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The earliest spectroscopy of the GRB 030329 afterglow with SAO RAS 6-m telescope and early spectra of core-collapse supernova(*)

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Summary. — The earliest BTA (SAO RAS 6-m telescope) spectroscopic observations of the GRB 030329 optical transient (OT) are presented, which almost coincide in time with the "first break" ($t \sim 0.5$ day after the GRB) of the OT light curve. The beginning of spectral changes are seen as early as ~ 10–12 hours after the GRB. So, the onset of the spectral changes for $t < 1$ day indicates that the contribution from Type Ic supernova (SN) into the OT optical flux can be detected earlier. The properties of early spectra of GRB 030329/SN 2003dh can be consistent with a shock moving into a stellar wind formed from the pre-SN. Such a behavior (similar to that near the UV shock breakout in SNe) can be explained by the existence of a dense matter in the immediate surroundings of massive stellar GRB/SN progenitor (see Young *et al.*, *ApJ*, **449** (1995) L51 and Imshennik and Nadyozhin, *Usp. Fiz. Nauk*, **5** (1988) 561). The urgency is emphasized of observation of early GRB/SN spectra for solving a question that is essential for understanding GRB physical mechanism: *Do all* long-duration gamma-ray bursts are caused by (or physically connected to) *ordinary* core-collapse supernovae? If clear association of normal/ordinary core-collapse SNe (SN Ib/c, and others SN types) and GRBs would be revealed in numbers of cases, we may have strong observational limits for gamma-ray beaming and for real energetics of the GRB sources.

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PACS 98.70.Rz – γ-ray sources; γ-ray bursts.
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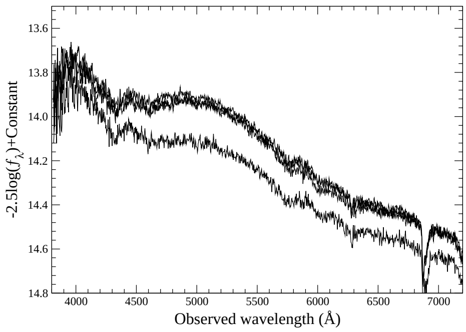

Fig. 1

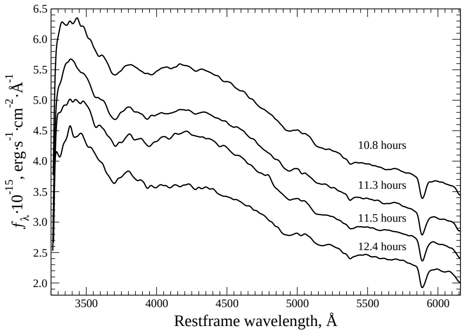

Fig. 2

Fig. 1. – The four BTA/MPFS spectra of GRB 030329 OT are presented in the order of flux decrease for 0.45 ($10^{\mathrm{h}}.8$), 0.47 ($11^{\mathrm{h}}.3$), 0.48 ($11^{\mathrm{h}}.5$) and 0.52 ($12^{\mathrm{h}}.4$) days after the burst, respectively. The $10^{\mathrm{h}}.8$, $11^{\mathrm{h}}.3$, and $11^{\mathrm{h}}.5$ spectra correspond to almost equal f_λ.

Fig. 2. – The MPFS spectra (in restframe wavelengths) smoothed by a Gaussian with FWHM equal to MPFS spectral resolution (12Å). The smoothed spectra of GRB 030329 OT were shifted up the scale of f_λ relative to the last (12.4 h) spectrum.

Spectroscopic observations of the GRB 030329 OT were performed on 29/30 March 2003 with the Multi-Pupil Fiber Spectrograph (MPFS) (see WWW-page at `http://www.sao.ru/~gafan/devices/mpfs/mpfs_main.htm`) at the 6 meter telescope (BTA) of SAO RAS starting 10.8 hours after the burst [12]. In order to control the absolute flux calibration, the photometry and spectroscopy were compared. We used UVR_cI_c photometric observations of the OT carried out with the Zeiss-1000 telescope at SAO RAS on the same epoch as the BTA/MPFS spectroscopy was carried out (the magnitudes and full $UBVR_cI_c$ light curves are reported by [4] and [5]). For the B band we used the Nordic Optical Telescope observations [1].

