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Observations of Comets C/2007 D1 (LINEAR), C/2007 D3 (LINEAR), C/2010 G3 (WISE), C/2010 S1 (LINEAR), and C/2012 K6 (McNaught) at large heliocentric distances

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ABSTRACT

Photometric and spectroscopic observations of five nearly parabolic comets with eccentricity larger than 0.99 at heliocentric distances greater than 4 AU were performed. No molecular emission was observed for any studied comet and the entire cometary activity in all cases was attributed to dust production. Upper limits of the gas production rates for the main neutral molecules in the cometary comae were calculated. The derived values of dust apparent magnitudes were used to estimate the upper limit of the geometric cross-section of cometary nuclei (upper limits of radii range from 2 km to 28 km). Due to the poor sublimation of water ice at these distances from the Sun, other mechanisms triggering activity in comets are discussed.

1. Introduction

As already pointed out by Roemer (1962), bright comets are the basic source of our knowledge about the physics of these celestial objects. The bright comets are mostly small objects observed at relatively short heliocentric distances during their favorable configuration relative to the Sun and the Earth. This fact means that the typical properties derived for them are not necessarily identical with the properties of larger objects observed at larger distances.

Progress in the development of the technologies of modern light detectors and a participation of a number of large telescopes has led to a great increase in the number of observations of distant comets with perihelion distances larger than 4 AU. Unfortunately, the studies of the comets, which are active beyond the orbit of Jupiter, are episodic. Only a small number of comets and centaurs active at large heliocentric distances have been studied (Korsun and Chorny, 2003; Bauer et al., 2003; Tozzi et al., 2003; Jewitt, 2009; Lowry and Fitzsimmons, 2005; Meech et al., 2009; Korsun et al., 2008, 2010; Mazzotta Epifani et al., 2010, 2014; Shi et al., 2014; Rousselot et al., 2014). Differences in the levels of activity, in the relative abundances of dust and different coma morphologies have been observed. In addition, the differences between the individual objects were large even for similar geometrical conditions.

Analysis of observations of distant comets allows us to study various physical mechanisms triggering the activity at large heliocentric distances. To explain the cometary activity at large heliocentric distances a few mechanisms (see, e.g., review by Meech and Svoren, 2004; Gronkowski, 2005) have been proposed. The most popular sources of the energy required to explain the activity are: the sublimation of more volatile compounds like CO or CO_2 (Houpis and Mendis, 1981; Prialnik and Bar-Nun, 1992; Hughes, 1992), the transition phase between amorphous and crystalline water ice (Prialnik, 1992; Gronkowski and Smela, 1998; De Sanctis et al., 2002), polymerization of HCN (Rettig et al., 1992), and the annealing of amorphous water ice (Meech et al., 2009).

Observations of distant comets by different methods (e.g., photometry, spectroscopy, and polarimetry) can be used to determine the sizes of cometary nuclei (Svoren, 1983), to study the brightness evolution and dust composition of cometary comae (Meech et al., 2009), as well as to detect gas emissions above the reflected solar

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continuum (Larson, 1980; Cochran et al., 1980, 1982; Bockelée-Morvan et al., 2001; Rauer et al., 2003; Cook et al., 2005; Korsun et al., 2006, 2008).

To enlarge the set of the comets studied at relatively large heliocentric distances, in Sections 2 and 3 we describe the observations and their analysis five comets with perihelia near or, mostly, beyond the snow line. The determined physical characteristics are given in related tables and the relations between some parameters are shown in several figures. Observations of the comets were performed utilizing the 6-m telescope of the Special Astrophysical Observatory and the 0.6-m telescope of the Peak Terskol Observatory, both located in Russia.

2. Observations and reduction

The data set of distant active comets presented in this paper was obtained within the period from 2008 to 2014. The images and spectra were obtained during several observing runs at two different sites: the Special Astrophysical Observatory (SAO RAS, Russia) and the Peak Terskol Observatory. We obtained images and spectra for a number of comets within the framework of a program of optical spectroscopic and photometric investigations of distant active comets. Table 1 summarizes the data and the geometric circumstances at the times of the observations. A general description of the comets and orbit planes is presented in Fig. 1.

