X-ray Line Morphologies (Might) Trace the Nature of the Progenitor!

Laura A. Lopez
University of California, Santa Cruz

Collaborators: Enrico Ramirez-Ruiz (UCSC), Daniela Huppenkothen (Amsterdam), Carles Badenes (Princeton) Tesla Jeltema (UCO/Lick), David Pooley (Wisconsin)

Motivation

Credit: Chandra Catalog of Galactic Supernova Remnants

Motivation

Credit: Chandra Catalog of Galactic Supernova Remnants

➡ Need ***systematic, quantitative*** way to compare sources

Quantitative Measures of X-ray Morphology

See Lopez et al. 2009, ApJ, 691, 875

Quantitative Measures of X-ray Morphology

- Multipole Expansion to measure symmetry/ellipticity

See Lopez et al. 2009, ApJ, 691, 875

Quantitative Measures of X-ray Morphology

➡ Multipole Expansion to measure symmetry/ellipticity

➡ Wavelet-Transform Analysis to measure substructure scale & location

See Lopez et al. 2009, ApJ, 691, 875

Quantitative Measures of X-ray Morphology

➡ Multipole Expansion to measure symmetry/ellipticity

➡ Wavelet-Transform Analysis to measure substructure scale & location

- ✳ define heating, cooling, and explosion properties

See Lopez et al. 2009, ApJ, 691, 875

Quantitative Measures of X-ray Morphology

➡ Multipole Expansion to measure symmetry/ellipticity

➡ Wavelet-Transform Analysis to measure substructure scale & location

- ✳ define heating, cooling, and explosion properties
- ✳ probe particle acceleration sites

See Lopez et al. 2009, ApJ, 691, 875

Quantitative Measures of X-ray Morphology

➡ Multipole Expansion to measure symmetry/ellipticity

➡ Wavelet-Transform Analysis to measure substructure scale & location

- ✳ define heating, cooling, and explosion properties
- ✳ probe particle acceleration sites

See Lopez et al. 2009, ApJ, 691, 875

Quantitative Measures of X-ray Morphology

➡ Multipole Expansion to measure symmetry/ellipticity

➡ Wavelet-Transform Analysis to measure substructure scale & location

- ✳ define heating, cooling, and explosion properties
- ✳ probe particle acceleration sites

➡ Two-Point Correlation to compare spatial distributions

See Lopez et al. 2009, ApJ, 691, 875

Quantitative Measures of X-ray Morphology

➡ Multipole Expansion to measure symmetry/ellipticity

➡ Wavelet-Transform Analysis to measure substructure scale & location

- ✳ define heating, cooling, and explosion properties
- ✳ probe particle acceleration sites

➡ Two-Point Correlation to compare spatial distributions

- ✳ quantify chemical mixing and segregation

See Lopez et al. 2009, ApJ, 691, 875

Quantitative Measures of X-ray Morphology

➡ Multipole Expansion to measure symmetry/ellipticity

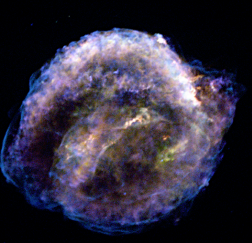
➡ Wavelet-Transform Analysis to measure substructure scale & location

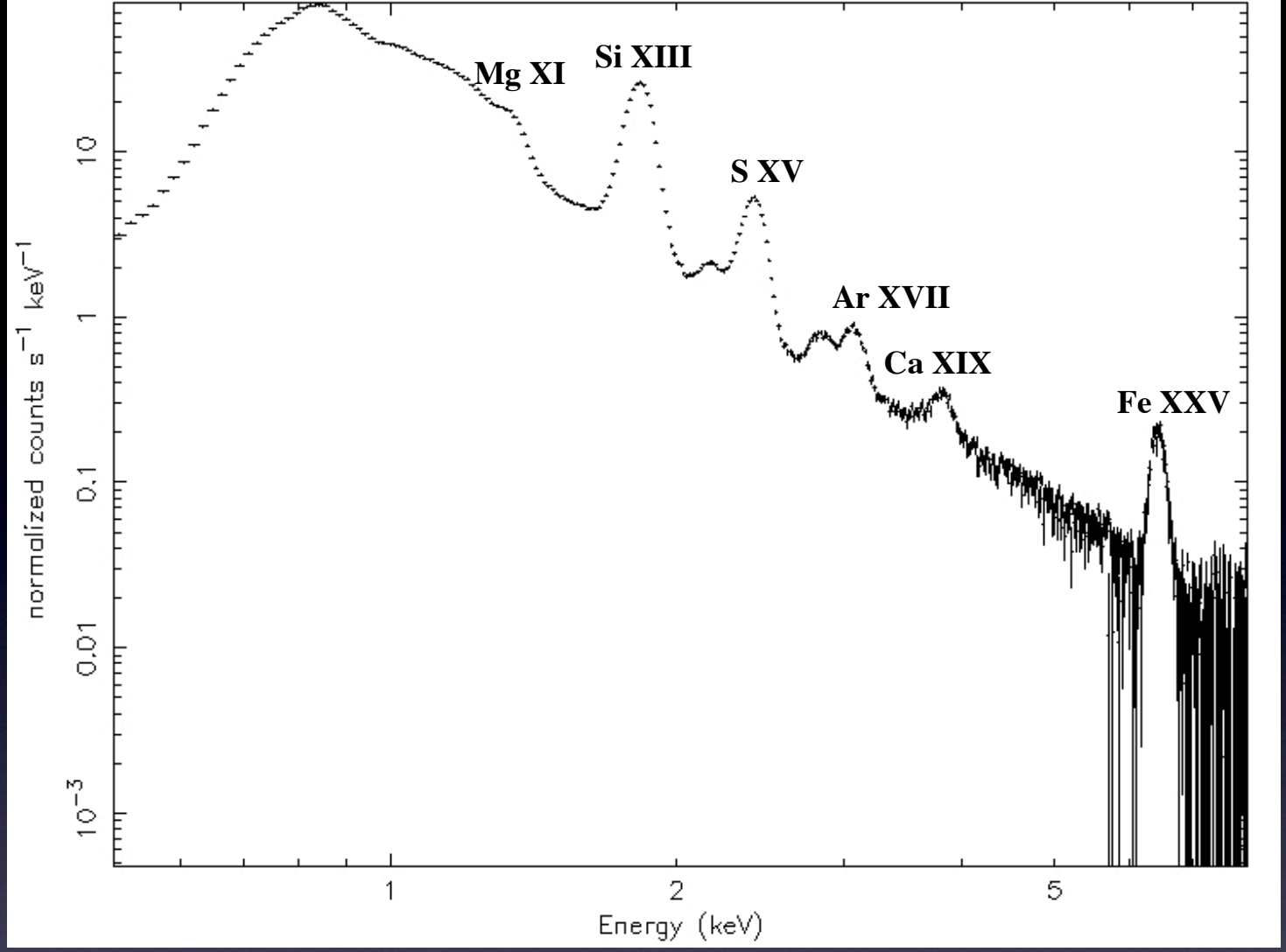
- ✳ define heating, cooling, and explosion properties
- ✳ probe particle acceleration sites

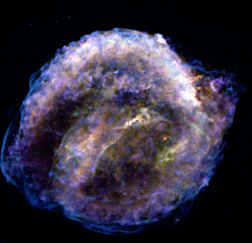
➡ Two-Point Correlation to compare spatial distributions

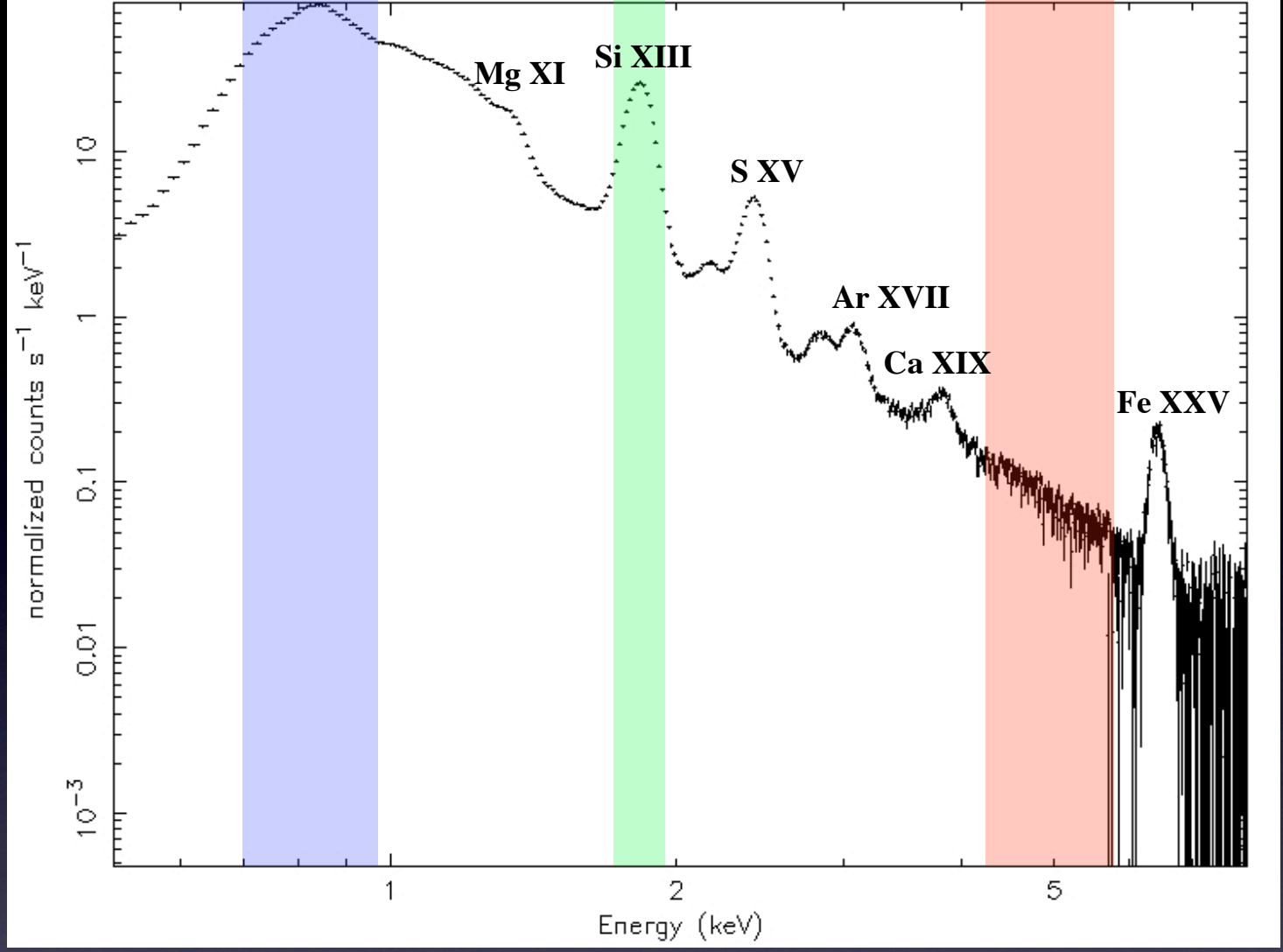
- ✳ quantify chemical mixing and segregation
- ✳ disentangle line from non-thermal emission

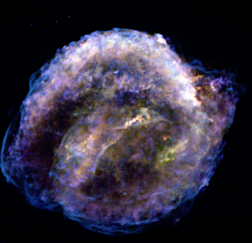
See Lopez et al. 2009, ApJ, 691, 875

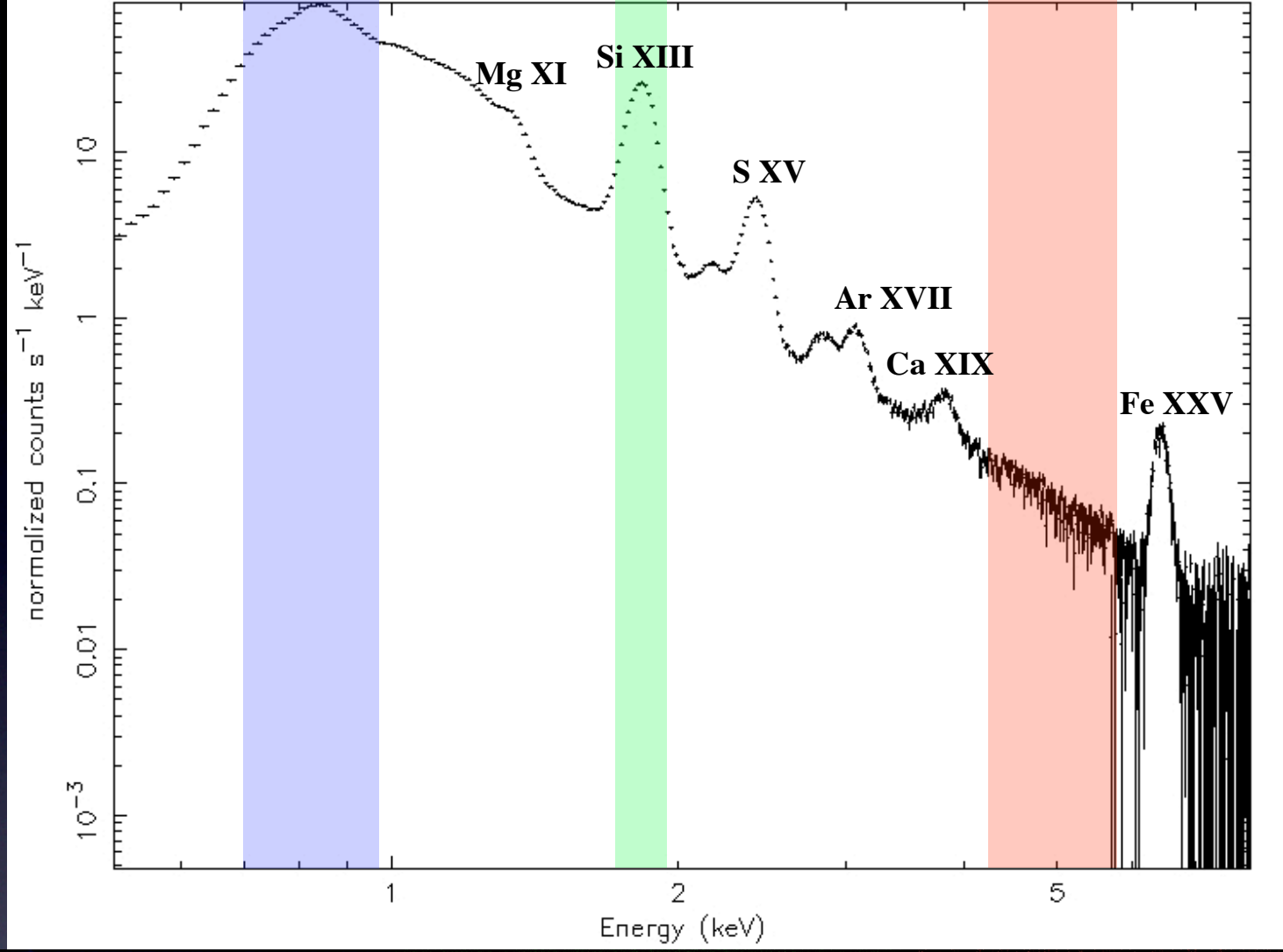


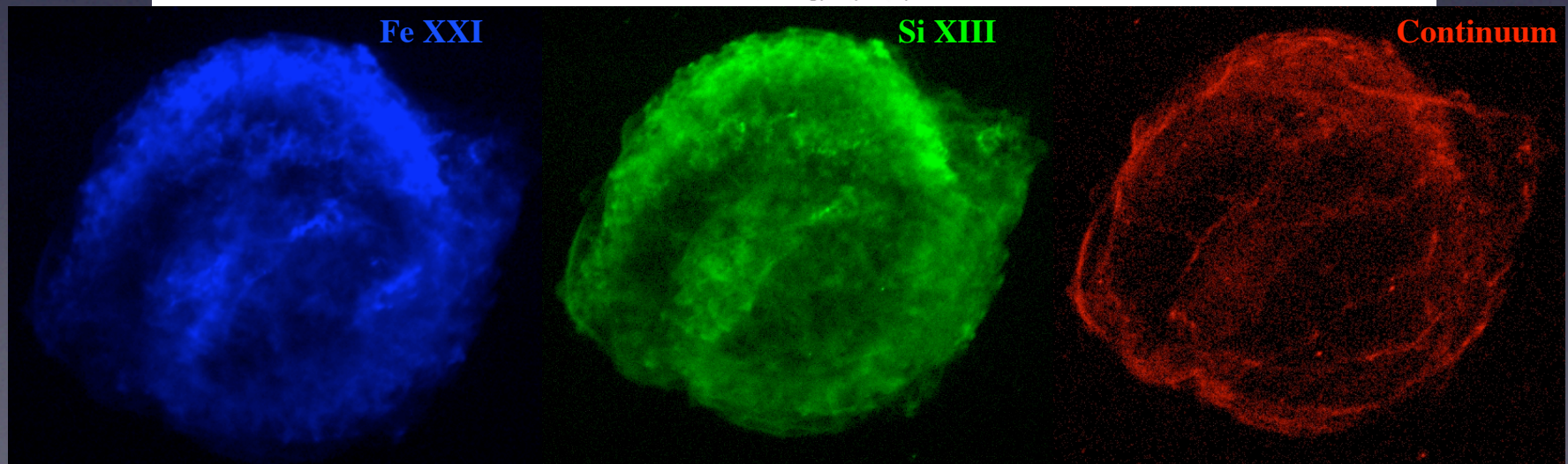

Mg XI
Si XIII
S XV
Ar XVII
Ca XIX
Fe XXV
normalized counts s^{-1} keV^{-1}
10
1
0.1
0.01
10^{-3}
1
2
5
Energy (keV)




Mg XI
Si XIII
S XV
Ar XVII
Ca XIX
Fe XXV
normalized counts s^{-1} keV^{-1}
10
1
0.1
0.01
10^{-3}
1
2
5
Energy (keV)




Mg XI
Si XIII
S XV
Ar XVII
Ca XIX
Fe XXV
normalized counts s^{-1} keV^{-1}
10
1
0.1
0.01
10^{-3}
1
2
5
Energy (keV)


