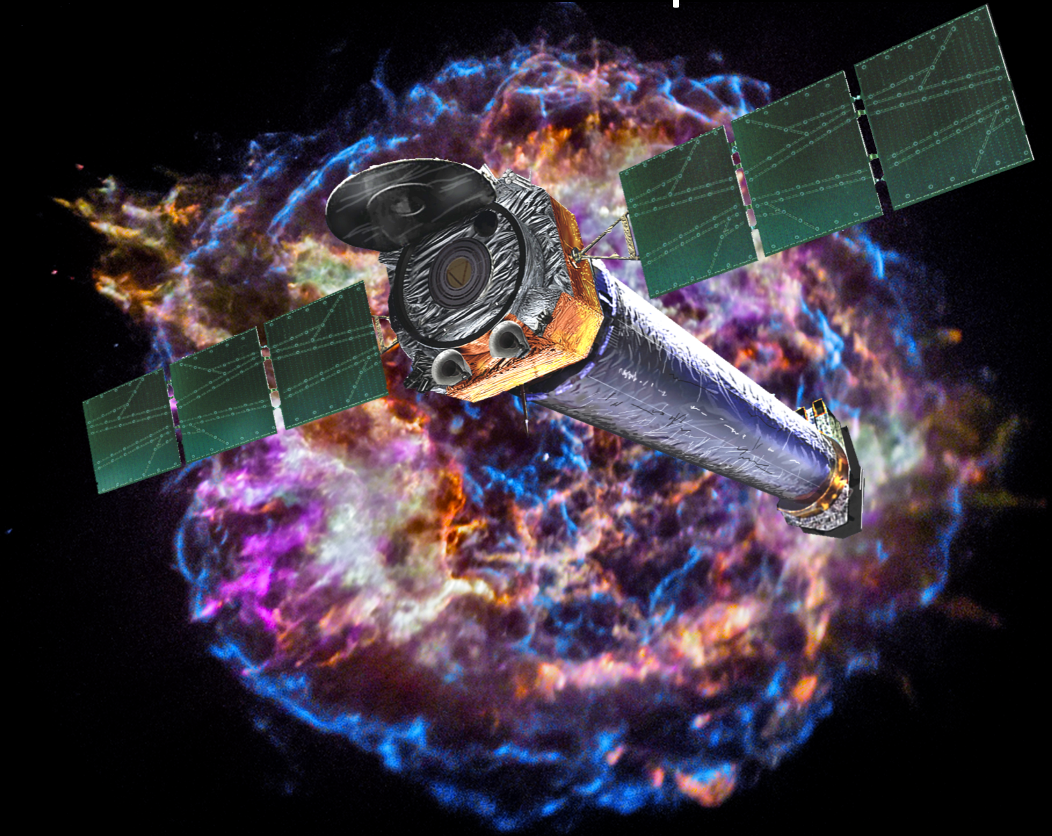
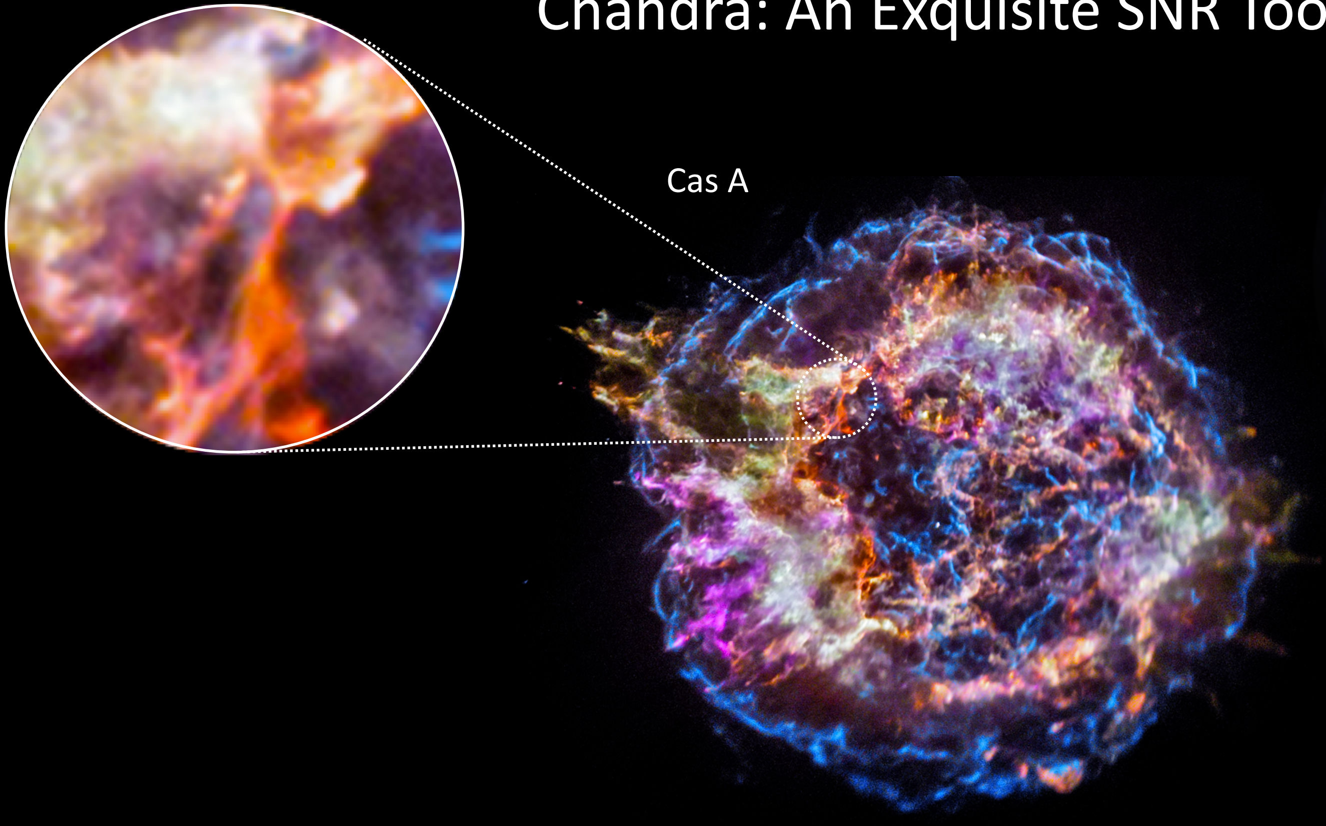
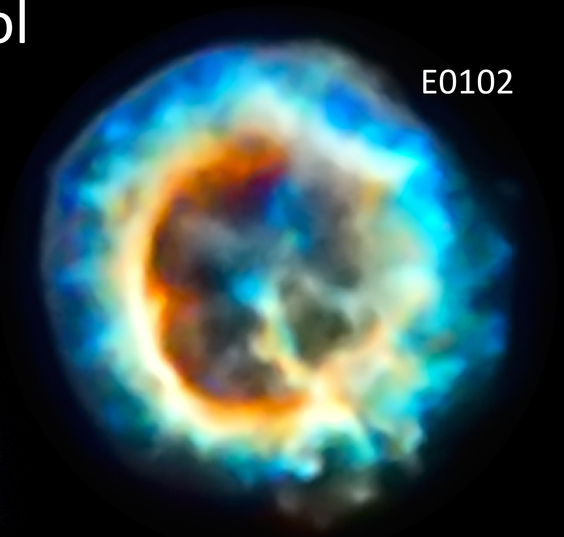
Probing the Relics of Stellar Explosions with Chandra



