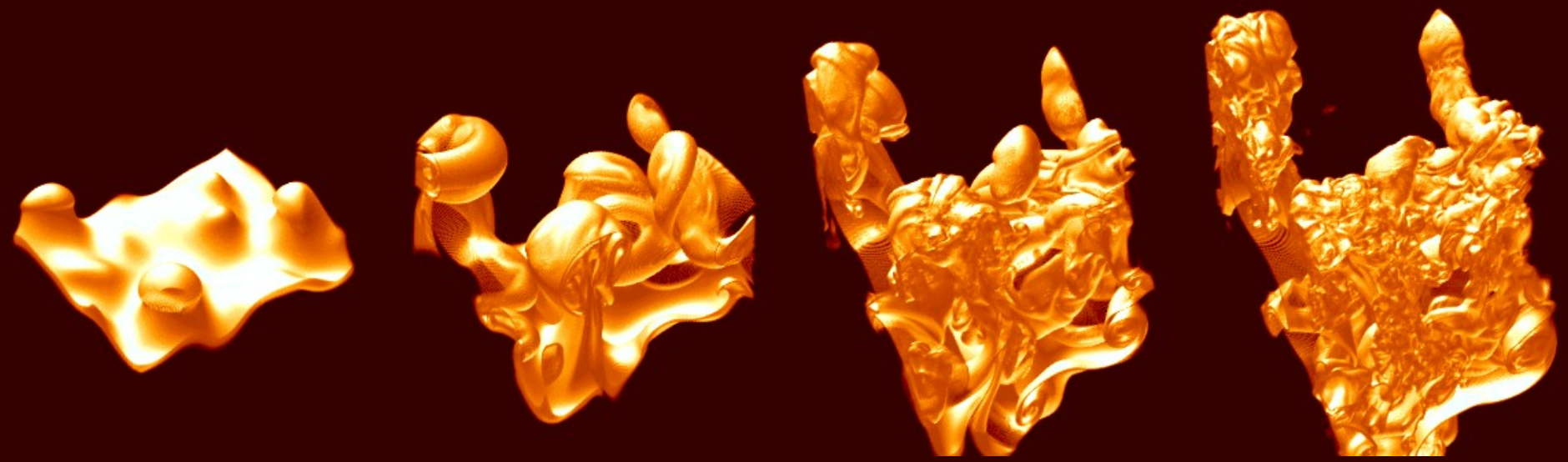
Modeling Type Ia Supernovae

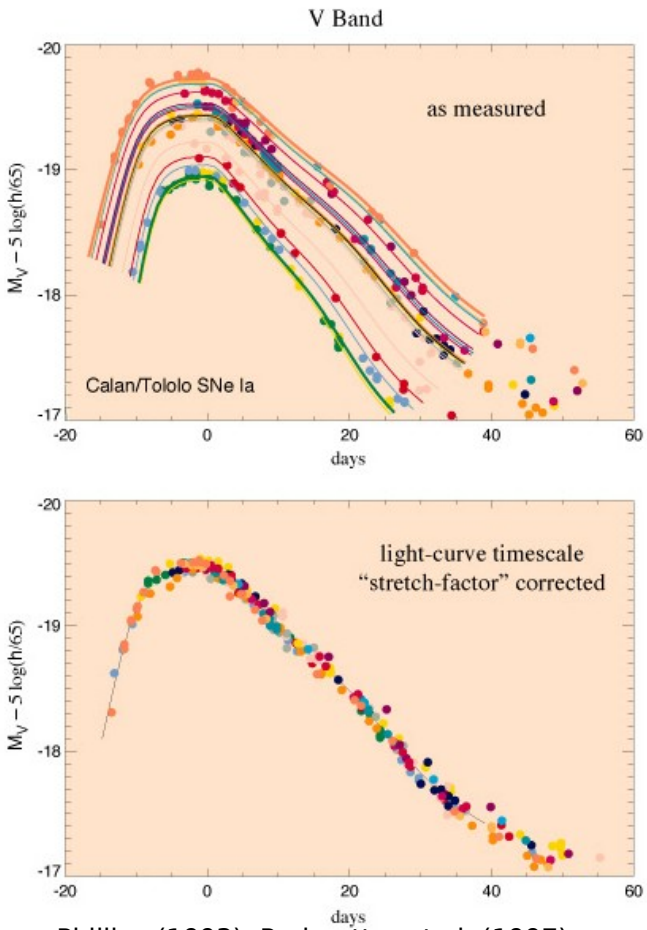


Ann Almgren, John Bell, Marc Day, Charles Rendleman (LBL), Stan Woosley (UCSC), and Michael Zingale (Stony Brook)

