No Smoke from the Gun:

The Quest for Signatures of Type Ia Supernova Progenitors

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Overture: A Bit of Poetry

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From Monty Python's *Life of Brian* (1979):

Always look on the bright side of life

(...)

Always look on the bright side of death

Just before you draw your terminal breath

death ⇒
Type Ia Supernova
Explosion

terminal breath ⇒
mass loss from the
SN progenitor

$$\dot{M} = \frac{dM}{dt}$$

Type Ia SNe

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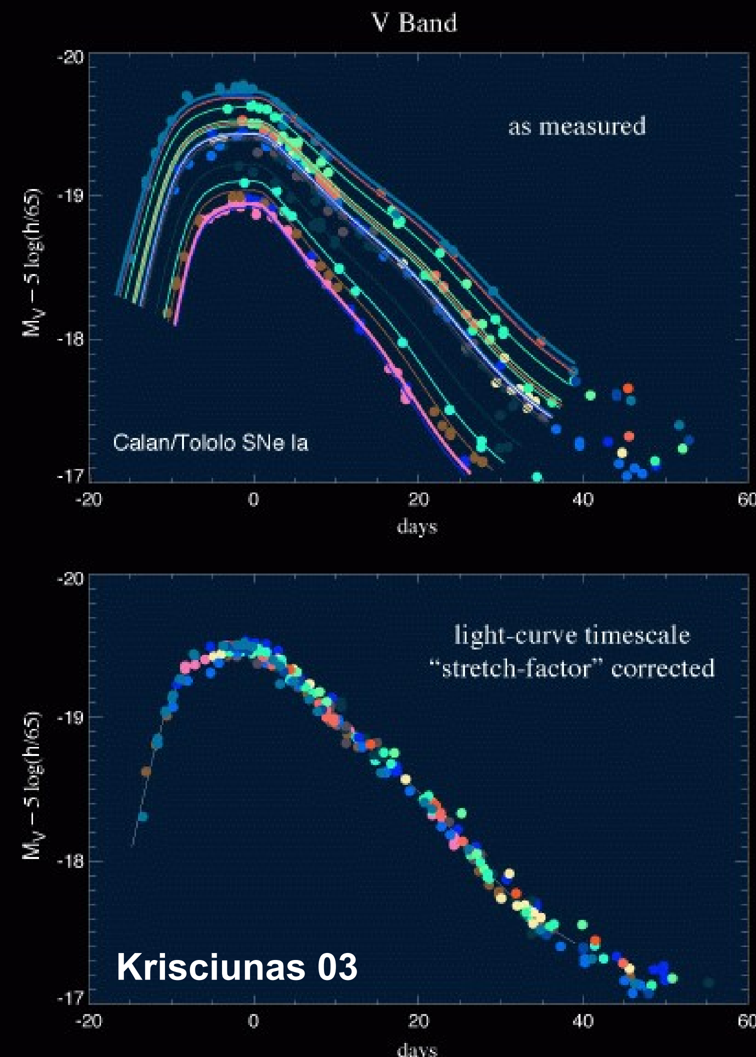
SN 1994D in
NGC 4526 (P. Challis)

Type Ia Supernovae (SNe) are the result of the thermonuclear explosion of a C+O white dwarf prompted by accretion in a binary system

REVIEWS: Branch et al. 95, PASP 107, 1019; Branch & Khokhlov 95, Phys. Rep. 265, 53; Hillebrandt & Niemeyer 00, ARA&A 38, 191.



- **Fundamentals are well understood**: energy budget, no H in spectra, rate of light curve decay.
- Some **key details remain obscure**: explosion mechanism, progenitor systems.
- **Light curves and spectra are strikingly uniform** ⇒ LC width / luminosity relation [Phillips 93, ApJ 4123, L105] ⇒ Cosmology.

Type Ia Progenitors: Two Populations?

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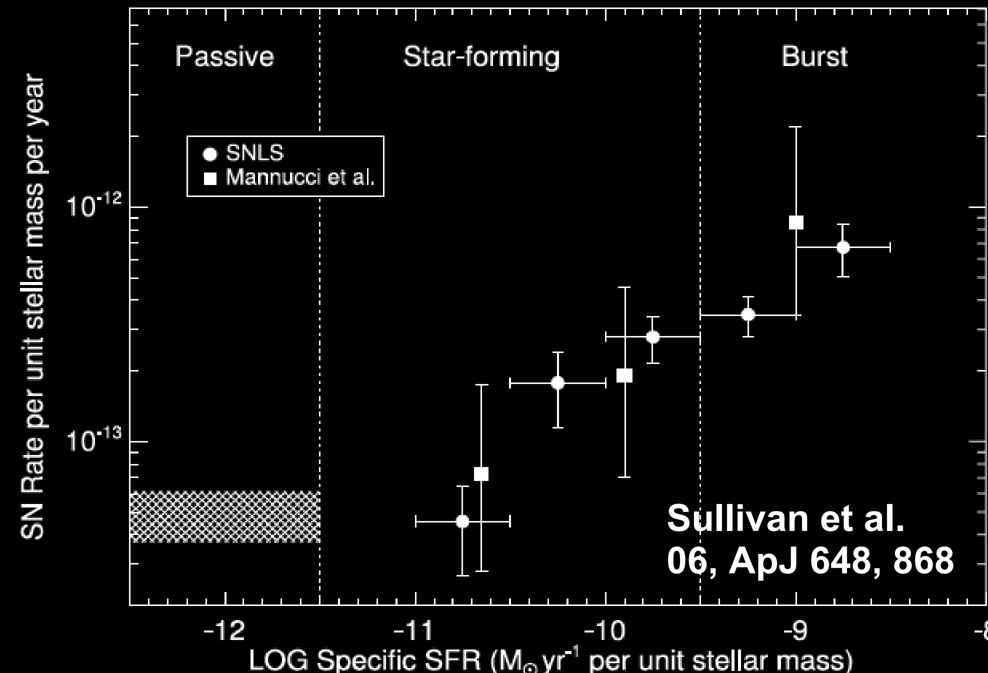
- **Type Ia SNe are the ONLY SNe observed in elliptical galaxies** ⇒ progenitors not necessarily associated with recent stellar formation.