P. Slane (CfA)

Chandra: An Exquisite SNR Tool





1 arcsec = 1000 AU D_{kpc}

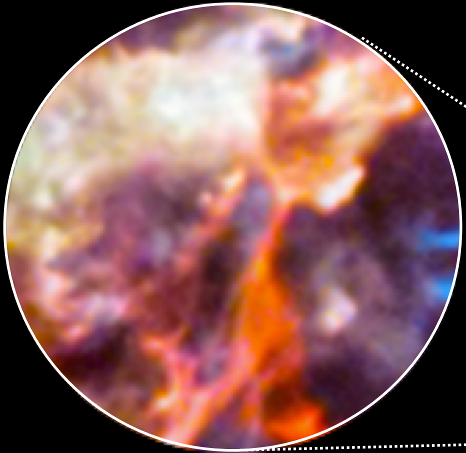
See posters:

P17 Hidetoshi Sano (Nagoya University) “ALMA and Chandra Studies of N63A”

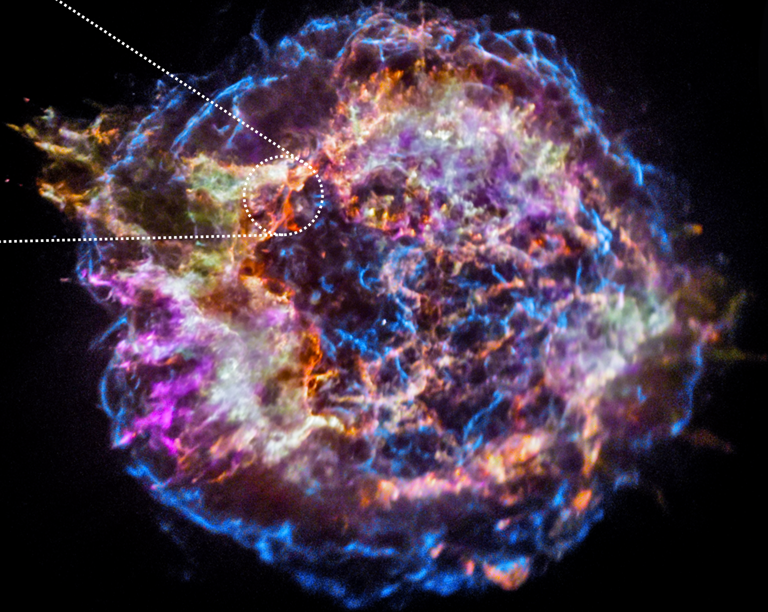
P21 Paul Plucinsky (SAO) “A Chandra Legacy Observation of N132D”

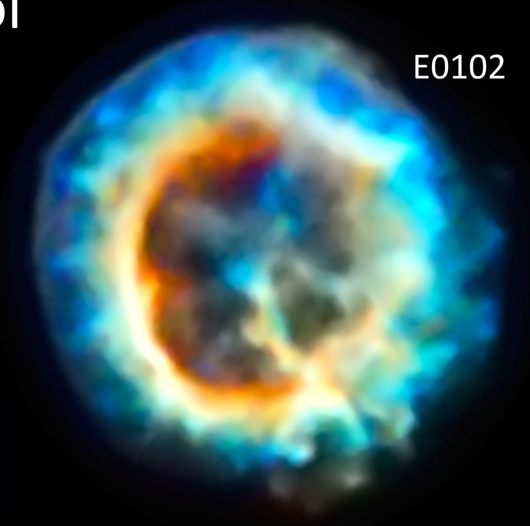
P27 Xi Long (Purple Mountain Observatory) “On the X-ray Spectrum of the Putative CCO in E0102”