Type Ia Supernovae

- Bright as host galaxy, L ~10^{43} erg s^{-1}
- Large amounts of ^{56}Ni produced
  - Radioactivity powers the lightcurve

SN 1994D (High-Z SN Search team)

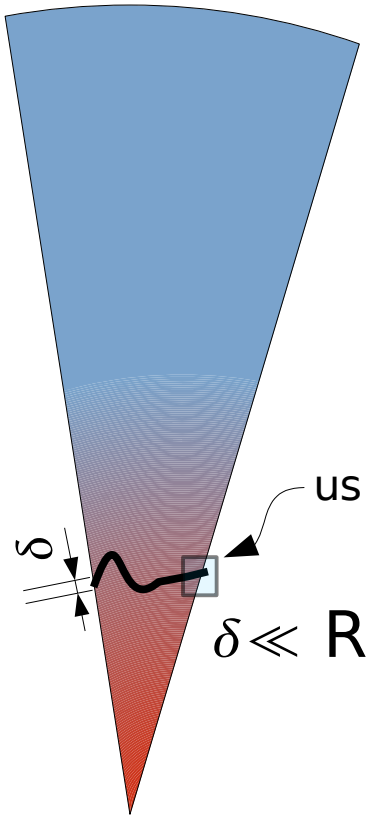


Phillips (1993), Perlmutter et al. (1997)

- Lightcurve is robust
  - Variations can be corrected for via a single parameter function.
- Thermonuclear explosion of C/O white dwarf.
  - Must begin as a deflagration
  - Considerable acceleration required

Bottom-Up Approach

- Simulations cannot resolve the star and the flame.
  - Modern adaptive mesh methods/ massively parallel computers can handle 3 orders of magnitude
- We resolve the structure of the flame and work up to large scales
  - Parameter free.
  - Resolved calculations can be used to validate flame models.
  - Sometimes we will need a supergrid model
- Look for scaling relations that will act as subgrid models.



Low Mach Number Hydrodynamics

(Bell et al. 2004 JCP 195, 677)

- Low Mach number formulation projects out the compressible components.
  - Pressure decomposed into thermodynamic and dynamic components.

$$p(x,t) = p_0(t) + Mp_1(t) + M^2\pi(x,t)$$

  - Elliptic constraint provided by thermodynamics.

$$0 \equiv \frac{Dp}{Dt} = \frac{\partial p}{\partial \rho}\frac{D\rho}{Dt} + \frac{\partial p}{\partial T}\frac{DT}{Dt} + \sum_k \frac{\partial p}{\partial X_k}\frac{DX_k}{Dt}$$

