Asymmetric Type-Ia origin of W49B

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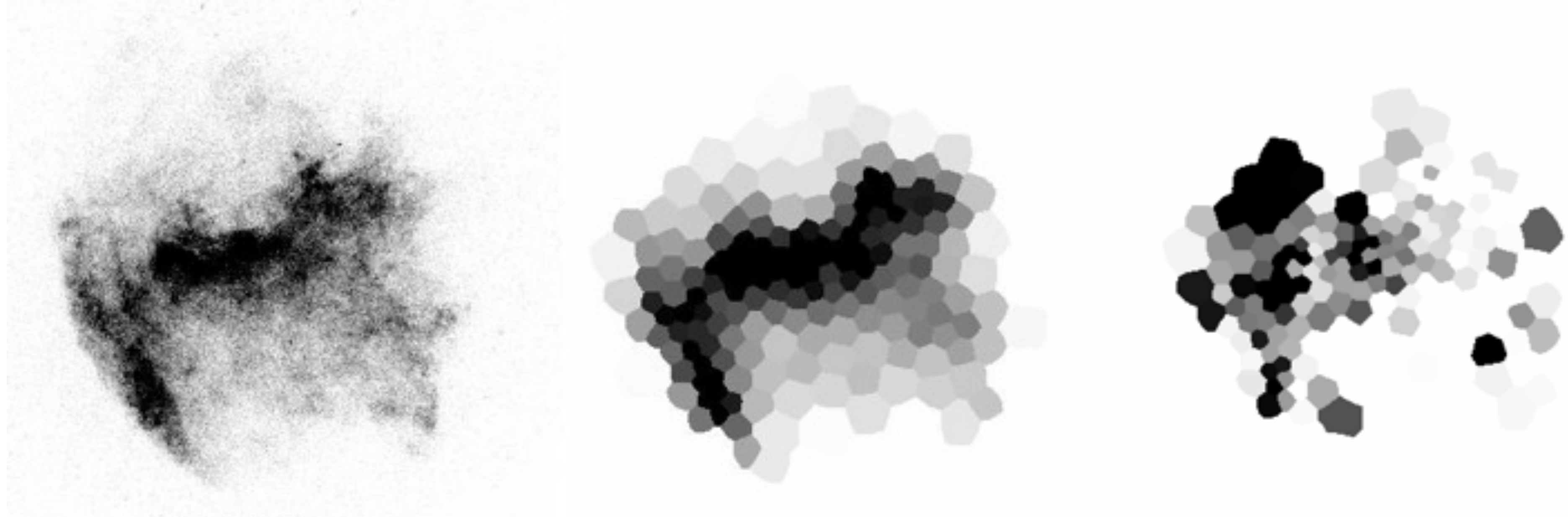
(Veni fellow)

collaborator: Jacco Vink



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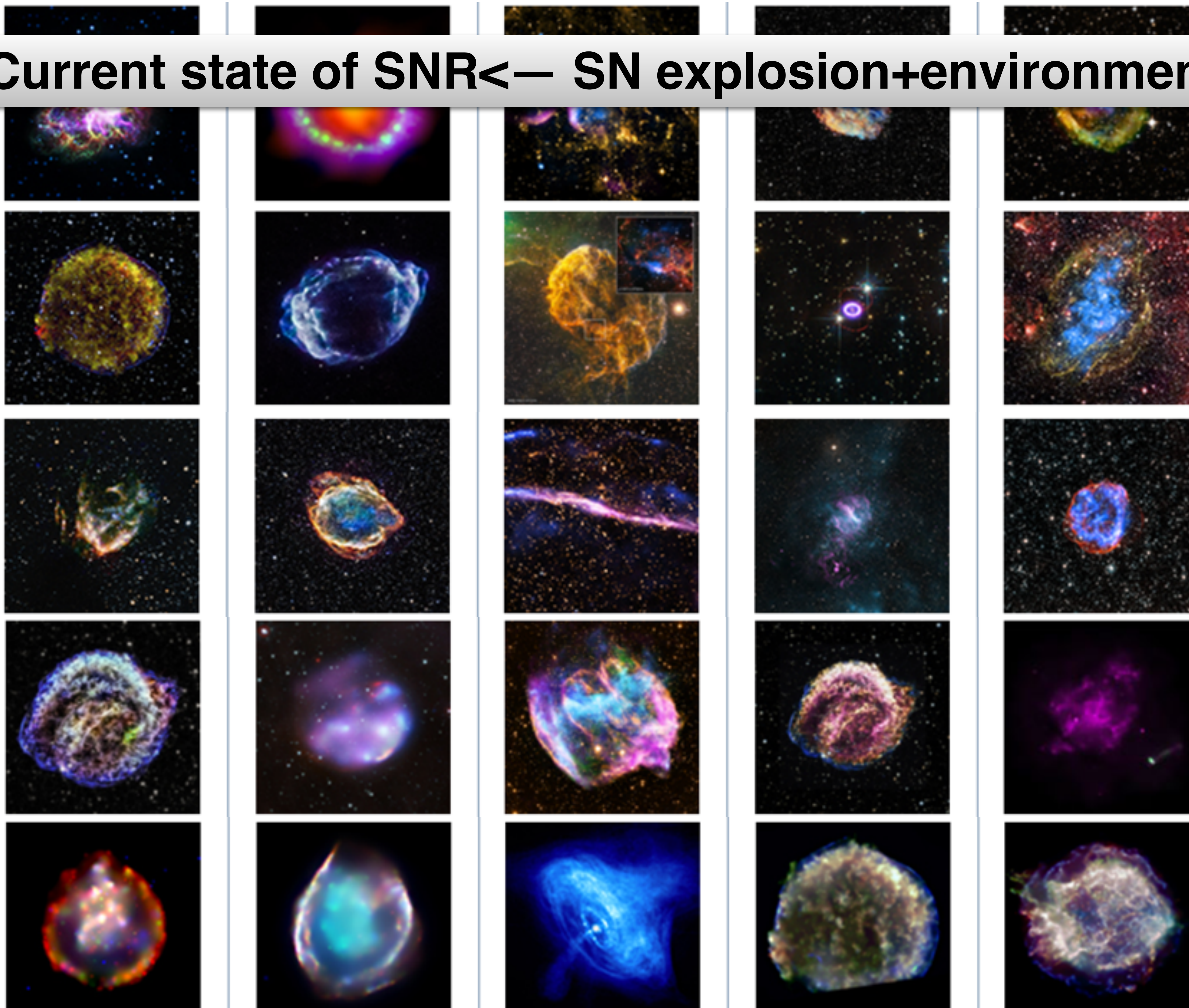
Current state of SNR<— SN explosion+environment



SNR gallery http://chandra.harvard.edu/photo/category/snr.html

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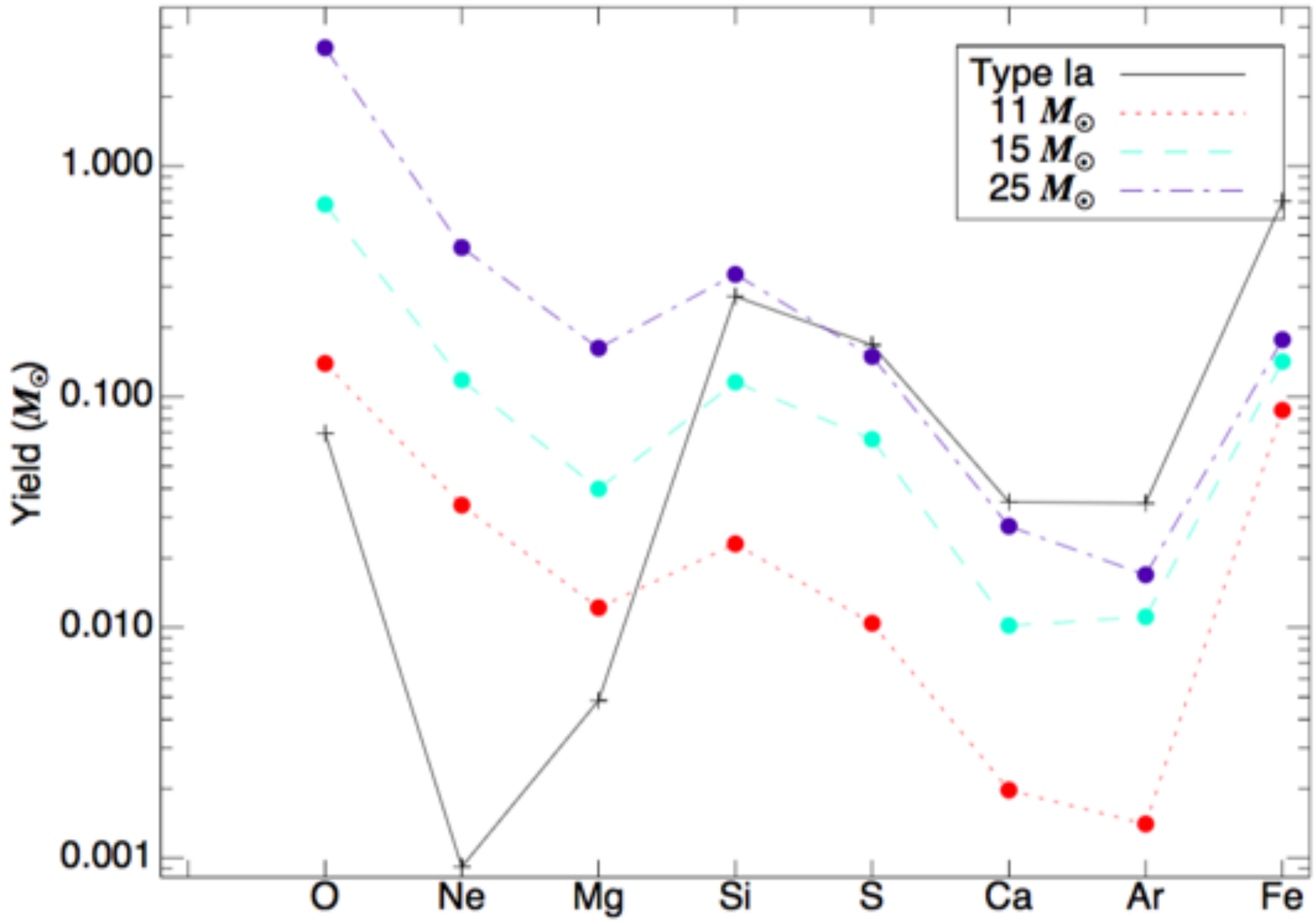
Typing SNR with SN yields



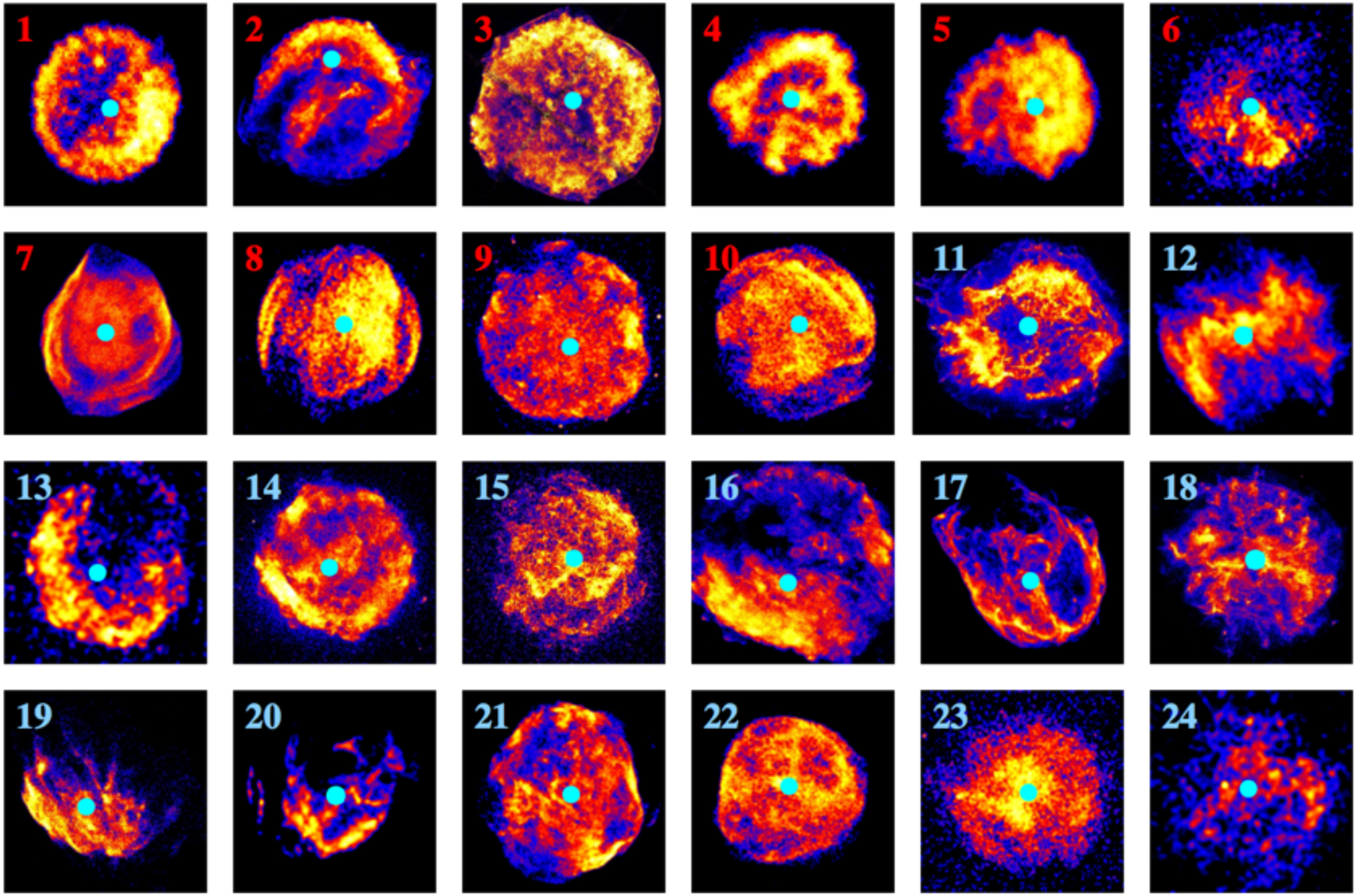
CC model: Woosley & Weaver 1995

Type-Ia: Nomoto +1997 (WDD2)

