Calculating PIEs with DJEHUTY

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PIE = Proton Ingestion Episode

- Where convection mixes protons into a region that is much hotter than normal Hburning
- Dual Core Flash
- Dual Shell Flash

Nomenclature

- Lots of names for these events
- Some ridiculous
  - HeFDDM-A/R = He Flash-driven Deep-mixing on the AGB or RGB
- Simon Campbell's thesis (also C&L 2010)
  - Dual Flashes
    - A He flash (core or shell) causes mixing of protons (PIE)
    - This results in a H flash
  - Dual Core Flash – mixing caused by core flash
  - Dual Shell Flash – mixing caused by shell flash
  - Both being examples of PIEs

Dual Core Flash: Very low Z

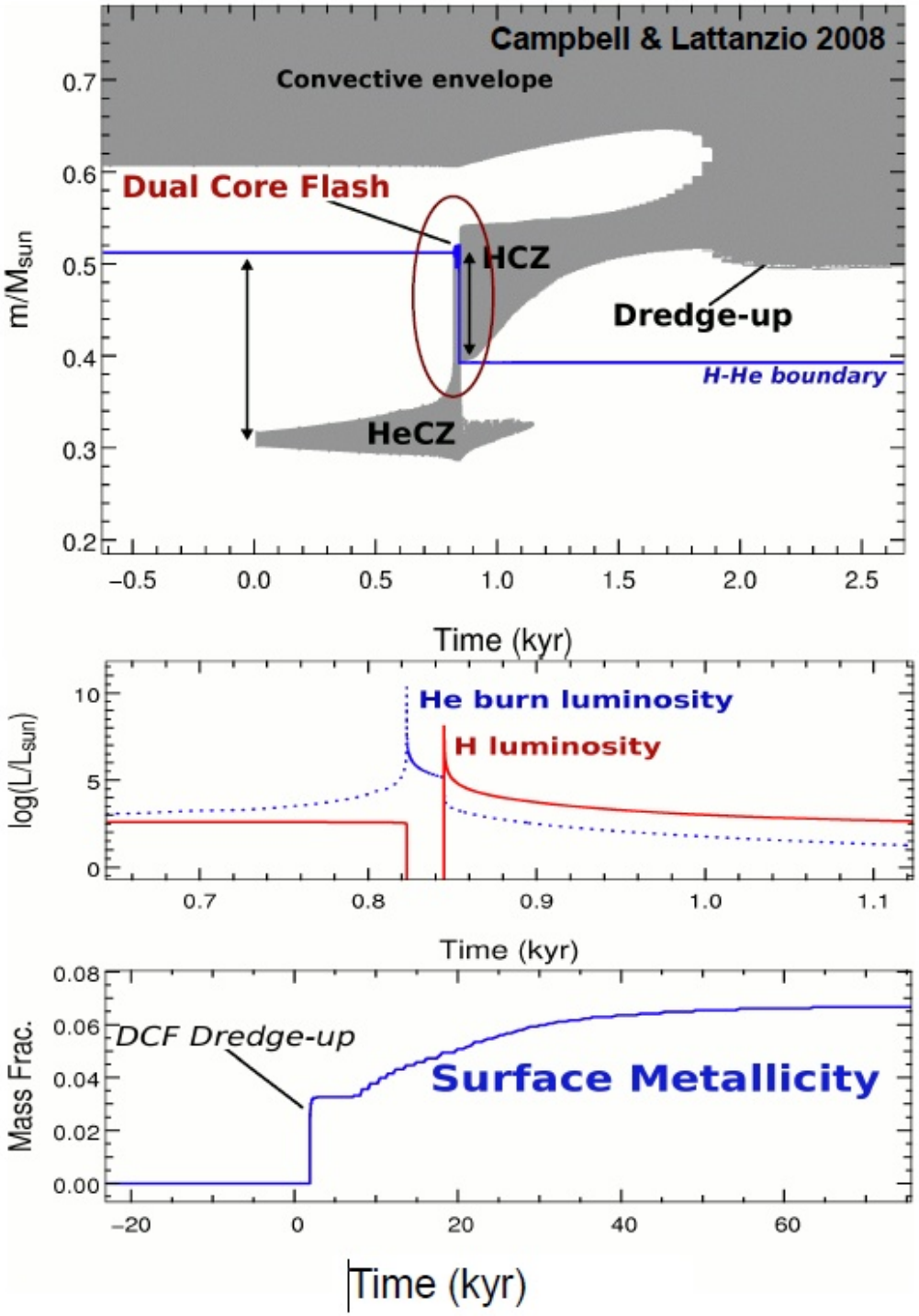
- Off-centre igntion
- But strong convection
- Mixing reaches H-rich envelope
- Does not (?)happen at “normal” Z

Dual Core Flash: Details

- The mixing of protons downwards into high temperature regions naturally causes very rapid H burning.
- → **Hydrogen Flash!**
- **The He flash is still ongoing** (hence name 'dual flash')
- He burning products are mixed upwards also.

➢ This material is later dredged up into the envelope, polluting the surface.

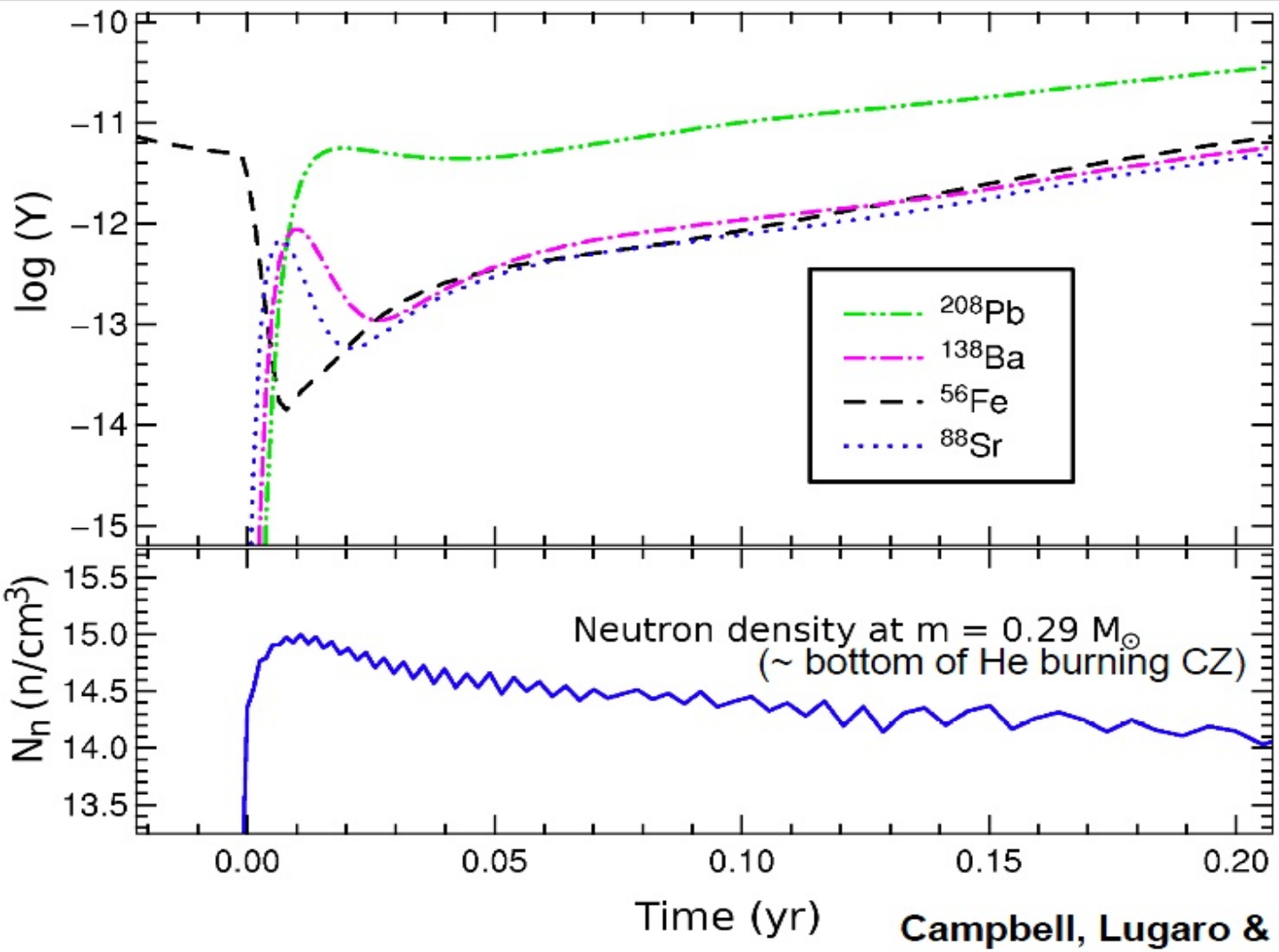
➢ Fujimoto et al. (1990) suggested **that the excess C in the CEMPs may come from these peculiar surface pollution events**.



