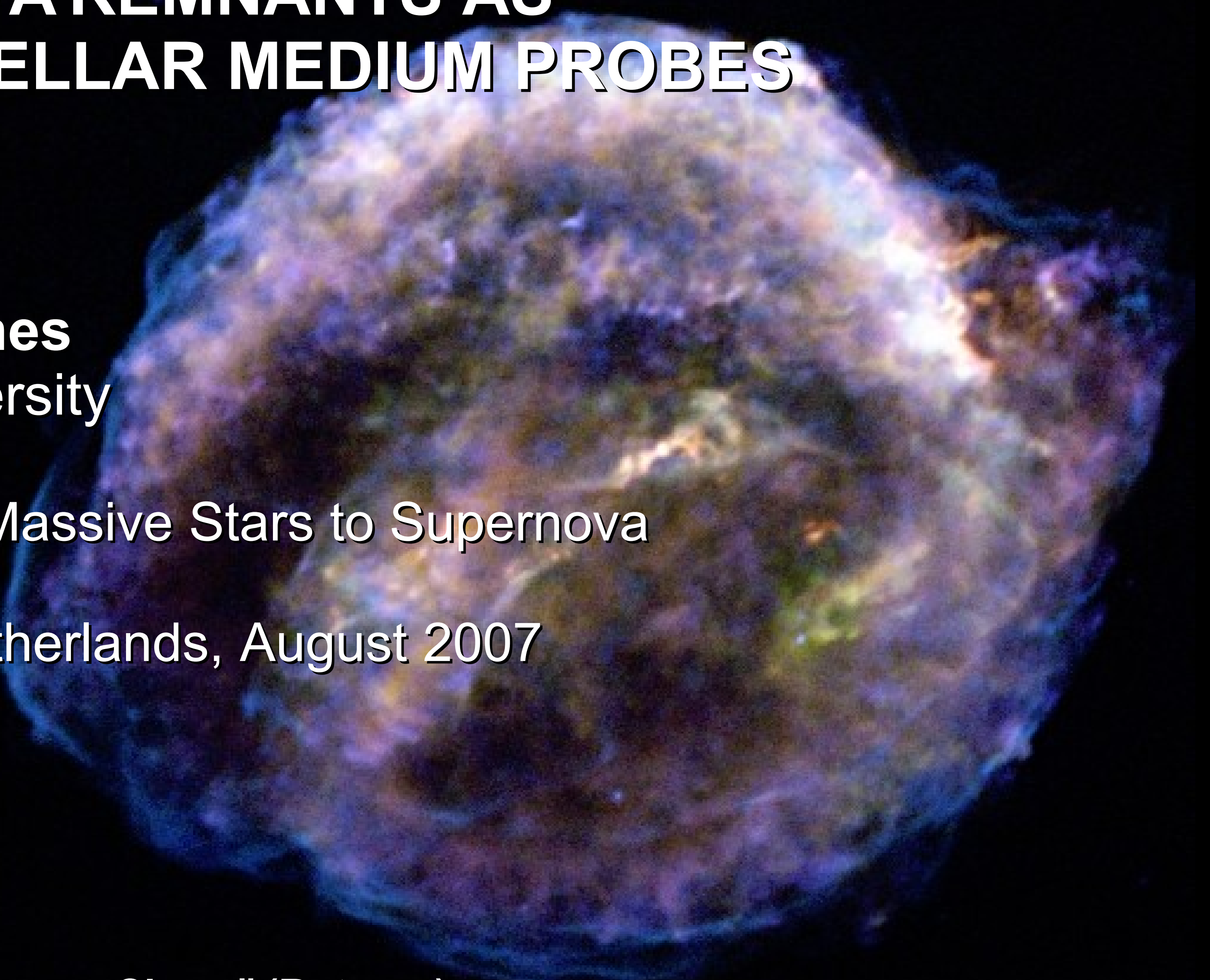
SUPERNOVA REMNANTS AS CIRCUMSTELLAR MEDIUM PROBES



Carles Badenes
Rutgers University

From (not so) Massive Stars to Supernova Remnants
Leiden, the Netherlands, August 2007

Collaborators:
J.P. Hughes, G. Cassam-Chenaï (Rutgers)
K.J. Borkowski, S. Reynolds, J. Blondin (NCSU)
E. Bravo (UPC/IEEC), N. Langer (U. Utrecht)

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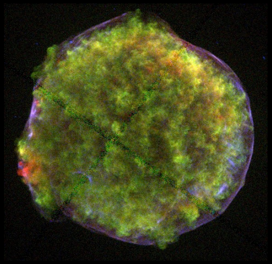
OUTLINE

SUPERNOVA REMNANTS AS CIRCUMSTELLAR MEDIUM PROBES



- The **dynamical and spectral properties of young supernova** remnants are determined by the nature of the supernova explosion and the structure of the circumstellar medium.

- **Core-collapse SNe**: the progenitors are known (in some cases, even identified: SN 1987A, SN 1993J, SN 2003gd, SN 2004A?). CSM is shaped by massive star outflows [Marston, García-Segura, Dwarkadas]. Binary interactions can introduce a lot of complexity [Podsiadlowski].

- **Thermonuclear SNe**: the progenitors are not known. What shapes the CSM?

What are the progenitors of Type Ia SNe?

