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# WHAT IS LEARNED FROM HIGH ENERGY BURSTS AND FLARES

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## ABSTRACT

The Energetic Gamma Ray Experiment Telescope (EGRET) with its large NaI Total Absorption Shower Counter (TASC) has the scientific capability of performing spectroscopy of high energy cosmic gamma ray bursts and solar flares. EGRET, with a spectroscopy energy range from 0.6 to 140 MeV, provides a unique opportunity to increase our understanding of the high energy mechanisms of gamma ray bursts and solar flares. A likely interpretation of gamma ray burst sources is that they are rotating, magnetized neutron stars. High magnetic fields can influence the emission of high energy gamma rays, so observational spectroscopic data at high energies can provide information on the upper limits of the magnetic fields in the GRB regions of magnetized neutron stars. Likewise spectroscopy of high energy gamma rays can provide information useful for deriving the flare proton spectrum which in turn can lead to an understanding of high energy solar flare particle acceleration mechanisms.

## I. INTRODUCTION

Many gamma ray bursts (GRB) and gamma ray solar flares have been observed with satellite borne instruments. These observations have provided valuable information about these objects but our understanding is not complete at this time. The NASA Gamma Ray Observatory (GRO) with four separate detector systems will provide a coordinated spectroscopic observation covering the gamma ray energy range extending beyond 140 MeV. The Energetic Gamma Ray Experiment Telescope (EGRET) will provide data for the energy range greater than 10 MeV that has not been measured in any detail before. These new data can be compared to the predictions from the models used for interpreting high energy bursts and flares.

## II. EGRET BURST AND FLARE MEASUREMENT CAPABILITIES

One component of the EGRET instrument is a large NaI Total Absorption Shower Counter (TASC) to determine the energy of the secondary electron-positron pair produced by high energy gamma rays. The TASC dimensions are 77. cm. square by 20. cm. thick. The TASC has a further scientific goal of providing spectroscopy of high energy cosmic GRB's and solar flares. For this purpose, a separate low energy processor performs a pulse height analysis of the omnidirectional radiation signals. These data are stored in a 256 channel spectrum that spans the range of 0.6 to 140 MeV. The details of these spectra are presented in Table 1. The energy spectrum is divided into seven energy bands having different energy resolution. Two modes of accumulation are possible for these TASC spectra. First, a background / solar mode in which a continuous energy analysis occurs and a spectrum is taken every 32.8 seconds. In the burst mode, a set of four consecutive spectra are accumulated in response to a signal from GRO Burst and Transient Source Experiment

(BATSE). In this mode, accumulation times of each spectra are preset by command in steps of 0.125 seconds up to 15.87 seconds.

Table 1. TASC LOW ENERGY PROCESSOR

LOW ENERGY SPECTRA

| Accumulation Channels | Compression Factor | Telemetered Channels | Energy Range(MeV) |
|---|---|---|---|
| 0-127 | 2 | 0-63 | 0.6-2.18 |
| 128-255 | 4 | 64-95 | 2.18-4.81 |
| 256-511 | 8 | 96-127 | 4.81-10.1 |
| 512-1023 | 16 | 128-159 | 10.1-20.6 |
| 1024-2047 | 32 | 160-191 | 20.6-41.6 |
| 2048-4095 | 64 | 192-223 | 41.6-83.6 |
| 4096-8191 | 128 | 224-256 | 83.6-167(140) |

ACCUMULATION TIMES

| | |
|---|---|
| Bgd / Solar | 32.768 seconds fixed |
| Burst (BATSE Triggered) | Four Sequential Spectra. Accumulation of each commandable in steps of 0.125 secs. from 0.125 to 15.875 seconds |

Background corrected TASC spectra will be generated for all detected burst and flare events. If the direction to the event is known, a correction for attenuation and spectral modification of the gamma rays due to the material of the spacecraft can be made. Utilizing the known response functions for the TASC, the source gamma ray emission spectra can be derived.

## III. THEORY OF GAMMA RAY BURSTS

The consensus on the likely origin of gamma ray bursts is that they are associated with magnetized neutron stars. This is based largely on the rapid oscillations seen in some events, low energy features in others that may be absorption or emission at cyclotron fundamentals, and a high energy 430 keV emission feature in a few events that may be red shifted annihilation radiation. Other explanations have been proposed such as neutron starquakes (Blaes, et. al., 1989) and Be/X-Ray binaries (Melia, 1988b) but are insufficient to account for the energy radiated in a single burst.

