Particle Acceleration in the Furiously Fast Shockwaves of SN 1006

Brian J. Williams (NASA/GSFC)

on behalf of

Satoru Katsuda
P. Frank Winkler
Knox S. Long
Robert Petre
Stephen P. Reynolds

THE LAST TALK!!!!

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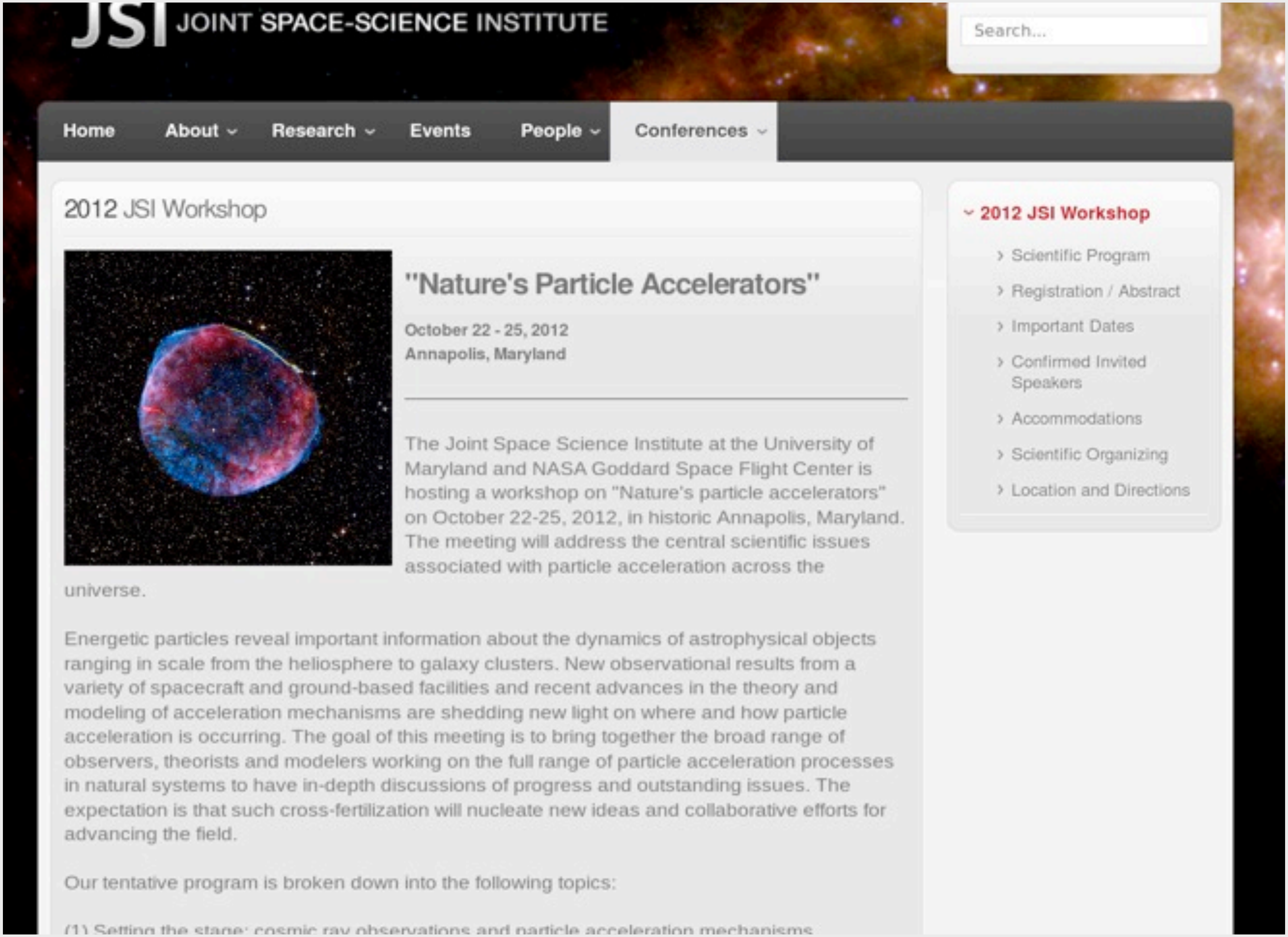
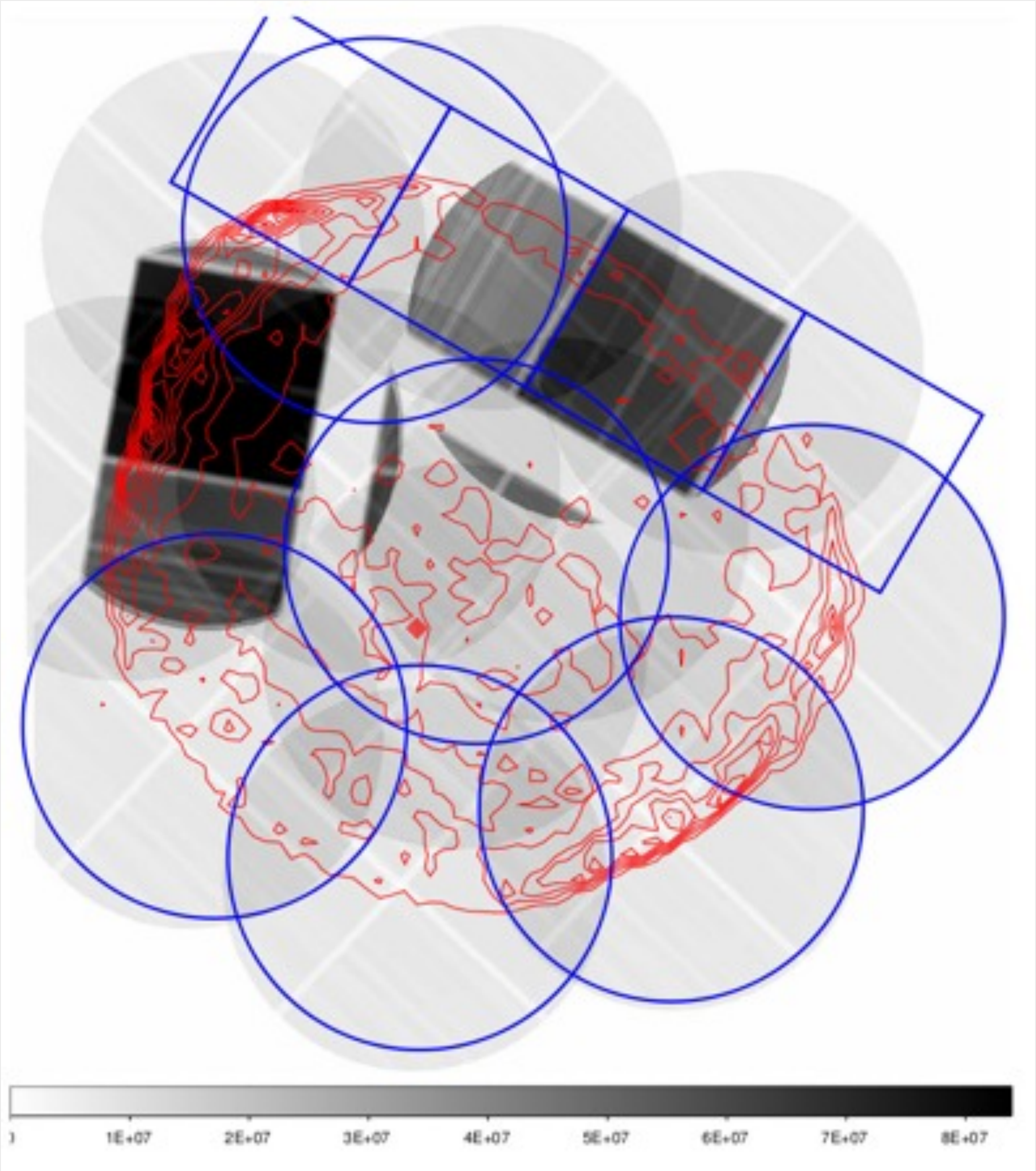
SN 1006 is, literally, the poster-child for particle acceleration



Website for “Nature’s Particle Accelerators,” Oct. 2012, Annapolis, MD

Motivation for Chandra Large Project



Exposure map of previous Chandra observations, depth varies from 140 ks to 20 ks, overlaid with our new observations in blue

Motivation for Chandra Large Project

- Fundamental questions:

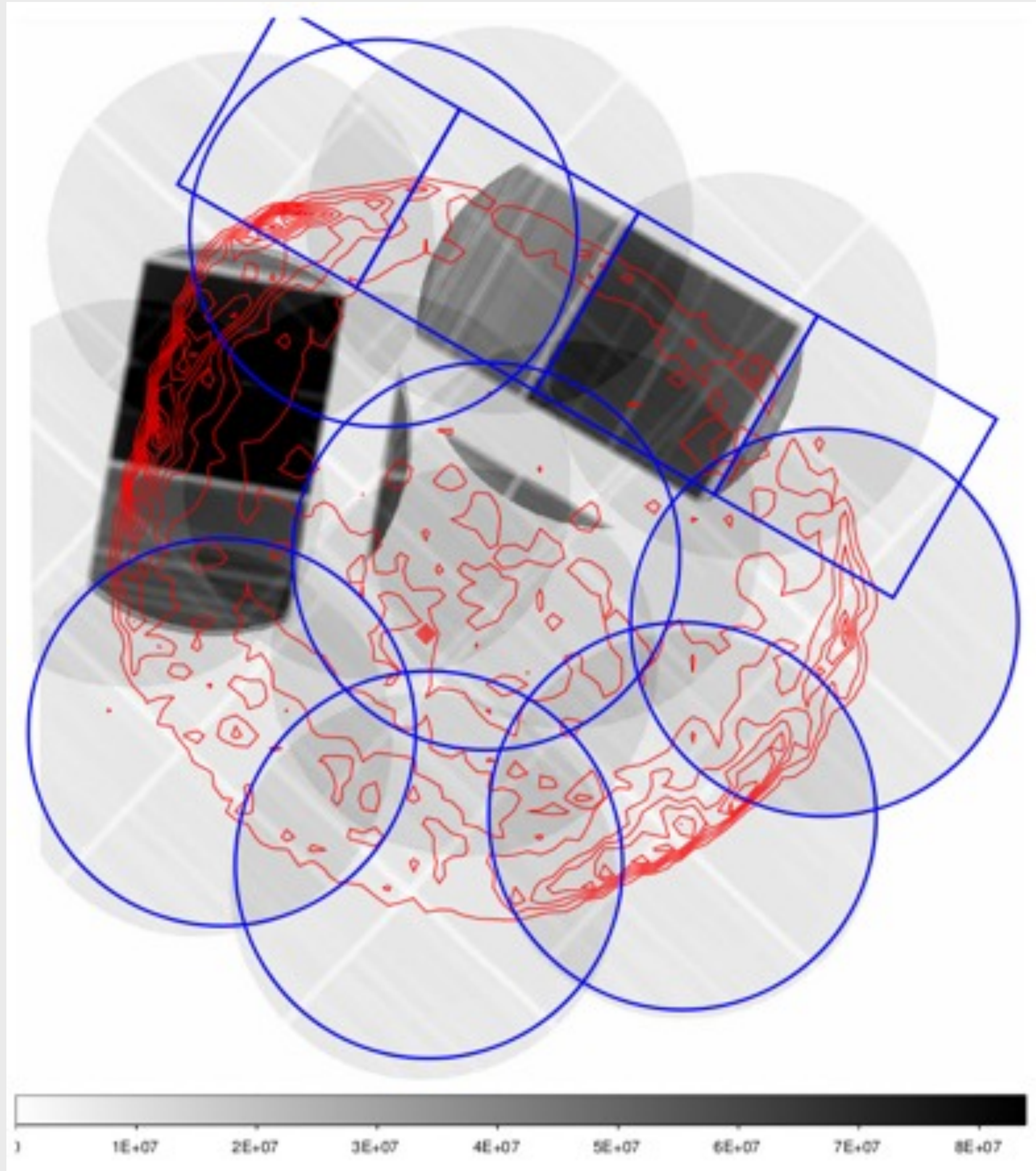
What mechanism limits e^- acceleration?