Neutron Super-burst!

Resulting abundances as function of time

(sampled at the location of the maximum of the neutron density)

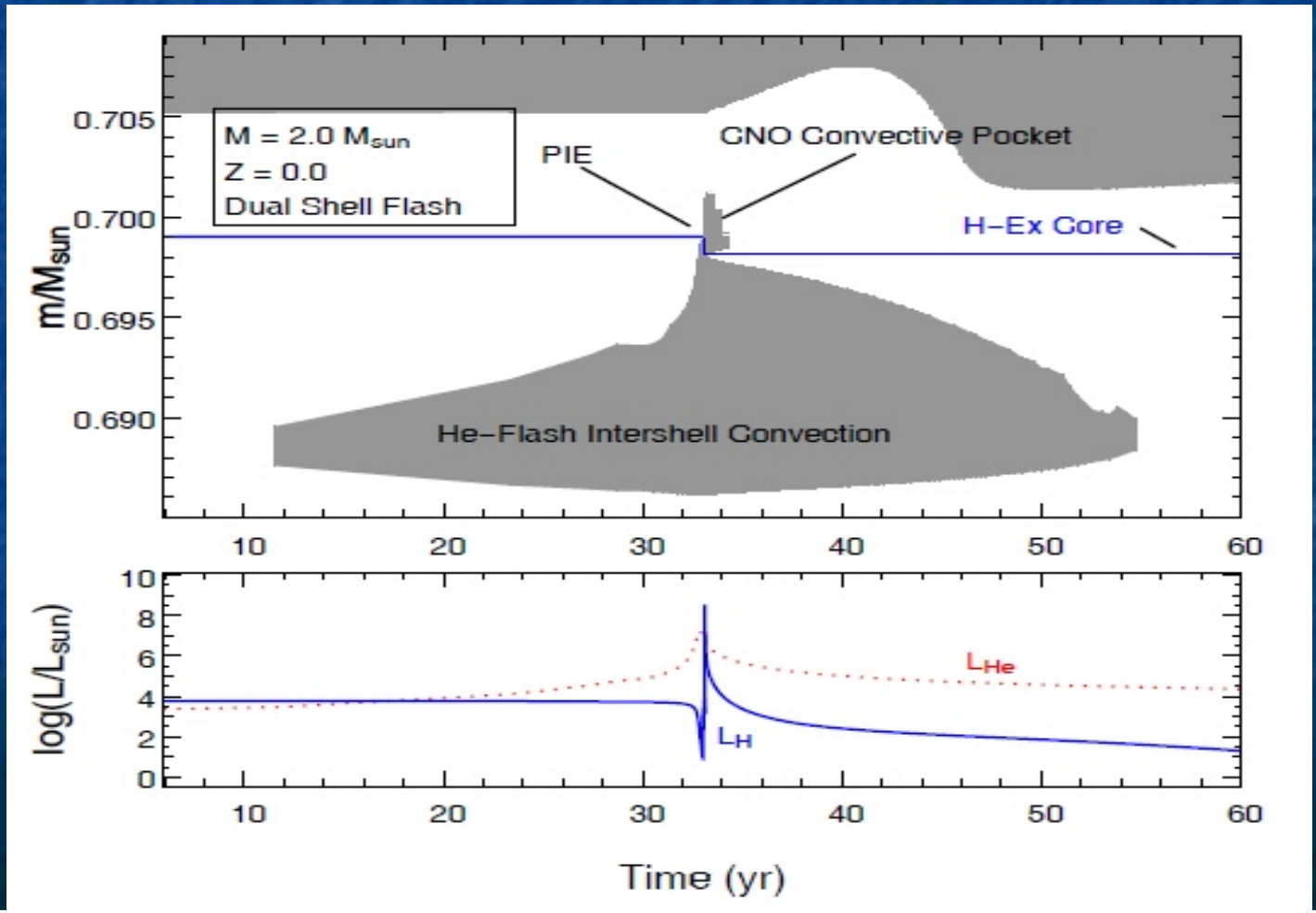


- **Strong s-processing!**
- **Abundances of Ba, Pb reach *absolute* Solar abundances!!**
- **[Pb/Fe] ~ +6 after dredge-up to surface**
- **s-process continues until ^{14}N becomes more abundant than ^{13}C and soaks up most of the free neutrons.**
- **n exposure ~ 250 mbarn^{-1}**

Campbell, Lugaro & Karakas 2010

Dual Shell Flashes

- For low Z stars on the AGB
- PIE can occur



PIEs

- Expect neutron production
- Expect s-processing
- But how to calculate the time-dependent mixing?

Wrong!

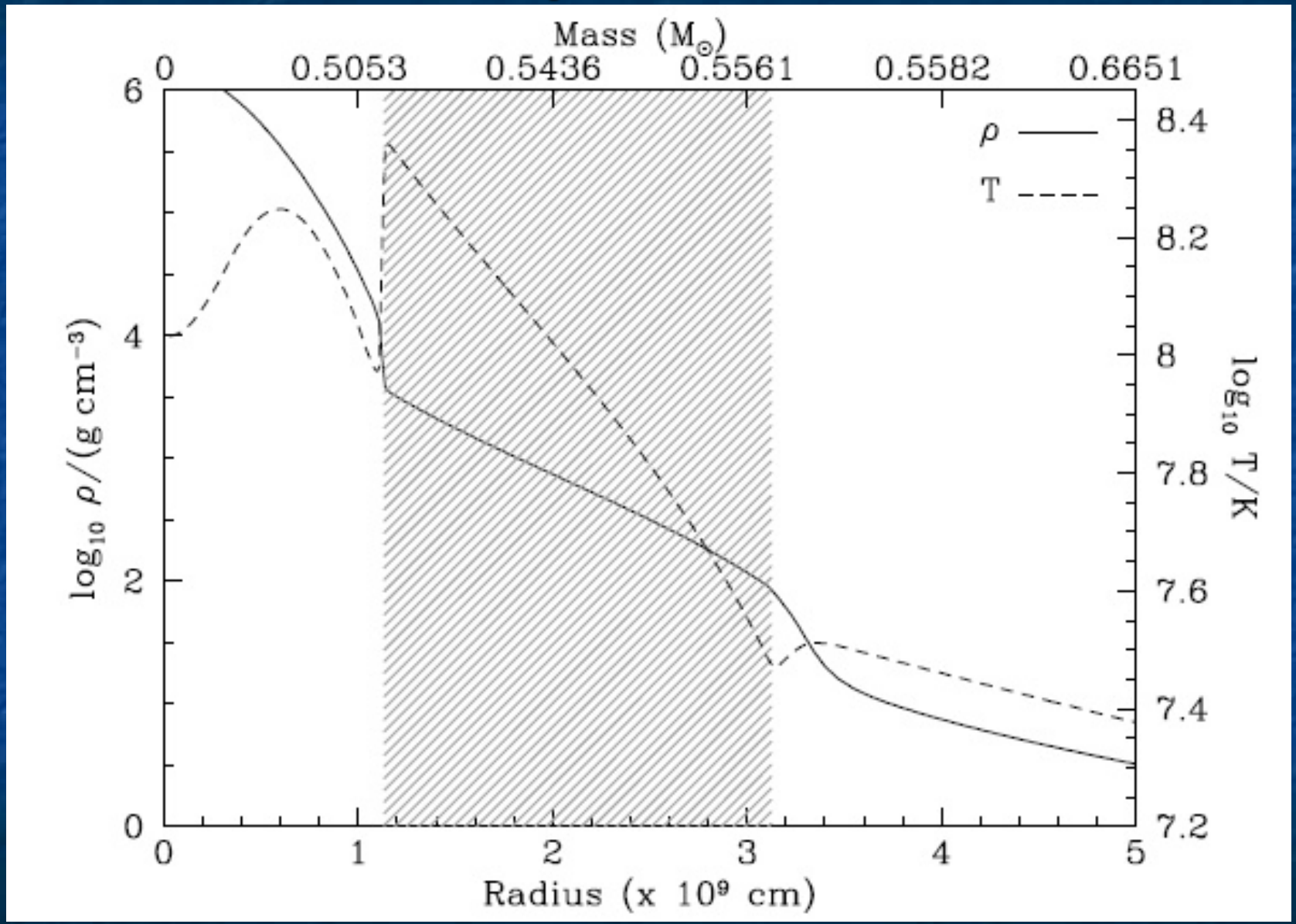
- Mostly treat mixing with diffusion equation
- Mostly use MLT for values of v

Wrong!

