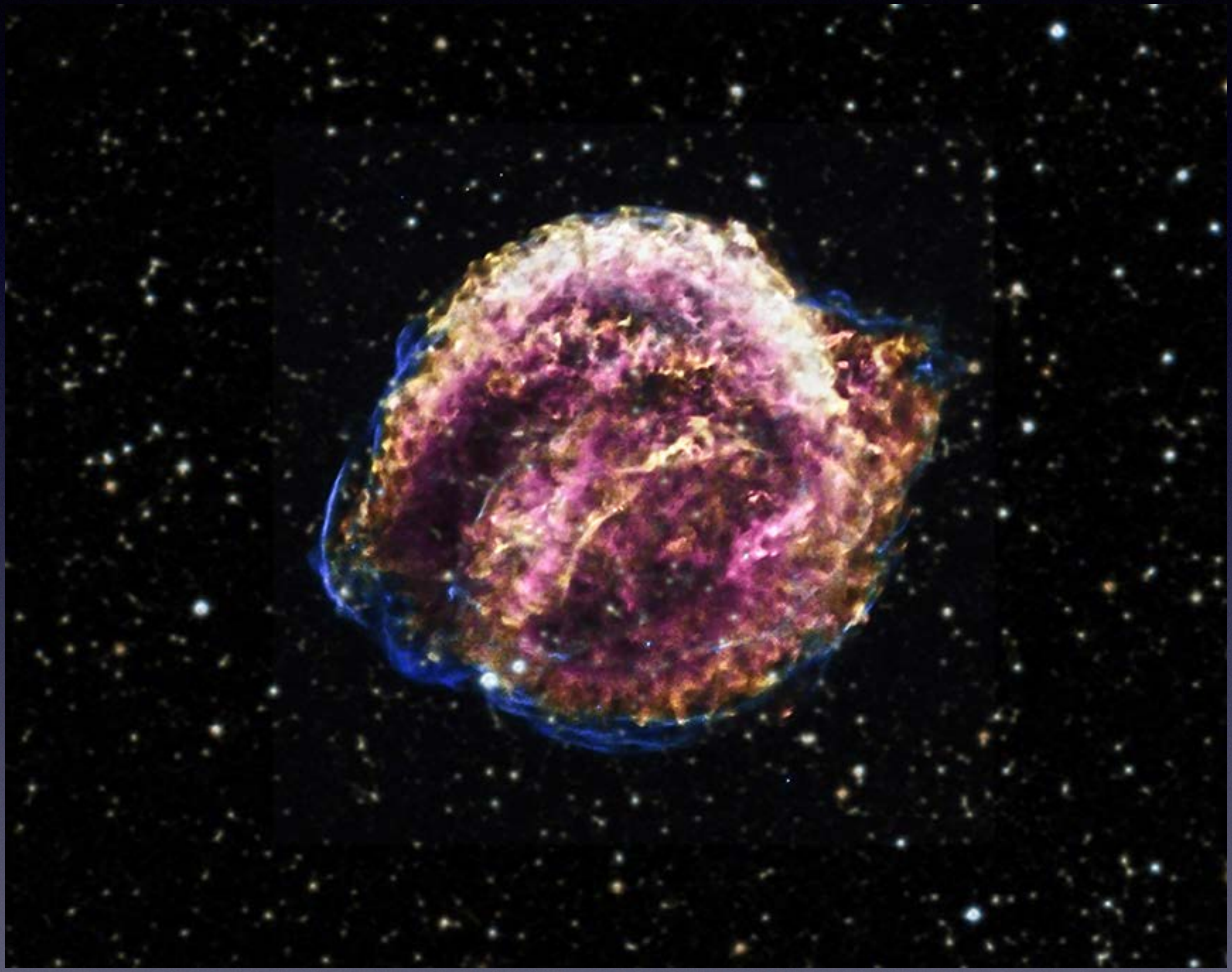
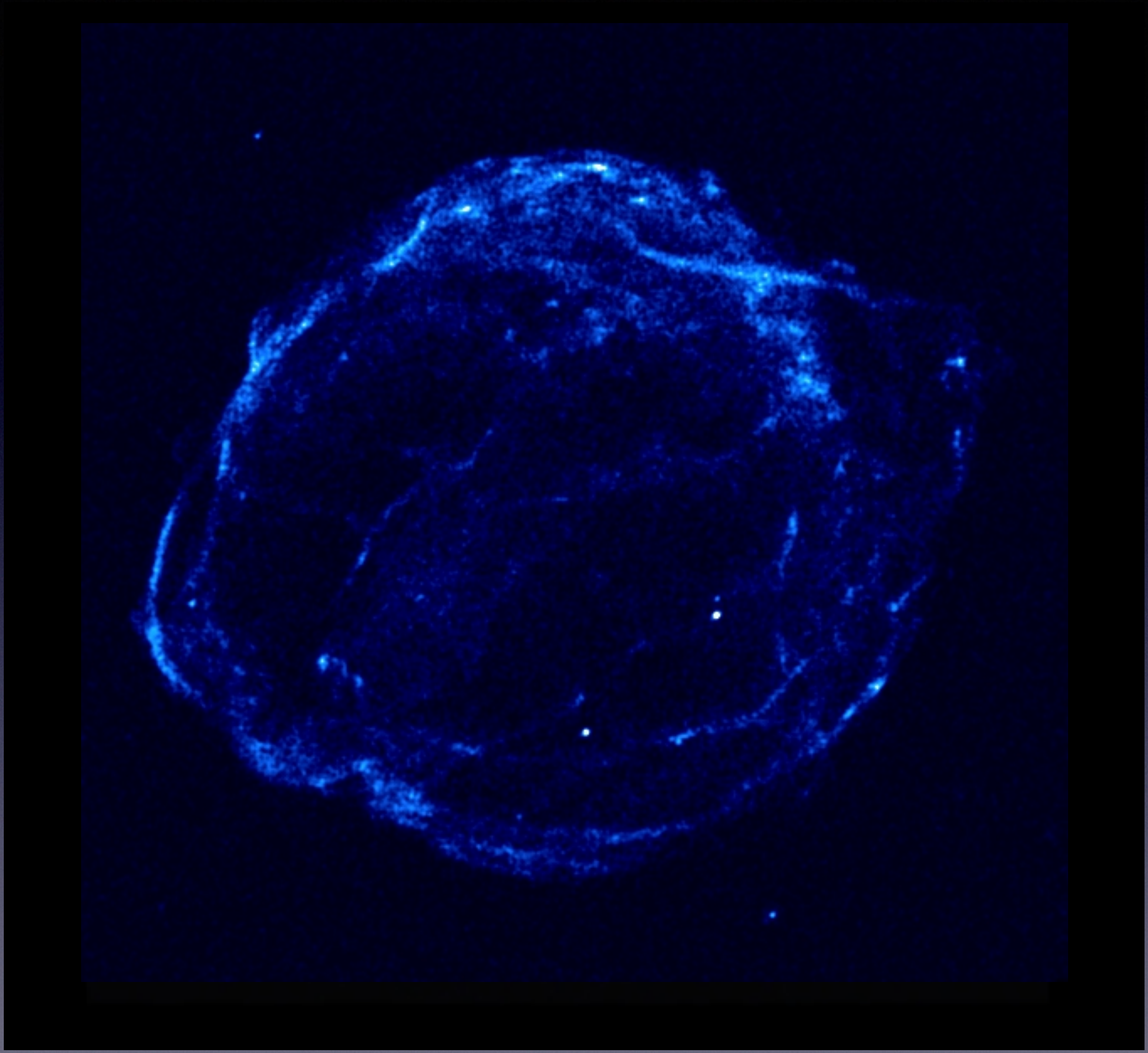
What Do We Learn From the Ejecta in SNRs?



Brian Williams (NASA GSFC)
@bjwilli2

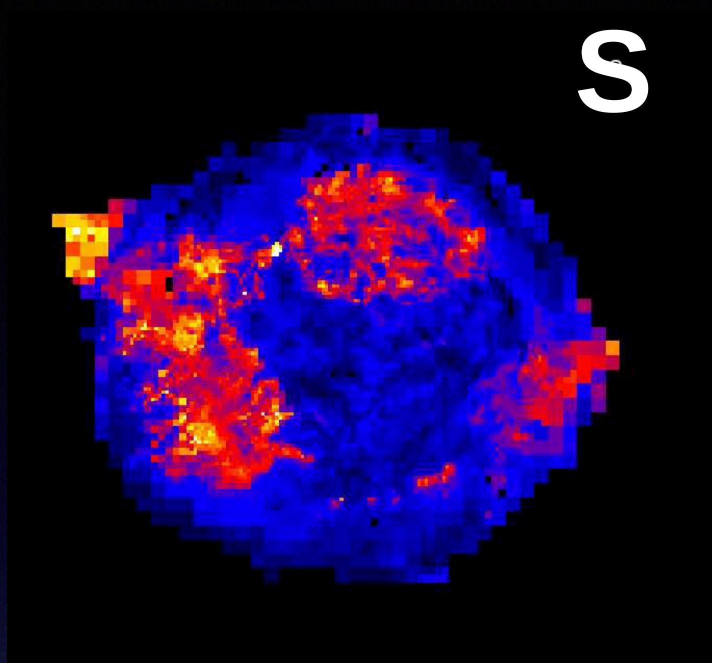
Disclaimers

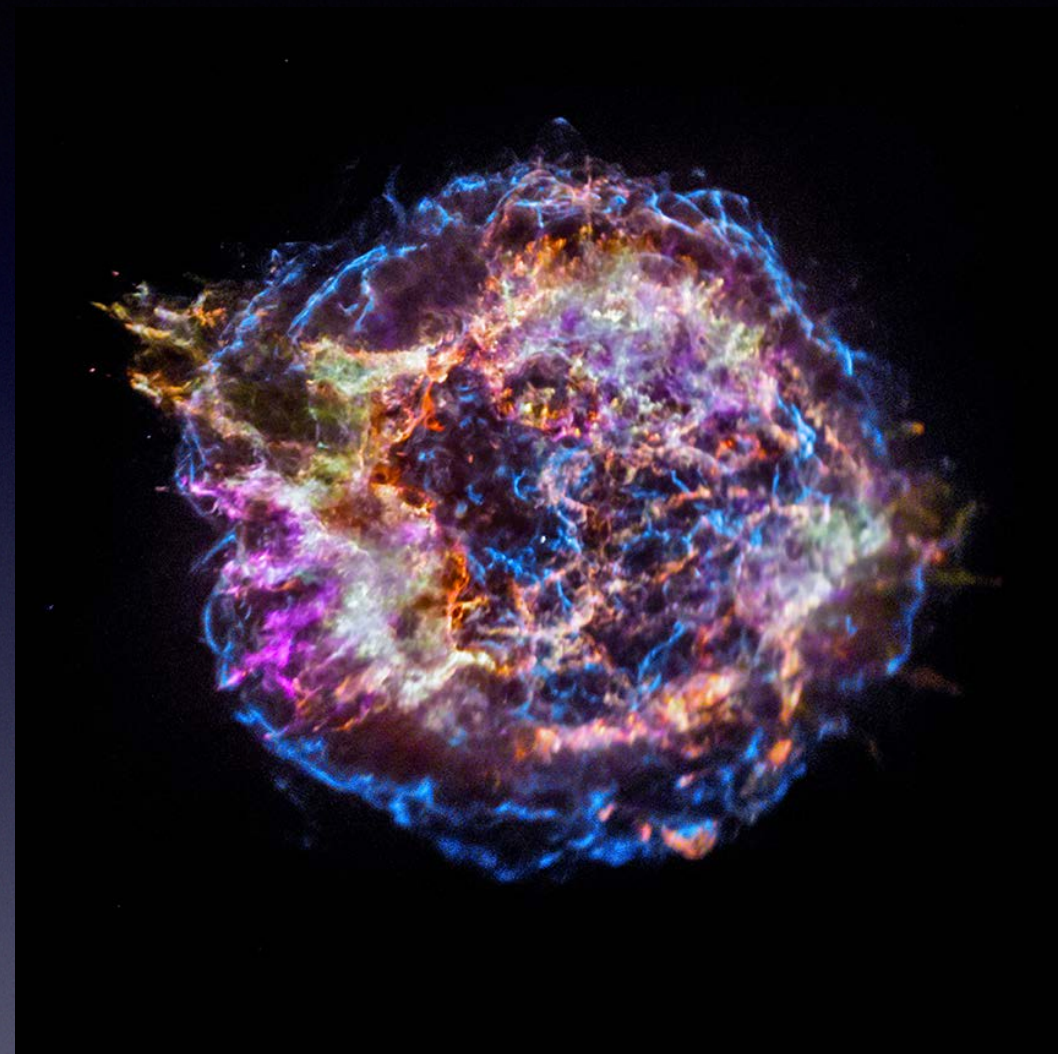
- This is a review talk of a very broad topic
- As much as I would love to, I can't cover everything, and I can't cite everyone
- Topics I won't cover include dust in SN ejecta (see review talk by ~~H. Gomez~~ M. Barlow), pulsar wind nebulae (see review talk by T. Temim)
- If I do cover your work, but I misrepresent it, I apologize, and please correct me afterwards!
- I've made every attempt to at least misrepresent everyone equally

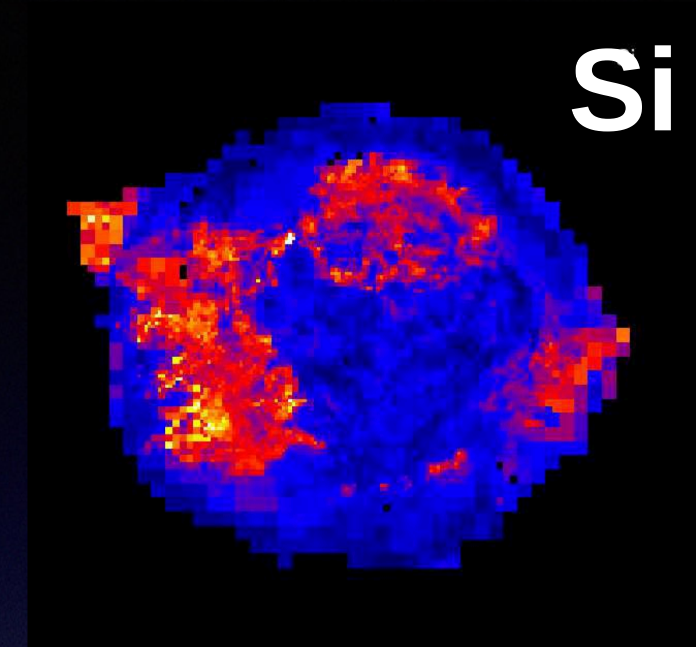


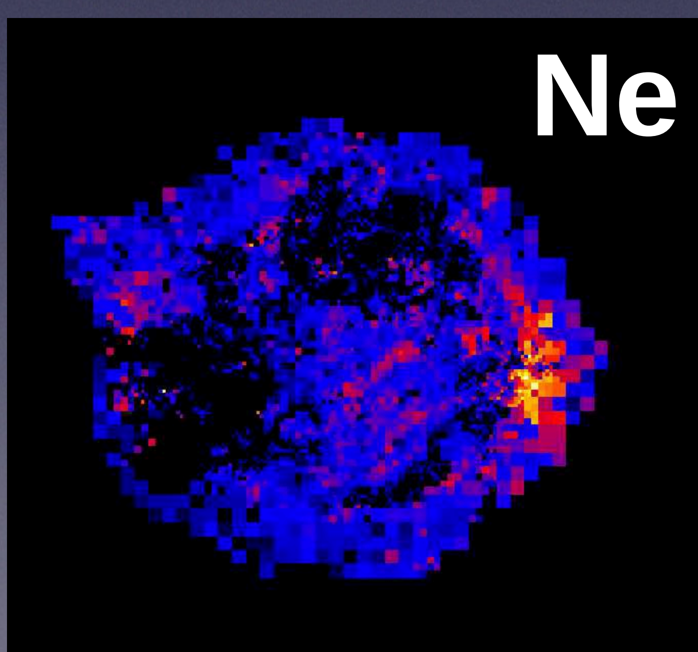
Forward Shock

Reverse-shocked Ejecta

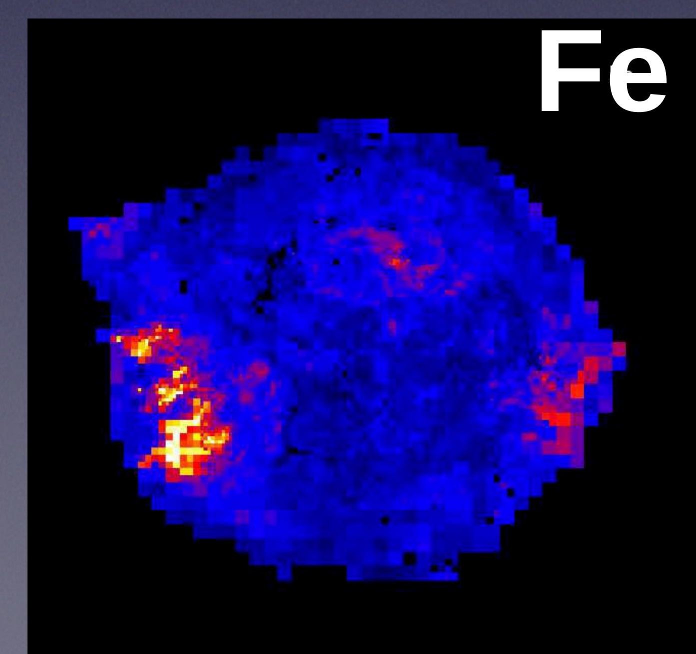


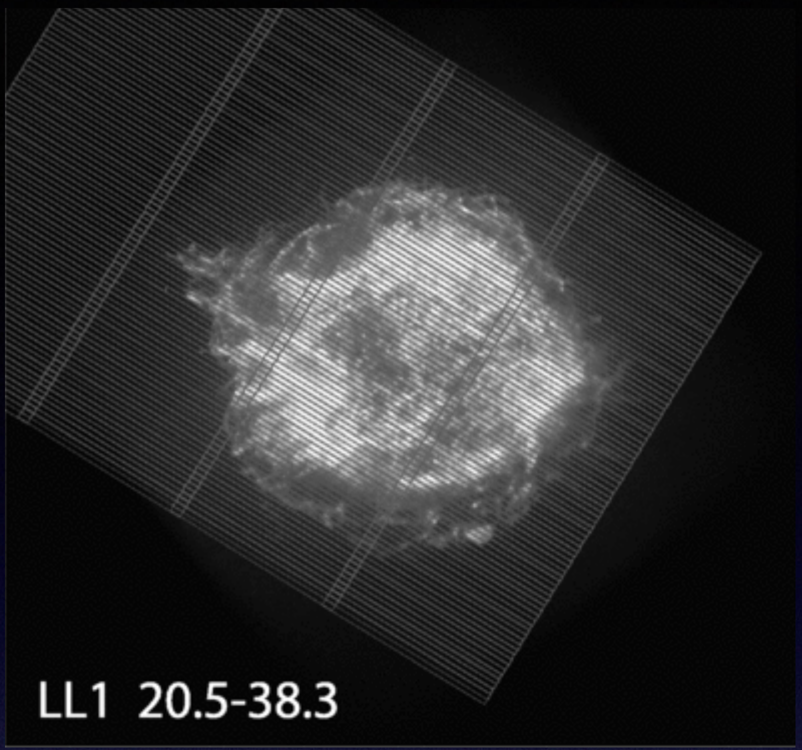




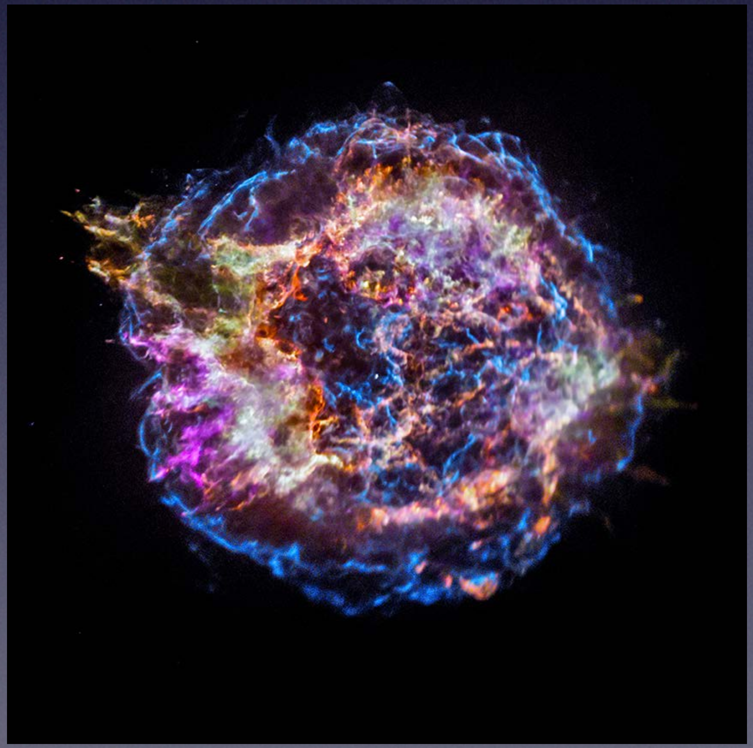


Distributions of various ejecta species in Cas A
Hwang & Laming (2012)