How do e^- acceleration rate & B-field amplification vary with azimuth?

How does B-field strength evolve behind shock?

- Chandra resolution is a must for: 1) shock proper motions, 2) detailed study of synchrotron emission, 3) small-scale ejecta structure

- AO-13 program (PI: P.F. Winkler) now complete. Observed entire remnant to minimum depth of 100 ks; more in most places; total time ~700 ks



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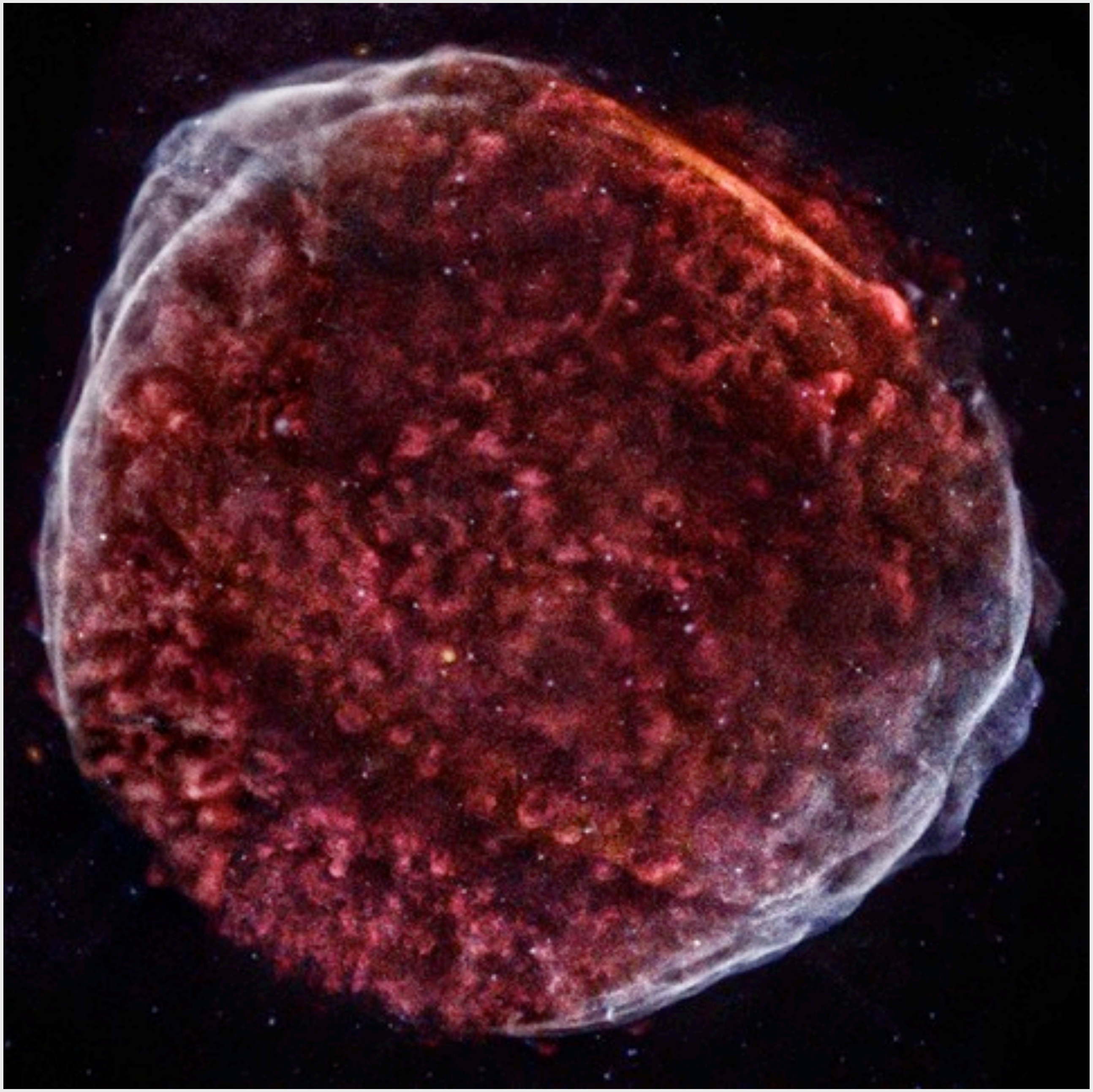
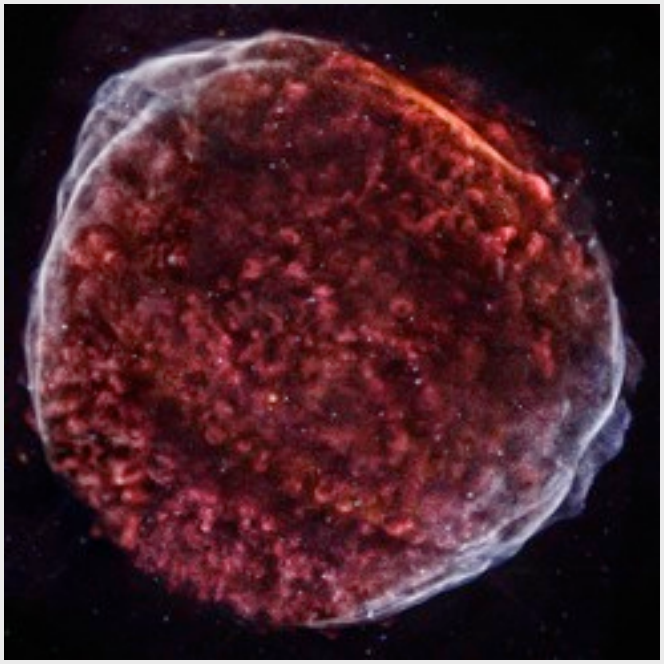
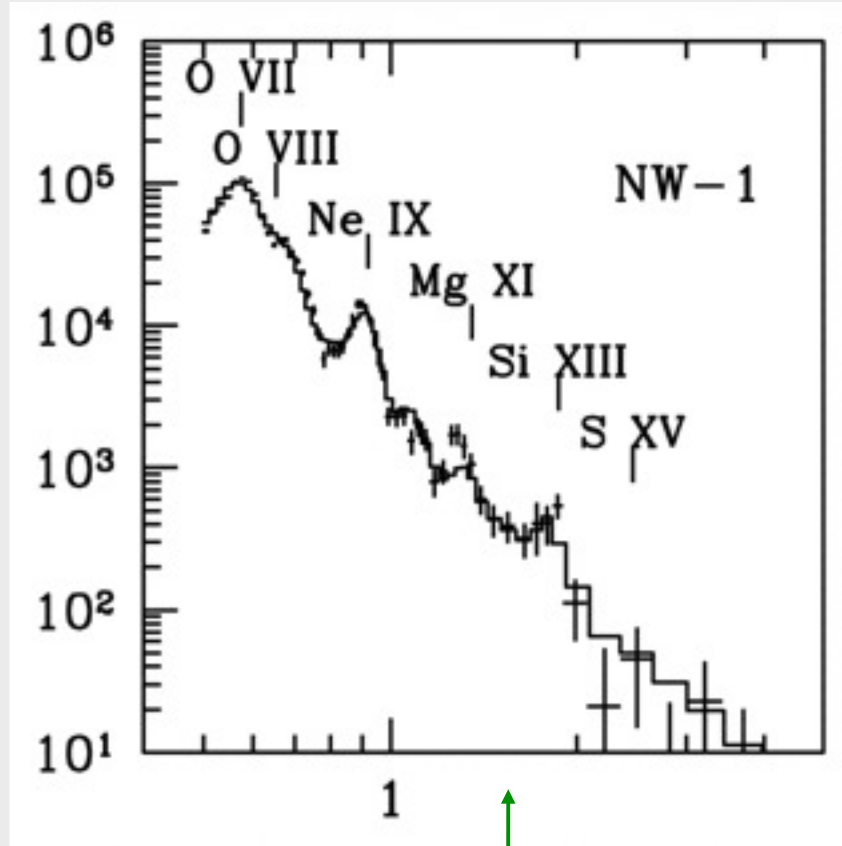
700 ks of SN 1006 from Chandra



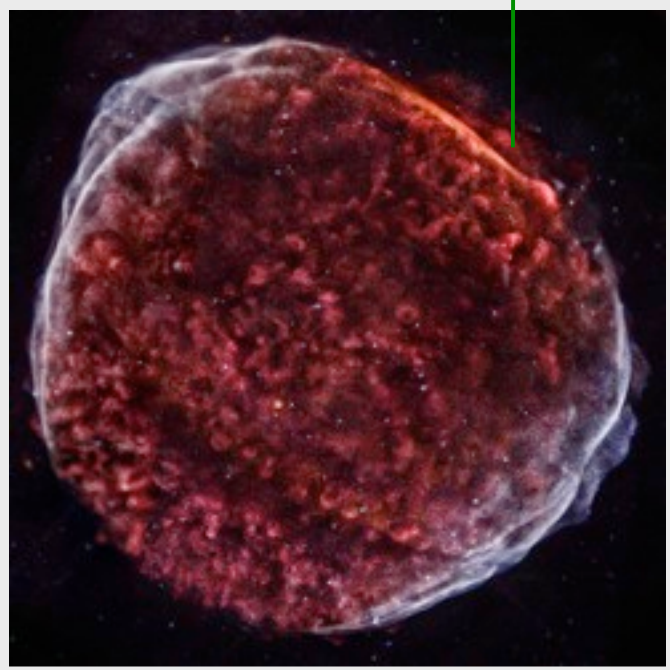
Chandra press release image, April 2013

0.5-1.2 keV
1.2-2.0 keV
2.0-7.0 keV
~6 million counts





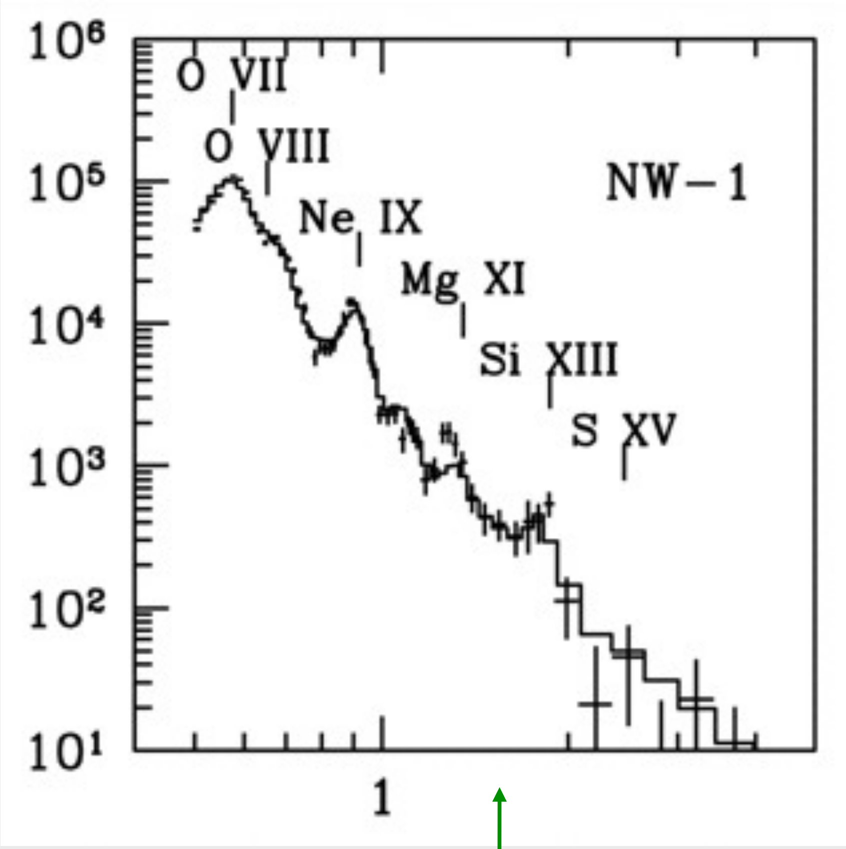
10^6
10^5
10^4
10^3
10^2
10^1
1
O VII
O VIII
Ne IX
Mg XI
Si XIII
S XV
NW−1



