AN UNUSUAL HIGH ENERGY TRANSIENT

T.E. STROHMAYER, E.E. FENIMORE, T. MURAKAMI, and A. YOSHIDA

LHEA

LABORATORY FOR HIGH ENERGY ASTROPHYSICS

National Aeronautics And Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

X-RAY: 95-07

AN UNUSUAL HIGH ENERGY TRANSIENT

T.E. Strohmayer[1], E.E. Fenimore[2], T. Murakami[3], and A. Yoshida[4]

Code 666
X-ray Astrophysics Branch
Laboratory for High Energy Astrophysics
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771 USA

Accepted for publication in The Astrophysical Journal

[1]Also Universities Space Research Association
[2]Los Alamos National Labortory
[3]Institute of Space and Astronautical Science
[4]Institute of Physical and Chemical Research

An Unusual High Energy Transient

T. E. Strohmayer[1], E. E. Fenimore[2], T. Murakami[3], and A. Yoshida[4]

To Appear in the Astrophysical Journal

Abstract

We report the detection of an unusual high-energy transient by the γ-ray burst detectors onboard the satellite *Ginga*. This event was much softer than classical γ-ray bursts, with a spectrum that peaks between 16-18 keV, and decreases both above and below the peak. A thermal bremsstrahlung fit to the 20-400 keV emission gives a characteristic temperature of $\approx$ 24 keV; much softer (cooler) than the $>$ 100 keV temperatures characteristic of the classical γ-ray bursts, but similar to that of the soft γ-ray repeaters (SGRs). The spectrum above the peak is similar to that of type I X-ray bursts, however, the peak energy is higher by about a factor of 5, well above the Eddington limit. We have established with high confidence that the spectrum rolls over below 15 keV. Spectral models which include photoelectric absorption from neutral matter with column densities of $\approx 10^{24}$ cm^{-2} give acceptable fits to the low energy rollover, as does a power law fit with an index $\alpha \approx -2.5$. Power law models with indices greater than -1.5 are strongly rejected by the data (A Rayleigh-Jeans spectrum has index -1.0). The time history of the event is simple, with a rise-time of $\approx$ 0.7 seconds followed by an exponential decay with a 3 second time-scale, similar to those seen from type I X-ray bursts as well as some classical γ-ray bursts, but somewhat unusual for a SGR.

[1] Laboratory for High Energy Astrophysics, NASA Goddard Space Flight Center, Greenbelt, MD 20771: stroh@pcasrv.gsfc.nasa.gov

[2] Los Alamos National Laboratory, Los Alamos, NM 87545

[3] Institute of Space and Astronautical Science, 1-1 Yoshinodai 3, Sagamihara, Kanagawa, 229 Japan

[4] Institute of Physical and Chemical Research (RIKEN), 2-1, Hirosawa, Wako, Saitama, 351-01, Japan

1. Introduction

At present there are three generally recognized classes of short duration high-energy transients, X-ray bursts, the classical γ-ray bursts, and the soft γ-ray repeaters (SGRs). The classical bursts are characterized by hard, often time-varying spectra, and are not known definitively to repeat. Below a few hundred keV their continuum spectra are often well fitted by thermal bremsstrahlung models with a mean temperature of about 300 keV, although there is considerable scatter around this value (Band *et al.* 1993; Mazets *et al.* 1982). The time histories of classical bursts are often multipeaked, and generally last longer than several seconds, although a perhaps distinct subset of bursts has been identified with durations less than a second (Kouveliotou *et al.* 1993). In contrast, SGRs typically show time-independent, soft, exponential spectra similar to thermal bremsstrahlung with $kT \approx 20-40$ keV (Atteia *et al.* 1987; Laros *et al.* 1986 ; Kouveliotou *et al.* 1987; and Fenimore, Laros & Ulmer 1994). Their time histories are generally simple, single peaked, and last less than 1 s. type I X-ray bursts represent a still softer short duration transient. These events typically show a 1-2 keV thermal spectrum, and often show evidence for cooling in the tail of the burst. Time histories of these events generally show a $\leq$ 1s rise followed by an exponential decay over several seconds. Sources of these transients are known to undergo periods of repeated bursting (Lewin, van Paradijs & Taam 1993).

In this work we report on the detection by *Ginga* of a transient which appears to share some of the characteristics of classical bursts, SGRs, and type I X-ray bursts, but which does not fit neatly into either of these classifications. This burst also shows a rollover in the spectrum below 16 keV which could be produced by absorption of photons, either in the immediate neighborhood of the source (source becoming optically thick) or from neutral absorbing material along the line of sight to the burst. In §2 we discuss the evidence supporting our interpretation of this event as of cosmic origin. In §3 we describe both its temporal and spectral properties. Finally, in §4 we discuss the classification of this event in terms of the known classes of high energy transients.