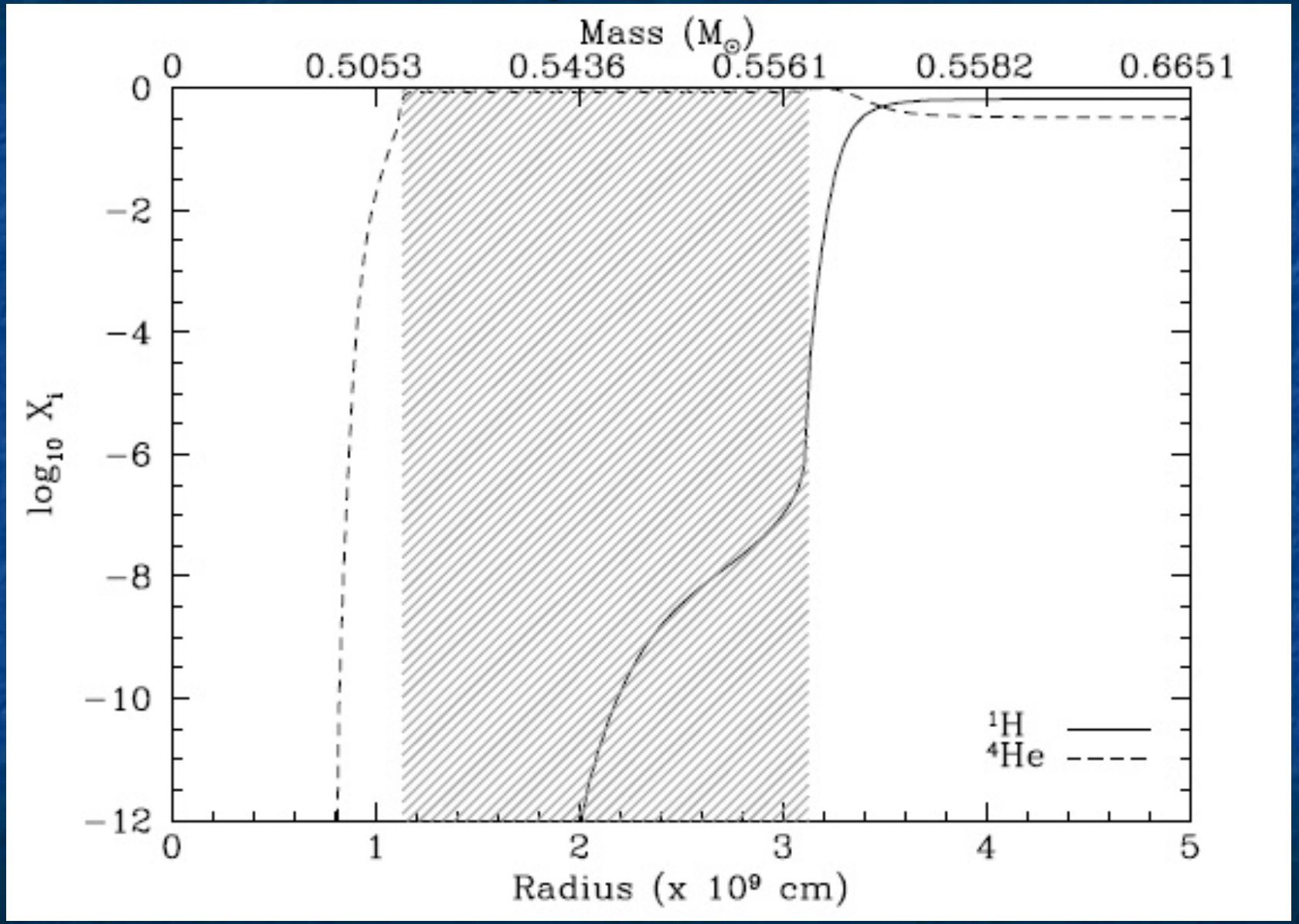
Try to do in 3D using DJEHUTY

- Paper just submitted to ApJ
- Dual shell flash
  - M=1
  - Z=0.0001
- He shell flash convection reaches bottom of H-shell and ingests protons