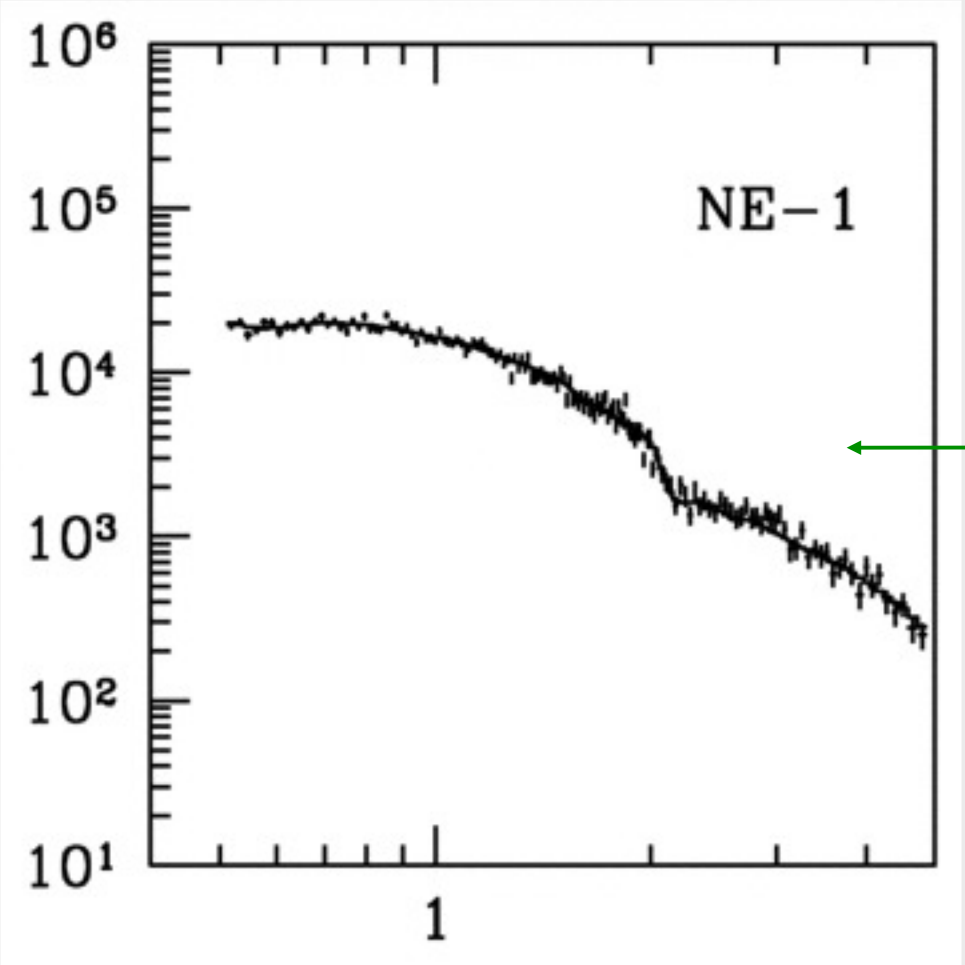
- X-rays in NE & SW entirely nonthermal, well-fit by synchrotron model, *srcut*

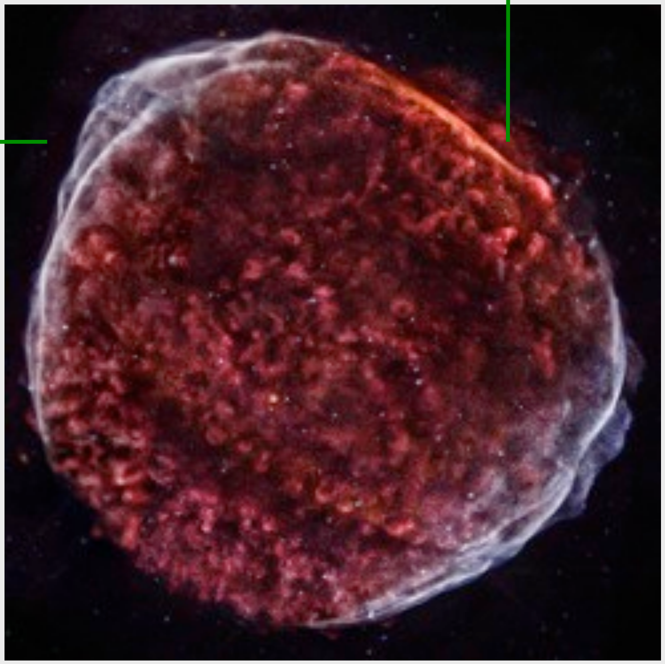
- *srcut* assumes power-law distribution of e^- energies (predicted by DSA theory), up to characteristic value E_{max}, ν_{roll} is peak frequency emitted by these e^-'s

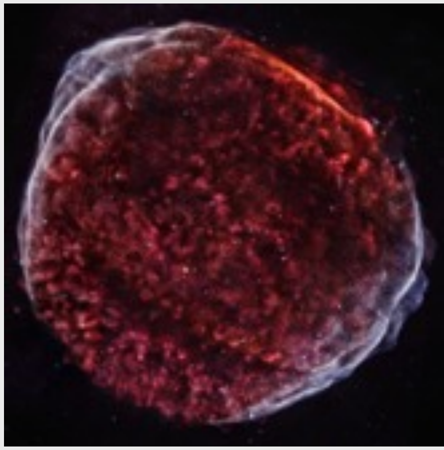
- Long+ 2003 found that rims are a few x 10" in width, ν_{roll} of 6.9 x 10^{17} Hz implies E_{max} for e^-'s of ~50 $B_{10}^{1/2}$ TeV.



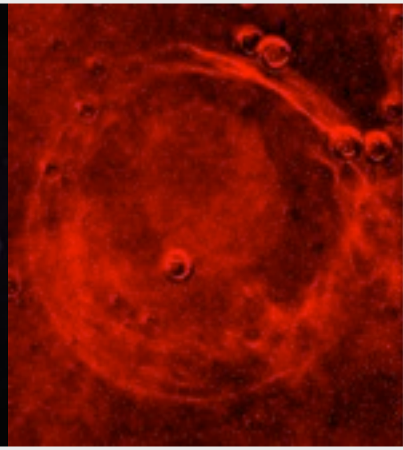
Figures from Long+ 2003



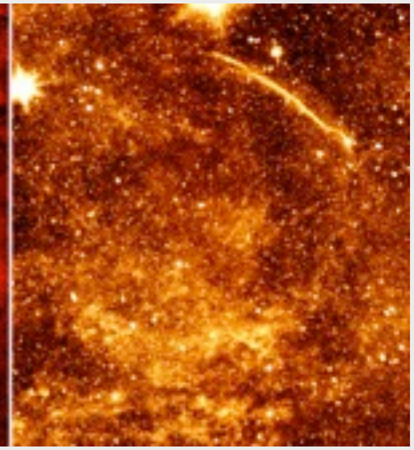




Chandra (2012)

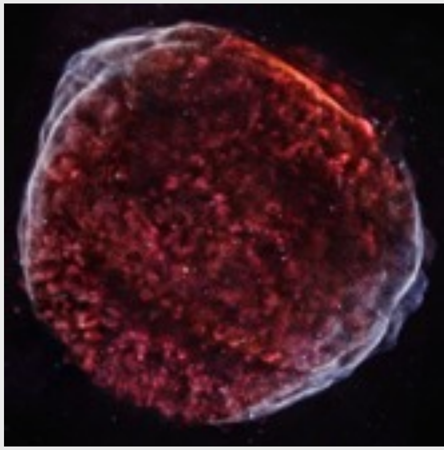


Hα (courtesy F. Winkler)



