Titanium-Powered Type Ia Supernovae and Remnants: Differentiating Between Type Ia Supernovae Progenitors with ^{44}Ti

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Double-degenerate White Dwarf Mergers

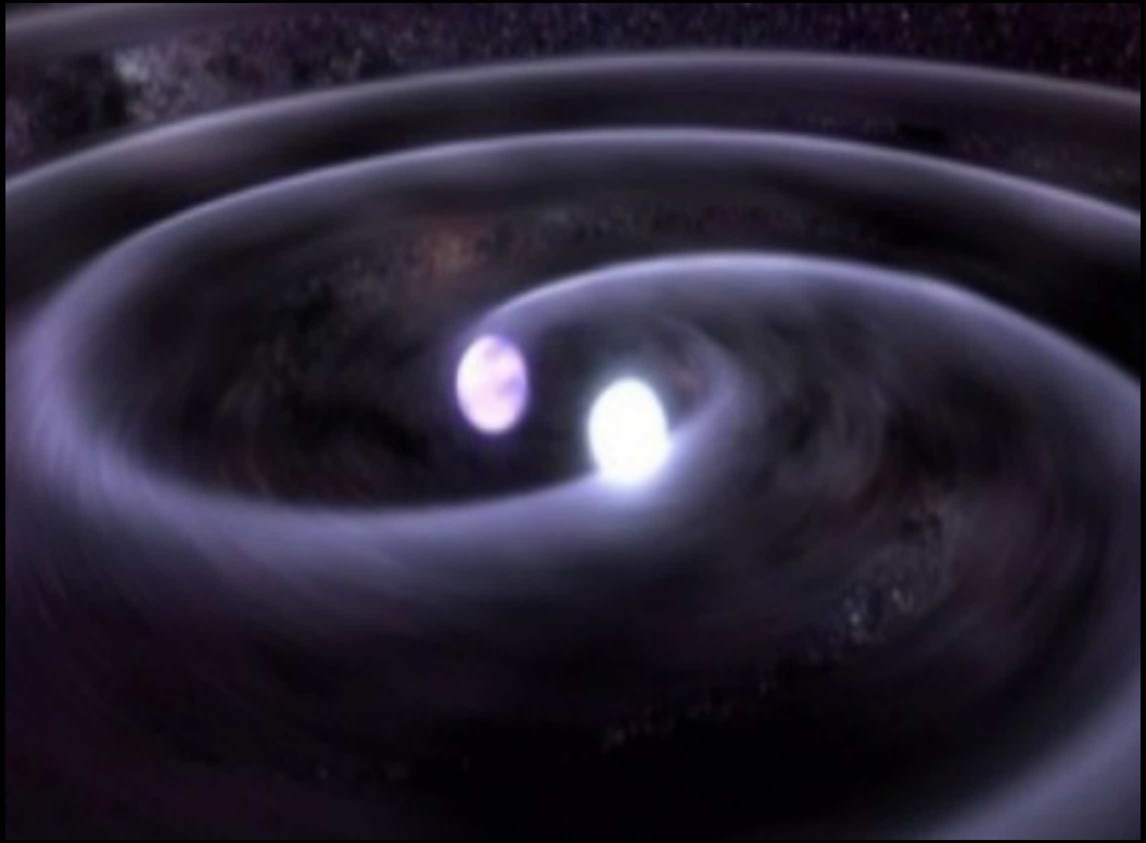


Image Credit: GSFC/D. Berry

Dynamically Driven Double-degenerate Double-detonation (D6)

- Accretion leads to helium detonation on primary
- Convergence of helium detonation front leads to second detonation in core

Key Questions Concerning D6

- Under what conditions does the core detonate, leading to a SN Ia?
- Under what conditions does the core fail to detonate?
- What are the signatures of surface helium detonation?

