Type Ia Supernova Archaeology: Searching for the relics of progenitors past

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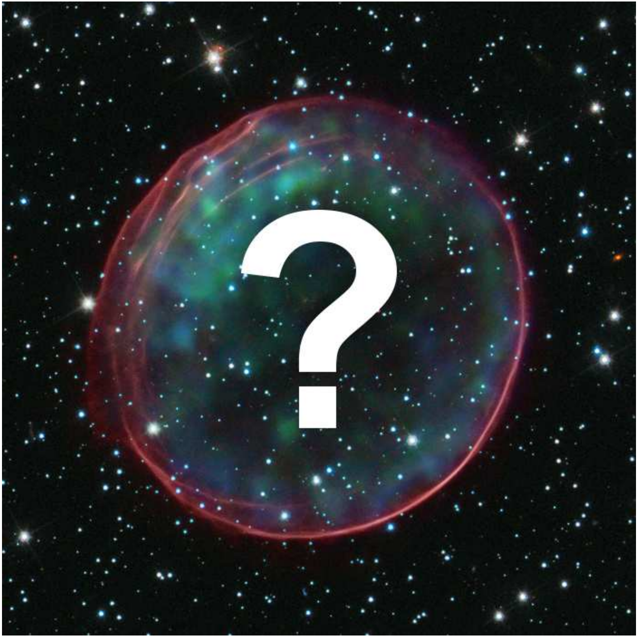
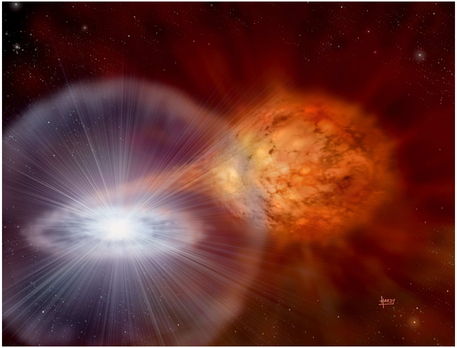
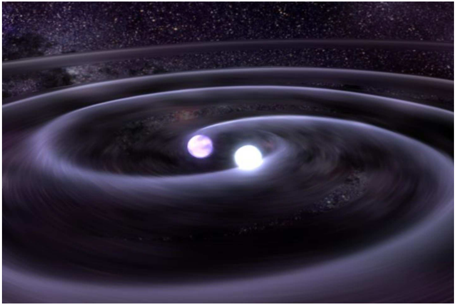
With Marat Gilfanov, Armin Rest, Alejandro Clocchiatti, Lev Yungelson, Jonas Johansson, Marc Sarzi, Hai-liang Chen, et al.



What **could** be the progenitors of SNe Ia?



Single Degenerate



Double Degenerate

What **could** be the progenitors of SNe Ia?

Observational diagnostics

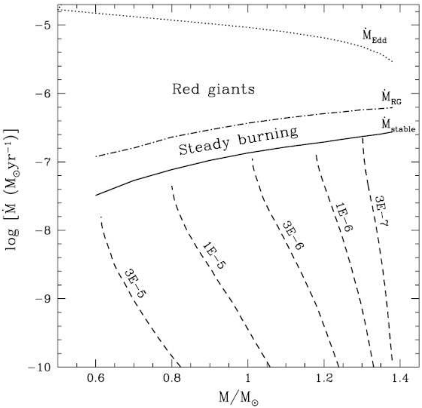
Single Degenerate channel

- Recurrent novae
- Optically-thick winds?
- Supersoft sources (SSSs)

  $L_{bol} \approx 10^{37} - 10^{38}$ erg/s
  $T_{eff} \approx 10^5 - 10^6$ K
  $\sim$ blackbody spectra

Double Degenerate channel

- None of the above?
- Mergers could eject matter, undergo short SSS phase prior to explosion



White dwarf accretion regimes
Nomoto et al. (2007)

What **could** be the progenitors of SNe Ia?

Upper limits from X-rays

Individual Objects

- Archival Chandra data can place limits on soft X-ray luminosity in $\sim$ few years prior to explosion (e.g., Nielsen et al.)
- Only most recent, nearby SNe Ia. Need to be lucky!
- Most constraining for higher temperatures than seen for most observed SSSs

Populations

- Constrain **integrated** emission from populations (Gilfanov & Bogdan (2010), Di Stefano (2010))
- For any single degenerate population: $\mathrm{L_{bol,tot}} \approx \epsilon \mathrm{X} \Delta \mathrm{M} \dot{\mathrm{N}}_{\mathrm{Ia}}$
- Need to account for lower temperatures, possibly additional local obscuration

What **could** be the progenitors of SNe Ia?

