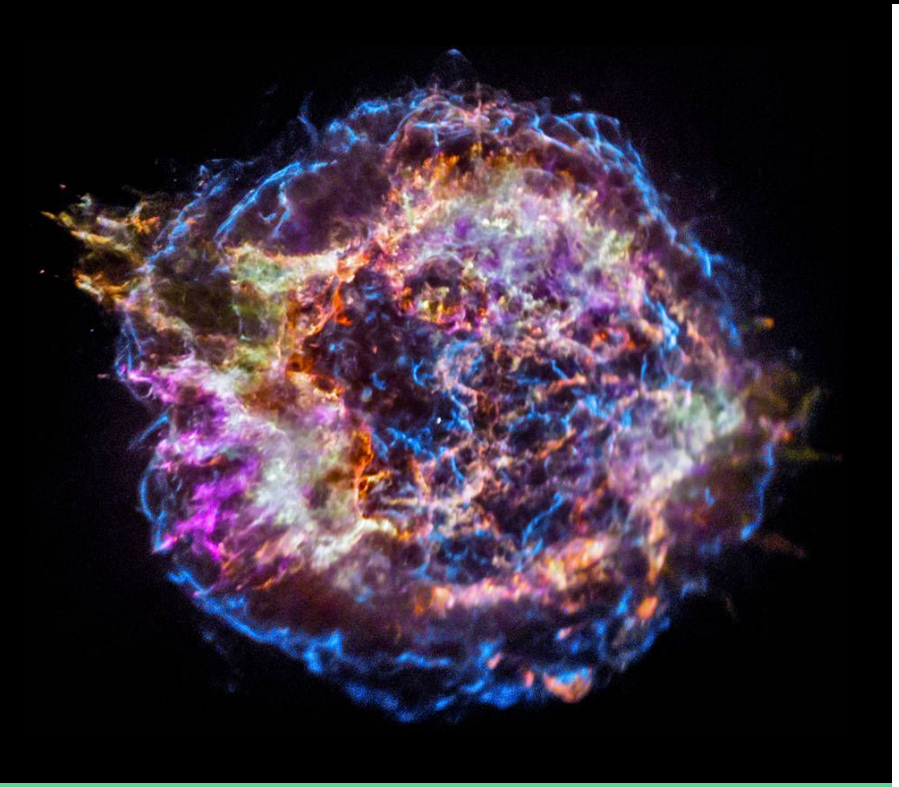
Asymmetries of Heavy Elements in Cassiopeia A

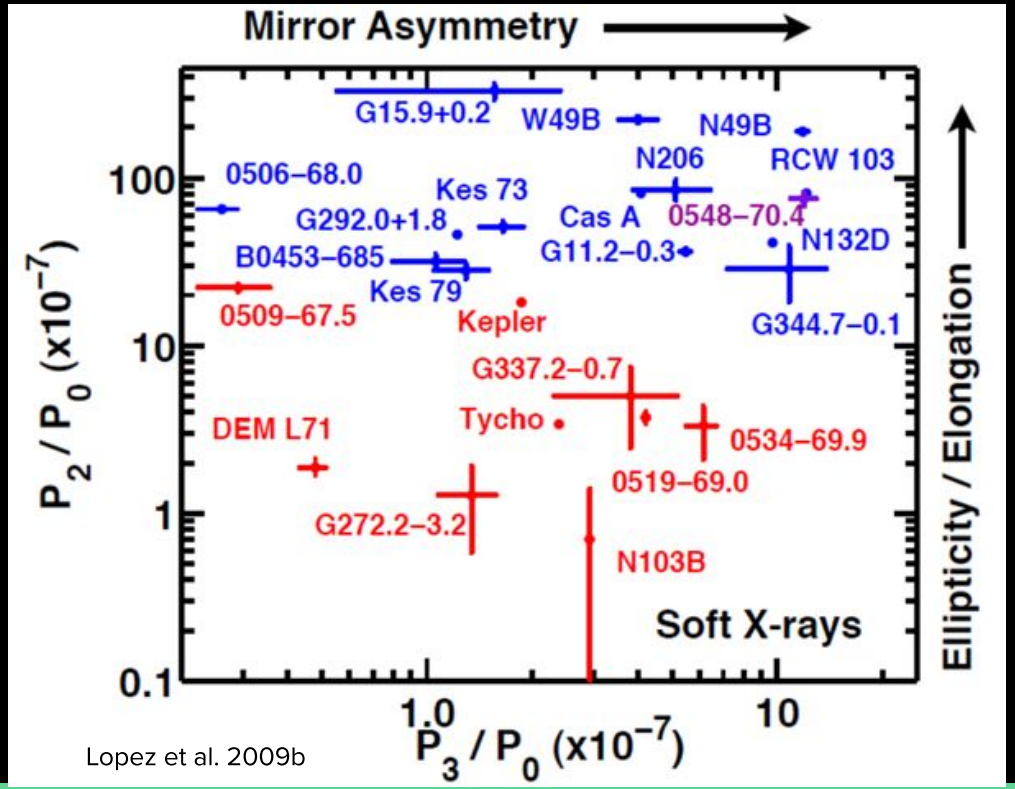
Tyler Holland-Ashford, Laura Lopez, & Katie Auchettl (2019)

Supernova Remnants II

Supernova Remnants are Asymmetric

- Blue = Core-Collapse
- Red = Type Ia





Lopez et al. 2009b

Supernovae are Asymmetric

- Combined evidence from Observations & Simulations
- New simulations run 10s of seconds to days post explosion
- **Asymmetric explosion mechanisms can reproduce observed SNe features**

Cassiopeia A Asymmetry Predictions

- Heavy elements should exhibit higher levels of asymmetry
  - Heavier = formed closer to asymmetric explosion forces

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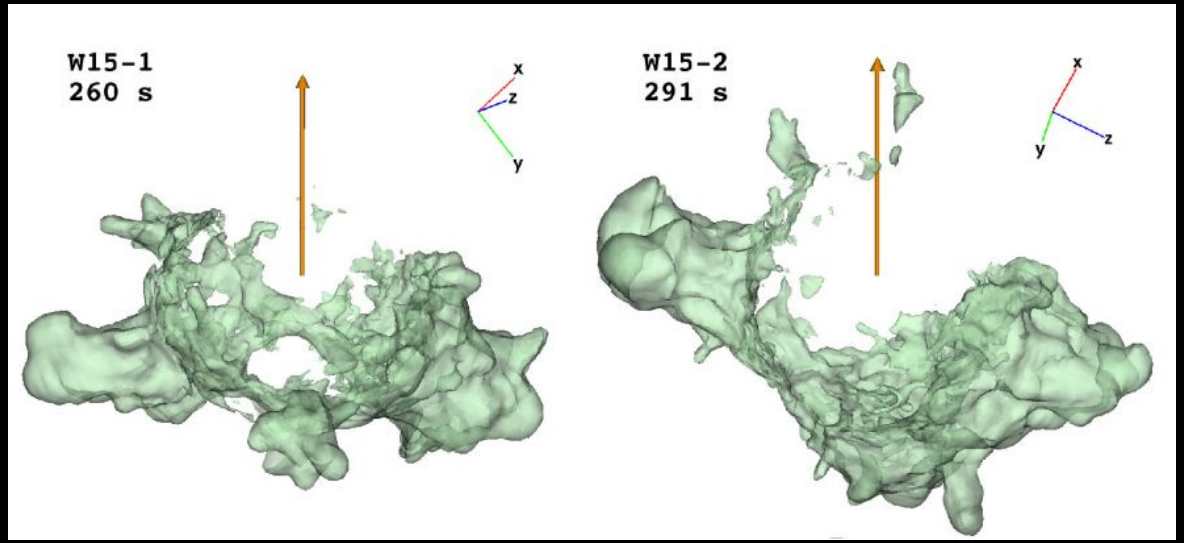
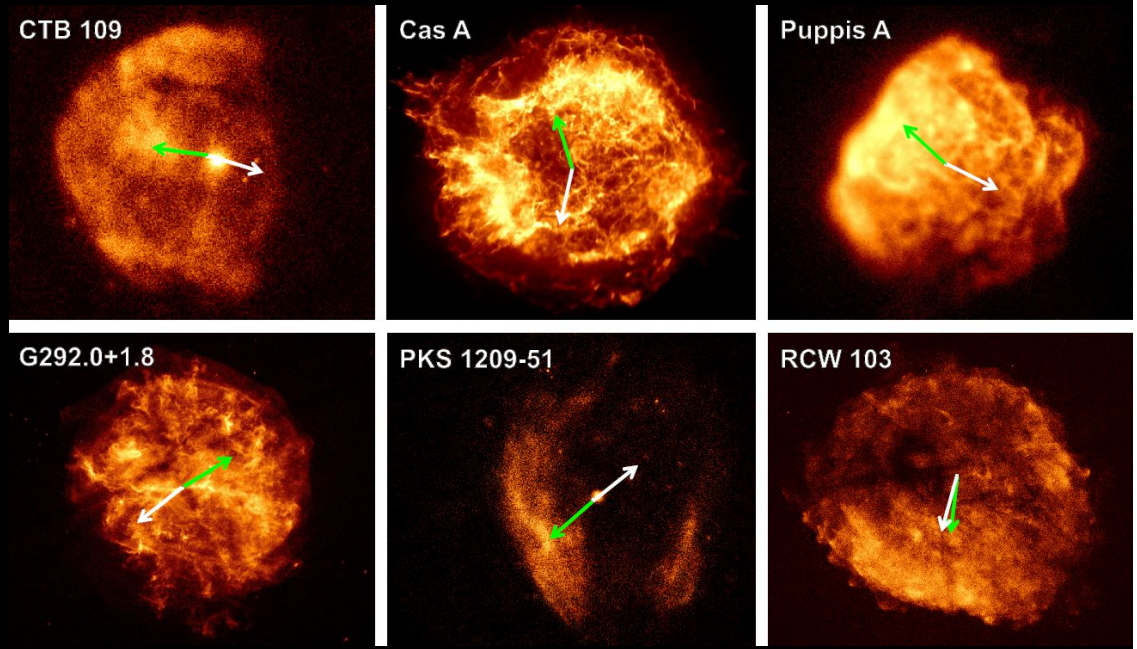
- NS kick should be anti-correlated with bulk ejecta motion
  - Gravitational Tugboat Mechanism (Wongwathanarat, Janka, & Müller, 2013)

