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Gamma-Ray Bursts from Fast, Galactic Neutron Stars

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ABSTRACT

What makes makes a Galactic model of gamma-ray bursts (GBs) feasible is the observation of a new population of objects, fast neutron stars, that are isotropic with respect to the Galaxy following a finite period, $\sim 30\text{My}$, after their formation (Bulik and Lamb, 1995). Our Galactic model for the isotropic component of (GBs) is based upon these high-velocity neutron stars (NSs) that have accretion disks. The fast NSs are formed in tidally locked binaries, where tidal locking occurs due to the meridional circulation caused by the conservation of angular momentum of the tidal lobes. These same lobes perturb the subsequent collapse to a supernova and forming a slowly rotating NS. Following the collapse to a NS and explosion, subsequent accretion occurs on the rear side of the initially perturbed NS, resulting in a run-away acceleration of the neutron star by neutrino emission from the hot accreted matter. The recoil momentum of the relativistic neutrino emission from the localized, down flowing matter far exceeds the momentum drag of the accreted matter. The recoil of the NS may be oriented towards the companion, but misses because of the initial orbital motion. The near miss captures matter from the companion and forms a disk around the NS. Accretion onto the neutron star from this initially gaseous disk due to the "alpha" viscosity results initially in the soft gamma-ray repeater phase, $\sim 10^4$ yr. Later, after the neutron star has moved ~ 30 kpc from its birthplace, solid bodies form in the disk, and accrete to planetoid size bodies after $\sim 3 \times 10^7$ years. Some of these planetoid bodies, with a mass of $\sim 10^{21\text{to}22}$ g, are perturbed into being captured by the magnetic field of the NS to create GBs. The high velocity and millions of years delay in forming planetoids, results in isotropy. The depletion of planetoids by planet accretion after 10^8 years and the evolution of planetoid mass with time results in the observed value of $\langle V/V_{\text{max}} \rangle$. The hard spectrum is produced by the collision with, twisting, and ultimately the reconnection, of the NS magnetic field. We also predict an observable optical pulse from the re-radiance of gamma ray energy first ablating and then illuminating the plasma ejected from the planetoids in orbit around the NS.

INTRODUCTION

The improbability of any mechanism that could produce the isotropy of gamma-ray bursts (GBs) has always contrasted with the improbability of a physically reasonable cosmological source. Here we argue that a physically reasonable sequence of events can lead to the observations. That such a sequence actually happens seems, *a priori*, to be highly improbable. On the other hand we have to recognize the awkward fact that the isotropy of GBs is achieved only by excluding the anisotropic events that presumably have a reasonable and mundane explanation, namely those events whose direction identifies them as coming from the earth, $\sim 10\%$, and the sun, $\sim 50\%$ (of the

triggers depending upon the trigger, J. Fishman, pvt. com.). These events have both a harder and a softer spectrum and a broader and a narrower time variability, but with mean characteristics different from each others yet overlapping in properties with the isotropic component. The importance of these events for understanding the isotropic component of GBs is that the mechanism for producing hard photons in a short time is apparently universal for a very wide range of initial circumstances. The strength of the ambient magnetic field of solar events is less than a few thousand gauss and that on the earth, presumably from lightning discharges may be the same or less. Thus the field necessary to make a hard spectrum of x-ray to gamma ray photons can be very small compared to the field typical of NSs, at least close to the NS so that the GB magnetosphere could in principle extend to 10^9 cm. When one recognizes this diversity of GB sources, then the following sequence of many physical processes necessary to make an isotropic Galactic component of GBs does not seem so serendipitous.

