Hydrogen-Powered Explosion on Accreting Neutron Stars

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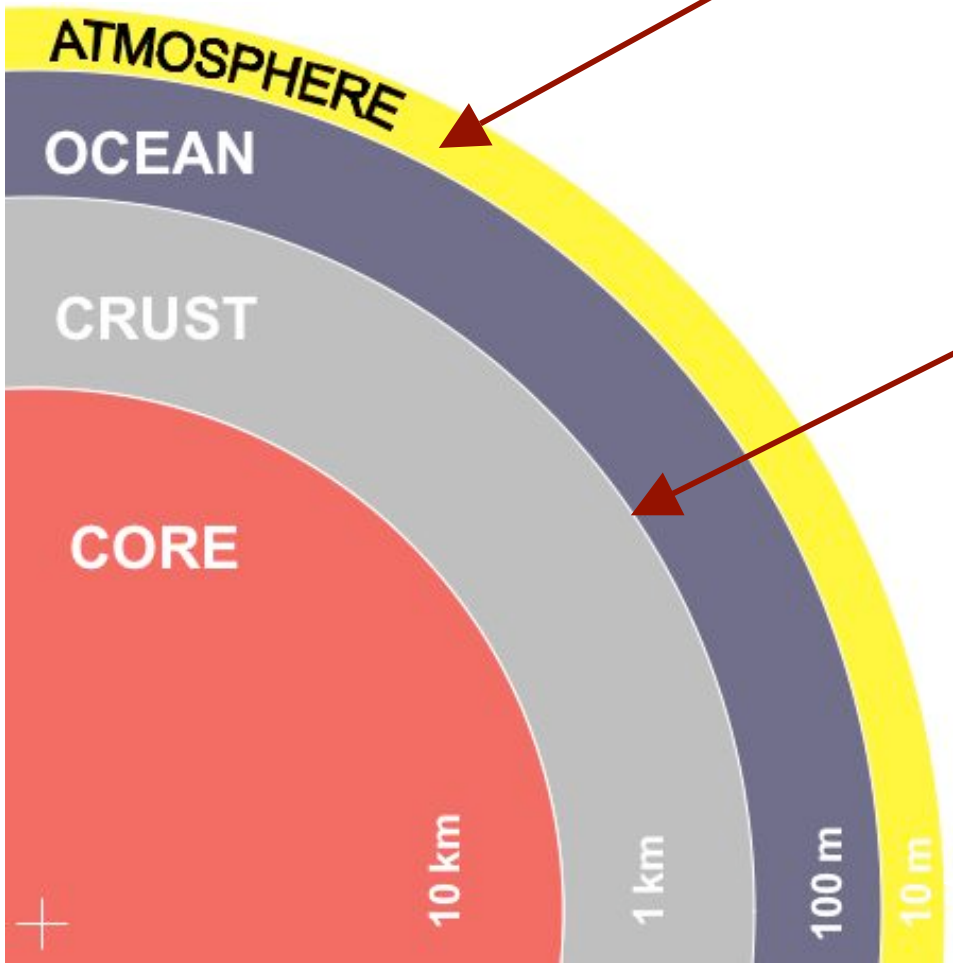
Accreting Neutron Stars

X-Ray Bursts
(explosive **H/He** burning)

10-100 sec
$E \sim 10^{39\text{-}40}$ erg



Superbursts
(explosive **C** burning)

10,000 sec
$E \sim 10^{42}$ erg

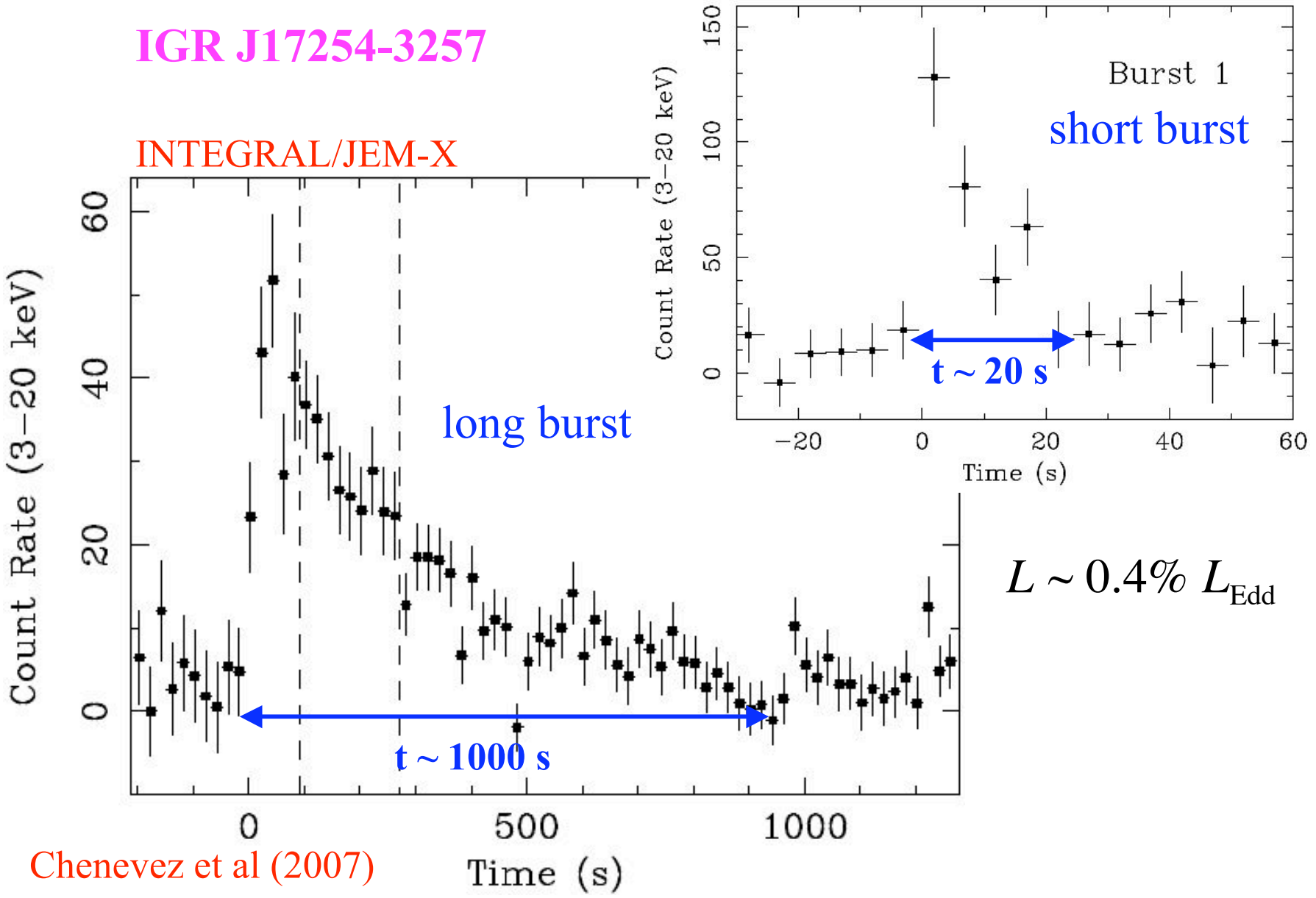
Burst energy depends on the amount of the fuel.

Accretion

Long Bursts

IGR J17254-3257

INTEGRAL/JEM-X



$L \sim 0.4\%\ L_{\rm Edd}$

Chenevez et al (2007)

Long Bursts

- ! In total ~ 10 sources now, L < 0.01 L_{Edd}, t ~ 1000 s, E ~ 10^{41} ergs
- ! One exception, GX 3+1, L ~ 0.4 L_{Edd}
- ! Most of them are in UCXBs: Porb < 1 hr, L < 0.01 L_{Edd} (in 't Zand et al. 2007)

