COHERENT OSCILLATIONS FROM X-RAY BURST SOURCES

MARIO LIVIO
Department of Physics and Astronomy, Tel-Aviv University, Ramat-Aviv, Israel

(Received 3 July, 1981)

Abstract. The possible origin or coherent oscillations in X-ray bursters is discussed. Such oscillations with a period of the order of 10 ms have recently been observed. At this point it seems impossible to draw final conclusions on their nature. Nevertheless, it is shown that nonradial pulsations of a neutron star or torsional oscillations of a neutron star's crust seem to be an attractive possibility.

1. Introduction

The X-ray burster MXB 1728-34 has been known for some time (Hoffman et al., 1976, 1979); it exhibits bursts with intervals of 4-8 hr (Hoffman et al., 1977). A periodic behaviour of the steady source 4U 1728-33, has been reported (White et al., 1976a,b) with a period of $7.9^m$ for data from April 1973 (which may be an interference from the nearby MXB 1730-335), and a period of 73 sec for data of March, 1976. Hoffman et al. (1977) failed to observe any periodicity. No optical counterpart for this source is known (Liller, 1977).

In a recent observation, Sadeh et al. (1980a) presented evidence for the existence of a coherent emission component with a period of 12.24 ms, which lasted for more than a few tens of seconds, during one of the bursts. The most prominent feature was observed during a 20.48 s data set taken on March 10, 1978; the fraction of the pulsed luminosity was about 6%. The examination of preburst data revealed the possible existence of a drift in the period at a rate of $-1 \mu s s^{-1}$ (Sadeh et al., 1980a).

In a different set of observations, of the source H 1909 + 096 (4U 1907 + 09, Forman et al., 1978), Sadeh et al. (1980b) find an indication to the fact that during three times at which the source was at a much higher luminosity than the usual (about 100 Uhuru counts compared to a regular of about 10), a coherent emission component was detected. The observed period was 15.25 ms (or possibly 30.5 ms). A possible, almost continuous shift in the period at a rate of $\dot{P} \sim +10 \mu s^{-1}$ may have been present during one of the observations, and a drift of $\dot{P} \sim 4 \mu s s^{-1}$ during another (Sadeh and Livio, 1981).

Assuming that the observed periodicities represent real oscillations occurring at the X-ray source, we try in the next section to discuss a few possible sources for such coherent oscillations.

Astrophysics and Space Science 82 (1982) 167-172. 0004-640X/82/0821-0167 $0.90.
Copyright © 1982 by D. Reidel Publishing Co., Dordrecht, Holland, and Boston, U.S.A.
2. Possible Models and Discussion

A quite convincing class of models for the X-ray bursters consists of thermonuclear runaways on the surface of accreting neutron stars (Joss, 1978; Taam and Picklum, 1978, after original suggestion by Woosley and Taam, 1976; and Maraschi and Cavaliere, 1977). If we accept this type of model, then the coherent oscillations can originate in principle from two likely sources:

(a) The accretion disk.
(b) The accreting neutron star itself or matter in its close vicinity.

Let us examine each of these possibilities separately:

2.1. Oscillations Originating in the Accretion Disk

The possibility exists that the oscillations are generated by the eclipses of luminous blobs in the accretion disk. This type of model has been suggested for the oscillations observed in dwarf novae by Bath (1973) (see also Patterson, 1980). The blobs may be generated, for example, by the interaction of the disk with the neutron star's magnetic field and become more luminous, due to reflected luminosity during bursts. The observed period in this case would simply be the Keplerian period of the blob which is given by

\[ P_{\text{kep}} \sim 17 \left( \frac{M_{\text{ns}}}{M_\odot} \right)^{-1/2} \left( \frac{R_{\text{orb}}}{10^7 \text{ cm}} \right)^{3/2} \text{ ms}, \]  

where \( M_{\text{ns}} \) is the mass of the neutron star and \( R_{\text{orb}} \) is the orbital radius of the blob. We see that this period agrees well with the observed ones (12 ms and 15 ms). The main problem with such a model stems from the duration of the oscillation. The lifetime of such a luminous blob against smearing by differential rotation can be estimated (Bath et al., 1974) by

\[ \tau_{\text{blob}} \leq \frac{2}{3} \frac{R_{\text{orb}} P_{\text{kep}}}{d}, \]  

where \( d \) is the linear dimension of the blob in the radial direction. If we assume that \( d \) is roughly equal to the disk thickness at \( R_{\text{orb}} \) which is given for a stationary disk model by (Novikov and Thorne, 1973) in the 'middle region')

\[ d \sim 1.2 \times 10^5 \alpha^{-1/10} \left( \frac{M_{\text{ns}}}{M_\odot} \right)^{-7/20} \left( \frac{\dot{M}}{10^{17} \text{ g s}^{-1}} \right) \left( \frac{R_{\text{orb}}}{10^7 \text{ cm}} \right)^{21/20} \text{ cm}, \]

where \( \alpha \) is the viscosity parameter (Shakura and Sunyaev, 1973) and \( \dot{M} \) is the accretion rate, we obtain for the lifetime of the blob

\[ \tau_{\text{blob}} \leq 0.9 \alpha^{1/10} \left( \frac{R_{\text{orb}}}{10^7 \text{ cm}} \right)^{23/10} \left( \frac{M_{\text{ns}}}{M_\odot} \right)^{-3/20} \left( \frac{\dot{M}}{10^{17} \text{ g s}^{-1}} \right)^{-1} \text{ s}. \]

This is much shorter than the time during which the oscillations have been observed (~40 s). We feel obliged to emphasize, however, that the crudeness of