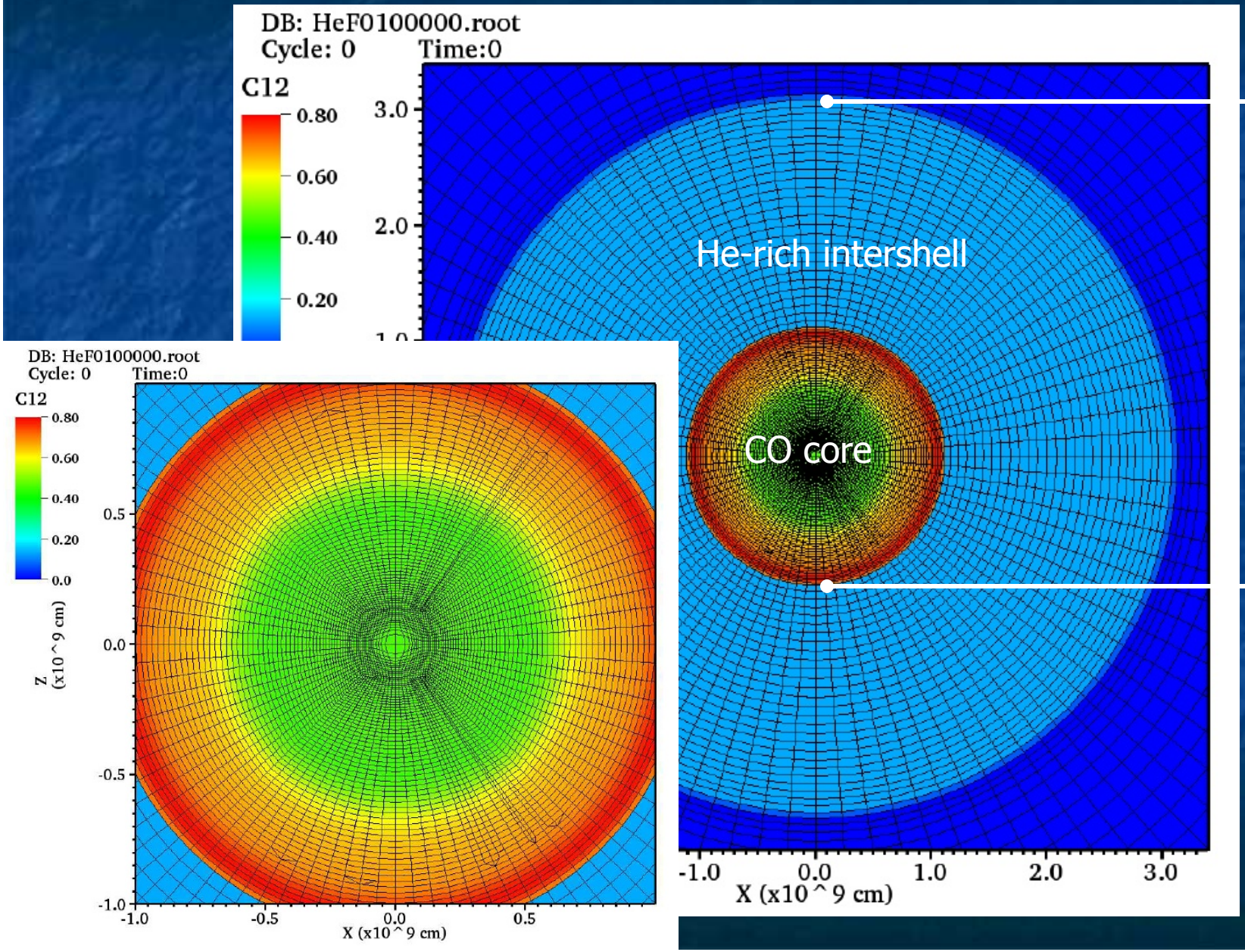
1D input model



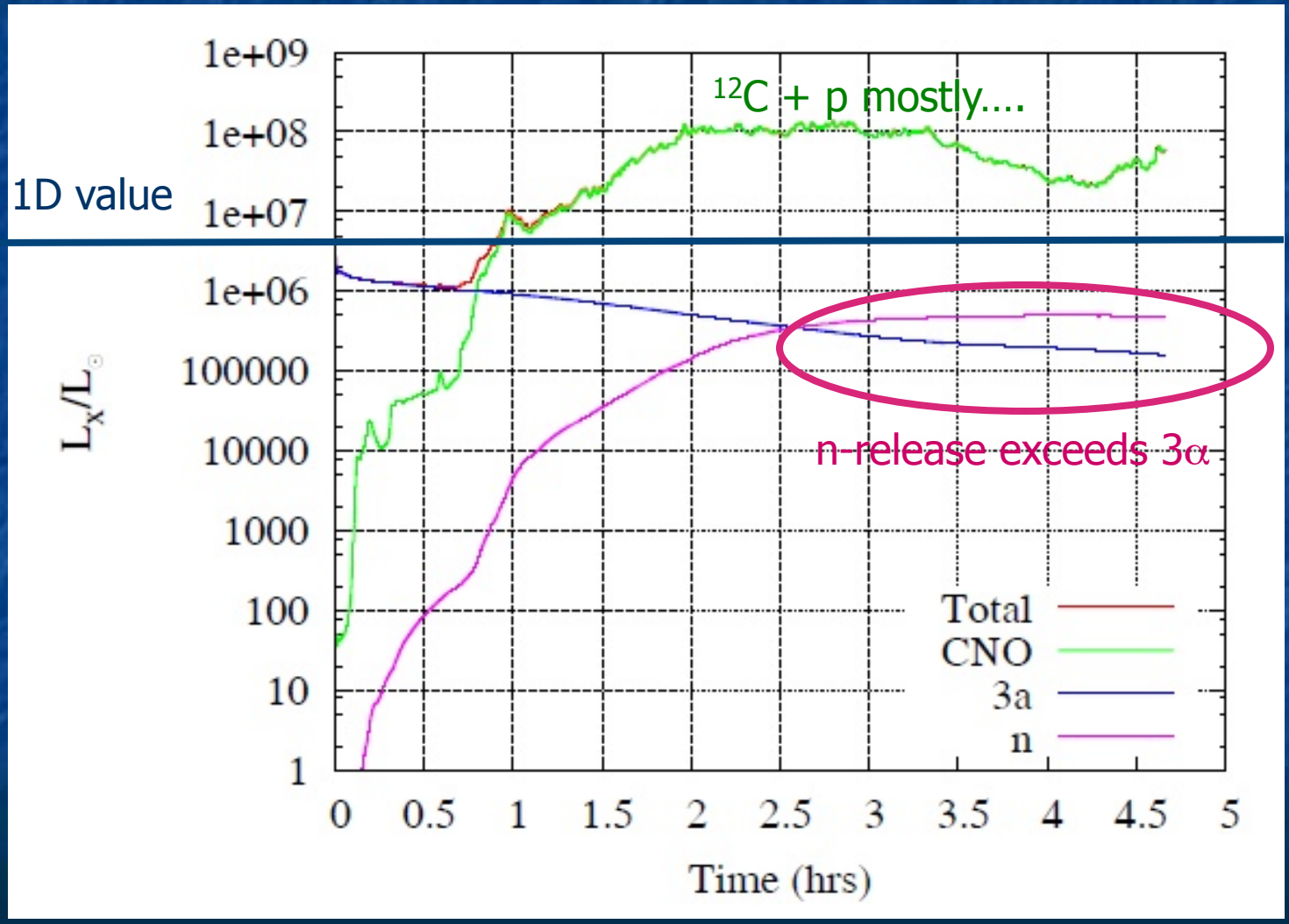
1D input model



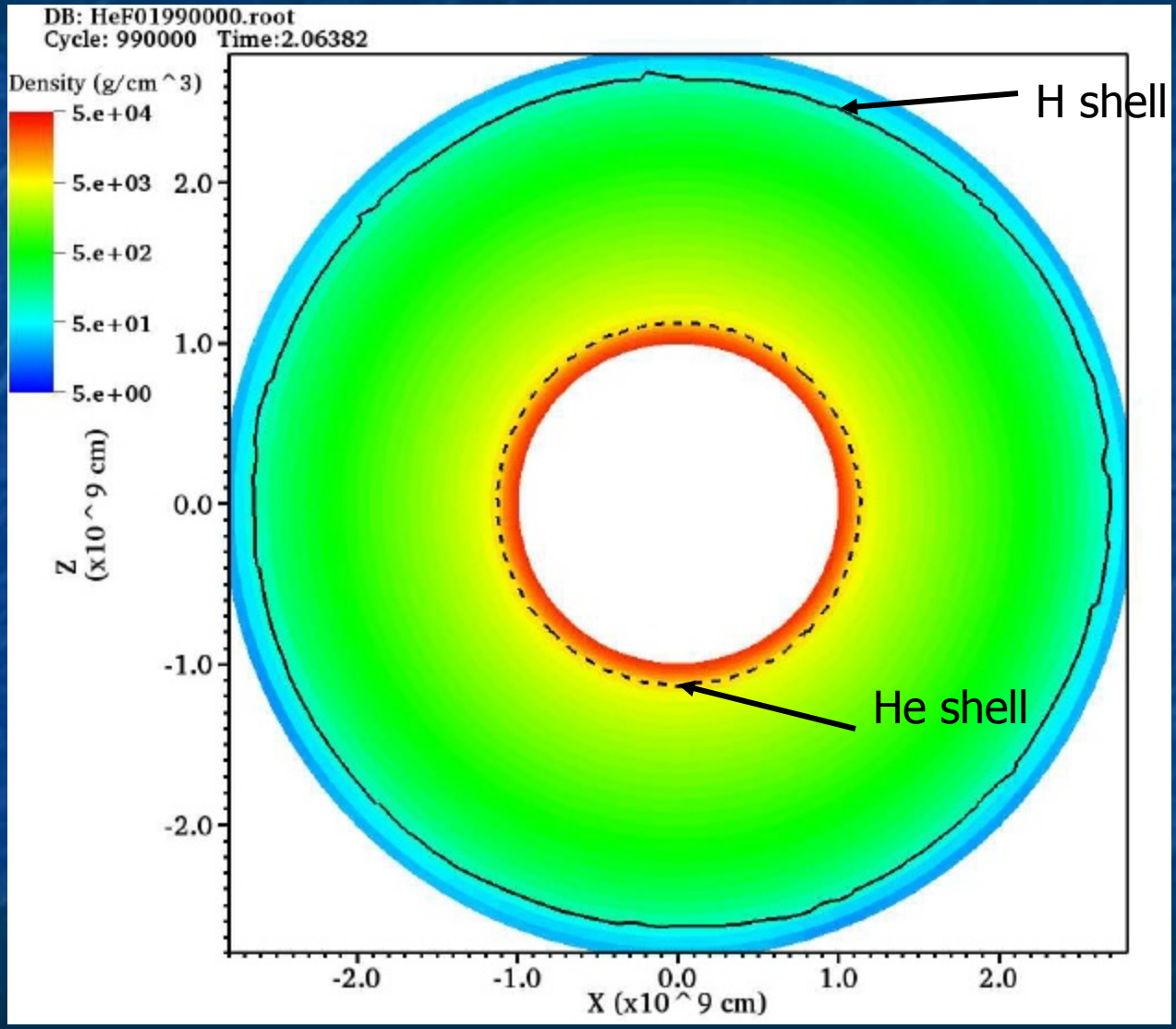
The 3D calculation (2 million zones)