Fe XXI
Si XIII
Continuum

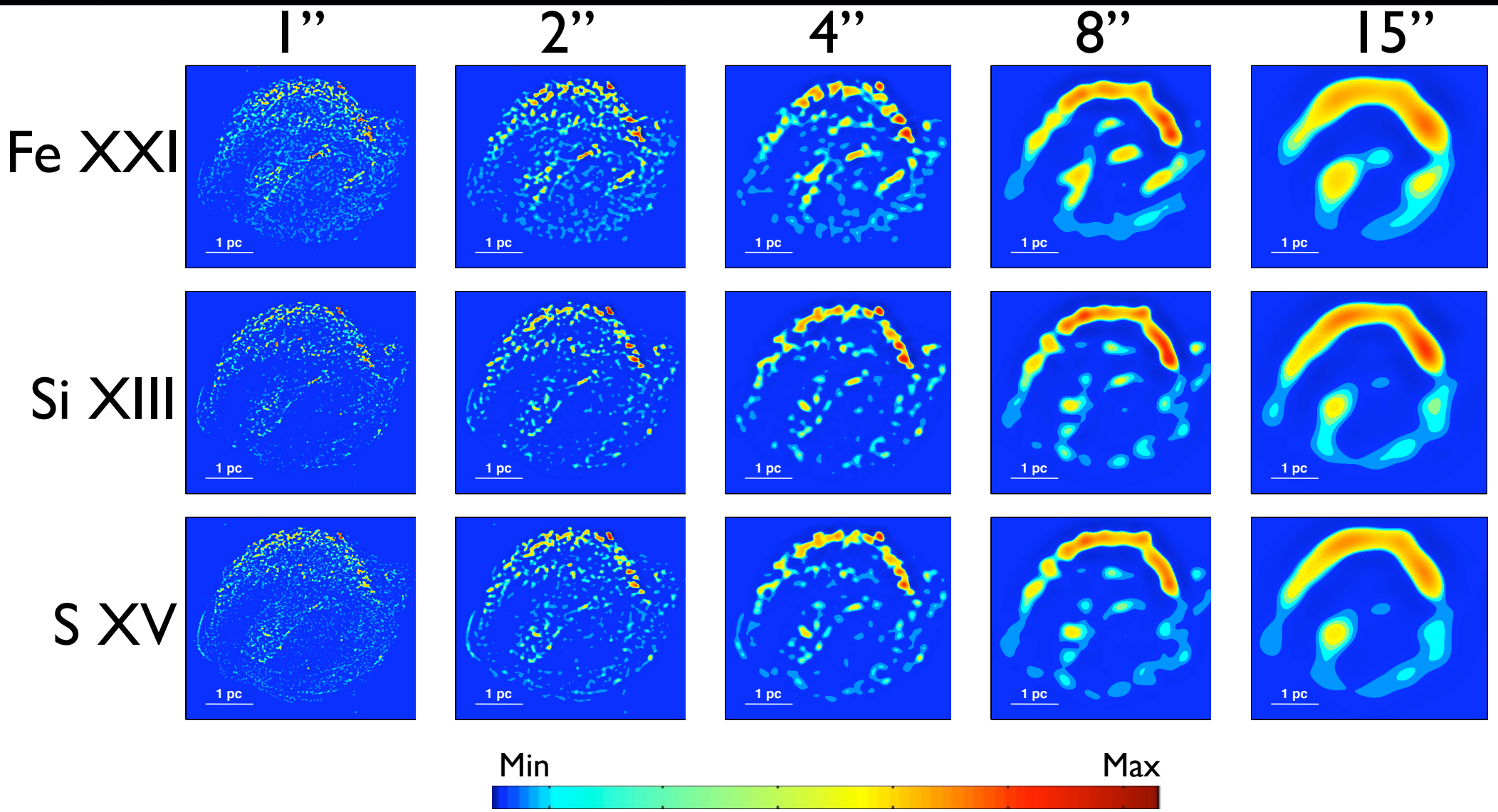
Measuring Power at Many Scales

Measuring Power at Many Scales

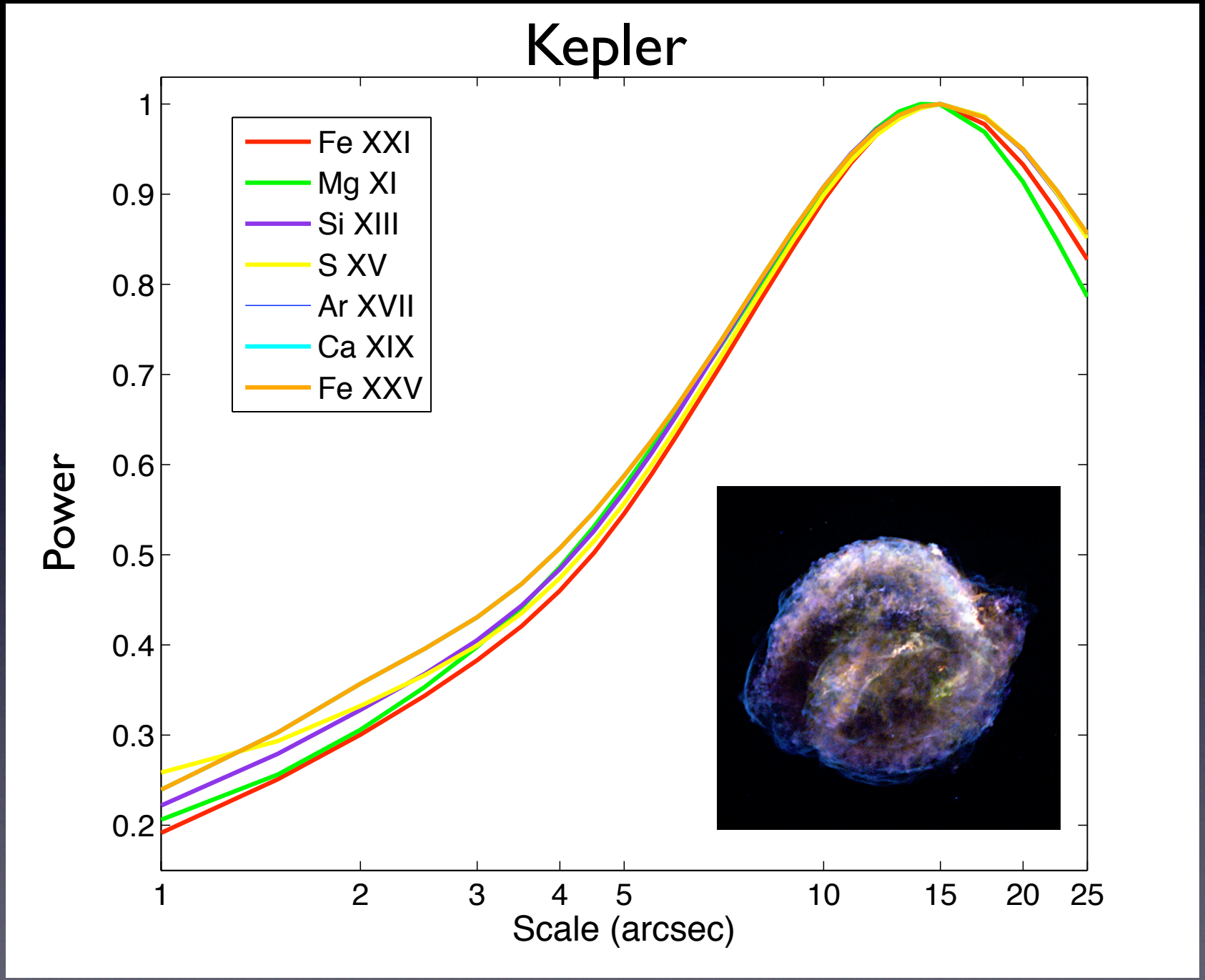
Wavelet Transform Analyisis: Characterize sub-structure scale and location by measuring/filtering power

Measuring Power at Many Scales

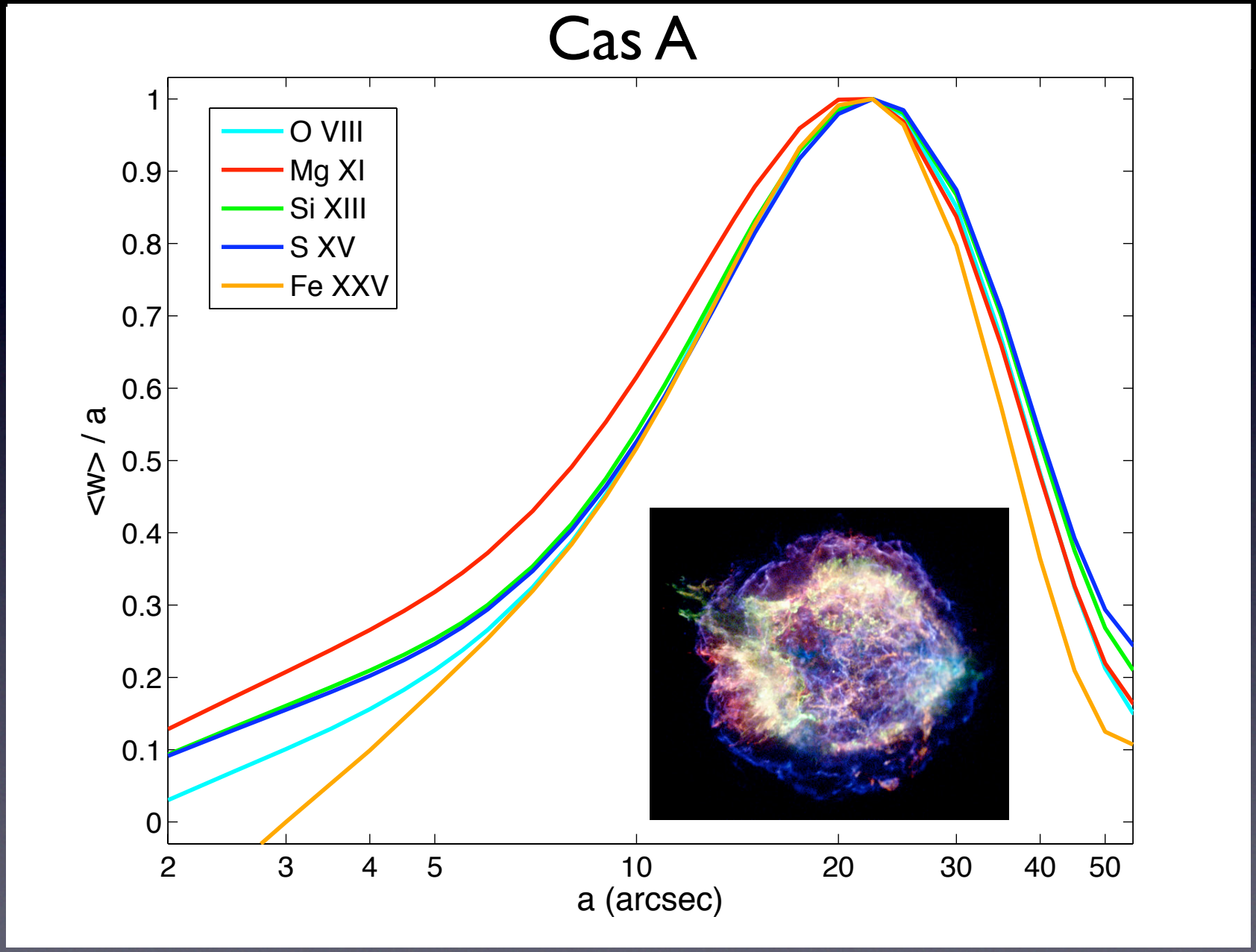
Wavelet Transform Analyisis: Characterize sub-structure scale and location by measuring/filtering power