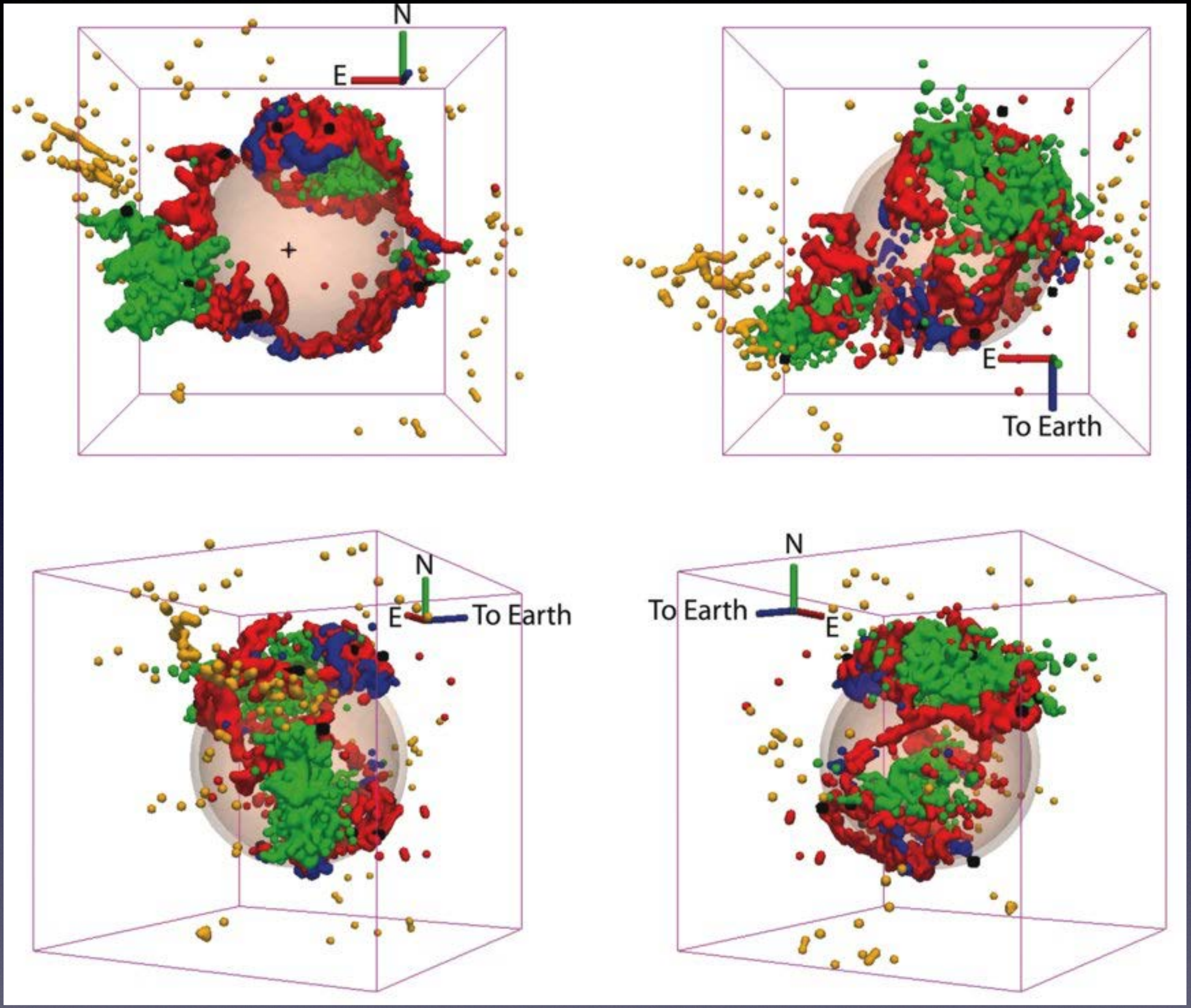




Spitzer IRS spectral map

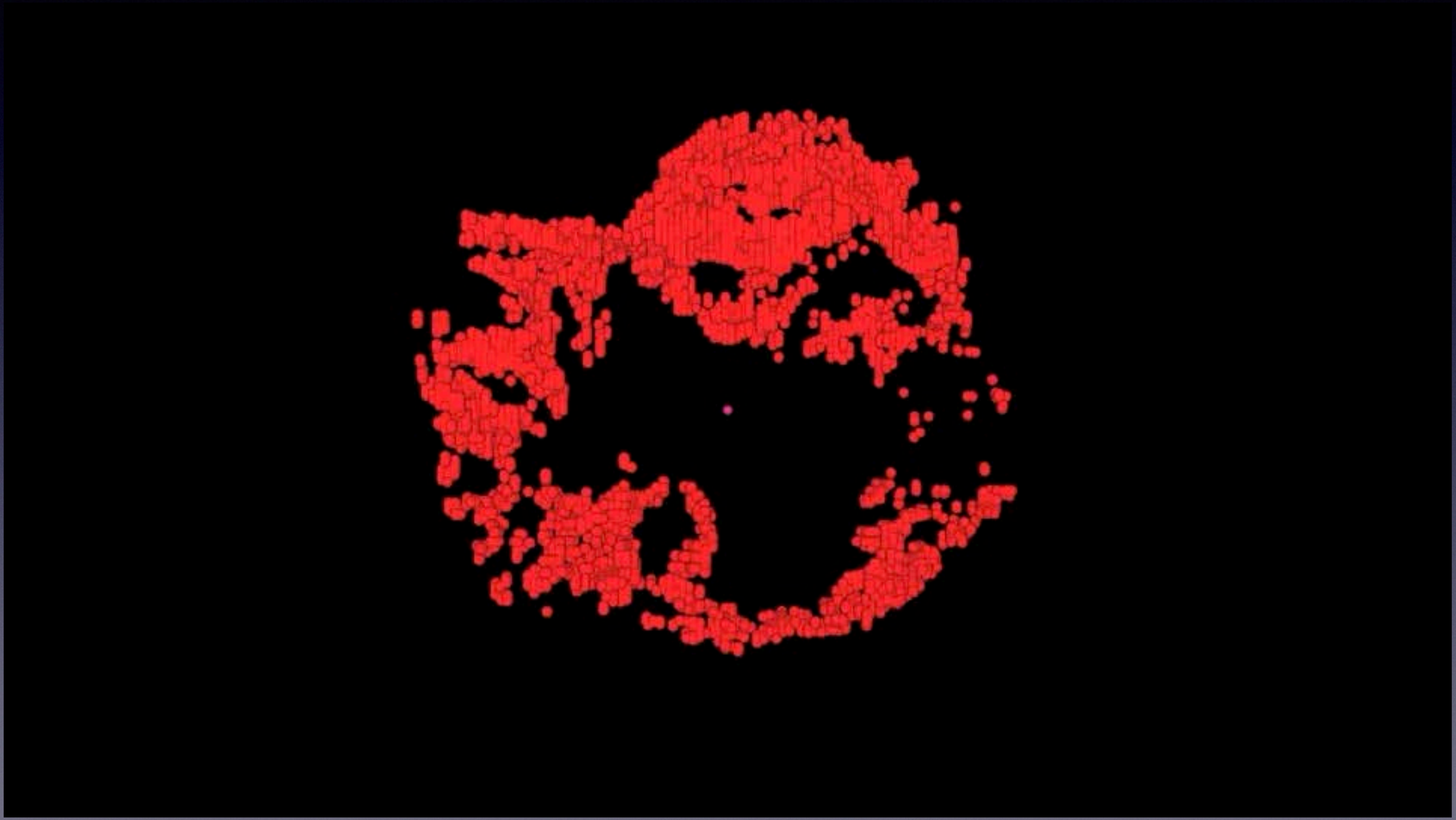


Chandra image, showing Si, S, Ca, Fe, and non-thermal emission



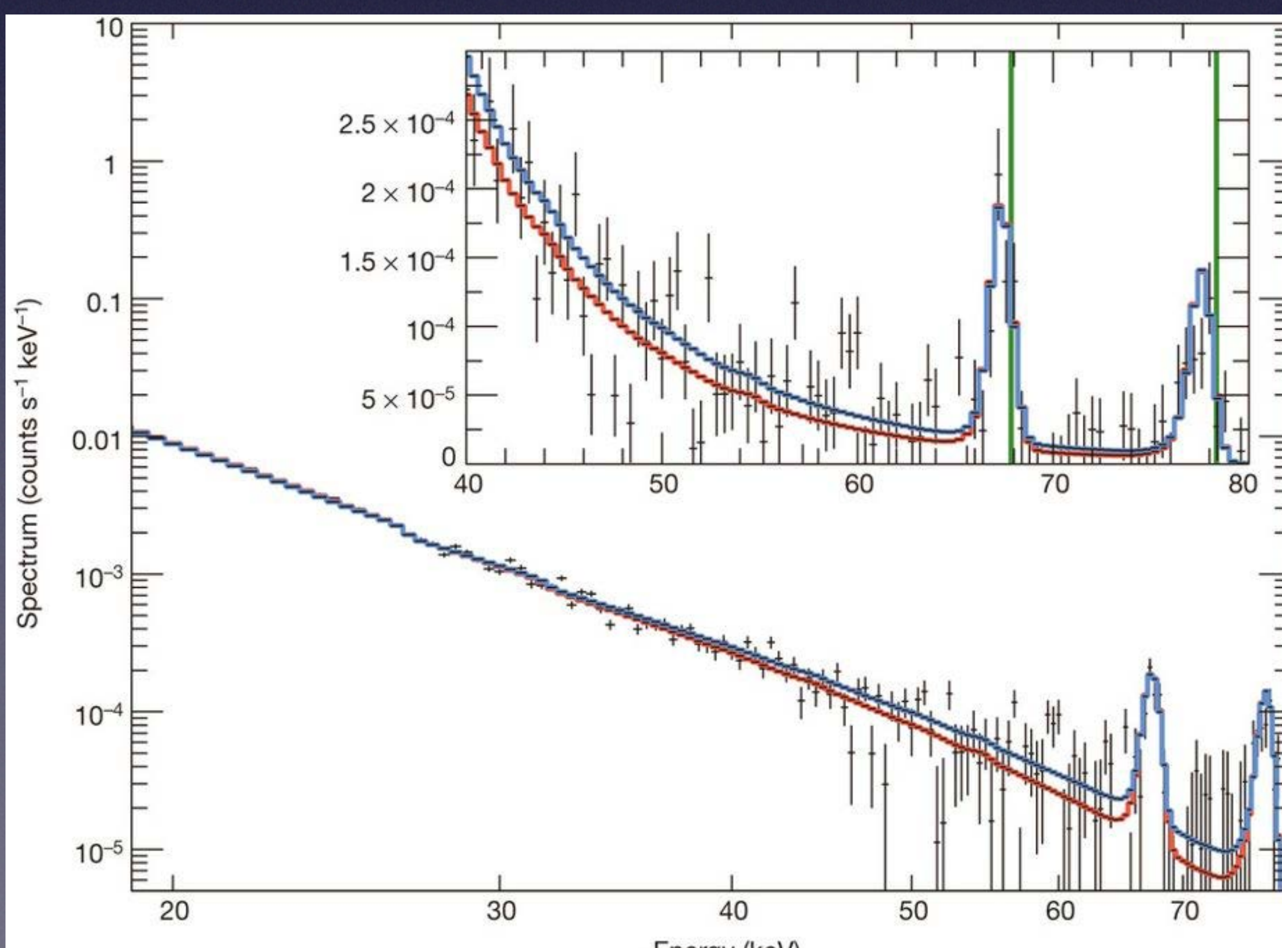
Infrared [Ar II] (red), high infrared [Ne II]/[Ar II] ratio (blue), X-ray Si XIII (black), X-ray Fe-K (green), outer optical ejecta (yellow), fiducial reverse shock (sphere), and CCO (cross). Image from Delaney et al. (2010)

Milisavljevic & Fesen (2013) added in optical data…



NuSTAR locates the radioactive ^{44}Ti… in the wrong place!

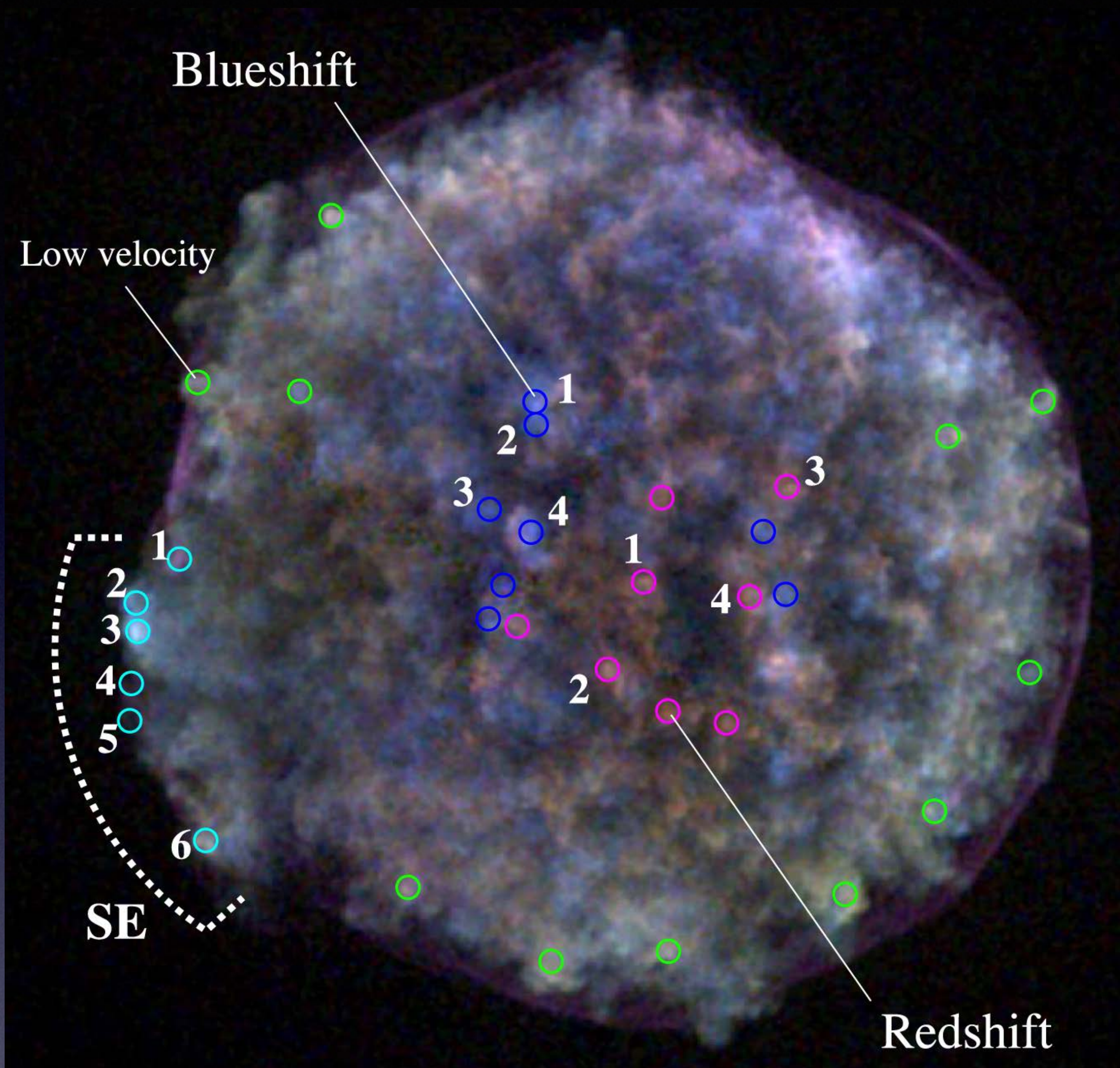
Most models predict that Ti and Fe are synthesized in close proximity; not seen here. ^{44}Ti is produced by radioactive decay; Fe Kα produced by reverse shock heating



Fe Kα in red, ^{44}Ti in blue, IMEs in green

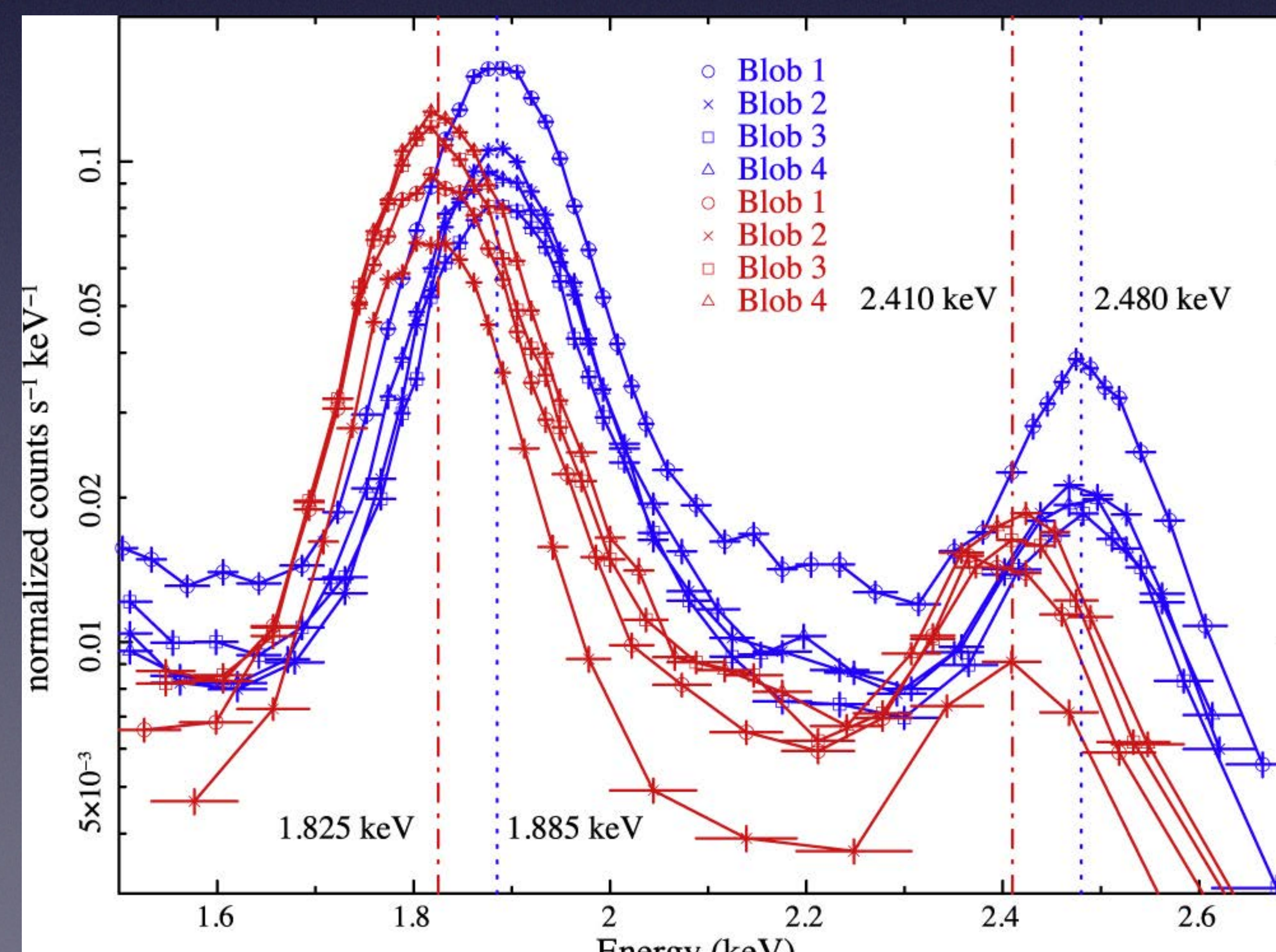
See Grefenstette et al. (2014, 2017) for more details

Tycho's SNR

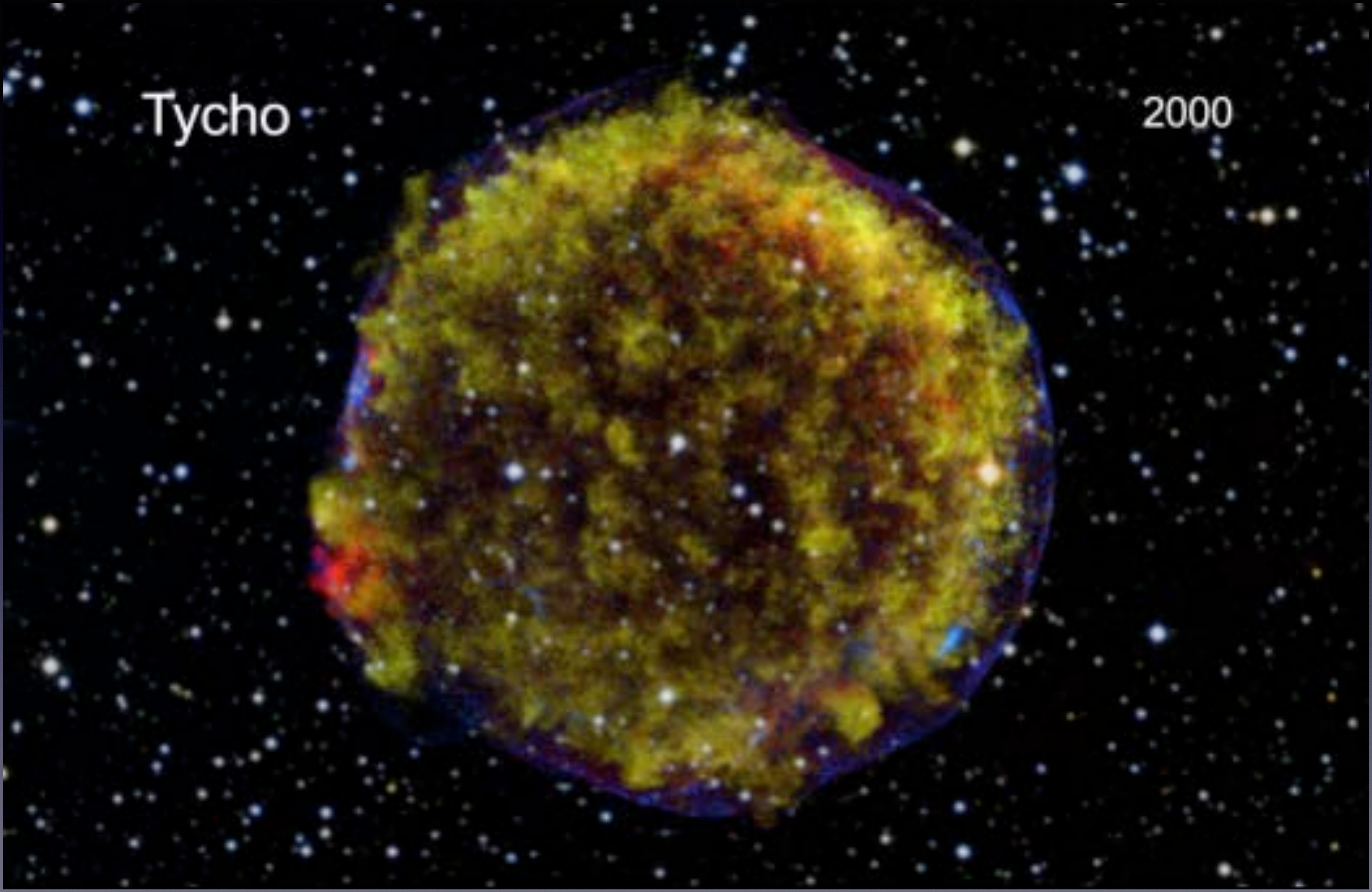


Spectral analysis of small knots of ejecta in Tycho show very high line-of-sight velocities

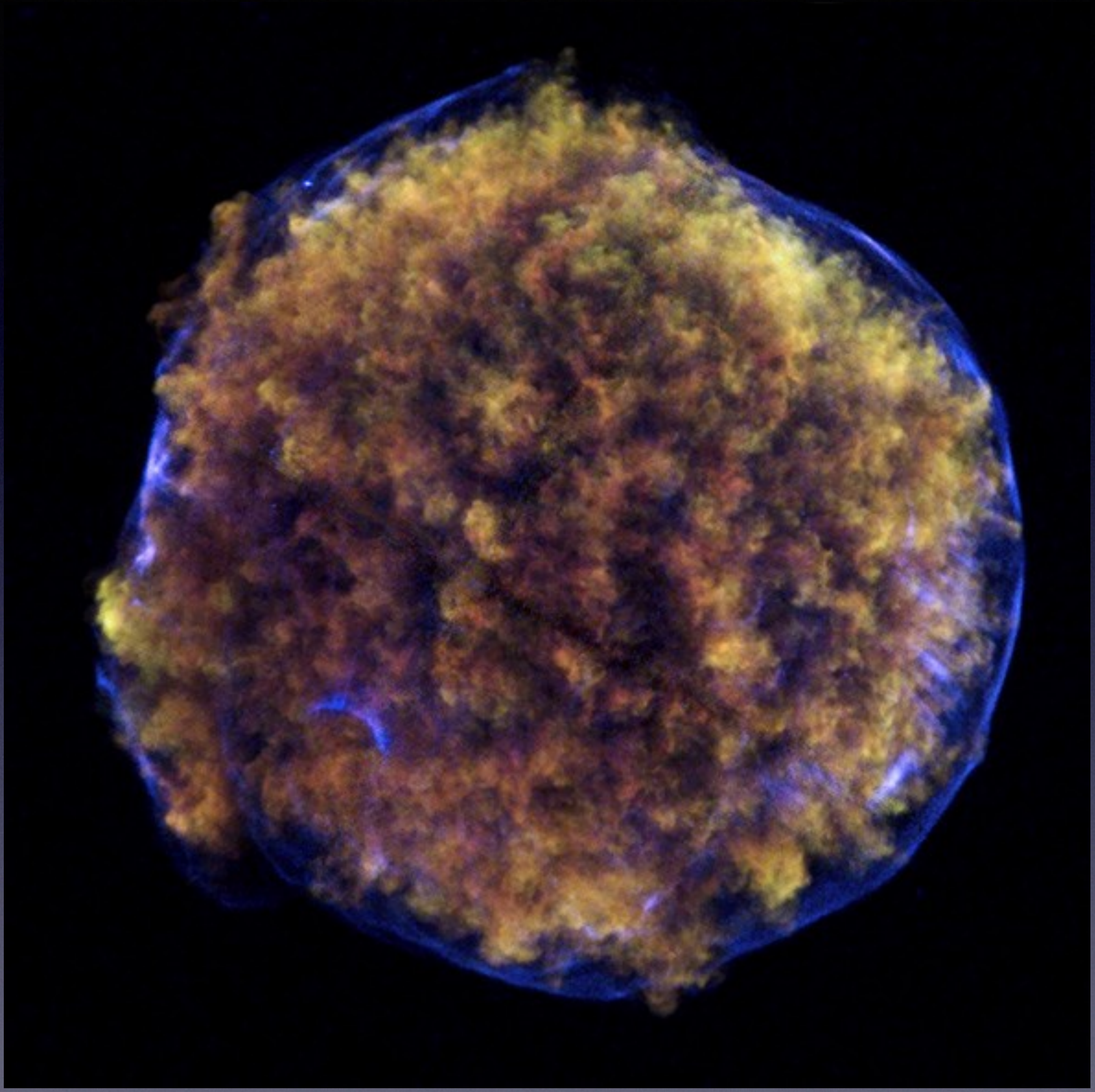
Blueshifted mean = -3220 km/s
Redshifted mean = 4980 km/s



