Gravitationally Confined Detonation Model of Type Ia SNe

Flash Center Type Ia Supernova Team:

Shimon Asida, Alan Calder, Robert Fisher, Carlo Graziani, Nathan Hearn, Tridivesh Jena, George Jordan, Alexei Khokhlov, DQL, Casey Meakin, Tomasz Plewa, Alexei Poludnenko, Ivo Seitenzahl, Dean Townsley, Jim Truran, Natashia Vladimirova, Ju Zhang, Andrey Zhiglo

Paths to Exploding Stars Conference
KITP, UC Santa Barbara
22 March 2007

Poster Papers

- Nathan Hearn – Simulating White Dwarf Merger Scenarios for Type Ia SNe
- Ju Zhang – Low Mach Number Reactive Flow Solver for Modeling Core Convection in Type Ia SN Progenitors
- Andrey Zhiglo – Numerical Flame Propagation
- Shimon Asida – Verification of an Advection-Diffusion-Reaction Flame Model for Type Ia SN Simulations
- Robert Fisher – Semi-Analytic Modelling of Nuclear Burning Bubbles and the Implications for Physically Consistent Initial Conditions in Type Ia SN Simulations
- Dean Townsley – Flame Evolution During the Deflagration Phase of Type Ia SNe
- George Jordan – 3-D Simulations of the Deflagration Phase in the GCD Model of Type Ia SNe
- Ivo Seitenzahl – Detonation Criteria in the GCD Model of Type Ia SNe
- Casey Meakin – Simulations of Detonations in the GCD Model of Type Ia SNe
- Alexei Poludnenko – From Seconds to Days: Modeling of Post-Explosion Evolution of Type Ia SN Explosions

Poster Papers

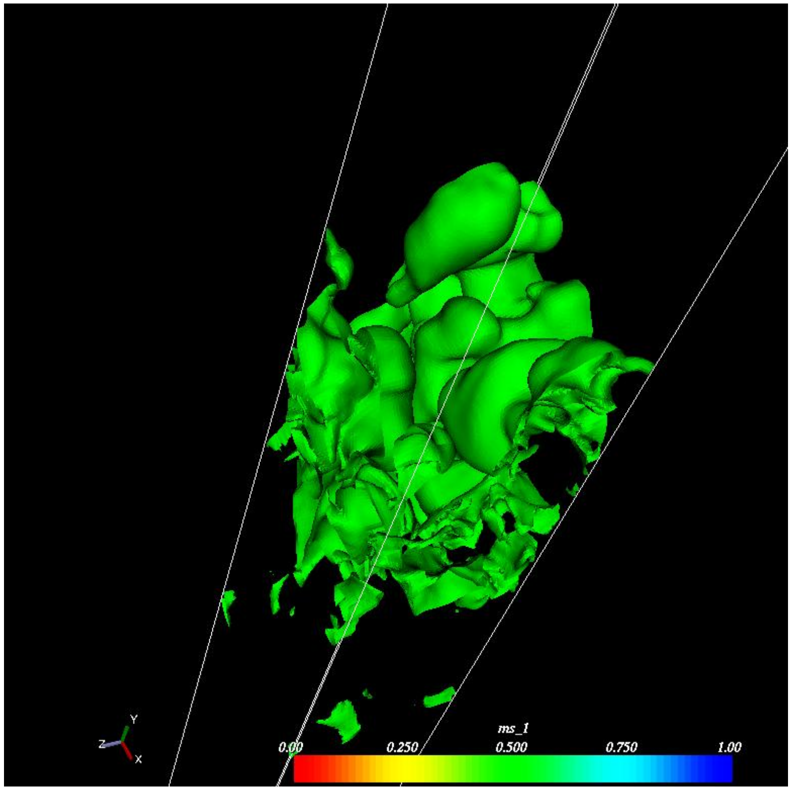
- Nathan Hearn – Simulating White Dwarf Merger Scenarios for Type Ia SNe
- Ju Zhang – Low Mach Number Reactive Flow Solver for Modeling Core Convection in Type Ia SN Progenitors
- Andrey Zhiglo – Numerical Flame Propagation
- Shimon Asida – Verification of an Advection-Diffusion-Reaction Flame Model for Type Ia SN Simulations
- Robert Fisher – Semi-Analytic Modelling of Nuclear Burning Bubbles and the Implications for Physically Consistent Initial Conditions in Type Ia SN Simulations
- Dean Townsley – Flame Evolution During the Deflagration Phase of Type Ia SNe
- George Jordan – 3-D Simulations of the Deflagration Phase in the GCD Model of Type Ia SNe
- Ivo Seitenzahl – Detonation Criteria in the GCD Model of Type Ia SNe
- Casey Meakin – Simulations of Detonations in the GCD Model of Type Ia SNe
- Alexei Poludnenko – From Seconds to Days: Modeling of Post-Explosion Evolution of Type Ia SN Explosions

Flame Model and Nuclear Energetics

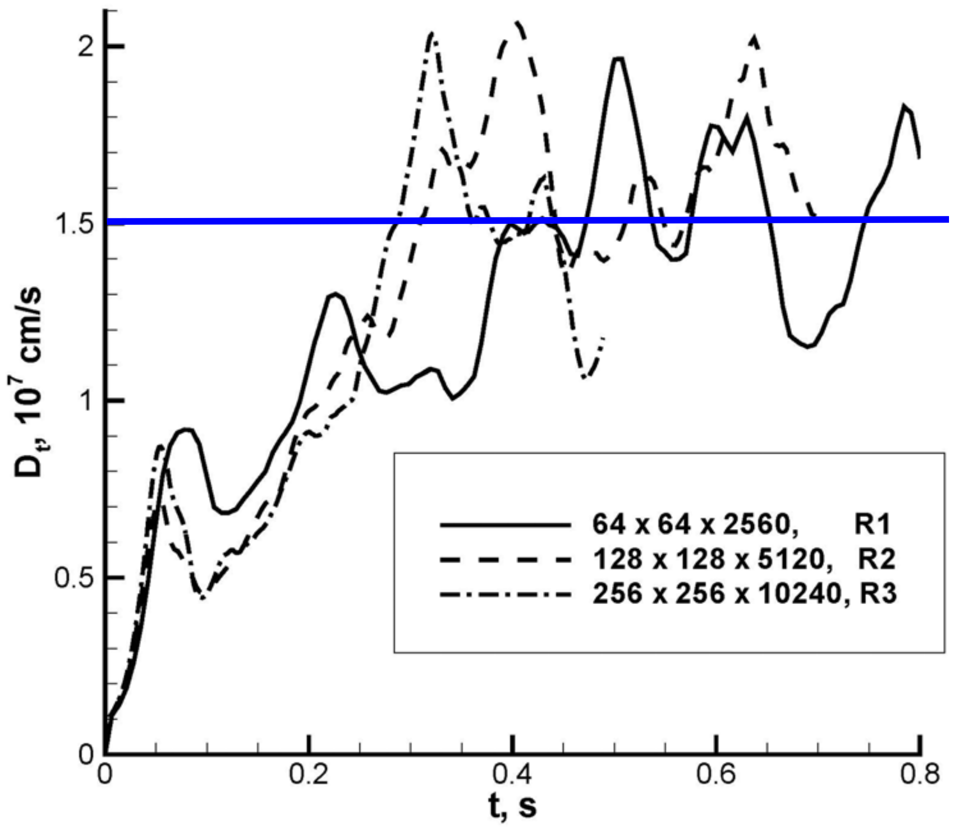
- We follow the nuclear flame using a new version of the advection-diffusion-reaction (ADR) flame model that we used previously
- The new prescription uses the KPP form of the reaction term in which this term is slightly truncated (Asida et al. 2007), as opposed to the top-hat form used previously by ourselves and others (Khokhlov 1995).
- The new flame model is numerically quieter, more stable, and exhibits smaller curvature effects
- We use a new 3-stage treatment of nuclear burning that includes neutronization and the evolution of NSE as the bubble rises and its density declines (Townsley et al. 2007)
- We start with a single ignition point and a quiet background; we will investigate multiple ignition points and a convective background in future work