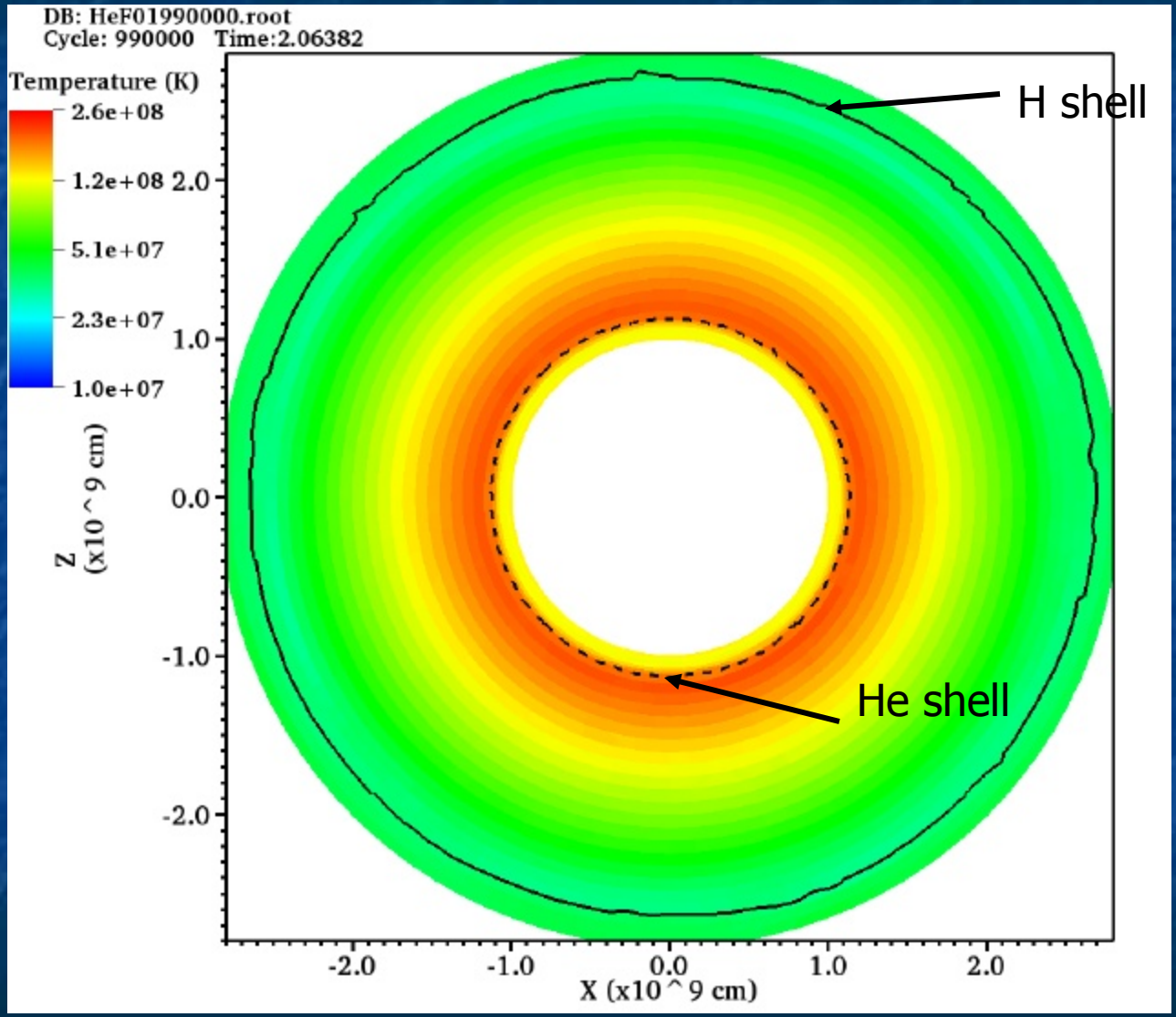
Luminosity variation/increase!