See Sato & Hughes 2017

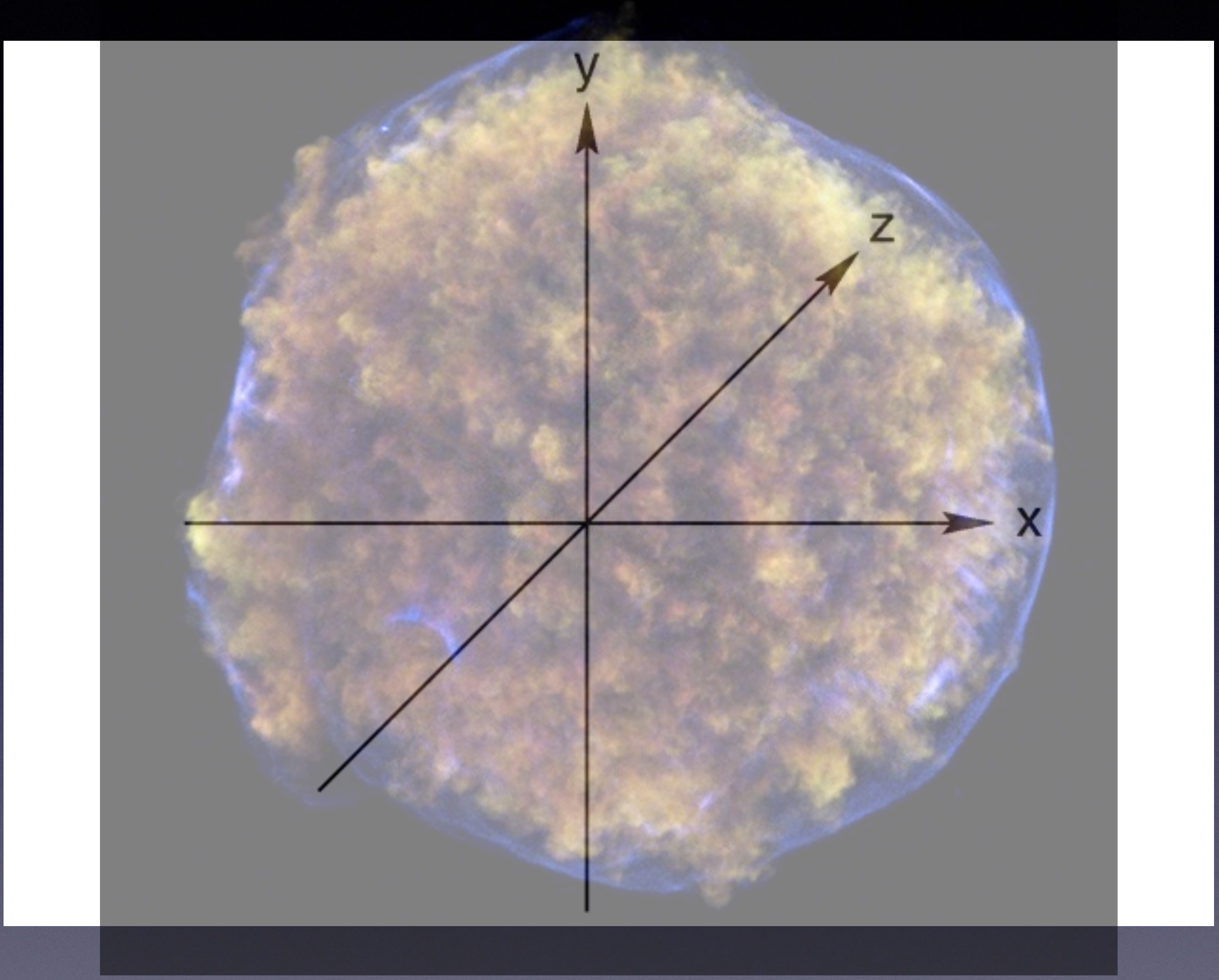

Tycho
2000

We can measure ejecta velocities in 3D!



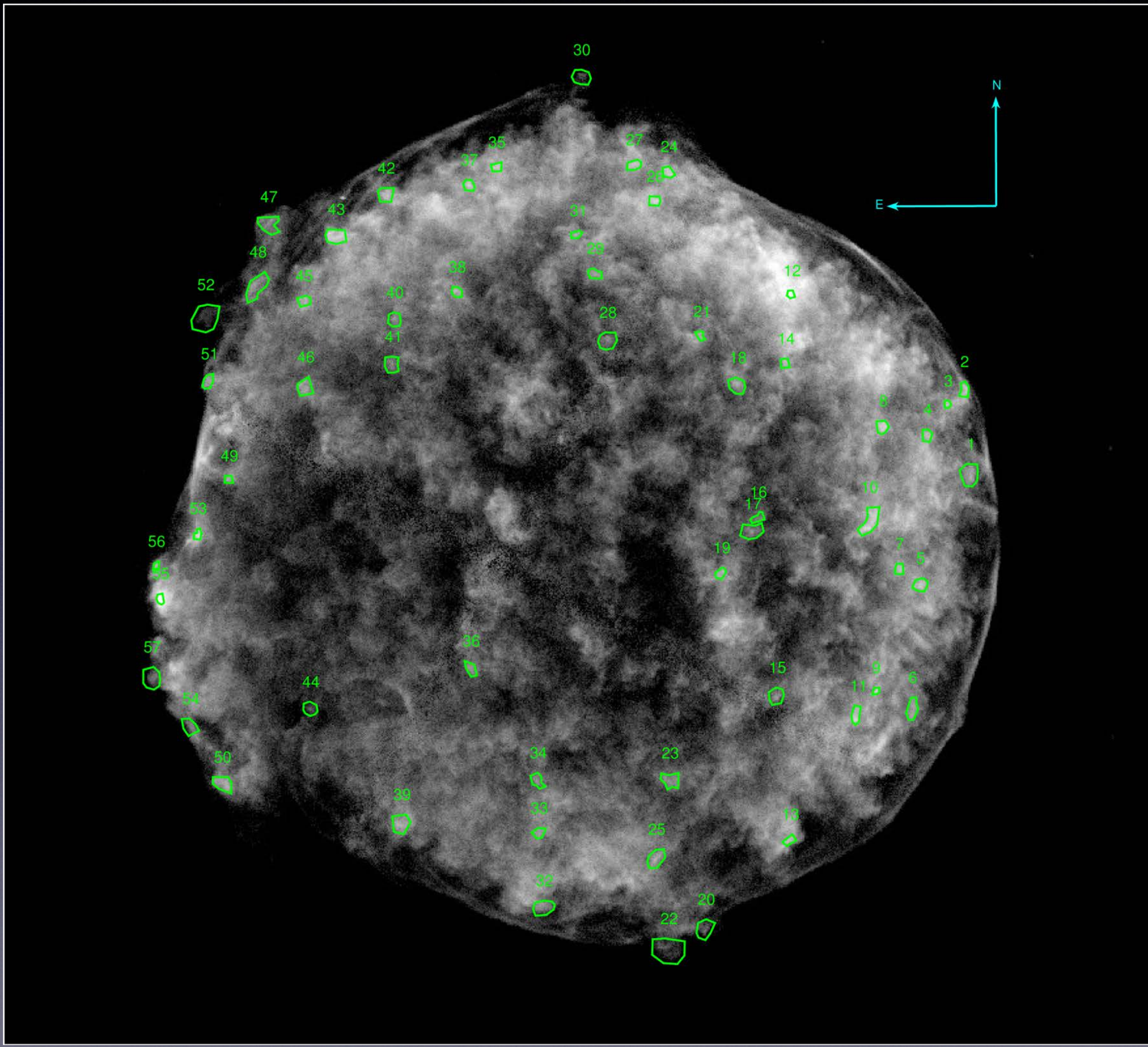
See Williams et al. (2017)

We can measure ejecta velocities in 3D!



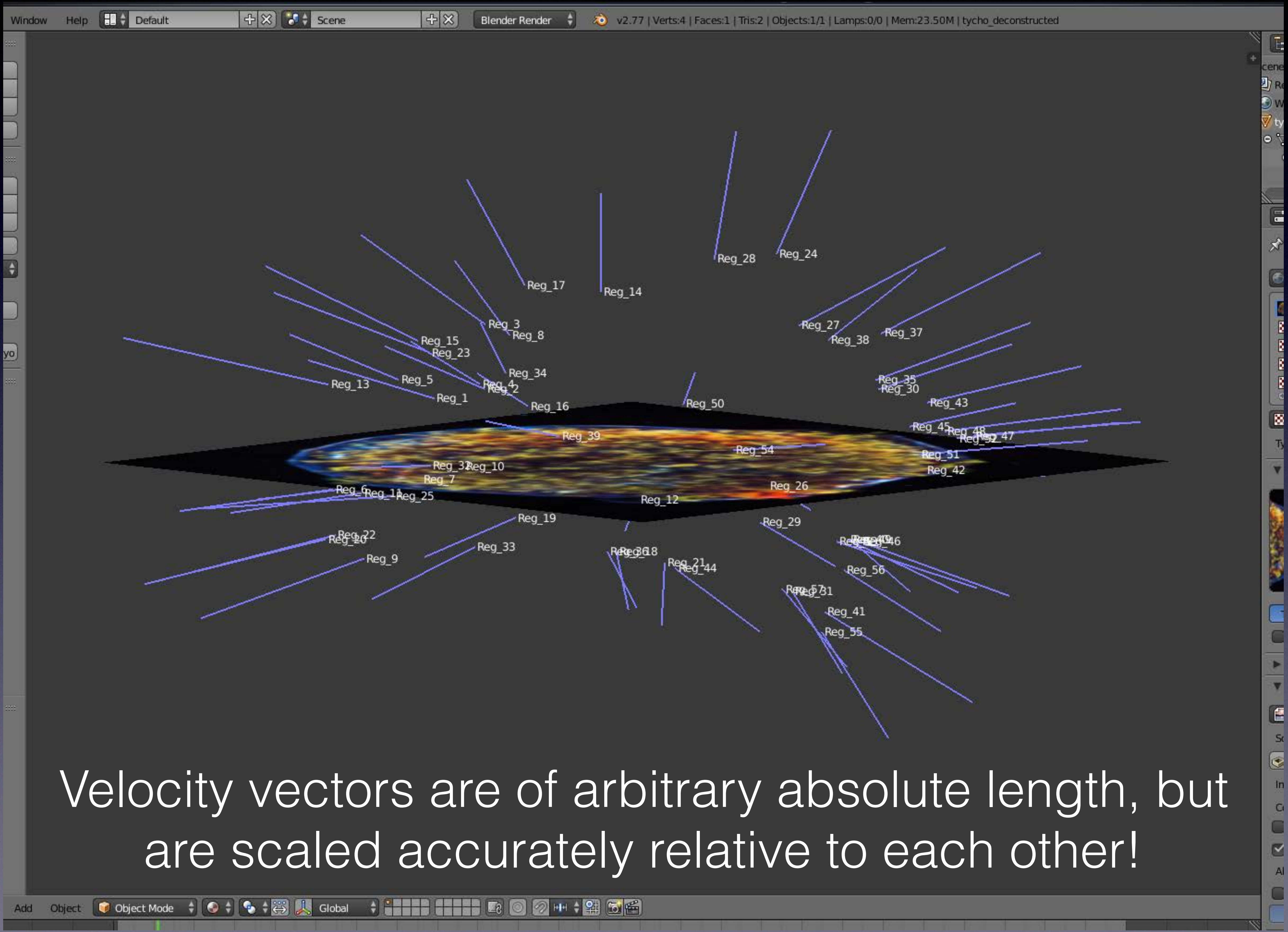
X,Y: Proper motions from 2003/2015 Chandra images
Z: Doppler shift of Si and S lines in Chandra spectra

3D ejecta velocities in Tycho

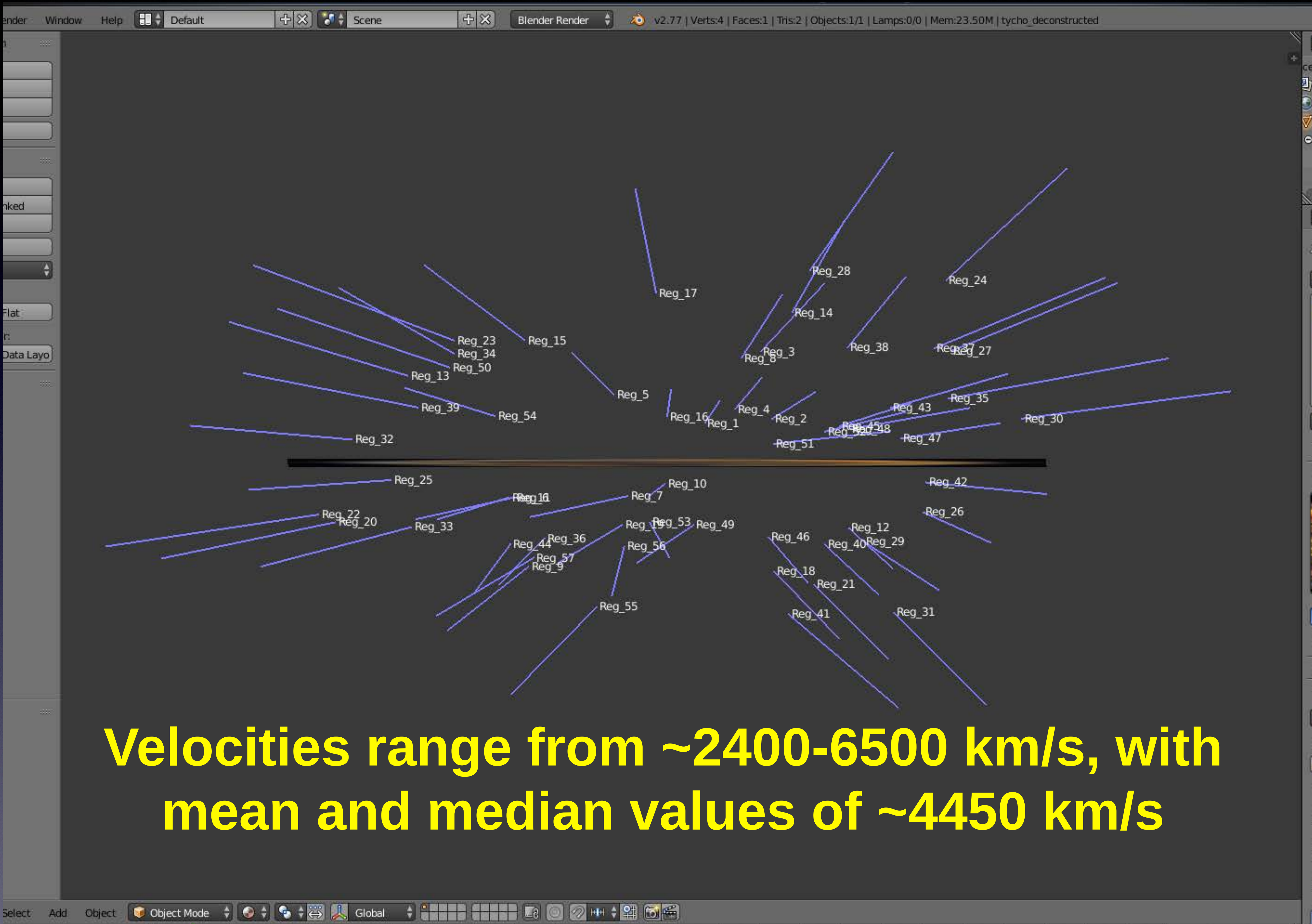


- we identified ~60 knots
- bright enough to get good spectra; and measurable proper motion
- center of remnant = no proper motions; covered by Sato & Hughes
- used various techniques to get spectroscopic redshift of knots, methods agree nearly perfectly

Results and 3D visualization

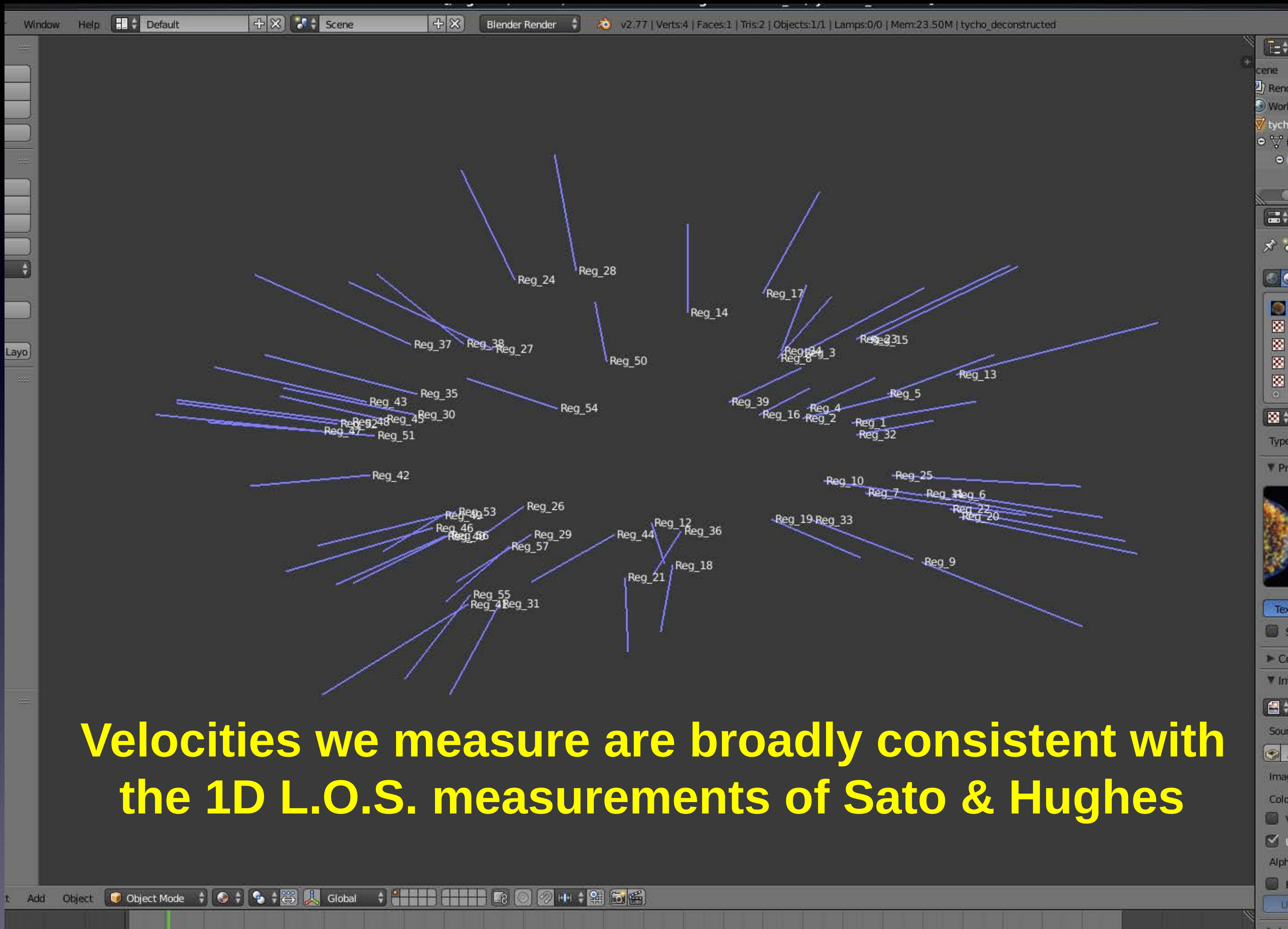


Velocity vectors are of arbitrary absolute length, but are scaled accurately relative to each other!



