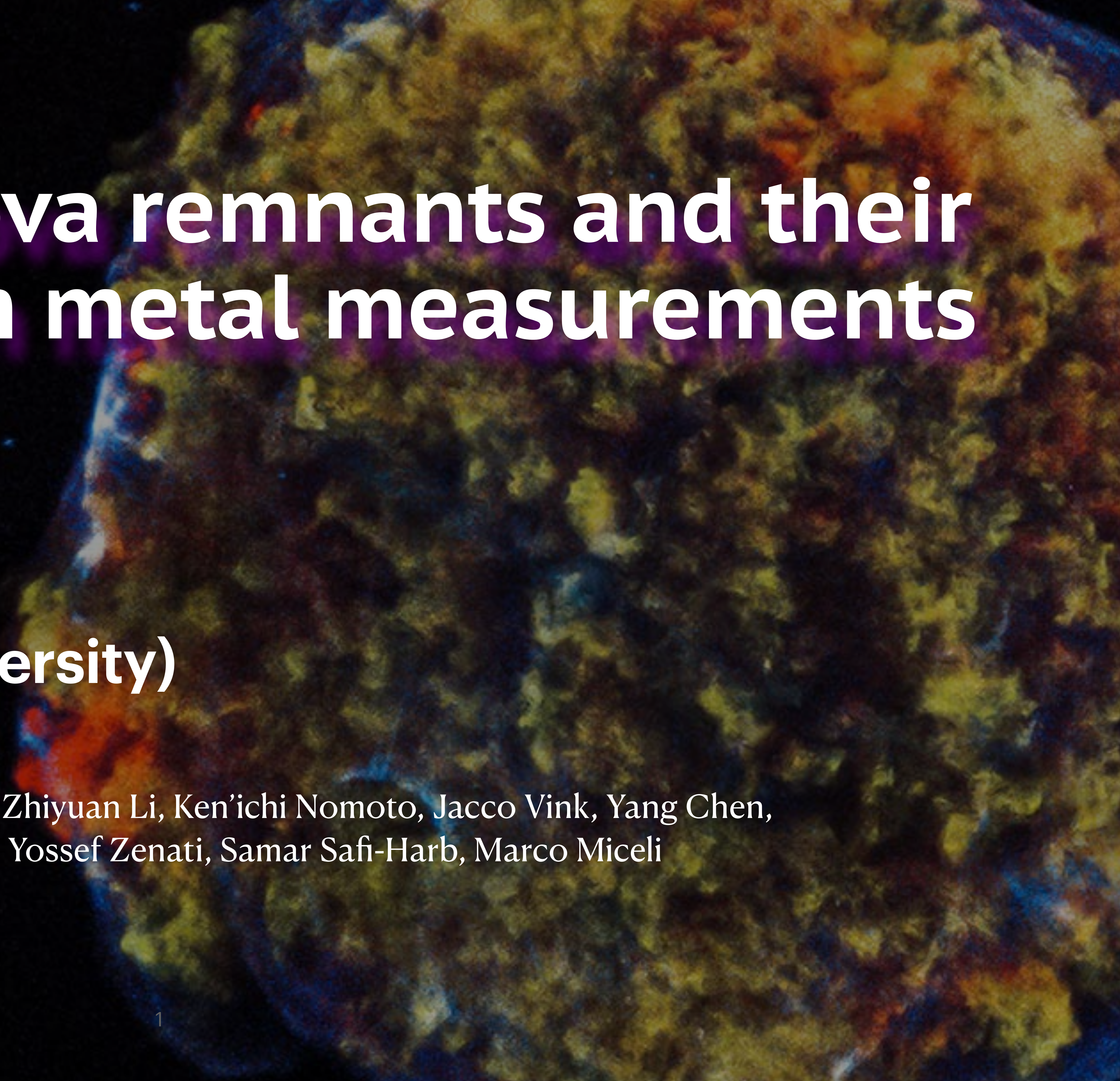
# Linking supernova remnants and their progenitors with metal measurements

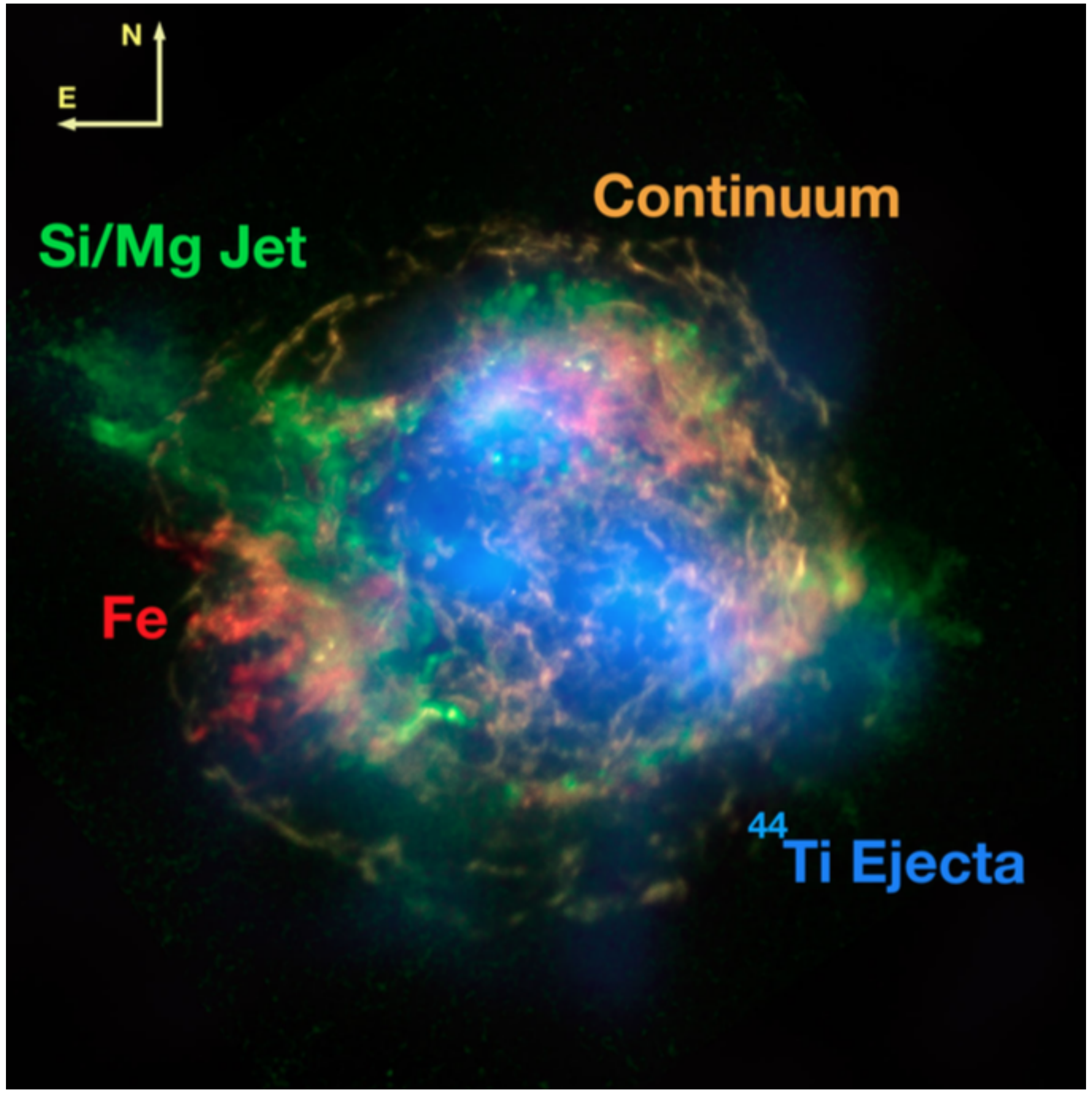
**Ping Zhou (Nanjing University)**

Collaborators: Jian-Bin Weng, Shing-Chi Leung, Zhiyuan Li, Ken'ichi Nomoto, Jacco Vink, Yang Chen, Hagai Perets, Daniel Wik, Silvian Toonen, Yossef Zenati, Samar Safi-Harb, Marco Miceli