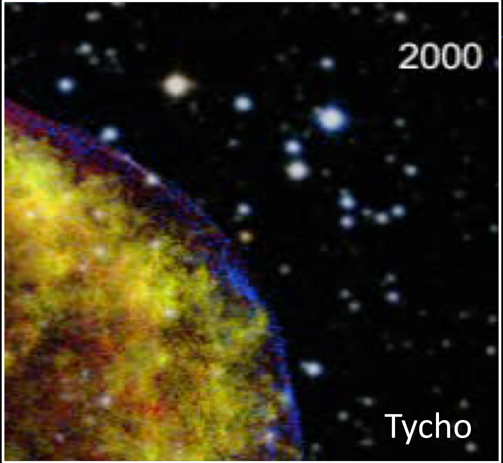
Chandra: An Exquisite SNR Tool



Cas A

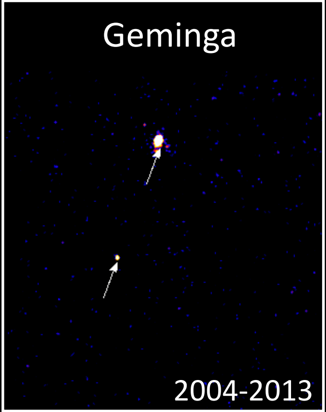




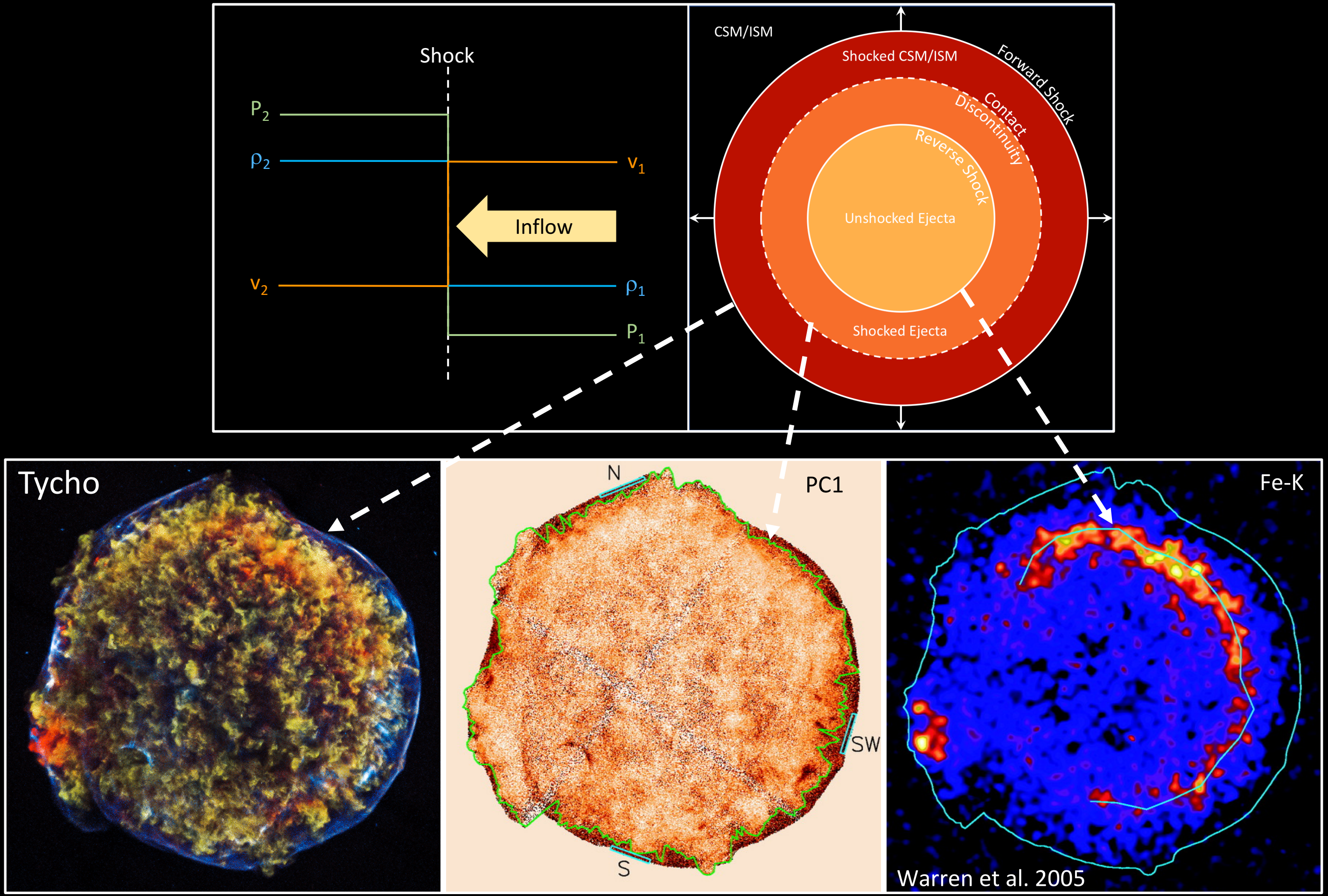


$$1 \text{ arcsec} = 1000 \text{ AU } D_{kpc}$$

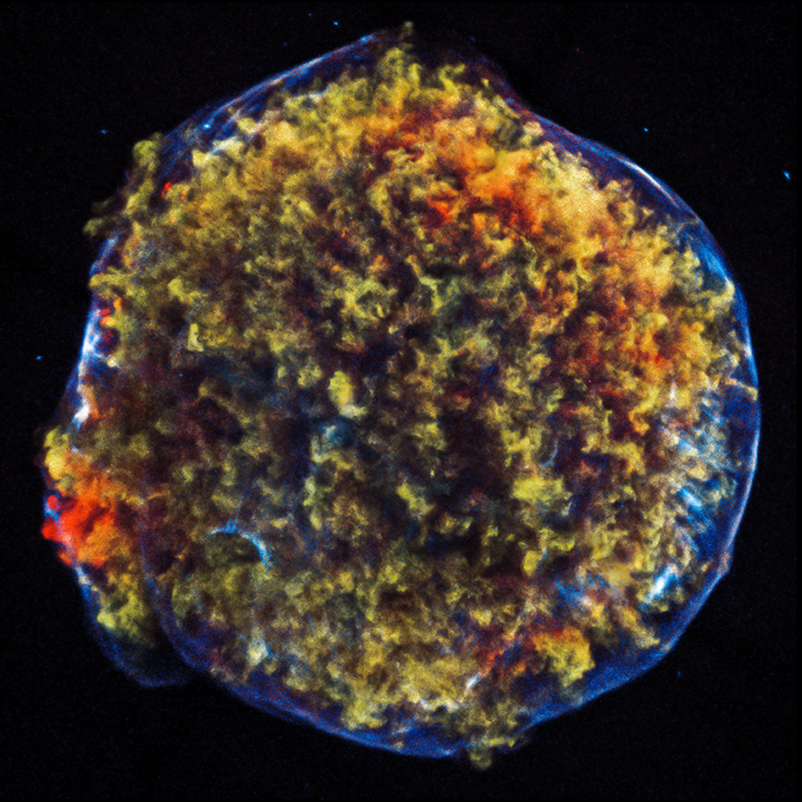
$$d\theta/dt = 0.2\ v_{1000}\ D_{kpc}^{-1} \text{ arcsec yr}^{-1}$$