Spitzer IR

- Often considered "prototypical" case of Type Ia SNR
- High gal. latitude; nearby (2.2 kpc), very large (~30' diameter); low-absorption = well-studied
- Very low density environment, uniform expansion(?)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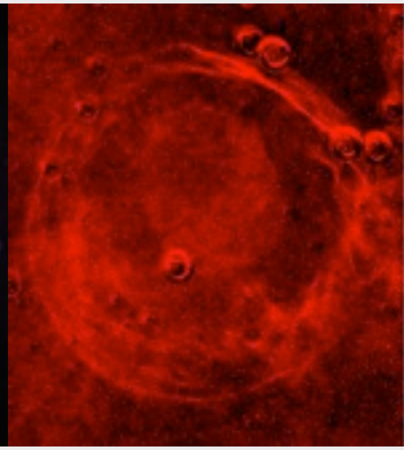
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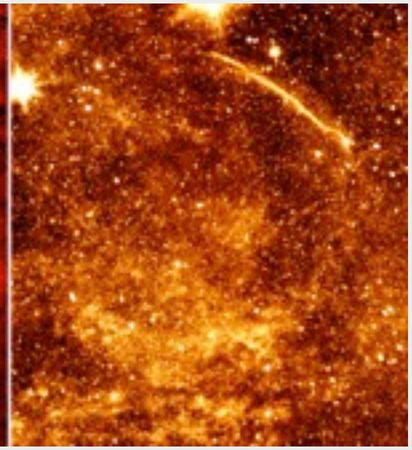
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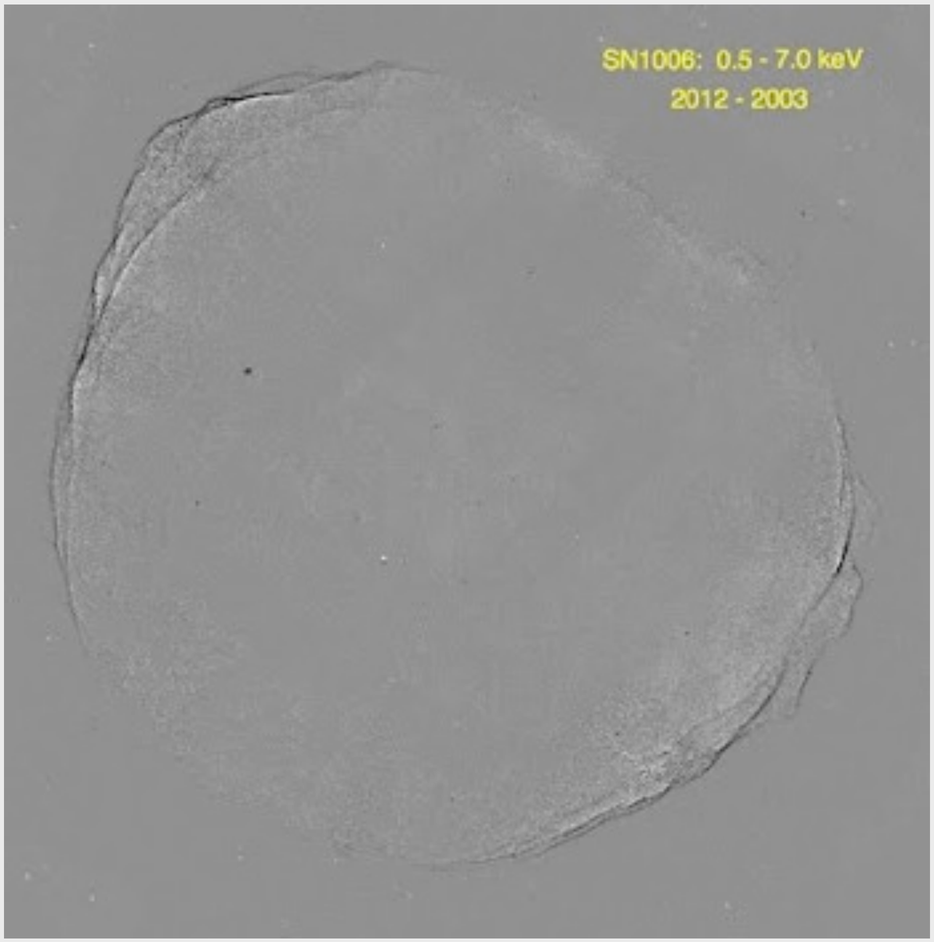
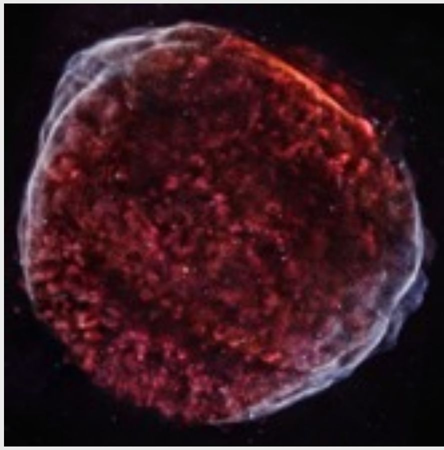


Chandra proper motions over 9-year baseline; known distance = shock velocity

Winkler, **BJW**+, in prep.



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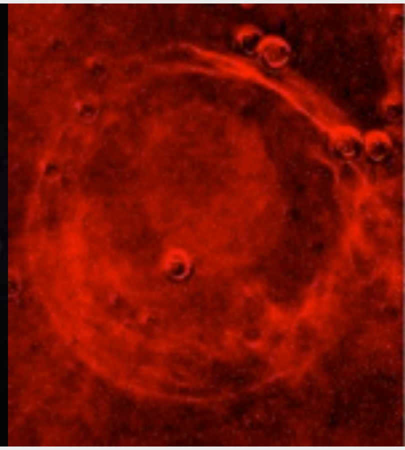

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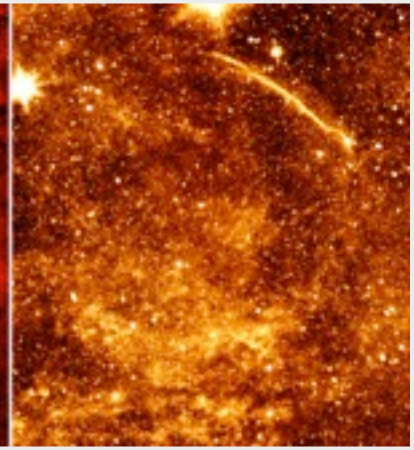

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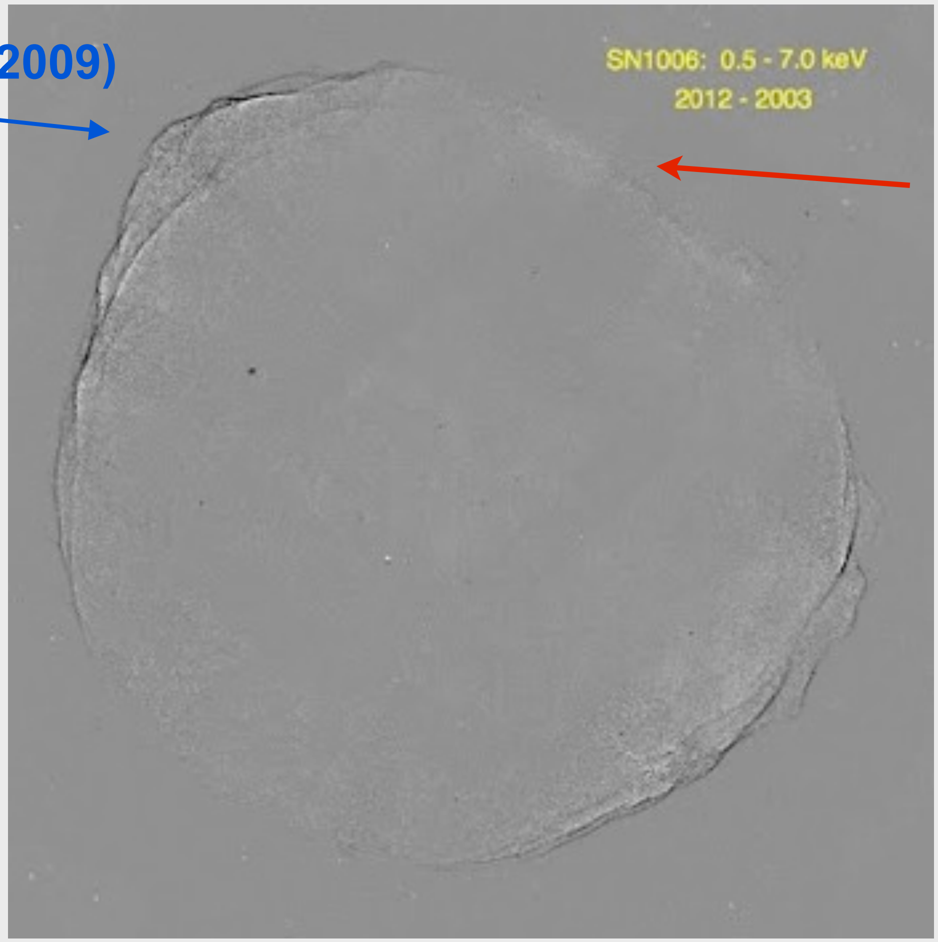
5000 km/s (Katsuda+ 2009)



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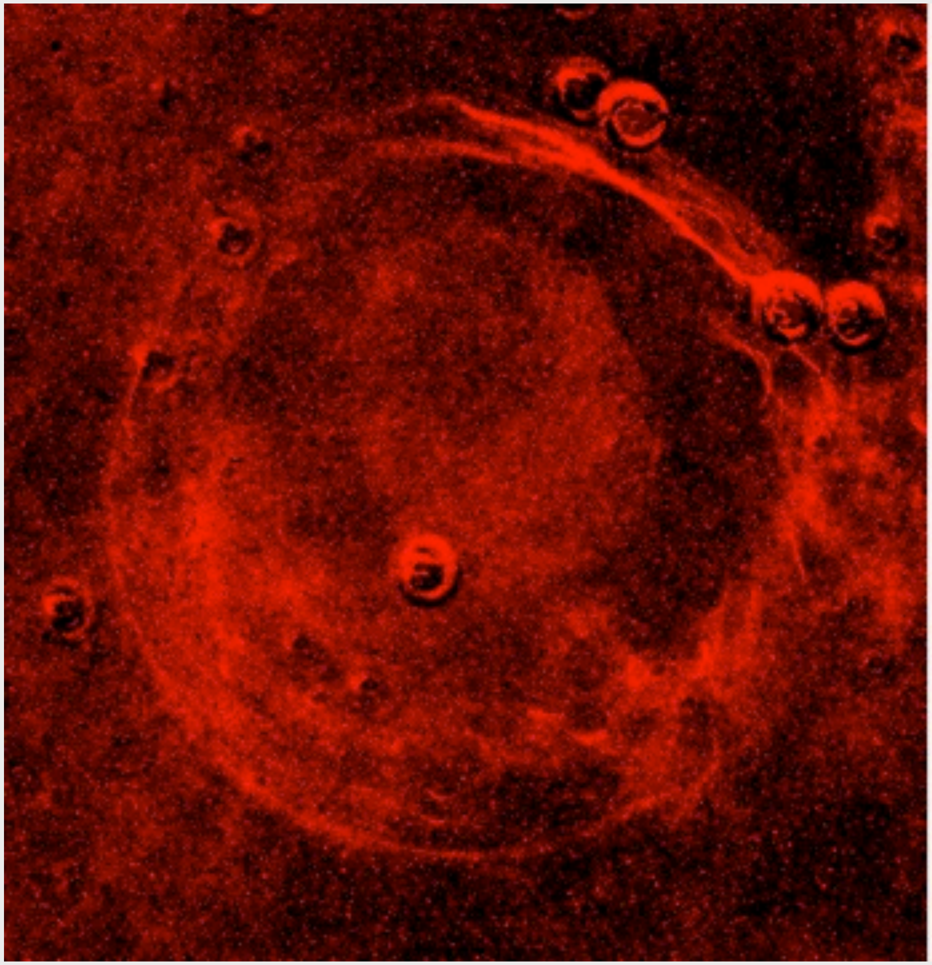
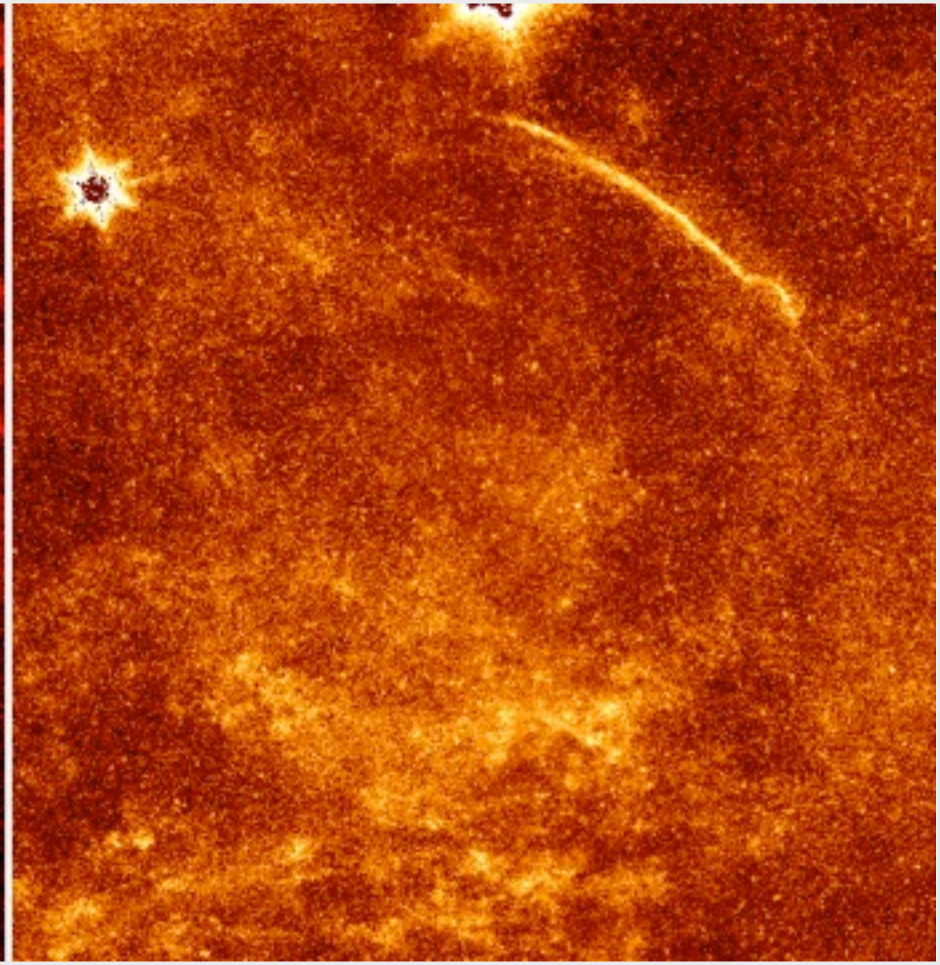


