Influence of the neutron star cooling on X-ray burst

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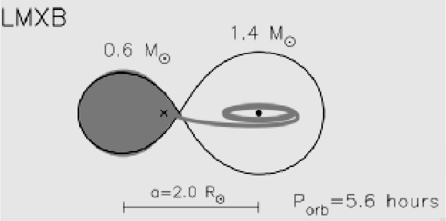
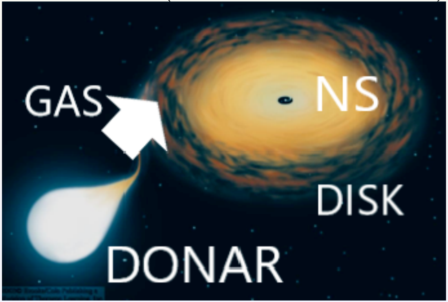
Low Mass X-ray Binary (LMXB) and X-ray Burst

- Property of LMXB
  - $M_{\text{donar}} \lesssim 1\ M_{\odot}$
  - Old system ($t \gtrsim 1$ Gyr) with weak magnetic field ($B \lesssim 10^{12}$ G)
  - Roche-Lobe Overflow
- X-ray burst
  1. Accreting matter on NS
  2. The flowing matter compresses NS until it becomes hot and dense enough to ignite
  3. Outburst by unstable H or He nuclear burning

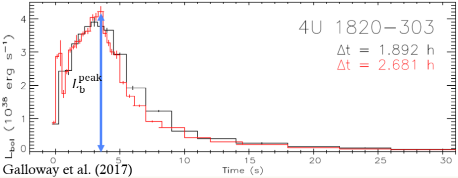


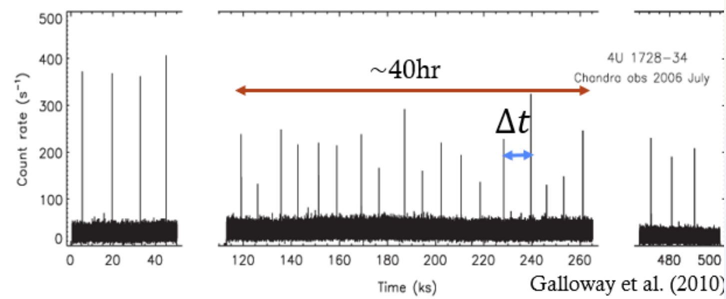
(Tauris & Heuvel. 2005)



The characteristic parameter of X-ray burst

- Peak luminosity L_b^{peak} [erg/s]
- Recurrence time Δt [hr]
- Burst duration τ [s]
- Burst energy E_b [erg/s]
- ……

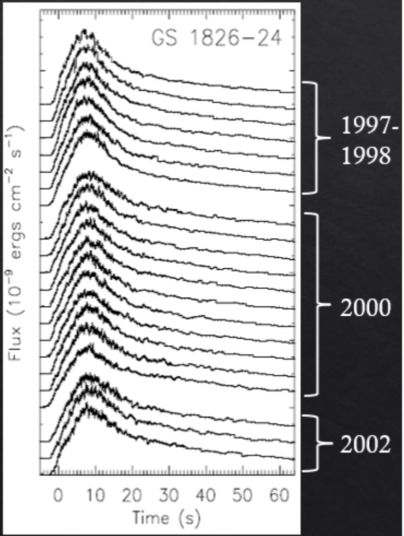




Textbook/Clocked burster GS1826-24

- Observed for the first time by *Ginga* in 1998.
- 3 series of outbursts have been observed in 1997(8), 2000, and 07.
- Mass accretion rate is not changed so much and the shape of the light curve is almost the same.
- All Non-Photospheric Radius Expansion bursts.
- It's useful to examine the validity of burst models.