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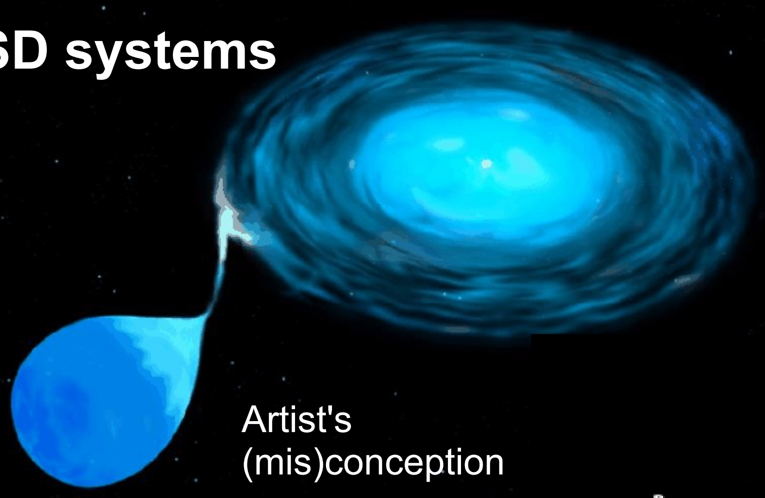
Type Ia SNe are the result of the thermonuclear explosion of a C+O White Dwarf that is destabilized by accretion in a close binary system

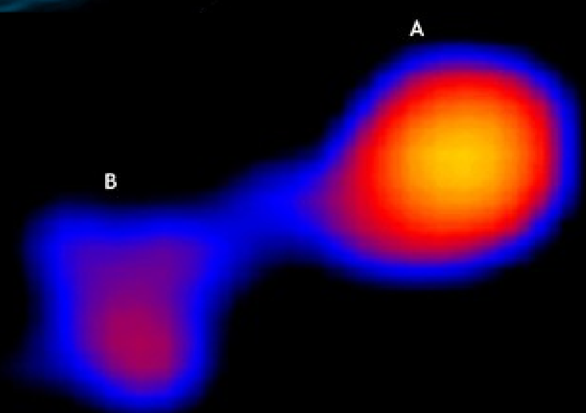
The nature of the WD companion is uncertain:

- A normal star: Single Degenerate (SD) systems. [Preferred by theorists].
- Another WD: Double Degenerate (DD) systems. [Explosion is uncertain – BUT 'Champagne Supernova' [Howell et al. 06, Nat 443, 308]].

