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A NUMERICAL SIMULATION OF THE MAGNETOSPHERIC GATE MODEL FOR THE X-RAY BURSTERS

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ABSTRACT

We have used a Lagrangian, fully implicit, one-dimensional hydrodynamic computer code to investigate the evolution of a gas cloud impacting the surface of a 20 km, 1 $M_{\odot}$ neutron star. This gas is initially at rest with respect to the surface of the neutron star, extends to 185 km above the surface, and is optically thick. The infall results in a burst which lasts about 0.1 seconds and reaches a peak luminosity and effective temperature of 2.4×10^5 $L_{\odot}$ and 9×10^6 K; respectively. The burst was followed by a phase of oscillations with a period 0.2 seconds.

INTRODUCTION

One of the more interesting scenarios for the cause of the X-ray Bursts is the magnetospheric gate theory of Lamb, et al.[1] In this scenario we have a rapidly rotating neutron star with a strong magnetic field in a binary system with a companion that is losing mass toward the neutron star. This material is impeded by the magnetic field in such a fashion that accretion is not continuous but occurs in episodic events. To our knowledge there have been no previous numerical simulations of this phenomena.

We use the same hydrodynamic code described in the last paper[2]. Because it is a Lagrangian, stellar interior, computer code which assumes radiation transport by diffusion; we cannot place a hole in the mesh and so assume that the blob of gas extends from the surface of the neutron star to a radius of 185 km. This blob is optically thick, has a mass of 10^{-11} $M_{\odot}$, and is initially at rest with respect to the surface of the neutron star. The mass of this blob was chosen so as to simulate a much smaller amount of material falling only onto the polar caps. The gas initially has a temperature of ~ 10^7 K and a surface luminosity of 0.1 $L_\odot$. We begin the calculation by allowing the material to fall onto the surface.

RESULTS

Once the infall has begun, an accretion shock forms at the boundary of the core. After about 100μ sec of evolution, the infall velocities have reached free fall and the temperature behind the shock has reached 10^9 K. It takes 3.5 milliseconds for the outer edge of the shock to reach the surface of the blob which has now fallen inward to 80 km. The entire envelope bounces imparting enough energy to the two outermost zones (2×10^{-14} $M_\odot$) for them to reach escape velocity. The light curve for the burst is shown in Figure 1. The peak luminosity and effective temperature produced by the infalling material is 2.4×10^5 $L_\odot$ and 9×10^6 K, respectively. Although, this effective temperature is too low for any of the

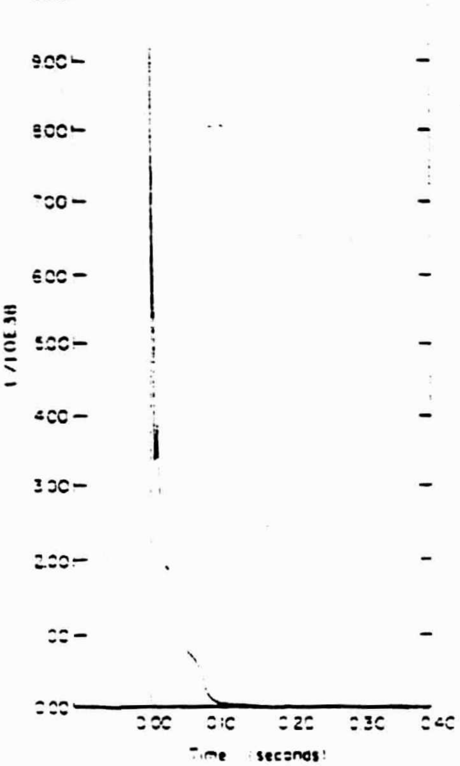

Fig. 1. The luminosity of the infalling material as a function of time.

