1.0 INTRODUCTION

We have succeeded in generating the first all-sky map at 2.2 MeV using CGRO/COMPTEL data from the first five years of the CGRO mission (McConnell et al. 1997a, 1997b). The purpose of this effort was to search for sources of unshifted neutron capture radiation, as one might expect in certain binary accretion scenarios. Although generally featureless, the maps do show one point-like feature (provisionally designated GRO J0332-87) at a significance level of ~4σ. Although X-ray coverage in this sky region is rather sparse, we have identified one possible counterpart – RE J0317-853, a unique DA white dwarf star with both an unusually high temperature (≈50,000° K) and an unusually strong magnetic field (≈340 MG). We speculate that the 2.2 MeV emission might arise from this source through some type of flaring process, although the exact mechanism remains unclear.

For Cycle 7, we requested two weeks of observation time with both COMPTEL and OSSE so that we might confirm the existence of the 2.2 MeV source. These observations will take place in June, 1998. Meanwhile, we have been made aware of an unpublished observation of a 6 cm radio flare from RE J0317-853 (Lim, private communications) that provides further support for the association between GRO J0332-87 and RE 0317-853. *We therefore propose to repeat the COMPTEL/OSSE observations of this region during cycle 8, augmenting the γ-ray data with coordinated observations in other wavelength bands.* Given the probable flaring nature of this source, we believe that these additional observations during cycle 8 will be warranted.

2.0 SCIENTIFIC MOTIVATION

The emission of 2.2 MeV γ-rays from neutron capture on hydrogen often dominates the γ-ray spectrum of solar flares. Scenarios that might lead to other astrophysical sources of 2.2 MeV radiation include:

Neutron Capture in the Companion Star of an X-Ray Binary. The accretion of matter onto a neutron star or black hole can lead to ion temperatures that are sufficient to break up heavier nuclei. Some fraction of the escaping neutrons may then interact in the atmosphere of a companion star, leading to line emission at 2.2 MeV (Guessom and Dermer, 1988). Several factors suggest that close binaries are more probable sources of significant 2.2 MeV emission. In this model, the flux originates on the side of the companion star irradiated by the neutrons. The flux would therefore be modulated by the binary period, peaking near the X-ray maximum. Guessom and Dermer (1988) predict a flux level for Cyg X-1 that may be as high as $\sim 10^{-5}$ cm^{-2} s^{-1}.

Neutron Capture Resulting from an Accelerated Particle Beam. The detection of VHE photons ($E > 10^{12}$ eV) has been reported from various accreting sources, including Cyg X-3, Vel X-1, Her X-1 and AE Aqr. These observations, coupled with the recent detection of Cen X-3 by EGRET (Vestrand et al. 1997) suggest the presence of very energetic protons accelerated in the magnetosphere of the X-ray binary. If the protons interact in the companion star atmosphere, we would expect a flux of 2.2 MeV photons that would be modulated with orbital phase. Vestrand (1989) has estimated the resulting 2.2 MeV line peak flux for Cyg X-3 to be $\sim 10^{-4}$ cm^{-2} s^{-1}, within the sensitive range of COMPTEL.

Neutron Capture in Stellar Flares. Following the solar flare analogy, we expect that stellar flares will lead to 2.2 MeV emission. Although it might be difficult to detect a solar flare at stellar distances, stellar flares are far more energetic than typical solar flares (e.g., Dulk 1985; Haisch, Strong and Rodonò 1991). Whereas the most intense solar flares exhibit $L_x \sim 6 \times 10^{27}$ ergs s^{-1}, RS CVn stars, for example, have been known to exhibit flares with $L_x > 10^{31}$ ergs s^{-1}. The transient nature of such events, however, would make it difficult to detect. On the other hand, some level of on-going microflaring, as has been observed in some RS Cvn and dMe stars (Haisch, Strong and Rodonò 1991), might lead to a more steady level of 2.2 MeV emission.

3.0 PREVIOUS WORK

The COMPTEL experiment on CGRO (Schönfelder et al. 1994) is ideally suited for studies of the 2.2 MeV line emission. Its wide field-of-view (~1 steradian) permits periodic exposure to a number of sources and has provided the first-ever all-sky survey at these energies. Despite the presence of a major background line at 2.2 MeV (resulting from neutron capture within the liquid scintillator of the D1 detectors), COMPTEL posesses an unprecedented sensitivity at this energy.