Average Power vs. Scale

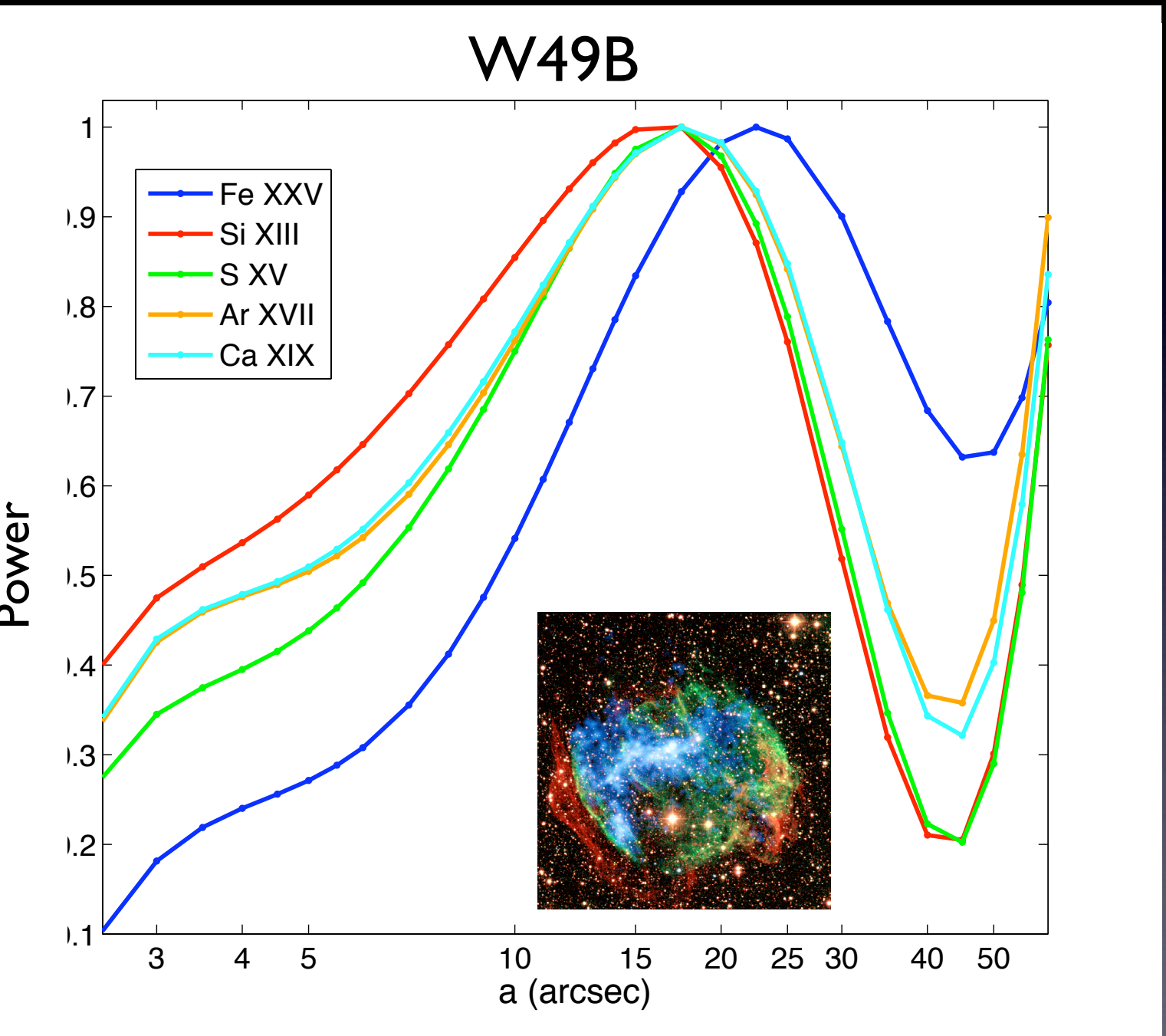


Average Power vs. Scale



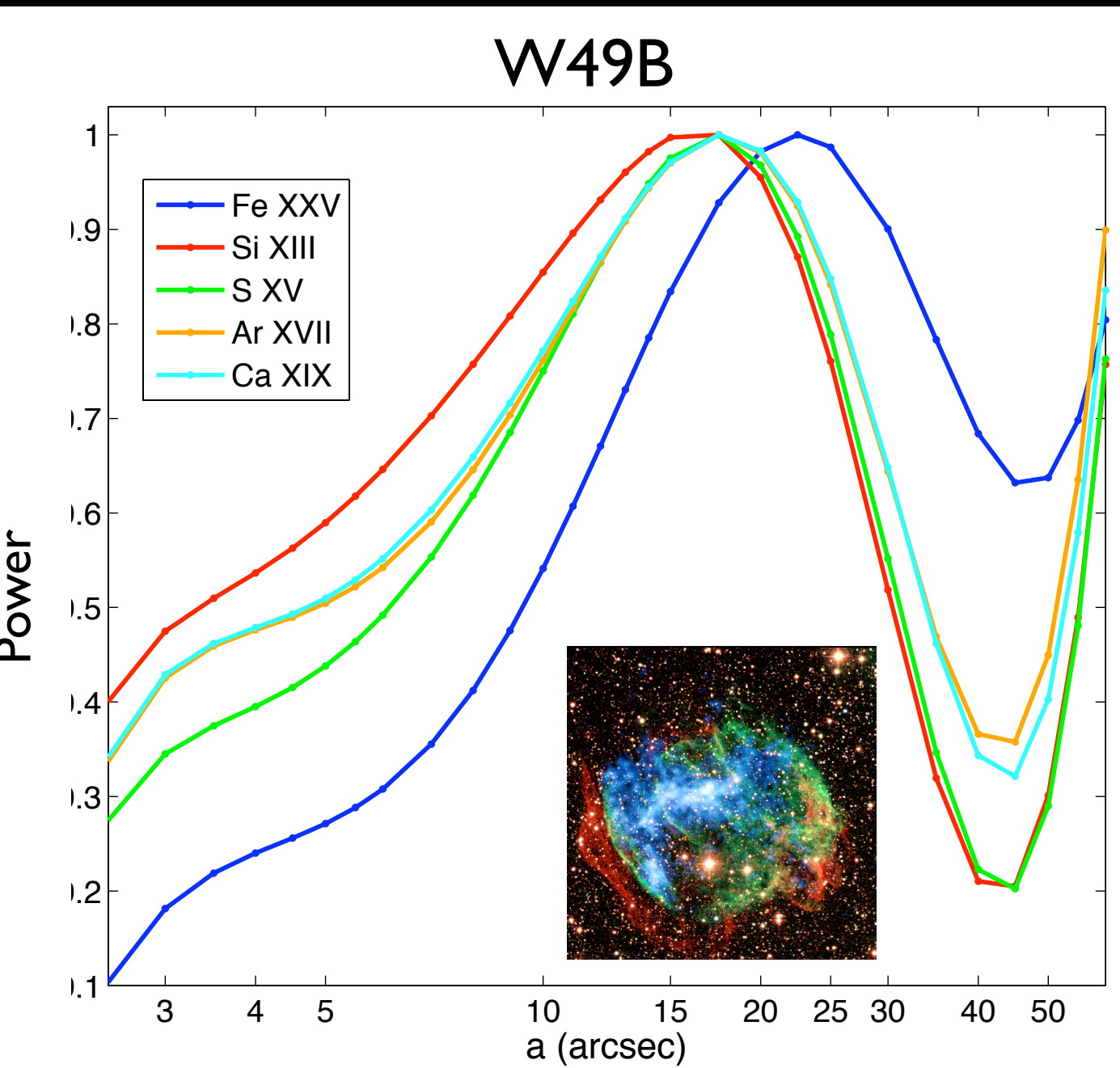
Average Power vs. Scale

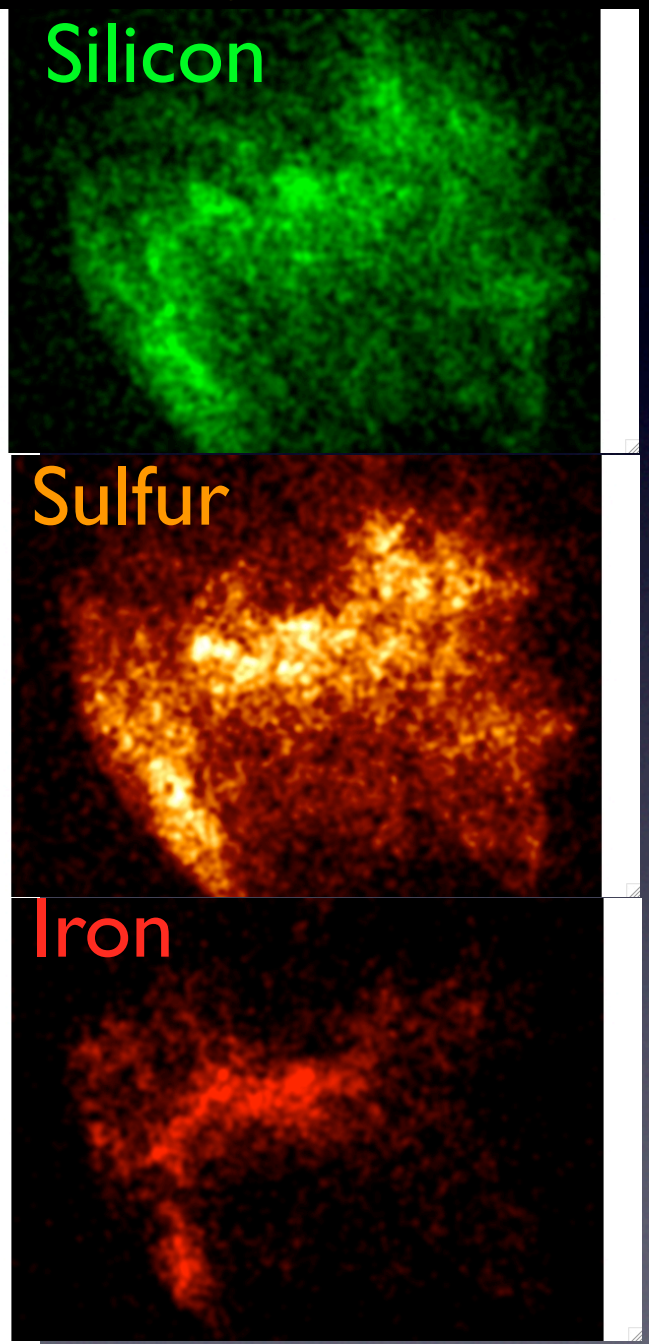
Lopez et al. 2009, ApJ, 691, 875



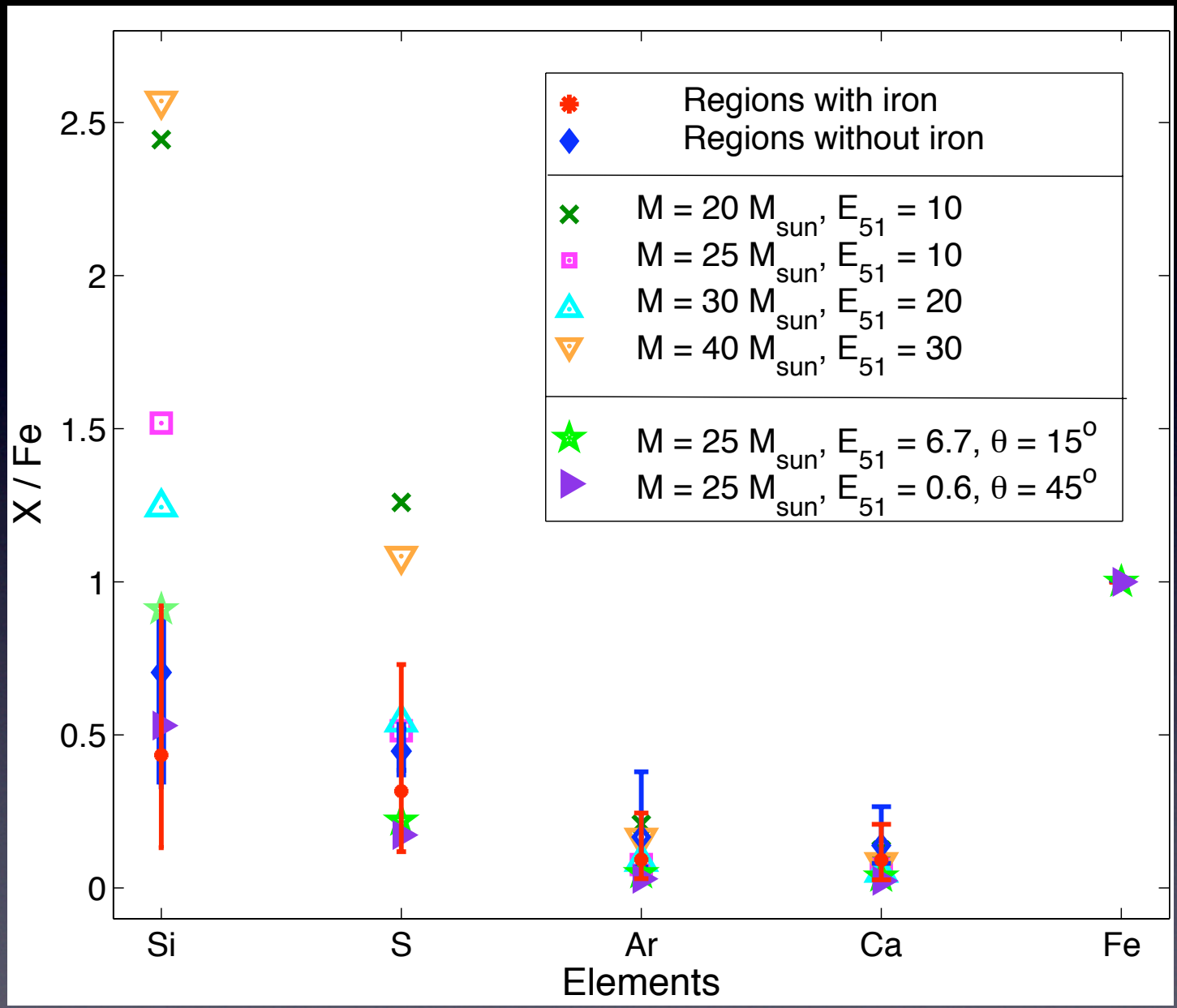
Average Power vs. Scale

Lopez et al. 2009, ApJ, 691, 875



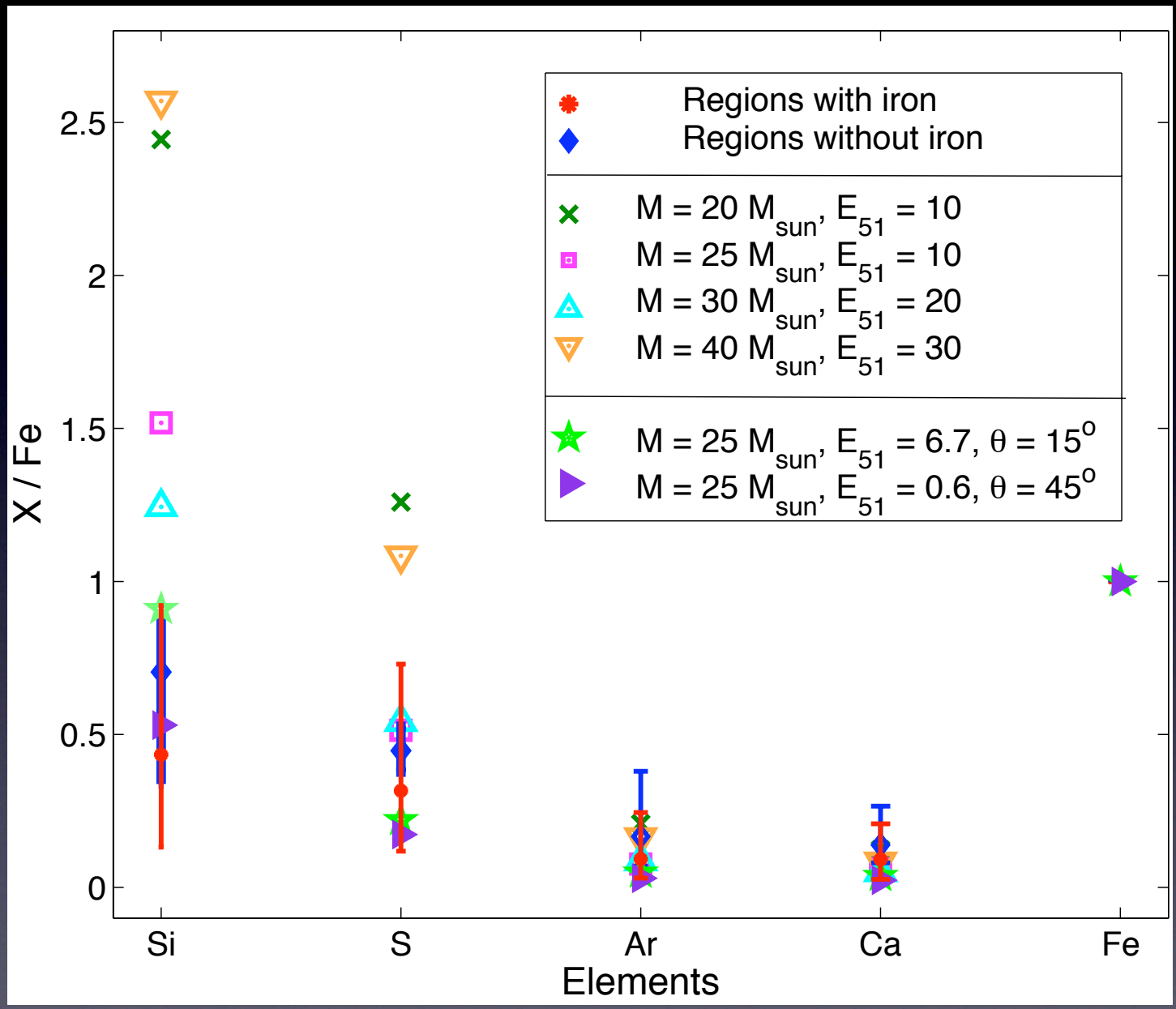


Lopez et al. 2009, ApJ, 691, 875



Spherical models from Nomoto et al. 2006; Aspherical models from Maeda & Nomoto 2003

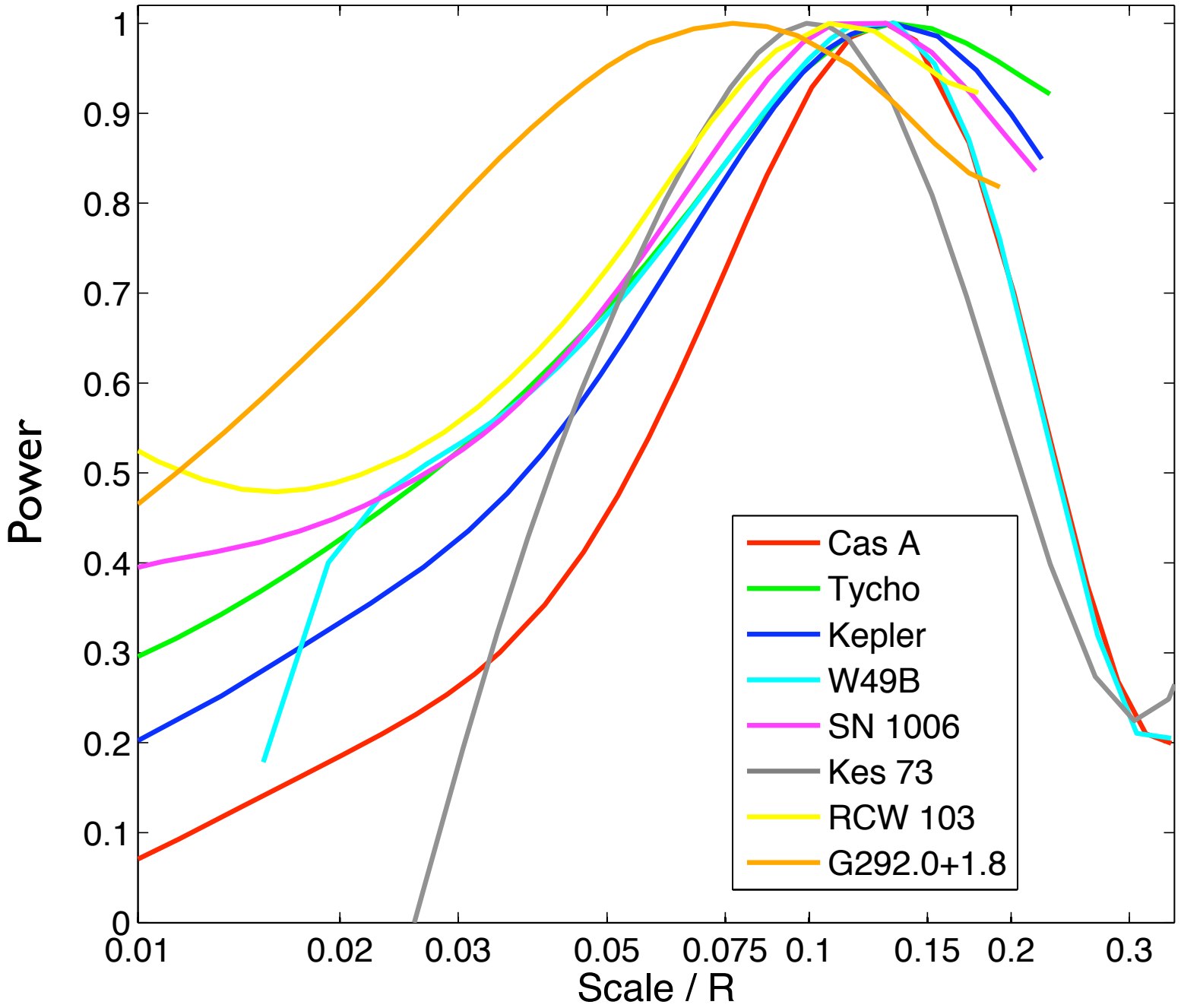
Lopez et al. 2009, ApJ, 691, 875



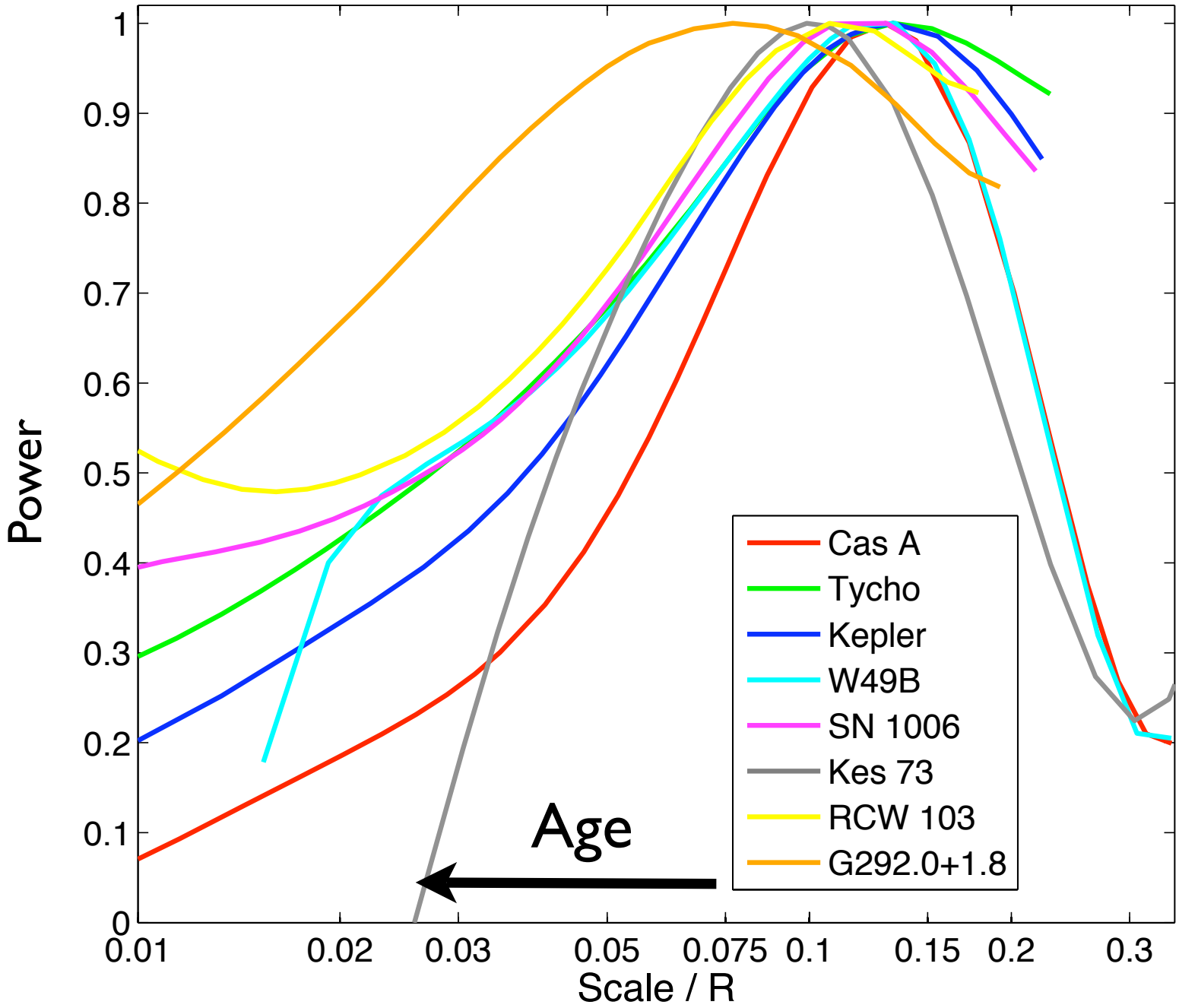
➡ Consistent with models of bipolar explosions

Spherical models from Nomoto et al. 2006; Aspherical models from Maeda & Nomoto 2003

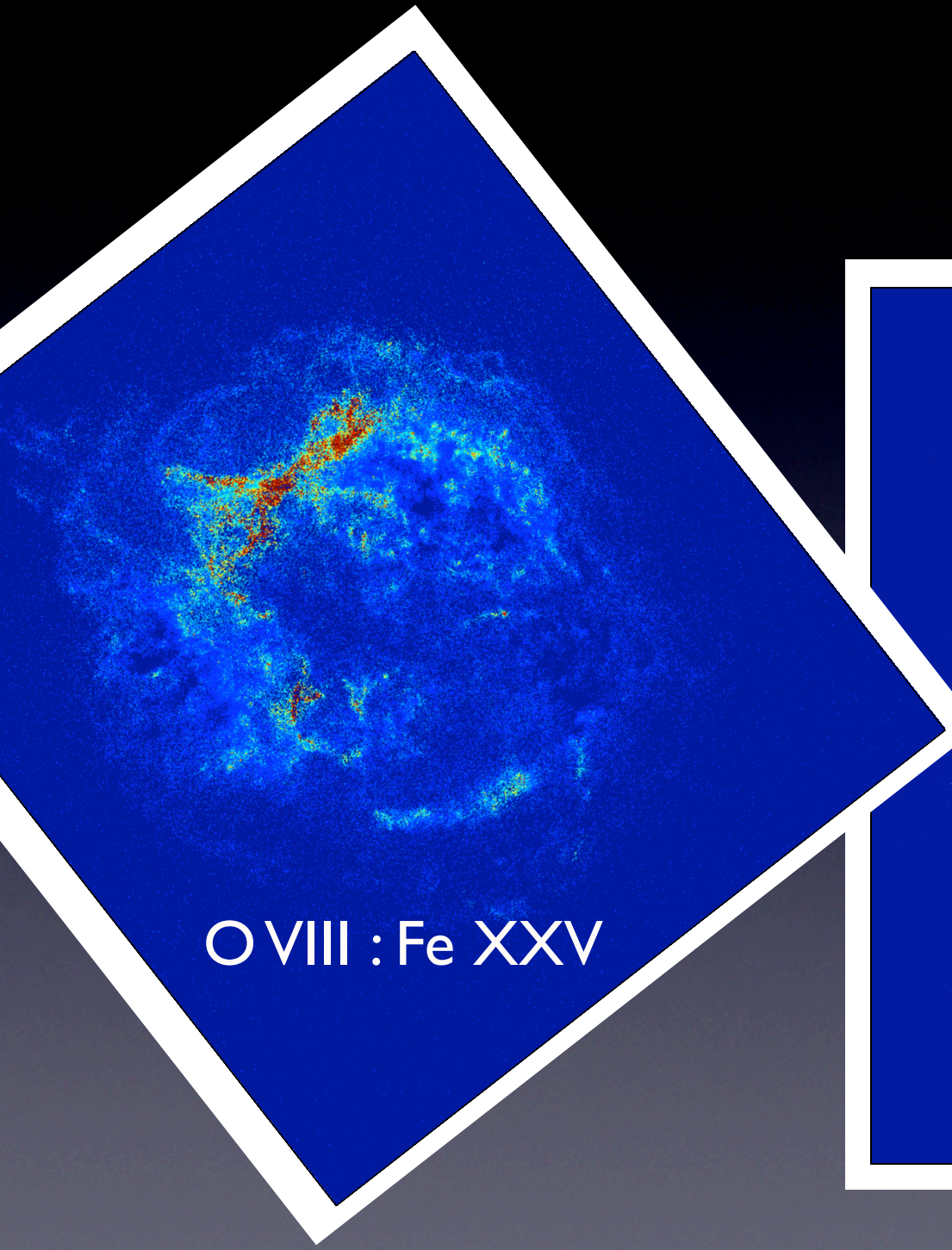
Scale vs. Age

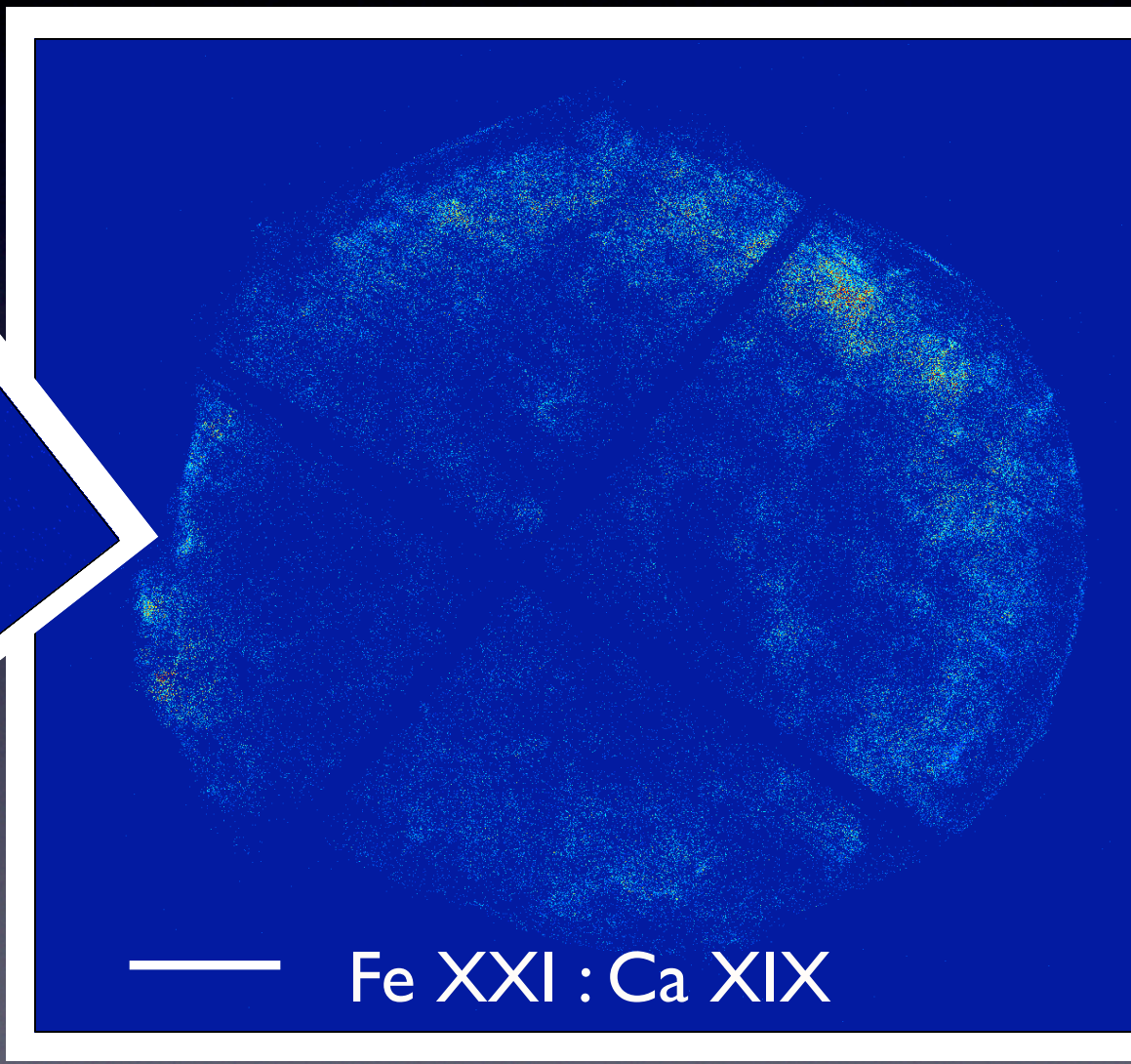

Power
Scale / R
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.01
0.02
0.03
0.05
0.075
0.1
0.15
0.2
0.3
Cas A
Tycho
Kepler
W49B
SN 1006
Kes 73
RCW 103
G292.0+1.8

