Simulations of X-ray Bursts and Superbursts

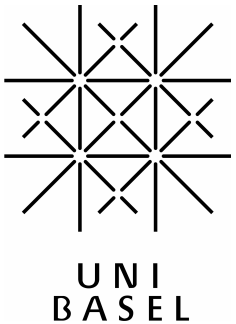
Sofie Fehlmann

J. Reichert, F.-K. Thielemann

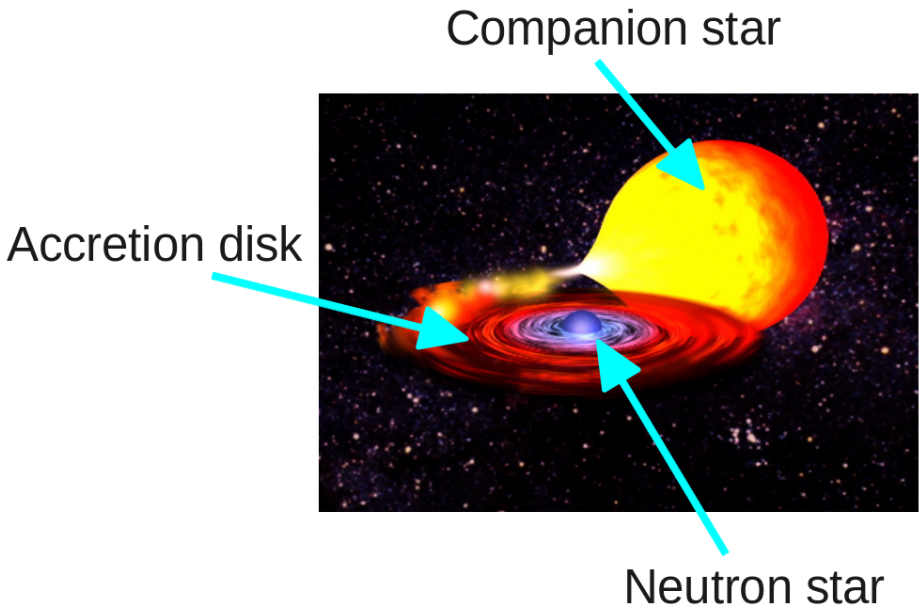
University of Basel, Switzerland

Structure and Signal of Neutron Stars, from Birth to Death 2014

Florence, 24-28 March 2014

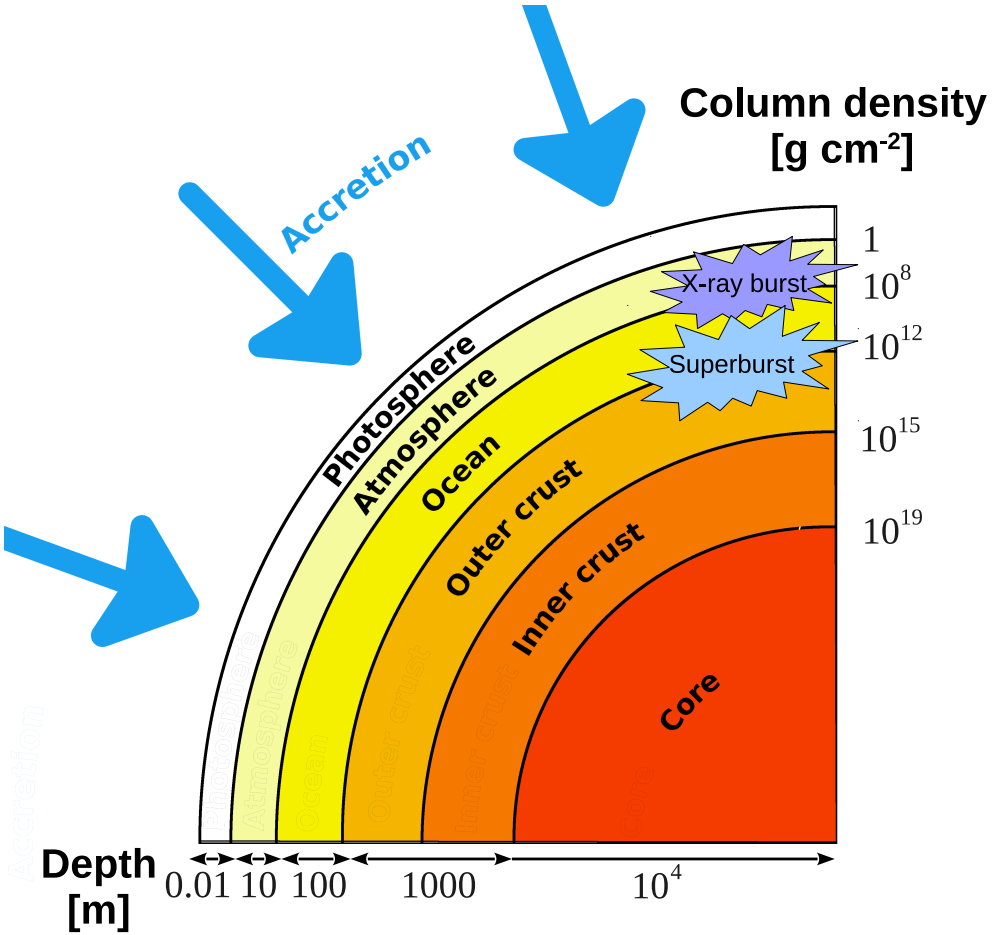


Introduction



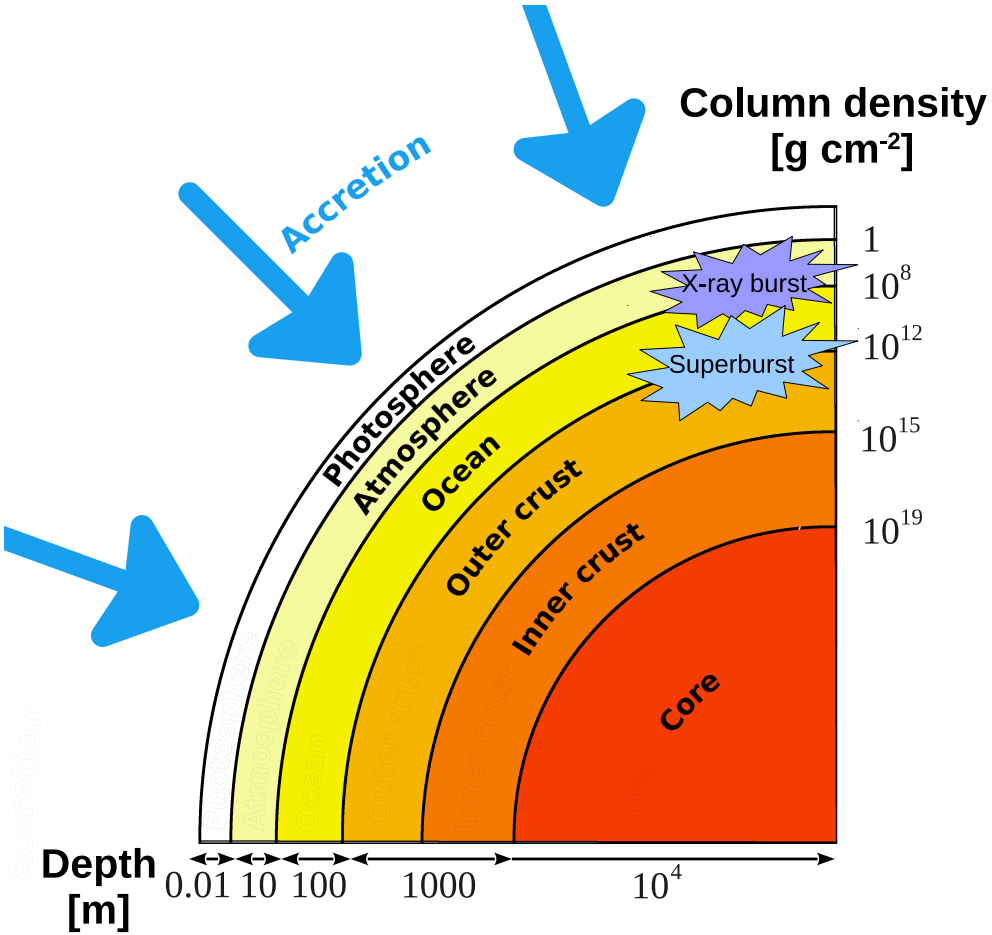
	X-ray burst	**Superburst**
Energy release [ergs]	10^{39}	10^{42}
Luminosity [ergs/s]	10^{38}	10^{38}
Burst time	seconds - minutes	hours - days
