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Concluding Remarks II

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Abstract The program of the conference was prepared so well (thanks to the organizers) that we got complete and competent reviews in all important fields of high energy cosmic sources. It is not easy to select just a few topics and any choice will be, necessarily, arbitrary. I decided to make brief comments on cosmology, on gamma ray bursts and on X-ray flashes. My personal nomination for the hit of the conference goes this year to the **"Rosetta stone"** of gamma ray bursts (term used by Elena Pian): **GRB030329 = SN 2003dh**.

1 COSMOLOGY

Using the wording (now several years old) of Sergio Colafrancesco, we entered the "era of precision" and we move steadily forward. There were no major break-throughs since our last meeting (I consider WMAP a highlight but not a major break-through), but the golden era of cosmology continues. We know now more parameters and we know them more precisely. WMAP contributed substantially to our present precision, but unfortunately, the effect of their excellent results was partially spoiled by publishing the unrealistically low error estimates. The case for inflationary scenario gets slowly but steadily stronger (and the future PLANCK mission gives the prospects for further progress in this field). We do not know yet the nature of the dark matter, but we are already able to set astrophysical limits on the mass of the particle which is the prime candidate (some sort of, as yet unobserved, WIMP type particle − the prime candidate is neutralino). The Hubble constant becomes slowly a real "constant" (the older of us remember, that in previous century, its value was highly variable). Let me just recall that five years ago at Vulcano, Nino Panagia was giving us value of Hubble constant as equal to $59\pm6\,\mathrm{km\ s^{-1}\ Mpc^{-1}}$. This year, his best estimate is $62\ \pm6\,\mathrm{km\ s^{-1}\ Mpc^{-1}}$. The most recent estimate on the other end of the scale, that of WMAP is $71(+3,\ -2)\,\mathrm{km\ s^{-1}\ Mpc^{-1}}$. This becomes almost consistent.

At the end of my cosmological remarks, I would like to emphasize the great role of clusters of galaxies as powerful tools in cosmological investigations. I stressed this point in my summary one year ago and it remains valid. This year, we were reminded about it by both Sergio Colafrancesco and Sabine Schindler.

2 GAMMA RAY BURSTS

Since the last year there was a break-through (or maybe even two). The definite one: the first secure association of a GRB with a SN event. This "airtight" association was demonstrated for

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the event GRB 030329 = SN 2003dh. But the term "break-through" is perhaps deserved also by the discovery of 80% polarization in prompt emission from GRB 021206. I shall return to both topics later.

We have heard six excellent review talks (K. Hurley, F. Frontera, G. Barbielini, L. Amati, E. Pian and G. Bisnovatyi-Kogan) plus one talk proposing a specific model (D. Fargion). Let us summarize very briefly the present knowledge (we are still considering only the long bursts).

• **Association with SNe**

The circumstantial evidence suggesting this association was accumulating for some time.

(1) The locations of GRBs (they seem to originate in star forming regions)
(2) The presence of lines of Mg, Si, S and other freshly synthesized elements in the afterglow spectra of some bursts
(3) The important evidence is provided by the optical afterglow light-curves: the characteristic "bumps" on the tails of afterglows revealing the probable contribution from the fading SN (Arnon Dar presented to us, one year ago, the evidence for 12 such associations).

But the "smoking gun" evidence came less than two months ago with the burst GRB030329 and the explosion of SN 2003dh. I shall discuss some details later. Now, I would like only to remind that this event made the case for the disputed GRB 980425/SN 1998bw association much stronger. It also helped to select a few more atypical SNe from the recent past, that could, possibly, also be associated with GRBs.

• **Beaming**

There seems to be a general consensus that the γ-ray emission is substantially beamed. However, the degree of beaming is a matter of dispute. The common wisdom estimate (based on the analysis of the breaks of the γ-ray light-curves) gives the width of the beam $\sim 5 \div 10^o$, which corresponds to a beaming factor $f \sim 10^{-3}$. However, some models (A. Dar, D. Fargion) require beaming as strong as $f \sim 10^{-7}$. Clearly, there is no consensus on this point, so far.

• **Nature of the Emission**

Very high ($\sim$ 80%) polarization found in the prompt emission from GRB021206 strongly supports the synchrotron radiation model. The typical shape of the afterglow spectrum (power law) is also consistent with this model.