What about searching for ISM ionized by these high-temperature sources?

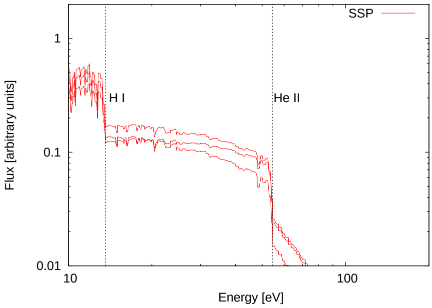
- Accreting, nuclear-burning WDs should also be strong ionizing sources through much of their growth to $\mathrm{M_{Ch}}$
- If steadily accreting, for typical SSS temperatures we expect individual nebulae to have strong He II, [O III], [O I] emission (e.g., CAL 83, and see Rappaport et al. (1994))
- How do nuclear-burning white dwarfs compare with other ionizing source populations?
    - In star-forming galaxies, expect O stars to easily dominate ionization budget
    - In passively-evolving (retired) early-type galaxies, less competition

SNe Ia progenitors at late delay times

The ionized gas in passively-evolving early-type galaxies

Low-Ionization Emission Line Regions (LIERs)

- Elliptical galaxies have warm (T $\approx 10^4$K) ISM (e.g., SAURON, CALIFA)
- Extended (kiloparsecs) LINER-like emission
- Often in smooth, disky distribution (covering fraction $\sim$1/2, e.g., ATLAS 3D), although other morphologies seen as well

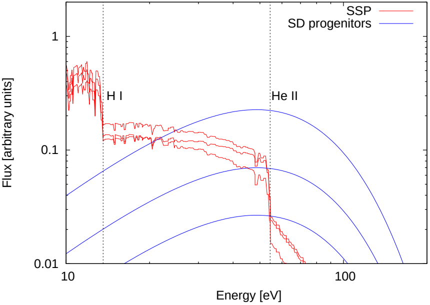


Simple stellar population (SSP)
Bruzual & Charlot (2003)

SNe Ia progenitors at late delay times

The single degenerate channel as a population of ionizing sources

- Should see strong He II 4686Å, [O I] 6300Å emission (Woods & Gilfanov (2013))
- He II is a good diagnostic, but intrinsically weak line $\rightarrow$ Need to stack carefully selected retired galaxy spectra (for details, see Johansson, Woods, et al. (2014))

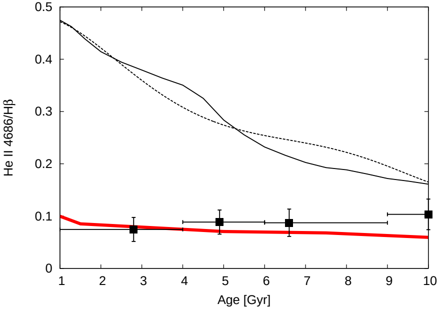


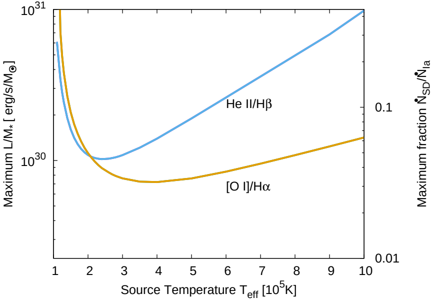
Inclusion of single degenerate population

SN Ia progenitors at late delay times

No room for hot SN Ia progenitors at late delay times

At late delay times (e.g., 1 Gyr $< t <$ 4 Gyr), we exclude $\gtrsim$10% hot single-degenerate progenitors

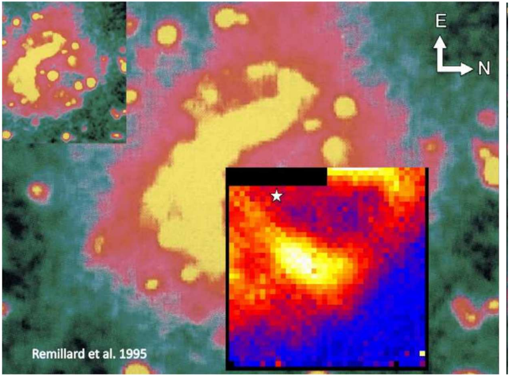




Johansson, Woods, et al. (2014), Woods & Gilfanov (2014), Johansson, Woods, et al. (2016)