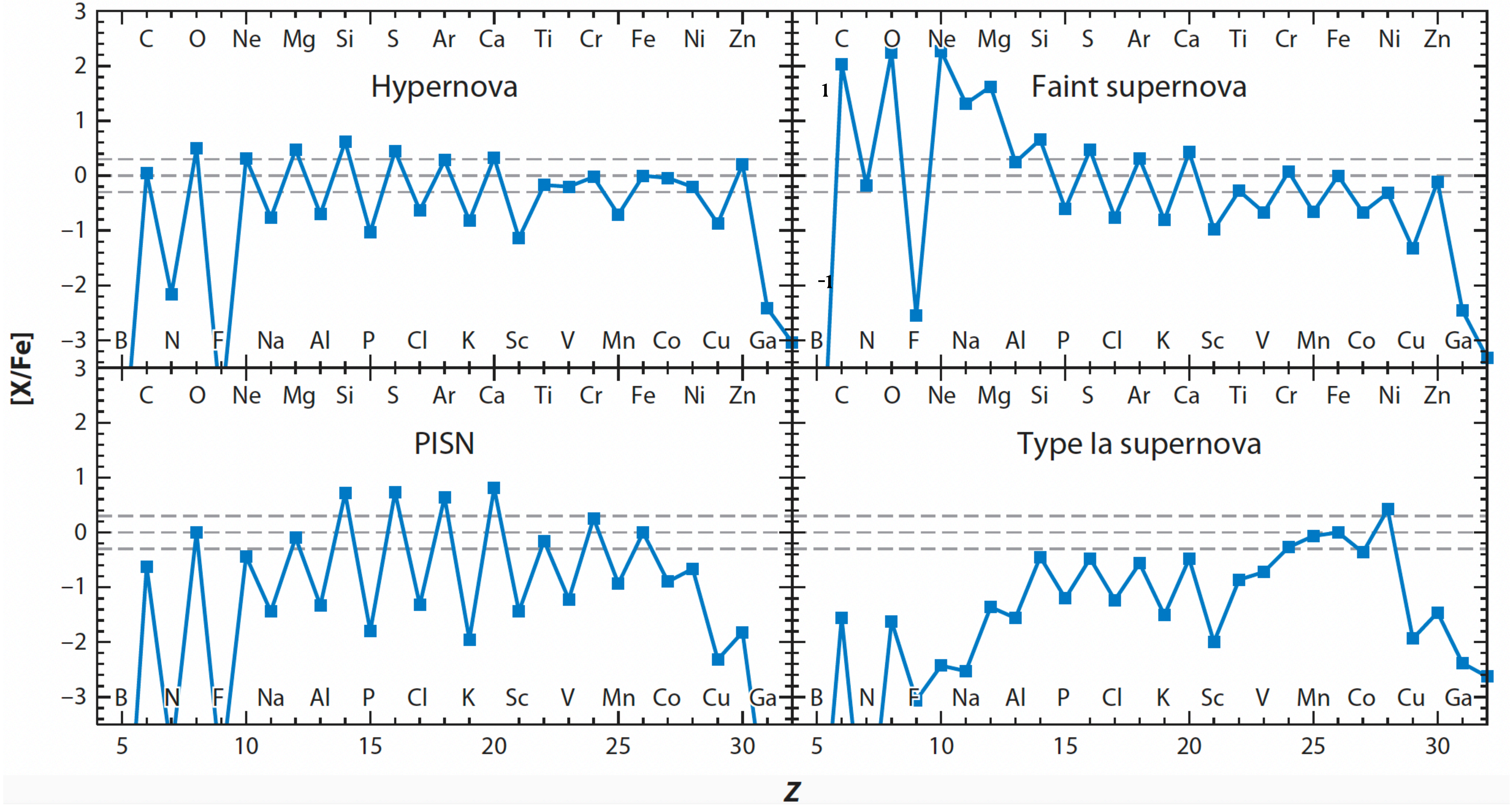
# Supernova remnants

- Nebulae resulted from the interaction between supernova materials and the interstellar medium
- 400 confirmed SNRs in our Galaxy (200 y—1My)
- SNRs keep memory of progenitor stars and supernova explosion mechanisms: **metals**
  - **How do stars/white dwarfs end their lives? How do supernovae explode?**




Grefenstette et al. 2014,2018

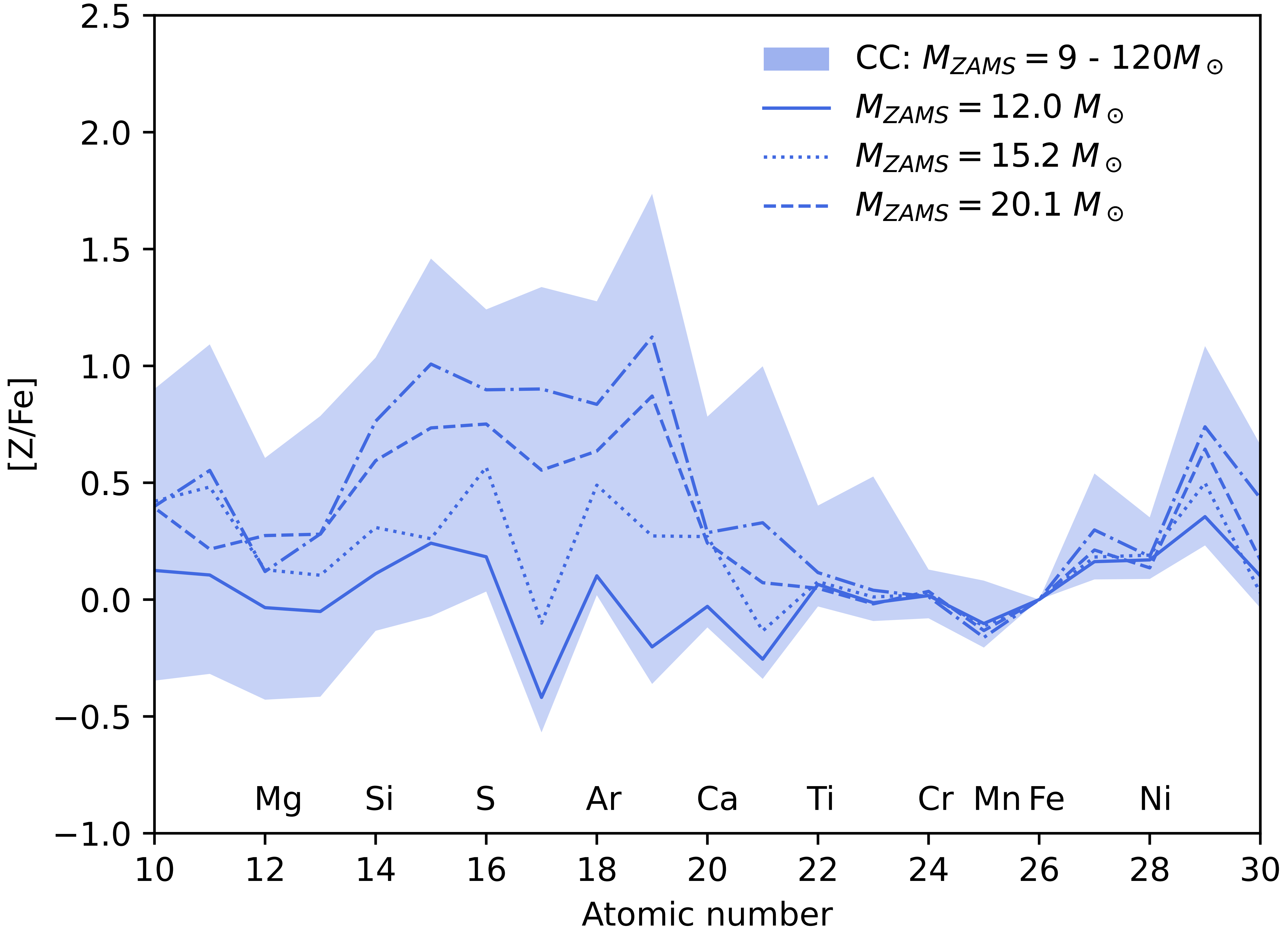
# Learn SN explosion mechanisms and progenitors from metals