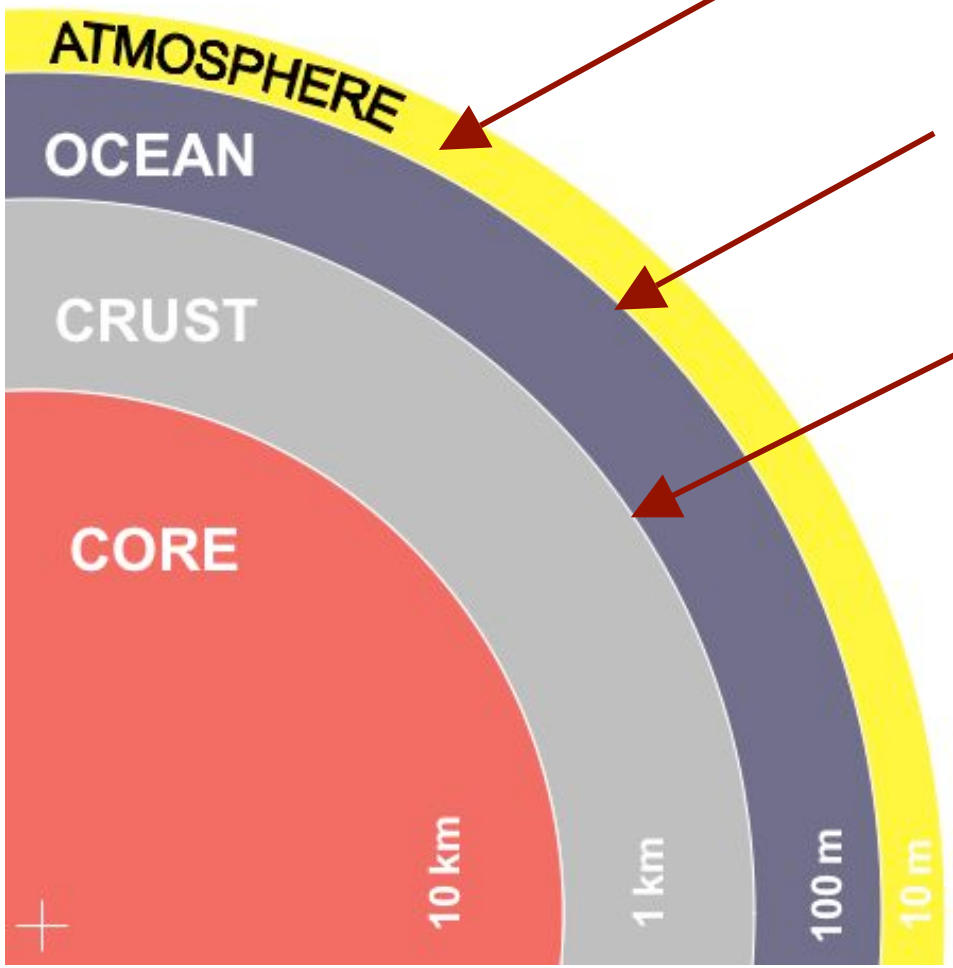
  Do they have He white dwarfs as companions?

Important points of low-luminosity sources:

1. Hydrogen, if there is any, burns unstably.
2. There is enough time for accreted matter to sediment.

How to produce long bursts?

How to Produce Long Bursts?



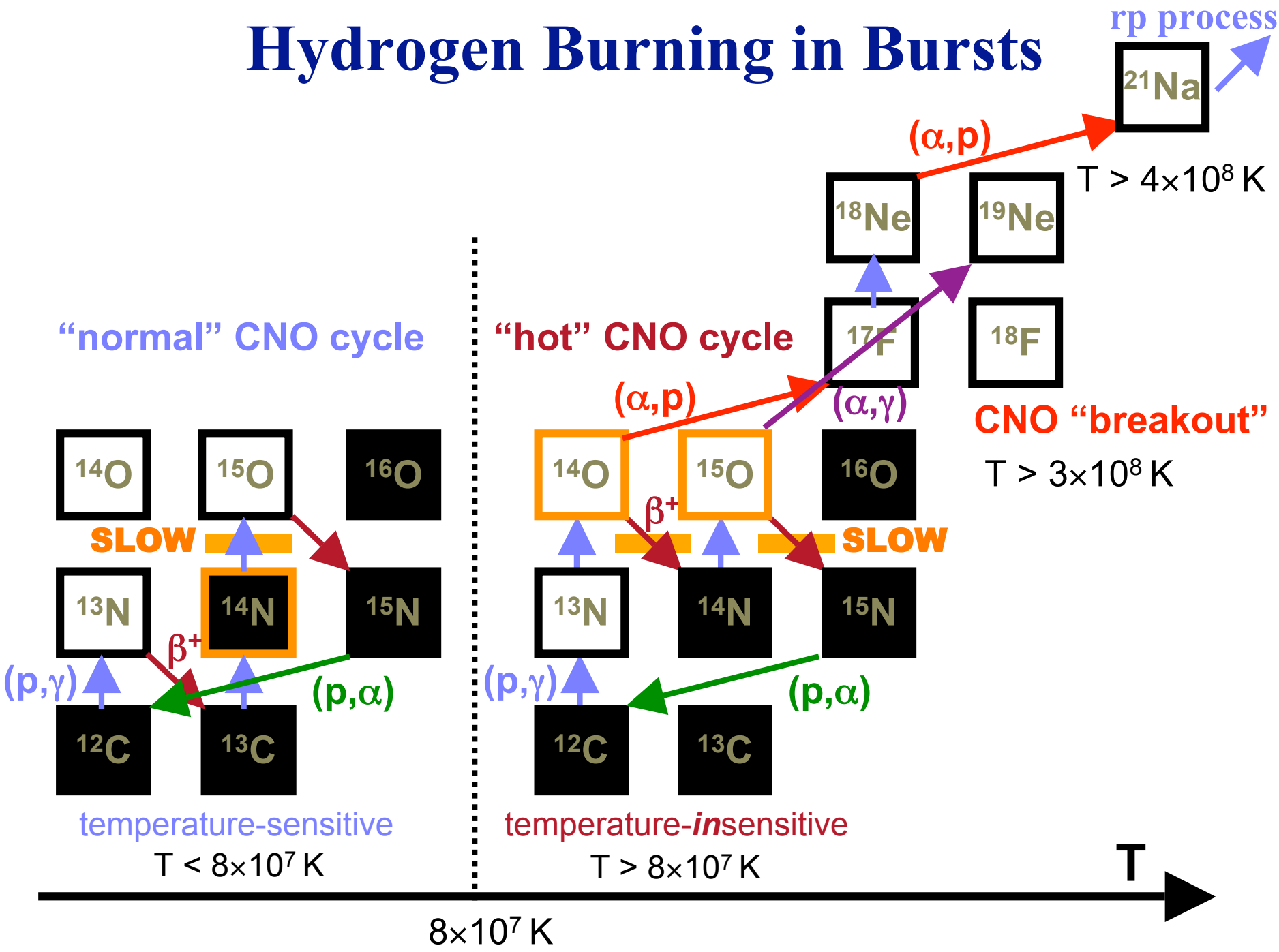
X-Ray Bursts (explosive **H/He** burning) ~10-100 sec