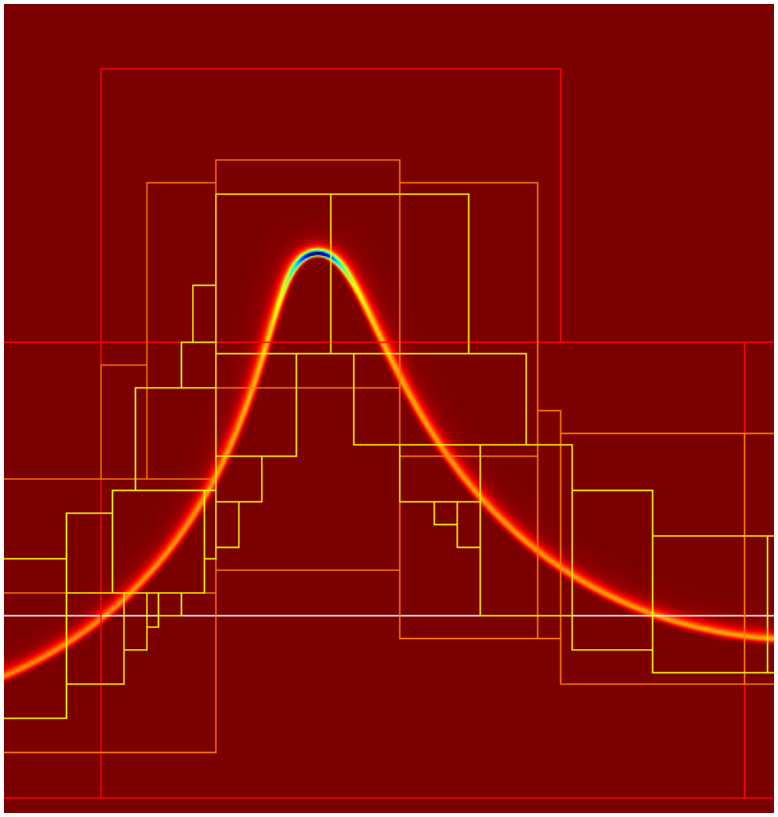
$$\nabla \cdot U = \frac{1}{\rho\frac{\partial p}{\partial \rho}}\left(\frac{\partial p}{\partial T}\frac{DT}{Dt} + \sum_k \frac{\partial p}{\partial X_k}\frac{DX_k}{Dt}\right)$$

