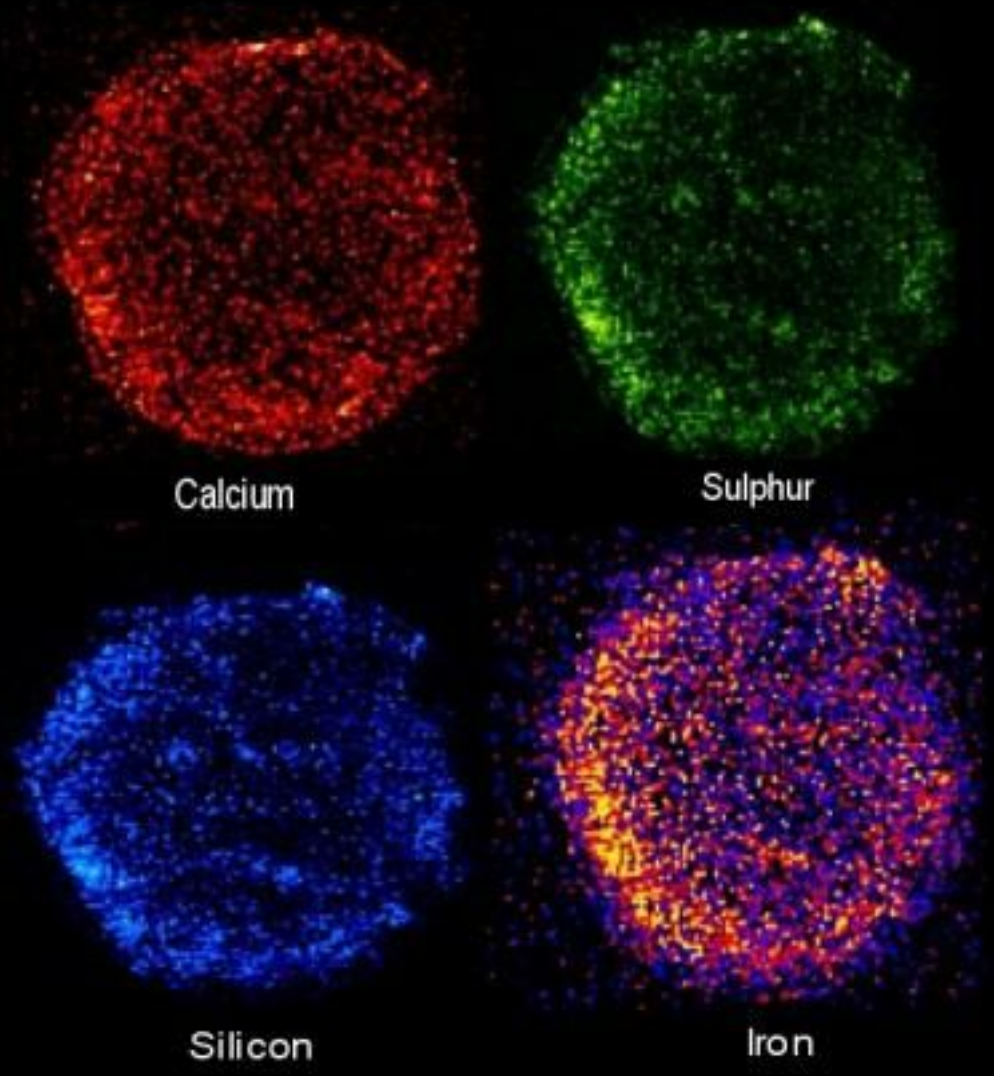
The Physics of Type Ia Supernovae Revealed in Dwarf Galaxies

Evan Kirby
Caltech



Tycho supernova remnant – ESA/XMM-Newton

Collaborators

Mia de los Reyes
Caltech

Justin Xie
The Harker School

Rachel Guo
Irvington High School

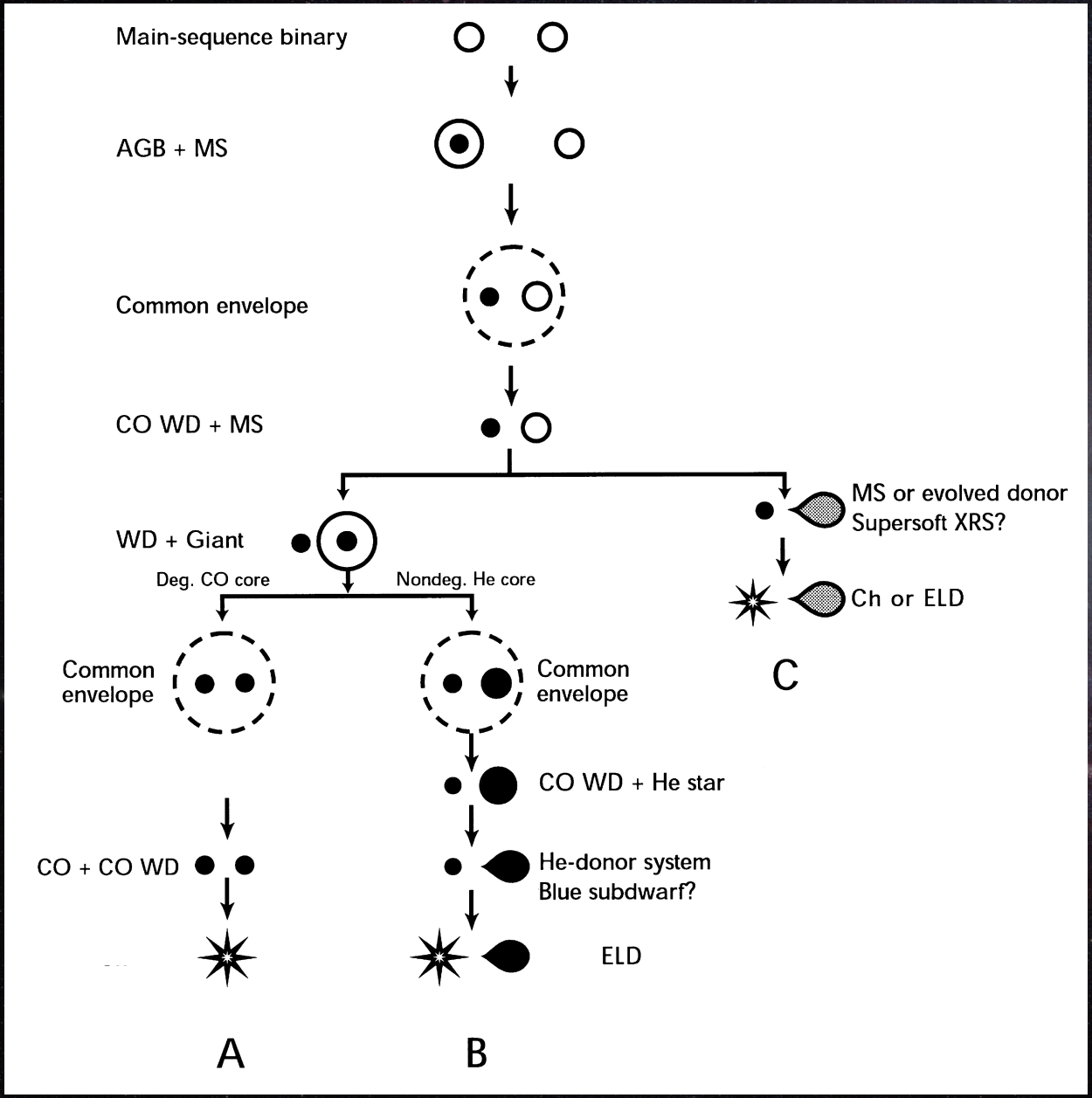
Ken Shen
UC Berkeley

Tony Piro, Andy McWilliam
Carnegie Observatories

Marten van Kerkwijk
University of Toronto

Maria Bergemann, Mikhail Kovalev
MPIA

There is more than one way to explode a white dwarf.