Velocities range from ~2400-6500 km/s, with mean and median values of ~4450 km/s

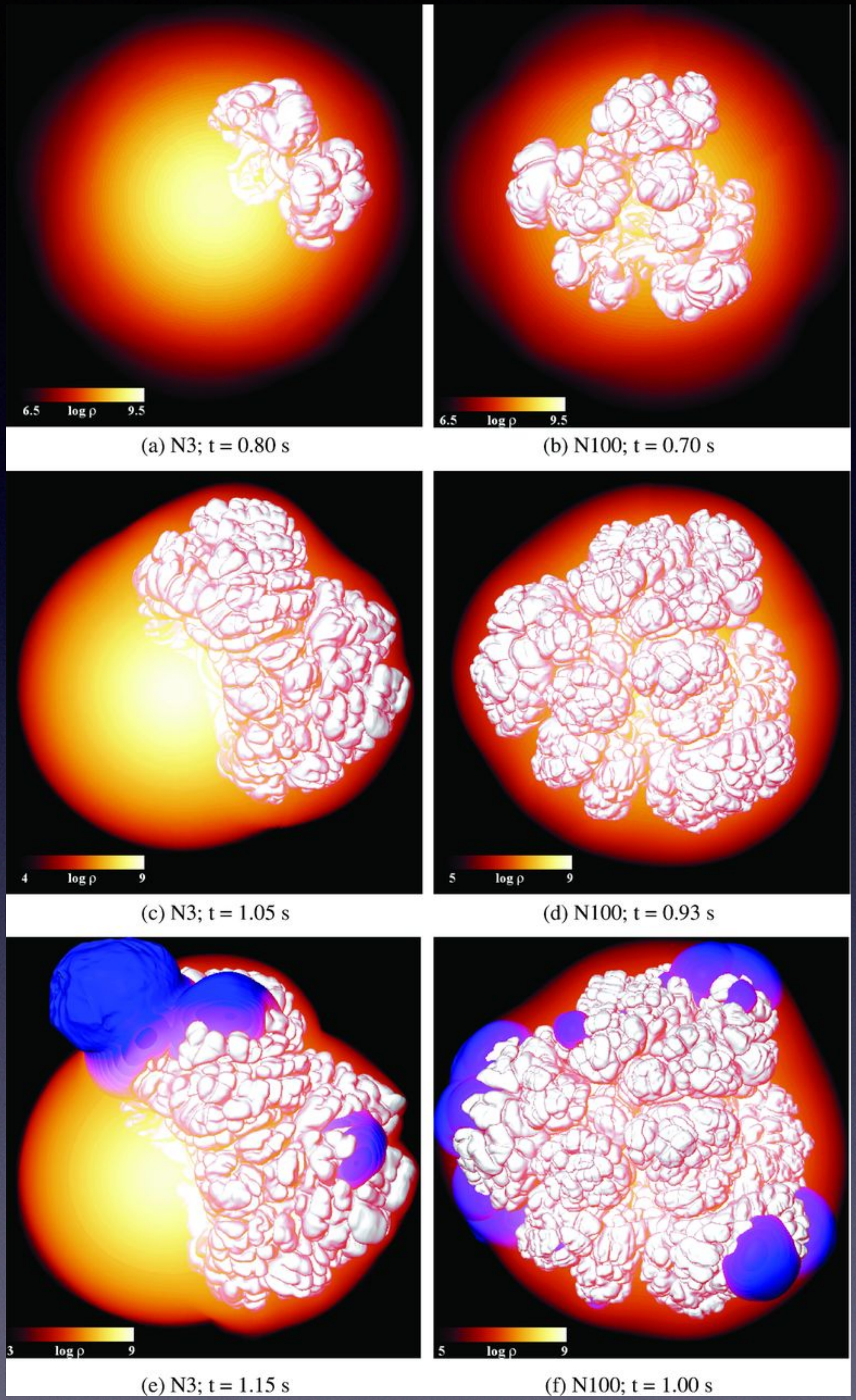
Note: apparent "flattening" is illusion caused by lack of data down the center of the remnant



Velocities we measure are broadly consistent with the 1D L.O.S. measurements of Sato & Hughes

Note: apparent "flattening" is illusion caused by lack of data down the center of the remnant

N3 Model
Fewer detonation points
Less symmetry

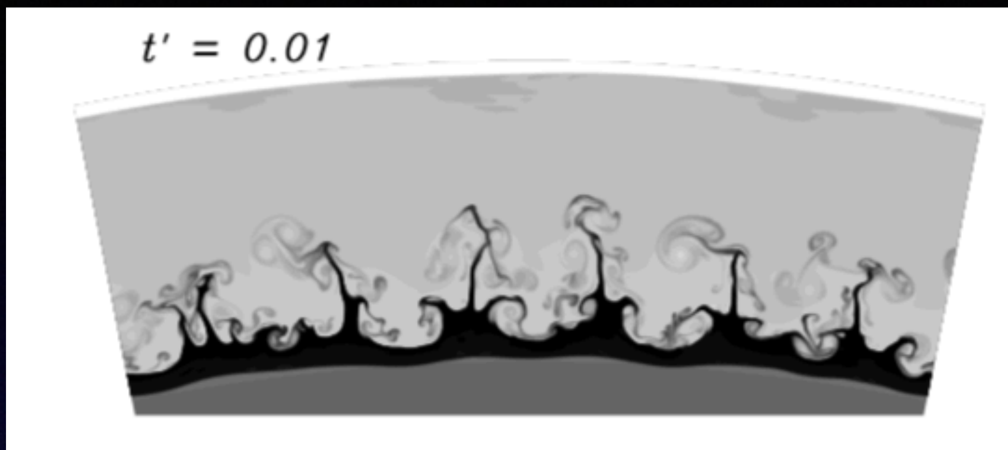


N100 Model
More detonation points
More symmetry

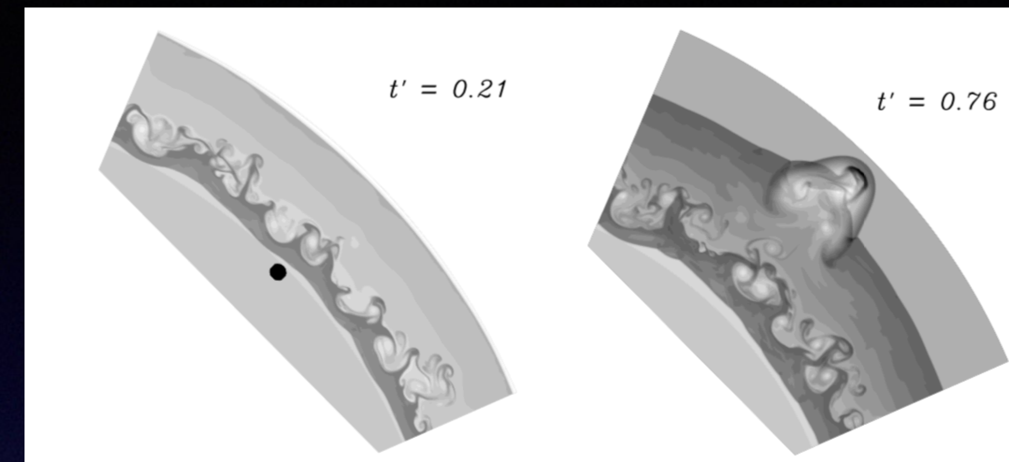
Models from Seitenzahl et al. (2013)

Tycho appears more consistent with symmetric expansion, perhaps implying more detonation points within the WD. LOTS of caveats here (possible selection biases, only Si ejecta used, substantial error bars, etc.)

Constraint on initial density profiles?

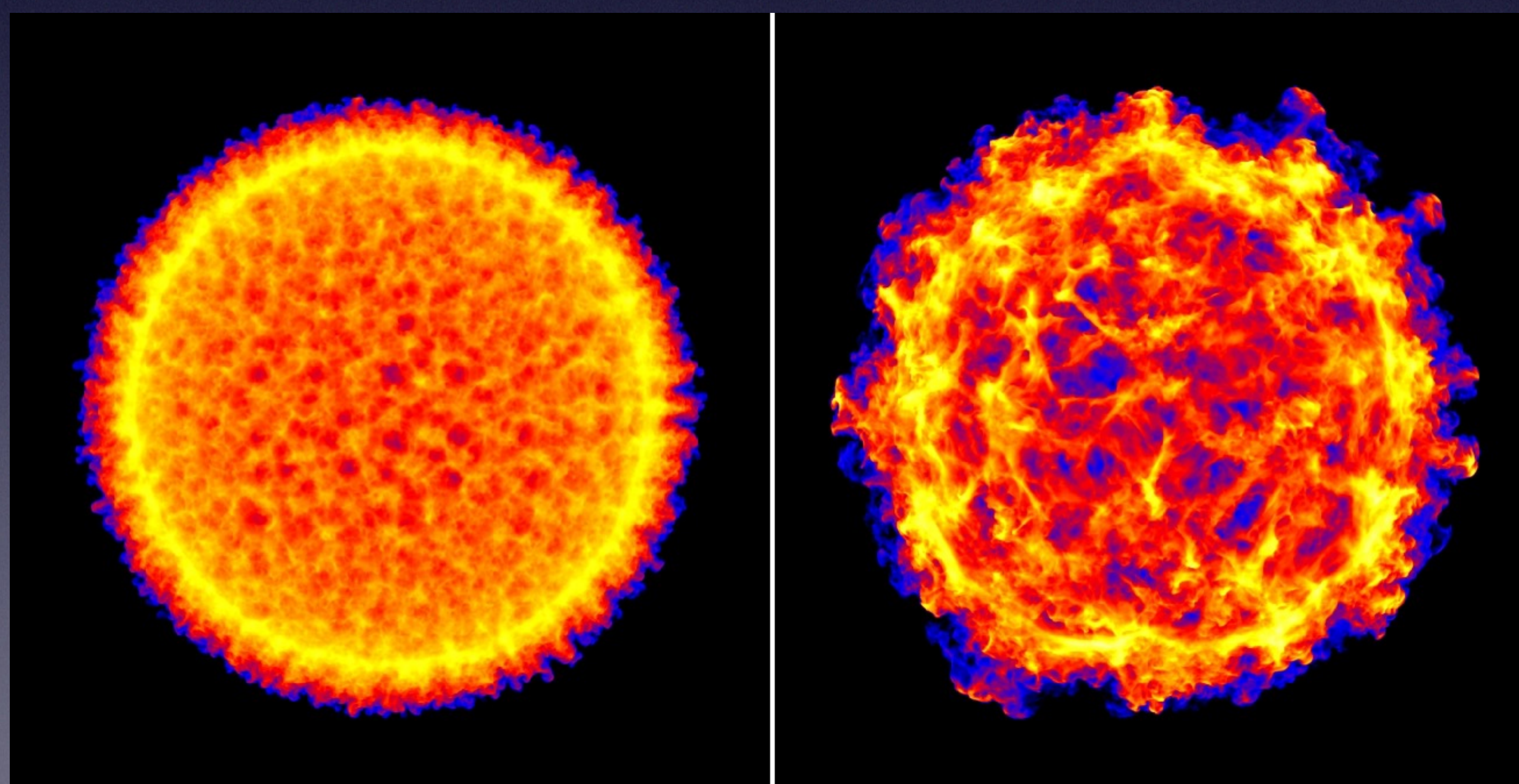


2D simulations from Wang & Chevalier (2001)

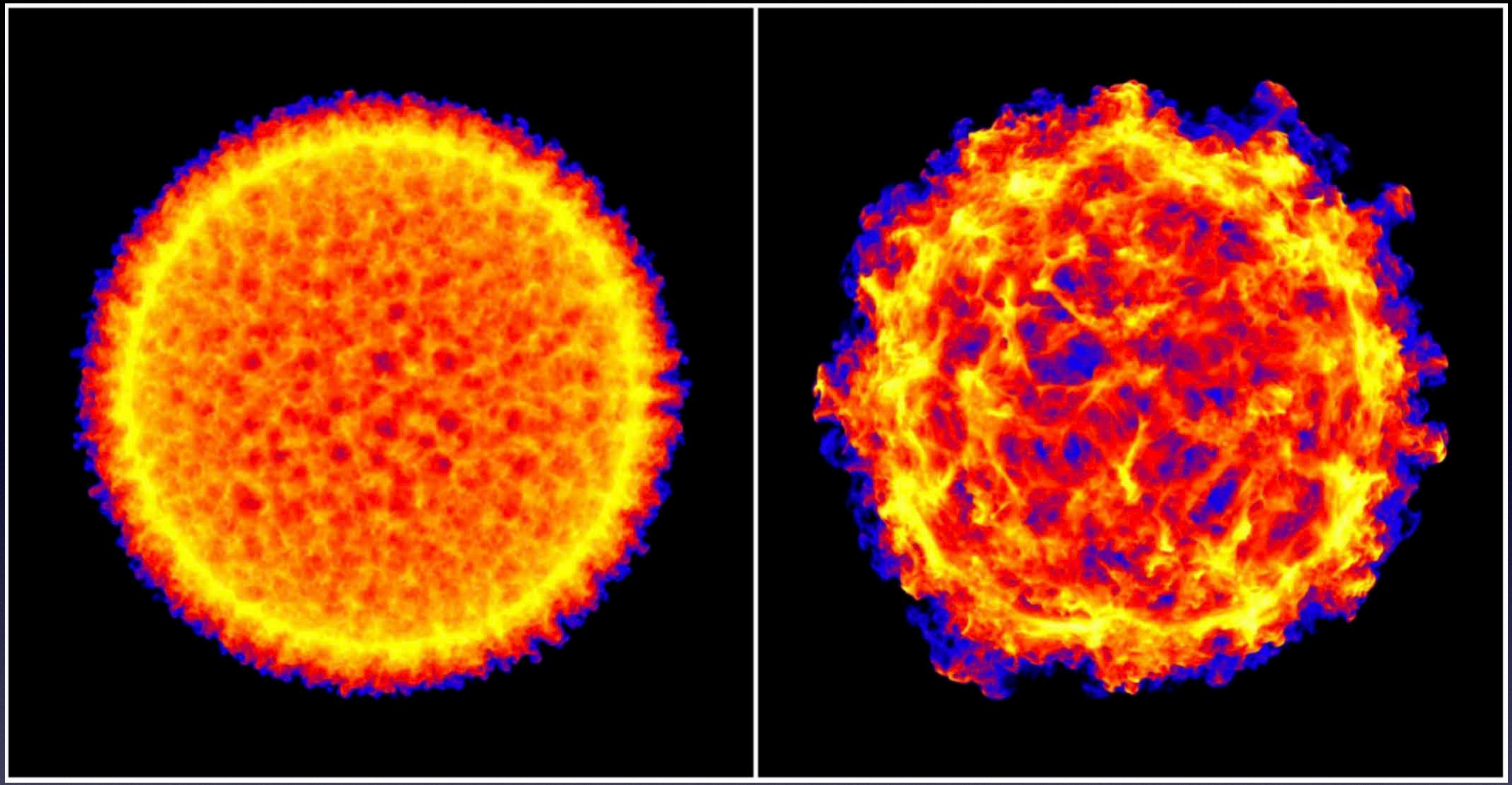


Smooth initial ejecta, structures due to Rayleigh-Taylor instabilities

Structures due to initial clumps (56Ni bubble?)



3D simulations of smooth and clumpy ejecta models at age of Tycho



The kinematics of two models are very similar but…

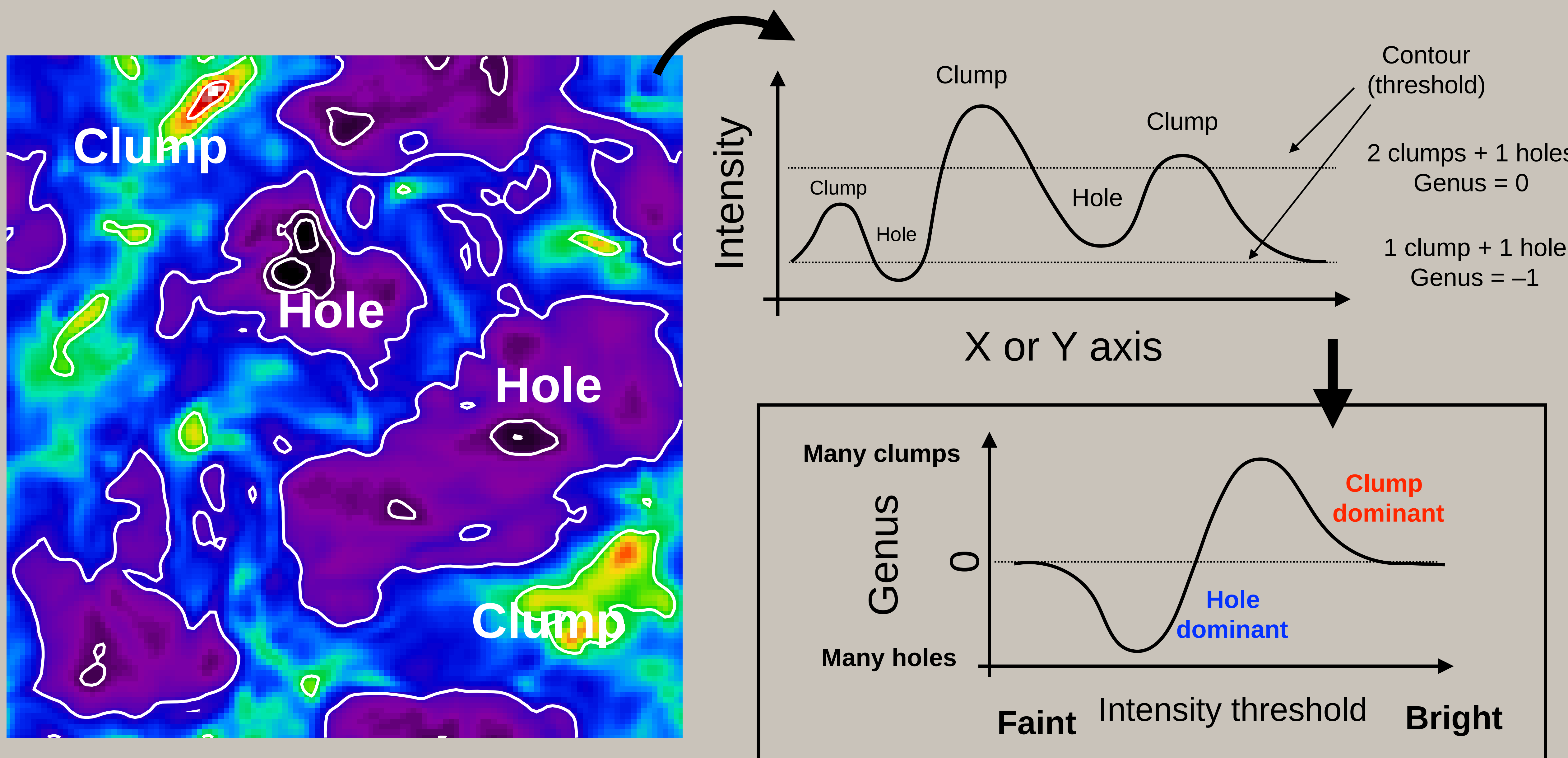
The clumpy structures seem to be very different.

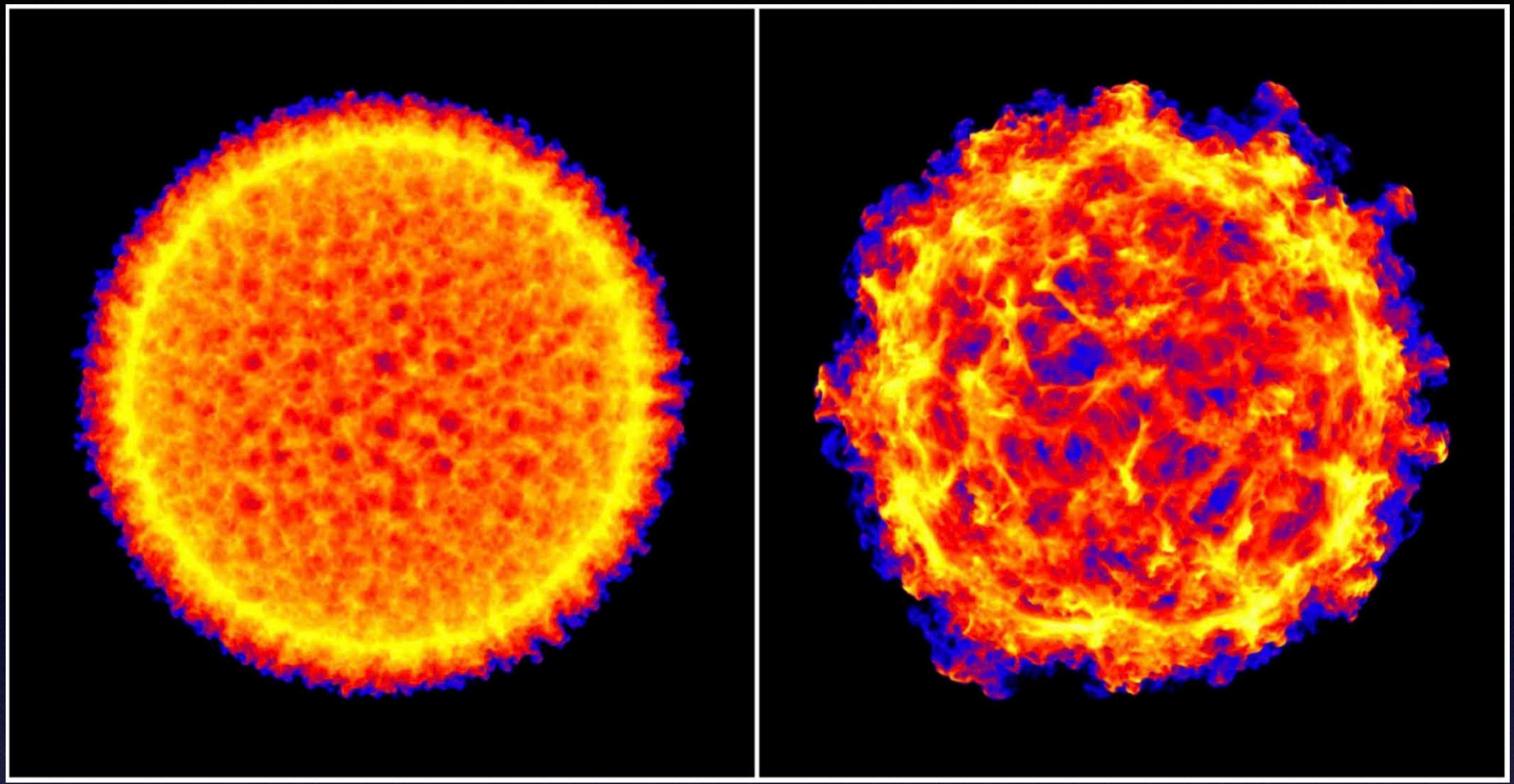
Genus Statistics

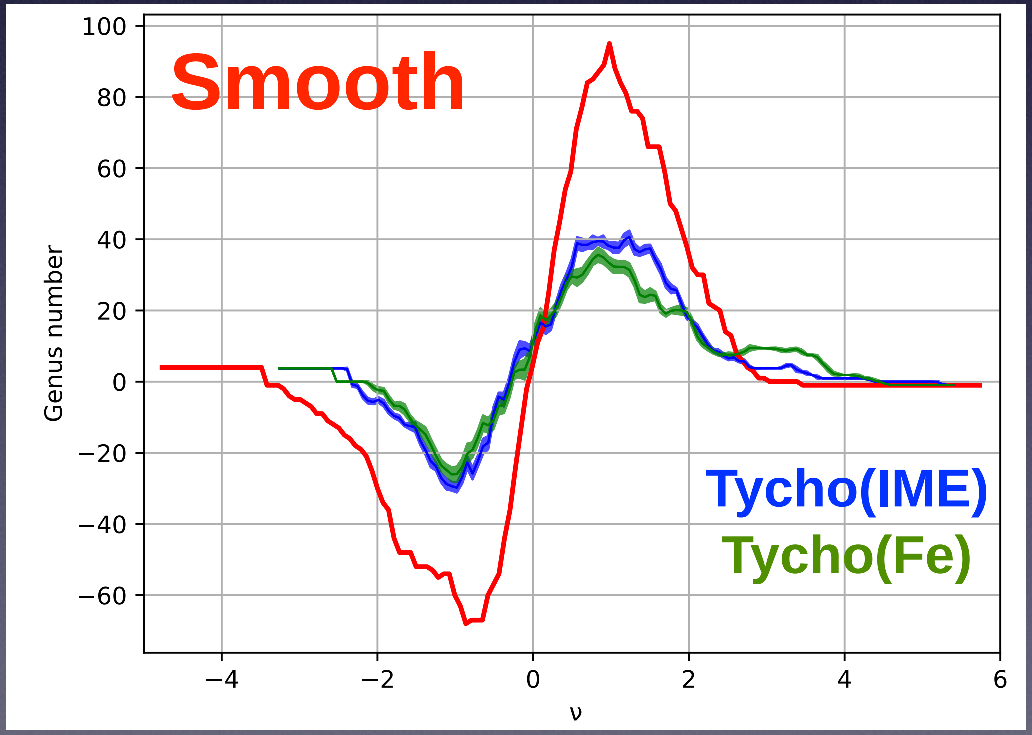
(slide courtesy of Toshiki Sato)

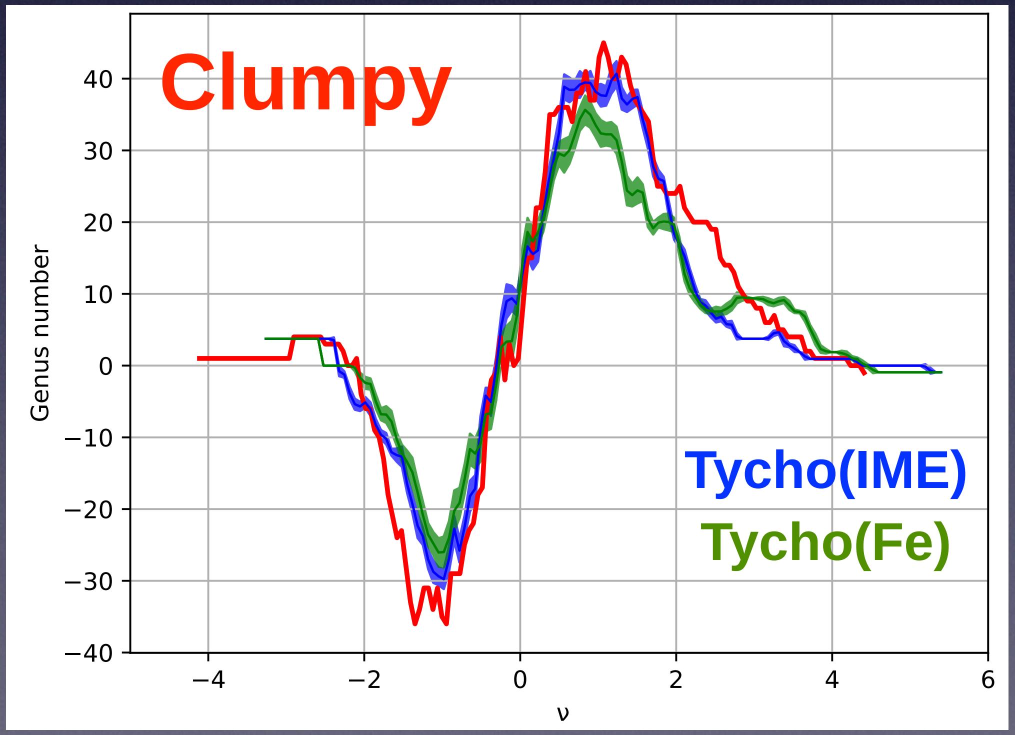
What are “Genus statistics”?

