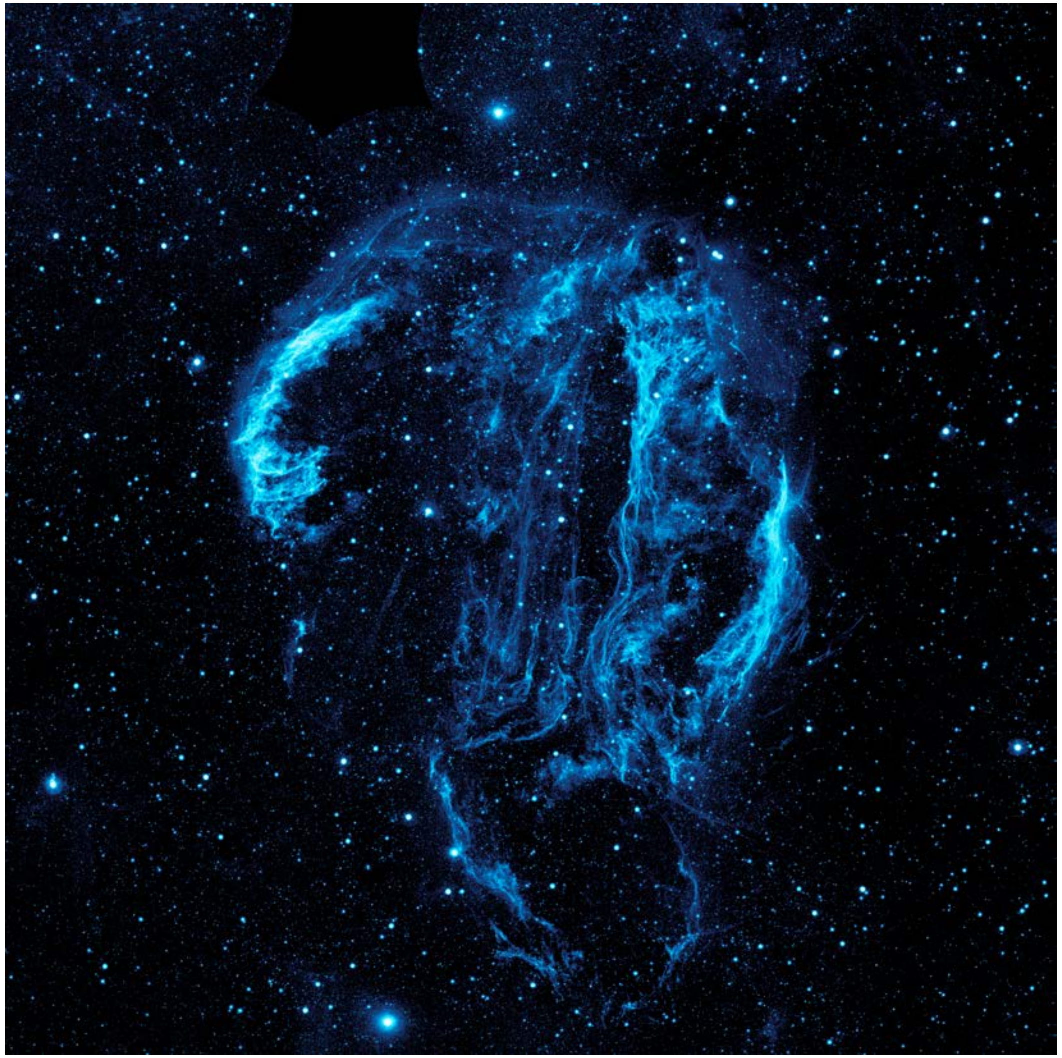
SNRs as Subgrid Physics

SNRs are vital for **Feedback** in cosmology and galaxy formation simulations.

Some mass in a cell forms stars, some of them explode, affecting future star formation.

Can we improve the handful of numbers that they use?



Cygnus Loop
Galex NUV image

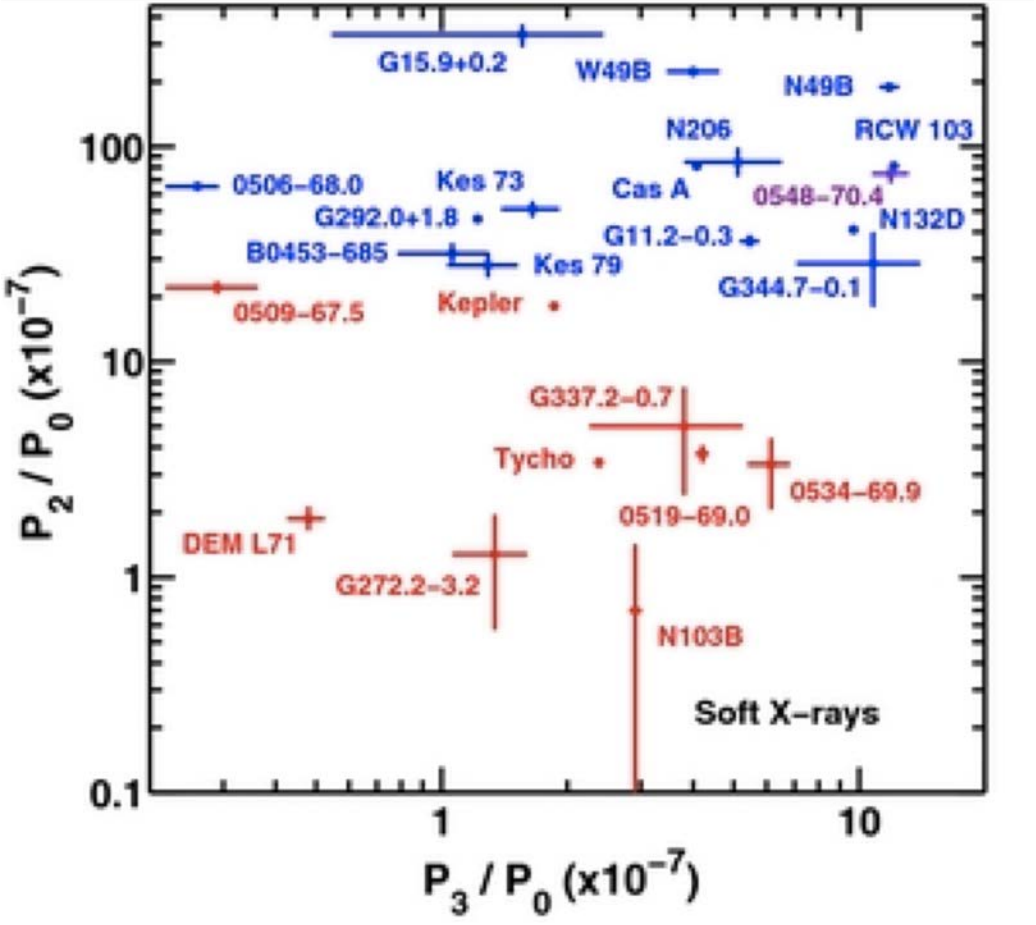
Mike Dopita

What do Simulations Need?

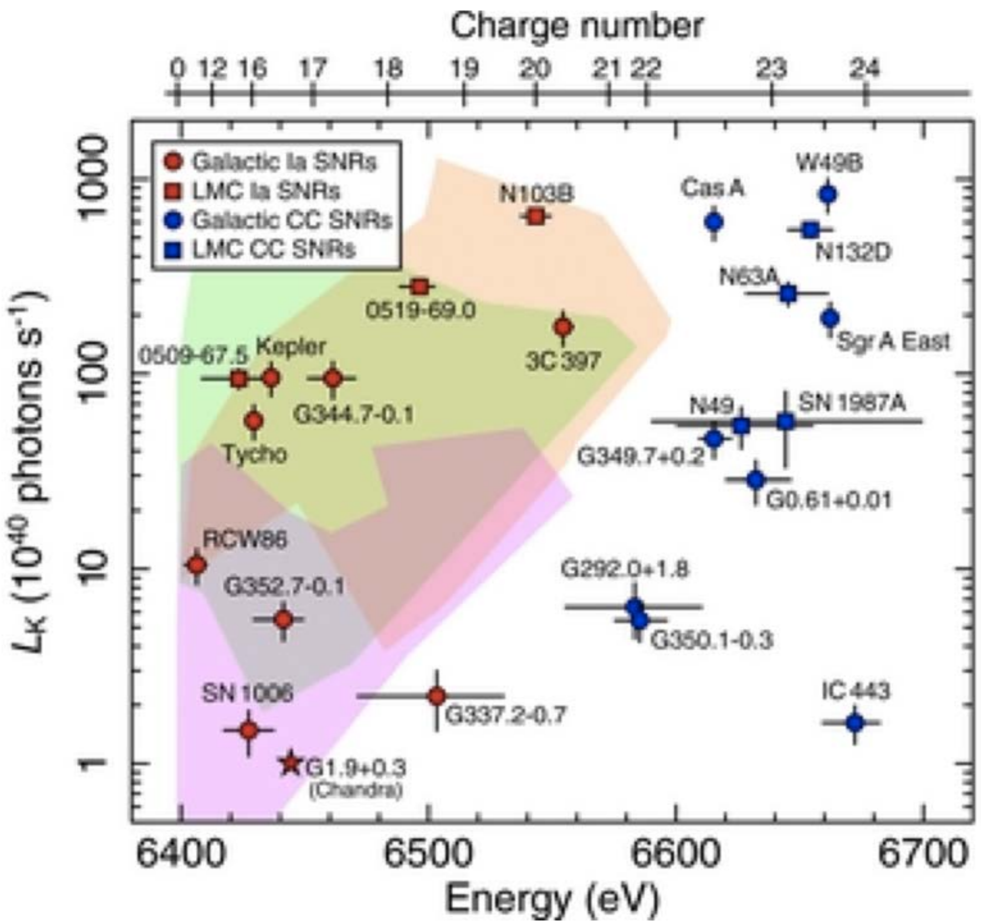
Progenitors:	How many stars explode, and when?
Kinetic energy:	What's left after radiative losses?
Heavy elements:	How do cooling rates evolve?
Dust:	How much is made and survives?
Cosmic rays:	What fraction of the energy?

Progenitors: Core Collapse vs Ia

Symmetry: **Lopez et al.**

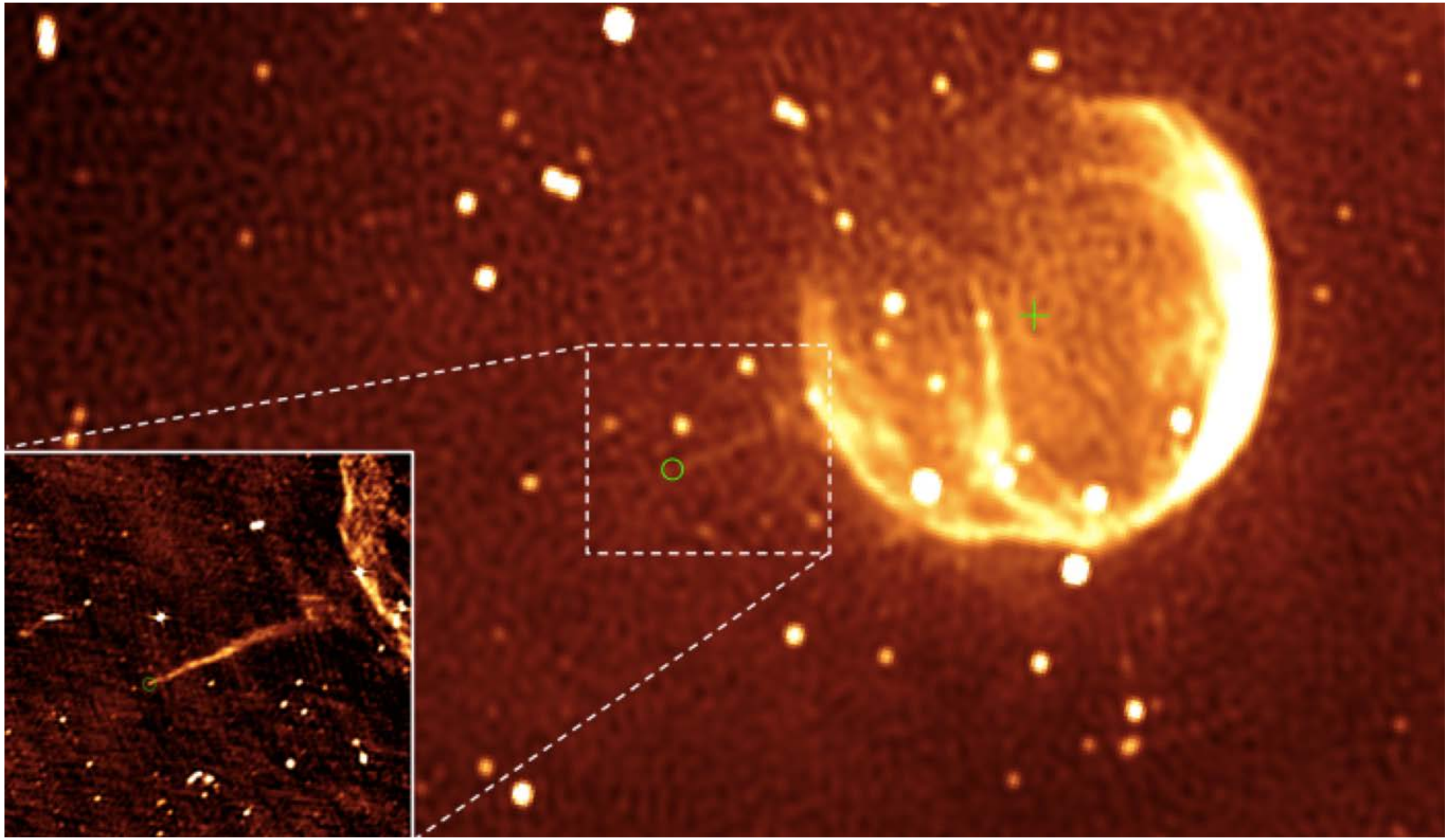


Fe Kα centroid: **Yamaguchi et al.**



Core Collapse Progenitors: Remnants

Remnants;
PSR/SNR associations
Crab, Cas A



CTB 1/PSR 0002+6216
Schinzel et al.