2. GB900129: A Local or Cosmic Transient?

The γ-ray burst detector (GBD) aboard *Ginga* consisted of a proportional counter (PC) sensitive to photons in the 2-25 keV range, and a scintillation counter (SC) covering the 15-400 keV range (Murakami *et al.* 1989) , each with an $\approx \pi$ steradian field of view. On January 29, 1990, an unusual event (GB900129) was observed which to our knowledge was not recorded by other space instruments capable of recording the event. The experiments which could have seen the event are Pioneer Venus Orbiter (PVO) and the WATCH X-ray monitor aboard GRANAT. PVO did not trigger on the event (which is not surprising given the softness of its observed spectrum), and real-time data from PVO for this epoch are not available. Similarly, the WATCH instruments have no available data for the relevant time and date (Castro-Tirado 1994). Since it was not observed by other instruments an accurate position for the burst is not known, however, the GBD was pointing in the general direction of the Galactic anticenter at the time of the event (field of view centered on $\alpha = 153.8°$, $\delta = 9.8°$).

We have rejected the possibility that this event was due to trapped particles striking the spacecraft or entering the detectors. The radiation background monitor (RBM) of the GBD, which continuously monitored the energetic particle background in the vicinity of the spacecraft, recorded a stable background during the time interval of this event. The ground track placed the spacecraft over longitude 273°, lattitude $-7°$, above the Pacific ocean about 500 km west of Peru at the time. This location is not known as a source of unusual particle flux (Horack *et al.* 1992). The observed spectrum (see below) implies that particles would have had to deposit roughly the same energy in both the PC and SC detectors to produce the observed event. However, particles lose different amounts of energy traversing the detector filters (0.984 mg/cm^2 for the PC, and 53.8 mg/cm^2 for the SC), thus no practical particle distribution could have produced the observed spectrum. Spurious particle events are known to be produced by orbiting power reactors, however, there were no reactors in orbit at the time of this burst. It therefore seems unlikely that this event was produced by particles. Although the sun was not occulted by the earth at the time of the burst, *Ginga* always points away from the sun, thus a solar origin for the event would require scattering from the earth's atmosphere which appears unlikely given the observed spectrum and time history. Finally, the agreement between the PC and SC channels in their overlap regions of the deconvolved spectrum indicates that this event was indeed due to photons and that the event did not enter the detectors through the back of the spacecraft. The background had a modest change in slope near the time interval of the burst. However, such changes are not that unusual for a low earth orbit experiment.

Because of the unusual properties of this event and because *Ginga* was the only satellite to record it, one might question whether this burst was actually due to a cosmic source. The Burst and Transient Source Experiment (BATSE) on the *Compton* Gamma Ray Observatory has also detected a pair of events with properties somewhat similar to those of the *Ginga* transient reported here (Kouveliotou 1993). The direction to these sources determined by BATSE indicates that the events occurred towards the limb of the earth. A small portion of the *Ginga* GBD field of view at the time of the burst (about 50° off axis) includes the limb of the earth, thus the orientation of *Ginga* at the time of the event cannot alone conclusively exclude an atmospheric origin. This allows the possibility that the source of photons was located in the earth's atmosphere, and was not cosmic in origin. In order to further explore this possibility we have conducted an extensive series of Monte Carlo atmospheric transfer experiments with photon sources located in the earth's atmosphere. We find that thermal bremsstrahlung sources located at approximately 60 km altitudes can produce a spectrum similar to that recorded by *Ginga* when viewed at angles toward the earth's limb. However, several factors argue against this interpretation. First, the region above the earth consistent with the orientation of the GBD field of view at the time of the event is within ±20° of the equator. With respect to the dipole magnetic field this implies an L-shell range of about 1.0 - 1.2. Observations of bremsstrahlung produced by precipitating electrons indicate that such processes occur mostly at more polar lattitudes in the interval $L \geq 4$ (*cf.* Imhof, Kilner & Reagan 1985; Imhof *et al.* 1992 and West & Parks 1984). Second, the time history, a single transient event of only a few seconds duration, is not typical of electron precipitation events or magnetospheric substorms (*cf.* Imhof *et al.* 1992). In addition, measurements of the trapped electron flux at geostationary orbit on the date of this event suggest that the magnetosphere was actually unusually quiet (Reeves 1993, private communication). Third, only electrons with energies greater than about 500 keV actually penetrate to an altitude of 60 km (*cf.* Berger & Seltzer 1972), therefore, the appearance together of the spectral peak at 18 keV and the strong rollover are extremely difficult to reconcile in terms of an atmospheric origin. Although the present data cannot definitively exclude such an origin for this event, the lack of any previous confirmation or detection of such electron precipitation induced transients, especially at low magnetic latitudes, supports our interpretation of this event as cosmic in origin.