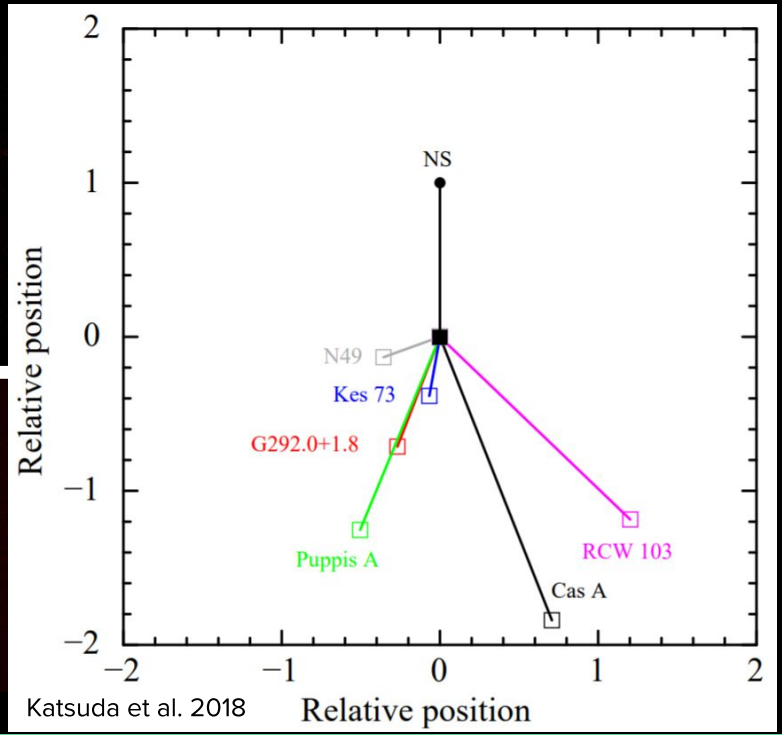


Gravitational Tugboat Mechanism

- NS's are kicked opposite to the bulk of ejecta
  - Wongwathanarat, Janka, & Müller (2013)



Holland-Ashford et al. (2017)

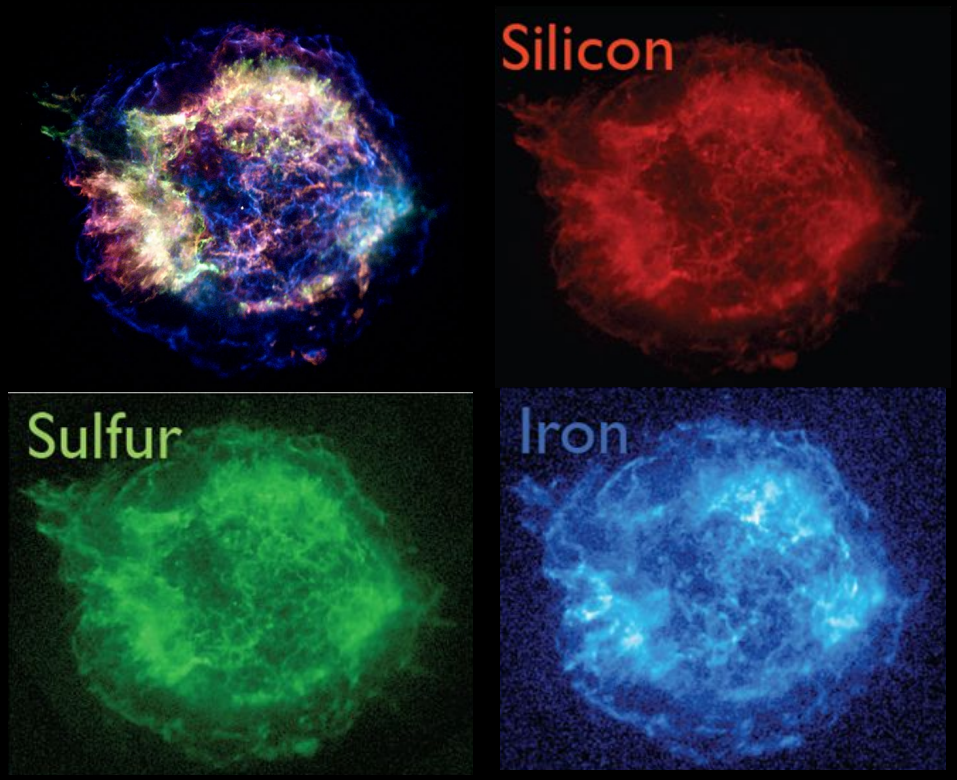


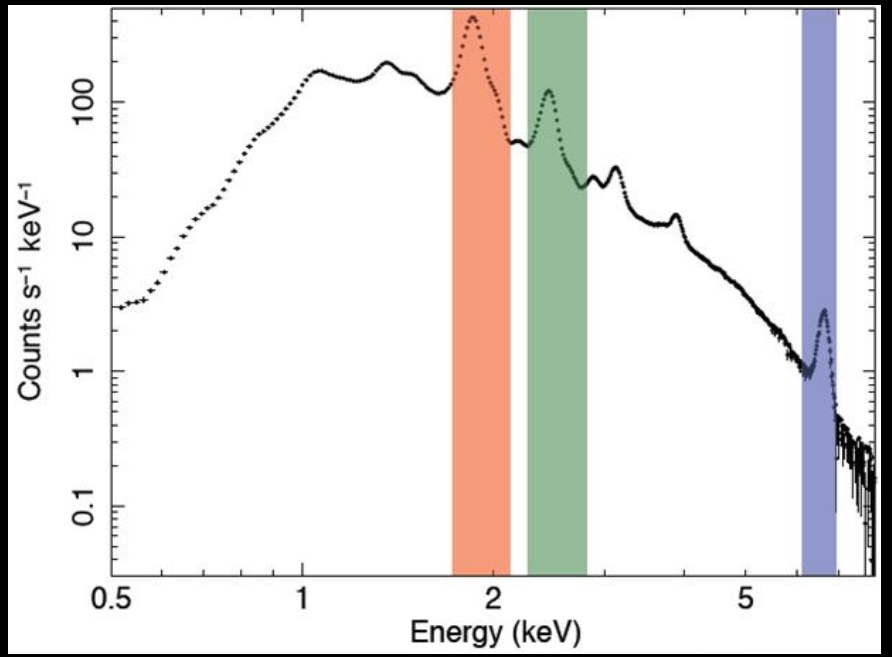
Katsuda et al. 2018

Cassiopeia A Asymmetry Predictions

- Heavy elements should exhibit higher levels of asymmetry
  - Heavier = formed closer to asymmetric explosion forces
- ~~NS kick should be anti-correlated with bulk ejecta motion~~ Shown!
- Ns kick should be most anti-correlated with the heaviest elements