Optical Hα image



Spitzer 24 μm

NW filament in SN 1006 is:

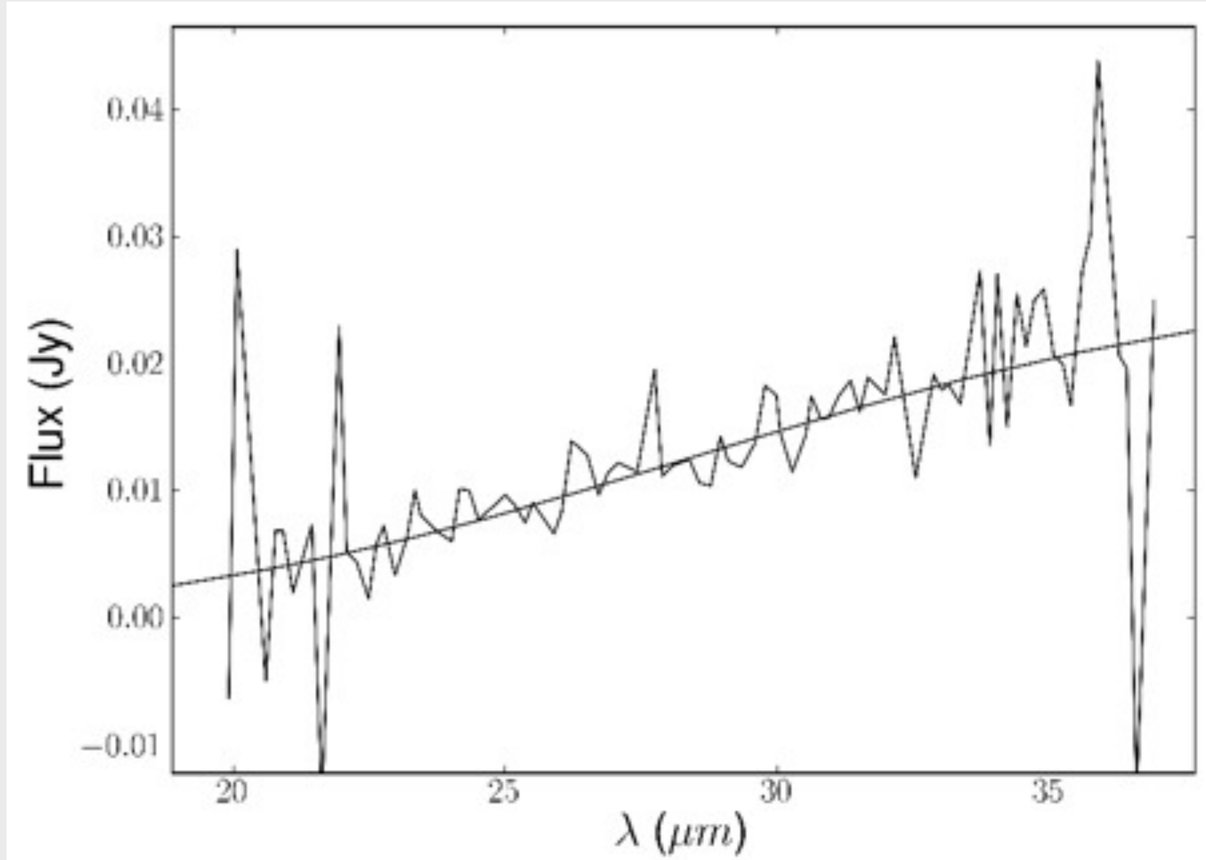
a) dominated by thermal X-ray emission
b) strongest region of optical emission, by far
c) only place where IR emission from warm dust is seen
d) all of the above

What is different about NW of SN 1006?

Northwest Filament

- **IR emission is sensitive function of post-shock density**

- IR spectrum implies post-shock density = 1 cm^{-3} (Winkler, **BJW**+ 2013), consistent with optical measurement (Heng+ 2007)



Spitzer IRS spectrum from NW filament of SN 1006

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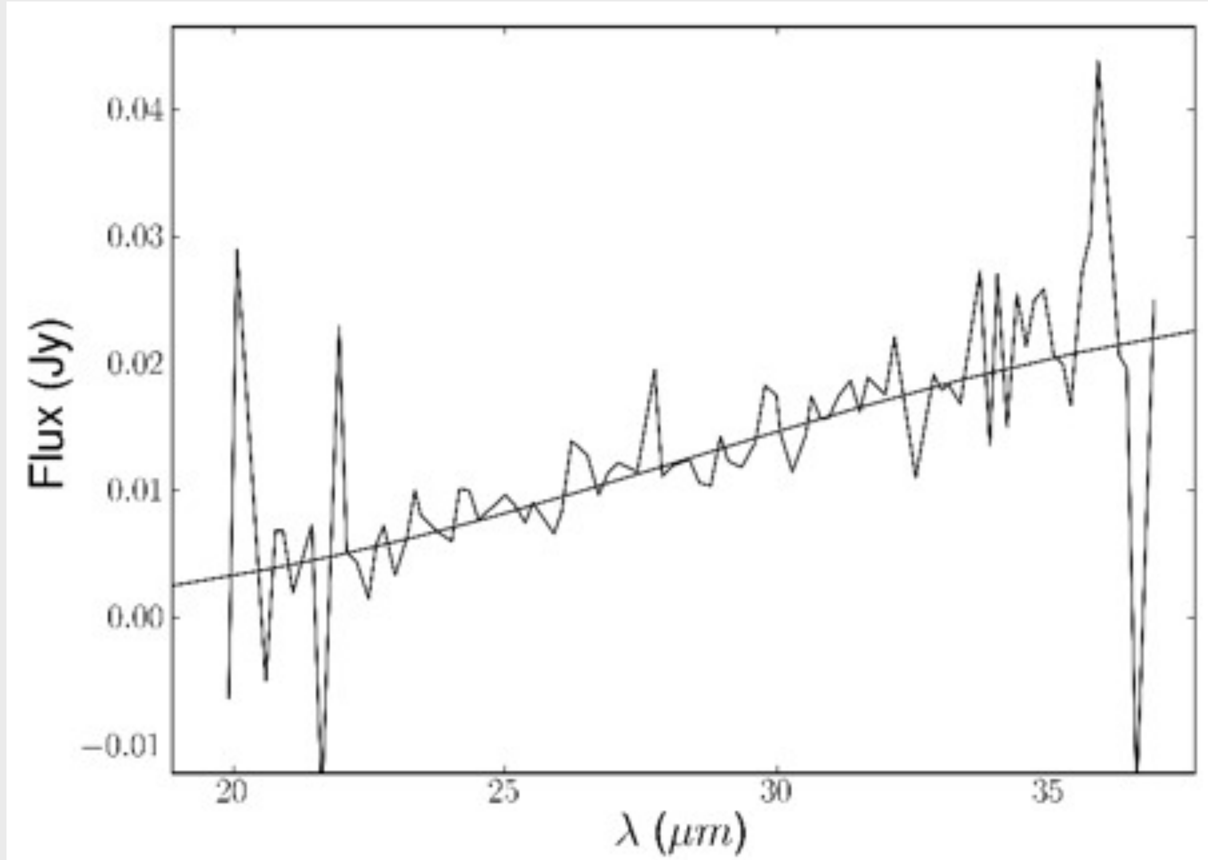