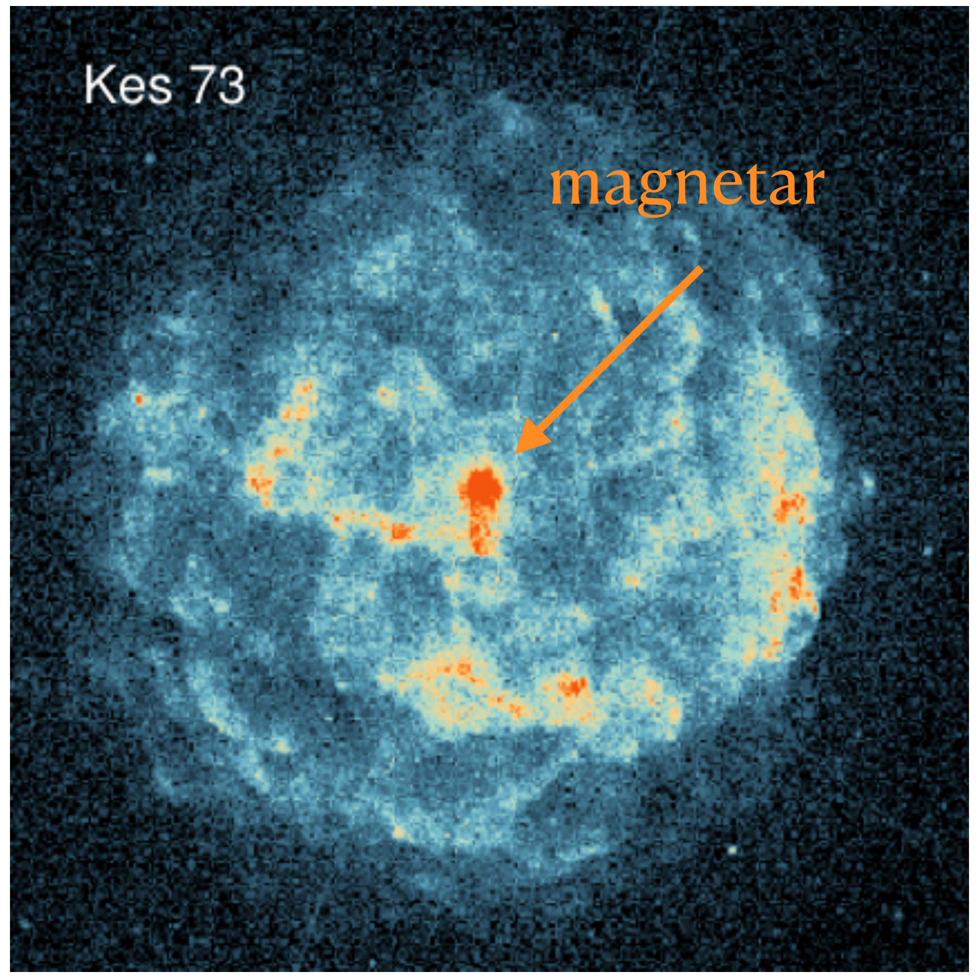

Nomoto et al. 2013

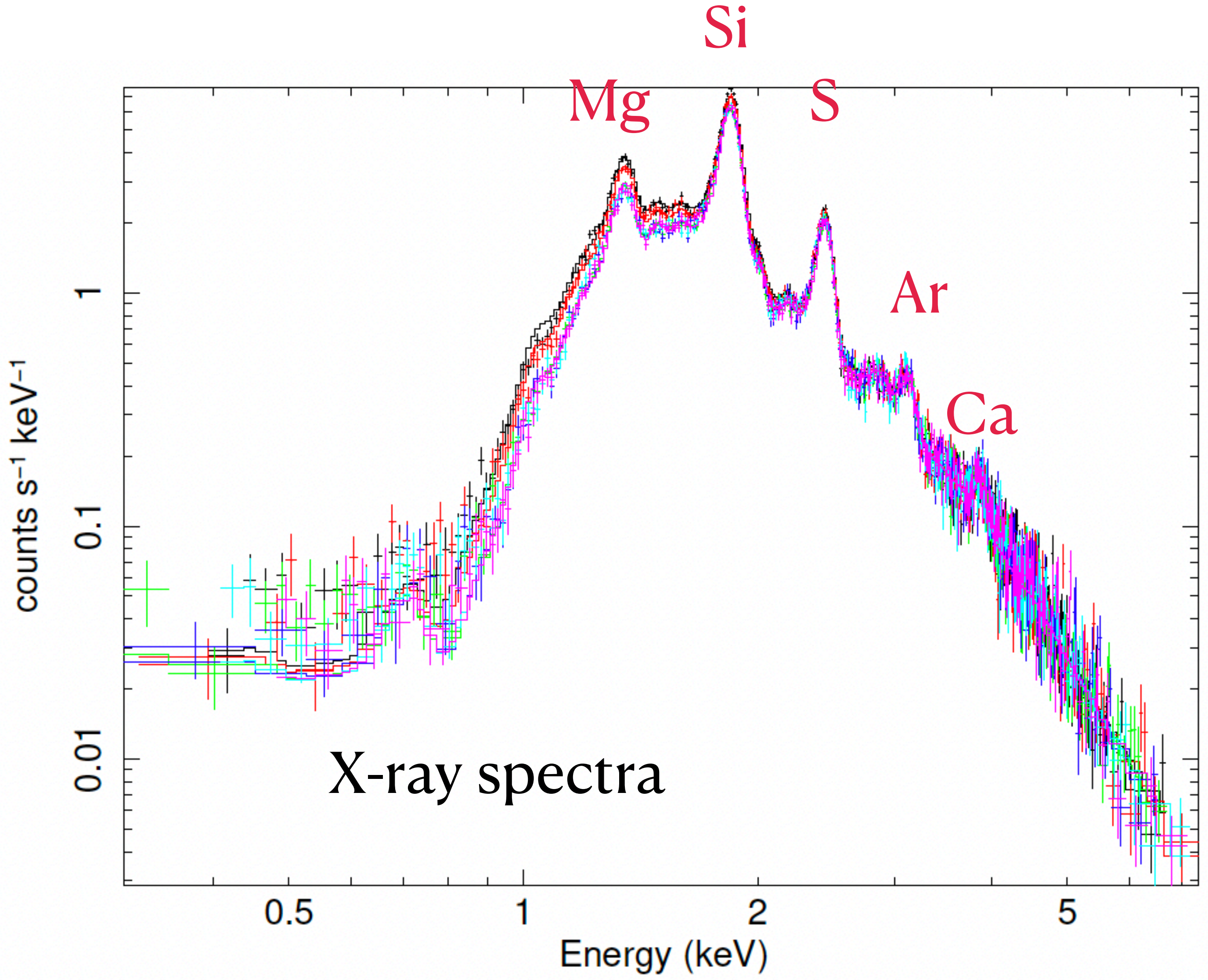
# Core-collapse SNe and their metal production

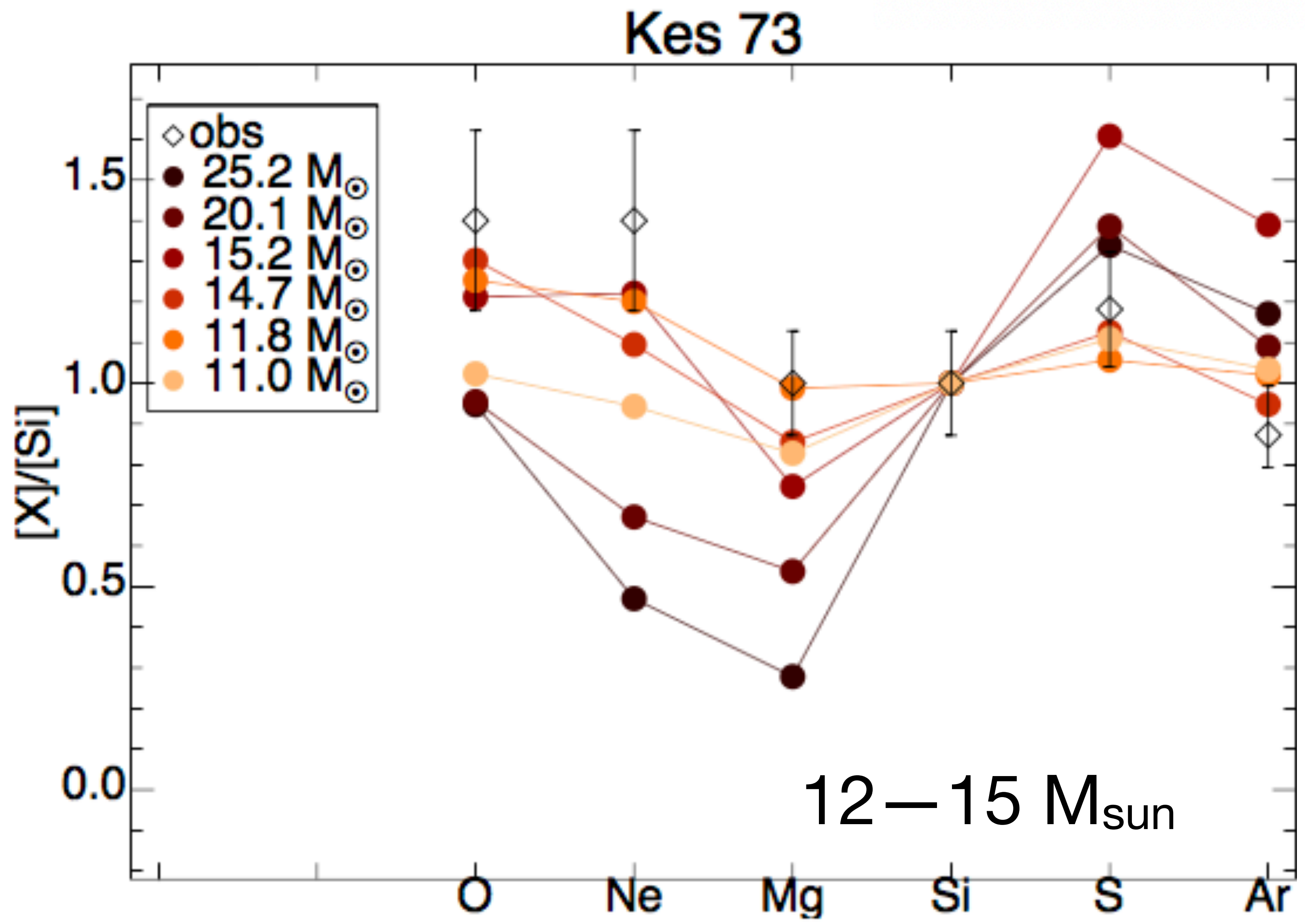
Stable elements (abundance ratio)