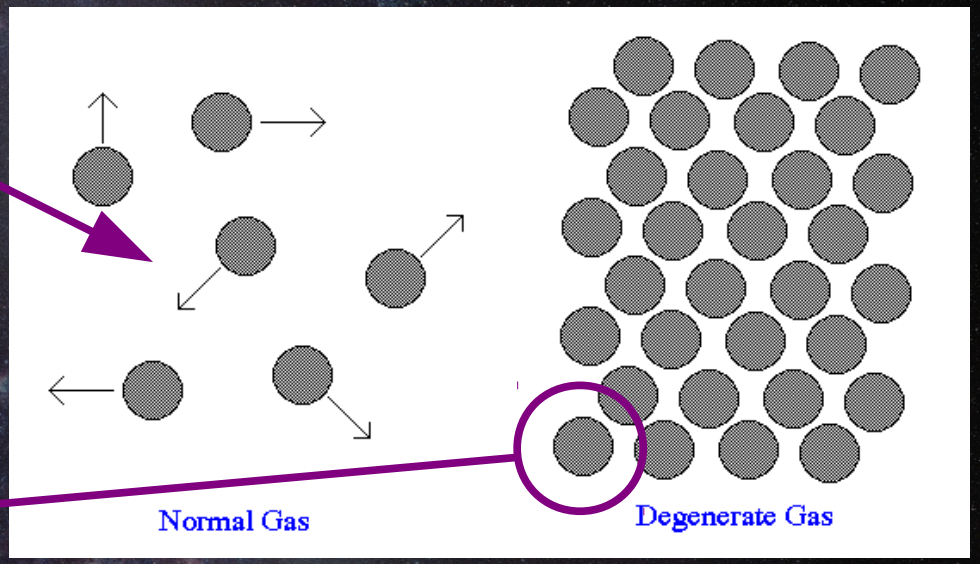
Model	Mass	Components
A	sub-M_{ch} or M_{Ch}	double degenerate
B	sub-M_{Ch}	single degenerate
C	M_{Ch}	single degenerate

Yungelson & Livio 2000, ApJ, 528, 108

Dense white dwarfs are neutron-rich.

beta decay:

$$n \rightarrow p + e^- + \overline{\nu}_e$$



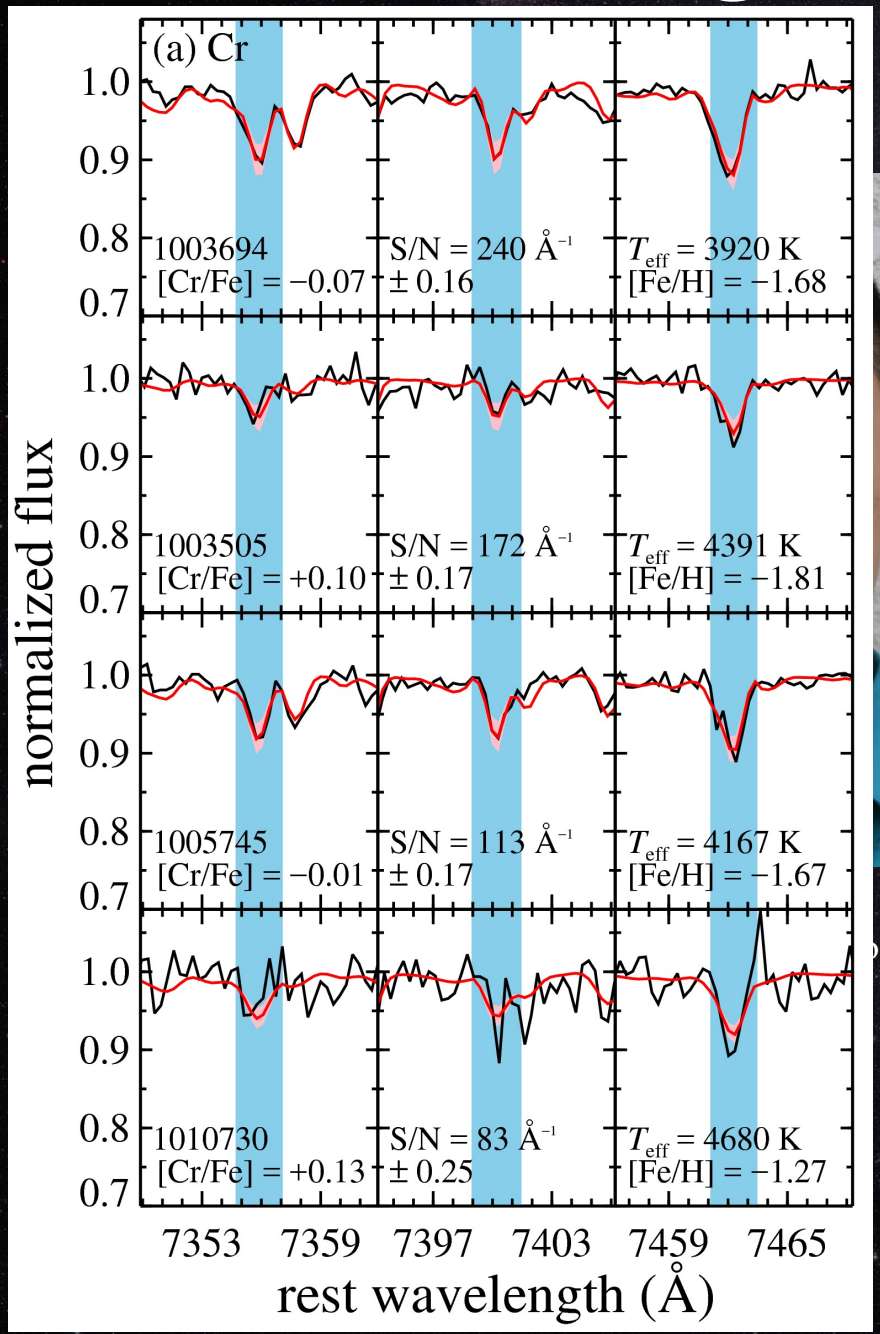
electron capture:

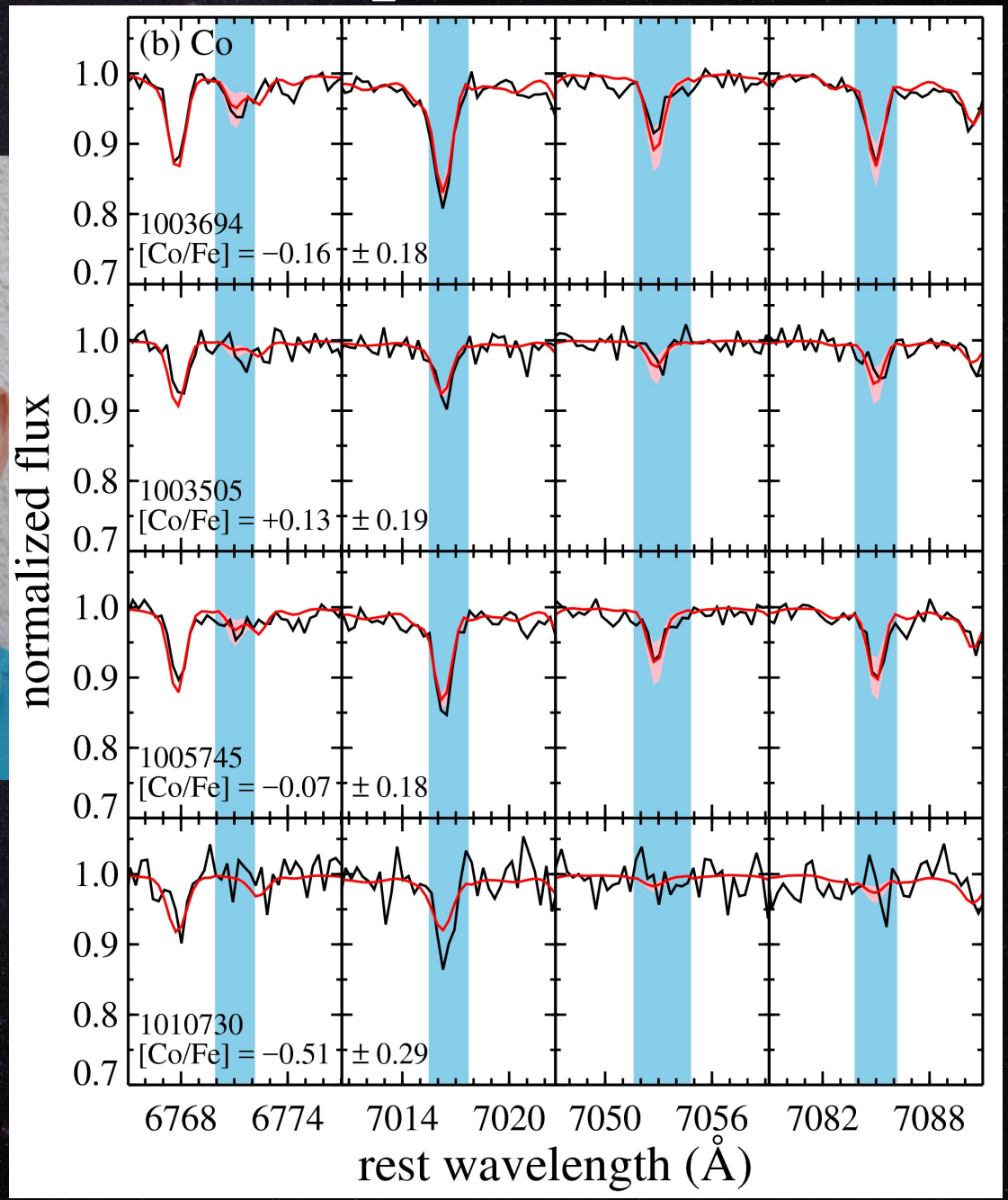
$$p + e^- \rightarrow n + \nu_e$$

Conclusions:

- **Less massive** (less dense) white dwarfs will produce fewer neutron-rich isotopes, like **stable Ni**.
- Alternatively, **deflagration** can reduce the neutron output of M_{Ch} white dwarfs.