Fe/IME —large —Type Ia

Fe/IME—small — core collapse(II and Ib/c)

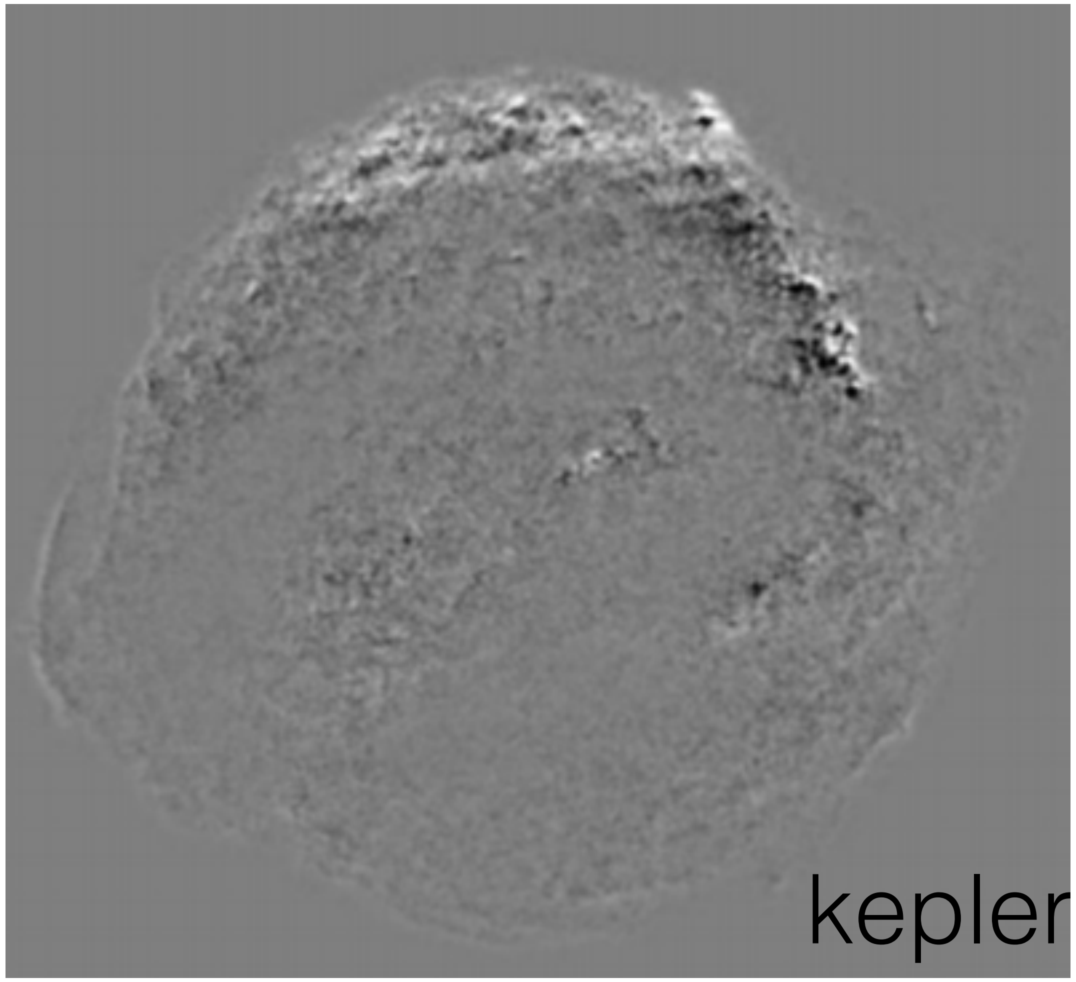
IME—intermediate mass element



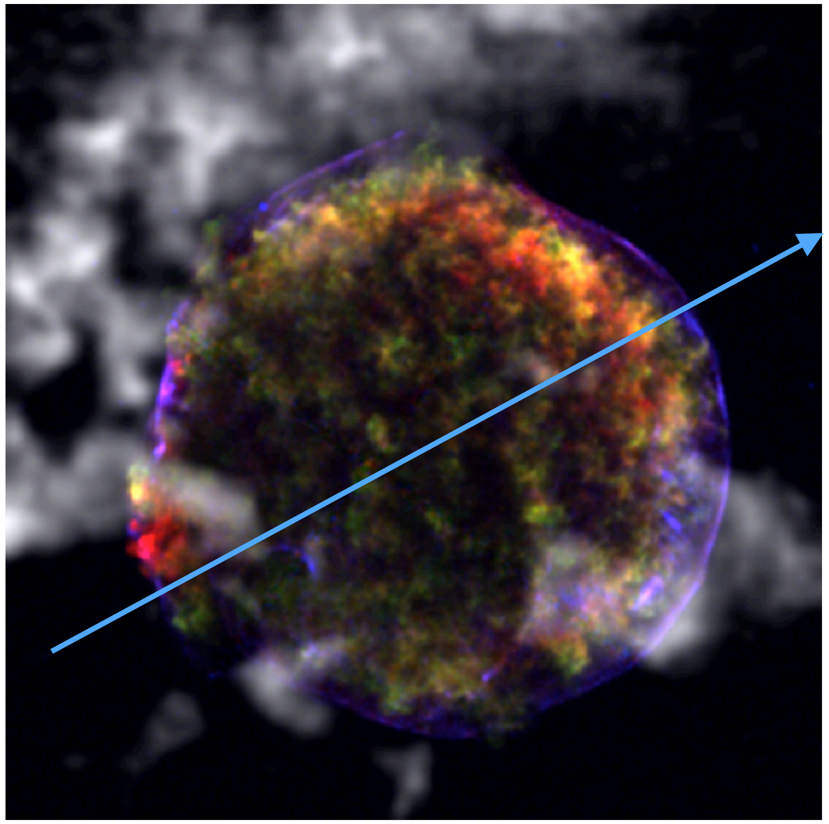
SNRs in X-ray band (Lopez + 2011)

Type-Ia SNRs are statistically more symmetric than CC SNRs—> uniform environment & more spherical explosion?

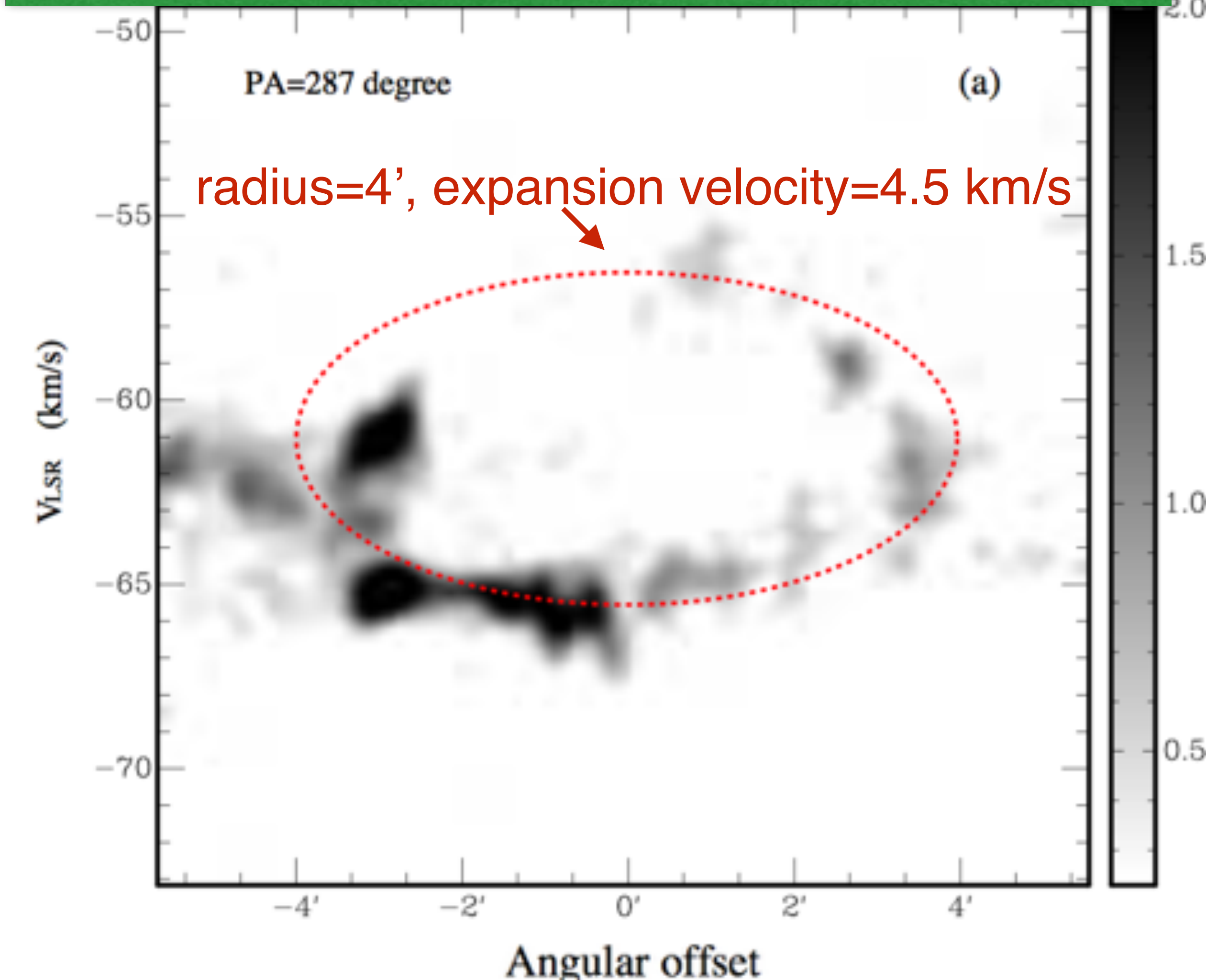
uniform ambient medium of Type-Ia?