- A method to analyze topology of the large-scale structure of the cosmos
- Calculate the Homology (count the number of holes and clumps) at each contour









The genus statistic **strongly supports an initial clumped ejecta distribution** as the origin of the clumps in Tycho's supernova remnant. <u>See Sato et al. (2019)</u>

Ejecta Asymmetries and Neutron Star Kicks

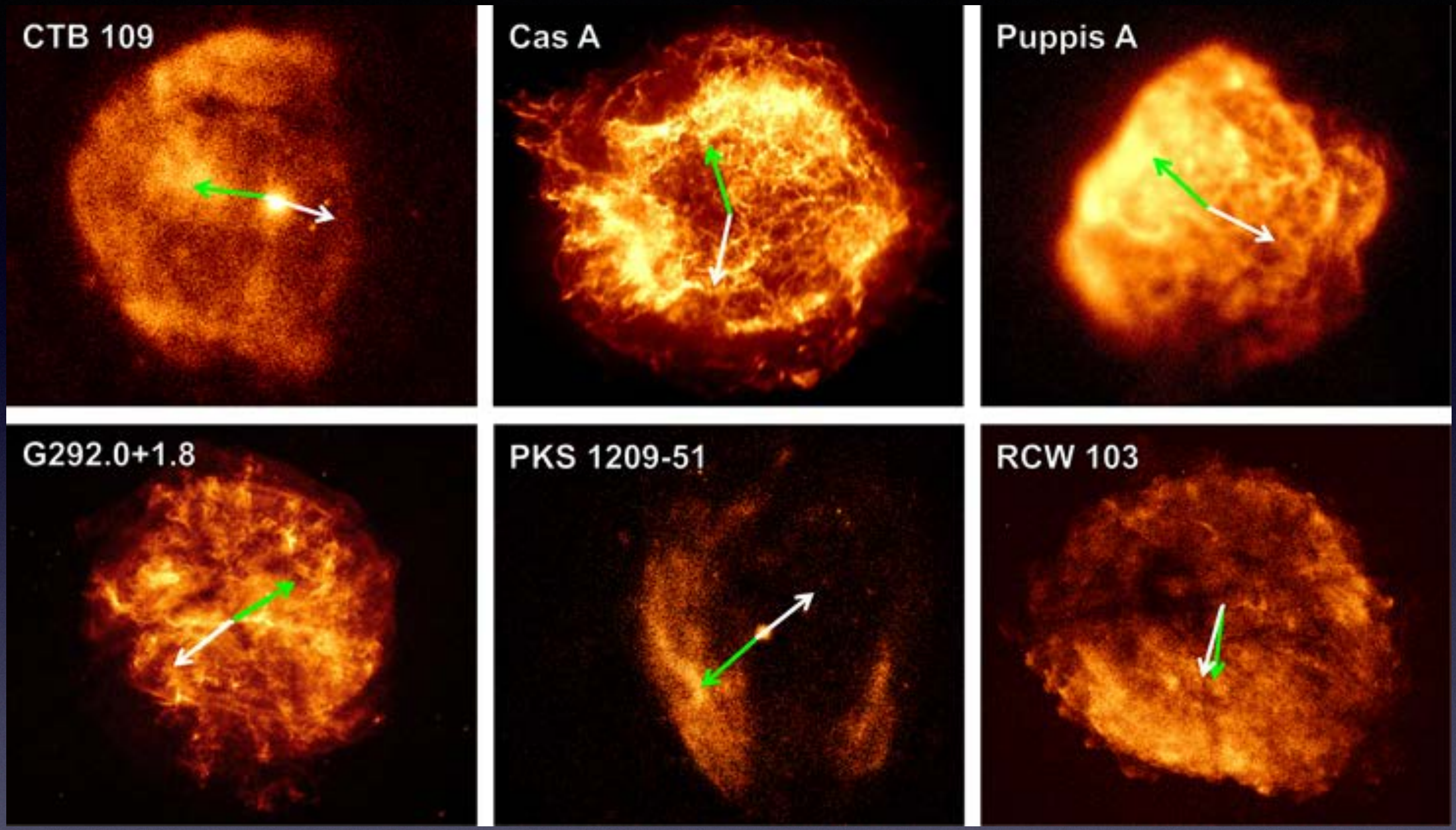
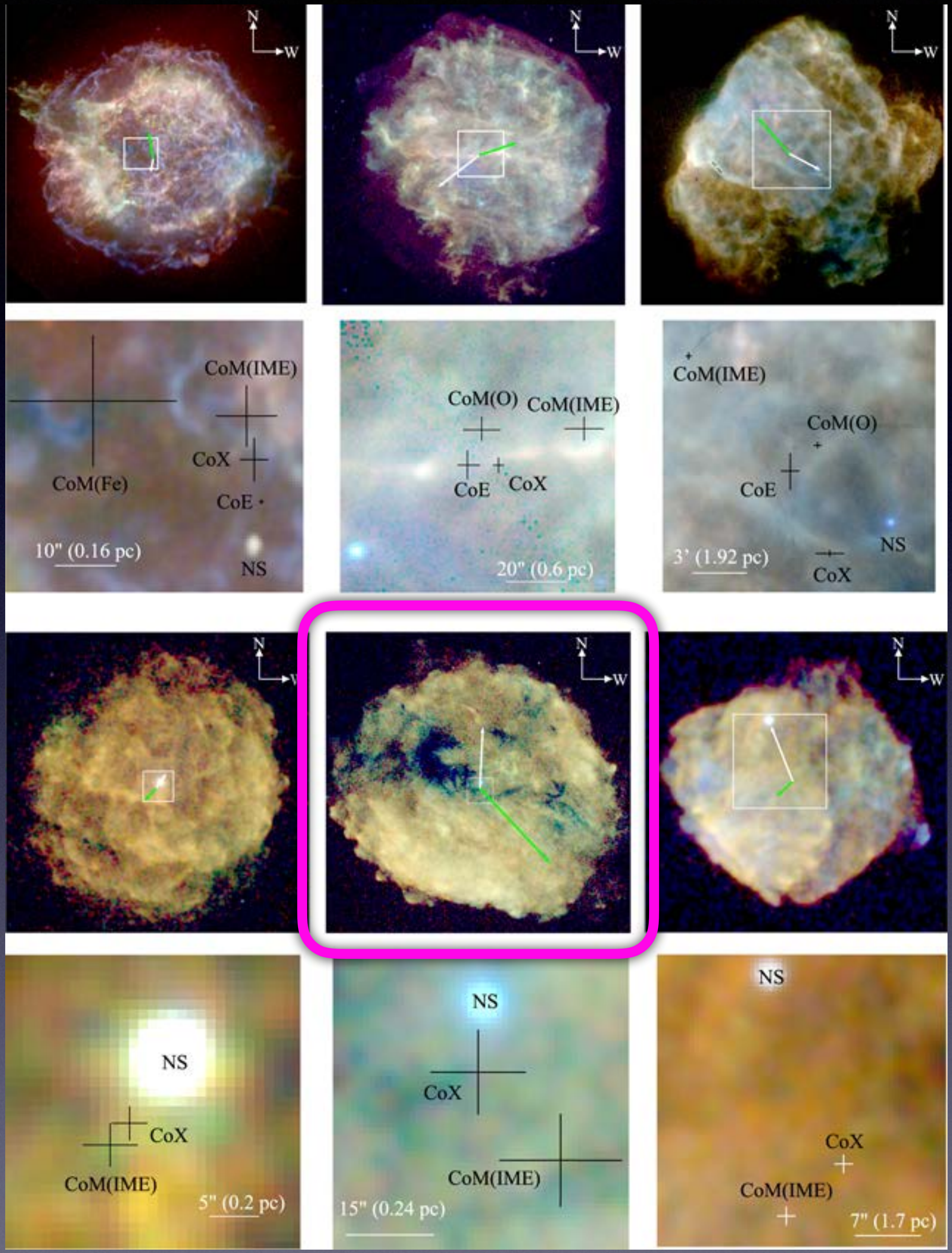


Figure from Holland-Ashford et al. 2017

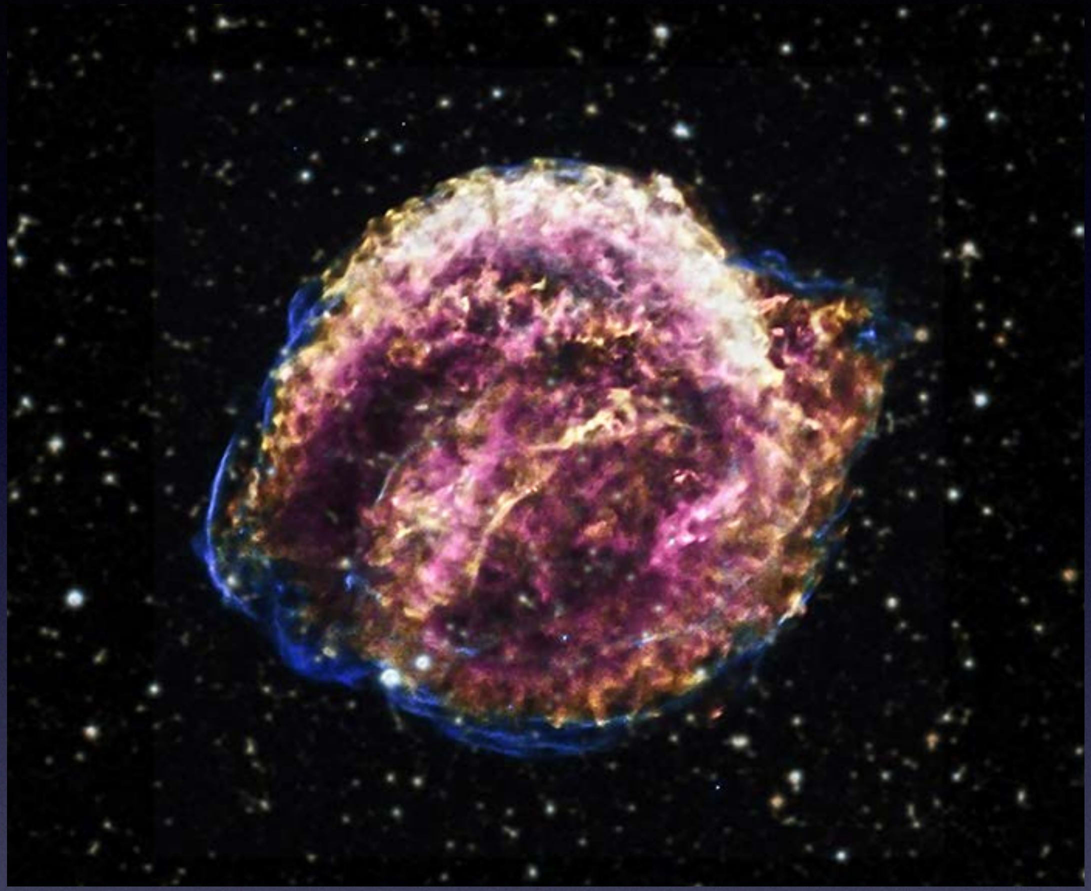
- NS often have high *v*… due to neutrino jets or asymmetric explosion?
- Holland-Ashford et al. (2017) use multiple expansion analysis of SNR morphologies to show anti-correlation of X-ray emission and NS velocity
- Favors ejecta asymmetry (con. of momentum), but several caveats

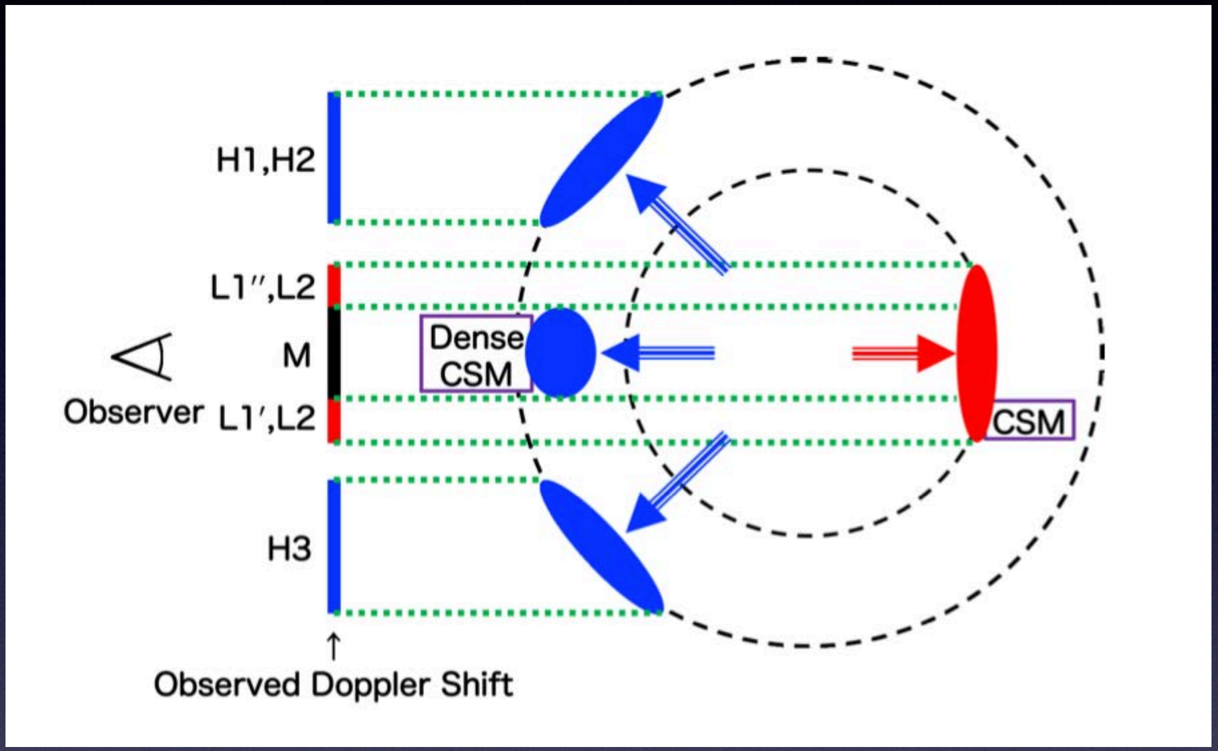


- Katsuda et al. (2017) went one step further, separating X-ray emission into ejecta and CSM/ISM components
- Results largely agree with H-A17, with exception of RCW 103
- Also explored correlation between *v* and B-field of neutron stars, find none
- Results also support ejecta asymmetries as cause of NS kicks, rather than neutrino propulsion

Figure from Katsuda et al. 2017

Ejecta asymmetries in Type Ia SNe?





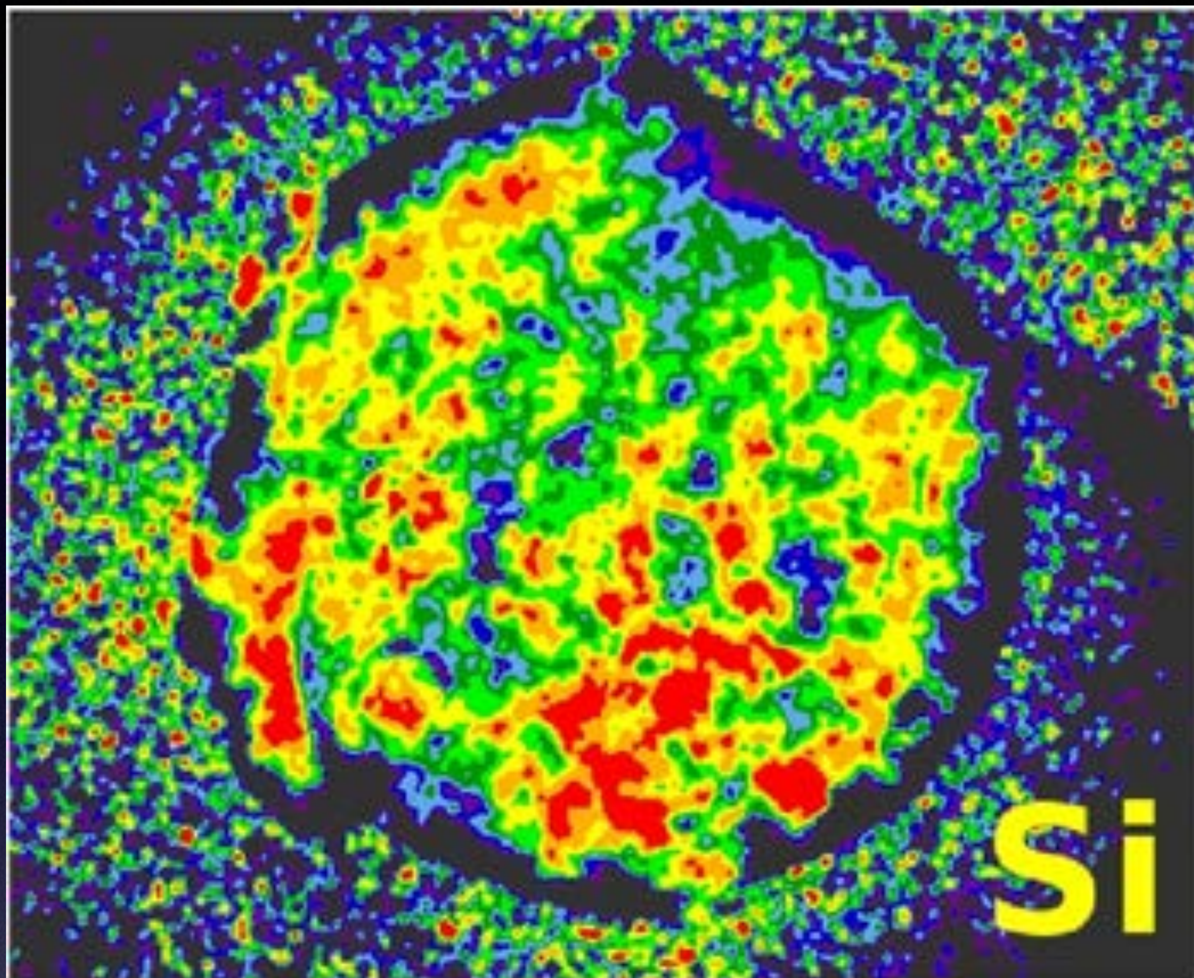
Asymmetric expansion of the Fe ejecta in Kepler's supernova remnant

Tomoaki Kasuga, Toshiki Sato, Koji Mori, Hiroya Yamaguchi, Aya Bamba

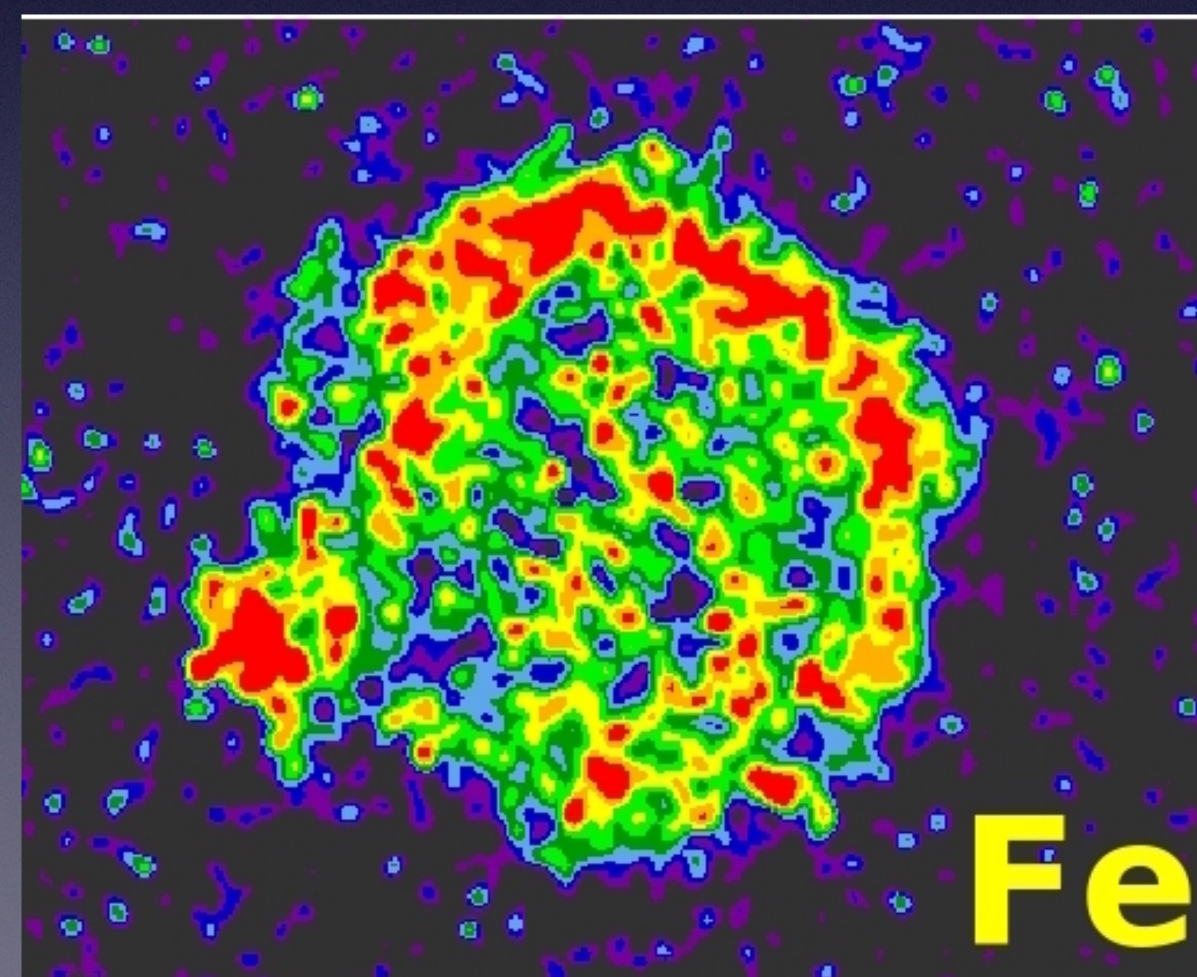
Publications of the Astronomical Society of Japan, Volume 70, Issue 5, October 2018, 88, https://doi.org/10.1093/pasj/psy085