Long Bursts (explosive **He** burning?) ~1000 sec

Superbursts (explosive **C** burning) ~10,000 sec

Accretion

Hydrogen Burning in Bursts

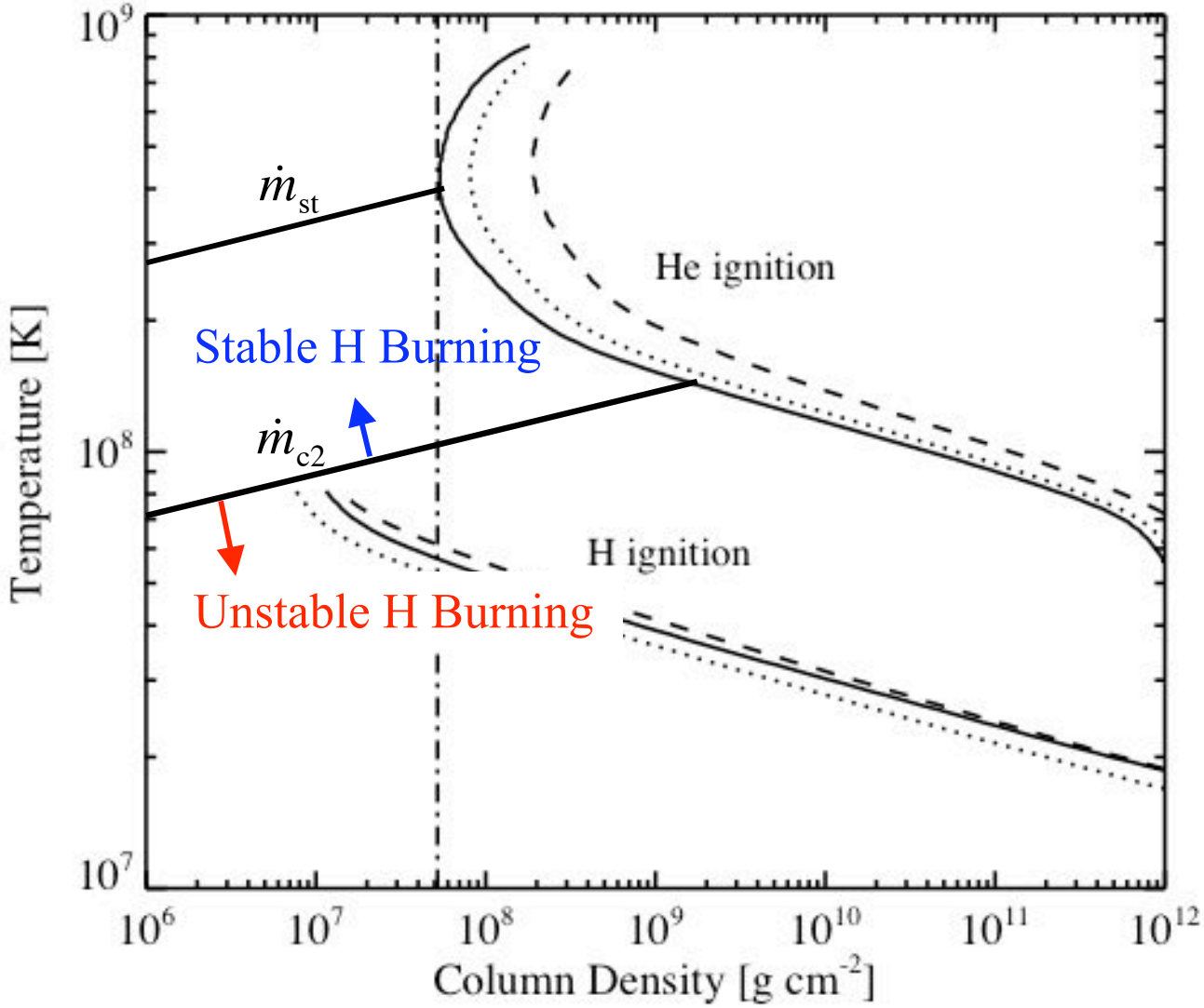


Ignition and Accretion Rate Dependence

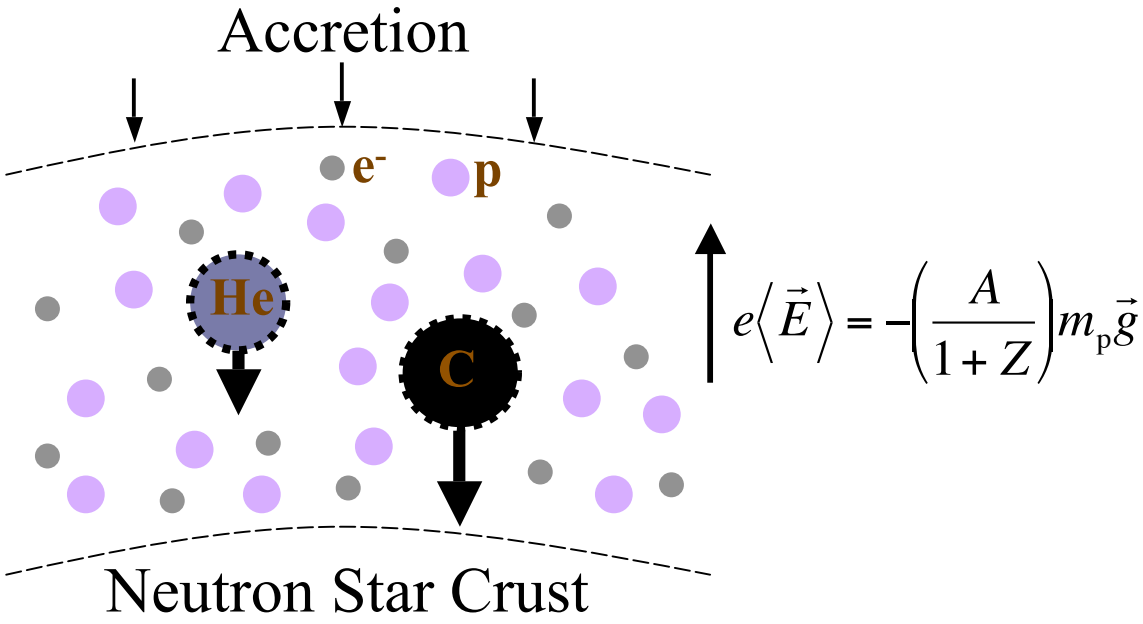
(Fujimoto et al. 1981 ; Bildsten 1998)

$\dot{m}_{st} \sim \dot{m}_{Edd}$

$\dot{m}_{c2} \sim 0.01\, \dot{m}_{Edd}$



Sedimentation

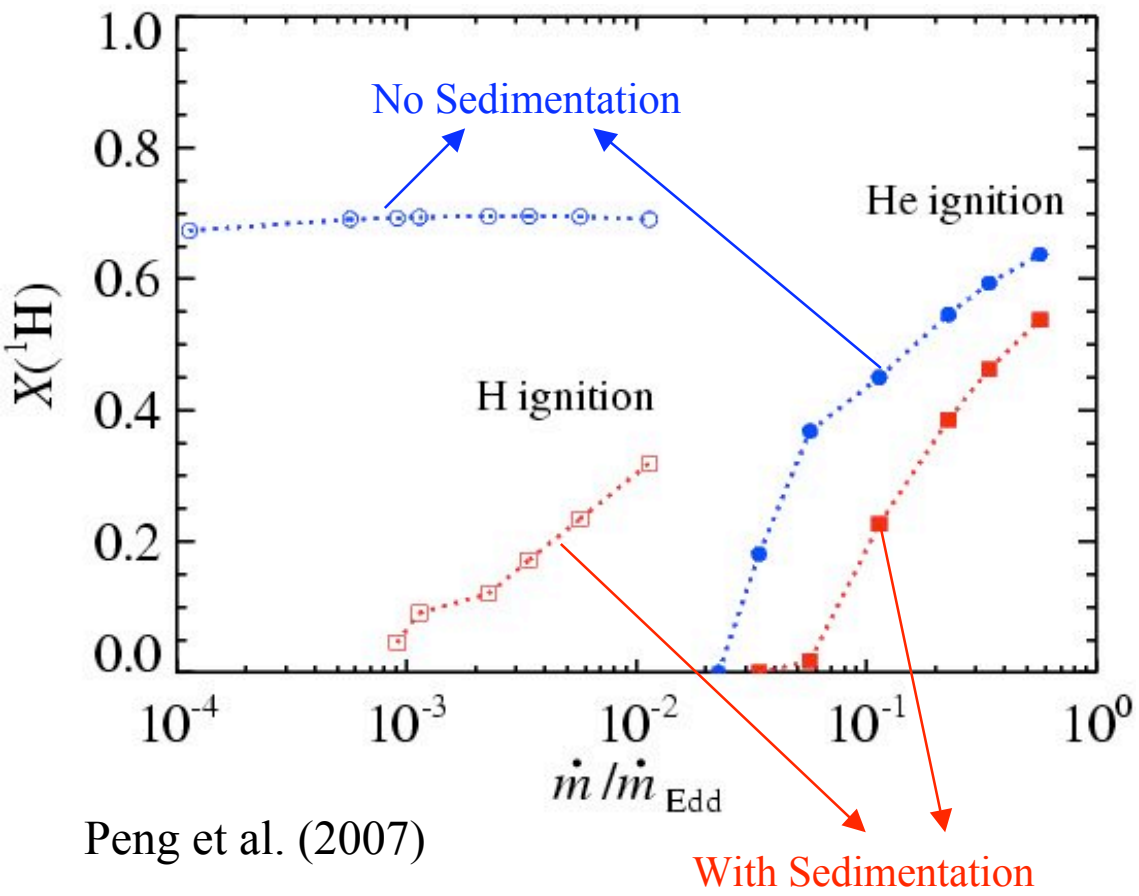


- For low-luminosity sources, accretion timescale is long, so that

$$\tau_{\rm sed} \leq \tau_{\rm acc}$$

- There is enough time for compositions to redistribute themselves.
- This will change the ignition condition of the bursts and the bursts themselves.