The energy spectrum of GRB's is roughly a broken power law consisting of a low energy spectrum that rises with a spectral index, 0.8 to1, and a high energy spectrum that falls with a spectral index, 1 to 2.5. The transition between the high and low energy regions occurs between 100 keV and 1 MeV suggesting a link to the rest mass energy of the electron. The hard spectral form for gamma rays > 1 MeV implies that most of the GRB luminosity is emitted in these high energy gamma rays.

Observation of absorption features in the 30-70 keV region have provided some estimate of the magnetic fields near the neutron stars. Figure 1 taken from Fenimore, et. al., 1988, shows fitted data acquired during a 5.0 second time period for gamma ray burst GB 880205. The curves represent various functions used to fit the spectral data and shows that the fits are complient with the assumed fitting functions. Fenimore was able to conclude from these analyses that the lines are associated with electron cyclotron harmonics in a magnetic field of 1.7 x $10^{12}$ G or from a combination of absorption by H-like and He-like ion in a 4 x $10^{13}$ G. These field estimates are consisted with the analyses of Konus events requiring fields of > $10^{12}$ G.

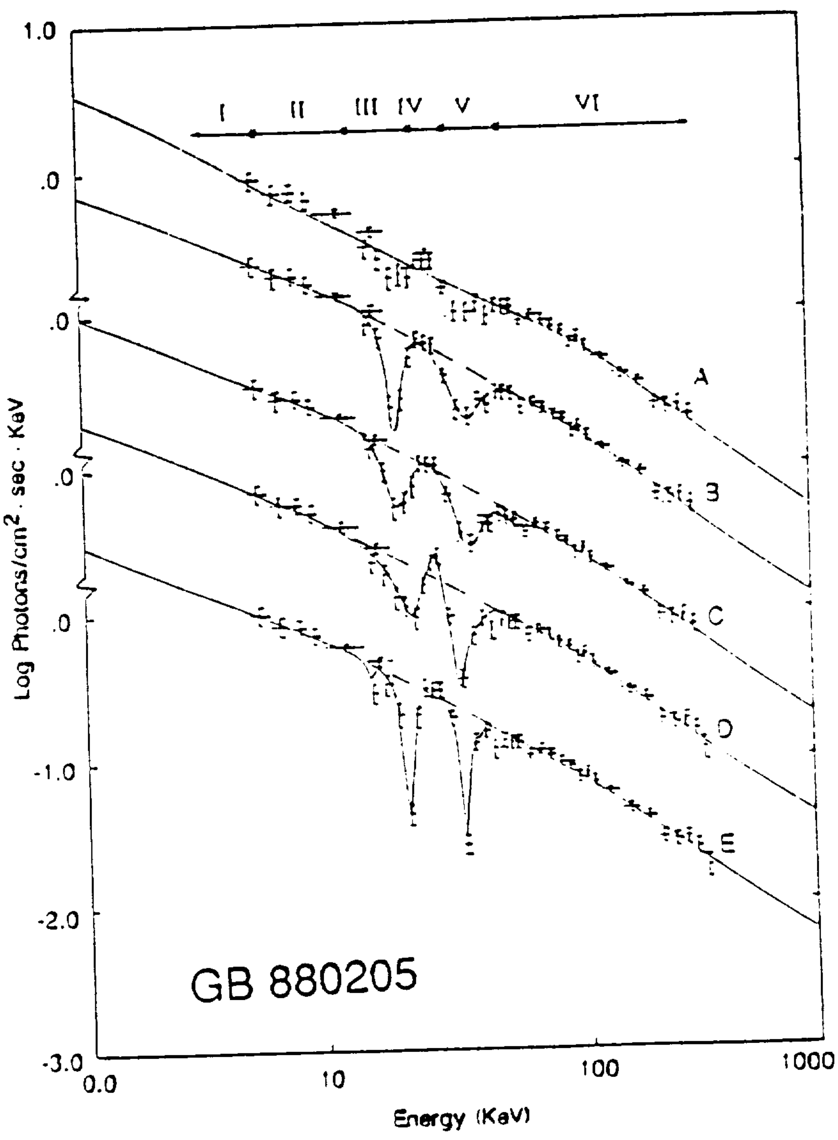



Fig. 1. Various functions fitted to the spectral acquired during the 5.0s time period of the gamma ray burst G B 880205. Curve A using three power law function shows line structure is still required. Curves B-E are fits with several spectral shape and line features.