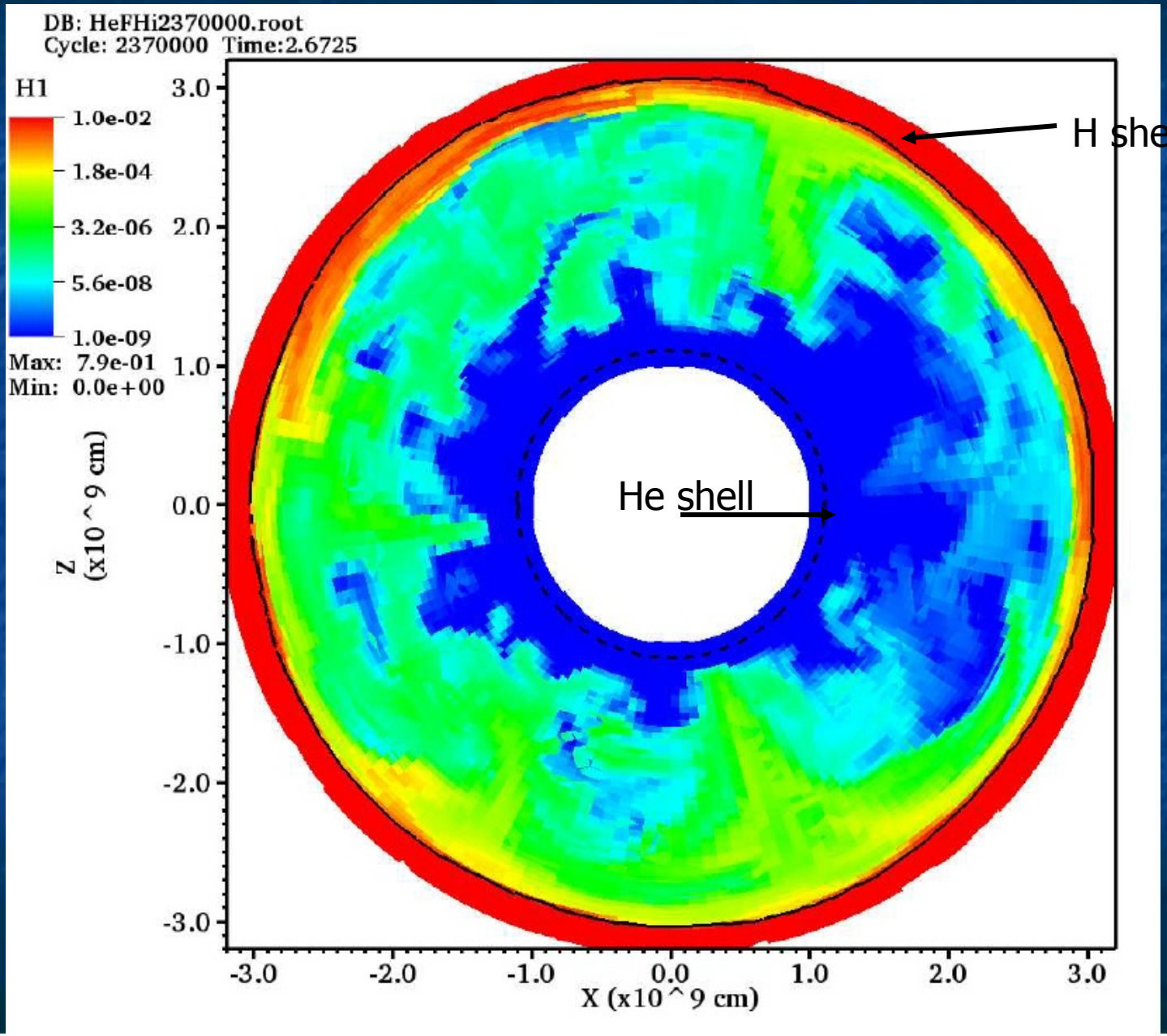
Density (on a slice) t=2.0hrs



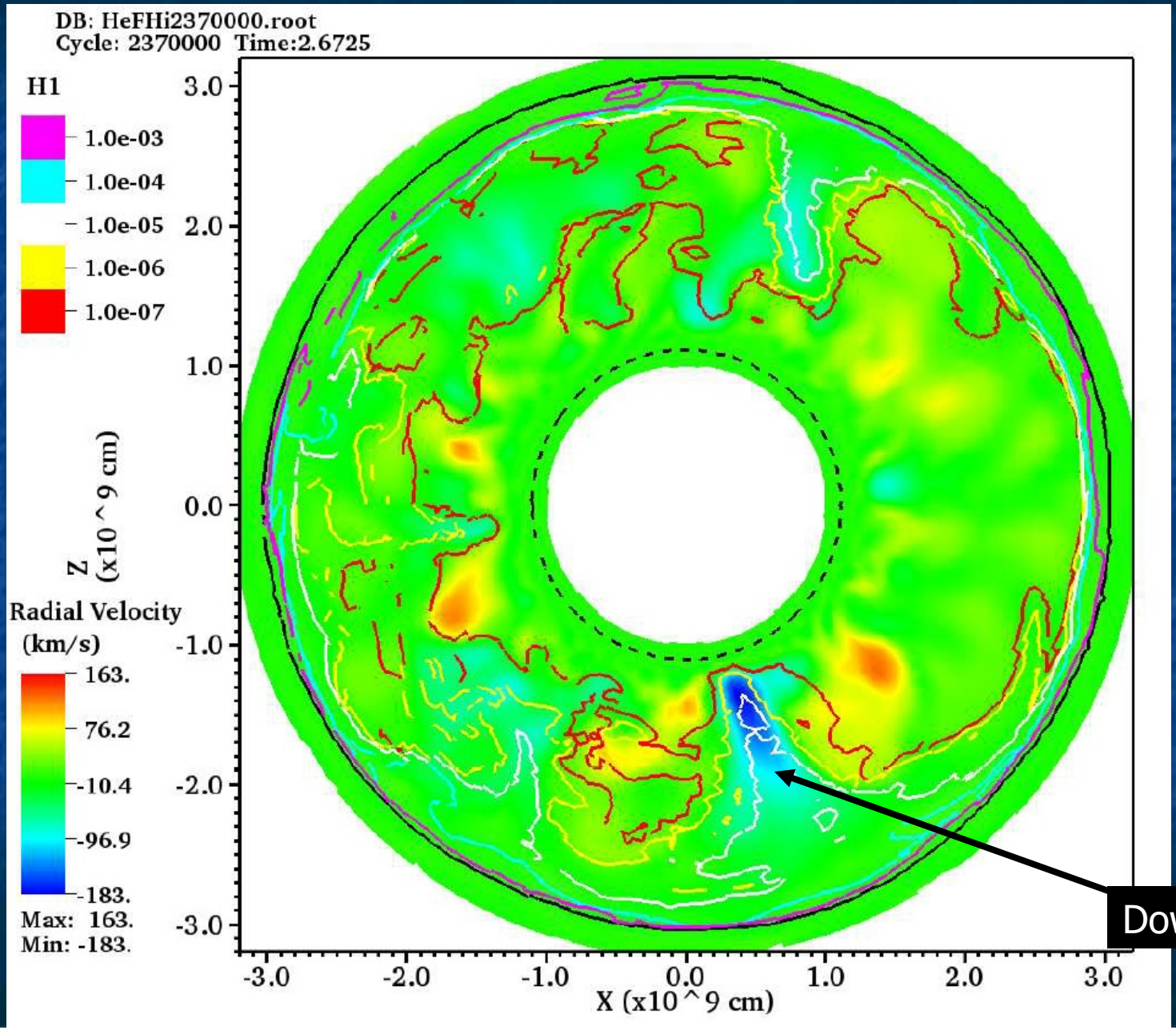
Temperature (on a slice) t=2.0hrs



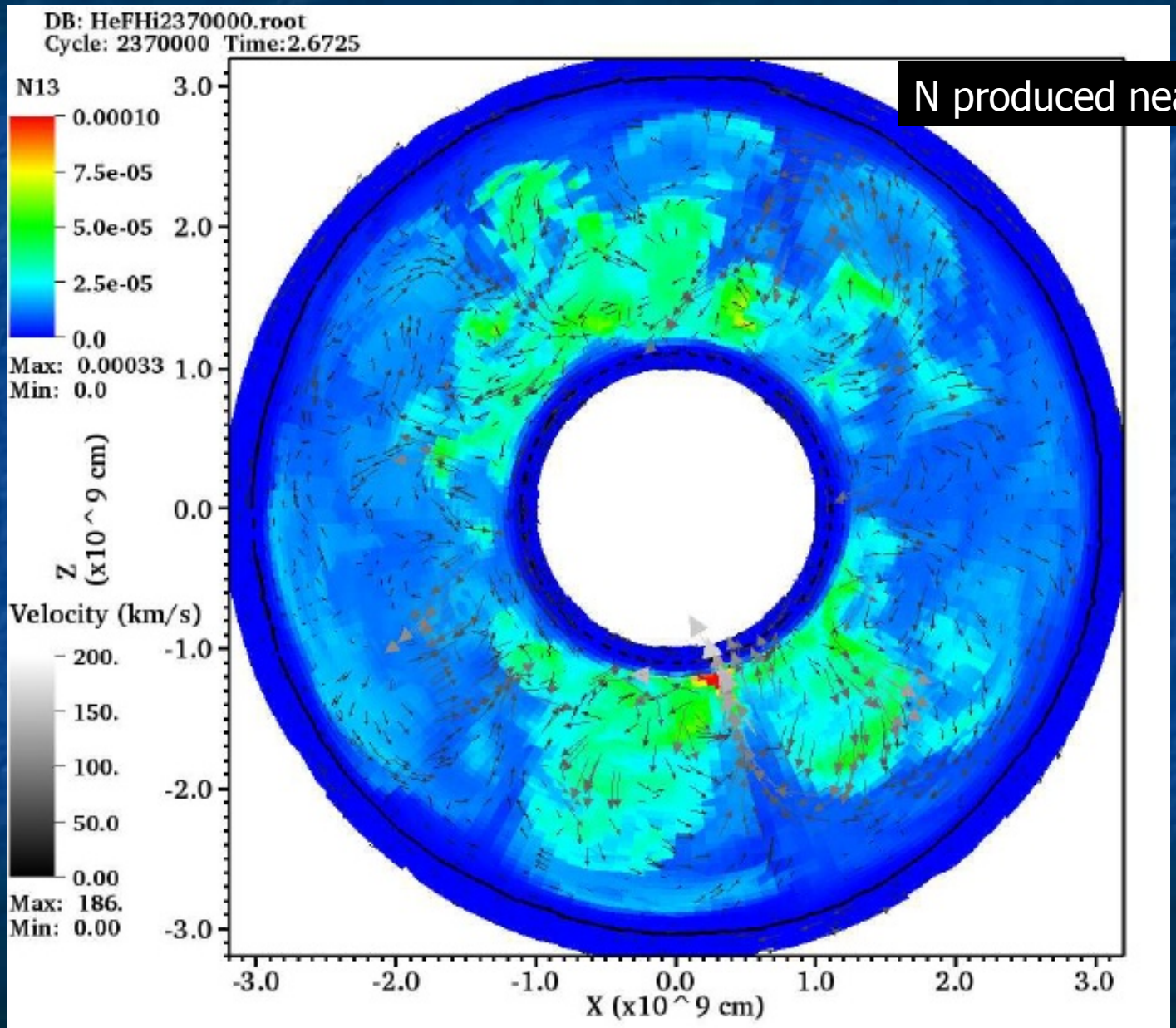
Hydrogen (on a slice) t=2.7hrs



Hydrogen (on a slice) t=2.7hrs

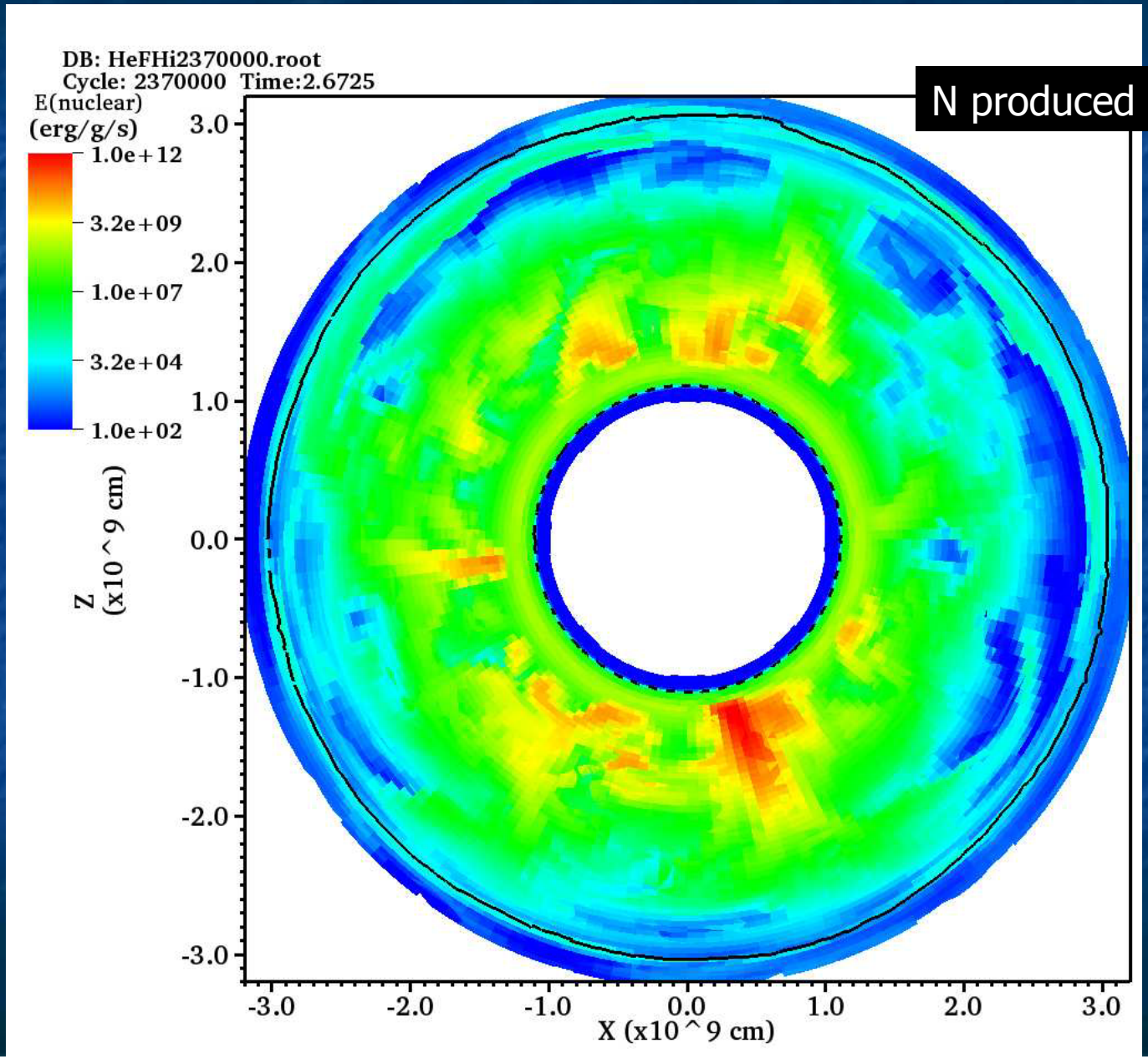