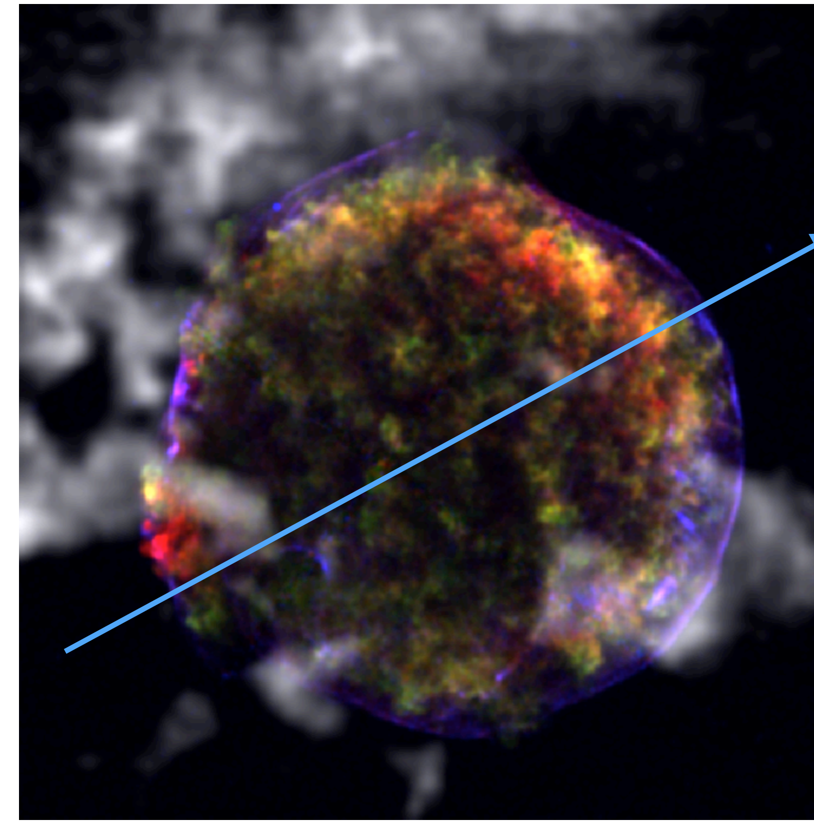
Difference image between X-ray images in 2000 and 2006 (Vink 2008)

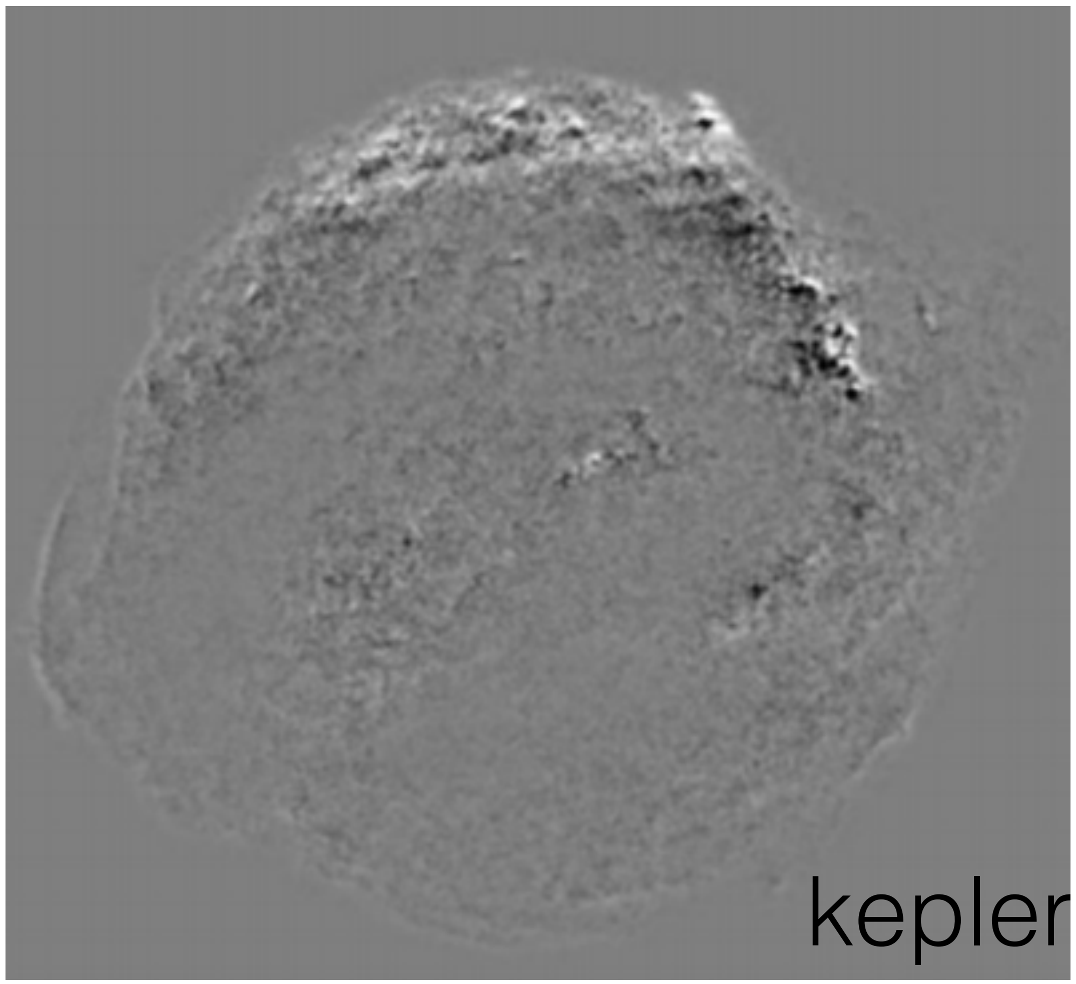


Tycho in an expanding molecular bubble (Zhou+2016b)



uniform ambient medium of Type-Ia?





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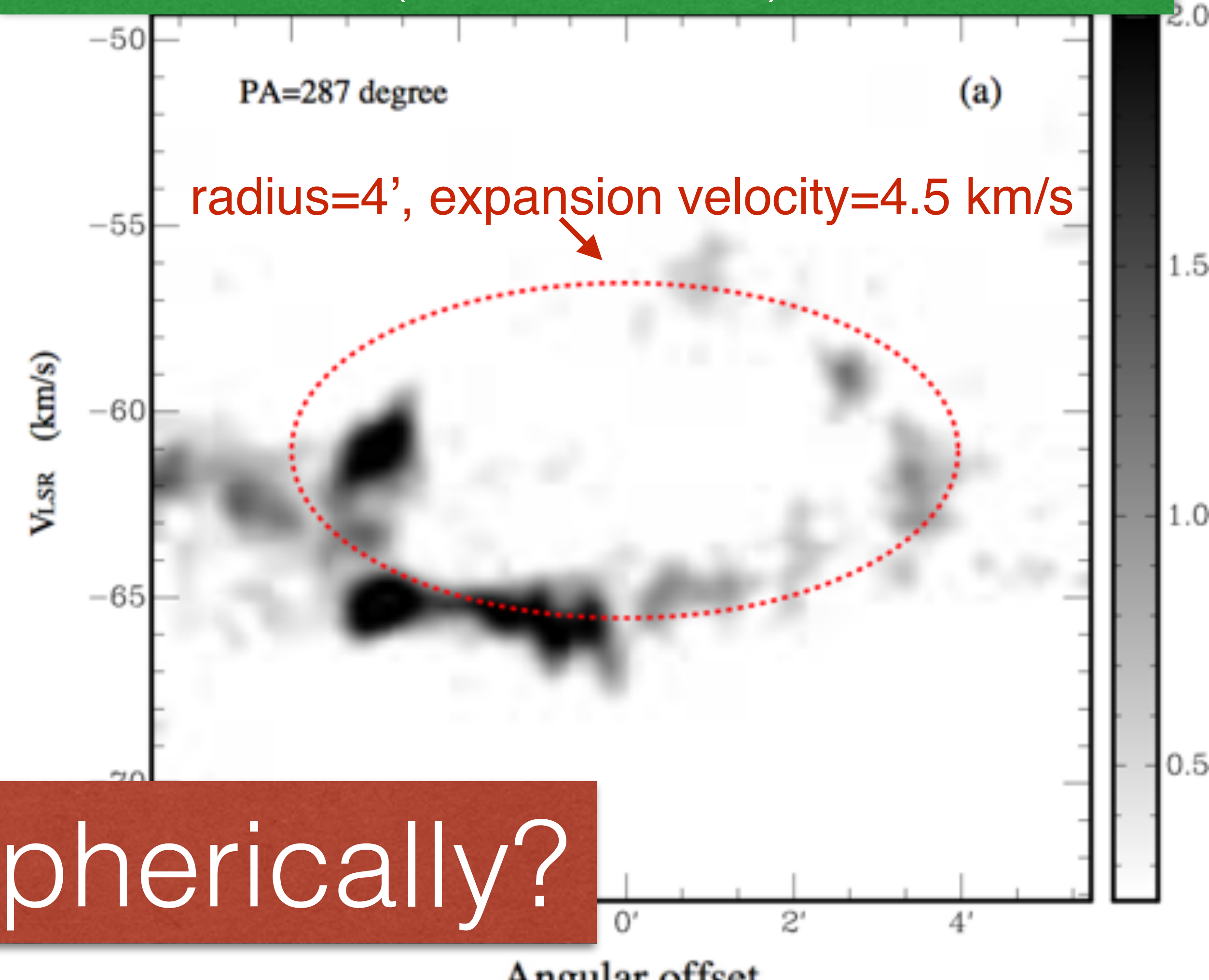
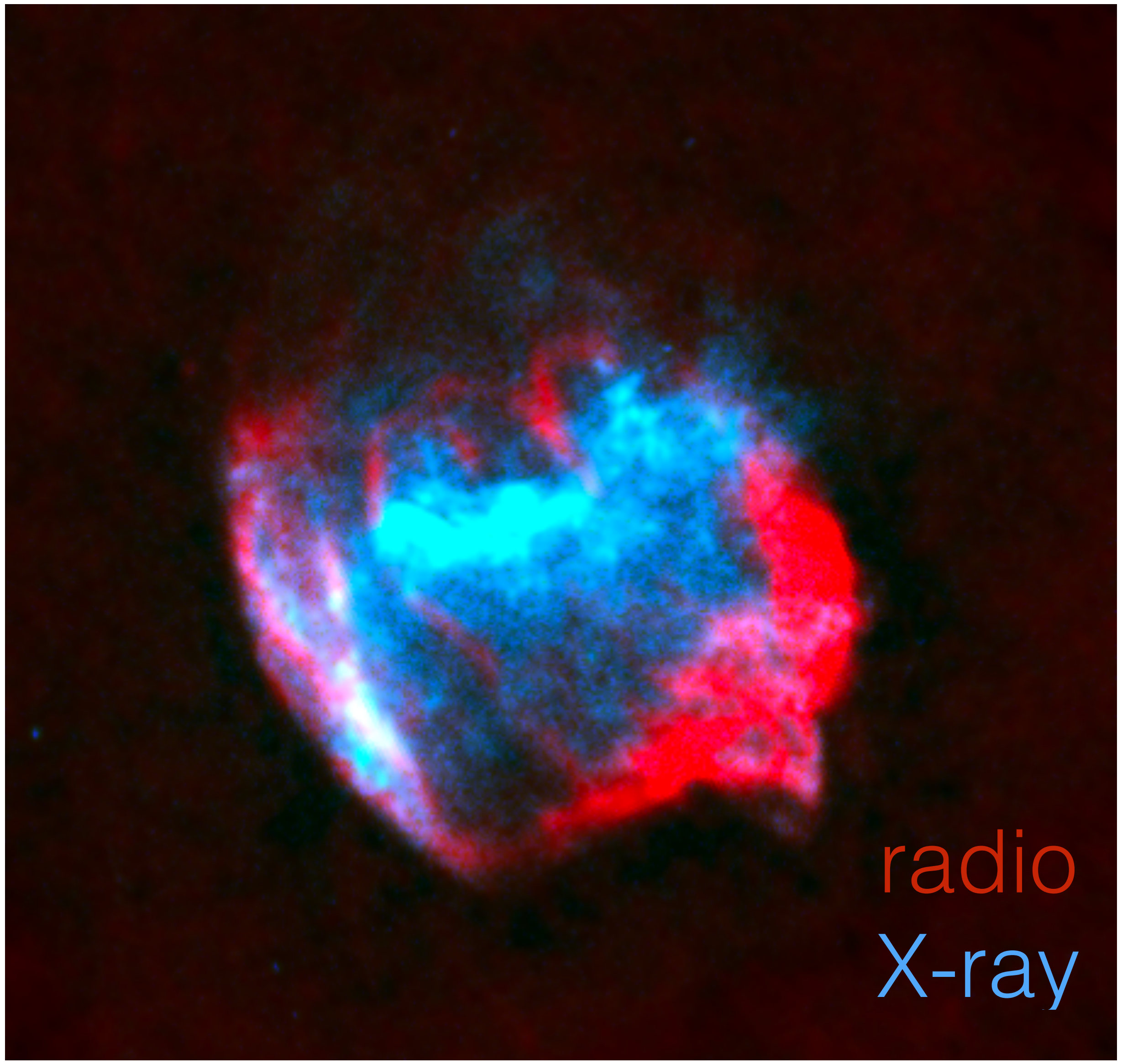


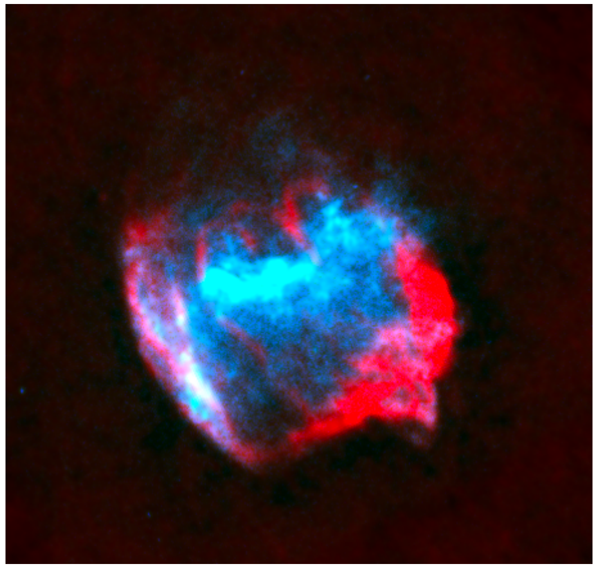
Are all SNe Ia exploded spherically?