We have used an imaging technique similar to that which has been successfully employed in studies of the diffuse galactic emission at 1.8 MeV (e.g., Diehl et al. 1995; Knödlseder et al. 1996). This approach generates images that are sensitive only to line emissions; continuum sources are suppressed. For 2.2 MeV studies, the imaging algorithm has been validated using solar flare observations, where strong 2.2 MeV emission is present. The lack of any significant response from the Crab in our maps provides a further validation of this method. The all-sky map generated from the first five years of the CGRO mission (VPs 1.0 - 523.0) is shown in Figure 1. At the sensitivity level of this map (~10^{-5} cm^{-2} sec^{-1}), the 2.2 MeV sky is relatively featureless. There is no evidence for any detectable level of diffuse galactic emission. The only significant feature (peak likelihood value of 32) is found at (l,b) = (300.5°, -29.6°). In the case of a known source location, this likelihood value would correspond to a significance of 5.7σ. However, given the number of independent trials associated with a full-sky survey (~500), the actual significance is ~3.7σ. The measured 2.2 MeV line flux is $1.7(\pm 0.4) \times 10^{-4}$ cm^{-2} sec^{-1}. Images generated using data from individual phases of the CGRO mission are consistent with a constant flux level. Using a standard imaging algorithm that is sensitive to both line and continuum fluxes (Bloemen et al. 1994), we have generated images in three separate energy bands surrounding the 2.2 MeV line, again based on data from VPs 1.0 - 523.0. These images, shown in Figure 2, clearly support the presence of a 2.2 MeV source. There is no evidence for continuum emission above 750 keV. The location contours for the 2.2 MeV line source are shown in Figure 3.

There is limited X-ray coverage in this part of the sky. The best available data come from the ROSAT All-Sky Survey Catalog, that lists 11 sources within the COMPTEL 3σ location contour. None of these sources corresponds to any known X-ray binary, cataclysmic variable or AGN. The most interesting of the ROSAT sources is RE J0317-853 (Barstow et al. 1995; Ferrario et al. 1997), the location of which is noted in Figure 3. First detected by the ROSAT Wide Field Camera (WFC), this source is also detected by the ROSAT PSPC (at energies below 0.28 keV) and by EUVE. It has been identified as one of the hottest (≈50,000° K) and most highly magnetized (≈340 MG) DA white dwarf. Its distance is estimated to be ~35 pc. A 725 s optical period appears to be rotational; the optical variations can be attributed largely to variations in the surface magnetic field which result from a large offset of the magnetic dipole (~35% of the white dwarf radius). There is also evidence for a circumstellar cloud of highly ionized heavy elements. *We speculate that the 2.2 MeV emission might arise through some type of flaring process, although the exact mechanism remains unclear.* The COMPTEL data could be consistent with either episodic flaring or some quasi-continuous process. At a distance of 35 pc, the observed 2.2 MeV flux implies a time-averaged line luminosity of ~10^{32} ergs s^{-1}. Such a value is comparable to the total energy content of a single solar flare (produced in a magnetic field of ~100 G).

For Cycle 7, we requested two weeks of observation time with both COMPTEL and OSSE so that we could confirm the existence of the 2.2 MeV source. The OSSE sensitivity with such an exposure is below the average flux level measured by COMPTEL. At that time, we had not yet made the link between GRO J0332-87 and the white dwarf RE J0317-853. Despite the fact that the OSSE observation was rated rather low (it received a class C rating due to the large size of the COMPTEL error box relative to the size of the OSSE collimator), a joint COMPTEL/OSSE observation was scheduled for the last two weeks of June in 1998. In addition, we obtained an RXTE scan of the COMPTEL error box region in February of 1998. The total RXTE observation lasted about 40 ksec, only a fraction of which included the location of RE J0317-853. A preliminary analysis of the PCA data showed no evidence for any source within the COMPTEL error box.

Interest in this source was heightened even further when we learned, after the submission of our CGRO and RXTE proposals, of an unpublished observation of a 6 cm radio flare from RE J0317-853 (Lim 1997, private communications). This detection was made during a single one hour observation at the Australia Telescope Compact Array (ATCA) in 1996. The 10 minute radio flare reached a few tens of mJy in strength and exhibited a nearly 100% circular polarization. The quiescent level of emission was below 1 mJy. Such flares are typical of those seen, for example, in AM Her and other cataclysmic variables (e.g., Dulk et al. 1983; Dulk 1985), where the total luminosity often exceeds 10^{30} ergs. Despite the radio similarity to cataclysmic variables, however, searches out to 8000Å have yielded no detection of a red dwarf companion (Ferrario et al. 1997; 1998, private communications), as might be expected in the case of a pre-cataclysmic binary. This supports the contention that RE J0317-853 is a high-mass white dwarf resulting from a double degenerate merger (e.g., Barstow et al. 1995; Ferrario et al. 1997). The radio flaring is perhaps more difficult to understand, in the context of present models, without the presence of a binary companion. Nonetheless, *the presence of radio flares does suggest the presence of some phenomena that might lead to 2.2 MeV emission.*

Motivated by these radio observations, we have scheduled additional observations at radio and optical wavelengths. By chance, these data will also be collected during the scheduled time of the cycle 7 CGRO observations, in late June of 1998. The radio data will be collected at 3 and 6 cm with ATCA on June 17 and June 25, while optical spectroscopy is scheduled for June 17 with the Siding Spring Observatory (SSO) 2.3m telescope. These observations should provide preliminary results on the multi-wavelength nature of the radio flares.

