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What Can Gamma Rays Tell Us about Binary X-Ray Sources and SNR's?

M. P. Ulmer
Department of Physics and Astronomy, Northwestern University

I. INTRODUCTION

This is a short, informal summary of the paper I presented at the EGRET Workshop. I divided this paper into 3 main areas: black holes, neutron stars in binary X-ray source systems, and SNR's.

II. BLACK HOLES

A good overall resource is Nolan's Ph.D. thesis (1982). Besides basic references, the thesis provides an analytic form of a spectrum from a comptonized plasma plus a broadened 0.5 MeV line that fit the spectrum of Cyg X-1. This may not be the correct model, but it is analytic and can be used to fit our data. The work of Liang and Dermer (1988) and references therein give a *theoretical* interpretation to the data which suggests that the gamma rays and X rays are coming from entirely different regions (Ling 1988; Dermer and Liang 1988; Liang and Dermer). The spectrum allegedly has a (transient?) bump at about 1 MeV. The predicted 50 to 300 keV count rate for OSSE is about 300 cts/sec. In the 300 keV to 1 MeV range, it is about 30 cts/sec. This leads to the exciting possibility of doing auto/cross-correlation analyses on the data. Also, the very hard spectrum plus the bump at about 1 MeV can be hypothesized to be a signature for black holes. Therefore, it will be interesting to observe others and see if they have this signature: 0620-00 (a transient, unfortunately), and GX339-4 (about 10 times weaker than Cyg X-1). Also, we can ask if the spectra of the Galactic Center and AGN's have the same distinctive shape as Cyg X-1 (Ling). Of course, the physics around a 10^6 to $10^8 M_\odot$ black hole is very different from that around 5 to $10 M_\odot$ black holes, so if the 1 MeV signature is not seen, we cannot/should not take this as evidence against the existence of massive black holes in AGN's. I also note that Ling and Wheaton (1989) claim a narrow feature in Cyg X-1, but it does *not* look real to me.

Bottom Line. Favorite sources: Cyg X-1, 0620-00, and GX339-4. Science: spectral signature of black hole accretion disks; physics of emission regions with spectral fitting and time variability studies.

III. NEUTRON STARS IN BINARY X-RAY SOURCE SYSTEMS

A major resource for a list of targets is Joss and Rappaport (1984). I found three observational areas related to these objects. First, there are cyclotron line features. So far these have only been observed at around 60 keV. We can hope to observe either higher harmonics of these features or other systems with higher energy features. (The energy of the feature that goes linearly with the magnetic field is about 12 keV for a 10^{12} G field.)

Second, there are lines that can come from the accretion of material onto the polar cap region. The main parameter that the gamma ray line flux depends on is the accretion rate. In terms of apparent brightness, this translates into the observed X-ray brightness. Brecher and Burrows (1980) predict a marginally observable flux from Sco X-1 at 2.2 MeV. The other strong lines are down by a factor of 10. These lines are 0.5 MeV, 4.4 MeV (C) and 6.1–6.3 MeV (O). Bildsten, Salpeter, and Wasserman (1989) have modified this theory slightly and have concentrated on binaries that they think are accreting nearly pure ^{4}He. These binaries are ones with low masses and short periods. They (Bildsten *et al.*) do not predict intensities, however. The best bet is to hope that Brecher and Burrows got the lines right, but the intensities wrong. If we can see these lines they should tell us the value of M/R for the accreting neutron star. In the case of a few of these (especially Her X-1) M is known quite well so that a detection should tell us the equation of state of a neutron star. Third, as rotating neutron stars are thought to be accelerators of cosmic rays, it is possible that cosmic ray winds from a pulsar will produce observable quantities of gamma ray lines *not redshifted* from the surface of the companion "normal star." Vestrand (1989) has an article on this; Cyg X-3 is his favorite target. One could easily imagine that other objects could fall into this class, from "normal systems" such as Her X-1 to "oddball systems" such as SS 433. Cyg X-3 should just be observable (naturally) at 2.2 MeV and 0.5 MeV (could this be the real source of the alleged 1 MeV bump from Cyg X-1, and the fact that all MeV detectors have had such a broad field of view that people have mistaken Cyg X-3 for Cyg X-1?)

Bottom Line. Favorite sources: Her X-1, Vela XR-1, Cen X-3, Sco X-1, Cyg X-3, SS 433. Also one can consider a cast of about 12 other (Joss and Rappaport 1984) pulsing X-ray sources plus the strongest galactic bulge sources. Further, based on the suggestion of Bildsten, Salpeter, and Wasserman (1989), I also include 1820-30, 1626-67, and 1916-05. Science: cyclotron lines; accretion induced gamma ray lines which will allow a M/R measurement; pulsar winds interacting with companion stars which will produce evidence that cosmic rays are accelerated in copious quantities by pulsars in binary systems.

