

Spectra of the comet C/2002 T7 (LINEAR)

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We present the results of spectral observations of comet C/2002 T7 (LINEAR) carried out at the 1-m Zeiss-1000 telescope of the Special Astrophysical Observatory (Russia). The spectra were obtained within the 3500–7500 Å wavelength range on November 13, 14, and 21, 2003, before the perihelion passage, when heliocentric and geocentric distances of the comet were about 2.7 AU and 1.8 AU, respectively. Spectra do not show any emission features from the strongest cometary emissions of the CN, C₂, and C₃ molecules. The normalised spectral gradient of reflectivity is 2.8% per 1000 Å and 5.4% per 1000 Å for November 14 and 21, respectively. The $Af\rho$ parameter, which characterises the dust production rate in the comet, is on average about 800 cm. Comet C/2002 T7 (LINEAR) can be classified as belonging to the group of dusty comets

Key words: comets: individual: C/2002 T7 (LINEAR)

INTRODUCTION

Comets are the unique objects for studying pristine material from which our Solar system was formed. As a consequence of their dynamical properties, comets spend almost all their lifetime in the cold outer regions of our planetary system. From this point of view, dynamically new comets are the best opportunity for such research since they are on their first trip into the inner part of the Solar system. Their material has been processed less than that of short-period comets. Therefore, observations comparing long- and short-period comets, which are believed to have had different places of origin, allow us to search for diversity in comets. Comet C/2002 T7 (LINEAR) (hereafter C/2002 T7) was discovered on October 14, 2002 at the heliocentric distance of 6.9 AU by the LINEAR (Lincoln Laboratory Near-Earth Asteroid Research) survey as an asteroidal object with the magnitude as bright as 17.5^m [3]. However, on October 28–29, this object appeared as ‘very slightly diffuse’ with the total magnitude of 17^m. Comet C/2002 T7 is a dynamically new object coming from the Oort cloud for the first time [15]. This type of comet is considered to be composed of primitive material that has not undergone considerable thermal processing. The comet moved in a hyperbolic orbit with the orbital param-

eters such as the eccentricity $e = 1.000485655$ and the inclination $i = 160.583^\circ$ taken from the website HORIZONS¹. The comet reached its perihelion on April 23, 2004 at the distance $q = 0.615$ AU from the Sun.

Comet C/2002 T7 was a fairly bright object, but the highest level of the observed activity was at its closest position to the Sun, i.e. near its perihelion in April–May 2004, about 2^m. Since it was quite bright for such a long time, numerous spectra of the comet were obtained in the range from ultraviolet (UV) through the visible and infrared (IR) domains and up to the radio range. The spectral observations of C/2002 T7 in the visible range were carried out by several scientific groups [6, 20, 24]. The authors reported the presence of emission species in spectra of the cometary coma. The results of spectroscopic studies of molecular features and isotope ratios with high resolution were presented by [23]. From the measurements of the line intensities in the spectra of comet C/2002 T7, the ratio of D/H in cometary water and isotopic ratio ¹⁶OH/¹⁸OH were derived which turned out to be close to the ratios evaluated in other comets, including the comet C/1995 O1 (Hale-Bopp) [19].

A’Hearn et al. [1] have classified comets into two groups of ‘typical’ comets and the ‘depleted’ comets,

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¹<https://ssd.jpl.nasa.gov/horizons.cgi#top>

Table 1: Log of observations of the comet C/2002 T7 (LINEAR).

Date UT, Nov 2003	r , AU	Δ , AU	α , deg	Sp. range, Å	ΔM
13.86	2.775	1.840	8.31	5500–7500	0.2701
14.79	2.762	1.824	8.01	3500–5500	0.0013
21.78	2.672	1.714	6.46	3500–5500	0.0240

showing a low abundance of the carbon-containing molecules C_2 and C_3 . The spectra of comet C/2002 T7 obtained on November 17 and 25, 2003 (at the heliocentric (r) and geocentric (Δ) distances approximately 2.7 AU and 1.7 AU, respectively) with the 2.6-m Shain telescope of the Crimean Astrophysical Observatory showed a strong continuum, bright CN emission, C_2 Swan bands of moderate intensity, and C_3 emission at the seeing limit [20]. For the same period of observations, Borysenko et al. [5] did not detect any emissions in the spectrum of the comet. It is likely that this discrepancy is caused by different telescopes and equipment used for observations. Weiler [24] found the production rates of C_3 and C_2 molecules from the spectral observations at $r = 1.20$ AU and $\Delta = 1.03$ AU and made the conclusion that the comet C/2002 T7 clearly falls within the ‘typical’ range.

In this work, we present the results of spectral observations of comet C/2002 T7 (LINEAR) performed at the pre-perihelion heliocentric distance of about 2.7 AU.