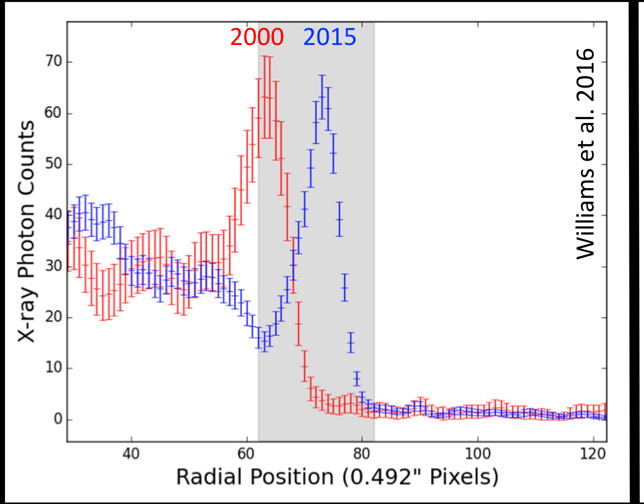


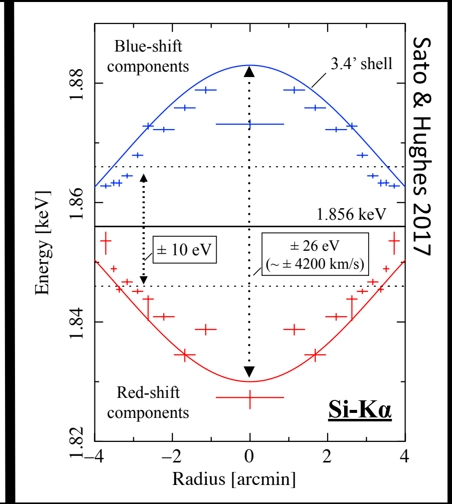
Shock Structure in SNRs



Dynamics of Tycho's SNR



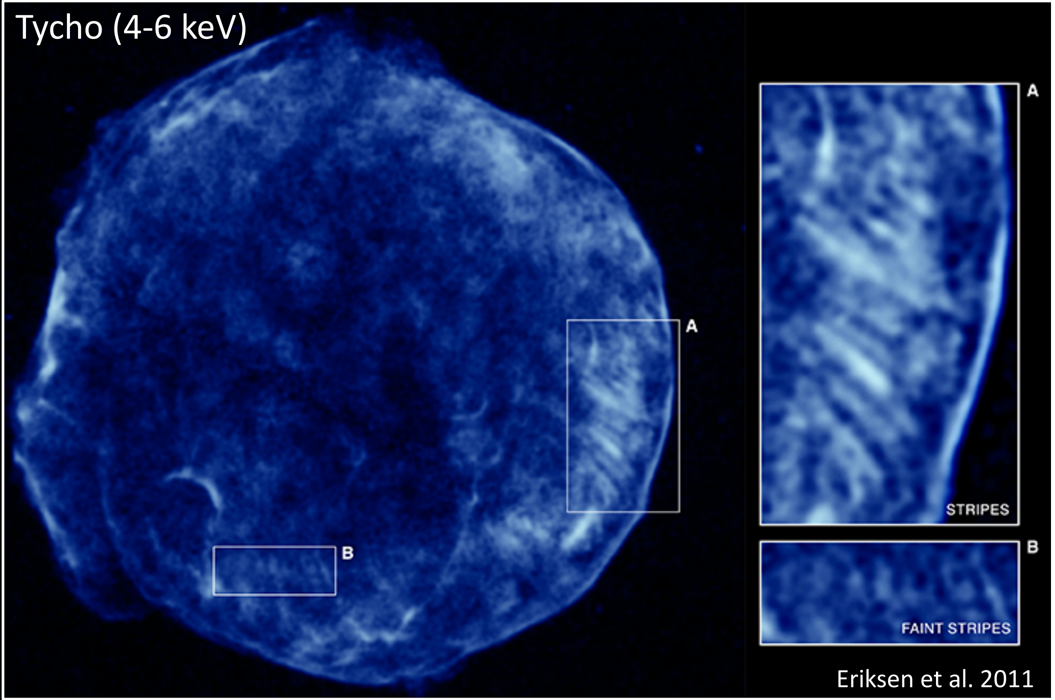




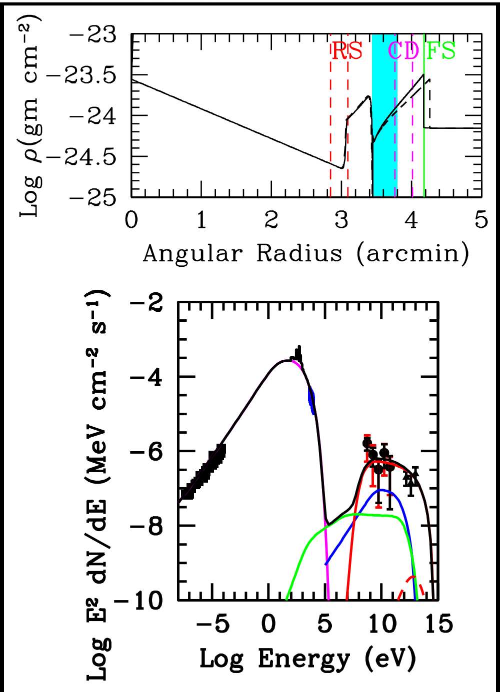
- Expansion measurements give $v_{FS} \sim$ 4000-6000 km s^{-1}
- Doppler shifts of Si Kα line reveals similar line-of-sight velocities.

See:
Talk: Brian Williams (NASA GSFC) "The Expansion of Tycho's Supernova Remnant"
Poster: **P23** Takaaki Tanaka (Kyoto University) "Deceleration of Blast Waves of Tycho's Supernova Remnant"

Cosmic Ray Acceleration in SNRs



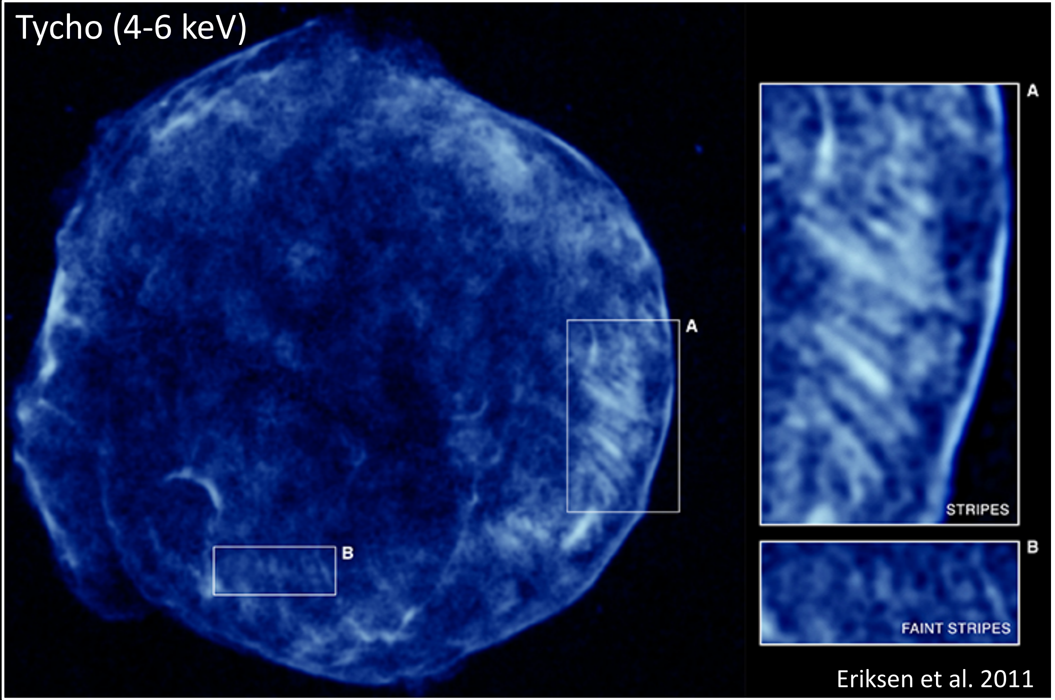
Eriksen et al. 2011

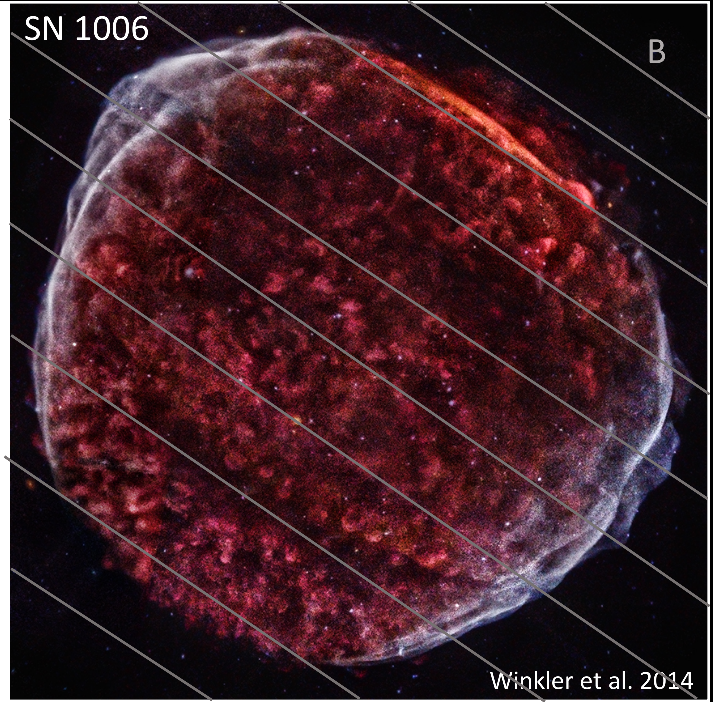


Slane et al. 2014

- Thin synchrotron rims represent relativistic electrons accelerated by SNR shock.
- Broadband modeling implies ion acceleration to >50 TeV.
  - Stripe structures consistent w/ energetic ions.