IV. SNR'S, OLD AND NEW

A good resource is Weiler and Sramek (1988). Also, see Seward (1989). For SN1987A, I refer you to the GRO Workshop and the Nuclear Spectroscopy workshop. From Leising (1989), the only line we can really expect to barely detect is 122 keV from ^{57}Co. If the SIGMA experiment is successfully launched in December 1989 and works well, we (OSSE) could be scooped on this. Our best hope for an exciting result is that the theory is wrong (enough) so that there are some detectable lines above approximately 1 MeV.

As far as the other remnants are concerned, the first thing that comes to mind is to look for a "Crab-like" non-thermal radiation effect, although one object, W28, may also be interacting with a molecular cloud and producing lines. Taking a *very* simplistic approach, we can normalize to the Crab Nebula radio flux and predict which should be the strongest SNR's for us to see in the gamma ray region (besides the Crab): W28 (molecular cloud interaction as well?), Vela, W50 (SS 433), and MSH 15-52 (contains PSR1509-58, radio and X-ray pulsars). Others that may be centrally influenced and hence interesting are CTB 80 (contains a milli-second pulsar with an optical bow shock), CTB 109 (contains a central binary X-ray source which is a "slow" pulsar, also close to a molecular cloud), G27.4+00

(Kes 73, contains an X-ray source in the center). Other objects that seem to be the most likely to be detectable based on radio and X-ray information from Seward (1989) are: CTA 1, G21.5-0.9, and G29.9-0.3 (Kes 75).

Two other points that were brought to my attention by Matz and Purcell (1989) are: (1) the hope of seeing ^{44}Ti at 1.157 MeV from fairly young SNR's. By fairly young SNR's we mean those less than about 100 years old which were missed by optical or radio surveys. Cas A at about 300 years old would produce about 10^{-5} photons cm^{-2} s^{-1} at the Earth (Woosley and Pinto 1988—from which we have taken the value of produced ^{44}Ca as $10^{-4} M_{\odot}$). Given the uncertainties in the theory, distance estimates, age estimates, and even type of supernova that produced Cas A, the overall uncertainty in our flux estimate from Cas A is nearly a factor of 10. If we are lucky, then, the flux from Cas A could be as high as 10^{-4} photons cm^{-2} s^{-1} at the Earth. (2) The existence of an e^+e^- pair wind could also produce detectable quantities of 0.5 MeV gamma rays. Taking the flux predicted from the Crab by Sturrock (1971), the Crab Nebula should be detectable at about 2×10^{-4} photons cm^{-2} s^{-1} at the Earth (assuming a 2 kpc distance to the Crab). Other particularly attractive pulsar/SNR systems are PSR 1951+32 (Hester and Kulkarni 1988) and 1957+20 (Kulkarni and Hester 1988) both of which have been shown to have bow shocks. Sturrock's paper predicts that the e^+e^- winds will be negligible for old ($\sim 10^8$ G magnetic field) milli-second pulsars such as 1951+32 and 1957+20. We have reason to hope, however, that the e^+e^- pair production is higher than predicted by Sturrock's model. For example, Kulkarni and Hester, referring to a preprint by Phinney and Evans, claim that radio studies may give "diagnostic information about the energy spectrum of e^+e^- pairs in the pulsar wind" of 1957+20. Certainly, gamma ray studies have the potential of providing invaluable information about the very existence of e^+e^- pairs in the pulsar wind. For further arguments for large e^+e^- pair winds, see Arons (1981, 1983) who argues for the existence of substantial e^+e^- winds from milli-second pulsars. Arons' wind model depends on the magnetic field to the 2/5 power and inversely on the pulsar period to the 9/5 power, so that milli-second pulsars can be more copious producers of e^+e^- pairs in Arons' models than in Sturrock's theory.

Bottom Line. Favorite sources: Crab, W28, Vela, W50, MSH 15-52, CTB 80, CTB 109, G27.4+00, PSR 1957+20, Cas A, plus a galactic plane scan searching for ^{44}Ti. Also, one can consider CTB 109, CTA 1, G21.5-09, and G29.9-0.3 (Kes 75). Science: acceleration of cosmic rays and their interaction with the surrounding magnetic field and interstellar medium, nucleosynthesis of ^{57}Co and ^{44}Ti, and e^+e^- winds.

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M. P. ULMER: Northwestern University, Department of Physics and Astronomy, 2145 Sheridan Road, Evanston, IL 60208