Convection in the Accreted Atmosphere of a Neutron Star: The Early Phase of a Type I X-ray Burst

Chris Malone, SUNY Stony Brook

Collaborators:
Ann Almgren, LBL
John Bell, LBL
Andy Nonaka, LBL
Mike Zingale, SUNY Stony Brook

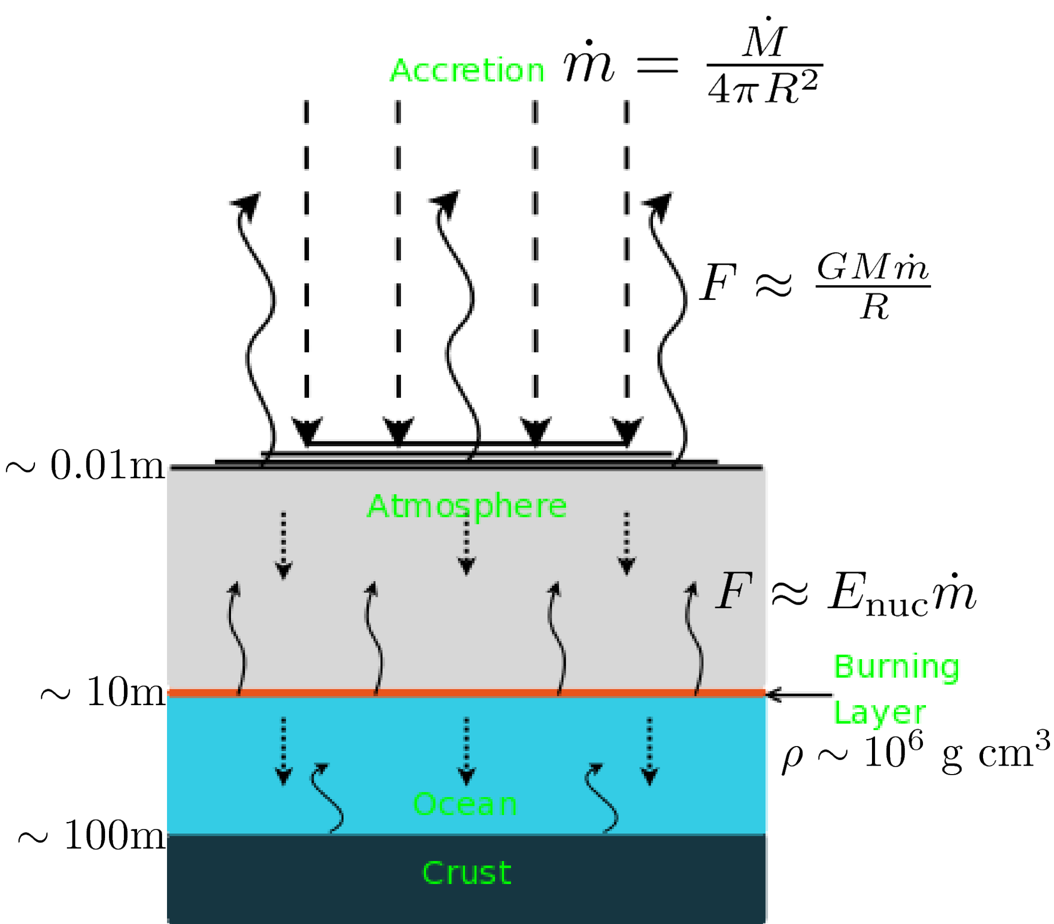
Initial Models Provided by:
Andrew Cumming, McGill University
Stan Woosley, UCSC

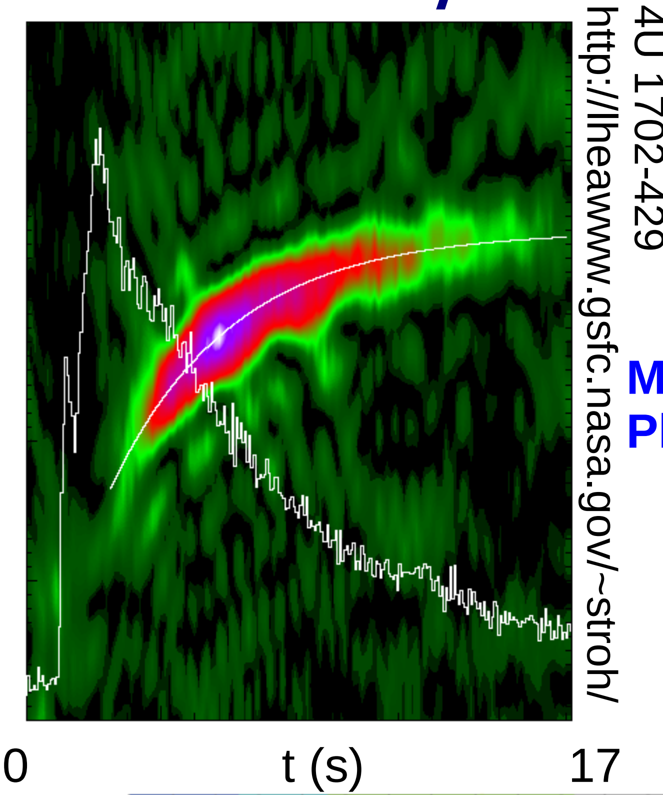
Type I X-ray Bursts and Why We Care

Accretion onto NS in LMXB; companions could be:

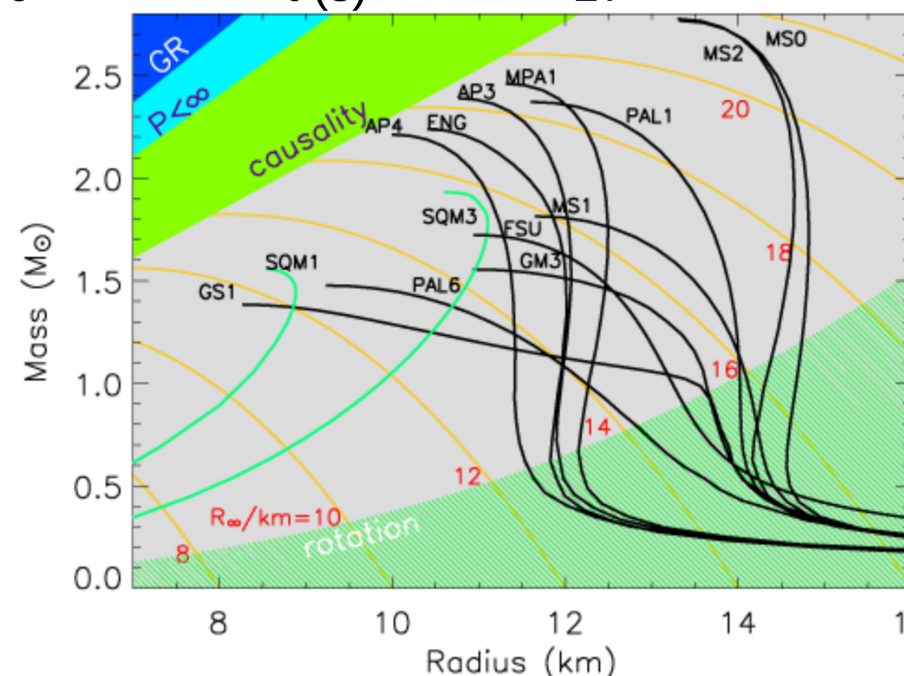
- Low mass main sequence star; Mixed H/He burst
- He White Dwarf; Pure He burst
- Deflagration; Low Mach number flow

$$E \sim 10^{39} - 10^{40}\ \mathrm{erg}$$
$$\tau_{\mathrm{dur}} \sim 10 - 100\ \mathrm{s}$$
$$\tau_{\mathrm{rec}} \sim 10^{4} - 10^{5}\ \mathrm{s}$$





Multidimensional Phenomena!



Lattimer, J.M., Ap&SS, **308**, 371 (2007)

Computational Issues: Low Mach Number Flow

Necessary condition for stability of explicit solution to hyperbolic PDEs (CFL condition):

information can not propagate more than a fraction, α, of a computational zone in a single timestep

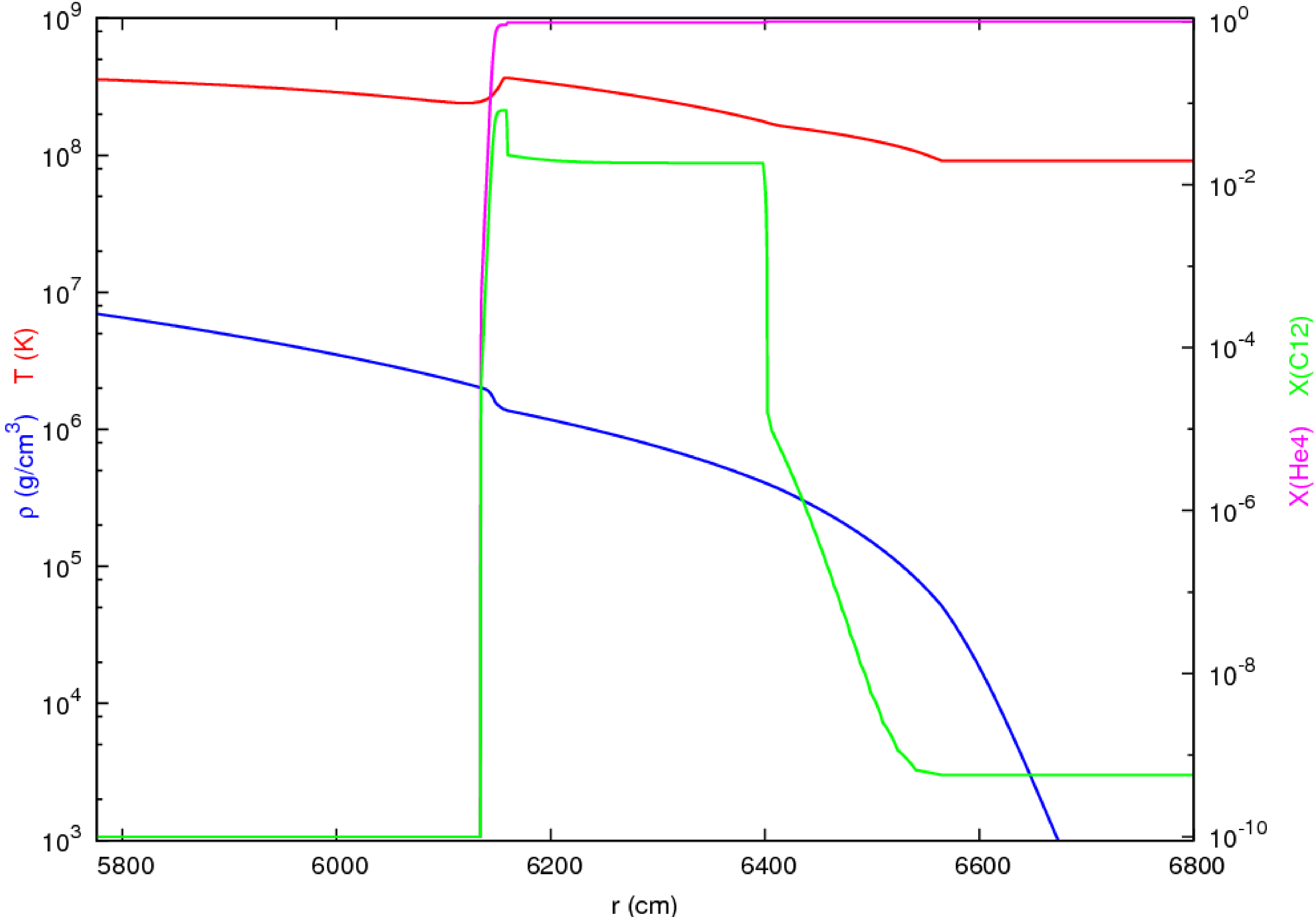
$$\Delta t \le \alpha \frac{\Delta x}{u + c_\mathrm{s}} = \alpha \frac{\Delta x}{u} \left(\frac{M}{1+M} \right) \underbrace{\approx \alpha M \frac{\Delta x}{u}}_{\text{for } M \ll 1}$$