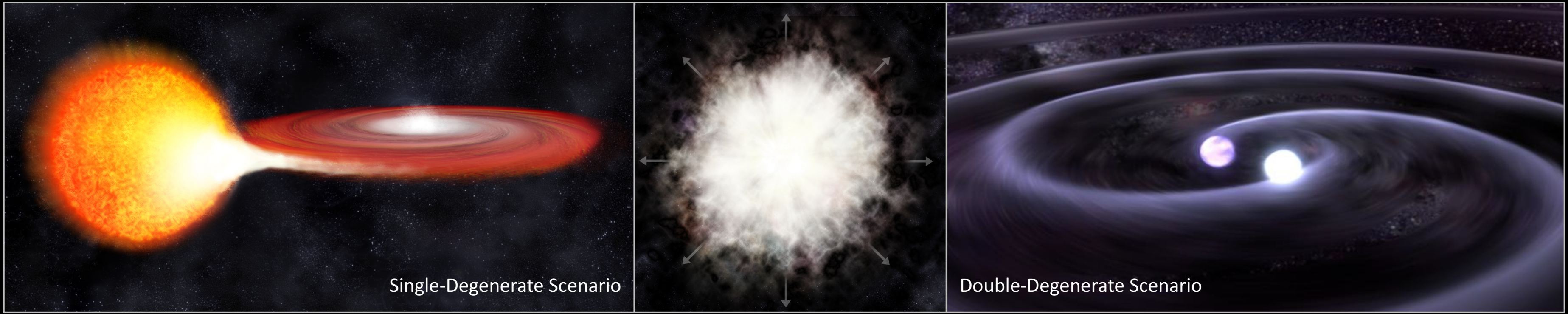
Cosmic Ray Acceleration in SNRs





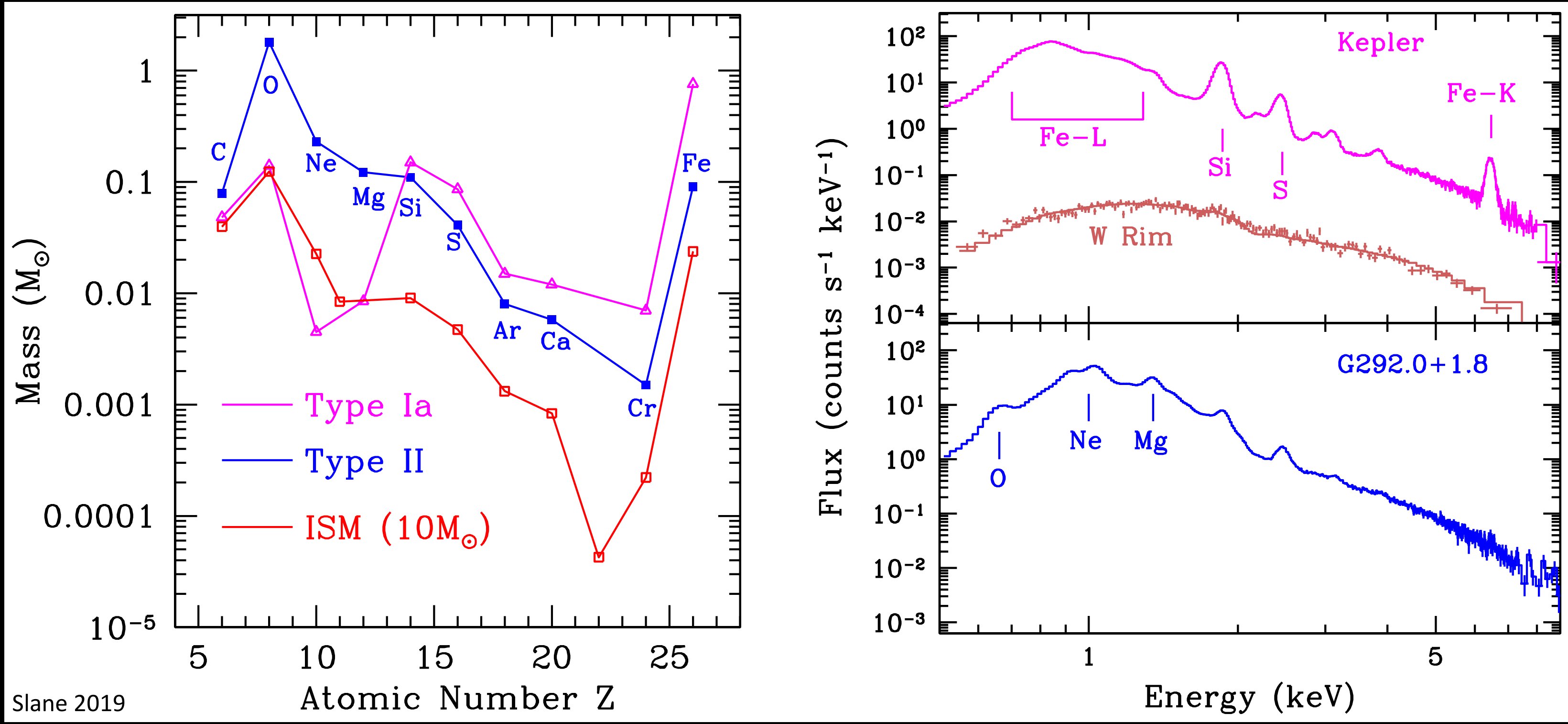
- Thin synchrotron rims represent relativistic electrons accelerated by SNR shock.
- Broadband modeling implies ion acceleration to >50 TeV.
  - Stripe structures consistent w/ energetic ions.
- Synchrotron rims only in SW/NE suggests effects of shock obliquity with uniform magnetic field structure.

Type Ia (Thermonuclear) Supernova

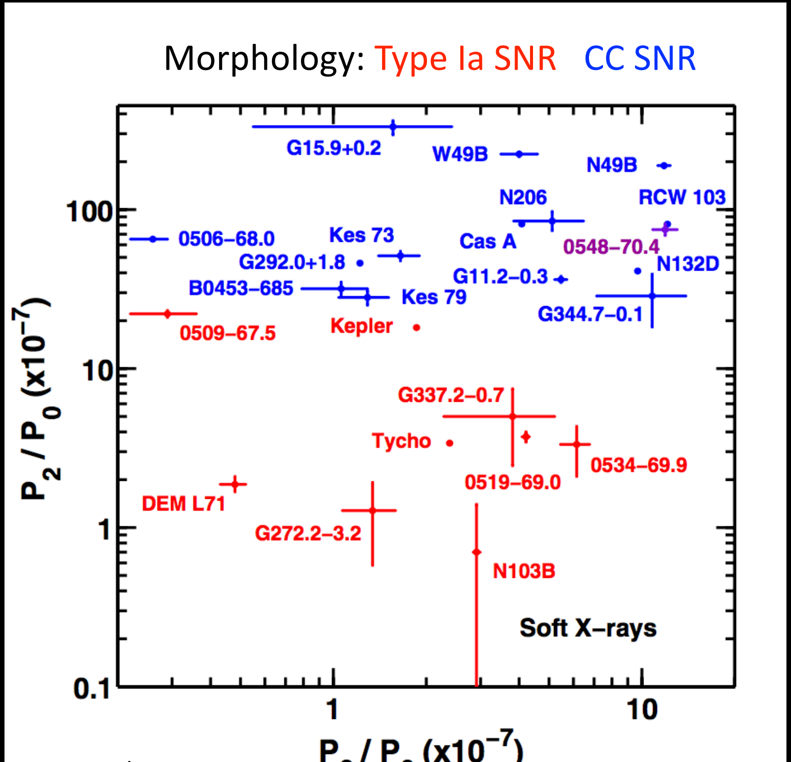


Super-critical accretion onto a white dwarf star → Thermonuclear Supernova Explosion ← Gravitational merger of two white dwarf stars