3. Temporal and Spectral Properties

In Figure 1a we show the time history of the burst as recorded by the PC (lower profile) and SC (upper profile) detectors. The time resolution for these observations was 0.5 seconds. The PC and SC profiles are quite similar and reveal a single peaked light curve. We have fit the following model to both time histories,

$$I(t) = At + B + C\exp(-(t - t_p)/\tau_d) \quad t > t_p$$

$$I(t) = At + B + C\exp(-(t_p - t)/\tau_r) \quad t < t_p \ . \qquad (1)$$

Here, t_p is the time of the peak intensity in the burst, τ_r is the rise-time, and τ_d the decay-time. The constants A and B, specify a linear background fit, while C gives the peak count level. Also shown in figure 1a are the best-fit curves for this model of the time history. The best-fit model parameters for both the PC and SC time histories are given in table 1. In addition to the above model parameters table 1 contains the reduced χ^2_{red} and the width of the peak W_{fwhm} for both the PC and SC profiles.

The time profiles indicate that the background was decreasing approximately linearly through the burst interval. The PC and SC profiles have rise-times of 0.74 and 1.18 s, respectively, but the SC profile has a shorter decay-time than the PC. In addition, the full width at half maximum of the SC profile is marginally smaller than that for the PC profile. Interestingly, this pattern appears to be consistent with classical γ-ray burst time histories whose emission features often appear narrower at higher energies (Link, Epstein & Priedshorsky 1993). Figure 1b shows the time history of the burst in five different energy ranges, two for the PC and three for the SC detectors.

The softness of this burst is evident in the paucity of photons above 100 keV. Also notice the lack of photons in the lowest energy ranges.

Spectral information was available in 16 PC channels and 32 SC channels at 0.5 second intervals across the entire burst profile. We have removed the lowest energy channels from both the PC and SC in our spectral fits since both of these channels have essentially zero effective area, and therefore do not significantly constrain the fitted spectra. To obtain an accurate estimate of the background in each energy channel we fit a linear function to 48 seconds of pre- and post-burst data. The burst signal to be modelled was obtained by subtracting these background estimates from the total observed counts in each energy channel. It is not unusual for the background to have some non-zero slope during a burst interval, and the spectral characteristics we discuss below cannot be caused by the non-zero slope in the background.

We have analysed the spectrum using a standard χ^2 fitting procedure in which a spectral model is constructed and then folded through the instrument response functions. The predicted counts are then compared to the actual detected counts and a χ^2 statistic is computed for the model. Note that in this kind of analysis the "data points" are model dependent. That is, they represent the residuals computed after folding the model spectrum through the detector response function and comparing the predicted counts with the observed counts (Loredo & Epstein 1989). This "obliging" nature of the inferred spectrum can be problematic, and requires some caution in interpretation of such spectra. Since this burst was not detected by other experiments we have no information about the incidence angle θ_{in} of the photons into the detectors. However, as mentioned previously, the z-axis direction of *Ginga* at the time of the burst indicates that the GBD was looking in the general direction of the galactic anti-center. Since the instrumental response is a function of incidence angle we have analysed models using angles of 0°, 37°, 45°, and 63°. We find that the form of the inferred spectrum is rather insensitive to the choice of viewing angle. All results quoted here were obtained assuming an incidence angle $\theta_{in} = 37°$.

To investigate the time-dependence of the spectrum we computed spectra from averages of two successive time bins across the entire burst profile. Since this analysis produced only weak evidence for spectral evolution (softening) during this burst, results given here are based on spectra computed by averaging 4 successive time samples centered on the burst peak. This time interval is delineated by the vertical dotted lines in Figure 1a, and was selected because the variation in the spectral shape was sufficiently small that acceptable values of χ^2 were obtainable.