past keywords of W49B



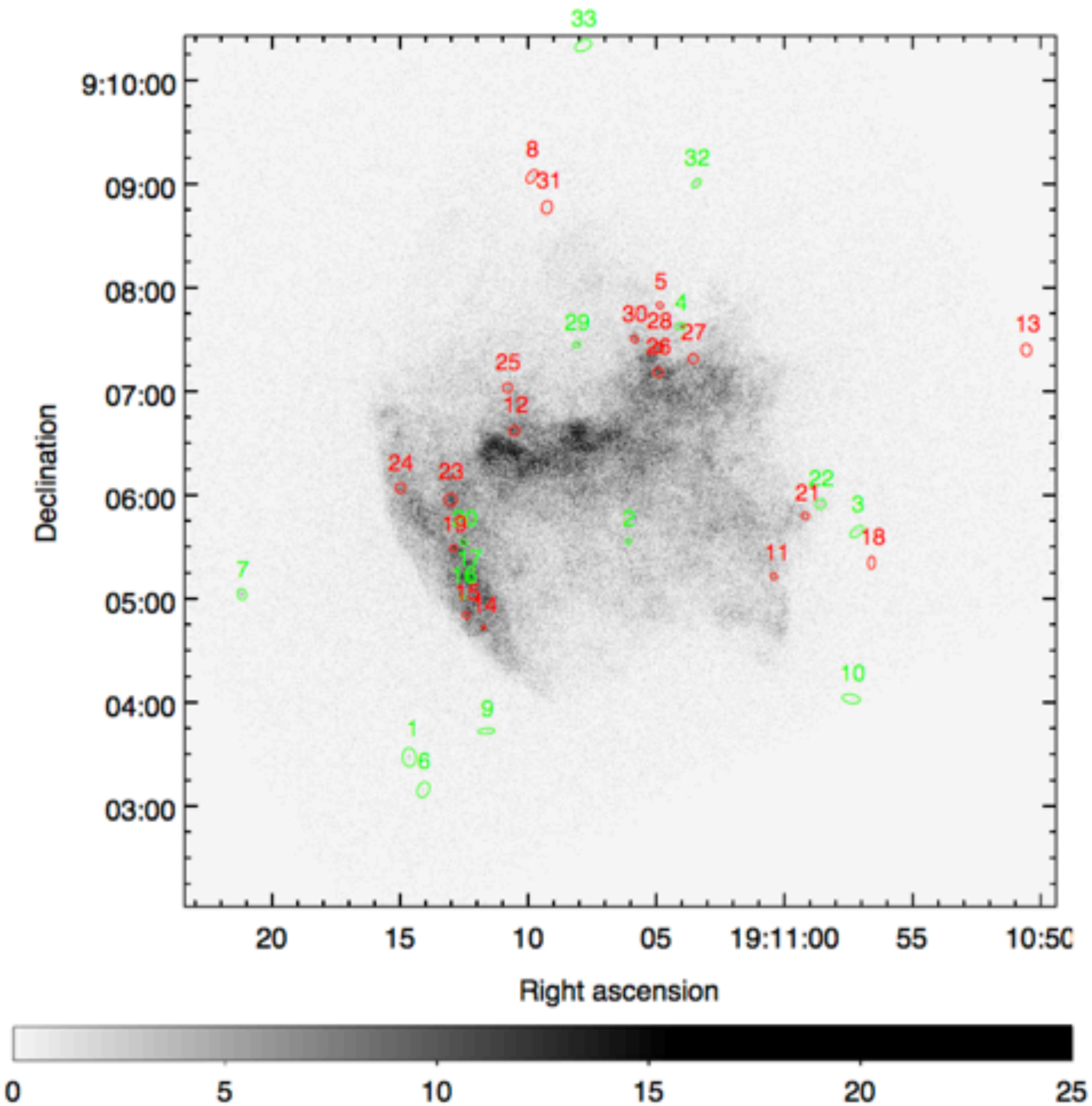
- massive progenitor~25 Msun and energetic explosion (Miceli+2006,2008,2010; Lopez +2009,2013)
  - **jet-driven** explosion (1/~300 SNRs, Lopez 2016)
  - likely associated with γ-ray burst
  - hosting a BH
- mixed-morphology (Rho & Petre 1998)
- dense environment (Keohane+2007, Zhou+2011, Chen+2014, Zhu+2014)
- over-ionised plasma (Kawasaki 2005; Ozawa+ 2009)
- TeV source (HESS+2016)

Doubts about energetic bipolar explosion origin of W49B



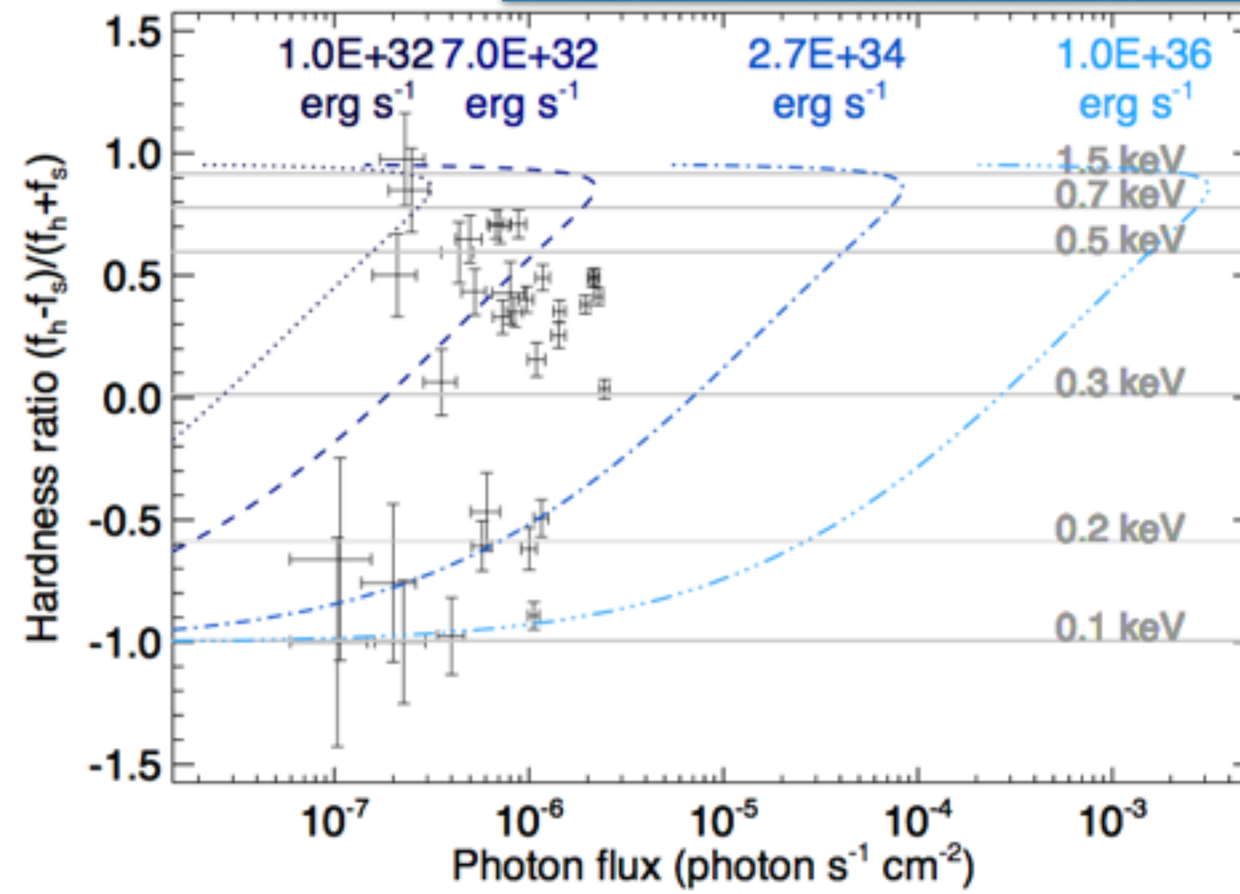
- Doubt 1: Is the jet-like structure really jet?
  - should not be across the centre now
- Doubt 2: No X-ray point-like sources (—>BH)?
  - we already see a few
- Doubt 3: small wind cavity (<6 pc) of a 25 M_{sun} star
  - very massive star can create a much larger cavity

Point-like sources in W49B

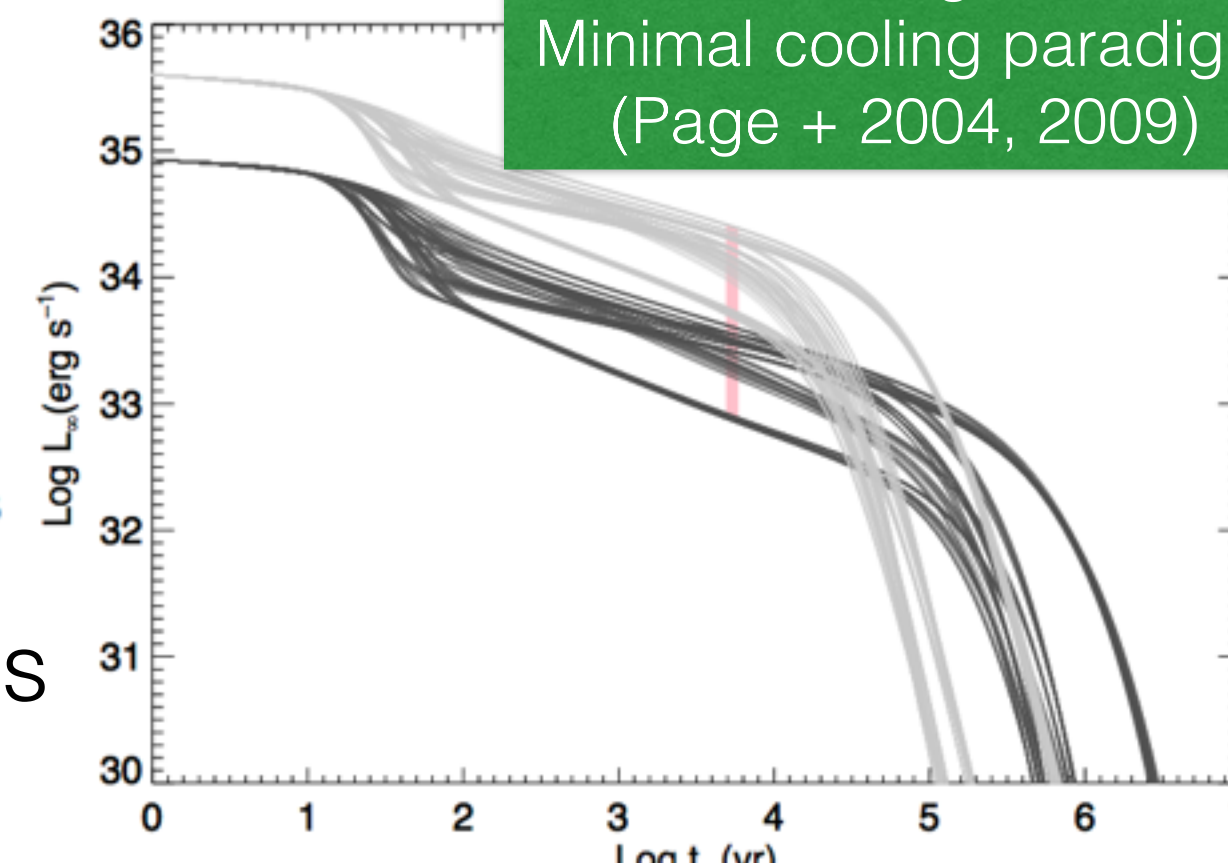


18 red regions— NS candidates

L_{BB} and T_{BB} of point sources

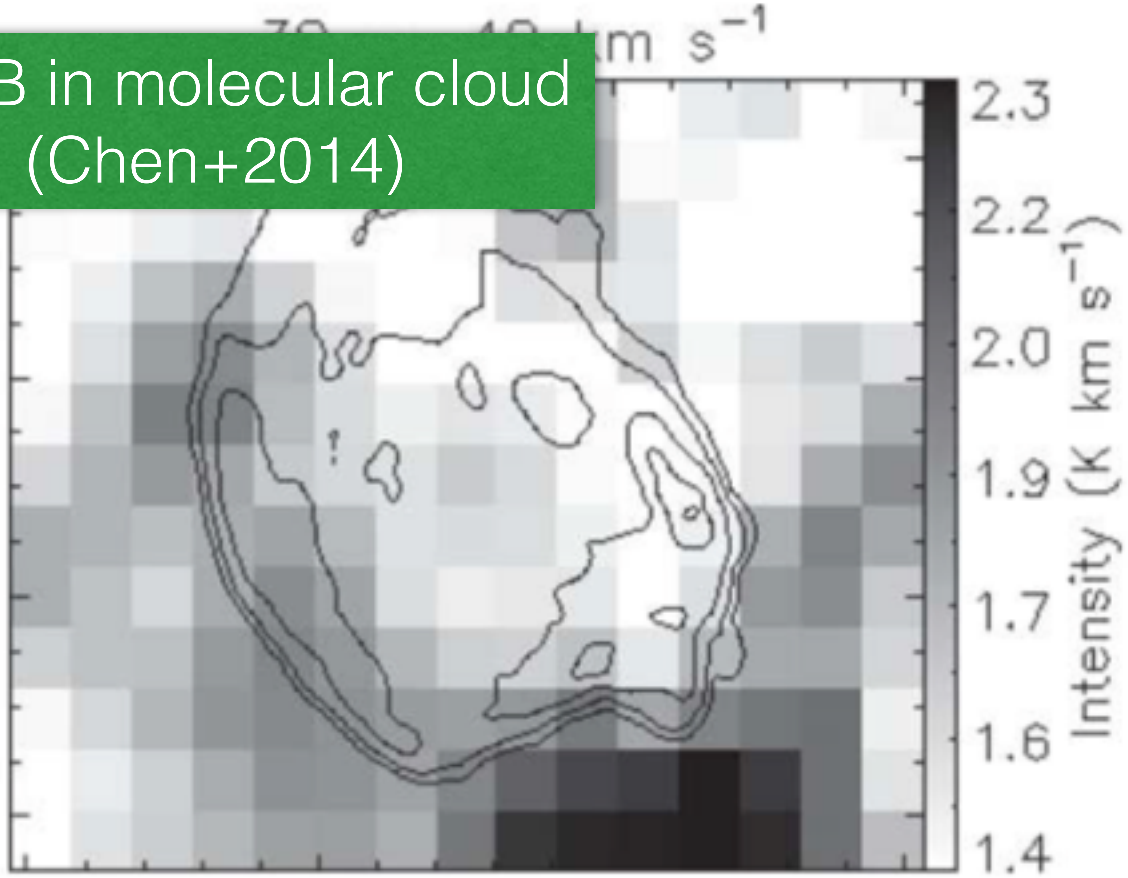


NS cooling curve
Minimal cooling paradigm
(Page + 2004, 2009)



