Detonability of white dwarf plasma: Turbulence models at transition densities

Ezra S. Brooker
Dept of Scientific Computing
Florida State University
AAS 236 Virtual Meeting
03 June 2020

The Problem

- What is the explosion mechanism for Type Ia supernovae?
    - Potentially the deflagration-to-detonation transition (DDT) is the key
    - Critical transition density for DDT (calibrated, Hoeflich et al. 1995)
- What is the detonability of white dwarf plasma?
    - Strongly compressively driven turbulence required to initiate detonation (Fenn & Plewa 2017)
    - Potentially shock-ignition in the limit of high Mach number (Fisher et al. 2019)
    - Interaction between deflagration and incompressible turbulence (Poludnenko et al. 2019)

The Model

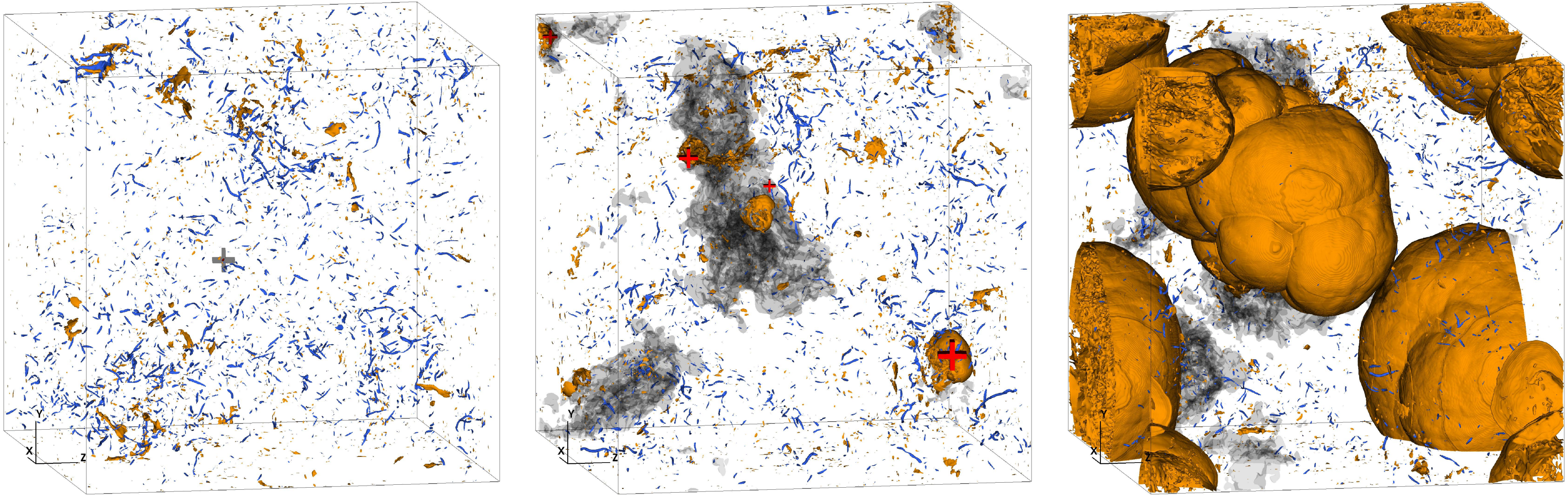
- Box of white dwarf plasma with 32 km length on each side
- Initial conditions: average density **1×10^7 g cm^{-3}**, average temperature **1×10^9 K**
- Composition 50/50 carbon/oxygen
- PPM hydro solver, Iso7 nuclear reaction network, and Helmholtz EOS
- Computational campaign planning necessary; a single 512^3 model requires
  - ~300,000 CPU hours
  - ~5 TB of data

3D Results

yellow contours = divergence (shocklets)

blue contours = enstrophy (vortex lines)

gray contours = carbon ash (carbon deflagrations)

