

Progenitors of Type Ia Supernovae

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Figure 1: G299.2-2.9 Type Ia Supernova Remnant from the Chandra X-Ray Observatory

Type Ia Supernova

- WD in binary system accretes mass and approaches Chandrasekhar limit.
- Precise progenitors are still poorly understood.

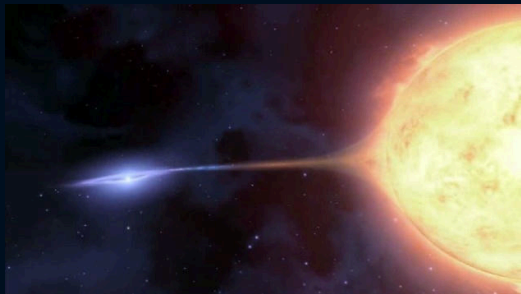


Figure 2: Artists rendition of single-degenerate type Ia supernova. [1]



Figure 3: Supernova remnant SNR 0509-67.5. [2]

Supernova Ignition

- Increased mass \Rightarrow increases density \Rightarrow increases core temperature
- Carbon ignites, leading to a runaway flash of fusion because star is degeneracy pressure dominated.
- Substantial increase in kinetic energy, unbinds the WD
- Fusion synthesizes Ni, Co, Fe in dense regions, Si, S, Ca, Mg, O in regions where burning is incomplete.
- Majority of luminosity provided by radioactive decay $^{56}\text{Ni} \rightarrow ^{56}\text{Co} \rightarrow ^{56}\text{Fe}$

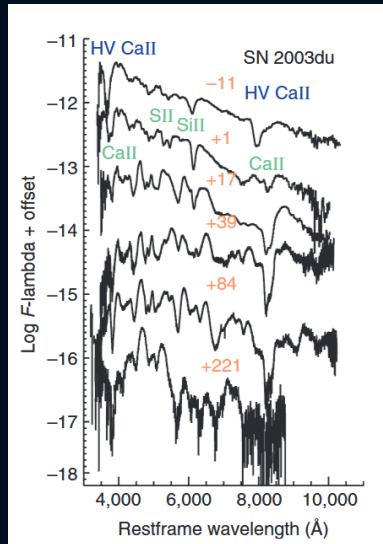


Figure 4: Selected spectra from supernova SN 2003du [3].

Use as Standard Candles

- Consistent range of masses at ignition, so peak luminosity can be deduced \Rightarrow good standard candles.
- Phillips Relation:
 - $M = -21.726 + 2.698\Delta m_{15}$.
 - $\Delta m_{15} \equiv$ decrease in brightness after 15 days.
- Correlated with amount of ^{56}Ni produced.

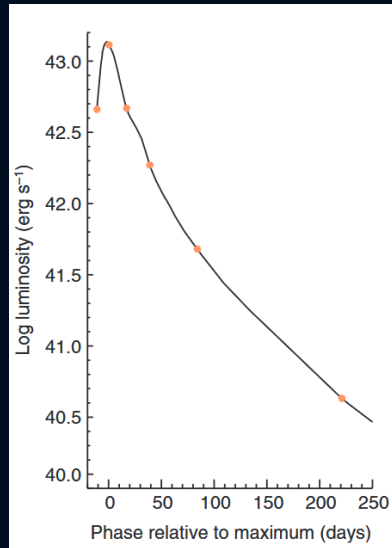


Figure 5: Bolometric lightcurve from supernova SN 2003du [3].

Progenitors

- Slow accretion of mass near Chandrasekhar limit: *single-degenerate*
 - Roch lobe overflow
 - Solar Wind
- Classical Double WD merger: *double-degenerate*
- Sub-Chandrasekhar mass detonation: *double-degenerate*

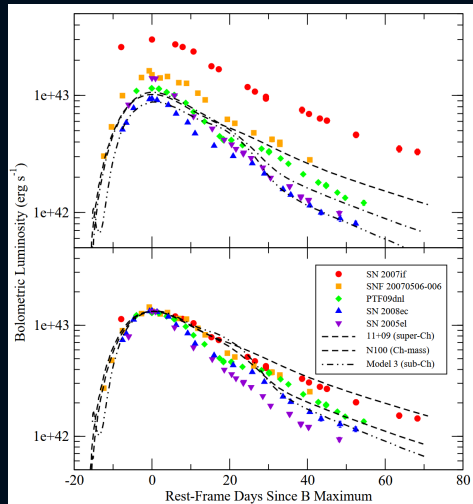


Figure 6: Observed bolometric light curves from SN in Nearby Supernova Factory dataset. Normalized light curves are plotted in the bottom panel.