Scale vs. Age

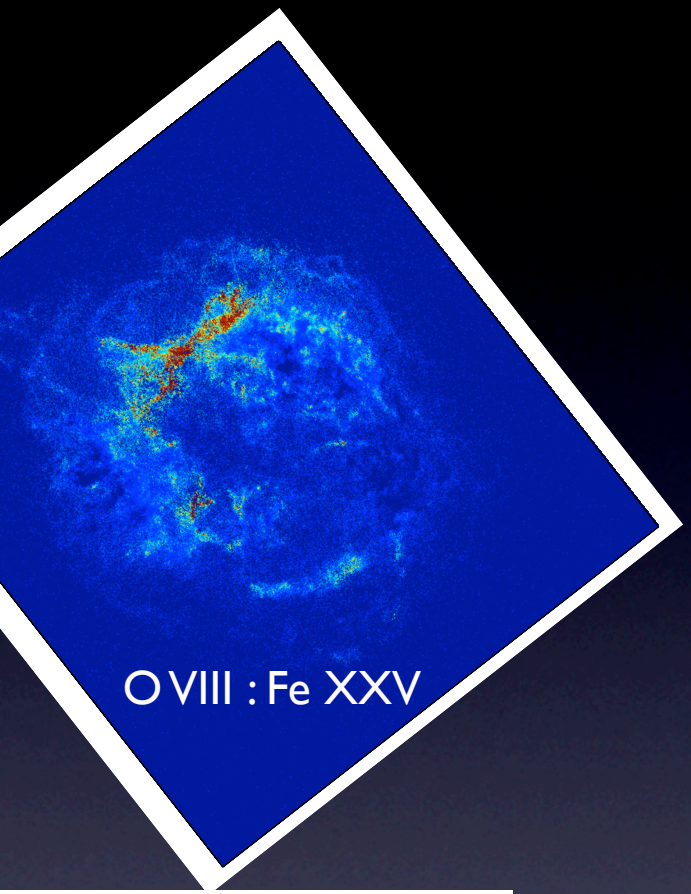

Power
Scale / R
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.01
0.02
0.03
0.05
0.075
0.1
0.15
0.2
0.3
Age
Cas A
Tycho
Kepler
W49B
SN 1006
Kes 73
RCW 103
G292.0+1.8

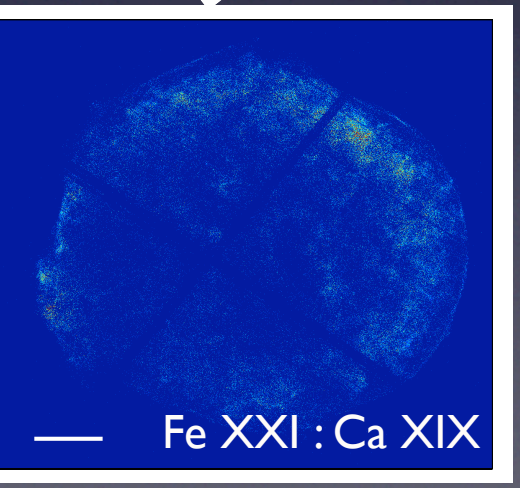
Small-Scale Asymmetries



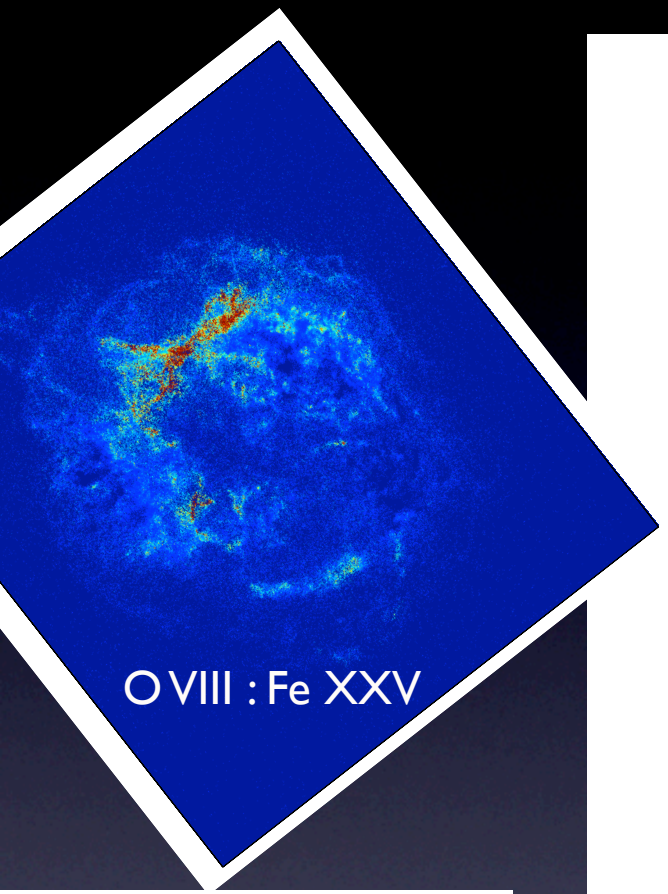


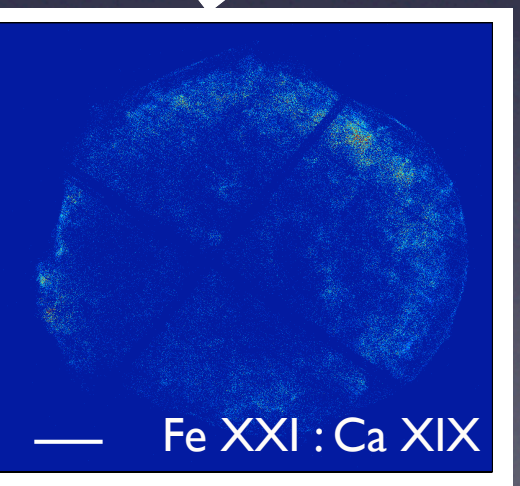
Small-Scale Asymmetries

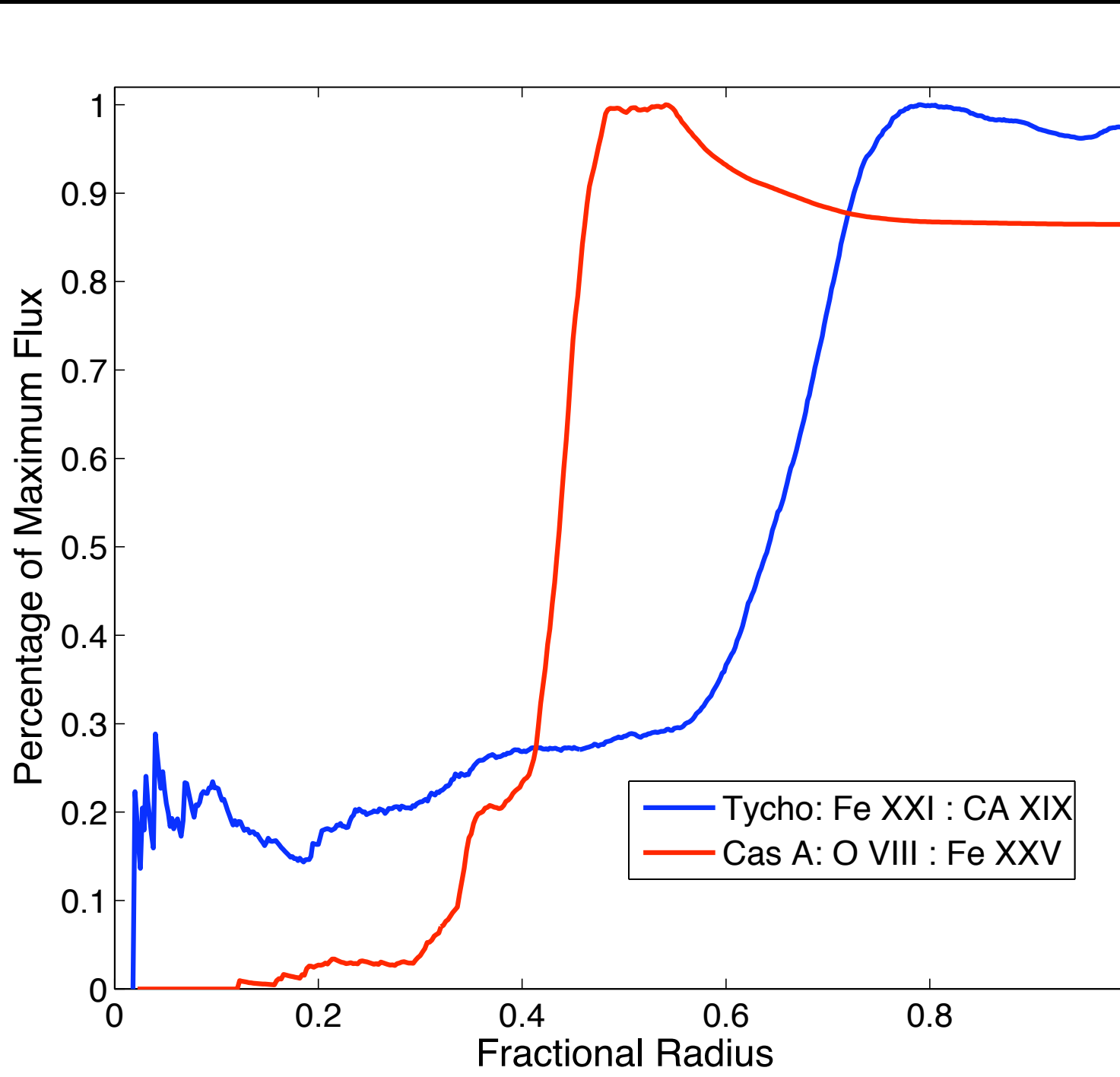




Small-Scale Asymmetries







Multipole Expansion

Multipole Expansion

Power-Ratio Method: Calculate multipole moments of the X-ray surface brightness

Multipole Expansion

Power-Ratio Method: Calculate multipole moments of the X-ray surface brightness

e.g. Buote & Tsai 1995, 1996; Jeltema et al. 2005

Multipole Expansion

Power-Ratio Method: Calculate multipole moments of the X-ray surface brightness

e.g. Buote & Tsai 1995, 1996; Jeltema et al. 2005

➡ P_2: measure of ellipticity / elongation

Multipole Expansion

Power-Ratio Method: Calculate multipole moments of the X-ray surface brightness

e.g. Buote & Tsai 1995, 1996; Jeltema et al. 2005

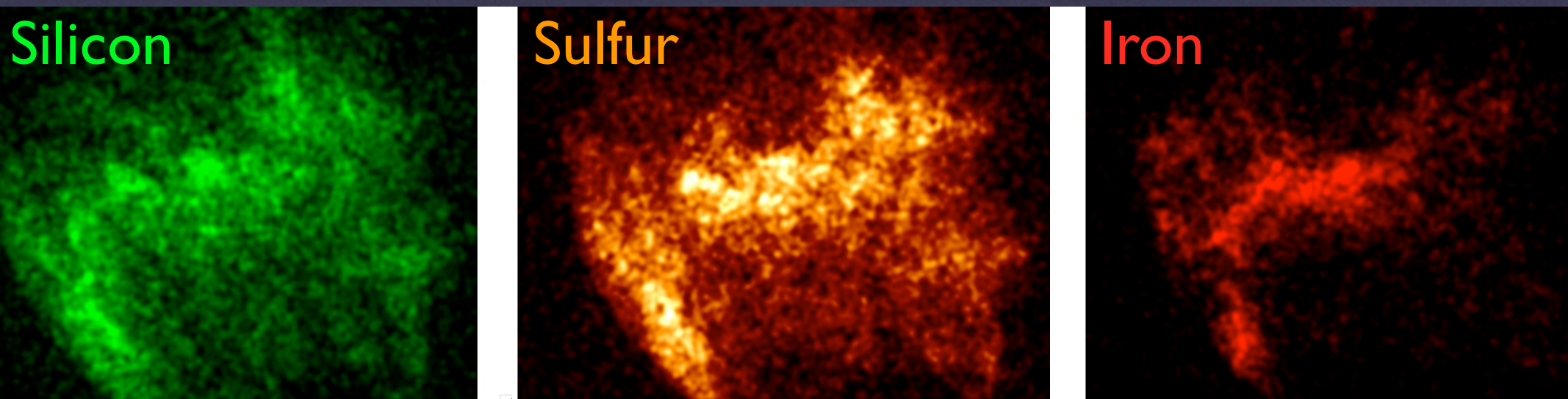
- P_2: measure of ellipticity / elongation
- P_3: measure of mirror asymmetry