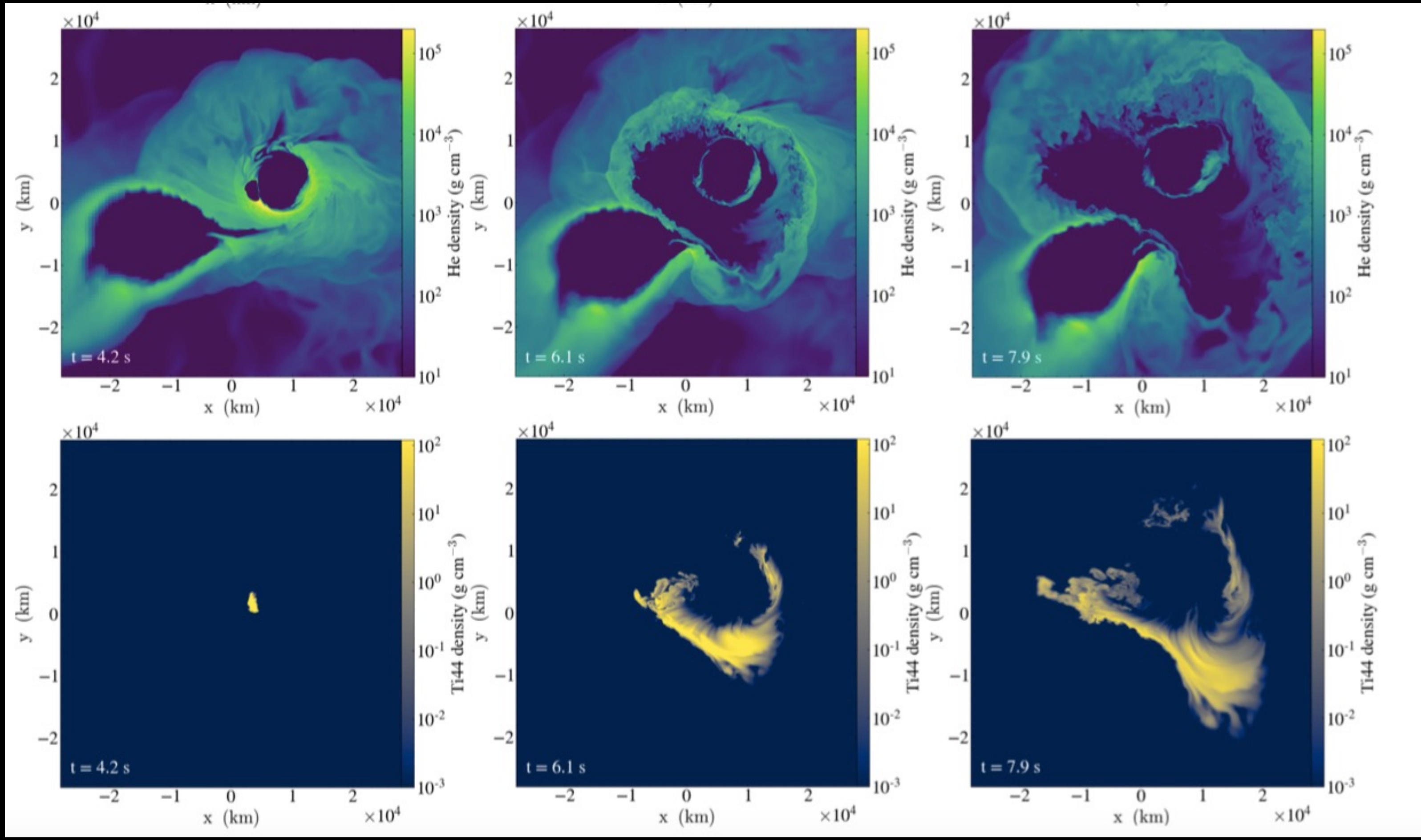
^{44}Ti in Recent Simulations

^{44}Ti in successful D6 = $1.5 \times 10^{-3} M_\odot$

(Pakmor R. et al., 2022, MNRAS, doi:10.1093/mnras/stac3107)

