ON CHANGES IN THE SPECTRA OF COMET C/1999 S4 (LINEAR) ON JULY 22–28, 2002

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Some spectra of Comet C/1999 S4 (LINEAR) are obtained with the UAGS spectrograph (long slit and CCD) installed on the 1-m Zeiss reflector of the SAO RAS (the Northern Caucasus, Nizhny Arkhyz) on July 23/24, 26/27, and 27/28, 2000. Sophisticated identification of emission lines in the spectra of Comet C/1999 S4 (LINEAR) is made. Emission lines of the molecules C_2, C_3, CN, NH, CH, NH_2, CO^+, H_2O^+, and others were identified in the spectra of Comet C/1999 S4 (LINEAR) derived on July 22/23, 2000 before splitting the cometary nucleus. Analysis of the CCD spectra obtained on July 27/28, 2000 reveals very weak emission lines superposed on the solar reflection spectrum, unlike the case of spectra obtained with the same instrument on July 22/23. From analysis of the surface brightness profile of C_2 along the slit, the velocity of expansion of two secondary fragments ($V = 10$ km/hr) and energy of fragment expansion ($E = 8.7 \cdot 10^{15}$ erg) are estimated. The luminescence cometary continuum is detected by a level of 26% at 5000 Å in the spectra of the comet. Possible mechanisms of nucleus splitting are discussed.

INTRODUCTION

Comet C/1999 S4 (LINEAR) belongs to a rare type of splitting comets. There are more than 30 comet nuclei of which were destroyed by action of poorly understood or unknown physical mechanisms. The physical mechanism of the unexpectedly destroyed nucleus of Comet C/1999 S4 (LINEAR) and its full disappearance before observers' eyes are one of the great riddles of comets. Therefore, every observation and especially spectral ones, obtained during the comet splitting process, is of considerable importance in deriving important information on physical and chemical properties of inner sheets of cometary icy nuclei and on early stages of solar nebula if, how are thought, comets are primitive substance of the protosolar nebula.

OBSERVATIONS AND DATA REDUCTION

The spectra of Comet C/1999 S4 (LINEAR) were obtained with the UAGS spectrograph (long slit and CCD) installed on the 1-m Zeiss reflector of the Special Astrophysical Observatory of the Russian Academy of Sciences (SAO RAS) (the Northern Caucasus, Nizhny Arkhyz) on July 23/24, 26/27, and 27/28, 2000. Detailed identification of emission lines in the spectra of Comet C/1999 S4 (LINEAR) was made. Emission lines of the molecules C_2, C_3, CN, NH, CH, NH_2, CO^+, H_2O^+, and others were identified in the spectra of Comet C/1999 S4 (LINEAR) obtained on July 22/23, 2000 before splitting of the cometary nucleus.

During three observational nights (July 23, 27, and 28, 2000) 12 spectra of Comet C/1999 S4 (LINEAR) were obtained. Processing was made with the "Long" ESO-MIDAS. For calibration, the standard star BD+28 4211 was used. Figure 1 shows the spectra of the comet for three dates. Identification of the cometary emission lines was made using the catalog of the spectral lines in Comet Brorsen–Metcalf [2]. For the spectra obtained on July 23, typical cometary emission lines were found: C_2, C_3, CN, NH, CH, NH_2, CO^+, H_2O^+, and others. The spectrum of the comet under investigation is a typical cometary spectrum with the spectral features which are specific to many other comets.

PROCESSING AND DISCUSSION

Figure 1 shows that the intensity of the cometary emissions during July 23–27 decreased considerably and on July 28 the cometary spectrum was practically completed by repeating reflected solar spectrum. One can see from Fig. 1 that the intensity of the cometary emissions changed very fast during this time interval.

