GAMMA RAY BURSTS AND NEUTRON STAR STRUCTURE

Edison Liang

This paper was prepared for submittal to The Fourth Marcel Grossmann Meeting on General Relativity Rome, Italy - June 17-21, 1985

June 1985

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.
DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.
GAMMA RAY BURSTS AND NEUTRON STAR STRUCTURE

Edison LIANG

Physics Department, Lawrence Livermore National Laboratory, University of California, Livermore, California, 94550 U.S.A.

We summarize new results on neutron star structure and vibrational frequencies using the redshift database derived from gamma ray burst annihilation lines.

1. INTRODUCTION

Many cosmic gamma ray bursts exhibit a line feature between 300 and 500 keV. These features have been widely interpreted as gravitationally redshifted 511 keV $e^+e^-$ annihilation lines from the surface of neutron stars. Despite the controversies surrounding the reality and interpretation of these lines, we have recently completed an analysis of neutron star redshift database using these gamma burst annihilation lines. This database strongly constrains neutron star structure models and the range of vibration frequencies. It thus has significant implications for gravitational wave astronomy as well as tests of relativity theory. Since most of the detailed results have already been submitted for publication elsewhere, here we will only give a brief summary of the key results and their implications.

2. GAMMA BURST REDSHIFT DISTRIBUTION

The apparent redshifts of roughly 40 gamma burst annihilation lines, based on the line center positions of the published spectral curves (c.f. Ref. 3 for data sources), are illustrated in Figure 1. These redshifts are obtained without taking into account potential corrections due to bulk Doppler shifts, optical depth effects, uncertainty of the underlying continuum or finite temperature of the annihilating pairs, which are all unknown. In practice, however, many of these corrections, even if they are significant, tend to cancel each other and there is a high probability that the combined correction factor may be less than the width of the line center energy channel itself, which is represented by the error bars in Figure 1.

From Figure 1 we see that there is a definite trend of clustering between redshifts 0.2-0.5, with the centroid lying between 0.25-0.35. This range includes the only two other purported measurements of neutron star redshifts: the 400 keV line from the Crab region and the burster X1636-536.
FIGURE 1
Redshift distribution of gamma burst annihilation lines. Filled data have less than 2-σ significance level. Triangles denote narrow (FWHM < 200keV) and circles denote broad (FWHM > 200keV) lines (from Ref. 3).

3. NEUTRON STAR STRUCTURE MODELS
Arnett and Bowers have compiled detailed relativistic neutron star models based on the most popular known equations of state (EOS). The mass versus surface redshift relations for these models are reproduced in Figure 2. See reference 7 for the sources of the different models. The present ranges of the gamma burst redshifts are denoted by the vertical lines. If in addition we invoke the mass range of 1.2-1.6M\(_{\odot}\) derived from X-ray and binary radio pulsars (hatched band), we see that the small rectangle
basically excludes both the very stiff (EOS I-O) and the very soft (EOS G,H) equations of state. The most favored ones are clearly the medium-soft ones (EOS A,D,E,F). The exclusion of the stiff EOS's are even stronger when we consider that gamma burst sources, which are speculated to be lone, slowly rotating neutron stars, likely have masses below that of accreting, rotating ones in binaries. For a median mass of 1.45 M\(_{\odot}\), the redshift range 0.25-0.35 corresponds to a radius of 9.6-12 km. These results are generally consistent with neutron star sizes based on other considerations, such as x-ray burst mechanisms\(^5\) and observational statistics.\(^6\) Future observations of gamma burst annihilation features should provide an increasingly large database to tighten the above limits.

4. NEUTRON STAR VIBRATIONS

Lindblom and Detweiler\(^7\) have computed the vibrational frequency of the fundamental quadrupole mode of neutron star models corresponding to the above equations of state. Since this is the lowest mode allowed for gravitational radiation when a neutron star is disturbed, the exact range of this frequency is very important for gravitational wave astronomy. Using the range 0.2-0.5 for the redshift together with the EOS's A-G we can constrain the vibrational
frequency to the range 2-4 kHz, while the narrower range 0.25-0.35 together with the EOS's A,D,E,F limit the frequency range to 2.2-2.9 kHz. For bar type detectors, this favors masses considerably smaller than the current generation of aluminium bars. For such small masses, it appears that sapphire or other high Q material may be better choice. The gravitational radiation damping time corresponding to the above EOS's and frequencies lie in the range 0.1-0.25 sec. For details see Ref. 3.

5. GRAVITATIONAL WAVES FROM GAMMA BURSTERS

If gamma ray bursts indeed represent catastrophic events on or inside neutron stars, then independent of the detailed radiative mechanisms, a significant fraction of the total energy released may be coupled to the vibrations of the star, with a good portion in the quadrupole mode. Of course in the case of the dramatic March 5th 1979 event, it has been proposed that the vibrations themselves are driving the gamma emissions. In that case we have estimated that the gravitational wave reaching earth may have a dimensionless amplitude h approaching $10^{-24}$ - $3 	imes 10^{-21}$ independent of the source distance. However, even when the vibration is only set off as a secondary reaction (e.g. to a polar thermonuclear flash at the surface or cometary impact), it may still lead to detectable modulation of the x-ray and gamma ray light curve, thus providing valuable information about the frequency range and, indirectly, stellar structure, even though the radiated gravitational wave may be too weak to be detectable. It is thus interesting to consider, for the future design of x-and-gamma ray observing space platforms, the possibility of searching for submillisecond modulations in the light curves of burst sources. This would require detectors with much lower thresholds and higher temporal resolutions. In any case the unsettled nature of gamma ray bursts makes such observations worthwhile if simply for the verification of the neutron star hypothesis itself, not to mention the outside possibility that the gravitational radiation output may indeed be much higher than the gamma ray output. In the latter case x-ray observations may be used to alert gravitational wave observers since x-ray precursors are known to often accompany the main gamma ray event.

ACKNOWLEDGEMENT

The author benefitted from conversations with many colleagues, in particular P. Michelson and K. Wood. This work is performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.
REFERENCES


