X-ray Luminosity and Size Relationship of Supernova Remnants

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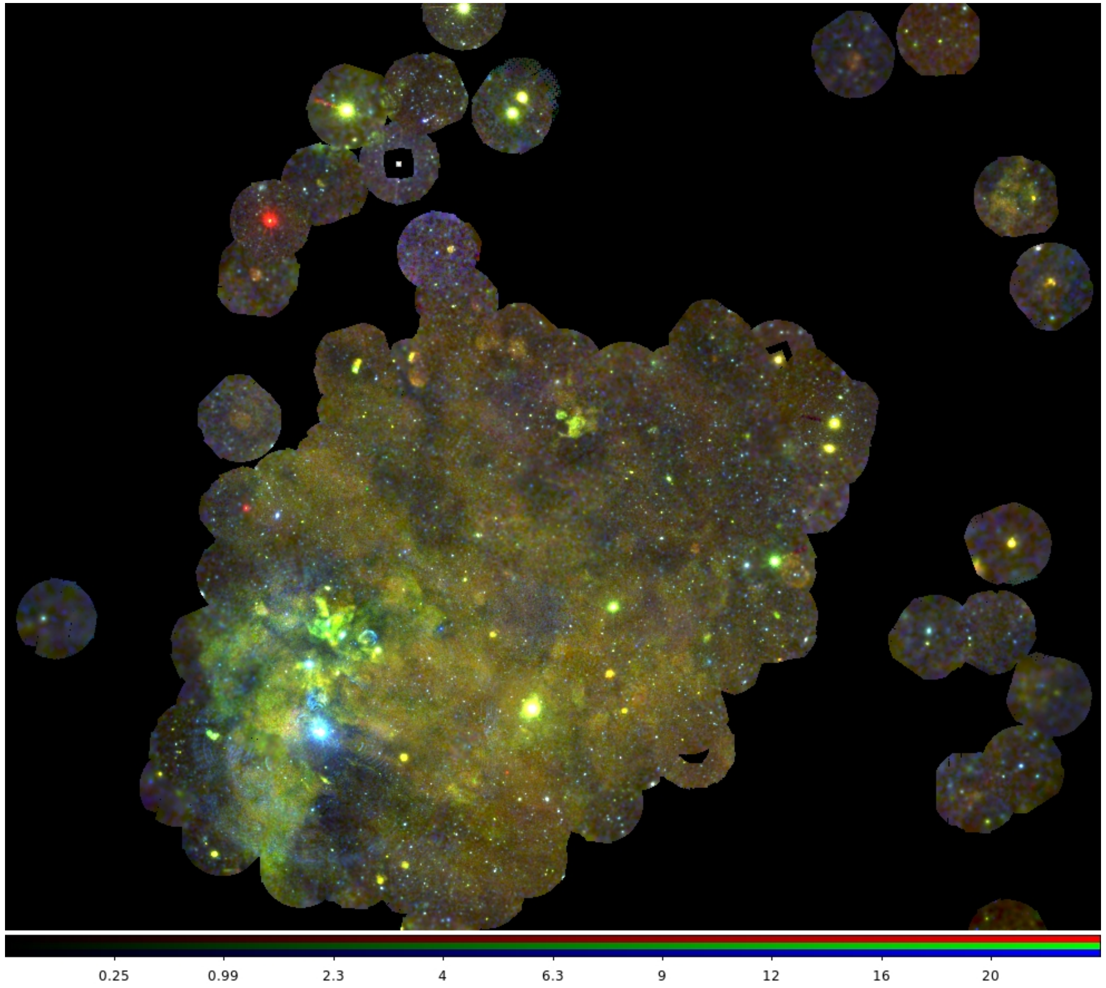
The Advantages of the LMC in SNR Studies

1. Low internal extinction
2. Known distance (50 kpc)

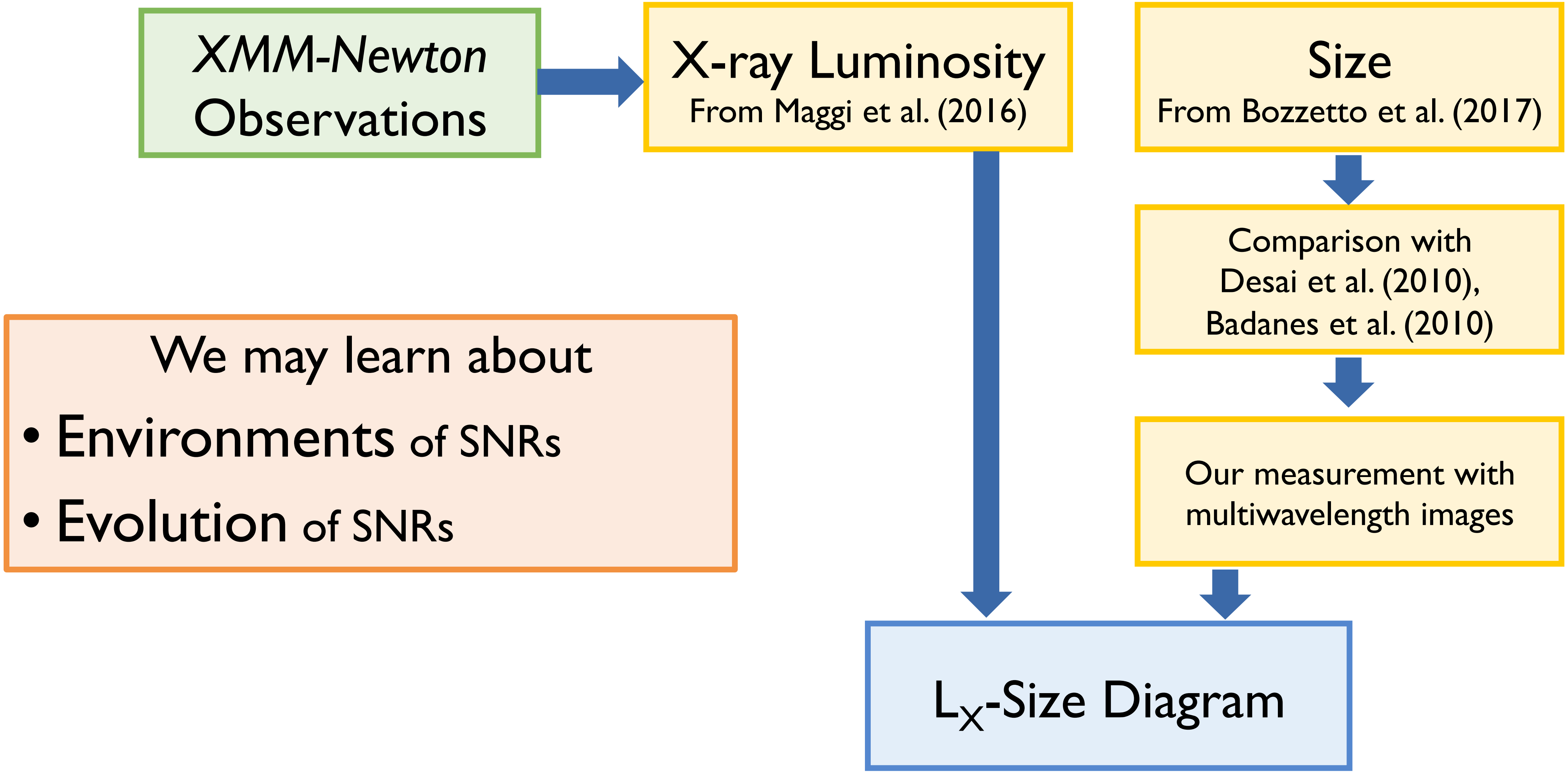
➡ Physical parameters of SNRs can be measured accurately.