  - Advection/Projection/Reaction formulation solves system.
  - Timestep limited by |v| and not |v| + c.

Simulation Method

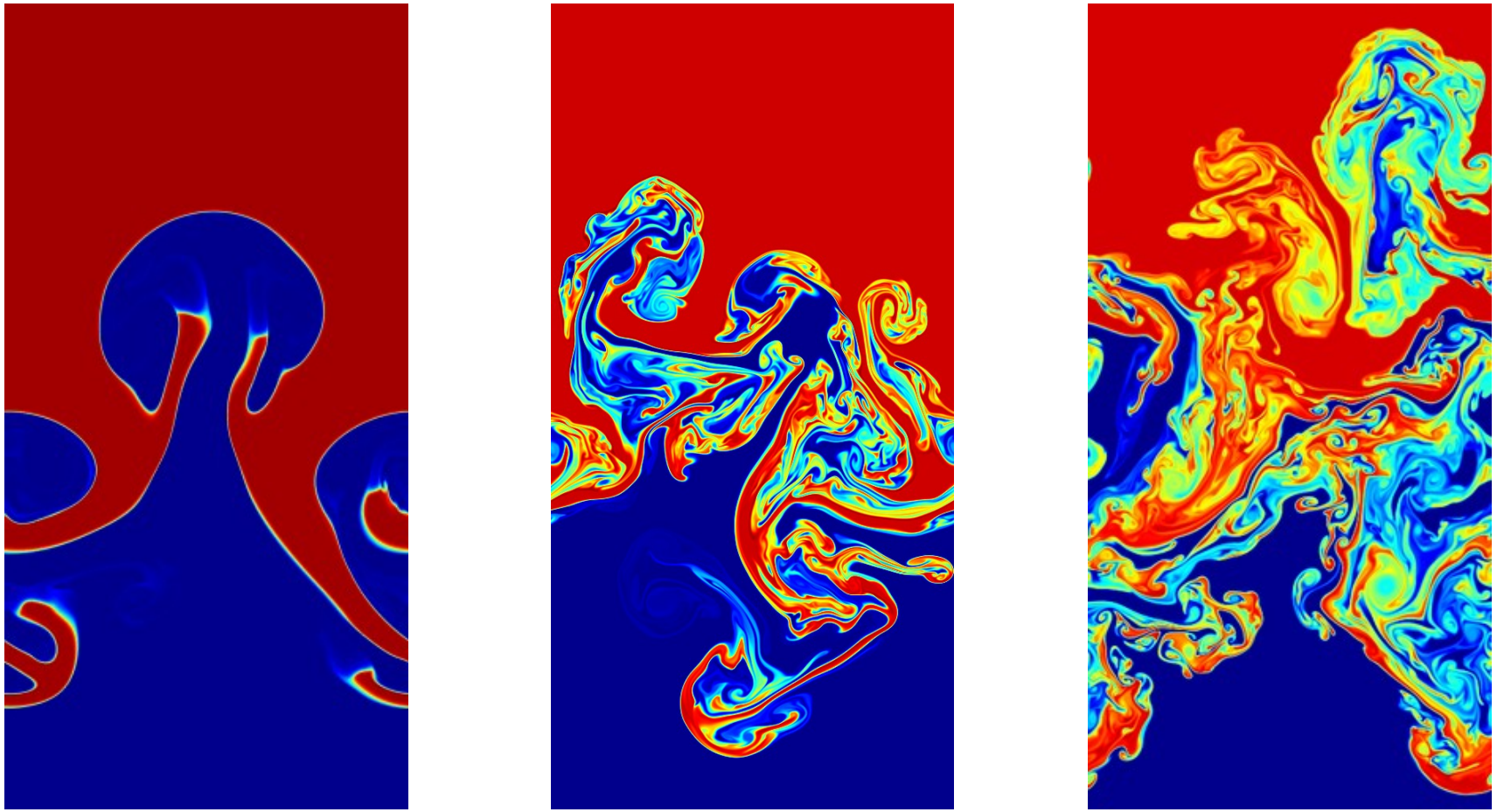
(Bell et al. 2004 JCP 195, 677)