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

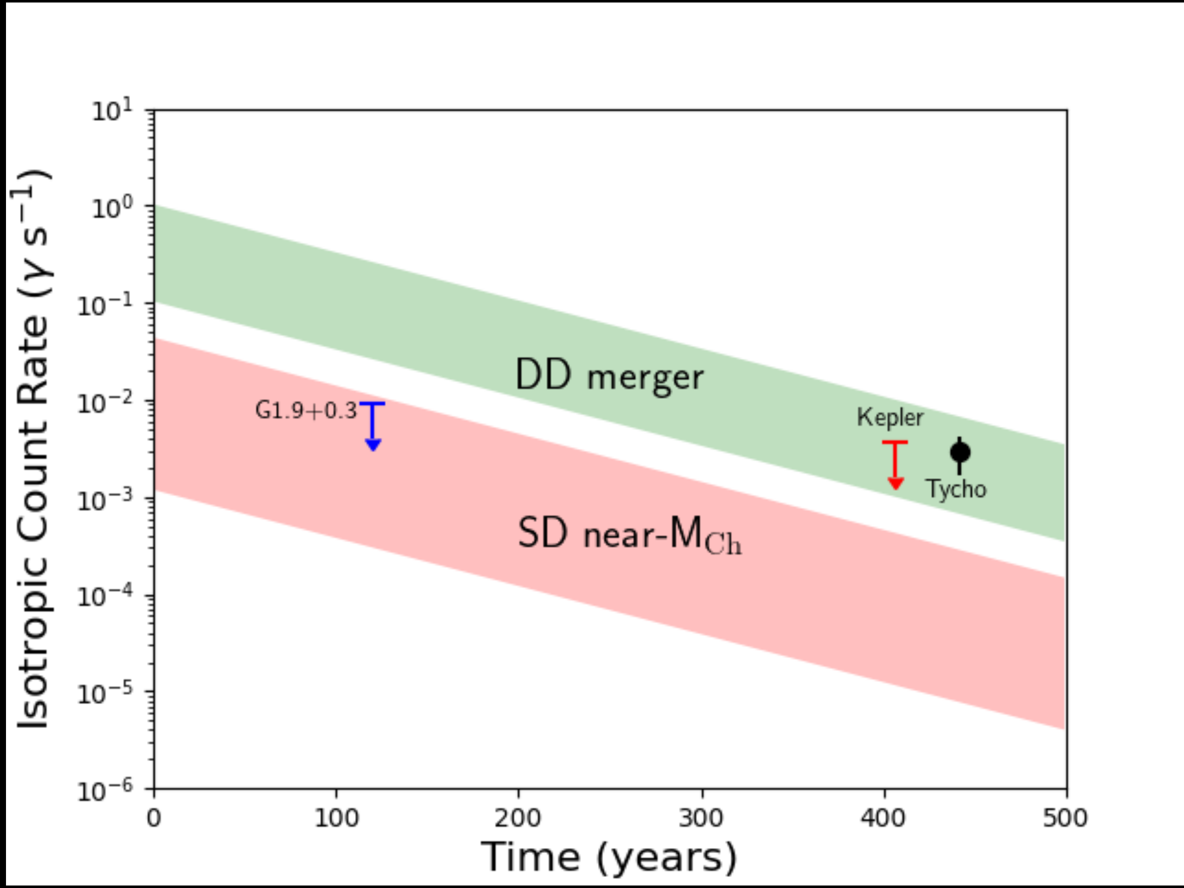
(Roy+Kosakowski et al., 2022, ApJL, 932, L24, doi: 10.3847/2041-8213/ac75e7)



(Roy+Kosakowski et al., 2022, ApJL, 932, L24, doi: 10.3847/2041-8213/ac75e7)

Detection of ^{44}Ti from Galactic SNRs in Gamma Rays

- Kepler
- G1.9+0.3
- Tycho



Inferred isotropic photon count rate ($4\pi \times F_\gamma \times d_{kpc}^2$)

(Kosakowski et al., 2022, arXiv:2210.10804, submitted to MNRAS)

Gamma Ray Flux

$$F_\gamma = \frac{8.21 \times 10^{-3} M_4 \exp\left(\frac{-t}{87.7yr}\right)}{d_{kpc}^2} \gamma \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

single degenerate (SD) near-M$_{Ch}$:

[^{44}Ti] = $1.15 \times 10^{-6} - 4.25 \times 10^{-5}$ M$_\odot$

(Leung S.-C., Nomoto K., 2018b, ApJ, 861, 143)