- *XMM-Newton* LMC survey (PI: Frank Haberl)
- Catalogue of 59 LMC SNRs observed in X-ray (Maggi et al. 2016)



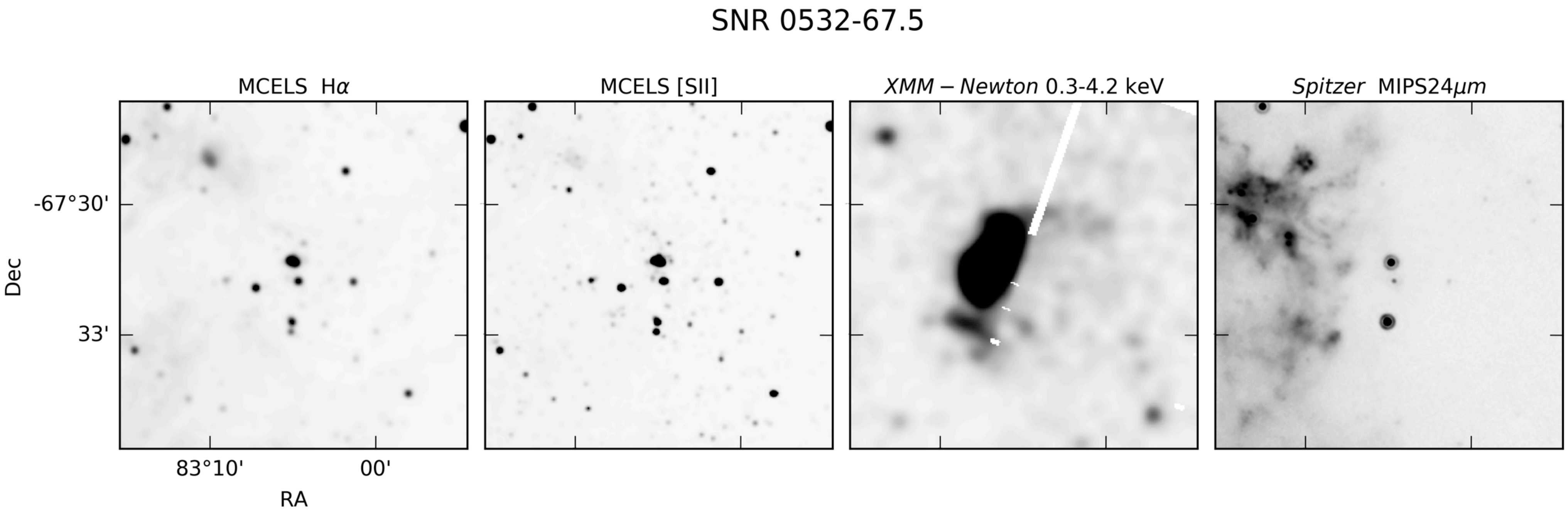
(Credit: Steve Snowden)

Plotting Lx vs Size of Supernova Remnants



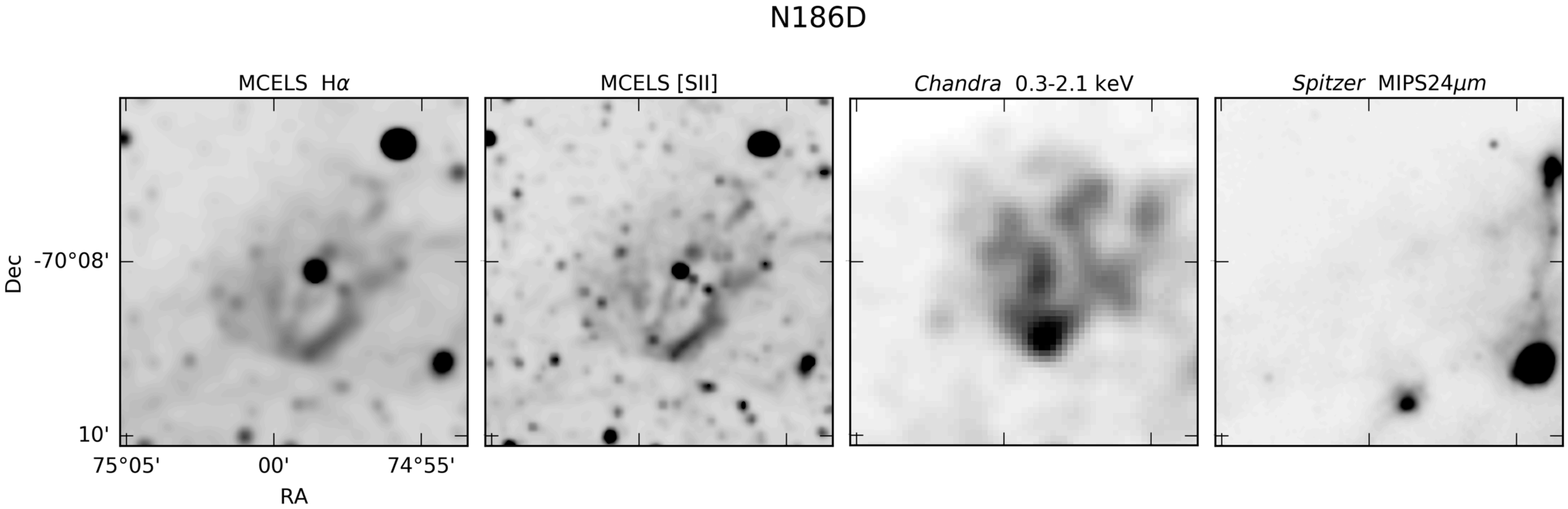
Discrepancies in Size Measurements

- X-ray SNR with nonuniform surface brightness or complex background



Discrepancies in Size Measurements

- X-ray SNR with nonuniform surface brightness or complex background
- Superposed on confusing Hα emission; use [S II] & X-rays



Discrepancies in Size Measurements

- X-ray SNR with nonuniform surface brightness or complex background
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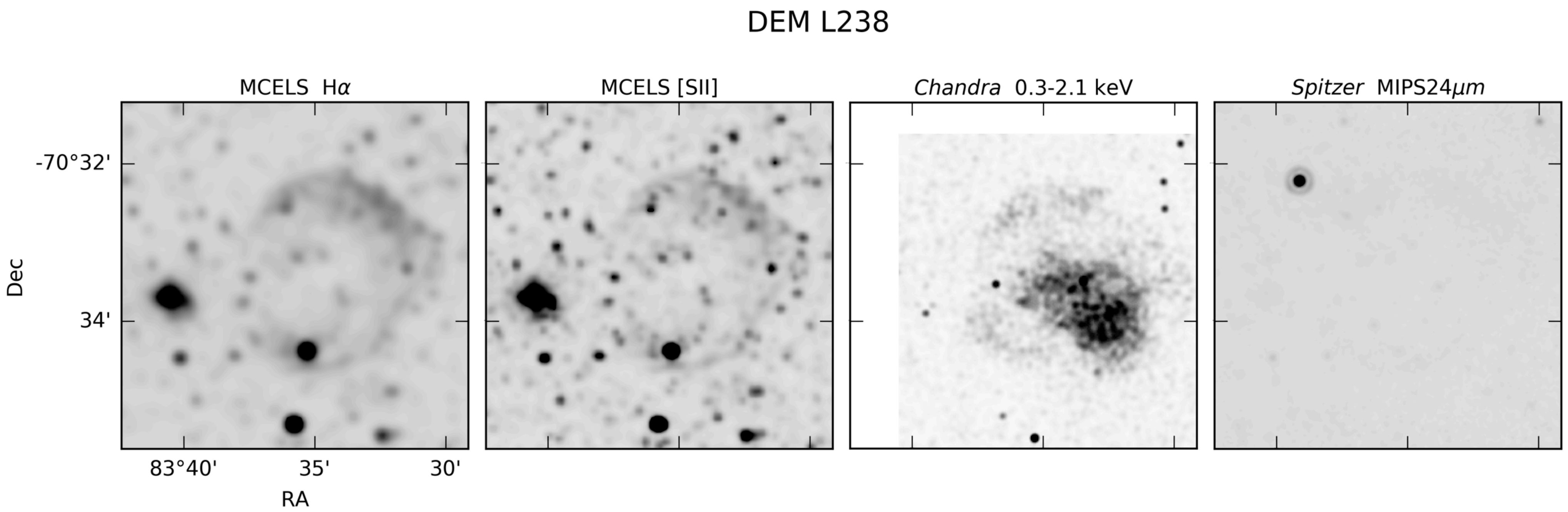
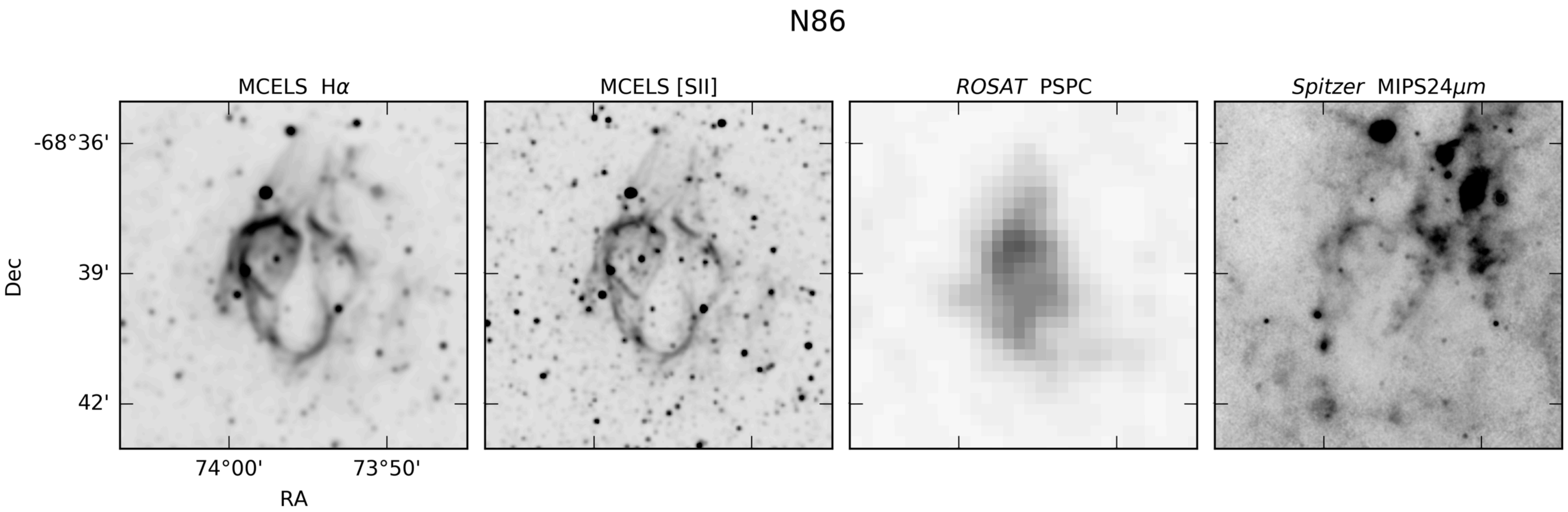
- SNR morphology is wavelength-dependent.