Burst recurrence	hours - days	years

Ignition of Superbursts



- Accretion of fuel
- Unstable He- and H-burning $\rightarrow$ X-ray burst
- Ashes are accumulated
- Superburst

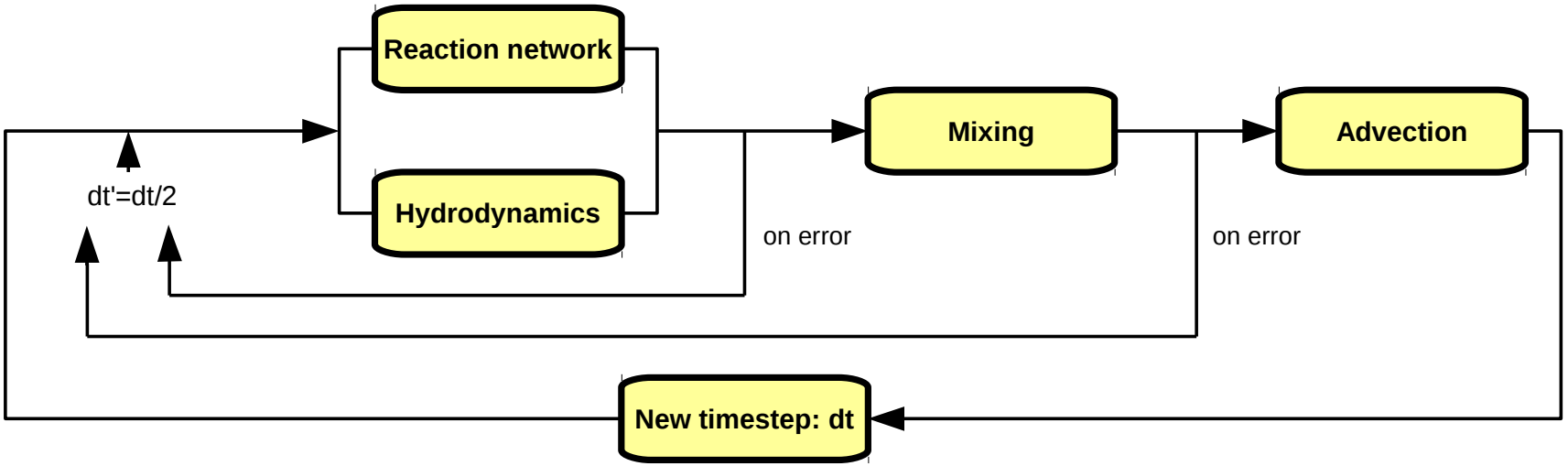
Ignition of Superbursts



- Accretion of fuel
- Unstable He- and H-burning $\rightarrow$ X-ray burst
- Ashes are accumulated
- Superburst

Superburst simulations are computationally expensive

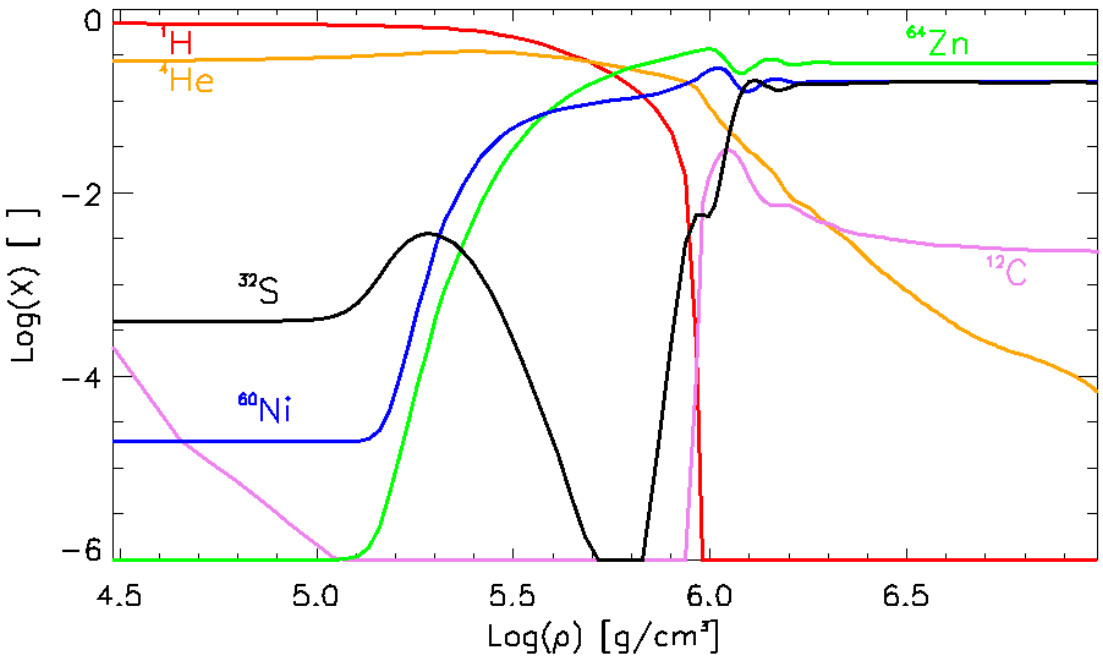
1D Simulation of the Outer Layers of a Neutron Star