SD systems

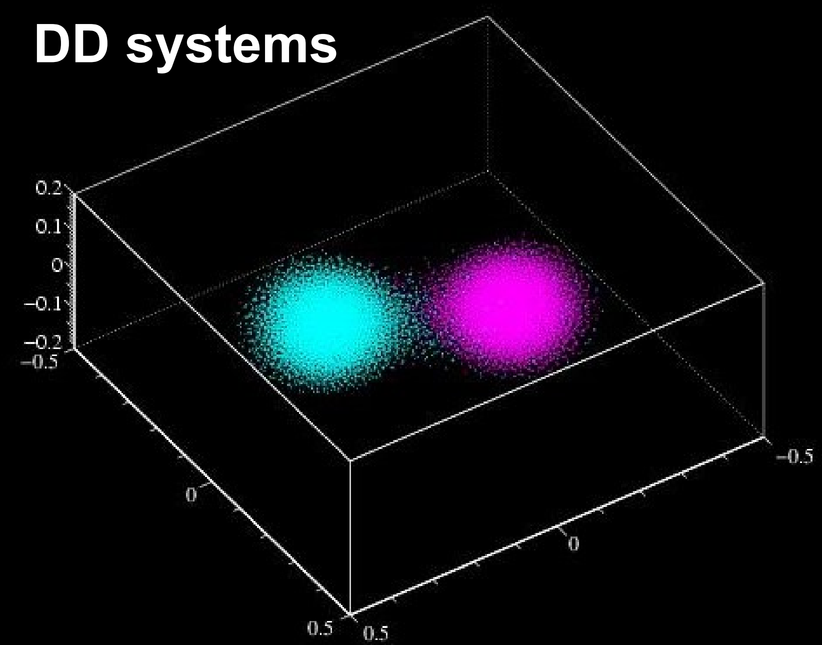


Artist's (mis)conception



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

SD SN Ia Progenitors: Open issues

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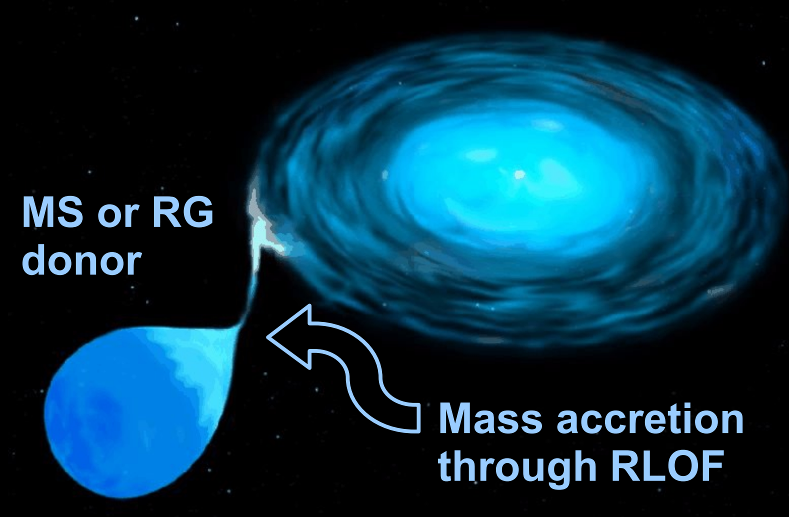
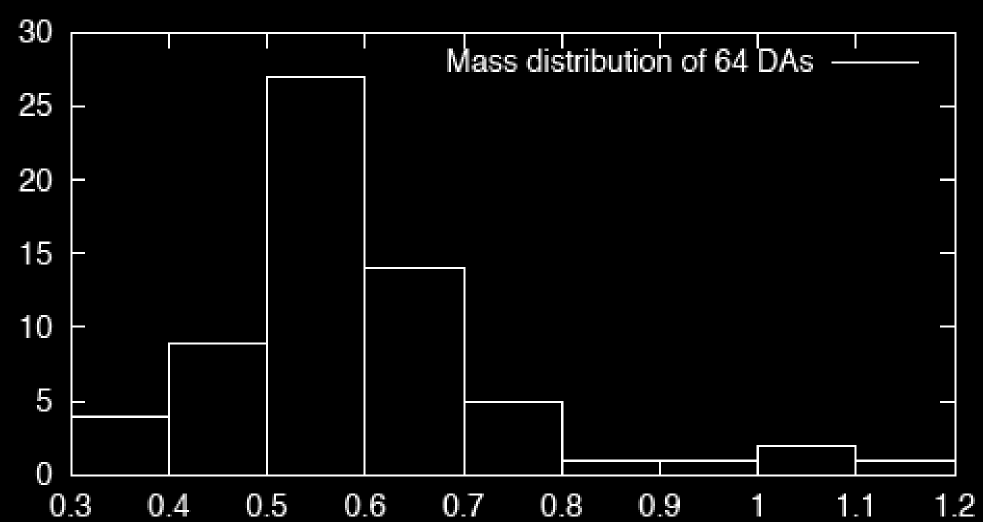
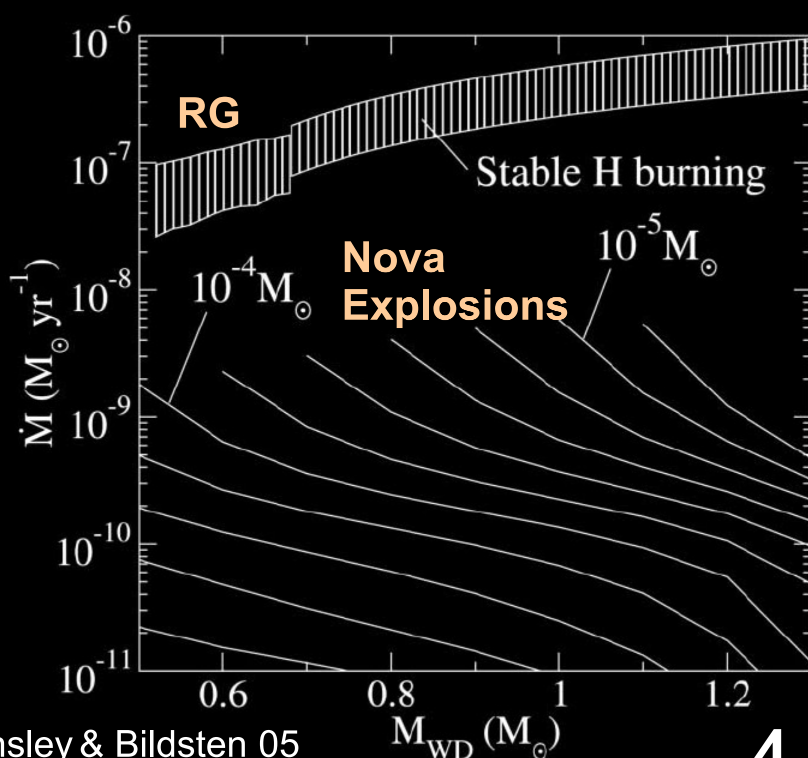
- Single degenerate binary systems are the preferred candidates for Type Ia SN progenitors [Branch et al. 95, PASP 107, 1019].
- **Their viability has not been proved!**
  - M_{WD}~ 0.6 $M_\odot$ and always < 1.2 $M_\odot$ ⇒ Need to accrete at least 0.2 $M_\odot$ to reach 1.38 $M_\odot$.
  - H-rich matter from the companion must burn to C and O **QUIETLY** ⇒ dM/dt has to be fine-tuned.