- Low Mach number hydrodynamics.
  - Advection/projection/reaction
  - Block structured adaptive mesh
  - Timestep restricted by |v| not |v| + c
  - Degenerate/Relativistic EOS used.
  - Single step $^{12}C+^{12}C$ rate
- Initialized by mapping 1-d steady-state laminar flame onto grid.
  - 5-10 zones inside thermal width.



Transition to Distributed Burning

(Bell et al. 2004, ApJ, 608, 883)

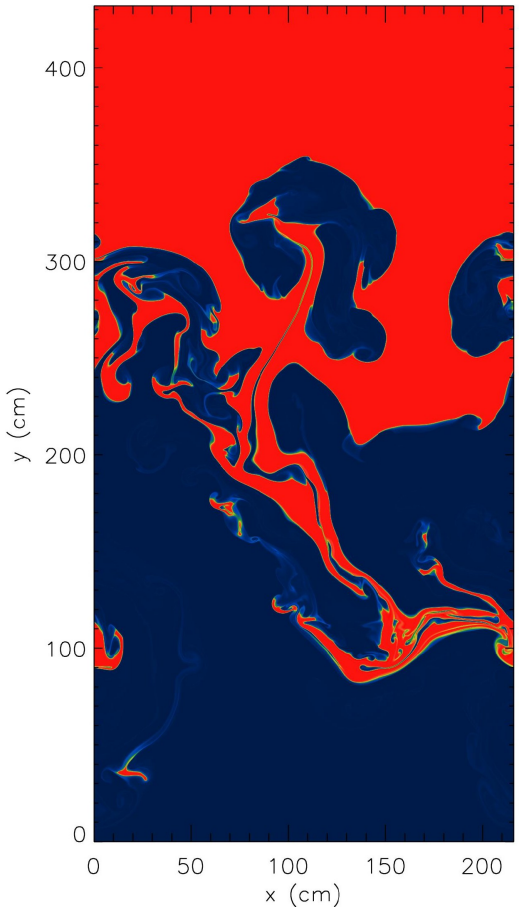


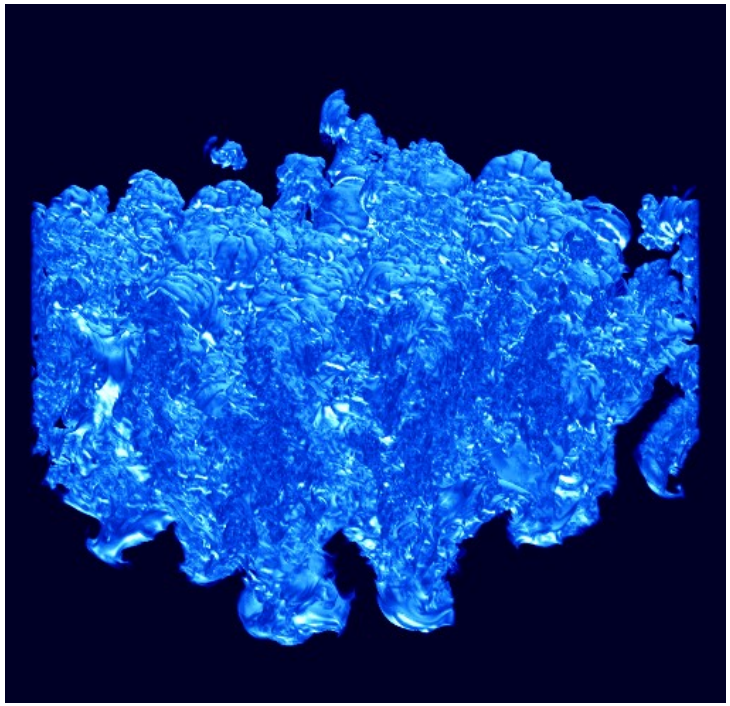
$\longleftarrow \rho$

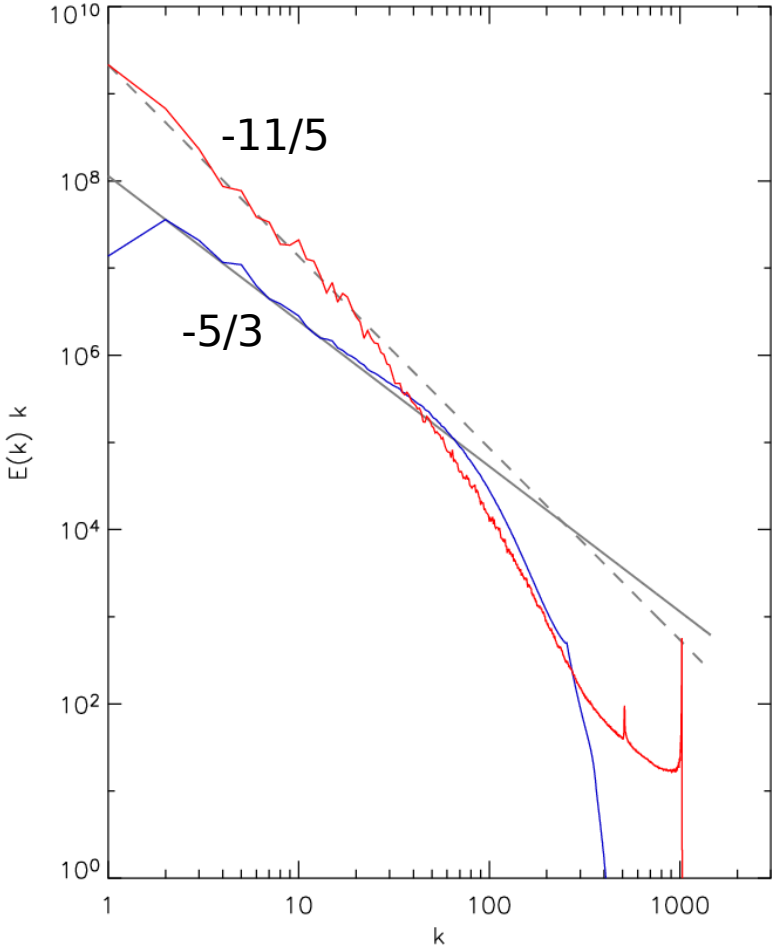
Our first simulations with this new technique showed the transition of the burning front from the flamelet regime to the distributed burning regime.