We measured Cr, Co, and Ni from existing DEIMOS spectra.





Kirby, Xie, Guo, Kovalev & Bergemann 2018, ApJS, 237, 18

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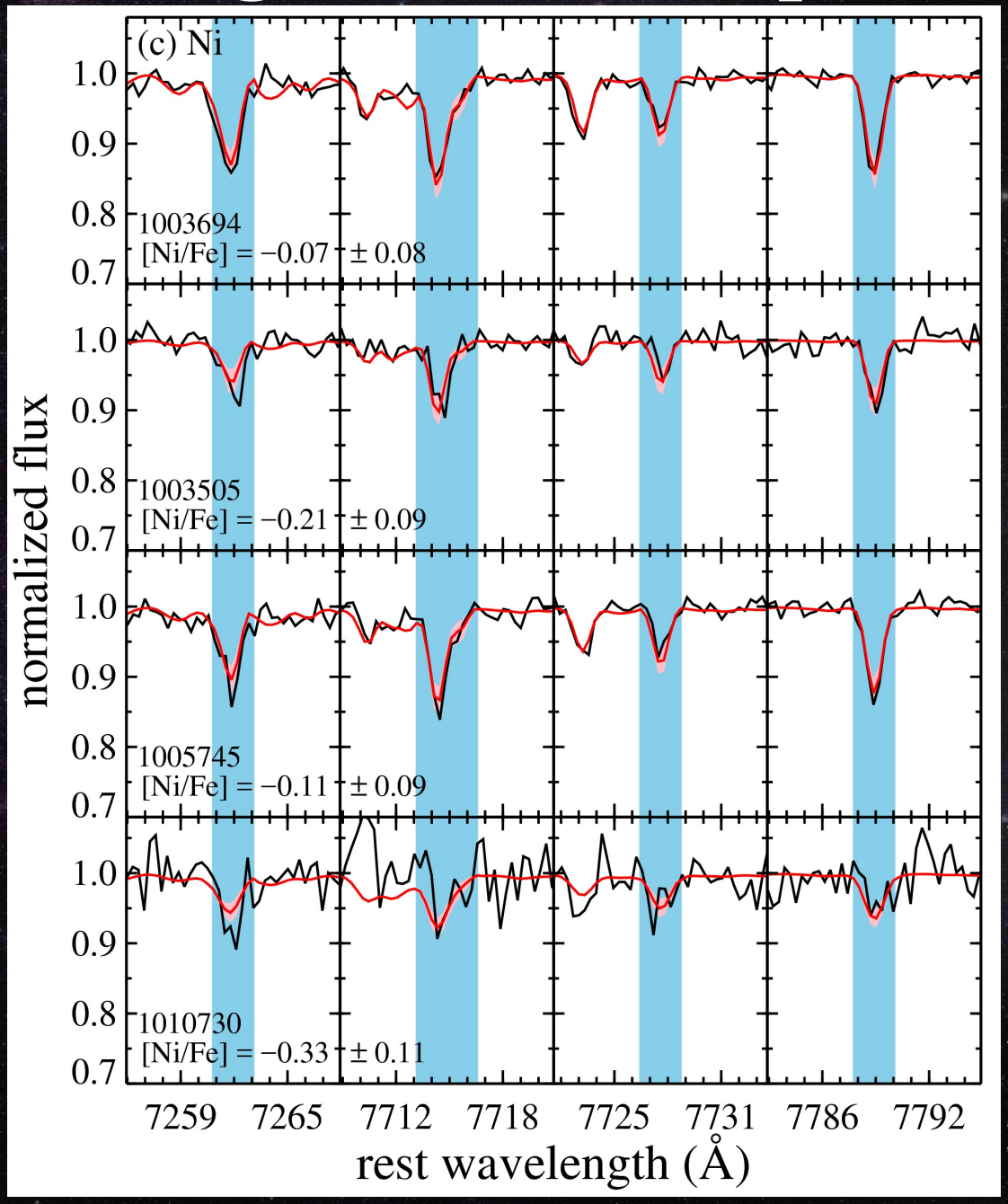
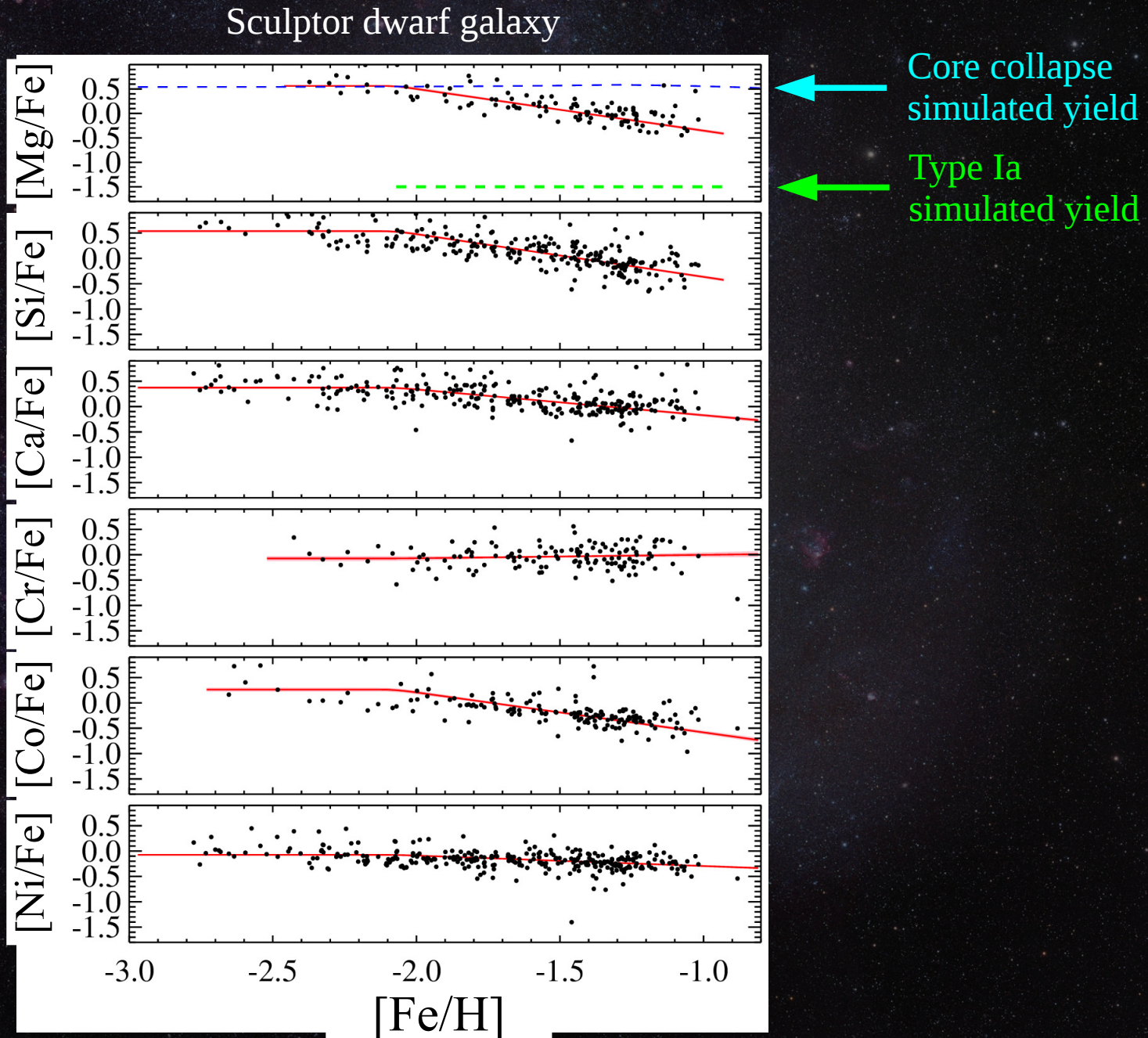
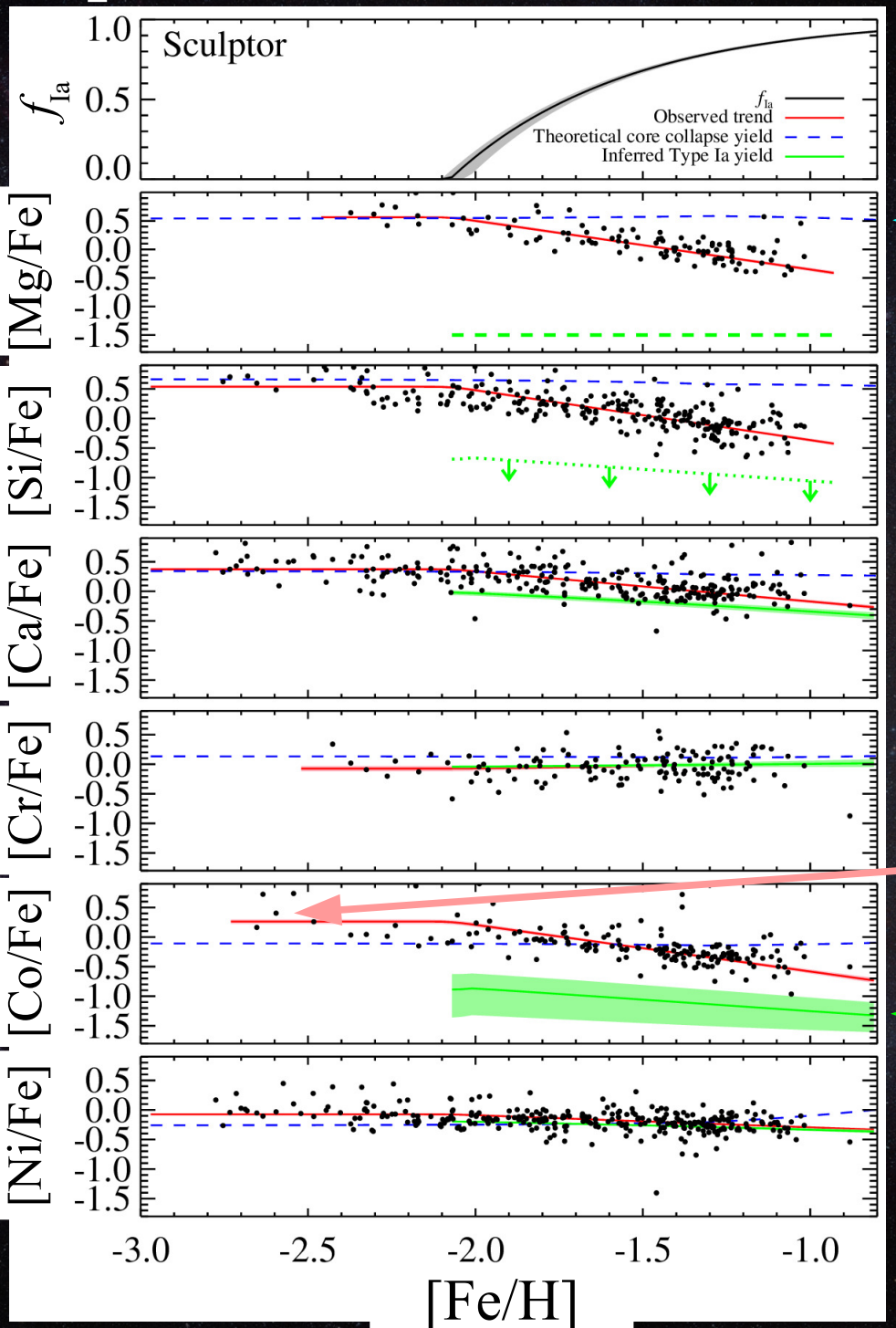


