# Multidimensional Hydrodynamical Simulations and Radiative Transfer Calculations of Thin Shell Double Detonations

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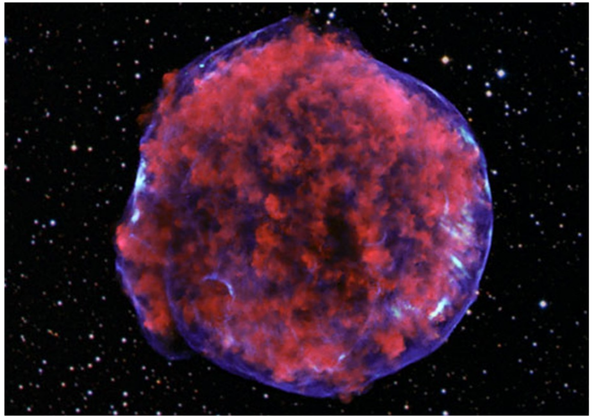
# Type Ia Supernovae

- Type Ia supernovae are necessary for a variety of astronomical interests (e.g. cosmology, chemical evolution), but their precise origins are unknown

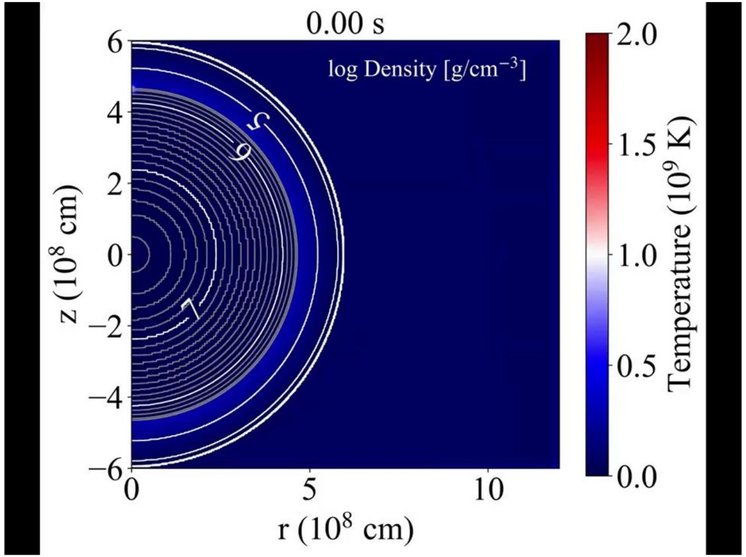
- The progenitor is a carbon-oxygen white dwarf in a binary, but the exact configuration of the system at the time of explosion are still a mystery

B. J. Fulton/Las Cumbres Observatory Global Telescope Network


Tycho remnant, NASA/CXC/Rutgers/K.Eriksen et al.

# Double Detonation Background

- The **double detonation** is a Type Ia explosion mechanism candidate where an accreted helium shell detonates and triggers a detonation of the underlying sub-Chandrasekhar white dwarf

# Advances in the Double Detonation Scenario

- It was long thought that the mass necessary for a helium shell to detonate would result in spectra that did not match observed normal Type Ia supernovae (Woosley & Weaver 1994, Nugent et al. 1997)