X-Ray Images: Element Bandpasses

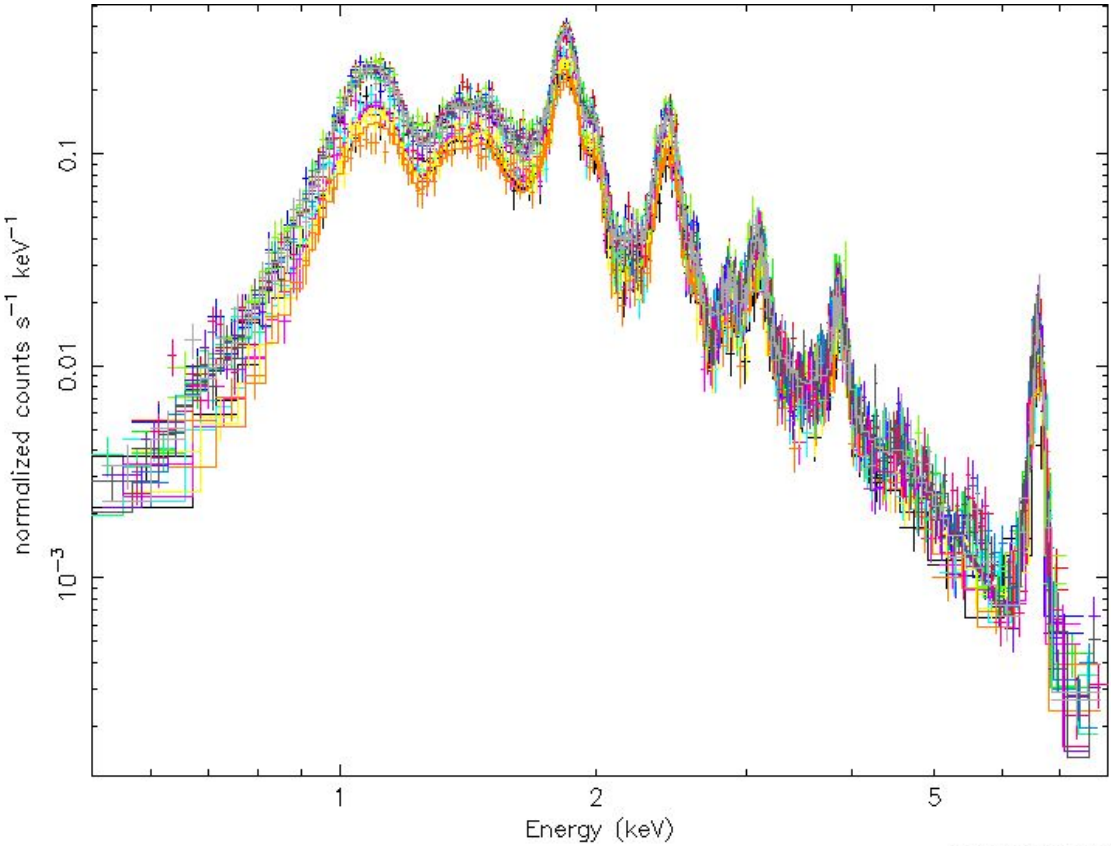




Bandpasses include continuum emission

Method

- 1.3 Ms of *Chandra* data
- Split into 2517 boxes
- Fit spectra of each

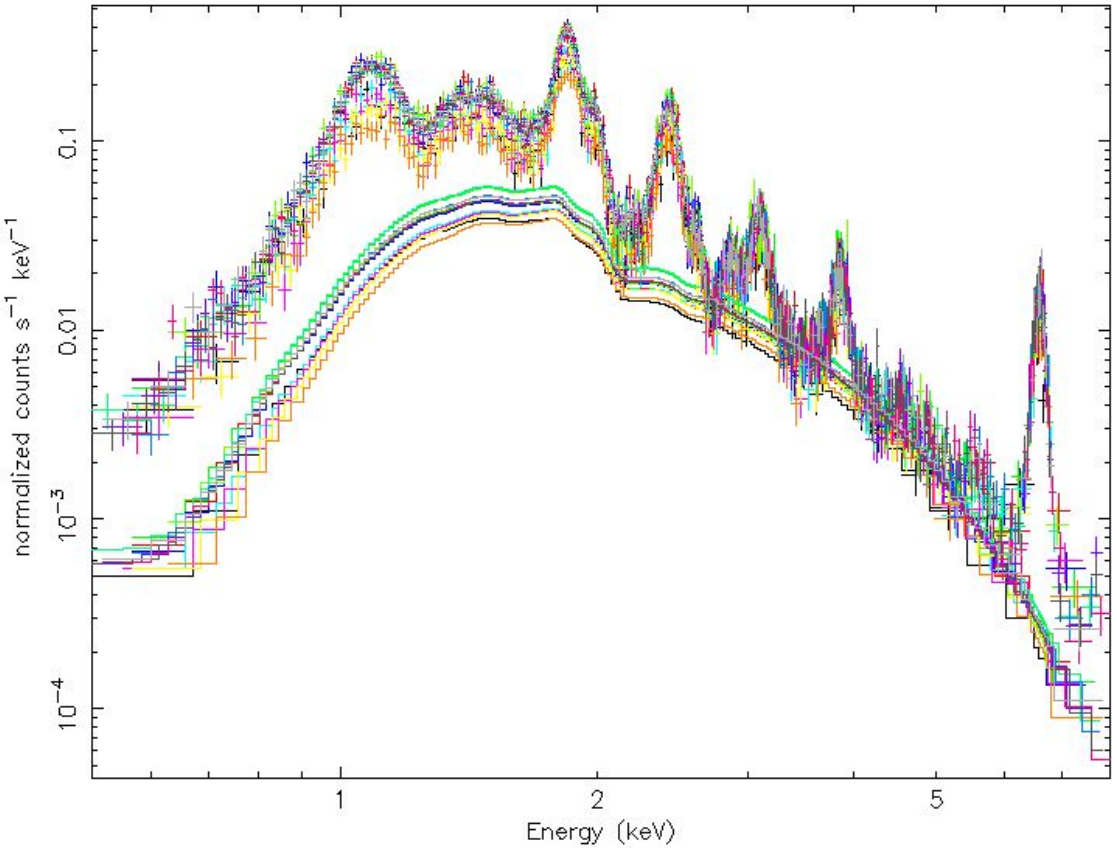


Method

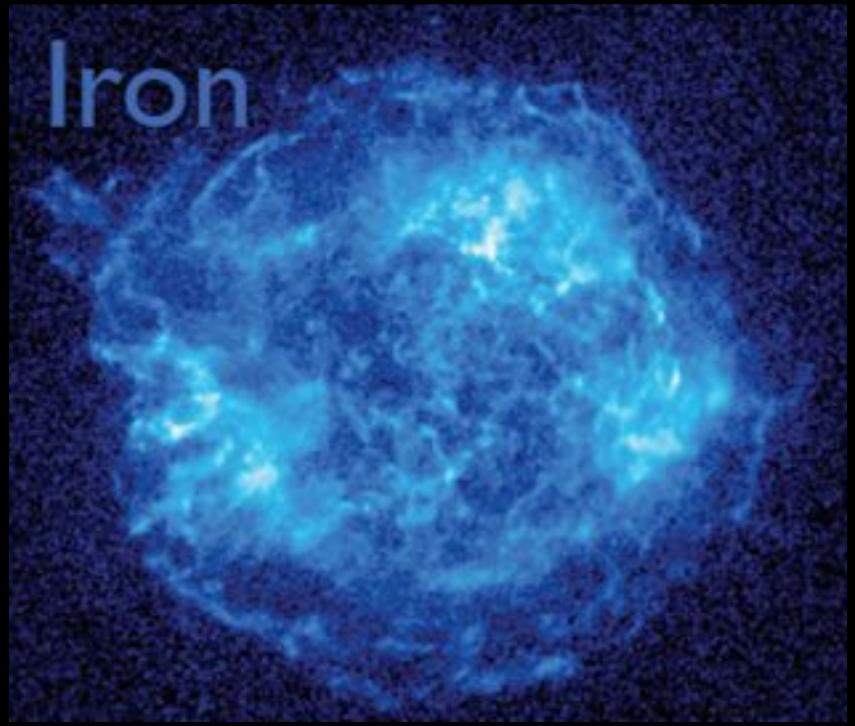
- 1.3 Ms of *Chandra* data
- Split into 2517 boxes
- Fit spectra of each
- Subtract Continuum

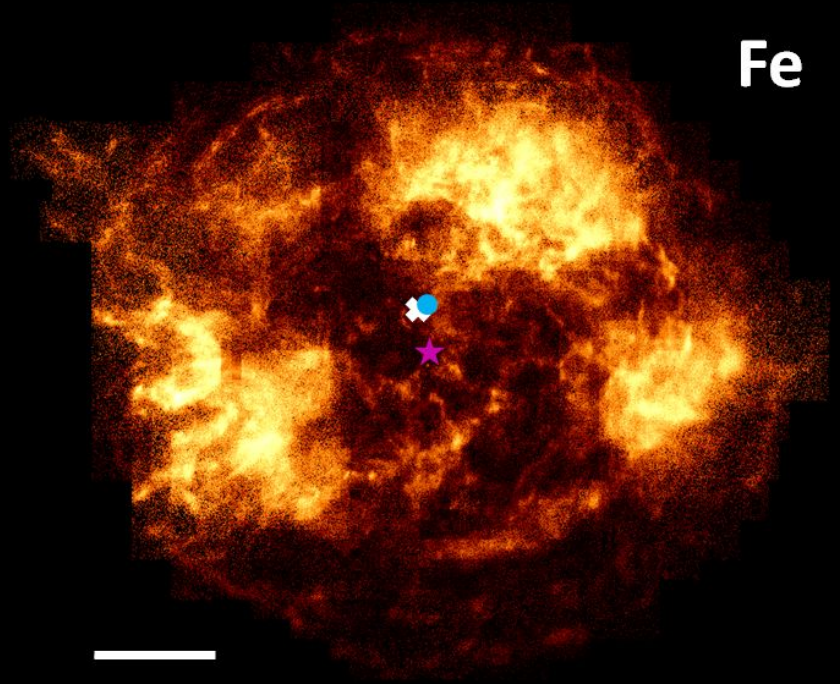
Line = Total - Continuum

(see A. Picquenot, next talk for a promising new method to do this type of analysis)

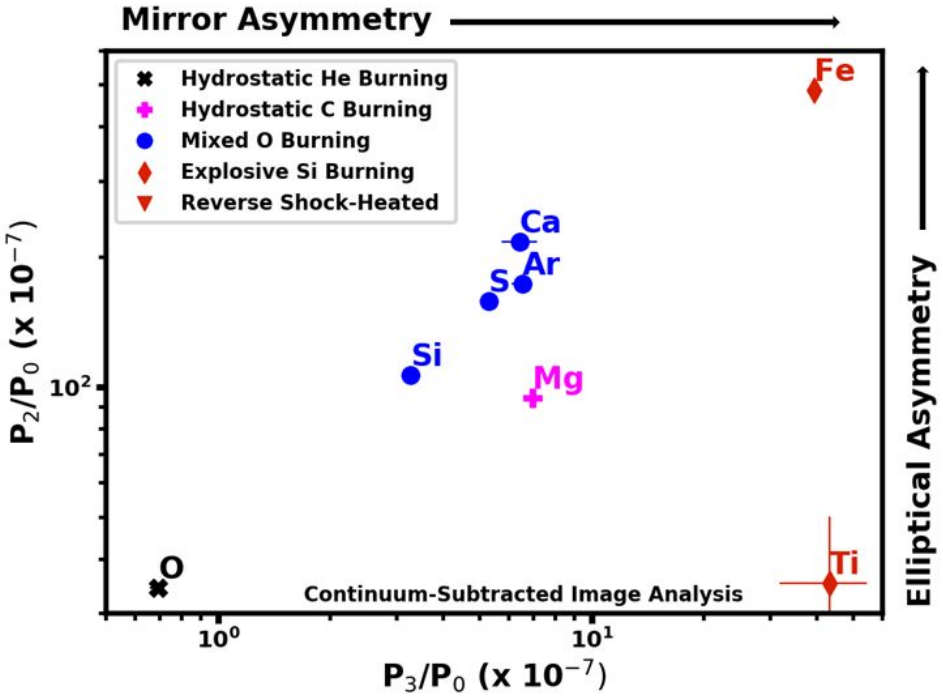


Bandpass vs Continuum-subtracted Fe





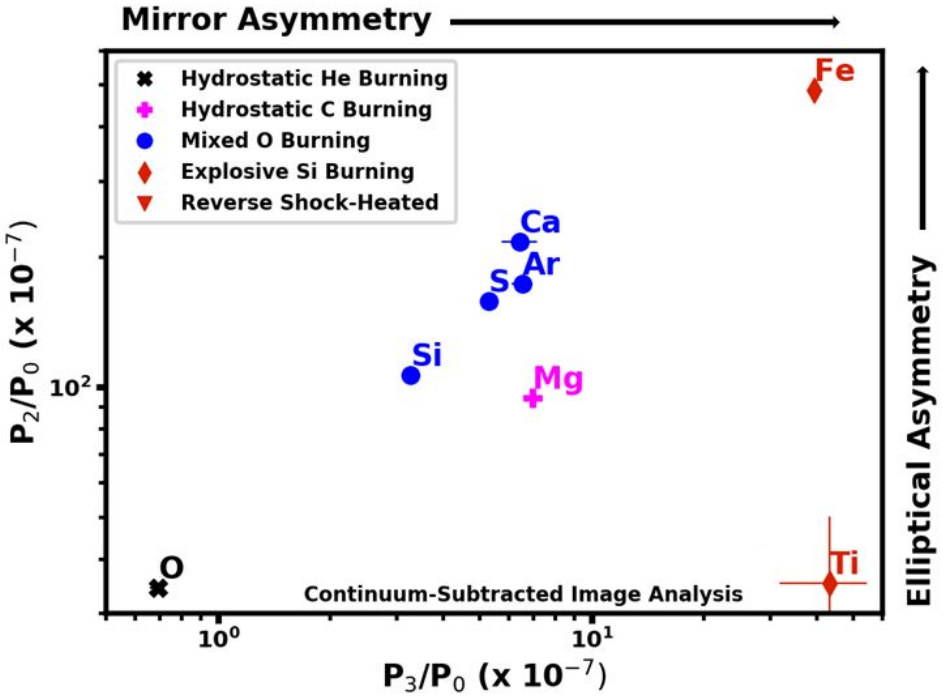
Results



- Elements exhibit a linear trend
  - Heavier ➡ more asymmetric
  - Proximity to asymmetric explosion forces
- Can be grouped by burning process
- Mg is *weird*