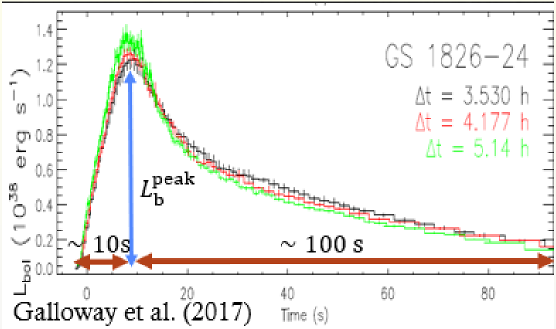
Light curve of GS 1826-24



Galloway et al. (2004)

Observed Δt of *clocked burster* GS1826-24

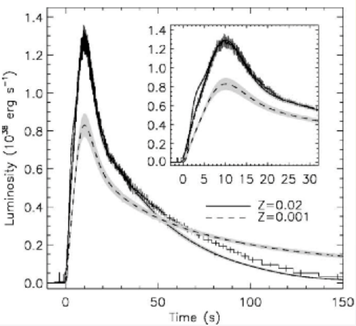
- 3 series of outbursts in 1997-98 (green), 2000 (red), and 2007 (black)
- The peak luminosity depends on a distance d and anisotropy factors ξ_b



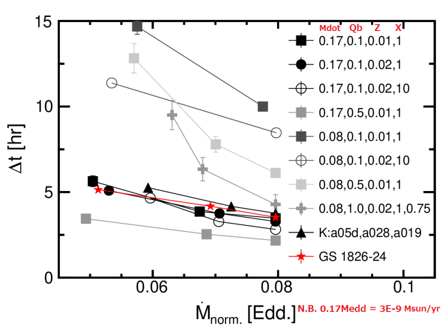
- $\Delta t_{\rm obs} \approx 3.5 - 5.2$ hr
- $L_{b,\rm obs}^{\rm peak} \approx 1.2 \times \mathrm{d}^2 \xi_b/(6.1\ \mathrm{kpc})^2 \times 10^{38}\ \mathrm{erg\ s^{-1}}$

The comparison of some previous X-ray burst models with *clocked burster* GS1826-24

- Heger et al. 2007 (*KEPLER*)



- Meisel. 2018 (*MESA*)



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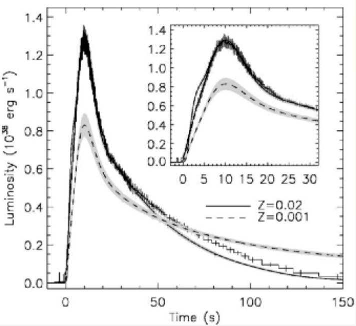

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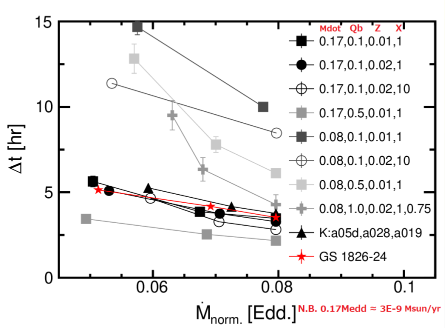


- However, they all consider only outside NS crust.
- Our aim is to calculate X-ray burst from center of NS in order to consider the inner physics (e.g. Crust Heating, ν Cooling)

Energy Sources in Accreting NS

- OUTER PHYSICS OF NS
  - Release of Gravitation
  - Nuclear Burning

    3α reaction→HCNO cycle

    (Wallance & Woosley 1981)

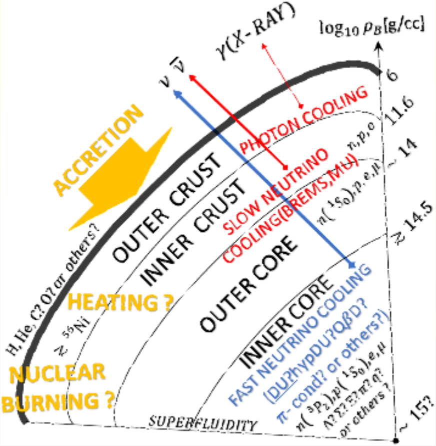
    →αp process→rp process

    (Woosley & Weaver 1981,84)

    →SnSbTe cycle (Schatz+ 2001)
- INNER PHYSICS OF NS
  - Crustal Heating

    (Haensel & Zdnick 1990, 2008)
  - Photon Emission
  - ν Emission

    (Slow + Fast Cooling)