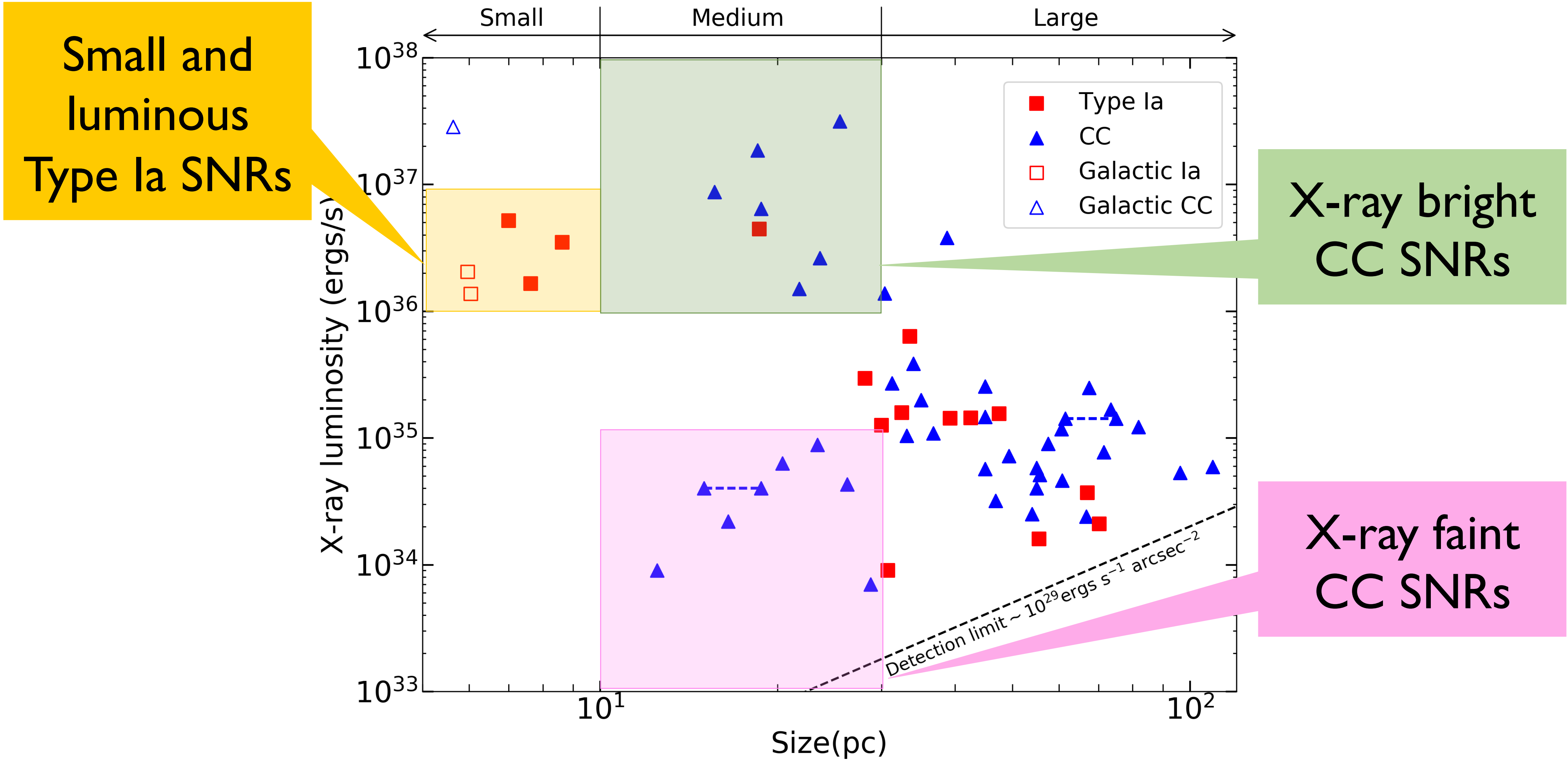


Discrepancies in Size Measurements

- X-ray SNR with nonuniform surface brightness or complex background
- Superposed on confusing Hα emission; use [S II] & X-rays
- SNR morphology is wavelength-dependent.
- Subjective size measurements of irregular SNRs; up to 20% uncertainty

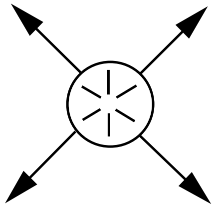


The Lx-Size Diagram



Evolution of SNRs- Canonical Picture

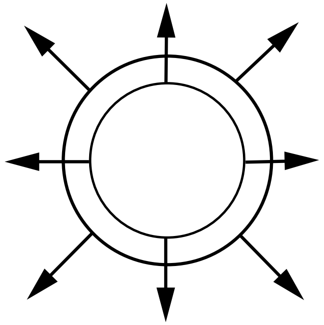
(1) Free Expansion phase/ Ejecta dominated phase