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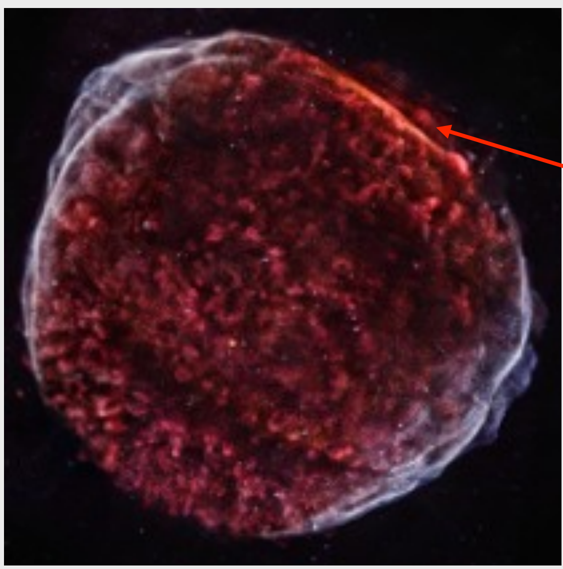
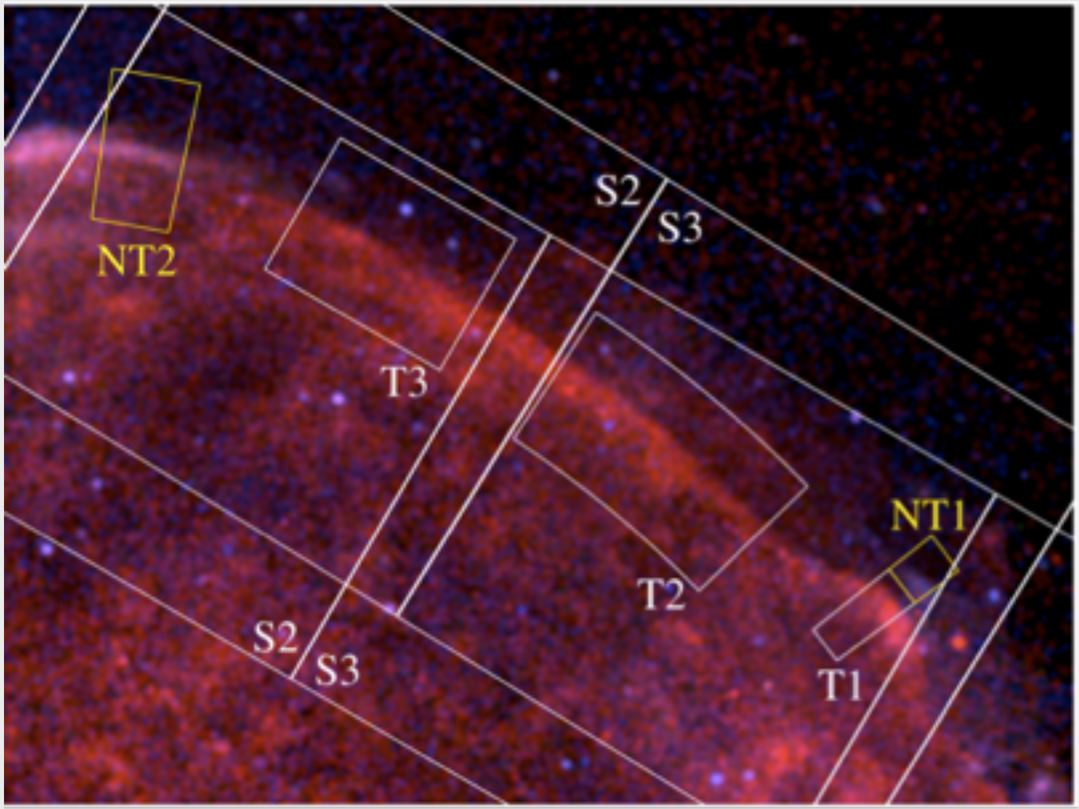
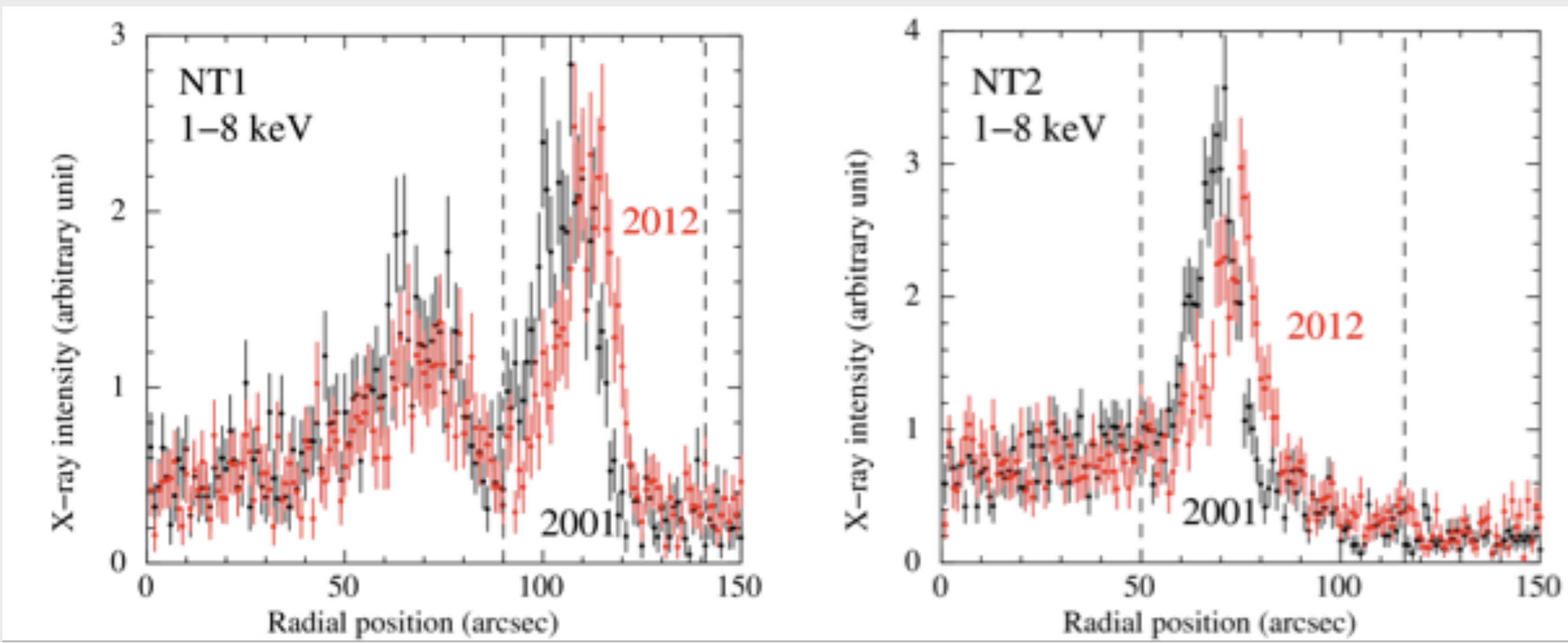


Here be ~~dragons~~ denser ISM

Perhaps nothing paradigm-shifting about SNIa, but means significant ISM density inhomogeneities exist on parsec scales, even 500 pc above Galactic plane

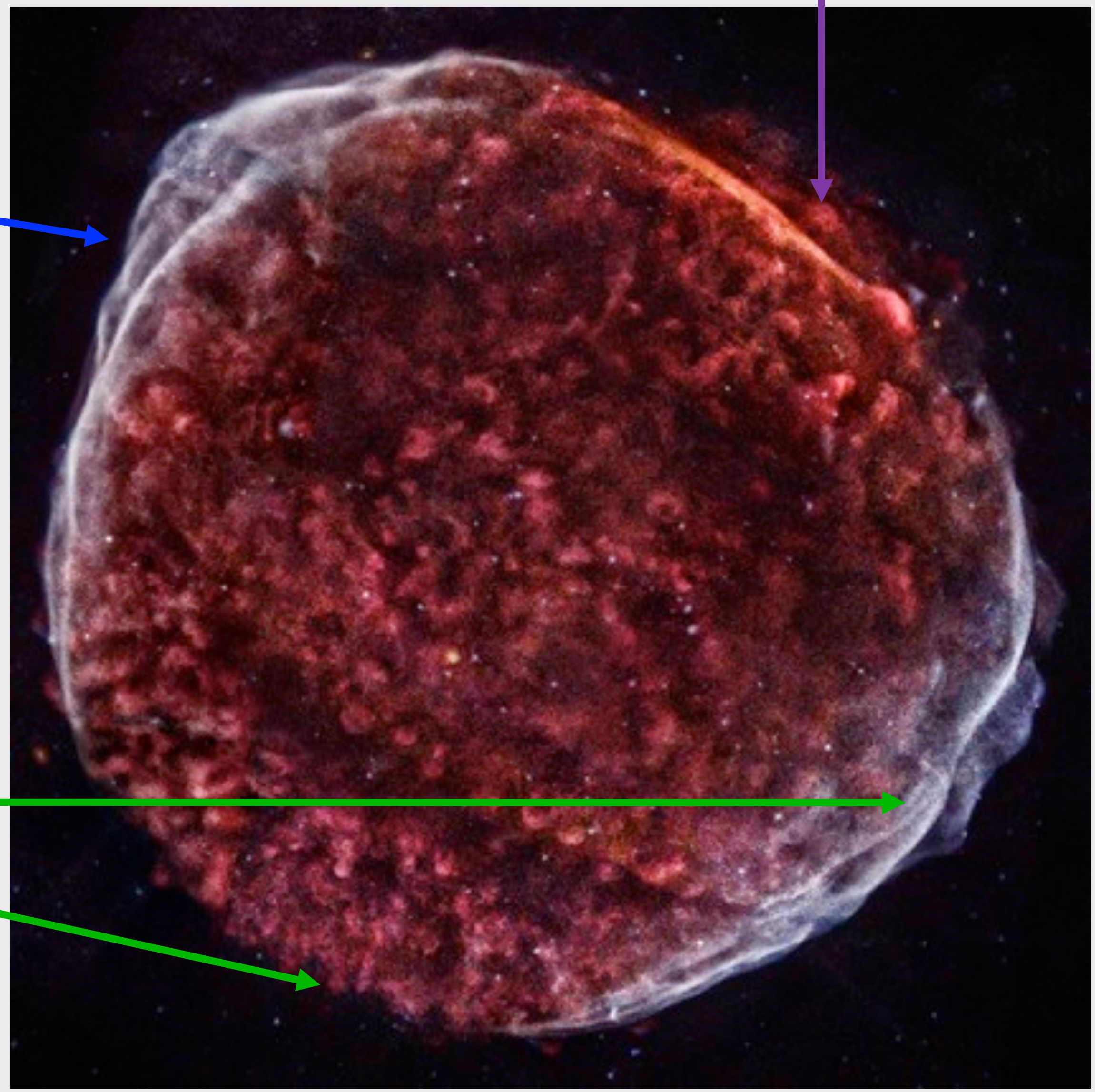


But localized regions of nonthermal emission exist in NW as well! ***In these regions, v_s = 5000 km/s,*** same as nonthermal-dominated regions in NE

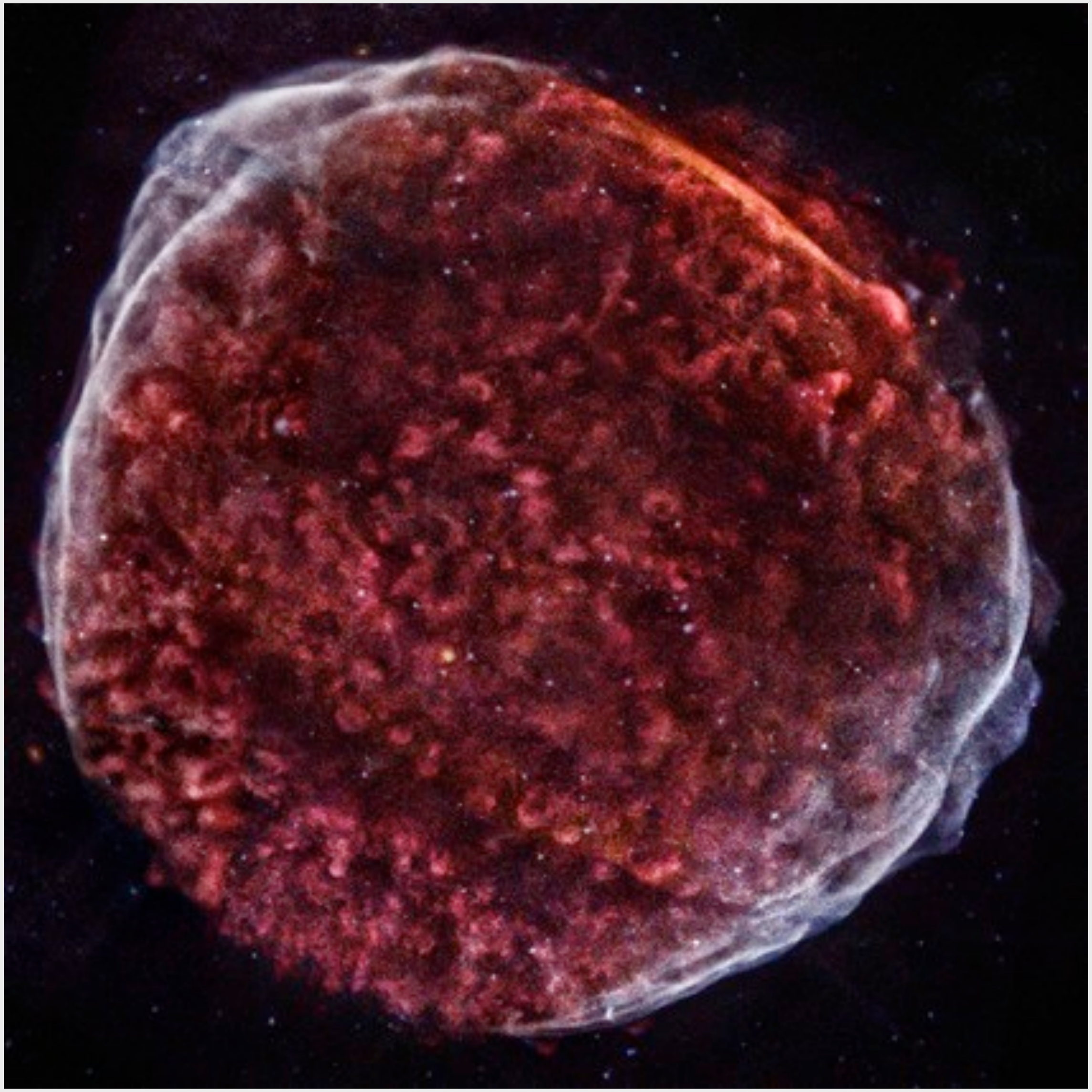


v_s = 3000 km/s, X-ray emission thermal, but little regions are nonthermal with v_s = 5000 km/s