Holland-Ashford et al. (2019)

Results



Holland-Ashford et al. (2019)

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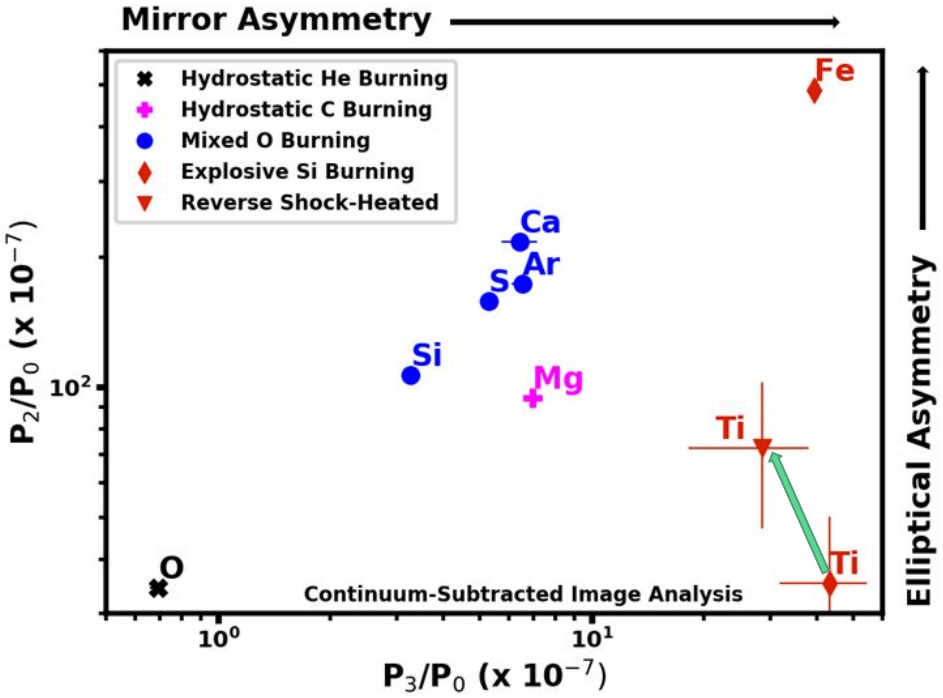
- Ti-44 is from different emission process (68 keV radioactive decay line)

Results



Holland-Ashford et al. (2019)

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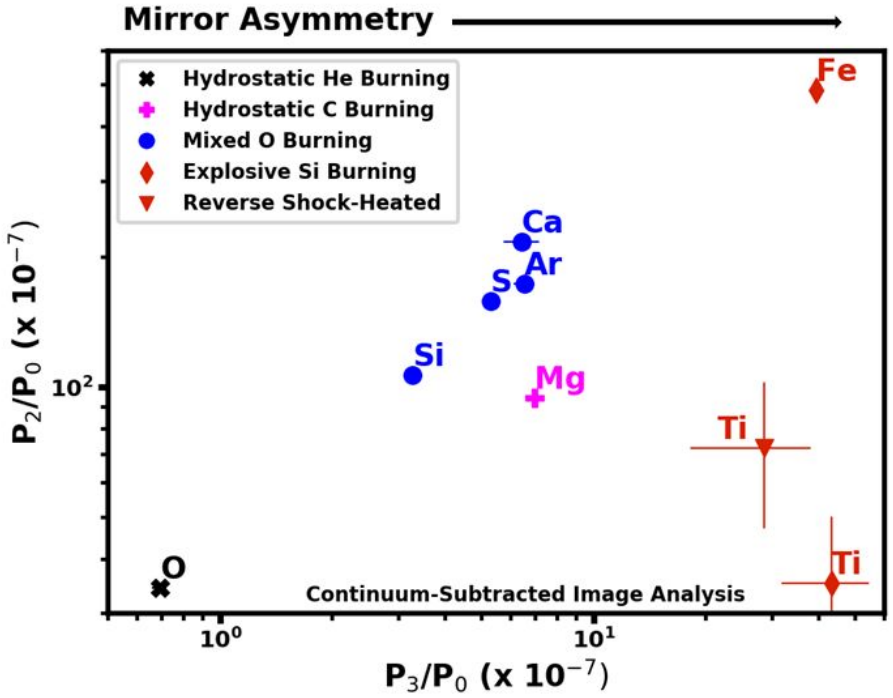
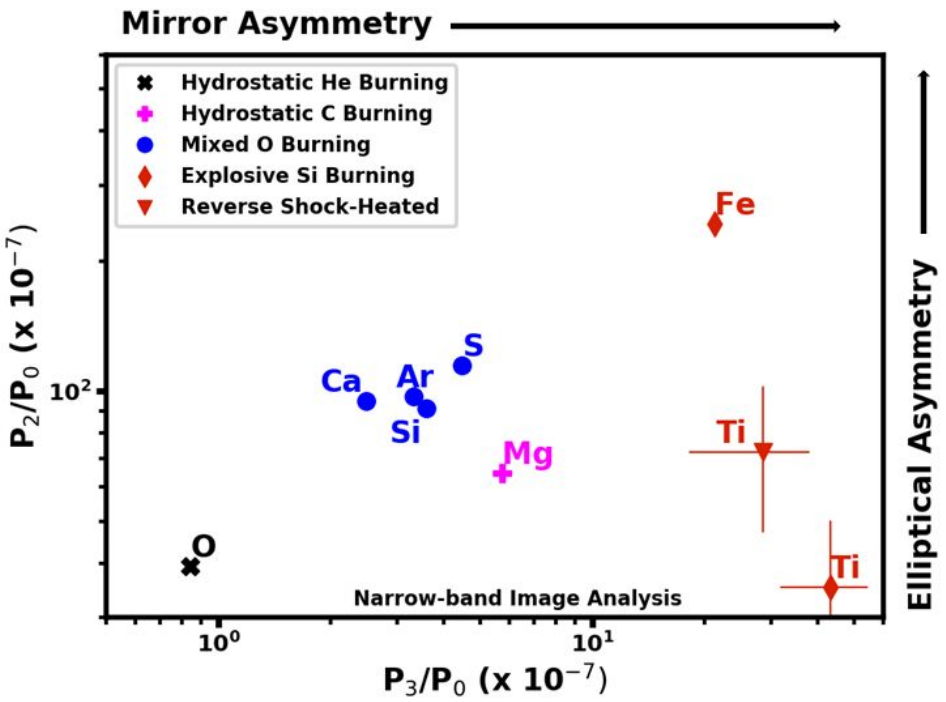
Continuum-subtracted vs. Bandpass Comparison





Holland-Ashford et al. (2019)