Code J. Fisker, S. Fehlmann, M. Liebendörfer

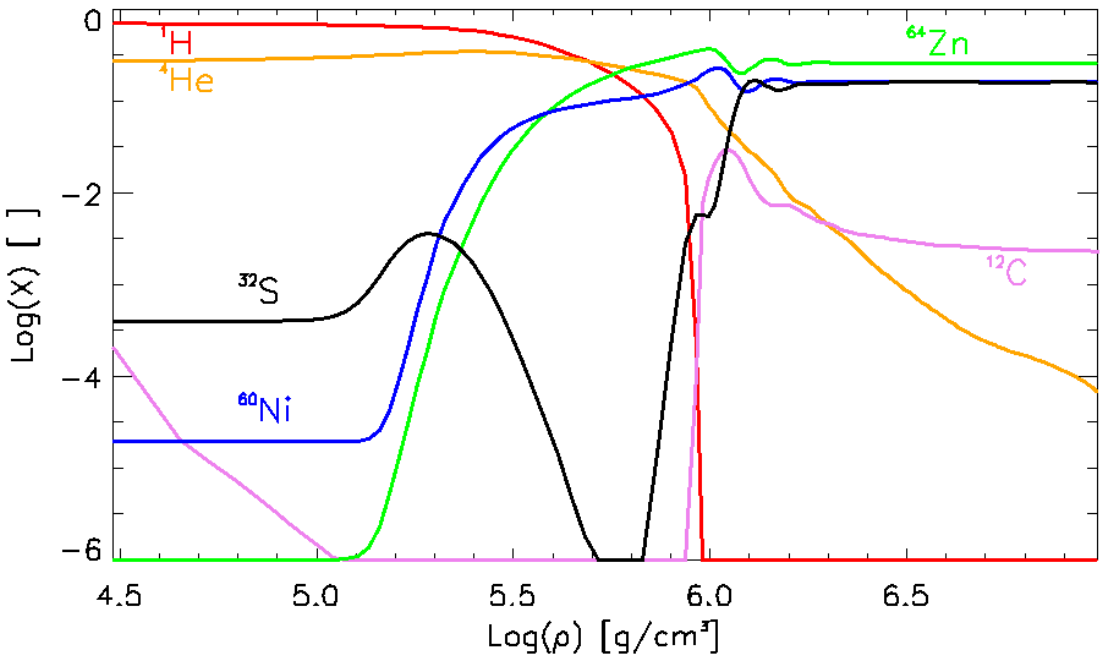
- General relativistic hydrodynamics: AGILE (M. Liebendörfer, 2002)
- Nuclear Network (W. R. Hix & F.-K. Thielemann, 1999)
- Convection
- Heat transport: Conduction and Radiation

Ashes: Composition after 100 X-ray Bursts



- Underlying neutron star: $R_{NS} = 11.06\text{km}$ $M_{NS} = 1.4\text{M}_{\odot}$
- Accretion rate: $0.18\dot{m}_{Edd}$
- $Q_{heat} = 0.1\text{MeV/nuc}$: Nuclear reactions, neutrino cooling, heat transport
  (Schatz et al. 2013)

Ashes: Composition after 100 X-ray Bursts



- Underlying neutron star: $R_{NS} = 11.06\text{km}$ $M_{NS} = 1.4\text{M}_\odot$
- Accretion rate: $0.18\dot{m}_{Edd}$
- $Q_{heat} = 0.1\text{MeV/nuc}$: Nuclear reactions, neutrino cooling, heat transport
  (Schatz et al. 2013)

Superburst ignition: $0.1 \lesssim X(^{12}C) \lesssim 0.3$ (Cumming et al. 2005, Keek et al. 2012)