Kirby, Xie, Guo, Kovalev & Bergemann 2018, ApJS, 237, 18

Sculptor's chemical evolution is easy to interpret.



We used Sculptor's SFH to infer the Type Ia yield.



Kirby et al. 2019, ApJ, in press, arXiv:1906.10126

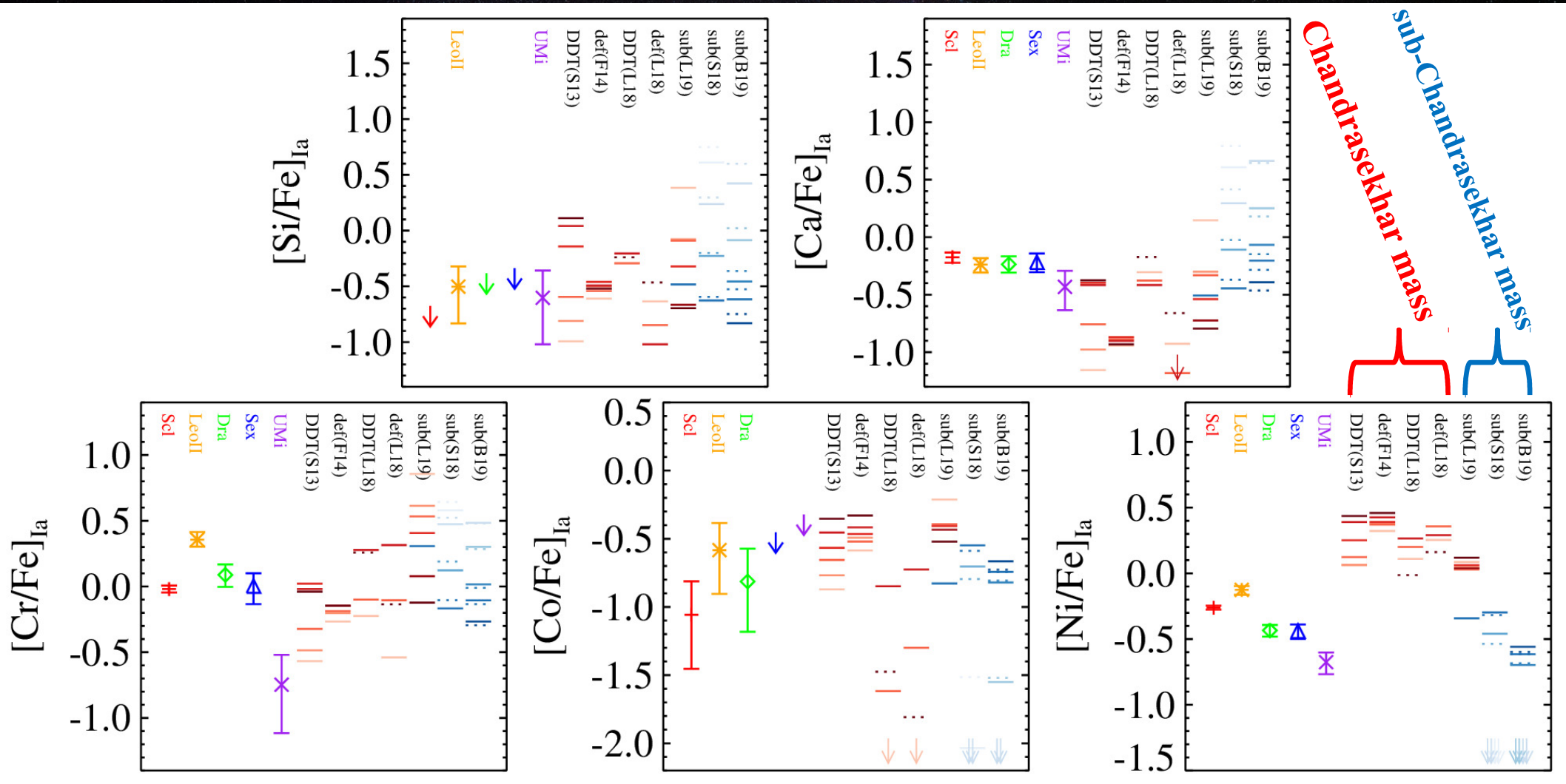
Core collapse simulated yield

Type Ia simulated yield

Core collapse inferred yield

Type Ia inferred yield

The data favor sub-Chandrasekhar-mass explosions.



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Theoretical yields:
S13: Seitenzahl et al. 2013, MNRAS, 429, 1156
F14: Fink et al. 2014, MNRAS, 438, 1762
L18: Leung & Nomoto 2018, ApJ, 861, 143
L19: Leung & Nomoto 2019, ApJS, accepted, arXiv:1901.10007
S18: Shen et al. 2018, ApJ, 854, 52
B19: Bravo et al. 2019, MNRAS, 482, 4346

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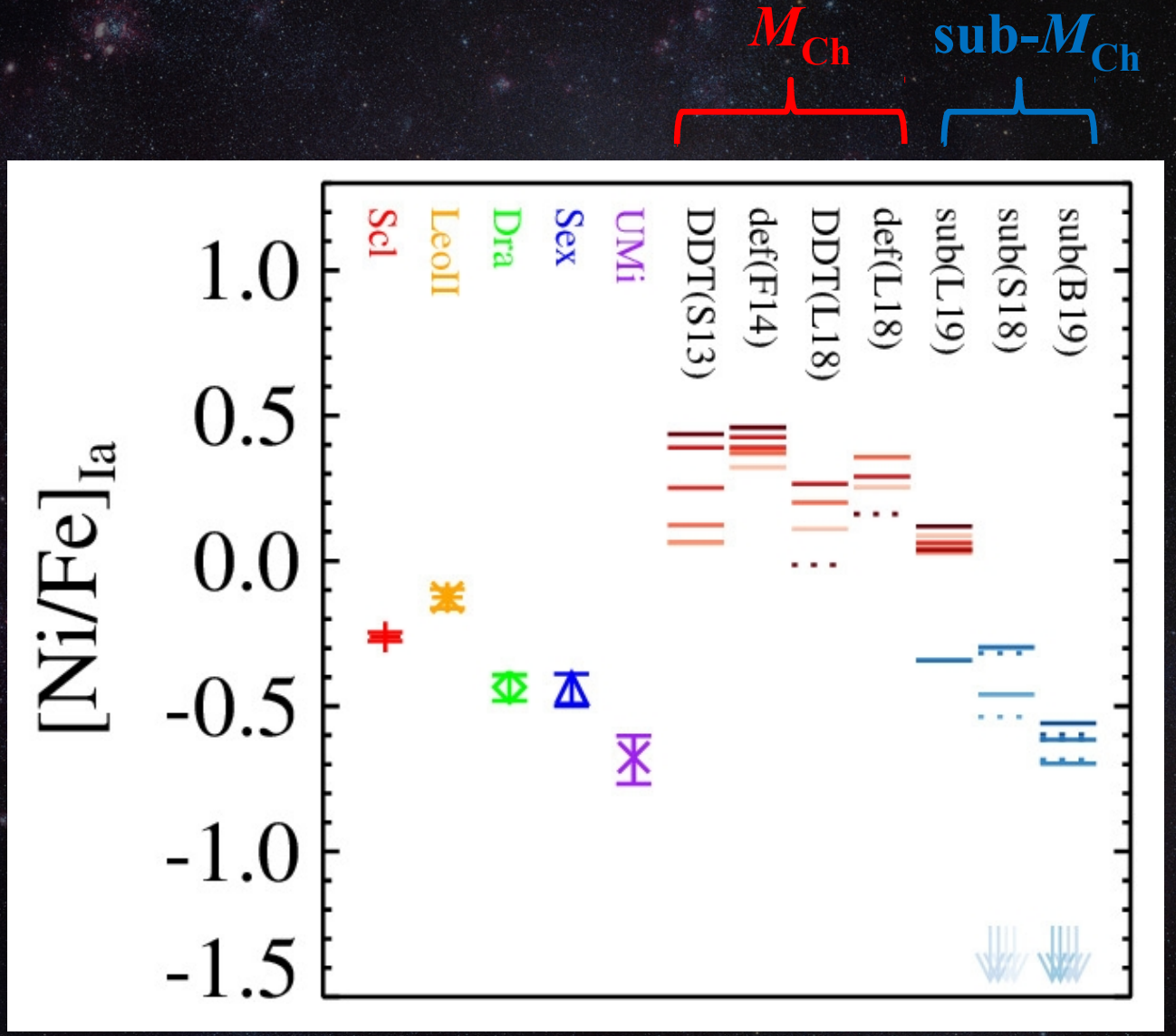

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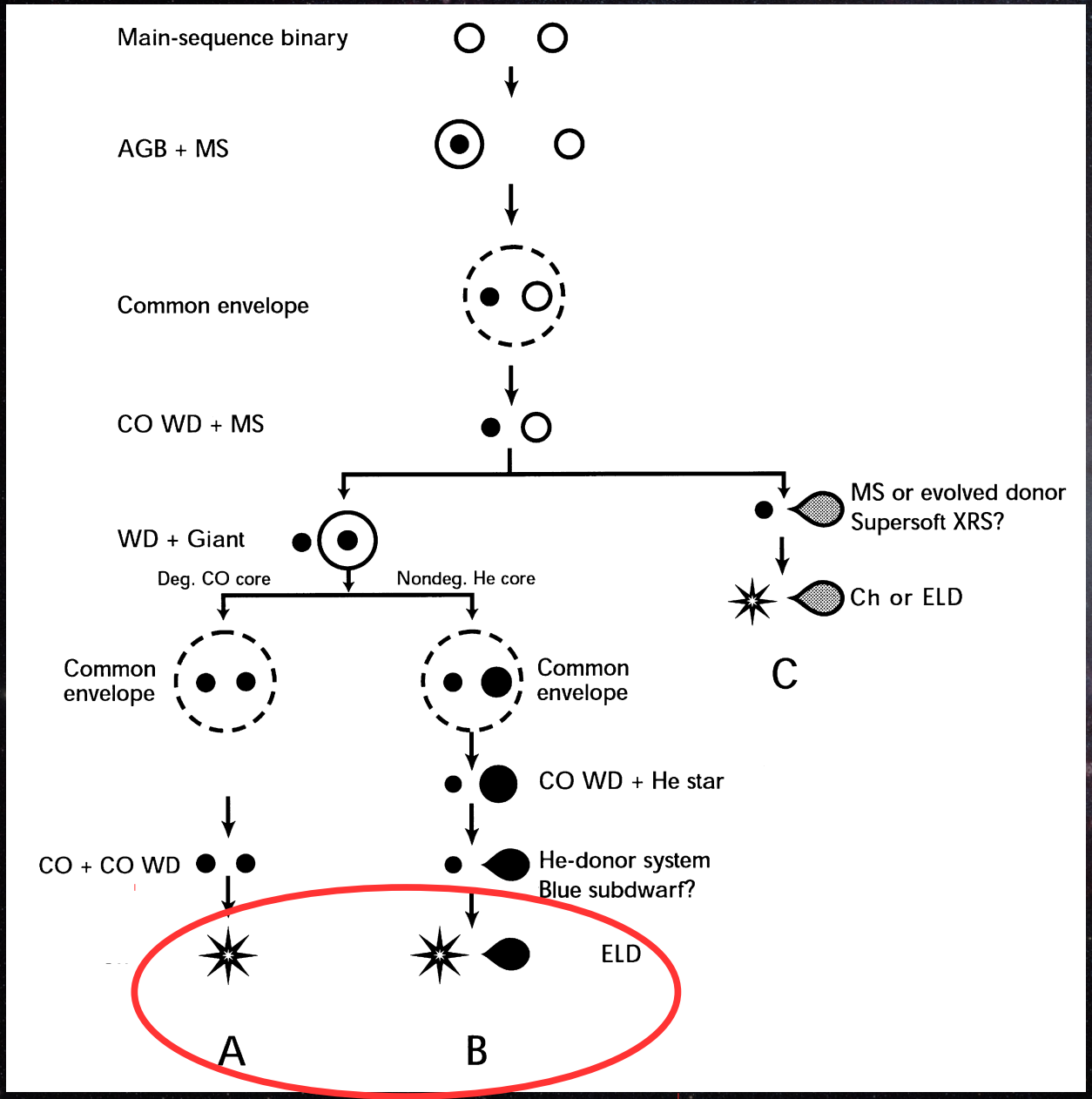

