GAMMA-RAY BURSTS

The following is an update on the subject of gamma-ray bursts, a selective progress report since the 1992 TEXAS/PASCOS '92 Conference on Relativistic Astrophysics and Particle Cosmology.

A large volume of data was published. This include the first BATSE Catalogue of burst variability (Fishman et al. 1994) and spectra (Schaefer et al. 1994). In the same volume of the ApJ Supplement there is a number of short review articles: observations by Kouveliotou (1994) and theories by Blaes (1994). The most recent proceedings of a conference on gamma-ray burst is that by Fishman et al (1993).

The strongest evidence for the cosmological distance scale remains the isotropic distribution of the bursts (cf. Figure 1 and Hakkila et al. 1994) combined with the relatively small number of weak BATSE bursts as demonstrated by the cumulative counts of the number of bursts as a function of their peak intensity (Fenimore et al 1993). In the last paper the BATSE and PVO bursts were combined (cf. Figure 2). This was essential, as PVO has a much better statistics on the bright end as a result of its 13 year long lifetime. It is clear that on the bright (PVO) end the cumulative counts follow closely the slope -1.5 of the dashed line, while at the faint (BATSE) end the observed counts are much flatter, a characteristic feature of the 'edge of the distribution'. The solid line follows from a theoretical model in which all bursts have the same peak luminosity of 5.2×10^{50} $erg\ s^{-1}$ (assuming isotropic emission) and they burst at the rate of 24 per year per comoving volume of Gpc^3.

The highlights of other papers are as follows. The first quantitative claim was published on the time dilation effect: weak bursts are stretched in time compared to strong bursts (Norris et al. 1994), suggesting that cosmological redshift may be responsible. However, this finding is disputed (Band 1994). The weak, and presumably distant BATSE gamma-ray bursts were found to be on average softer than the strong bursts, which are presumably relatively nearby (Nemiroff et al. 1994). The apparent softening of weak events is expected if they are cosmologically redshifted. However, the analysis is difficult and it is hard to asses its reliability.

Many papers with the burst spectral analysis were published. No evidence was found for any spectral lines (Palmer et al. 1994, Band et al. 1994b). Continuum spectra were analyzed by Pendleton et al. (1994) and by Band et al. (1993). In the last paper it was found that a broken power law provides a reasonably good fit to most spectra, with the break occurring at different energies for different bursts, anywhere between 100 keV and 1 MeV. The limits on this range are presumably instrumental. On the high energy side the most common spectrum is a power law with equal power per decade of photon energies. The hardest photons ever detected (by EGRET experiment on Compton GRO) were in excess of 10 GeV.

There was no breakthrough on the theoretical side. The community seems to be split between the proponents of the galactic and the cosmological distance scales. A general model in which the ultimate source (the central engine) remains active for the duration of the burst and ejects a large number of highly relativistic shells (jets?) with a range of Lorentz factor is my personal favorite (Paczyński & Xu 1994, Rees & Meszaros 1994). In this scenario the gamma-ray photons are produced as a result of collisions between the shells. This way, the long duration of the whole event and the rapid time variability can be both satisfied, at least in principle. It is my personal opinion that we have no clue as to the nature of the central engine. If, for whatever reasons, we restrict ourselves to the kinds of objects which almost certainly are known to be formed, my favored is a neutron density disk around a Kerr black hole of a stellar mass (Witt et al. 1994), a micro-quasar. It may be relevant (or not) that the first superluminal sources (micro-quasars) were found in our galaxy (Mirabel & Rodriguez 1994). They resembe quasars in many respects, though it is hard to imagine that neutron density disks are involved in them. It is also interesting that spectra of quasars that have ultra-relativistic jets beaming at us have hard gamma-ray spectra similar to those of gamma-ray bursts, and they also show large amplitude variability on time scales as short as a week or so (Hartman et al. 1992).

It is clear that not much progress will be made without identifying gamma-ray bursts in some other energy bands. There is no doubt that the bursts are explosive phenomena. It is known that all energetic explosive phenomena, supernovae, active galactic nuclei, form radio remnants, large volumes within which the interaction between the ejecta and the ambient matter (interstellar or intergalactic) leads to synchrotron radio emission. Therefore, it makes sense to look for radio remnants around gamma-ray bursts (Paczyński & Rhoads 1994). Such searches are now in progress but no success has been reported yet.