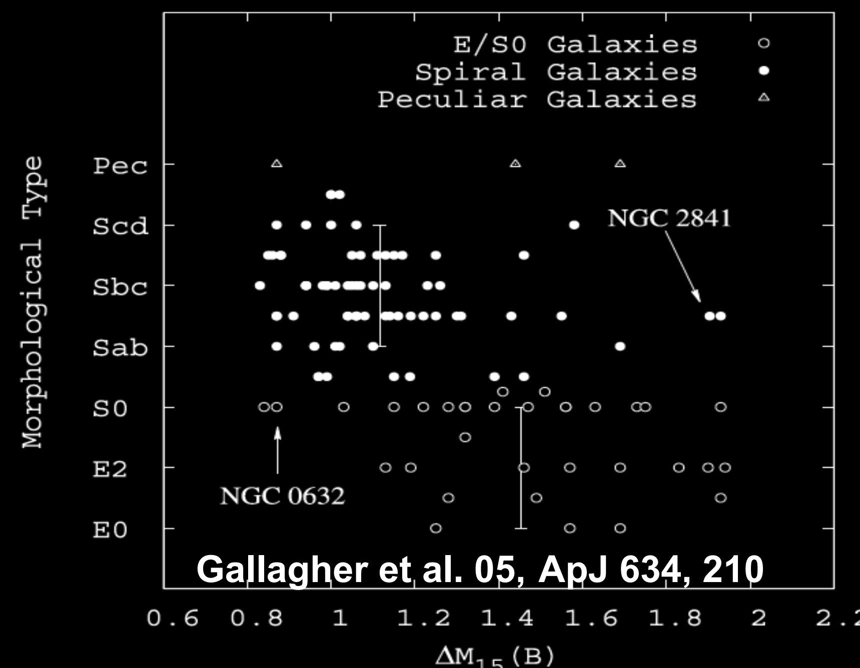
- Evidence for **TWO progenitor populations**: A+B models [Scannapieco & Bildsten 05, ApJ 629, L85]:

  - **'Prompt'** ⇒ 'younger' progenitors, rate ∝ star formation rate, brighter Type Ia SNe.

  - **'Delayed'** ⇒ 'older' progenitors, rate ∝ total stellar mass, dimmer Type Ia SNe.

- Both appear to follow the same Phillips relation!





Theoretical Scenarios

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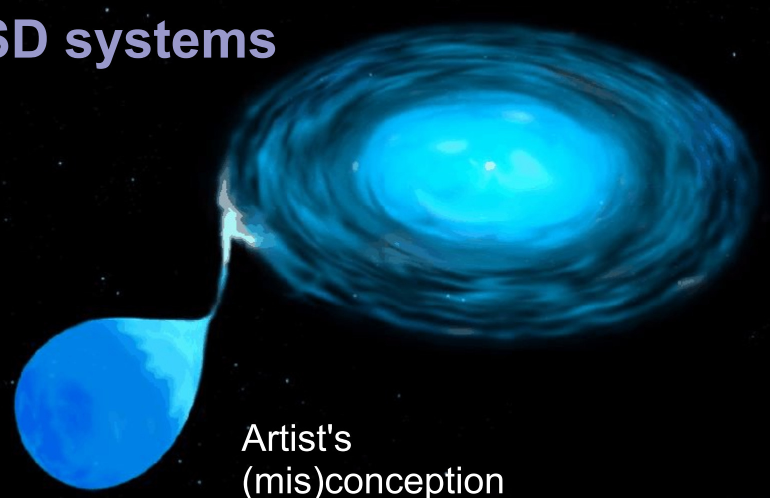
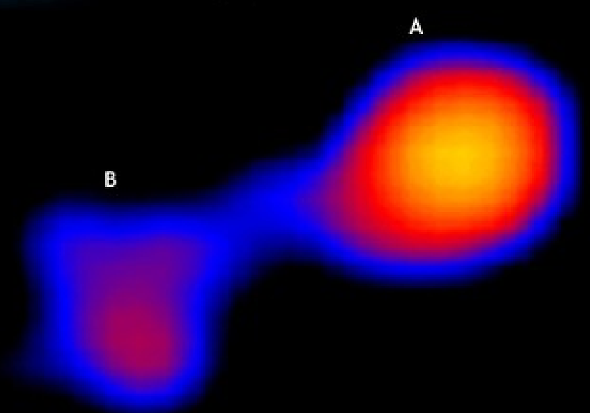
Depending on the nature of the **WD companion:**

- A normal star: **Single Degenerate** (SD) systems. Many known examples of WD binaries [Parthasarathy et al. 07, NewAR 51, 524]. Outflows: stellar winds, mass transfer, accretion disk.
- Another WD: **Double Degenerate** (DD) systems. Surprising lack of known examples [Napiwotzki et al 05, C.P.]. Explosion is uncertain [Guerrero et al. 04, A&A 413, 257] BUT Super-CH Type Ia [Howell et al. 06, Nat 443, 308]. No outflows if merging due to GW emission.