Table 1. Instruments for observations of Comet C/1999 S4 (LINEAR) and their characteristics

Collimator	Parabolic mirror, $F/4$ ($F = 300$ mm)
Camera	Schmidt camera, $F/0.9$ ($F = 110$ mm)
Comparison spectrum	He+Ne+Ar spectral lamp
Slit length	140 arcsec
Image scale	0.41 arcsec/pixel
Wavelength range	4000–6000 Å
Gratings	651(8) grooves/mm
Linear dispersion	3.1 Å/pixel
TV-guide field	3 arcmin
CCD detector	ISD015A ("Electron" St.-Petersburg), 530×580 pixel
Pixel size	18×24 mkm
Readout noise	12 electron

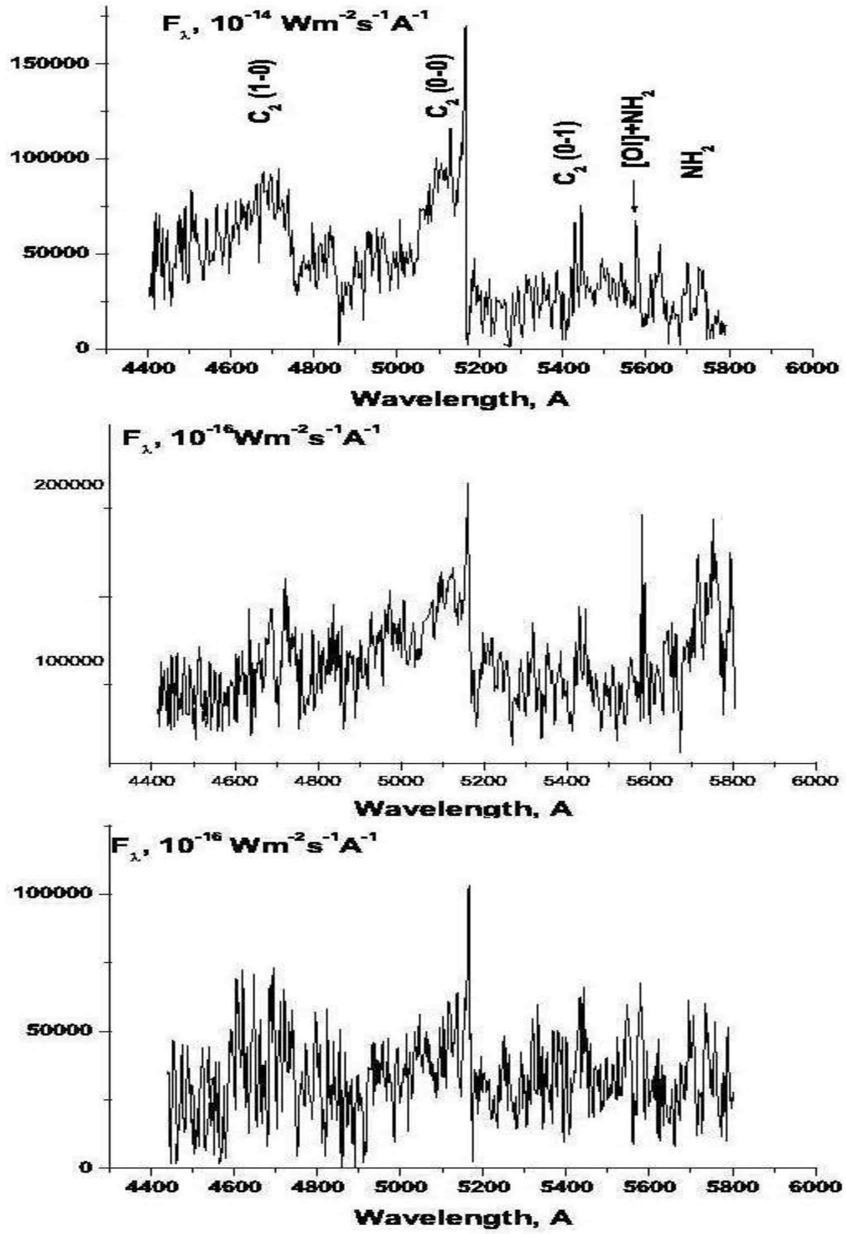

Figure 1. Evolution of the spectra of Comet C/1999 S4 (LINEAR) from July 23 to July 28, 2000