Differences Between 2- and 3-D

(Zingale et al. 2005, ApJ, 632, 1021; Zingale et al. 2005, J Phys Conf Series, 16, 405)



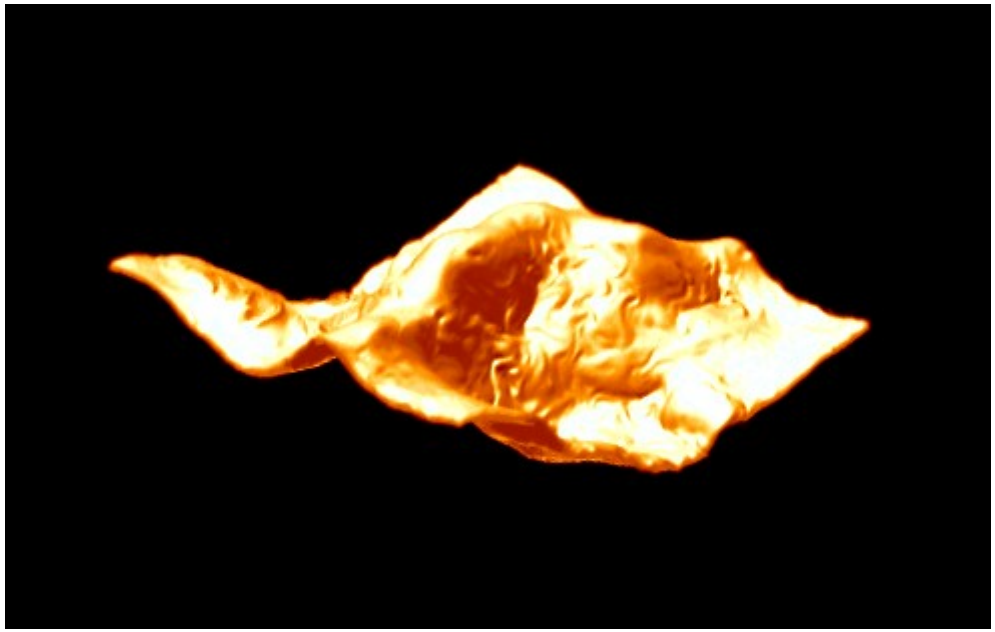




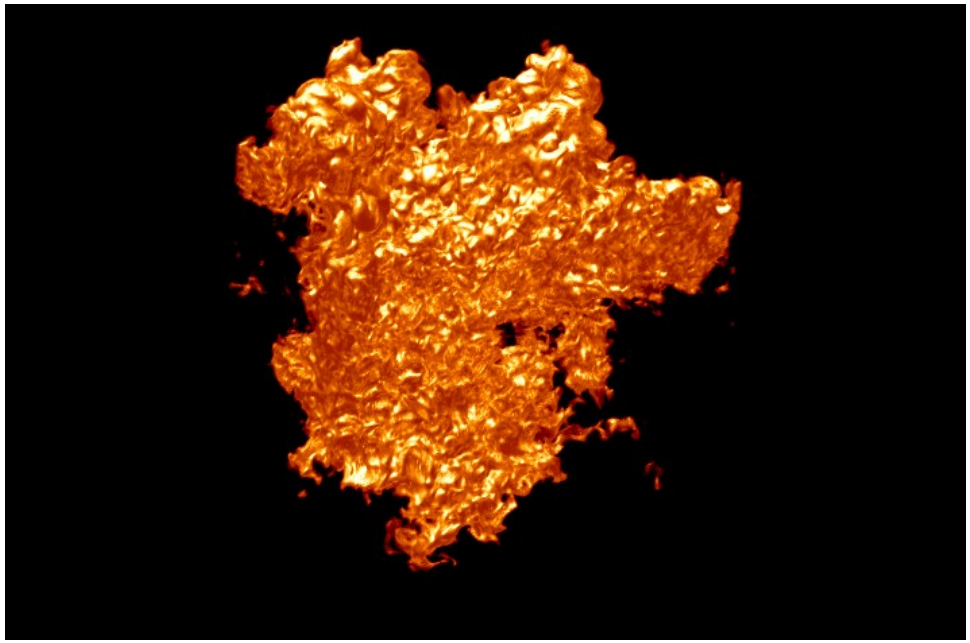
Our application to 3-D flames showed that the turbulence obeys Kolmogorov statistics only in 3-D.

Turbulent Flames

With our LCF allocation, we will continue of studies of turbulent flames through 3-D resolved simulations.



