002 CE_{10} the sky conditions were photometric with an average seeing of 1″.

The basic reduction for C/2002 CE_{10} data makes use the TIMMI2 reduction pipeline (Relke et al., 2000; Siebenmorgen et al., 2004). The pipeline procedure automatically subtracts the pairs of "chopped" images and co-adds all the frames of the whole chopping/nodding sequence (equivalent to one exposure series). Hence, the resulting image shows 2 positive and 2 negative sub-images of C/2002 CE_{10}. The two negative ones are multiplied by −1 and all sub-images of C/2002 CE_{10} are shifted such that the pixel positions of the brightness center in the sub-images overlap. At the end the shifted subimages are coadded to the result frame of the respective exposure series. The TIMMI2 data are flux-calibrated using observations of standard star HD156277 which were obtained during the same night applying the same filter setup and observing mode as for the observations of C/2002 CE_{10}. An airmass correction factor of 7 % is applied to compensate for the different airmasses of the standard star (airmass = 1.29) and target observations (airmass = 1.615) (see: http://www.ls.eso.org/sci/facilities/lasilla/instruments/timmi/Reports/oschuetz/Projects/T2_Extinc/TIMMI2_extinc.html) and Schütz and Sterzik (2005)). Because of the different spectral types of the standard star (K2-III) and the