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

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Motivation

Credit: Chandra Catalog of Galactic Supernova Remnants
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➡ Need *systematic, quantitative* way to compare sources

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Quantitative Measures of X-ray Morphology

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  - disentangle line from non-thermal emission

Fe XXI
Ar XVII
S XV
Si XIII
Mg XI
Ca XIX
Fe XXV
Continuum
Si XIII

Energy (keV)

normalized counts s⁻¹ keV⁻¹
Measuring Power at Many Scales
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Wavelet Transform Analysis: Characterize sub-structure scale and location by measuring/filtering power.
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Average Power vs. Scale

Kepler

- Fe XXI
- Mg XI
- Si XIII
- S XV
- Ar XVII
- Ca XIX
- Fe XXV

Power vs. Scale (arcsec)
Average Power vs. Scale

Cas A

- O VIII
- Mg XI
- Si XIII
- S XV
- Fe XXV

\[
\frac{\langle w \rangle}{a}
\]

\[a \text{ (arcsec)}\]

\[a \text{ (pc)}\]
Average Power vs. Scale


W49B

L. A. Lopez -- DARK

X-ray; 1.64 μm [Fe II]; 2.12 μm [HI]

Average Power vs. Scale

W49B

Power vs. Scale

Fe XXV
Si XIII
S XV
Ar XVII
Ca XIX

Iron
Sulfur
Silicon

W49B
L. A. Lopez -- DARK
X-ray; 1.64 μm [Fe II]; 2.12 μm [HI]


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

![Graph showing the distribution of elements Si, S, Ar, Ca, Fe with their respective X/Fe ratios and Iron regions.](image)

Consistent with models of bipolar explosions

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

Power vs. Scale / R

- Cas A
- Tycho
- Kepler
- W49B
- SN 1006
- Kes 73
- RCW 103
- G292.0+1.8
Scale vs. Age

Age

Power

Scale / R

Cas A
Tycho
Kepler
W49B
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Small-Scale Asymmetries

O VIII : Fe XXV

Fe XXI : Ca XIX
Small-Scale Asymmetries

O VIII : Fe XXV

Fe XXI : Ca XIX
Small-Scale Asymmetries

Percentage of Maximum Flux vs. Fractional Radius for Tycho: Fe XXI : Ca XIX and Cas A: O VIII : Fe XXV.

Inset images show ionized regions: O VIII : Fe XXV and Fe XXI : Ca XIX.
Multipole Expansion
Power-Ratio Method: Calculate multipole moments of the X-ray surface brightness
Multipole Expansion

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*e.g.* Buote & Tsai 1995, 1996; Jeltema et al. 2005
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\[ P_2: \text{measure of ellipticity / elongation} \]

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Multipole Expansion of Line Images
Multipole Expansion of Line Images

Core-Collapse

Type Ia

Mirror Symmetry

Ellipticity/Elongation

RCW 103
GI 2.0.2
Cas A

Tycho
Kepler
Dem L71

W49B
Kes 73
G292.0+1.8
X-ray Line Diagnostics
Type Ia and CC have similar emitting regions for all measurable emission lines
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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!
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Iron must have been anisotropically ejected

Average Power vs. Scale

Tycho

- Red: Si XIII
- Blue: Fe XXI
- Green: S XV

Power vs. Scale $a$ (arcsec)
Average Power vs. Scale

SN 1006

Power

Scale (arcsec)

O VIII
Mg XI

Inset image of SN 1006
Average Power vs. Scale

![Graph showing average power versus scale for Mg XI, Si XIII, and S XV. The graph includes a scale from 2 to 25 arcsec and power values from 0.1 to 1.0. The inset image depicts the distribution of power across different scales.]
Average Power vs. Scale

G292.0+1.8

Scale (arcsec)

Ne IX
Mg XI
Si XIII

Power

Scale (arcsec)
Average Power vs. Scale

RCW 103

Power

Scale (arcsec)

Ne IX
Mg XI
Si XIII
Lx vs. Clump Size

\[ L_x = 1.96x + 35.3 \]
\[ \text{Kepler: } y = 2.93x + 34.9 \]
\[ \text{Tycho: } y = 2.01x + 34.5 \]
\[ \text{W49B: } y = 2.52x + 33.1 \]
\[ \text{Kes 73: } y = 2.07x + 33.5 \]
\[ \text{RCW 103: } y = 2.09x + 33.4 \]
\[ \text{3C391: } y = 2.05x + 32.8 \]
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Slope of Lx vs 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