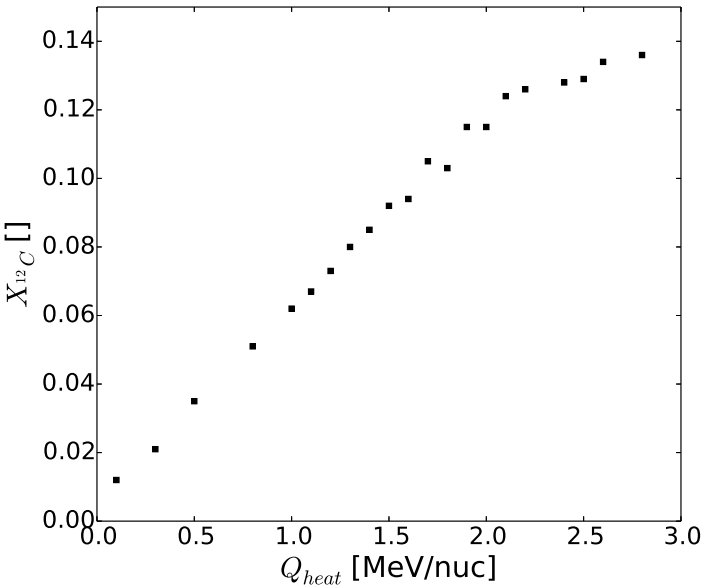
Varying the heat source

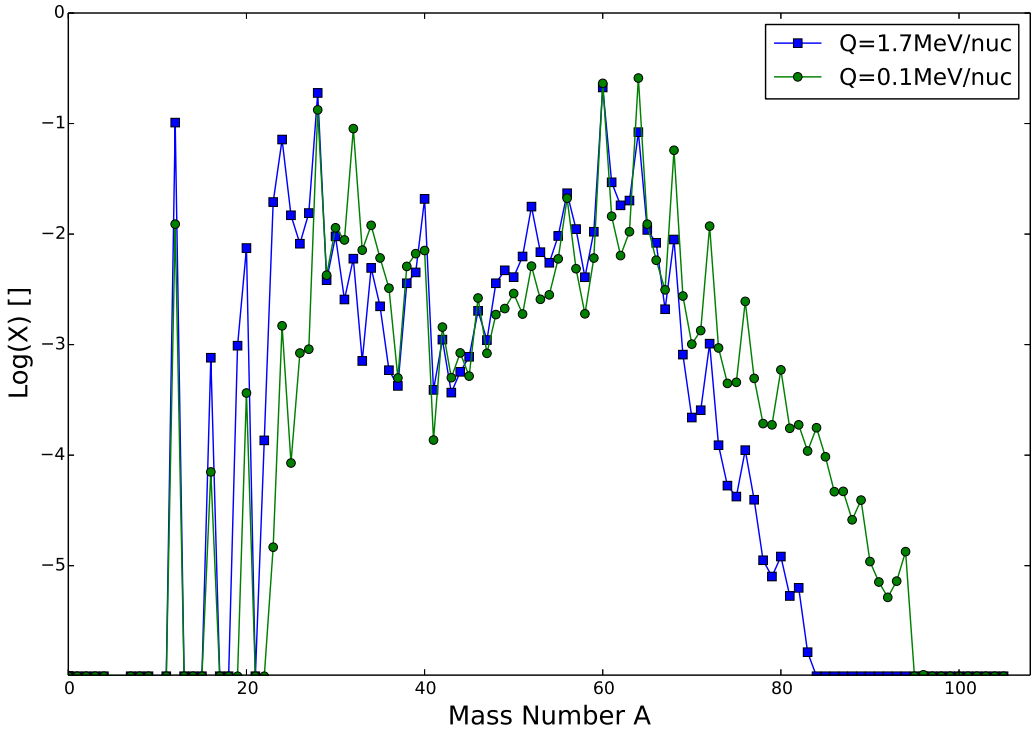
Thermal relaxation of neutron stars

Unknown heat source of several MeVs/nuc

A. Turlione et al. 2013, N. Degenaar et al. 2014

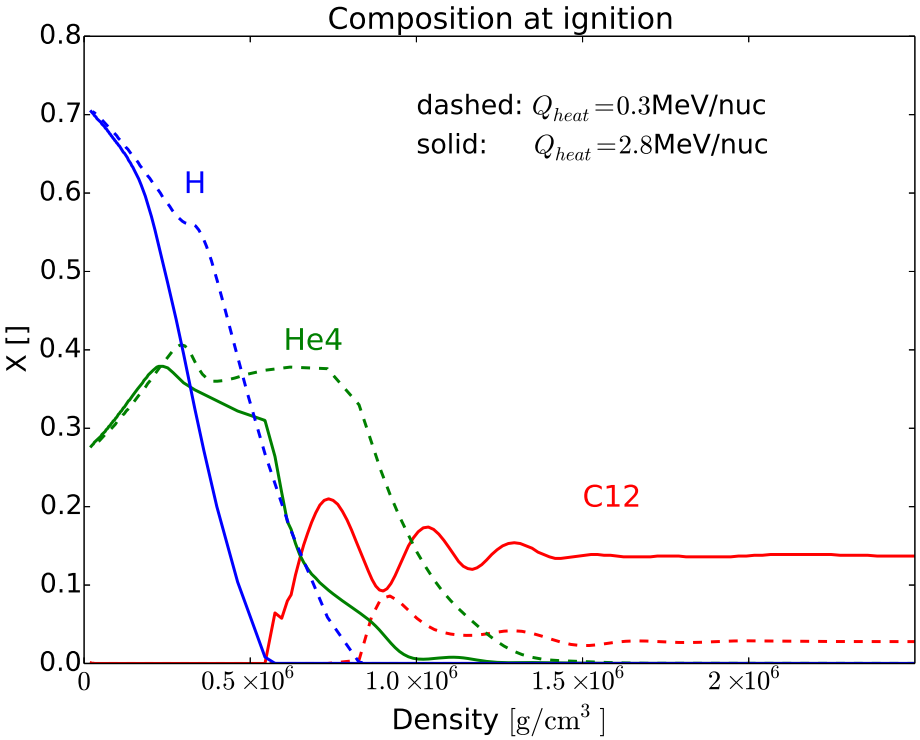
Heat source at $\rho = 7 \cdot 10^7 \mathrm{g/cm^3}$