Figure 1 presents the resulting spectra of the GRB 030329 OT. Broad spectral features (figs. 1 and 2) detected in the spectra are confidently real. As can be seen in fig. 3, the photometry and spectroscopy are in good agreement. The spectra showed an unsmooth continuum with several broad spectral features at about 4000, 4450, 5900Å. From fig. 4 one can conclude that broad spectral features remained significant during the first three nights. It is clearly seen from the figures that systematic deviation of V-band flux from formal smooth power-law is due to real unsmooth OT spectra. Also fig. 4 shows that there is some evidence of reddening in the OT broad-band spectrum of the first three nights. Moreover it should be noted that during about a month after the burst the colors of the OT are redder than during first three days, which is in turn consistent with continuing reddening of the broad-band spectrum. Such a behavior of the broad-band spectrum can be explained by an increase of a SN fraction in the GRB OT light.

We obtained our earlier BTA/MPFS spectra of the OT just during the most rapid variations in the huge OT luminosity ($\sim 10^{45}\,\mathrm{ergs\,s^{-1}}$ at the moment $\sim$ 11 h) and physical conditions in the source, which almost coincide in time with the first "break" ($t \sim 0.5$ day after the GRB) of the OT light curve. This phase is like some SNe (1993J, 1997A) observed during the first light curves UV peaks (or during the UV breakout phase), specially by their similar fast luminosity variations, spectra, and bolometric luminosities. The bolometric luminosities in the first SNe UV peaks can be also approximately of the same values as in the GRB OTs.

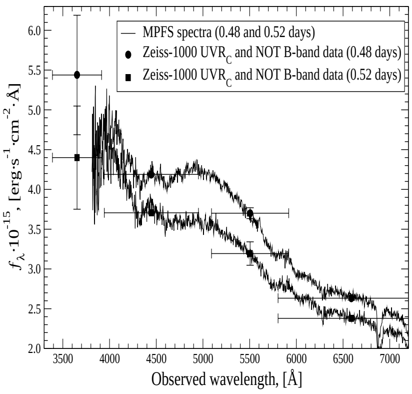

Fig. 3

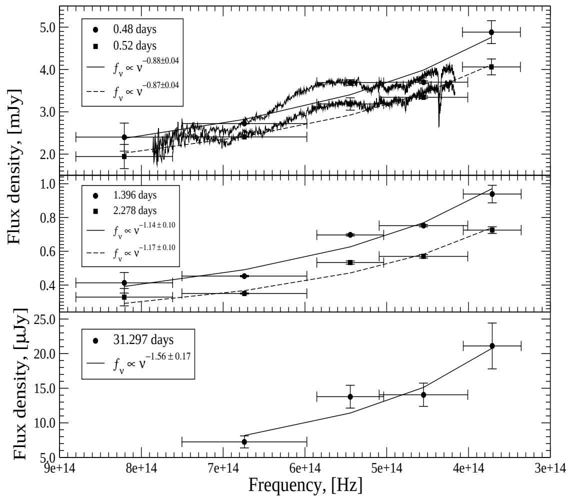

Fig. 4

Fig. 3. – Comparison of spectroscopy and photometry. By horizontal bars the FWHM (full width at half maximum) of corresponding filters are shown.

Fig. 4. – Evolution of the $UBVR_cI_c$ broad-band spectra during the first three nights. The MPFS spectra are also shown. As in fig. 3 by horizontal bars the FWHM of corresponding filters are shown.

If SNe and GRBs are indeed produced by the same astrophysical cauldron [7], then most probably the spectra of SN and the GRB afterglow can be mixed so closely that it would be rather difficult to divide them in the earliest stages of the most rapid changes in the source. It is natural to assume that at the very beginning of the GRB/SN explosion (in the SN rise time or in the onset time) the contributions of *early* spectra of the SN and the spectrum of the GRB afterglow can change quickly into the common (observable) spectrum of the GRB OT. Thus, the relative SN/OT contribution to the earliest integrated spectra might be rapidly variable. At some moment these contributions can become even comparable in bolometric luminosities (as an example, see estimations of

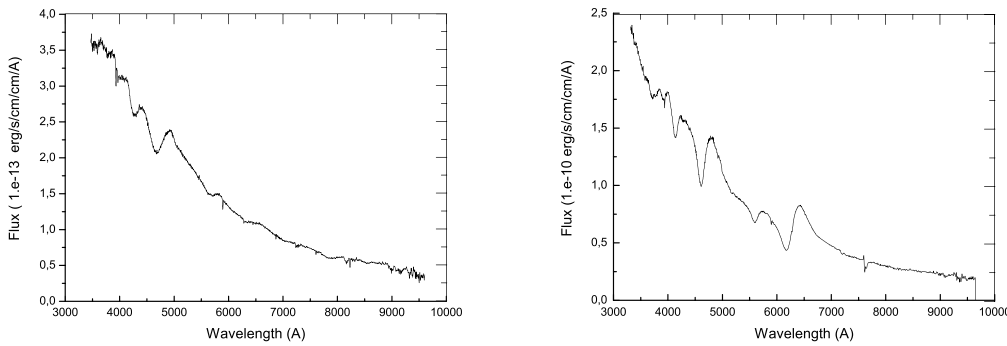

Fig. 5. – The examples of earliest optical spectra SN 1993J and SN 1987A are given. Spectra are taken from the database SUSPECT—The Online Supernova Spectrum Database http://bruford.nhn.ou.edu/ suspect/ [10].