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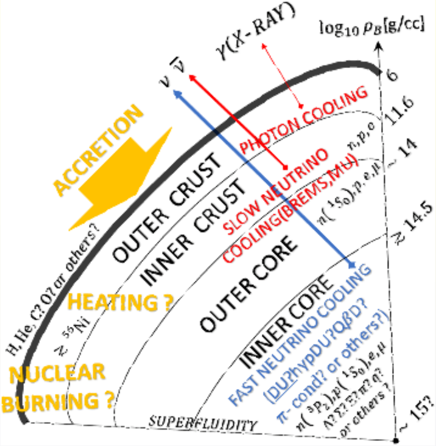
- INNER PHYSICS OF NS
  - Crustal Heating

    (Haensel & Zdnick 1990, 2008)
  - Photon Emission
  - ν Emission

    (Slow + Fast Cooling)
  - Above all, DU may influence the burst parameters.



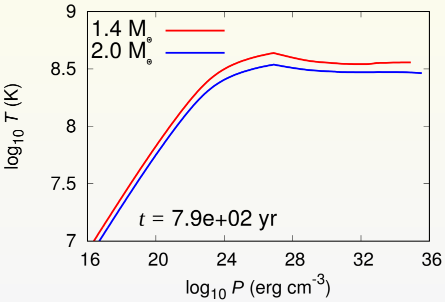
⇒ We investigate the influence of DU on recurrence time Δt.

Setup

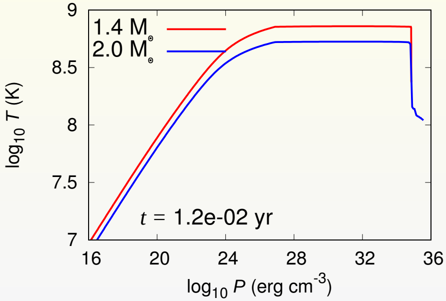
- *M.Y.Fujimoto*'s code which can solve relativistic steller evolution equations (Fujimoto et al. 1984)
- Approximate reaction network with 88 nuclei is adopted (M. Hashimoto, AD et al., 2019, *submitted*)
- 11 burst profiles for analysis, considering the maximum times of observed series of outbursts (2000)
- Accretion rate $\dot{M}_{-9} = 3 \;\; [10^{-9} \; M_{\odot}/\mathrm{yr}]$
- $X/Y = 2.9$ and $Z = 0.002, 0.02$
- $M = 1.4M_{\odot}, 2.0M_{\odot}$ (R=12.7, 11.3km), respectively.
- Slow ν cooling processes (Modified Urca + Bremsstrahlung) are considered in all models.
- No rotation, no magnetic field

Construction of Initial Models in Quiescence

- w/o DU



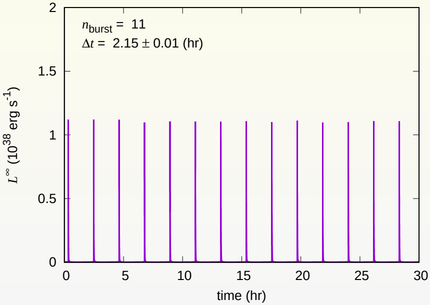
- w DU

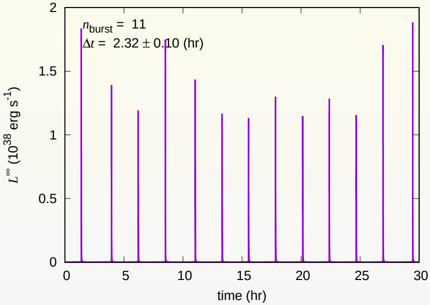


- With DU, the temperature at interior NS cools rapidly.
- We use the temperature structure being constant ($\gtrsim 10^5$ yr) as initial model of burst calculation.