Roche Lobe Overflow Mass Transfer

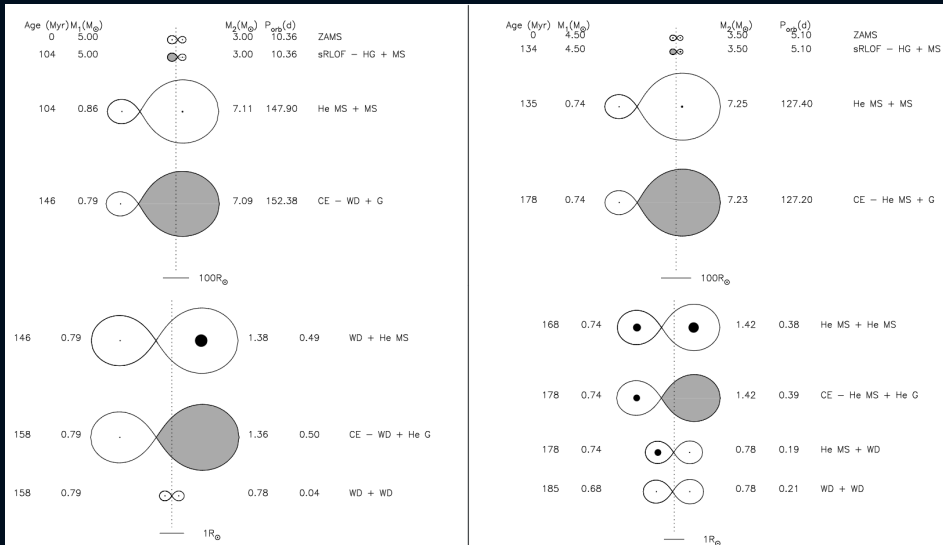


Figure 7: Evolutionary tracks for the merger of two CO WD exceeding the Chandrasekhar, with stable mass transfer after donor exceeds Roche lobe. [5]

D6 mechanism

- Dynamically driven, double degenerate, double detonation (D6)
 - Dynamically driven: mass ratio $\gtrsim 0.2$
 - Double degenerate: WD merger
 - Double detonation: Outer layer of helium detonation, triggers carbon ignition
- Shen *et al.* observes 3 runaway WDs which are plausibly driven by D6 mechanism

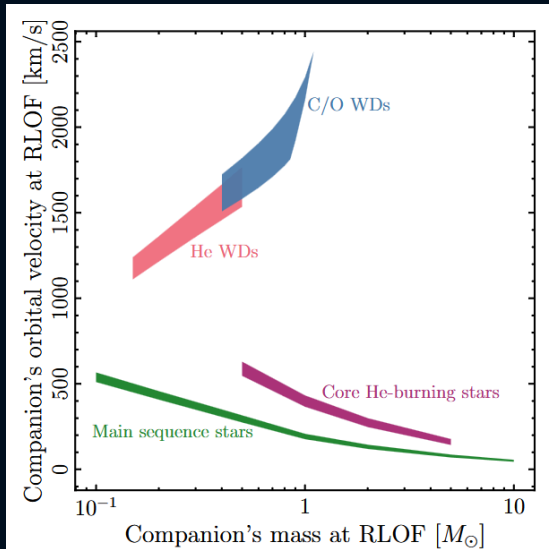


Figure 8: Orbital velocity of companion as a function of companion mass [6].

3D hydrodynamical simulations of D6 merger

- Primary massive WD ($1M_{\odot}$) typical secondary donor ($0.6M_{\odot}$).
- $0.01M_{\odot}$ He on surface.
- Mass transfers from donor \rightarrow accretor, induce Kelvin-Helmholtz instabilities.
- Turbulent heating yields a detonation, propagates through outer layer.
- Adaptive mesh with highest resolution of 17km to capture shocks and detonation fronts.
 - FLASH
 - Refine when cell exceeds 5×10^{26} g

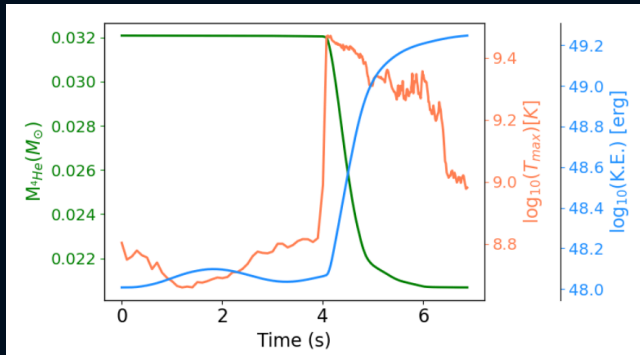


Figure 9: Plot of ${}^4\text{He}$ mass, maximum temperature, and total kinetic energy for a D6 merger. Helium ignition occurs around time $t \approx 4.1$ s and the detonation front circles the star around $t \approx 6$ s. [7].