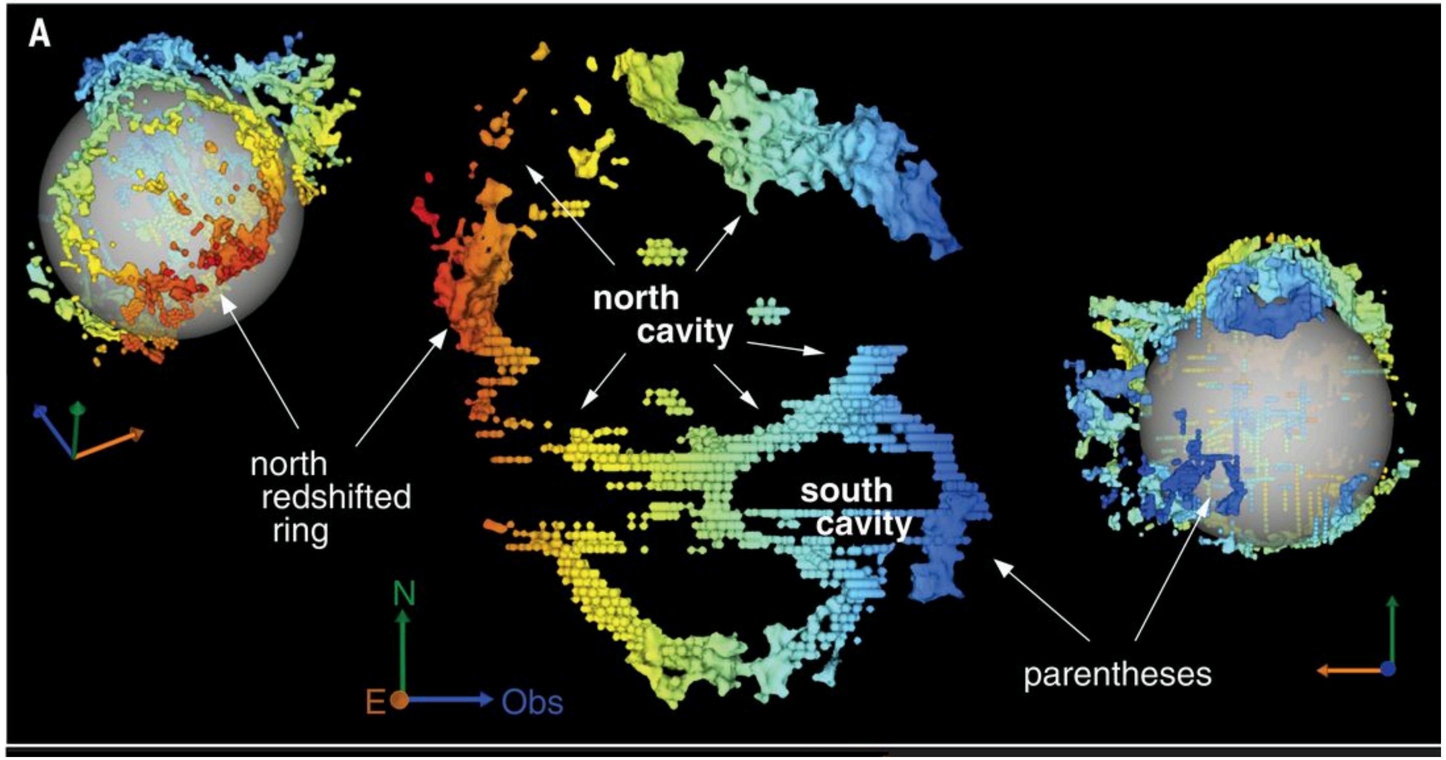
Core Collapse Progenitors: Morphology

O-rich Remnants
  Cas A and 7 others

Why only a (NGC4999) outside local group?