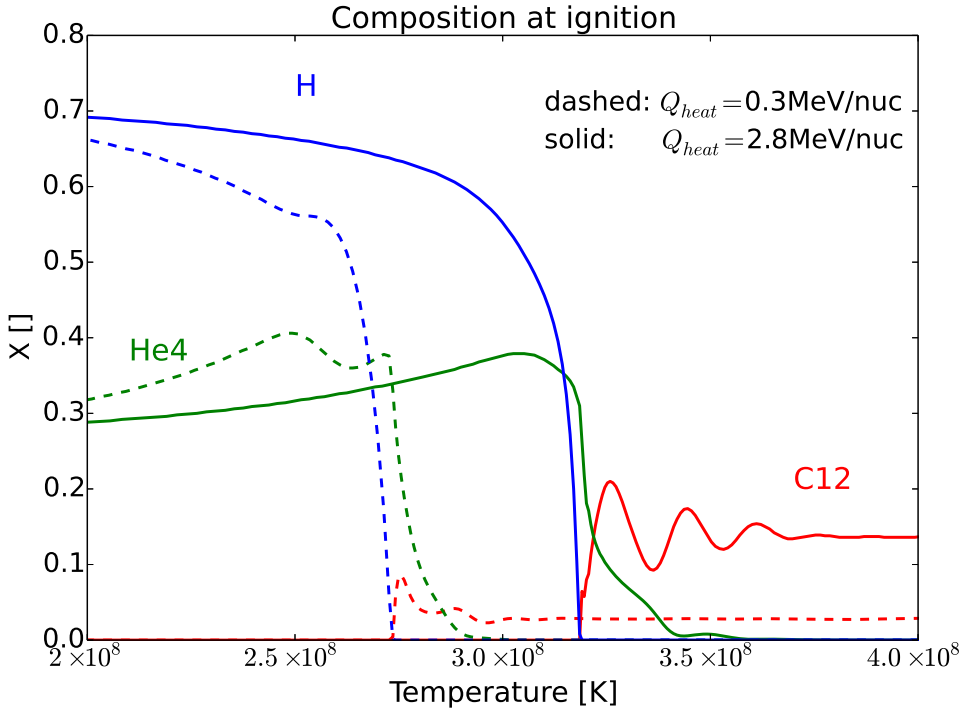




Limits of heating

Ignition Conditions

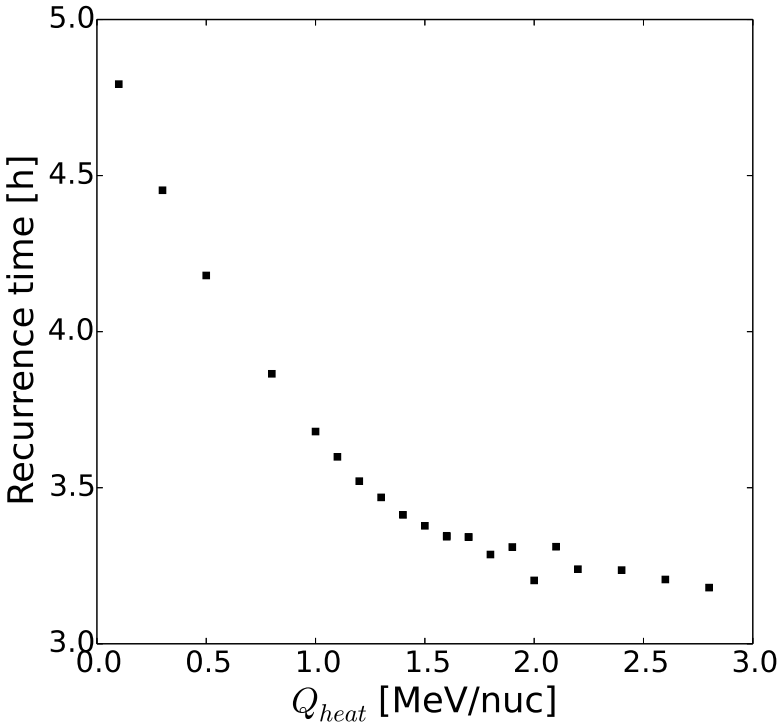


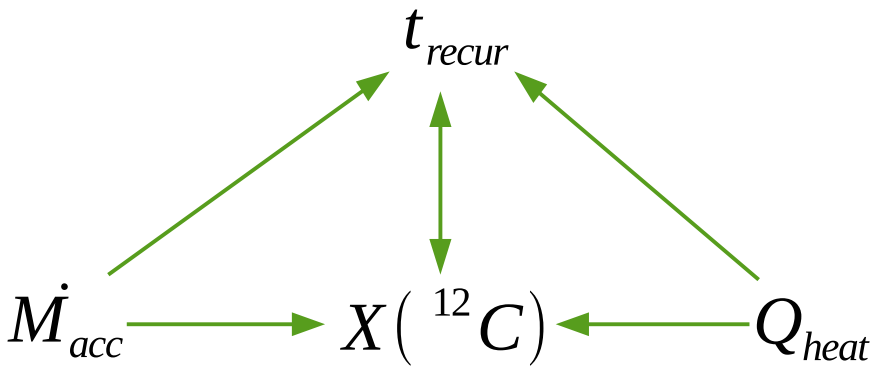


Limits with constant accretion rate

$$Q_{heat} = 2.8\text{MeV/nuc} \quad \Rightarrow \quad X(^{12}C) \approx 0.14$$
$$Q_{heat} > 2.9\text{MeV/nuc} \quad \Rightarrow \quad \text{stable burning}$$