• **Many still Unanswered Questions**

I will mention only few of them.

(1) The nature of the dark GRBs (about half of the bursts have neither X-ray nor optical or radio afterglows)
(2) The atypical bursts: very long ones (up to $\sim$ 5000 s), bursts with precursors
(3) The central engine: we still do not know
(4) The nature of the short bursts: mechanism (mergers?), spatial distribution

3 X-RAY FLASHES

In the shadow of the GRBs there remains a large class of objects known as X-ray flashes (or XRFs). We have heard a nice review talk on these beasts by John Heise. These objects are, in many respects, quite similar to their famous brothers, but their emission is much softer. The typical energy range of XRFs' emission is $\sim 1 \div 10$ keV (as opposed to $\sim 10 \div 10^{4-5}$ keV for GRBs). The other properties are similar for both classes of objects:

(1) The rate of the events is ~ 0.5 d^{-1} (similar to that of GRBs).
(2) They are not recurrent

(3) The spatial distribution is isotropic but not homogeneous (like for GRBs). This indicates that they originate at cosmological distances. In one case (XRF020903), a redshift was determined from the optical afterglow: $z = 0.25$ (which translates into the isotropic energy of the explosion $E_{\rm x} \sim 10^{50}$ erg.
(4) XRF 020903 obeys Amati (2003) relation between the peak energy $E_{\rm peak}$ and the total amount of the radiated energy E_γ, found for GRBs (harder bursts are more energetic).

Three different models were proposed to explain XRFs. The first one suggested that they are highly redshifted GRBs. This explanation is not consistent with observations (redshifted GRBs would be weaker than the observed XRFs). The second model suggests that they might be GRBs with narrow beams, seen nearly edge-on. The third model proposes that the typical energy of GRB explosion might be used to propel much larger amount of mass than in "classical" GRB. If this is a case, then the expected Lorentz factor will be much smaller (e.g. $\sim 10^2$ for XRFs as opposed to $\sim 10^3 - 10^4$ in GRBs).

There is no consensus on the nature of XRFs. I believe, that we shall hear, in near future, many more news from these interesting objects, which suffer undeserved discrimination, being overshadowed by their powerful hard brothers.

4 NOMINATION FOR THE CONFERENCE HIT

This year, my personal nominations for the conference hit goes to **GRB030329 = SN 2003dh**, the **"Rosetta stone"** of gamma ray bursts (E. Pian) or the **"smoking gun"** evidence of GRBs-SNe connections (G. Barbiellini).

This event provided the first secure association of GRB with a SN explosion. The optical spectrum of 2003dh, after subtracting the afterglow (i.e. the power law) component, was found to be strikingly similar to that of 1998bw (both the shape and the temporal evolution). Also the initial expansion velocity ($\sim 30\,000$ km s^{-1} – unusually high) was very similar for both SNe. So, finally, we start gathering some knowledge about this particular subclass of SNe that are associated with GRBs. It seems, that one of their properties are extreme kinematical conditions. It seems also, that Arnon Dar and his coworkers were right to claim that optical spectrum of SN 1998bw might be used as a template to search for the underlying SNe in the more distant afterglows.

The event made the case for GRB 980425/SN 1998bw association (which was, until now, disputed) much stronger. Let me remind that the energy of GRB030329 (E_γ(isotropic) $\sim 10^{52}$ erg) is perfectly normal for a GRB, while the energy of GRB 980425 (E_γ(isotropic) $\sim 10^{48}$ 1erg) was unusually low. Now, when the association with SN 1998bw is no longer questioned, the most likely explanation of its low luminosity is, that indeed, the burst was misaligned (seen nearly edge of the beam-on).

The X-ray light-curve of SN 1998bw is known for more than 1000 d. Now, when we know that SN 1998bw is a sort of the template, we might search for the past SNe with similar late X-ray light-curves. Three such SNe were found: SN 1980k, SN 1994I and SN 2002ap. In one case (SN 1980k) the X-ray light-curve is known for more than 4000 d. All these SNe could be associated with GRBs.

5 ACKNOWLEDGEMENTS

And now, traditionally, let me join the previous speakers and thank Lola, Franco and all organizers for their great efforts that led to such a pleasant and succesful meeting.