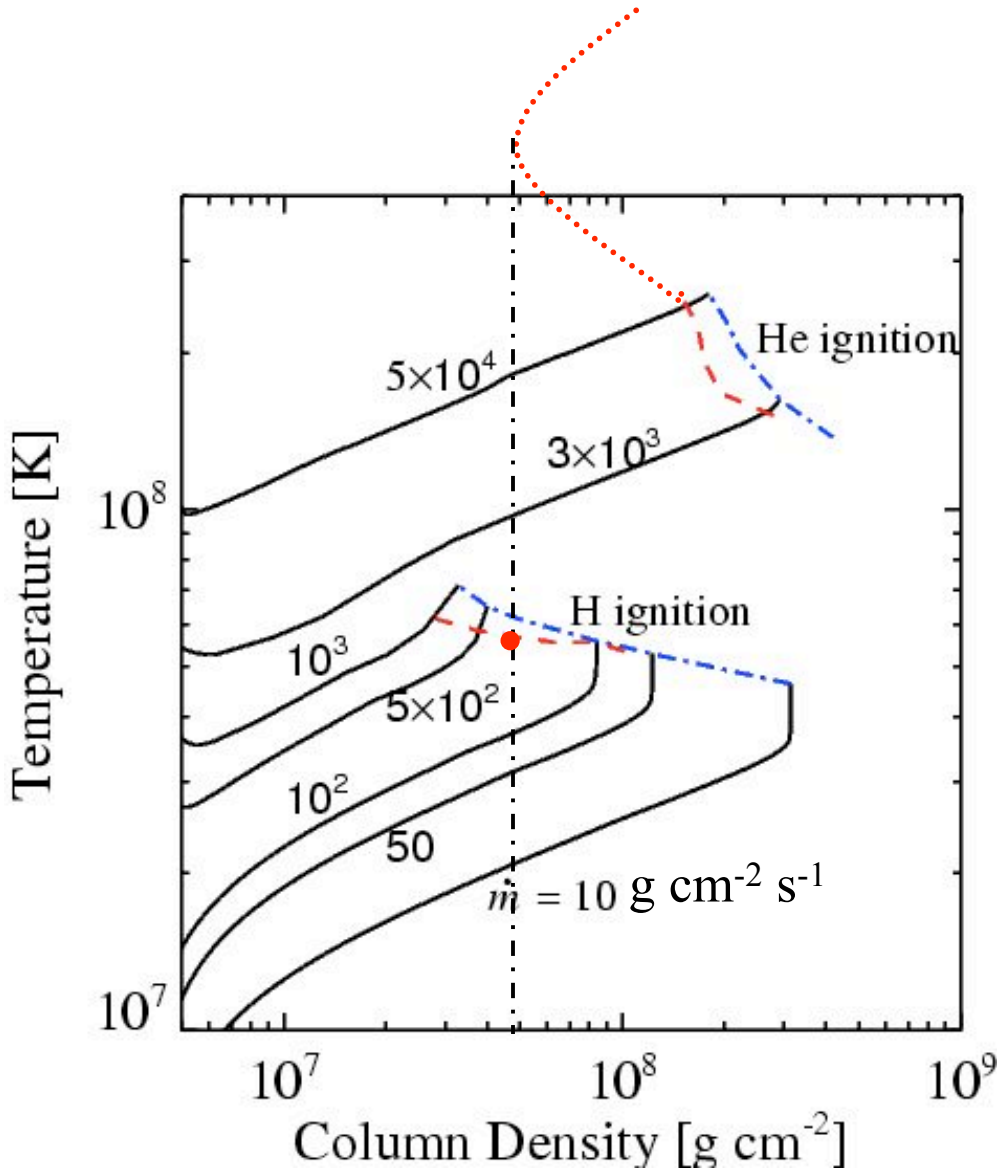
Hydrogen Abundance at Ignition



Peng et al. (2007)

- Less hydrogen left at the ignition zone when sedimentation and diffusion is considered.
- The amount of hydrogen at the ignition zone is crucial for the rp process

Two Regimes of Accretion Rates



He ignition curve has a turning point,

$$y_{turn} = 5 \times 10^7 \ \text{g cm}^{-2}$$

Regime 1: $0.4\% \le \dot{m}/\dot{m}_{\rm Edd} \le 0.01$

$$y_{ign}^{\rm H} < y_{turn}$$

H ignition **cannot** trigger He ignition at the same depth.

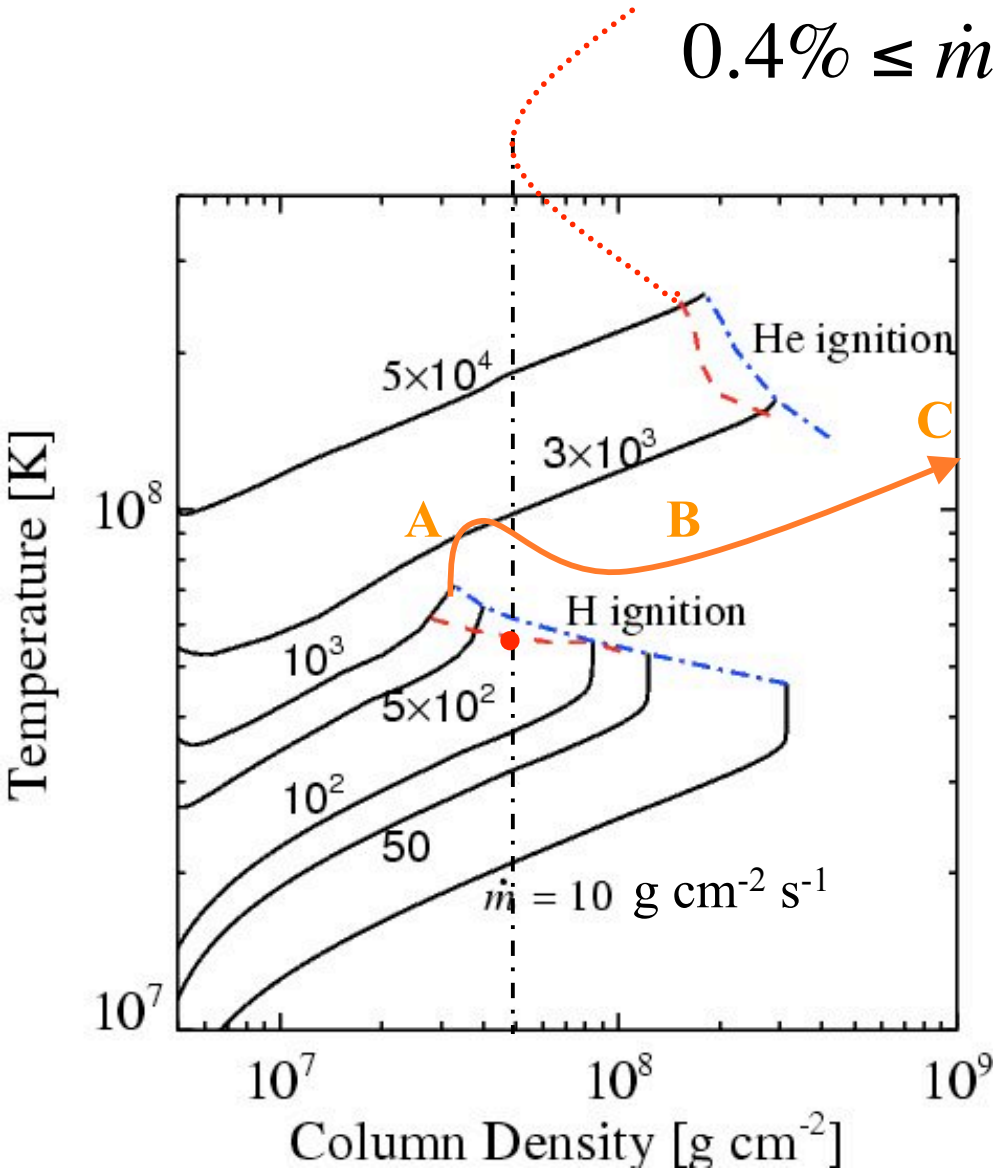
Regime 2: $\dot{m}/\dot{m}_{\rm Edd} < 0.4\%$

$$y_{ign}^{\rm H} > y_{turn}$$

H ignition **can** trigger He ignition at the same depth.

