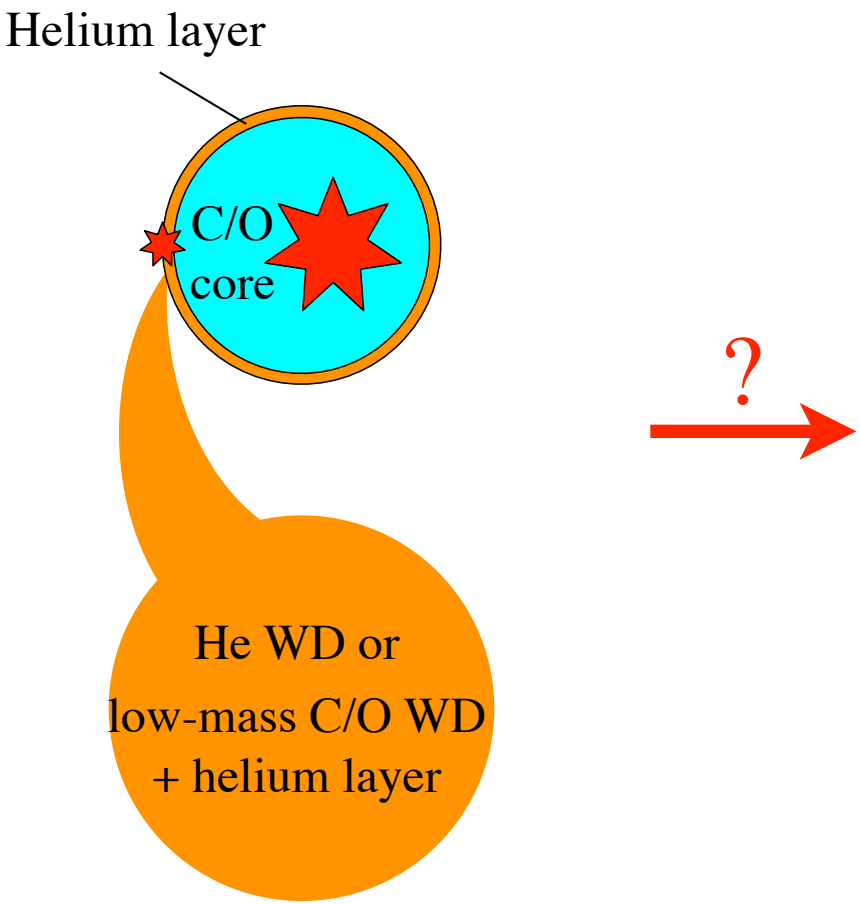
Do double degenerate double detonations drive destructive dwarf death?

Ken Shen (UC Berkeley)



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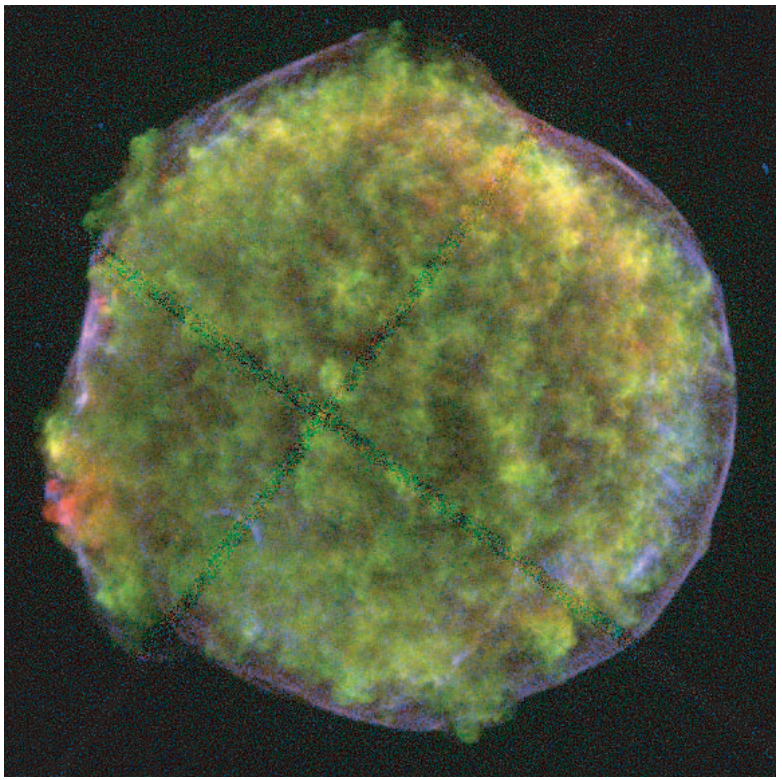
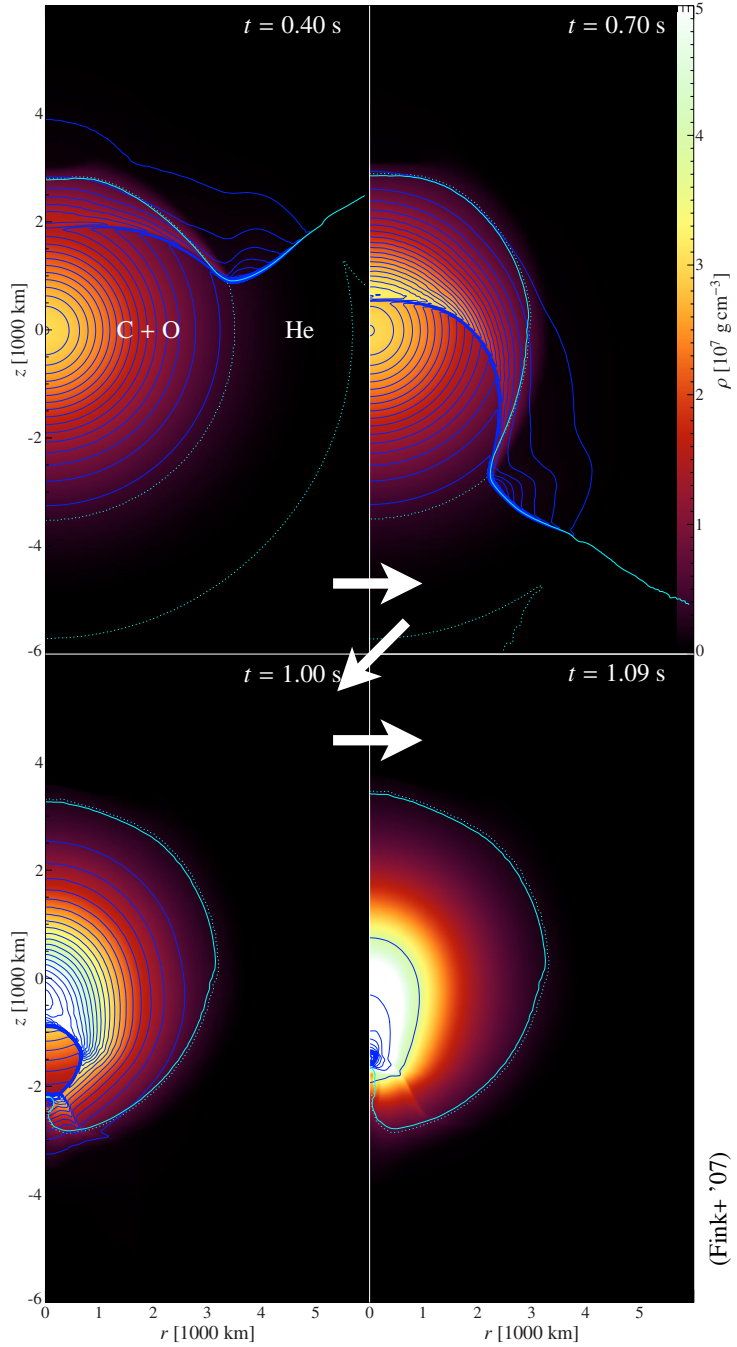