SD systems

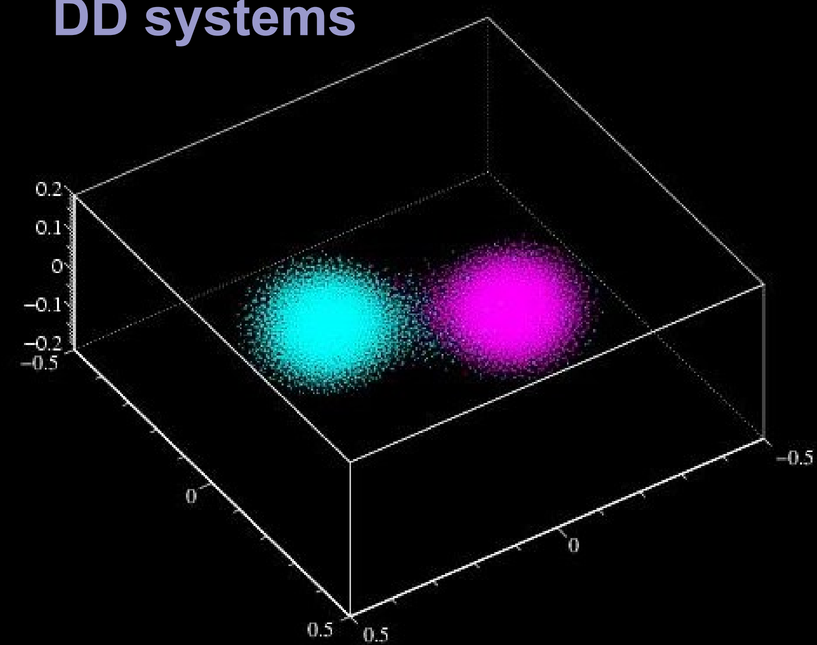


Artist's (mis)conception



Real thing: *Chandra* image of Mira (o Ceti) Karovska et al. 05, ApJ 623, L137

DD systems



Guerrero et al. 04, A&A 413, 257

Open Issues in SD Type Ia Progenitors

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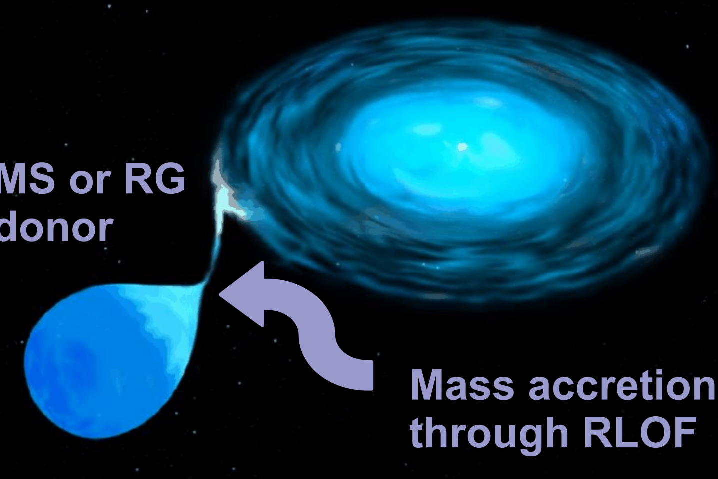
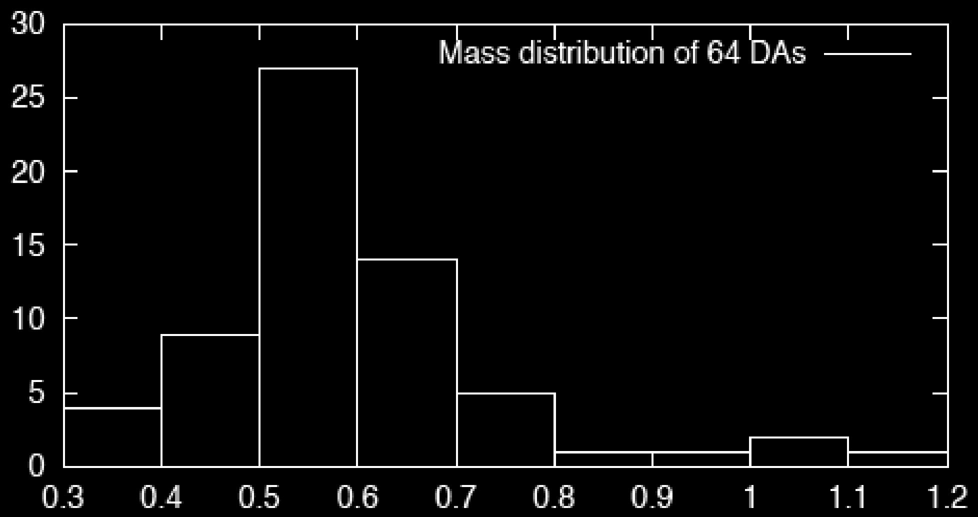
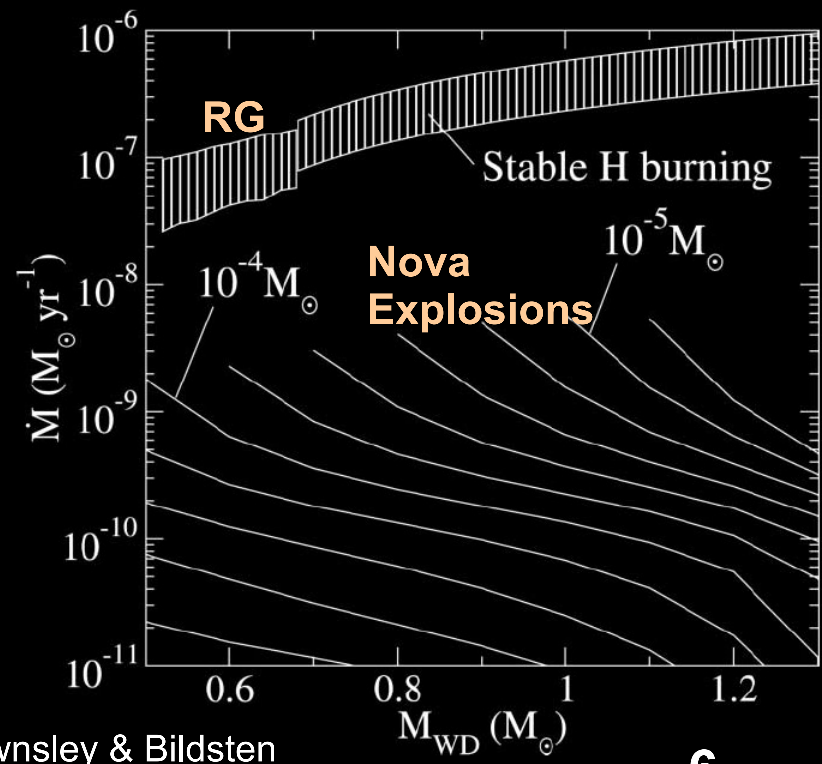
- **The viability of SD systems as Type Ia progenitors has not been proved!**
  - $M_{WD} \sim 0.6\ M_\odot$ and always $< 1.2\ M_\odot \Rightarrow$ Need to accrete at least $0.2\ M_\odot$ to reach $1.38\ M_\odot$.
  - H-rich matter from the companion must burn to C and O **QUIETLY** $\Rightarrow$ dM/dt has to be fine-tuned.





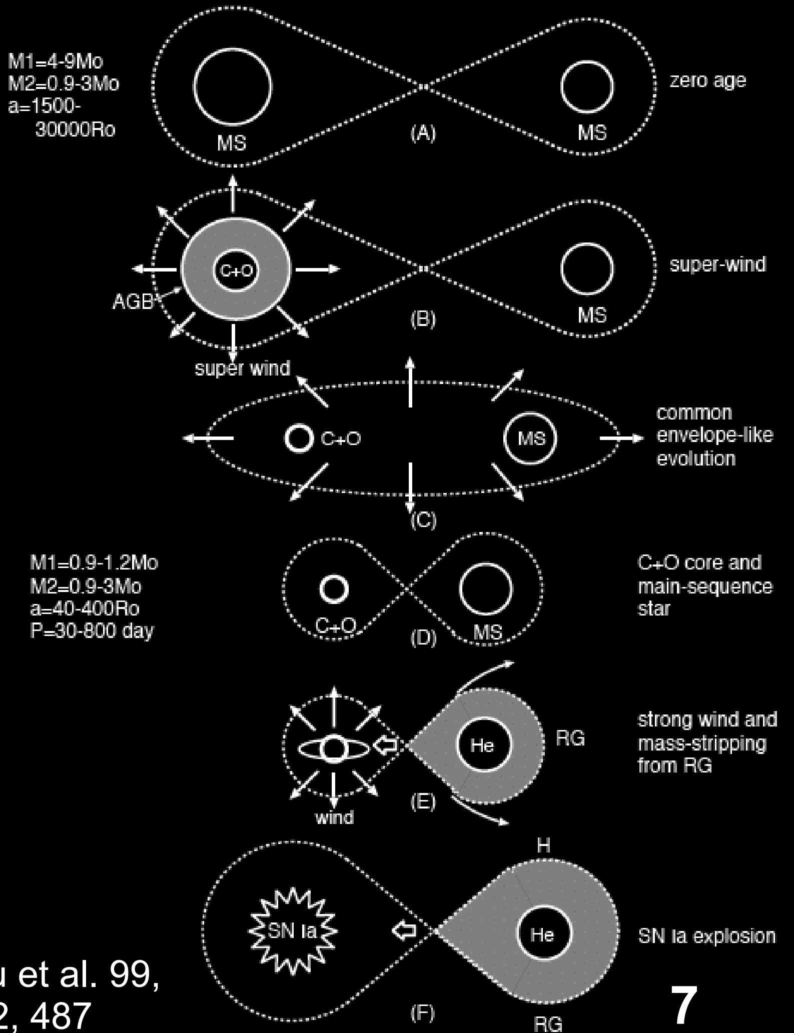
Homeier et al. 98, A&A 338, 563



Townsley & Bildsten 05 ApJ 628, 395

Accretion Winds
(Hachisu et al. 96, ApJ 470, L97)
The luminosity from the WD surface drives a fast, optically thick outflow that gets rid of the excess material.