- MAESTRO – multidimensional hydrodynamics code for low Mach number astrophysical flows

- asymptotic expansion in Mach number about a background HSE state allows for decomposition of pressure such that acoustics are filtered out

- timestep is *dynamically* restricted; effectively *M* is removed from CFL condition

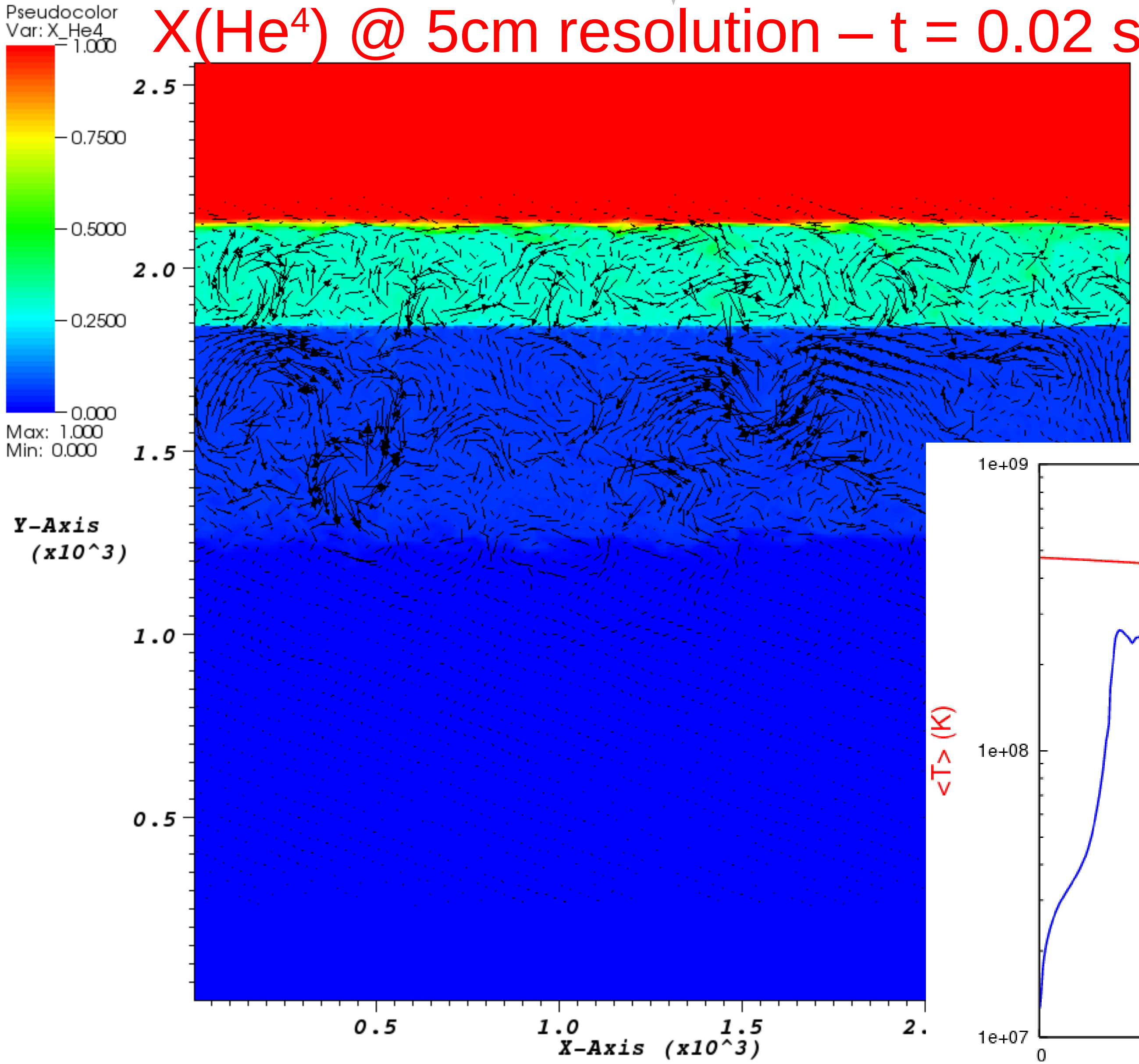
Initial Models



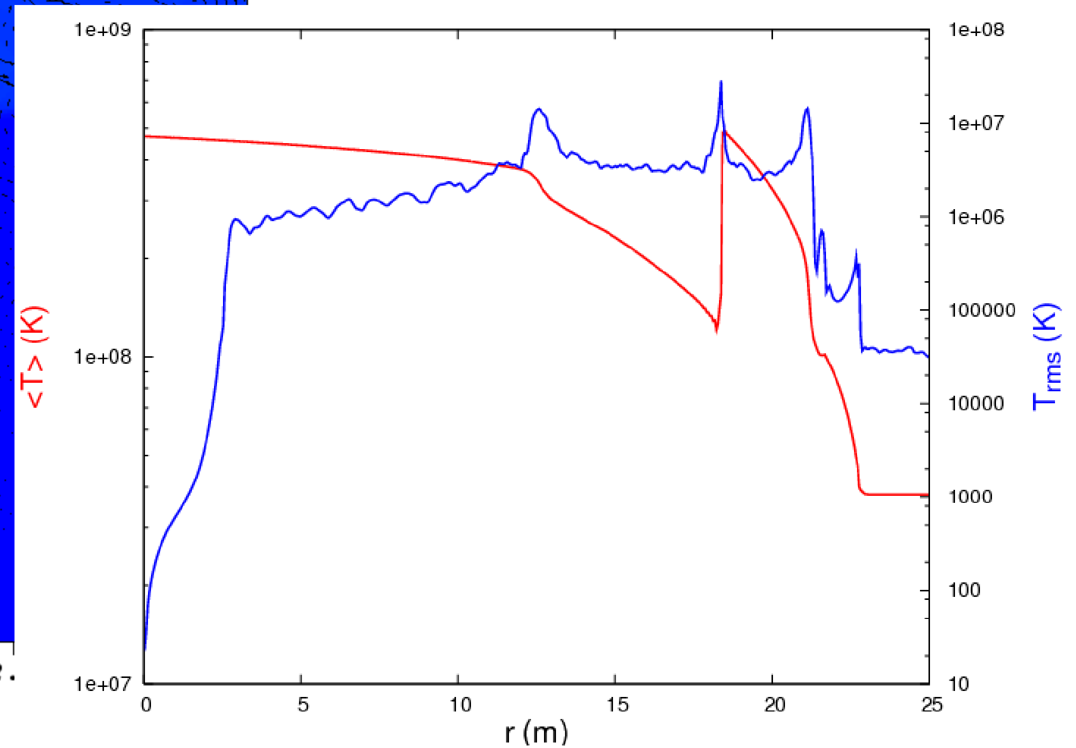
Previous Results

Our work, presented @ ASNY 2008