The presence of gamma rays greater than 10 MeV in a large number of GRB's places a constraint on the GRB models having on magnetized neutron stars with strong fields. High energy gamma rays can interact with the magnetic field and create electron- positron pairs. These interactions can lead to a cut-off in the spectrum. The attenuation length for these high energy gamma rays is strongly dependent on the field strength and the direction of the gamma ray relative to the magnetic field.

Analysis of the Solar Maximun Mission (SMM) data by Matz, et. al., 1985, concluded that the magnetic fields for the high energy region must be less than the $10^{12}$ G required by the low energy absorption features. Matz analyzed 72 statistically significant events identified as having cosmic origin based on spectral and temporal characteristics as well as coincident observation by other experiments. The magnetic fields required for the low energy absorption features can produce spectral cut-offs within the < 9 MeV region of the SMM data. The cut-off depends on the energy of the photon, the field strength, and the sine of the angle between the photon direction and the direction of the magnetic field. For a fixed field, there is a maximum angle for which a photon can escape the region of the field. At higher energies the angle decreases, therefore a burst is observable at smaller solid angles, i.e., the emissions are beamed. At any given field strength, the fraction of all bursts which are observable above any energy should be the solid angle of escape divided by the two pi (the solid angle for isotropic emission at the surface of the star). The 72 SMM events are assumed to represent a random set of observation angles. Figure 2 shows a comparison between the experimental data and the fraction of predicted events for two magnetic field strengths. The results for a field strength of $2 \times 10^{12}$ G, would predict far fewer events than seen by the SMM experimentat the higher energies. Agreement with the SMM data would require a field of less than $10^{12}$ G in the high energy burst region. In a later article by Meszarios, et. al., 1989, an analysis was performed that showed that the SMM detection

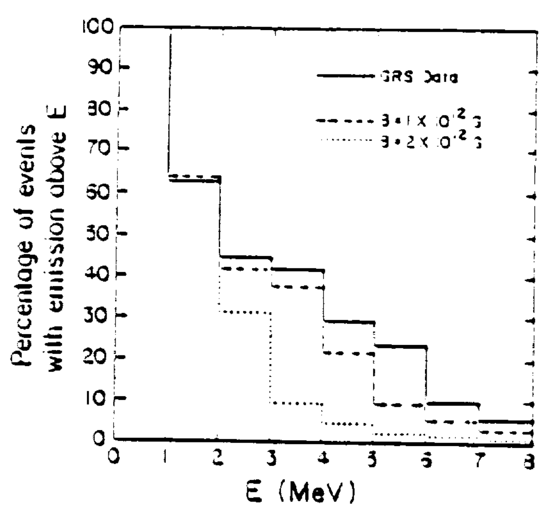



Fig. 2. The solid line is the burst event data in terms of percentages of all observed events. The dashed line indicates the power-low spectra and percentage of burst spectra with observable photon emission >E assuming a field of $1 \times 10^{12}$ gauss at the source. The dotted line shows the result for a field of $2 \times 10^{12}$ gauss.

rates at high photon energies could still be compatible with some of the neutron stars having magnetic fields strength extending to 4 x $10^{12}$ G.

The previous analyses are based on the statistical analysis of a set of the number of GRB events detected. EGRET measurements of GRB spectra at high energies that either show no cut-off or a clear energy cut-off can establish the limits of the strength of the magnetic field in the region of the GRB's.

It is possible to conceive of models that have the high energy emissions coming from a different region of the star and away from the strong field regions where the absorption features are produced. Figure 3 taken from Hartmann, et. al., 1988, graphically illustrates such a model. The power law GRB occurs in the low field region and heats the plasma near the neutron star to the generate the other spectral features of the GRB's. Melia, 1988a, studied GRB's with a similiar model that reprocesses the GRB high energy emission and was able to fit the observed data from GB 811016. Figure 4, taken from the paper of Melia, shows the composite spectrum from the irradiation of a neutron star and a cold accretion disk by an incident power law spectrum. Clearly for this case, multi region models can describe the data but provides no additional information on initiating causes of the GRB event or the strength of the magnetic field in the GRB region.