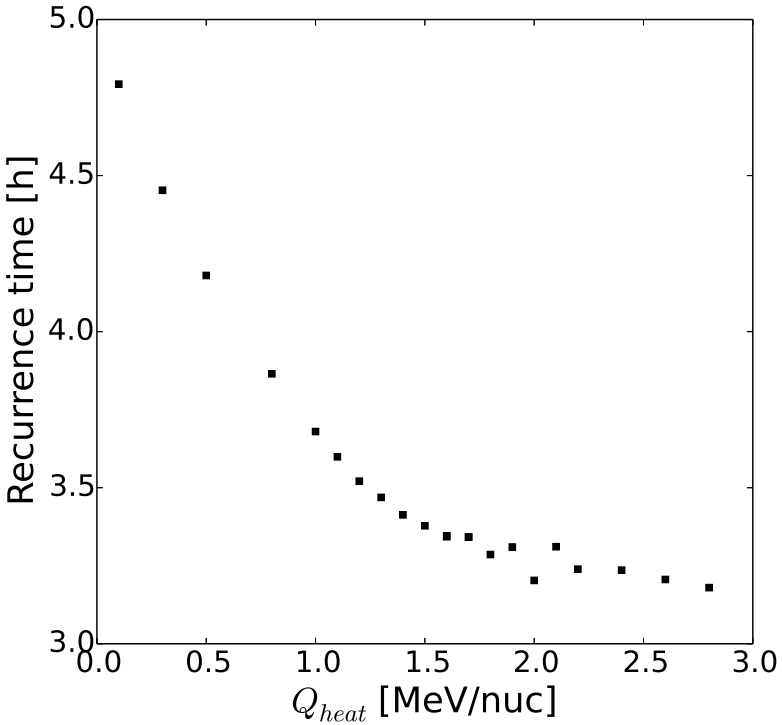
Recurrence time versus crust heating

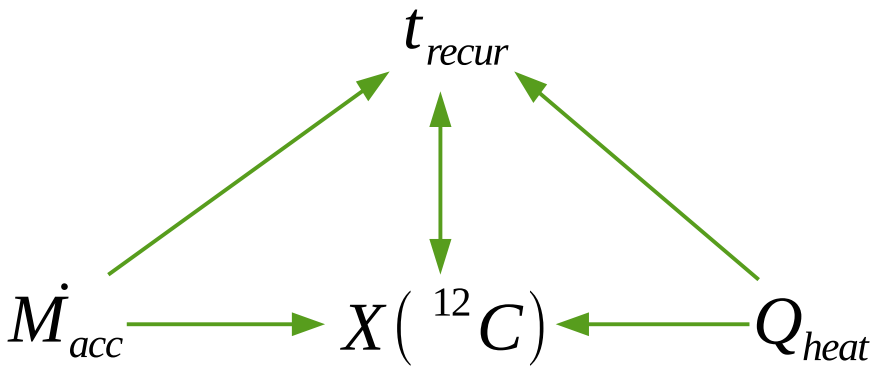




t_{recur} **is observable**

Recurrence time versus crust heating



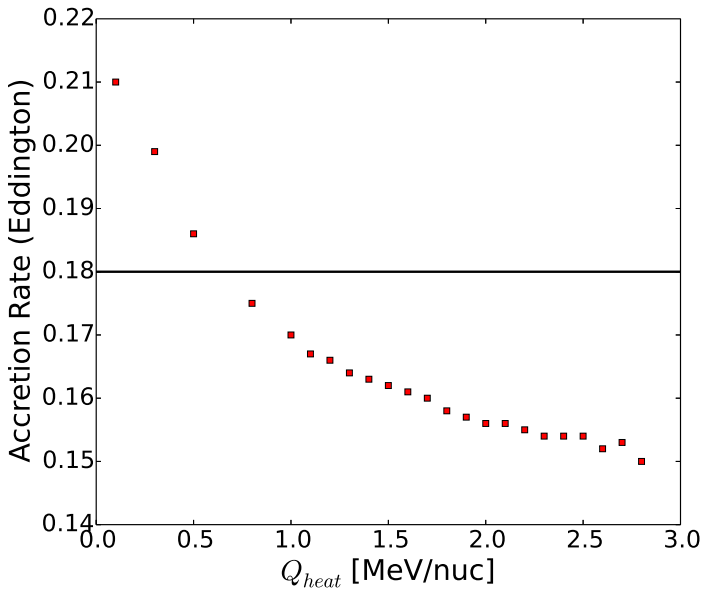


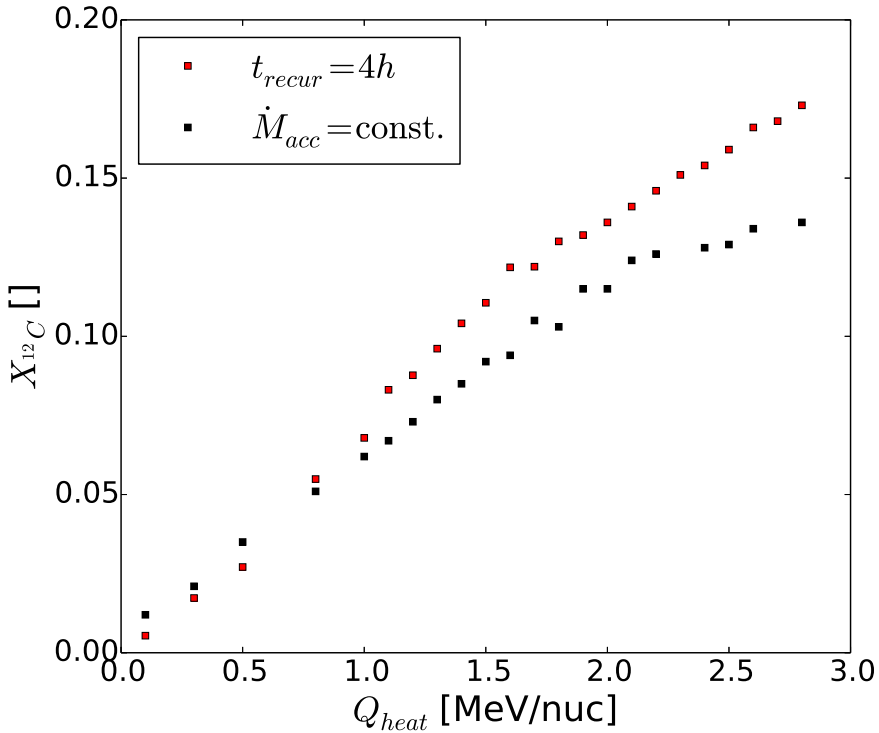
t_{recur} **is observable**

Fixing the reccurence time

- Set $t_{recur} = 4\text{h}$: Typical $t_{recur} = 2 - 6h$ (Galloway et al. 2007)
- Adjust the accretion rate $\dot{M}_{acc}$
- Vary the heat Q_{heat}