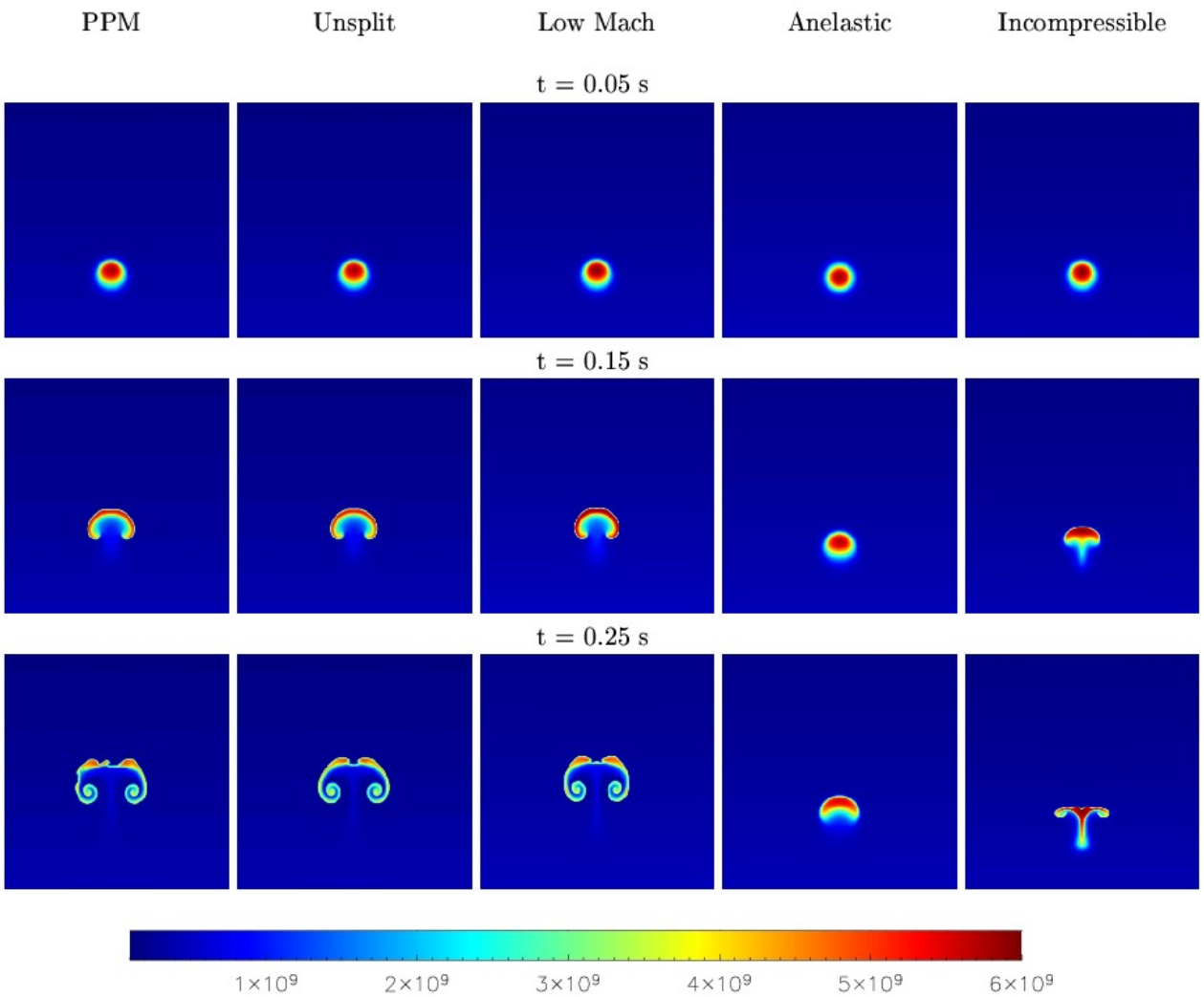
At high densities, the flame is smooth on the scale of the flame thickness



At low densities, the turbulence disrupts the flame structure itself.

Stratified Low Mach Number Code

(Almgren et al. 2006 ApJ, 637, 922)



We have created a new version of our low Mach number algorithm incorporating the background stratification. This allows for full star simulations of low Mach number flows (i.e. the initial convective phase of the white dwarf).

These simulations will be a focus of our LCF work.