Regime 1: Weak H Flashes and Long Bursts

$$0.4\% \leq \dot{m}/\dot{m}_{\rm Edd} \leq 0.01$$

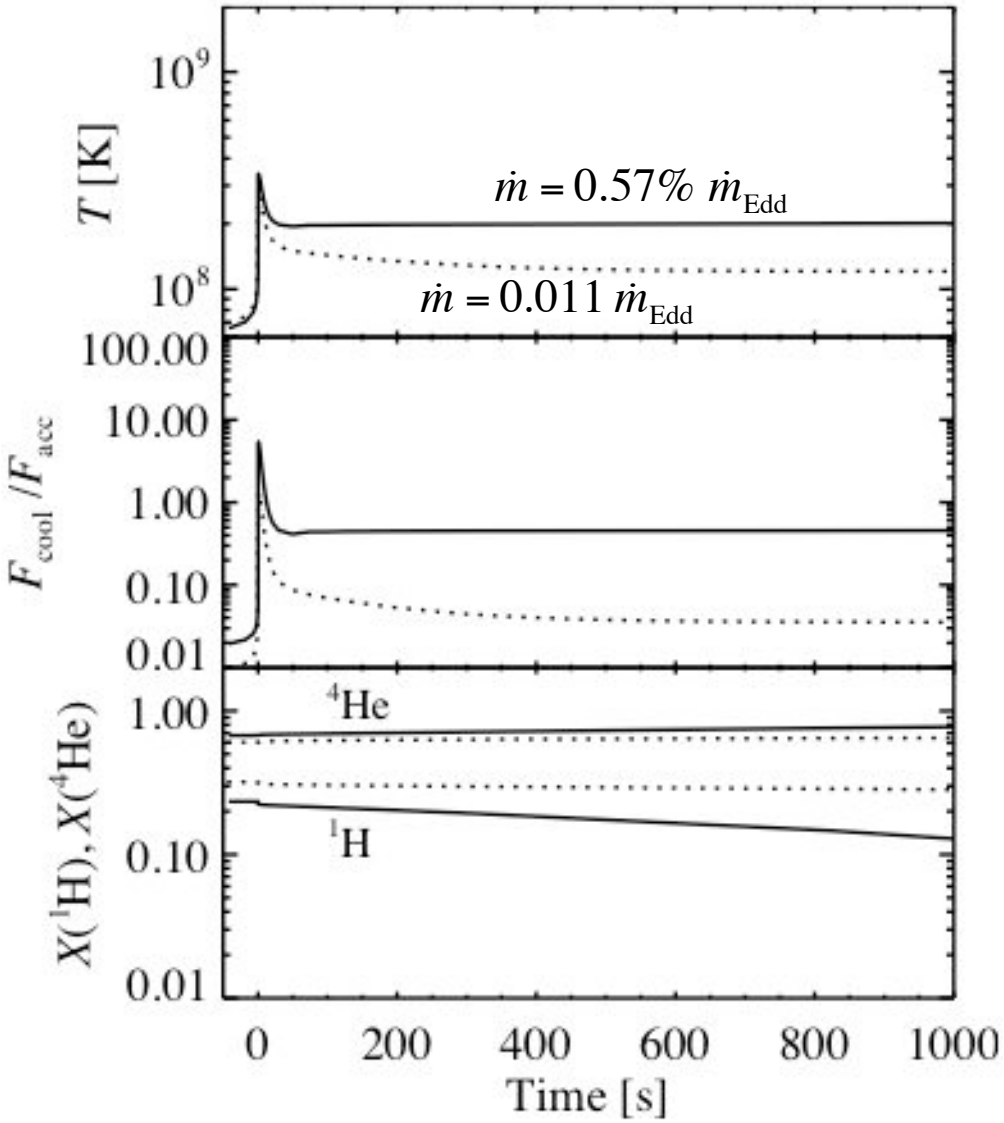


(A) H ignition cannot trigger He ignition at the same depth.

(B) H burns out slowly (~ 1day) and keeps the atmosphere cool. A large amount of He is accumulated before ignition.

(C) The He ignition could lead to **long bursts**.

Long Bursts: (A) weak H flashes

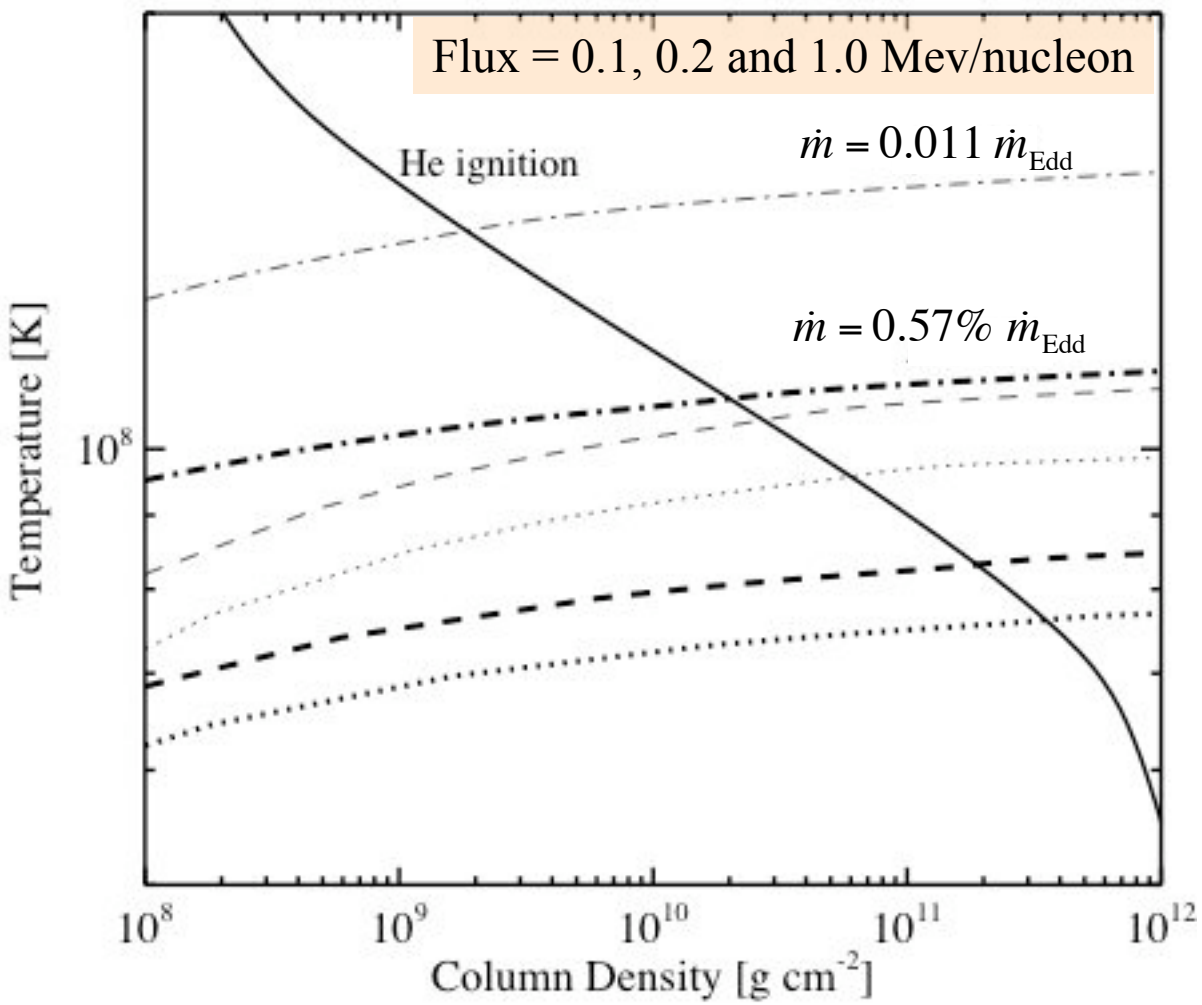


Temperature doesn't reach high enough values to drive energetic flashes.

Weak H flashes
Convection cannot be initiated

H burns to He via HCNO cycle

Long Bursts: (B) He Ignition Column



- High flux from the crust heats the atmosphere to higher temperature; He ignites at a lower column density.