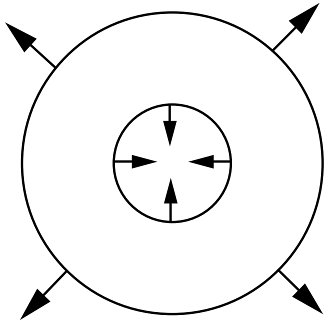
Free expansion

$M_{swept\text{-}up} > M_{ejecta}$

(2) Sedov phase/ adiabatic phase

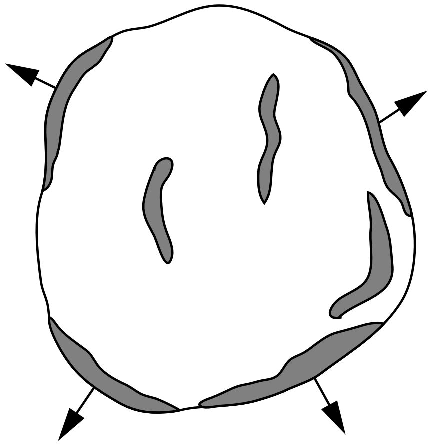


Expansion slows



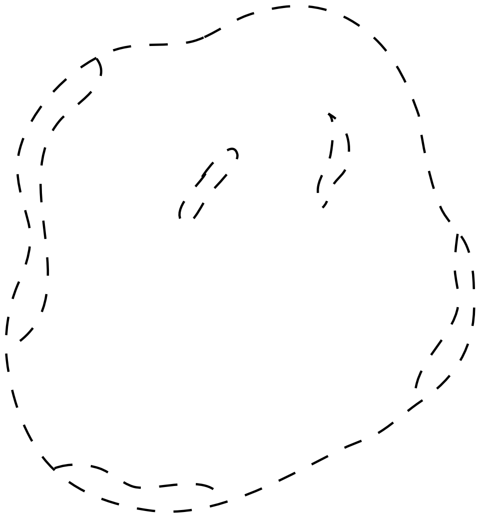
Reverse shock propagates inwards

(3) Radiative phase



Energy of expansion radiated away, bright optical filaments

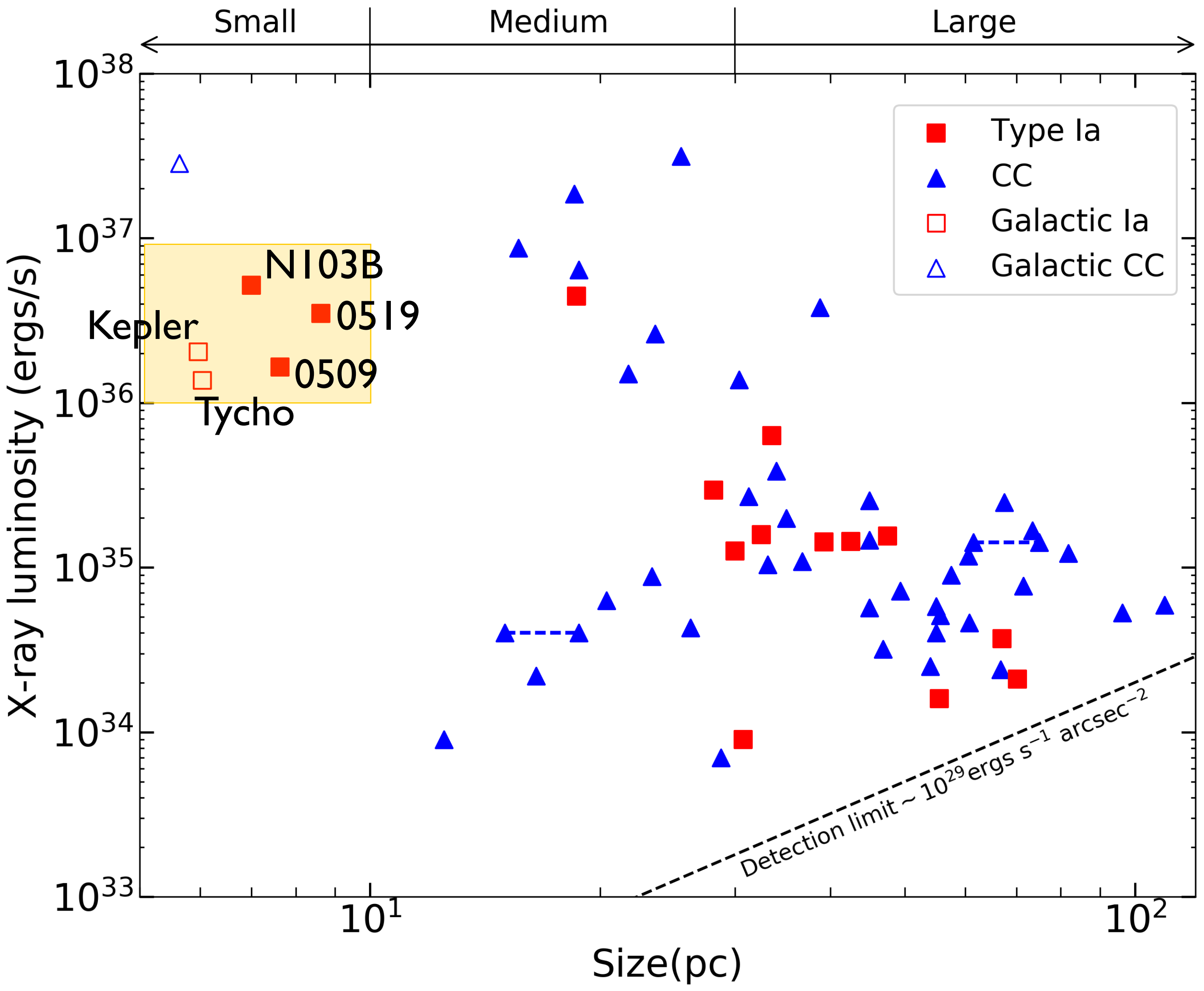
(4) Merging phase



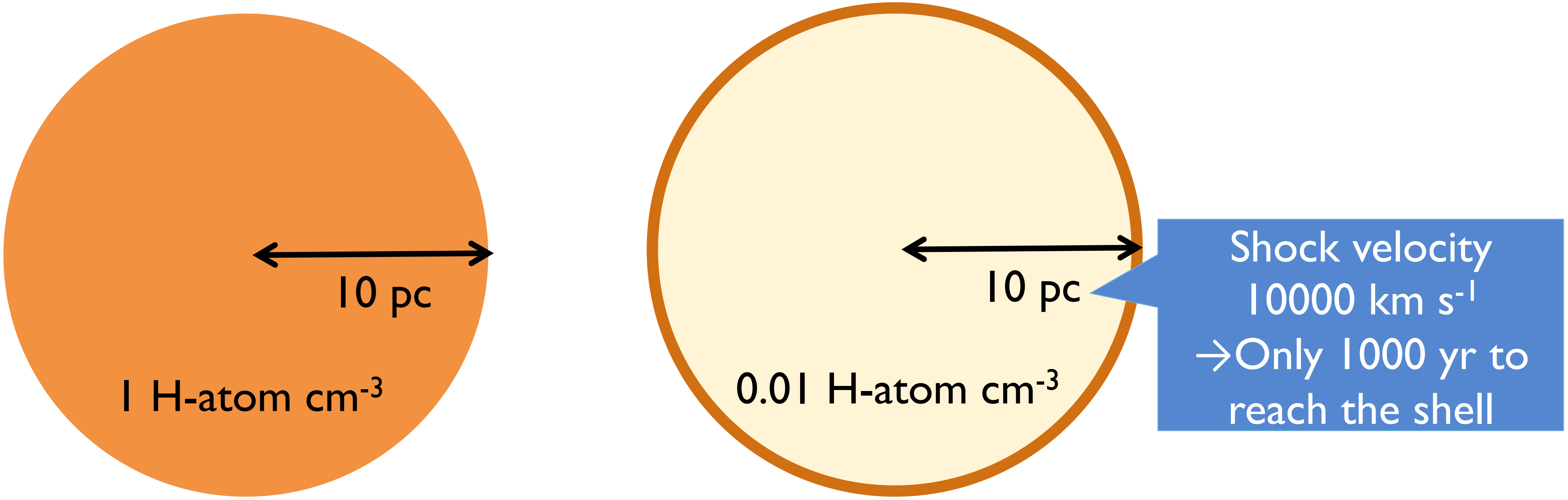
Fade to invisibility

Figures taken from Seward & Charles (2010)