Multipole Expansion

Power-Ratio Method: Calculate multipole moments of the X-ray surface brightness

e.g. Buote & Tsai 1995, 1996; Jeltema et al. 2005

- P_2: measure of ellipticity / elongation
- P_3: measure of mirror asymmetry

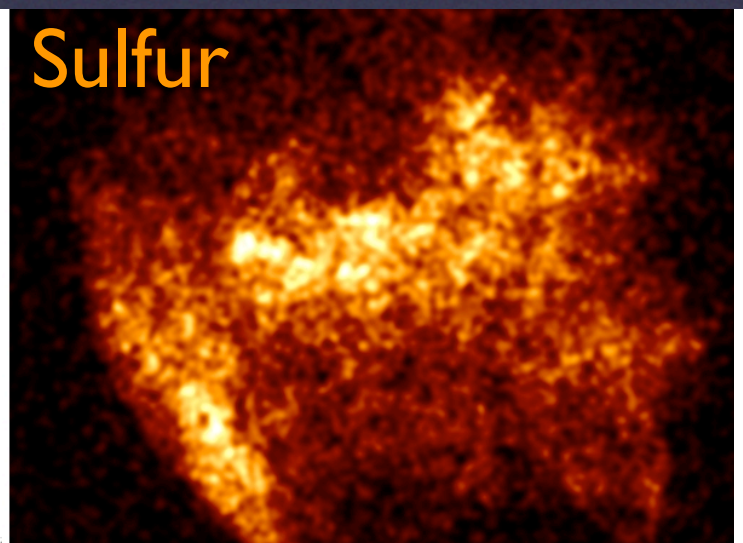


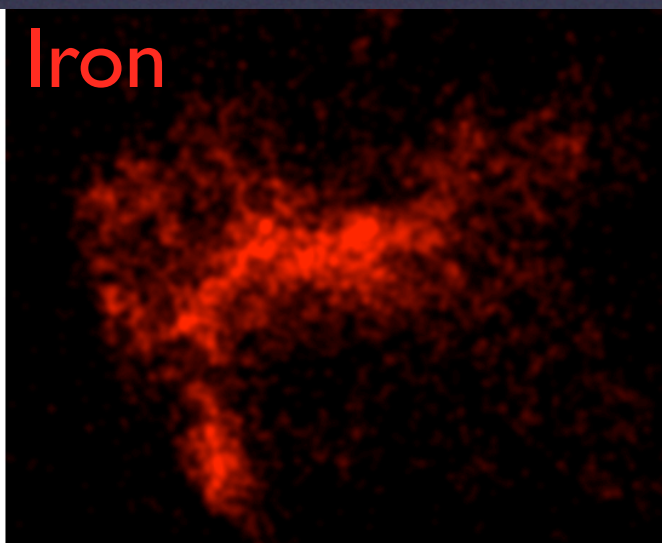
Multipole Expansion

Power-Ratio Method: Calculate multipole moments of the X-ray surface brightness

e.g. Buote & Tsai 1995, 1996; Jeltema et al. 2005

- P_2: measure of ellipticity / elongation
- P_3: measure of mirror asymmetry



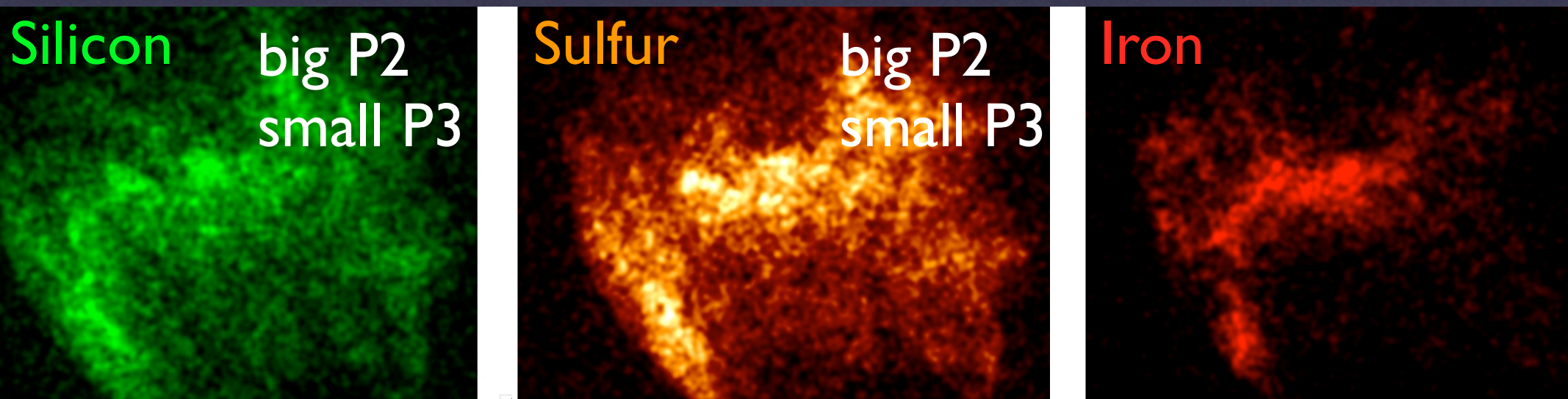


Multipole Expansion

Power-Ratio Method: Calculate multipole moments of the X-ray surface brightness

e.g. Buote & Tsai 1995, 1996; Jeltema et al. 2005

- P_2: measure of ellipticity / elongation
- P_3: measure of mirror asymmetry

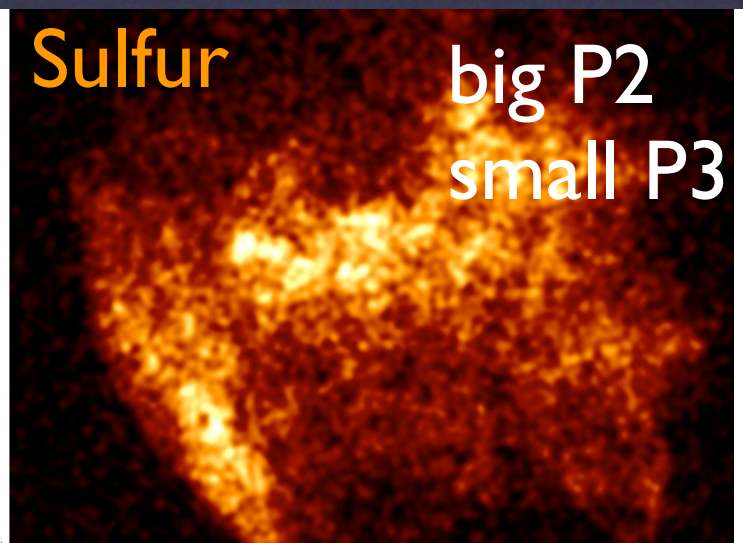


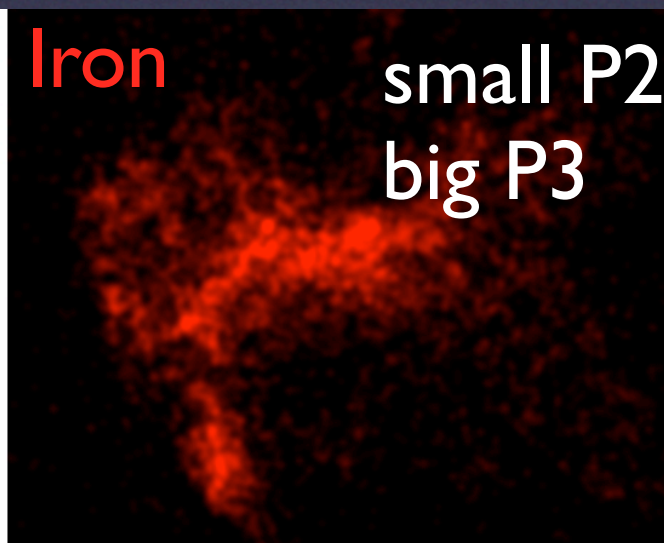
Multipole Expansion

Power-Ratio Method: Calculate multipole moments of the X-ray surface brightness

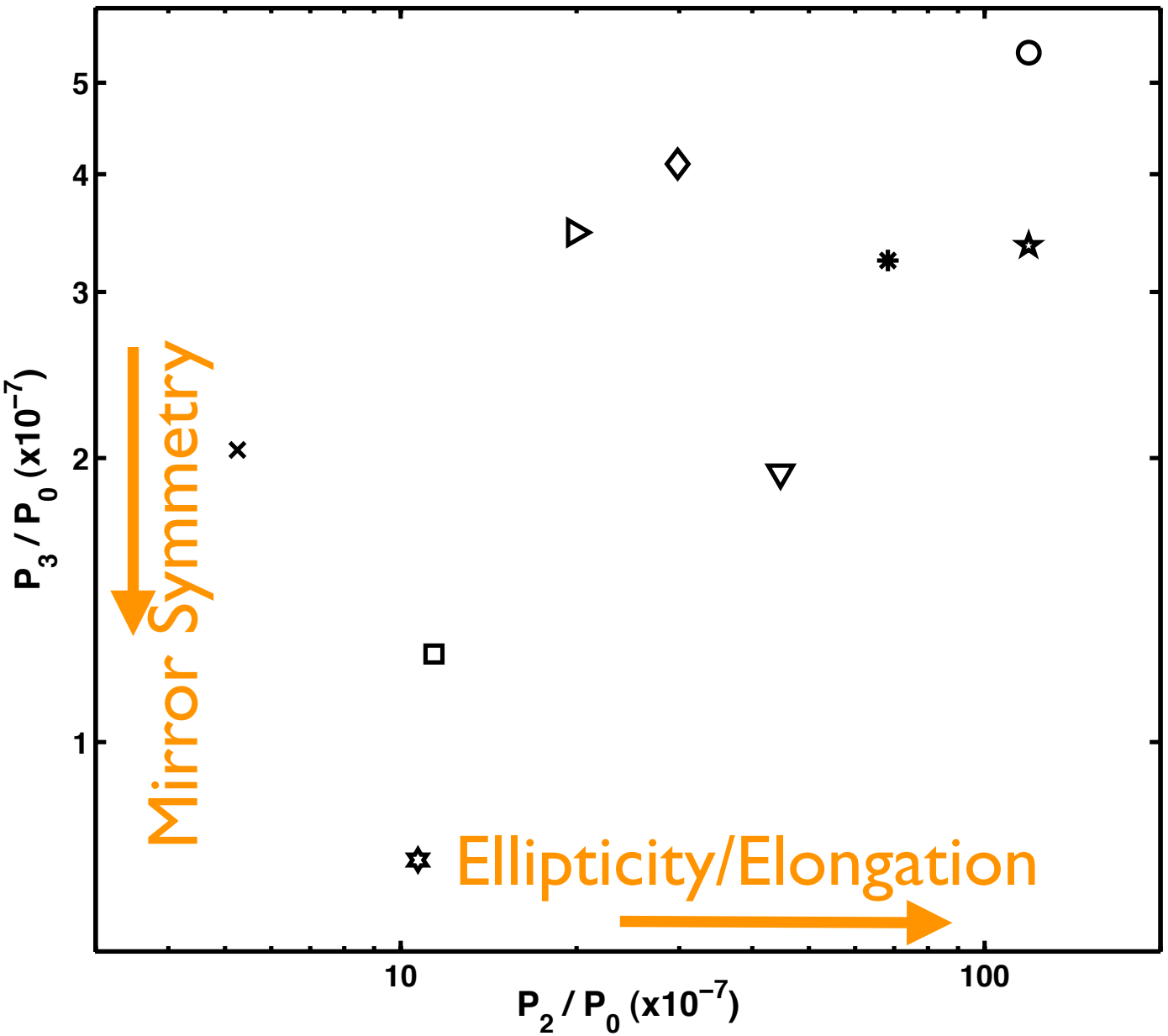
e.g. Buote & Tsai 1995, 1996; Jeltema et al. 2005

- P_2: measure of ellipticity / elongation
- P_3: measure of mirror asymmetry

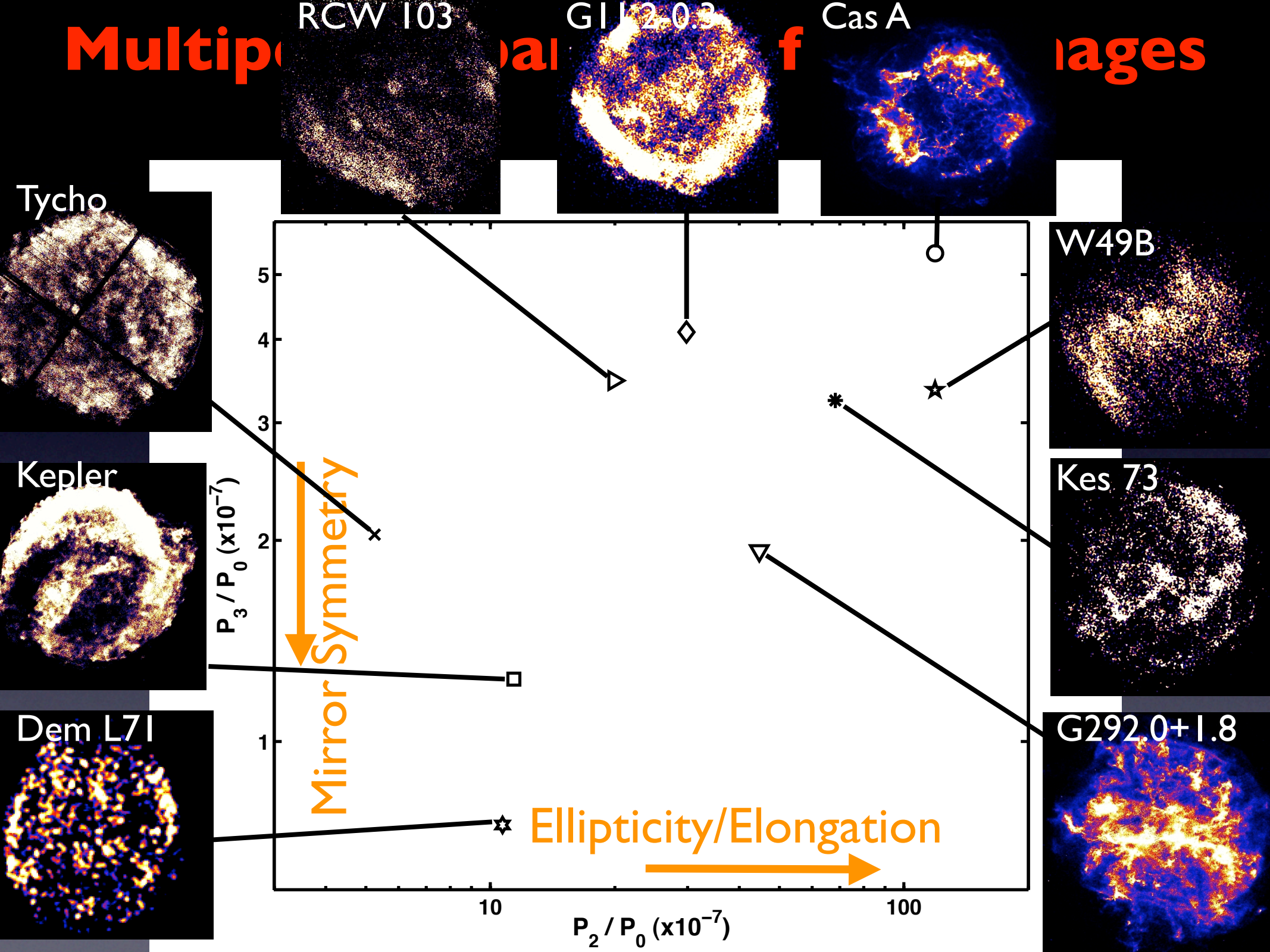




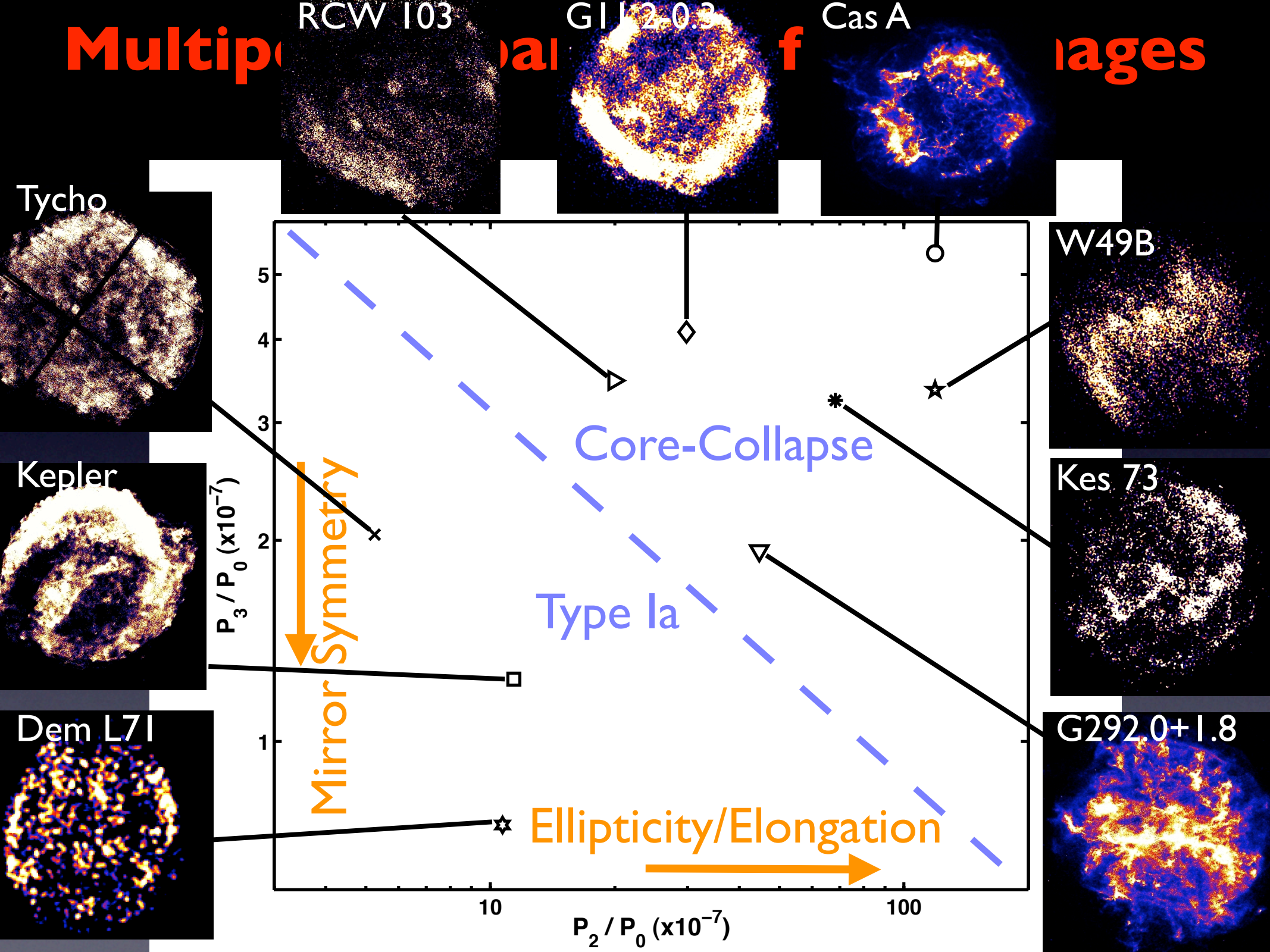
Multipole Expansion of Line Images



Multip[illegible]pa[illegible]f [illegible]ages



Multip[illegible]pa[illegible]f [illegible]ages



X-ray Line Diagnostics

X-ray Line Diagnostics

➡ Type Ia and CC have similar emitting regions for all measurable emission lines

X-ray Line Diagnostics

➡ Type Ia and CC have similar emitting regions for all measurable emission lines

➡ The relative sizes are a function of age with smaller sizes corresponding to older remnants

X-ray Line Diagnostics

➡ Type Ia and CC have similar emitting regions for all measurable emission lines

➡ The relative sizes are a function of age with smaller sizes corresponding to older remnants

➡ Large scale asymmetries in the brightness profiles seem to be a good discriminant of progenitor type

X-ray Line Diagnostics

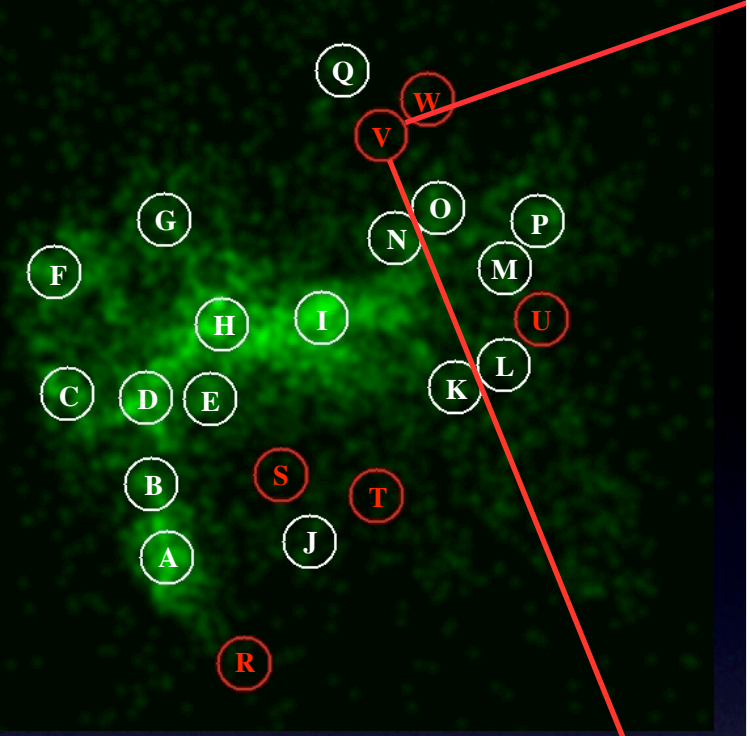
➡ Type Ia and CC have similar emitting regions for all measurable emission lines

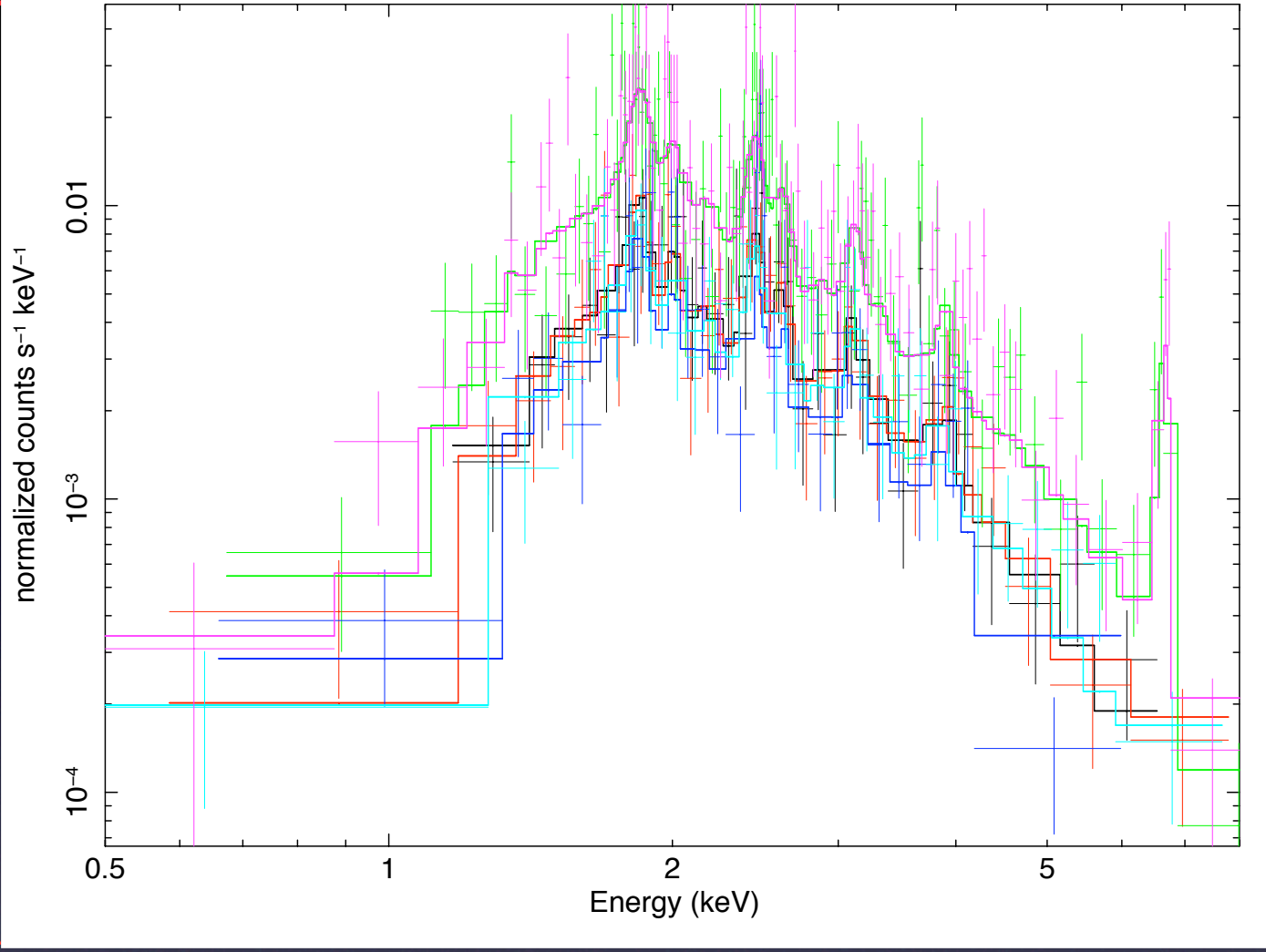
➡ The relative sizes are a function of age with smaller sizes corresponding to older remnants