$$y_{ign}^{\rm He} \approx 10^9 - 10^{11}\ {\rm g\ cm^{-2}}$$

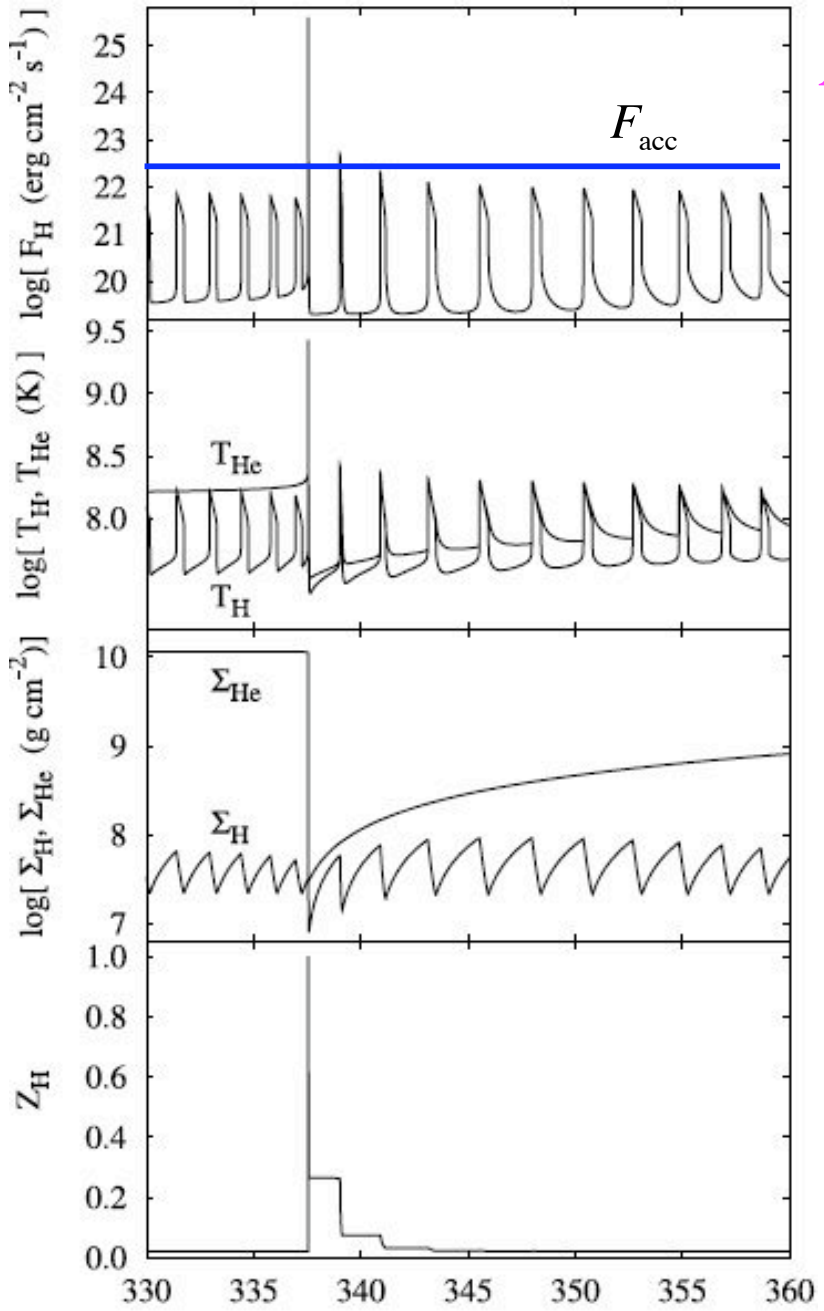
Long Bursts: (C) Cooling Time

One-zone cooling approximation

$$\tau \approx 4\pi R^2 \, y_{\rm ign} \, Q_{\rm nuc}/L_{\rm Edd}$$
$$\approx 400 \text{ sec } (y_{\rm ign}/10^{10} \text{ g cm}^{-2})$$

agrees with the decay time of the long bursts.

A Two-Zone Model



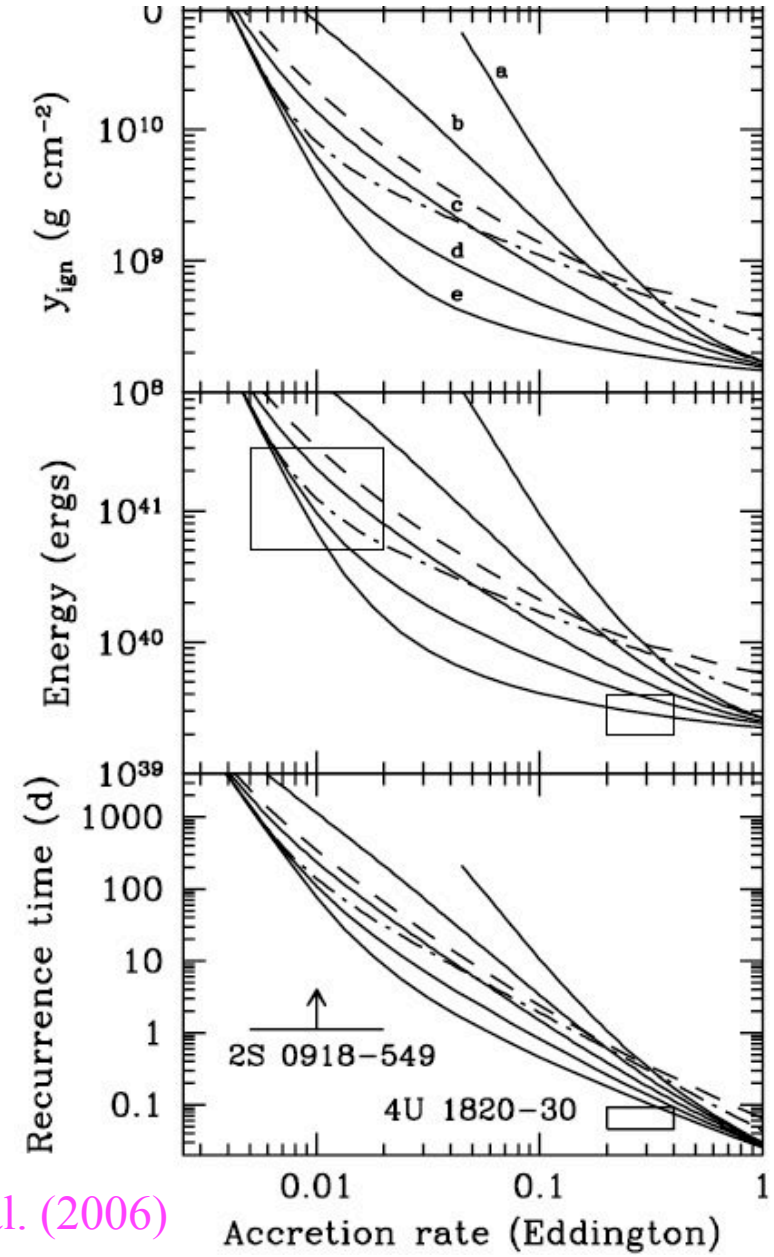
Randall Cooper & Ramesh Narayan (2007)

Long Bursts from Pure He Accretors?

Burst sources of long bursts are in UCXBs, suggesting He white dwarfs as companion stars (in 't Zand et al. 2007)

Cumming et al. (2006) did calculations for pure He accretors.

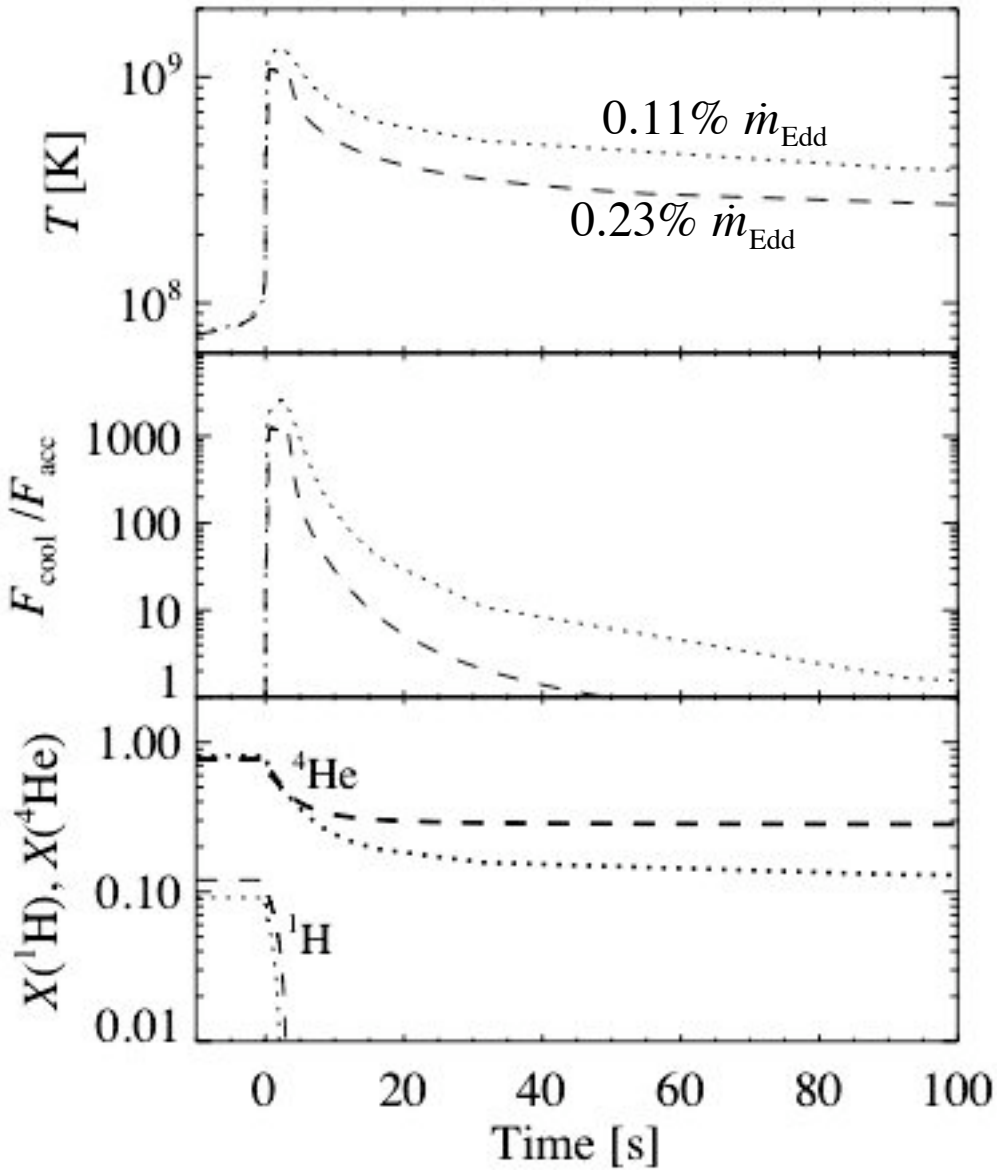
But to me, it is not clear how to explain the short bursts observed in these sources with a pure He accretor.