Based on SN models by Sukhbold et al. 2016



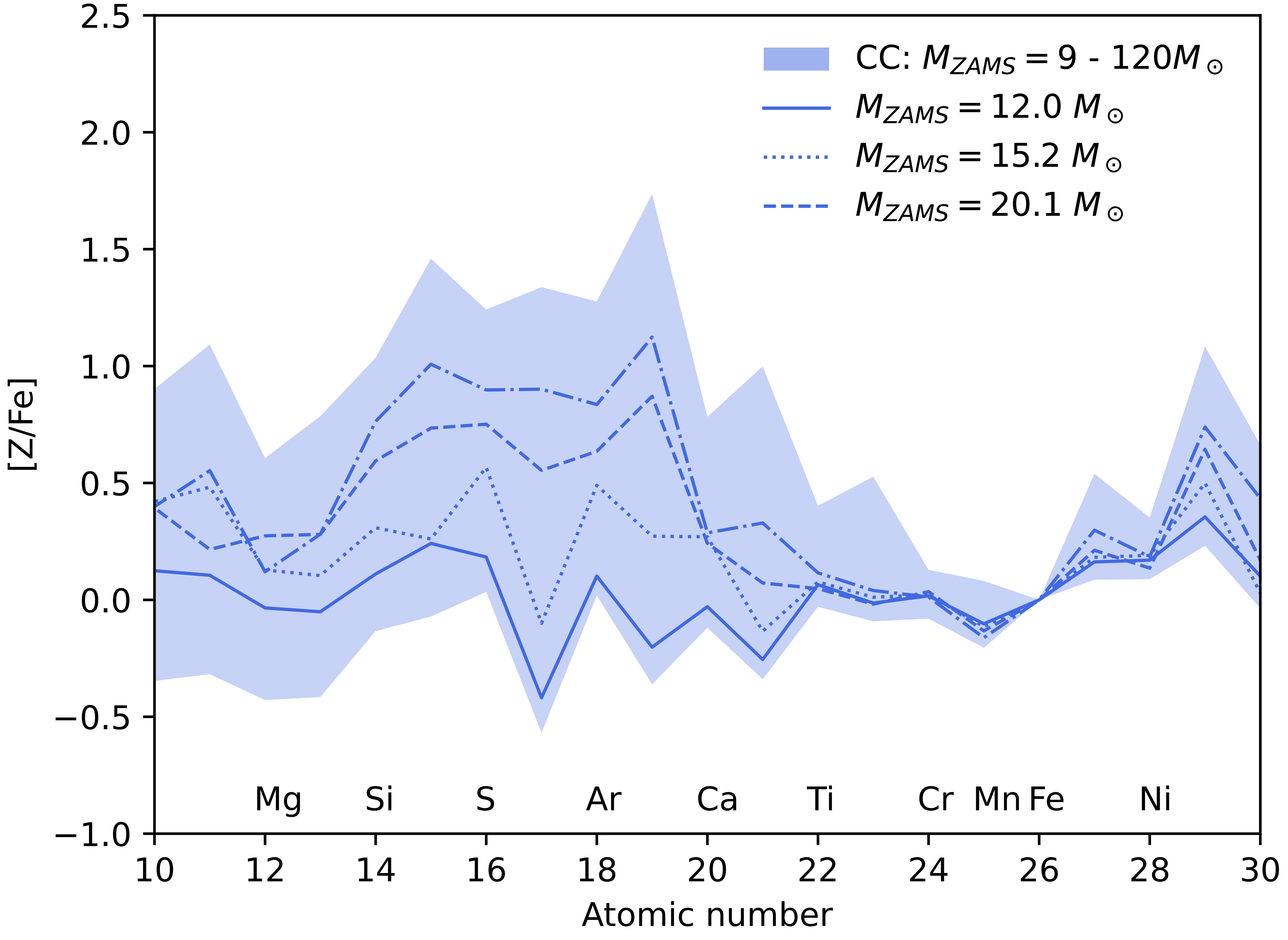




Zhou+2019

# Core-collapse SNe and their metal production

Stable elements (abundance ratio)

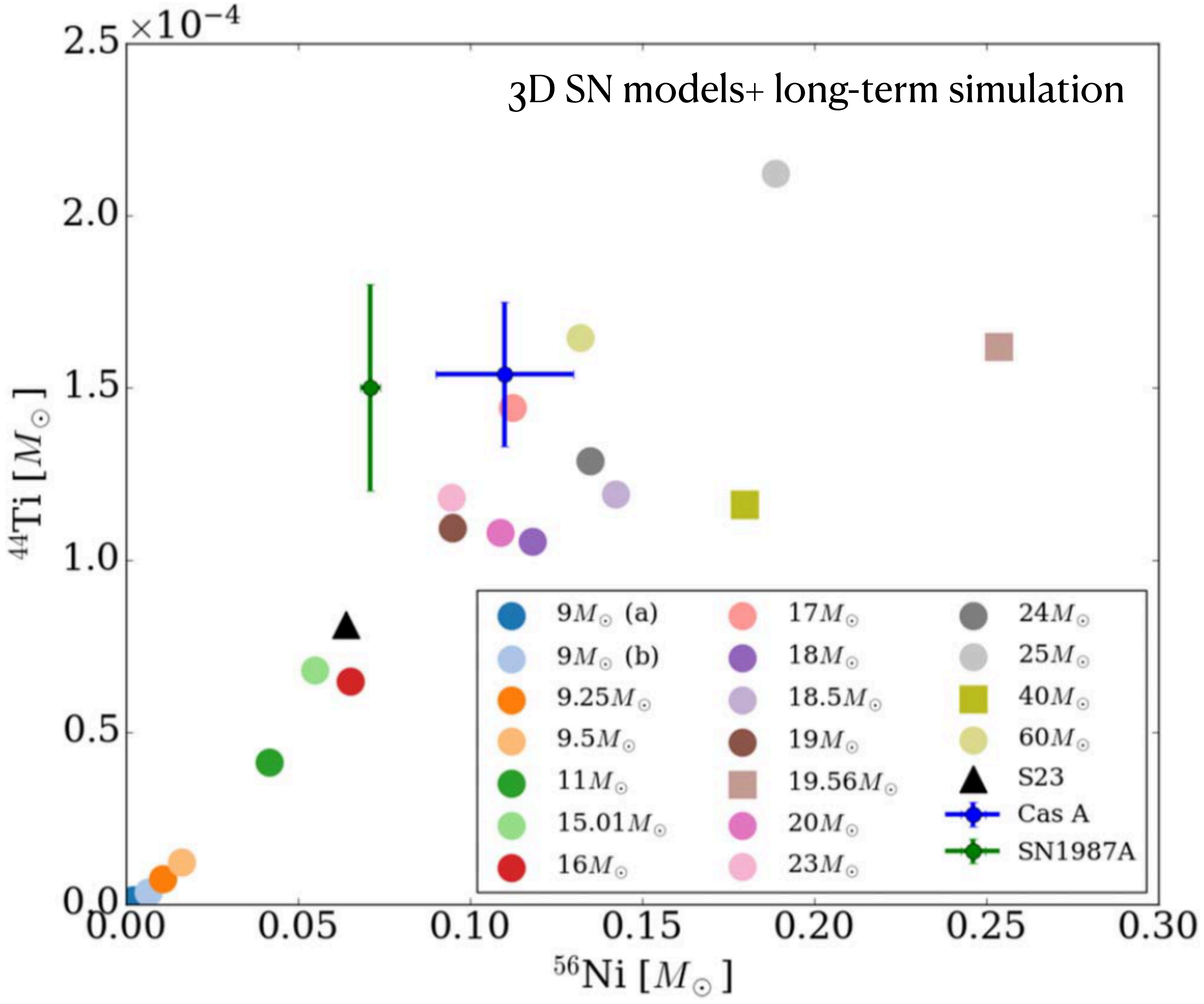



Based on SN models by Sukhbold et al. 2016

Radioactive isotopes (yields)

Advantage: independent of temperature, etc.