Small and Luminous Type Ia SNRs



Cavity Explosion of CC SNe

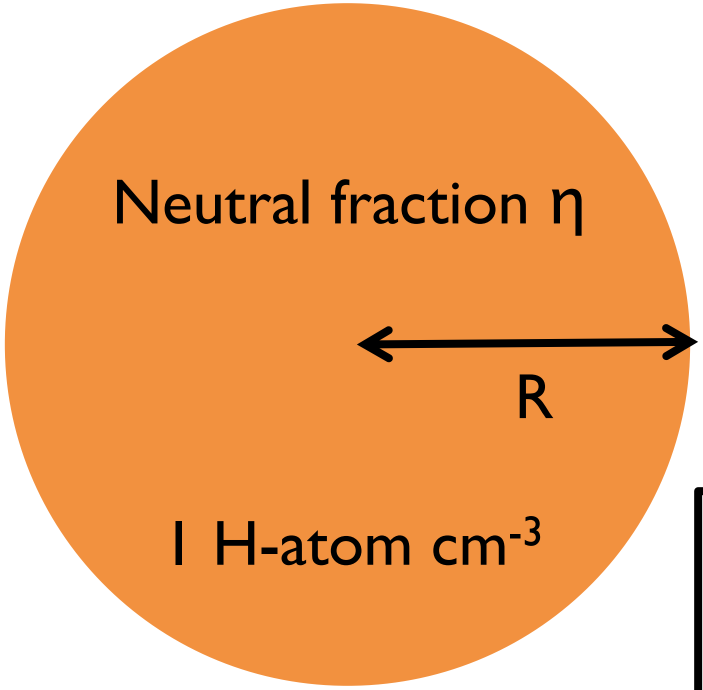


$M_{swept\text{-}up} \sim 100\ M_{\odot}$

Before reaching the shell: $M_{swept\text{-}up} \sim 1\ M_{\odot}$

After reaching the shell: $M_{swept\text{-}up} \sim 100\ M_{\odot}$

Balmer-Dominated: Collisionless Shocks

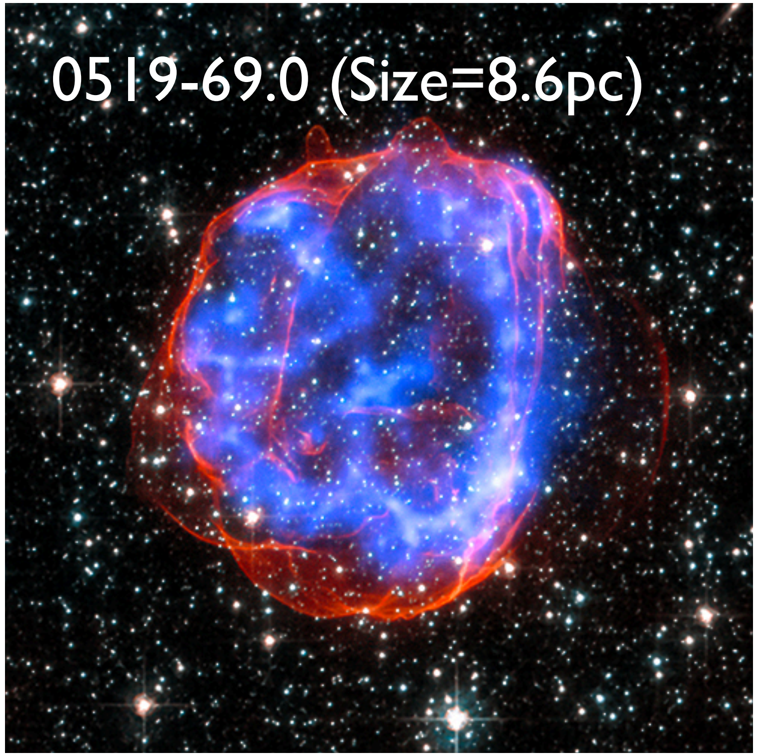


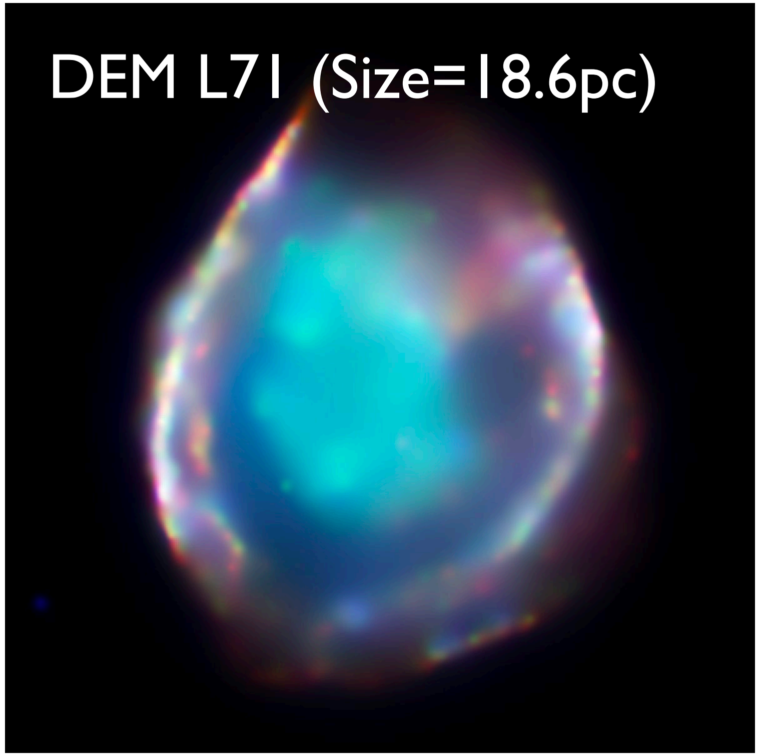
- "Balmer-dominated": no forbidden line emission
- Origin: in a partially neutral gas

To enter the Sedov phase, $M_{swept\text{-}up} \sim 1.4\ M_{\odot}$
➔ $R \sim 2.4(1-\eta)^{-1/3}$ pc
✧ $\eta=0.9$: $R\sim5.2$ pc
✧ $\eta=0.5$: $R\sim3.0$ pc

Young Type Ia SNRs
(size=6~10pc)
entering the Sedov phase

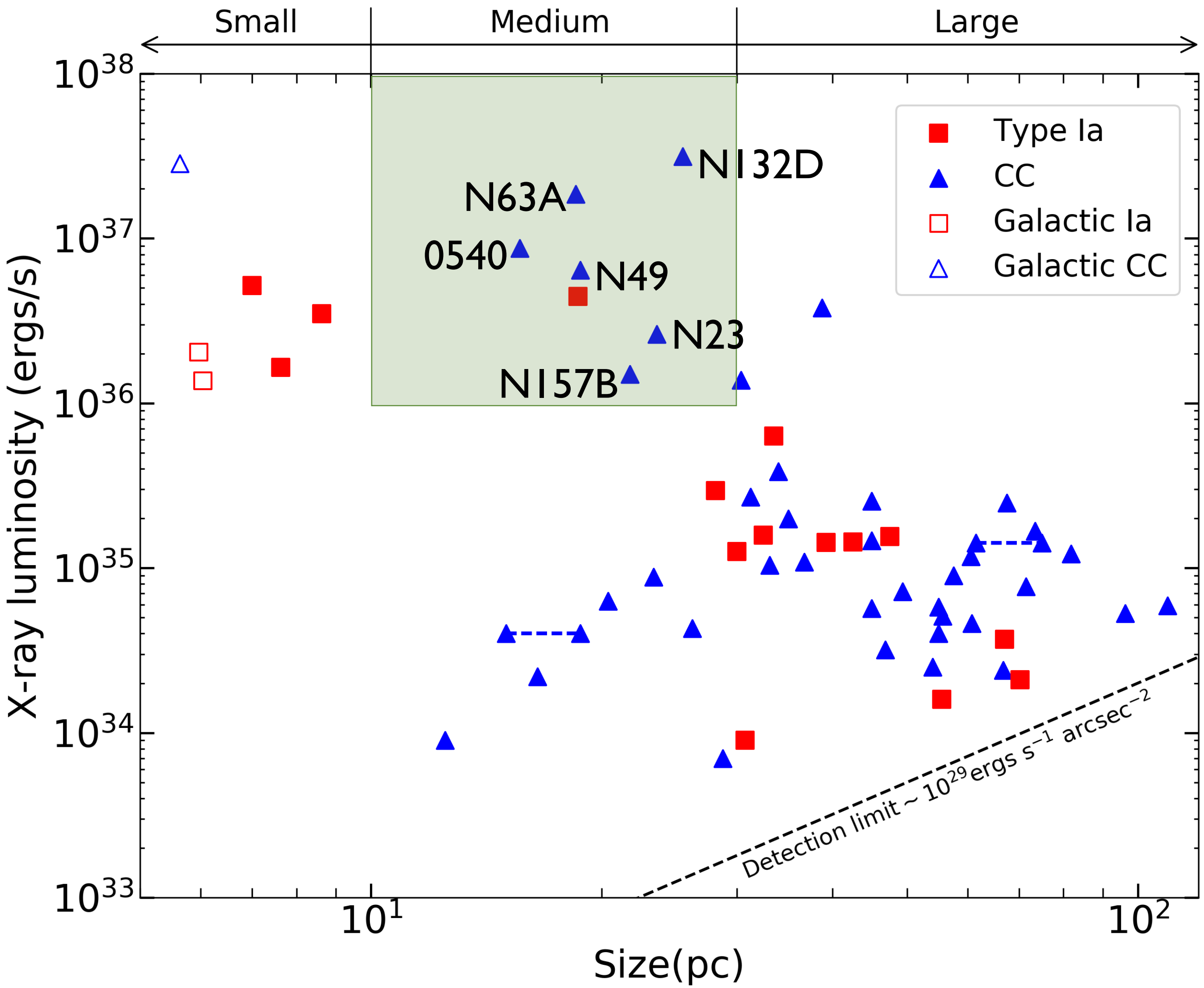
Evolution of Young Type Ia SNRs





Reverse shocks cause the high L_X of young Type Ia SNRs.