(Warren+ '05)

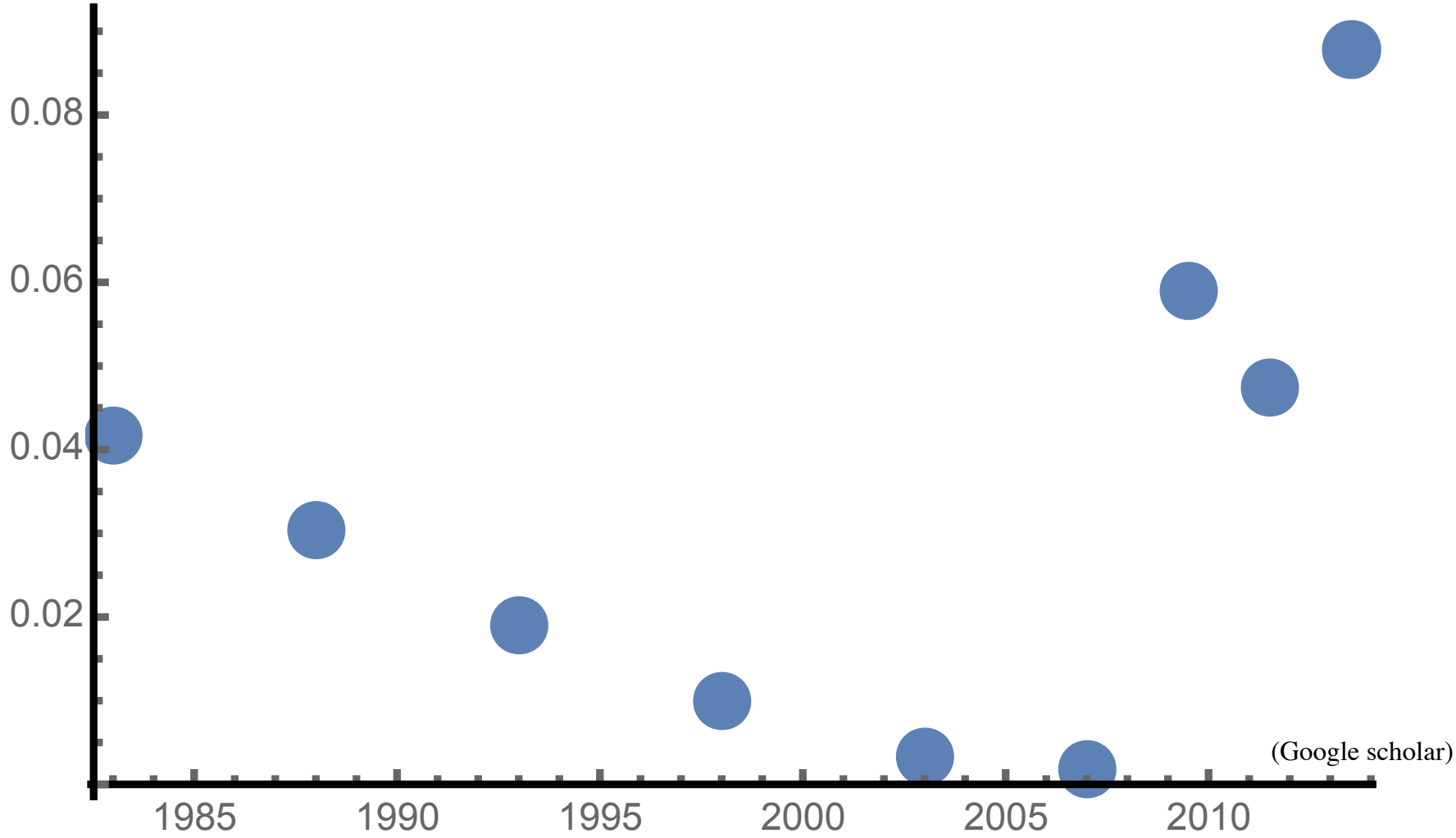
Double detonations: Overview

- Taam / Nomoto / Woosley+ / Livne+ in 1980s-1990s
- MPA / etc. in 2000s-2010s
- Helium shell detonation → inward converging shock wave → carbon core detonation
- Pure detonations of ~1.0 Msol C/O WDs:
  decent match to SNe Ia (Sim+ '10, Kromer+ '10)