Type Ia vs. Core-Collapse SNRs



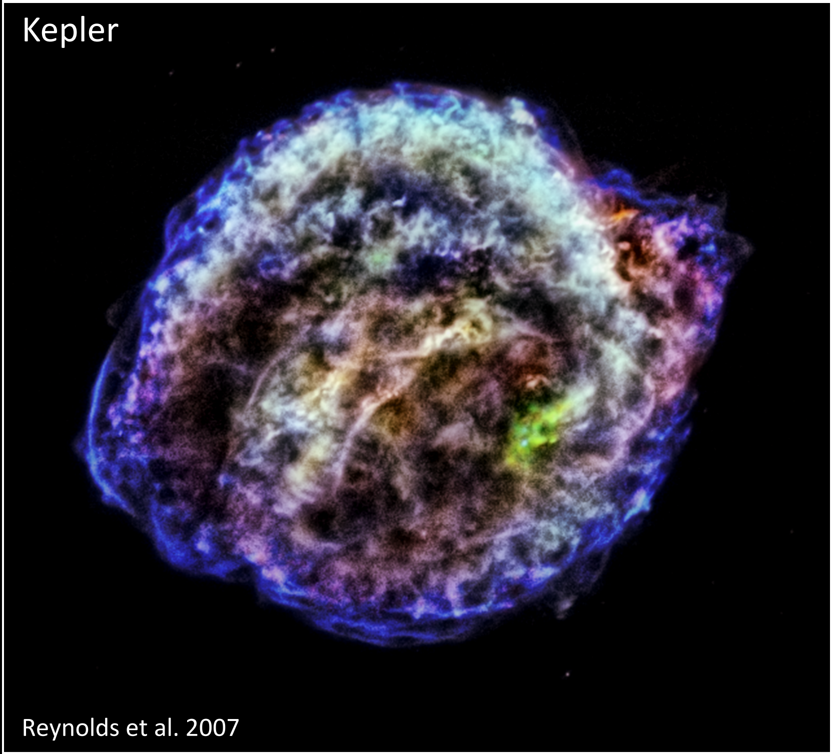
Type Ia vs. Core-Collapse SNRs



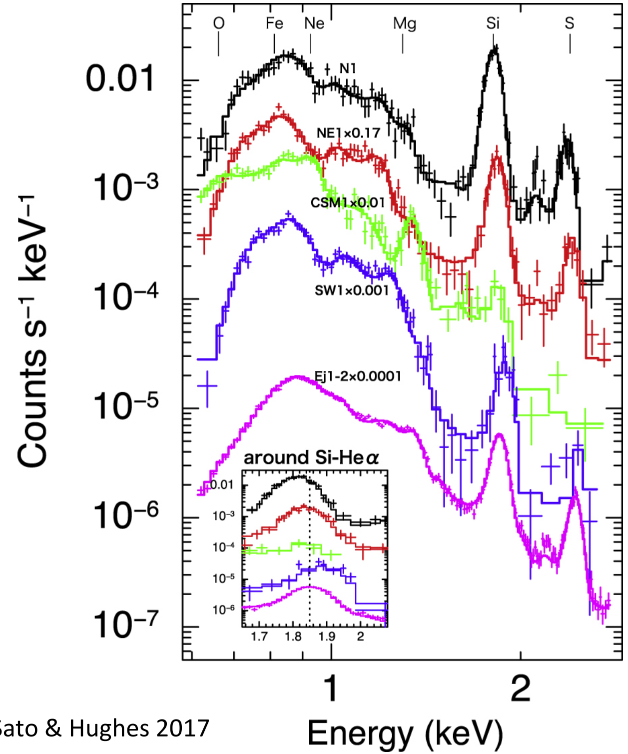
Lopez et al. 2011

- C-C SNRs have higher ellipticity.
  - Environments? Explosion dynamics?

Ejecta and Circumstellar Material in Kepler



Reynolds et al. 2007

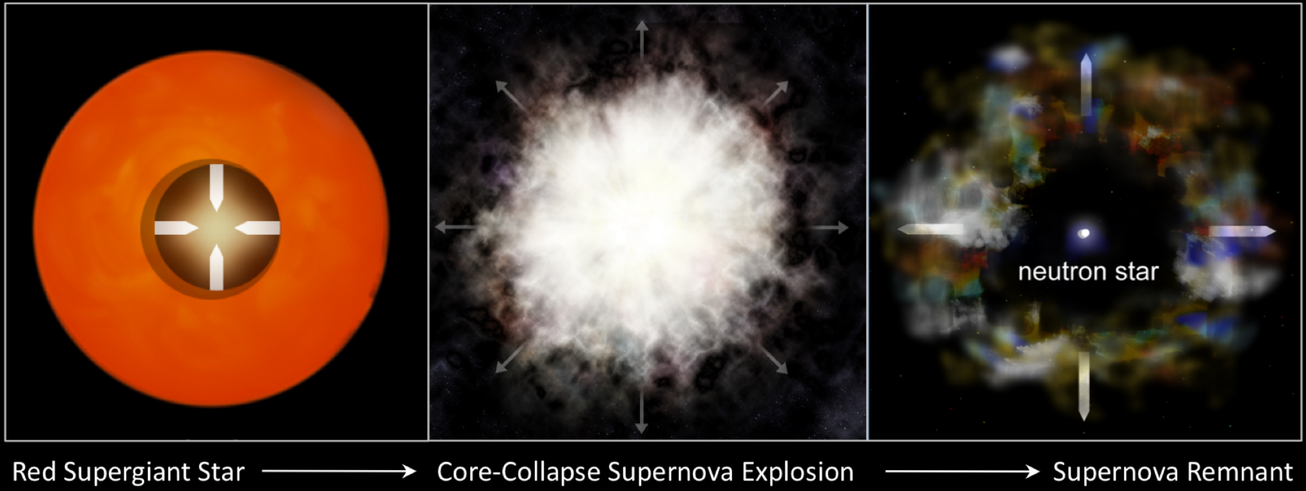


Sato & Hughes 2017

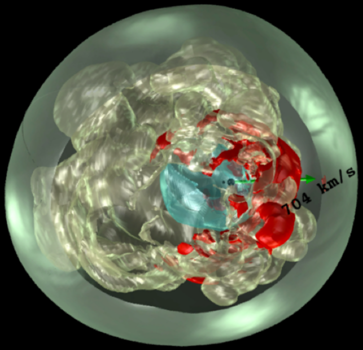
See posters:

P20 Kotaro Fukushima (Tokyo University of Science) “Ejecta distribution of the Type Ia SNR”
P24 Tomoaki Kasuga (The University of Tokyo) “Doppler Expansion Measurement of Heated Ejecta in Type Ia SNRs”