Simulations Show Nuclear Burning Rate Is Dominated by Largest Scales

S_l=1.07 x 10^6 cm/s



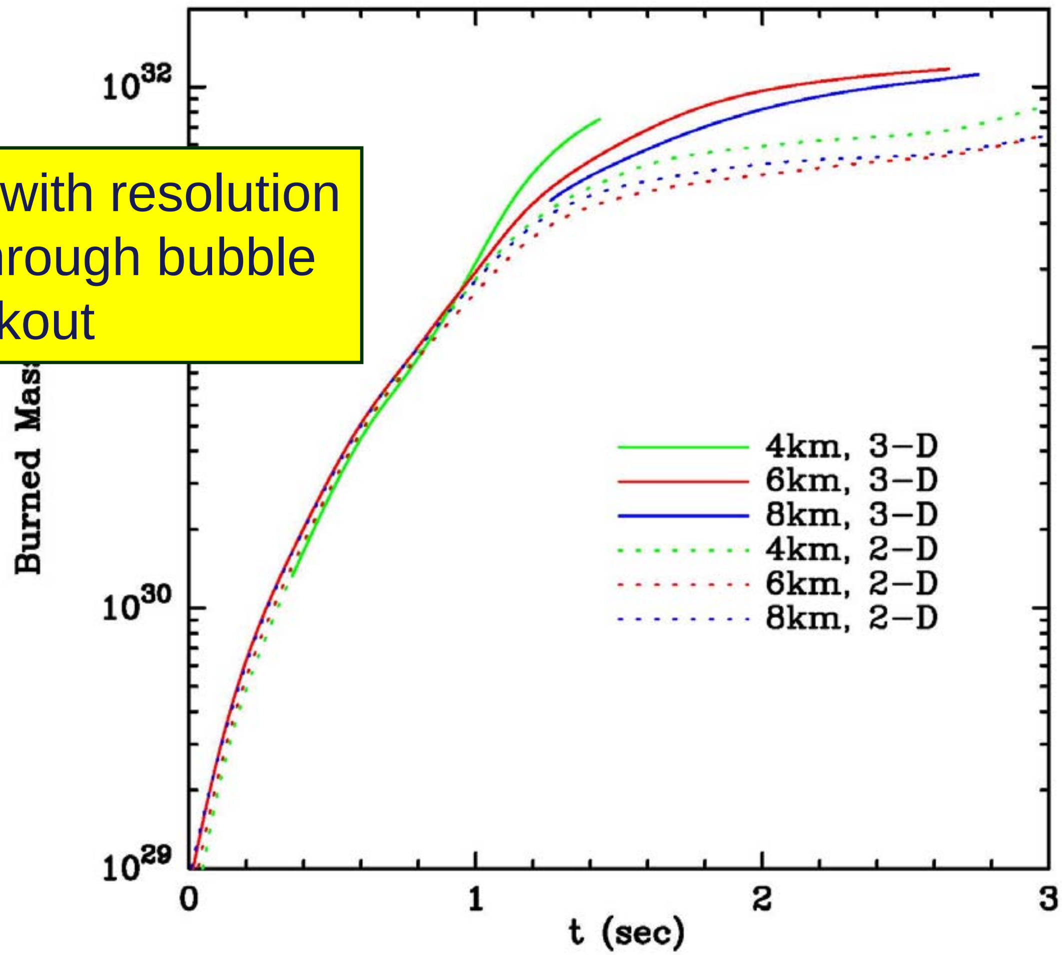
Σ = 2.84 x 10^{13} cm^2



Zhang et al. (2007)