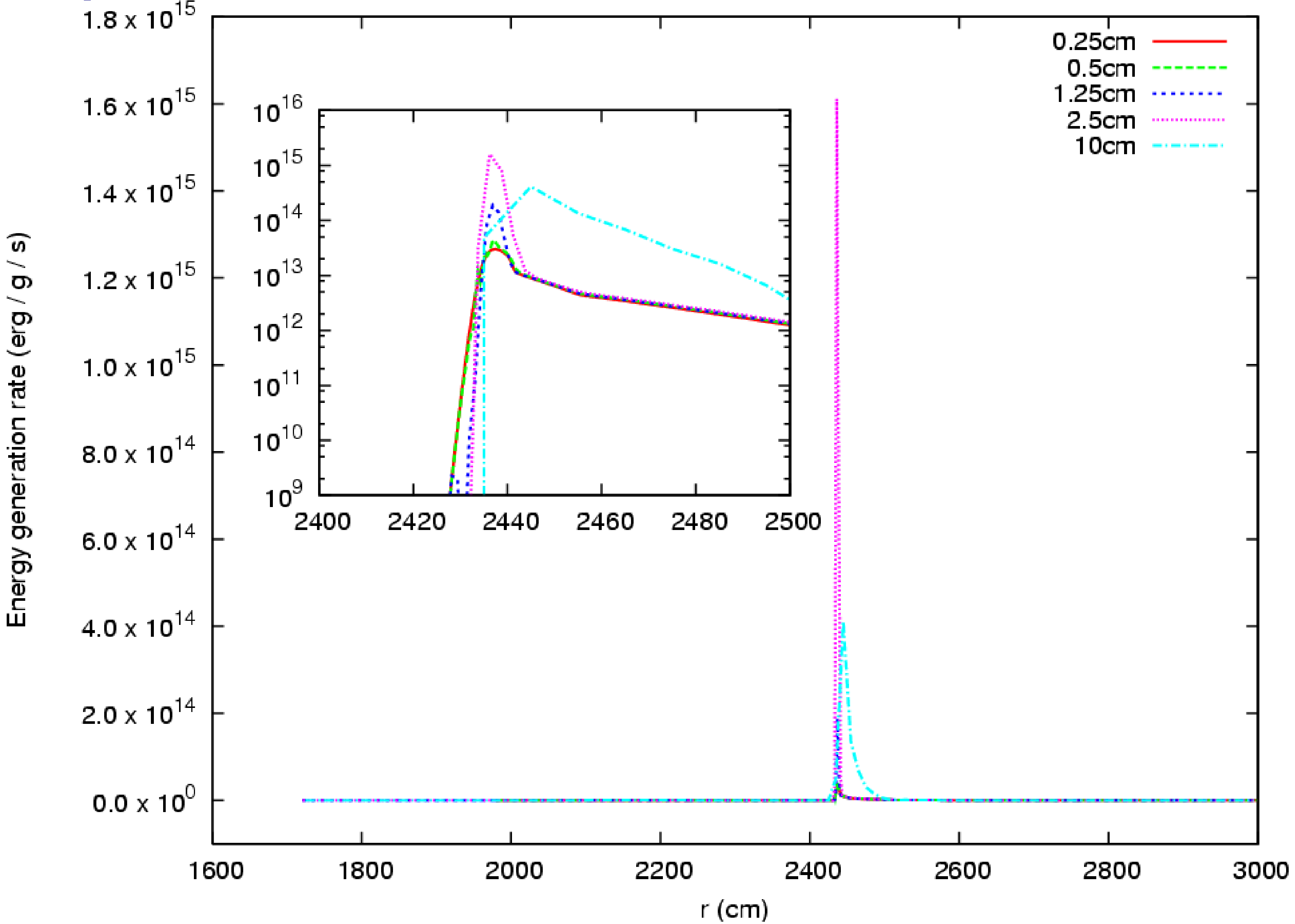
X(He^4) @ 5cm resolution – t = 0.02 s



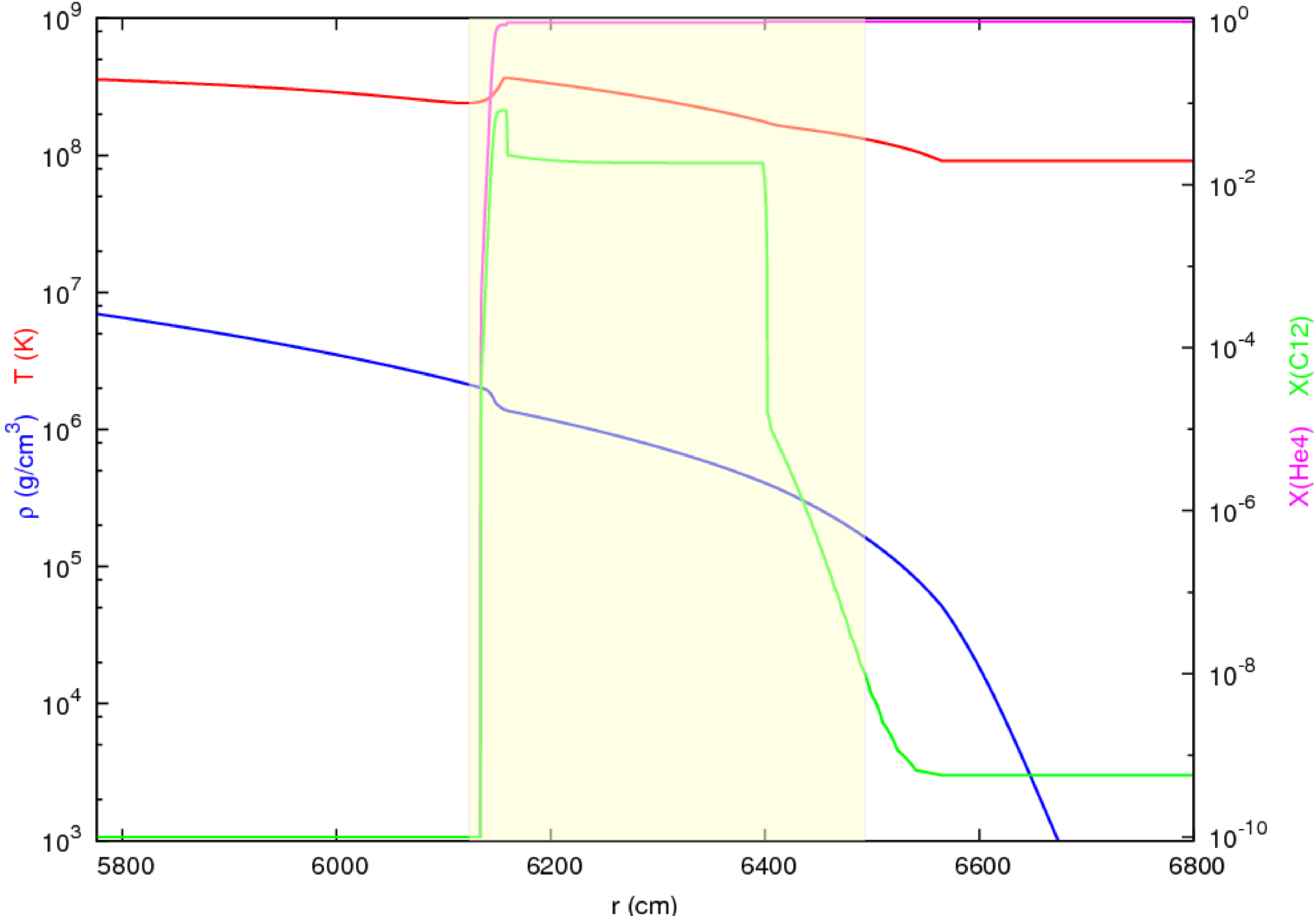
The only other group to do multidimensional simulations of deflagrating XRBs was Lin et al. (2006). Their finest resolution was 5 cm.