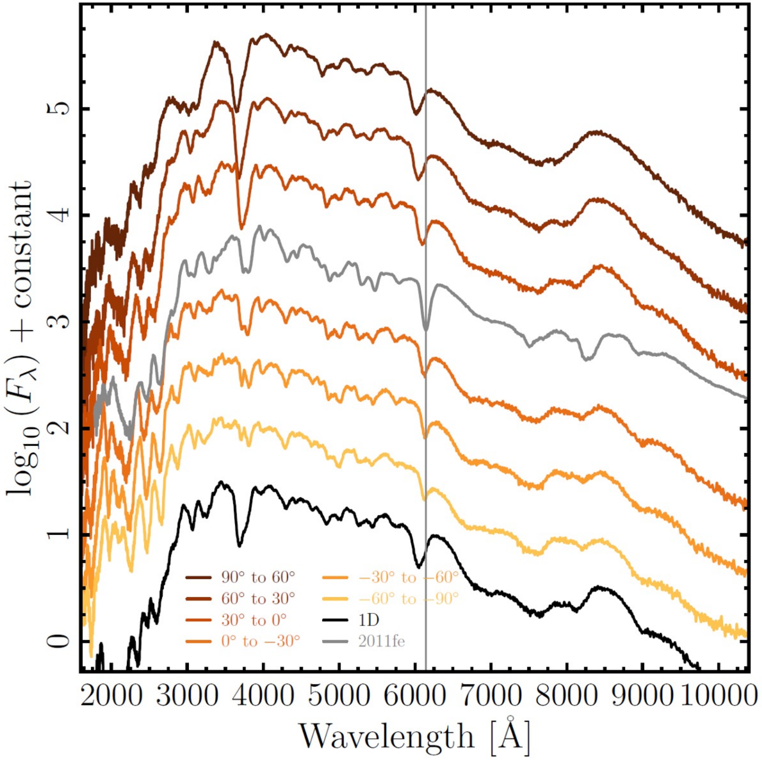
- When the ashes of the helium detonation are removed, the double detonation produce observables that mimic observation (Kromer et al. 2010)
    - It was also shown that significant C/O enrichment of the shell can limit the adverse effects of the helium shell detonation

- Shen & Moore 2014 showed that the threshold helium shell mass is much lower given the use of an expanded nuclear network and inclusion of $^{14}N$
    - Minimum shell mass for 1 $M_{\odot}$ WD decreases from ~$10^{-1}$ to ~$10^{-2}$ $M_{\odot}$

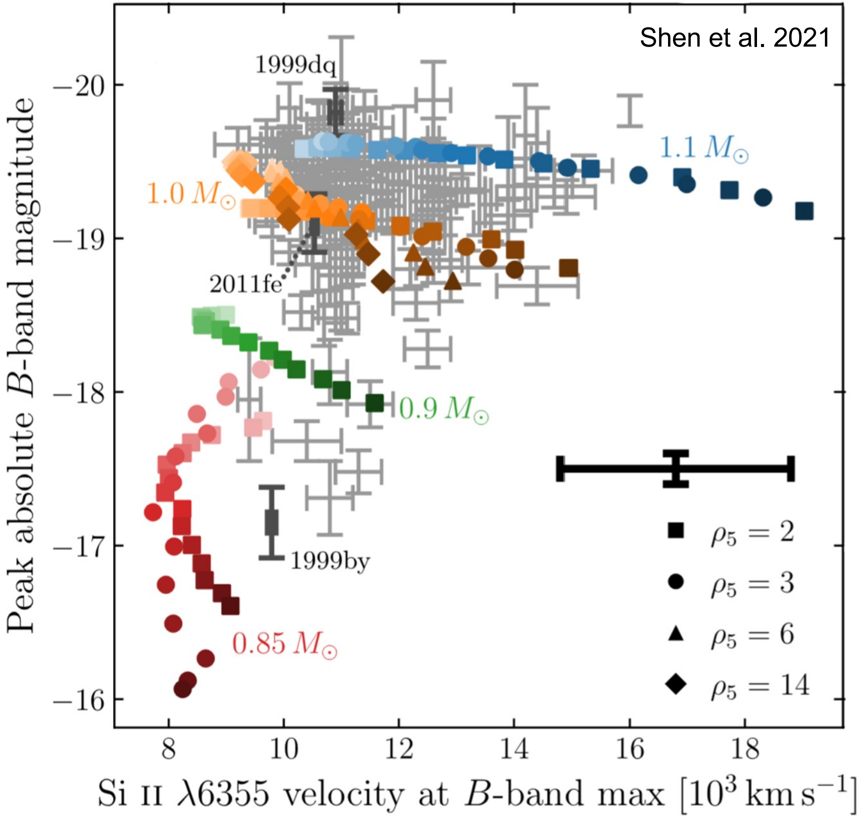
# Townsley et al. 2019

- Using a 2D simulation, Townsley et al. 2019 showed that a thin-shelled sub-Chandrasekhar mass white dwarf that undergoes a double detonation can indeed produce a normal Type Ia supernova
    - Only one model examined