^{13}N and v (in plane) (on a slice) t=2.7hrs



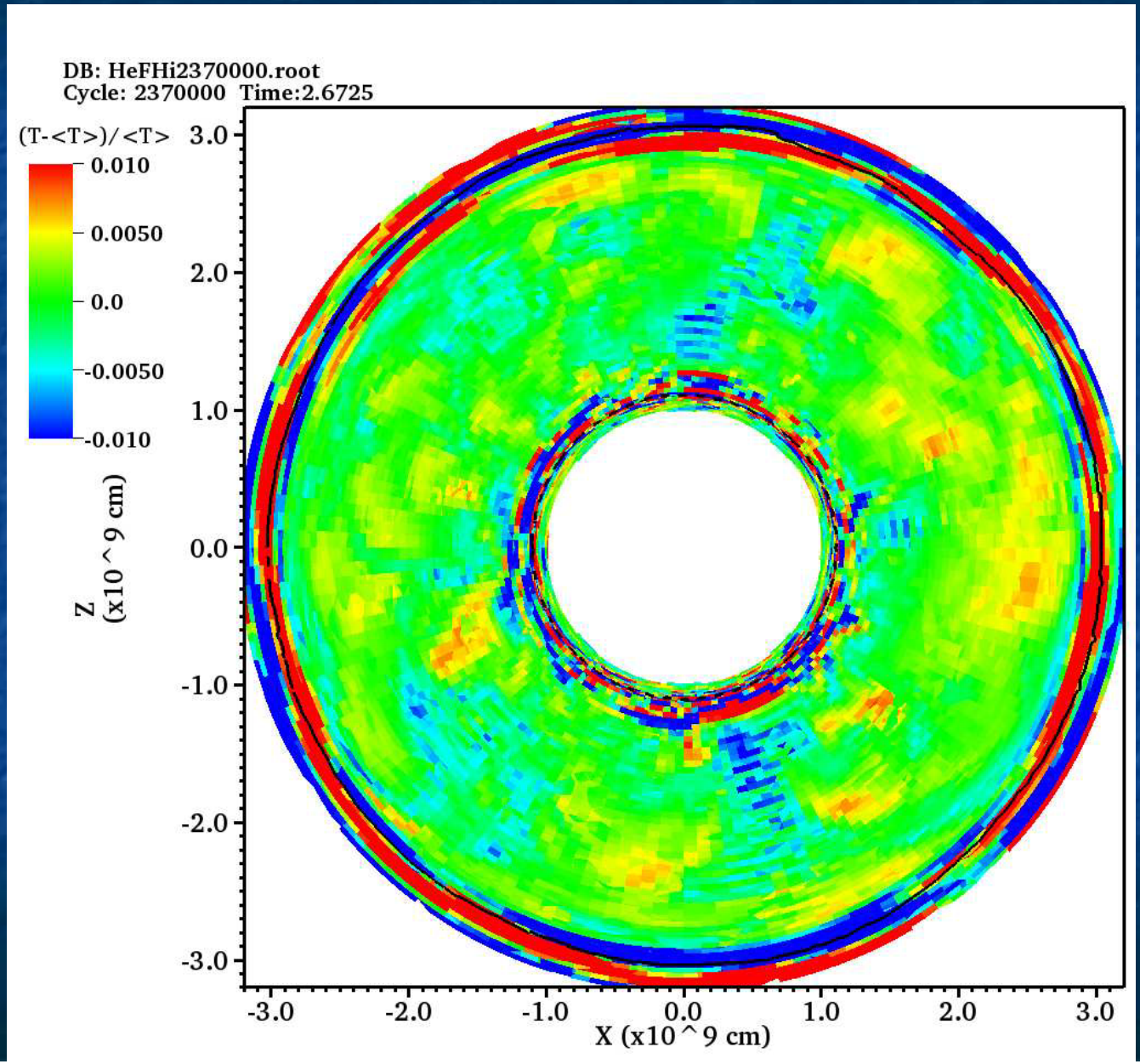
N produced near the He shell

Energy generation (on a slice) t=2.7hrs



N produced near the He shell

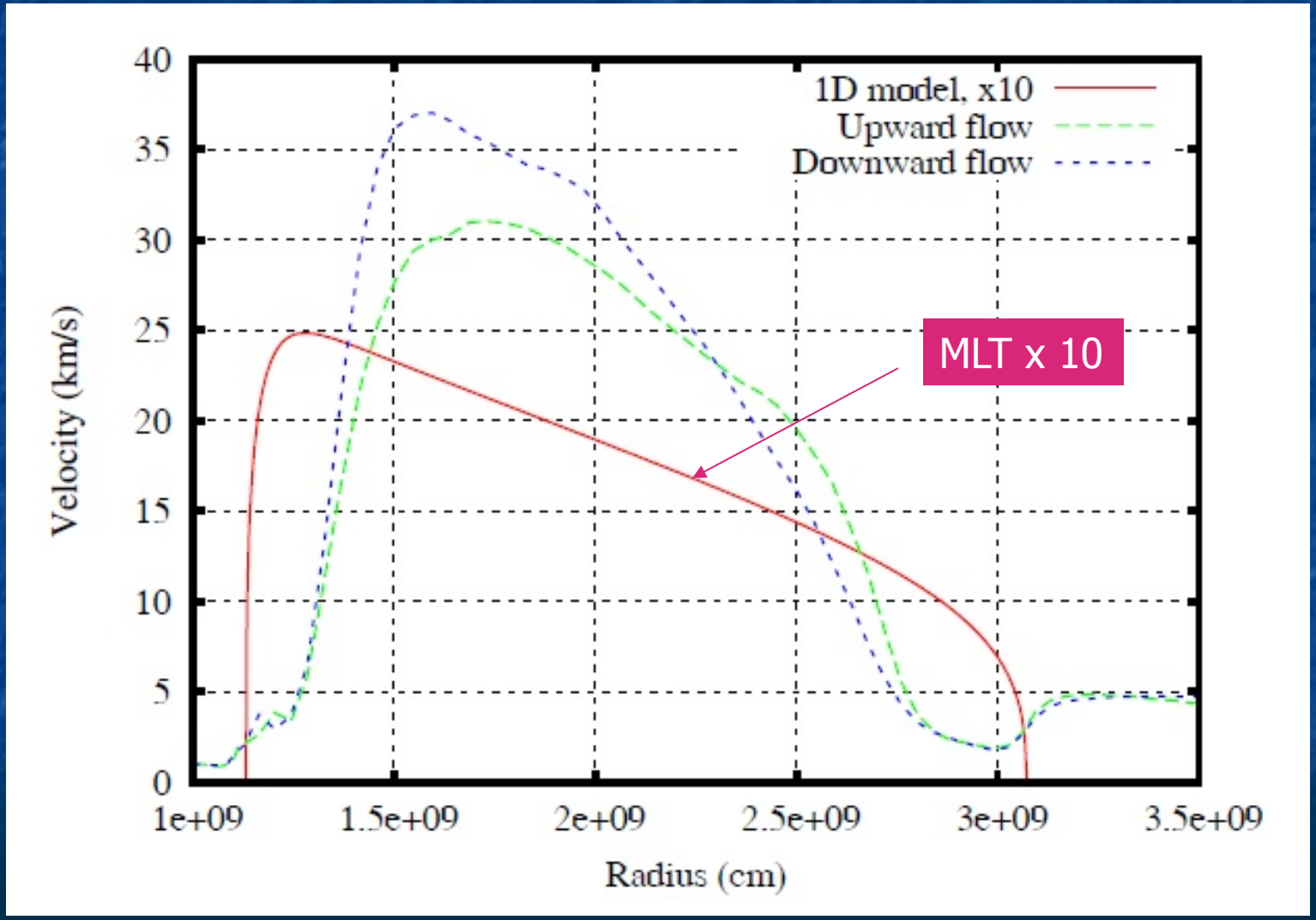
T variation (on a slice) t=2.7hrs



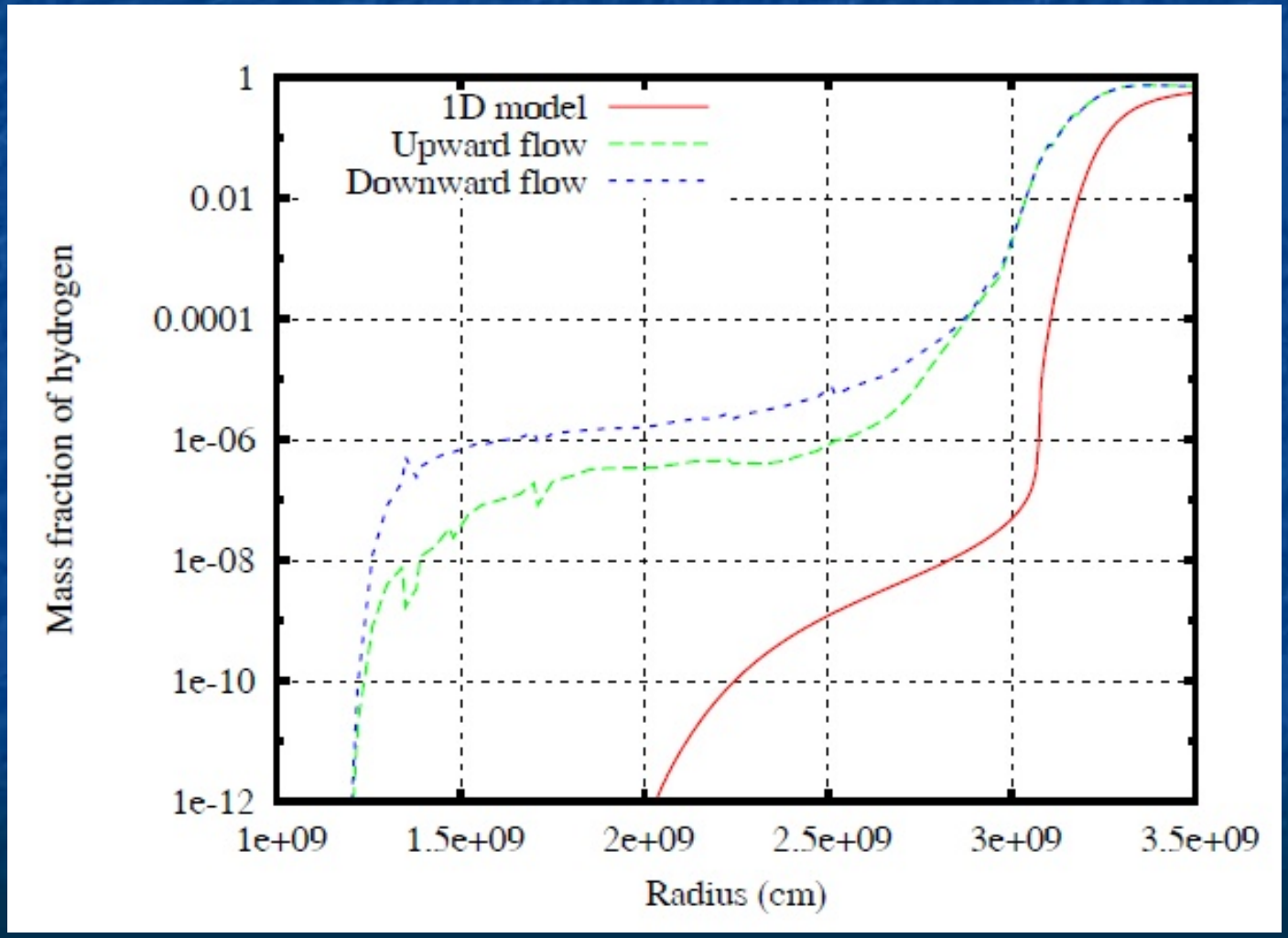
