SPECTRA OF SPLIT COMET C/1999 S4 (LINEAR)

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Abstract. We obtained spectra of comet C/1999 S4 (LINEAR) with the UAGS spectrograph (long slit and CCD) installed on the 1-m Zeiss reflector of the SAO of the RAS (Northern Caucuses, Nizhny Arkhyz) on July 23/24, 26/27 and 27/28, 2000. On July 22/23, before the splitting of the cometary nucleus, several emission lines, such as C_2, C_3, CN, NH, CH, NH_2, CO^+, H_2O^+ were clearly identified in the spectra. The inspections of the CCD spectra obtained on July 27/28, 2000 reveals only very weak emission lines superimposed on the solar reflection spectrum. From analyzing the surface brightness profile of C_2 along the slit the velocity of separation of two secondary fragments (V = 10 km/h) and the energy of the fragment separation (E = 8.7 $\times$ 10^{15} erg) were estimated. A luminescence cometary continuum of 26% of the total continuum level is detected in the spectra of the comet at 5000 Å. Possible mechanisms of nucleus splitting are discussed.

Keywords: Comets, continuum, luminescence, nucleus, spectra, splitting

1. Observations and 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 SAO of the RAS (Northern Caucuses, Nizhny Arkhyz) on July 23/24, 26/27 and 27/28, 2000. Table I gives the technical details of the equipment used for the observations.

During 3 observating nights (July 23, 27 and 28, 2000) 12 spectra of the comet were obtained. The processing was done with the ESO-MIDAS standard reduction context "LONG". For flux calibration the standard star BD+28 4211 was used. Figure 1 gives an example of the spectra obtained on the 3 observing dates. To identify the cometary emission lines we used the catalog of the spectral lines in comet Brorsen–Metcalf (Brown et al., 1992). A number of emissions lines could be identified. On July 23, 2000, before splitting of the cometary nucleus, we identified among others the typical cometary emission lines of C_2, C_3, CN, NH, CH, NH_2, CO^+, H_2O^+. On that date the spectrum is a typical comet spectrum showing the spectral features which are characteristic for many other comets.

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TABLE I
Apparatus used for the observations of C/1999 S4 (LINEAR)

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

2. Results

Figure 1 shows that the intensity of the cometary emission bands changed very fast during the time span covered by the observations. It decreased considerably between 23 and 27 July and on 28 July the spectrum resembles practically completely the reflected solar spectrum without any emission lines.

The rather sharp decrease of the emission line fluxes is confirmed by a noticeable decrease of the comet visual magnitude. One of the authors (Churyumov) observed comet C/1999 S4 in Kyiv with binoculars and estimated its visual integral magnitudes on July 22.90 UT ($m_1 = 6.4^m$) and 23.90 UT ($m_1 = 6.3^m$). Together with the estimations of the integral visual magnitude made by M. Lehky (Chech Rep.) on July 31.85 UT ($m_1 = 8.5^m$) and D.Sergent (Australia) on Aug. 2.35 UT ($m_1 = 9.0^m$) it shows that the comet magnitude decreased by 2.5^m between July 22–Aug. 2, 2000. On Aug. 9 the comet brightness was $< 11^m - 12^m$.

Noticeable changes in the brightness profiles of some emission lines were also observed. Figure 2 shows the spatial profiles of the C_2 emission line on July 23, 27 and 28. On July 23 the profile is quite smooth, single-peaked and asymmetric (elongated in projected tail direction). On July 27 and 28 a double-peaked profile is present. These double-peaked C_2 profiles indicate the existence of a secondary maximum of brightness in the near nucleus region presumably representing a secondary fragment of the nucleus. The images of the comet obtained during this time show an elongated coma with no clear maximum of brightness. However, at least 16 fragments were detected in images of comet C/1999 S4 (LINEAR) taken on 5 August 2000 with the Hubble Space Telescope (HST) and on 6 August with the Very Large Telescope (VLT) (Weaver et al., 2001).