Townsley et al. 2019



# Filling in the Observational Parameter Space



# Methods

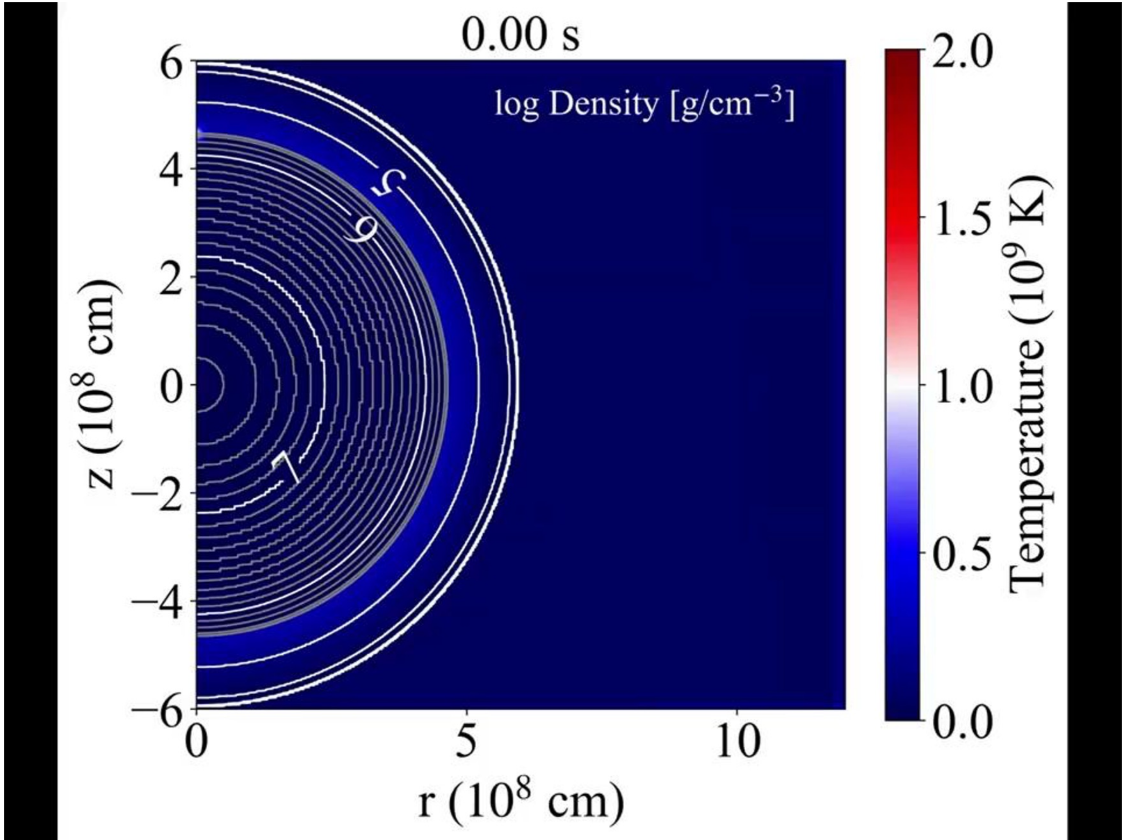
- In Boos et al. 2021/Shen et al. 2021, we present 2D double detonations of carbon/oxygen white dwarfs across a range of masses and their corresponding observables

- Progenitors range in both core and shell mass, spanning both thin and thick shell models
  - Thinnest shells have a base density of 2 x $10^5$ g/cc and have masses of a few $10^{-2}$ $M_\odot$
  - Helium shells are modestly enriched with 10% C/O and 0.5% $^{14}N$

