Conference Report: Highlights of the Second
Huntsville Gamma Ray Burst Workshop
(20–22 October 1993, Huntsville, Alabama)

Since its launch in April 1991, the Compton Gamma Ray Observatory (CGRO) has provided a vast amount of data on both the "classical" γ-ray bursts and the soft gamma repeaters (SGRs). Combined with data obtained from other satellites, there is now a wealth of information on the γ-ray burst phenomenon. For the "classical" bursts, however, this wealth of information has provided more questions and controversies than answers, and so their nature remains an enigma. In contrast, owing to the discovery of possible counterparts at other wavelengths, the nature of the SGRs appears closer to a solution. I give a critical discussion here of the major questions and controversies concerning the "classical" bursts that were covered at the workshop. Following this, I summarize the new observations of a possible Galactic supernova remnant counterpart to one of the three known SGR sources, SGR1806–20. If confirmed, this would strongly suggest that neutron stars are the sites of the SGR phenomenon.

Key Words: classical γ-ray bursts, soft gamma repeaters (SGRs), BATSE, repetition, reprocessing, lines

1. INTRODUCTION

The Huntsville Gamma Ray Burst Workshop held in Huntsville, Alabama on October 20–22, 1993 was the second of these workshops dedicated to a discussion of new developments in the study of "classical" γ-ray bursts and soft gamma repeaters (SGRs). The first such workshop was held in Huntsville in October 1991, six months after the launch of the Compton Gamma Ray Observatory.
(CGRO). In October 1992, the subject of γ-ray bursts shared center stage with other phenomena at the Compton Symposium, which was held at the Washington University in St. Louis, Missouri. The topics covered in the first Huntsville workshop and the Compton Symposium are described in the AIP Conference Proceedings Nos. 265 and 280, respectively.

Over 170 contributions were presented at this year’s workshop. Instead of undertaking the virtually impossible task of reporting on every contribution, I focus my discussion here on what I consider the major highlights of the workshop. Regarding the “classical” bursts, they are: (1) the classification of bursts, (2) the burst sky distribution, (3) burst repetition, and (4) the status of the search for absorption-like features in burst spectra obtained from the Burst and Transient Source Experiment (BATSE) onboard the CGRO.

On the SGRs, a flurry of excitement surrounded the observations of a possible Galactic supernova remnant counterpart to one of the three known SGR sources, SGR1806–20. A special session during the workshop was organized to allow for the presentation and discussion of these observations. I shall summarize these observations and briefly mention a plausible neutron star model for SGRs that was presented.

The discussion in this paper is oriented towards the observations. This is deliberate because with regard to the “classical” bursts, many of the issues covered at the workshop concern the data and their interpretation. At present, the data are still not sufficiently constraining to allow for significant theoretical progress. On the other hand, the situation may be quite different for the SGRs, especially if the observations of counterparts in supernova remnants are confirmed.

2. CLASSICAL GAMMA RAY BURSTS

2.1 Burst Classification

The discussion centered on two main questions: (a) Are there two classes of bursts and (b) what is the proper classification scheme?

C. Kouveliotou (USRA, NASA/MSFC) and her colleagues on the BATSE team find that classical γ-ray bursts are bimodal in burst duration with the minimum lying around 2 sec. The duration definition is called T90, which is the time interval of the burst encompassing 90% of the total counts, 5% of the counts at the beginning and end of the burst being excluded. D. Q. Lamb (Chicago) and C. Graziani (Chicago) find that bursts can be classified according to variability (V) with \( V = \frac{C_{\text{max}}(64 \text{ ms})}{C_{\text{max}}(1024 \text{ ms})} \).

Smooth (Type I) bursts have \( V < 0.16 \) while spiky (Type II) bursts have \( V > 0.16 \). Are the two classification schemes the same? W. H. G. Lewin (MIT) and R. Rutledge (MIT) point out that if burst time profiles are top hats, then there exists a definite relationship between \( V \) and duration and so the two variables are equivalent. However, burst time profiles are not top hats. Specifically, there are bursts which have a sharp spike only, and bursts which have a sharp spike together with some low level emission. Duration-wise, one is short and one is long, but both have the same \( V \) owing to the spike. Thus, \( V \) and T90 are not the same. Which scheme then is more fundamental? No consensus was reached on this point. This is because, at present, it is hard to discern a difference in the \( V \) and T90 classifications. In particular, in the current burst sample, most spiky (Type II) bursts are short and most smooth (Type I) bursts are long. The exceptions to these cases are classified differently according to T90 and \( V \), but are few in number. It will be necessary to build up their numbers before it becomes possible to decide which classification scheme is superior. This, however, may take a long time. Nevertheless, the bottom line is that classical bursts do indeed seem to fall into (at least) two classes. R. Narayan (Harvard) points out that this does not necessarily mean that there is more than one parent population. In fact, all parties agree that the typical peak luminosities in the two classes could be the same. The bursts may therefore still be drawn from the same parent population, though this is not required.