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



Townsley & Bildsten 05
ApJ 628, 395

SN Ia Progenitors: Accretion Winds

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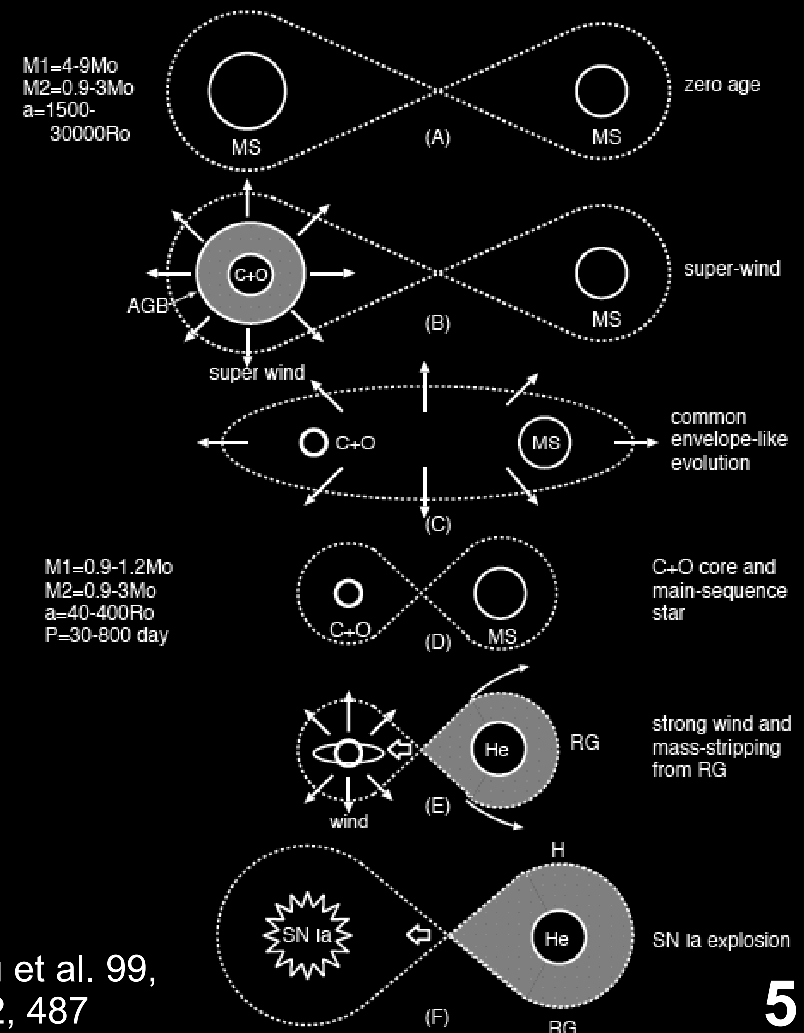
Accretion Winds
(Hachisu et al. 96, ApJ 470, L97)
The luminosity from the WD surface drives a fast, optically thick outflow that gets rid of the excess material.

- **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. [Langer et al. 00, A&A 362, 1046; Han & Podsiadlowski 04, MNRAS 350, 1301].
- 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