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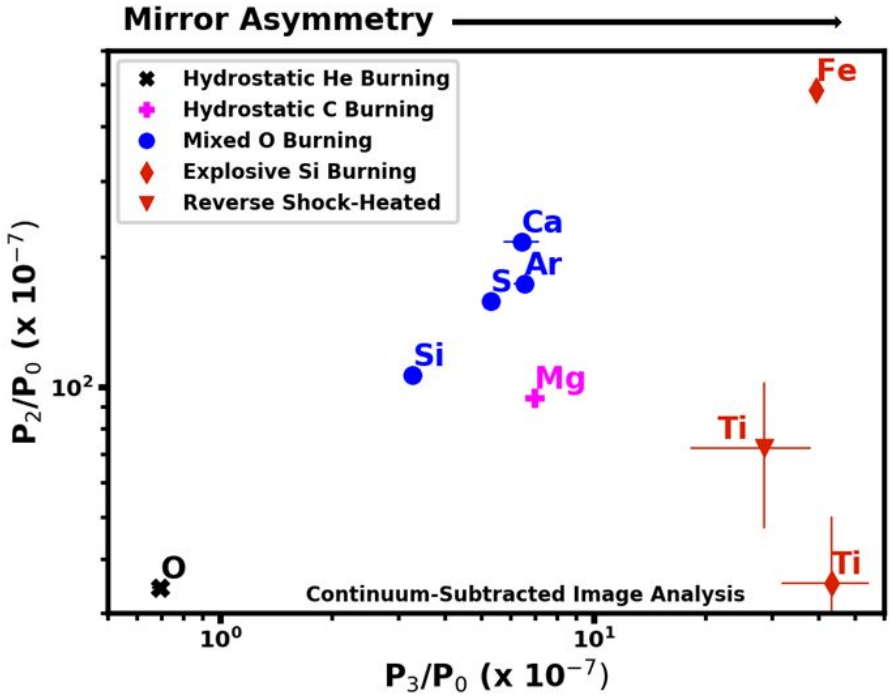
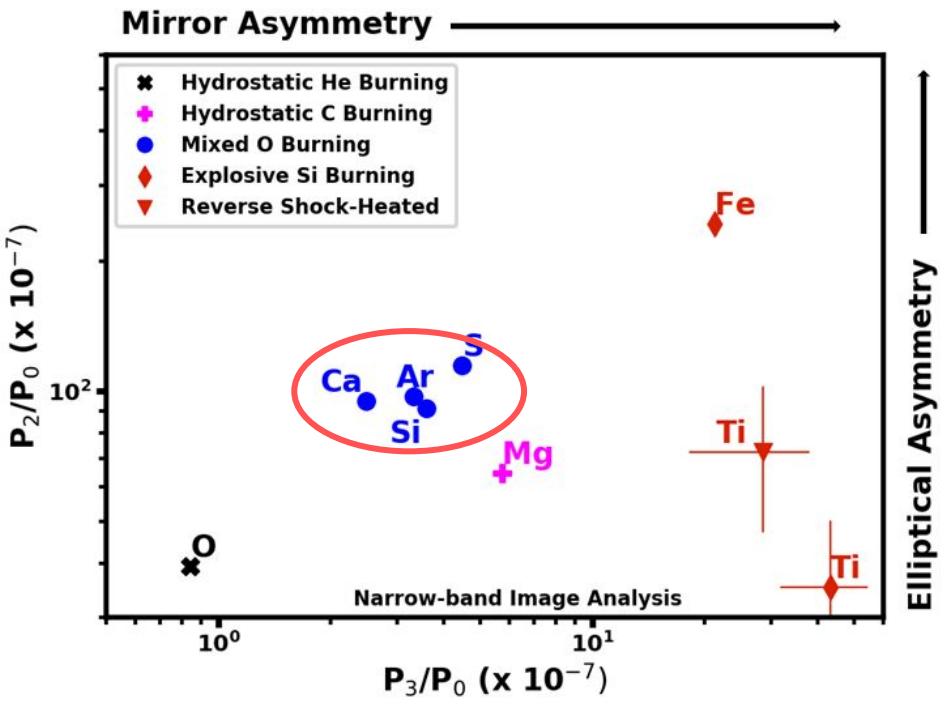
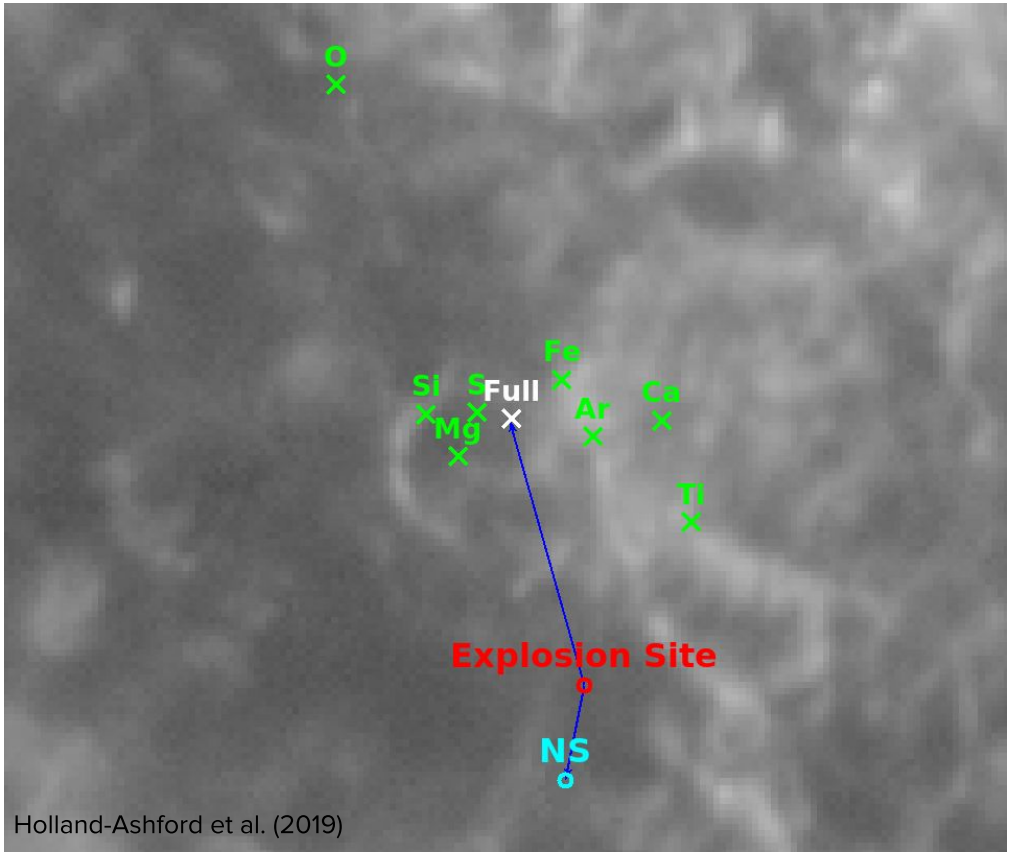




Holland-Ashford et al. (2019)

Neutron Star Kick Correlation



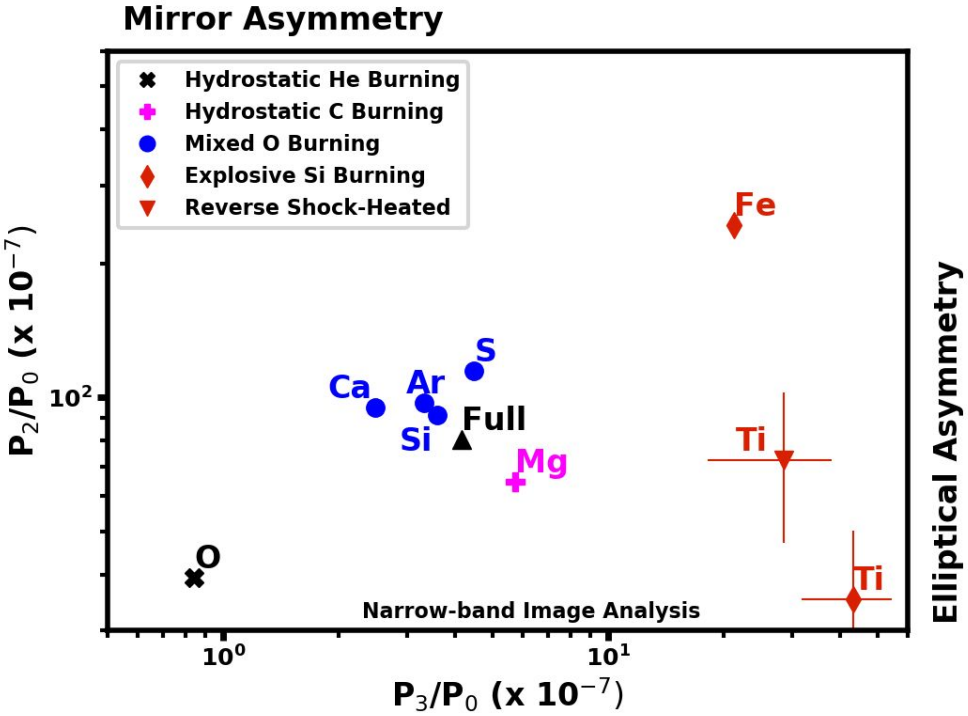
- Heavier elements are oriented most opposite to the NS kick direction
  - NS to Full: 155 degrees
  - NS to Ca+Ar: 178 degrees

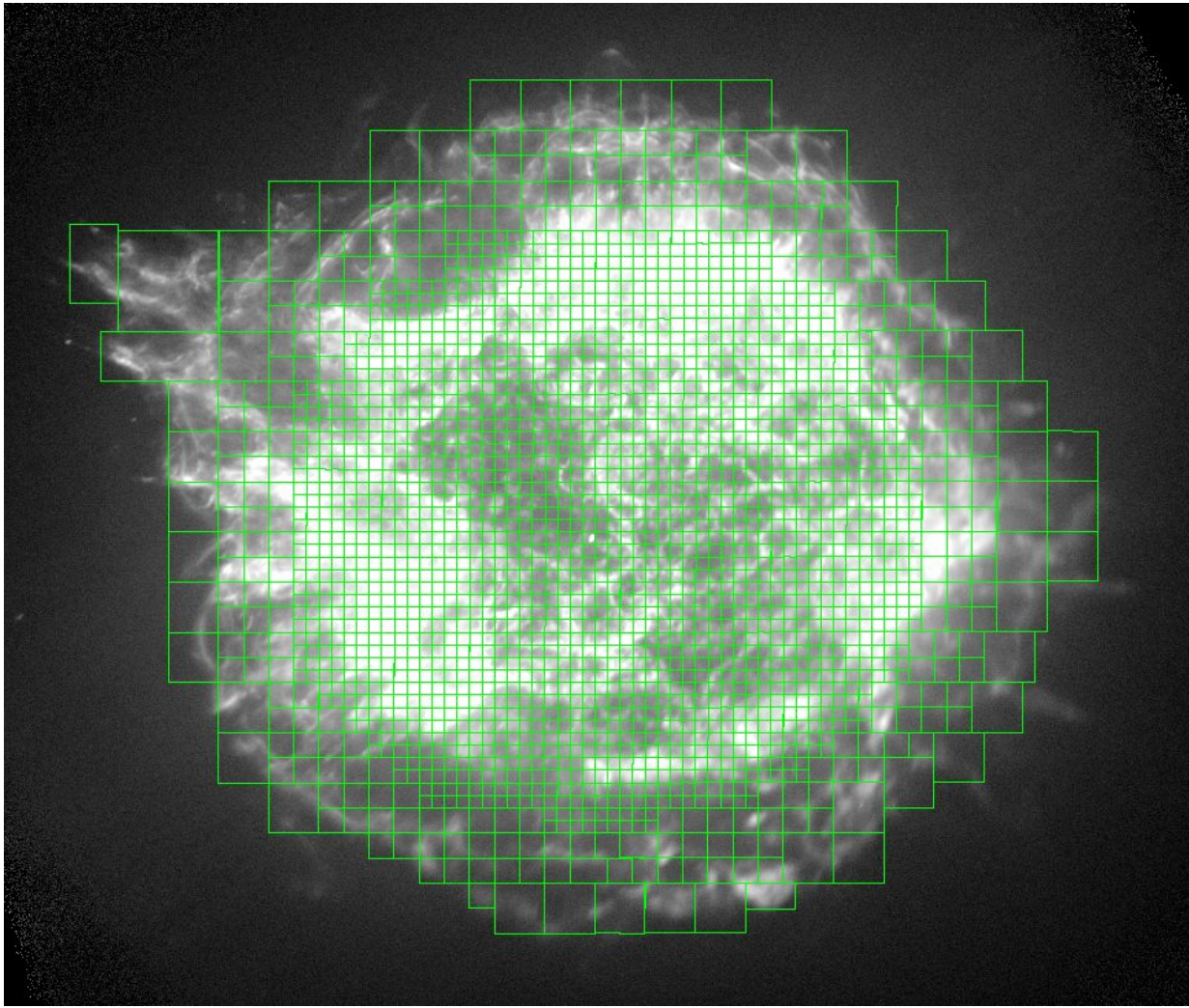
Conclusions and Future Work

- Validates recent SN simulations and theorized explosion mechanisms
  - Heavier elements exhibit more asymmetric profiles than lighter elements
  - The neutron star is kicked in a direction opposed to the heaviest elements
- Does this hold for other Core-Collapse SNRs?
- What about Type Ia SNRs?