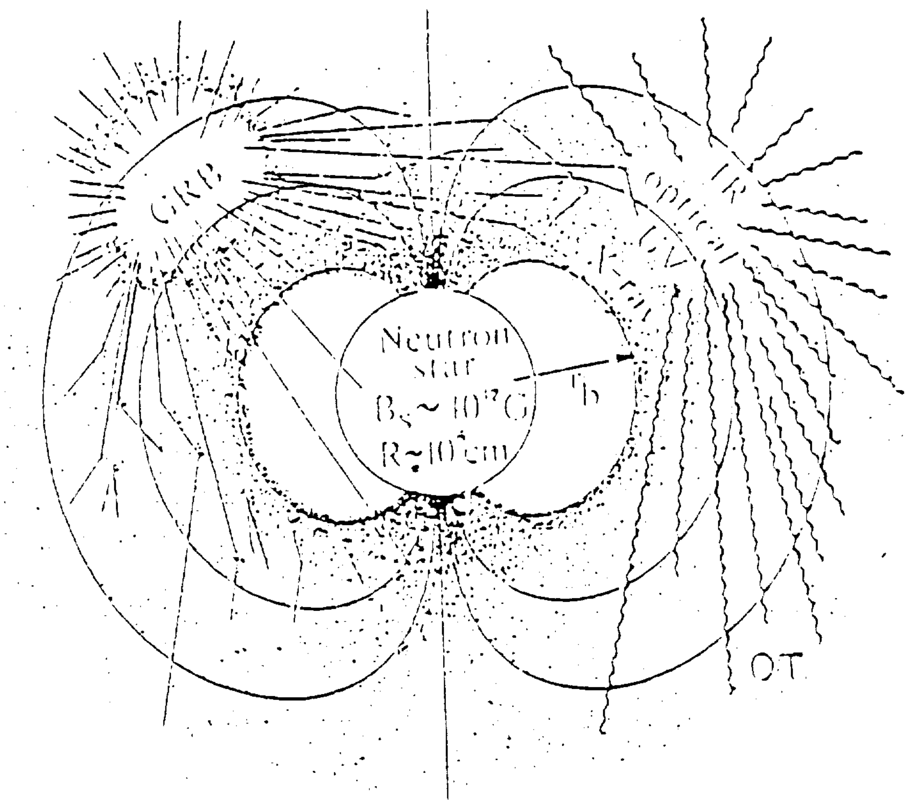



Fig. 3. Schematic view of the reprocessing model. The burst of hard photons energizes the plasma electrons resulting in the observed low energy emission features.