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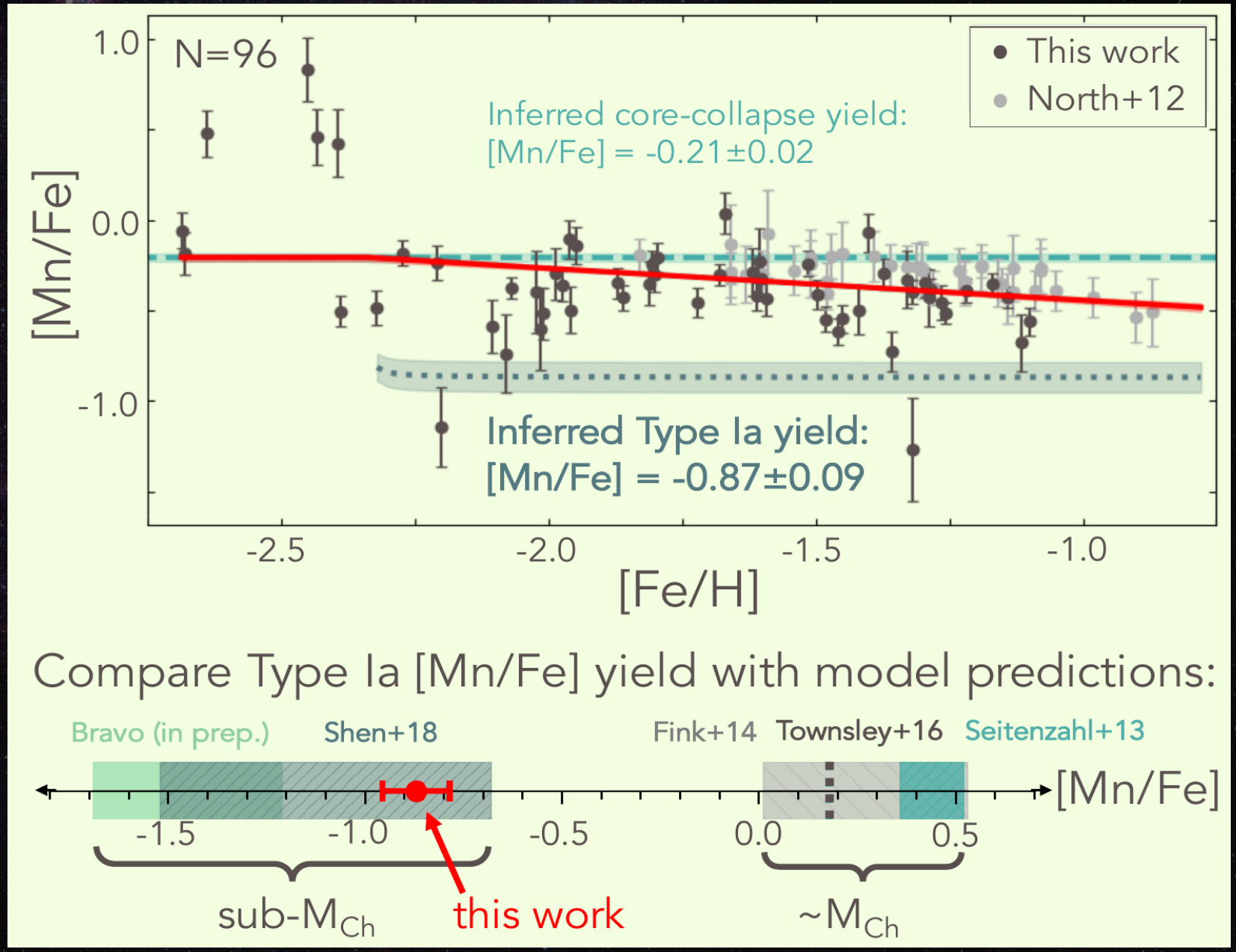
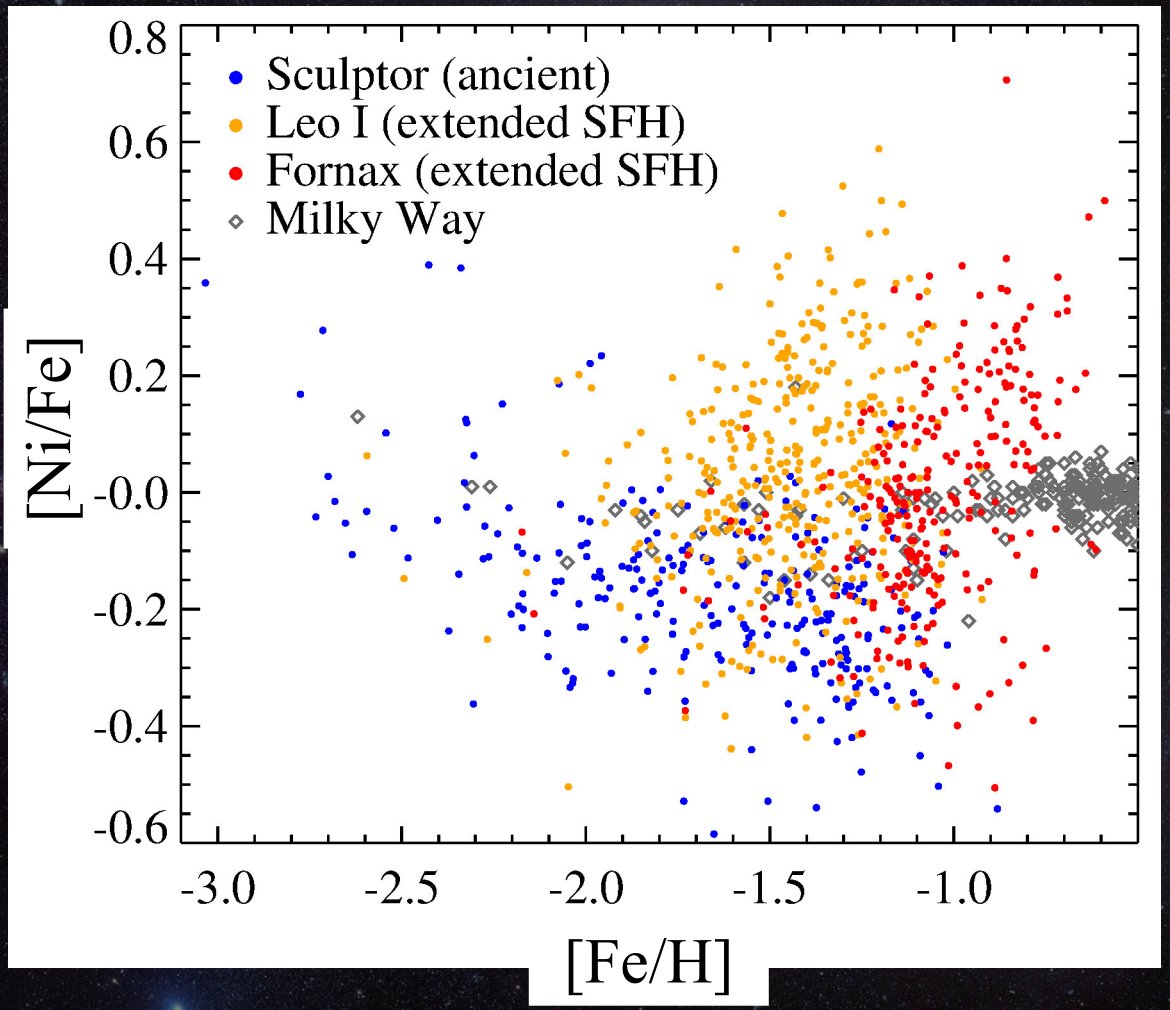
Manganese is even more constraining than nickel.