2.2. Burst Sky Distribution

Much of the discussions here centered on the viability of a Galactic model for the burst sky distribution proposed by J. M. Quashnock (Chicago) and D. Q. Lamb.

C. A. Meegan (NASA/MSFC) of the BATSE team presented
the sky distribution of 743 bursts. The overall distribution is indeed highly isotropic. Combining this with the fact that BATSE sees an edge in the brightness distribution, and assuming a single population to account for all the bursts, D. H. Hartmann (Clemson) concludes that Galactic (halo) models are virtually ruled out. However, multiple populations are not ruled out. They may not satisfy Ockham's Razor, but then in astrophysics, Ockham's Razor is not always reliable. The most well known and controversial of the multi-population models is the Galactic model of J. M. Quashnock and D. Q. Lamb (hereafter Q&L). They assert that faint and bright bursts are isotropic while the medium bright bursts are anisotropic with a concentration towards the Galactic center and Galactic plane. They picture a spiral arm association for the bursts with the bright and faint bursts coming from the local (Orion) and Perseus arms and the medium bright bursts coming from the Sagittarius arm. Their work is based upon the 260 bursts in the public catalogue. BATSE now has seen 743 bursts. The BATSE team claims that the effects reported by Q&L do not exist in the new dataset. However, the BATSE team has not yet reprocessed the positions of the new bursts (see the end of this section for an explanation of reprocessing). Q&L claim that the reprocessed positions may significantly affect the quadrupole moments in the burst brightness subsamples, though how it does so they did not make clear. In addition, owing to tape recorder problems on the CGRO, there exists a large number of bursts in the new sample which have gaps in their time histories. For these bursts, it will not be possible to determine their $C_{\text{max}}$ and hence their brightness category. Thus, although the number of bursts has increased, the actual number of bursts in the brightness subsamples that Q&L use in their distribution analysis may not increase substantially. Consequently, it may not be possible to confirm or rule out the results of their analysis for some time.

A note on "reprocessing": Reprocessing means calculating burst positions using a new algorithm that provides a more careful treatment of effects such as atmospheric scattering. According to M. S. Briggs (UA—Huntsville) of the BATSE team, the difference compared to the unprocessed positions is of the order of one statistical standard deviation (anywhere from < 1 deg to 20 deg), but can be as large as two or three standard deviations. How the various effects give rise to the change in the burst positions after reprocessing is not understood.

2.3. Burst Repetition

The debate here focused on the question of whether the classical bursts repeat.

Q&L claim that not only is there evidence that bursts repeat, but that there is evidence for multiple repeaters. This would explain why the clustering angular size obtained from their nearest neighbor analysis (~ 5 deg) is less than the size expected from the individual burst error circles (~ 7 deg). The evidence against nearest neighbor clustering is that there is also farthest neighbor clustering, seen both in nearest (farthest) neighbor analysis and in two-point angular correlation analysis. The farthest neighbor (antipodal) signal is quite narrow, being confined to a 4 deg bin near 180 deg in the two-point angular correlation analysis done by R. Narayan and T. Piran (Hebrew). Q&L claim that the anisotropic medium bright population gives the antipodal peak and that removing this population removes this peak. Thus, the farthest neighbor peak is a manifestation of anisotropy. Although it seems reasonable that a (anisotropic) disk subpopulation could give rise to an antipodal signal, it is not clear how Q&L's anisotropic medium bright population could account for the precise form of the observed antipodal signal (specifically, its narrowness).

Q&L assert that multiple repeaters are mainly responsible for the nearest neighbor correlation. This explains why the nearest neighbor signal using two-point angular correlation analysis is small (< 2$\sigma$, cf. Narayan and Piran) since this analysis is sensitive only to pair-wise correlations, i.e., to bursts that repeat only once. In contrast, the nearest neighbor analysis contains all the higher moments and so is more general than the two-point angular correlation analysis. Some of the people that did the two-point angular correlation analysis (e.g., Narayan and Piran) suspect that the higher moments (and hence multiple repetitions) are not important, but they have not calculated the higher moments and shown that they are small.

