A MODEL FOR THE RAPID X-RAY BURSTER

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Abstract. A model for the Rapid X-ray Burster (MXB 1730-333) based on an accreting rotating magnetized neutron star in a binary system is proposed. The bursts are attributed to instabilities produced at an equilibrium surface above the poles of the neutron star, which is created by the infalling gas supported by a combination of radiation and relativistic gas pressures. The special feature of the proposed model is that, when accretion onto the poles is prevented by radiation pressure, relativistic gas streams out of the polar region.

The discovery of more than thirty X-ray burst sources over the last few years (Lewin and Joss, 1977) has stimulated considerable interest in the mechanism responsible for producing these bursts. A typical burst is characterized by a rise time of less than a few seconds and a decay time ranging from several seconds to several minutes with the interval between bursts varying from seconds to several hours. The Rapid Burster (MXB 1730-333) differs from all the other burst sources in that it is observed to emit several thousands of bursts per day with their energy varying between $10^{38} - 10^{40}$ ergs (Lewin and Joss, 1977). Observational data also show that there is a waiting period after each burst and before the commencement of the next, which for the large bursts is approximately proportional to the energy of the preceding burst. However, this relationship does not seem to hold for the smaller bursts; in fact the waiting time seems to be independent of the burst-size for the smaller ones (Lewin, 1977). The bursts of the Rapid Burster are termed Type-II from the development of their energy spectra with time, in contrast to Type-I bursts which occur in the other X-ray burst sources with intervals of hours or days between bursts (Hoffmann et al. 1978). The Type-I bursts are suggested to be resulting from thermonuclear flashes due to ignition of accumulated accreting gas near the surface of the neutron star (Joss, 1978 and references therein). Another suggestion is that the Type-I bursts arise because of the instabilities occurring near the magnetosphere of an accreting magnetized neutron star (Baan, 1977, Lamb et al. 1977). It is, however, significant (Hoffmann et al. 1978) that in the Rapid Burster the Type-I bursts occur occasionally but apparently they do not disturb the waiting-time energy relation displayed by the Type-II bursts. Hoffmann et al. (1978) have pointed out that this indicates that the Type-II bursts are due to a mechanism different from that producing the Type-I bursts. They also suggested that the Type-II bursts are due to instabilities in the accretion process. Here we consider instabilities near the poles of a rotating accretion neutron star in a binary system as the origin for Type-II bursts.

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The present model for the Rapid Burster is based on a rotating magnetized neutron star capturing matter onto its poles from its primary companion. The luminosity of the bursts ($\sim 10^{38}$ erg s$^{-1}$) corresponds to an accretion rate of $\sim 10^{19}$ gm s$^{-1}$ (using an efficiency factor of 0.1 for conversion of gravitational energy into thermal energy) which is adequate to generate emergent radiation of sufficient intensity to halt further infall of matter. Thus the accretion process is assumed to operate at the Eddington limit (Rees, 1974). The various stages in the sequence we suggest here, starting from a big burst, proceed as follows. The accretion process operating at the Eddington limit (as indicated by the luminosity of the big bursts) is suddenly stopped by the emergent burst X-radiation. This results in the production and streaming out of relativistic gas from the poles of the neutron star (Sturrock, 1971), which is otherwise suppressed during the process of accretion. Thus when the X-radiation terminates due to the cooling of the thermal gas, the relativistic gas becomes effective in further inhibiting accretion. This leads to the formation of an 'interaction surface' at which the relativistic gas opposes the weight of the overlying gas. The 'interaction surface' slowly moves up above the polar region under the influence of the impact of the relativistic gas until it is stopped by the weight of the continually accreting gas. The surface is then subjected to Rayleigh-Taylor instabilities, the growth of which leads to dumping of gas onto the surface of the neutron star resulting in X-ray burst emission. We infer from these considerations that for this model to be operative, the rotation period of the underlying neutron star should be of the order of 0.1 s.

It is well-known that the Eddington limit to the luminosity generated by steady spherical accretion onto an object of mass $M$ is given by (cf. Rees, 1974)

$$L_{\text{Edd}} = \frac{4\pi G M m_p c}{\sigma_T} \approx 10^{38} \frac{(M/M_\odot)}{\sigma_T} \text{ erg s}^{-1},$$

where $G$ is the gravitational constant, $m_p$ the mass of the proton, $c$ the velocity of light, $\sigma_T$ the Thomson cross-section for the electron, and $M_\odot$ the mass of the Sun. This limit is however valid for steady accretion, but in unsteady situations the Eddington luminosity may be exceeded (Rees, 1974). The limit may even be lowered (Ostriker et al., 1976) by the heating of the gas by radiation. In the polar regions of a neutron star the cross-section $\sigma_T$ may be influenced by the strong surface magnetic field (Gnedin and Sunyaev, 1974). But it turns out that for a neutron star with a surface magnetic field of $10^{12}$ gauss, except within a distance of a few neutron star radii, the scattering cross-section of X-rays with energy in excess of a few keV is virtually unaffected by the presence of the magnetic field. Consequently the Eddington limit near the poles of the neutron star is the same as that given by the usual expression, except very close to the surface of the neutron star.

The creation of an 'equilibrium surface' due to the interaction of radiation (Eddington limit) and the accreting gas implies a quasi-equilibrium between the radiation pressure $P_r$ and gravitational force in the gas given by the equation of hydrostatic support

$$\frac{dP_r}{dr} = -\frac{G M \rho_g}{r^2},$$