Simulation Results

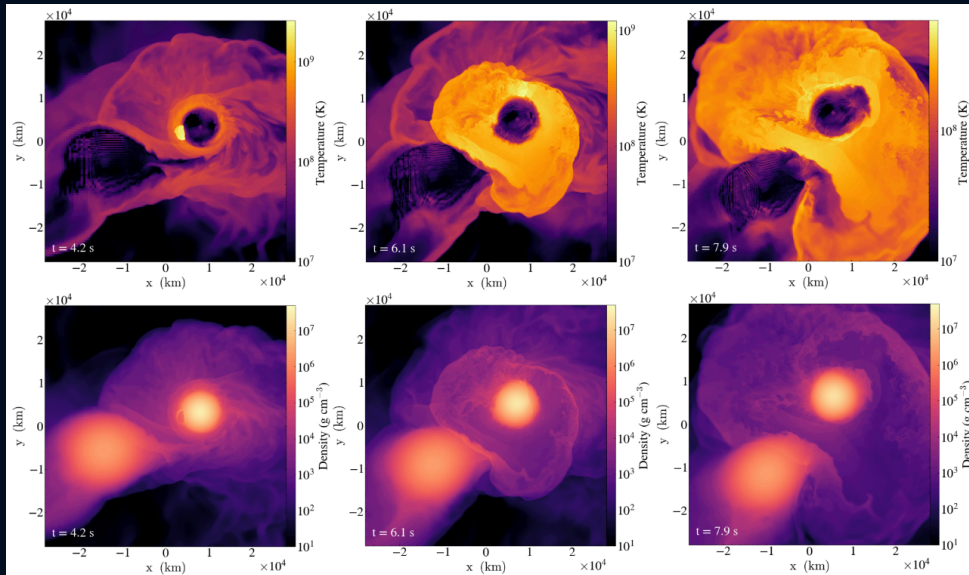


Figure 10: Temperature and density on $z = 0$ slice during and after He detonation [7].

Simulation Results

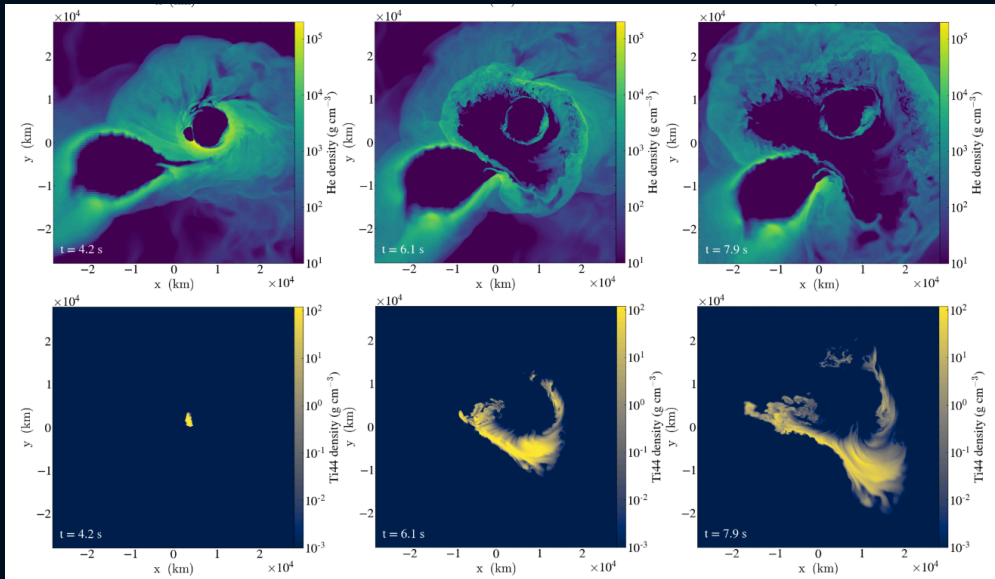


Figure 11: ${}^4\text{He}$ and ${}^{44}\text{Ti}$ density on $z = 0$ slice during and after He detonation [7].