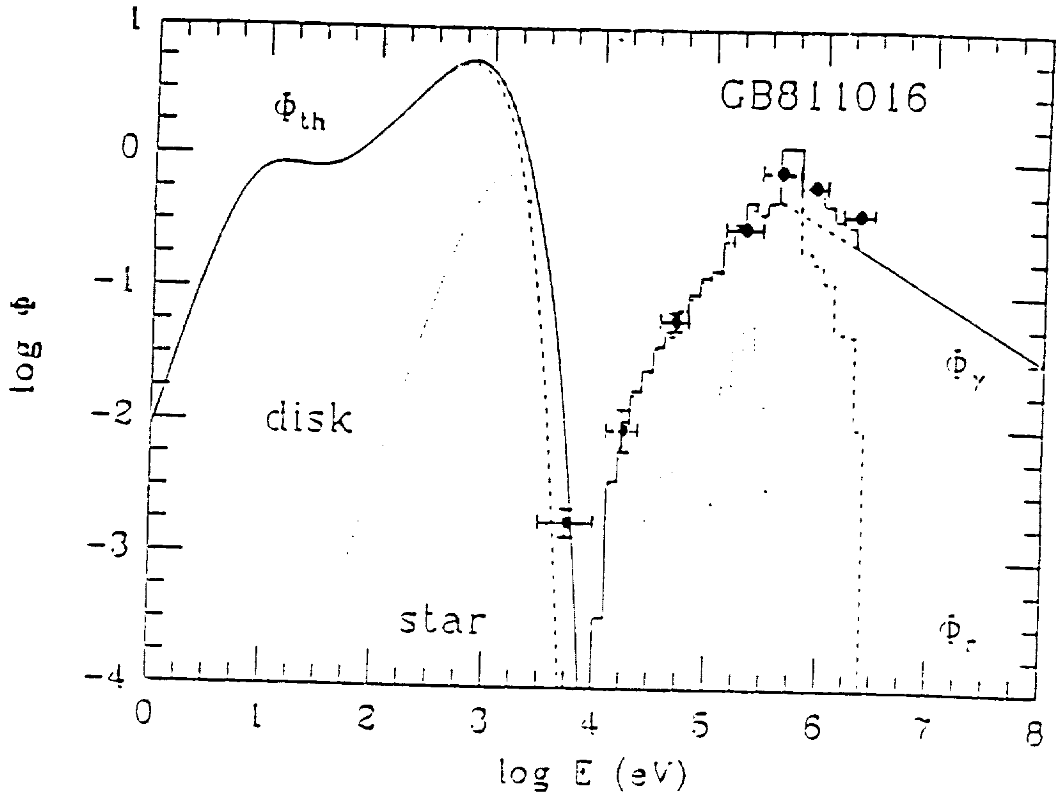


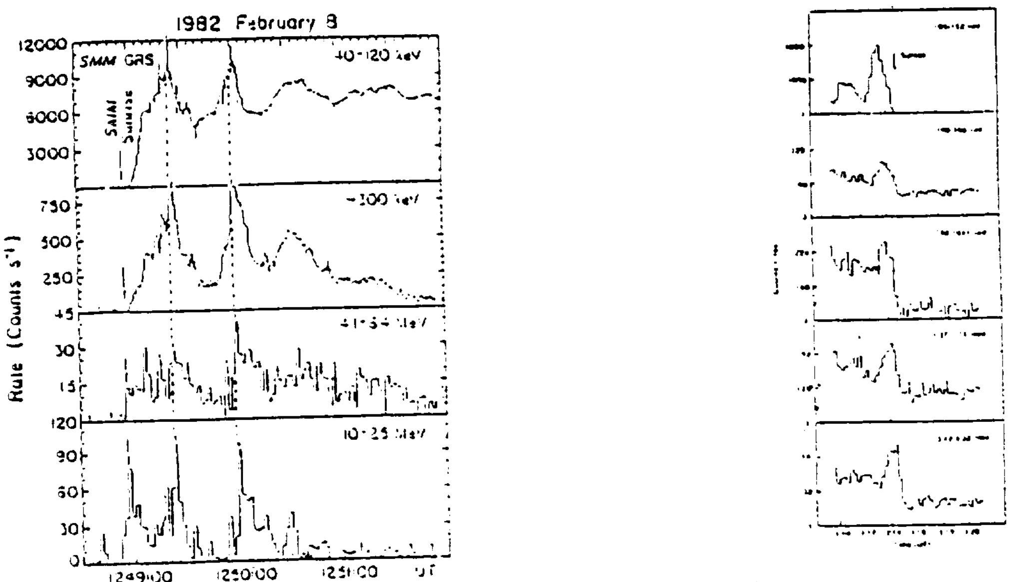

Fig. 4. This figure shows the composite spectrum resulting from the irradiation of a neutron star and an accretion disk by an incident power law gamma ray spectrum. The full spectrum is indicated by a solid line. The components are the thermal contributions from the disk and the star, the reflection of gamma rays at the reprocessing boundary, and the incident power law flux. The data points are simultaneous measurements by PVO (circles) and Hakucho (squares).

## IV. HIGH ENERGY SOLAR FLARES

Gamma rays from energetic solar flares provide information on the acceleration mechanisms of protons in solar flares whereas the X-rays provide information on the acceleration of the electrons. The time delay between the electron and proton acceleration varies greatly depending on the type of the flare. Figure 5 shows examples of two flares. In the impulsive flare of Feb 8, 1982, the protons (10-25 MeV gamma rays) were accelerated within 2 seconds of the electrons (40-120 keV X- rays) Whereas, in the gradual flare of April 27, 1981, the protons were accelerated nearly 48 seconds after the electrons. Clearly the details of the time histories associated with these two flares are different. Simultaneous measurements of the X-ray and high energy gamma ray data are needed to gain a better understanding of the flare mechanisms in the different flare types.