SN Ia Progenitors: Accretion Wind Outflows

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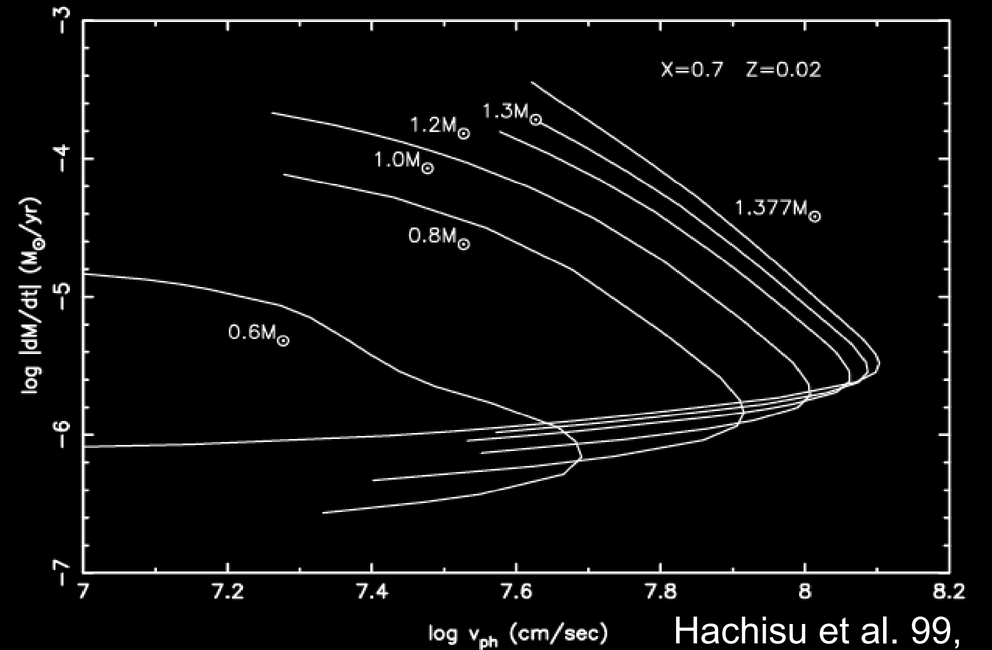
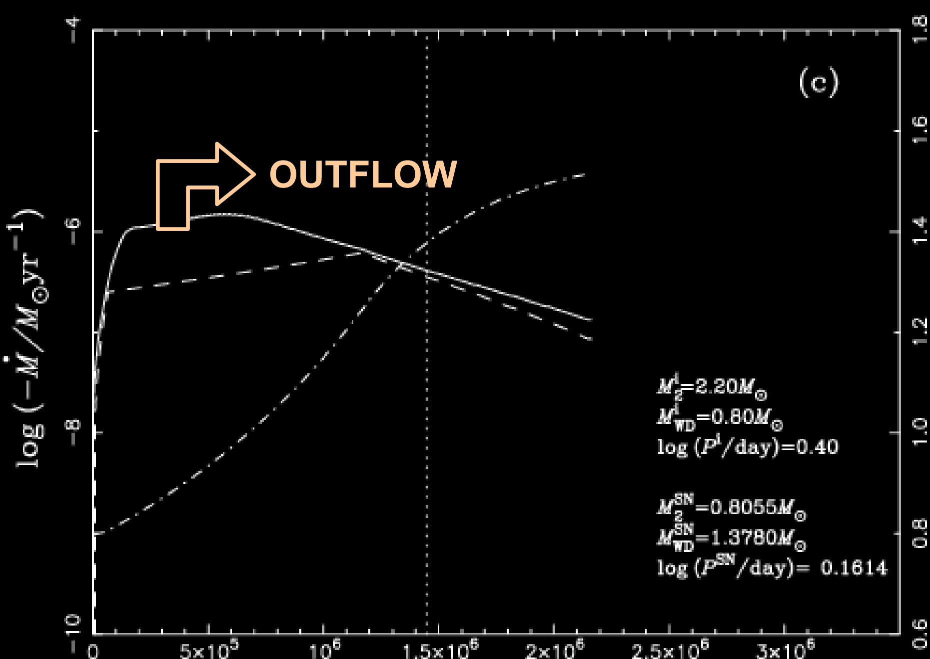
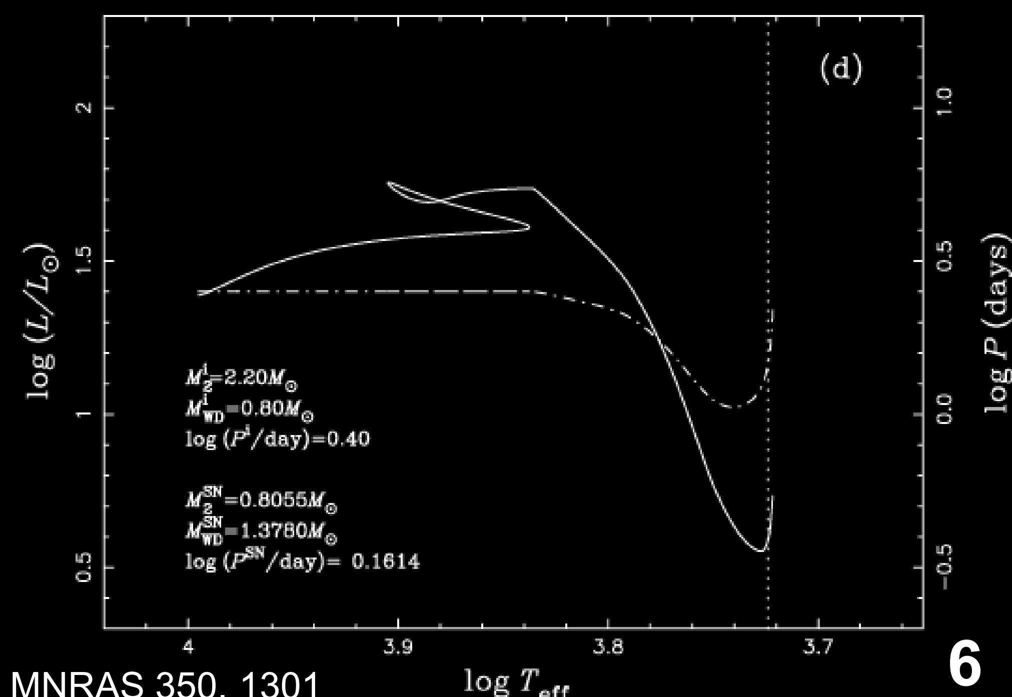
- Part of the material accreted from the companion is not burnt at the WD surface ⇒ fast accretion wind outflow. Typical scales:
  - $dM/dt_{of} \sim 10^{-7}$ to $10^{-6}\,M_{\odot}yr^{-1}$.
  - $t_{of} \sim 10^{6}$ yr.
  - $u_{of} \sim 10^{3}$ km s^{-1}.
- How does this modify the CSM?