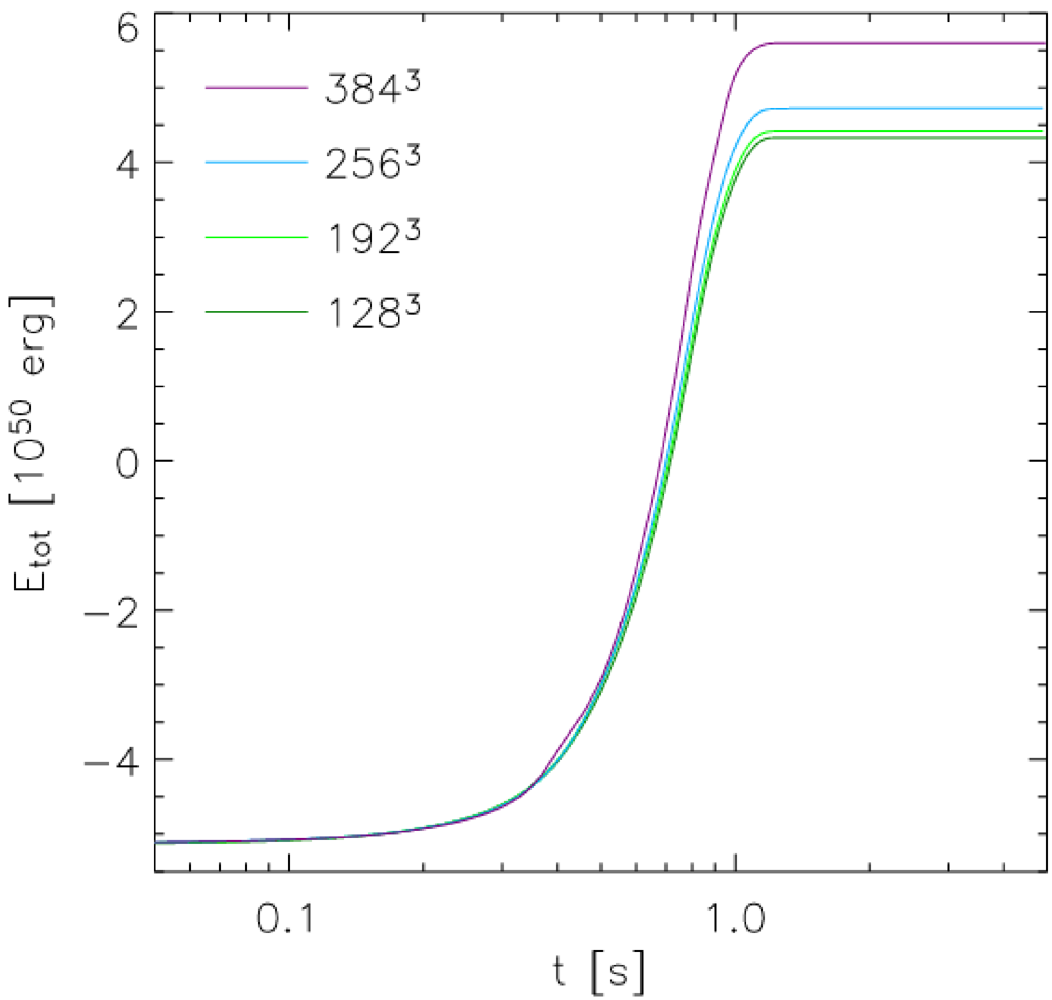
Convergence With Resolution

Convergence with resolution is excellent through bubble breakout



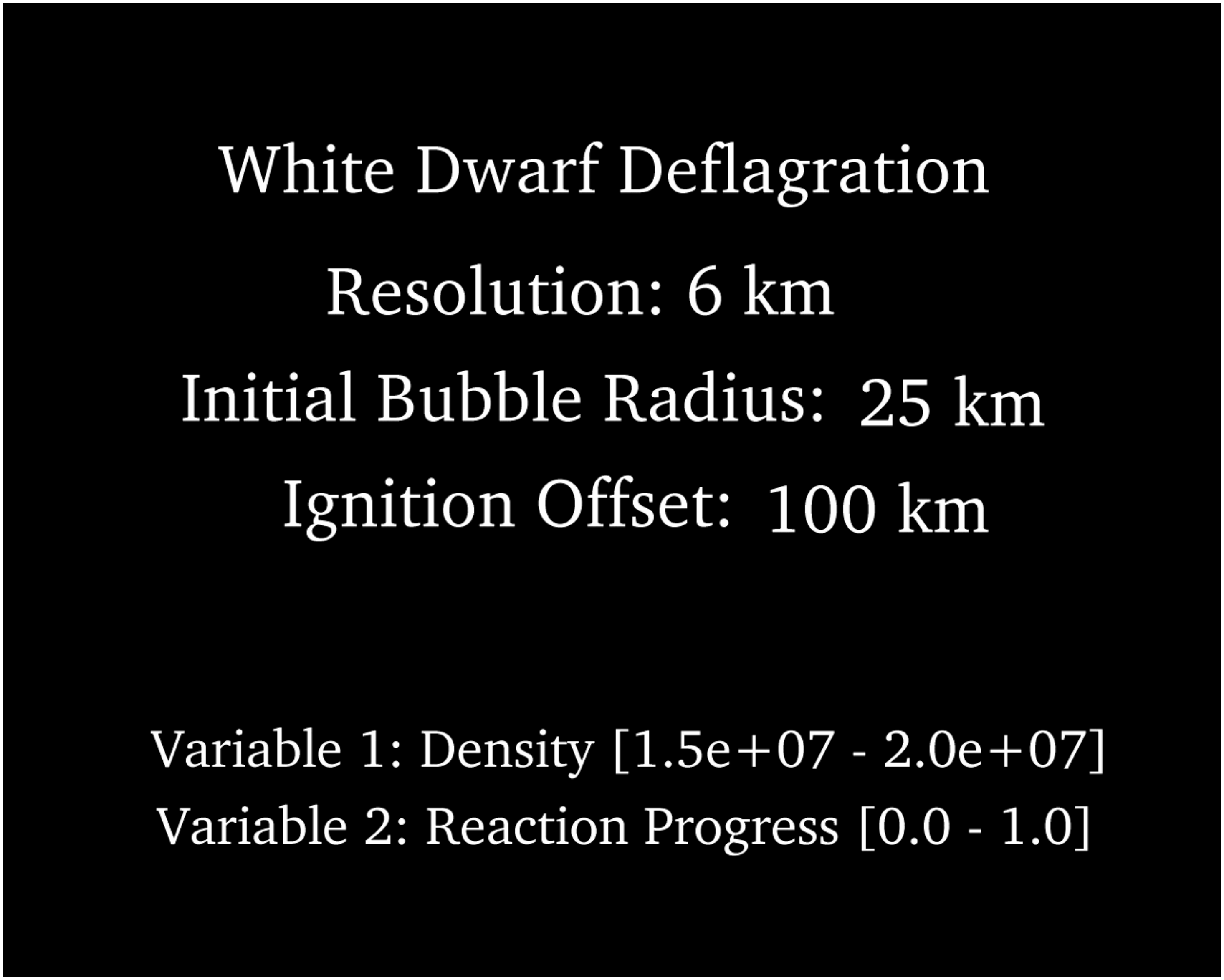
Jordan et al. (2007)

Convergence With Resolution



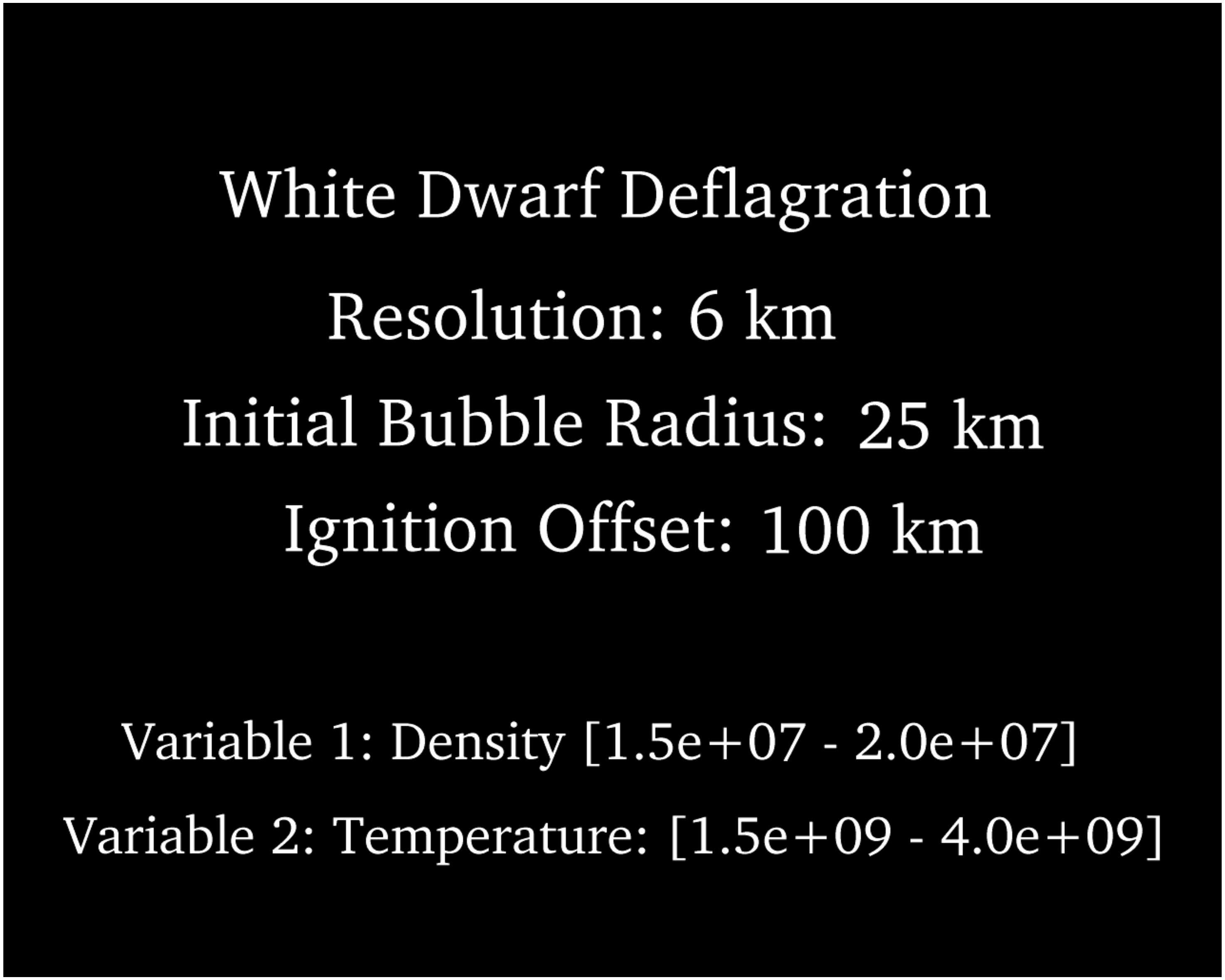
Schmidt et al. (2006)