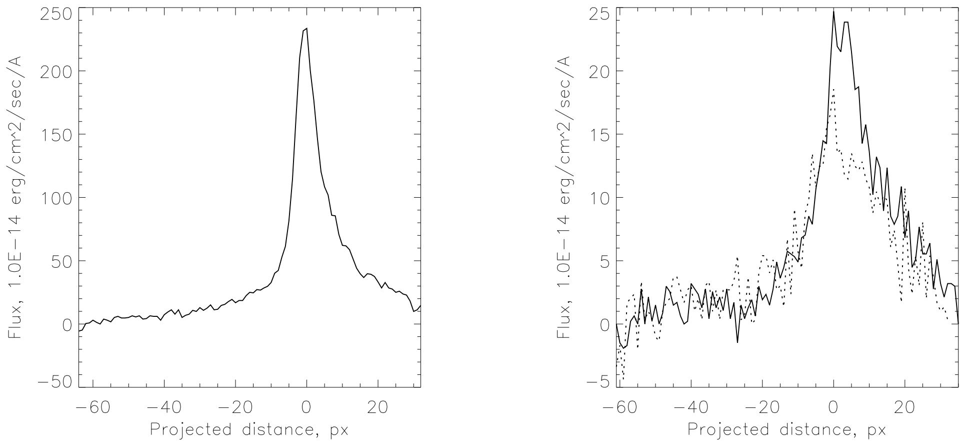

Figure 2. Distribution of surface brightness along the slit for emission line C_2 from July 23 to July 28, 2000

Rather sharp decrease of fluxes in the emission lines is confirmed by a noticeable decreasing of the comet visual magnitude, which characterized the luminosity of the comet mainly in the C_2 Swan bands. One of the authors (Churyumov) observed Comet C/1999 S4 (LINEAR) in Kyiv with a binocular and estimated its visual integral magnitudes on July 22.90 UT ($m_1 = 6.4^m$) and 23.90 UT ($m_1 = 6.3^m$).

The estimations of the integral visual magnitude made by M. Lehky (Czech Republic) on July 31.85 UT ($m_1 = 8.5^m$) and D. Sergent (Australia) on August 2.35 UT ($m_1 = 9.0^m$) show that during July 22 – August 2, 2000 the comet magnitude decreased by 2.5^m, and on August 9 the comet magnitude became less than 11–12^m.

Noticeable changes took place in the profile of the comet brightness in some emission lines. Figure 2 shows space profiles of the surface brightness of the C_2 emission line along the slit on July 23, 27, and 28. On July 23 the space profile of the C_2 emission line is quite smooth, asymmetric, elongated in the opposite side direction from the Sun, that is to the tail, and has one maximum peak. Figure 2 also shows the profiles of brightness of the emission line on July 27 and 28, 2000. We believed that two-peak profiles of C_2 in the spectra of Comet C/1999 S4 (LINEAR), obtained on July 27 and 28, 2000 could be explained by the existence of the secondary maximum of brightness in the near-nucleus region of the comet tied presumably with any secondary fragments of the nucleus. In this time the comet image have prolonged form without the evidence maximum of the brightness. But at least 16 fragments were detected in images of Comet C/1999 S4 (LINEAR) taken on August 5, 2000 with the Hubble Space Telescope (HST) and on August 6 with the Very Large Telescope (VLT) [7].

Figure 2 shows that the distance between the brightness maxima on July 27 and 28 changed. Using the sizes of the pixels on the image we estimated the velocity of fragments escaping in the near-nucleus region (10 km/hr). It supports probably the fact that escaping fragments are monolithic (not gaseous) objects.

To estimate the size and possible mass of the cometary nucleus, we determined the absolute magnitude of the comet H_0. For this aim we built the light curve of Comet C/1999 S4 (LINEAR). To build the light curve and to find its photometric parameters, the observations published in the International Comet Quarterly [1] were used. After the exclusion of rough errors using Tompson's rule, the data per day were averaged. The photometric parameters were calculated by Orlov's formula:

$$m = H_y + 5 \log \Delta + 2.5n \log r, \tag{1}$$

where Δ, r are the geo- and heliocentric distances, respectively.