Hachisu et al. 99, ApJ 522, 487





Han & Podsiadlowski 04 MNRAS 350, 1301

SN Ia Progenitors: Shaping the CSM

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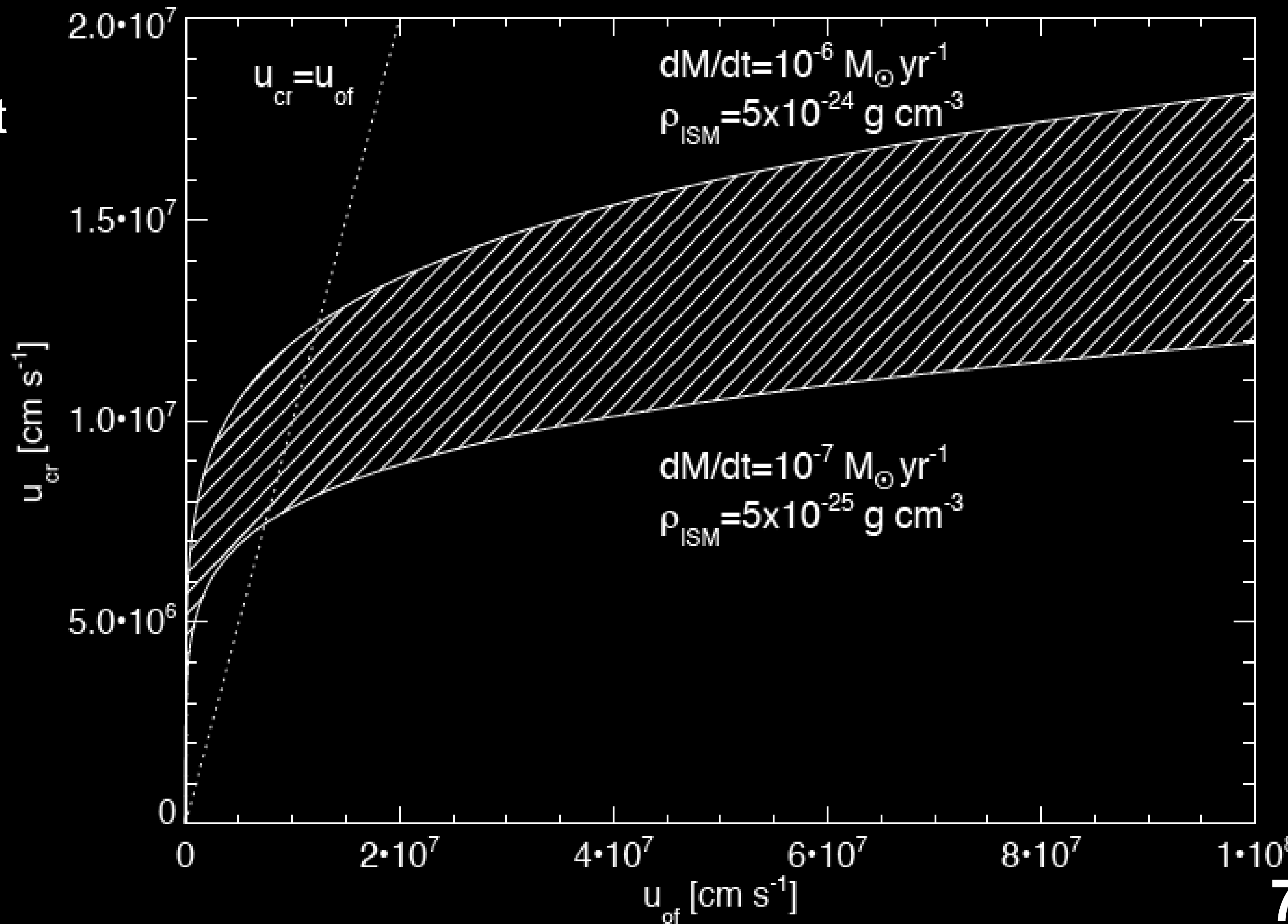
- Outflows into the ISM ⇔ wind cavities.
- Properties of the cavity determined by outflow velocity u_{of} ⇔ critical limit u_{cr} [Koo & McKee 92, ApJ 388, 93]:

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

$u_{of} > u_{cr}$ ⇒ 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.



SN Ia Progenitors: Sculpting the CSM

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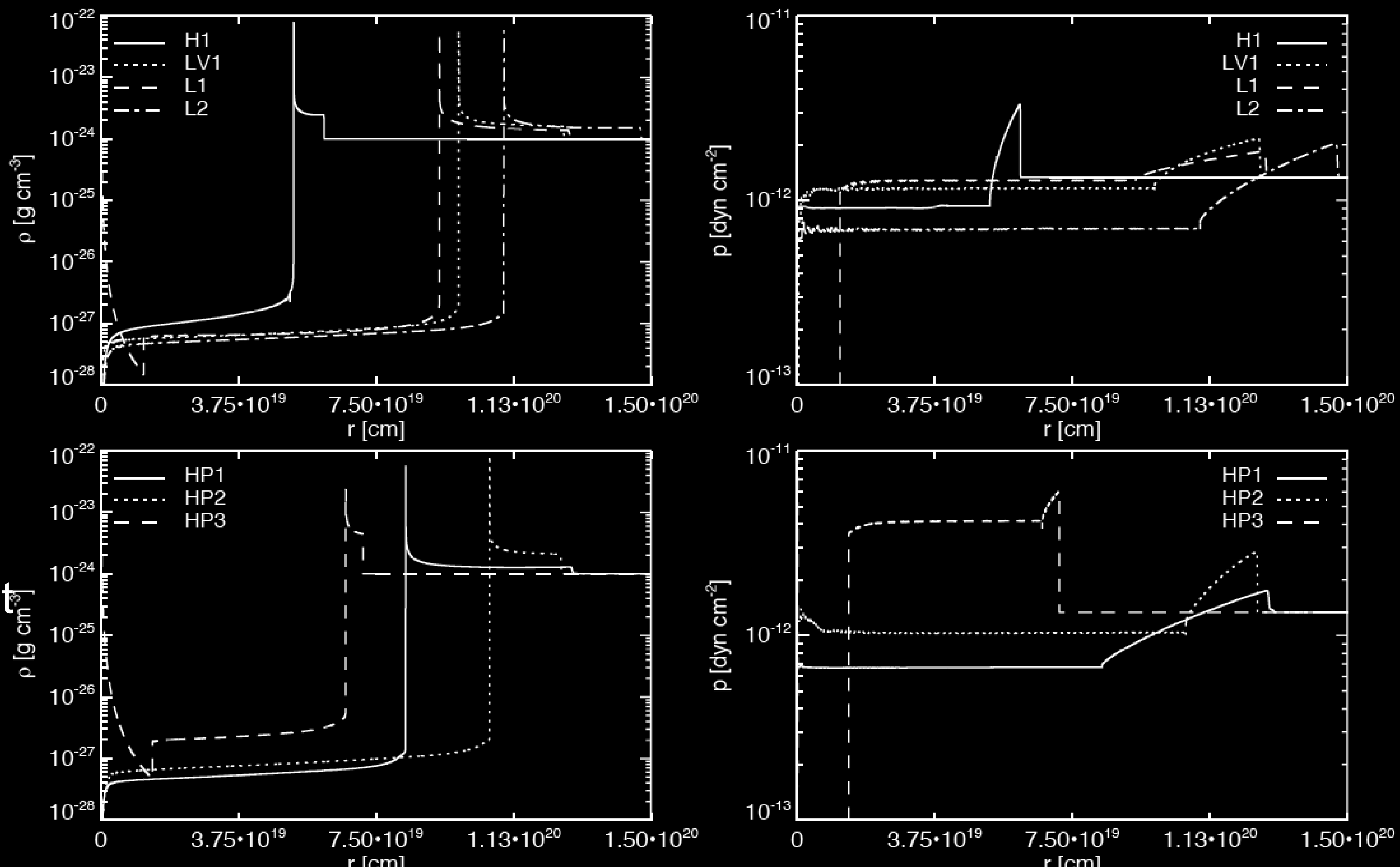
- When these fast, continuous outflows expand into the warm phase of the ISM, they excavate large (~10^{20} cm) interstellar bubbles around the SN Ia progenitors.
- Variations in ρ_{ISM} and p_{ISM} do not affect the bubbles significantly.