GALACTIC HALO MODEL

Then happened the March 5, 1979 event, and as Fenimore (in press) points out, it was a "near" garden variety gamma burst originating in the LMC from a slowly rotating NS, but with disconcertingly large, $\times 10^5$, or small, $\times 10^{-9}$, fluence depending upon your point of view, that is, locally Galactic or cosmological. Here we have given up the parochial view of a locally Galactic origin and chosen instead to take March 5 at face value and say the observable, isotropic GBs originate from NSs in our own Galactic halo and that March 5 was exceptional only in that a small planet or planetoid was captured shortly after the supernova rather than waiting the typical 3×10^7 years necessary for planetoid formation from an accretion disk. As B. Paczynski has pointed out (GB Debate, 4/22/95), this had to be an unusual circumstances, because most GBs must occur only after 3×10^7 year delay. If this was a capture of a preformed planet as suggested by Katz (1994), then one might expect only a few per NS and hence, only a few per 100 years. On the other hand there must be $\sim 10^5$ GBs per NS in order for one fast NS to be created with a disk per 100 years to give 1000 observed bursts per year. The mass of the planetoids in the disk, however, is presumably 100 to 10^3 times that required to make 10^5 total events per neutron star. This then requires 10^{29} g captured in the disk.

This is reasonable because we have a Galactic halo of fast NSs (Frail & Kulkarni, 1991, Cordes, et.al. 1993). Then Bulik and Lamb (1995) have found that isotropy could be simulated, within the statistical constraints of the data by transporting the sources far enough from the Galaxy before they turned on and then programming them to turn off before they got too close to M31. What Bulik realized was that Podsiadlowski et.al. (1995) had used a model for the Galaxy which greatly exaggerated the potential in the mid-plane at large distances from the Galactic center. As a consequence isotropy required that the sources be gravitationally bound to the Galaxy and lasting long enough, $> 10^9$ years, so that their orbits could be scrambled by M31. This requirement was different from our model (Colgate and Leonard, 1993) where

fast sources, NSs, turned on and off during their probable escape from the Galaxy.

Fig. 1 shows an initially tidally locked binary, and exaggerated tidal lobes that rotate less rapidly than the cores, driving meridional circulation and thereby rapid Ekman layer damping. Fig. 2 shows the debris from the supernova explosion striking the companion and ejecting additional mass.

Fig. 3 shows a process of forming the high velocity kick of the neutron star, in presumably a bimodal distribution. A constant, high entropy atmosphere or bubble

forms around the contracted NS after a fraction of a second. The NS is initially perturbed towards the companion star because of the larger tidal bulge. The Bondi-Hoyle accretion takes place preferentially at the rear of the motion. The center of mass motion is little affected by the accreted mass alone, but the emission of the rest mass of the binding energy, $c^2/5$, of the accreted mass in high temperature neutrinos results in a kick velocity of $c/300$ with the accretion of only $1/60$ the mass of the NS. This trajectory is altered by the initial orbital velocity of the binary, shown in Fig. 4.

The fast NS then captures 10^{-4} to $10^{-5} M_{\odot}$ of matter from the companion into a disk ~ 1 AU diameter. This disk evolves as an alpha-disk for 10^4 years forming soft gamma-ray repeater events. After a period of $\sim 3 \times 10^7$ yr, a disk of planetoids has formed, one of which is large enough to scatter a portion of the planetoids into the NS. This happens when the disk has evolved to be thin, $\sim 10^{-3}$ AU, and one planetoid has evolved to $> 10^{23}$ g.

Fig 5 shows a planetoid that collides with the magnetic field of the NS at a radius of 1000 km (3×10^6 gauss), one that misses and returns, and a third that suffers a near miss. Fig 6 shows the collision with the magnetic field of the NS and the Helmholtz mixing with the field. Actually this mixing is by way of twisting the field lines resulting in magnetic helicity. The reconnection of the helicity results in E parallel and the acceleration of electrons that make the photons of the GB.

Fig 7 shows the optical pulse created by the GB flux that penetrates, heats, and blows off the outer layer ($\sim 10 \text{ g cm}^{-2}$) of the 10^8 planetoids in orbit around the NS. The expanding low density plasma within one second creates a secondary target of $\sim 3 \times 10^{23} \text{ cm}^{-2}$ or $\sim 3 \times 10^{-4}$ solid angle of the emitted fluence. A GB fluence of $10^{-6} \text{ ergs cm}^{-2}$ at earth creates an optical flux of 100 hv cm^{-2} . The background optical flux is $\sim 1/10 \text{ hv cm}^{-2} \text{ s}^{-1} \text{ arcsec}^{-1}$, and so the optical signal is detectable with a delay and lasting for $\sim 1000 \text{ s}$.

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