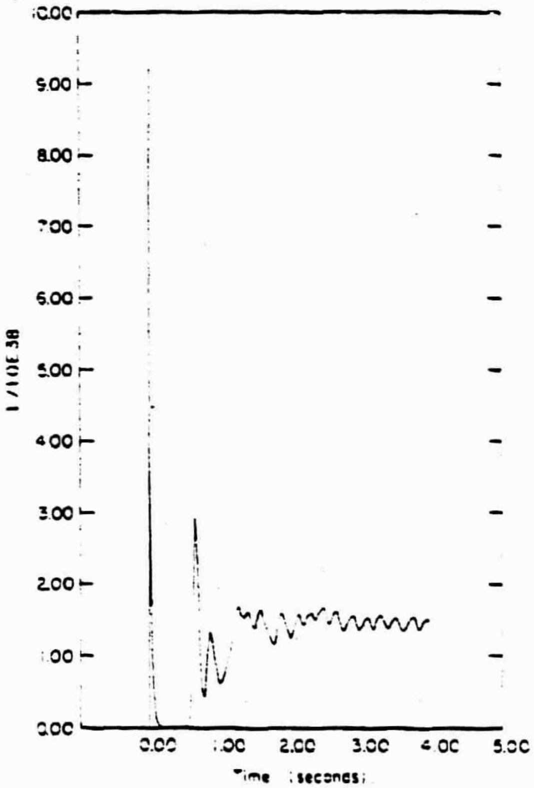

Fig. 2. The luminosity of the surface as a function of time.

observed bursts, we could raise this temperature by reducing the inner radius of the neutron star and reducing the amount of infalling material.

The temperature in the shell source at the core-envelope interface (CEI) has remained at 10^9 K and enough triple-α reactions are occurring to keep the rate of nuclear energy generation at 10^{18} erg gm^{-1} sec^{-1}. In addition, the deeper layers of the envelope are convective, which is mixing fresh unburned nuclei into the shell source which also is maintaining the large rate of nuclear burning. However, the outer layers are expanding too rapidly for the energy produced in the shell source to reach them and their luminosity drops rapidly. For a short period the β^+-decays in the surface layers are able to halt the decreasing luminosity but the rapid expansion again overcomes this energy source. The entire burst lasts about 0.3 sec.

The decline in luminosity continues until the escaping shells become optically thin. At this time the energy from the interior can now escape and the luminosity begins to increase. Now that we can see into the deeper layers we find that the accreted material remaining on the neutron star is pulsating with a period of $\sim$ 0.2 sec (Figure 2). The average luminosity of this object is $\sim 10^4$ $L_\odot$ and the effective temperature is 0.3 kev. It has a radius of 150km (average).

These pulsations are a direct result of the infall and are not caused by a partial ionization mechanism such as in the Cepheids or ZZ Ceti variables. We also find that these pulsations must be occurring in high overtones since we find a number of nodes in the eigenfunction and the largest amplitudes are in the surface zones.

We closely followed these pulsations for 4 seconds of star time. However, the computer time was becoming prohibitive and we ended this part of the calculation. We removed the escaping zones and followed the resulting evolution for another thousand seconds. No further changes occurred and we ended the calculation. It is estimated that at least one day of further evolution would be necessary to completely burn the hydrogen in the envelope.

We also studied a purely cooling sequence in which we followed the contraction of the extended envelope assuming only neutrino losses - no nuclear energy production. The envelope contracts from about 200 km to 100 km in 10^3 sec with the luminosity climbing to 2 x 10^5 $L_\odot$ and the effective temperature to about 1 kev. It takes another 40 minutes to contract to 20 km. During the cooling phase the surface luminosity reaches a peak luminosity of 2 x 10^5 $L_\odot$ and a peak effective temperature of 1.9 kev.

CONCLUSIONS

We find that our Burst was too cool and too rapid to resemble the normal bursts although the time scale is in agreement with some of the rapid bursts that have been observed for some objects[4]. It is certainly possible that more realistic initial conditions, such as assuming the material was already infalling, could improve the correspondence between our calculations and the observations.

We also found that the infall produced a ringing of the envelope which showed short period pulsations. Such pulsations have been observed in at least one burst event[5].

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