- **Essential** for the evolution of Type Ia progenitors in the SD channel (only way to avoid a common envelope phase).
- The details of the binary evolution can be quite complex.
- RXJ0513.9-6951 and V Sge are systems with active accretion winds [Hachisu & Kato 03, ApJ 590, 445; ApJ 598, 527].
- Some authors claim that a H-accreting WD **cannot** grow to 1.38 $M_\odot$ [Cassisi et al. 98, ApJ 496, 376].



Hachisu et al. 99, ApJ 522, 487

SD SN Ia Progenitors: Accretion Winds

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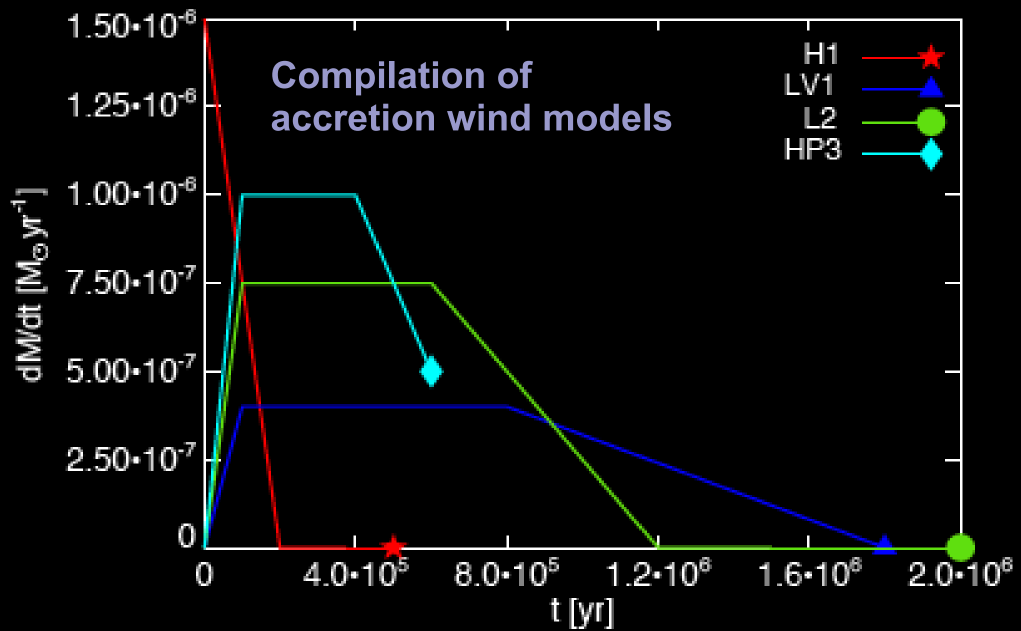
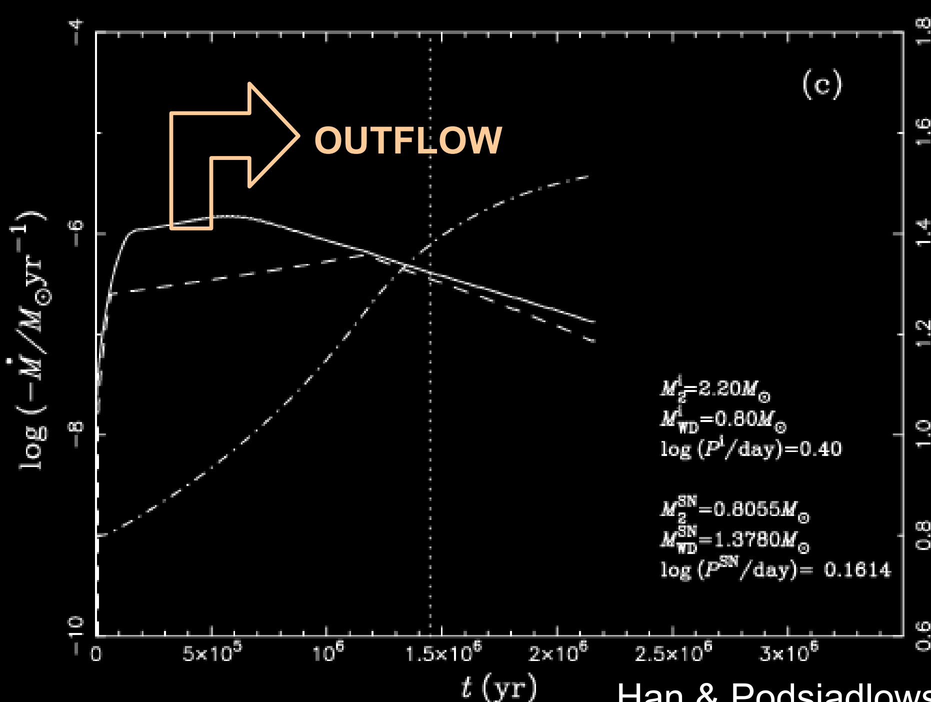
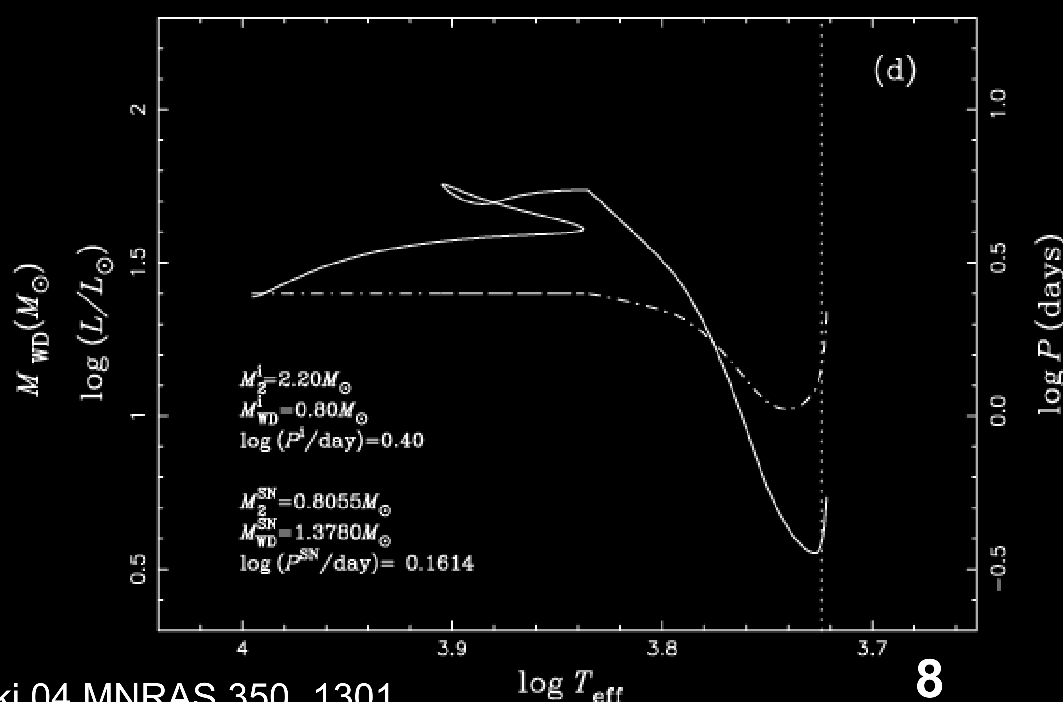
- All **evolutionary studies** of SD Type Ia progenitors include accretion wind outflows [Langer et al. 00, A&A 362, 1046; Han & Podsiadlowski 04, MNRAS 350, 1301, etc.].
- **Typical outflow scales:**
  - $dM/dt_{of} \sim 10^{-7}$ to $10^{-6}\, M_{\odot} yr^{-1}$.
  - $t_{of} \sim 10^{6}$ yr.
  - $u_{of} \sim 10^{3}$ km s^{-1}.
- **How does this shape the CSM?**