Movie of 3-D Simulation of Deflagration Phase of GCD Model



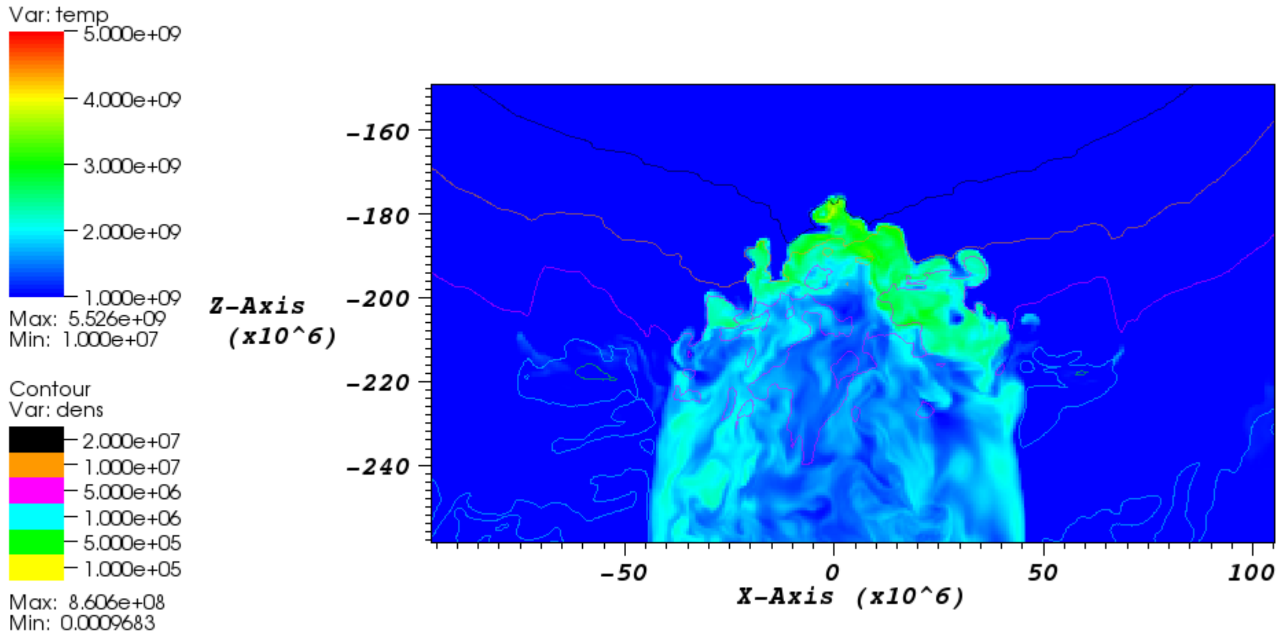
Jordan et al. (2007)

Movie of 3-D Simulation of Deflagration Phase of GCD Model



Jordan et al. (2007)