Jets; rotation

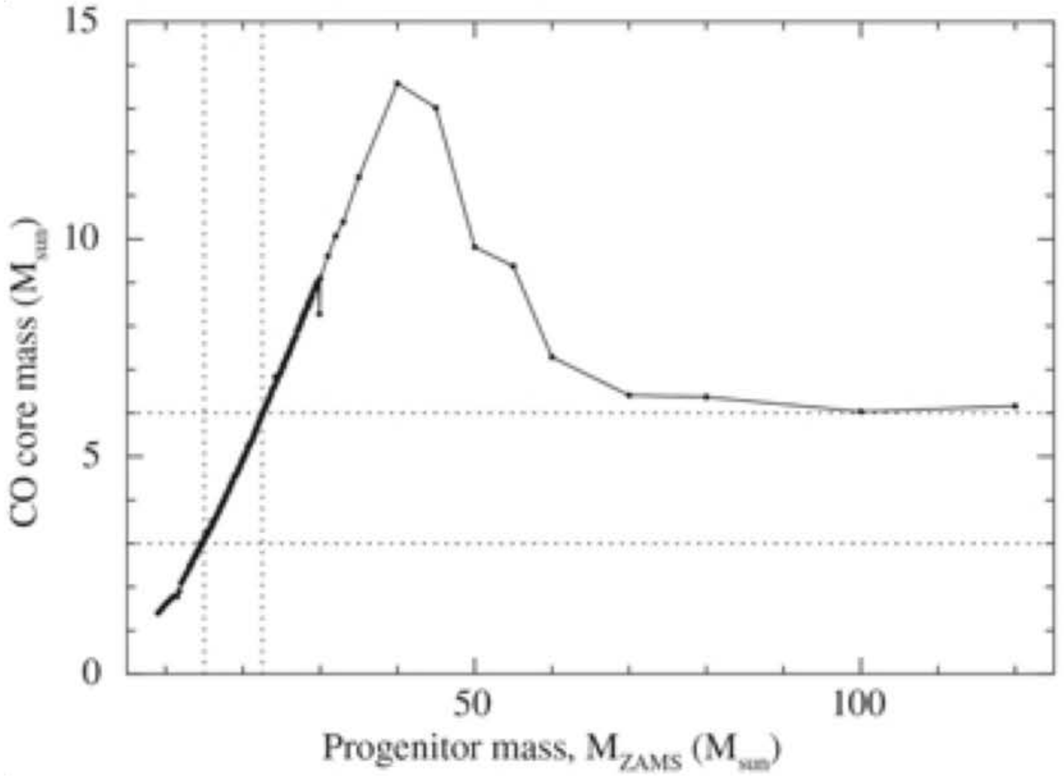
Rings; bubbles

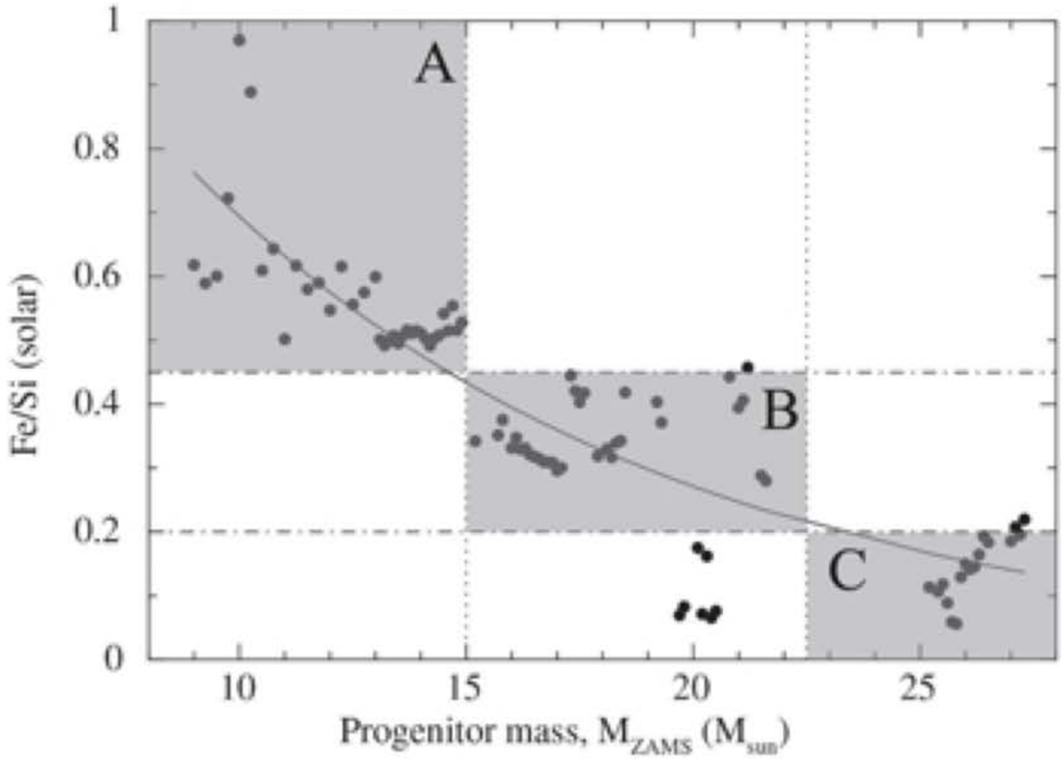


Milisavljevic & Fesen 2015

Core Collapse Progenitors: X-ray abundances

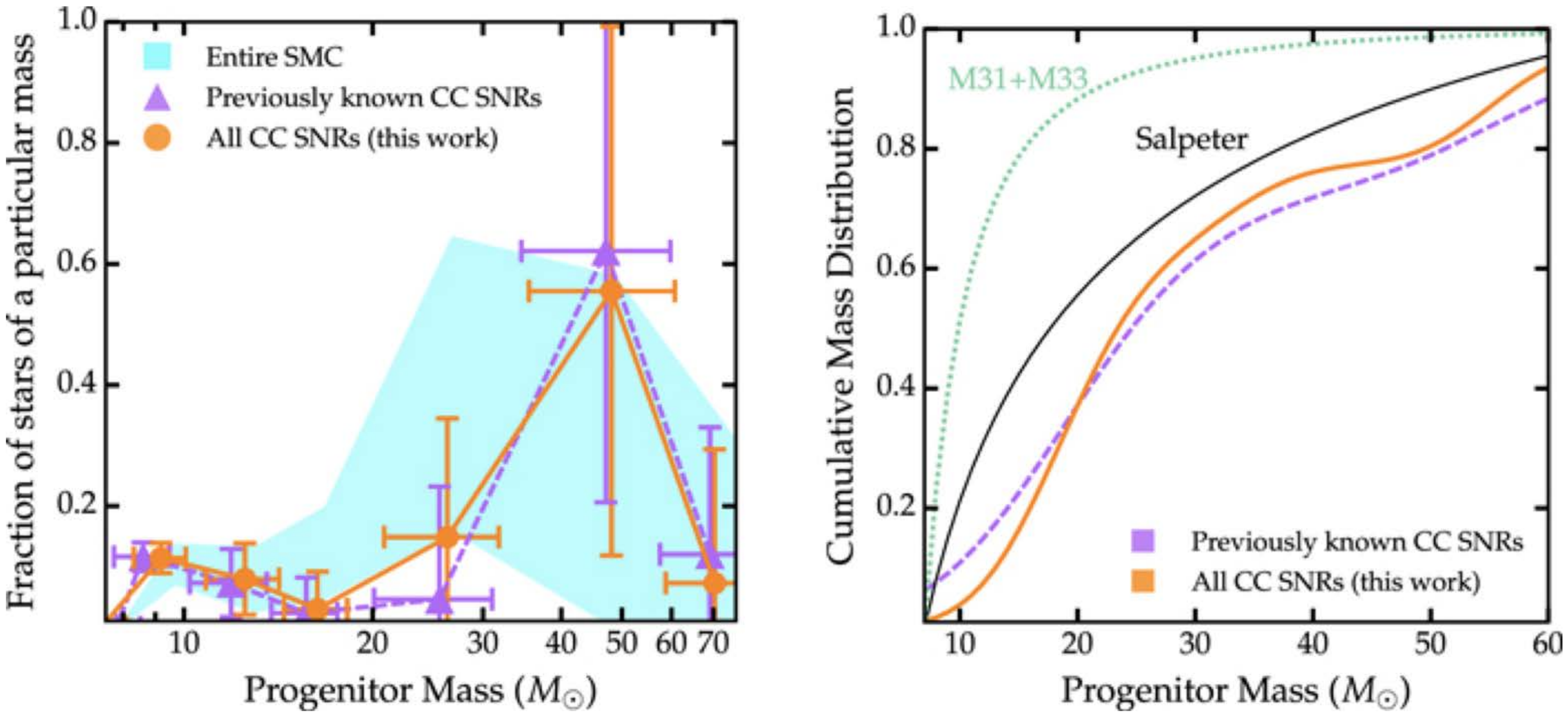
Katsuda et al. 2018   MW and MC





Core Collapse Progenitors: Stellar Populations

Auchettl et al.; SMC star formation history



Type Ia Progenitors

Single vs double degenerate

Delay time

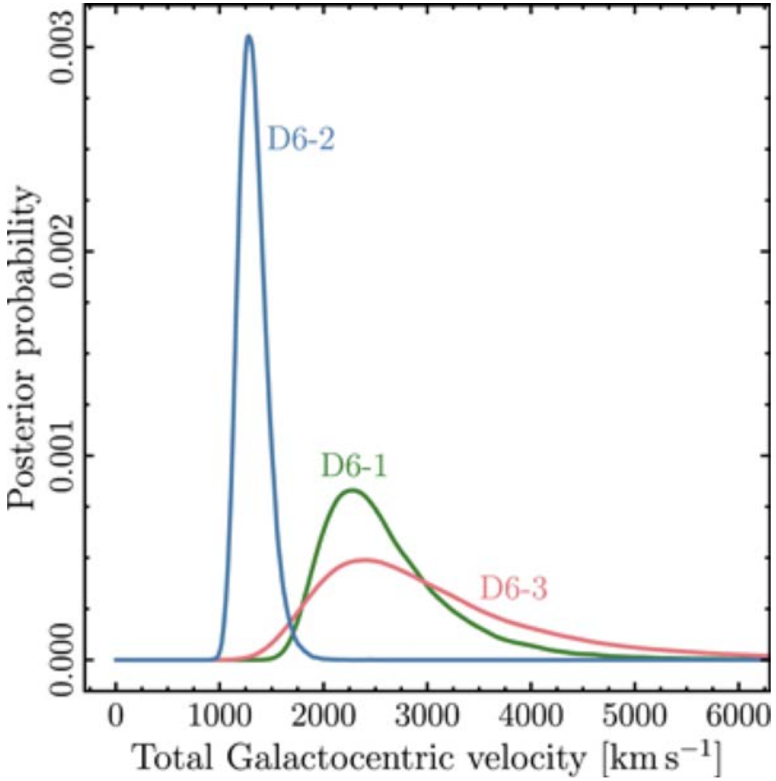
Galaxy metallicity

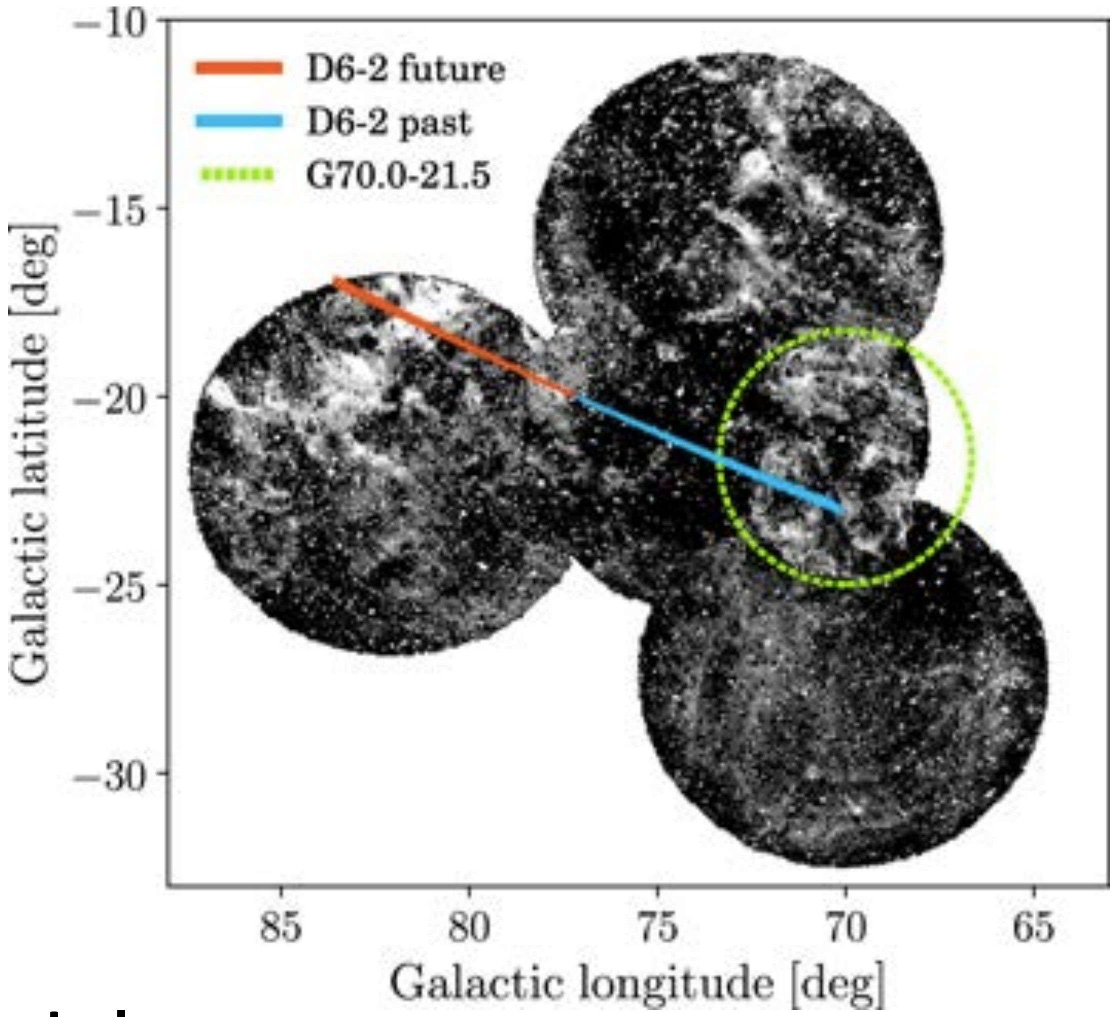
Inside Pne?

Fast WD;   G70.0-21

Type Ia: G70.0-21.5

High velocity WDs from double Degenerate systems with GAIA





Shen et al.

1 kpc, 50,000 yrs

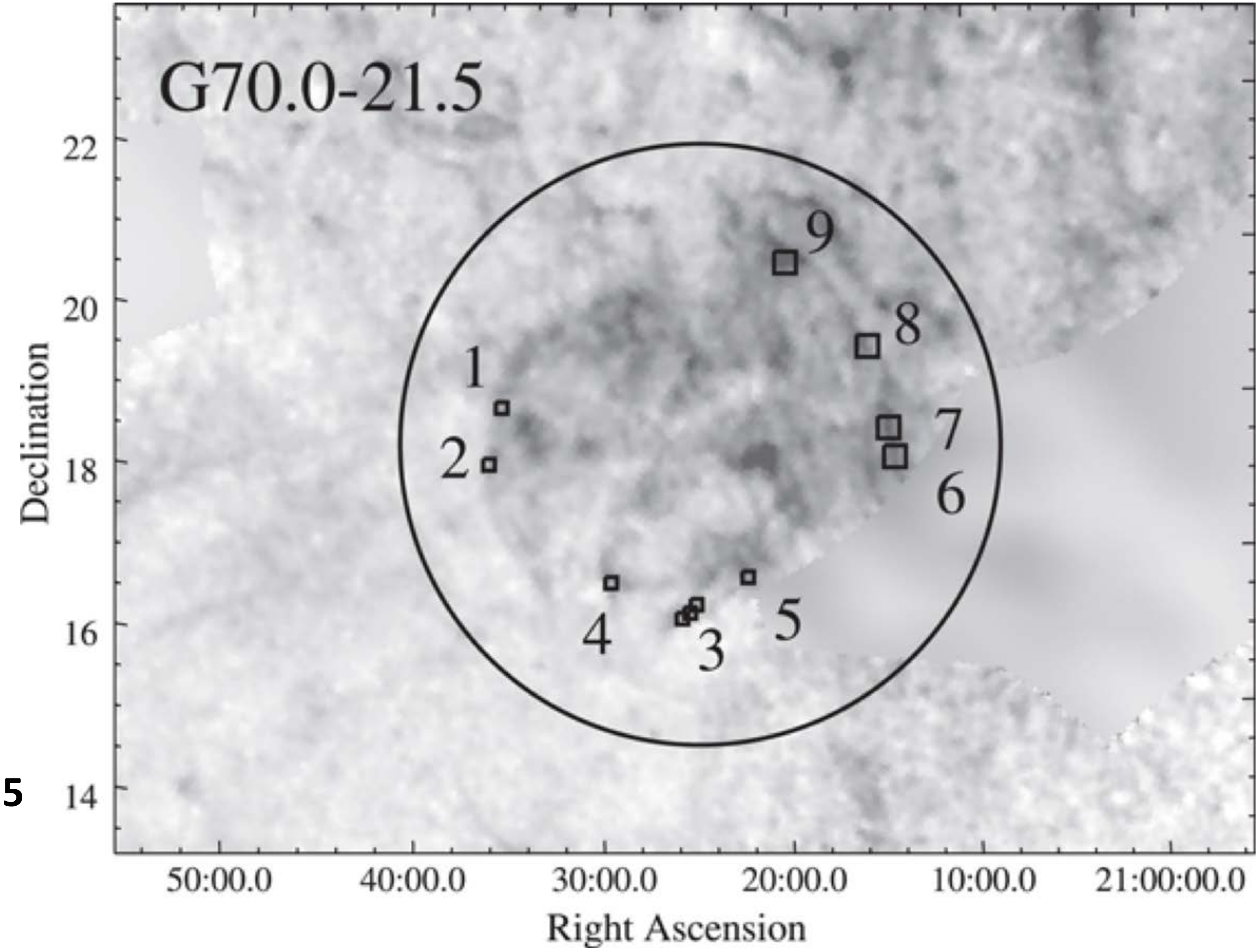
Type Ia: G70.0-21.5

Enormous:

4x5 degrees

350 pc from plane

Evolution in Halo



Fesen et al. 2015
VTSS Hα image

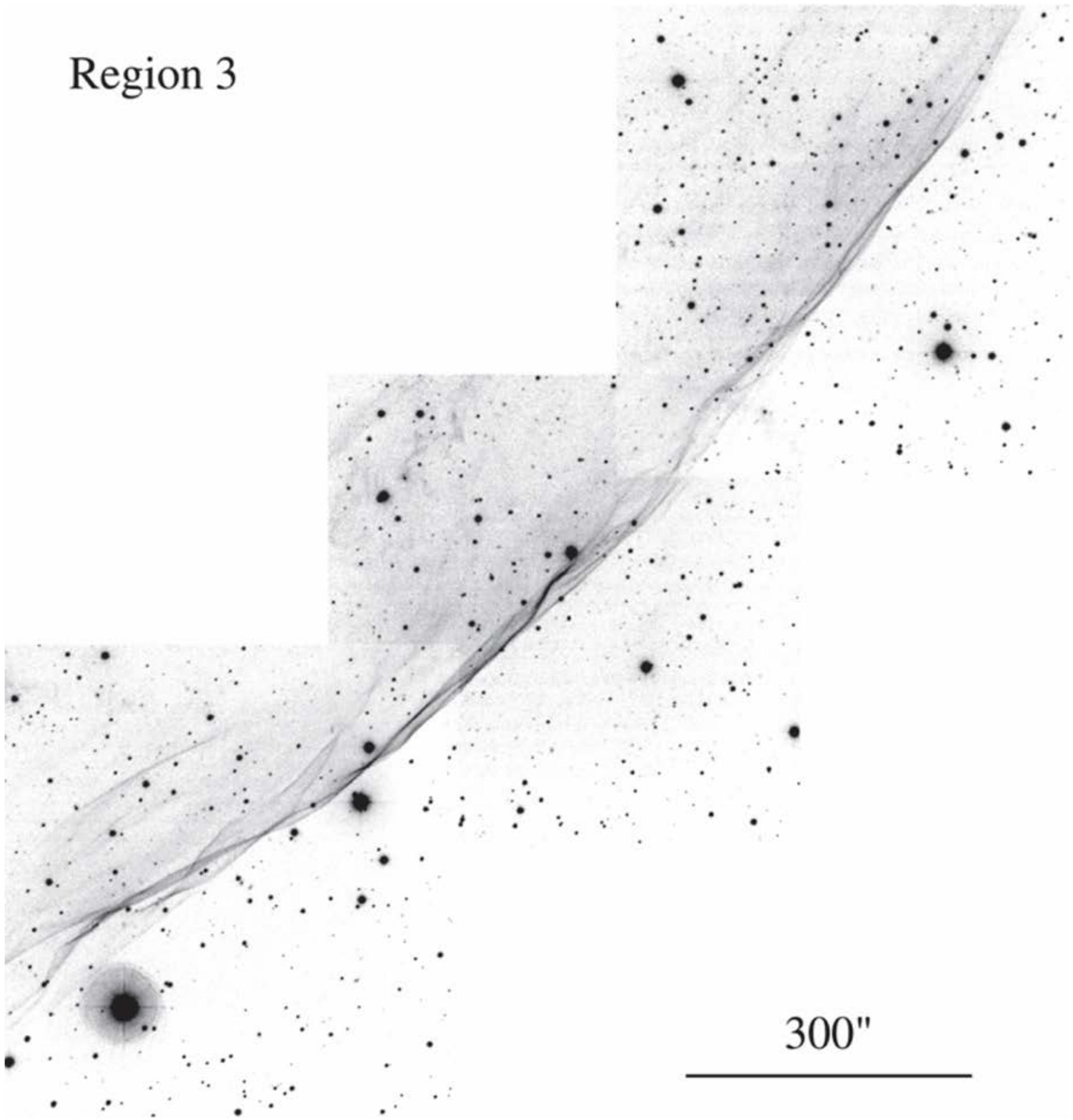
Type Ia: G70.0-21.5

Faint X-ray and optical

60-90 km/s shocks in partly neutral, low density gas,

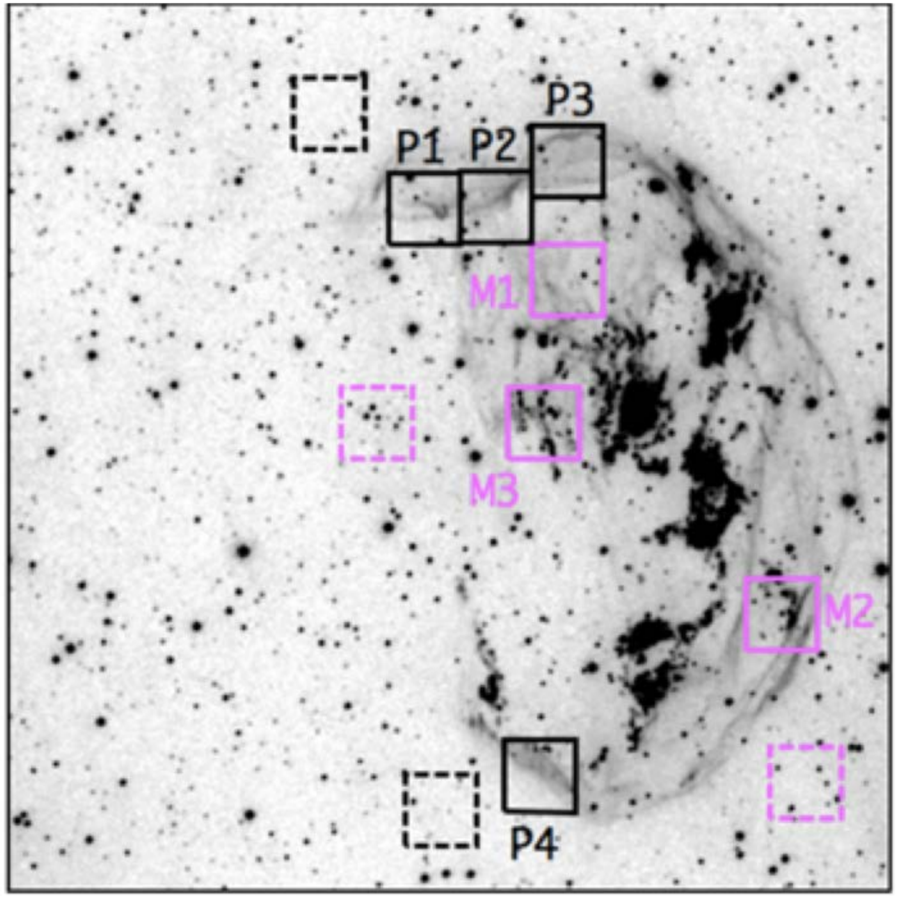
Evolution in the Galactic Halo

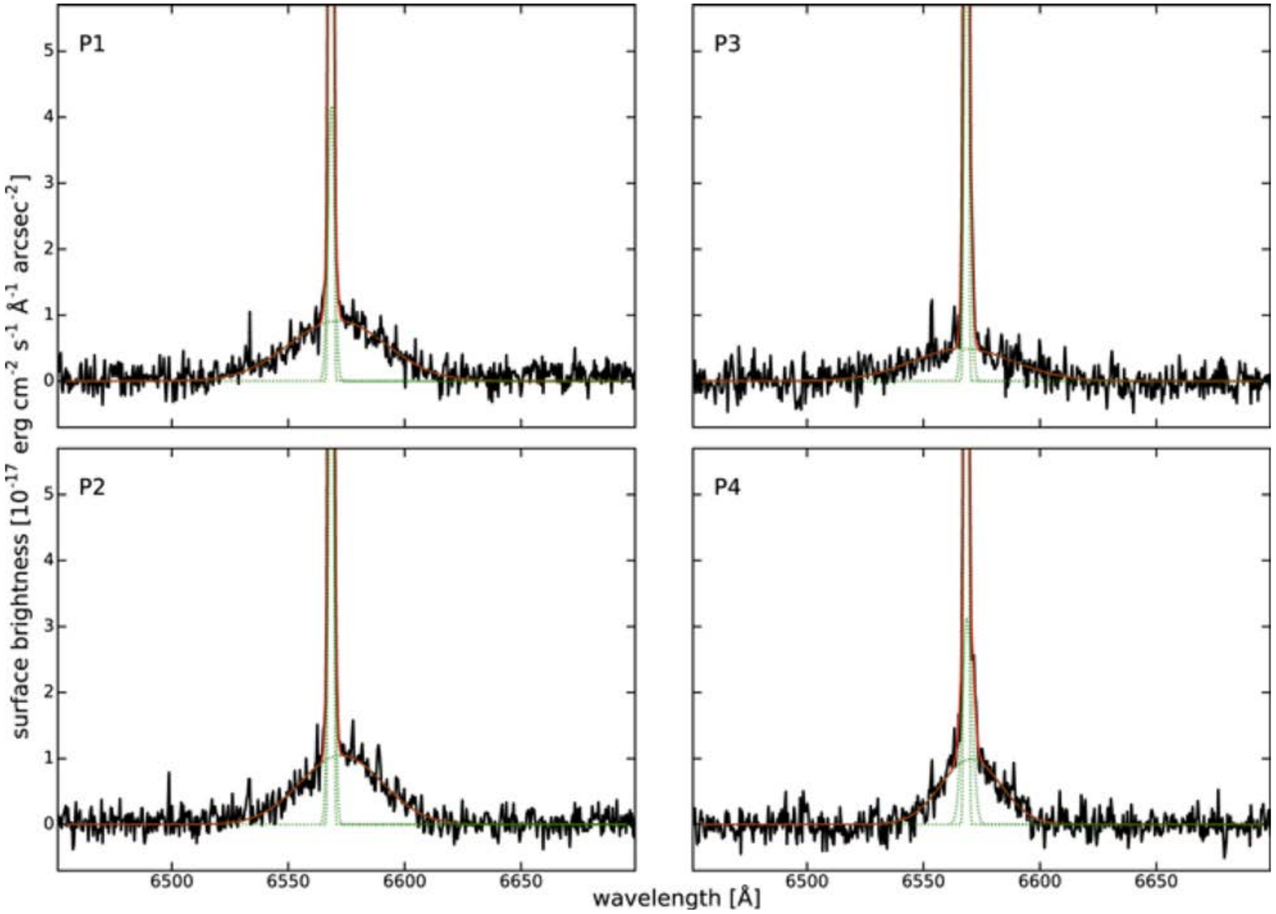
Hα Mosaic
Fesen et al.



Type Ia: LMC Balmer filaments

N103B; Ghavamian et al.





Not SSS progenitors; Kuuttila et al.

Type Ia: CSM interaction; Kepler

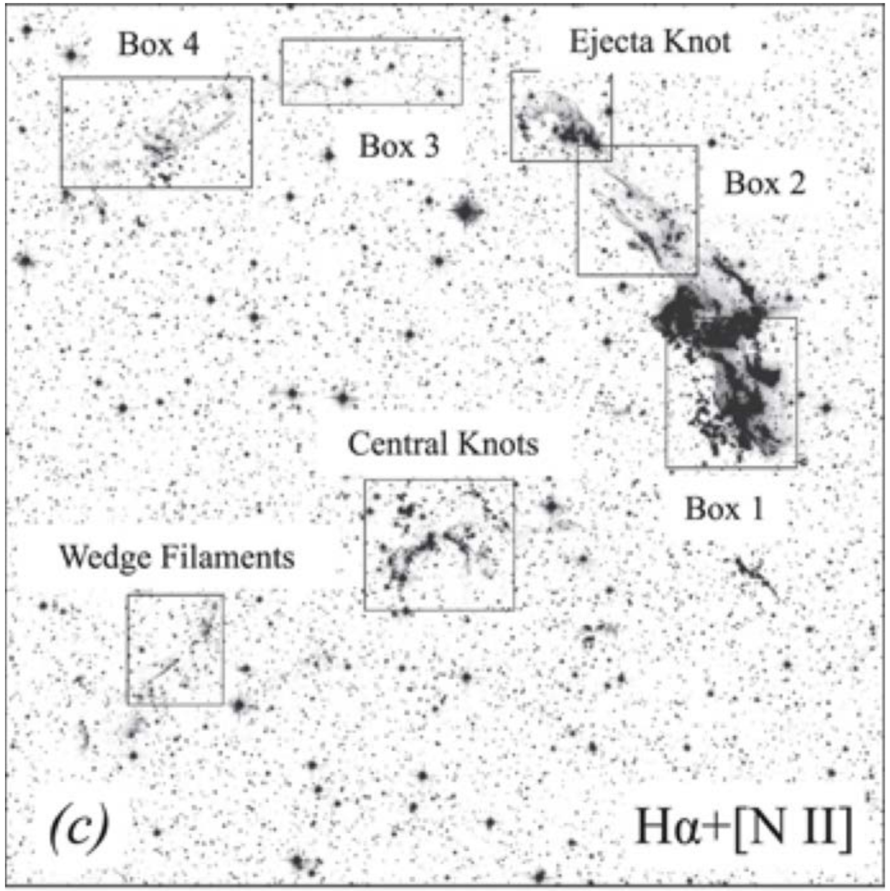
600 pc from plane, 10 to 10^3 cm^{-3} density.

$\geq 0.3\ M_{SUN}$ from companion mass loss?

N overabundance? Katsuda et al., Dopita et al.
Dust from progenitor; Williams et al.
High velocity; Blair et al.
No bright companion; Ruiz-Lapuente et al.

PN? Tsebrenko & Soker,
but ears show strong Si, S; ejecta

Core-Degenerate? Tsebrenko & Soker



Sankrit et al. HST proper motion

Kinetic Energy

Are they all 10^{51} ergs ?

Subluminous, superluminous

After radiating away most of energy (snowplow)

Depends on ISM environment over many pc

Need Distances

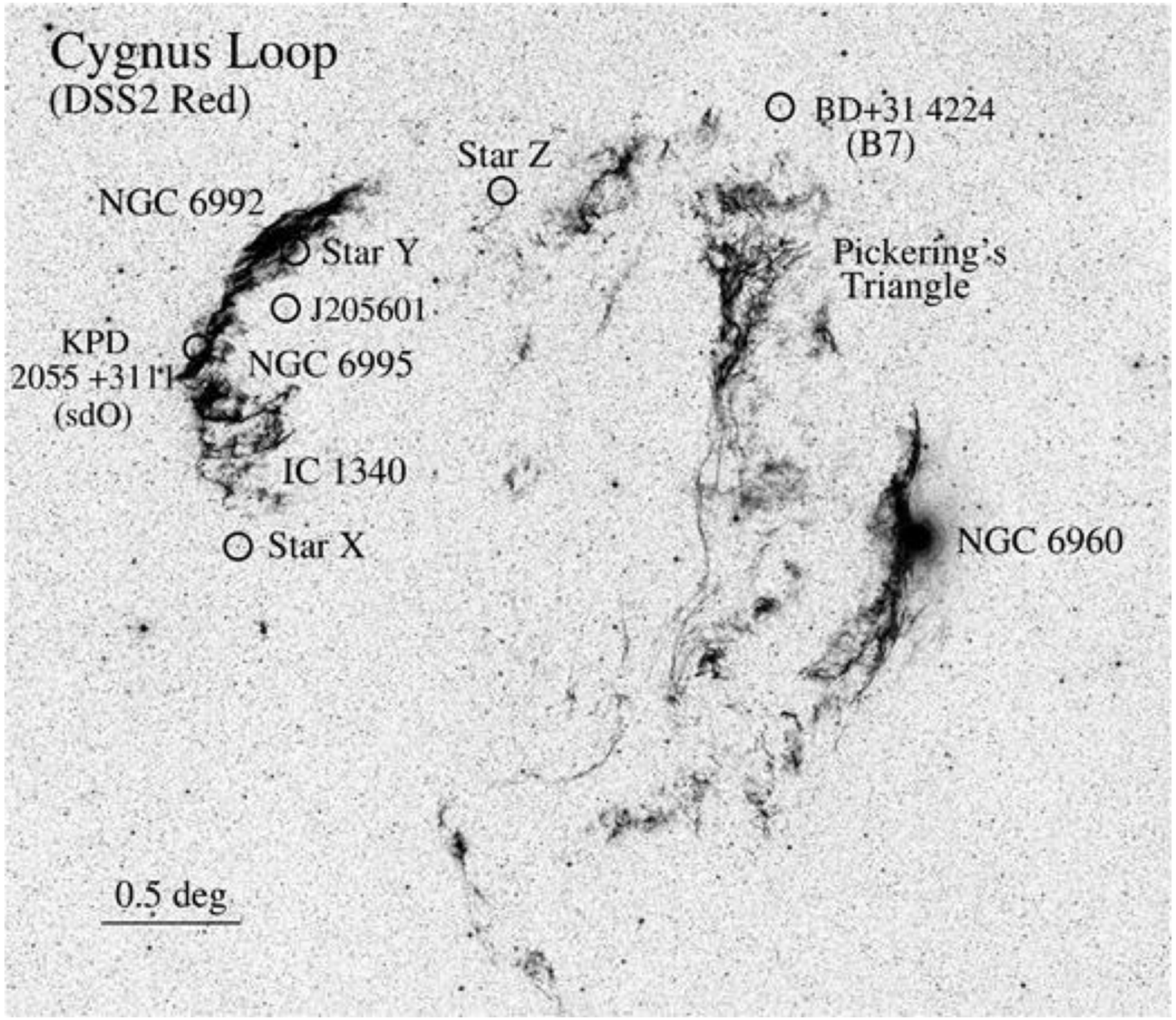
Distances: GAIA

Cygnus Loop

Absorption lines to
BD +31 4224

Dust absorption in
interacting cloud
from Green et al.

735±25 pc



Fesen et al.

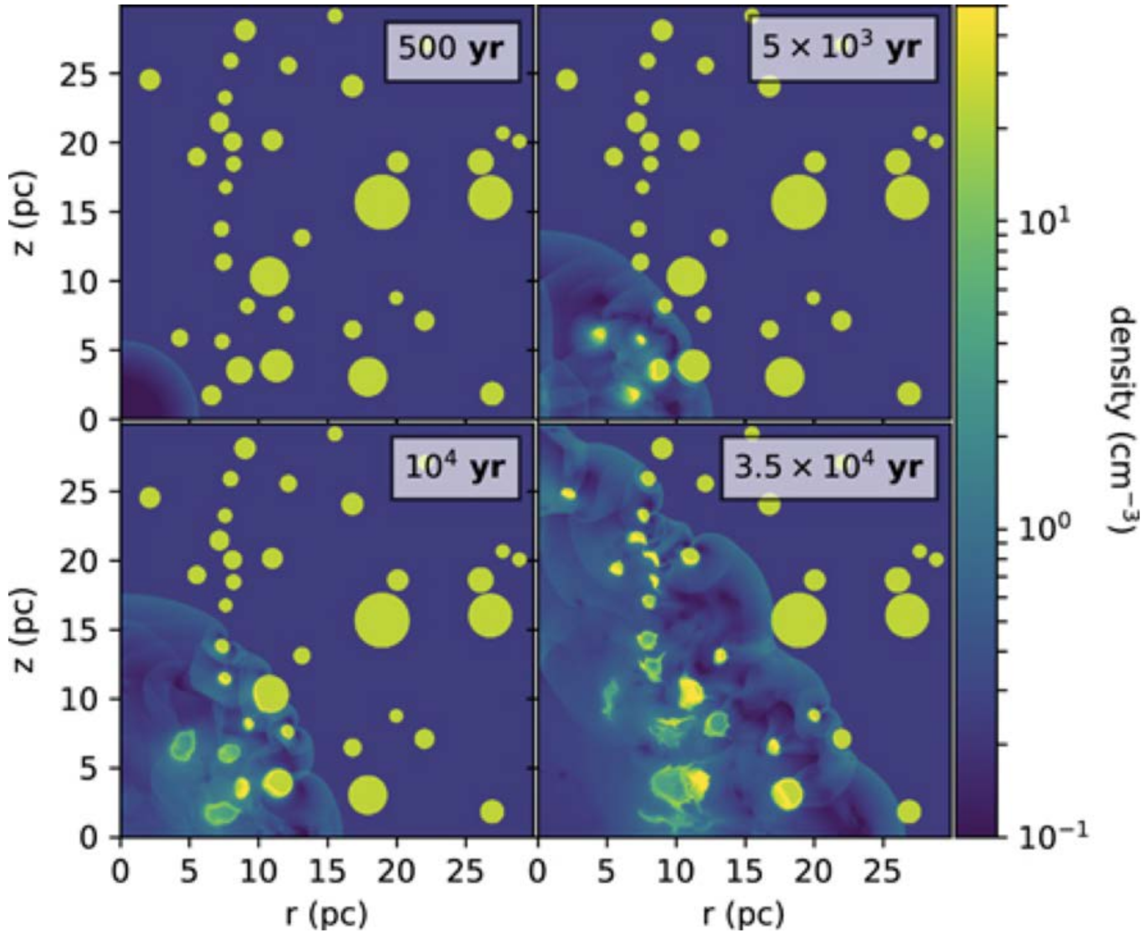
Energy Remaining after Radiation

Drives Turbulence, governs star Formation

1D, uniform medium 0.48 E_0
after shell formation;
Most of energy radiated in EUV
Cox 1972