Han & Podsiadlowski 04 MNRAS 350, 1301

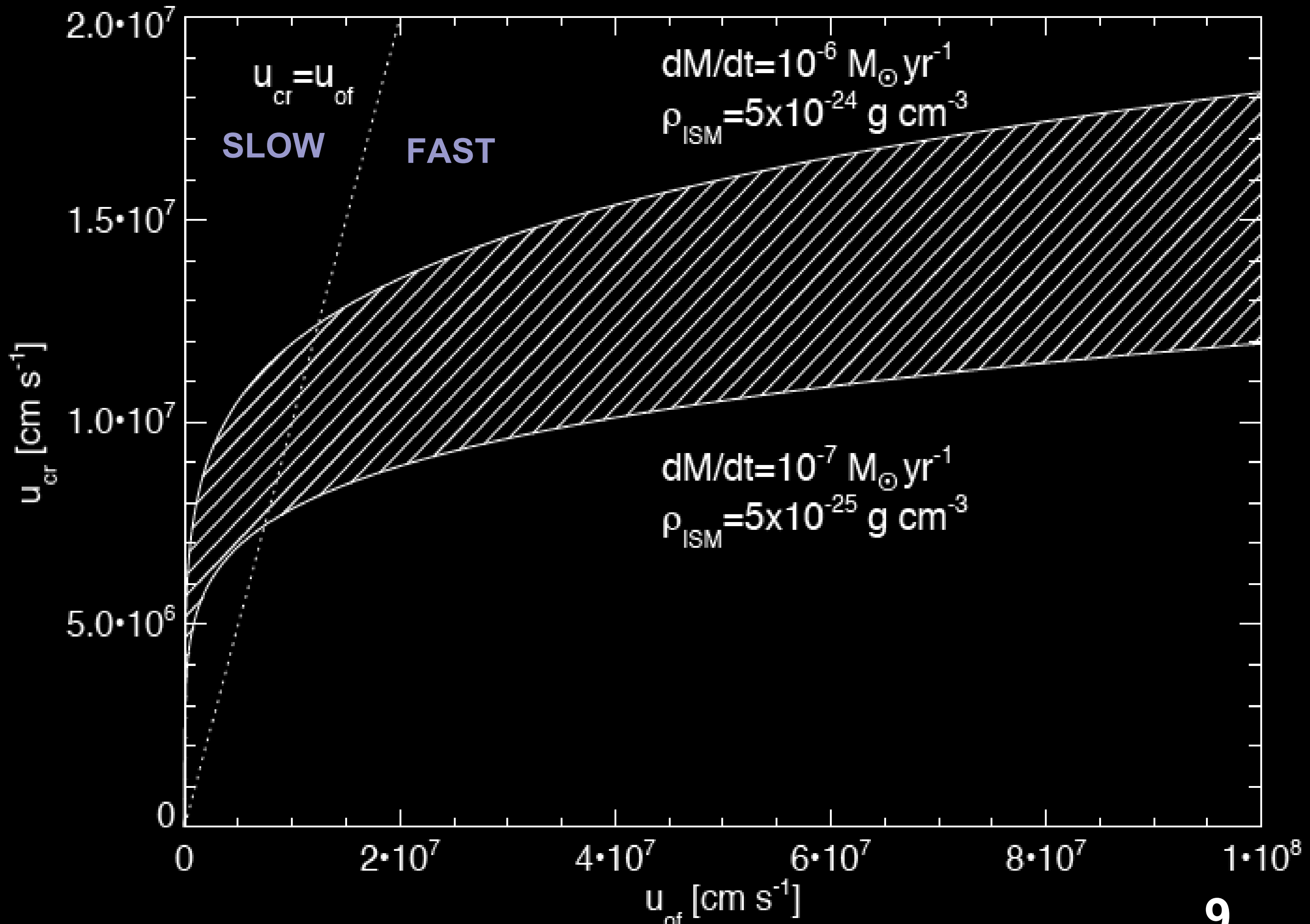
Shaping the CSM

• Outflows into the ISM: theory of stellar winds [Koo & McKee 92, ApJ 388, 93] ⇒ **critical outflow velocity u_{cr}**.

$$u_{cr} = 10^4 \left[\frac{\dot{M}_{of} u_{of}^2}{2} \frac{\rho_{ISM}}{\mu_H} \right]^{1/11}$$

$u_{of} > u_{cr}$ ⇒ fast
Radiative losses do not affect the shocked outflow. Cavity is energy-driven.

$u_{of} < u_{cr}$ ⇒ slow
Radiative losses affect the shocked outflow. Cavity is momentum-driven.