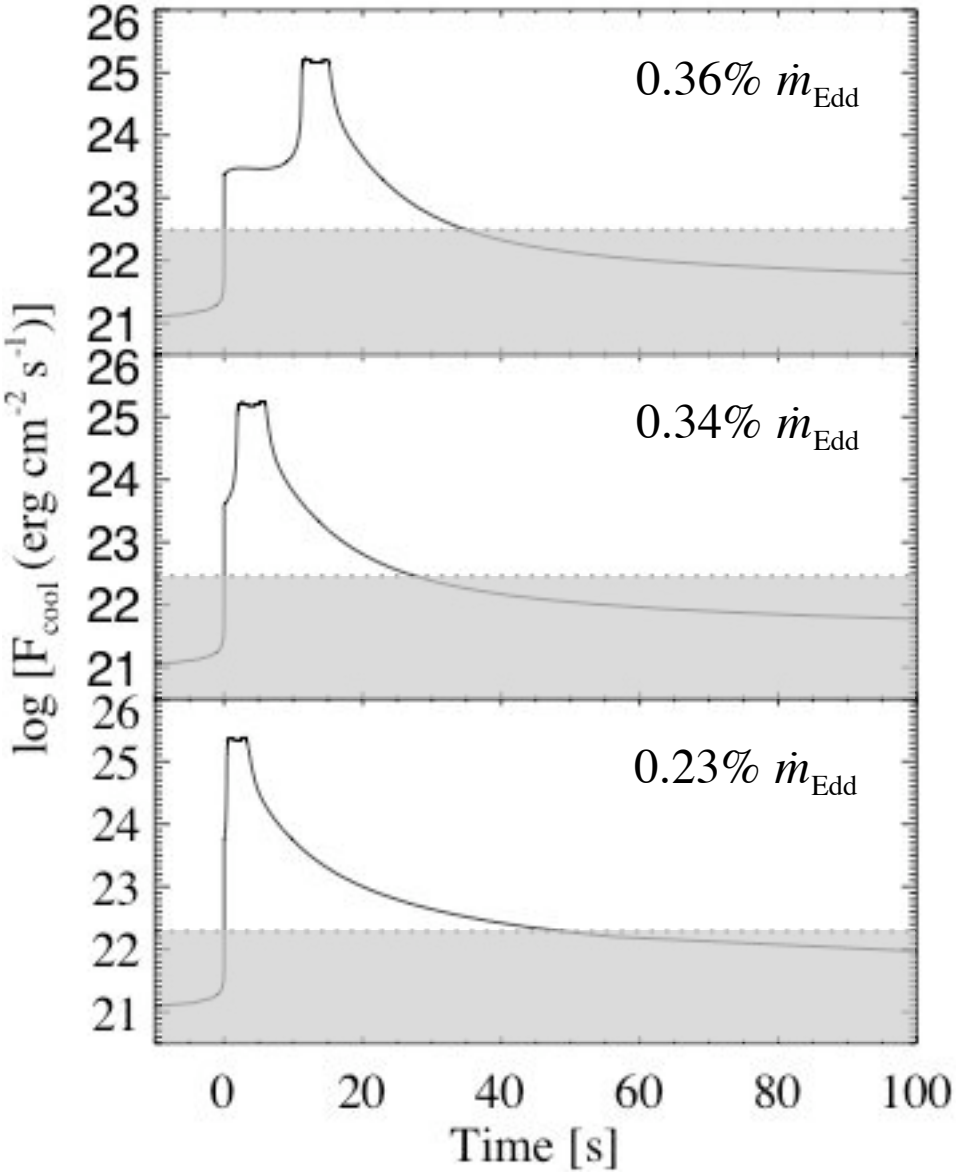
Cumming et al. (2006)

Regime 2: H-Triggered He Bursts

$$\dot{m}/\dot{m}_{\rm Edd} < 0.4\%$$



A closer look of H-Triggered He Bursts

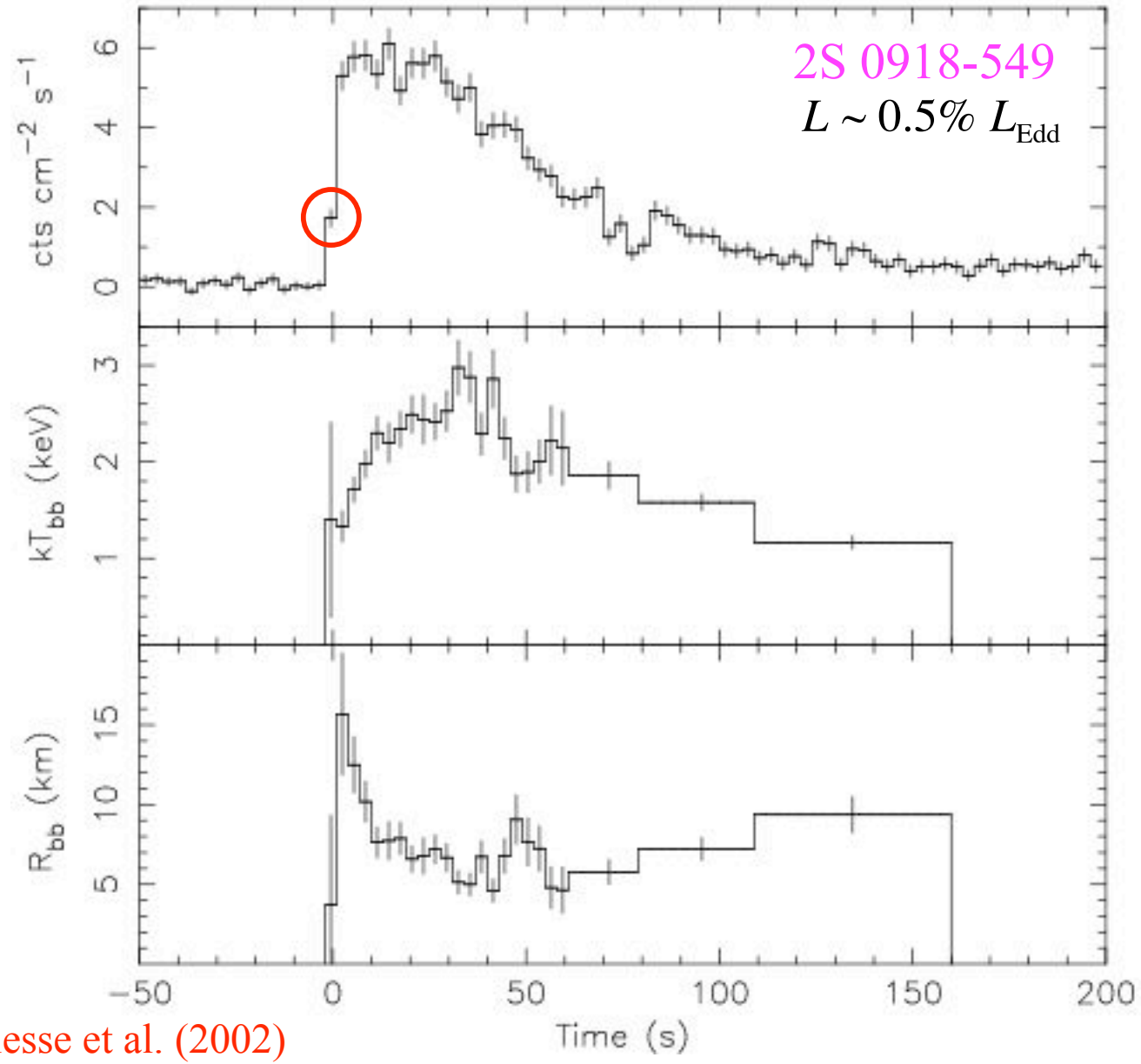


There is a delay between H ignition and He ignition.

A knee-like feature implies the existence of hydrogen.

Need light curves with good resolution to tell.