Simulation Results

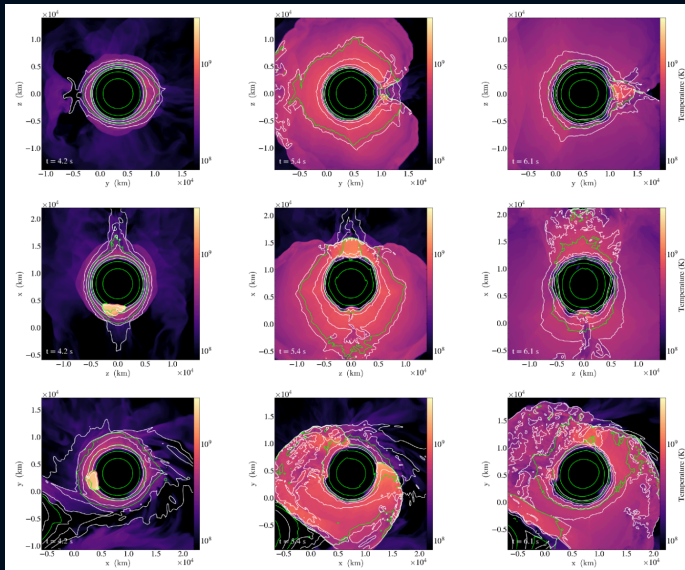


Figure 12: Density (white) and pressure (lime) overlaid on temperature along $X = 0$, $Y = 0$, and $Z = 0$ for each row [7].

Nucleosynthesis

Species	Bound Mass (M_{\odot})	Unbound Mass (M_{\odot})
${}^4\text{He}$	1.6×10^{-2}	4.68×10^{-3}
${}^{12}\text{C}$	6.32×10^{-1}	3.371×10^{-3}
${}^{16}\text{O}$	9.41×10^{-1}	1.515×10^{-3}
${}^{20}\text{Ne}$	2.572×10^{-3}	3.473×10^{-4}
${}^{24}\text{Mg}$	2.58×10^{-3}	5.17×10^{-4}
${}^{28}\text{Si}$	5.73×10^{-3}	2.693×10^{-3}
${}^{32}\text{S}$	2.144×10^{-3}	1.435×10^{-3}
${}^{36}\text{Ar}$	2.011×10^{-3}	1.988×10^{-3}
${}^{40}\text{Ca}$	1.574×10^{-3}	2.698×10^{-3}
${}^{44}\text{Ti}$	7.02×10^{-5}	1.567×10^{-4}
${}^{48}\text{Cr}$	5.24×10^{-7}	1.262×10^{-6}
${}^{52}\text{Fe}$	1.553×10^{-9}	4.03×10^{-9}

Figure 13: Bound and unbound nucleosynthesis yield for important species [7]. Total bound mass is $1.606M_{\odot}$ and unbound is $1.9 \times 10^{-2}M_{\odot}$.

Conclusions

- Carbon core detonation fails for these masses, yielding a faint nova-like transient.
- Disrupts donor, eventually leading to a classical double-degenerate merger.
- Implies that relatively few SN Ia are driven by the D6 mechanism, corroborated by Shen *et al* [6] who observe few hypervelocity WDs.
- ^{44}Ti provides a metric differentiating various progenitor scenarios

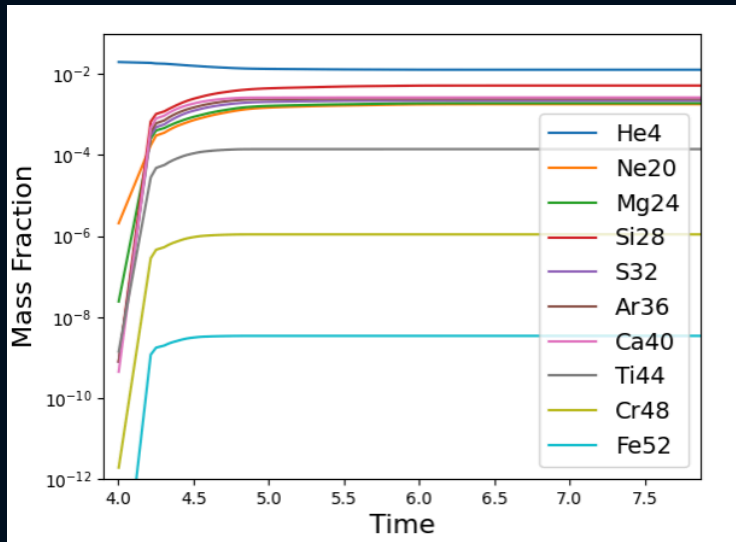


Figure 14: Nucleosynthetic abundances after D6 event [7].

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