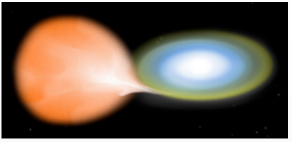
The Joint Institute for Nuclear Astrophysics

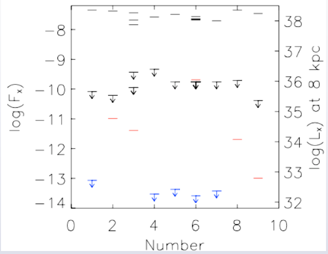
Sedimentation and X-Ray bursts at Low Accretion Rates

Fang Peng[1,2,3], Edward Brown[2,4] , and James Truran[1,2,3,5]
[1] University of Chicago, [2] Joint Institute for Nuclear Astrophysics, [3] ASC Flash Center, [4] Michigan State University, [5] Argonne National Laboratory
fpeng@oddjob.uchicago.edu, ebrown@pa.msu.edu, truran@nova.uchicago.edu

1. Introduction



Neutron stars, with their strong surface gravity, have interestingly short timescales for the sedimentation of heavy elements. Motivated by observations of X-ray bursts from sources with extremely low persistent luminosities, we study how sedimentation affects the distribution of isotopes and the ignition of H and He in the envelope of an accreting neutron star and we apply the sedimentation model to bursts with low mass accretion rates.



X-ray bursts are the phenomena of explosive nuclear burning on the surface of accreting neutron stars in low-mass X-ray binaries (LMXBs). About half of the observed LMXBs show X-ray bursts. Cornelisse et al (2004) summarized nine burst-only sources with very low persistent luminosities, $L_p \leq 10^{36}$ erg s^{-1} (see **Fig. 1**). These sources are good candidates for examining the effect of sedimentation effect on composition redistribution during the long accretion history.

Fig. 1: Nine burst-only sources of $L_p \leq 10^{36}$ erg s^{-1}. The top bars are the peak luminosities of the bursts. The middle bars are upper-limit persistent luminosities constrained from the sensitivity of BeppoSAX. The bottom bars are the persistent luminosities from the follow-up instruments (e.g. Chandra) (from Cornelisse et al 2004).

The normal X-ray burst shows a fast rise of luminosity in ~ 1 s followed with an exponential decay ~ 5-50 s. However, recently there are several long bursts observed with exponential decay ~ 100-10^3 s. The persistent luminosities of these sources are ~ 0.01 Eddington limit ($L_{Edd} \approx 2\times10^{38}$ erg s^{-1}) . The lightcurve of one long burst from SLX 1735-269 is shown in **Fig. 2**. The relation between the long bursts and the mass accretion rates is investigated in the work.

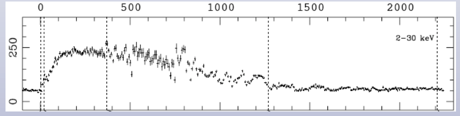
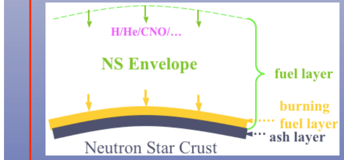


Fig. 2: The lightcurve of the long burst of SLX 1735-269 observed by Integral/JEM-X (from Molkov et al 2004).

2. Evolution of An Accreting Envelope with Diffusion



At the low mass accretion rates (≤ 0.01 Eddington accretion rate) inferred from the burst-only sources, the sedimentation timescale for CNO nuclei, defined as the time required to move a scale height relative to the center of mass of a fluid element, is less than the accretion timescale. The partial separation of the H and He layers is important in setting the ignition conditions and subsequent burst nucleosynthesis.

We implement the abundance evolution in a model of an accumulating neutron star envelope. One example of how the composition of the base of the accreted layer changes due to sedimentation is shown in **Fig. 3**.

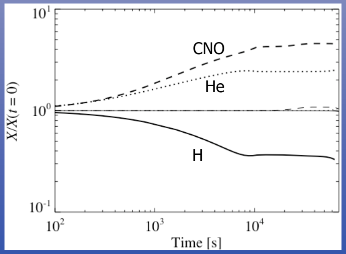


Fig. 3: The evolution of mass fraction of the base fuel layer for accretion rate of 0.006 Eddington limit. We show cases when sedimentation and diffusion is (*thick lines*) and is not *(thin lines*) included. The curves terminate where He ignites unstably.