Mia de los Reyes
Caltech



But wait … galaxies with extended SFH show higher [Ni/Fe].



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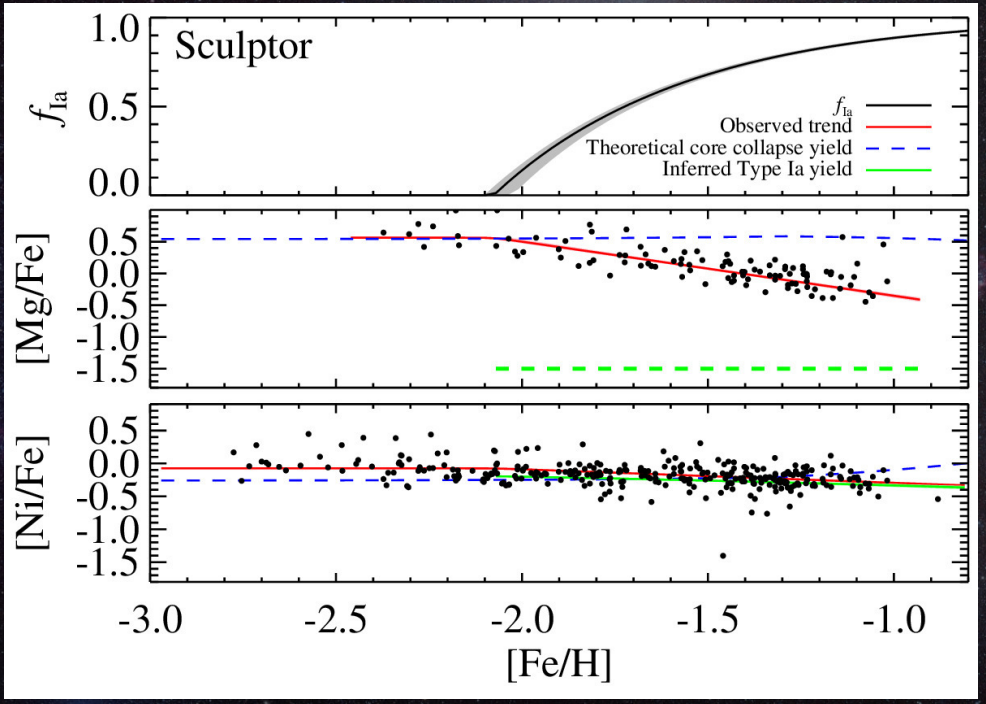
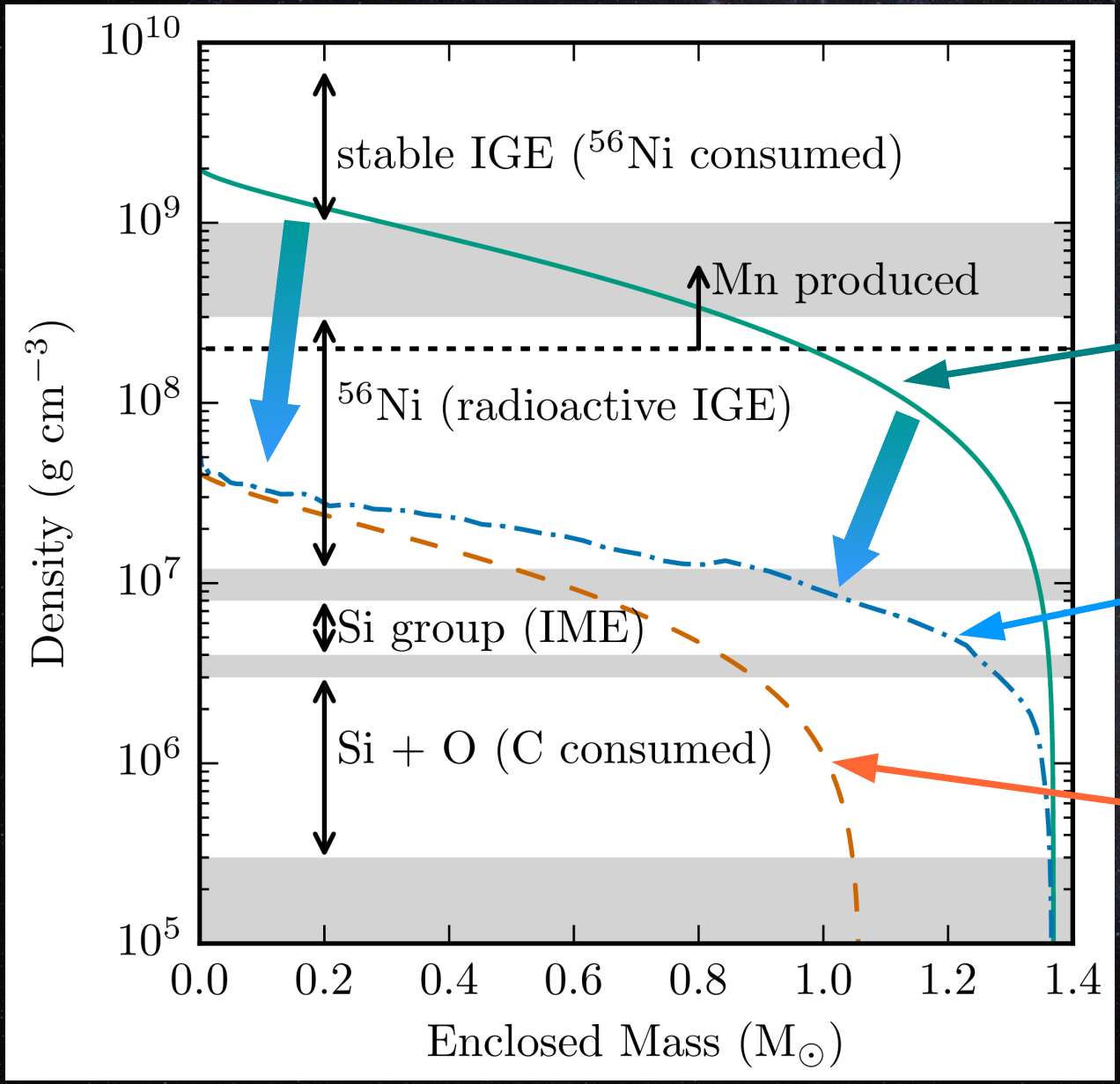
Conclusion

The Type Ia supernova yields of iron-peak elements inferred from Keck/DEIMOS measurements of ancient dwarf galaxies favor **sub-Chandrasekhar-mass detonations**.



Sub-M_{Ch} Type Ia's struggle to make neutron-rich species, like stable Ni.