Late-time Light Curves

- ➢ SN2019ehk = Ca-rich transient

- ➢ SN2011fe = SN Ia

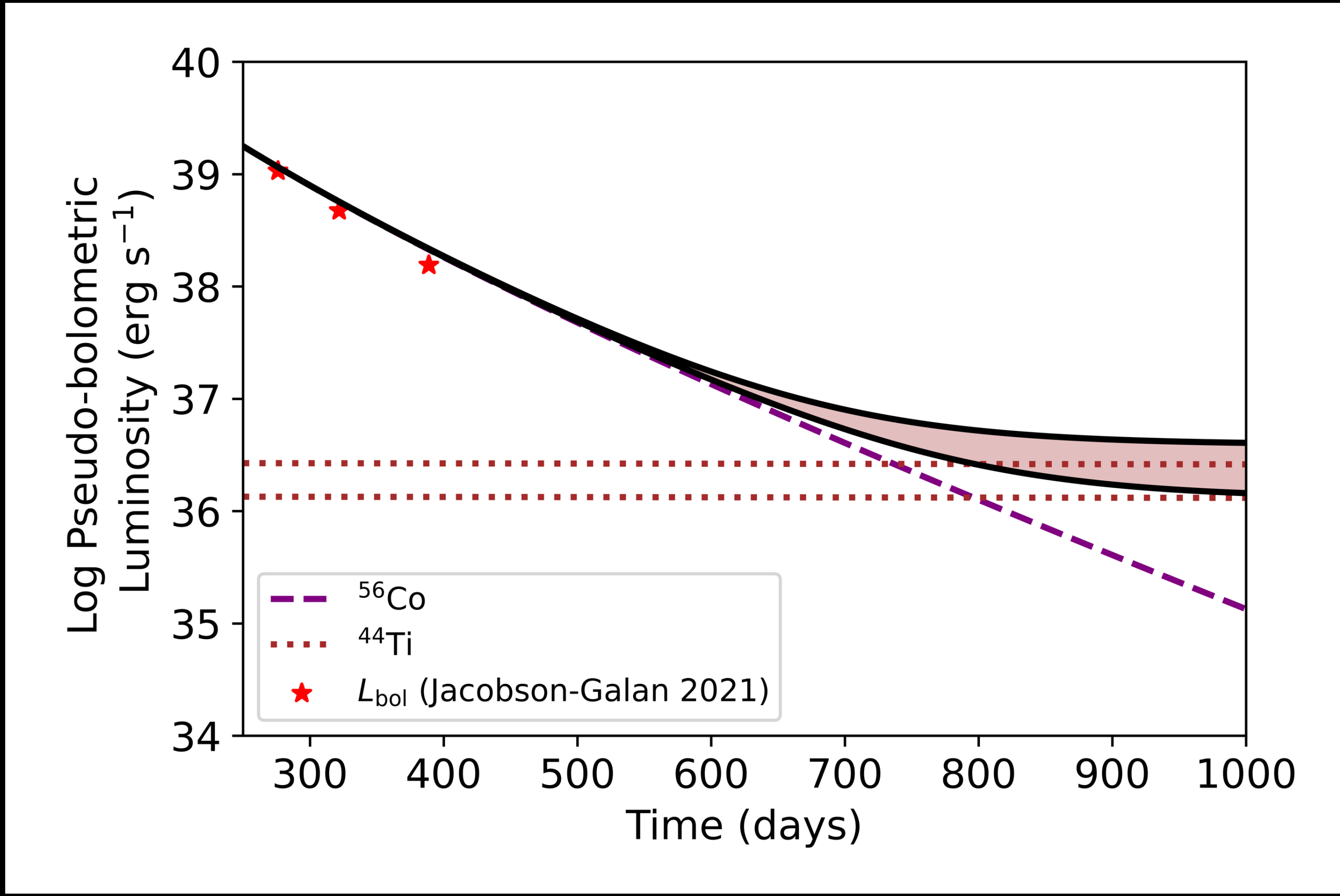
$L(t) = S(t)_{^{56}Co} + S(t)_{^{44}Ti}$

(Cappellaro et al. 1997, A&A, 328, 203;
Jacobson-Galán W. V., et al., 2021, ApJ, 908, L32)

^{44}Ti contribution: $S(t)_A = M(A)\ \varepsilon_A e^{-\lambda_A t}$

$$\frac{M(B)}{M(A)} > \frac{\lambda_A \varepsilon_A}{\lambda_B \varepsilon_B} \Rightarrow \begin{cases} \dfrac{M(^{44}\mathrm{Ti})}{M(^{57}\mathrm{Co})} > 115 \\ \dfrac{M(^{44}\mathrm{Ti})}{M(^{55}\mathrm{Fe})} > 8.19 \end{cases}$$

^{44}Ti Dominated SN2019ehk



(Kosakowski et al., 2022, arXiv:2210.10804, submitted to MNRAS)

➢ Light curve will be powered by ^{44}Ti decay after 740 – 800 days (~2.0 – 2.2 yrs)

Yields Used

- **$[^{56}Co] = 2.8 \times 10^{-2}\ M_\odot$**

(Jacobson-Galán W. V., et al., 2021, ApJ, 908, L32)

- **$[^{44}Ti] = 7.34 \times 10^{-3} - 1.46 \times 10^{-2}\ M_\odot$**

(Zenati Y., et al., 2022, arXiv e-prints, p. arXiv:2207.13110)

SN 2011fe

$$L(t) = S(t)_{^{56}\mathrm{Co}} + S(t)_{^{44}\mathrm{Ti}} + S(t)_{^{57}\mathrm{Co}} + S(t)_{^{55}\mathrm{Fe}}$$

Estimate for when radioactive decay will be dominated by ^{44}Ti

- Double detonations: $(11.0 - 26.6)$ years
- Double-degenerate mergers: $(12.3 - 21.9)$ years
- Single-degenerate Near-M_{Ch} : $(25.5 - 40.5)$ years

More detailed calculations including recombination effects need to be done!

Conclusions

- Gamma ray flux: we find the Tycho detection to be consistent with a double-degenerate merger, while the upper bound for G1.9+0.3 is consistent with a single degenerate near-M_{Ch} event and rules out a double-degenerate merger. Kepler's upper bound is consistent with either of the two channels.

- Predict the light curve of SN 2019ehk will be powered by ^{44}Ti decay after $\sim(740 - 800)$ days

- Suggest SN 2011fe might become dominated by ^{44}Ti decay at different time scales depending on whether it was a a double detonation ($(11.0 - 26.6)$ years), double-degenerate merger ($(12.3 - 21.9)$ years), or a single-degenerate near-M_{Ch} explosion ($(25.5 - 40.5)$ years)