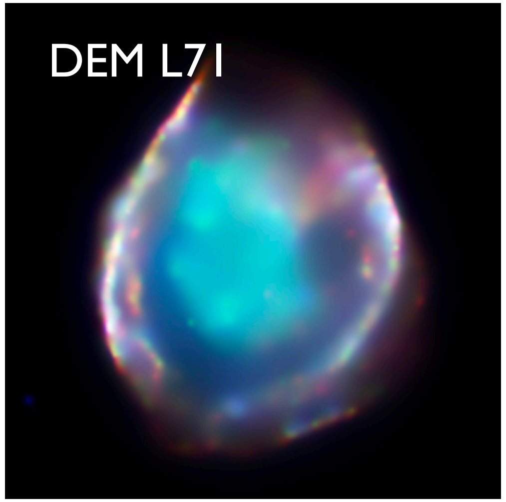
X-ray Bright CC SNRs



X-ray emission from SNRs

Thermal X-ray

- Shocked ISM
- Shocked SN ejecta



Nonthermal X-ray

- Pulsar wind nebulae
- Shock front

Causes of Enhanced X-ray Emission

0540-69.3

N157B

X-ray emission dominated by synchrotron radiation from the PWNe

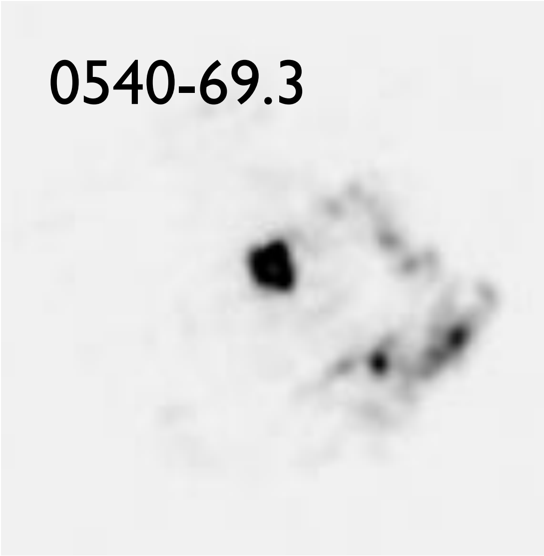
N132D

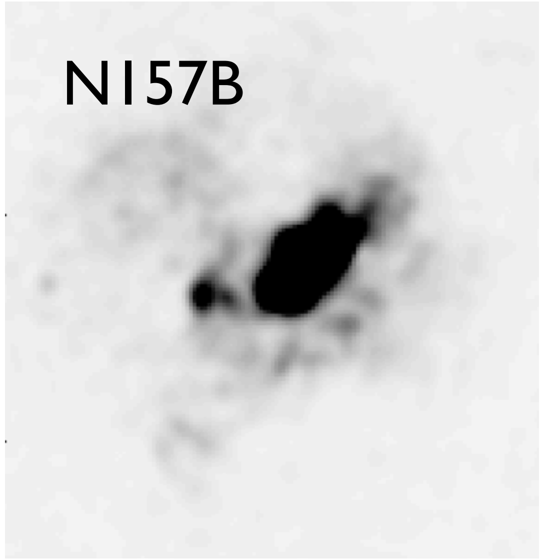
N63A

N49

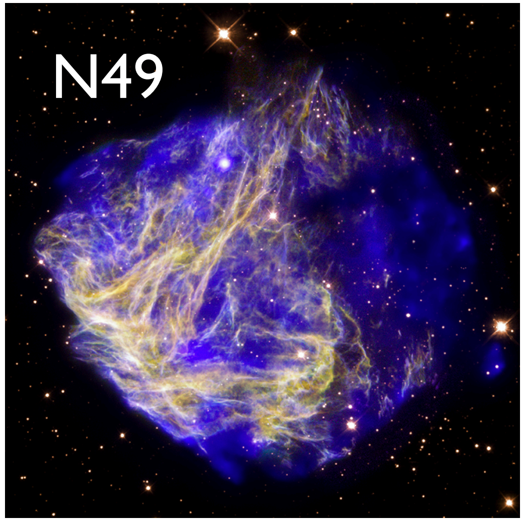
N23

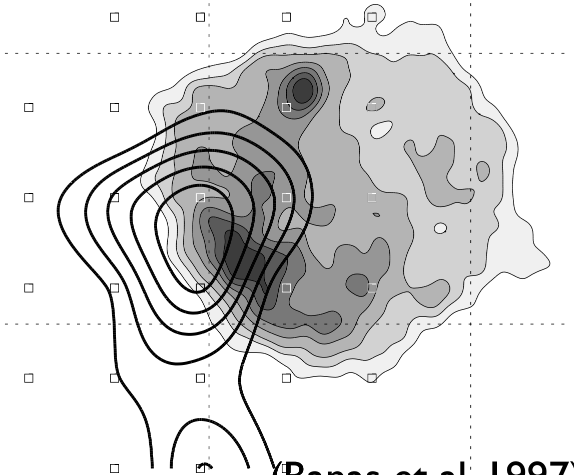
Associated with molecular clouds



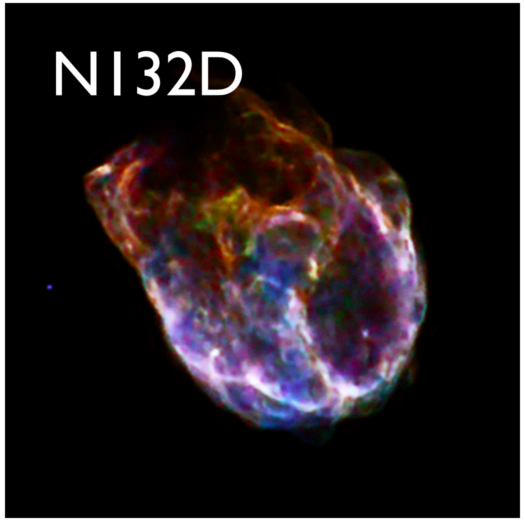


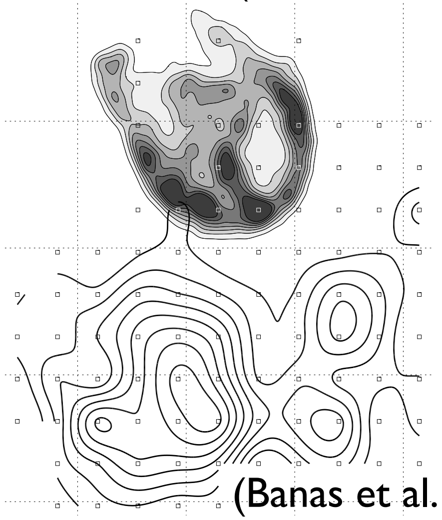
SNRs Associated with Molecular Clouds





(Banas et al. 1997)





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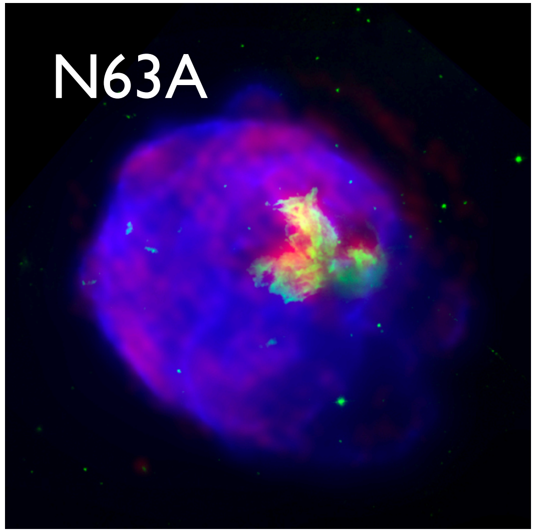
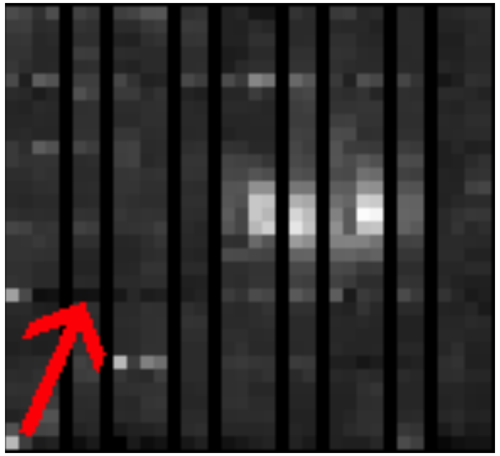
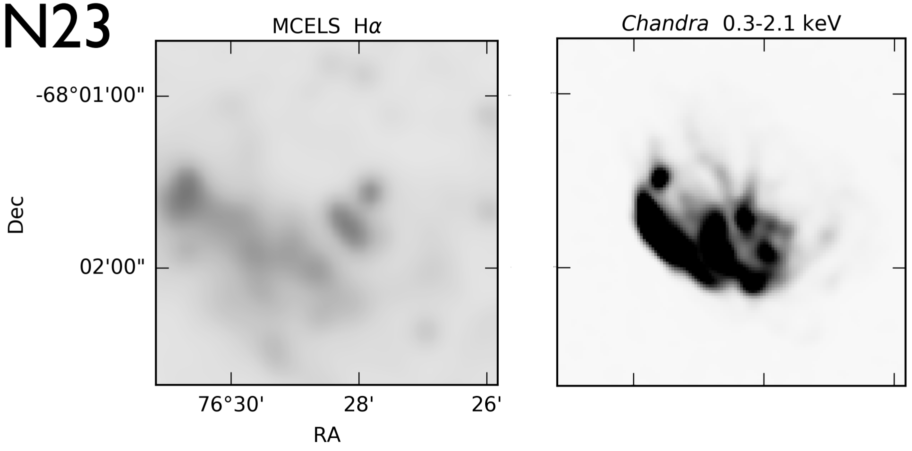


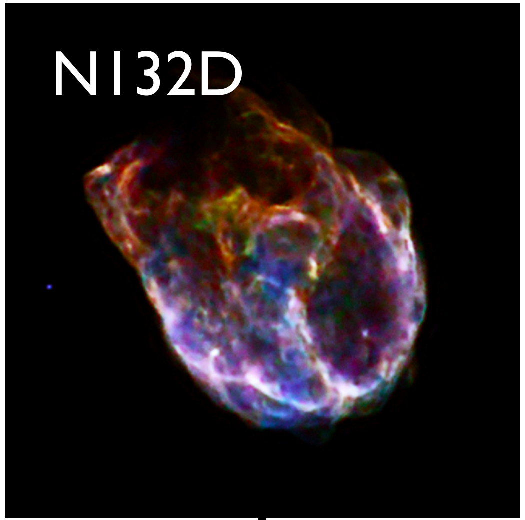


(Segura-Cox et al., in prep.)

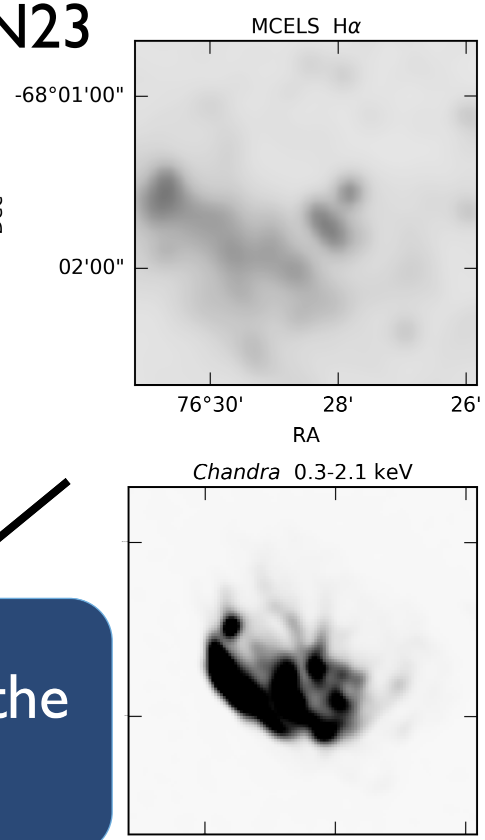
N23



• Have they reached the bubble shells?