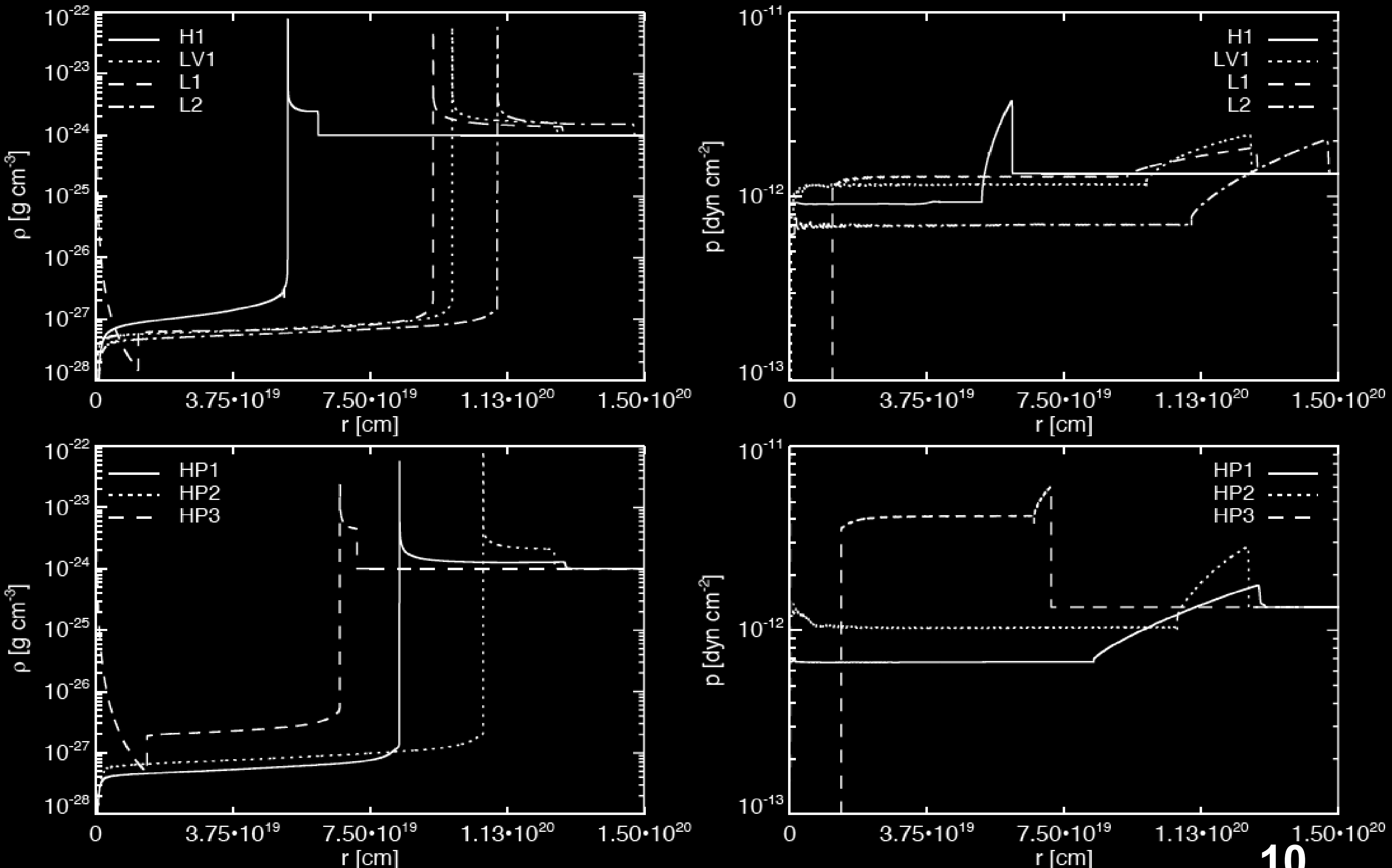


Shaping the CSM

- Fast, continuous accretion wind outflows expanding into the warm phase of the ISM excavate **large (~10^{20} cm) energy-driven cavities** (interstellar bubbles).
- Reasonable **variations of ρ_{ISM} and p_{ISM}** do not affect the cavities.

CSM configuration at the time of the SN explosion:

Note that most bubbles are pressure-confined!



SNRs in the CSM: Radii and Velocities

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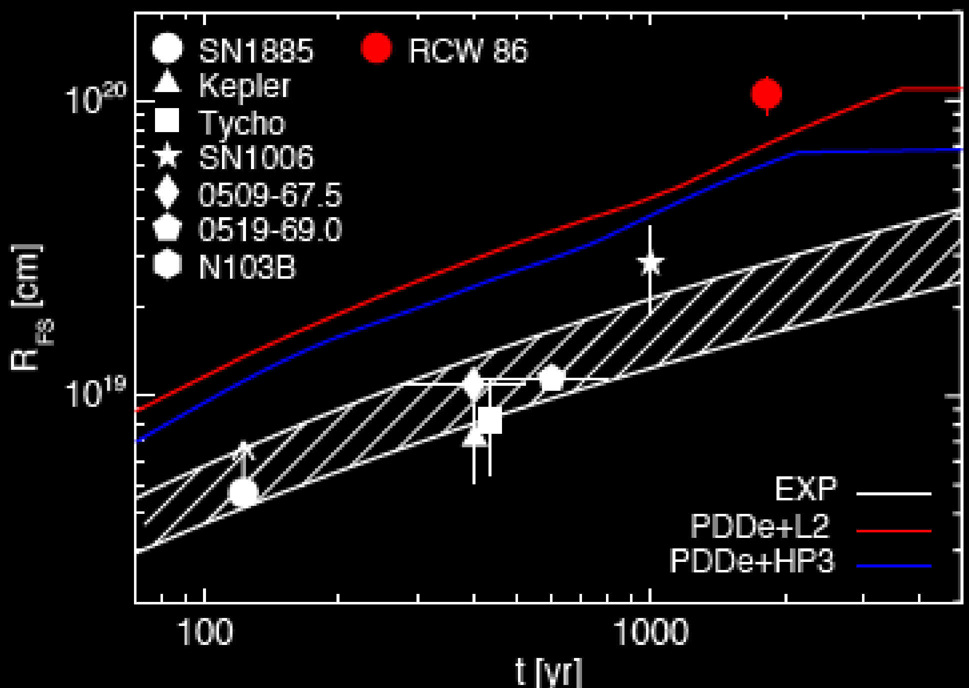
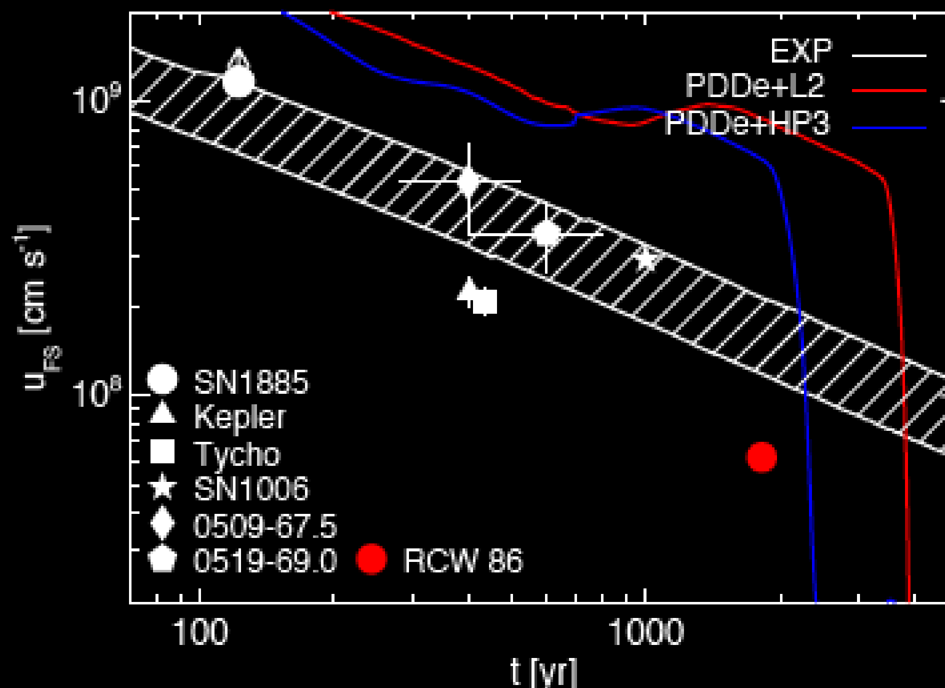
- The dynamics (FS radii and velocities) of SNR models expanding into accretion wind cavities are very different from the canonical uniform ISM interaction.
- **Models**: EXP+ISM (E_k=0.8 .. 1.4 foe; $\rho_{ISM}=5\times10^{-25}$ .. 5×10^{-24} g cm^{-3}); SNRs in accretion wind cavities (PDDe+L2, PDDe+HP3).
- **Data**: SNRs with reliable age estimates: historical (SN1885, Kepler, Tycho, SN1006), light echoes (0509-67.5, 0519-69.0, N103B) + RCW 86 (IF Type Ia SNR of SN185)