Published: 16 August 2018 **Article history** ▾

Tycho EQW images

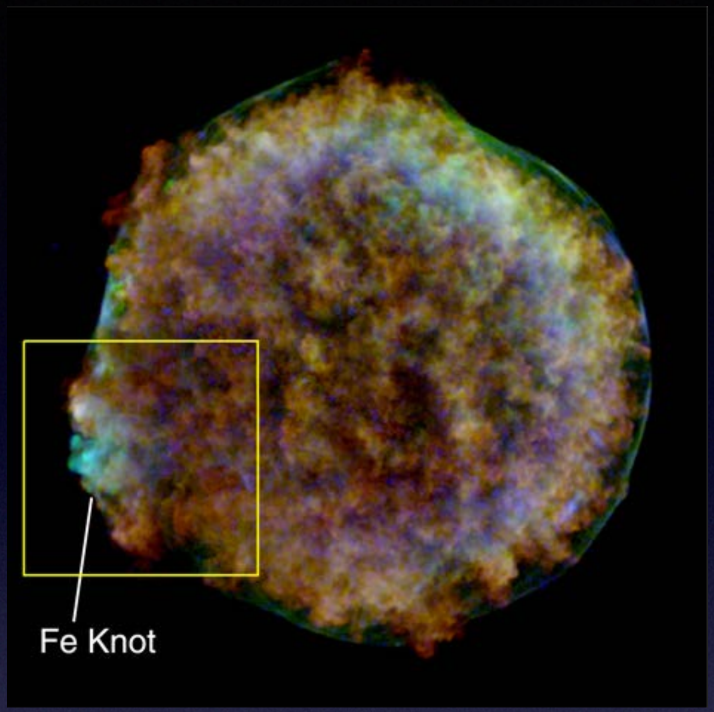


Si relatively evenly distributed (only about 5% more in the southern half)

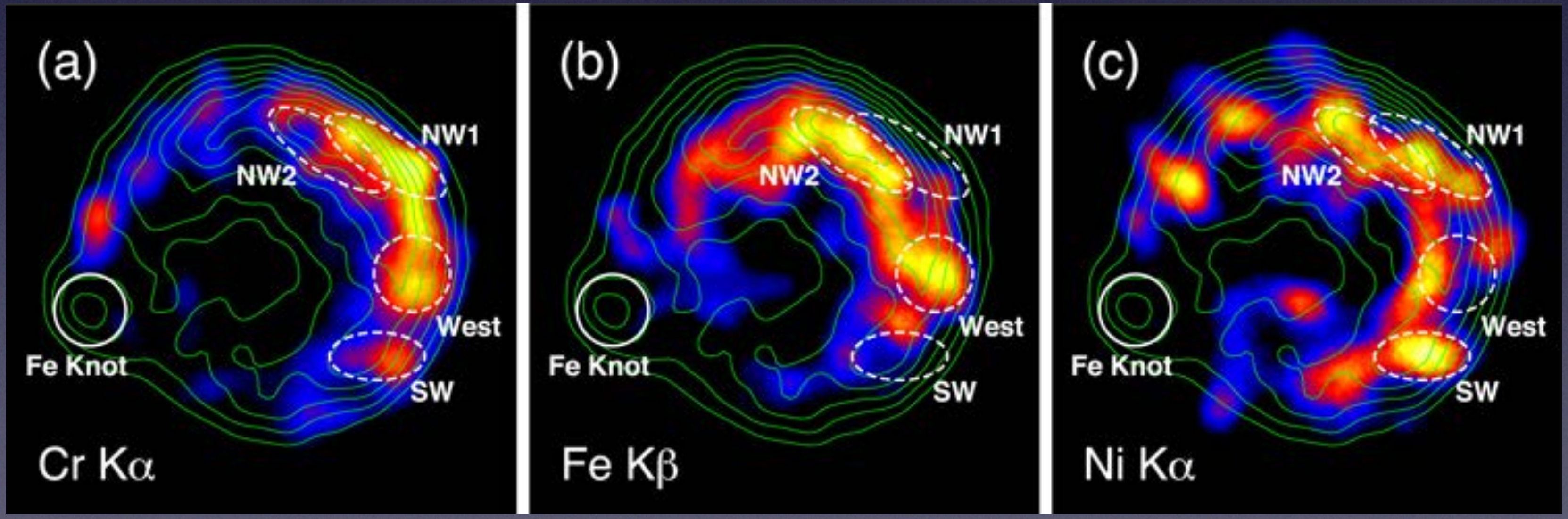


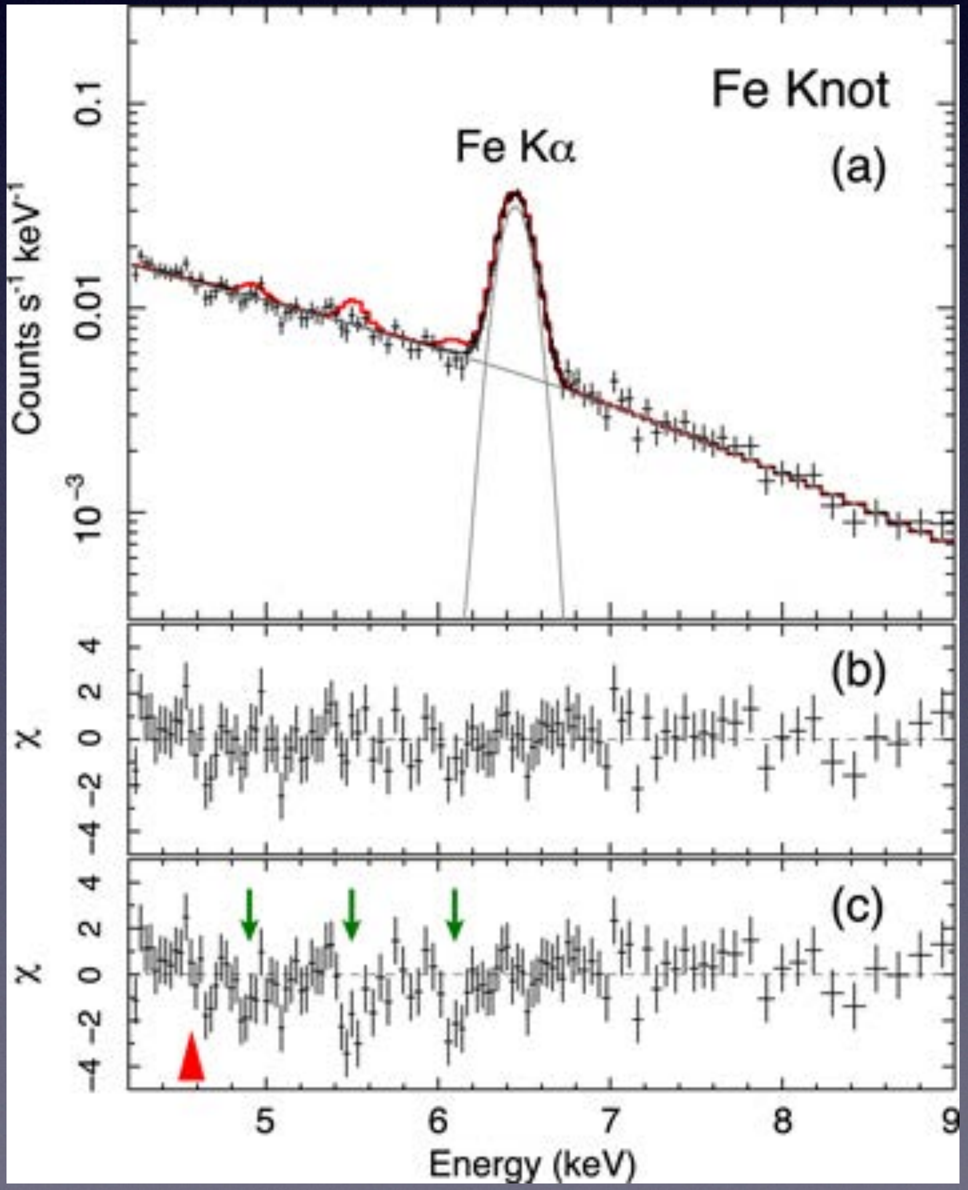
Fe much less even, with bright knot in SW

More on the Fe knot in Tycho… other Fe-group elements?



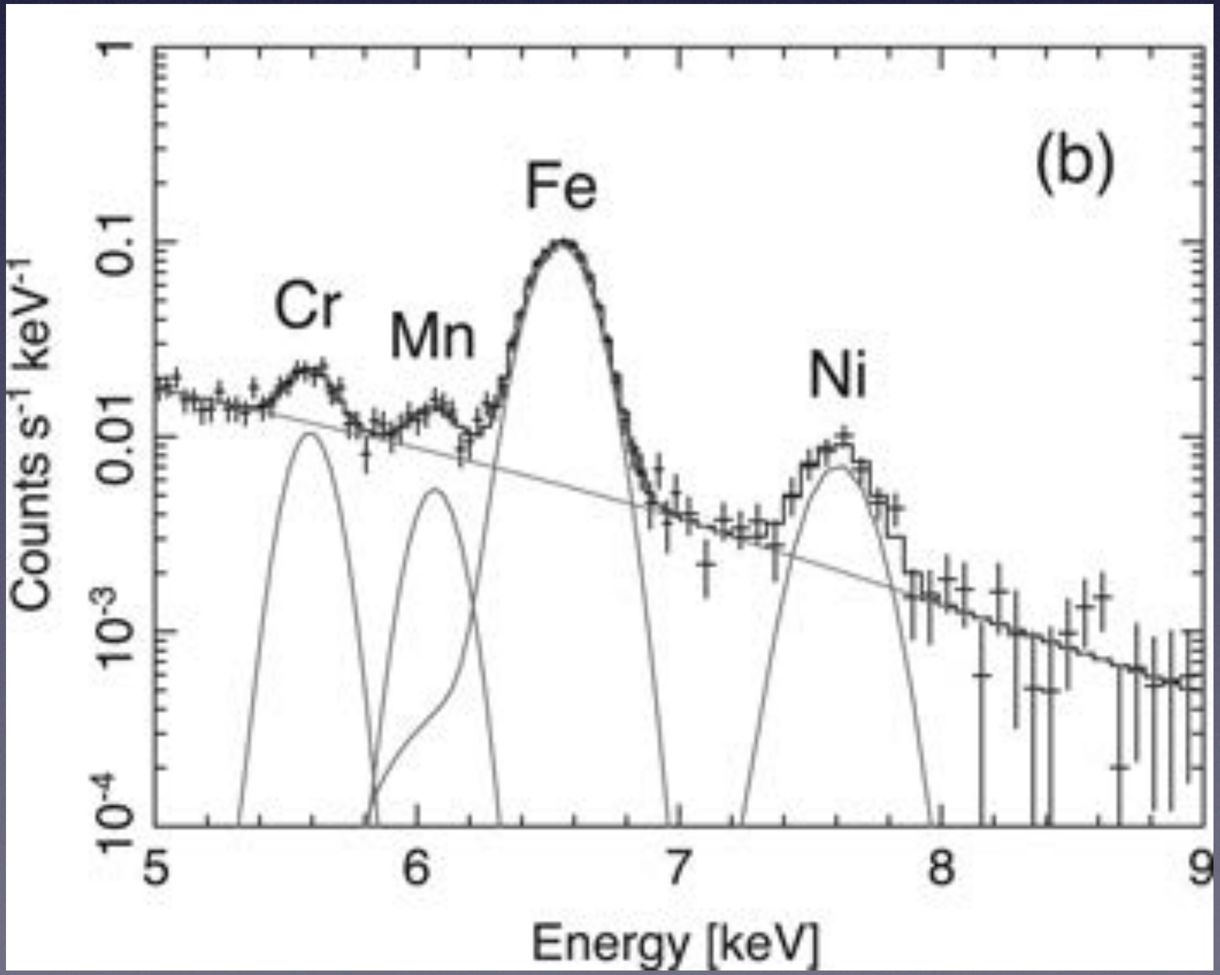
Miceli et al. (2015) report detections of Cr (5.5 keV) in some regions of Fe-rich ejecta (~6.5 keV)





However, Yamaguchi et al. (2017) were unable to confirm this for Fe knot, and in fact put tight limits on any Cr, Mn, and Ni line emission

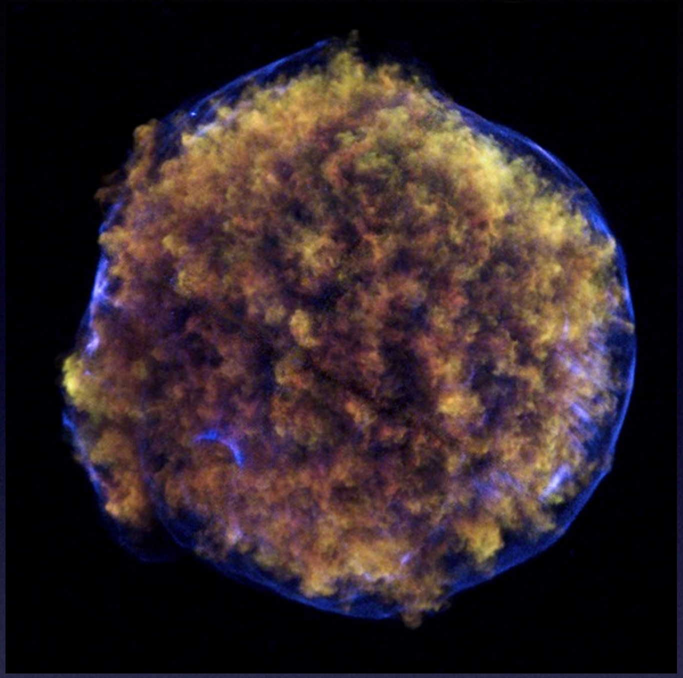
3C 397



Mass ratios of Ni/Fe and Mn/Fe, combined with what we know about nuclear burning in WDs, indicate a high degree of neutronization that can only be achieved in the dense core of a near Chandrasekhar-mass WD. Perhaps indicative of a single degenerate progenitor

See Yamaguchi et al. (2015) for more.

Tycho



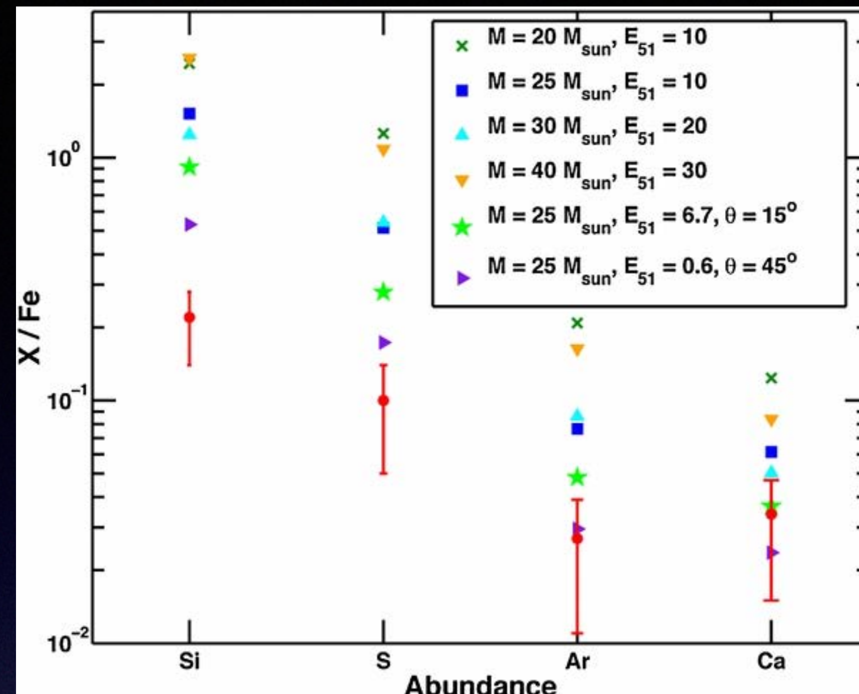
Lots of Fe, but little or no Fe-group elements. Favors sub-Ch mass WD. Double degenerate?

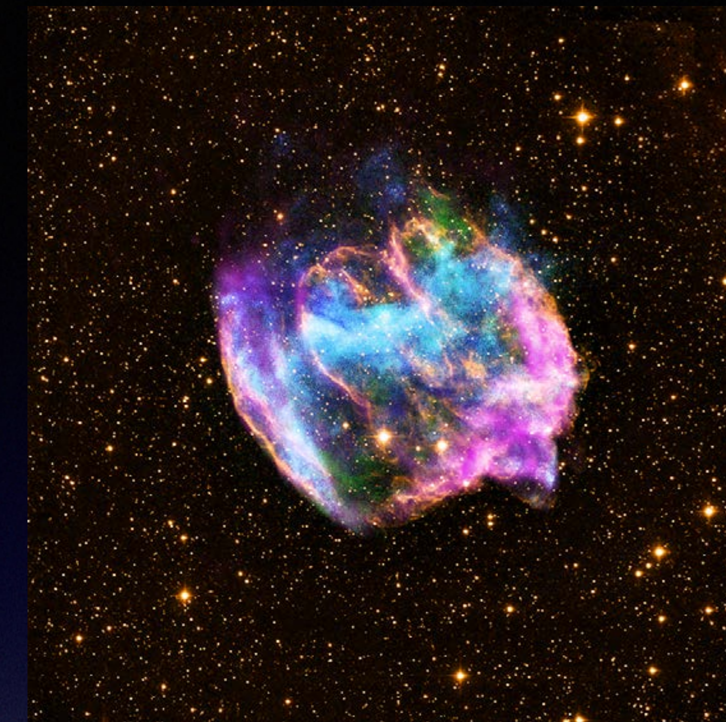
3C 397

Lots of Fe, and also lots of Fe-group elements. Favors Ch-mass WD. Single degenerate?

Two bright, local SNRs in our galaxy show evidence for very different nuclear burning regimes in the exploding WD. Perhaps evidence for more than one channel for SNe Ia?

W49B





Lopez et al. 2013 analyzed ejecta abundances and concluded that W49B was a CCSN

THE GALACTIC SUPERNOVA REMNANT W49B LIKELY ORIGINATES FROM A JET-DRIVEN, CORE-COLLAPSE EXPLOSION

Laura A. Lopez[1,4,5], Enrico Ramirez-Ruiz[2], Daniel Castro[1], and Sarah Pearson[3]

Published 2013 January 24 • © 2013. The American Astronomical Society. All rights reserved.

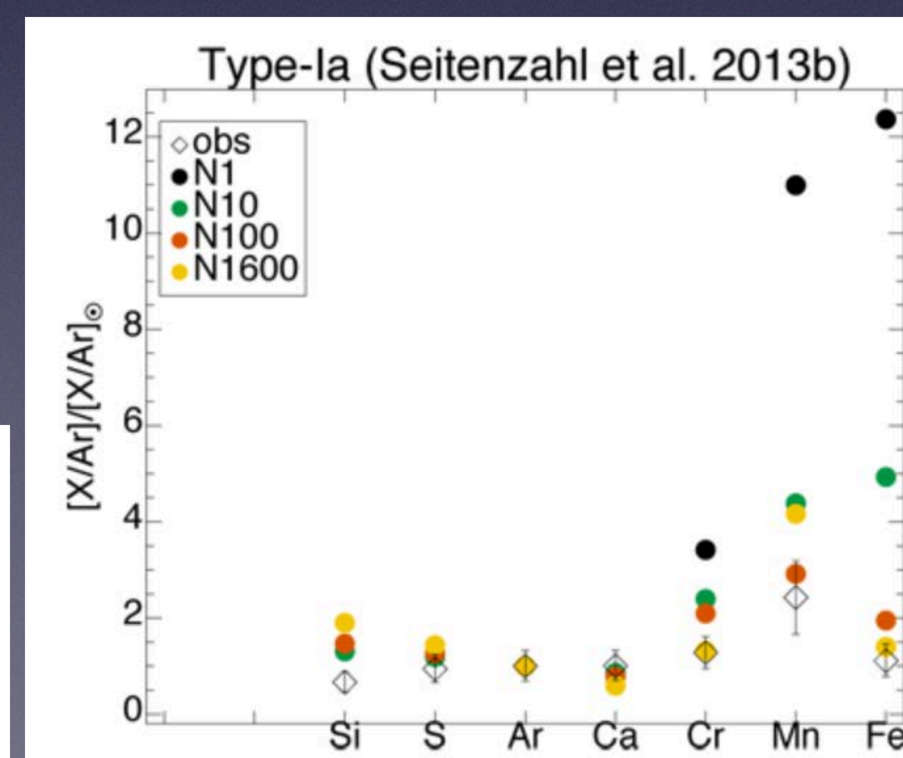
The Astrophysical Journal, Volume 764, Number 1

Zhou and Vink 2018 analyzed ejecta abundances and concluded that W49B was a Type Ia SN

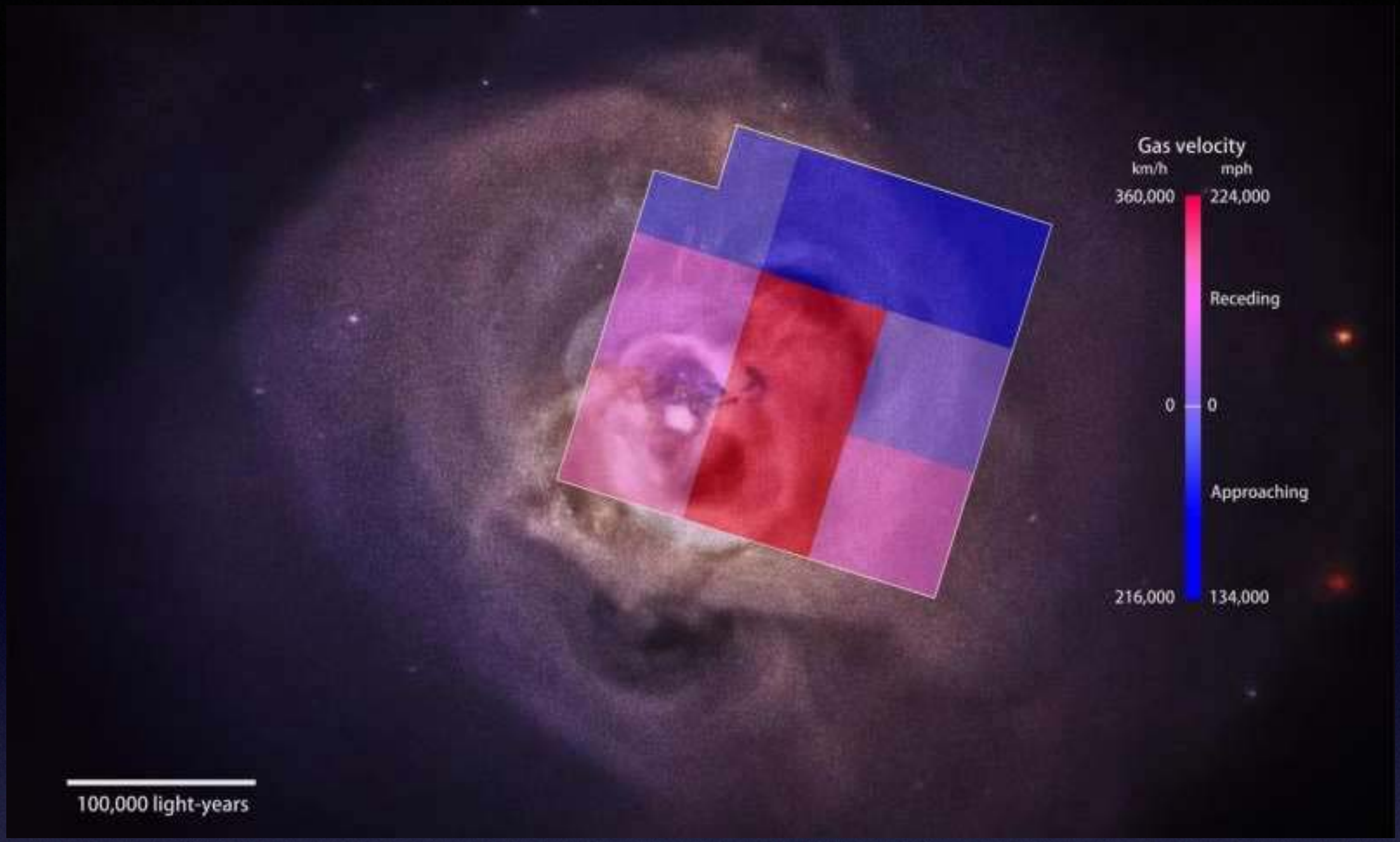
A&A 615, A150 (2018)