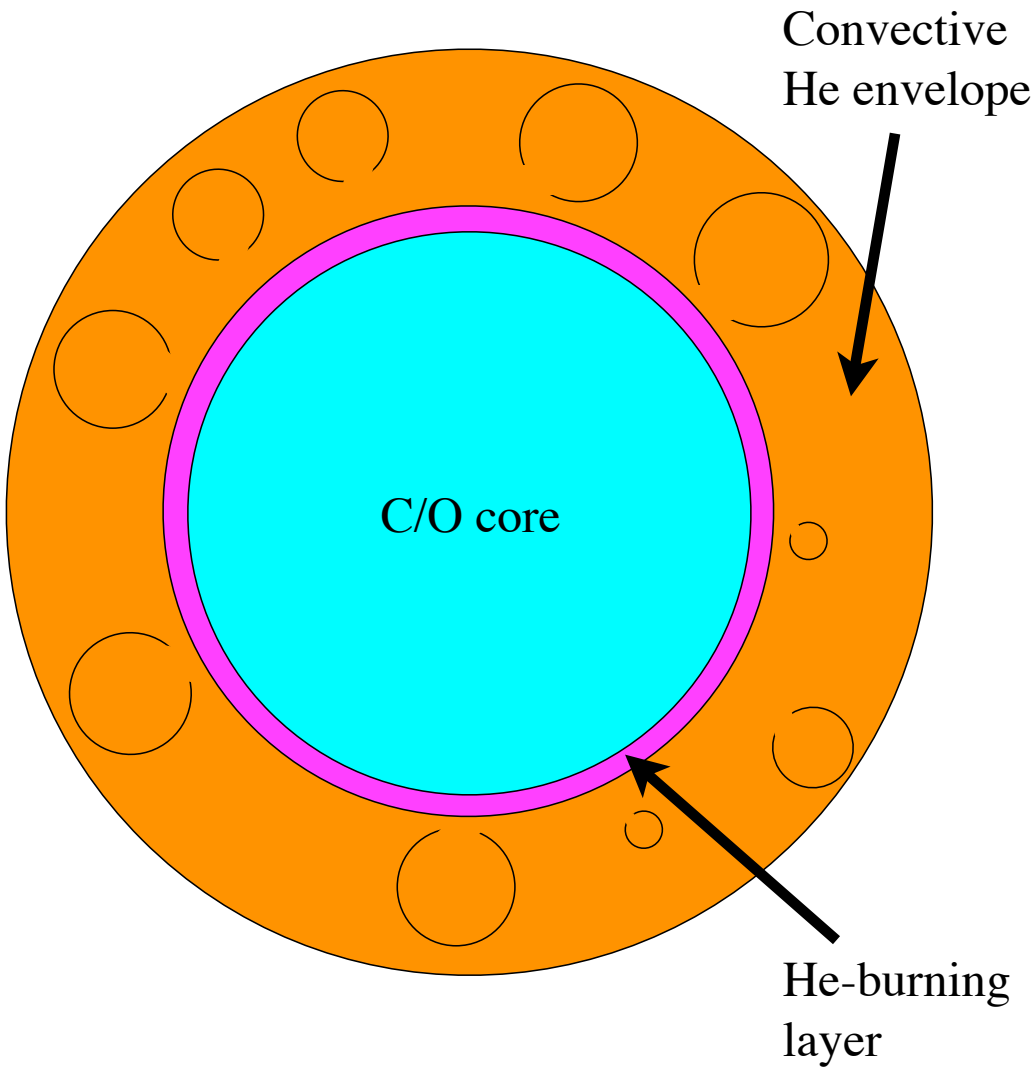
Double detonations: Overview

$$\frac{\text{\# of papers mentioning “double detonation” and “white dwarf”}}{\text{\# of papers mentioning “supernova” and “white dwarf”}}$$



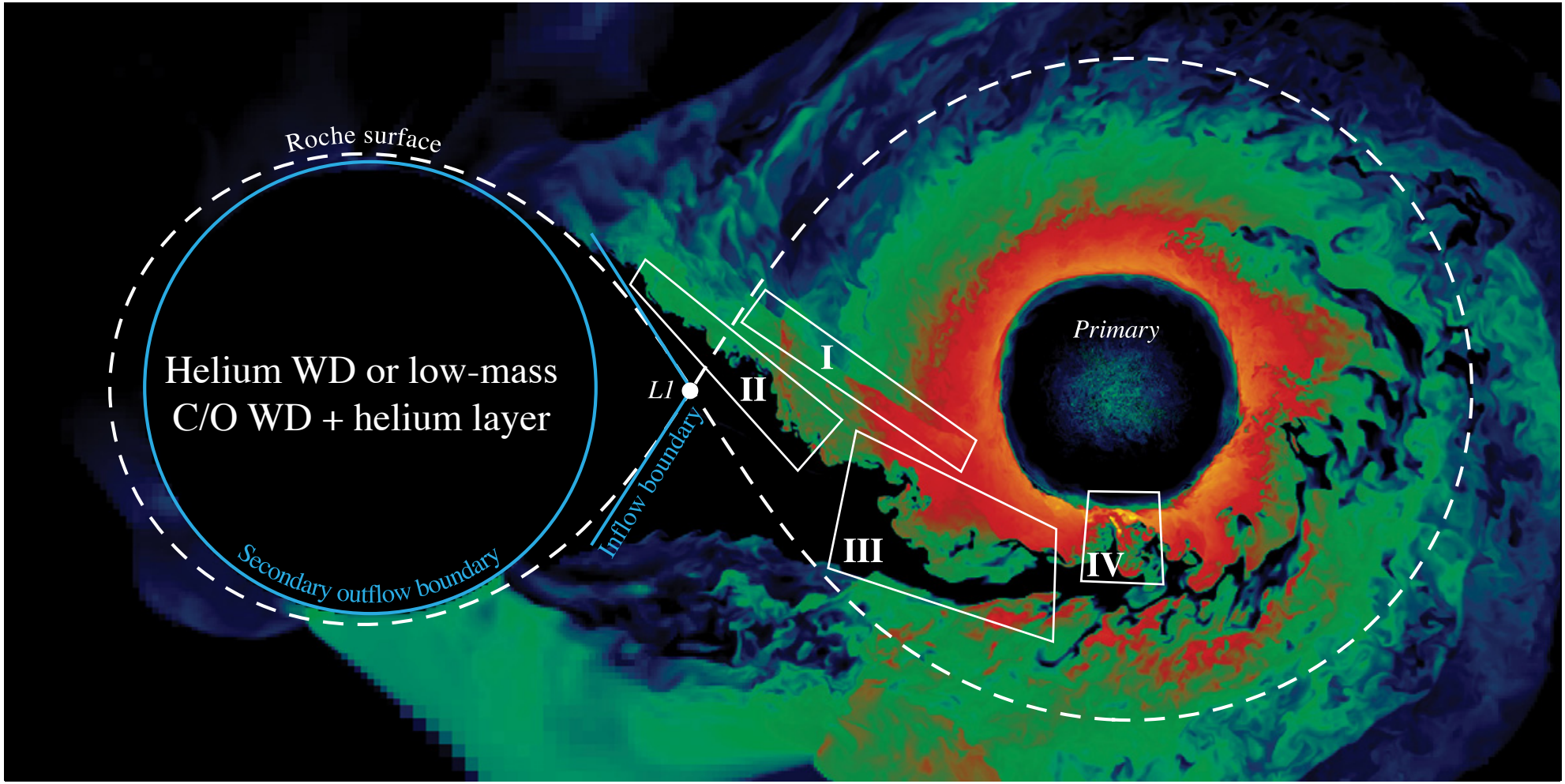
He detonations via stable accretion and convection (~10^6 yr)…

- 1980s-1990s (Nomoto / Woosley / et al.): *He MS donor* (sdB/sdO)
- Late 2000s (Bildsten, Shen, et al.): *low-mass He WD donor* (low mass ratio, pre-AM CVn)
- For "large enough" He shell, convective transport is inefficient → strong turbulent fluctuations