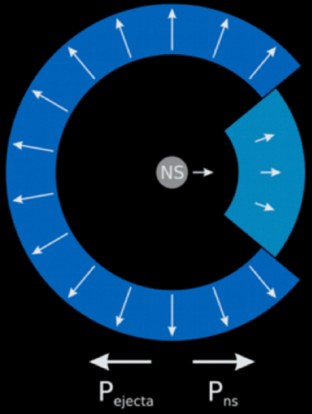
Core Collapse Supernova



Instabilities drive explosion and produce ejecta asymmetries and NS kicks

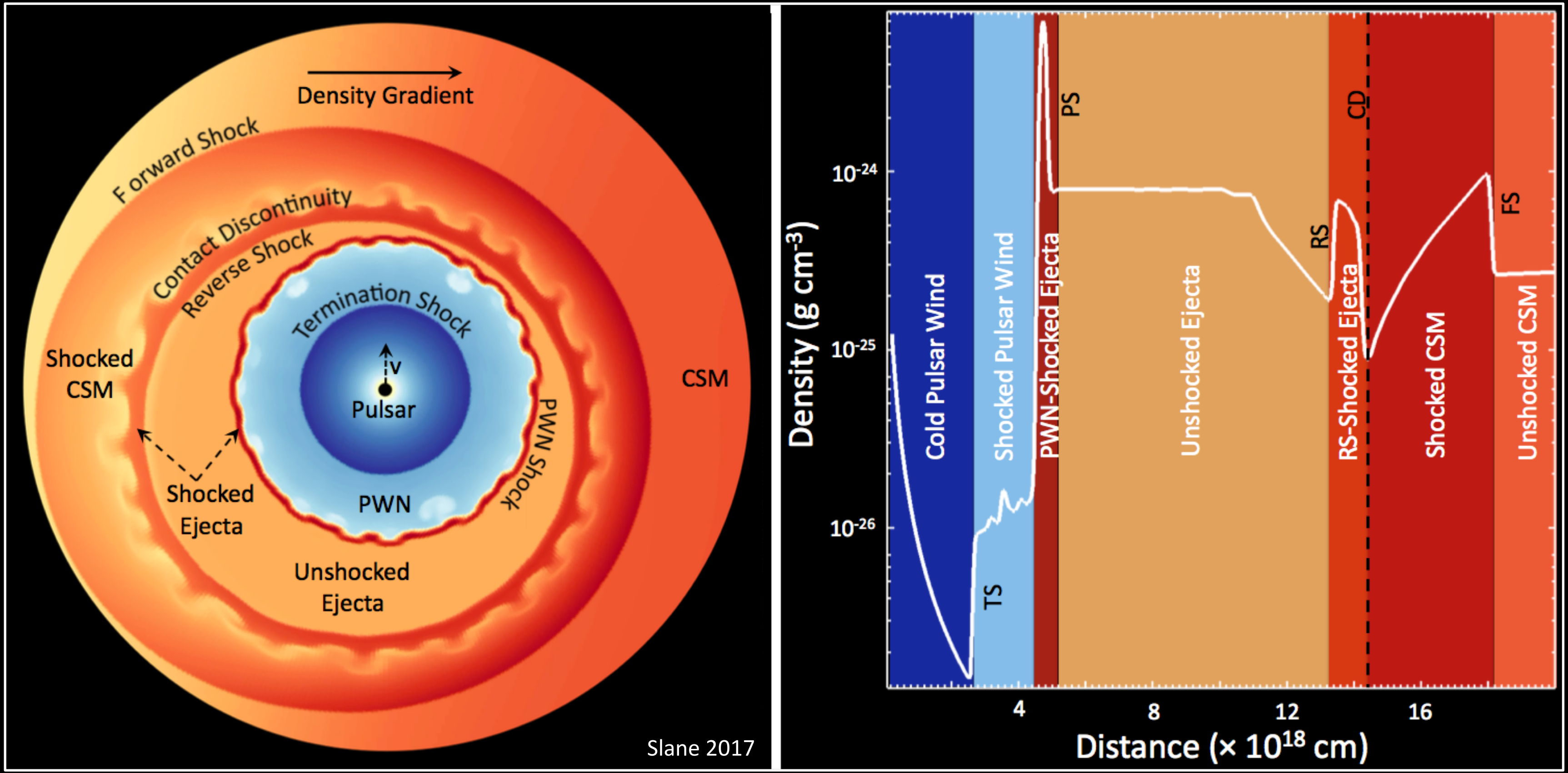


Wongwathanarat et al. 2013

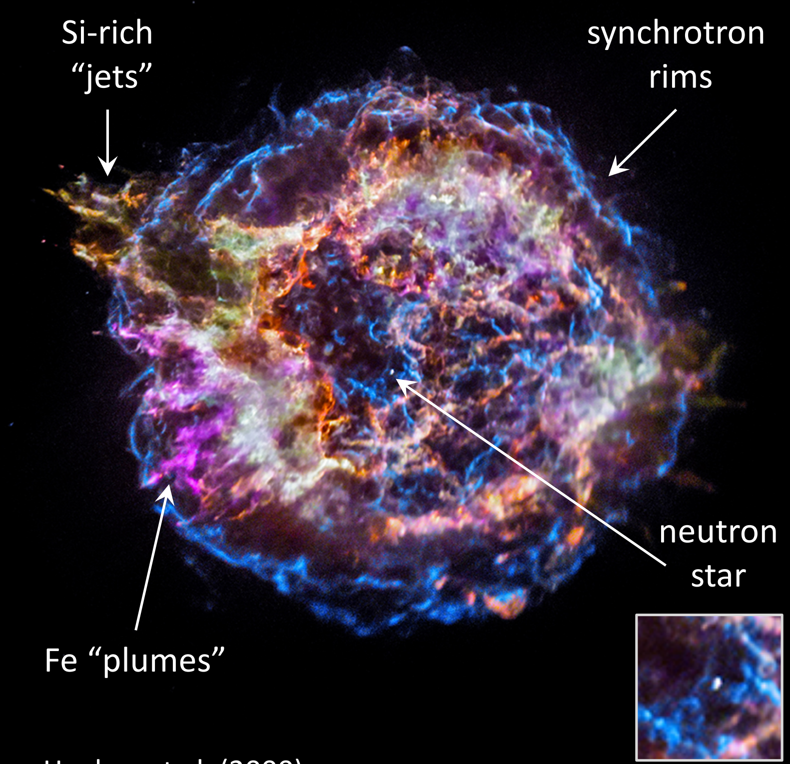


Explosion ejects stellar debris, driving shock into ISM and distributing metal-enriched ejecta