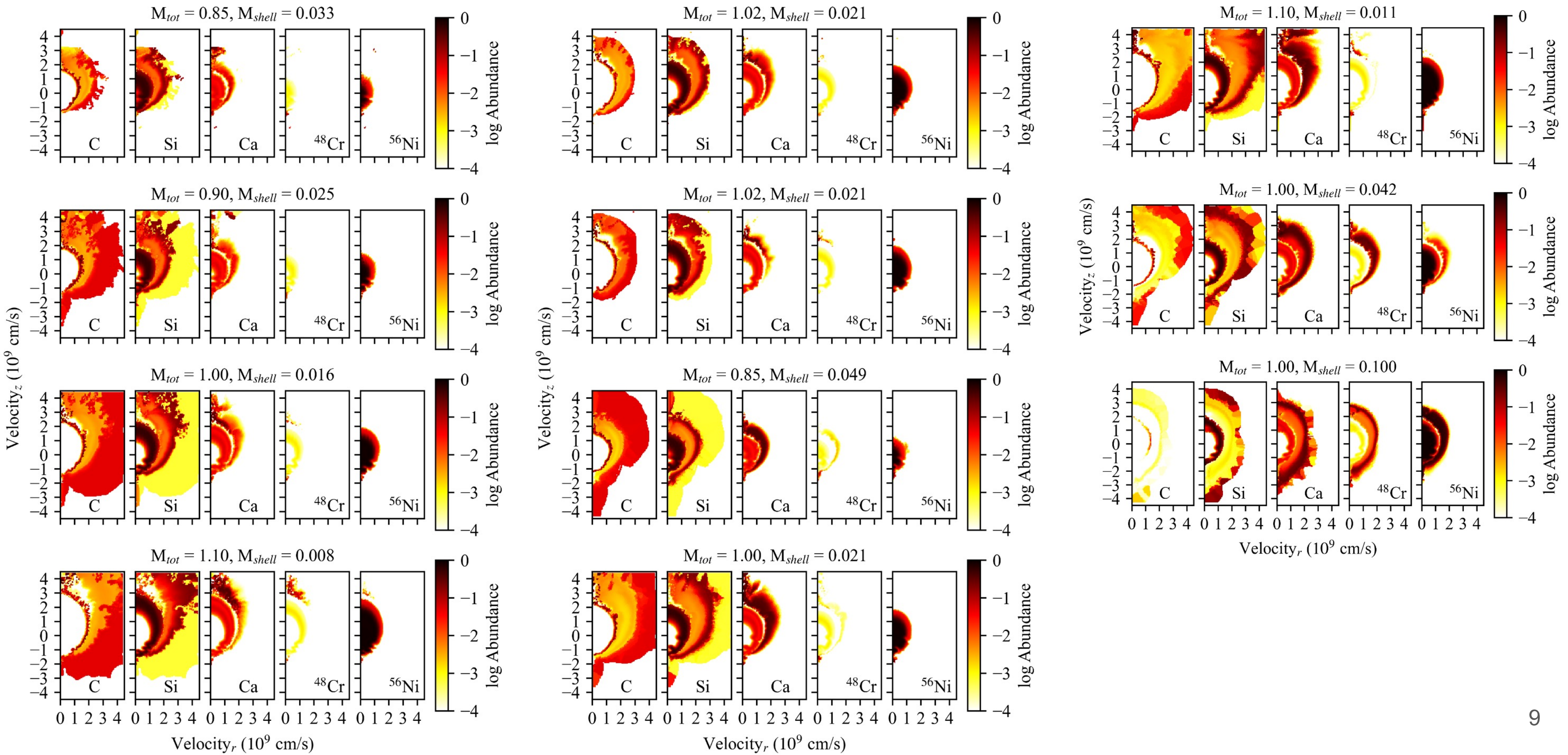
- 2D multiphysics simulations carried out using FLASH, with the burning supplemented by MESA
  - Burning limiter used
  - 55-isotope nuclear network during simulation, later post-processed with 205-isotope network