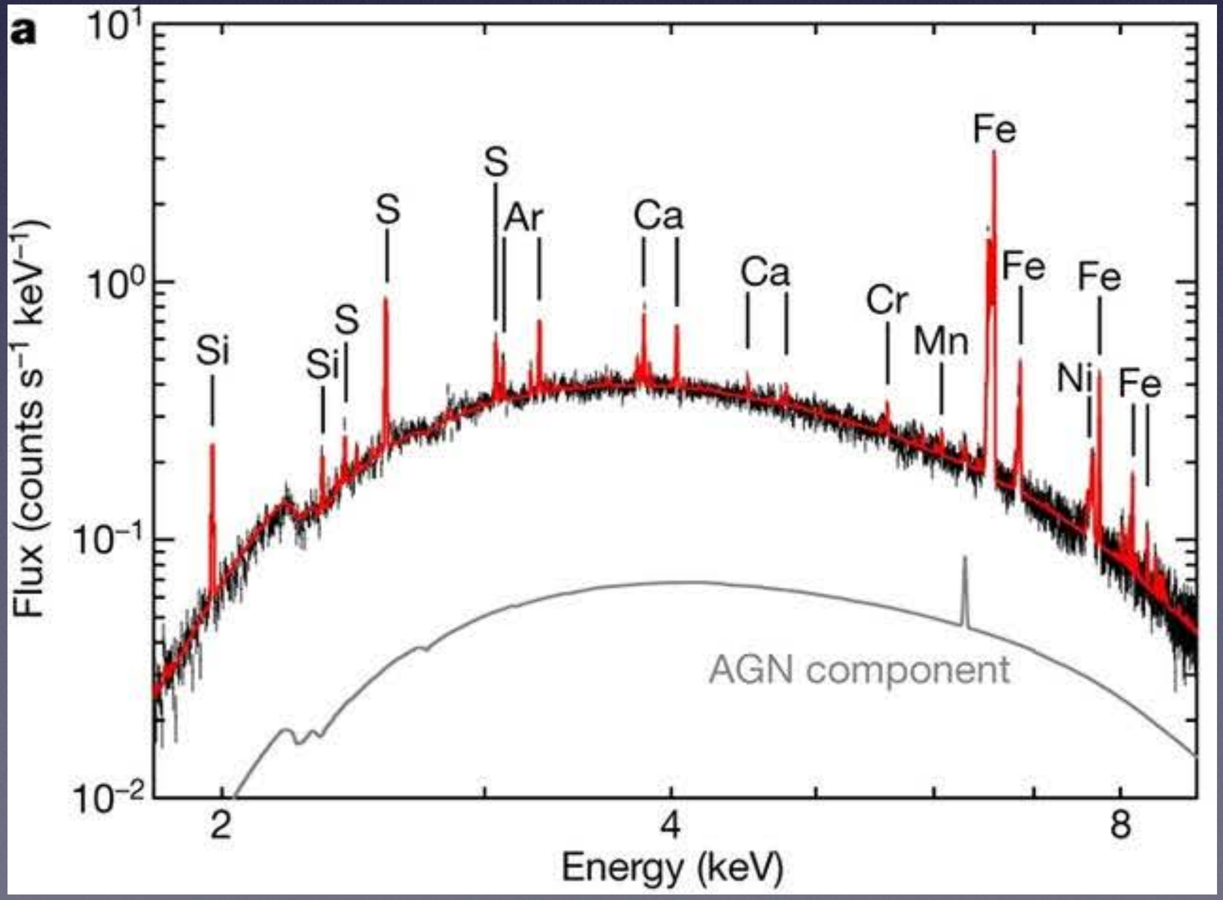
Asymmetric Type-Ia supernova origin of W49B as revealed from spatially resolved X-ray spectroscopic study

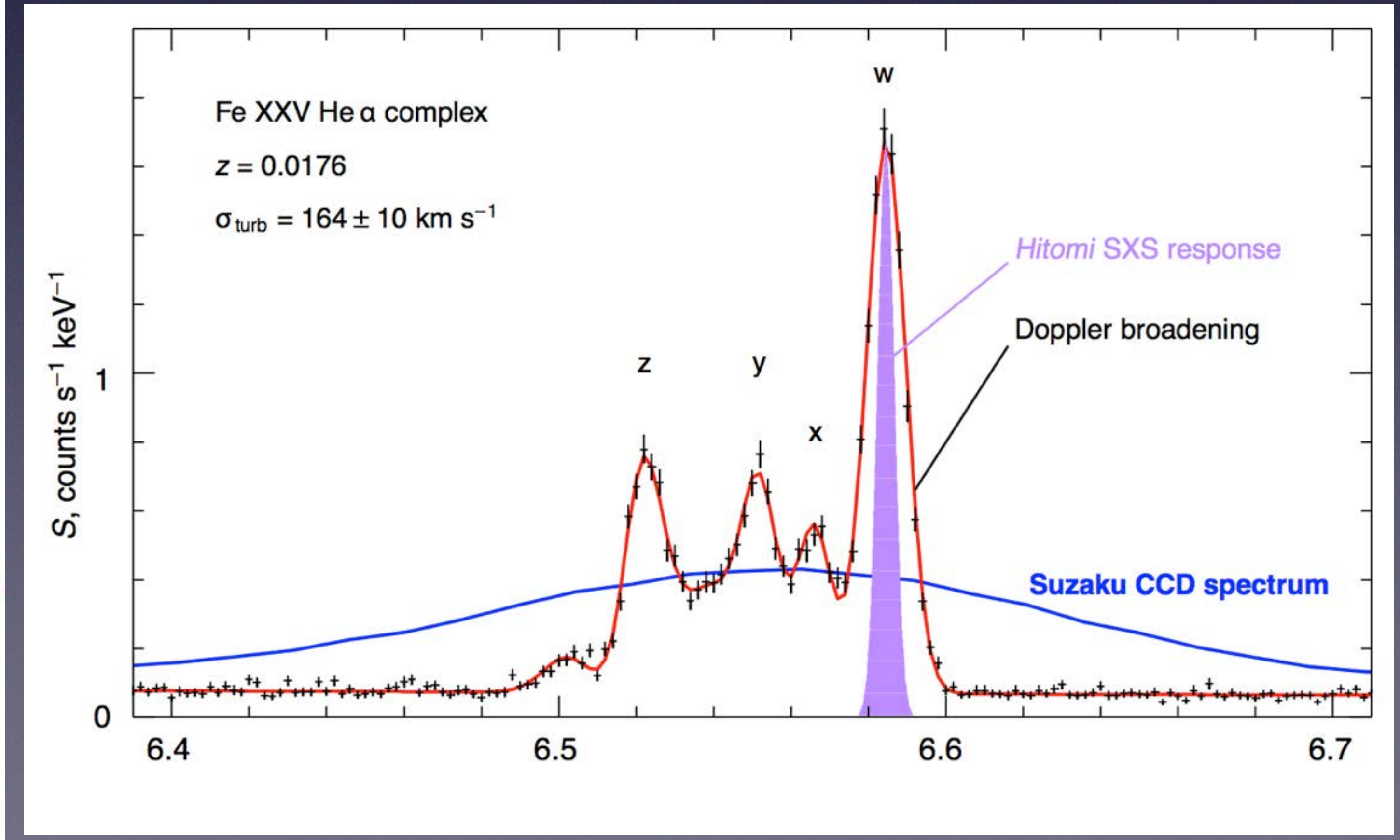
Ping Zhou[1,2] and Jacco Vink[1,3]



Hitomi (Astro-H)

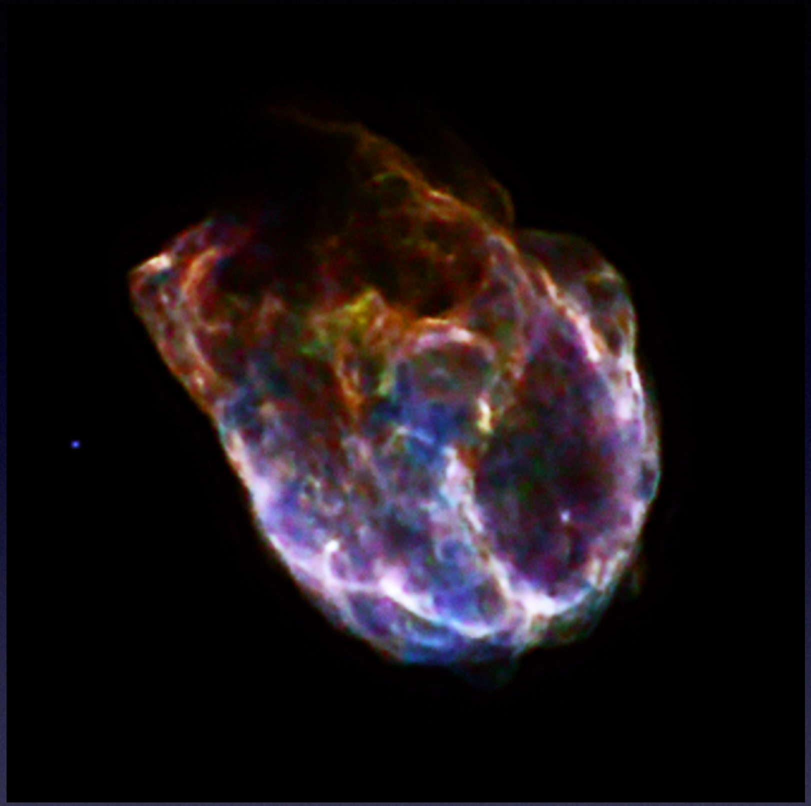




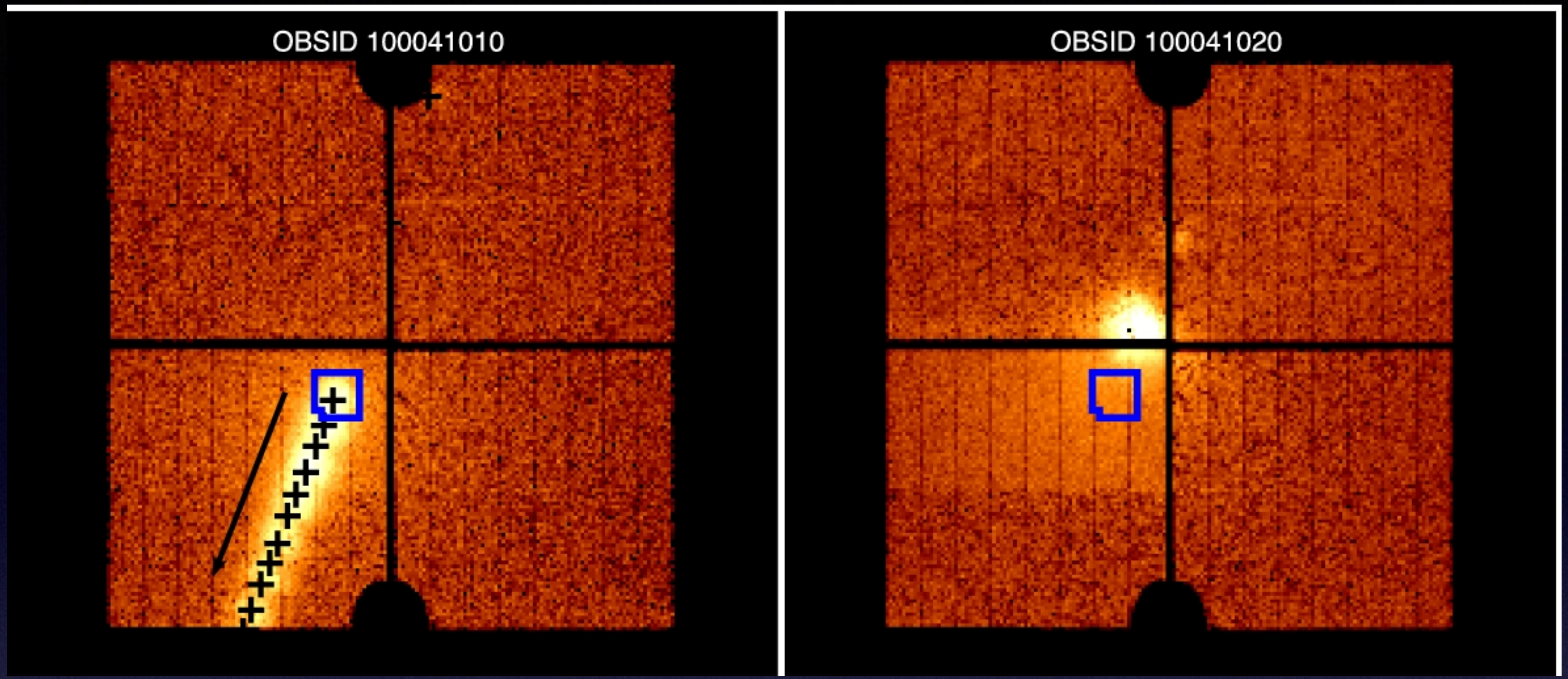


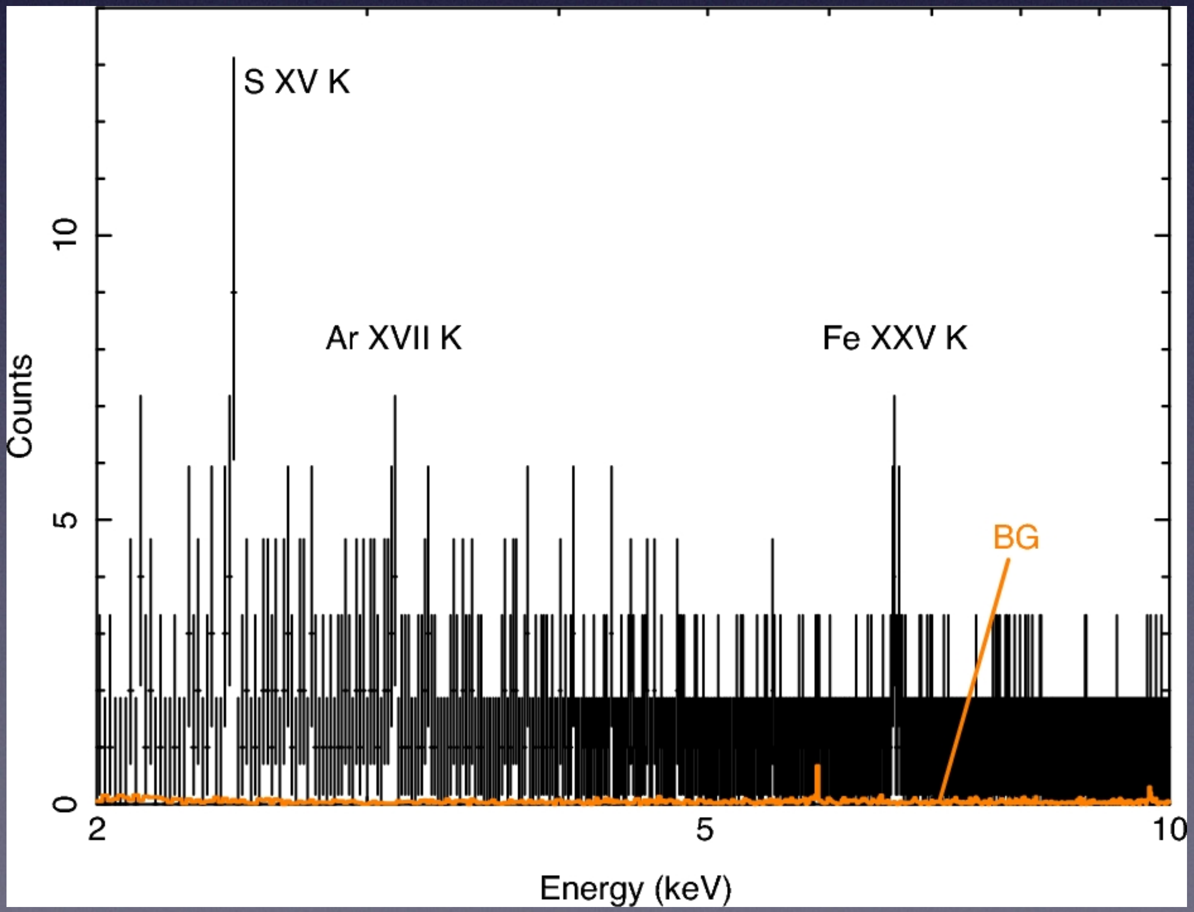
SNR N132D

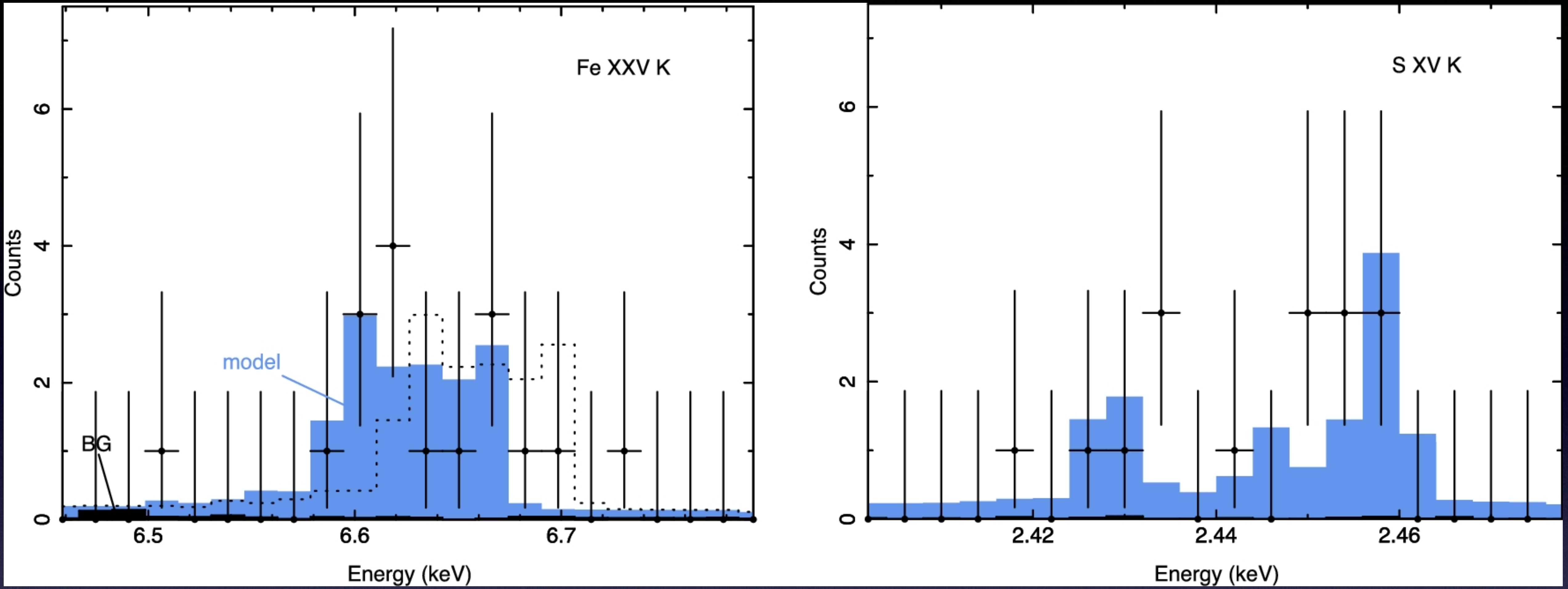
Chandra Image



Few thousand year old SNR in the LMC (50 kpc). Very bright X-ray source

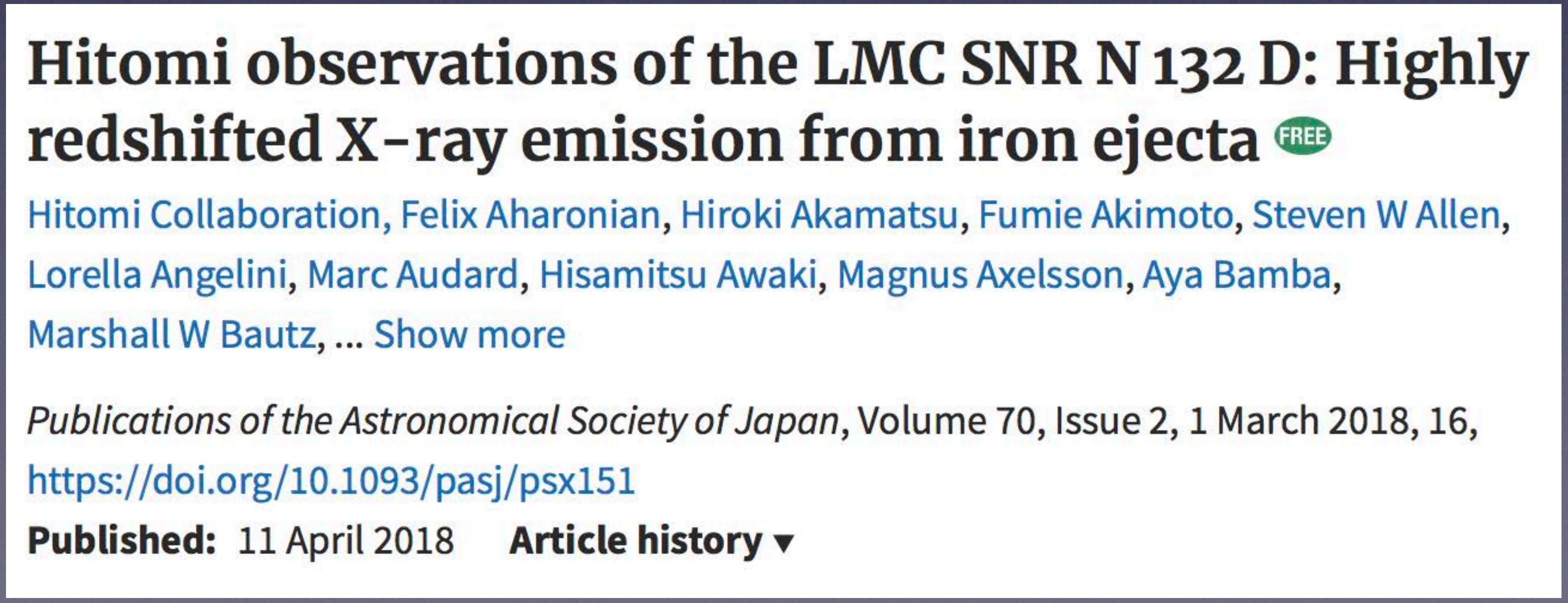






~16 counts in each of these spectral line energy ranges, but still enough to extract results!

While the S emission is consistent with a bulk velocity of 0, the Fe emission is best fit with a bulk velocity of 800 km/s. This almost certainly has implications for explosion model of progenitor SN, but caveat that error bars are large.