The BATSE team claims to find no evidence for repetition in the latest sample of 743 bursts. But this claim is based upon the
unreprocessed burst positions and is therefore not convincing. It is important to note that in their original analysis using the unreprocessed positions of 191 bursts in the public catalog, Q&L do not find the repetition signal. This signal appeared only when the reprocessed positions were used. The BATSE people assert that they don’t think the reprocessed positions in the latest sample will make a difference, but they also admit that they really don’t know for sure. It is important to check for the repetition signal in the new data using the reprocessed positions. This will take several months.

Assuming that bursts repeat, T. E. Strohmayer (LANL), E. E. Fenimore (LANL), and J. A. Miralles (Valencia) find from Monte Carlo simulations using a burst repetition model that uncertainties in the locations of the 260 BATSE catalog bursts (the same sample used by Q&L in their analysis) make it very difficult to determine with confidence whether repetition is present if the repeating fraction is < 15%. From a fit of their burst repetition model to the 260 bursts they find a “best fit” of 21% for the repeating fraction with a 90% confidence range of 5–30%. However, they also find from modifying the positional uncertainties in their simulations that both the best fit value and the confidence region depend sensitively on the burst positional uncertainties. As a result, they emphasize that a resolution to the repetition issue will come not so much with more bursts, but with better burst localizations. In particular, it will be very essential to reduce the current systematic errors (∼ 4 deg) in the BATSE burst positions—a very challenging task.

Two other developments make the repetition picture more intriguing. V. C. Wang (UCSD) and R. E. Lingenfelter (UCSD) did cuts on time in looking for spatial clustering. Using 4 days as a cut, they looked for pairs which are separated spatially by 4 deg or less. They expected to find one pair in the burst sample (260 bursts) by chance. Instead, they found eight pairs. The chance probability is 2 × 10^{-5}. In the other development, A. J. Castro-Tirado of the WATCH/GRANAT team reported on the analysis of the 32 bursts in their sample of 55 which had good localizations, i.e., 3σ error circles of ≤1 deg. He reports finding two pairs of bursts among the 32 bursts which are within their 3σ error circles. The chance probability is about 1%. It is tantalizing to note that these four bursts are also the closest ones to the Galactic plane in their sample of 32—all four lie within 2 deg of the Galactic plane. The members in each pair also have superficially similar light curves, though no quantitative comparisons have yet been made. Despite this, the curves appear sufficiently different that they can be ruled out as gravitational lensing events. The time separations for the members in each pair are 8 months and two years.

All the above taken together suggests that bursts may repeat on all timescales. Indeed, R. E. Lingenfelter and V. C. Wang point out that if one adopts the repetition criterion for SGRs, then some classical bursts already repeat on timescales of seconds to hundreds of seconds. Towards the end of the conference, it appeared evident that the case for repetition must be examined more closely and cannot be discarded lightly. When put to a vote, even ardent proponents of cosmological burst models like B. Paczyński (Princeton) cannot be sure that classical bursters do not repeat. However, T. Piran points out that repetition does not rule out cosmological models, though it would rule out models involving neutron star–neutron star collisions.

2.4. Status of Line Search

There were discussions on the existence of lines, specifically, absorption-like features in the tens of keV range, in burst spectra. The presence of such lines in the spectra of several bursts seen by experiments previous to BATSE (KONUS, HEAO-1, Ginga) has been the strongest evidence for a Galactic neutron star origin for the classical bursts. This is because when interpreted as electron cyclotron scattering features, the lines imply the presence of strong magnetic fields (several × 10^{12} G) in the sources, and only neutron stars are known to possess such strong fields. These neutron stars cannot be at cosmological distances because the energy release required (∼ 10^{42} ergs) far exceeds the free energy available in the magnetic field (∼ 10^{42} ergs). (The energy required could come from the destruction of the star, as in, for example, a neutron star–neutron star collision. But in this case, no lines would be expected.)

According to D. M. Palmer (NASA/GSFC) of the BATSE team, they have not found any significant lines after looking at 150 spectra. However, D. L. Band (UCSD) reports that this still does not
contradict the Ginga line observations. In the discussions, there arose questions about the effectiveness with which the BATSE spectroscopy detectors (SDs) could detect lines.