small wind cavity—> not a very massive progenitor star

W49B in molecular cloud
(Chen+2014)



red: warm H_2 gas, green:[FeII]
(Keohane+2007)

$$R_b = 15.8 \left(\frac{\dot{M}}{10^{-7}\,M_\odot\,\mathrm{yr}^{-1}} \right)^{1/3} \left(\frac{\tau_{\mathrm{ms}}}{10^7\,\mathrm{yr}} \right)^{1/3} \left(\frac{v_w}{10^3\,\mathrm{km\,s^{-1}}} \right)^{2/3} \times \left(\frac{p/k}{10^5\,\mathrm{cm^{-3}\,K}} \right)^{-1/3} \mathrm{pc},$$

Chevalier 1999

Size of wind bubble —> stellar mass

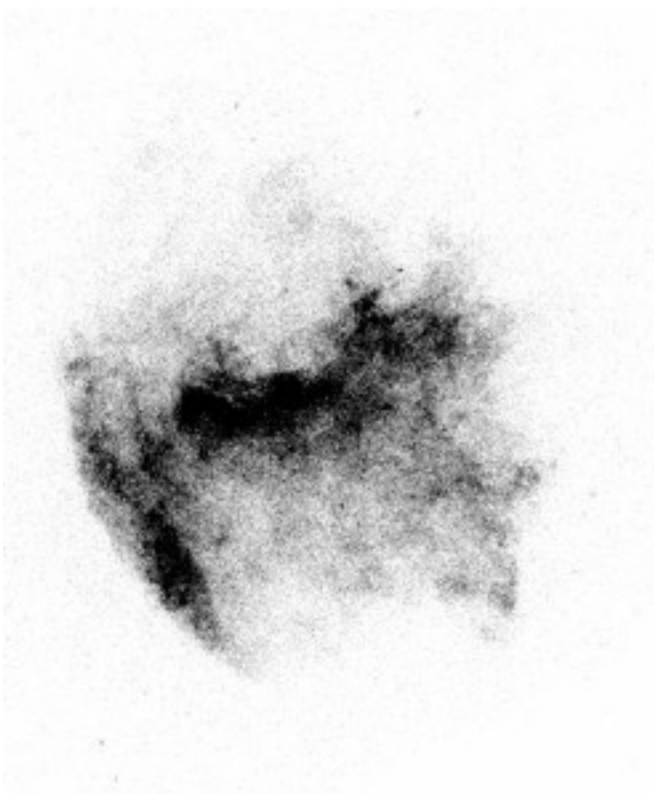
$$p_5^{1/3} R_b = 1.22\, M/M_\odot - 9.16\,\mathrm{pc}$$

(Chen+2013)

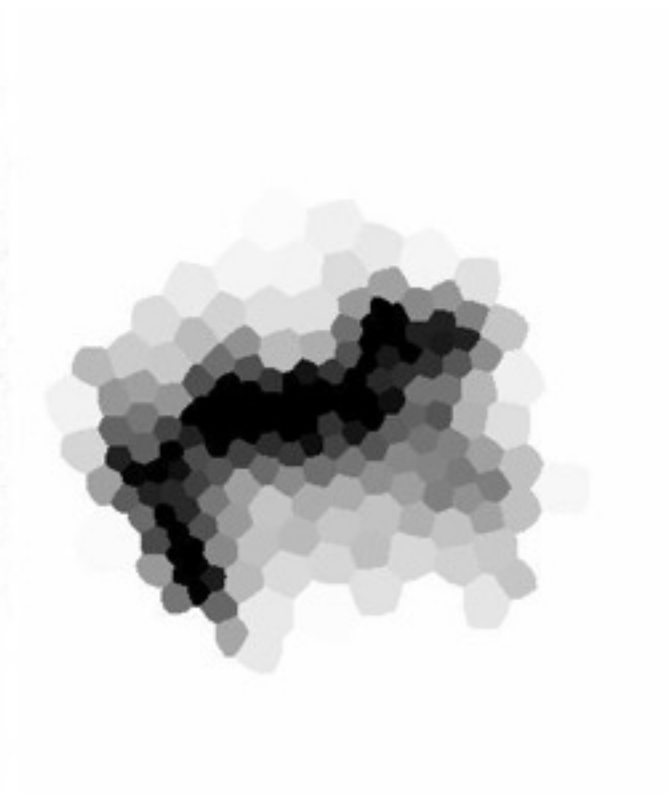
p_5~1 in giant molecular cloud

Stellar mass M~13 Msun —> Rb~**6 pc**
M~25 Msun—> **Rb~21 pc**

spatially resolved spectroscopy



raw X-ray image

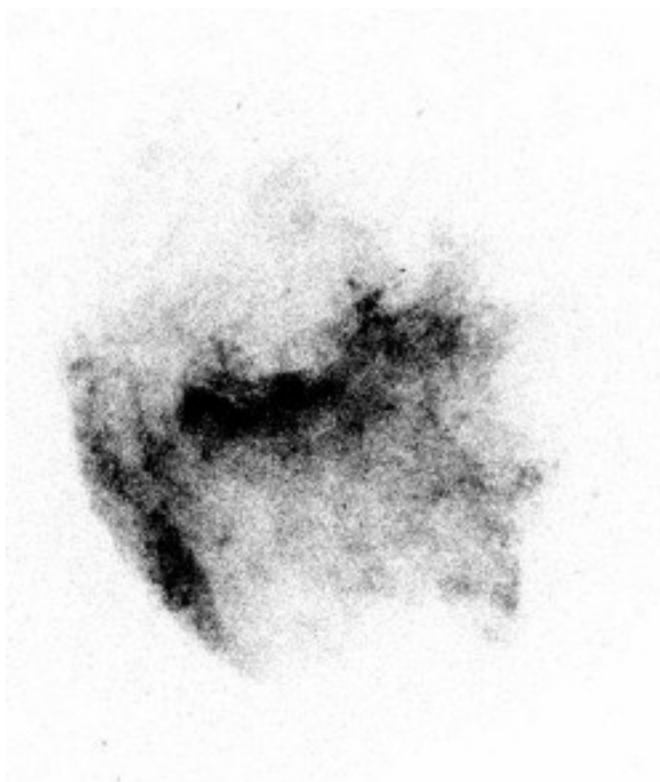


binned image

276 bins
3600 counts each bin

weighted Voronoi tessellations (WVT) binning algorithm (Diehl & Statler 2006)

spatially resolved spectroscopy



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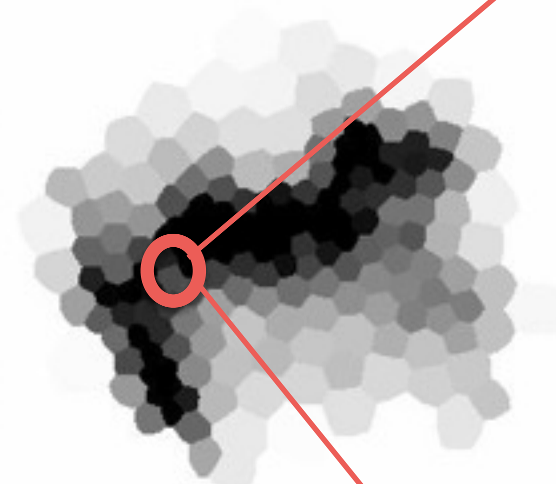

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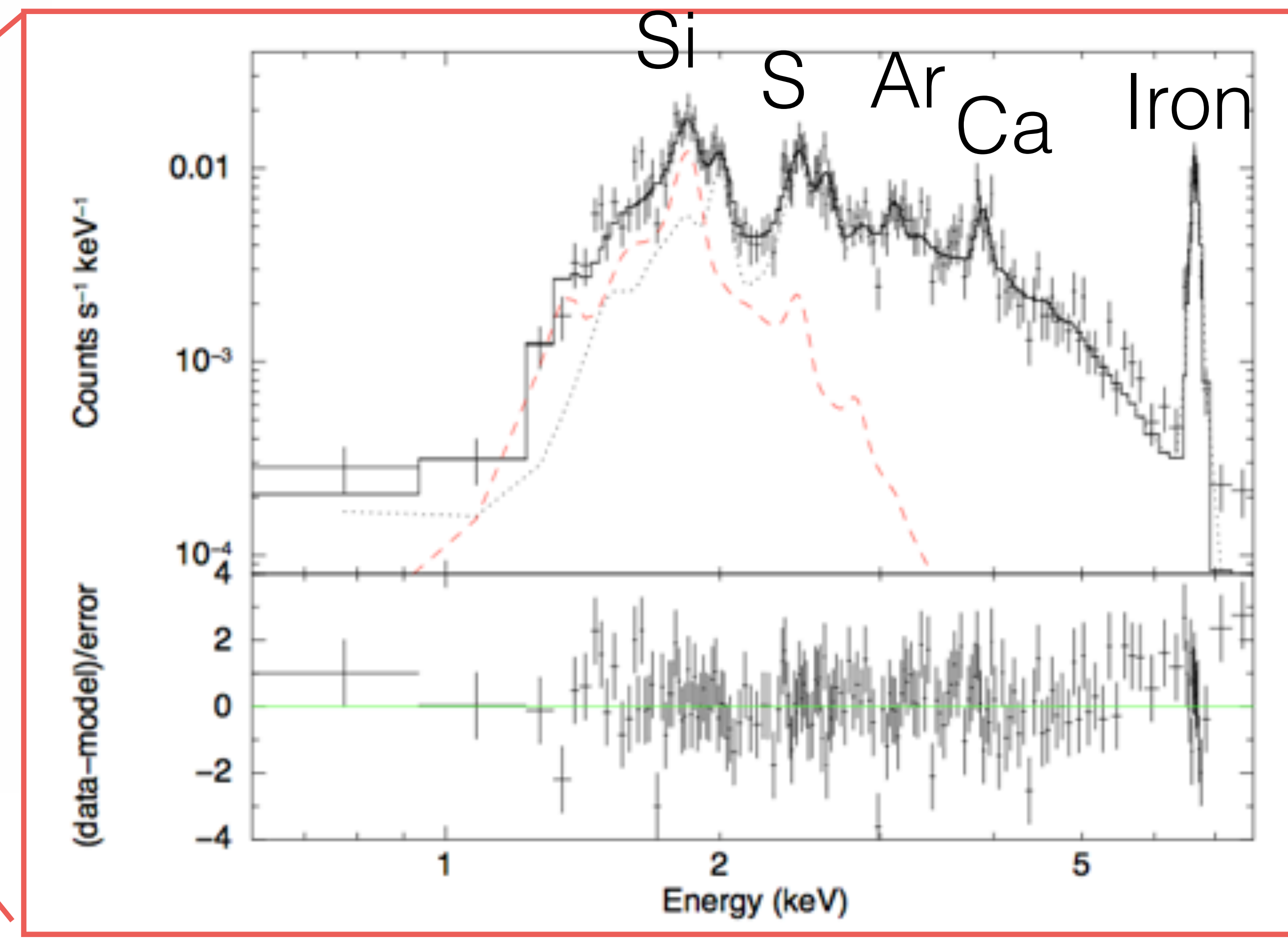