- 2D radiative transfer calculations using Sedona
  - Using local thermodynamic equilibrium (LTE)

# Standard Thin Shell Double Detonation



# Boos et al. 2021 Ejecta

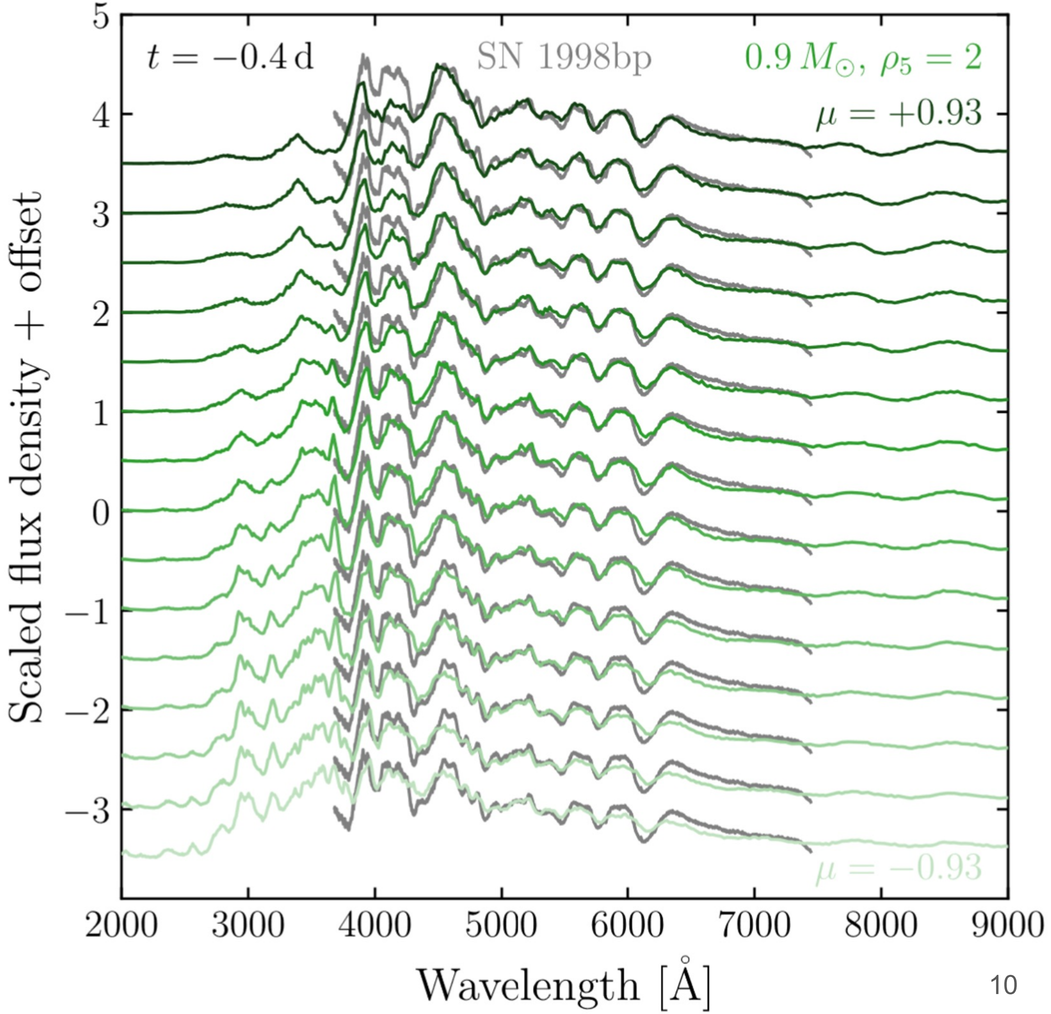