First, the issue of consistency with Ginga. One spectrum out of about 40 in the Ginga sample showed lines at a significance level of better than $10^{-4}$ (that is, the chance probability that a spectrum with really no line(s) would give rise to the observed line(s) is $10^{-4}$ or less). This is the famous pair of lines at 20 and 40 keV in GB880205 (significance = $3 \times 10^{-7}$) seen by the Ginga detectors. Monte Carlo simulations by E. E. Fenimore indicate that the Ginga detectors can see GB880205-like lines about 20% of the time, that is, its detection efficiency for GB880205-like lines is 20%. Since only one GB880205-like set of lines was detected among 40 spectra instead of 8, this indicates that the true occurrence rate of GB880205-like lines among bursts is $1/8 \pm 1/8$. Since BATSE does not report any GB880205-like lines in 150 spectra, the true occurrence rate is probably $< 1/75$ since the BATSE SD detectors have about a 50% efficiency in detecting GB880205-like lines (the BATSE detectors are sensitive only to the 40 keV line). This is still consistent with $1/8 \pm 1/8$, though it suggests that GB880205-like lines are rare. It should be noted, however, that all studies regarding the consistency between Ginga line detection and BATSE non-detections assume lines that are like those seen in GB880205. The burst GB880205 is one of the brightest (and hardest) Ginga bursts. If one selected only those spectra out of the 150 in the BATSE sample that belonged to bright bursts, one would obtain an upper limit to the true occurrence rate for GB880205-like lines which is larger than 1/75. Indeed, if one were to restrict oneself to bursts which resemble GB880205 in other aspects (e.g., hardness and duration), the upper limit would be further increased from 1/75. Thus, one should regard the value of 1/75 as a lower upper bound for the fraction of bursts that possesses GB880205-like lines in their spectra.

Secondly, the issue of BATSE's line detection capability. For a line to be deemed significant, BATSE protocol requires (1) the line(s) be seen with significance $10^{-3}$ or better in at least one detector, and (2) consistency between detectors. In one burst (GB930506), L. Ford (UCSD) of the BATSE team reports that a third rank SD detected an absorption feature with $6 \times 10^{-3}$ significance at about 56 keV. Photons entered this detector at a large incidence angle (~ 70 deg) so the detector response was not great, hence the ranking. Photons entered the second rank SD at about 50 deg. The spectrum from the second rank detector had instrumental distortions below about 55 keV which complicated the determination of the continuum below the candidate line feature and the line feature itself (the instrumental distortions are called SLEDs for Spectral Low Energy Distortions). After applying a "reasonable but ad hoc" correction to account for the SLED, a poor significance (0.73) was obtained for the line feature from the second rank detector alone. Since a significance level of better than $6 \times 10^{-3}$ was expected, the consistency condition was not satisfied and a definite detection of the line could therefore not be claimed. Joint fits including the count rate data from both detectors to assess the significance of the line feature have not yet been carried out. The photons from this burst entered the first rank detector at about 40 deg. However, the low gain setting on the first rank detector made it sensitive only to photons above 150 keV which rendered it incapable of verifying the candidate line feature. Since at least two of the eight SDs have the low gain settings to date, the BATSE line detection capability is almost certainly compromised.

Another point concerning the SD's ability to detect lines has to do with the SD observations of Her X–1. The SDs were pointed at Her X–1 to check if they could see the cyclotron absorption-like feature at 35 keV. The BATSE team claims that the SDs do indeed see the feature, though it appears at 45 keV instead of 35 keV. It is not possible to fit the spectrum with an absorption feature at 35 keV. Since all previous instruments that observed Her X–1 (e.g., balloon experiments, HEAO-1, Ginga) see an absorption-like feature at 35 keV, this is cause for some worry. One explanation the BATSE team offers is that the emission region on the neutron star has somehow shifted since the Ginga observations (3–4 yrs ago). While this cannot be ruled out, it appears implausible given the steadiness of the line feature as verified by many instruments across nearly 15 years of observations. One way to resolve this discrepancy is to make further observations of Her X–1 with the SDs to improve the statistics of the line feature.

At the conclusion of these discussions, the issue of whether lines exist in classical bursts remains unresolved.
2.5. Summary

At the end of the workshop, the debate over whether the classical bursts are cosmological or Galactic in origin was put to a vote. Compared to the Compton Symposium in St. Louis one year ago where the split was 50–50, the split this time was roughly 60–40 in favor of the cosmological model. Most people, including M. Rees (Cambridge), seem swayed by the high isotropy of the latest sample of bursts (taken as a whole).

For the classical bursts, the results of the discussions on the four issues described above may be very briefly summarized as follows:

1. Are there two classes of bursts? Yes.
2. Is there an anisotropic medium bright population of bursts? Unresolved.
4. Do lines exist? Unresolved.