CSM configuration at the time of the SN explosion:



Note that most bubbles are pressure-confined!

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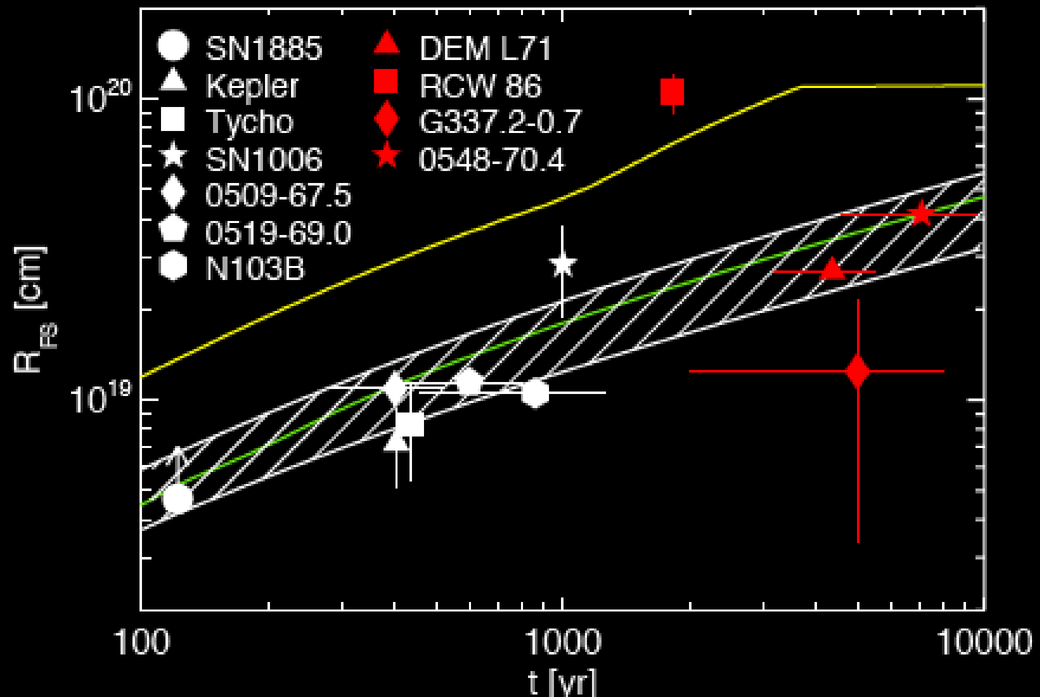
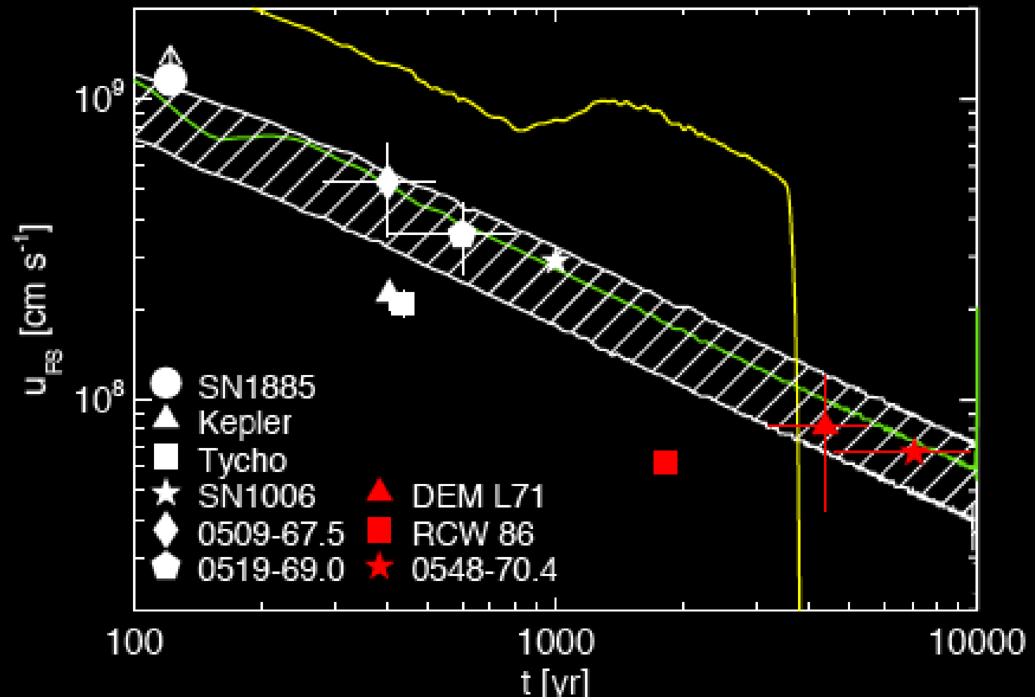
SN Ia Progenitors: Constraints from SNR dynamics