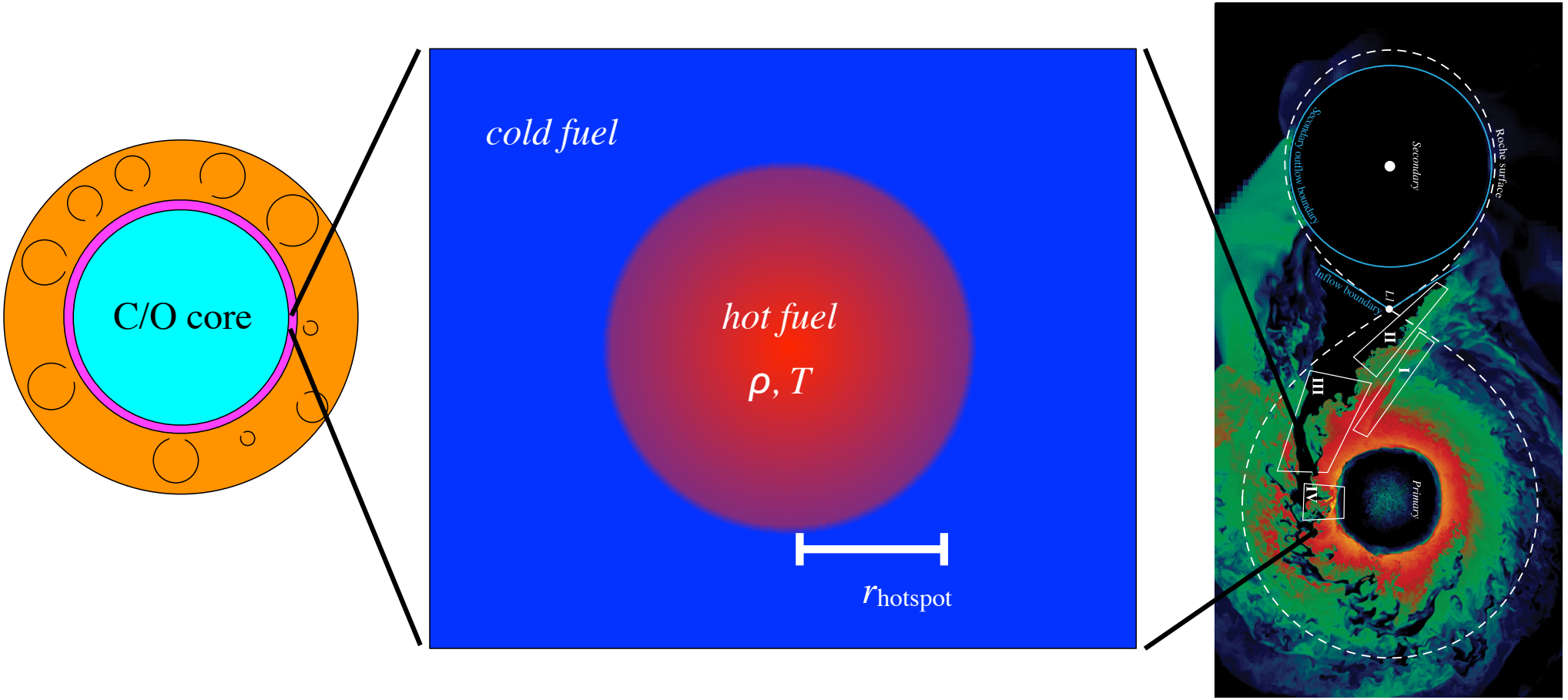
…Or He detonations via dynamical accretion (~100 s)

- 2010s (Guillochon / Dan / Raskin / Pakmor):
  Dynamical processes during He + C/O or C/O + C/O WD merger
- Could be dominant channel if all double WD binaries merge (Shen ’15a)



(Guillochon+ ’10)

First detonation: Does the helium ignite? Likely yes



- Spontaneous initiation via Zel'dovich gradient mechanism → minimum $r_{hotspot}$
- Hotspot expectations: $T \sim 10^9$ K, $\rho = 10^5$ - 10^6 g/cm^3
- Shen & Moore '14: Small CNO pollution + complete nuclear network
  → **Minimum $r_{hotspot}$ < 10-100 km, helium detonation easy to ignite and propagate**
  → **Smallest helium shells produce Si and Ca at high velocities**

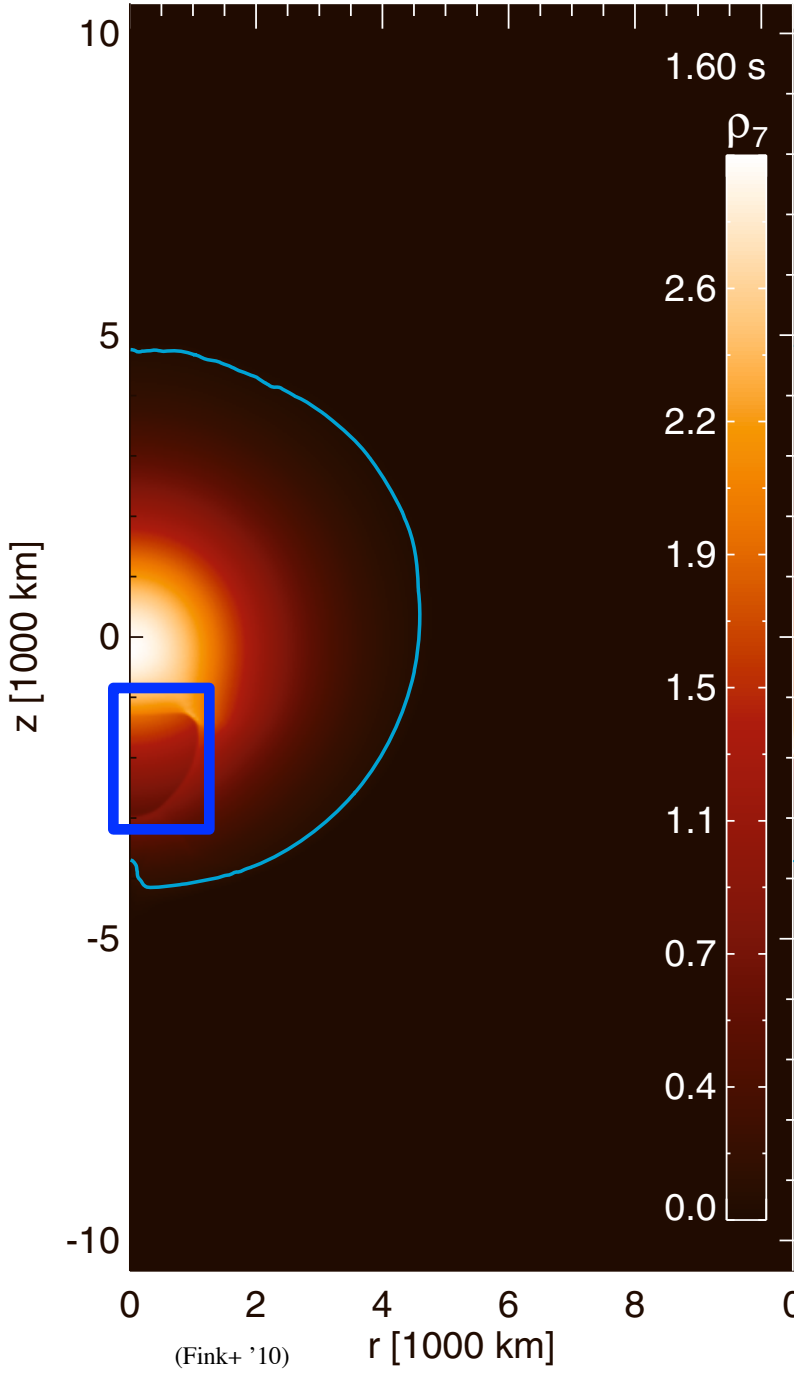
Ken Shen (UCB)