bolometric luminosity in the first maximum of SN 1993J from [11]). This is reinforced by the fact that the earliest spectra of SNe are very similar to the GRB afterglow spectra in their powerful UV continuum. And especially since (as [8] note for SNe Ic) the rise time (more exactly, the beginning/onset time of the explosion) of the majority of known SNe are not well defined (see [9] for more detailed discussion of this problem.) As an illustration, we show in fig. 5 the examples of such early spectra corresponding to the UV shock breakout in two core collapse SNe (SN 1993J, SN 1987A), which have the most exactly defined times of the explosion onset.

The SN 1993J was similar to a SN Ib, with a low-mass outer layer of hydrogen (that gave the early impression of a SN II). It can be said that its emission comes from the collision of supernova ejecta with circumstellar gas that was released by the progenitor star prior to the explosion. Such a mass loss is consistent with the fact that the SN properties indicate that most of the stellar H envelope is present at the time of the SN explosion. SN 1987A is another core collapse supernova that exploded with a (massive) H envelope. But the immediate surrounding of the progenitor star (the pre-SN is a blue supergiant) was determined by the fast wind from that star. The variety of envelopes surrounding pre-SNe is quite natural in the evolution of a massive star [2, 3].

It is very important to emphasize also that the bolometric luminosity of SN 1993J can reach the first maximum (according to different model estimates) of order of $\sim 10^{45}\,\mathrm{ergs\,s^{-1}}$ 4–5 hours after the core collapse or $\approx$ *onset time* of the SN [11]. This luminosity is approximately equal to that of GRB 030329 OT at the moment when (at $\sim$ 11 h) we obtained spectra with the BTA.

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REFERENCES

[1] Castro-Tirado A. J., private communication (2003).
[2] Chevalier R., *The surroundings of gamma-ray bursts: constraints on progenitor*, in *Supernovae: 10 years of 1993J (IAU Col. 192)*, edited by Marcaide J. M. and Weiler K. W. (Springer Verlag, Heidelberg) 2004, pp. 441-451.
[3] Chevalier R., to appear in *Young Neutron Stars and Their Environments (IAU Symp. 218)*, edited by Camilo F. and Gaensler B. M., *ASP Conference Proceedings* (2004), astro-ph/0310730.
[4] Gorosabel J. *et al.*, submitted to *A&A* (2005).
[5] Guziy S. *et al.*, in preparation.
[6] Imshennik V. S. and Nadyozhin D. K., *Usp. Fiz. Nauk*, **5**, issue 4 (1988) 561.
[7] Kawabata K., Deng J., Wang L. *et al.*, *ApJ*, **593** (2003) L19.
[8] Matheson T., Garnavich P., Stanek K. *et al.*, *ApJ*, **599** (2003) 394.
[9] Norris J. P. and Bonnel J. T., *How can the SN-GRB time delay be measured?* in *Gamma-Ray Bursts: 30 Years of Discovery: Gamma-Ray Burst Symposium*, edited by Fenimore E. E. and Galassi M. (Melville, New York), *AIP Conference Proceedings*, Vol. **727** (2004), pp. 412-415.
[10] Richardson D., Thomas R. C., Casebeer D., Blankenship Z., Ratowt S., Baron E. and Branch D., *Bull. Am. Astron. Soc.*, **34** (2002) 4.
[11] Shigeyama T., Suzuki T., Kumagai S. *et al.*, *ApJ*, **420** (1994) 341.
[12] Sokolov V.V., Fatkhullin T. A., Komarova V. N., Kurt V. G., Lebedev V. S., Castro-Tirado A. J., Guziy S., Gorosabel J., de Ugarte Postigo A., Cherepaschuk A. M. and Postnov K. A., *BSAO*, **56** (2003) 5 (astro-ph/0312359).
[13] Young T. R., Baron E. and Branch D., *ApJ*, **449** (1995) L51.