4.0 PROPOSED ACTIVITIES FOR CYCLE 8

Given the nature of RE J0317-853, we believe that additional observations during cycle 8 are justified. If the source is indeed flaring, as suggested by the radio data, then a null measurement during cycle 7 may simply imply that we missed any flaring activity. In that case, additional observations will be justified in an effort to detect a flaring event (or events). On the other hand, if we do detect the source during cycle 7, then further observations would be of interest to more clearly define the nature of the emission. *The observations that we propose for cycle 8 will insure that such observations are acquired in a timely fashion.*

Observations at other wavelengths will help us to assemble a more complete picture of this enigmatic source. X-ray and radio data will, in general, provide useful information on the accelerated *electron* population. The presence of 2.2 MeV emission, however, suggests the presence of accelerated *protons*. A useful signature of medium-energy proton beams would be the presence of an increased flux in the red wing of the Ly-α line near 1223Å, resulting from charge exchange between the downward moving proton bream and the ambient hydrogen (Orrall & Zirker 1976; Canfield & Chang 1985; Haisch, Strong & Rodonò 1991). Such a signature has, in fact, been detected in an HST observation of a flare in AU Mic (Woodgate et al. 1992). A similar signature might also be seen by EUVE in the Ly-α line of He II near 310Å (Peter et al. 1990). Unfortunately, the analysis of spectral data for RE J0317-853 is severely complicated by effects (such as Zeeman splitting) resulting from the strong B-field.

For cycle 8, we propose to obtain a 3-week exposure of RE J0317-853 with both OSSE and COMPTEL. In parallel, we will seek coordinated X-ray observations with BeppoSAX, RXTE, ASCA and/or ROSAT, optical observations at the SSO 2.3m, and radio observations with the ATCA. We will also explore the possibility of using HST and/or EUVE data to search for signatures of proton beams. Because of the source proximity to the south celestial pole, the observational constraints (other than relative timing of the observations) are not too severe.

Finally, we will use the COMPTEL all-sky map to search for evidence of 2.2 MeV emission from other sources (such as highly magnetized white dwarfs and cataclysmic variables) that are similar to in nature to RE J0317-853. We will also seek to improve upon the present COMPTEL result by reanalyzing the data with different event selections (viz., with events selected at high geomagnetic rigidity) in an effort to improve the signal-to-background.

The proposed level of funding of $18,000 would be used to support the analysis of CGRO data, activities (such as travel and data analysis) associated with the multiwavelength observations, and the preparation of publications resulting from these observations.

References

Barstow, M.A., et al., 1995, *MNRAS*, **277**, 971.
Bildsten, L., 1991, in AIP Conf. Proc. 232, *Gamma-Ray Line Astrophysics*, p. 401.
Bildsten, L., Salpeter, E.E., & Wasserman, I. 1993, *ApJ*, **408**, 615.
Bloemen, H., et al., 1994, *ApJS*, **92**, 419.
Canfield, R.C. & Chang, C.-R. 1985, *ApJ*, **295**, 275.
Diehl, R., et al. 1995, *A&A*, **298**, 445.
Dulk, G.A., et al., 1983, *ApJ*, **273**, 249.
Dulk, G.A., 1985, *Ann. Rev. Astron. Astrophys*., **23**, 169.
Ferrario, L., et al., 1997, *MNRAS*, **292**, 205.
Guessom, N. & Dermer, C.D. 1988, in AIP Conf. Proc. 107, *Nuclear Spectroscopy of Astrophysical Sources*, p. 332.
Haisch, B., Strong, K.T., and Rodonò, M. 1991, *Ann. Rev. Astron. Astrophys*., **29**,
Knödlseder, J., et al. 1996, SPIE Conf. Proc, **2806**, 386.
McConnell, M., et al. 1997a, Proc. of the 25th ICRC (Durban, South Africa), Vol. 3, p. 393.
McConnell, M., et al. 1997b, in AIP Conf. Proc. 410, *Proceedings of the Fourth Compton Symposium*, p. 1099.
Orrall, F.Q. & Zirker, J.B. 1976, *ApJ*, **208**, 618.
Peter, T., et al. 1990, *ApJ*, **351**, 317.
Schönfelder, V., et al. 1994, *ApJS*, **86**, 629.
Shvartsman, V.F. 1972, *Astrophysics*, **6**, 56.
Vestrand, W.T. 1989, in the *Proceedings of the Gamma Ray Observatory Workshop*, ed. N. Johnson, p. 4-274.
Vestrand, W.T., et al., 1997, *ApJ*, **483**, L49.
Woodgate, B.E., et al., 1992, *ApJ*, **397**, L95.