Second detonation: Does the C/O ignite? Likely yes

- Impossible to resolve ignition in full-star 2D sim (burning lengthscale ~ 0.1-1 cm ; $R_{WD} \sim 10^{8\text{-}9}$ cm)

- Shen & Bildsten '14: zoom in on the inner 10^3 – 10^5 cm around focal point in 1D spherical symmetry
  - **C/O easy to ignite via converging shocks**
  - O/Ne very difficult

- Also the possibility of "edge-lit" detonation
  - Not well-studied yet



(Fink+ '10)

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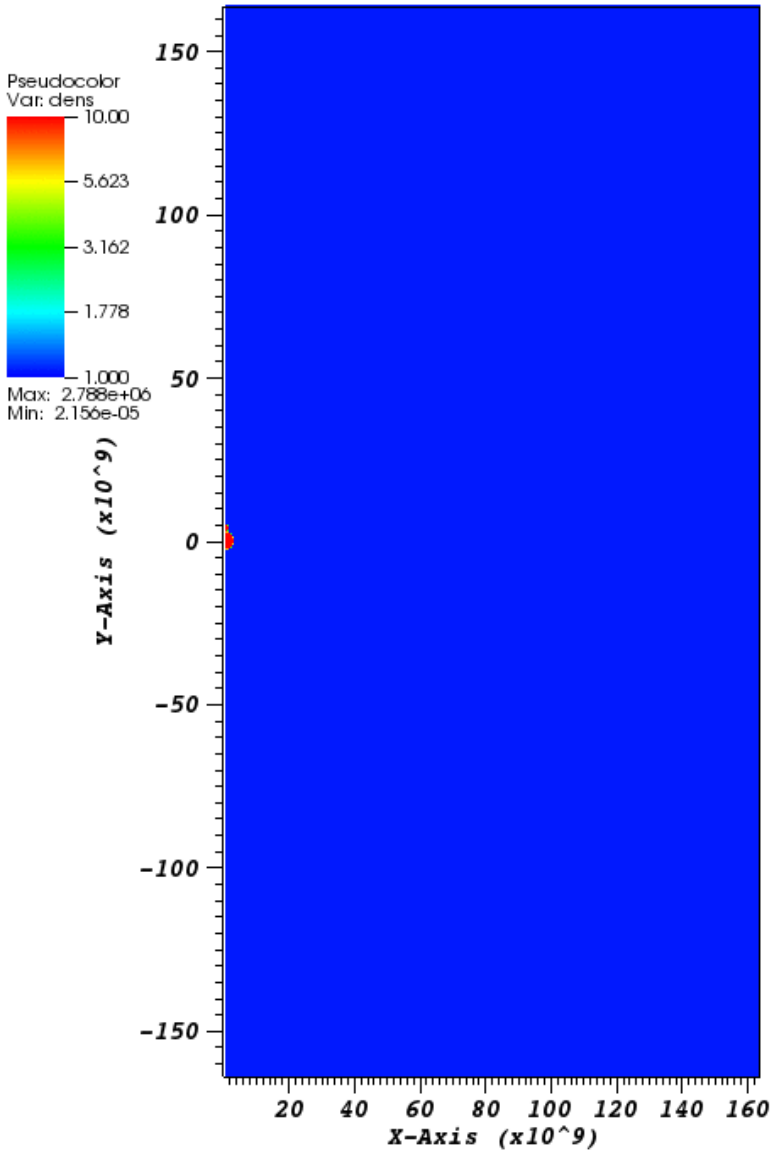
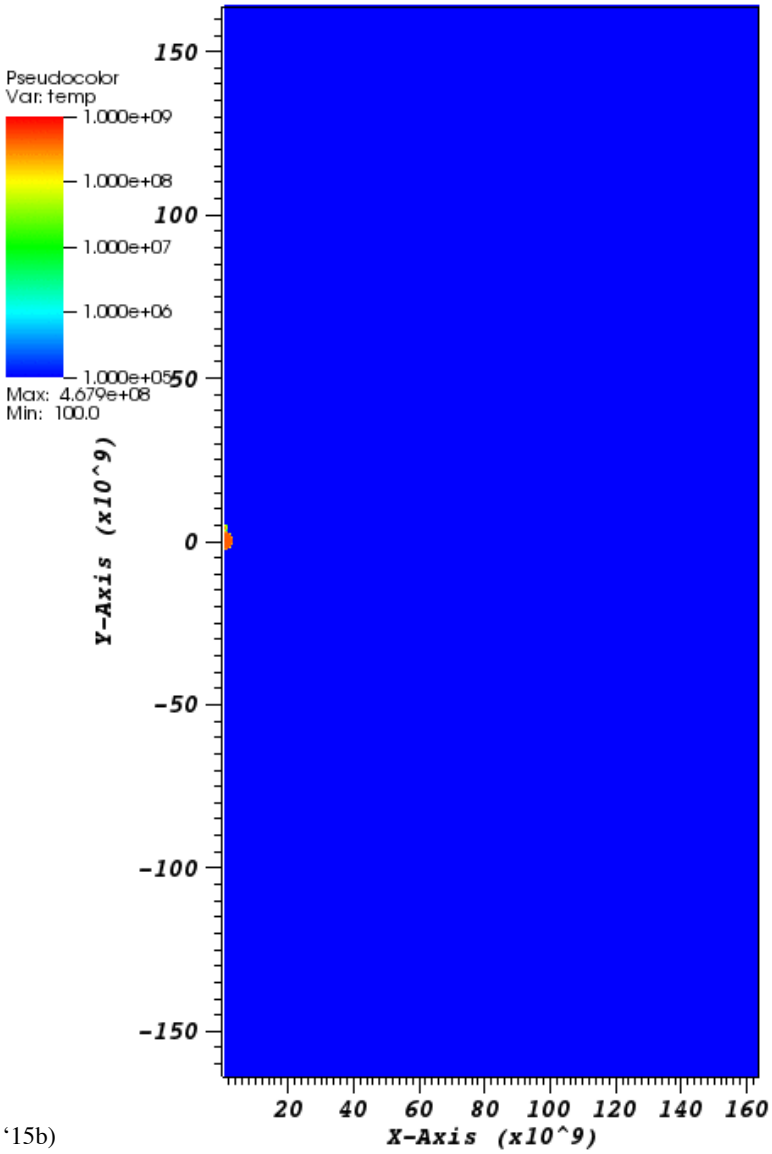
How does a surviving companion influence the remnant?