# Max Light Spectra

- Spectra from thin shell models generally mimic observed Type Ias

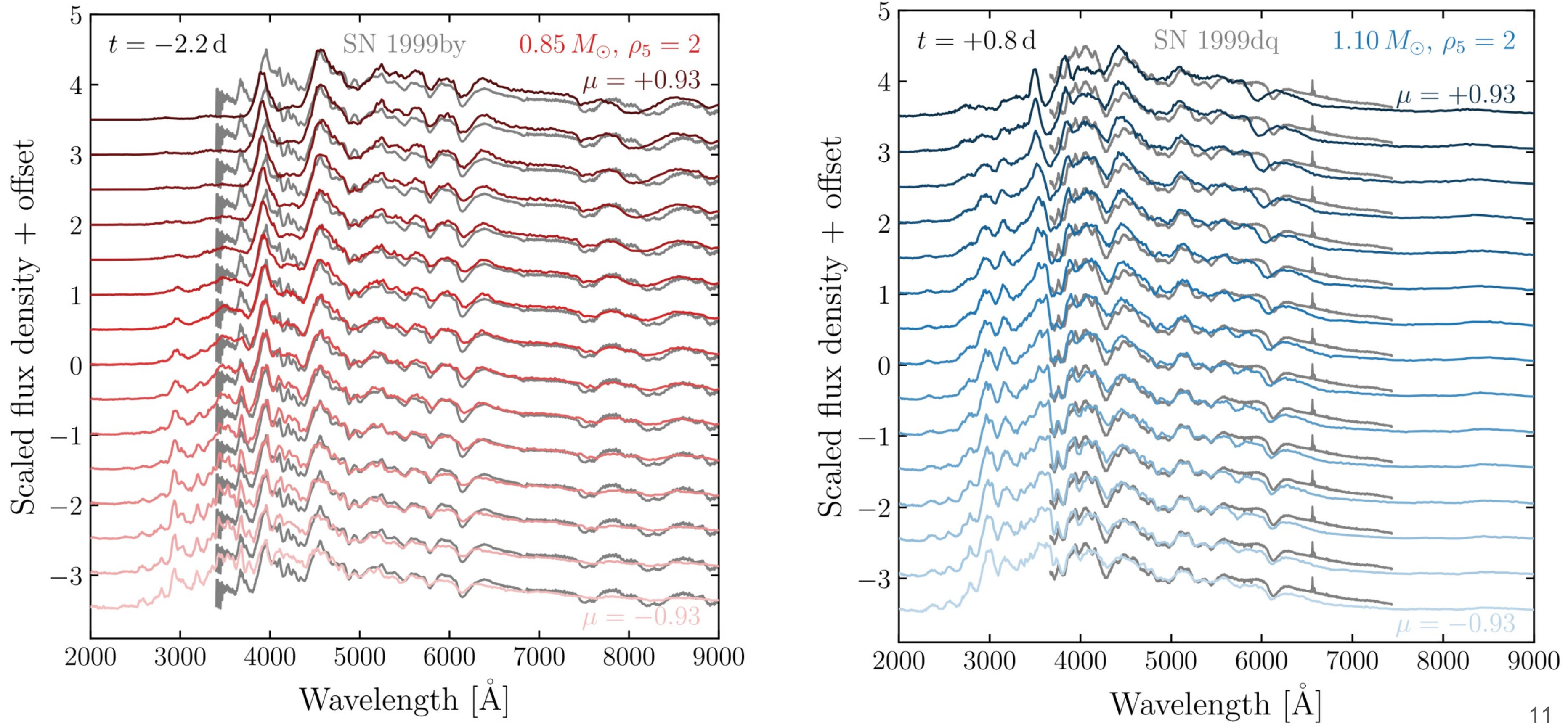
- Spectra is fairly dependent on line of sight due to asymmetric ejecta