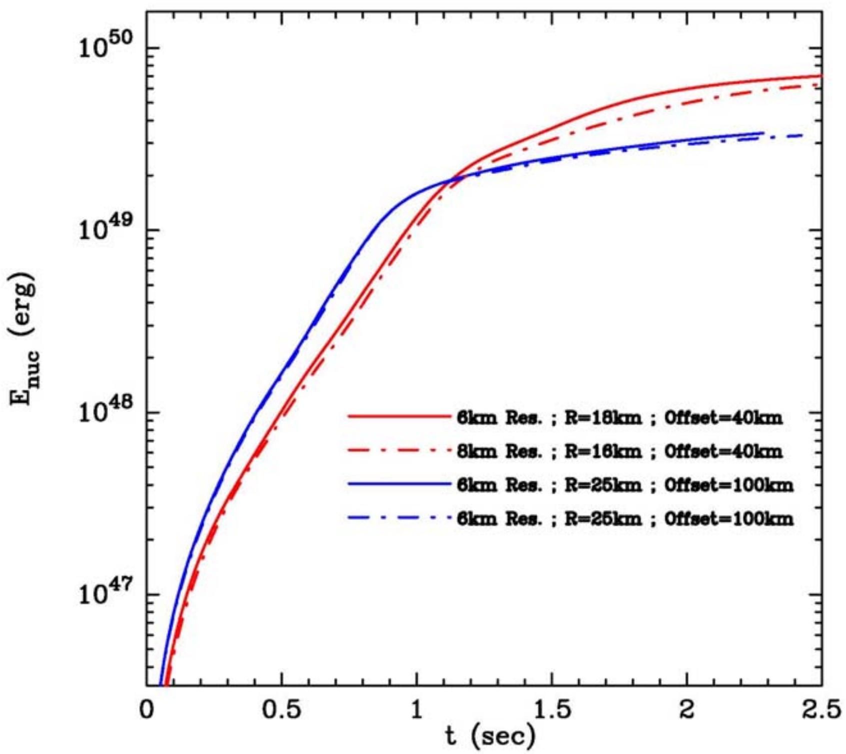
Close-Up of Collision Region

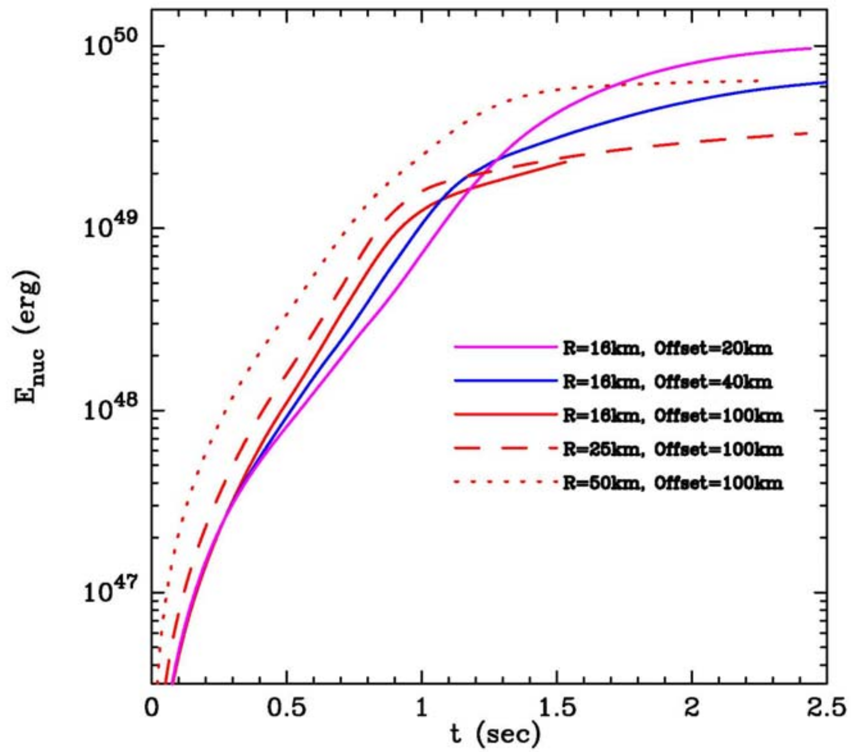


- Collision creates outwardly and inwardly directed jets
- Inwardly directed jet "punches" into the dense stellar surface, causing matter in the jet to reach temperatures $T > 3 \times 10^9$ K and densities $> (1\text{-}2) \times 10^7$ g/cc in the jet

Jordan et al. (2007)

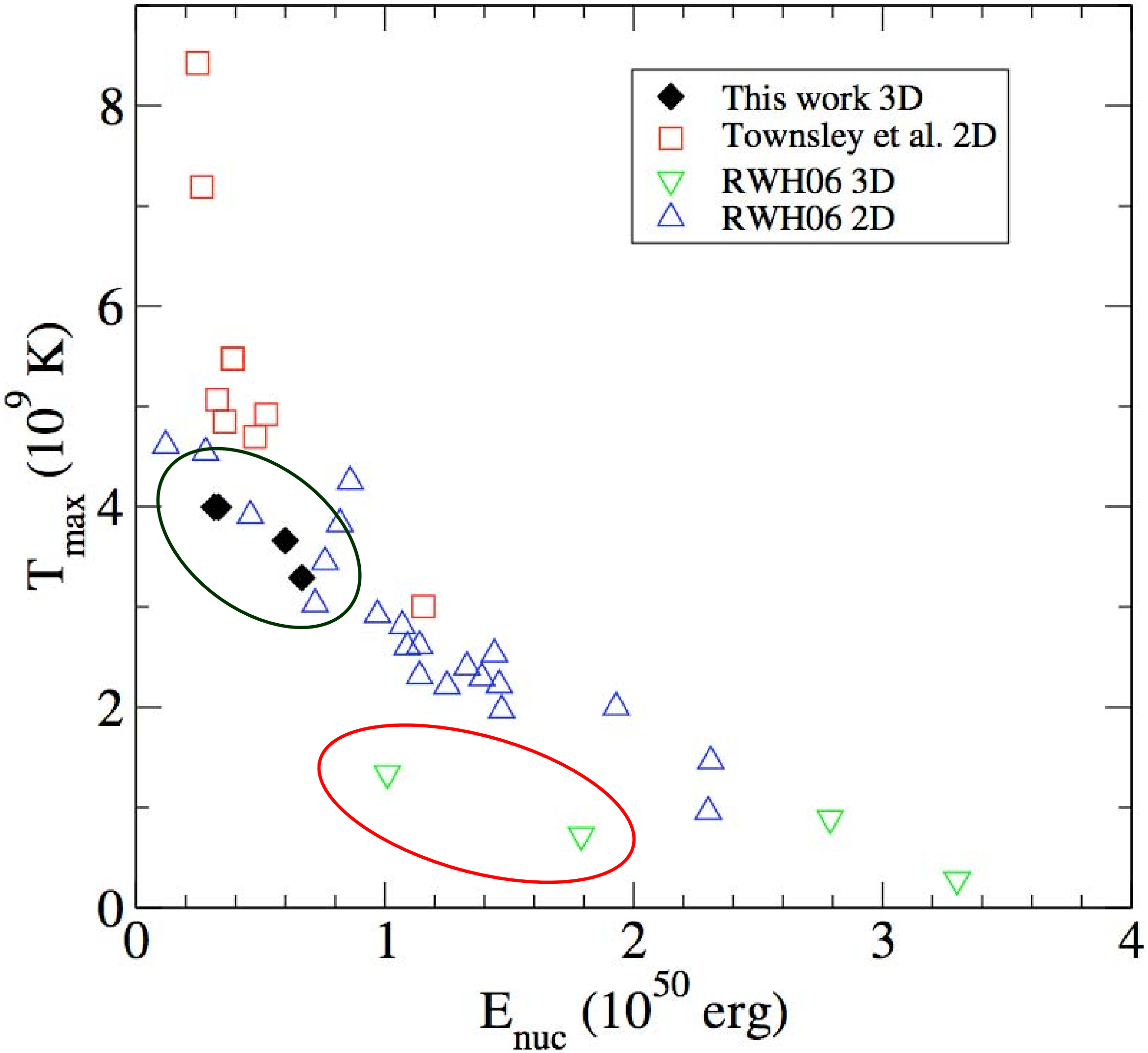
Nuclear Energy Released During Deflagration Phase of GCD Mechanism





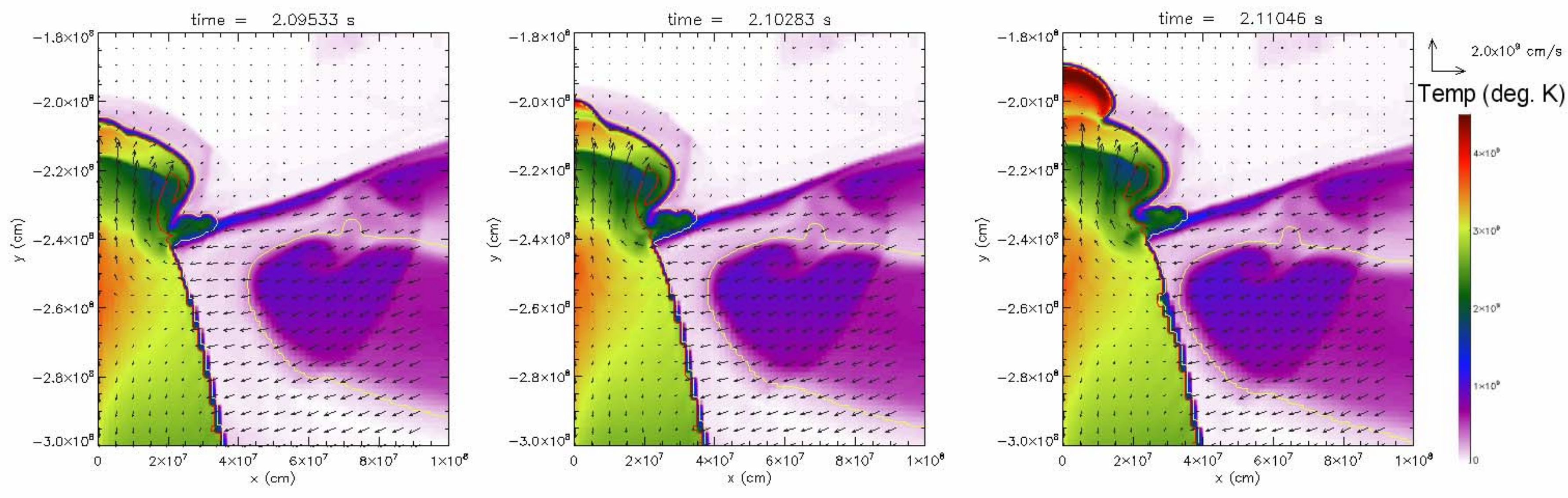
Jordan et al. (2007)