- Surviving RLOF companion (non-degenerate or WD) casts shadow

Density



Temperature



(Shen '15b)

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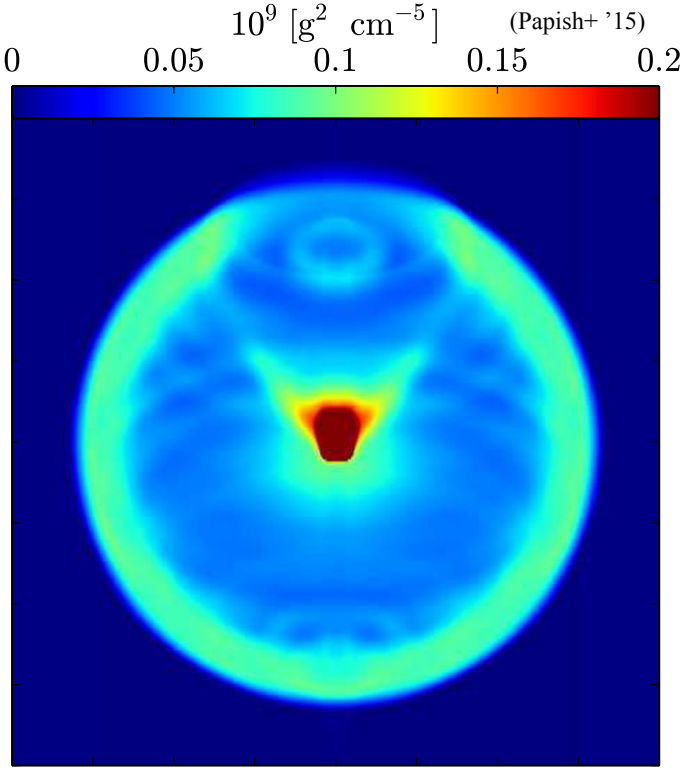
Previous work

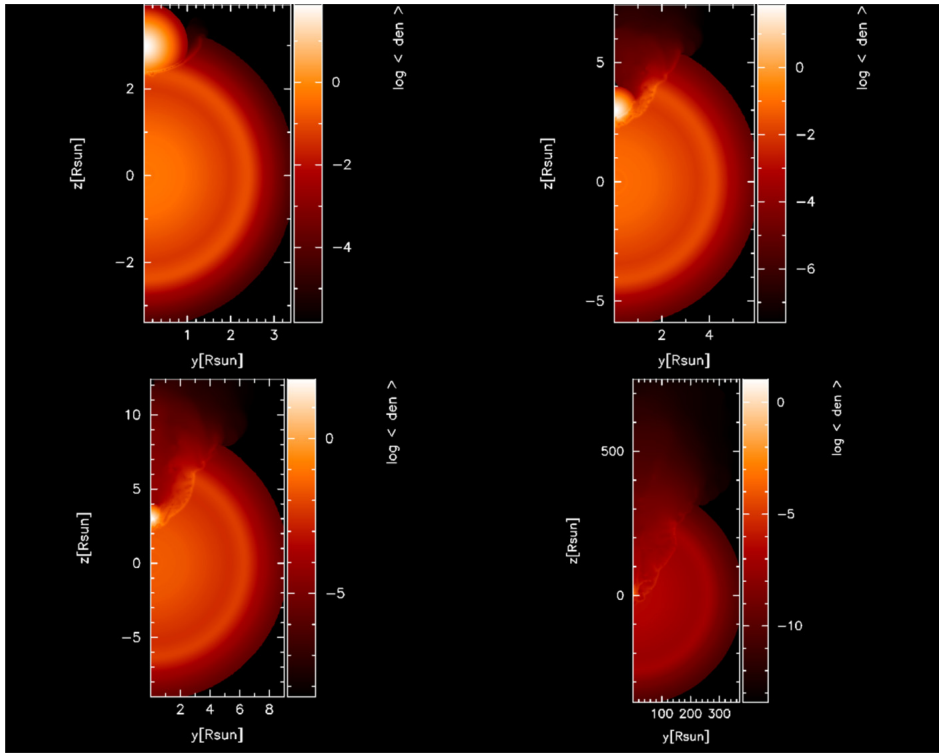


$M_{\rm swept}$ = 1 Msol

$V_{\rm forward\ shock}$ ~ 6000 km/s

- Papish+ '15: FLASH simulation of sub-Chandrasekhar explosion with surviving WD companion

- Can helium WD companion be detonated by ejecta?
  - Yes…but only if placed artificially close
  - **No detonation if companion at proper distance**

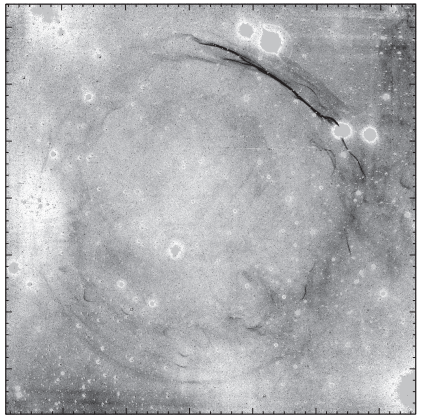


(García-Senz+ '12)

- García-Senz+ '12: SPH simulation of Chandrasekhar explosion with 1 Msol MS companion

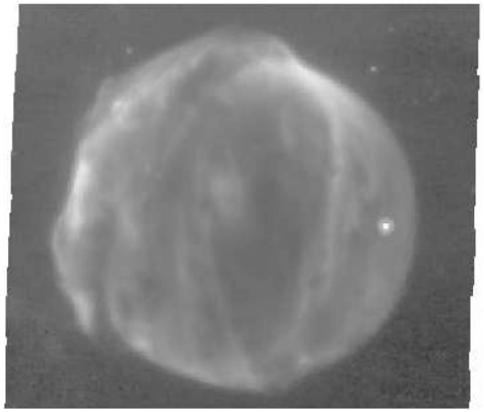
SNR forward shock is usually spherical (more or less)