Shen et al. 2021

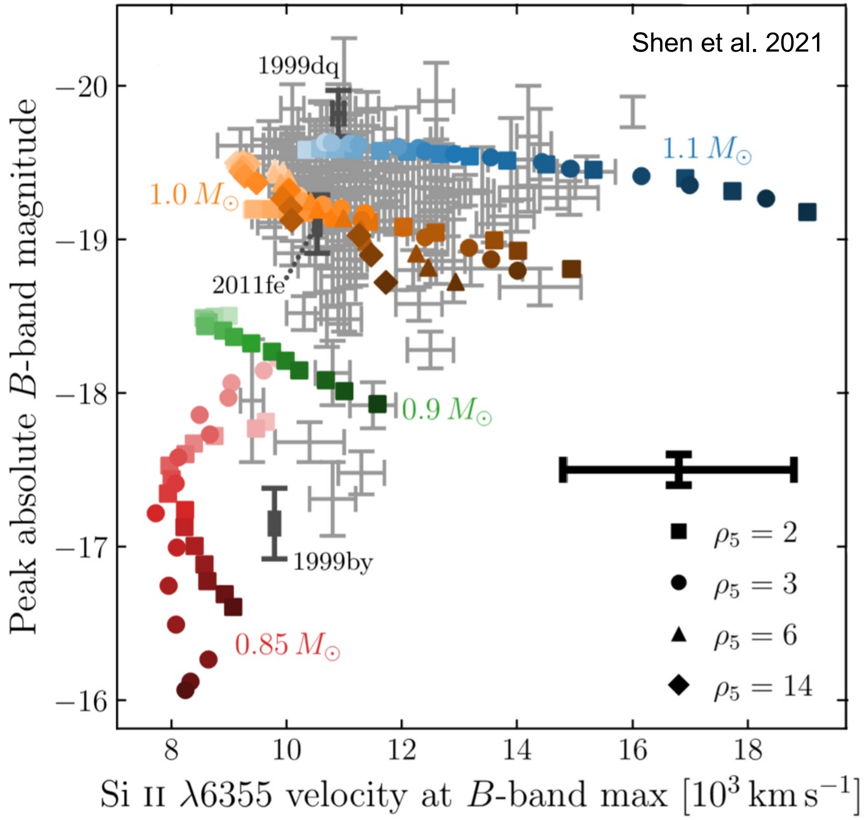


# Low and High Mass Spectra

Shen et al. 2021



# Observable Quantities

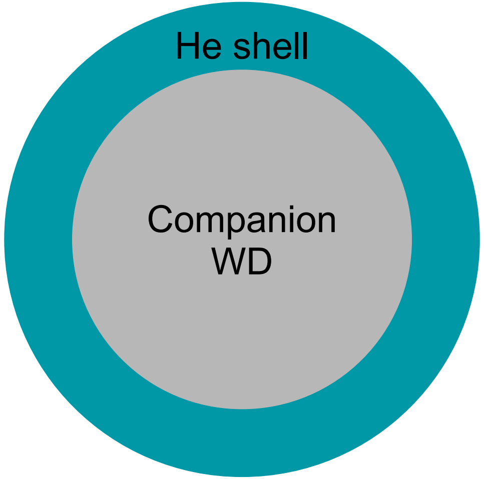


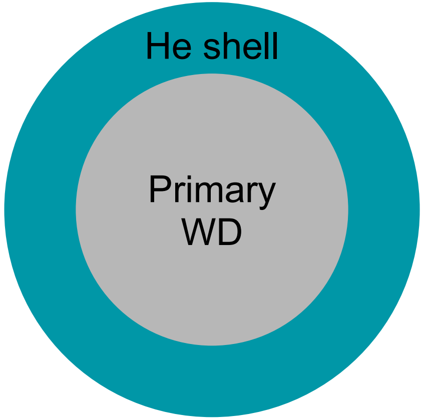

- Across a range of white dwarf masses, the thin shell double detonation produces events that span the diversity of observed Type Ia supernovae
- A few inconsistencies with observation
  - Most models are too red, but expected from LTE calculations
  - Si II velocities are fairly high for the mid-high mass models

# What about the companion?

- Given that the double detonation must occur in a binary system, what are the outcomes for the companion and the corresponding effects?