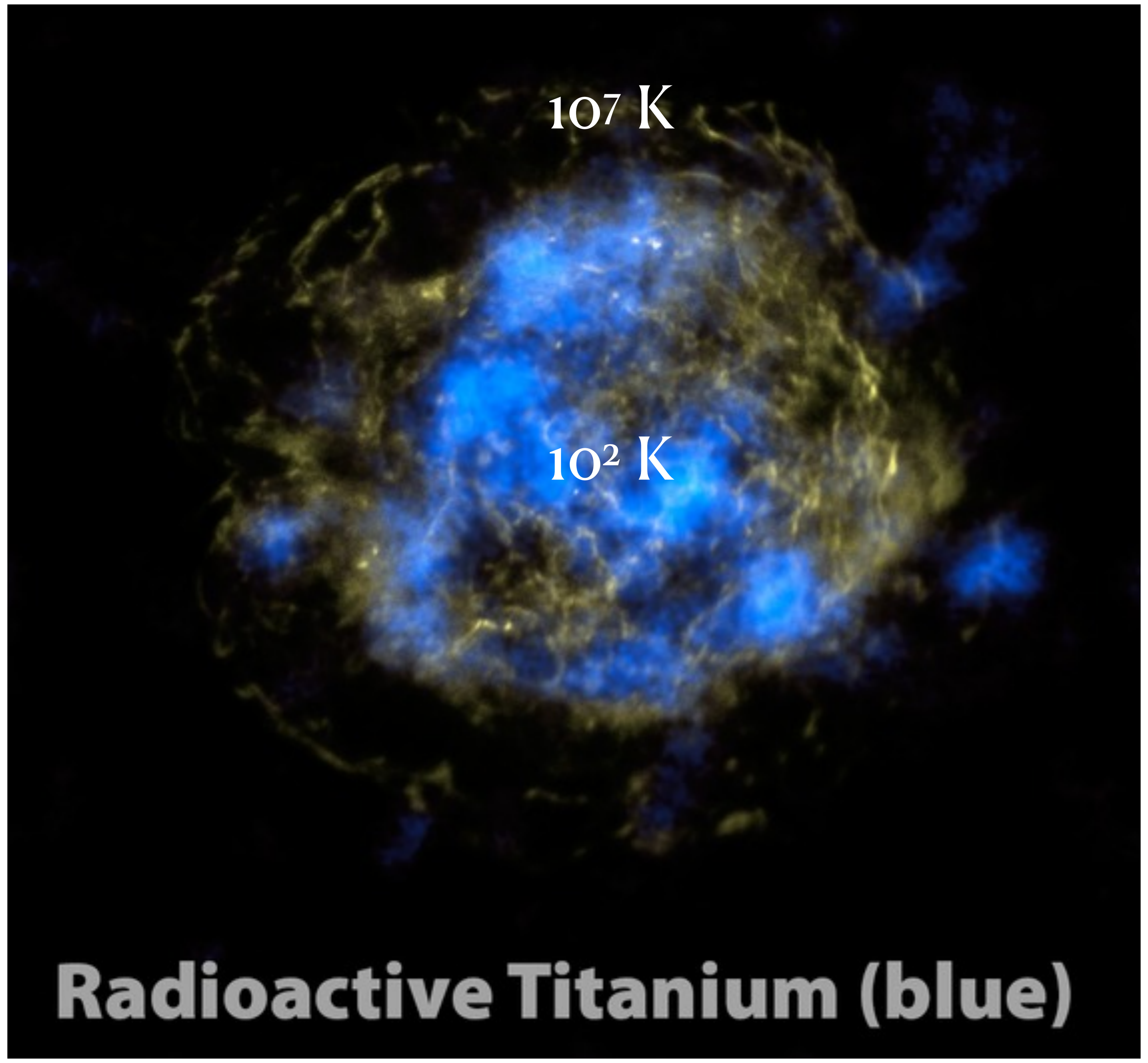
Disadvantage: difficult to measure with current instr.




Wang et al. 2024

# Radioactive elements measured in young SNRs

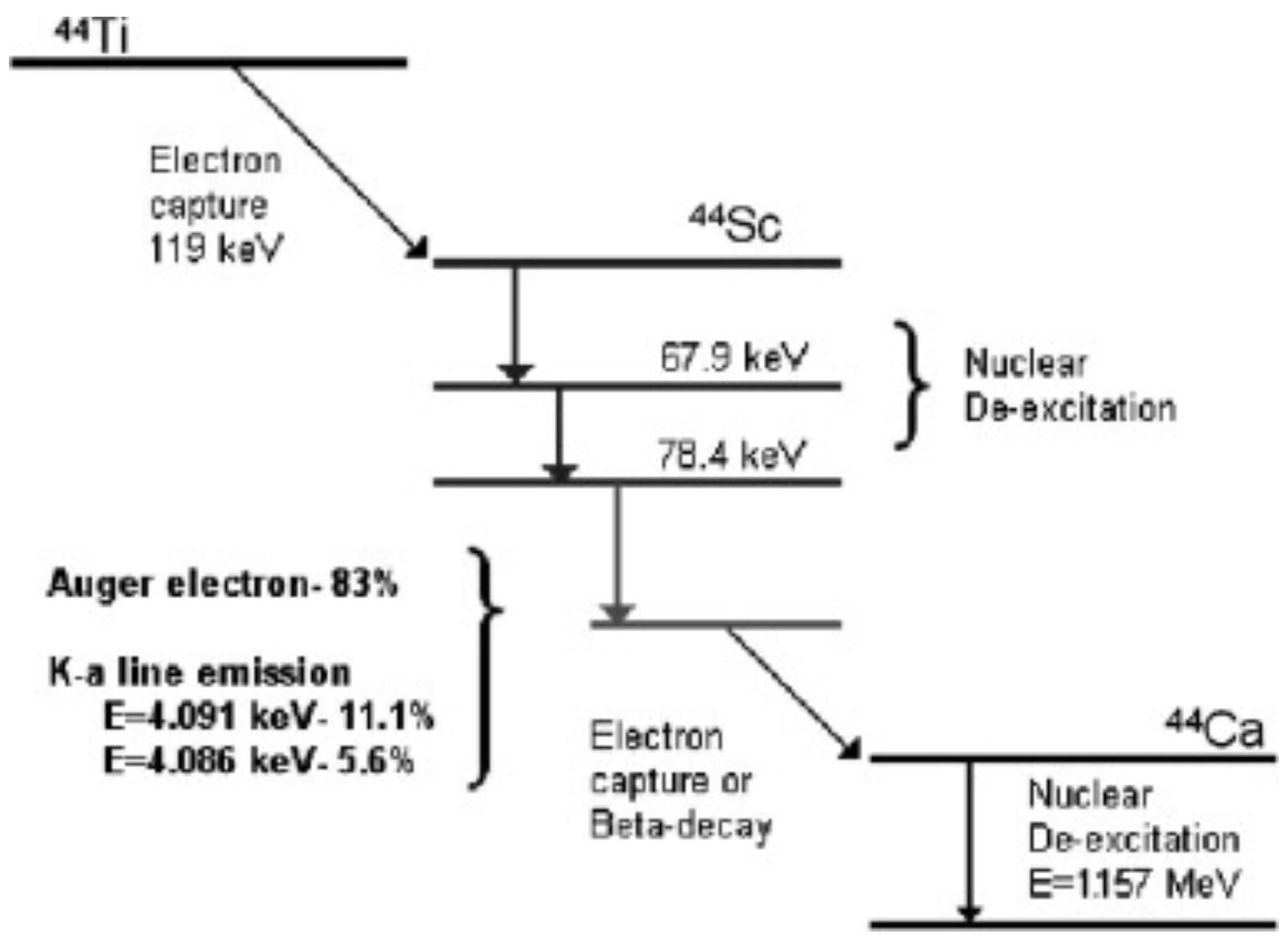
**44Ti ejecta in the cold interior**
(from 68 keV and 78 keV lines)




initial 44Ti mass of $1.6^{+0.6}_{-0.3} \times 10^{-4}\ M_\odot$
Moderately asymmetric CCSN explosion