3. Results and Applications

Burst at Low Accretion Rates

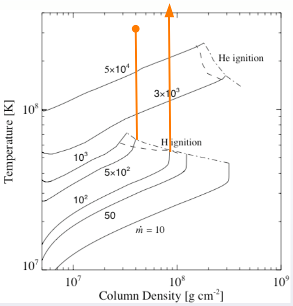
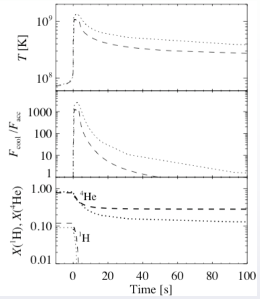


Fig. 4 (left) shows the temperature evolution of the base of the accreted layer. The tracks (*solid lines*) are for different mass accretion rates (in unit of g cm^{-2} s^{-1}).. The ignition curves of H and He when sedimentation is (dashed lines) and is not (dot-dashed lines) taken into account are shown as well. The **orange curves** are sketches of the increase of temperature after H ignites. We adopt 0.1 Mev/nucleon as the inner flux from the crust.

The local Eddington accretion rate ≈ 10^5 g cm^{-2} s^{-1}



In **Fig. 5 (right)**, we show the one- zone burst calculation following H ignition for two mass accretion rates: 100 (*solid lines*) and 200 (*dotted lines*) g cm^{-2} s^{-1}, respectively. The temperature rise is sufficient to trigger He ignition and to produce strong bursts.

Long bursts

At accretion rates ≥ 500 g cm^{-2} s^{-1}, weak H flashes which do not ignite He burning can lead to the buildup of He layer large enough to explain the long bursts, as shown in **Fig. 6** and **Fig. 7**.

1. Weak H flashes

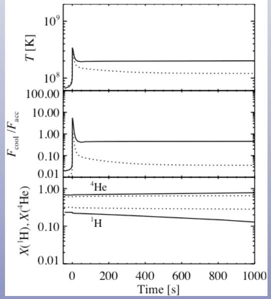


Fig.6: One-zone burst calculation following H ignition for two mass accretion rates: 500 (*solid lines*) and 10^3 (*dotted lines*) g cm^{-2} s^{-1}, respectively. The temperature rise is not sufficient to trigger He ignition.

2. Accumulation of a large He layer

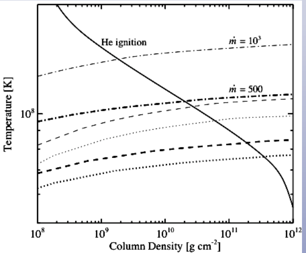


Fig. 7: Steady-state thermal structure of an accumulated pure He layer for two accretion rates: 500 (*thick lines*) and 10^3 (*thin lines*) g cm^{-2} s^{-1}, respectively. The results for three different inner fluxes, 0.1 (*dotted lines*), 0.2 (*dashed lines*) and 1.0 (*dot-dashed lines*) Mev/nucleon, are presented.

3. Cooling Time: One-zone cooling time at ignition column density (~ 10^{10} g cm^{-2}) roughly agrees with the observed luminosity decay time.

$$\tau_{cool} \approx 4\pi R_{NS}^2\, y_{ign}\, E_{nuc}/L_{Edd}$$
$$\approx 400 \text{ sec } (y_{ign}/10^{10} \text{ g cm}^{-2})(E_{nuc}/1 \text{ Mev per nucleon})$$

4. Summary

- ❑ Sedimentation plays an important role in the ignition of X-ray bursts, even for accretion rates as high as 0.1 Eddington.
- ❑ There is a region of mass accretion rates where the large reservoir of accumulated He may explain the long bursts observed from some sources.
- ❑ At accretion rates less than this region, the H ignition triggers strong H mixed He bursts.
- ❑ No convection is included in these models yet. A hydro code is needed to study further the effect of sedimentation on multiple bursts.

This project is partly supported by the Department of Energy under grant B523820 to the Center for Astrophysical Nuclear Flashes at University of Chicago.
This project is funded by the NSF through grant PHY0216783, and the Universities of JINA.