ionisation equilibrium
+over-ionised/ionisation equilibrium

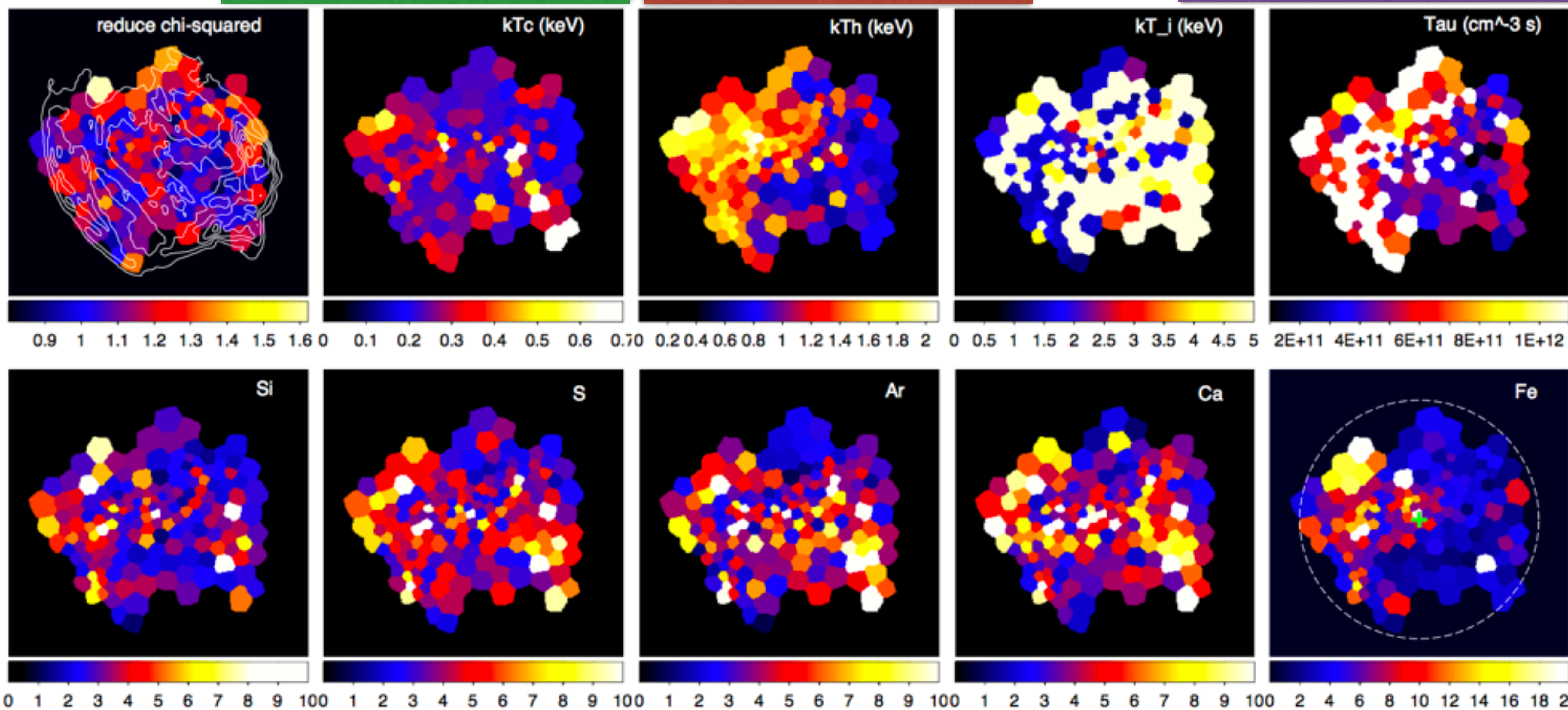
weighted Voronoi tessellations (WVT) binning algorithm (Diehl & Statler 2006)

decompose the spectra into gas properties

cold phase temperature

hot phase temperature

recombination timescale



abundances of metal elements

metal abundances and masses in the hot phase

mass-weighted:

[Si]~3.4

[S]~4.7

[Ar]~4.7

[Ca]~5.2

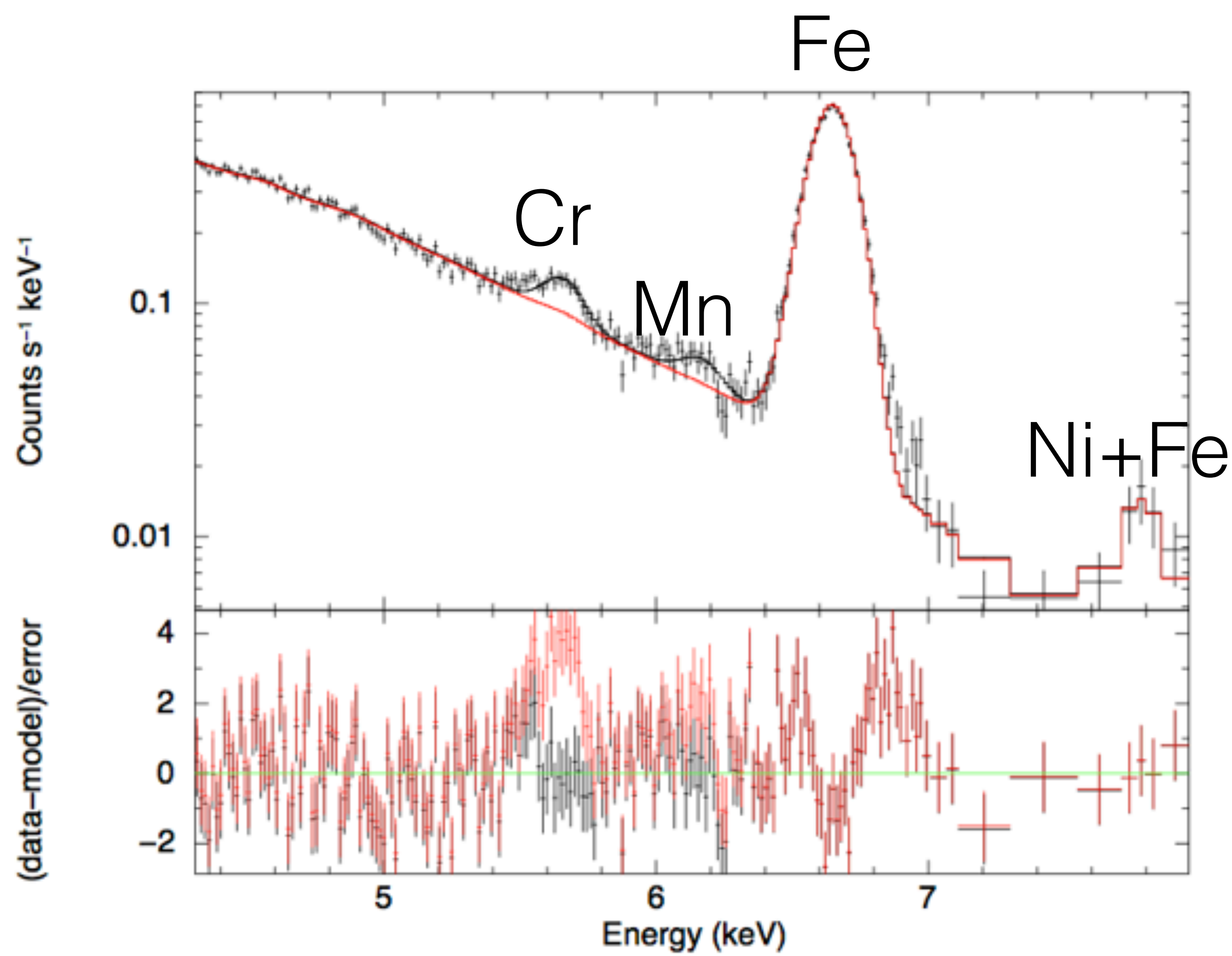
[Fe]~6.1 $M_{Fe} \sim 0.34\, M_{\odot}$

From global spectrum:

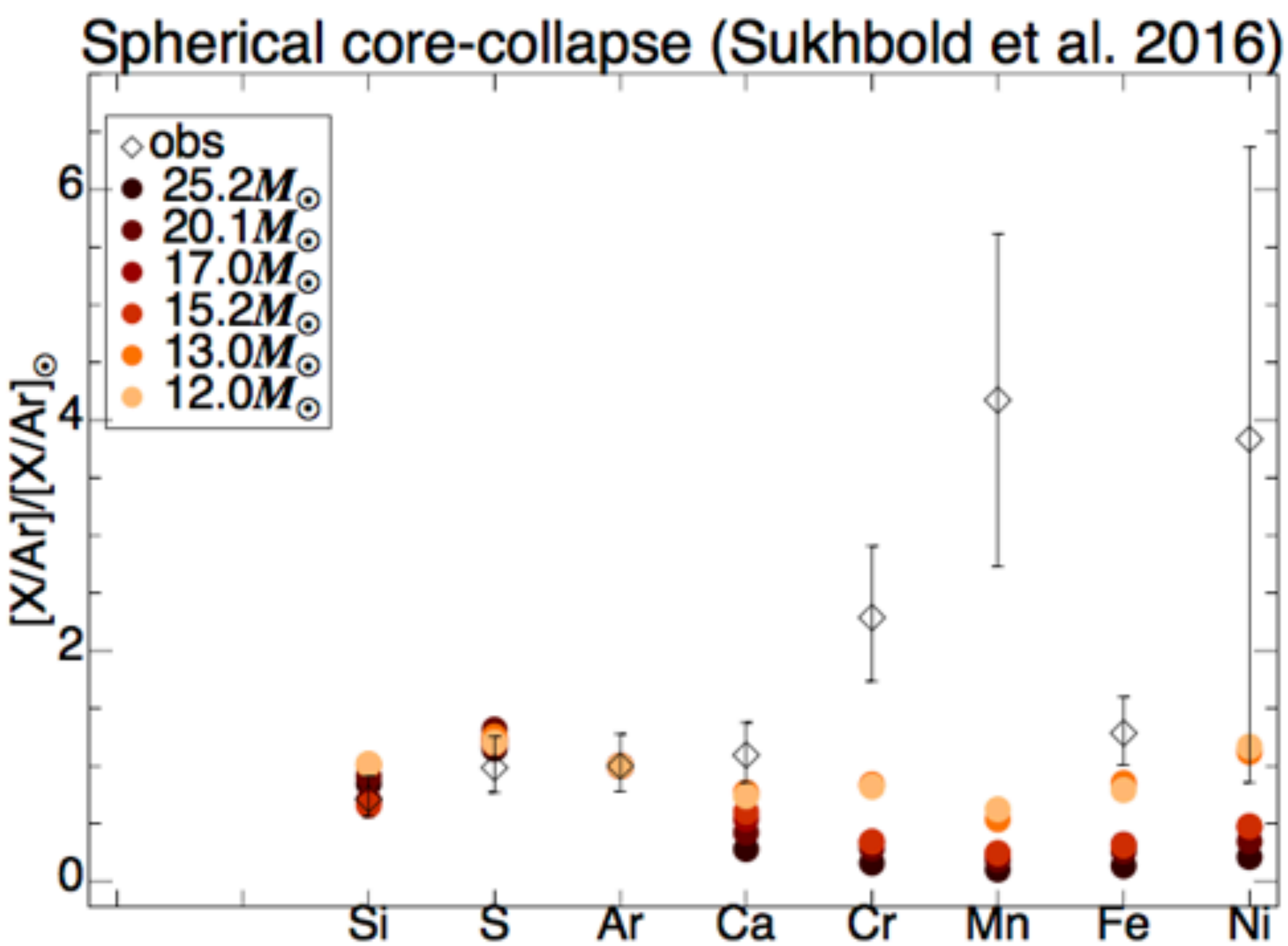
$[\mathrm{Cr}]=10.8^{+2.0}_{-1.5}$ $M_{\mathrm{Cr}} \sim 0.008\, M_{\odot}$