SN 1006, Hα



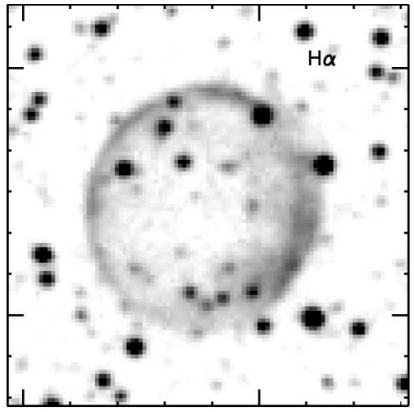
(Winkler+ ’14)

Tycho, 24 μm



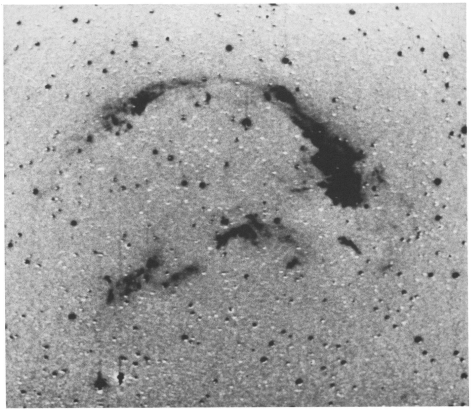
(Williams+ ’13)

LMC 0509, Hα



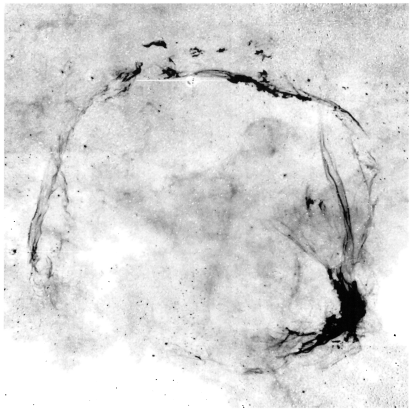
(Warren & Hughes ’04)

Kepler, Hα



(Blair+ ’91)

RCW 86, Hα

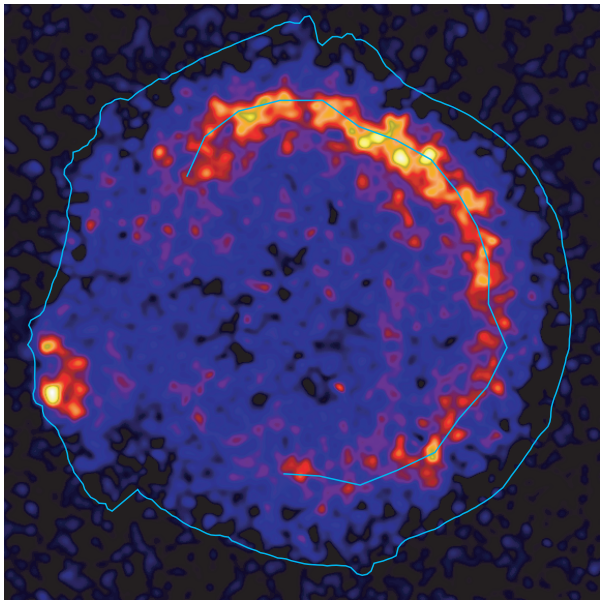


(Smith ’97)

- Almost certainly dominated by ISM inhomogeneities, but could mask ejecta asymmetry

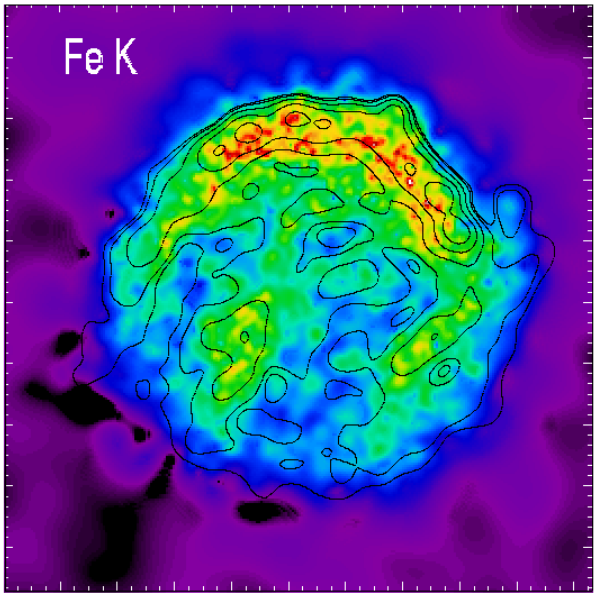
Reverse-shocked ejecta less spherical

Tycho, Fe Kα



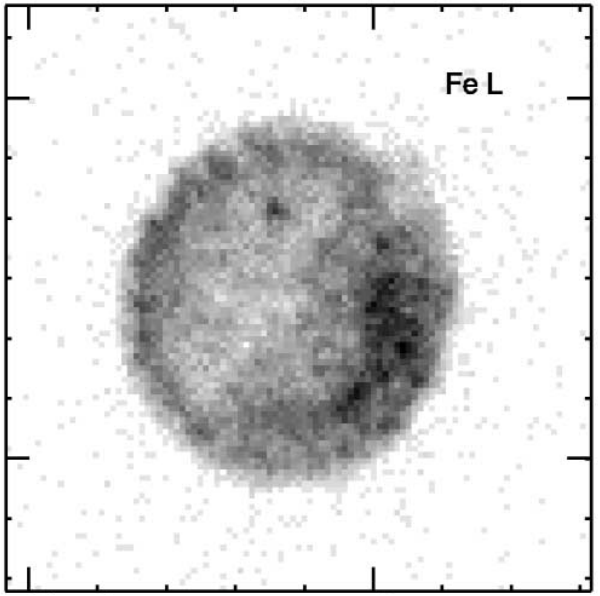
(Warren+ ’05)