DU effect on burst with 1.4 $M_\odot$ and $Z = 0.02$

- w/o DU: $\langle \Delta t \rangle = 2.15$ hr
- w DU: $\langle \Delta t \rangle = 2.32$ hr

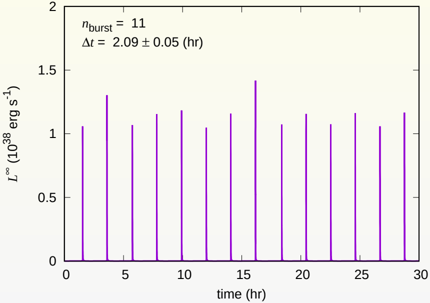


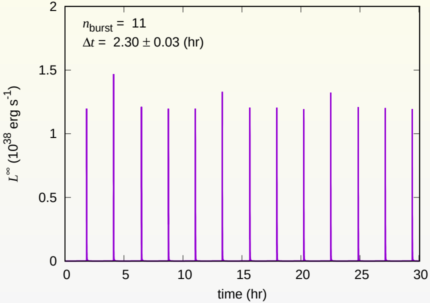


- Δt becomes longer for another 0.17 hr(+8%) by DU.
- Neglegible in conparison with GS1826-24.

DU effect on burst with 2.0 $M_\odot$ and $Z = 0.02$

- w/o DU: $\langle \Delta t \rangle = 2.09$ hr
- w DU: $\langle \Delta t \rangle = 2.30$ hr

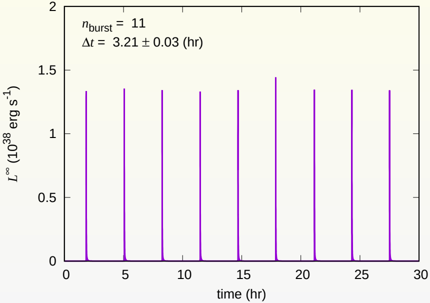


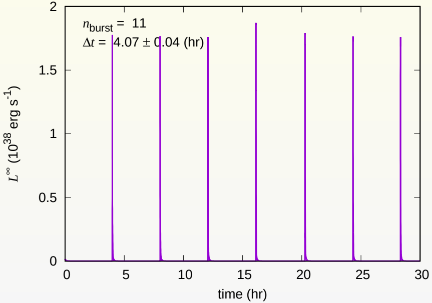


- Δt becomes longer for another 0.21 hr(+10%) by DU
- Longer than in case of 1.4 $M_\odot$ due to higher central density
- However neglegible in conparison with GS1826-24.

DU effect on burst with 2.0 $M_\odot$ and $Z = 0.002$

- w/o DU: $\langle \Delta t \rangle = 3.21$ hr
- w DU: $\langle \Delta t \rangle = 4.07$ hr

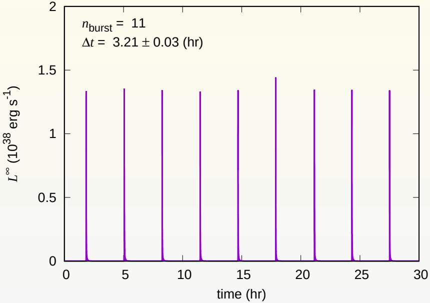


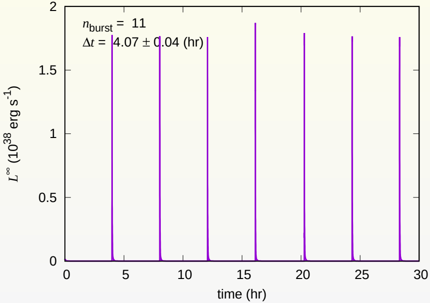


- Δt becomes longer for another 0.86 hr(+27%) by DU.
- The model with DU is consistent with GS1826-24

DU effect on burst with 2.0 $M_\odot$ and $Z = 0.002$

- w/o DU: $\langle \Delta t \rangle = 3.21$ hr
- w DU: $\langle \Delta t \rangle = 4.07$ hr





- Δt becomes longer for another 0.86 hr(+27%) by DU.
- The model with DU is consistent with GS1826-24
- ν Cooling could be a parameter to account for GS1826-24

Summary of My Talk

- We calculated X-ray burst with the Direct Urca process as inner physics of neutron star and show that ν cooling is one of the important factors for X-ray burst.
- In our model with $M = 2M_{\odot}$, $Z = 0.002$, $\dot{M}_{-9} = 3$, we can see the effect of DU on Δt (+27%)
- However, we should compare the model with the light curve of GS1826-24 every burst as well.

** In future work **

- Another calculations with some input parameters ($M, R, \dot{M}_{-9}$, Z, X/Y, and so on)

Thank you for your attention