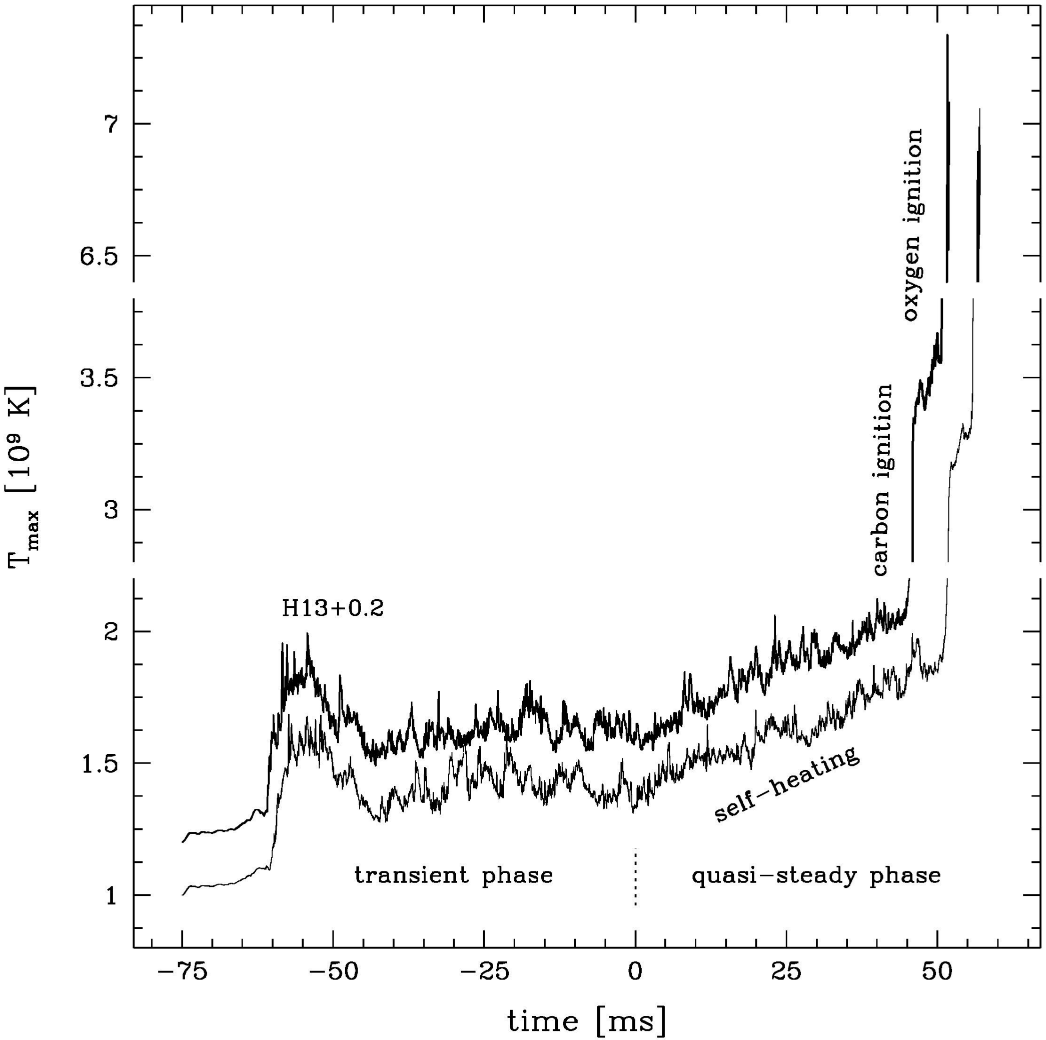


51.9 ms | 56.1 ms | 56.9 ms

3D Results

Evolution of the maximum temperature in H11 and H13 512^3 models over time

- During the transient phases fluctuations exceed the average temperature by 40-60%
- Steadily increases after that mainly due to self-heating
- Eventually a mild ignition of carbon is observed
- Ultimately oxygen detonates



Summary and Outlook

Current Findings

- Interplay between turbulence and burning
  - Dependence on turbulence compressibility
  - Controls time available for fluid parcels to detonate within eddy turnover time
- Clear contribution of the SWACER mechanism
- Two-stage DDT process
- Potential observation signatures!
  - Inhomogeneous turbulence medium with complete carbon burning (nucleosynthetic yields, observations at early times)

Potential future work

- More work needed on deflagration-turbulence interactions (also Poludnenko's model)
- Turbulence properties in the outer layers of accreting massive white dwarfs

The End

Thank you for listening!

Email: eb11d@my.fsu.edu

Special thanks to my PhD advisor, Tomasz Plewa

Research made possible in part by the National Energy Research Scientific Computing Center, the FLASH code developed at University of Chicago, and VisIt developed at Lawrence Livermore National Lab.