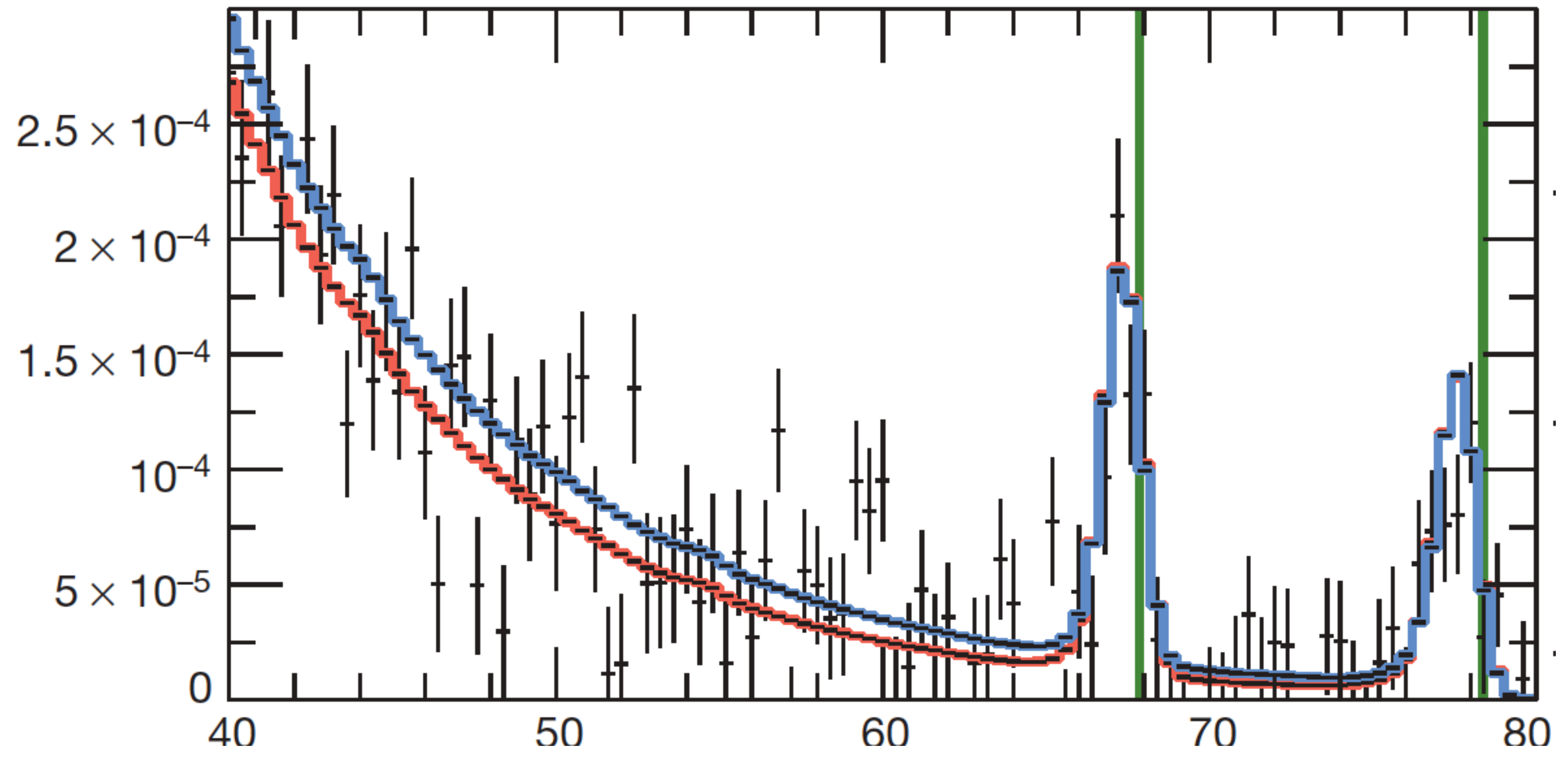
Grefenstette et al. 2014

44Ti decay chain
half lifetime ~60 yr

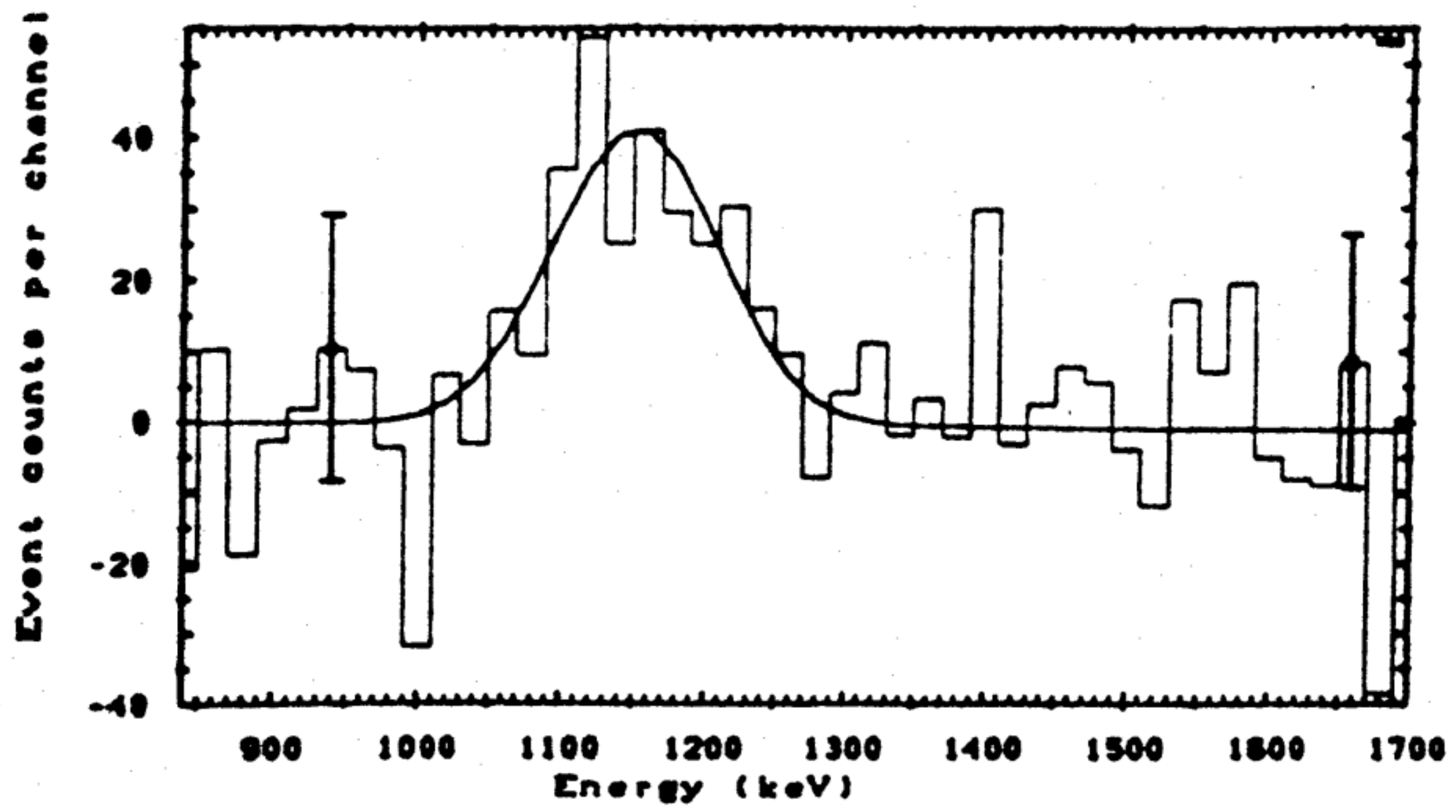



Theiling et al. 2006

NuSTAR (Grefenstette et al. 2014)

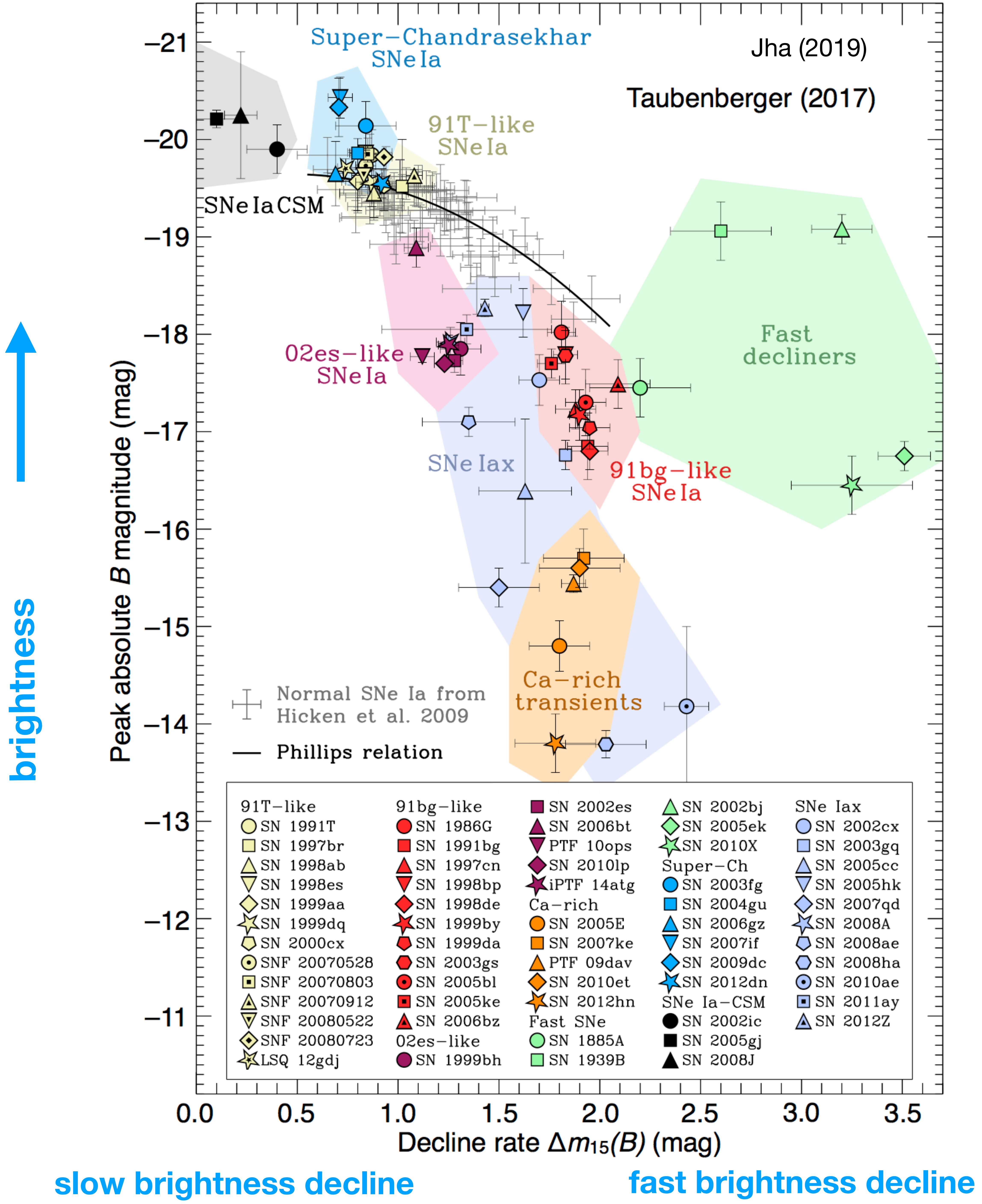



COMPTEL (Lyudin et al. 1994)