The results of our spectral fitting are summarized in Table 2, where the values of the best-fit parameters are given for each model. Several models were found to give acceptable fits to the data in this time interval, however, all the acceptable models indicate that the spectrum is extremely soft above 20 keV; with an $\approx$ 20 keV temperature for the thermal brehmsstrahlung model with photoelectric absorption (TBPA), and that the spectrum rolls over below 16 keV. In Figure 2 we show the best fit spectrum for the comptonized black-body model also with photoelectric absorption (BBCOM) (Sunyaev & Titarchuk 1980). Note the high column density to the source implied by the two models which include photoelectric absorption. Such a value would seem excessively large for a direction near the galactic anti-center, unless the source was embedded in an exceptionally dense molecular cloud. Such high column densities are more likely to be found in circumstellar material associated with the burst. Removing the absorption component from the BBCOM model (elimination of one parameter) results in an increase in χ^2 of $\approx$ 160, producing an unacceptable fit. Figure 3 shows the best fit spectrum for a model which includes thermal brehmsstrahlung above the peak, and a power law spectrum ($\phi_{pl} \propto E^{-\alpha_{pl}}$) below the peak (TBPL). This model is somewhat artificial since the cusp region where the two components of the model join is likely unphysical. Nonetheless, comparison of the BBCOM and TBPL spectral models reveals that the burst spectrum is well constrained in the region above 18 keV, and is extremely soft. Unfortunately, it also indicates that below 15 keV the form of the spectral rollover is not as well constrained.

In order to further investigate the rollover, we have used a four component, segmented power law model to fit the spectrum. In this model one power law segment describes the rollover region below the spectral peak, while the remaining three segments describe the higher signal to noise region above the peak. We chose this model to investigate the rollover because it provides an accurate description of the spectrum above 20 keV (based on the acceptable values of χ^2), and provides a simple, one-parameter description of the steepness of the rollover region. Using this model, the best-fit slope for the rollover is $\alpha_r = -2.41$, with $P(> \chi^2) = 0.4$ for the overall fit.

We then performed a series of spectral simulations to investigate the probability of obtaining the observed (best-fit) rollover slope from simulated spectra with different rollover slopes. If we assume the true spectral index in the energy range of the rollover is -1.75 (note the Rayleigh-Jeans limit is -1.0) we find that in only 3 % of simulations computed using the other best-fit parameters (which describe the well constrained, high energy portion of the spectrum), and $\alpha_r = -1.75$, is the resulting best-fit value for α_r less than or equal to -2.41. It is, therefore, extremely unlikely that the power law index below 18 keV is greater than -1.75. This effectively rules out all models that have a thermal, Rayleigh-Jeans component. There are only a few physical processes other than photoelectric absorption by neutral material that can produce a slope steeper than Rayleigh-Jeans. Synchrotron self-absorption in a non-thermal population of electrons can produce a slope of -1.5, however, this value is even more strongly rejected than $\alpha_r = -1.75$. Optically thin synchrotron emission from a thermal population of electrons can also produce a steep spectral rollover below the fundamental cyclotron energy (Brainerd & Lamb 1987). We have fitted such models to the data and were able to obtain reasonably acceptable values of χ^2 (*cf.* model OTTS in table 1). Thus we cannot distinguish between photoelectric absorption and optically thin thermal synchrotron as the cause of the low energy rollover.

4. Discussion

How should this event be classified? Our spectral analysis indicates that it is softer than classical γ-ray bursts, which are generally distinguished by hard spectra with thermal bremsstrahlung temperatures $>$ 100 keV, and usually near 300 keV (*cf.* Band *et al.* 1993). In addition, classical bursts often show substantial spectral evolution over the course of the event. GB900129 does not satisfy either of these criteria. However, it seems to share with classical bursts the characteristic that the time profile is narrower at higher energy.

In some ways the event resembles a type I X-ray burst. The overall spectral shape, and the simple, exponential light curve are both suggestive of an X-ray burst. However, the spectrum peaks at energies about a factor of 5-6 too high for standard type I X-ray bursts. Recent work by Melia & Fatuzzo (1993) suggests that SGR spectra, like X-ray bursts, may be essentially thermal in nature but that the SGR spectral peak at higher energies than is typical for type I X-ray bursts results from a blueshift induced by bulk relativistic motion of the emitting plasma.

The spectrum of GB900129 is most closely related to those of the SGRs, being both soft and essentially time-independent, especially in light of the recent results on the X-ray spectra of SGR 1806-20 (Fenimore, Laros, & Ulmer 1994). A possible difficulty associated with this classification is the light curve, with a duration longer than is typical for most SGRs. However, SGR 0526-66, the source of the intense 1979, March 5th event has produced events with durations longer than a few seconds (Mazets *et al.* 1979), thus the duration of GB900129 does not preclude its classification as a SGR. Indeed, if such a classification can be verified it would likely mean the detection of a new SGR, since the direction of the *Ginga* GBD field of view at the time of ocurrence of GB900129 was greater than 90° away from each of the positions of the known SGRs.