➡ Large scale asymmetries in the brightness profiles seem to be a good discriminant of progenitor type

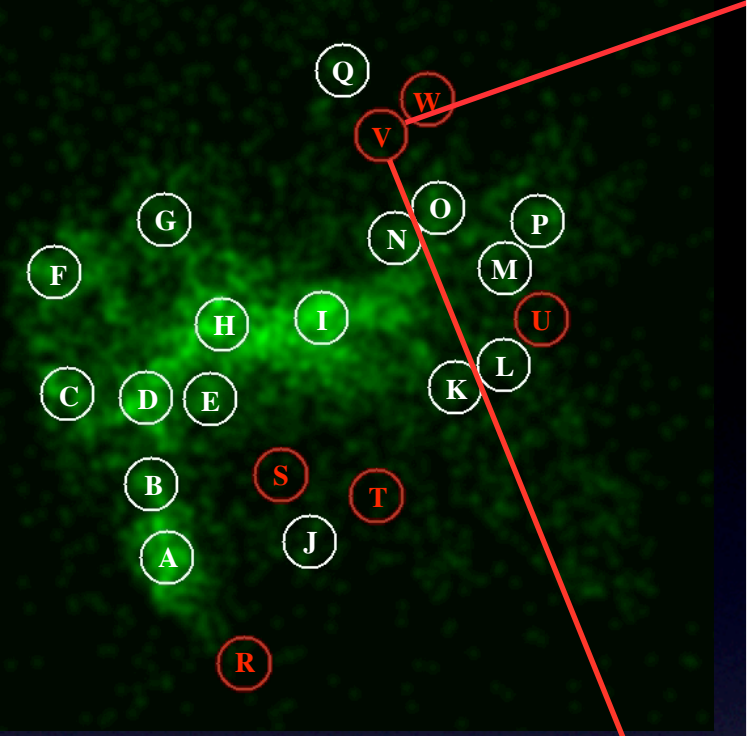
➡ Small-scale asymmetries may be a useful discriminant as well (with caveat)

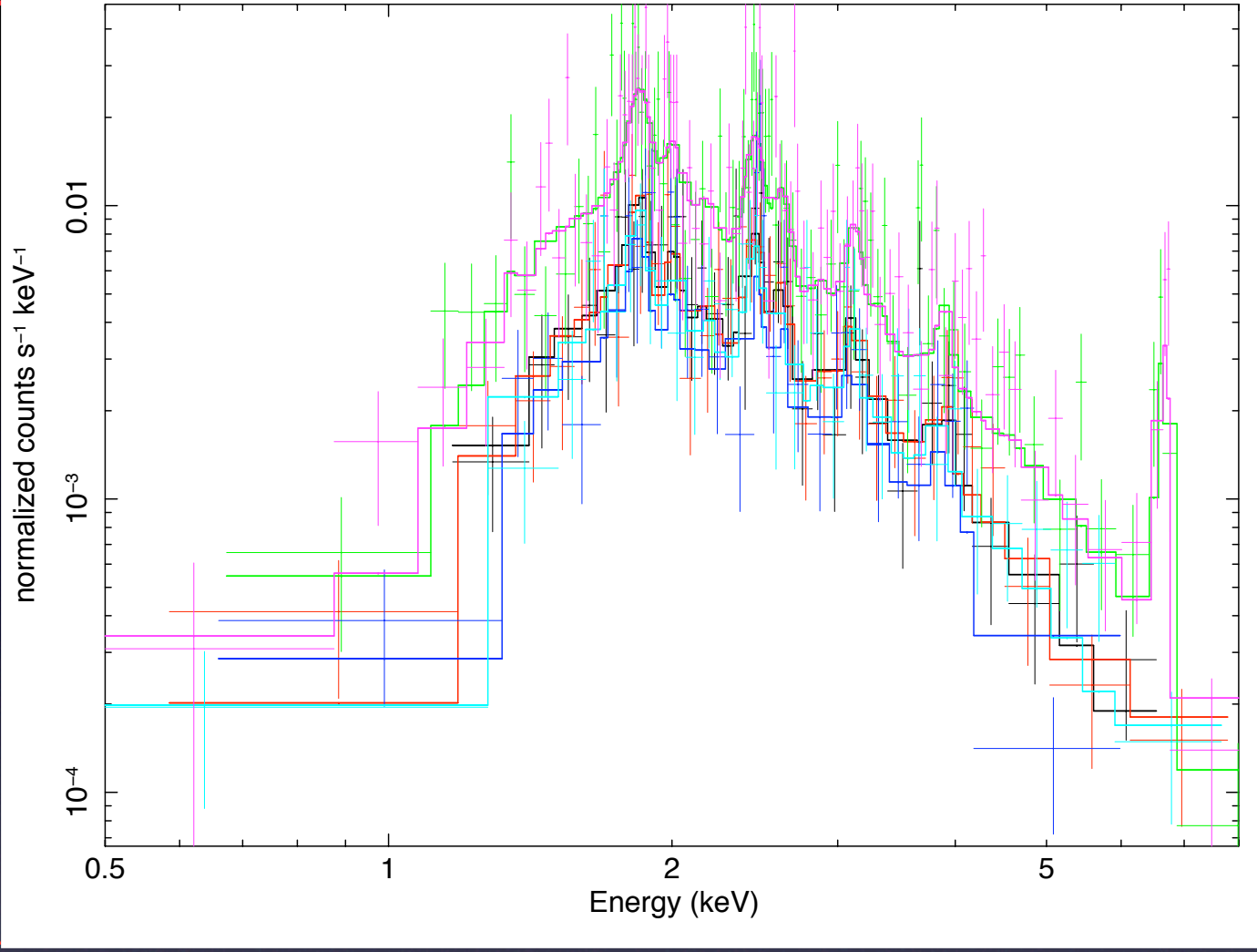
Thank you!