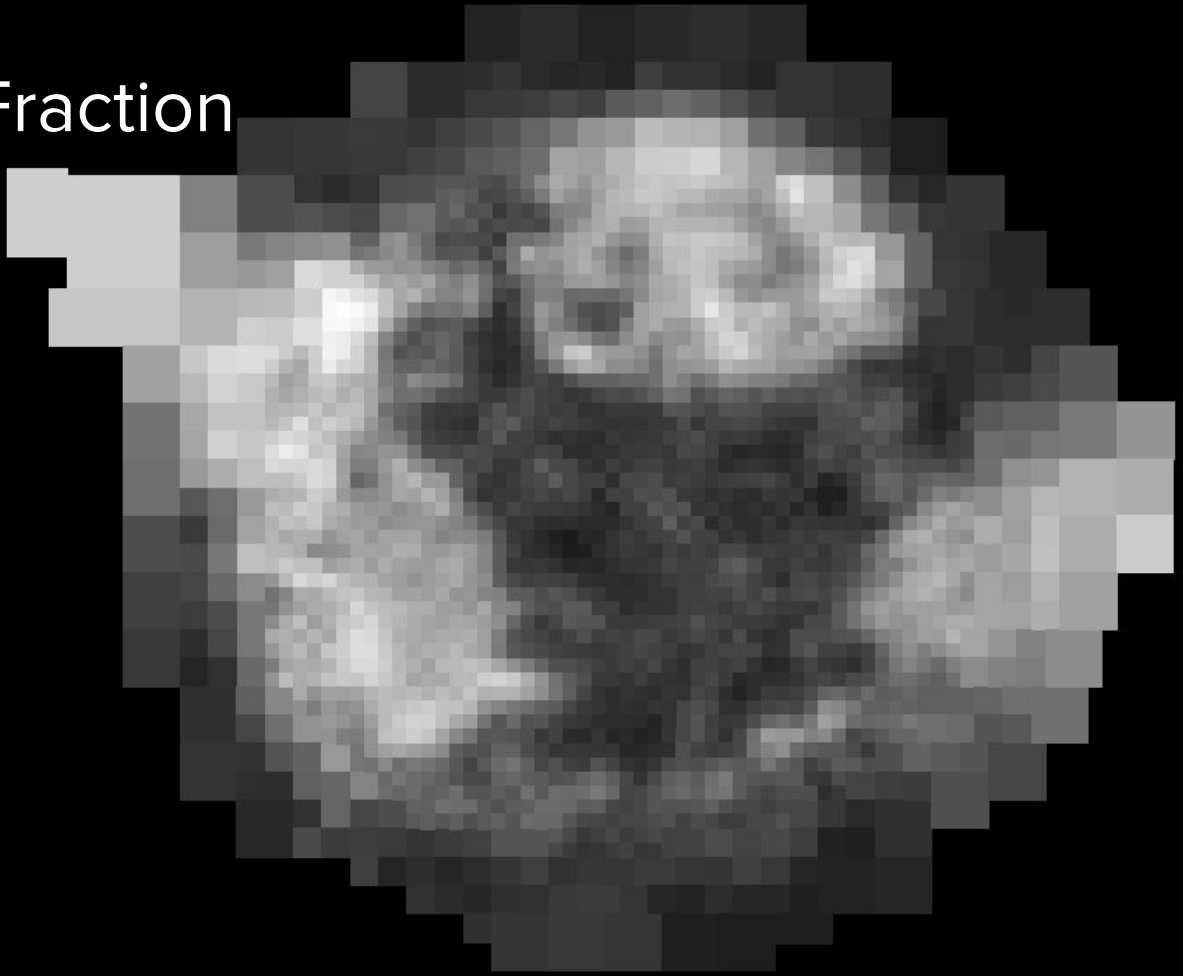
Thank You

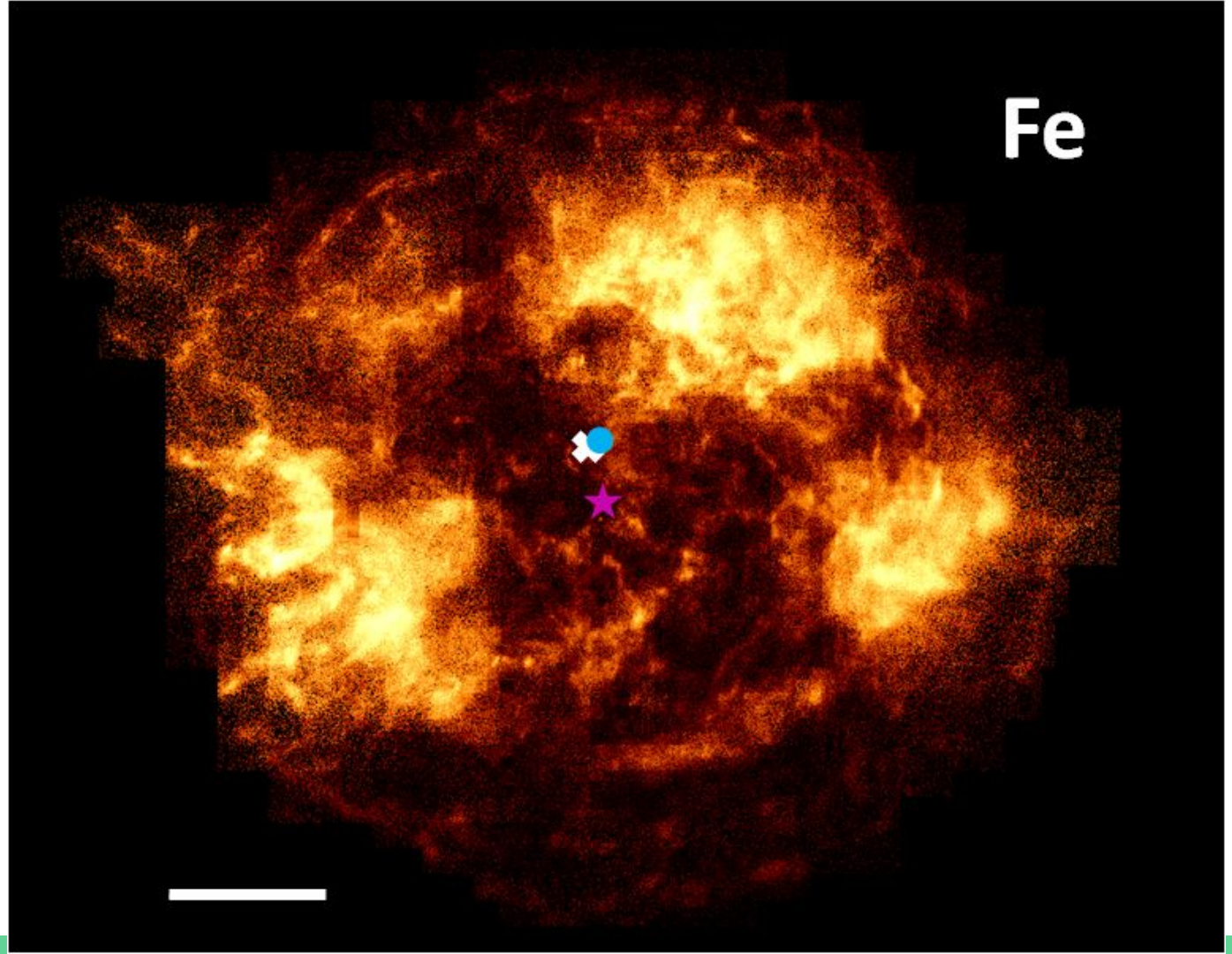
- 3D simulations (Wongwathanarat 2013, Orlando 2016, Janka et al. 2017, Müller et al. 2018, Chen et al. 2018, Utrobin et al. 2017, Curtis et al. 2019, Summa et al. 2018, and many more)

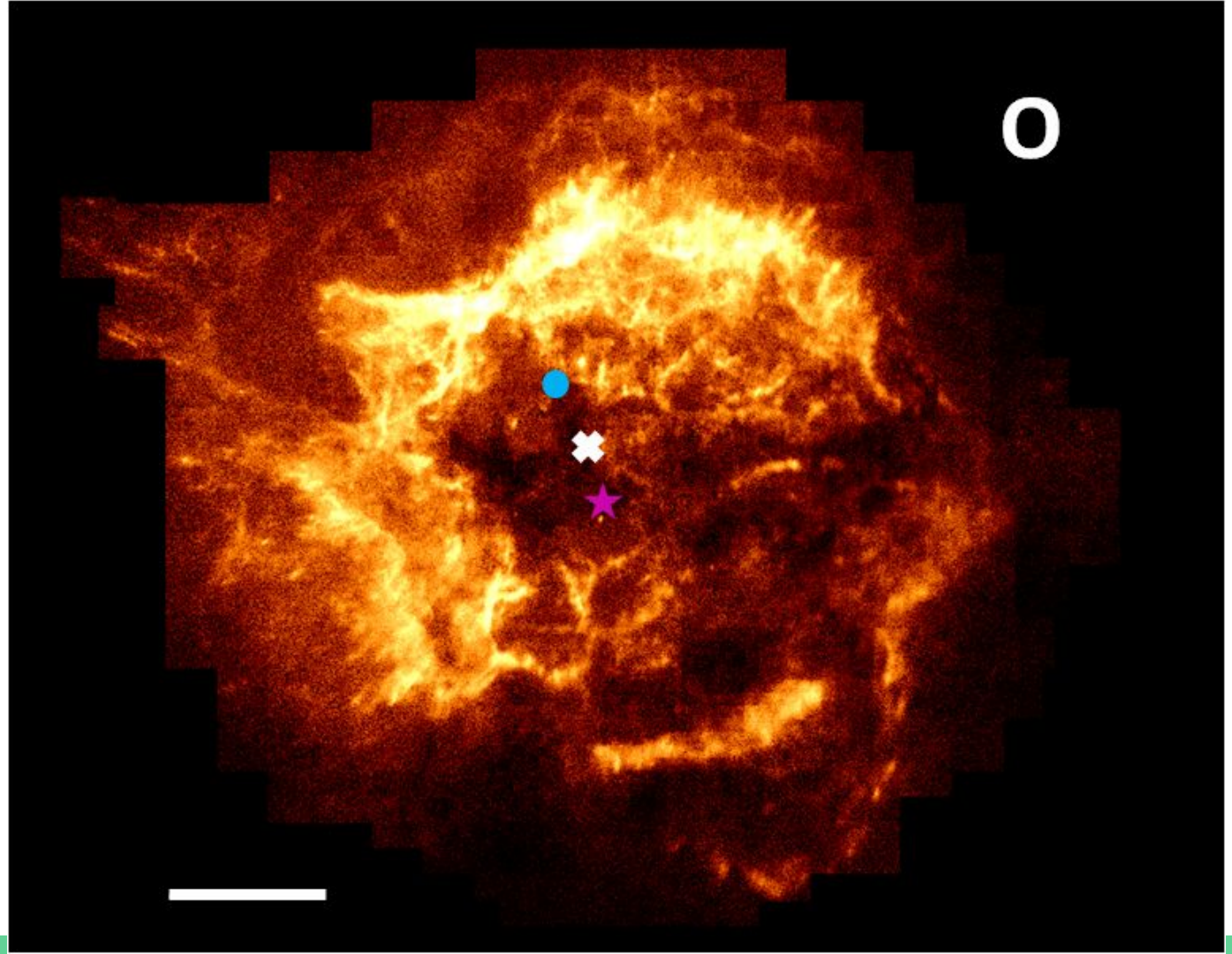

Mirror Asymmetry
Hydrostatic He Burning
Hydrostatic C Burning
Mixed O Burning
Explosive Si Burning
Reverse Shock-Heated
Fe
S
Ca
Ar
Full
Si
Mg
Ti
Ti
O
Narrow-band Image Analysis
P_2/P_0 (x 10^{-7})
10^2
10^0
10^1
P_3/P_0 (x 10^{-7})
Elliptical Asymmetry