⇒ **Most SNRs are compatible with a uniform ISM** (not RCW 86)

SNRs in the CSM: Ionization Timescales

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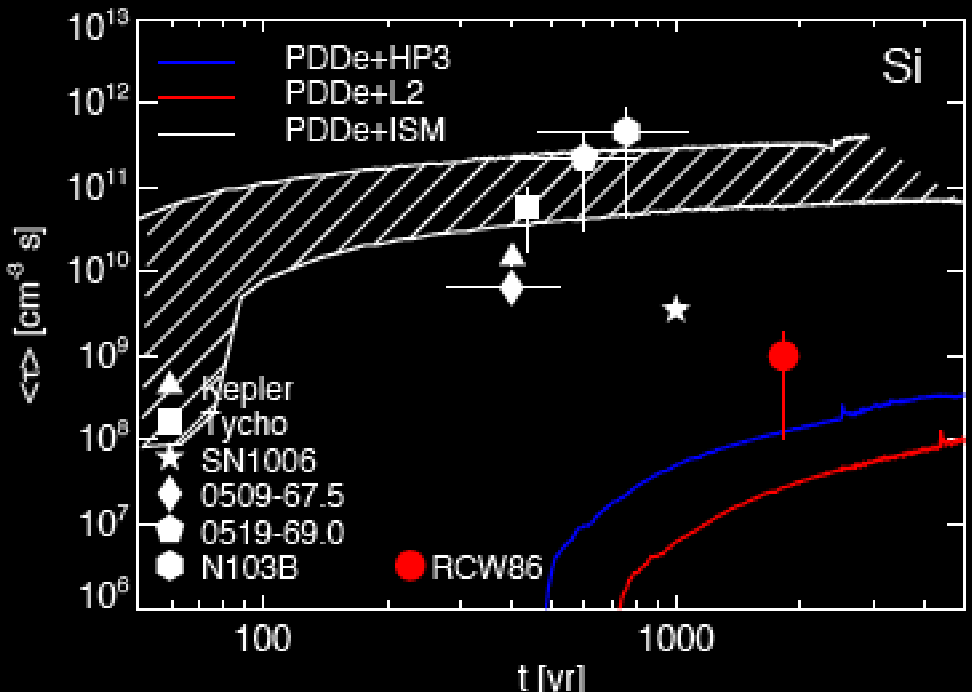
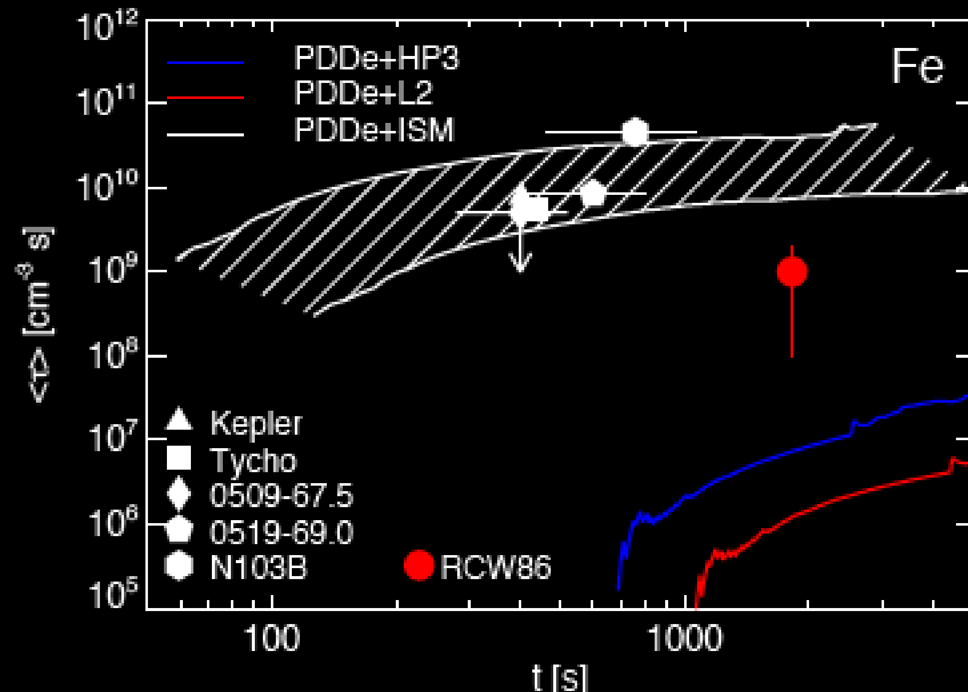
• A similar comparison can be performed using the **ionization timescale of the shocked ejecta**. Models: PDDe+ISM ($\rho_{ISM}=5x10^{-25}$ .. $5x10^{-24}$ g cm^{-3}); PDDe+L2; PDDe+HP3.