Correlation Between E_{nuc} and T_{max}



Jordan et al. (2007)

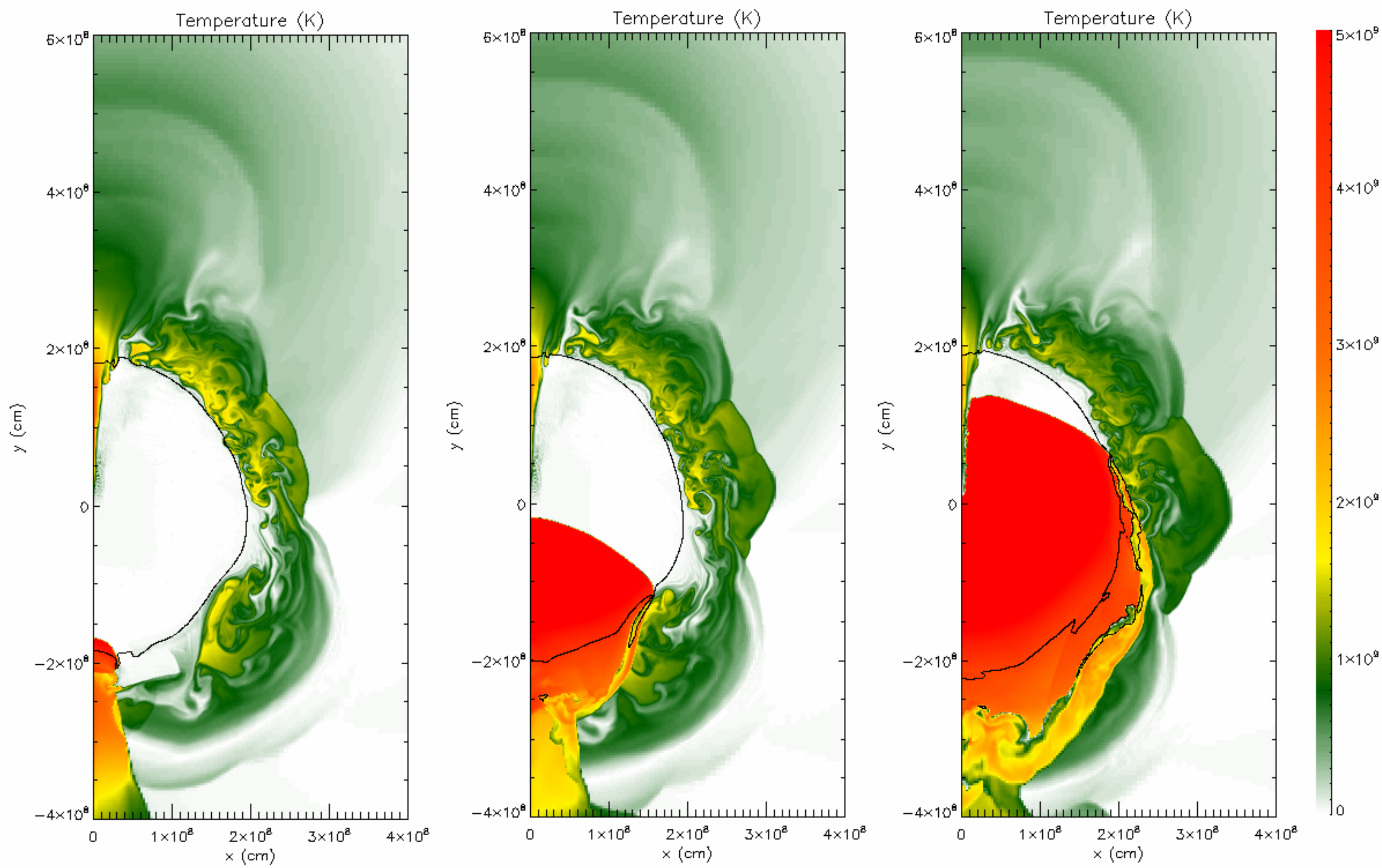
Images of 3-D Simulations of Detonation Phase of GCD Model



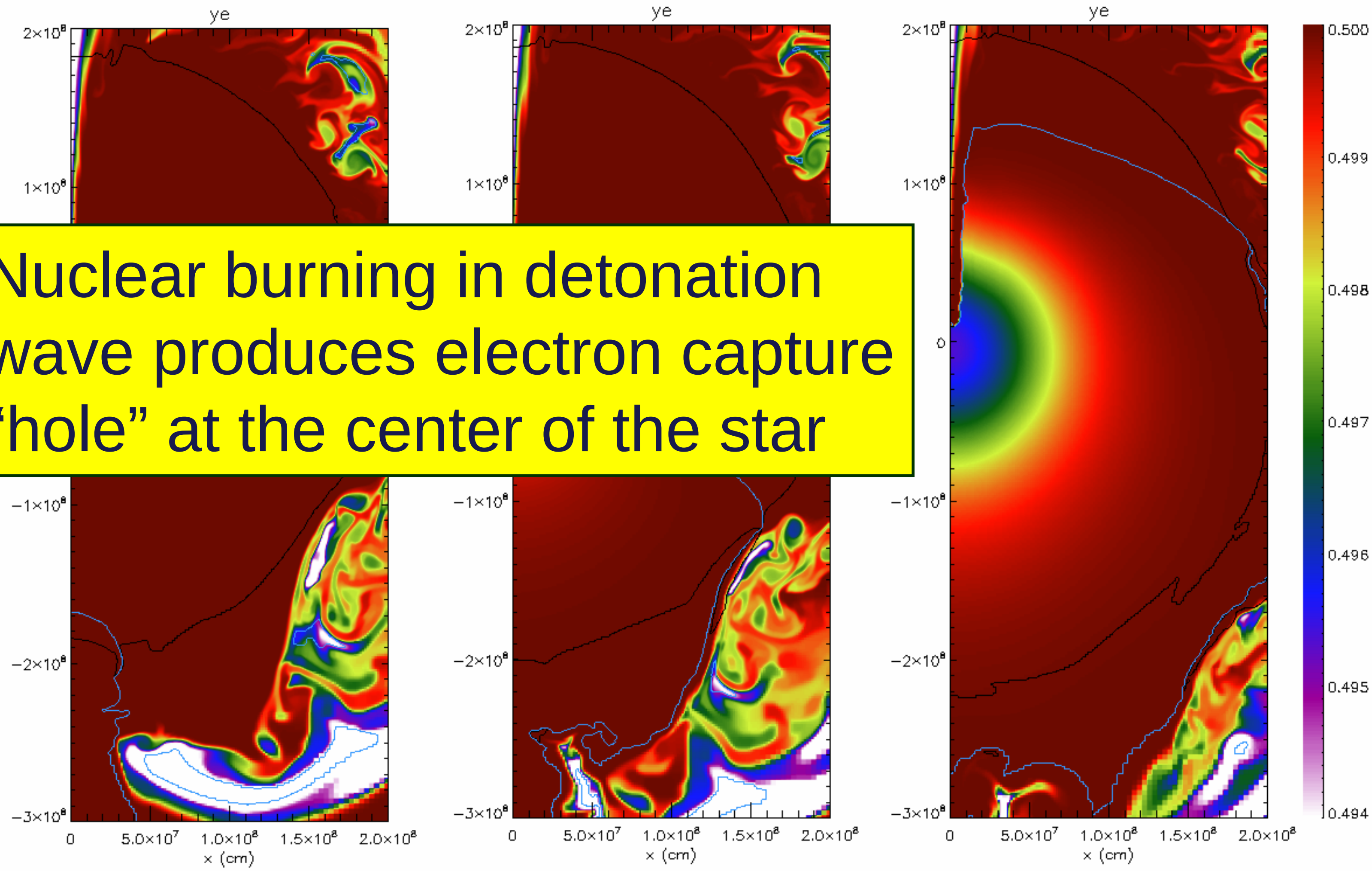
- Inwardly directed jet “punches” into the dense stellar surface, causing matter in the jet to reach temperatures T > 3 x 10^9 K and densities > (1-2) x 10^7 g/cc in the jet
- Detonation starts in the high-T, high-density matter just behind the head of the jet