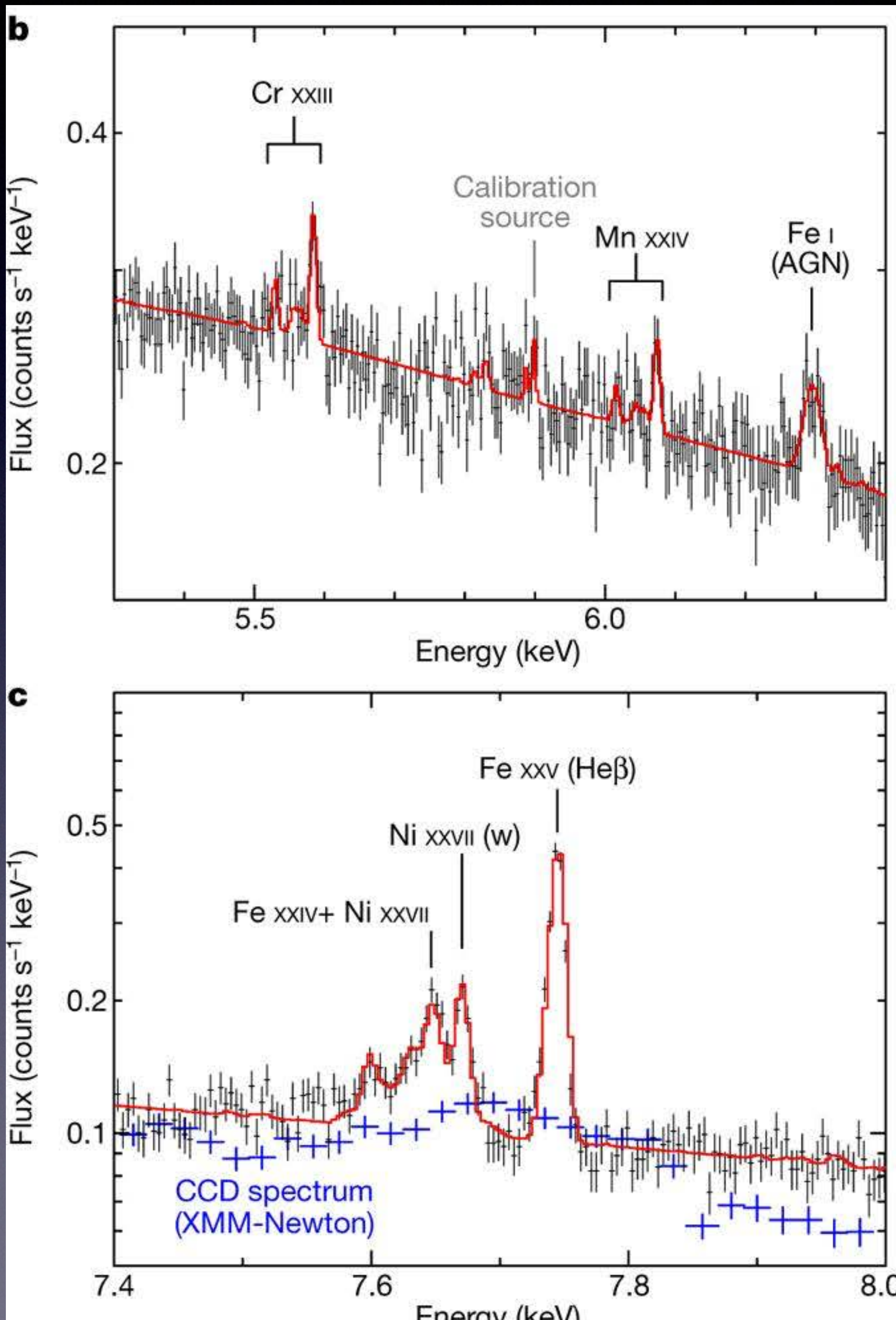
Hitomi observations of the LMC SNR N 132 D: Highly redshifted X-ray emission from iron ejecta FREE

Hitomi Collaboration, Felix Aharonian, Hiroki Akamatsu, Fumie Akimoto, Steven W Allen, Lorella Angelini, Marc Audard, Hisamitsu Awaki, Magnus Axelsson, Aya Bamba, Marshall W Bautz, ... Show more

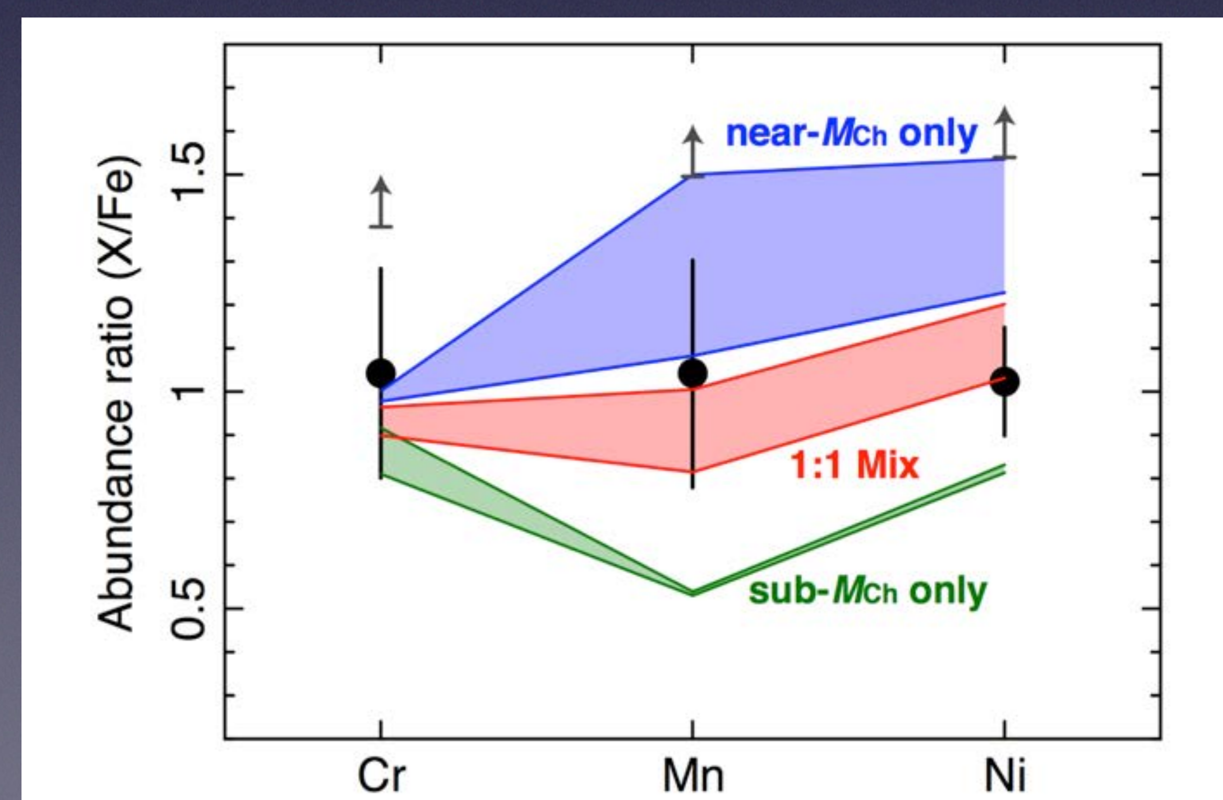
Publications of the Astronomical Society of Japan, Volume 70, Issue 2, 1 March 2018, 16, https://doi.org/10.1093/pasj/psx151

Published: 11 April 2018 **Article history ▾**

Perseus Cluster



- Metal abundance in intracluster medium is result of billions of SNe over age of universe.
- Fe-group elements (Cr, Mn, Ni) are produced in Type Ia SNe
- Features are weak, so hard to detect with CCD instruments
- Abundance of Perseus Cluster spectrum with Hitomi indicates that neither near-M_{Ch} or sub-M_{Ch} channels alone can account for observed abundances



Other SNR results from Hitomi

Search for thermal X-ray features from the Crab nebula with the Hitomi soft X-ray spectrometer FREE

Hitomi Collaboration, Felix Aharonian, Hiroki Akamatsu, Fumie Akimoto, Steven W Allen, Lorella Angelini, Marc Audard, Hisamitsu Awaki, Magnus Axelsson, Aya Bamba, Marshall W Bautz ... Show more

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Hitomi X-ray studies of giant radio pulses from the Crab pulsar FREE

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Publications of the Astronomical Society of Japan, Volume 70, Issue 2, March 2018, 15, https://doi.org/10.1093/pasj/psx083

Published: 11 April 2018 **Article history ▾**

Hitomi X-ray observation of the pulsar wind nebula G21.5−0.9 FREE

Hitomi Collaboration, Felix Aharonian, Hiroki Akamatsu, Fumie Akimoto, Steven W Allen, Lorella Angelini, Marc Audard, Hisamitsu Awaki, Magnus Axelsson, Aya Bamba ... Show more

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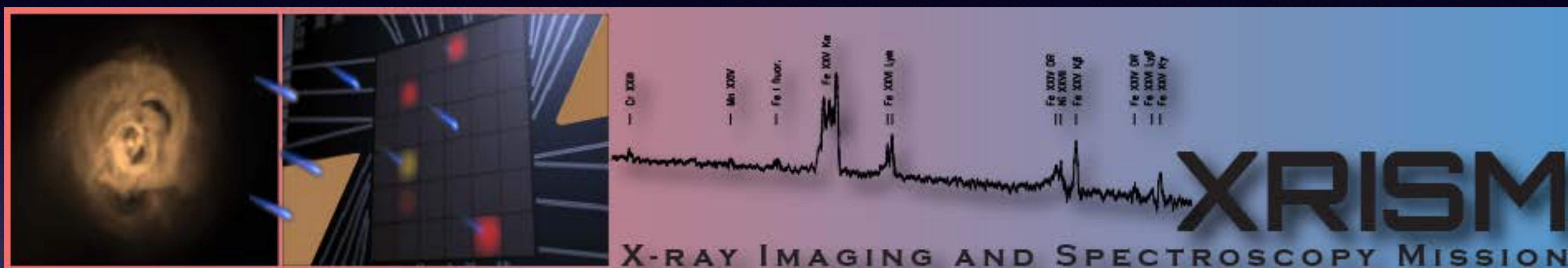
Published: 03 April 2018 **Article history ▾**

Hitomi Legacy

- Hitomi lost to an operations mishap on Day 38, but prior to that, had been working perfectly (even exceeding requirements)
- Even with only a few weeks of operations, we observed ~half-dozen targets, and have 13 scientific papers and counting, plus a few dozen instrumental papers
- We got a brief glimpse into the power of high-resolution X-ray spectroscopy.
- This is a *transformational* leap forward, and is the future of X-ray astronomy

Hitomi launch
credit: Scott Porter

The X-ray Imaging and Spectroscopy Mission (XRISM[1,2])



NASA Deputy Project Scientist

[1]Pronounced “krizz-em”

[2]formerly known as “XARM”

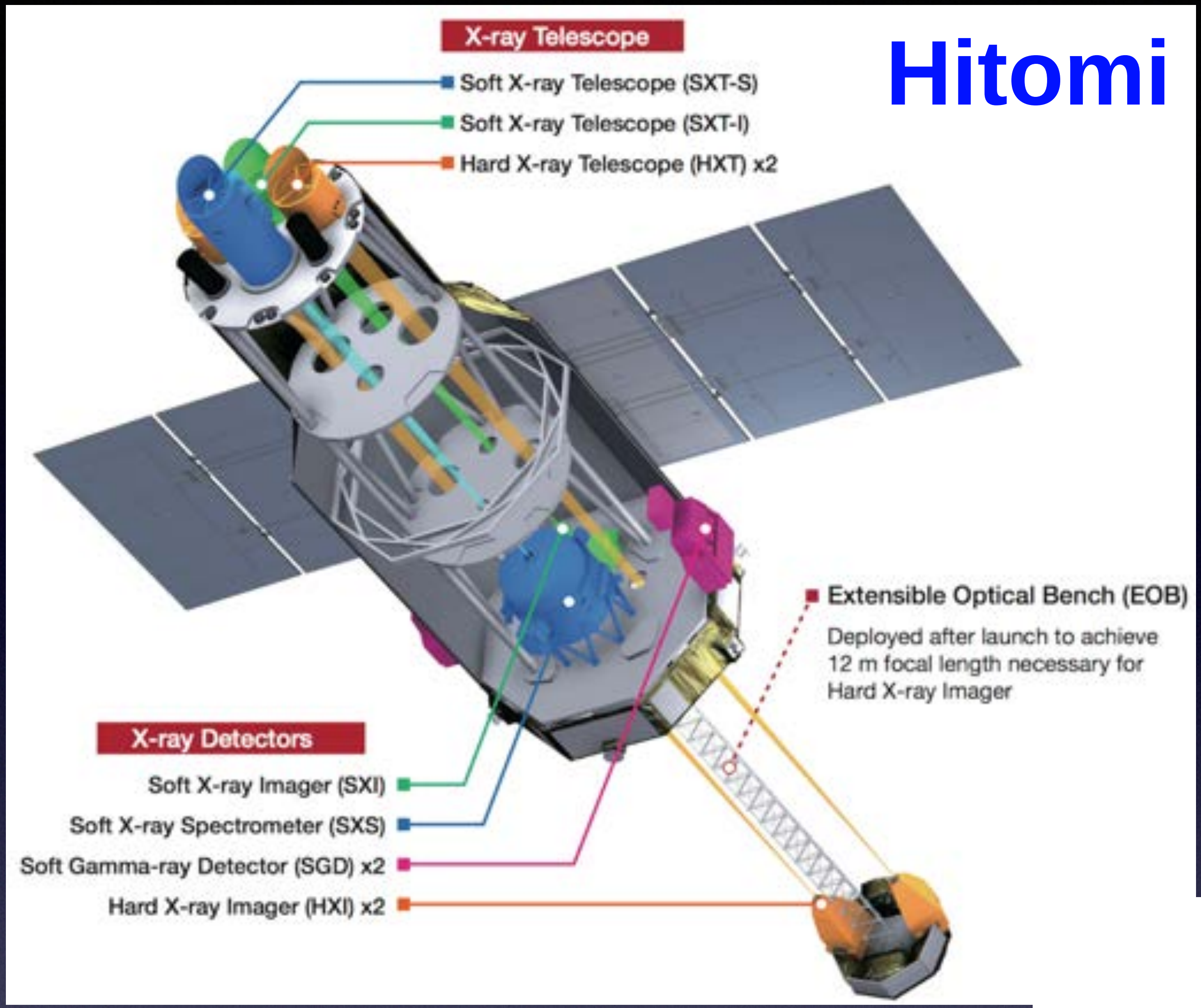
XRISM Executive Summary

XRISM, formerly the X-ray Astronomy Recovery Mission (XARM), is a JAXA/NASA collaborative mission with ESA participation. XRISM is expected to launch in February 2022 on a JAXA H-IIA rocket.

The XRISM payload consists of two instruments:

- Resolve: a soft X-ray spectrometer, which combines a lightweight X-Ray Mirror Assembly paired with an X-ray microcalorimeter spectrometer, and provides non-dispersive 5-7 eV energy resolution in the 0.3-12 keV bandpass with a field of view of about 3 arcmin.

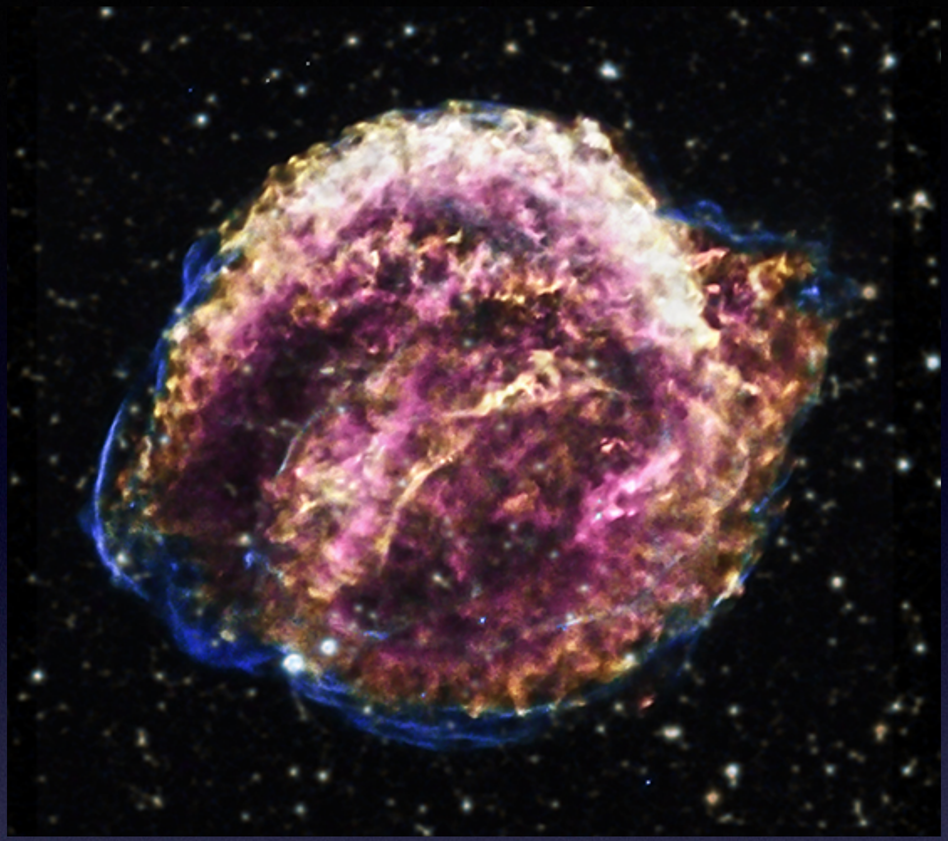
- Xtend: a soft X-ray imager, is a CCD detector that extends the field of the observatory to 38 arcmin over the energy range 0.4-13 keV, using an identical lightweight X-Ray Mirror Assembly.



Two Instruments:
SXS+SXT ➔ *"Resolve"*
SXI+SXT ➔ *"Xtend"*

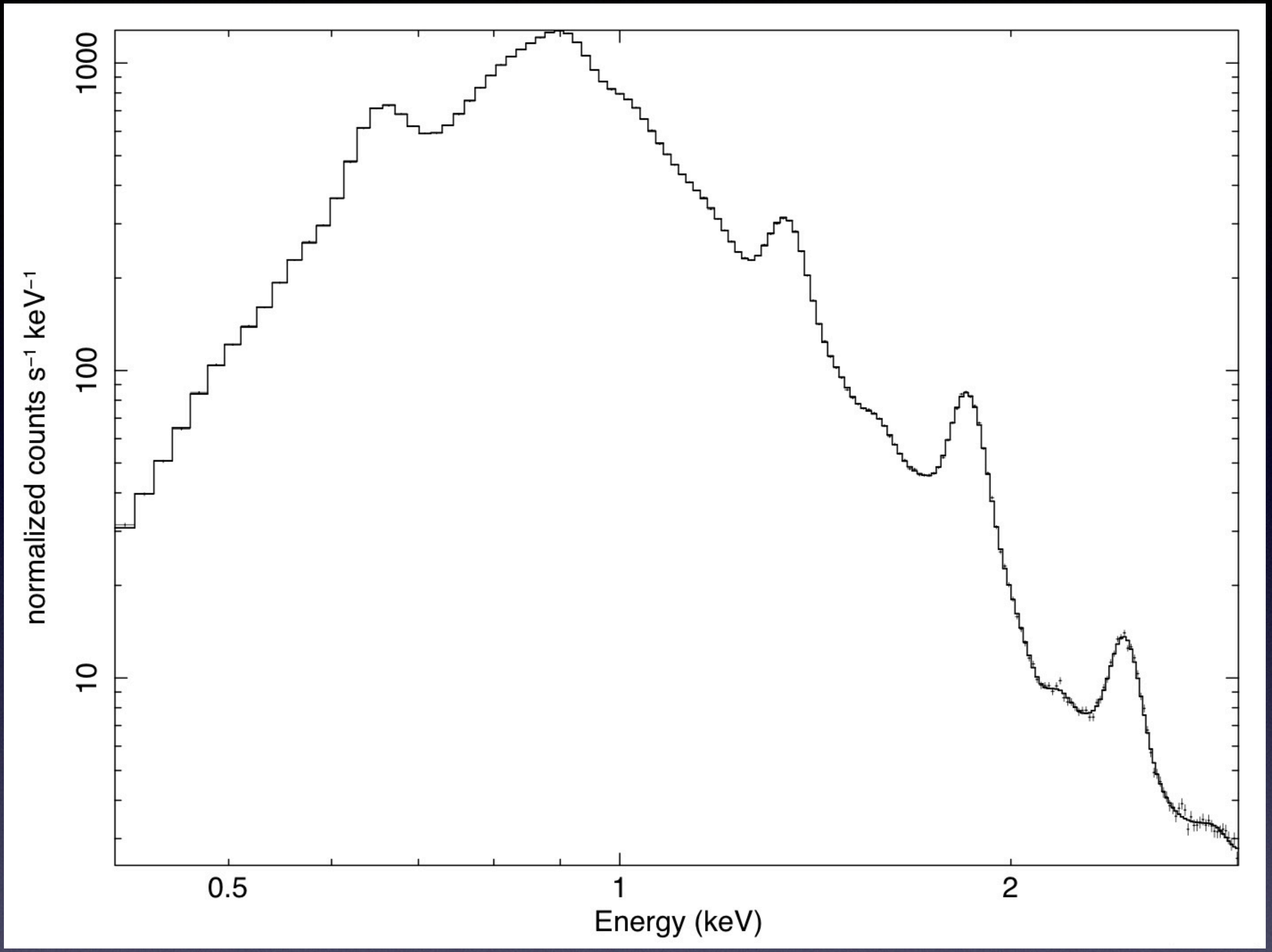
Resolve Top-Level Performance Requirements

Parameter	Requirement	Hitomi Values
Energy resolution	7 eV (FWHM)	5.0 eV
Energy scale accuracy	± 2 eV	± 0.5 eV
Residual Background	2 x 10^{-3} counts/s/keV	0.8 x 10^{-3} counts/s/keV
Field of view	2.9 x 2.9 arcmin	same, by design
Angular resolution	1.7 arcmin (HPD)	1.2 arcmin
Effective area (1 keV)	> 160 cm^2	250 cm^2
Effective area (6 keV)	> 210 cm^2	312 cm^2
Cryogen-mode Lifetime	3 years	4.2 years (projected)
Operational Efficiency	> 90%	> 98%



Kepler's SNR

Thermal emission from a ~1 keV shocked plasma



After ~3 month commissioning and ~6 month performance verification phase, the duration of the mission will be GO phase, open to competitive proposals from anywhere in the world, so start thinking of your ideas!

Postdoc Hire in SN/SNR science at NASA GSFC

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Postdoctoral Associate - High Energy Astrophysics

Submission Information

Publish Date: Friday, March 8, 2019
Archive Date: Friday, June 21, 2019
To event remaining 16 days

Job Summary

Job Category: Post-doctoral Positions and Fellowships
Institution Classification/Type: Large Academic
Institution/Company: University of Maryland
Department Name: Astronomy/CRESST II
City: College Park
State/Province: MD
Zip/Postal: 20742
Country: United States of America

Announcement

Job Announcement Text:

- 2 years initial funding, could be extended
- (most) non-US citizens ok!
- pursue various research topics that interest you
- flexible on start date (late 2019 - 2020)
- NASA Goddard is a great place to work

Final Thoughts…

- Thank you to the organizers for giving me the privilege (and significant workload) of trying to review such a broad topic
- I can only scratch the surface of what you all have done and are doing
- Please come and tell me about your work!