OBSERVATIONS AND DATA

PROCESSING

Spectral observations of comet C/2002 T7 were carried out with the 1-m telescope Zeiss-1000 of the Special Astrophysical Observatory of the Russian Academy of Sciences (SAO RAS) over three nights on November 13, 14, and 21, 2003. Optical spectra were obtained with the Universal Astronomical Grating Spectrograph (UAGS) attached to the primary focus of the telescope. The two-dimensional spectrograms were recorded on the EEV 42-20 CCD chip. The dimension of the used CCD is 2048×2048 pixels with a pixel size of $13.5 \times 13.5 \mu\text{m}$. The slit with the sizes of $4'' \times 3.5'$ was placed on the nucleus position in the sky and oriented along the comet’s motion. The obtained spectra cover the wavelength range 3500–7500 Å and have spectral resolution about 5 Å. But, it should be noted that in the analysis, we used the range from 4000 Å due to a low signal-to-noise ratio and a low sensitivity of the CCD-chip within the

3500–4000 Å wavelength interval. The heliocentric (r) and geocentric (Δ) distances and the phase angles (α) at which comet C/2002 T7 was observed are presented in Table 1. This table also includes the wavelength ranges (Sp. range) covered by the spectrum and the difference between the air masses of the comet and the observed standard star ΔM .

The specialised software packages in the IDL² environment developed by the authors were used to perform the primary reductions of the observational data, including bias subtraction, flat fields correction, cleaning the frames from cosmic ray traces, the sky background subtraction, the spectral wavelength calibration, and preparation of the images for processing. In order to estimate the level of sky background, we used the parts of the image free of the expected cometary emissions. The wavelength calibration was made by fitting a polynomial function of the second degree to the spectrum of a He-Ne-Ar lamp. On this step the correction for Doppler shift was made. The spectral response of the used telescope-instrument configuration and the spectral dependence on the atmospheric extinction were obtained using the spectrophotometric standard stars G191-B2B (for observations on November 14 and 21) and BD+28 4211 (for observations on November 13) [18]. To increase the signal-to-noise ratio of the data, we coadded the available spectra and summed the counts across the entire range of the spatial dimension without trying to preserve the spatial information for each night of observations. Thus, we formed one-dimensional spectra.

The observed intensities in the cometary spectrum were converted to the radiation fluxes according to the following expression:

$$F_c(\lambda) = F_{st}(\lambda) \frac{I_c(\lambda)}{I_{st}(\lambda)} p^{-\Delta M}(\lambda),$$

where $F_c(\lambda)$, $F_{st}(\lambda)$, $I_c(\lambda)$, and $I_{st}(\lambda)$ are absolute fluxes and observed intensities of the comet and the standard star, respectively; $p(\lambda)$ is the spectral transparency of the Earth atmosphere taken from [11]; ΔM is the difference between the air masses of the comet and the standard.

²<http://www.itvis.com/idl>

RESULTS

To reveal possible molecular emissions, we studied the energy distribution in the obtained one-dimensional spectra of comet C/2002 T7. Qualitative analysis did not show significant molecular emissions in the cometary spectra. Therefore, to isolate the emission spectrum, we subtracted the fitted continuum from the observed spectrum of the comet. The level of continuum was estimated using the solar spectrum. A high-resolution spectrum of the Sun [16] was convolved with an appropriate instrumental profile to the cometary spectrum resolution and normalised to the flux of the comet. The reddening effect was also taken into account. Figure 1 presents the observed spectra of comet C/2002 T7 and the scaled solar spectrum for three dates of the observations. Detailed analysis of the emission spectra of the comet did not reveal the presence of significant emission features from the cometary molecules CN, C₃, or C₂. The general trend of the obtained cometary spectra on November 14 and 21 is in a good agreement with those presented in [5]. The authors did not also reveal any molecular emission features in the spectrum of comet C/2002 T7 obtained on November 24, 2003.

The energy distribution in the continuum spectrum of the comet is characterised by the so-called reddening effect, i.e. the increase in the light scattering efficiency with increasing the wavelength: $S(\lambda) = F_{com}(\lambda)/F_{Sun}(\lambda)$, where $F_{com}(\lambda)$ and $F_{Sun}(\lambda)$ are the radiation fluxes from the comet and the Sun, respectively. The normalised spectral gradient of the reflectivity for the dust can be written as follows:

$$S' = \frac{2 \cdot 10^5}{\lambda_2 - \lambda_1} \frac{S_2 - S_1}{S_2 + S_1},$$

where $S_i = F_{com}(\lambda_i)/F_{Sun}(\lambda_i)$ and $\lambda_2 > \lambda_1$. Applying this formula to our data, we derived the values S' , which are presented in Table 2. There are also the wavelength ranges in which the parameter S' was obtained ($\Delta\lambda$). The derived values of the normalised reflectivity gradient are comparable to the value of 3% per 1000 Å found for the comet C/2002 T7 between the BC and RC cometary continuum bands on February 21, 2004 by Rosenbush et al. [20]. However, it should be noted that these authors derived the spectral gradient from the photometric observation.