Realistic ISM

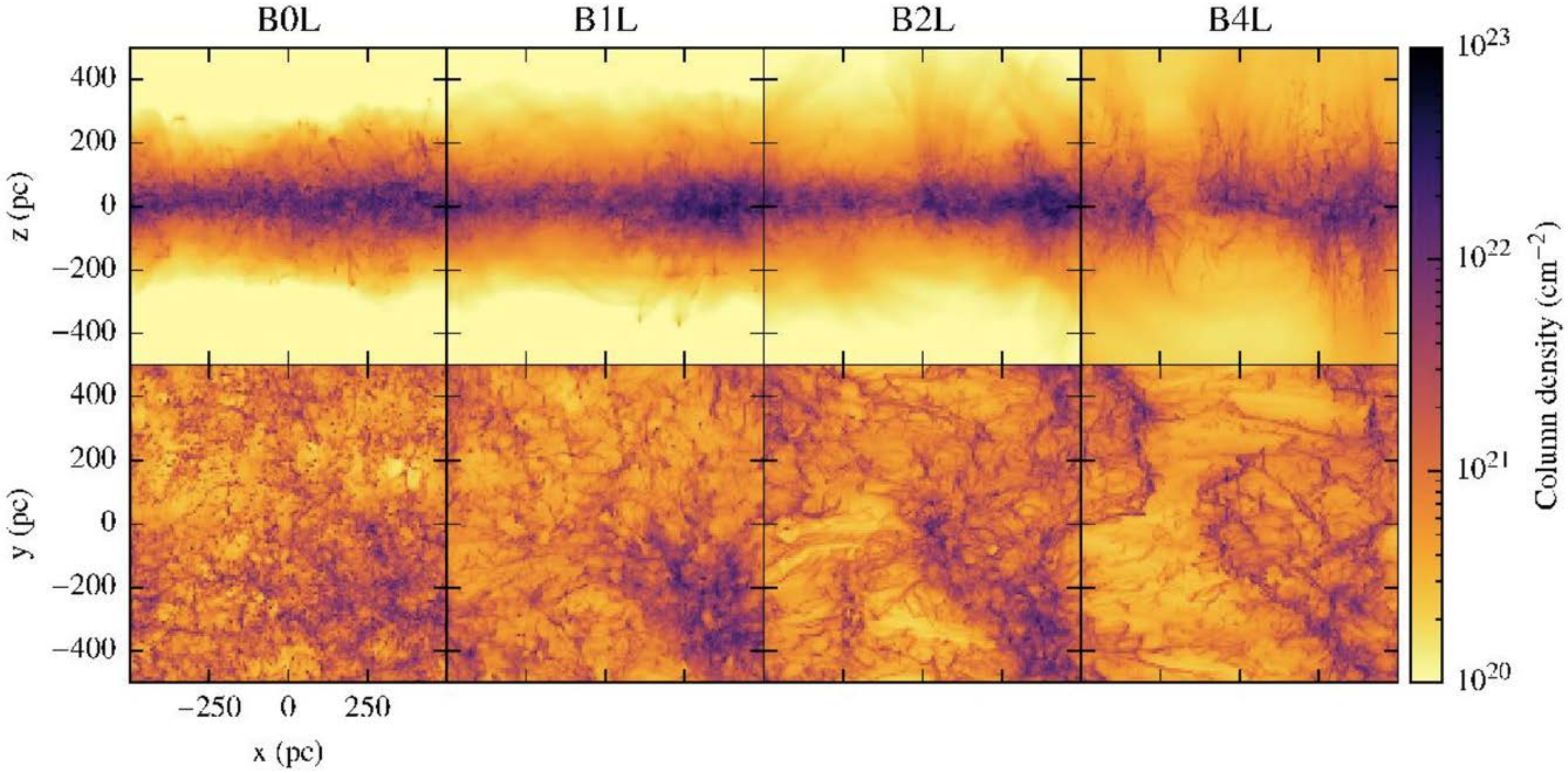
Slavin et al.



Energy Remaining after Radiation

Drives Turbulence, governs star formation

Complex feedback



Iffrig & Hennebelle

Heavy Elements

For cooling and diagnostics

Fe/O and R-process

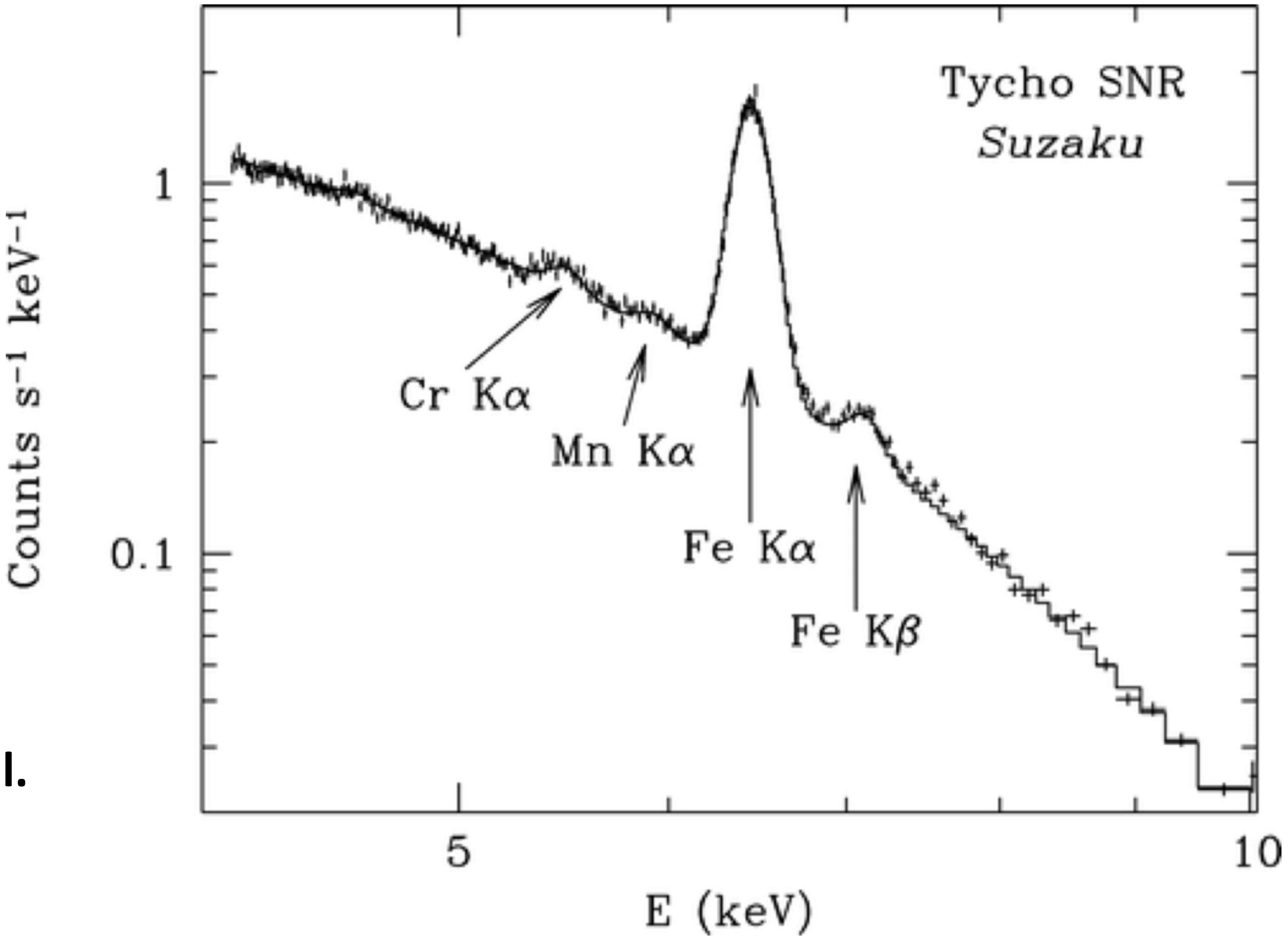
To measure from X-rays:

- Separate ejecta from ISM
- need T and $n_e t$; fit simultaneously with abundances
- need density; filling factor
- need dust; X-rays see gas phase
- He, C bremsstrahlung
- Spatial resolution

Heavy Elements

Tycho:

Cr and Mn as diagnostics
for explosion mechanism

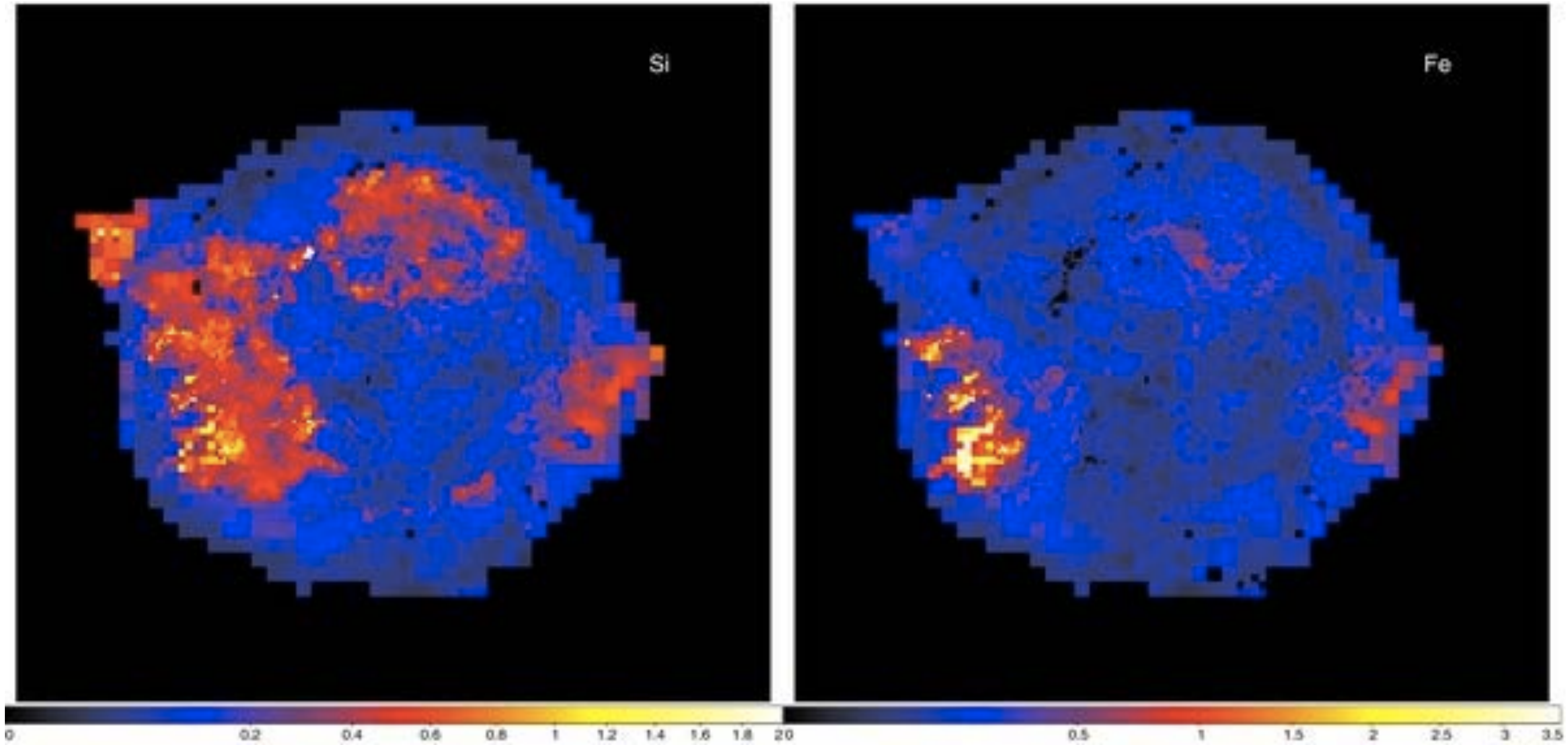


Badenes et al.

Heavy Elements

Fitting multi-temperature plasma with single T gives wrong abundances

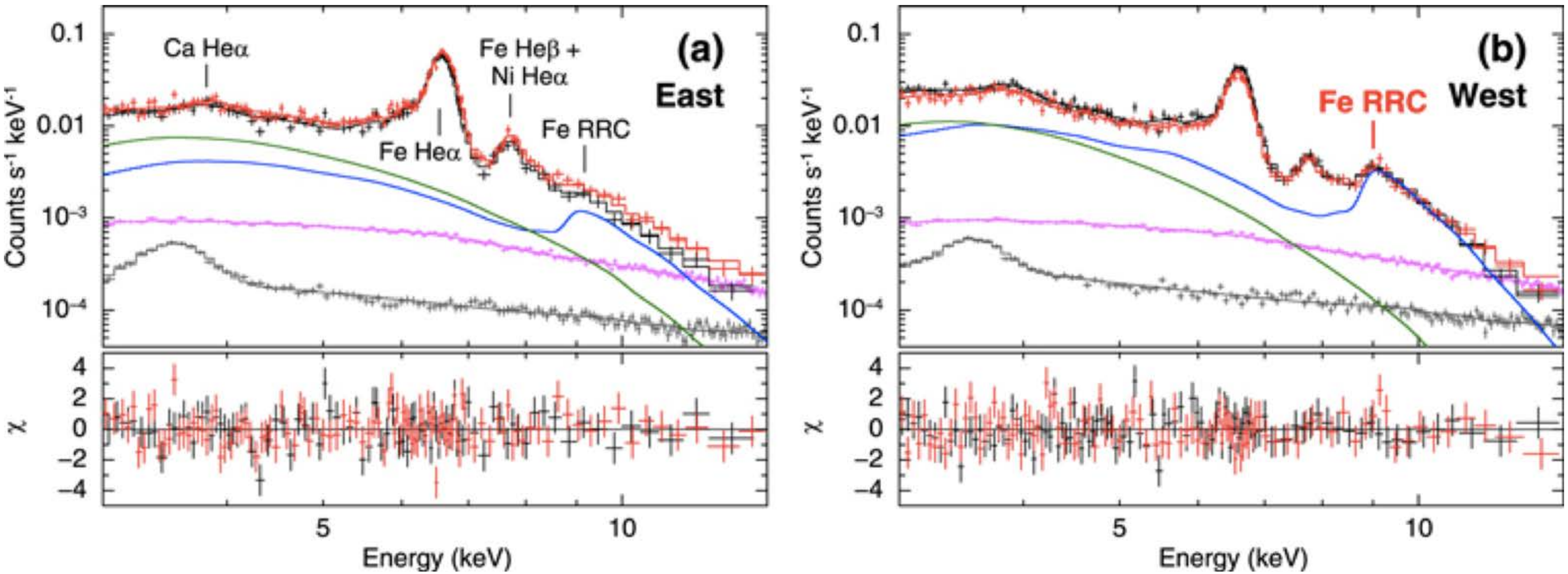
Cas A Si and Fe abundances; Hwang & Laming



Heavy Elements

Models: need T and $n_e t$

Yamaguchi et al.