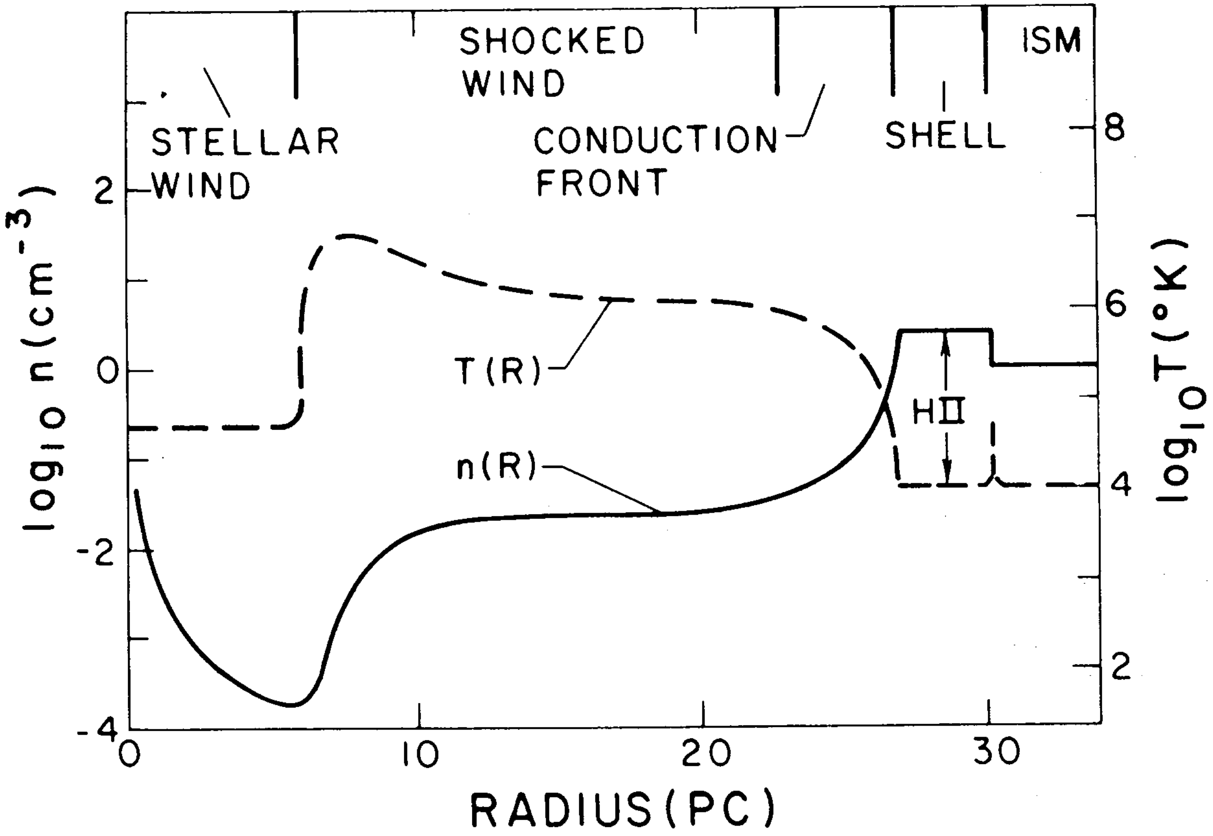


N23



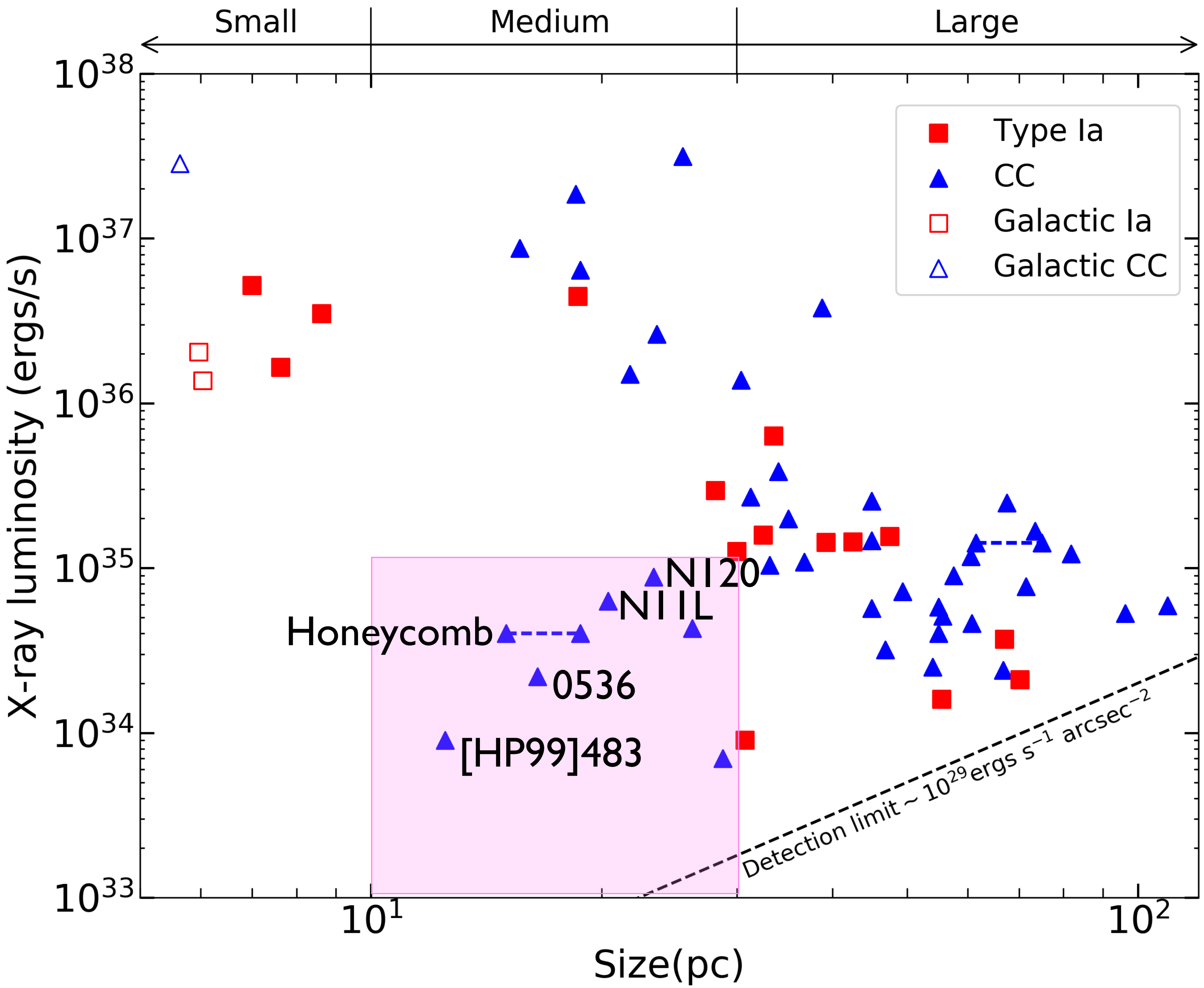
Probably reaching the conduction layer

Structure of an interstellar bubble



(Weaver et al. 1977)