Figure 3 represents light curves. Photometric parameters of Comet C/1999 S4 (LINEAR) before perihelion are $H_y = 8.79 \pm 0.03$ and $n = 6.7 \pm 0.1$. To build the light curve, we used shorter intervals of the heliocentric distances than Yoshida's ones [`http://www.aerith.net/comet/catalog/1999S4/1999S4.html`]. Therefore, the absolute magnitude of the comet obtained by us ($H_0 = 8.8^m$) differs from the absolute magnitude of the comet deduced by Yoshida ($H_0 = 7.7^m$) approximately by 1^m.

As shown by photographic observations of the comet made by T. Kryachko at Mount Pastukhov with the 40-cm Zeiss astrograph and also from the analysis of the cometary light curve (Fig. 3), the intense destruction of the cometary nucleus began probably on July 23, 2000. The light curve shows that the maximum brightness of the comet occurred on July 23, 2000 or three days before the moment of the perihelion passage. Using the absolute magnitude of the comet ($H_0 = 8.8^m$), we estimated approximately the cometary nucleus size by

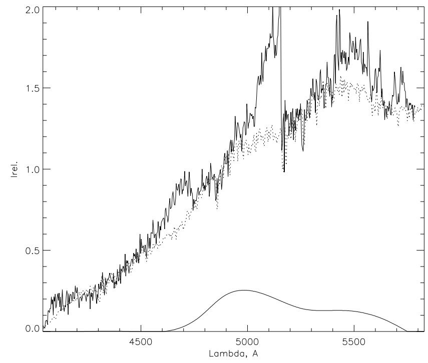

Figure 3. Detection of fluorescent continuum in the spectrum of Comet C/1999 S4 (LINEAR) on July 23, 2000

Whipple's formula [8] as $R \approx 1.7$ km. Supposing that the average density of the matter of the comet icy nucleus is close to 1 g/cm^3, we estimated approximately minimal kinetic energy which is needed for escaping of secondary fragments as $E = 8.7 \cdot 10^{15}$ erg.

What physical mechanism may explain splitting of Comet C/1999 S4 (LINEAR) nucleus? We can assume that a high level of the solar activity influences the nucleus splitting. The cometary nucleus splitting was developed at the time close to the phase of maximum of the 23rd cycle of the solar activity and more likely the splitting of the cometary nucleus was initiated by a powerful ejection of the coronal matter (transient) on July 14, 2000 which was detected by the SOHO satellite. As the result of the interaction of the coronal plasma of the transient with the cometary nucleus ice electrolysis of the ice took place according to a physical mechanism suggested by E. Drobyshevsky. As the result of electrolysis in the outer sheets of the cometary nucleus a mixture of H_2O_2 was formed which exploded by the action of the next transient thrown from the solar corona. Solar transients are formed very often during the maximum phase of the solar activity.

One of possible mechanisms of explosion may be Shulman's mechanism according to which disintegration of the ion-molecular clusters in the cometary icy nucleus may be a basic source of energy of the outburst. The existence of solvate ions in Comet C/1999 S4 (LINEAR) nucleus is most likely because this comet belongs to "new" comets in the Oort sense.

Explosion may be a result of heating of the icy cometary nucleus during its approaching to the Sun at a distance of 0.76 AU. The heating led to formation numerous microcracks in the icy nucleus and later to outburst escaping of gases from the nucleus caves.

It is possible that the decoding of the real reason of Comet C/1999 S4 (LINEAR) destruction and death basing on the obtained observational data will allow one to solve the enigma of the possible destruction of famous Comet Halley which happened on February 14, 1991, 14.3 AU away from the Sun. The analysis of CCD images obtained with the 1.5-m telescope at the ESO in Chile shows that during the outburst from the Comet Halley nucleus the dusty cloud erupted was 300 times as bright as a supposed dusty cloud for Comet Halley.