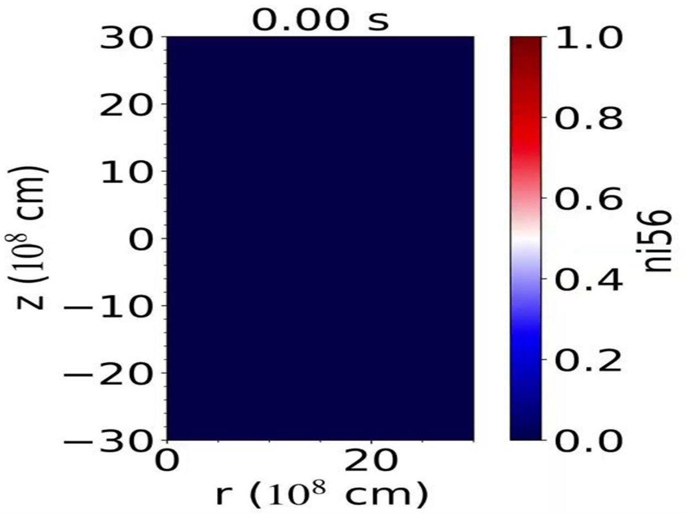
- Pakmor et al. 2022 conducted 3D double detonations with the complete binary system and showed that the helium shell of the companion may detonate as a result of the primary detonations
  - Intriguingly, the detonation of the low mass companion had relatively little effect on the observables

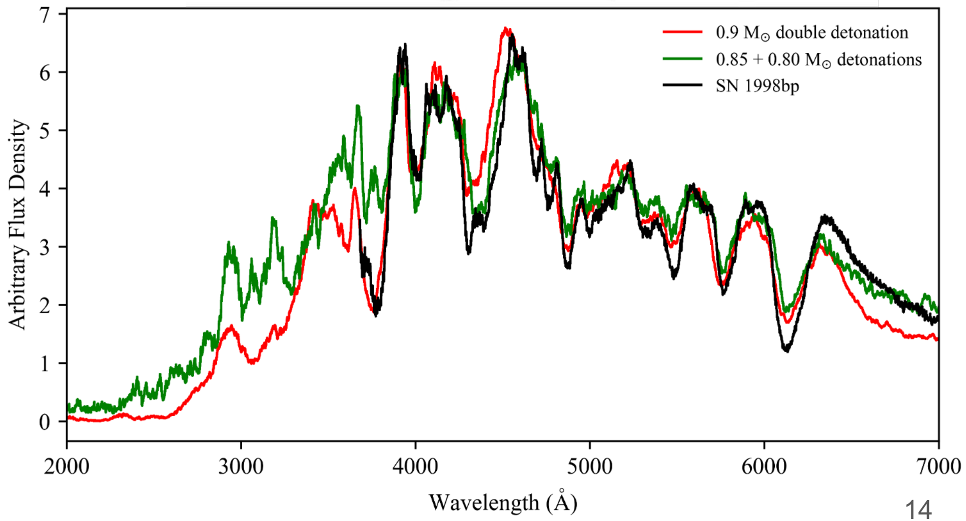


# Boos et al. 2022 (in prep)

- I have completed a series of simulations with similar setups as Boos et al. 2021/Shen et al. 2021, but with a companion that detonates shortly after the primary
  - Due to the short delay of the core detonations, the companion ejecta is imbedded within the primary ejecta
  - The spectra from the two star explosion models are strikingly similar to the one star double detonation cases



# Summary

- In 2D, the thin shell double detonation is able to reproduce both realistic spectra and the diversity of observed Type Ia supernovae across a range of progenitor mass configurations

- Early results indicate that the scenario in which both white dwarfs undergo a double detonation can also produce Type Ia-like observables

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