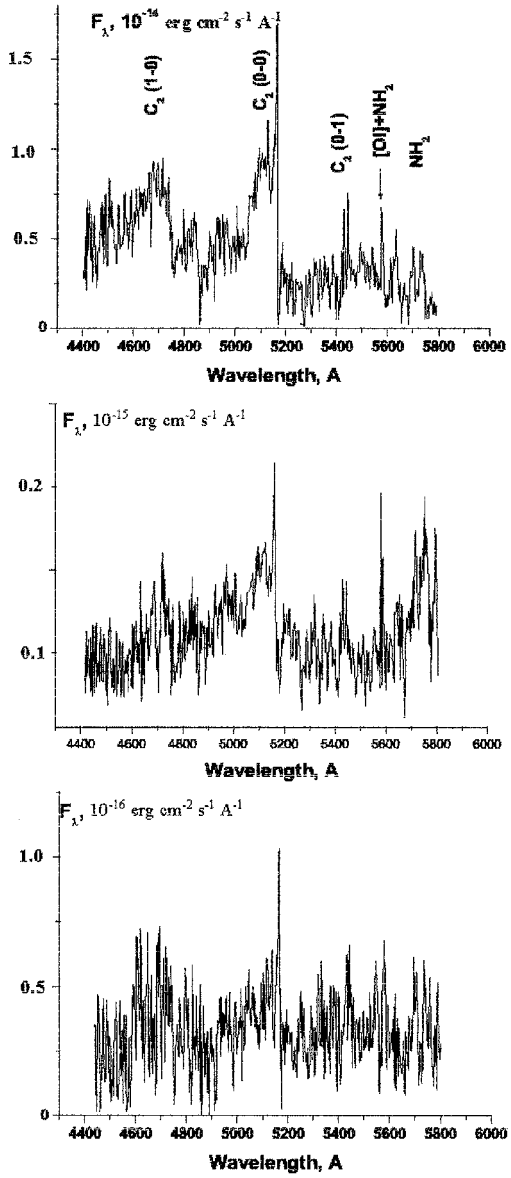

Figure 1. Evolution of the spectra of comet C/1999 S4 during July 23 to July 28, 2000.

Figure 2 shows that the distance between the brightness maxima changes between July 27 and 28. From the shift of the maxima we estimated the the velocity of fragments escaping in the near nucleus region to be about 10 km/h. Unfortunately, no confirmation measurement for this very high separation speed of the fragments is available.

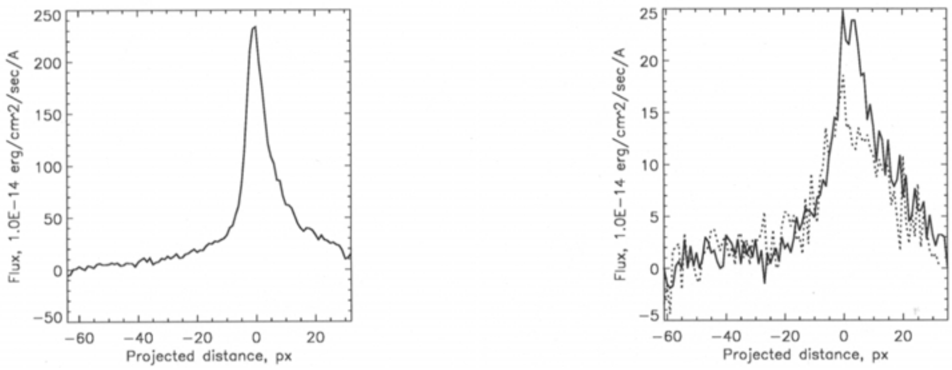

Figure 2. The surface brightness along the slit for the C_2 emission line on 23 July 2000 (left) and 27–28 July 2000 (right).

To estimate the size and possible mass of the nucleus we determined the absolute magnitude of the comet, H_0, from its light curve. We used the observations published in the International Comet Quarterly (2000) to produce the light curve shown in Figure 3 and to find its photometric parameters. After the exclusion of large errors using Tompson's rule the data were averaged over each day. The photometric parameters were calculated by Orlov's formula: $m = H_y + 5 \lg \Delta + 2.5n \lg r$, with Δ = geocentric distance and r = heliocentric distance. The photometric parameters of the comet before perighelion are $H_y = 8.79 \pm 0.03$ and $n = 6.7 \pm 0.1$. We used smaller intervals in the heliocentric distance than Yoshida (http://www.aerith.net/comet/catalog/1999S4/1999S4.html). Therefore the absolute magnitude of the comet obtained by us differs from that by Yoshida by approximately 1^m (H_0 = 8.8 – authors and H_0 = 7.7 –Yoshida).

Photographic observations of the comet made by T. Kryachko on the Pastoukhov mountain with the 40-cm Zeiss astrograph, and the analysis of the cometary light curve (Figure 3) indicate that the intense destruction of the comet nucleus began probably on July 23, 2000. The light curve shows that the comet had its maximum brightness on July 23, 2000, three days before the perihelion passage. Using the absolute magnitude of the comet ($H_0 = 8.8^m$), we estimated the approximate size of the comet nucleus by Whipple's formula (Whipple, 1987) to be R $\approx$ 1.7 km. Assuming that average density of the comet nucleus is close to 1 g/cm^3, we estimate the minimal kinetic energy needed for the escape of secondary fragments to be E $\approx 8.7 \times 10^{15}$ erg.

In the spectrum of comet C/1999 S4 we also detected the luminescence comet continuum which has non-solar origin. This effect is claimed to be present for a number of comets and may be caused by luminescence from cometary dust (Nazarchuk, 1987a). It was first described for comet Halley by Nazarchuk (Nazarchuk, 1987a, b) on the basis of decreasing of the Fraunhofer lines contrast. According to her technique the optical depth, τ_c, of the comet atmosphere is determined by

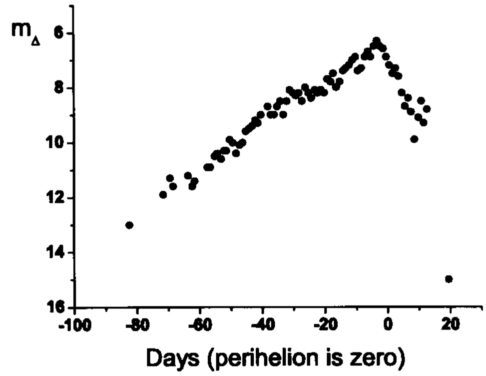

Figure 3. The light curve of comet C/1999 S4 (LINEAR).