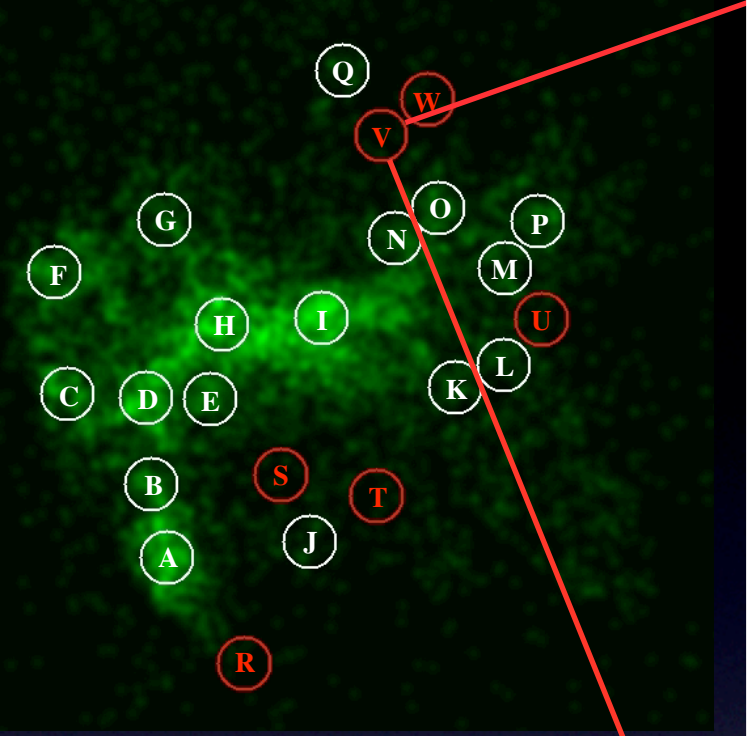
Lopez et al. 2009, ApJ, 691, 875

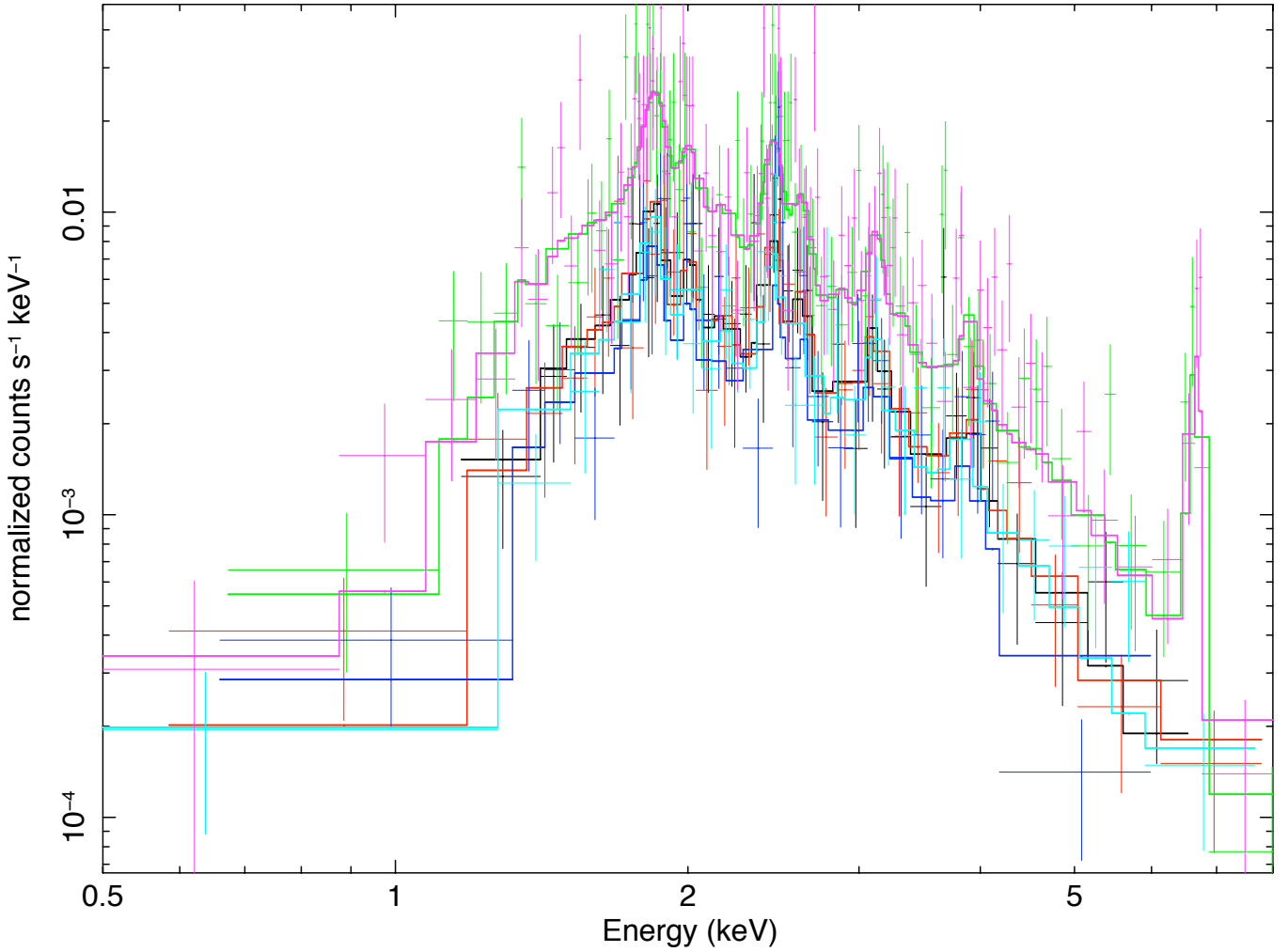




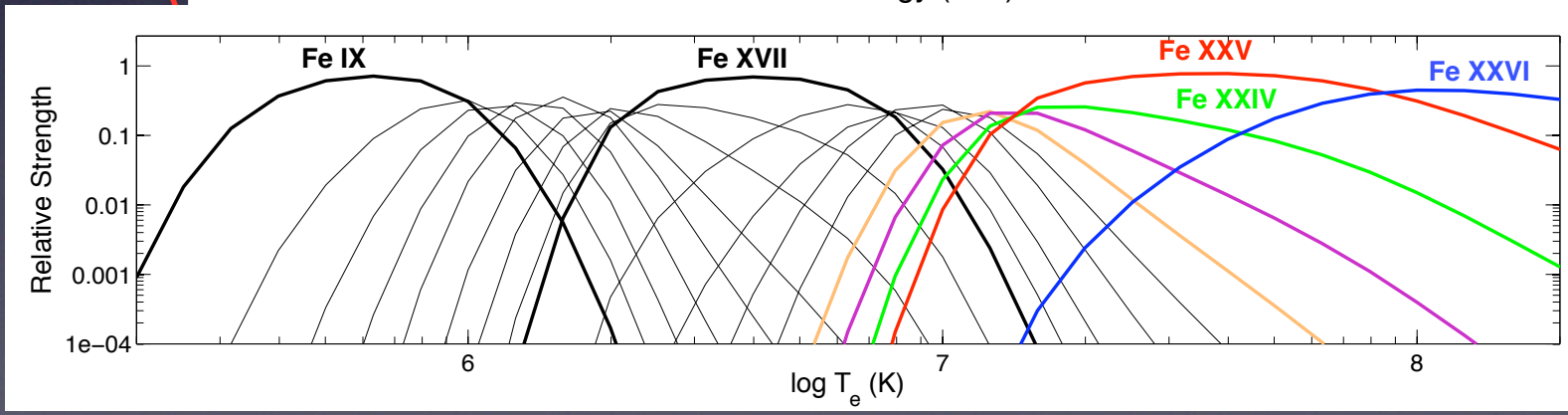
$T_e \sim 2\text{-}4 \times 10^7$ K

Lopez et al. 2009, ApJ, 691, 875

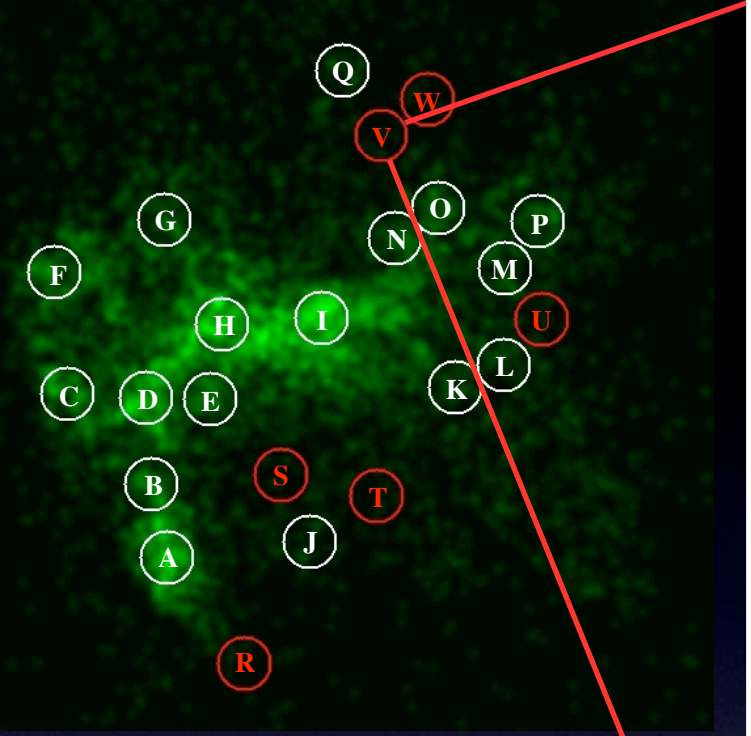


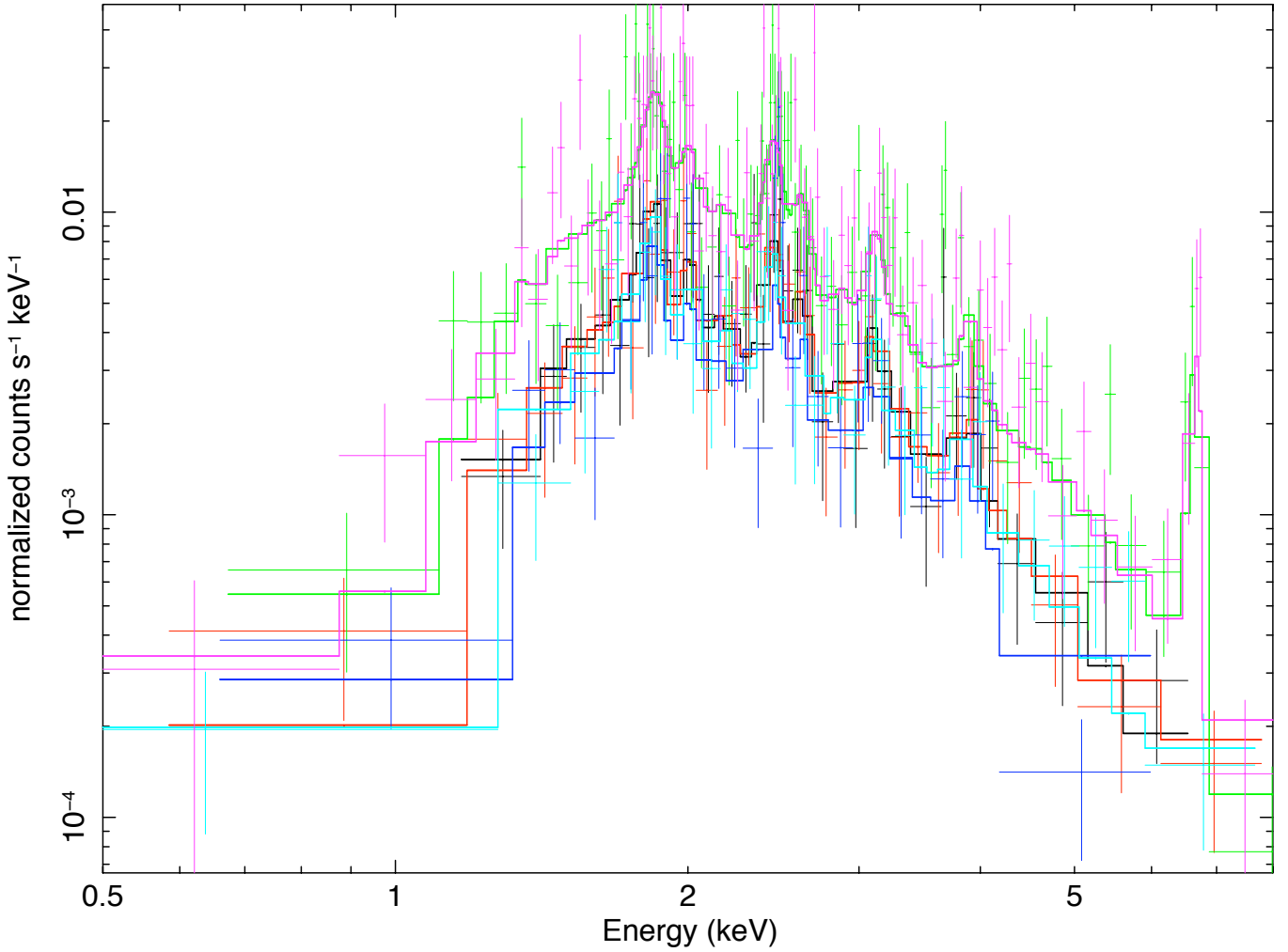


$T_e \sim 2\text{-}4 \times 10^7$ K

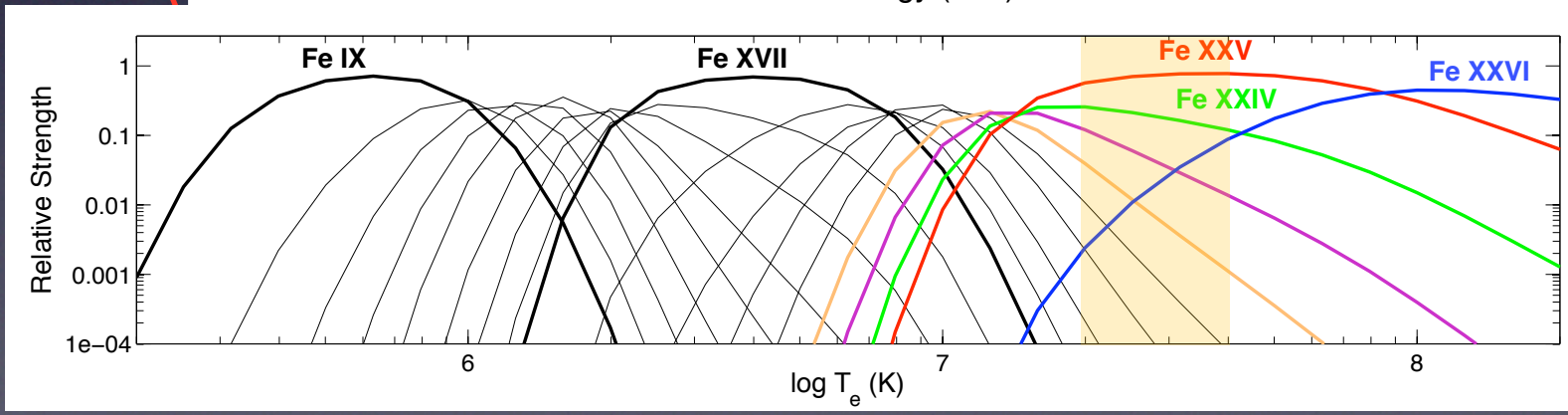


Lopez et al. 2009, ApJ, 691, 875

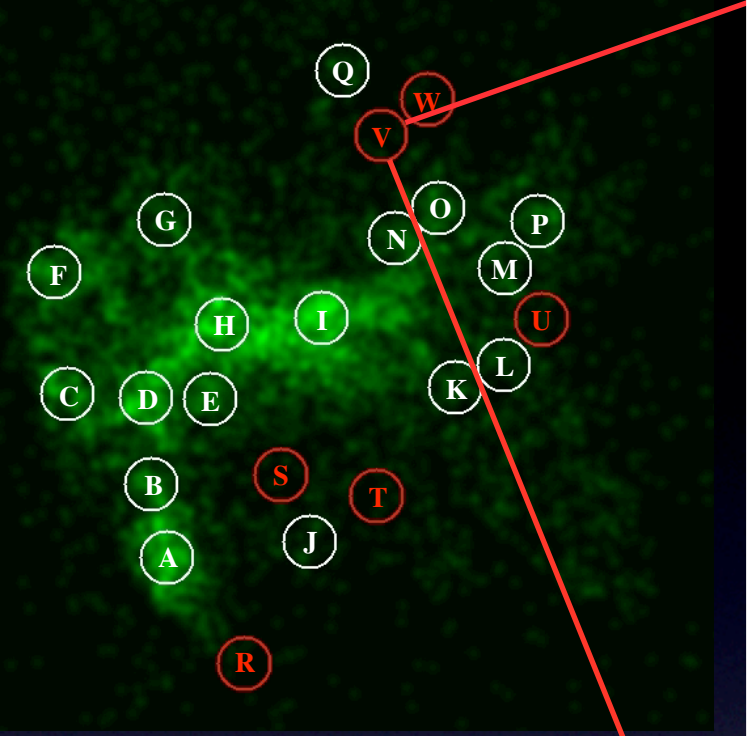


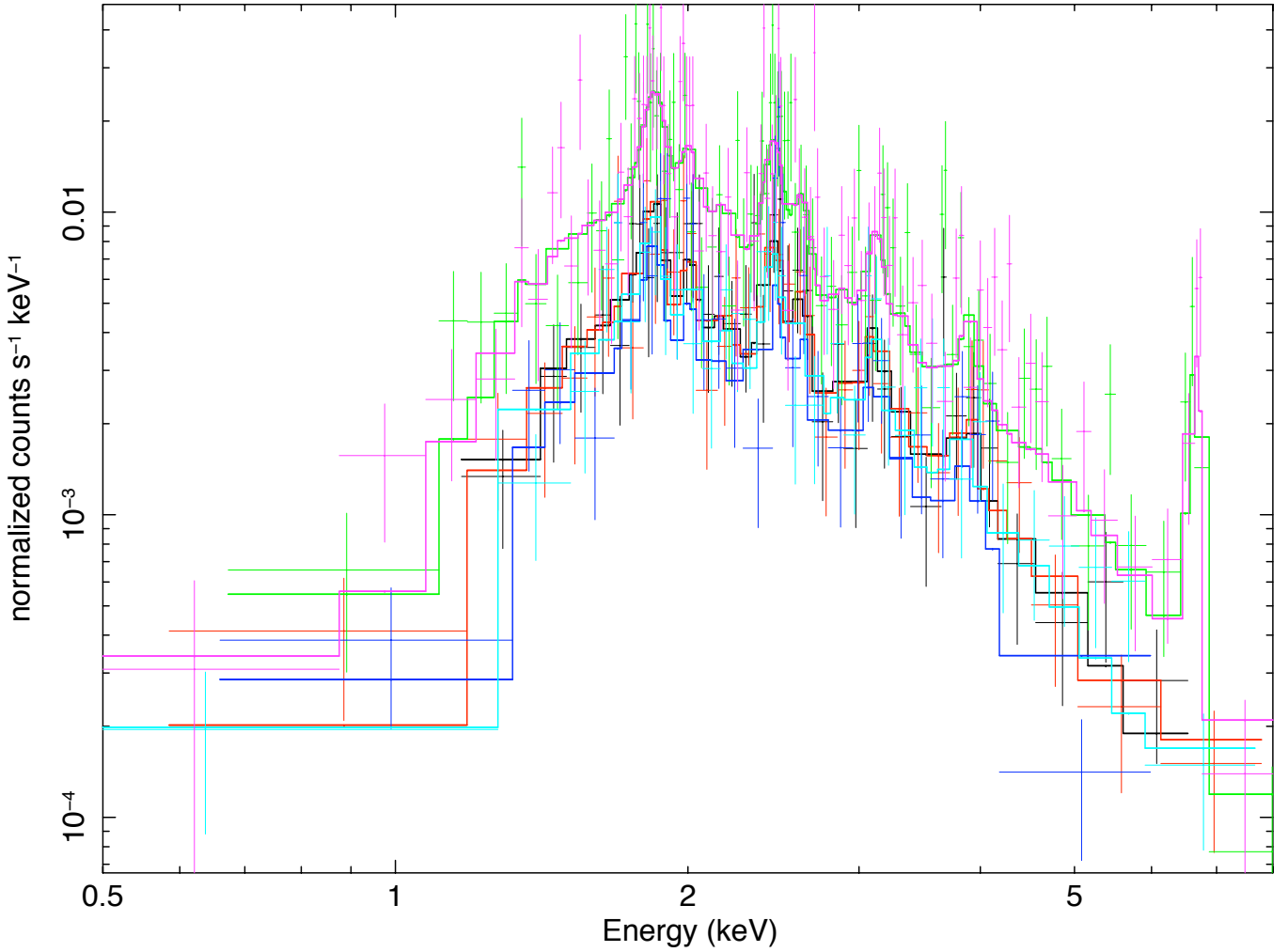


$T_e \sim 2\text{-}4 \times 10^7$ K

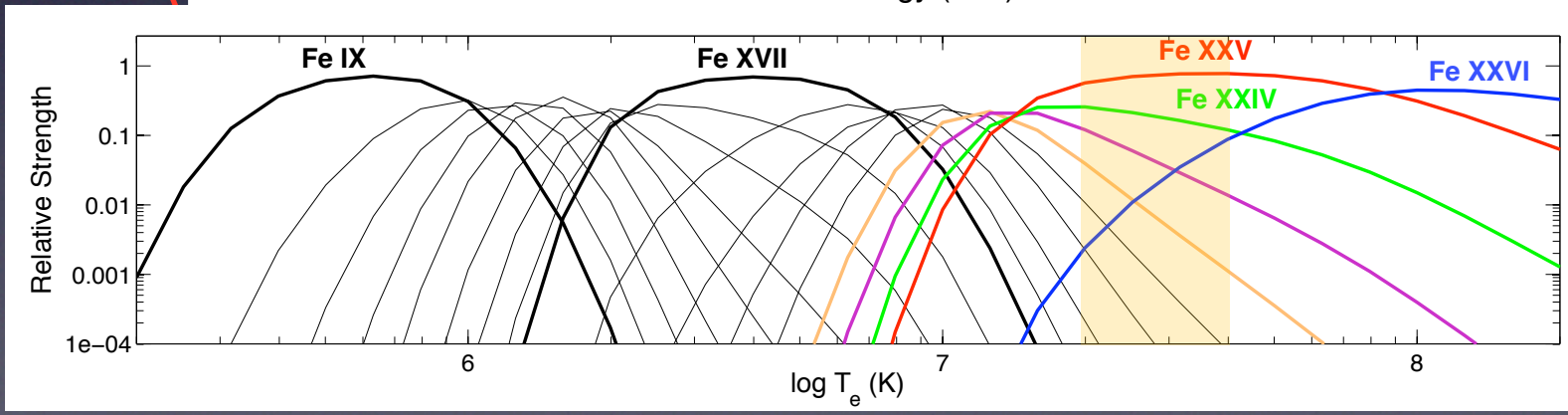


Lopez et al. 2009, ApJ, 691, 875





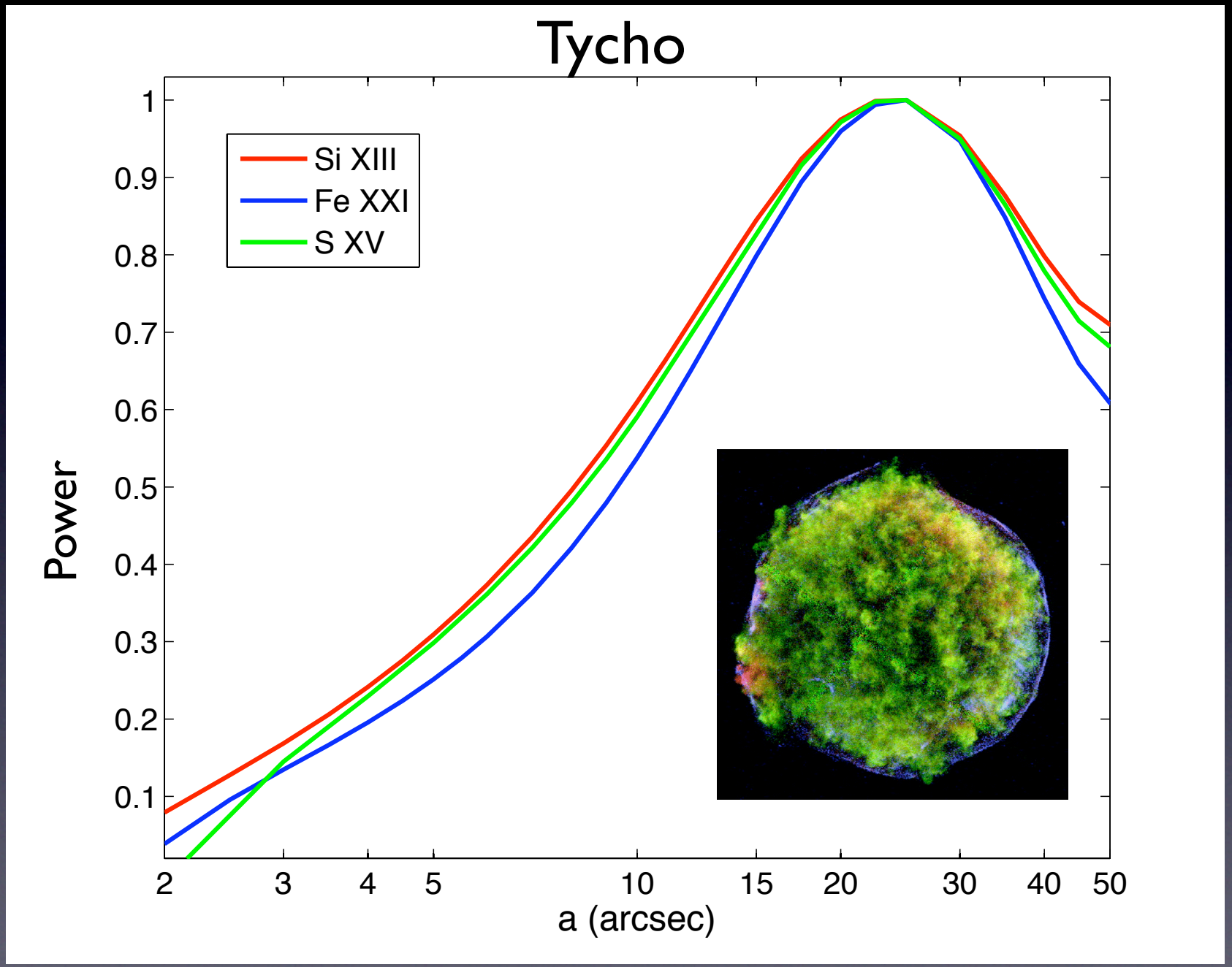
$T_e \sim 2\text{-}4 \times 10^7$ K



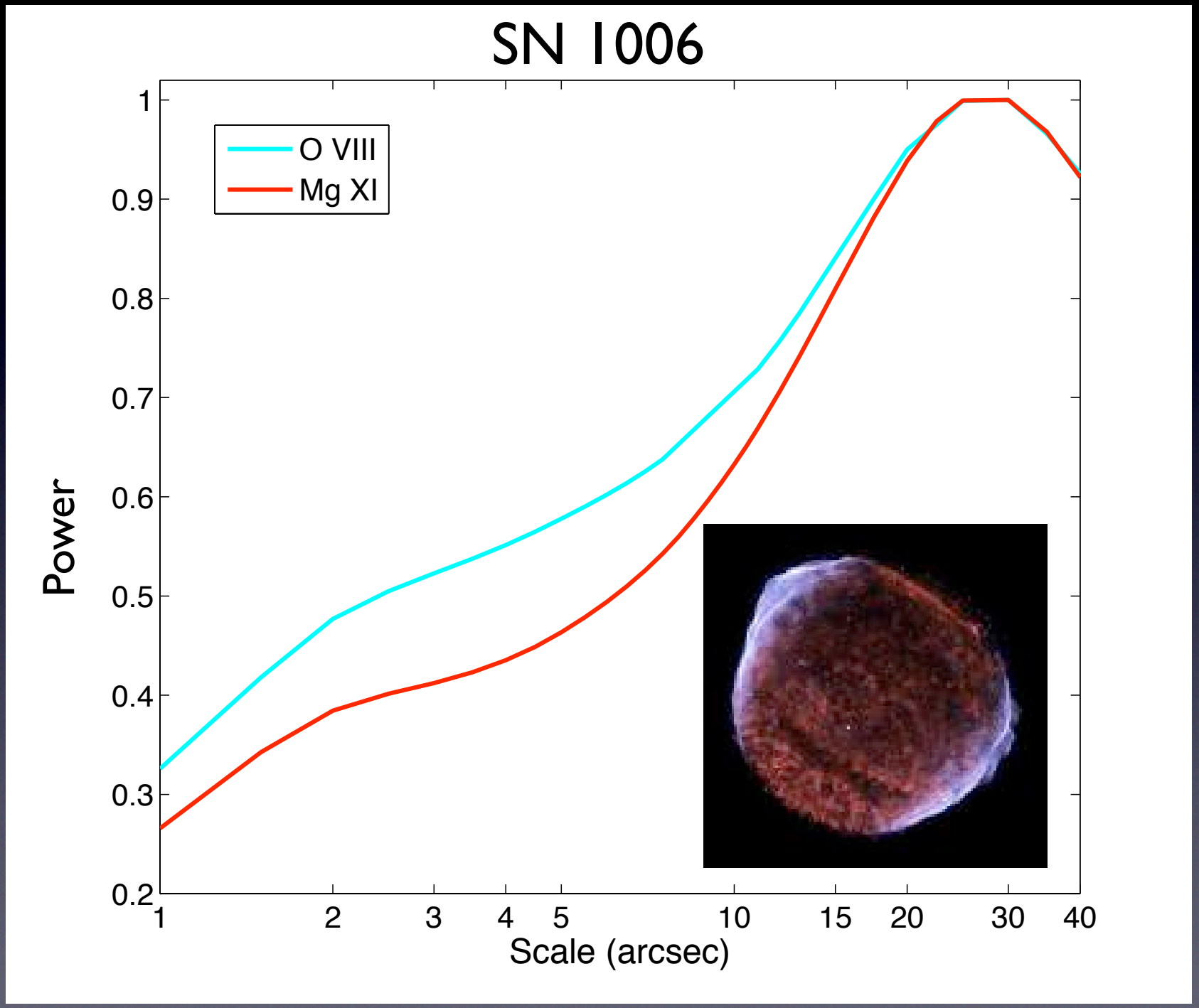
➡ Iron must have been anisotropically ejected