The nature of the classical bursts remains an enigma.

3. SOFT GAMMA REPEATERS (SGRs)

In contrast to the classical (hard) γ-ray bursters, the nature of the SGRs appears closer to a solution. There are now possible quiescent counterparts in radio and X-rays to the SGR SGR1806–20 which is located within 7 deg of the Galactic center. The latest development, reported by T. Murakami (ISAS/Japan), is that the instruments onboard the ASCA satellite sees an X-ray quiescent counterpart to SGR1806–20. The spectrum below 1 keV has photon spectral index $\alpha = 1(dN/dE \propto E^{-\alpha})$, consistent with a Rayleigh–Jeans spectrum, $\alpha = 0$ between 1 and 3 keV, and $\alpha = -1.8$ above 3 keV to the detector limit of 10 keV. The spectrum below 1 keV can be modeled as absorption with an $N_H = 10^{24}$ cm$^{-2}$, a very reasonable column density towards the Galactic center.

D. A. Frail (NRAO) reported on radio, optical, and IR observations of the young ($\lesssim 10^4$ yrs) radio supernova remnant (SNR) G10.0–0.3 which lies inside the error box of SGR1806–20. This SNR is about 15 kpc (from surface brightness/diameter relation for SNR) in the direction of the Galactic center, though the uncertainties in the distance determination are large. There are three SGRs observed to date, two in the Galaxy (SGR1806–20 and SGR1900+14) and one in the LMC (SGR0526–22, repeaters of the famous March 5 event). Both the Galactic SGRs lie close to the Galactic plane ($b < 4$ deg) in the general direction of the Galactic center. Two of the three are now associated with young ($\lesssim 10^4$ yrs) SNRs, N49 for SGR0526–22 and G10.0–0.3 for SGR1806–20. The radio photon spectral index (90 cm, 20 cm) for the radio source in G10.0–0.3 is $\alpha = -1.8$ (note the similarity in the spectral index between radio and X-rays). Frail notes that this spectral index is steeper than expected for a plerion source (e.g., $\alpha = -1.3$ for the Crab SNR). There is an optical source ($I = 21$ mag) sitting atop the radio source, but it is mostly likely not associated with the SNR owing to the large extinction towards the Galactic center. There is also an IR source 2.5" west of the radio source, but Frail thinks it is probably also not associated with the SNR because it is displaced 2.5 standard deviations from the radio source.

Both BATSE and ASCA have seen SGR1806–20 in outburst. One of the BATSE burst spectra has been analyzed. As shown by R. D. Price (NASA/MSFC), the ASCA spectrum is well fit by a thermal bremsstrahlung spectrum with $kT = 30$ keV, fairly typical for SGRs in outburst. Murakami reports that the ASCA spectrum shows a peak at 7 keV with rapid fall-off below 7 keV. The spectral shapes below and above the peak have not been determined, all the reports being labeled as extremely preliminary (even as he spoke, ASCA was making more observations of SGR1806–20). If one interprets the fall-off below 7 keV as due to absorption, a hydrogen column density of $\sim 10^{24}$ cm$^{-2}$ is required. This may be too large for comfort. Alternatively, the spectrum may be an emission hump with peak at 7 keV.

Assuming SGR1806–20 lies at 15 kpc, the X-ray luminosity in quiescence ($1 - 10^7$ keV) is about $10^{41}$ erg/sec—highly sub-Eddington if the source is an $\sim 1$ solar mass object. One of the bursts BATSE observed has a luminosity between 75 and 100 keV of about $3 \times 10^{40}$ erg/sec—highly super-Eddington. The bursts have similar time profiles but very different intensities. In addition, the spectra of SGRs display little or no evolution throughout each burst event.
On the theory side, R. C. Duncan (UT–Austin) reported on a model of SGRs that he constructed with C. Thompson (CITA) in which the sudden energy release for each burst event is triggered by magnetic reconnection near the surface of ultra-strongly magnetized neutron stars with surface fields \( \approx 10^{14} \) G. He showed that this model can explain reasonably well the observed flux, spectra, and durations of SGR events.

With the latest observational developments, one may expect a flood of theory papers on the SGR phenomenon.

Acknowledgments

I thank Dave Band, Don Lamb and Tom Loredo for critical discussions on the many points presented in this paper. This work was supported in part by NASA grant NAGW-766 and NSF grant AST91-20599.

JOHN C. L. WANG
JILA,
University of Colorado,
Campus Box 440,
Boulder, Colorado 80309