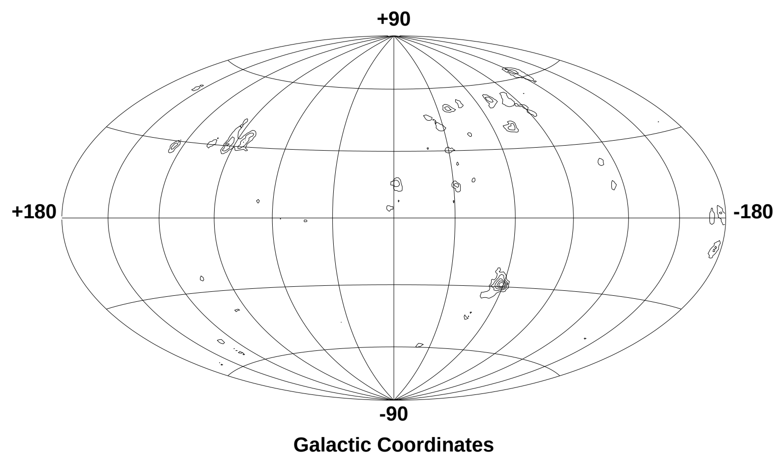

FIGURE 1 *COMPTEL map showing the distribution of 2.2 MeV emission (McConnell et al. 1997a,b). The only significant source emission, at a position near (l=300°, b = -30°), has been associated with the highly magnetized white dwarf RE J0317-853.*

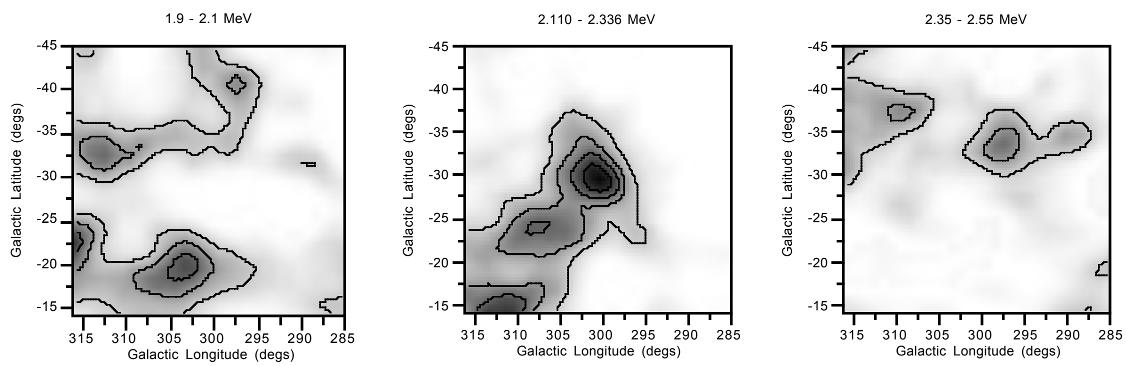

FIGURE 2 *Standard COMPTEL maps of the 2.2 MeV source region for 1.9-2.1 MeV (left), 2.110-2.336 MeV (middle) and 2.35-2.55 MeV (right). The source appears only in the line interval, thus providing supporting evidence for the presence of a source of line emission.*

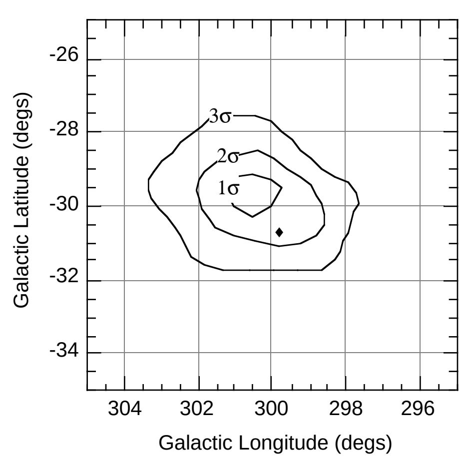

FIGURE 3. *Location contours for GRO J0332-87 based on COMPTEL maximum likelihood data. The location of RE J0317-853 is indicated by the diamond.*