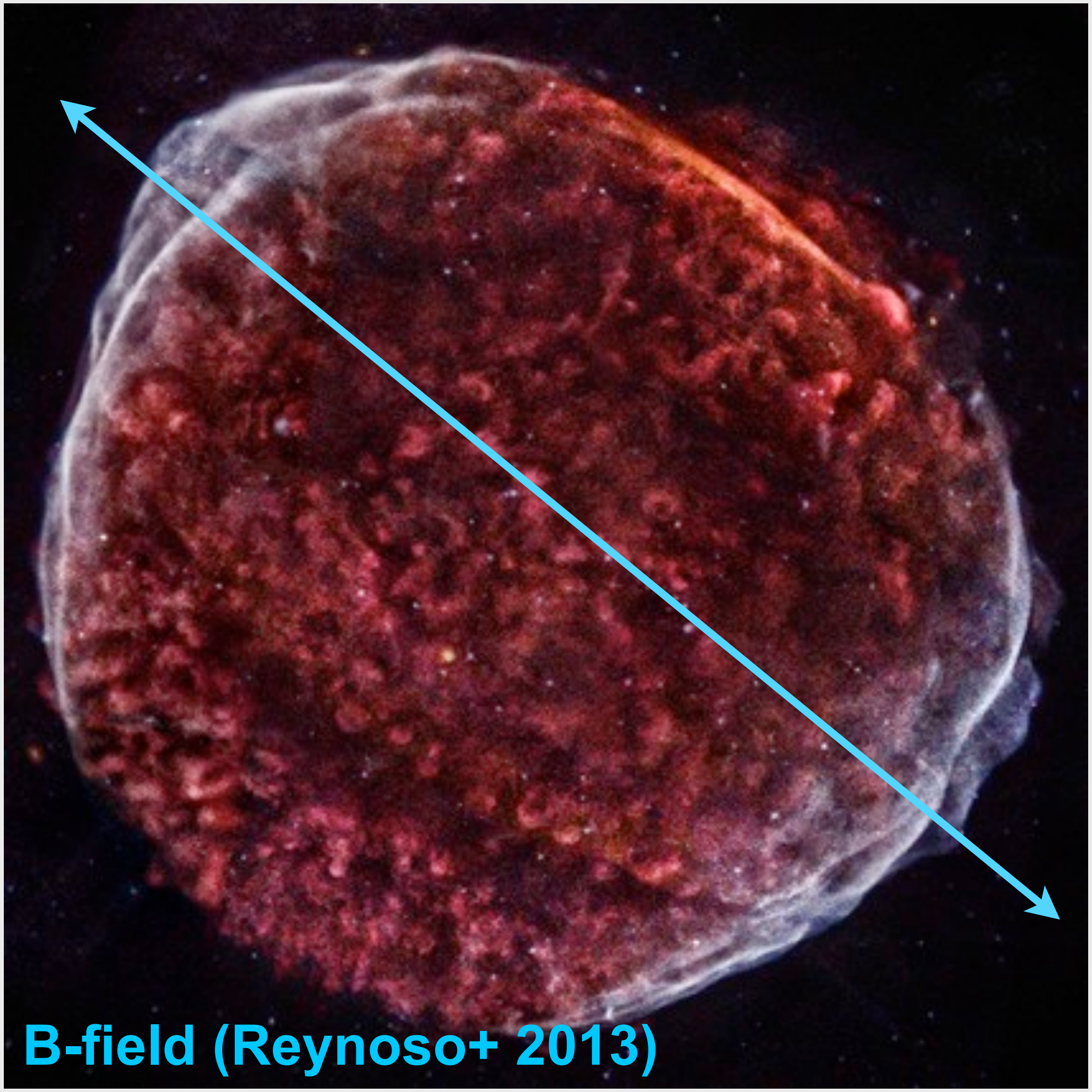
v_s = 5000 km/s, X-ray emission nonthermal



Still need to measure here and here...



Shock speed does **not** seem to be primary determiner of thermal vs. nonthermal emission (see poster on RCW 86 by Dan Castro for synchrotron emission from slower shocks)



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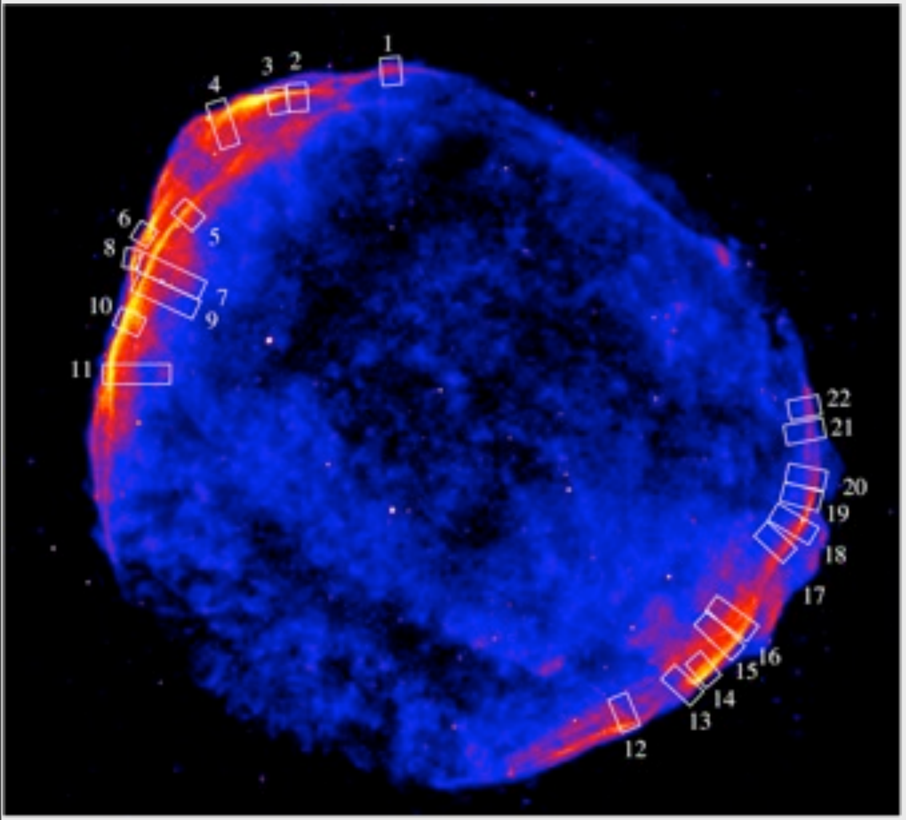
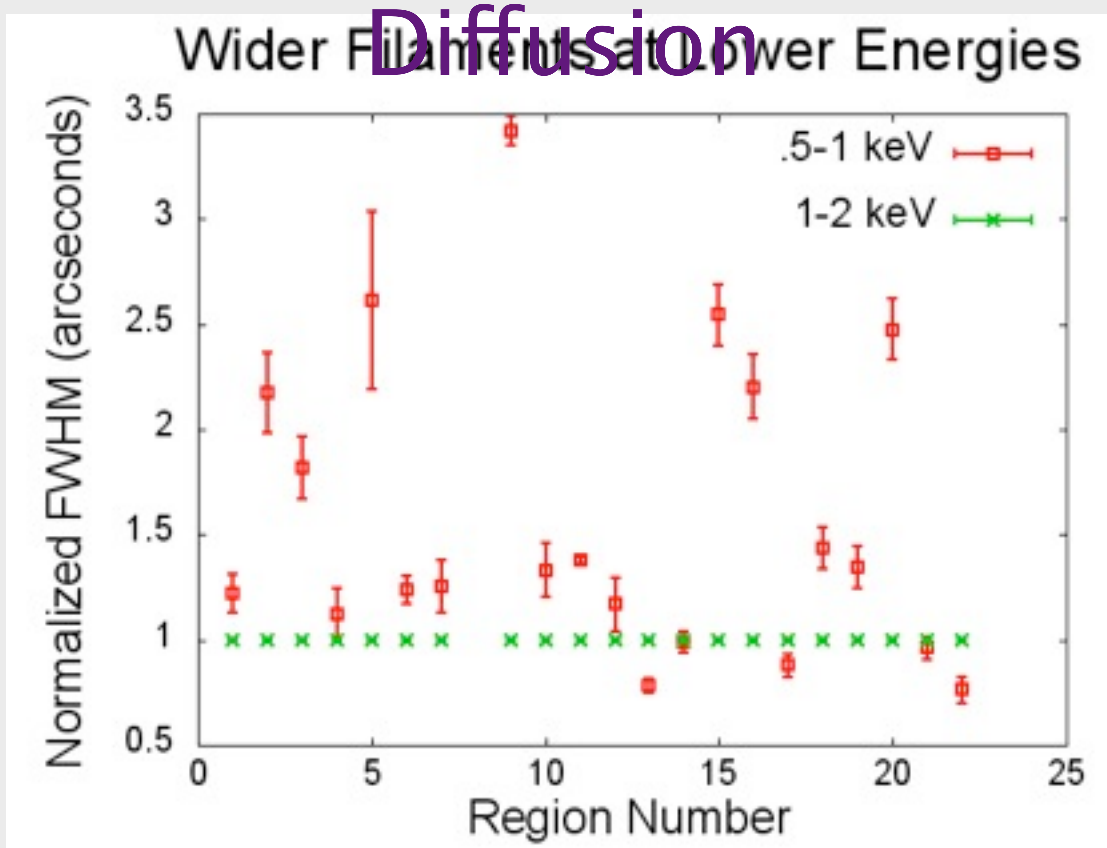
Must be more related to B-field