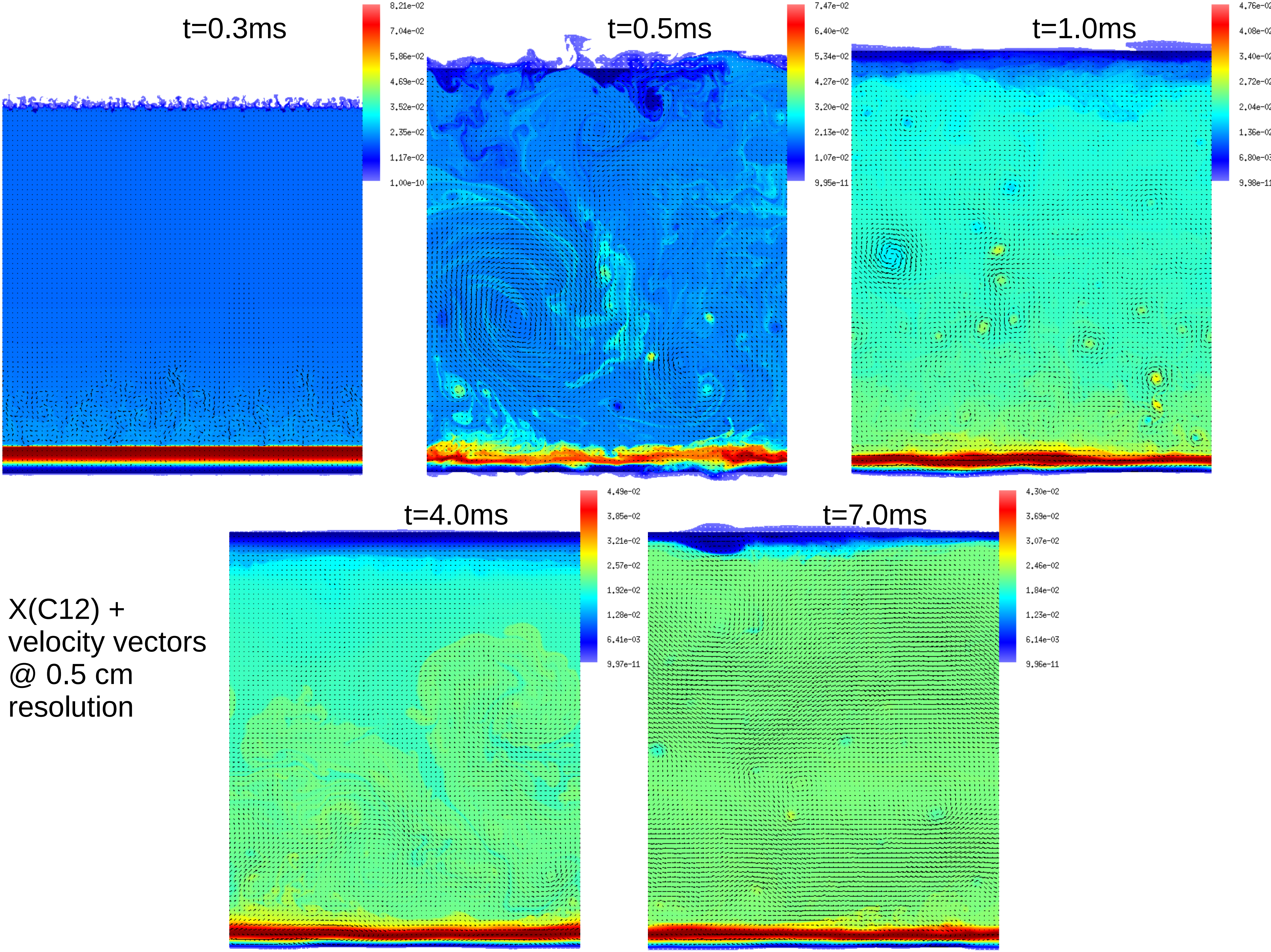
Computational Issues: Resolution



We find we need at least an order of magnitude more zones per spatial direction to properly resolve burning layer!