Meakin et al. (2007)

Images of 2-D Simulation of Detonation Phase of GCD Mechanism



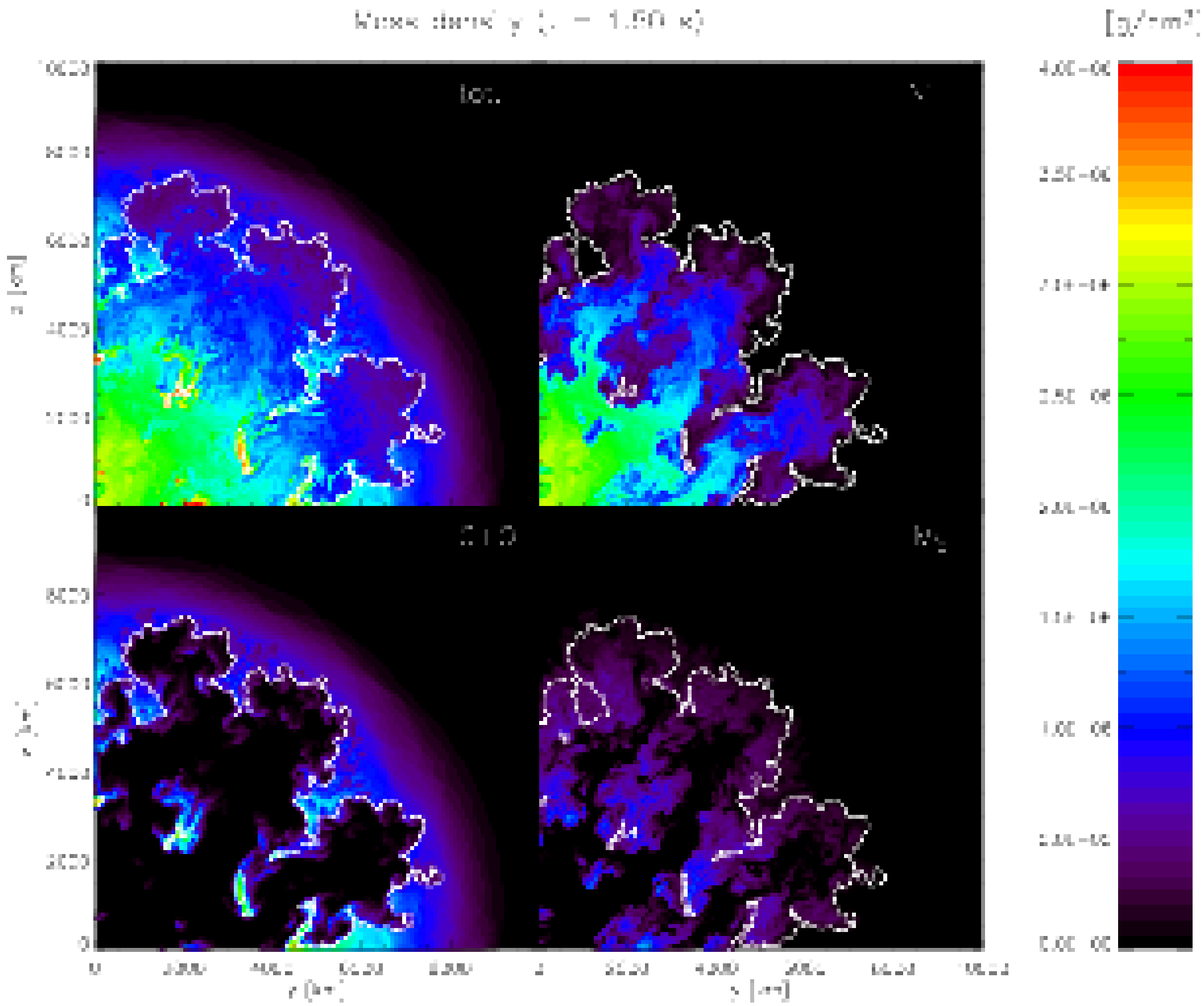
Meakin et al. (2007)



Nuclear burning in detonation wave produces electron capture “hole” at the center of the star