Argon Fraction




Fe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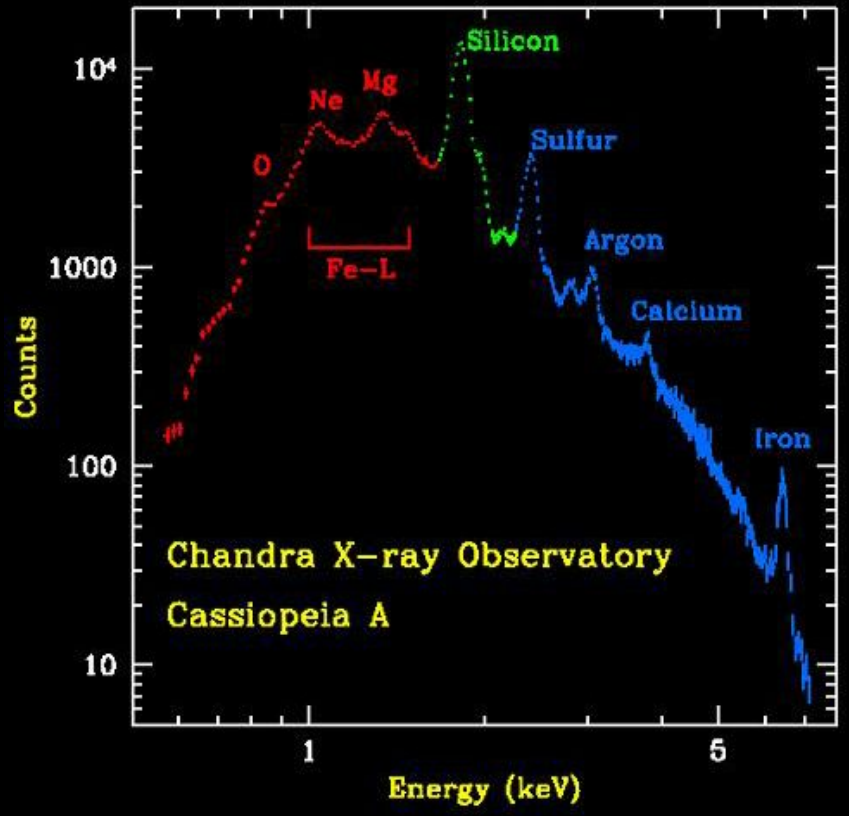
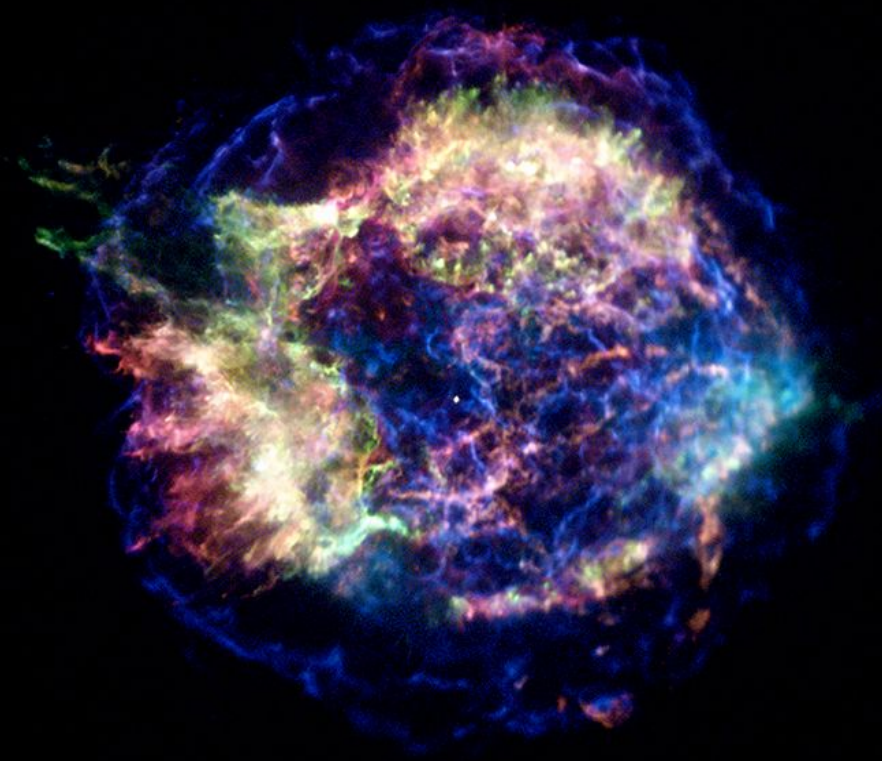
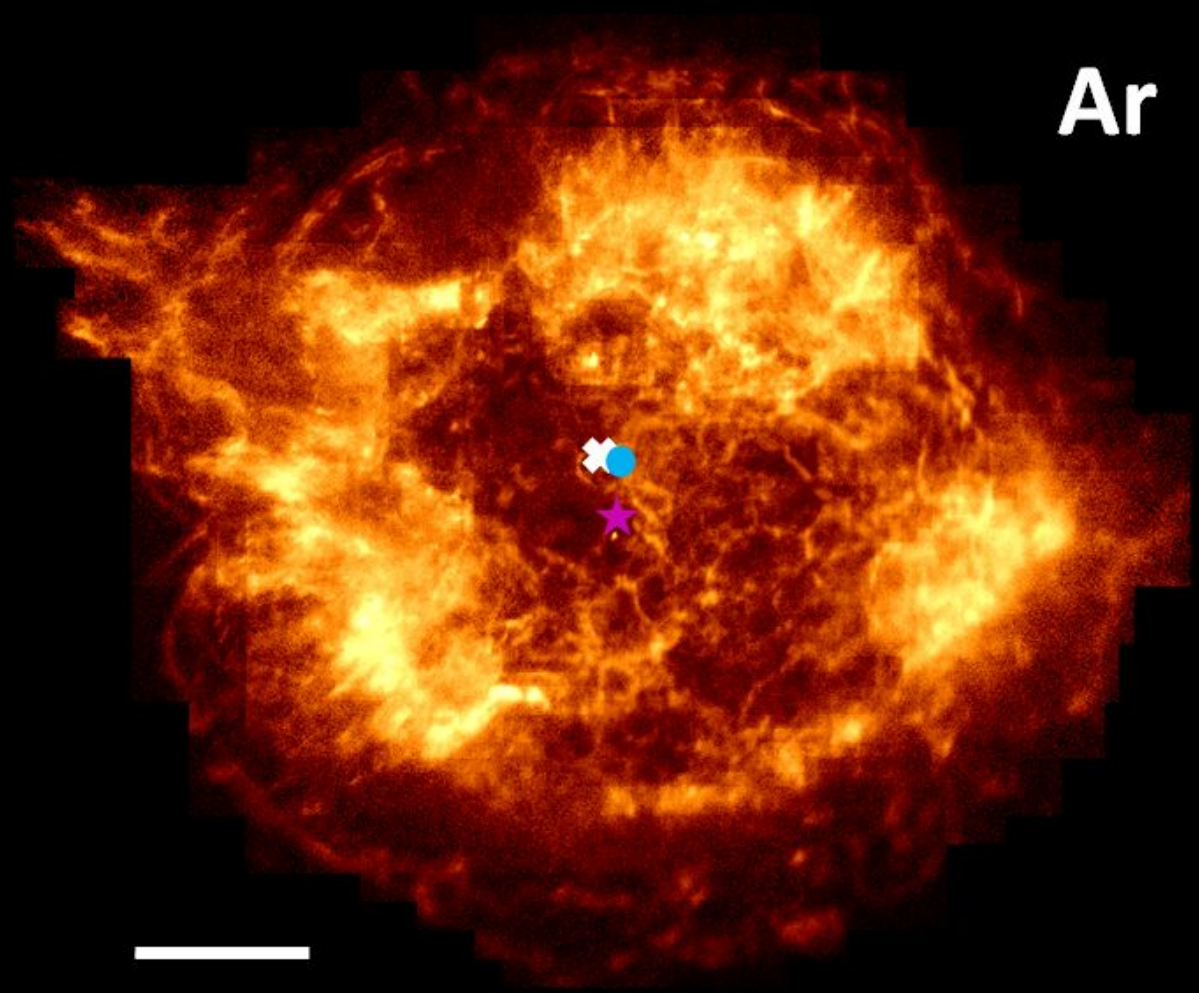
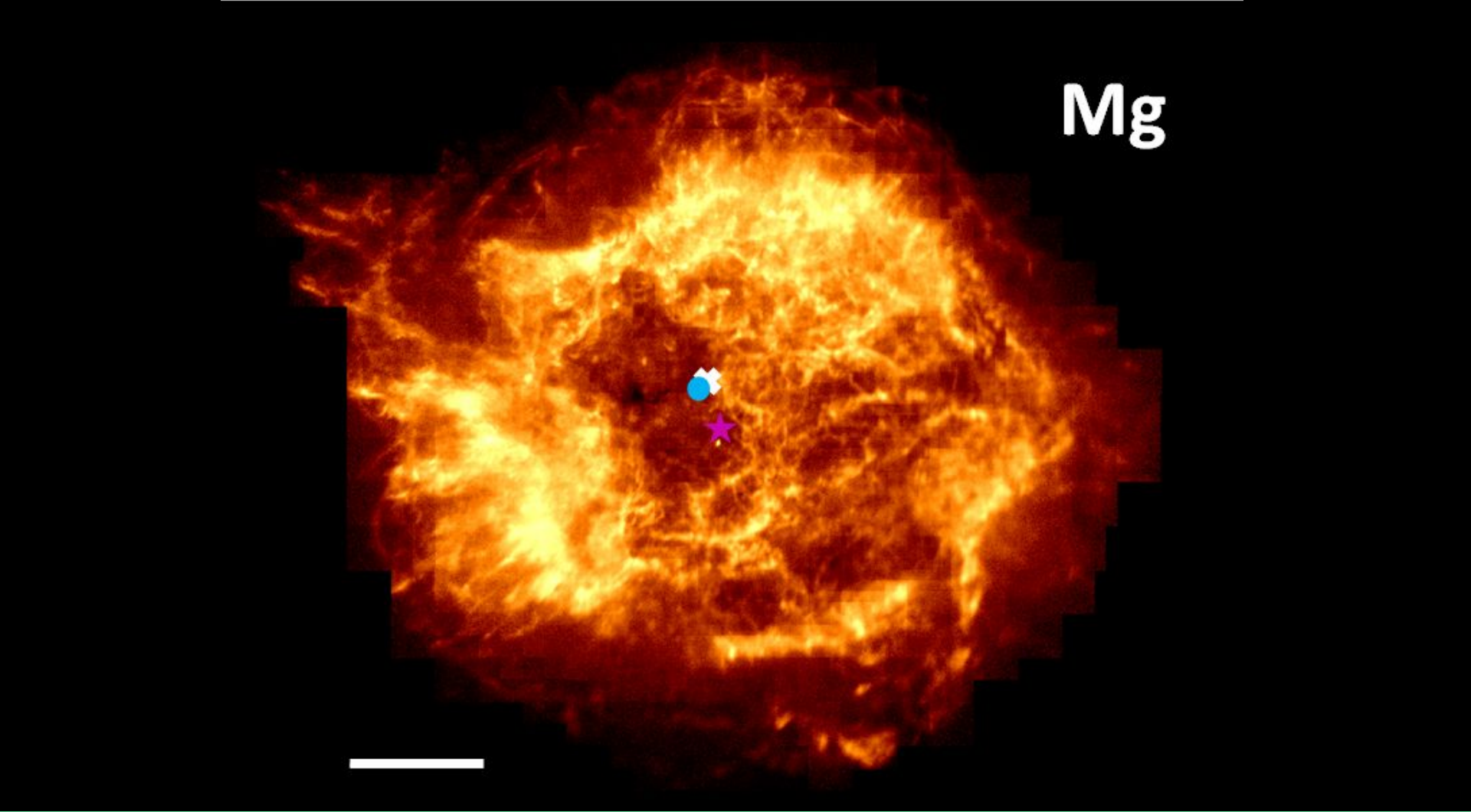
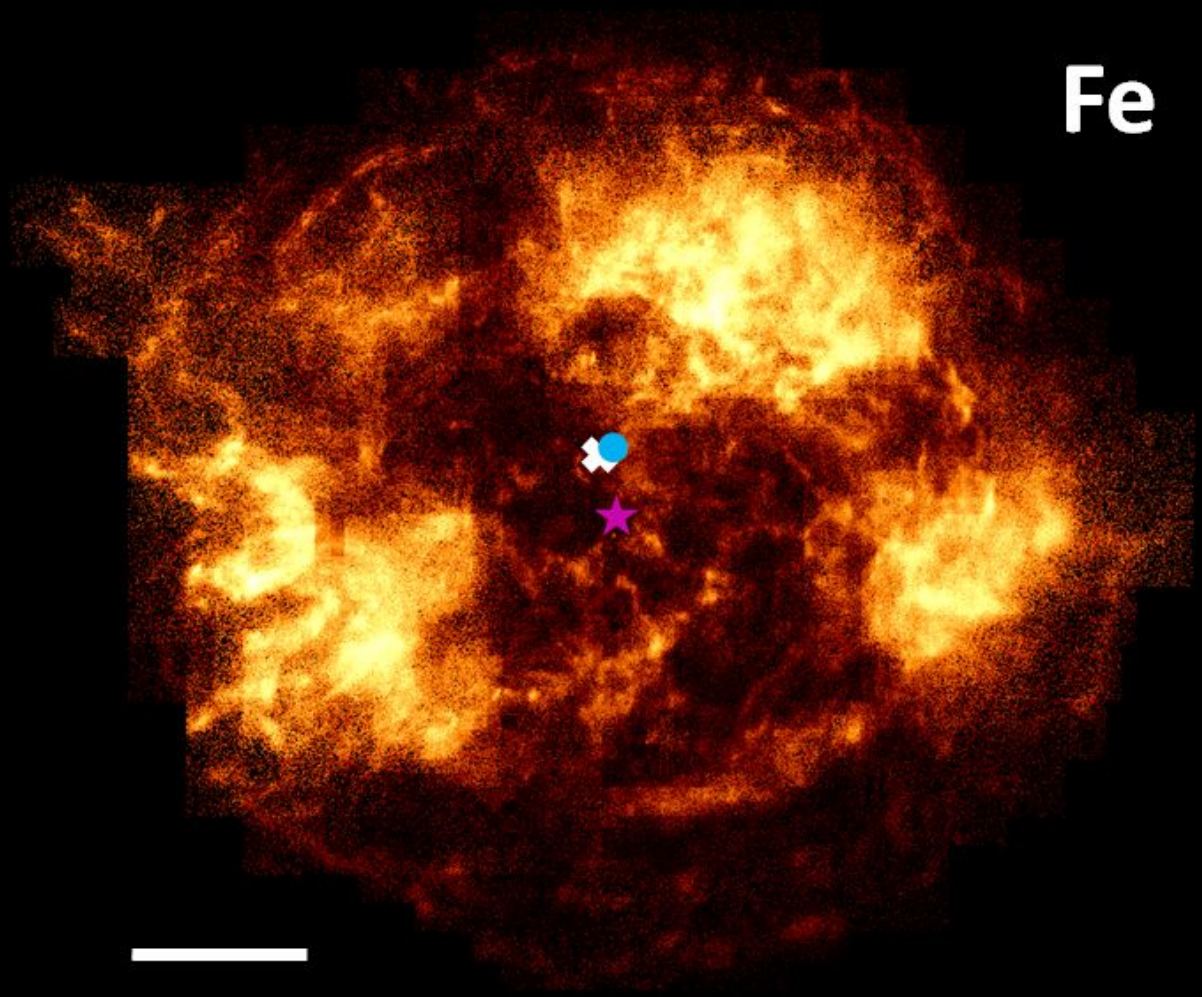
Elemental Abundances of SNRs