With the recent identification of SGR 1806-20 with a plerionic supernova remnant (Kulkarni & Frail 1993; and Murakami *et al.* 1994) and therefore most likely a neutron star origin, interest has been renewed in the physical mechanisms which could produce these transients. Interestingly, recent spectral analysis of data from SGR 1806-20 recorded by the X-ray detectors aboard the International Cometary Explorer (ICE) suggest the possibility that column densities as high as 10^{24} cm^{-2} are present in this source (Fenimore, Laros & Ulmer 1994). As noted above, such a high column density is also consistent with the spectrum of GB900129. This, coupled with the virtually identical spectra of bursts from SGR 1806-20 and the spectrum of GB900129 suggests that a similar physical process may be at work in these events, and that they may therefore have the same progenitors, this lends additional support toward its identification as an SGR.

Based on the observed properties of GB900129 several possibilities exist with regard to its nature. As discussed previously, we cannot definitively rule out an atmospheric origin for this event. However, based on spectral characteristics, especially the similarities with SGR 1806-20, the SGR identification would seem to be the most plausible. Future detections of similar events from the region of the sky consistent with the GBD field of view would provide strong evidence supporting this interpretation.

It is a pleasure to acknowledge helpful discussions with G. Reeves, W. Feldman, and M. Thompson. This work was supported at Los Alamos by the United States Department of Energy.

References

Atteia, J. L., *et al.* ApJ, 1987, 320, L105

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

Berger, M. J., & Seltzer, S. M., 1987, J. Atm. Terr. Phys., 34, 85

Brainerd, J. J., and Lamb, D. Q., 1987, ApJ, 313, 231

Castro-Tirado, A. J., 1994, private communication

Fenimore, E. E., Laros, J., & Ulmer, A., 1994, ApJ, 432, 742

Horack, J. M., *et al.* 1992, in Gamma-Ray Bursts, ed. W. Paciesas, & G. Fishman, (AIP press: NY), 373

Imhof, W. L., Kilner, J. R., & Reagan, J. B. 1985, J. Geophys. Res., 90, 1543

Imhof, W. L., *et al.* 1992, J. Geophys. Res., 97, 13892

Kouveliotou, C. *et al.* 1993, ApJ, 413, L101

Kouveliotou, C. *et al.* 1987, ApJ, 322, L21

Kouveliotou, C., 1993, private communication

Kulkarni, S., & Frail, D. 1993, Nature, 365, 33

Laros, J. G., *et al.* 1986, Nature, 322, 152

Lewin, W. H. G., van Paradijs, J., & Taam, R. 1993, Space Sci. Rev., 62, 233

Link, B. K., Epstein, R. I., & Priedhorsky, W. C. 1993, ApJ, 408, L81

Loredo, T., & Epstein, R. I. 1989, ApJ, 336, 896

Mazets, E. P., Golenetskii, S. V., Ilyinskii, V. N., Aptekar, R. L. 1982, Ap&SS, 82, 261

Melia, F., & Fatuzzo, M. 1993, ApJ, 408, L9

Murakami, T. *et al.* 1989, PASJ, 41, 405

Murakami, T. *et al.* 1994, Nature, 368, 127

Reeves, G. 1993, private communication.

Ricker, G. R. *et al.* 1992, Proc. Los Alamos Workshop on Gamma-Ray Bursts, Gamma Ray Bursts: Observations, Analyses, and Theories, ed. C. Ho, R. I. Epstein, & E. E. Fenimore, (Cambridge: Cambridge Univ. Press), 288

Sunyaev, R. A., & Titarchuk, L. G. 1980, A&A, 86, 121

West, R. H., & Parks, G. K., 1984, J. Geophys. Res., 89, 159

Figure Captions

Figure 1a—Time history of GB900129 measured at 0.5 second intervals by the PC (lower trace) and SC (upper trace) detectors of the *Ginga* GBD. The SC profile has been displaced vertically by 400 counts for clarity. The background has not been subtracted from either profile. The dashed curves are the best fit time histories computed from the model described in the text. The dotted vertical lines denote the time interval in which the spectral fits were computed.

Figure 1b—Time history of GB900129 measured at 0.5 second intervals in five different energy ranges. From bottom to top the profiles are for 3-8 keV, 8-25 keV from the PC, and 15-36 keV, 36-110 keV, 110-400 keV from the SC. For clarity, each successive profile has been displaced vertically from the preceding one by 500 counts. The background has not been subtracted. Notice the paucity of photons below 8 keV, and above 100 keV.

Figure 2—Best fit spectrum for the comptonized blackbody model including photoelectric absorption (BBCOM in Table 1). The deep edge at 7 keV is due to absorption by Fe with cosmic abundance.

Figure 3—Best fit spectrum for the combination thermal bremsstrahlung and power law model (TBPL in Table 1).