Progenitors of individual SNe Ia in star-forming galaxies

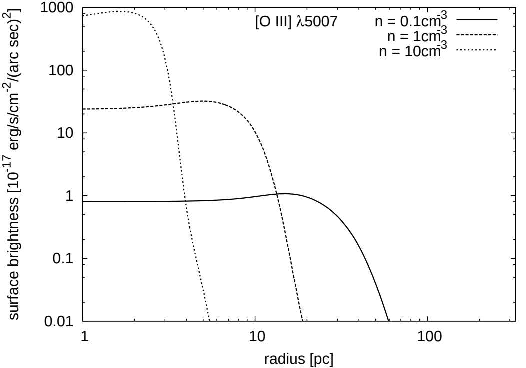
- What about individual sources?
- Most SSSs found without a nebula (Remillard et al. (1995))
- Unclear if this indicates sources have low average ionizing L, or little surrounding ISM



[O III] 5007Å image of the CAL 83 nebula. Remillard et al. (1995), with inset from Gruyters et al. (2012). Image size: 15 × 20 pc.

SN Ia “Archaeology”: Relic nebulae of past progenitors

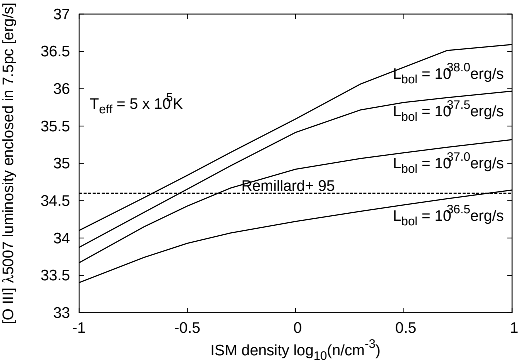
- Can detect nebulae surrounding individual sources (if sufficiently dense ISM)
- True even after explosion of SN Ia! (for ∼recombination time, 10^5 years!)



[O III] 5007Å surface brightness profiles for SSSs. Woods & Gilfanov (2016)

SN Ia "Archaeology": Relic nebulae of past progenitors

- But, never put to much use (except Graur+ 2014)
- Why? Remillard+ 1995 looked for nebulae around LMC SSSs, found only 1 out of 6
- But, not constraining for typical ISM densities!



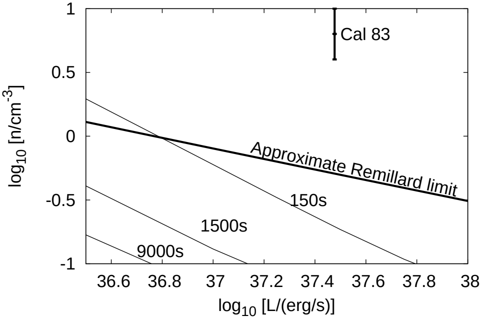
Woods & Gilfanov (2016)

SN Ia "Archaeology": Relic nebulae of past progenitors

- ISM composed of hot ($n_{ISM} \sim 10^{-2}\text{cm}^{-3}$), warm ($n_{ISM}$ $\sim$0.1–1cm^{-3}), and cold phases ($n_{ISM} \gtrsim$ 10cm^{-3})
- Filling factors of $\sim$45%, $\sim$45%, and $\sim$5% respectively
- Remillard et al. (1995) only constraining if $n_{ISM} \sim$ few cm^{-3}
- More detailed treatment in Woods & Gilfanov (2016) gives $\sim$18% probability of a SSS having a dense, CAL 83-like nebula

SN Ia "Archaeology": Relic nebulae of past progenitors

- Observations (with the Magellan Baade 6.5m telescope) of LMC SSSs, SN Ia remnants (PI: A. Clocchiatti)
- Important regardless of outcome!
  - No detections: No hot, luminous progenitor
  - Detection: Measure progenitor's L,T!



Woods & Gilfanov (2016)

Summary

- Many models of SN Ia progenitors predict a hot, luminous phase prior to explosion – can be strong ionizing sources!
- No contribution from "hot" (10^5K $\lesssim$ T $\lesssim$ 10^6K) single degenerate channel at late delay times ($\lesssim$10% of total rate, or no more than $\lesssim 0.01 M_\odot$ accreted if all SNe Ia were single degenerate)
- We can constrain (or hopefully measure!) the temperature and ionizing luminosity of the progenitors of individual, nearby SNe Ia by searching for faint, extended emission-line regions – underway now!