H-Triggered He Burst



Cornelesse et al. (2002)

H-Triggered He Burst

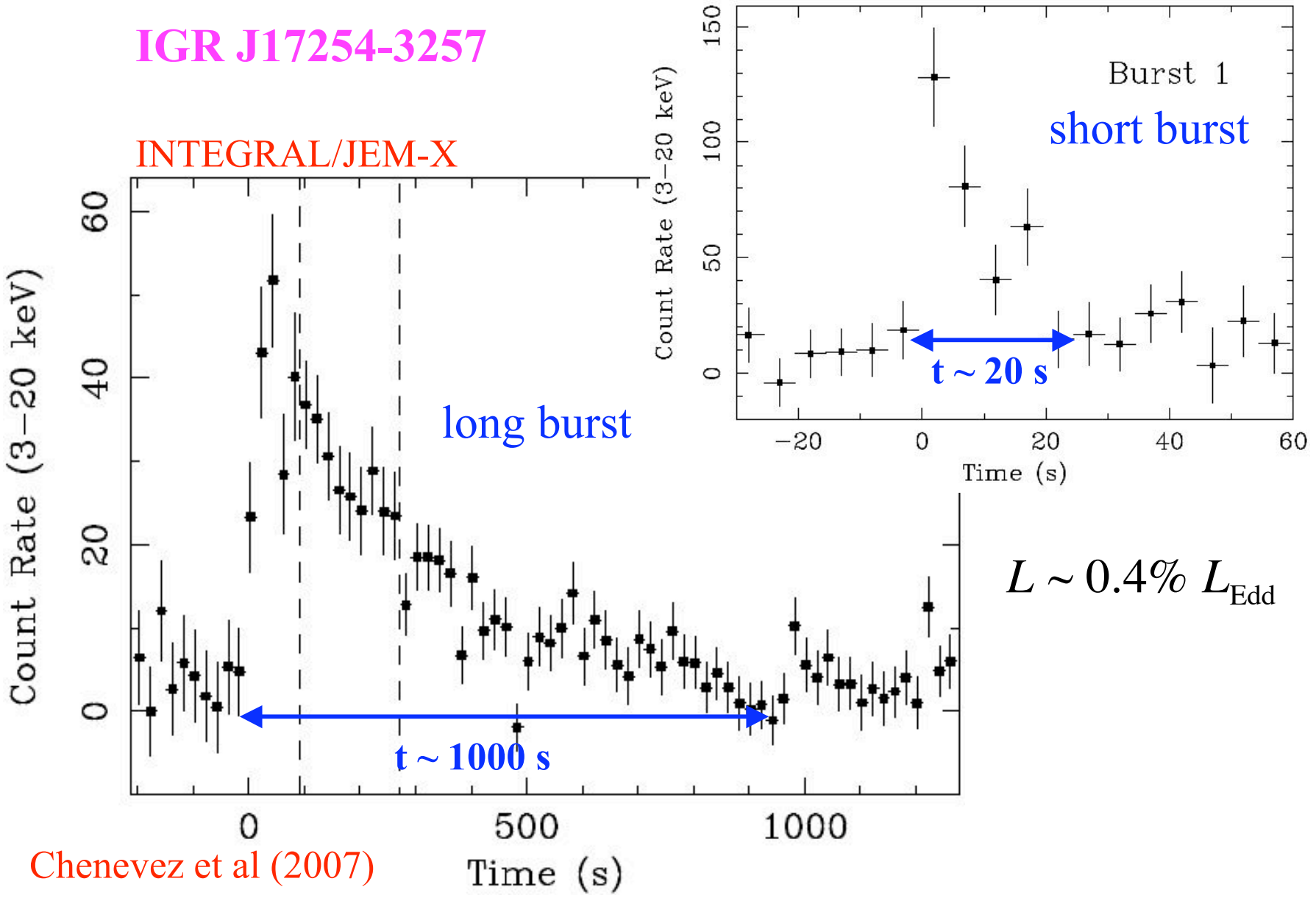
- > 50% of the bursts in burst-only sources are bursts of short durations. Cornelesse et al. 2002

  Sedimentation decreases the hydrogen fraction.

Transition between Two Regimes?

IGR J17254-3257

INTEGRAL/JEM-X

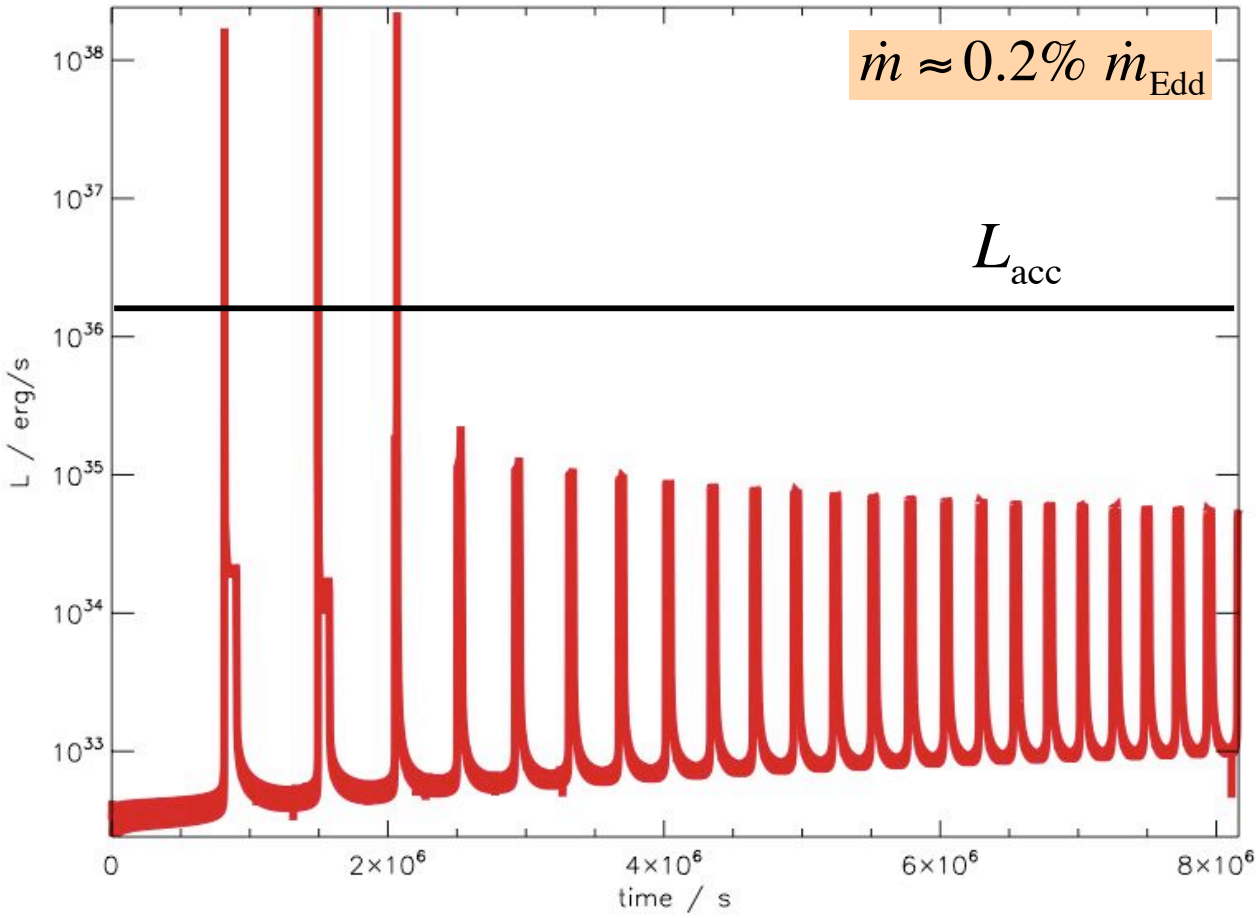


$L \sim 0.4\%\ L_{\rm Edd}$

Chenevez et al (2007)

Transition between Two Regimes

• Alexander Heger (LANL) did 1D multi-zone calculation by using the Kepler code. The strong short bursts heat up the atmosphere, which is equivalent to the result by raising the mass accretion rate.



Summary

- There are two regimes of accretion rates in low-luminosity sources. They are corresponding to weak H flashes/long bursts and H-triggered He burst, respectively.

Q: How to explain long burst at large accretion rates, as in GX 3+1 (Chenevez et al. 2006).

Are the sources of long bursts in UCXBs? If so, can they be H-rich accretors?

- The expected peculiar features of light curves of H-triggered He burst can tell whether the companion star has H-rich matter or not.

Messages to...

- nuclear theorists: X-ray bursts modeling depends on the heating from the crust.

- astronomy observers: X-ray bursts in low-luminosity sources, search for long bursts, weak H flashes, or peculiar bursts, need high resolution light curves.