Table 1: Temporal Analysis of GB900129[1]

Parameters	PC	SC
A (cts/sec)	-0.27	-0.50
B (cts)	425.6	249.9
C (cts)	174.4	467.2
t_p (sec)	15.21	15.63
τ_r (sec)	0.74	1.18
τ_d (sec)	2.96	2.45
χ^2_{red}	0.98	1.19
W_{fwhm}(sec)	2.56	2.51

[1] The temporal model is described in section 3.

Table 2: Spectral Analysis of GB900129[1]

BBCOM[a]	kT (keV)	T_{scat} (keV)	β	E_p	$\log(n_h)$	P $(>\chi^2)$
	2.12	139.7	2.251	0.265	24.53	0.18
TBPL[b]	kT (keV)	E_b	$\log \phi$	α_{pl}	P $(>\chi^2)$	
	24.10	18.8	0.23	-2.25	0.41	
OTTS[c]	kT (keV)	B_{12}	n - m	P $(>\chi^2)$		
	90.7	2.0	1 - 4	0.14		
TBPA[d]	kT (keV)	$\log(n_h)$	P $(>\chi^2)$			
	20.10	24.53	0.11			

[1]Each model is briefly described in the text.

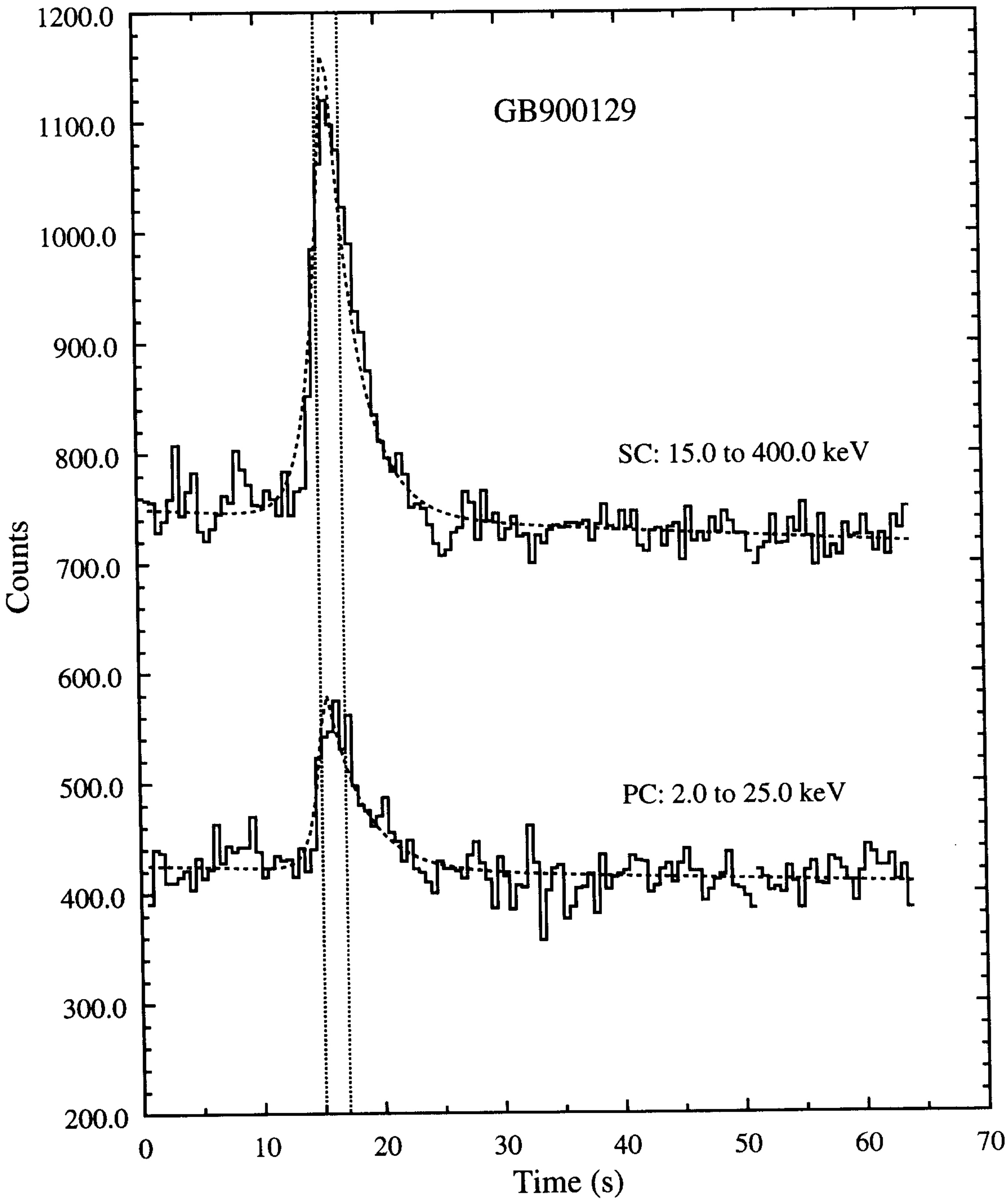
[a]The BBCOM model is a comptonized blackbody model.