2.1. Observations at 6 m telescope of SAO RAS

The observations of Comets C/2007 D1 (LINEAR), C/2007 D3 (LINEAR), C/2010 G3 (WISE) and C/2010 S1 (LINEAR) were made with the 6-m telescope of the Special Astrophysical Observatory (SAO RAS). The heliocentric distances of the comets in the observation period ranged from 4.22 AU to 8.93 AU. More detailed information about the observations of the comets is given in Table 1. The observations were made using the universal SCORPIO and SCORPIO-2 focal reducers mounted in the primary focus of the 6-m BTA telescope of the SAO RAS (Afanasiev and Moiseev, 2011). We used the photometric and spectroscopic modes of the focal reducers. An EEV 42–40 chip of 2048 × 2048 pixels was employed as the detector with the reducer SCORPIO. The SCORPIO-2 device was used with a CCD radiation detector E2V 42–90. The size of an image was 2048 × 2048 pixels. The image scale was 0.18 arcsec/pix and the full field of view of the detectors was 6.1 × 6.1 arcmin.

We applied 2 × 2 and 2 × 1 binning to the photometric and spectroscopic frames respectively during the observations. The reduction of the raw data including bias subtraction and flat-field corrections was made. The telescope was tracked on the comet to compensate its apparent motion during the exposure. The frames with morning sky were obtained to create the averaged flat-field image for the photometric data, while a smoothed spectrum of an incandescent lamp was observed for the spectral data. We used routine sky (http://www.astro.washington.edu/docs/idl/cgi-bin/getpro/library01.html?SKY) of the IDL library (Goddard Space Flight Center) to calculate the sky background count (Landsman, 1993). Observed frames were cleaned from cosmic events. The recorded events were removed automatically when we computed a composite image from the individual ones. For this purpose, the robust routine of IDL library (http://www.astro.washington.edu/docs/idl/cgi-bin/getpro/library30.html?ROBOMEAN) was applied to the stacked images.

The spectroscopic data were obtained using the VPHG1200B grism (in 2008) and VPHG940@600 grism (in 2011) in combination with a long, narrow-slit mask having dimensions of 1.0″ × 6.1′. The spectral resolution of the spectra was defined by the width of the slit and was about 5 Å. The photometric data of the comets were obtained in Johnson–Cousins broadband filters *BVR*. We obtained the observations in 2008 in a crowded field with seeing being stable to about 1.8″, while the observing conditions were much better in 2011 (seeing ~1.3″). All nights were photometric.

We observed the spectrophotometric standard stars BD+28d4211, HZ44, and GD108 (Oke, 1990) to make the absolute calibration of the observed spectra and photometry of the comets at 6-m telescope SAO RAS. To perform an absolute flux calibration of the comet images obtained at 0.6 m telescope of Peak Terskol Observatory, the field stars were used. The background stars were identified on a comet image. We selected all bright stars as photometric standards with the signal-to-noise ratio greater than 100. The stellar magnitudes of the standard stars were taken from the catalog NOMAD (Zacharias et al., 2005) (http://vizier.u-strasbg.fr/viz-bin/VizieR). We used the correspondence between instrumental and catalogue magnitudes in each filter to derive the transformation coefficient from the instrumental to the *B*, *V*, and *R* system. After studying the star in the field of view, we used for our study only those standard stars, which were not variable. For

Table 1
Log of observations.

Object	Date, UT	Exp. times (s)	Orb.[a]	r^b, AU	Δ^c, AU	Phase angle, (°)	Filter/spectrum	Telescope
C/2007 D1 (LINEAR)	2008-03-14	7 × 60	O	8.93	7.94	1.0	*V*	6-m SCORPIO
		5 × 60					*R*	
		4 × 900					Spectra	
C/2007 D3 (LINEAR)	2008-12-04	7 × 60	O	6.62	6.51	8.6	*V*	6-m SCORPIO
		4 × 900					Spectra	
C/2010 G3 (WISE)	2011-03-29	6 × 90	O	5.60	5.19	9.7	*V*	6-m SCORPIO-2
		6 × 60					*R*	
		4 × 900					Spectra	
C/2010 S1 (LINEAR)	2011-11-25	10 × 30	I	7.00	6.52	7.3	*B*	6-m SCORPIO-2
		7 × 30					*V*	
		5 × 30					*R*	
		4 × 900					Spectra	
C/2012 K6 (McNaught)	2014-02-13	10 × 180	O	4.16	3.52	11.3	*B*	0.6-m Zeiss
		11 × 120					*V*	
		11 × 120					*R*	
	2014-02-23	7 × 180	O	4.22	3.45	9.4	*B*	0.6-m Zeiss
		5 × 180					*V*	

[a] Orbital arc: I is inbound leg of orbit (pre-perihelion); O is outbound leg of orbit (post-perihelion).
[b] *r* is heliocentric distance.
[c] Δ is geocentric distance.