Very minor!

$$\frac{T-\langle T\rangle}{\langle T\rangle} \approx \pm 1\%$$

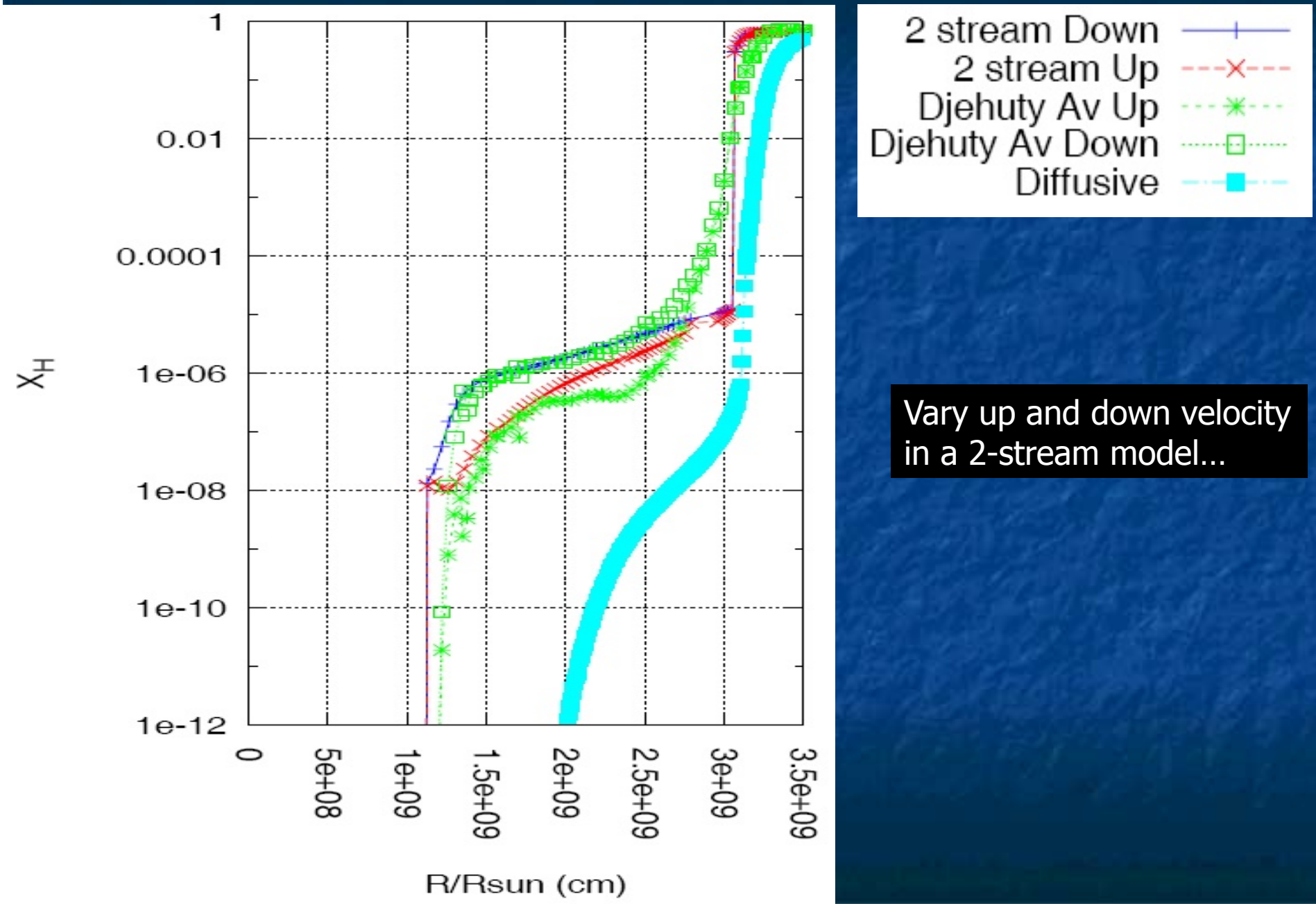
Comparison to 1D: velocity profiles



Comparison to 1D: H profiles



321D Theory (with Arnett et al)



Vary up and down velocity in a 2-stream model…

Show Movies

- H1
- V_rad
- e_nuc
- N13