Dust

How much is made?

SNe -- up to 0.5 M_{SUN} in SN 1987A; Matsuura et al.

How much survives?

Cas A; ejecta and AGB wind

How much ISM dust is destroyed?

Dust

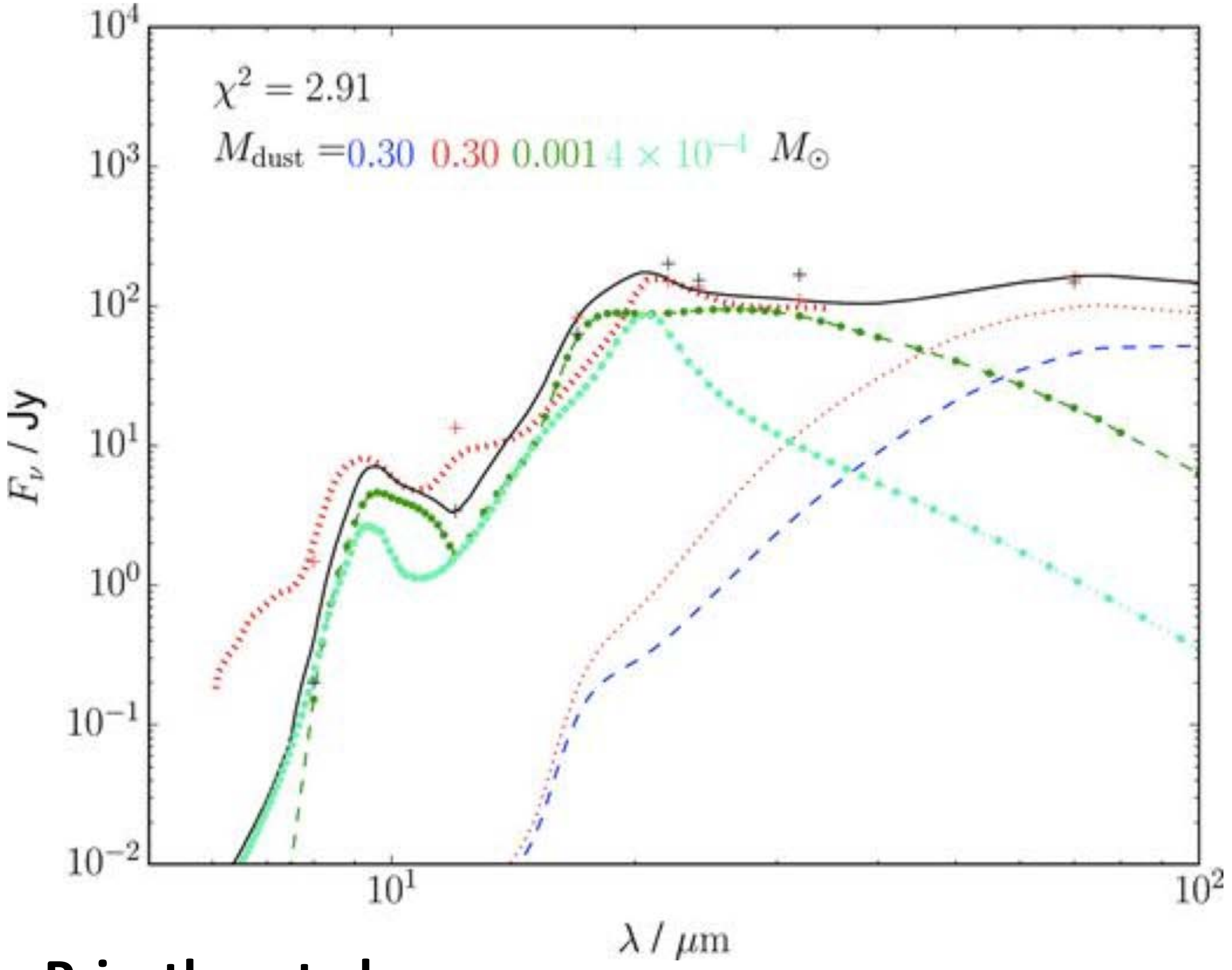
How much survives?

Cas A

Unshocked ejecta
Clumps
Shocked ejecta
X-ray CSM

Dust to gas ~ 0.2 in clumps
0.001 in hot gas

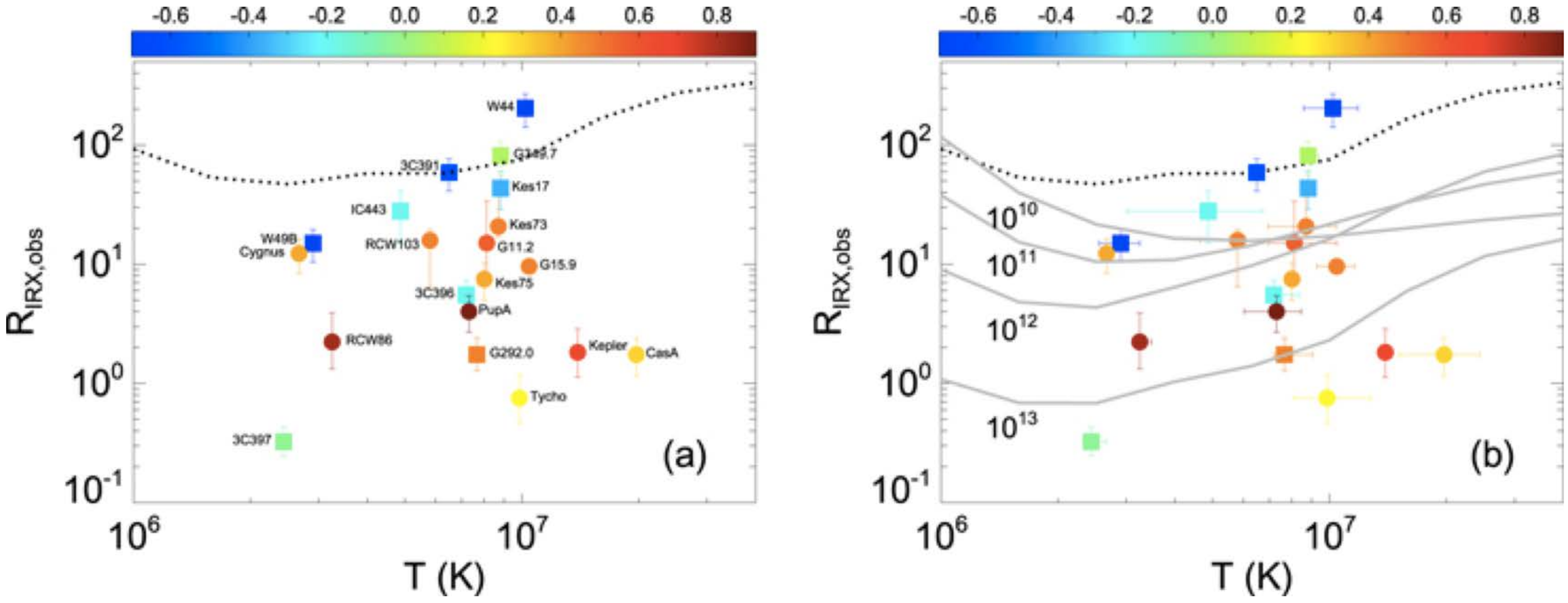
Survival of progenitor AGB dust?



Priestley et al.

Dust

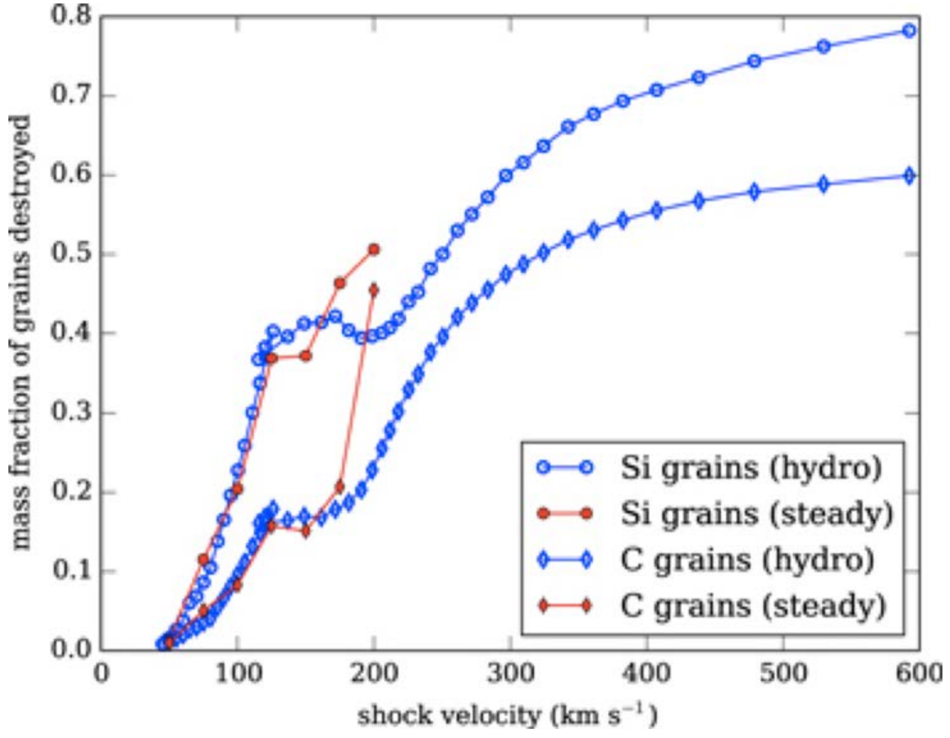
Important coolant for SNR evolution



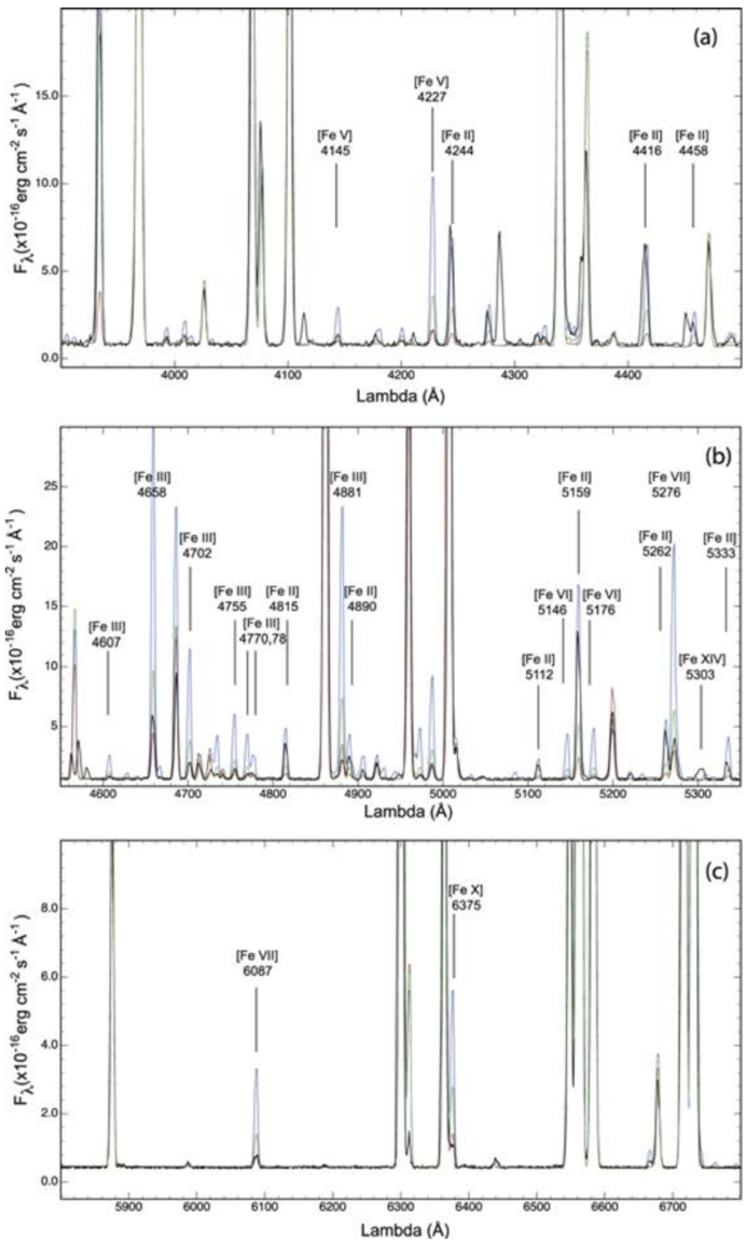
Koo et al.

Dust

How much ISM dust is destroyed?