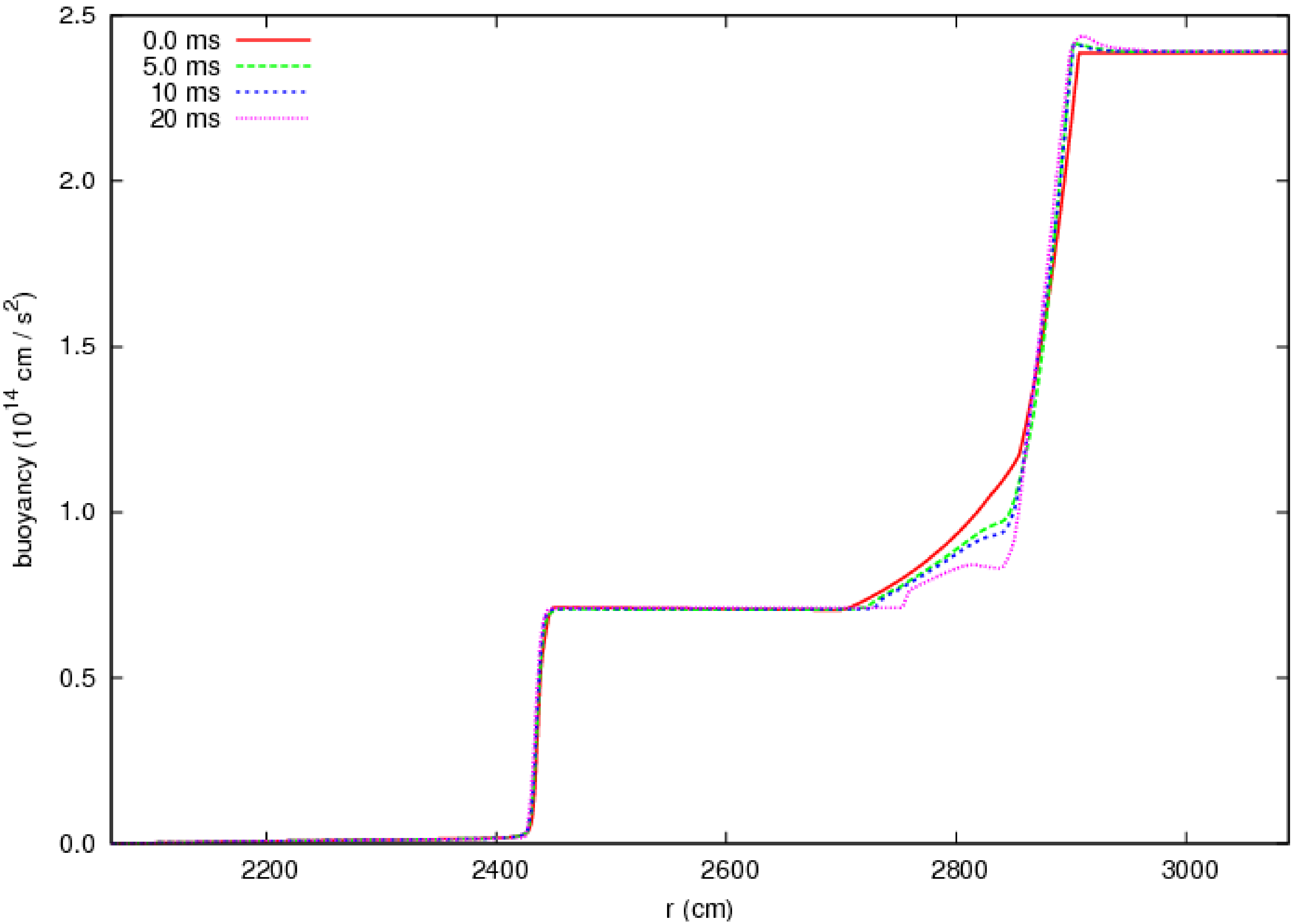
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^0
10^-2
10^-4
10^-6
10^-8
10^-10
5800
6000
6200
6400
6600
6800
r (cm)
ρ (g/cm^3)
T (K)
X(He4)
X(C12)



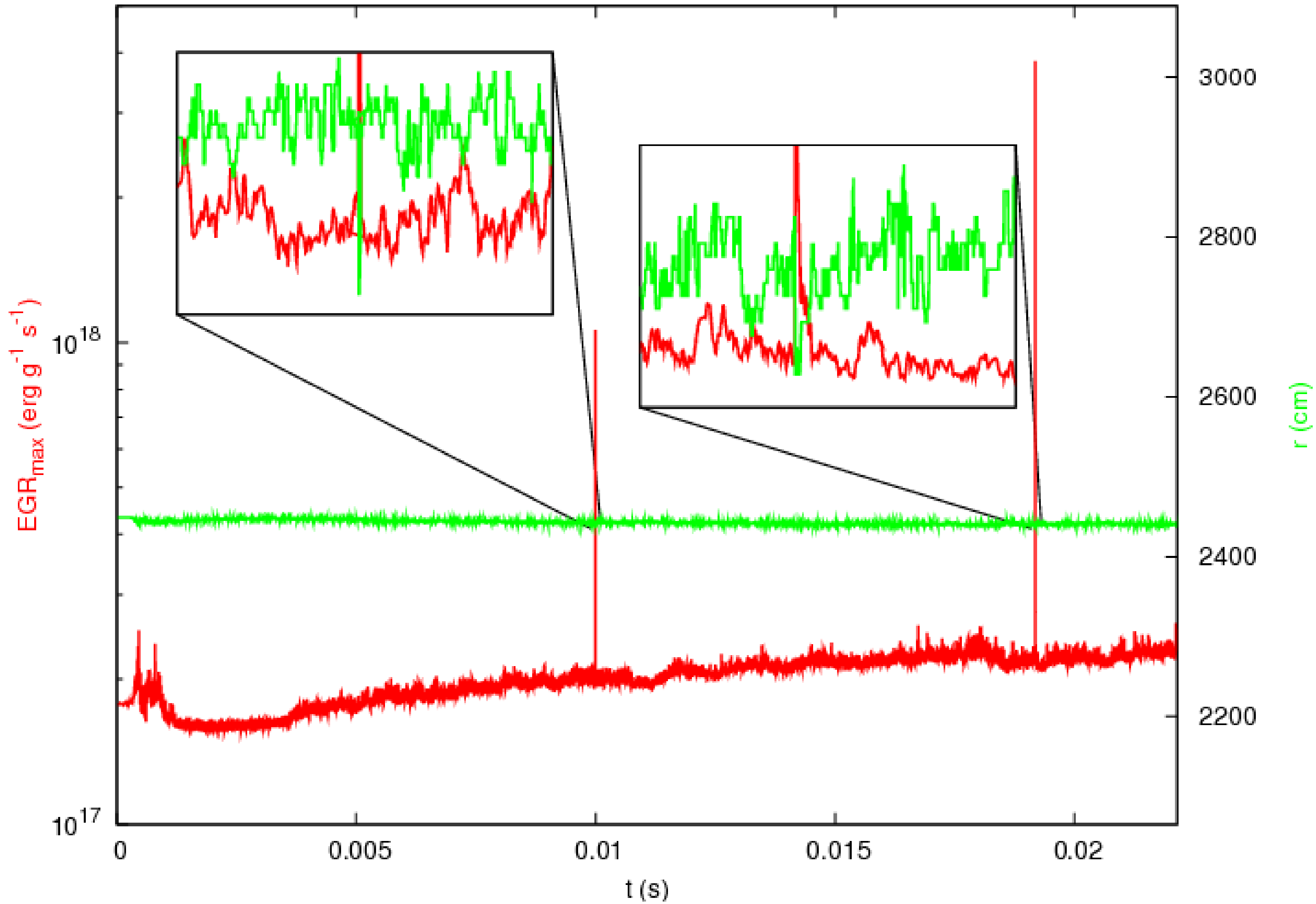
X(C12) + velocity vectors @ 0.5 cm resolution