Studying the scattering properties of grains in nine comets (8 of which are short-period comets), Jewitt and Meech [10] found that the reflectivity gradient varies from 5% to 18% per 1000 Å in the optical wavelength range, and the averaged value is about 13%/1000 Å. Earlier research of 17 comets [17] found the spectral gradient equal on average to about 7% per 1000 Å. Kulyk et al. [13] studied the dust properties in distant comets and defined that the reflectivity gradient within the VR spectral

range is 7%/1000 Å and in the BV domain it is 12%/1000 Å. On the other hand, investigation of 18 ecliptic comets [22] showed that the mean value of the spectral gradient is 22%/1000 Å in the 4400–5600 Å range. Thus, the values of the spectral gradient for comets range from 5 to 22%/1000 Å, and our mean value $\sim 4\%/1000 \text{ \AA}$ is close to the lower limit of the reflectivity gradients seen for most comets.

Since there is a wide dispersion of the spectral gradient values, it is important to compare our data with those obtained for other comets at similar heliocentric distances, especially long-period ones. For example, Korsun et al. [12] and Ivanova et al. [8] found higher values of the spectral gradient, 20.7%/1000 Å for the comet C/2010 X1 (Elenin) and 21%/1000 Å for the comet C/2014 A4 (SONEAR), respectively. Bonev et al. [4] and Ivanova et al. [9] obtained slightly lower than previous results, but significantly higher than our results: 15% and 17% per 1000 Å for the comets C/2000 WM1 (LINEAR) and C/2012 J1 (Catalina), respectively. Meanwhile, the reflectivity gradient for the comet C/2004 Q2 (Machholz) varied from 0.6% to 9% per 1000 Å [14].

Table 2: The normalised spectral gradient of reflectivity for dust in the comet C/2002 T7 (LINEAR).

Date	$\Delta\lambda, \text{ \AA}$	$S', \% \text{ per } 10^3 \text{ \AA}$
14 Nov 2003	4845–5260	2.8 ± 1.6
21 Nov 2003	4845–5260	5.4 ± 2.3

Another parameter that characterises the dust component of comets is $Af\rho$ [2]. This parameter describes the level of dust production rate in a comet, typically expressed in cm, and allows one to compare the results for various comets observed in different epochs with different equipment. To calculate this parameter, we used the following equation:

$$Af\rho = \frac{(2r\Delta)^2 F_{com}}{\rho F_{Sun}} \quad (1)$$

where r and Δ are heliocentric (in AU) and geocentric (in cm) distances of the comet, ρ is the aperture size (in cm), F_{com} and F_{Sun} are fluxes of the comet and the Sun, respectively. In photometric observations, Eq. (1) is usually used for a circular aperture, while spectra are obtained with a slit. Therefore, we adopted corresponding corrections. To minimise the effect of possible molecular emissions, we computed $Af\rho$ in the blue (BC) and green (GC) bands of a cometary continuum. For this purpose, the spectra of comet C/2002 T7 and the Sun were convolved with the corresponding filters [21]. The results of our calculations for $\rho = 2.1 \times 10^4 \text{ km}$ are presented

in Table 3. The parameters of corresponding filters such as the central wavelength (λ_{eff}) and the full width at the half maximum ($\Delta\lambda$) are also indicated.

The obtained values of the $Af\rho$ parameter are in good agreement with the corresponding value derived in [5] almost the same observational period, 846 cm at $r = 2.7$ AU. Note that Rosenbush et al. [20] obtained $Af\rho = 370$ cm at much smaller heliocentric distance from the Sun, $r = 1.36$ AU. Such large differences in the dust production rate can be explained by the non-stationary processes which were characteristic for the comet C/2002 T7 [7].

Table 3: Dust production rate $Af\rho$ (in cm) in comet C/2002 T7 (LINEAR).