Slavin et al, 2015



N49: Dopita et al. 2016

Cosmic Rays

10% of energy, γ=4/3

Immune to radiative losses

SNRs are favored source of CRs up to ~10^{15} eV

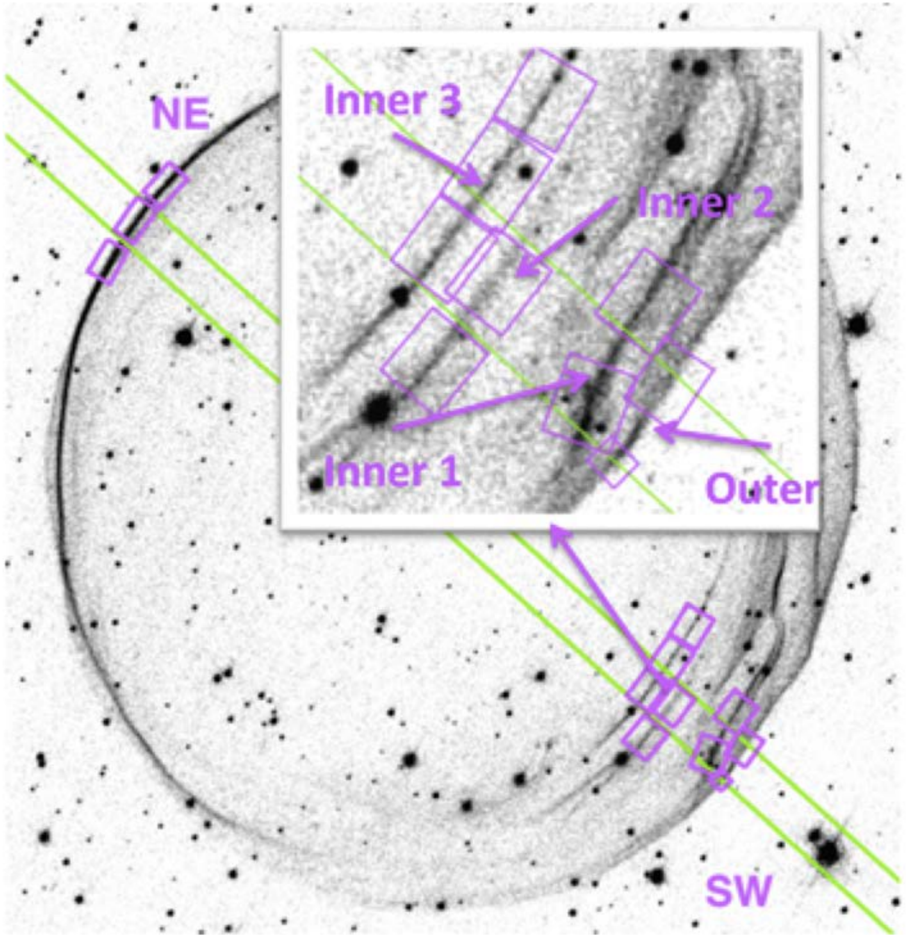
Cosmic Rays

$T = 140{,}000\ V_{100}^{2}$ --- if no energy in CR

V_s from proper motion and distance
T_i from line widths
T_e from X-rays (small)

Proper motion V = 2900 – 4000 km/s

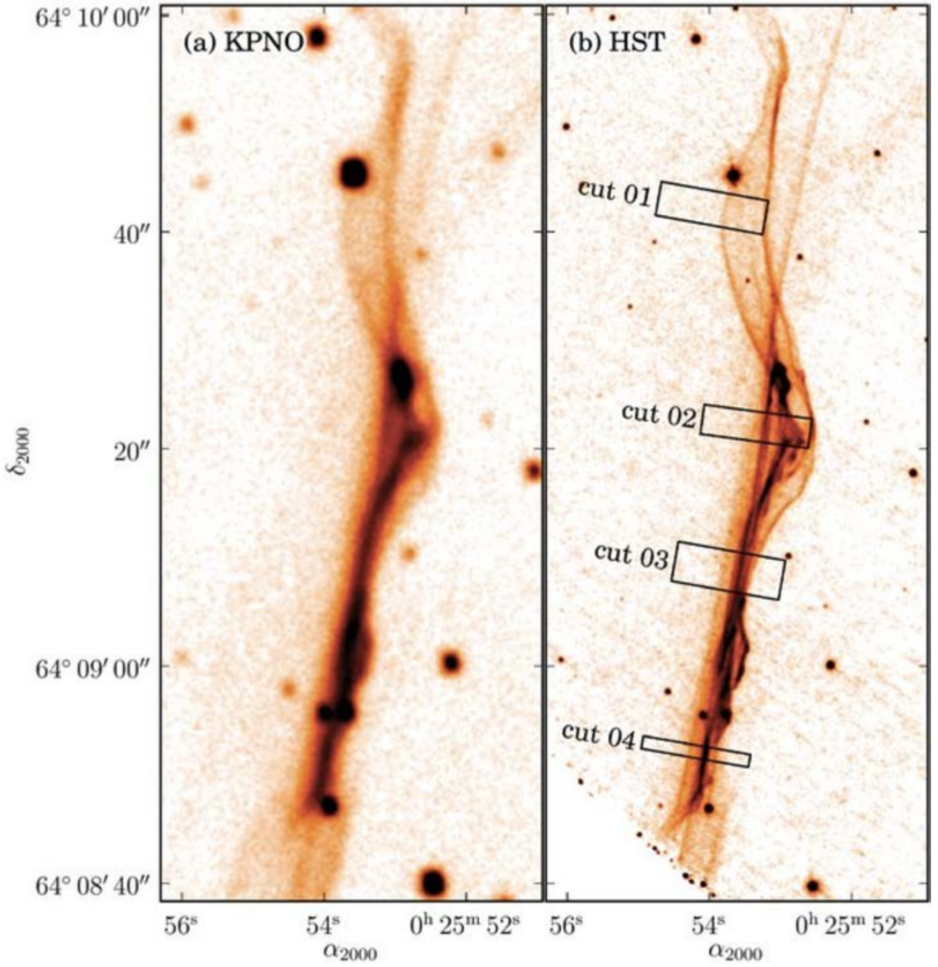
Efficiency < 6%/f_0 in these Balmer-dominated shocks



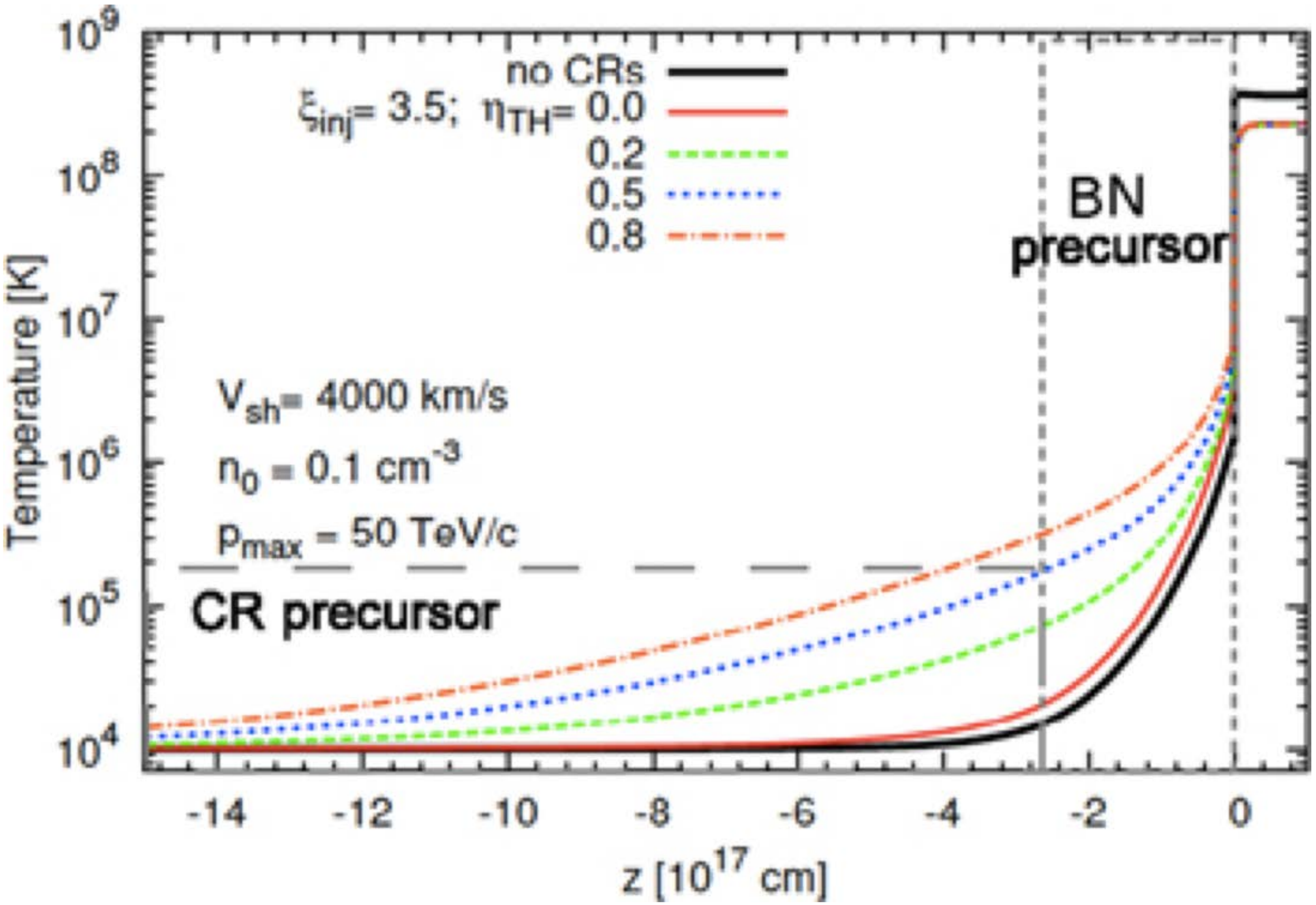
Hovey et al. -- 0509-67.5

Cosmic Ray of fast neutral Precursor?

Tycho: Lee et al.



Knežević et al.



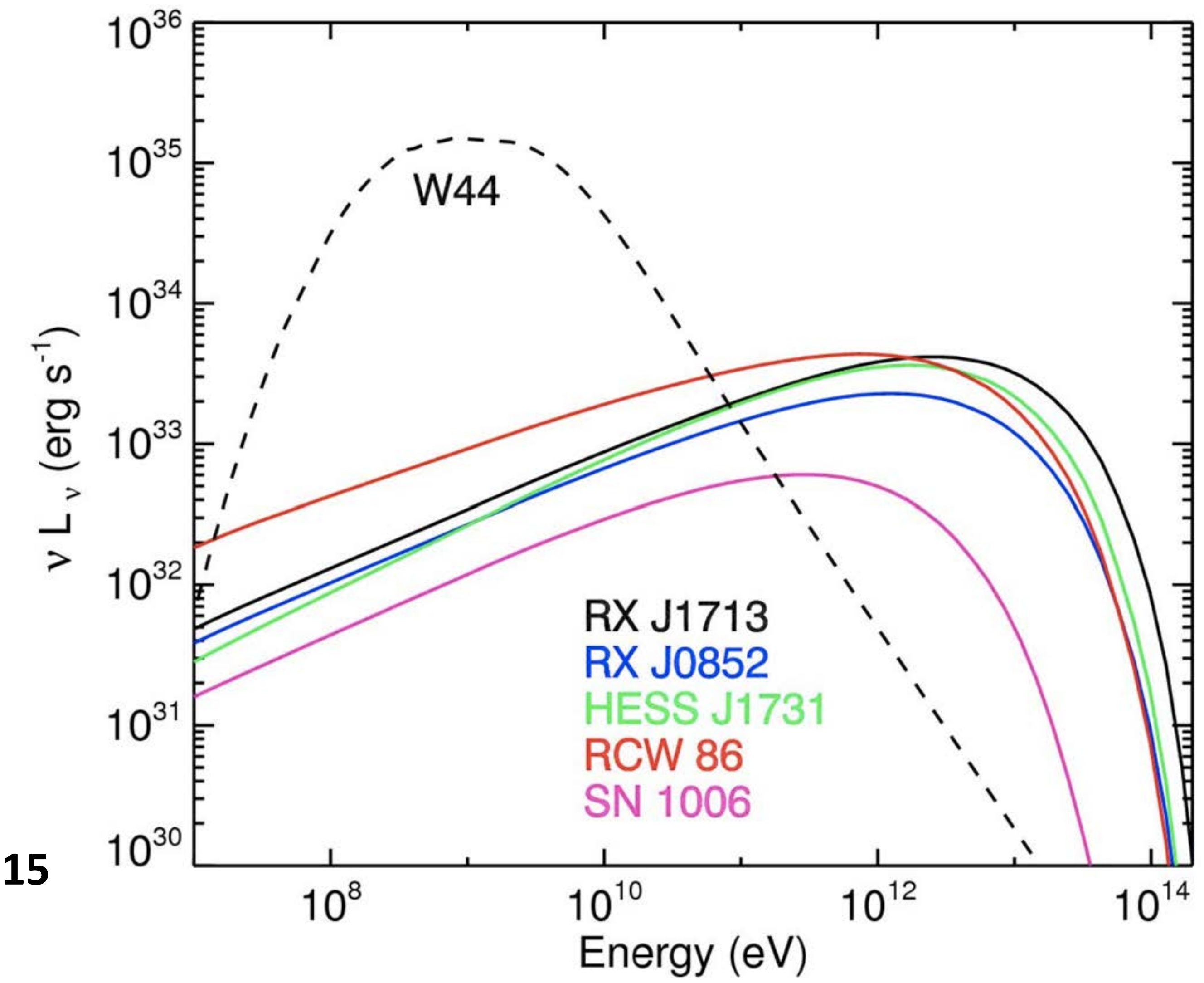
Gamma-Rays

Older, hadronic remnant W44

vs.