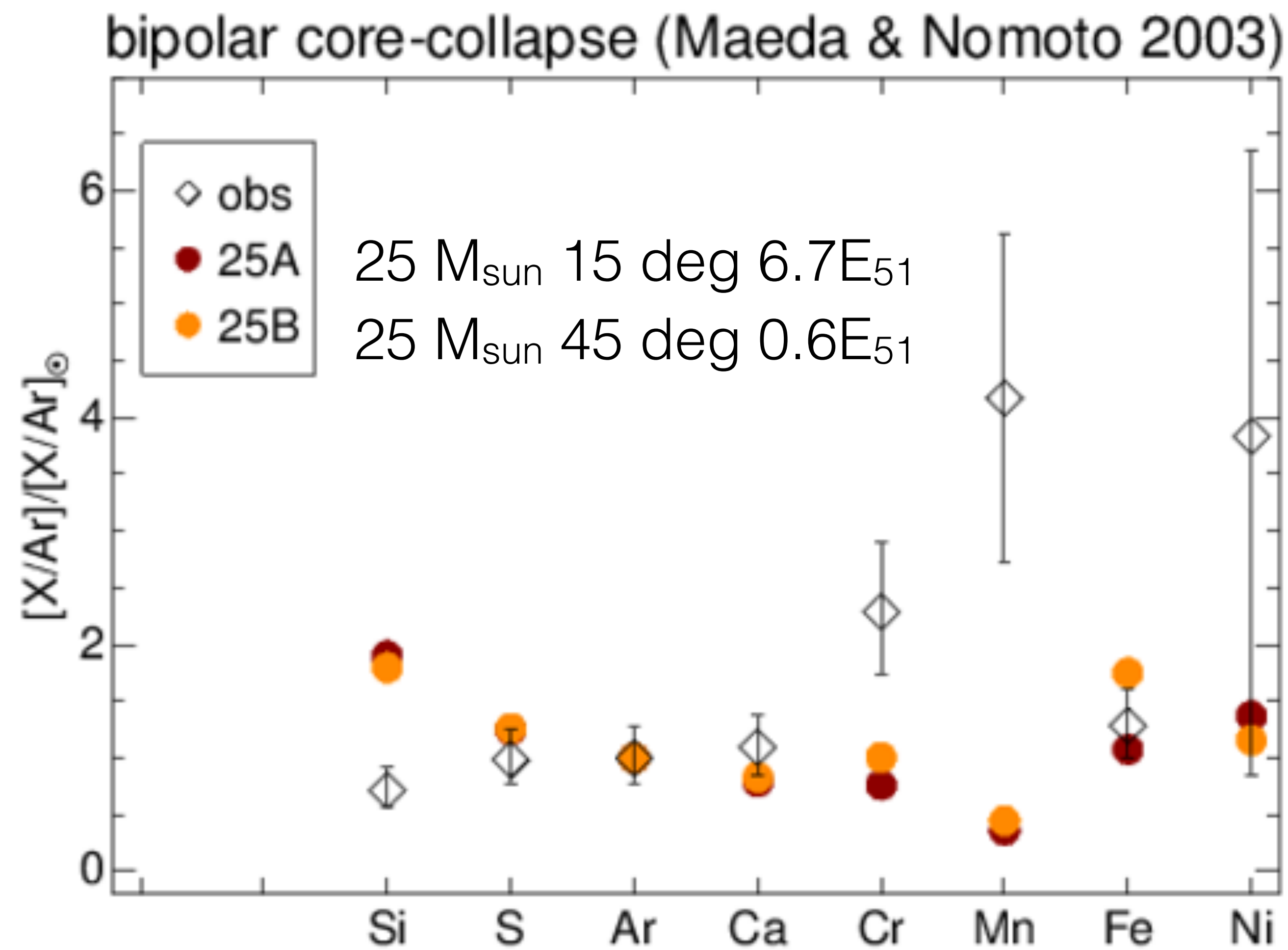
$[\mathrm{Mn}]=19.7 \pm 5.6$ $M_{Mn} \sim 0.01 M_{\odot}$

$[\mathrm{Ni}]=18.1^{+11.4}_{-13.6}$ $M_{Ni} \sim 0.06 M_{\odot}$



Compare the observed values with CC nucleosynthesis models

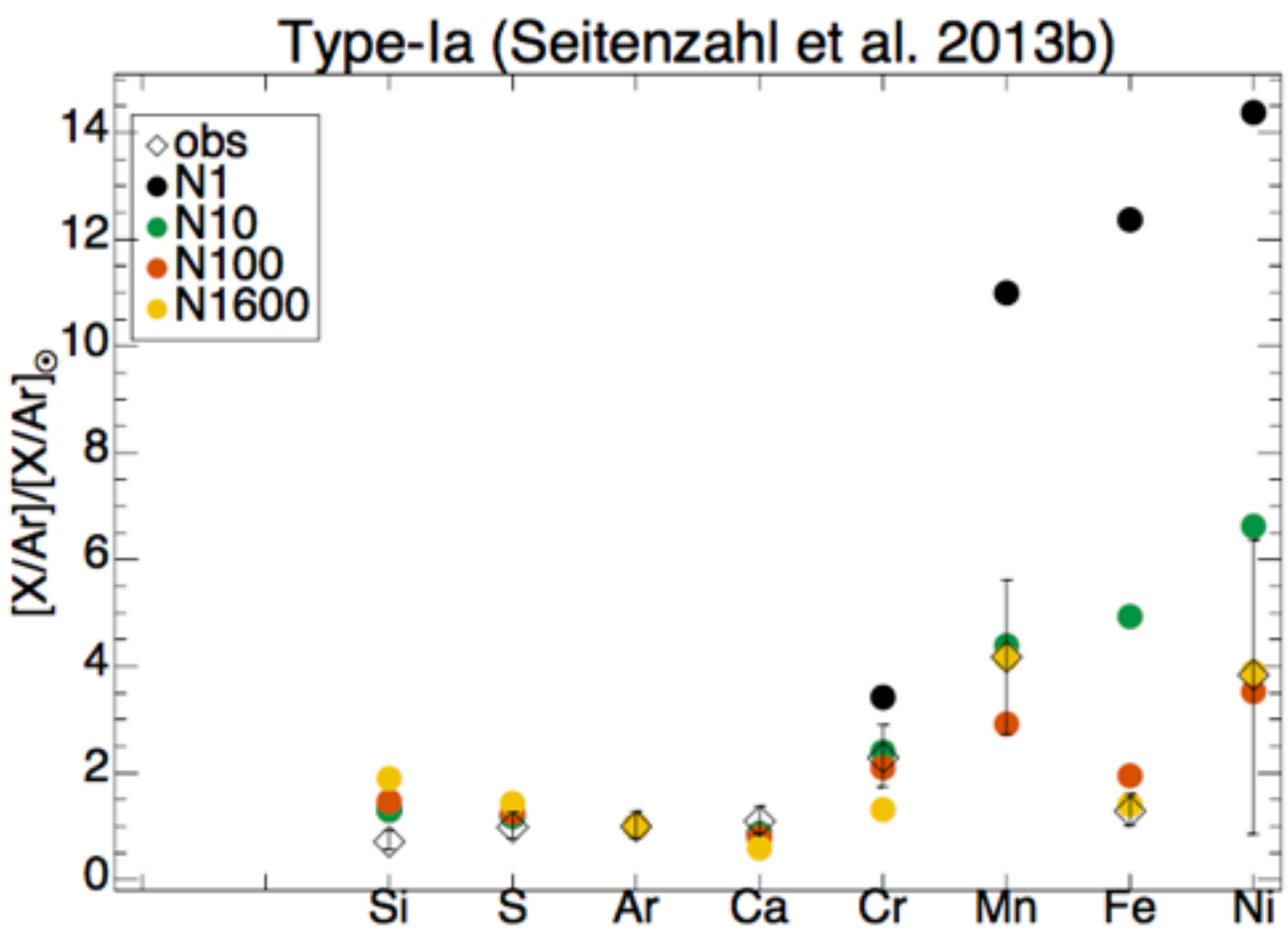


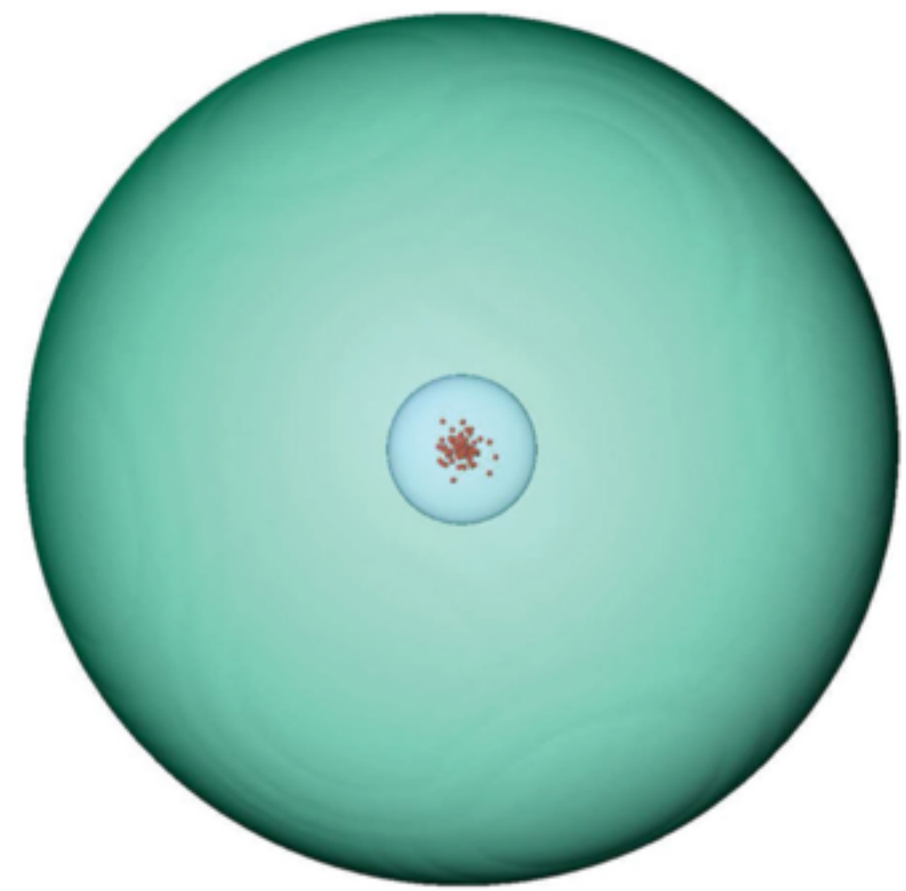


mass (Msun)	M(Cr)	M(Fe)	M(Ni)
W49B	8E-03	0.34	6E-02
CC model 25 Msun	6E-04	4.8E-02	4E-03
bipolar CC 25 Msun	<=1E-03	<=0.16	<=6E-03