[b]The TBPL model is a combination of a power law spectrum below the peak and a thermal bremsstrahlung spectrum above the peak

[c]The OTTS model is an optically thin thermal synchrotron spectrum with thermal distribution characterized by kT (keV), and magnetic field B_{12}. The integers n - m indicate the harmonics included in the calculation of the spectrum.

[d]The TBPA model is characterized by two parameters, the temperature of the source, kT (keV), and the total column density of hydrogen along the line of sight n_h.

Figure 1a



GB900129
SC: 15.0 to 400.0 keV
PC: 2.0 to 25.0 keV
Counts
Time (s)
1200.0
1100.0
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
0
10
20
30
40
50
60
70

Figure 1b

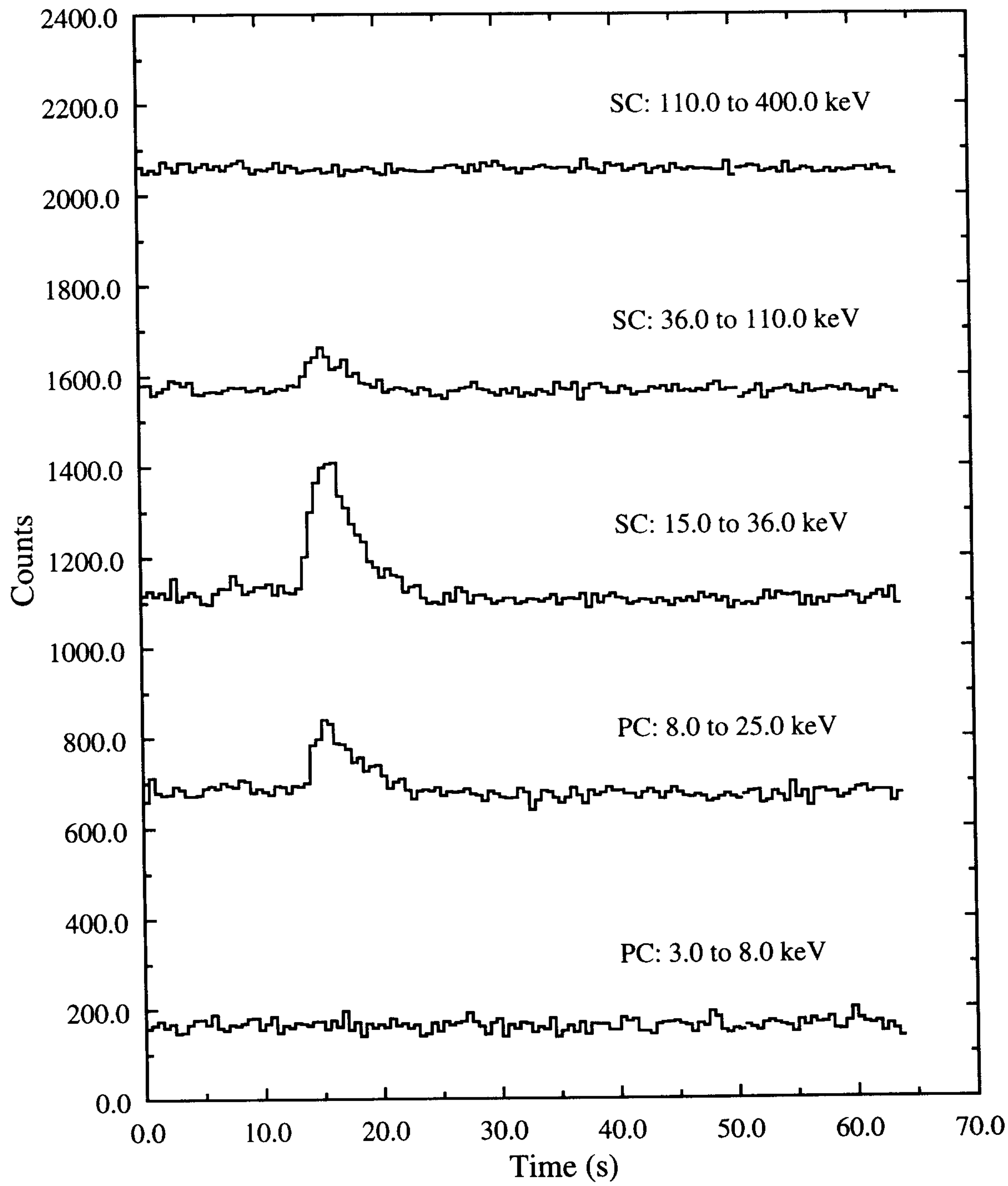

SC: 110.0 to 400.0 keV
SC: 36.0 to 110.0 keV
SC: 15.0 to 36.0 keV
PC: 8.0 to 25.0 keV
PC: 3.0 to 8.0 keV
Counts
2400.0
2200.0
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
Time (s)