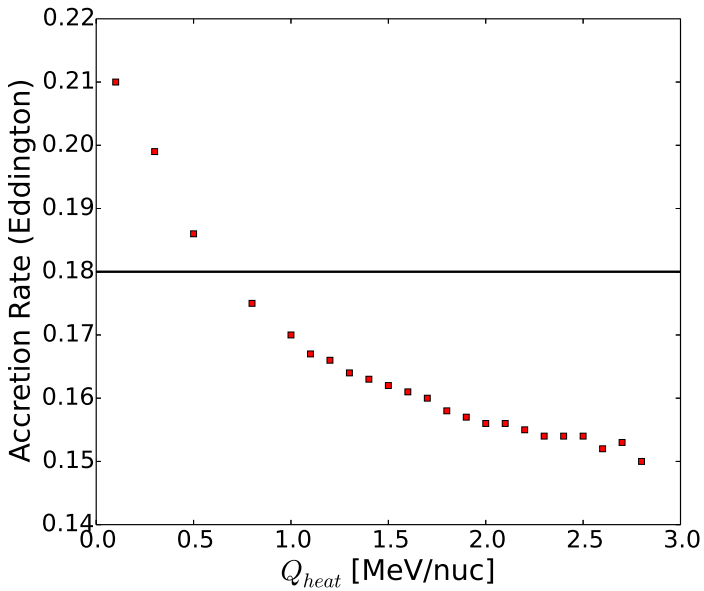
New Model with constant recurrence time

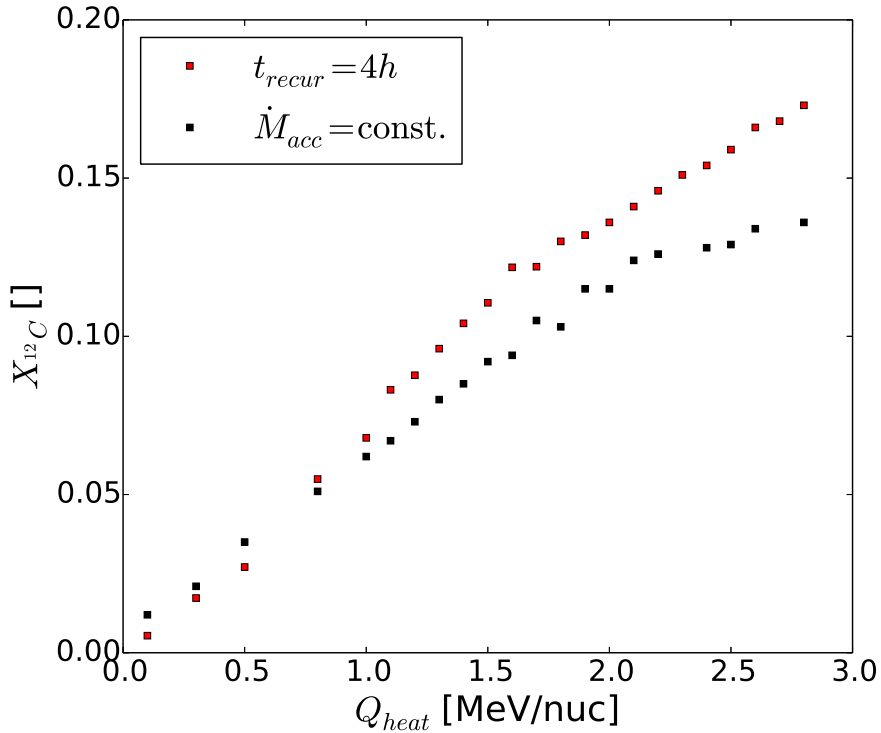




$$\Rightarrow \quad X(^{12}C) \leq 0.17$$

New Model with constant recurrence time



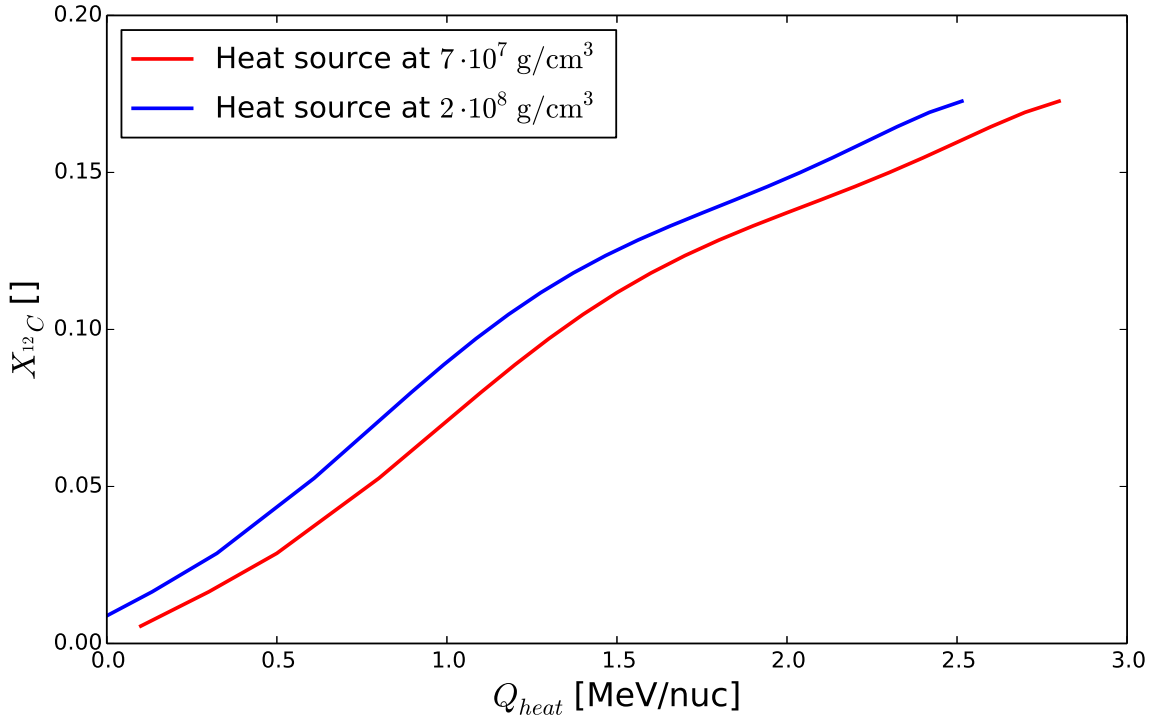


$$\Rightarrow \quad X(^{12}C) \leq 0.17$$

Is this enough ^{12}C for a superburst?

Shift downwards to superburst

Heat source shifted down to $\rho = 2 \cdot 10^8 \mathrm{g/cm^3}$



Superburst with constant X-ray burst recurrence time of 4h

Superburst ignition at $\rho \approx 10^9 \mathrm{g/cm^3}$ with $X(^{12}C) \geq 0.1$

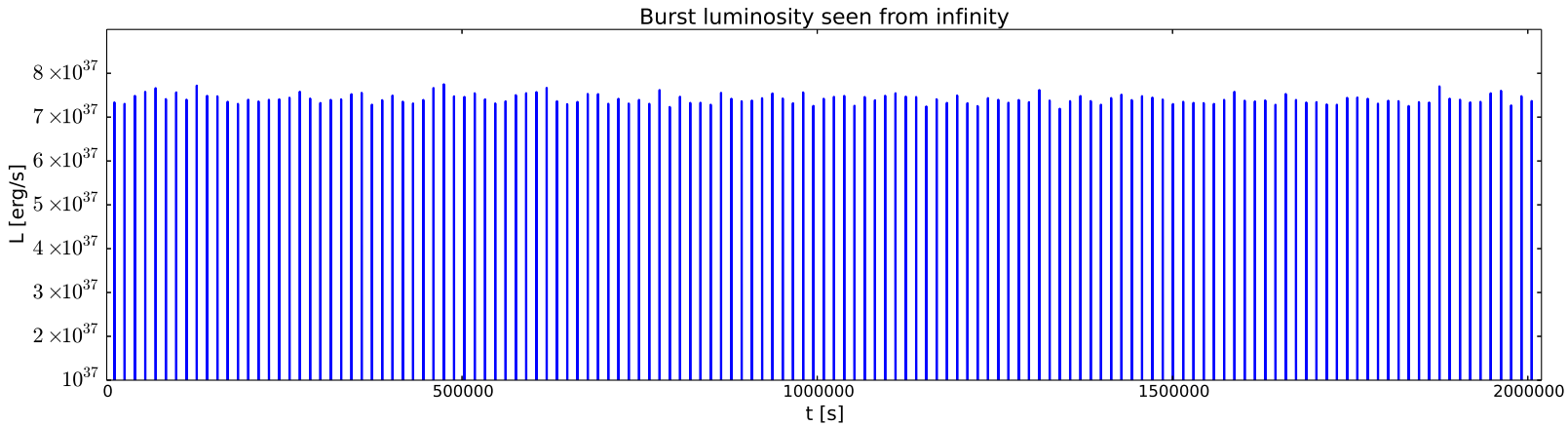
$$\Rightarrow \quad 0.8\mathrm{MeV/nuc} \leq Q_{heat} < 2.2\mathrm{MeV/nuc} \quad (?)$$