X-ray Faint CC SNRs



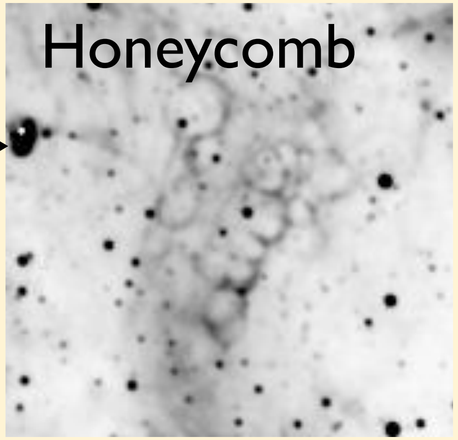
X-ray Faint CC SNRs

[Size=10-20 pc]
No optical shell

- J0536-6914
- [HP99] 483

} No optical counterpart

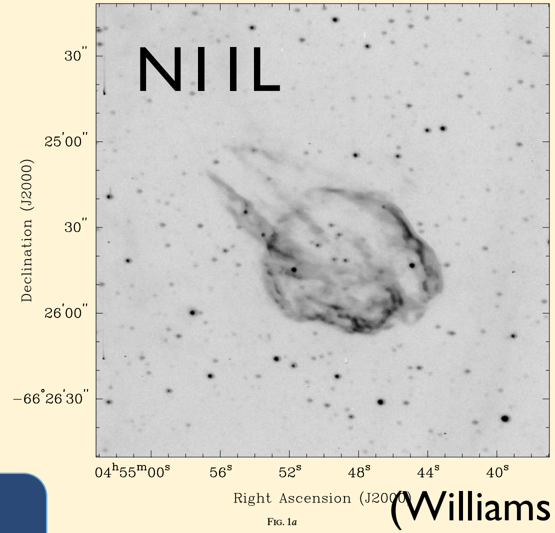
- Honeycomb →



[Size=20-30 pc]
With optical shell

- N11L
- N120

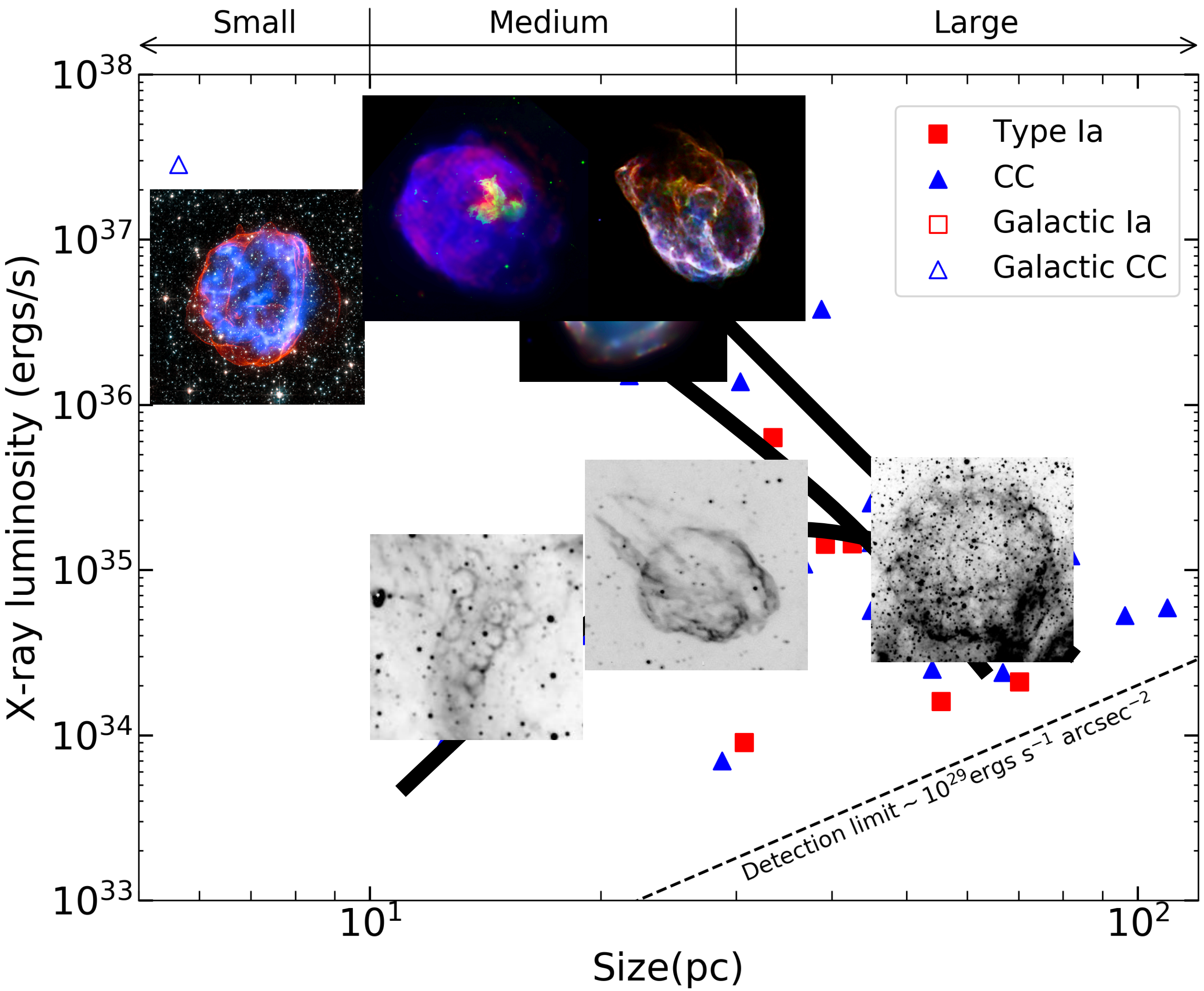
Already reached the bubble shell, but the ISM density is too low.



(Williams et al. 1999)

No interaction with dense clouds.

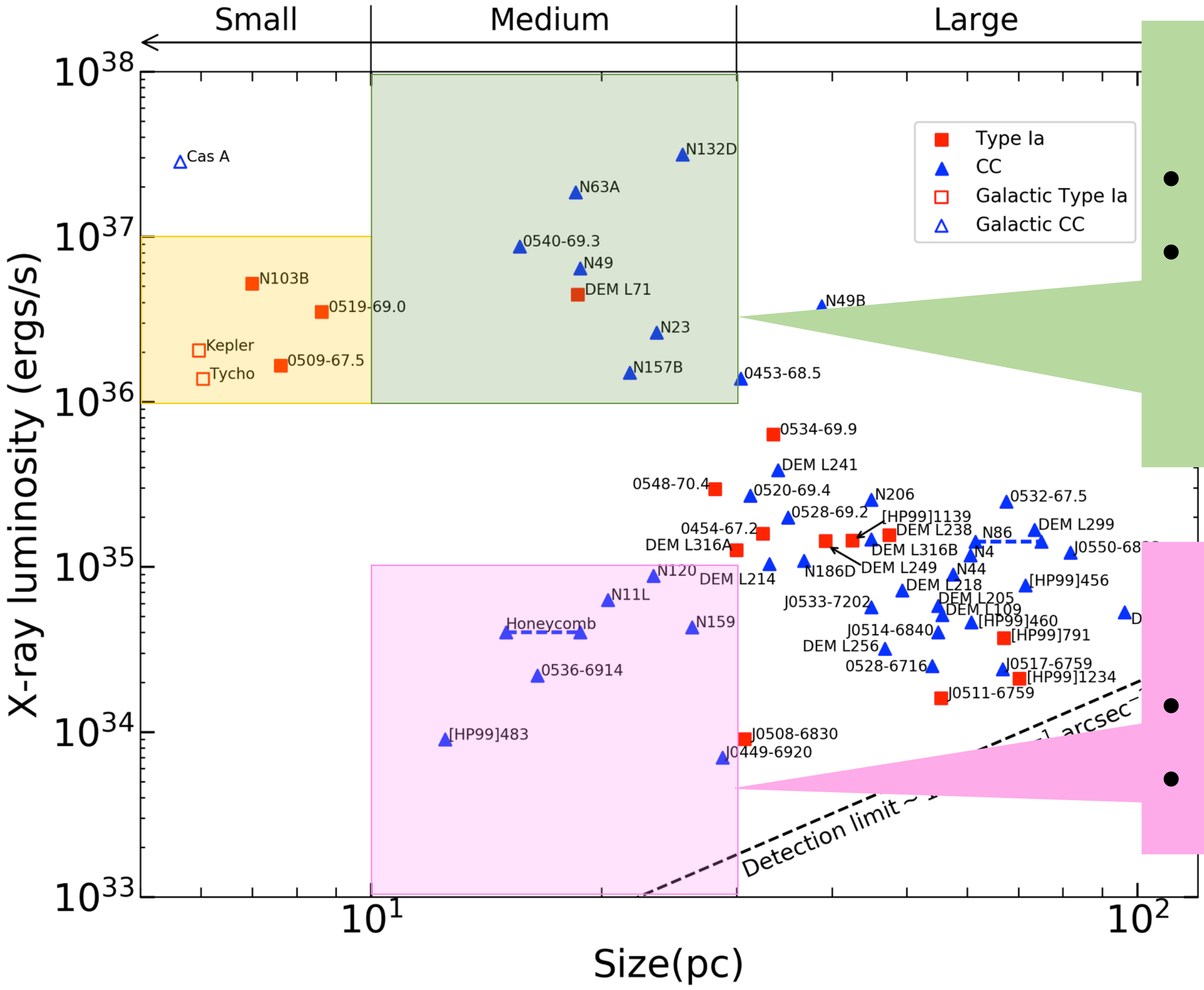
What are the evolution routes?



Summary

Small Type Ia SNRs:

- Lack of small CC SNRs is consistent with cavity explosions.
- L_X of small Type Ia SNRs are enhanced by reverse shocks.



X-ray bright CC SNRs:

- Some of them have PWNe.
- Others are associated with molecular clouds. Shocks hit dense medium and produce bright X-ray.

X-ray faint CC SNRs:

- w/o interactions with dense clouds.
- 20-30pc: reached bubble shells.