In the spectrum of Comet C/1999 S4 (LINEAR) we also detected the luminescence comet continuum which has a non-solar origin. This effect was observed for a real number of comets and is caused by contribution of luminescence of cometary dust [5]. For the first time this effect was detected in Comet Halley by [5, 6] from decrease of the Fraunhofer lines contrast. According to the procedure from [5, 6] the optical depth τ_c of the cometary atmosphere is determined by scattering of the solar light. It is a cometary characteristic which is proportional to the ratio of the spectral intensities of the comet I_c and the Sun $I_\odot$. In the presence of luminescence the optical depth must be determined for this component by the formula:

$$\tau_c(\lambda) = \frac{R_\odot^2}{4r_c^2} \frac{I_c(\lambda) - I_c^f(\lambda)}{I_\odot(\lambda)}, \tag{2}$$

where $R_\odot$ is the radius of the Sun, r is the heliocentric distance of the comet, and $I_c^f(\lambda)$ is the intensity of the comet dust luminescence.

The test of real determination of additional component $I_c^f(\lambda)$ is the absence of traces of the Fraunhofer lines in dependence $\tau_c(\lambda)$. For the given spectrum a level of the fluorescent continuum in the spectral region near the wave length λ 5000 Å is equal to 26% of the comet continuum.

In [4], spectra of three comets are investigated to determine the real level of the non-solar-origin continuum in the spectral region from 350 to 500 nm. Spectra of three comets, 24P (Schaumasse), C/1989 Y1

(Scoritchenko–George), and C/1995 O1 (Hale–Bopp), were observed with the help of the 6-m BTA telescope and the spectrograph with the long slit at the SAO RAS. Spectra of Comet Hale–Bopp (C/1995 O1) were also obtained with the 1-m Zeiss telescope and echelle spectrometer of the SAO RAS.

Below are some results of processing of spectra of several comets.

1. For Comet Schaumasse (24P) on March 14–15, 1993, the level of the non-solar-origin continuum is equal to 44% of the sum continuum level at 430 nm.
2. For Comet Scoritchenko–George (C/1989 Y1) on February 27, 1990, the level of the non-solar-origin continuum is equal to 40% of the sum continuum level at 387 nm, 68% at 430 nm (max), and 23% at 480 nm.
3. For Comet Hale–Bopp (C/1995 O1) on April 17, 1997, the level of the non-solar-origin continuum is equal to 32% of the sum continuum level at 397 nm and 77% at 438 nm (maximum).

Analysis of Comet C/1999 S4 (LINEAR) spectra also showed the presence of comet luminescence continuum (non-solar origin) with its maximum at 5000 Å by a level of 26% of the sum continuum level. Similar position of the maximum for luminescence continuum was detected in the spectrum of Comet C/2001 A2 (LINEAR). The number of comets studied by us showed that this maximum is in the blue part of the comet spectra (at 4300 Å). Possibly, this shift of the luminescence continuum maximum to the green part of the spectral region close to 5000 Å is related to the presence (in the coma) of a special type of organic particles-luminofors sublimated from the icy nucleus of Comet C/1999 S4 (LINEAR).

CONCLUSION

During three observational nights (July 23, 27, and 28, 2000) 12 middle resolution spectra of the splitting of Comet C/1999 S4 (LINEAR) were obtained at the SAO RAS (the Northern Caucasus). Emission lines of the molecules C_2, C_3, CN, NH, CH, NH_2, CO^+, H_2O^+, and others were identified in the spectra of Comet C/1999 S4 (LINEAR) obtained on July 22/23, 2000 before splitting of the cometary nucleus. Analysis of the CCD spectrum obtained on July 27/28, 2000 reveals very weak emission lines superposed on the solar reflection spectrum, unlike the case of the spectra obtained with the same instrument on July 22/23. Changes in the spectra and fast decrease of fluxes in the cometary emission lines are found and discussed. From analysis of the surface brightness profile of C_2 along the slit, the velocity of expansion of two secondary fragments ($V = 10$ km/hr) and energy of fragments expansion ($E = 8.7 \cdot 10^{15}$ erg) are estimated. The luminescence cometary continuum by a level of 26% of the sum continuum level at 5000 Å in the spectra of the comet is detected. Possible mechanisms of nucleus splitting are discussed.

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