Convective Dynamics

$$b(r) = \int_{r_0}^{r} N^2(r')\, dr', \quad N^2 = -g\left[\frac{\partial \ln \rho}{\partial r} - \left(\frac{\partial \ln \rho}{\partial r}\right)_s\right]$$



Convective Dynamics

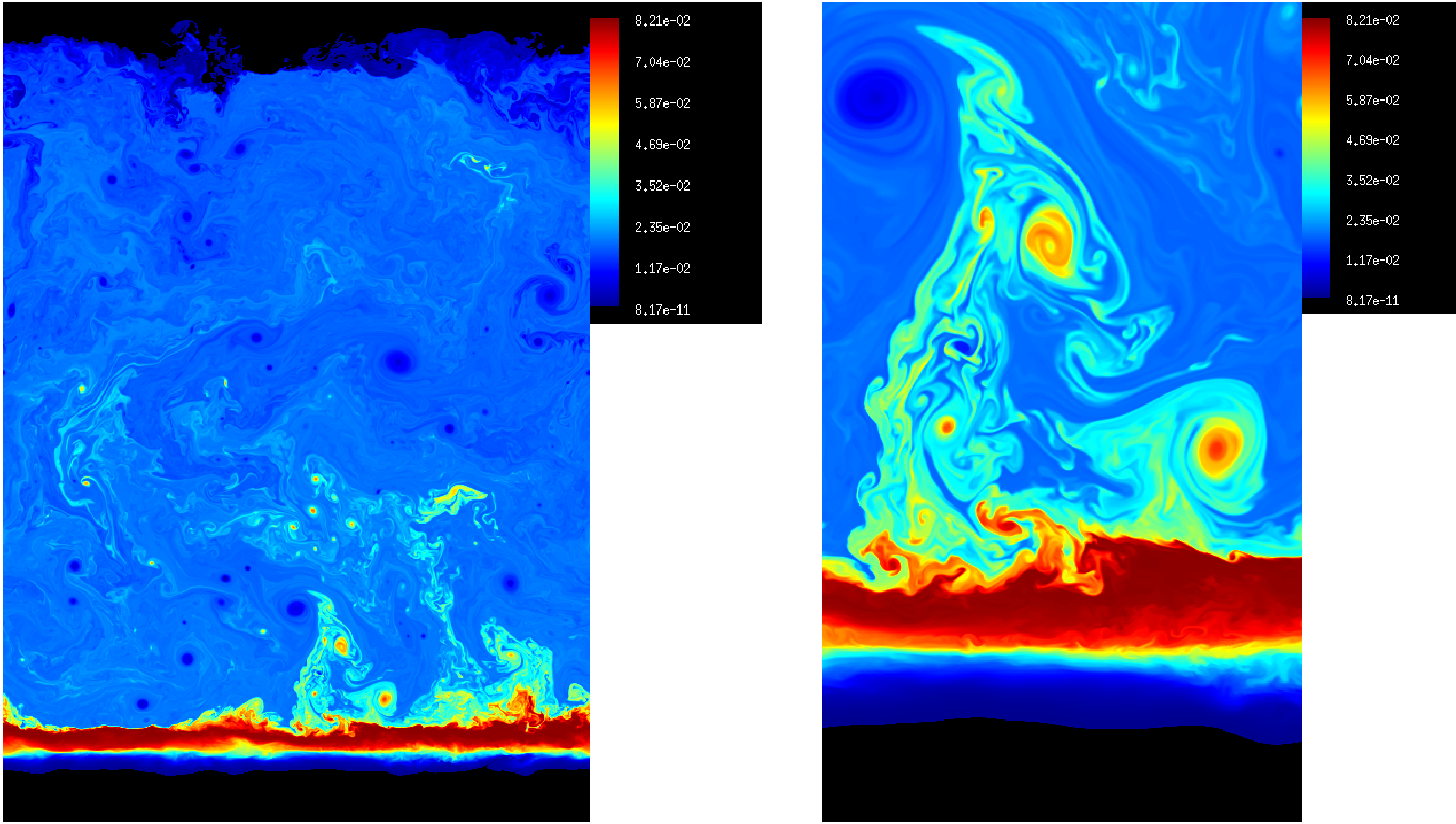


Spikes in EGR seem to occur when convection drags material deeper into the accreted layer.

Conclusions and Future Work

- Previously published multidimensional simulation results were under-resolved.
- Convection appears to be extremely efficient at mixing and regulating the thin burning layer.
- Run with a “hotter” model to see if we can get runaway.
- Try a burst with H – more complex reaction network but resolution requirements might be more relaxed...

Convective Dynamics



X(C12) after 0.5ms of evolution; finest resolution 0.125 cm