Summary & Conclusion

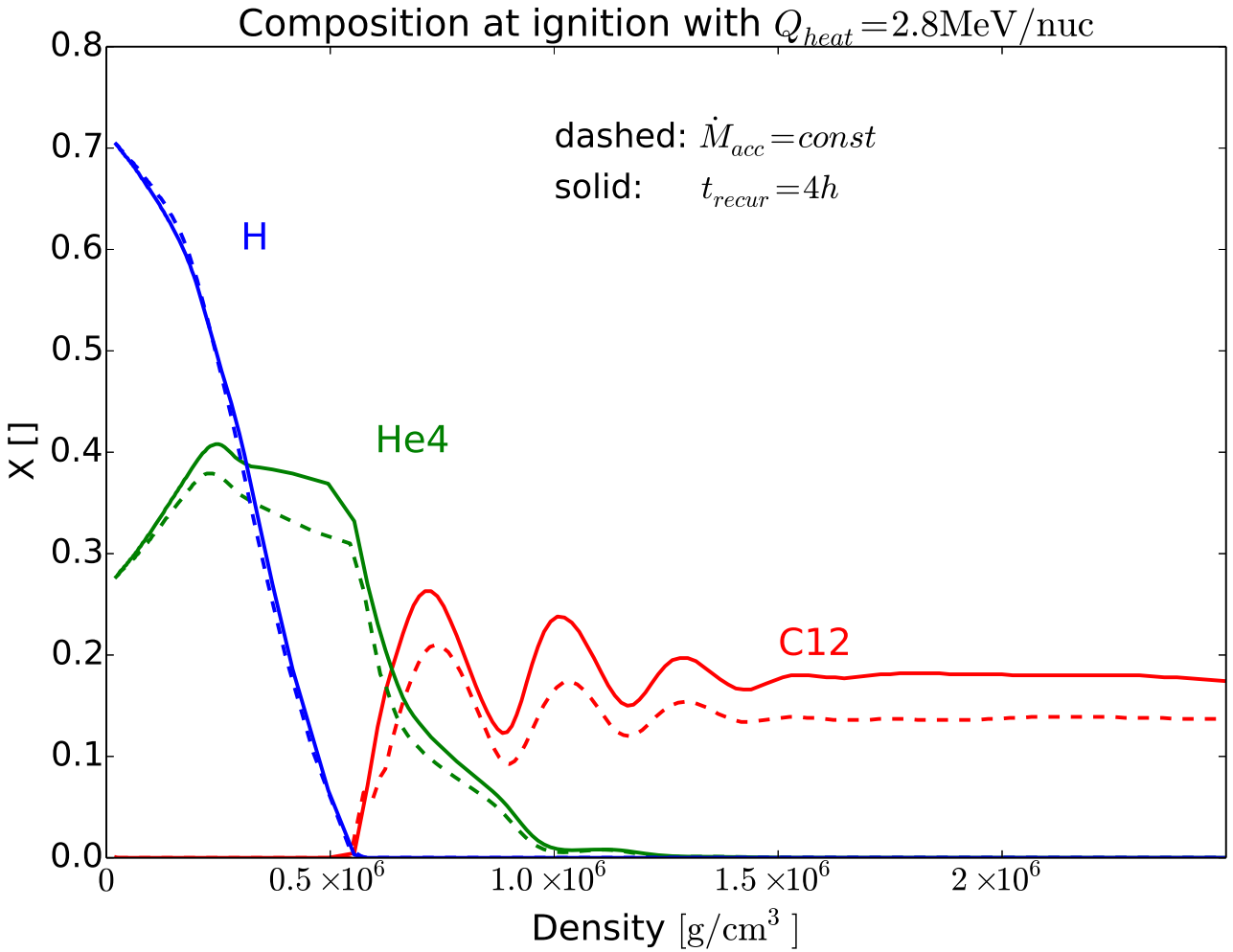
- Simulations of X-ray burst produce not enough ^{12}C to ignite superburst
- Unknown heating leads to more ^{12}C
- Mass fraction of ^{12}C above 0.2 are not explainable with heat source
- Crust heating at $\rho = 10^9 \mathrm{g/cm^3}$ with $X(^{12}C) \geq 0.1$:

$$0.8\mathrm{MeV/nuc} \leq Q_{heat} < 2.2\mathrm{MeV/nuc}$$

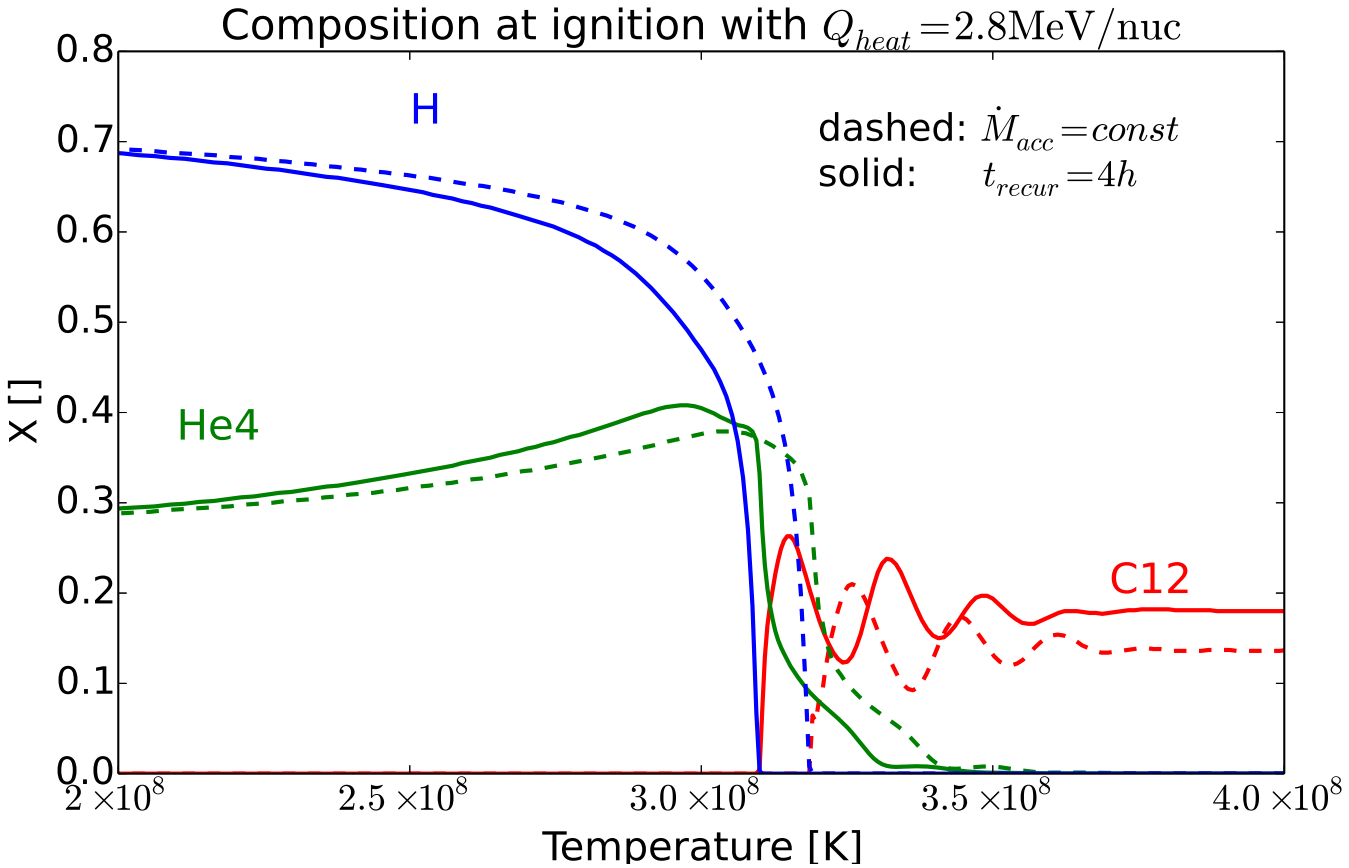
Superburst models are currently running



Ignition Conditions: Density



Ignition Conditions: Temperature



Temperature Profile