the large amount of Cr, Fe, Ni can not be produced with normal/biploar CC models

Delayed detonation (DDT) Type-Ia models

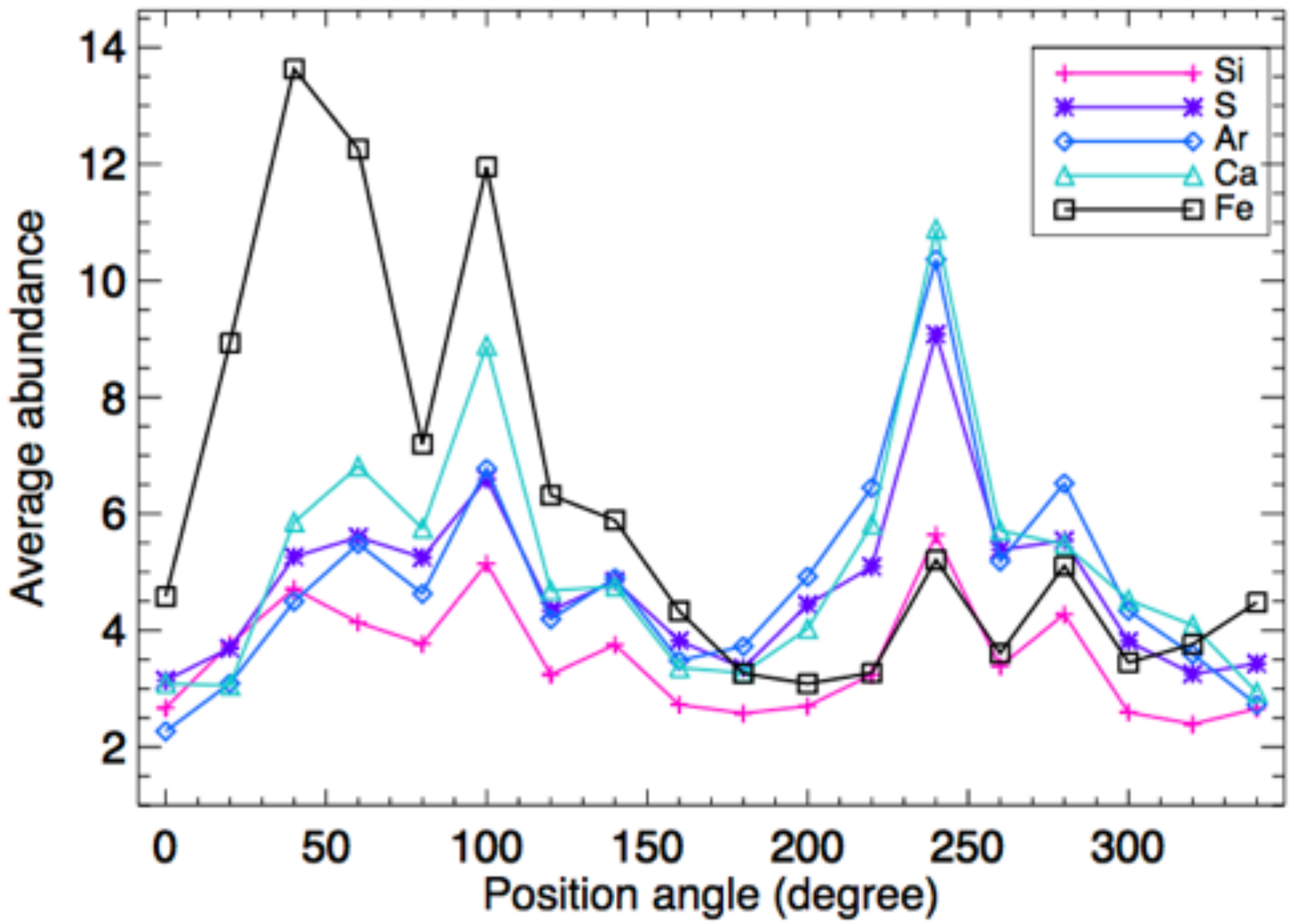


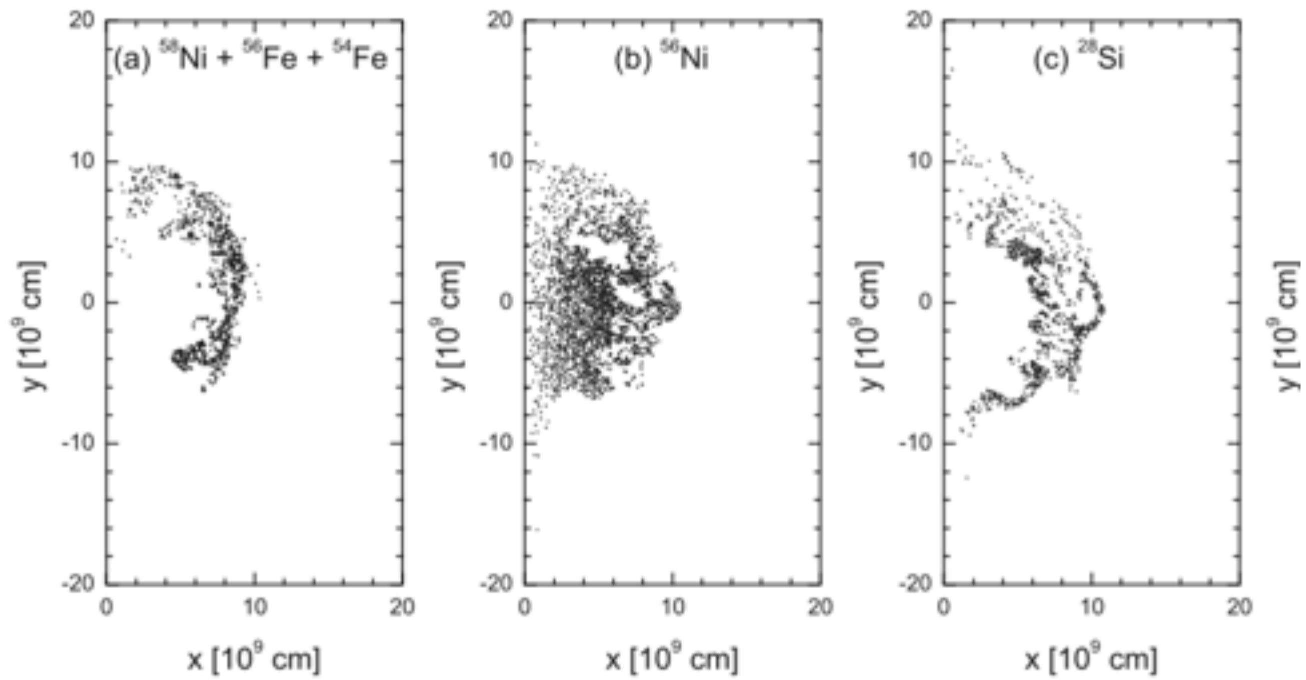


(a) Central ignition region deep inside the WD (for model N100)

multi-spark ignition

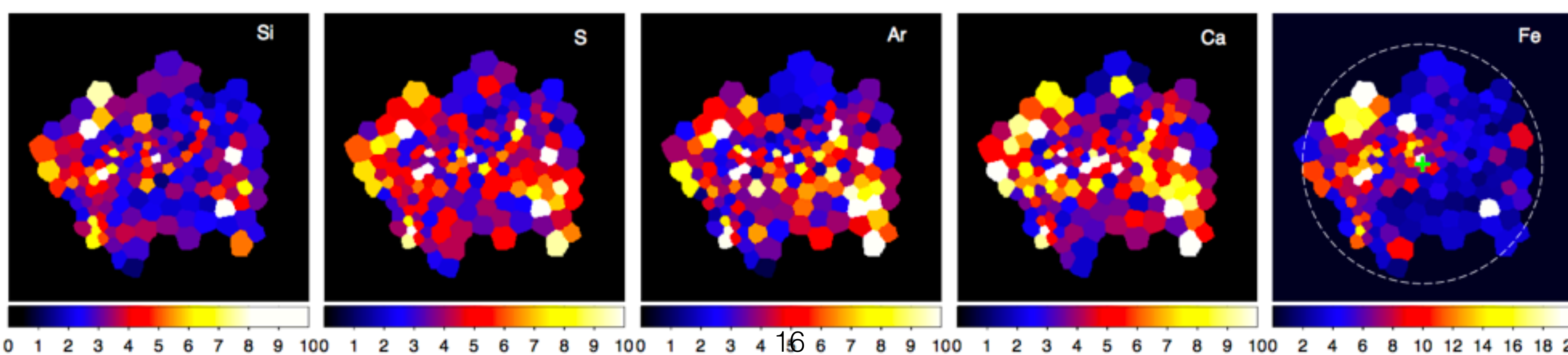
Intrinsic SN asymmetries reflected from the Fe distribution



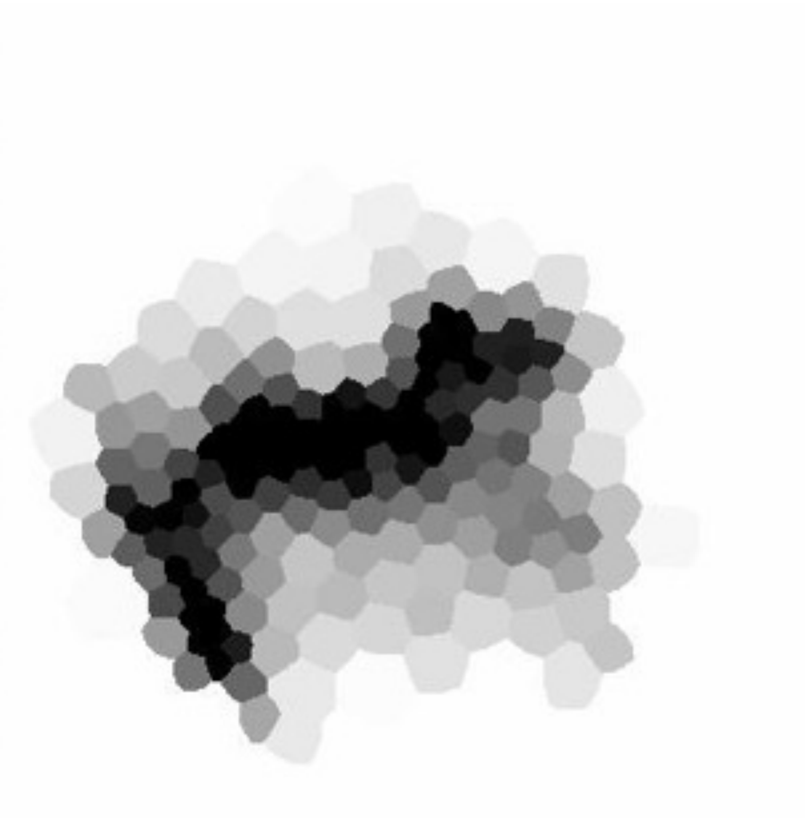


off-center ignition DDT?

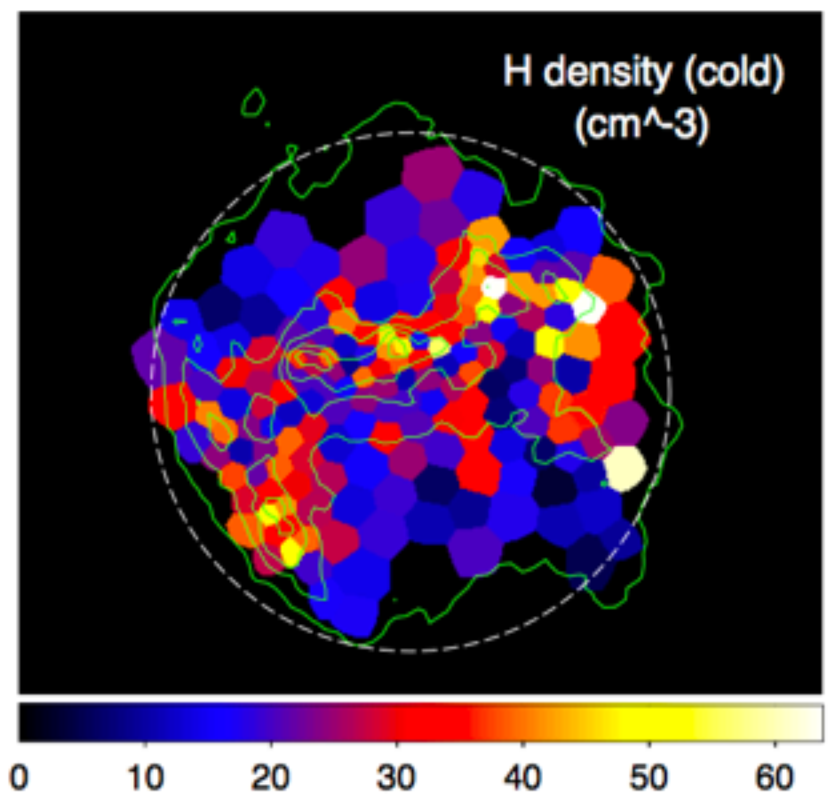
(Maeda+2012)

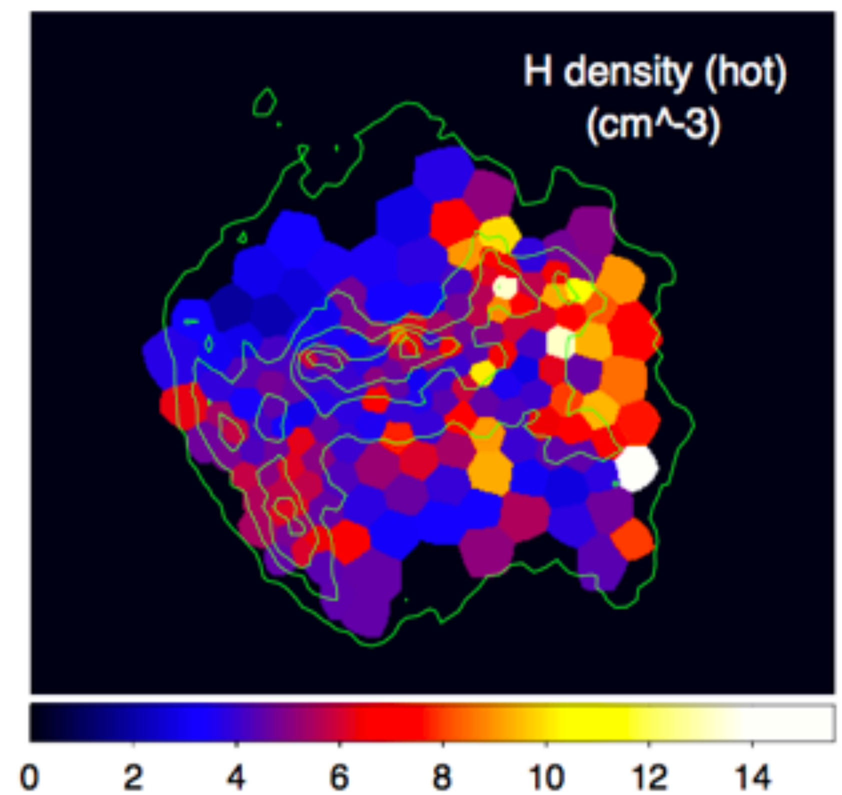


origin of the jet-like morphology—density enhancement



0.3—10 keV image





summary

https://arxiv.org/abs/1707.05107

- **W49B likely has an asymmetric Type-Ia origin,** because:
    - 1. the metal abundances match the Type-Ia models, but deviate the normal/bipolar SNR models
    - 2. the large masses of Fe-group elements can not be produced by CC models.
    - 3. Best-fit model fitting the abundances is a multi-spark ignition DDT of Chandrasekhar-mass WD.
    - 4. Fe-distribution is strongly lateral, while intermediate-mass elements has more uniform (axial symmetric) distribution.
- The bipolar explosion is not favoured, because
    - **The jet-like morphology is mainly due to an interior density enhancement**
    - small wind bubble
    - There are NS candidates, but should be sources projected inside the SNR
- **Type-Ia SNe can also evolve to mixed-morphology SNRs**

Thanks!