Kepler, Fe Kα



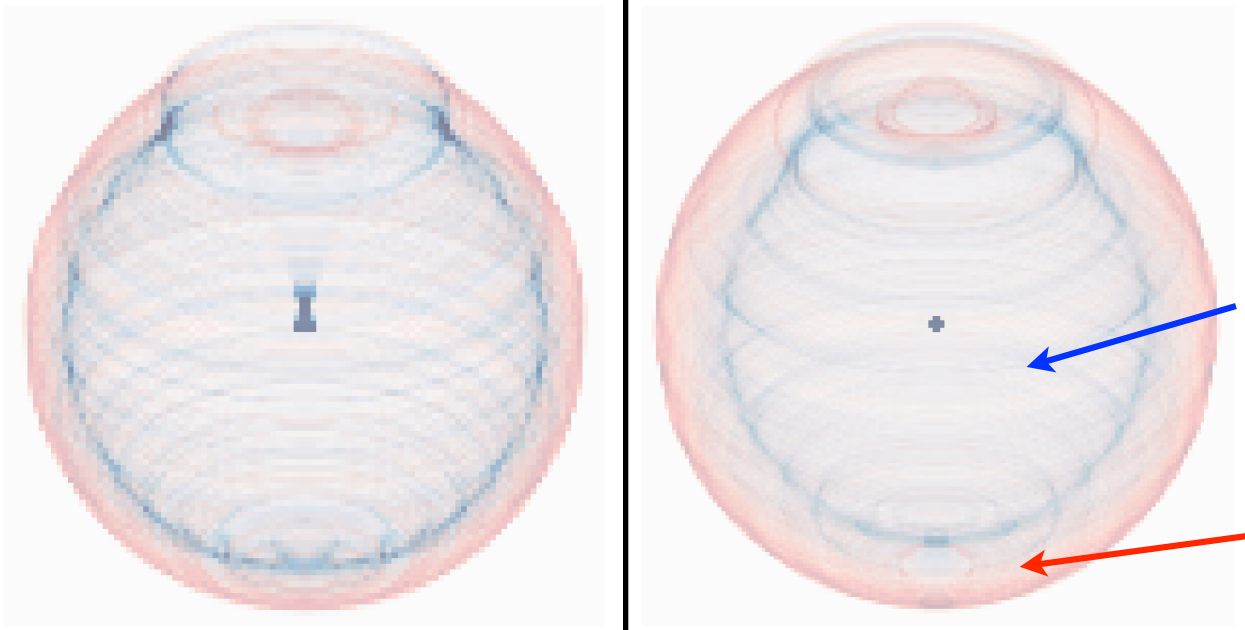
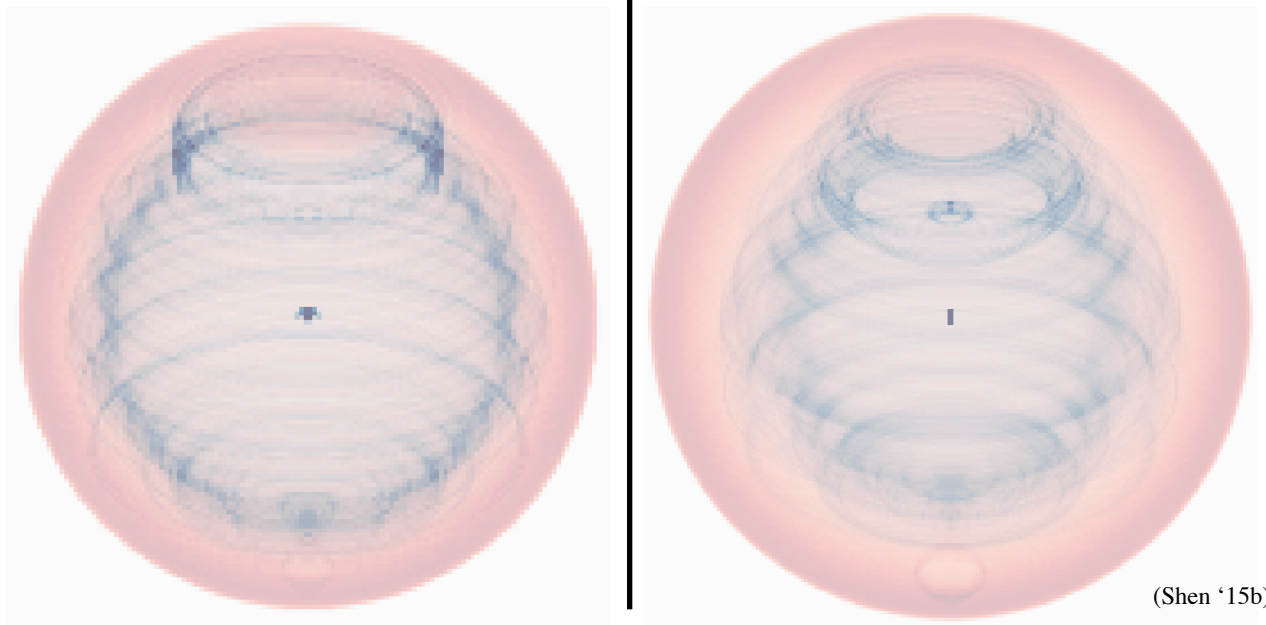
(Cassam-Chenaï+ ’04)

LMC 0509, Fe L



(Warren & Hughes ’04)

Emission maps

	$v_{\text{forward shock}}$ = 5000 km/s	$v_{\text{forward shock}}$ = 3000 km/s
γ = 1.2		
γ = 5/3		

Density^2 integrated along line of sight, viewed at 30°

Reverse-shocked SN ejecta

Forward-shocked ISM

(Shen '15b)

Ken Shen (UCB)

Summary

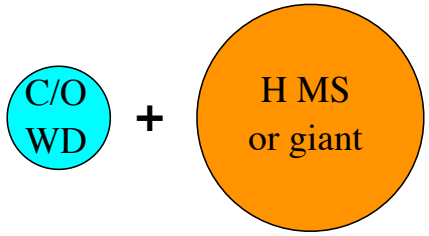
- **Merging double WD systems with primary WD mass > 0.9 Msol likely lead to detonation**
  - Companion WD < 0.7 Msol: helium triggers double detonation
  - Companion WD > 0.7 Msol: direct carbon ignition ("violent merger") can occur

- **Helium WD companion not detonated by the SN ejecta if at the proper binary separation**

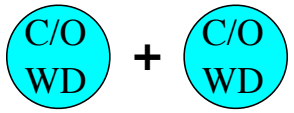
- **Supernova remnant consistent with observed SNRs**
  - Forward-shocked ISM spherical
  - Reverse-shocked ejecta roughly spherical

- Ongoing work: Appearance of surviving WD companion
  - Likely bright and blue
  - Very high proper motion

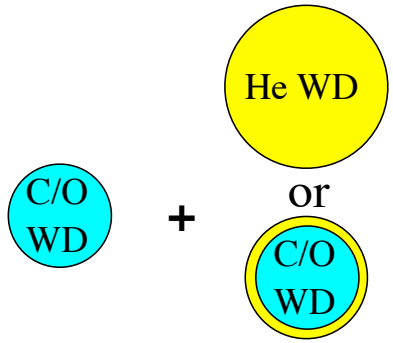
Summary



Single degenerate



Long-lived double degenerate merger



Detonation during double degenerate merger

Explode			
No shock interaction		Depending on timescale	
No H seen			
Nothing seen pre-explosion			
Ex-companion not seen post-Ia			
Rates		Off by factor of a few	Off by factor of a few
Circumstellar absorption	Okay for some, but not for all	Depending on timescale	Depending on clumping
SN remnant			
IGE production			

Ken Shen (UCB)