It has been known for many years that there are three objects, called Soft Gamma Repeaters (SGR) which have much softer spectra than the classical gamma-ray bursts (GRB). In fact the SGR spectra may be reasonably approximated with a black body at $T \approx 15\ keV$. All three are known to repeat. One, the famous March 5 1979 event, was known to have its very small error box $\sim 10'' \times 40''$ superposed on a supernova remnant in the Large Magellanic Cloud. The other two SGRs were known to be near the galactic plane, and in the last two years young supernova remnants were found in their error boxes (Cline et al. 1982, Kulkarni et al. 1994, Murakhami et al. 1994, Vasisht et al. 1994) supporting the suggestion by Kouveliotou et al. (1987) and by Norris et al. (1991) that these objects are related to the young Population I. Among the SGR events one is rather unique: the first 0.2 seconds of the March 5 1979. It was a few hundred times more intense than the soft tail which lasted for a few minutes, and oscillated with the 8 second period. Also, the spectrum was much harder during the first 0.2 seconds, while the rapid rise to the peak took less than 0.2 milliseconds. There was nothing like that among the 100+ events observed to date from all three SGRs. Given the known (or reasonably well guessed) distance to SGRs their typical peak luminosity is $\sim 10^4\ L_{Edd}$, and for the initial spike of the March 5 1979 it was more like $\sim 10^7\ L_{Edd}$ for a neutron star mass object.

The only rational reason to expect classical gamma-ray bursts to be within our galaxy is the analogy with X-ray bursts (XRB) and with SGRs. In case of XRBs there was never a problem with their distance scale: their distribution over the sky, i.e. the concentration of sources towards the galactic plane and the galactic center, as well as association with some globular clusters put them at $\sim 8\ kpc$. The identification of young supernova remnants with the three SGRs also leaves no doubt about the distance scale. The sky distribution of the GRBs is dramatically different, being isotropic to within statistical noise. At the same time we see GRBs to the "edge" of their distribution, the "edge" being at the same intensity, and presumably the same distance in all directions. If GRBs were in our galaxy our offset of 8 kpc away from the galactic center has to be undetectable. This required that the core of the distribution, the region over which GRBs have constant volume density, must have a radius of over 30 kpc, unprecedented by any galactic component. Notice, that not only XRBs and SGRs, also all other known types of the galactic objects show strong concentration towards the galactic center and/or towards the galactic plane. I think the analogy between GRBs and SGRs and XRBs is too weak to be of any significance.

On the following few pages you will find the distribution of the first 1000 BATSE bursts over the sky, shown in the galactic coordinates (Fig. 1), and the distribution of the number of PVO and BATSE bursts as a function of their peak intensity (Fig. 2). The last three figures show examples of time variability among randomly chosen 24 BATSE bursts.

REFERENCES

Band, D. et al. 1993, ApJ, 413, 281

Band, D. L. et al. 1994a, ApJ, 432, L23

Band, D. L. et al. 1994b, ApJ, 434, 560

Blaes, O. N. 1994, ApJSuppl., 92, 643

Cline, T. L. et al. 1982, ApJ, 255, L45

Fenimore, E. et al. 1993, Nature, 366, 40

Fishman, G. J., Brainerd, J., & Hurley, K., Editors, 1993, AIP Conf. Proc. 307: "Gamma-Ray Bursts" (New York, American Institute of Physics)

Fishman, G. J. et al. 1994, ApJSuppl., 92, 229

Hakkila, J. et al. 1994, ApJ, 422, 659

Hartman, R. C. et al. 1992, ApJ, 385, L1

Kouvolietou, C. et al 1987, ApJ, 322, L21

Kouvolietou, C. 1994, ApJSuppl., 92, 637

Kulkarni, S. R. et al. 1994, Nature, 368, 129

Mirabel, I. F., & Rodriguez, L. F. 1994, Nature, 371, 46

Murakhami, T. et al. 1994, Nature, 368, 127

Nemiroff, R. et al. 1994, ApJLett, 435, L133

Norris, J. P. et al. 1991, ApJ, 366, 240

Norris, J. P. et al. 1994, ApJ, 424, 540

Paczyński, B., & Rhoads, J. 1994, ApJ, 418, L5

Paczyński, B., & Xu, G. 1994, ApJ, 427, 708

Palmer, D. M. et al. 1994, ApJ, 433. L77

Pendleton, G. N. et al. 1994, ApJ, 431, 416

Rees, M. J., & Meszaros, P. 1994, ApJ, 430, L93

Schaefer, B. E. 1993, ApJ, 404, L87

Schaefer, B. E. et al. 1994, ApJSuppl., 92, 285

Vasisht, G. et al. 1994, ApJ, 431, L35

Witt, H. J. et al. 1994, ApJ, 422, 219