Ar


Mg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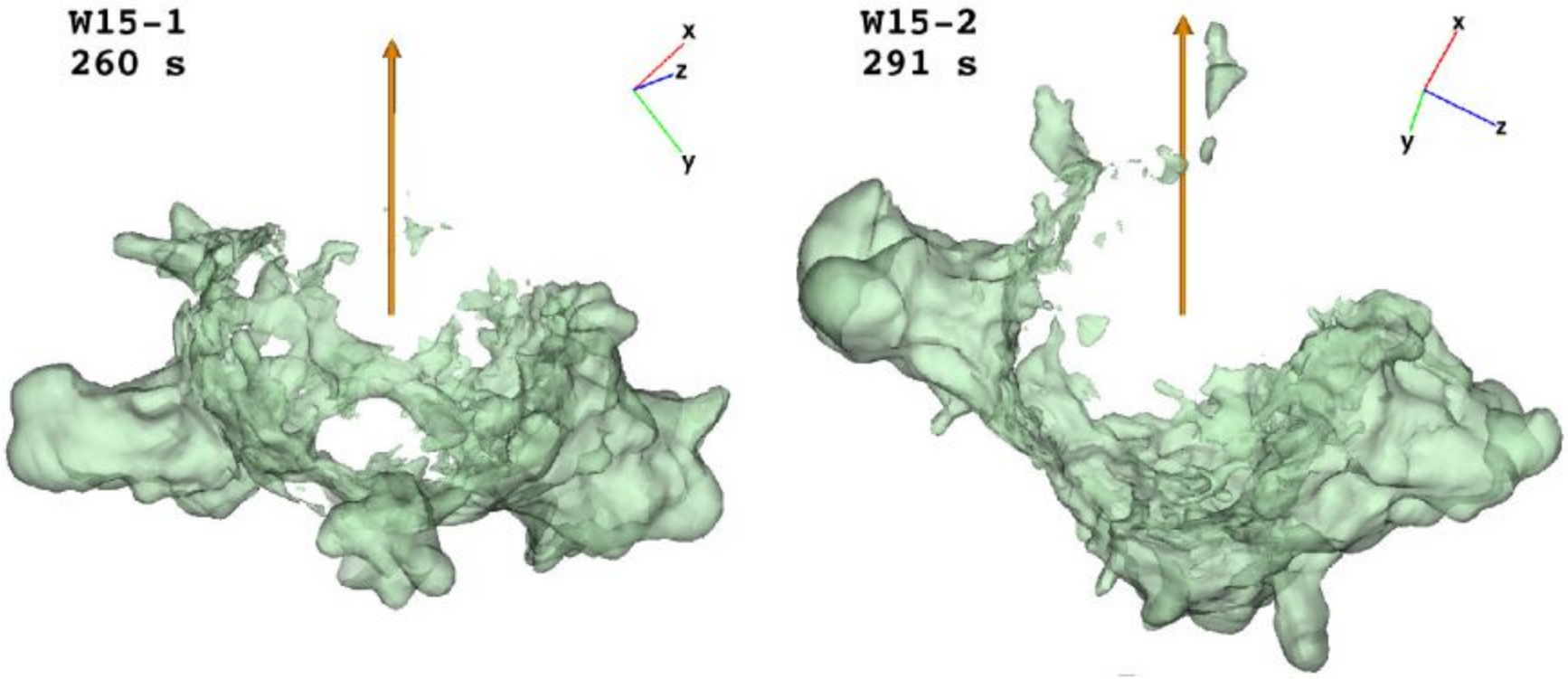
W15-1
260 s
x
z
y
W15-2
291 s
x
y
z

Solution: Supernova Remnants!