ORIGINAL PAGE IS
OF POOR QUALITY

IMPULSIVE | GRADUAL




1981 APRIL 27

p acceleration delay time

~2s | ~48 sec.

Fig. 5. This figure contains two examples of the time histories of solar flares. The February, 1982 is an impulsive flare and the April, 1981 is a gradual flare. The gamma rays indicating proton acceleration are delayed by different amounts relative to the x-rays.

The protons can also produce secondary reactions that can be observed by gamma ray line emissions unique the reactions. Two prominent lines are the 2.22 and the 4.44 MeV lines associated with capture of secondary neutrons and the de-excitation carbon nuclei respectively. Yoshimori, 1989, showed that using a knowledge of the reaction cross sections as a function of proton energy,and assuming a spectral model for the proton spectrum, predictions of the ratio of the 4.44/2.22 MeV gamma rays can be made as a function of the value of the model parameters. From these predictions and the observed ratio of the 4.44/2.22 MeV lines,the proton spectrum at the flare site can be derived. Figure 6 shows the calculated ratios of the 4.44 MeV fluence to the 2.22 MeV fluence for a power law model, a exponential rigidity model, and a Bessel function model as a function of the value of the model parameters. The shaded area in the figure is the ratio observed for the flare of April 1, 1981. The deduced value of the parameters to be used with this flare falls within the overlap of the data and the predictions. Yoshimori found that the proton spectra derived from the gamma ray data did not vary too much from flare to flare.

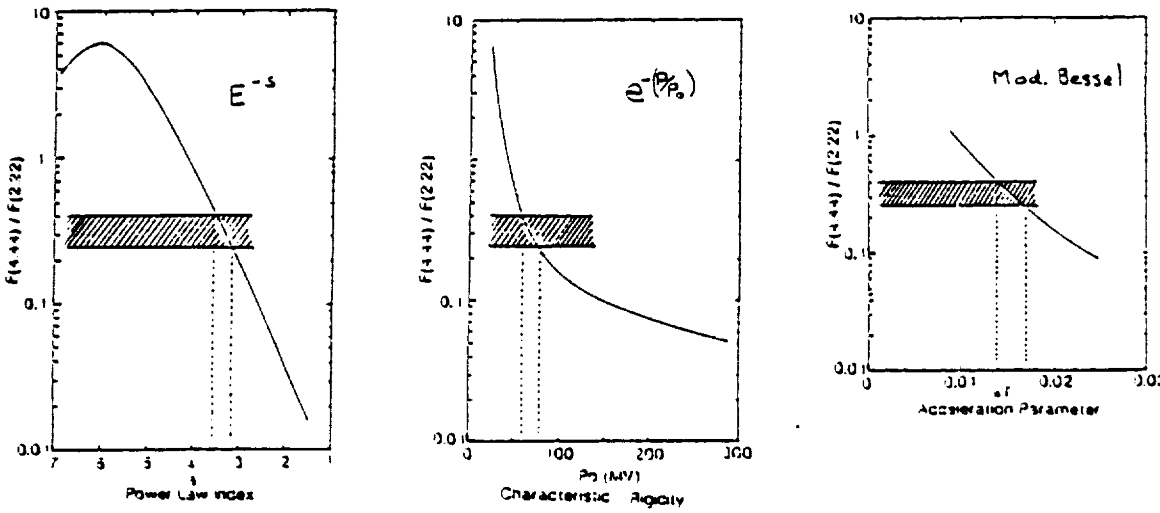



Fig. 6. The calculated ration of the 4.44 MeV/2.22 MeV fluences are shown as a function of parameters value for a power low, exponential rigidity, and a Bessel function for the proton spectrum. The shaded area in the ratio observed for the April 1, 1981 flare.