Filter	$\lambda_{eff}/\Delta\lambda, \text{\AA}$	Nov 14	Nov 21
BC	4845/60	741±27	716±27
GC	5260/56	834±29	872±29

CONCLUSIONS

Spectra of comet C/2002 T7 (LINEAR) were obtained on November 13, 14, and 21, 2003 at the 1-m telescope of SAO RAS when the comet was at the heliocentric distance ~ 2.7 AU and the geocentric distance ~ 1.8 AU. The obtained spectra cover the wavelength range between 3500 Å and 7500 Å and have the spectral resolution ~ 5 Å. We did not detect any significant molecular emissions. The normalised spectral gradient of reflectivity is estimated at the level of 2.8% per 1000 Å and 5.4% per 1000 Å for November 14 and 21, respectively. These values agree with the similar results for other comets at the observed range of distances. The $Af\rho$ parameter, which characterises the dust production rate in the comet, varies within the range 716–872 cm. These findings confirm the assumption, made by Rosenbush et al. [20], that C/2002 T7 (LINEAR) can be classified as belonging to the group of dusty comets.

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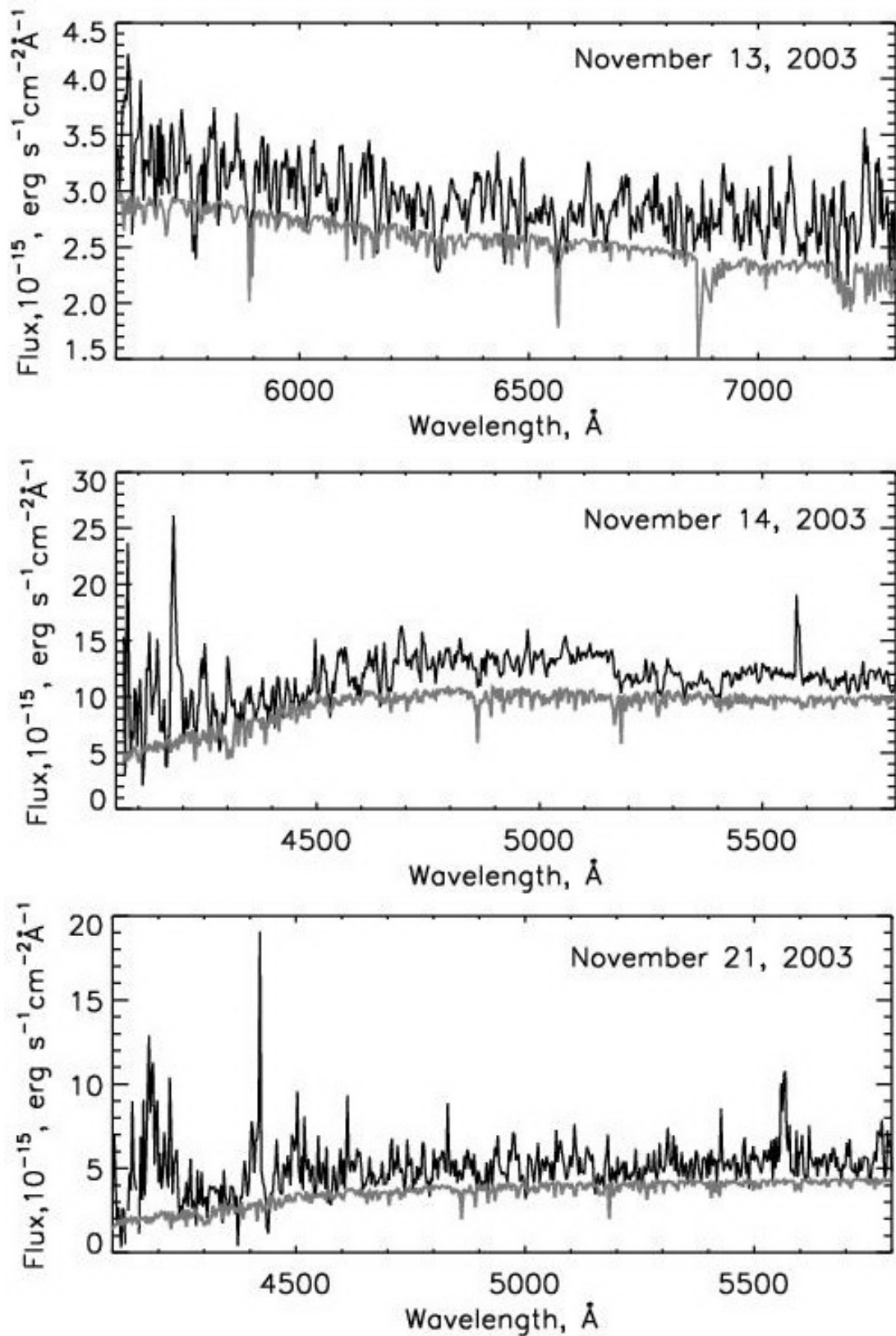


Fig. 1: Spectra of comet C/2002 T7 (LINEAR) obtained on November 13, 14, and 21, 2003. Black line is energy distribution in the observed spectrum of the comet, and gray line is the scaled solar spectrum taken from [16].