M_{Ch} detonation

M_{Ch} with delayed deflagration-to-detonation transition (DDT)

Sub-M_{Ch} detonation

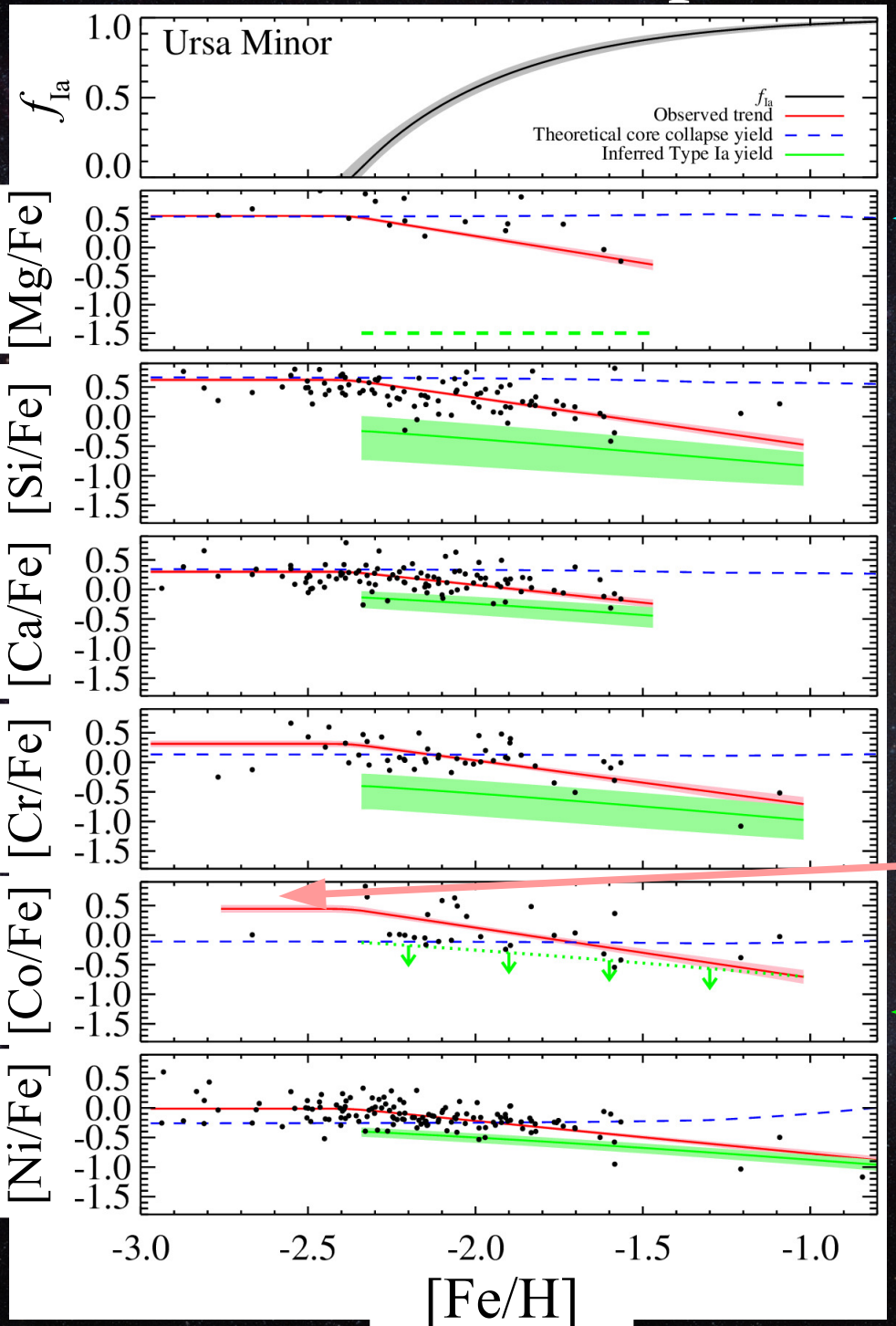
Seitenzahl & Townsley 2017, arXiv:1704.00415

Neutron excess influences stable iron-peak nucleosynthesis.

Isotope	Protons (Z)	Neutrons (N)	Nucleosynthesis	Site	Abundance
^{52}Cr	24	28	incomplete Si burning, normal NSE	sub-M_{Ch}?	84%
^{55}Mn	25	30	normal NSE	M_{Ch}	100%
^{54}Fe	26	28	normal NSE	M_{Ch}	6%
^{56}Fe†	26	30	NSE	all supernovae	92%
^{59}Co	27	32	α-rich NSE, *s*-process	?	100%
^{58}Ni	28	30	normal NSE	M_{Ch}	68%
^{60}Ni	28	32	normal NSE	M_{Ch}	26%

$$\dagger\ {}^{56}\mathrm{Ni} + e^- \rightarrow {}^{56}\mathrm{Co} + \nu_e$$
$${}^{56}\mathrm{Co} + e^- \rightarrow {}^{56}\mathrm{Fe} + \nu_e$$

Ursa Minor shows a similar pattern to Sculptor.



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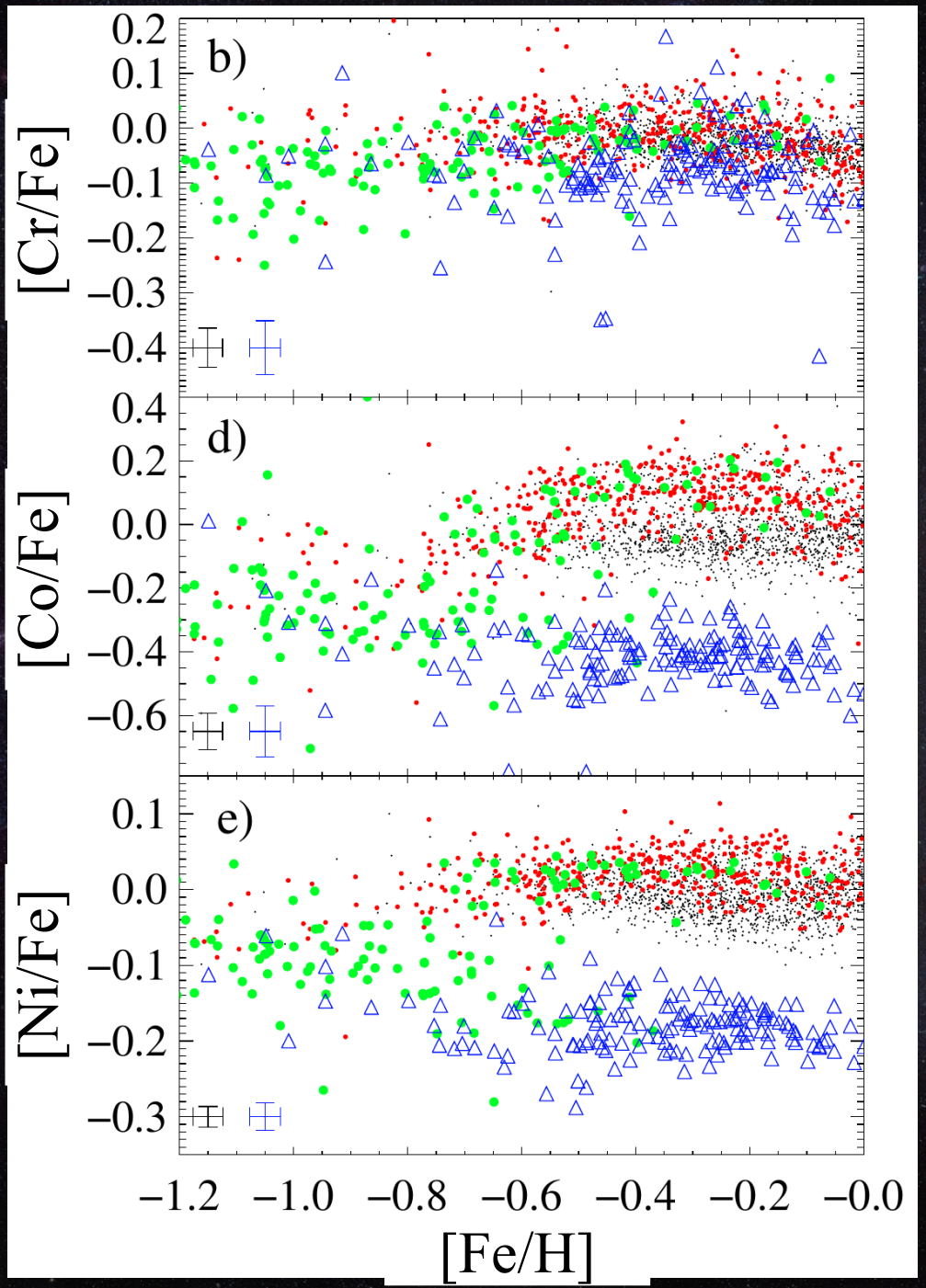
Sagittarius shows the same pattern.



Sagittarius
MW disk
MW bulge
MW halo

Hasselquist et al. 2017, ApJ, 845, 162