- Forward shock radii and velocities. Historical Type Ia SNRs (SN 1885, Kepler, Tycho, SN 1006) + LMC Type Ia SNRs with good age estimates [Rest et al. 05, Nat. 438, 1132] (0509-67.5, 0519-69.0, N103B) + other (suspect) objects: RCW 86, DEM L71, G337.2-0.7, 0548-70.4.

- Models: PDDe+accretion wind bubble; PDDe+RG wind, EXP+ISM (E_k=0.8 .. 1.4 foe; $\rho_{ISM}=5\times10^{-25}$ .. 5×10^{-24} g cm^{-3}).





⇒ Most objects are compatible with a uniform ISM (exception: RCW 86)
⇒ CSM structures from low L_w outflows cannot be discarded easily.

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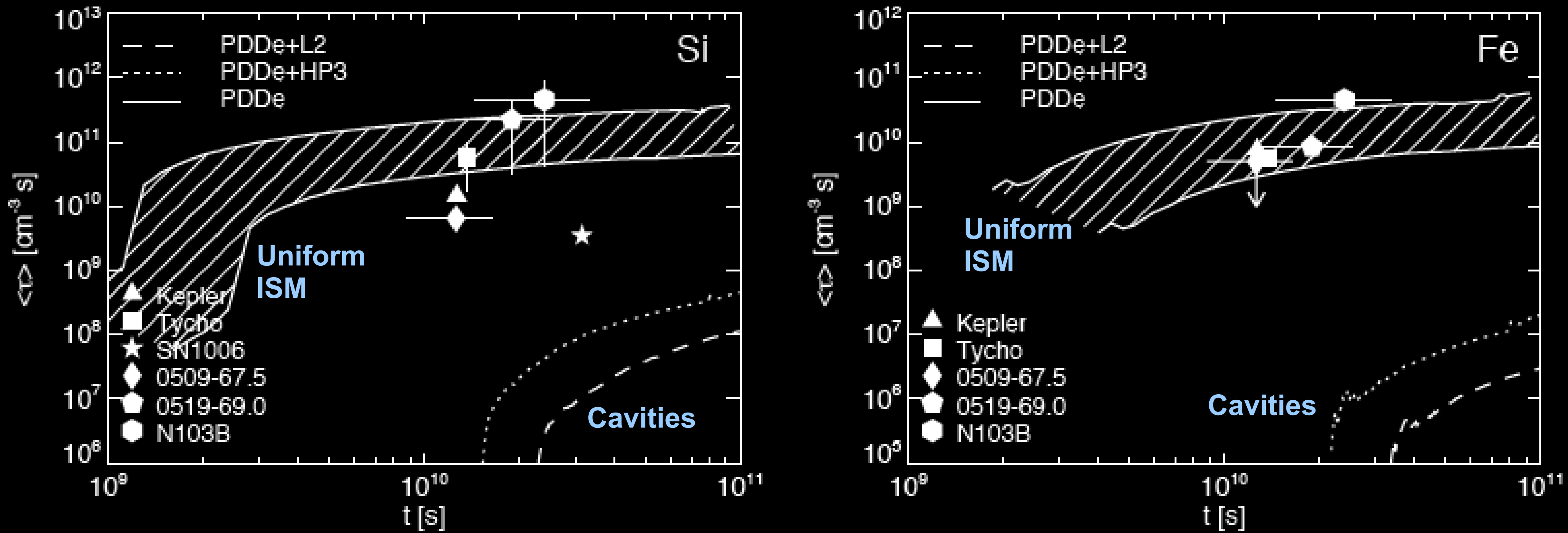
SN Ia Progenitors: Constraints from ejecta emission in the SNR

- A similar comparison can be done based on the spectral properties of the X-ray emission from the shocked SN ejecta.

- 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 SNR properties constrain the CSM structure independently of the dynamics.

The Kepler SNR (SN 1604)

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750 ks *Chandra* exposure [Reynolds et al. 07, ApJ submitted]

- 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?

Conclusions

- **The dynamics and spectral properties of young SNRs** can provide insights into the pre-SN outflows of the progenitors.

  - Reliable age estimates are needed (more light echoes, please!).

  - The imprint of CSM structures associated with low mechanical luminosity outflows might be hard (or impossible) to find.

- In the known Type Ia SNRs with good age estimates, there is no trace of the fast WD winds commonly associated with SD progenitors [Badenes et al. 07, ApJ 662, 472]. Type Ia progenitor models are in serious trouble for several other reasons [Maoz 07, arXiv/0707.4598].

- The Kepler SNR is an interesting case. Fe-rich, O-poor ejecta point almost certainly at a thermonuclear explosion, but clear signs of a CSM interaction are also present [Reynolds et al. 07, ApJ submitted].