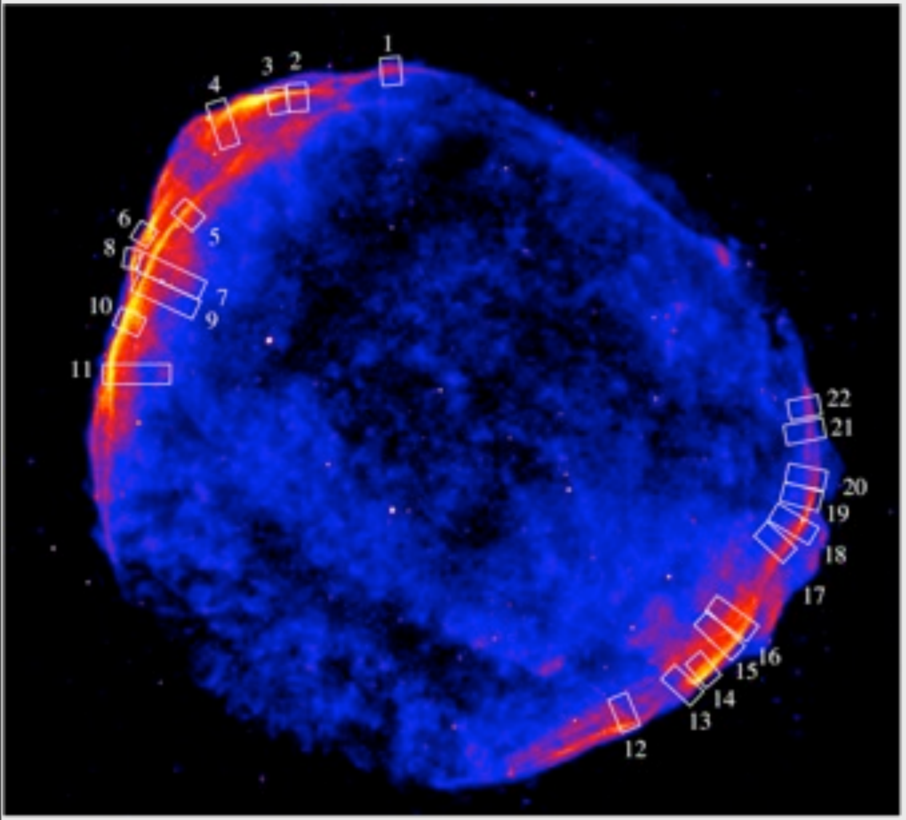
The Nonthermal Filaments: Probing the B-field and Electron Diffusion





Ressler,...,**BJW**+, in prep

Filament widths are **energy-dependent**



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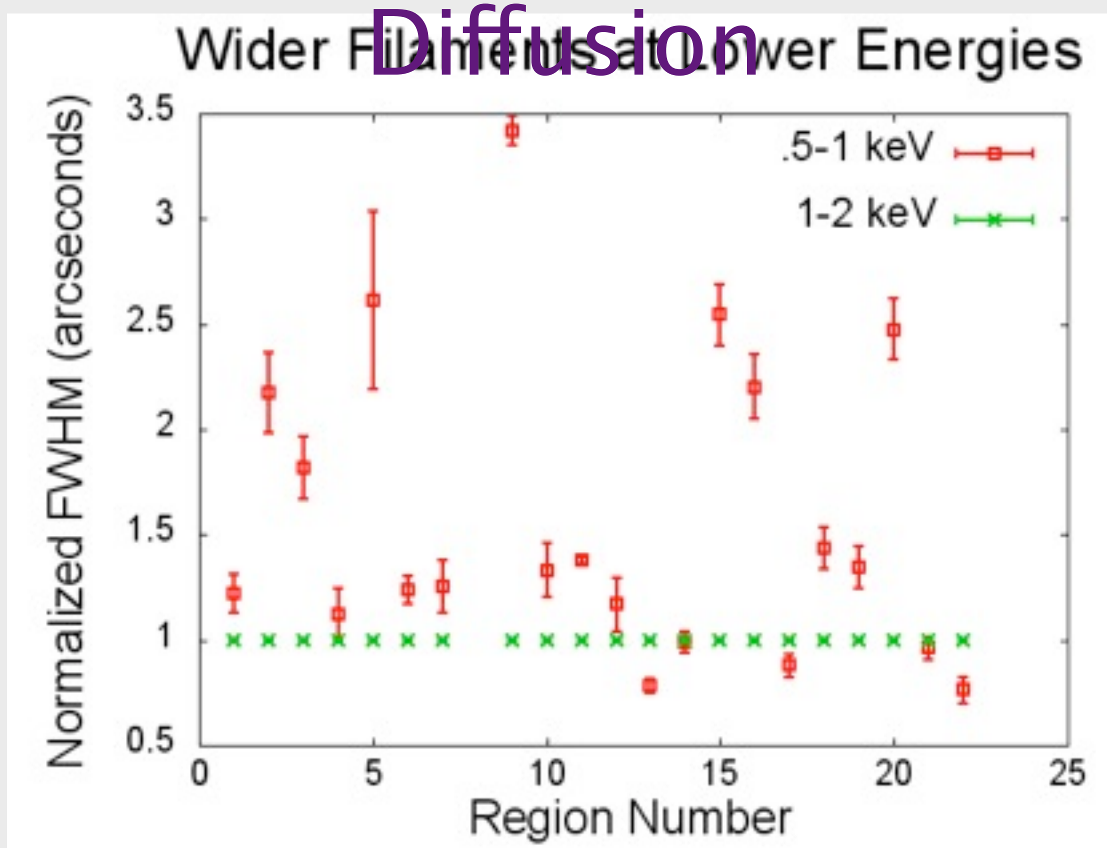

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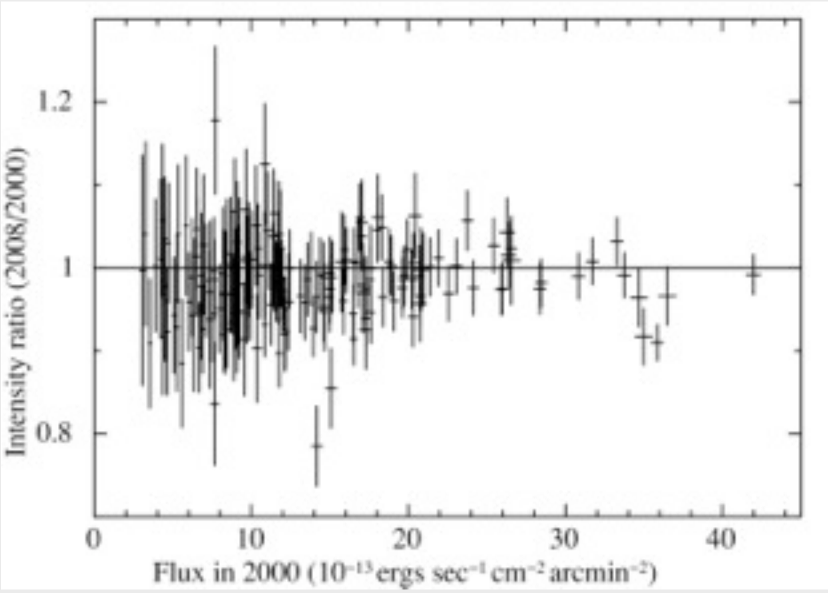
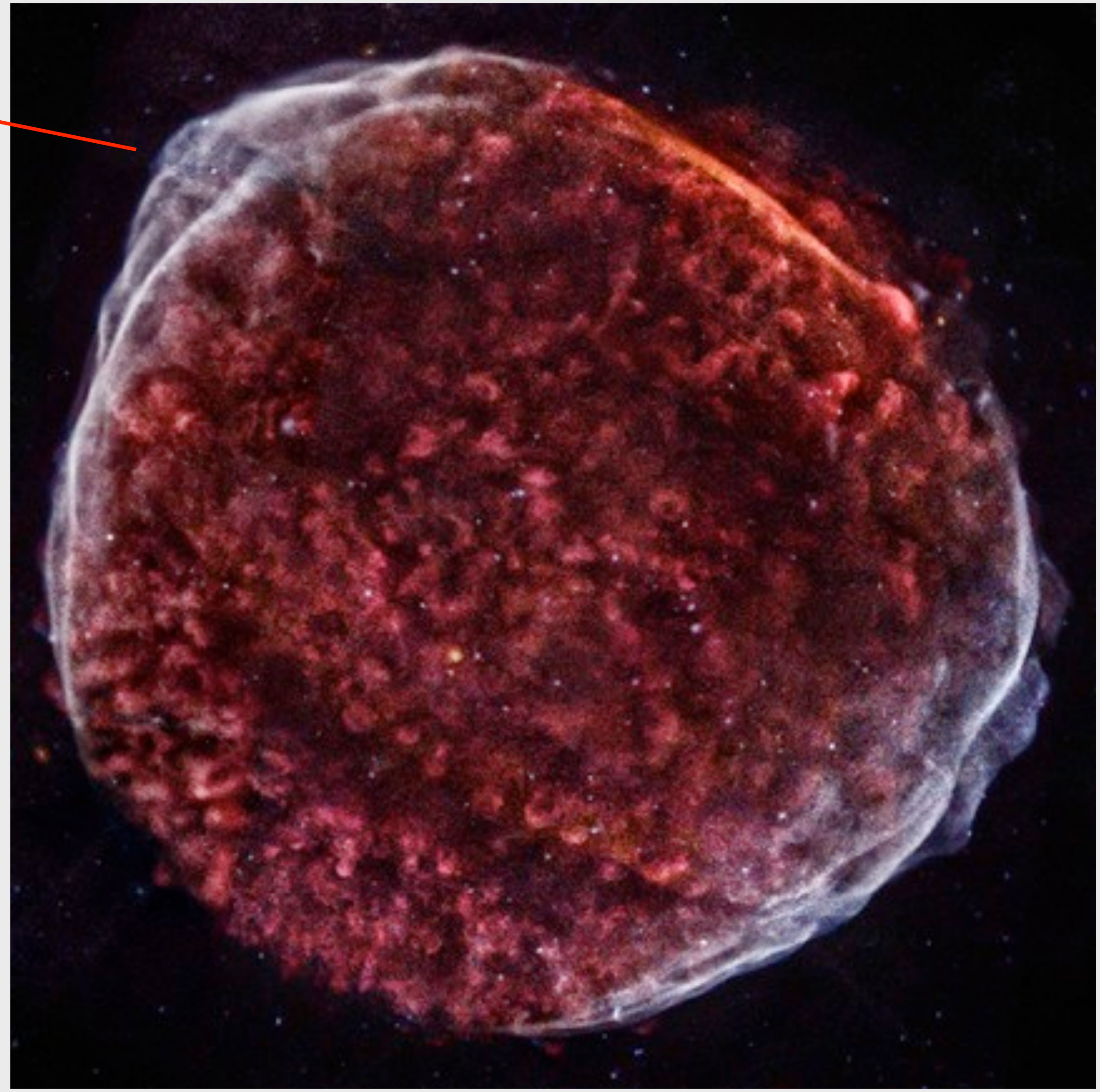
Filament widths are **energy-dependent**

Preliminary results: **Filaments widths due to synchrotron losses, not B-field damping; strong B-field amplification favored**

No time-variability in synchrotron X-rays



Katsuda+ 2008



- Unlike RX J1713 and Cas A, significant flux variations are not seen from NE shell of 1006

- Does NOT imply weak B-field; could simply be uniform medium

- With new data, we can now examine other parts of shell…

Summary

- Proper motions = 3000/5000 km/s in thermal/nonthermal regions, respectively
- Densities in NW ~order of magnitude higher than elsewhere
- Filament widths energy-dependent, can be explained by synchrotron losses
- No time variability in nonthermal X-rays