• In SNR models evolving inside large cavities, the SN ejecta expand to very low densities before any significant interaction can take place ⇒ low values for the ionization timescales of Si and Fe in the shocked ejecta.

• Spectral properties constrain the CSM structure independently of the dynamics.





⇒ **Most SNRs are compatible with a uniform ISM**, albeit with a larger spread (issues w/ PDDe). RCW 86 is again closest to the cavity models.

Progenitor Imprints in Type Ia SNRs?

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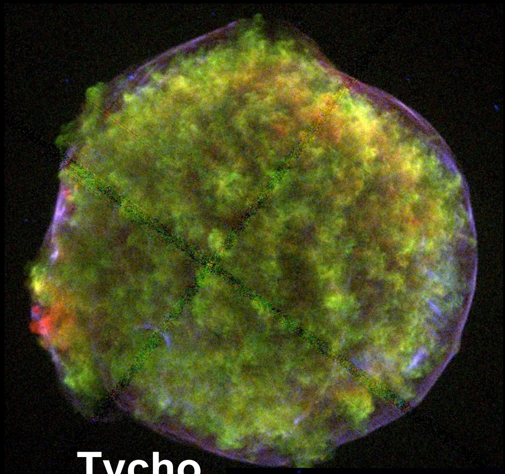
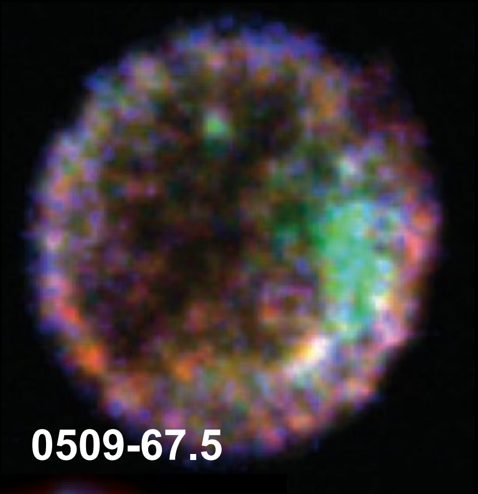
Most Type Ia SNRs show **no evidence for CSM interaction**



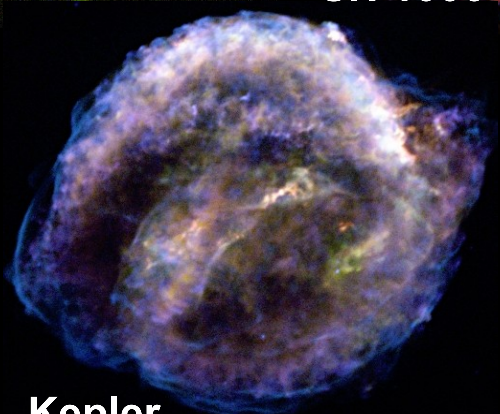
Tycho

SN 1006

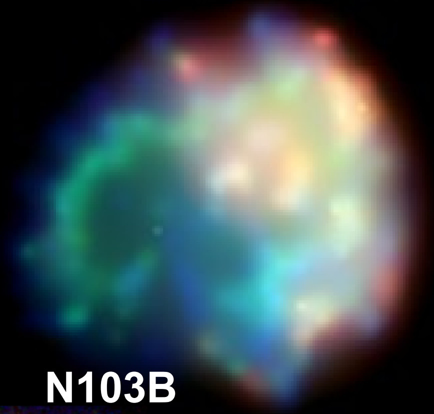


0509-67.5

A few (two!) Type Ia SNRs show **evidence for some kind of CSM interaction** (probably not accretion winds!)

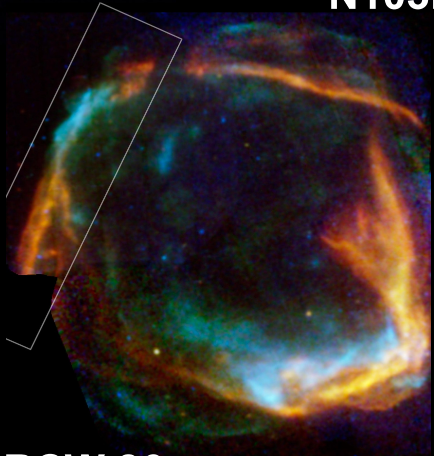


Kepler



N103B

There **might** be a population of Type Ia SNRs interacting with accretion wind bubbles! ⇒ RCW 86 (IF Type Ia SNR of SN 185)



RCW 86

Image Credits: Warren et al. 05, ApJ 634, 376; Hughes et al., in prep.; Warren & Hughes 04, ApJ 608, 261; Reynolds et al. 07, arXiv: 0708.3858.; Lewis et al. 03, ApJ 582, 770; Vink et al. 06, ApJ 648, L33

Conclusions

SNRs can provide valuable insights on the mass outflows from Type Ia SN progenitor systems [Badenes et al. 07, ApJ 662, 472]

- Fast accretion winds lead to large cavities around the Type Ia progenitors. Cavities are excavated by **mechanical luminosity** ⇒ bipolar and/or episodic outflows, thermal conduction, etc. are unlikely to change this.

- The existence of such cavities is incompatible with the fundamental properties (forward shock dynamics, X-ray emission) of known Type Ia SNRs: Tycho, SN1006, Kepler, 0509-67.5, 0519-69.0, N103B, SN1885.

- A population of Type Ia SNRs expanding into accretion wind blown cavities cannot be discarded (RCW 86?).

OPEN ISSUES: Outflows with moderate mechanical luminosity (Kepler SNR); Relationship to 'prompt' and 'delayed' progenitor populations; Problems with the SD scenario [Maoz 07, ArXiv:0707.4598] ⇒ revival of the DD scenario?

A Few Words On The Kepler SNR

750 ks *Chandra* exposure [Reynolds et al. 07, ApJL in press, arXiv:0708.3858]

Kepler: A Type Ia SNR with circumstellar interaction

- Optical: dense knots (N enriched), radiative shocks. ~500 pc above the Galactic plane, high systemic velocity (>200 km.s^{-1}) ⇒ Massive runaway progenitor interacting with a bow shock CSM [Bandiera 87, ApJ 319, 885].

- X-rays: lots of Fe in the ejecta, but no detectable O. No compact object (>10^{-2} $L_{Cas\ A}$). Balmer shocks (require partially neutral CSM) ⇒ Thermonuclear SN.

- Is it possible to ignite a thermonuclear runaway in the degenerate C+O core of a massive star? ⇒ Type I.5 SN [Iben & Renzini 83 ARA&A 21, 271] (many problems)
- More complex multiple-star progenitor?
- Is this the nearest example of the 'prompt' channel to Type Ia SNe?