Younger, leptonic shell remnants

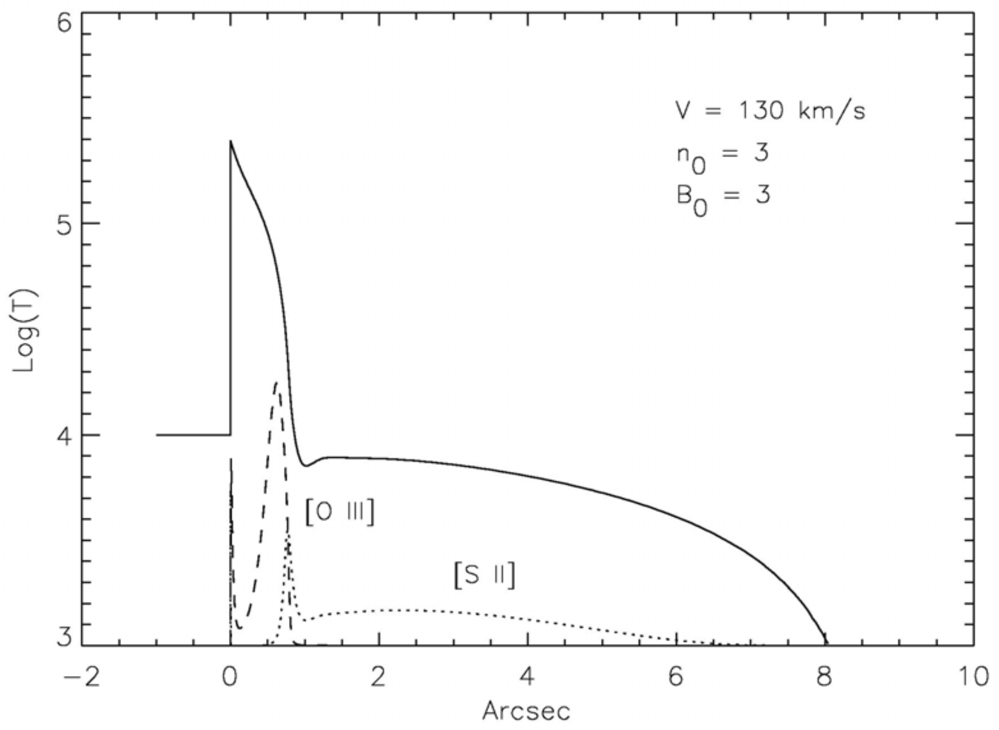
Cutoff ~ 10 TeV



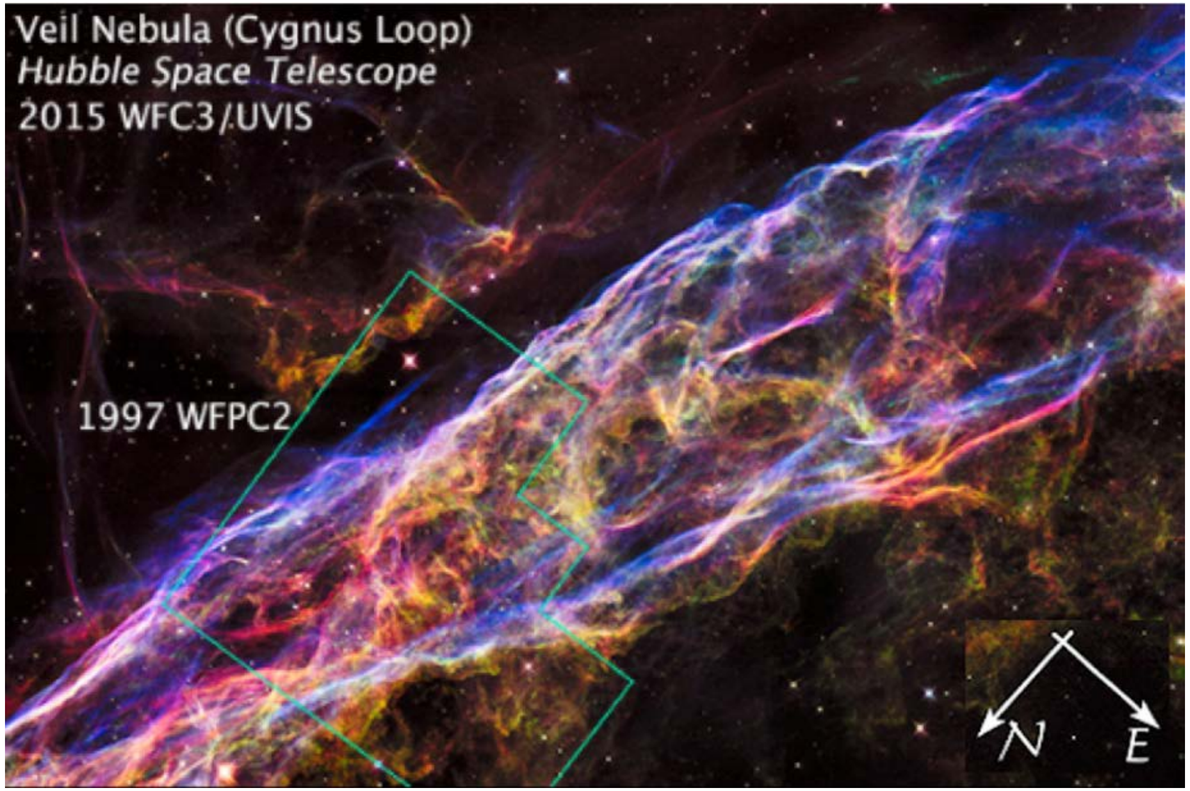
Acero et al. 2015

Room for Improvement

Model



Reality
Hubble Heritage Mosaic



What Did I Leave Out?

CSM interaction

Cas A QSFs

SNRs in superbubbles

How can we see them?

Important for CRs

Molecules

Radio

...

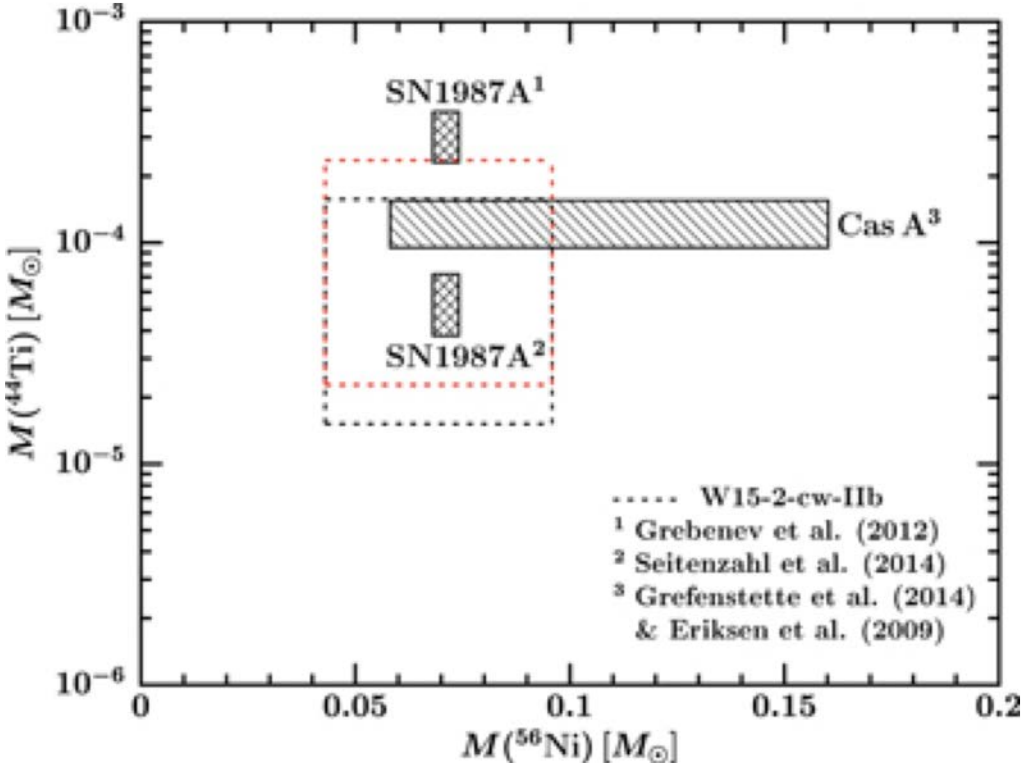
Core Collapse Progenitors

IMF plus mass cut   8 M_{SUN}?

Sensitive function of mass cut
Evolution, binary interaction?
Rotation?
Dependence on metallicity? $\dot{M}_{WIND}$

SNe and SNR are complementary

Hints from CSM interaction SNe IIn
Hints from SNR jets
Remnants: PSR, BH
^{44}Ti

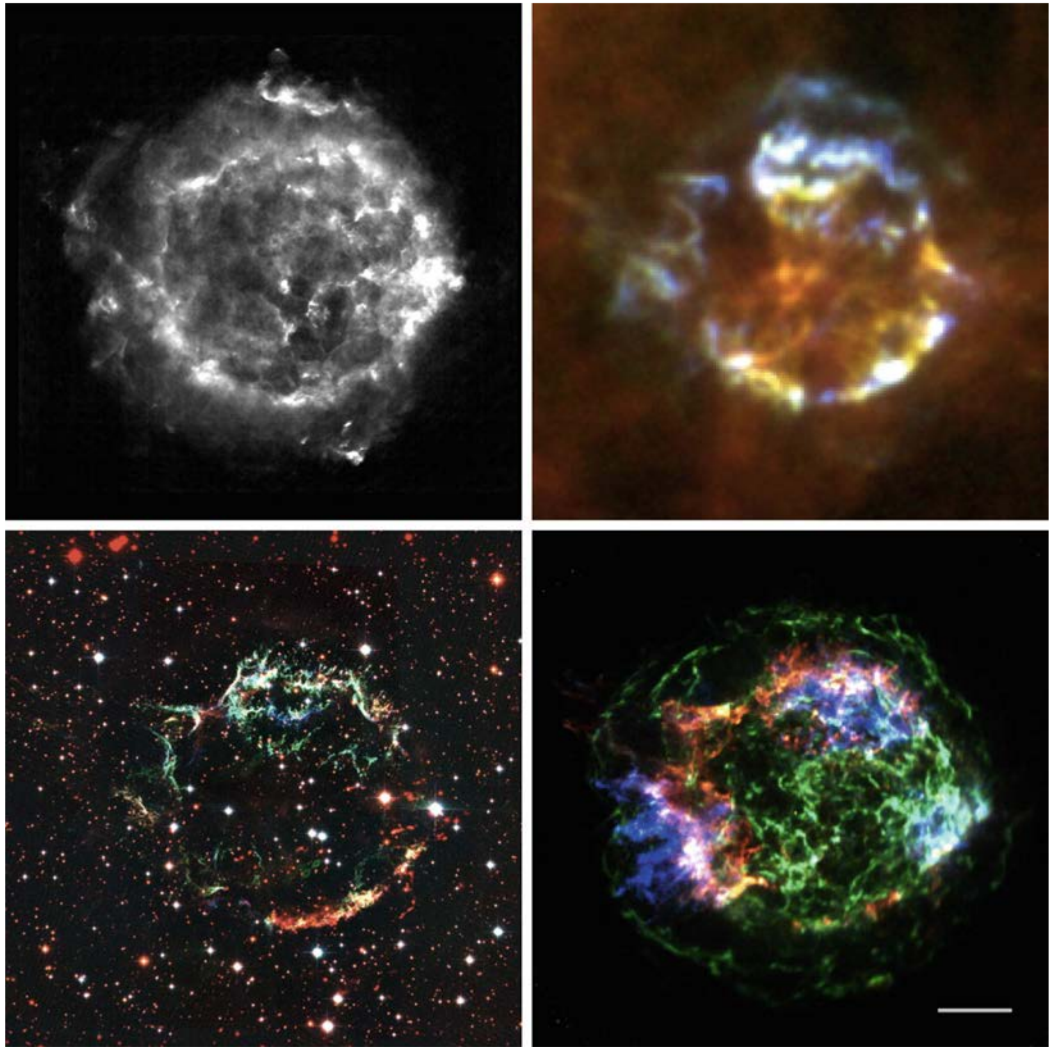


Wongwathanarat et al.

Core Collapse Progenitors: Cas A

6 cm radio
(DeLaney)

B   Spitzer 24μ
G Herschel 70μ
R Herschel 100μ



B   HST 775
G HST 850LP
R WIRC [Fe II]

B Chandra   Fe K
G Chandra synchrotron
R Chandra Si K

Koo & Park

Room for Improvement

Non-radiative shocks:

Single component gives wrong abundances

Recombing spectra

Non-Maxwellian electron velocities?

Room for Improvement

Distances

Gaia

Radio	ALMA, SKA, LOFAR, MWA
IR	JWST, ground-based
UV	
Optical	IFUs
X-ray	XARM, LYNX, ATHENA
Gamma-ray	CTA

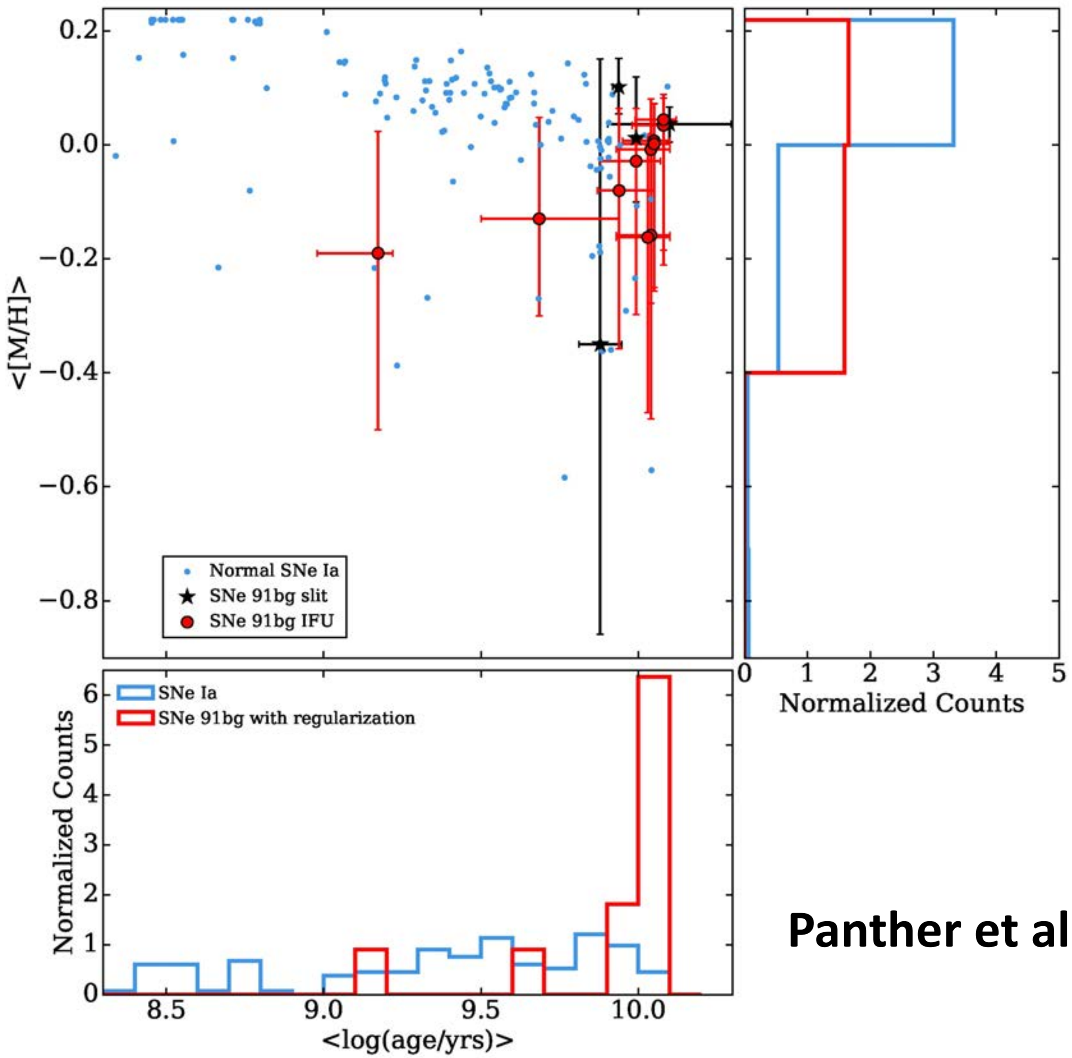
Type Ia Delay Times

SN1991bg-like

15% subluminous

Merger?

6 Gyr compared to 1 Gyr typically from age of stellar population



Panther et al.