Figure 2

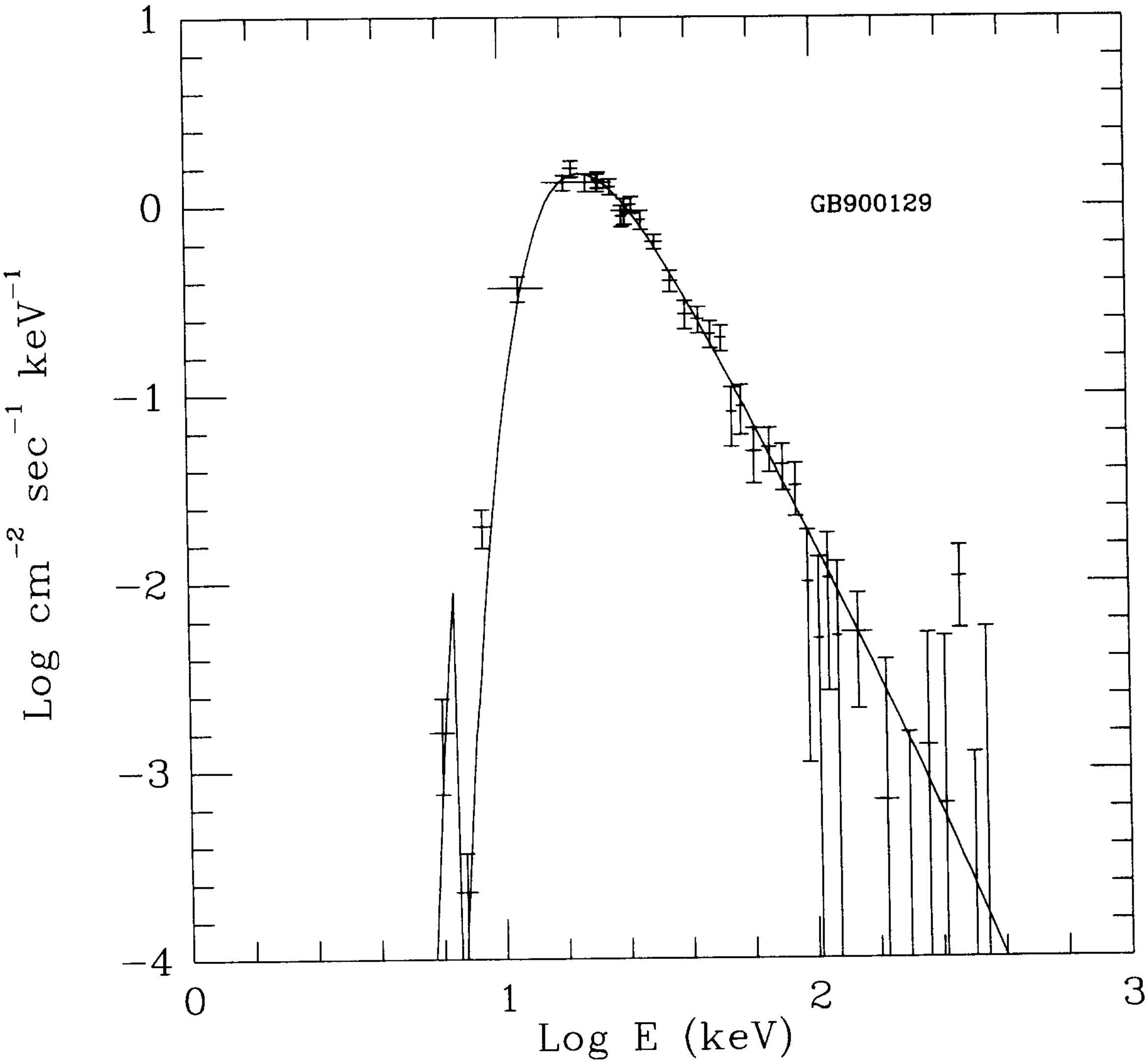


Figure 3