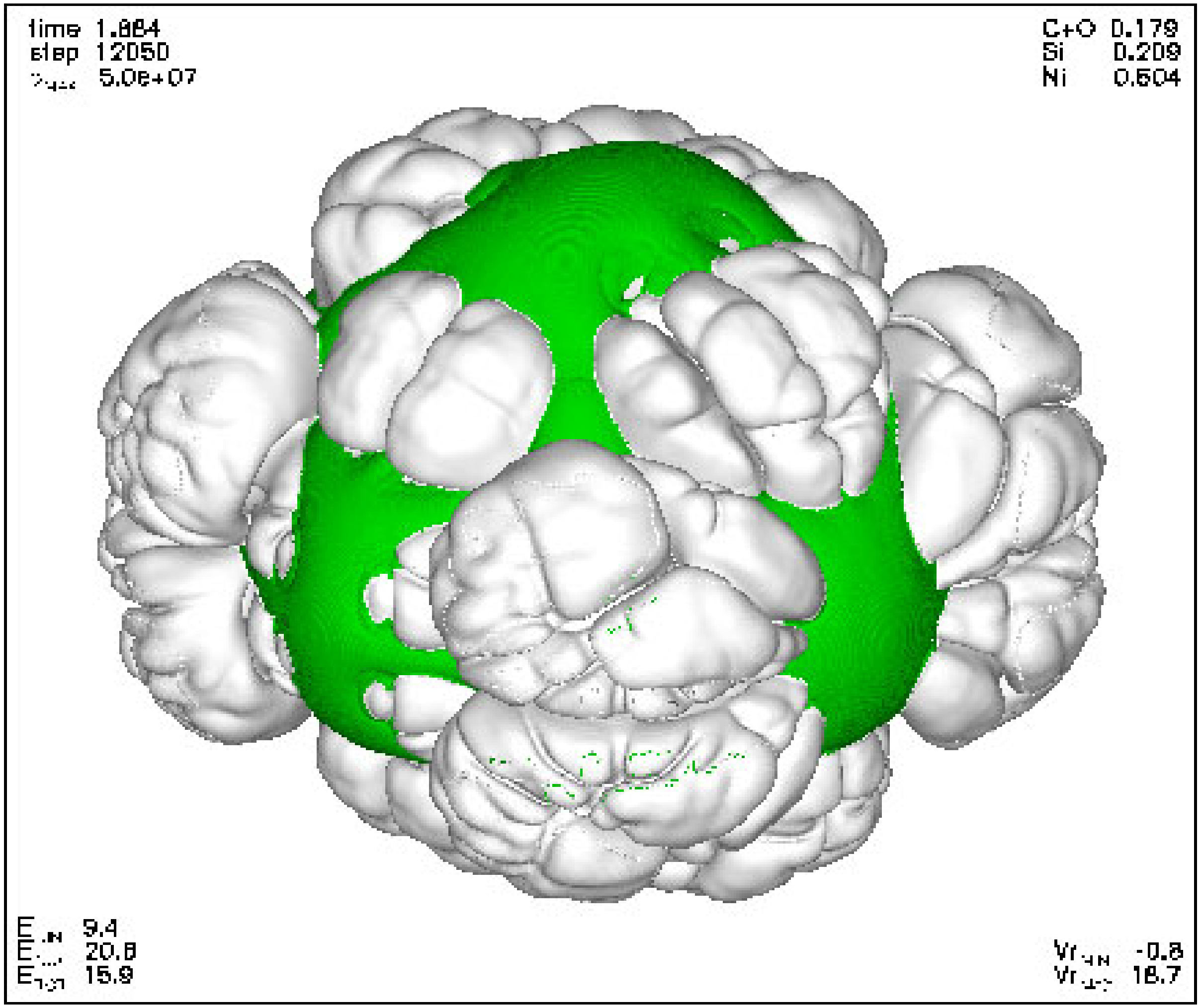
Meakin et al. (2007)

Simulation of Pure Deflagration Model



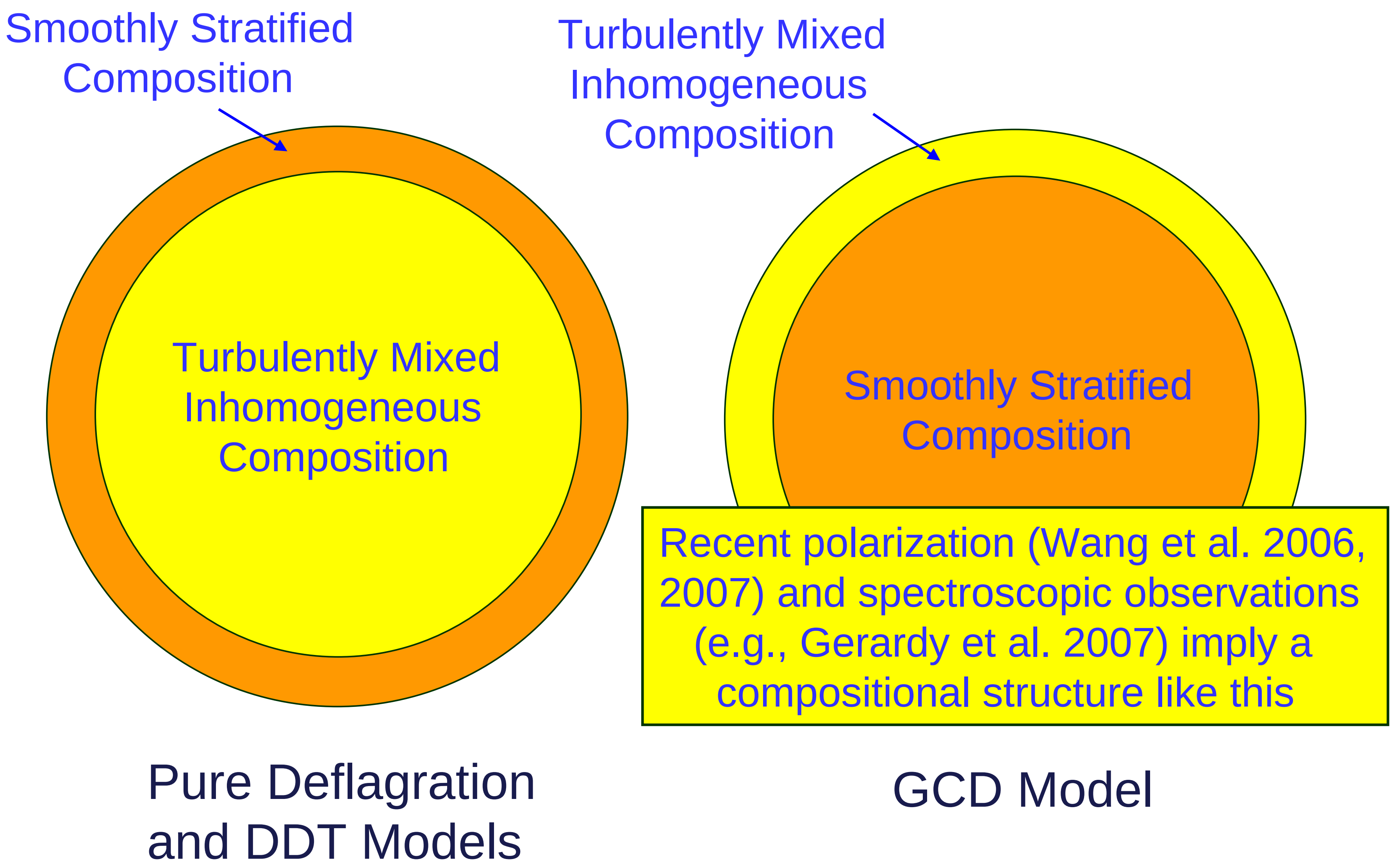
Schmidt et al. (2006)

Simulation of Deflagration to Detonation Transition Model



Gamezo et al (2004)

Predictions of Pure Deflagration and DDT vs. GCD for Composition of Star



Conclusions

- We have conducted a series of 3-D simlations of the GCD mechanism for several different offset distances and resolutions
- Conservative conditions for detonation are robustly achieved in all cases
- We find a correlation between the central density of the star at detonation and both the offset distance and the radius of the initial bubble – these correlations offer a possible explanation forr the observed variation in nickel mass in Type Ia SNe
- In addition, the uniform, homogeneous cores and the turbulent, heterogeneous composition of the outer layers of the stars at the time when conditions for detonation are reached match the properties inferred from recent polarization, and NIR and MIR, spectroscopic observations