Lopez et al. 2009, ApJ, 691, 875

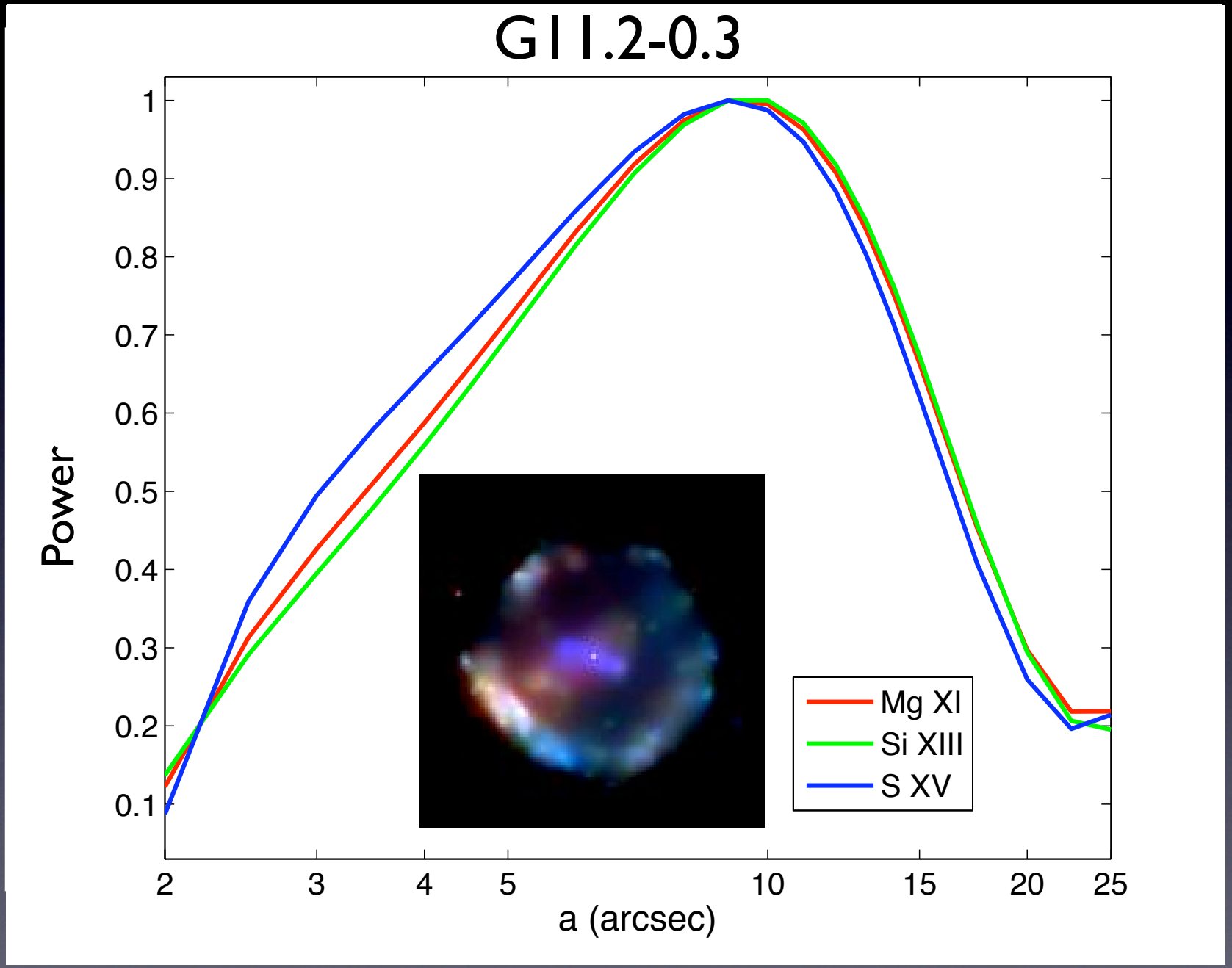
Average Power vs. Scale



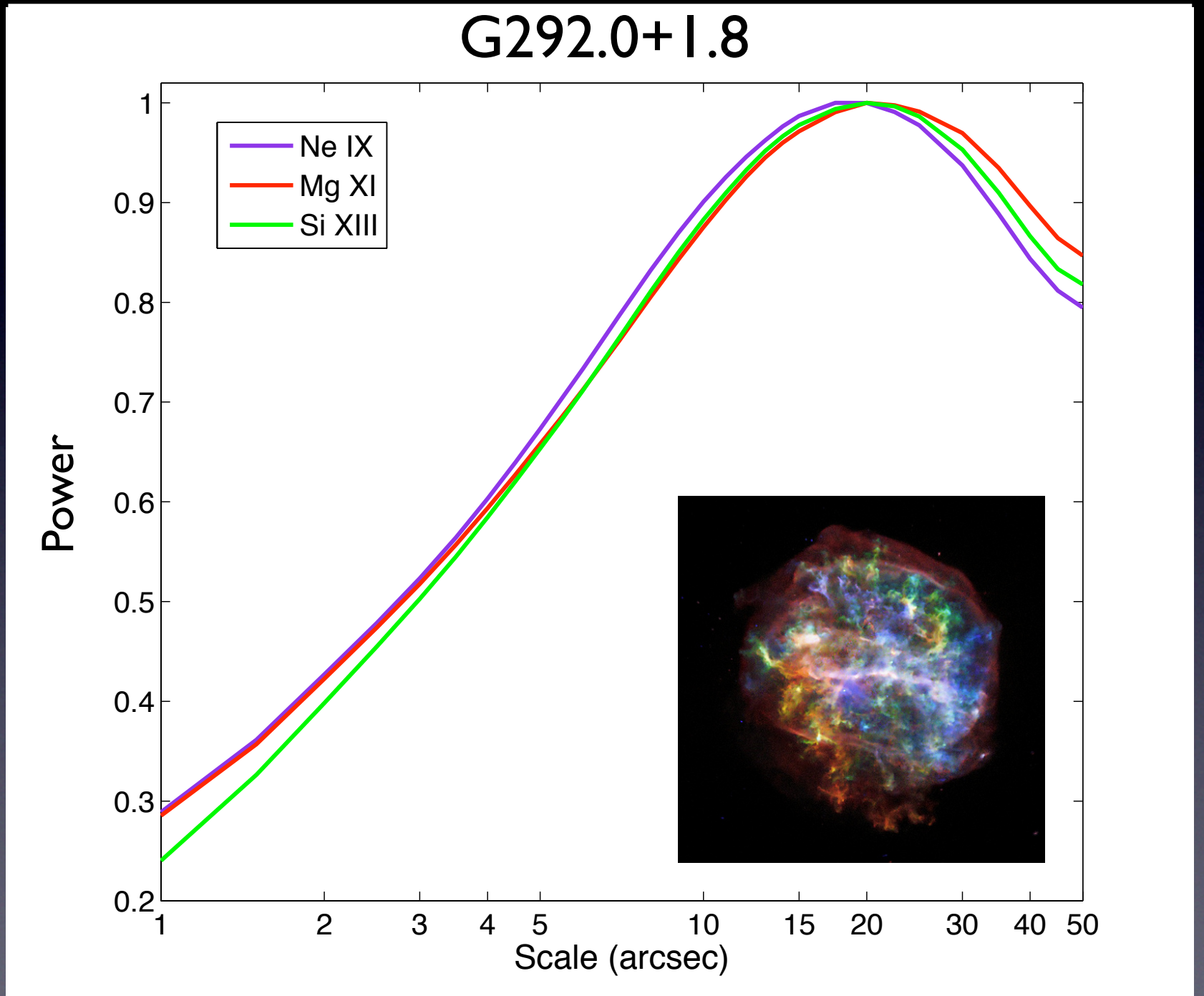
Average Power vs. Scale



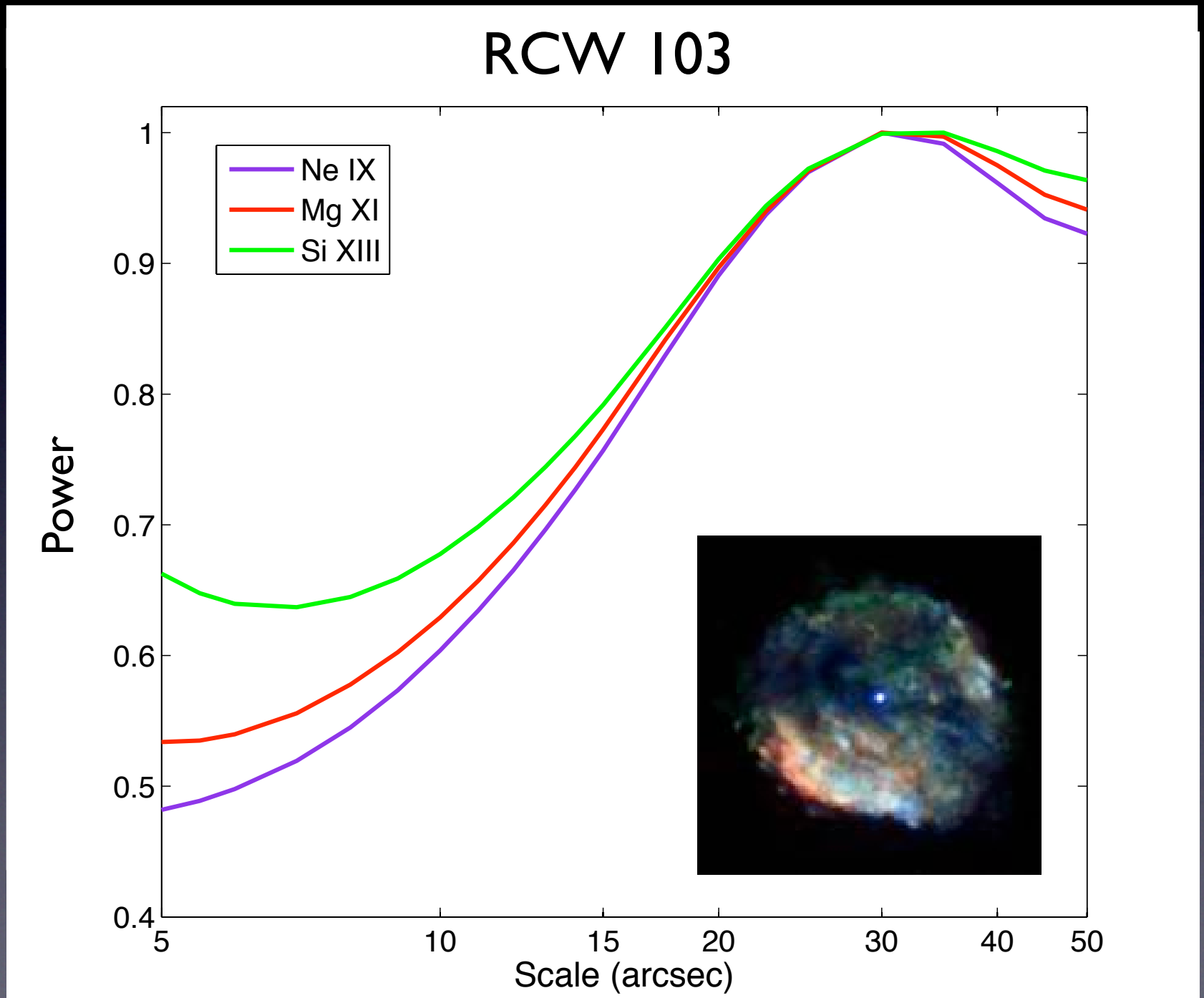
Average Power vs. Scale



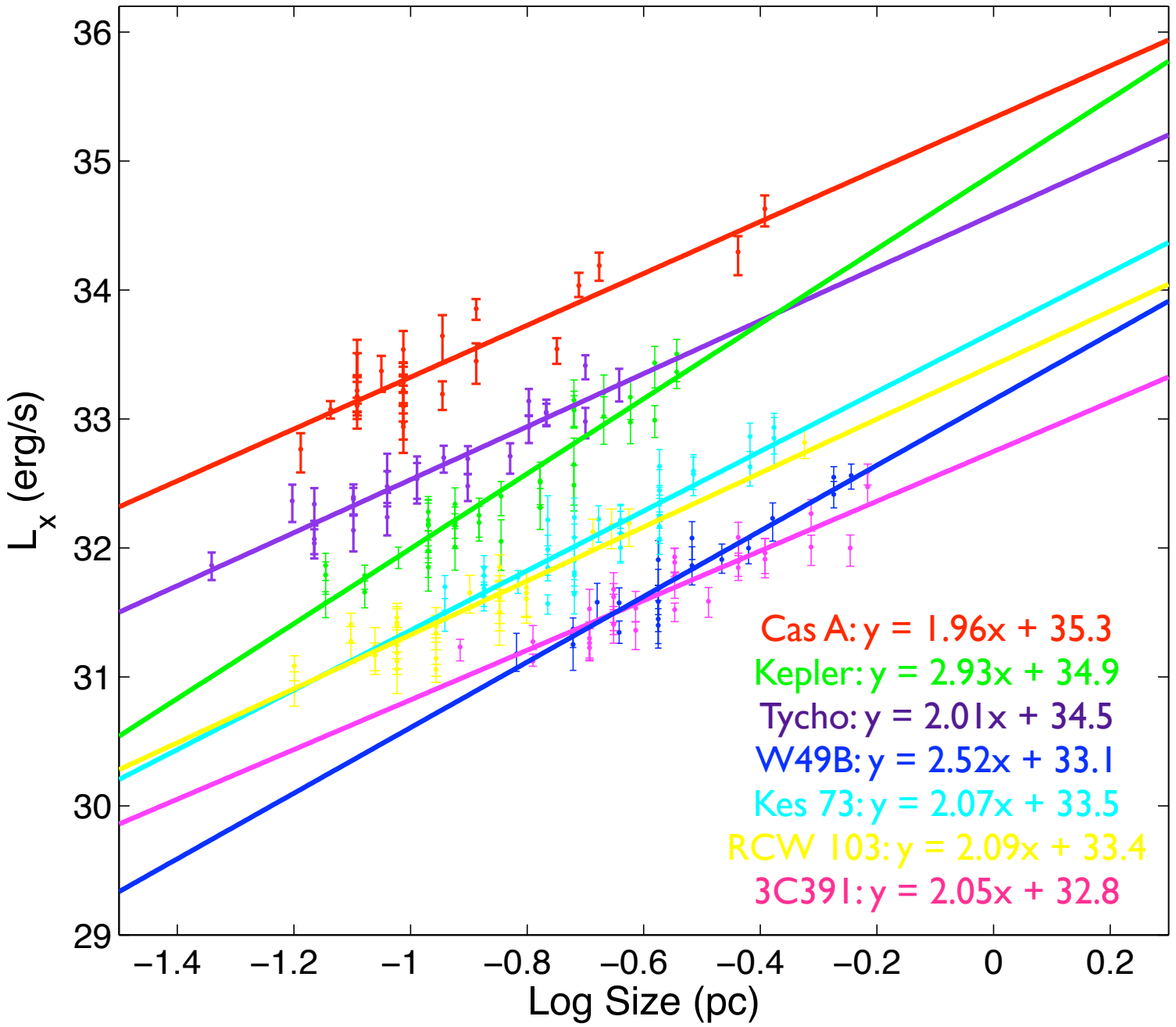
Average Power vs. Scale



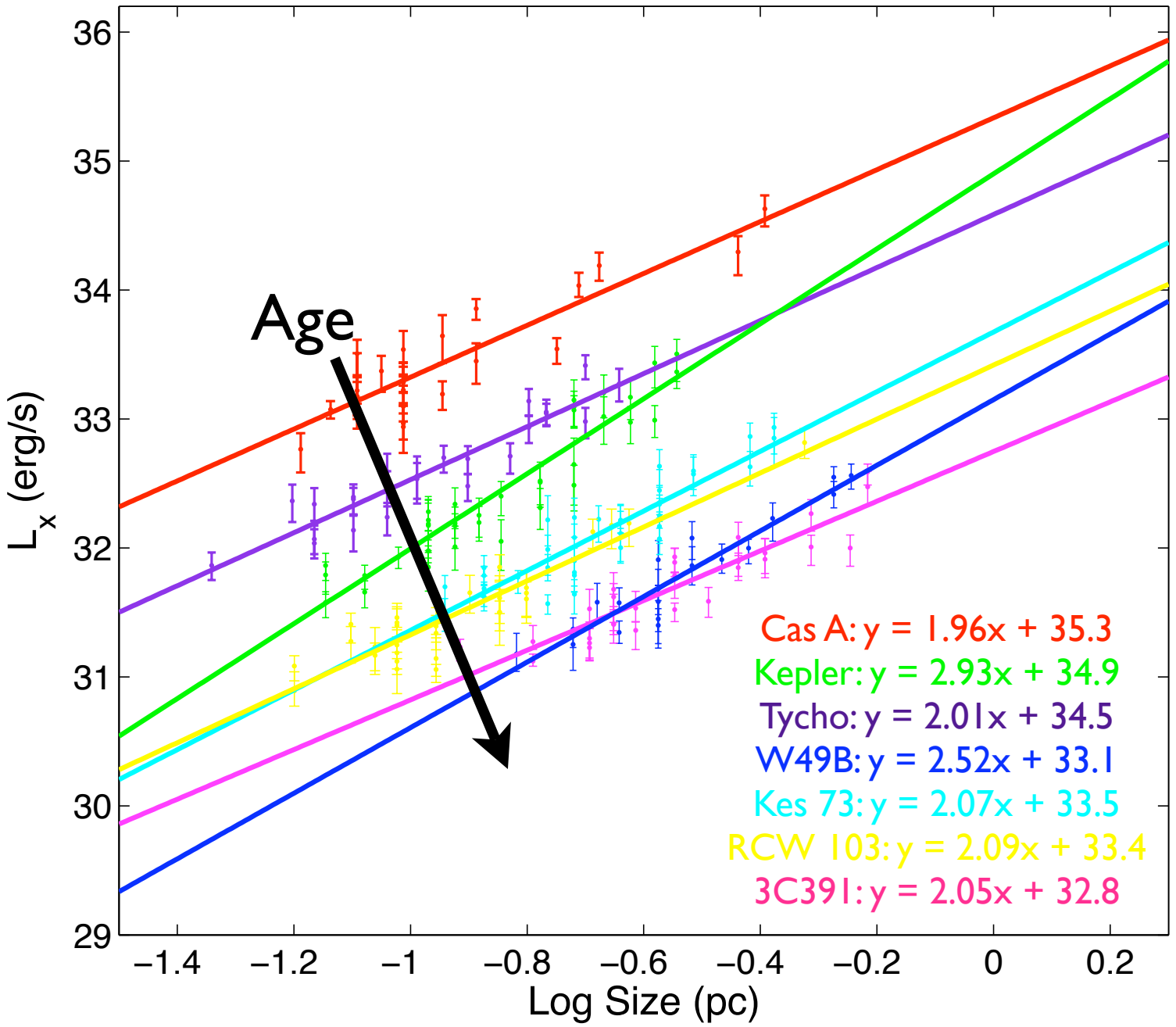
Average Power vs. Scale

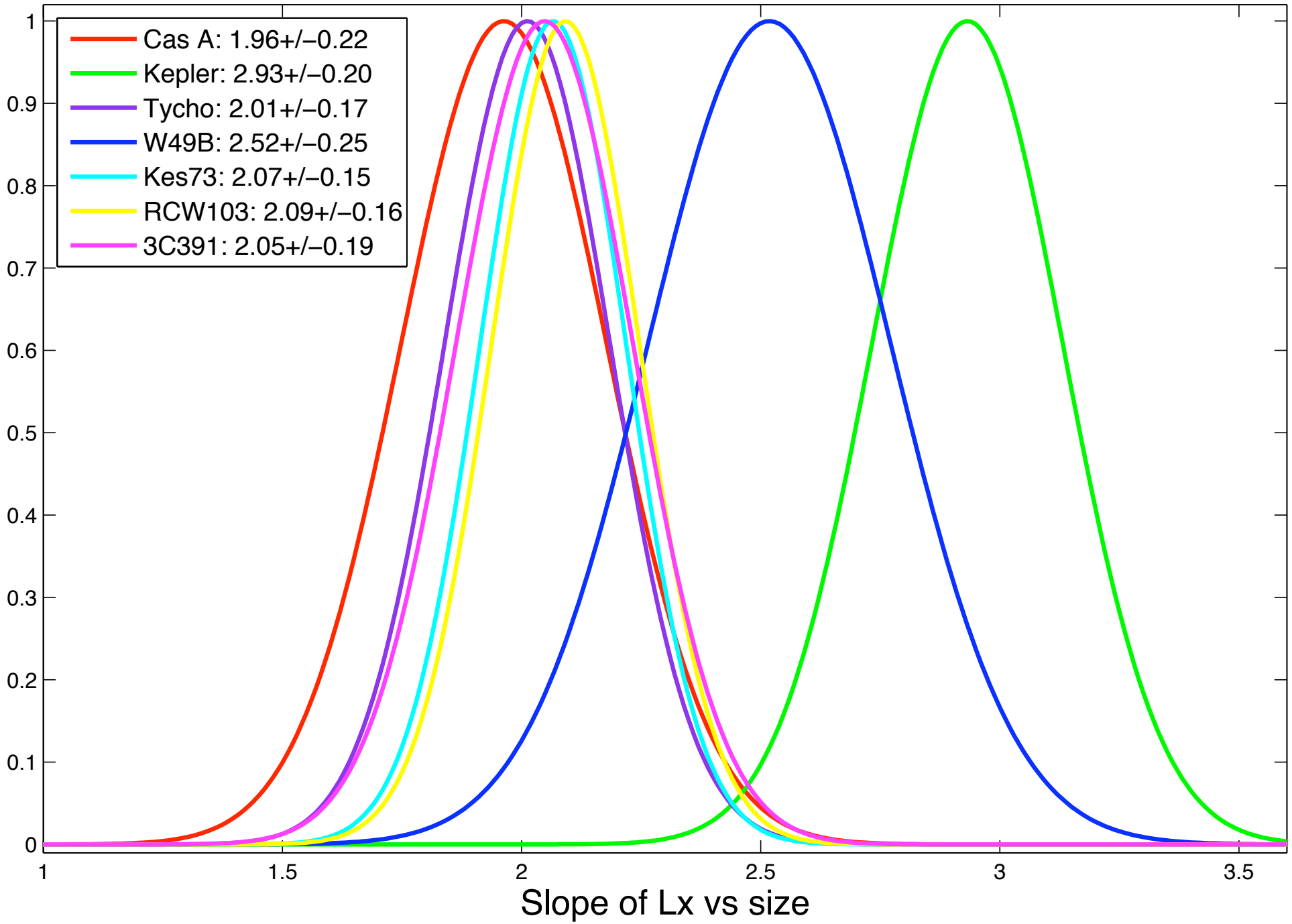


Lx vs. Clump Size



Lx vs. Clump Size




Cas A: 1.96+/−0.22
Kepler: 2.93+/−0.20
Tycho: 2.01+/−0.17
W49B: 2.52+/−0.25
Kes73: 2.07+/−0.15
RCW103: 2.09+/−0.16
3C391: 2.05+/−0.19
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
1.5
2
2.5
3
3.5
Slope of Lx vs size