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 is determined for this component by:

$$\tau_c(\lambda) = \frac{R_\odot^2}{4r_c^2}\frac{I_c(\lambda) - I_c^f(\lambda)}{I_\odot(\lambda)}, \tag{1}$$

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

The determination of the additional component $I_c^f(\lambda)$ can be checked by the absence of traces of the Fraunhofer lines. For the given spectrum the level of the fluorescent continuum at the spectral range near λ 5000 Å is equal to 26% of the comet continuum.

Churyumov and Kleshchonok (2001) investigated spectra of three comets with the aim to determine the level of the non-solar-origin continuum in the spectral region 350–500 nm. Spectra of comets 24P/Schaumasse, C/1989 Y1 (Scoritchenko-George) and C/1995 O1 (Hale–Bopp) were observed with the 6-m BTA telescope and the long-slit spectrograph at the Special Astrophysical Observatory of the Russian Academy of Sciences. Spectra of comet Hale–Bopp (C/1995 O1) were also obtained with the 1 m Zeiss telescope and echelle-spectrometer of the SAO of RAS.

Analysis of the spectra of comet C/1999 S4 (LINEAR) also showed the presence of comet luminescence continuum (non-solar origin) with its maximum at 5000 Å, i.e. 26% of the total continuum level. A similar position of the maximum of the luminescence continuum was detected in the spectrum of comet C/2001 A2 (LINEAR) (see Lukyanyk et al., these proceedings). The number of comets studied by us showed that the maximum usually lies in the blue part of the spectra (at 4300 Å). The shift of the maximum of the luminescence continuum to the green spectral range (close to 5000 Å) is probably related to the presence of a special type of

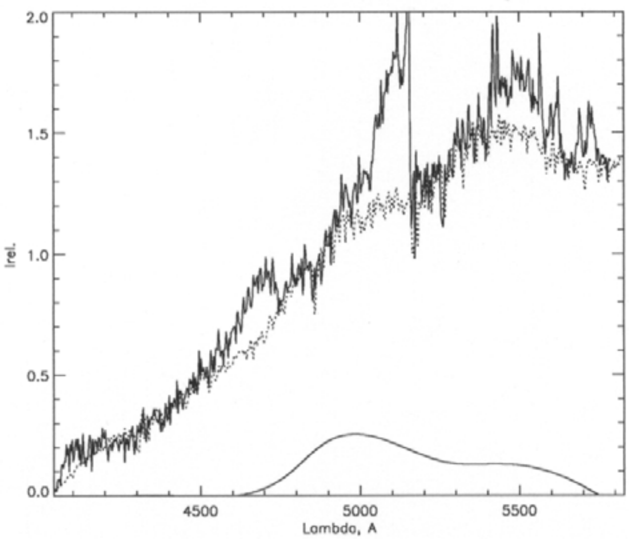

Figure 4. Detection of fluorescent continuum in the spectrum of comet C/1999 S4 (LINEAR) on July 23, 2000.

organic particles-luminofors in the coma that sublimated from the icy nucleus of comet C/1999 S4 (LINEAR).

3. Conclusion

The existence of a bright secondary nucleus in comet C/1999 S4, the high separation velocity of the fragments and the luminescence continuum of organic dust particles, needs to be confirmed by more and better observations.

References

Brown, M. E., Bouches, A. H., Spinrad, H., and Johns-Krull, C. M.: 1996, *Astrophys. J.* **112**, 1197.

Churyumov, K. I. and Kleshchonok, V. V.: 2001, *JENAM-01*, Astronomishe Gesellschaft, Abstract Series, Munich, p. 257.

Churyumov, K. I., Kleshchonok, V. V., and Vlassyuk, V. V.: 1997, *JENAM-97*, p. 70.

Nazarchuk, H. K.: 1987a, *Kometnyj Tsirkulyar* **372**, 2.

Nazarchuk, H. K.: 1987b, *Kometnyj Tsirkulyar* **377**, 2.

Weaver, H. A., Sekanina, Z., Toth, I., Delahodde, C. E., Hainaut, O. R., Lamy, P. L., Bauer, J. M., A'Hearn, M. F., Arpigny, C., Combi, M. R., Davies, J. K., Feldman, P. D., Festou, M. C., Hook, R., Jorda, L., Keesey, M. S. W., Lisse, C. M., Marsden, B. G., Meech, K. J., Tozzi, G. P., and West, R.: 2001, *Science* **292**(5520), 1329–1334.

Whipple, F. L.: 1987, *Astron. Astrophys.* **187**, 852–858.