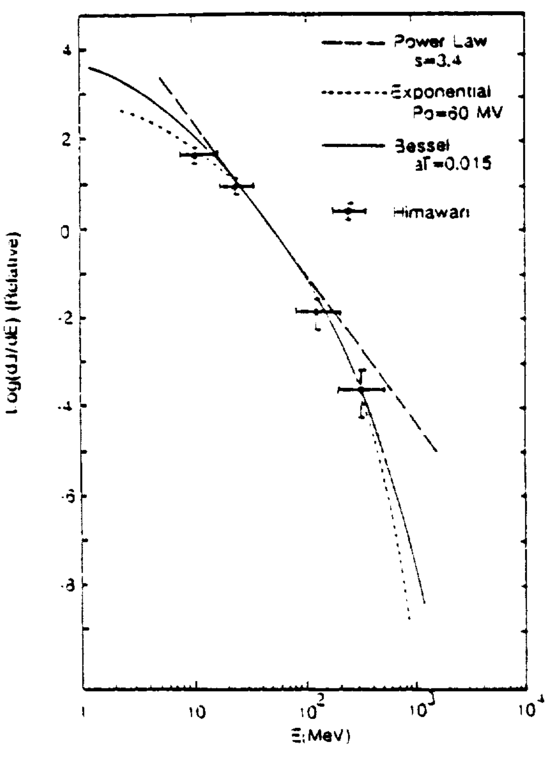



Fig. 7. Proton data obtained by HIMAWARI for the April 1, 1981 flare are compared to the normalized proton spectra derived from the fluence ratios.

Yoshimori studied the correlation between the flare associated gamma ray lines and the interplanetary protons. This correlation attempts to establish the relationship between trapping and escaping of accelerated protons. The HIMAWARI satellite located between the Sun and the earth has a silicon detector that measures the protons with energies of 1.2 to 500 MeV. For the April 1, 1981 flare, three proton spectra can be deduced from the previous analysis. These spectra are normalized at 60 MeV and compared to the proton data obtained by the HIMAWARI satellite (see Figure 7). The observed proton spectrum is in agreement with exponential spectrum derived from the gamma ray line emissions within error. However, this correlation between the gamma ray derived spectrum and the measured proton data near earth does not always hold up because the protons escaping the Sun are subject to complex propagation effects in the corona and interplanetary space. Therefore the gamma ray line measurements give the best estimate of the spectrum of the protons accelerated in a solar flare.

## V. CONCLUSIONS

The high energy spectroscopy measurements of the EGRET instrument on the GRO can provide important information on GRB's and energetic solar flares. The observation of GRB high energy gamma rays showing either a definite cut-off or no cut-off can help establish the upper limits of the magnetic fields in the GRB region of the magnetized neutron star. Likewise, the observation of the reaction lines and the total gamma ray spectrum can be used to derive the spectra of the accelerated protons. Interpretation of the proton spectrum can lead to a understanding of the flare acceleration mechanisms. The launch of the GRO should enhance the data base from which we can extract a better understanding of these high energy events.

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## DISCUSSION

*Chuck Dermer:*

The SMM analysis shows that strong magnetic fields are inconsistent with beaming of the high energy emission for small-angle polar cap geometrics. If a large fraction of the neutron star radiates during a burst, this constraint is weakened. How large does this angle have to be for consistency?

*Ed Schneid:*

For fields greater than $B=2x10^{12}$ G, only the surface within 15 degrees of the poles will allow radiation of high energy gamma rays to get out because gamma rays from the surfaces at large angles would be crossing more field lines and therefore, would be attenuated. The field would have to be reduced in order for a larger fraction of the neutron stars to contribute.

*Daryl Leiter:*

What is the directional sensitivity of TASC in the 0.6 - 5 MeV region to Gamma Ray Transients as compared to COMPTEL & OSSE on the GRO?

*Ed Schneid:*

The calculation of effective area as a function of angle and energy due to spacecraft/TASC geometry is not completed. However, the TASC spectra does not have any field of view constraints due to experiment logic so it is ommidirectional and only modified by attenuation due to material and projected area of the TASC.

*Alice Harding:*

Peter Meszaros and his colleagues have shown that the SMM upper limit to the magnetic field strength in gamma-ray bursts may be misleading. They showed that a distribution of fields with some fraction of bursts having very high fields, is also consistent with the SMM data. Thus, some bursts may have beamed high energy emission.

*Ed Schneid:*

Yes, that is very possible with the statistics of the data so far.

*Chris Winkler:*

Could EGRET detect polarization of a strong GRB at high energies (e.g. GRB840805, see Share et al. (1986) Adv. Space Res. 6, No. 4, p. 15) assuming 100% polarization?

*Ed Schneid:*

No. An earlier presentation by John Mattox, showed that it would take a large number of photons, with spark chamber pictures for EGRET to measure polarization. Our Burst mode would have very few at most sparkchamber pictures.

# Normal Galaxies