# Thermonuclear SN diversity

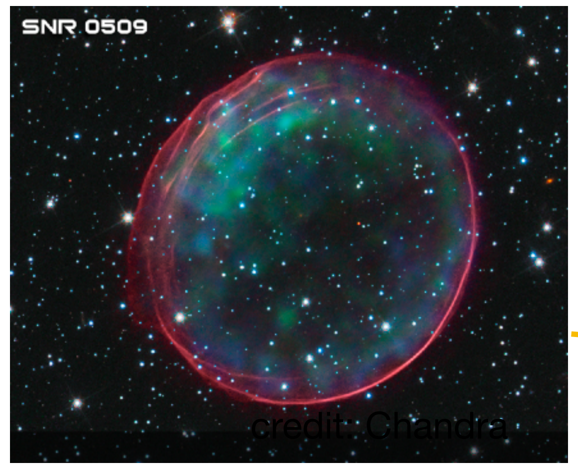
many sub-groups of Type Ia SNe -> different explosion mechanisms?



# SNR metal study helps to understand TN SN diversity

**91T-like**

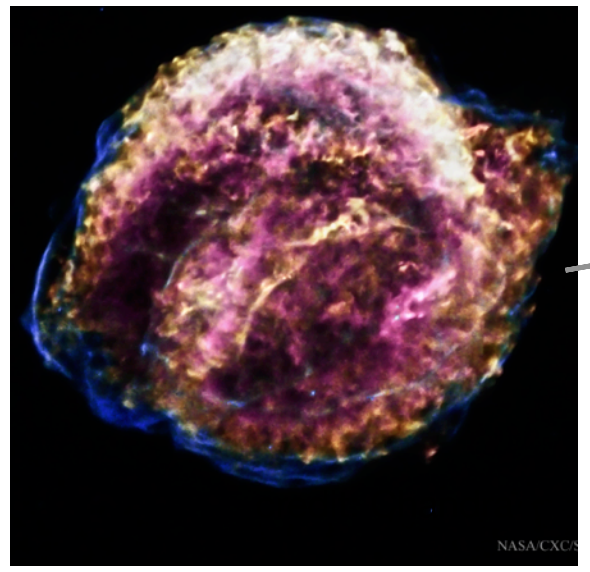
Badenes+2008, Seitenzahl + 2019




SNR 0509

**normal Type Ia**

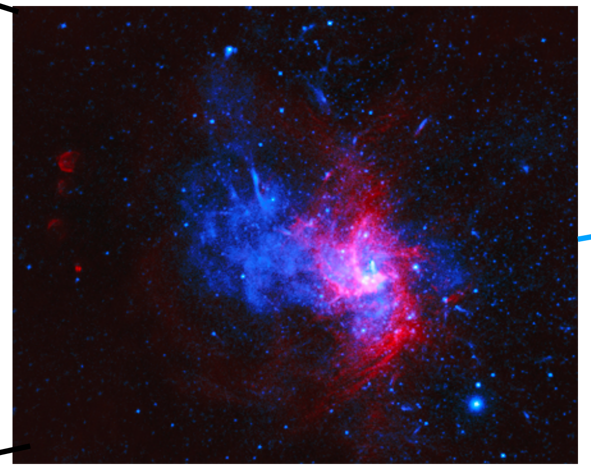
Sun & Chen 2019



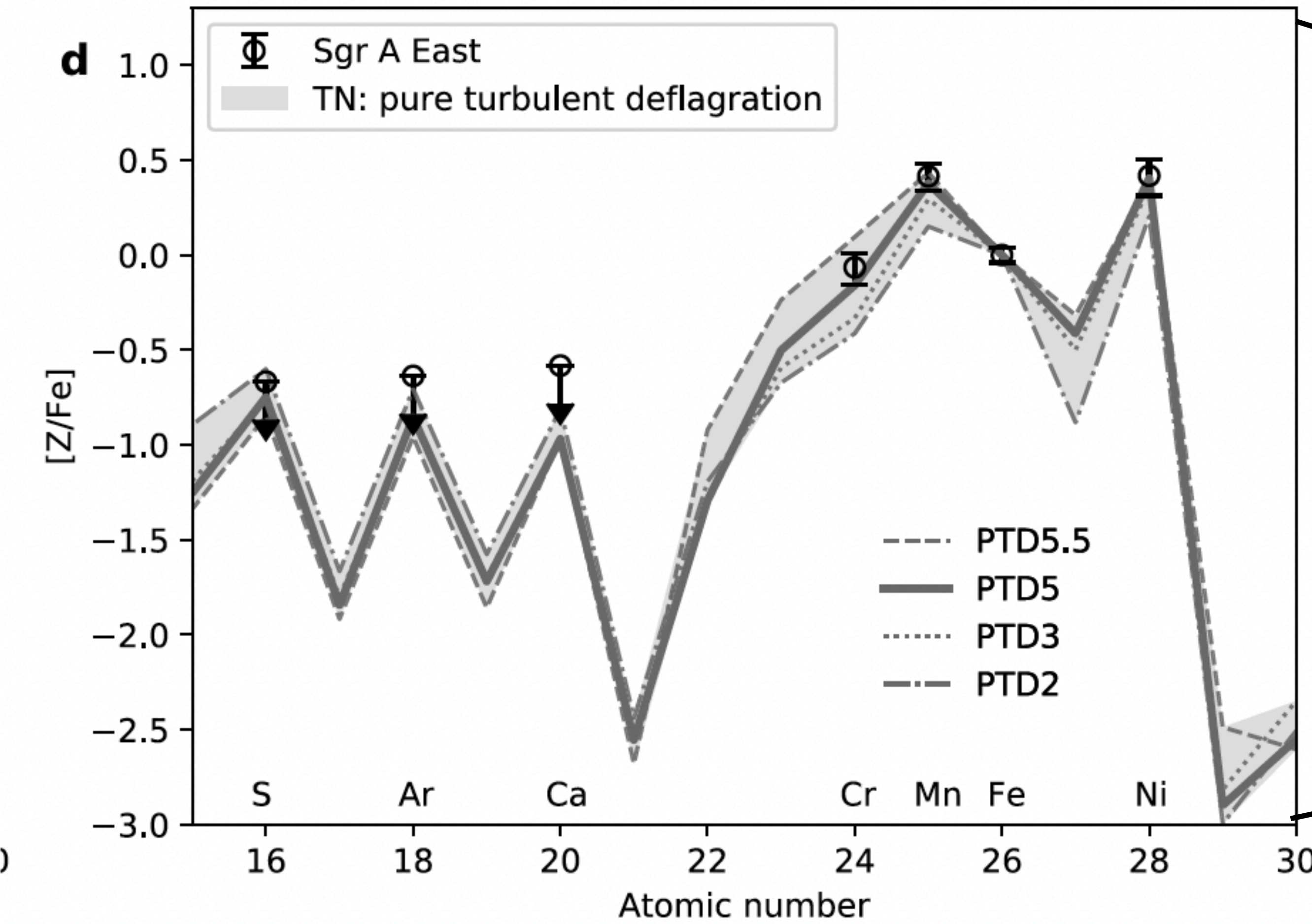
Kepler

**Type Iax**

Zhou+2021



Sgr A East

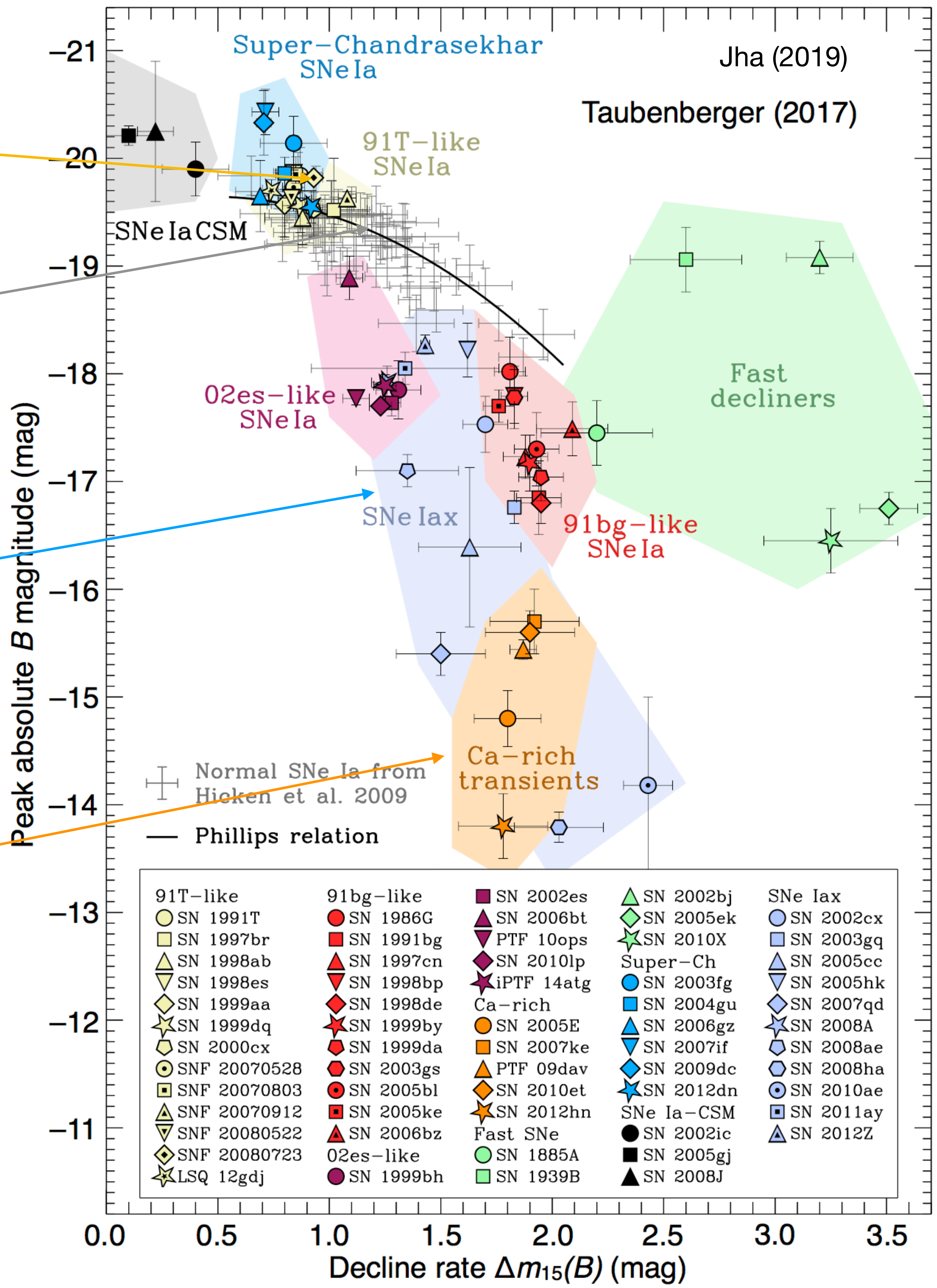



**Ca-rich transient**

Weng, Zhou +2022

G306.3-0.9

brightness

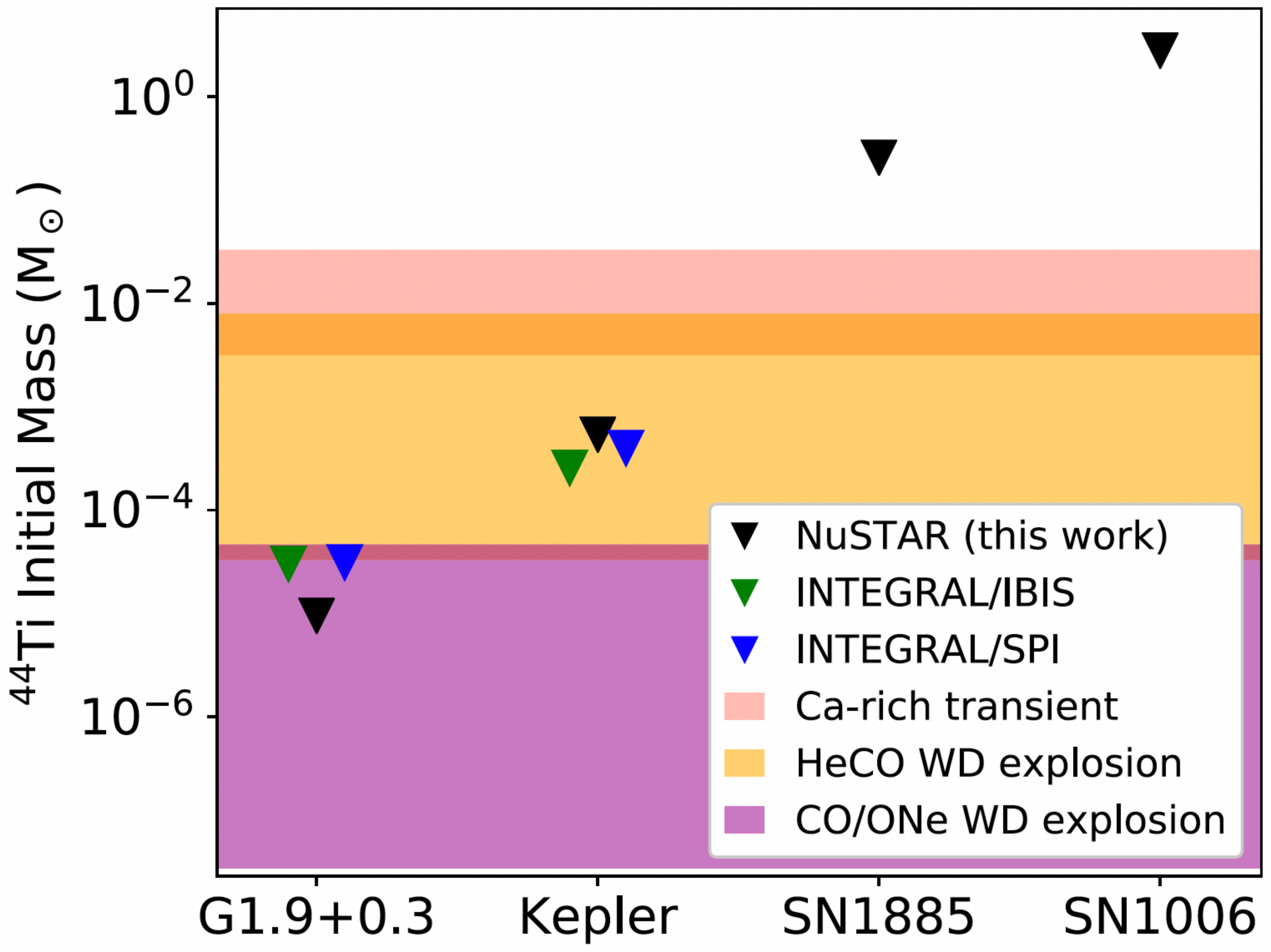


# $^{44}$Ti in thermonuclear SNe

- **$^{44}$Ti production channels**
  - α-rich freeze out (high-T, density <3e8 g cm-3)
  - explosive He burning
- ***M*($^{44}$Ti) sensitive WD density (mass) and composition**
  - CO/ONe WD: <~ 1e-5 $M_{sun}$
  - HeCO : 1e-4 — 1e-2 $M_{sun}$
  - Ca-rich Transient (thick He-shell detonation): >~ 1e-2 $M_{sun}$!
- **No significant $^{44}$Ti detection in any known TN SNR …**
  (G1.9+0.3? Tycho?an opportunity for future MeV missions)

See e.g. Timmes et al. 1996

Upper limits of $^{44}$Ti initial masses of TN SNRs vs. SN models




Weng, Zhou, et al. 2024; see also Weinberger, Diehl et al. 2020

# Future MeV observations of Radioactive elements in SNRs

- **Explosion mechanisms and progenitors of SNRs**
  - Youngest SNRs (<~1 kyr): G1.9+0.3 (~200 yr), Kepler (SN 1604), Tycho (SN 1572), SN 1006, SN 1181, Crab (SN 1054)
  - More young SNRs: RCW 86 (SN 185), RX J1713 (SN 393)
- **Search for young, hidden SNRs in our Galaxy**
  - Missing SNR problem:
    - The known SNR number is much less than predicted
    - 2—3 SNe per century, but the last known Galactic SN happened ~200 years ago
  - May not be bright in radio or X-ray, but should have radioactive isotopes