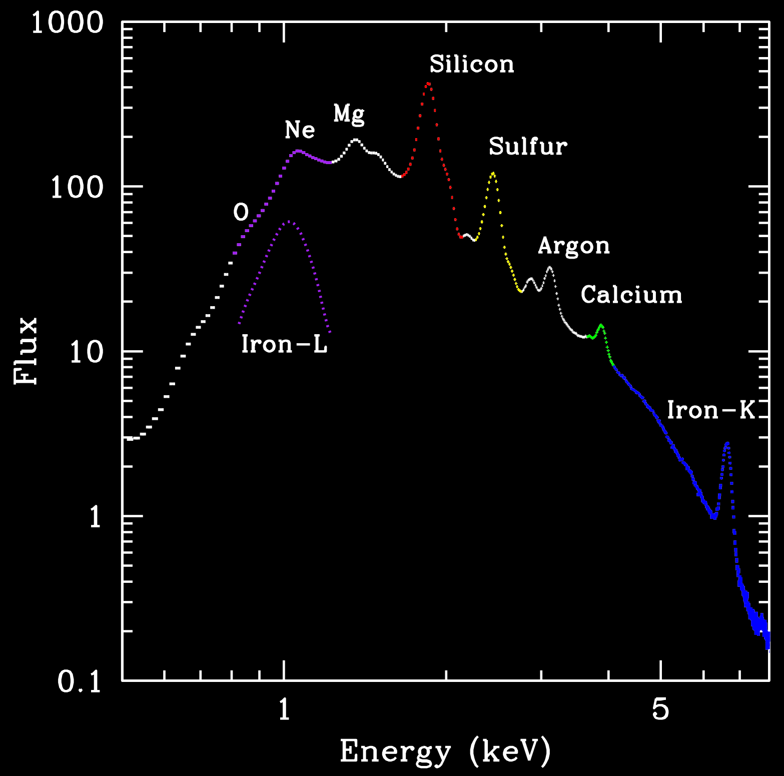
Shock Structure in Composite SNRs



Unraveling the Structure of Cas A

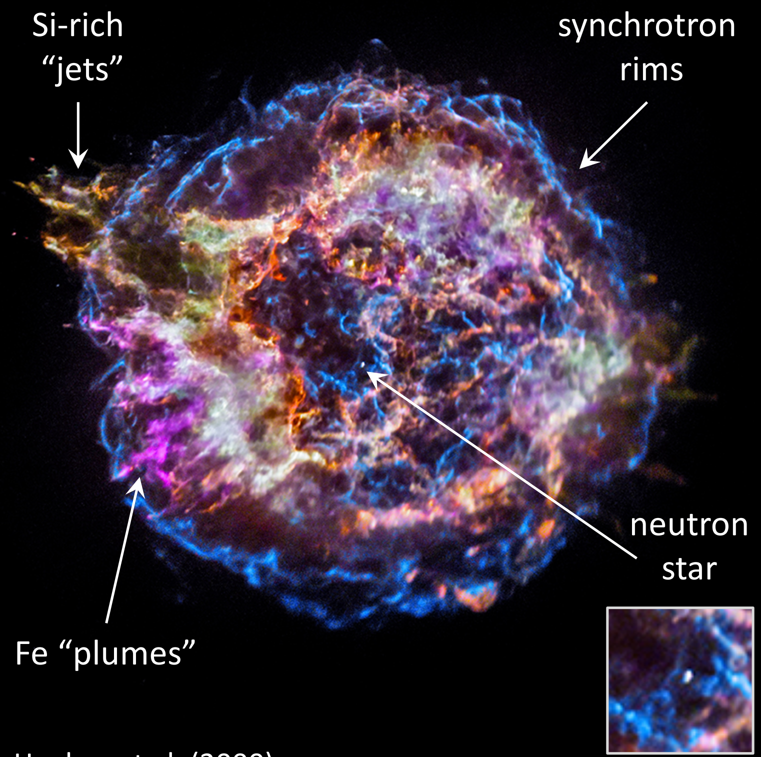


Hughes et al. (2000)
Hwang & Laming (2012

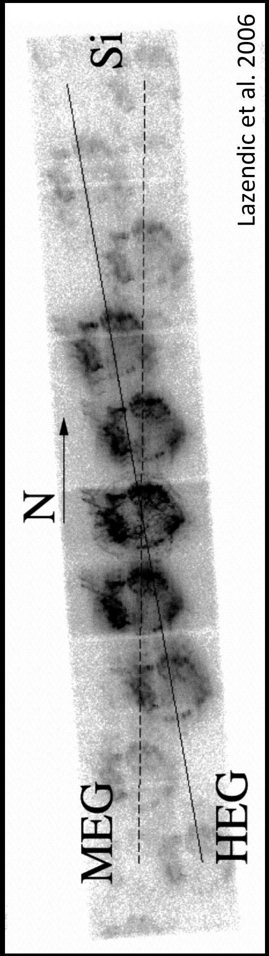


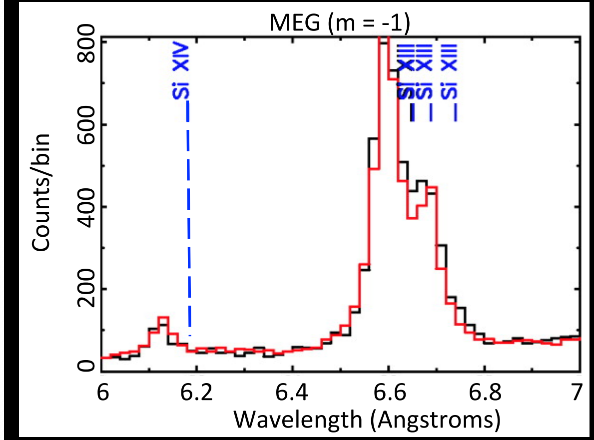
See talk: Daniel Patnaude (CfA) "20 Years of Cas A with the Chandra X-ray Observatory"

Unraveling the Structure of Cas A

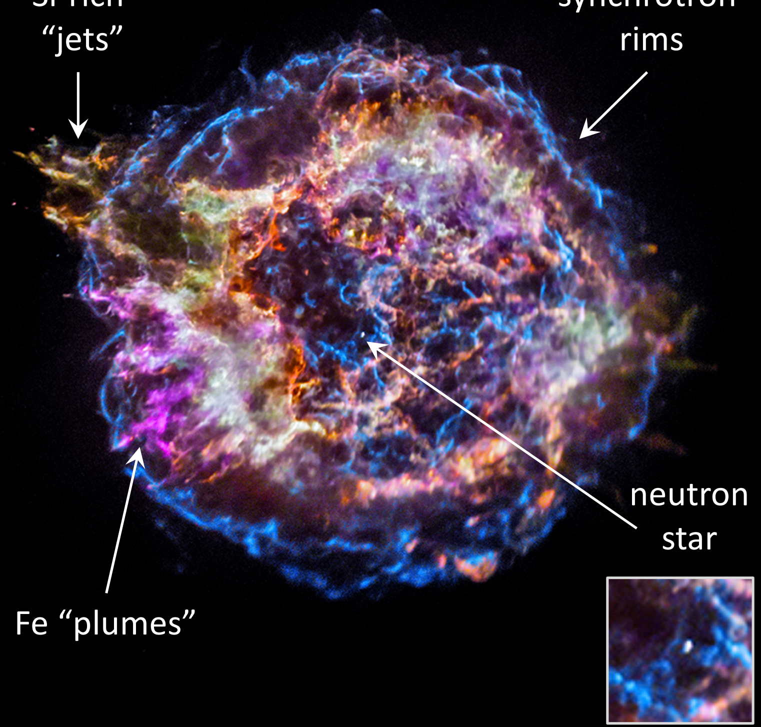


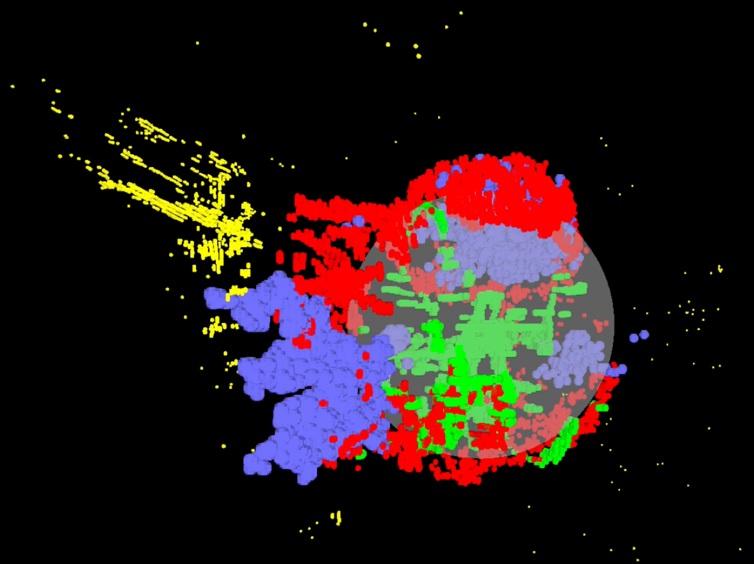
Hughes et al. (2000)
Hwang & Laming (2012





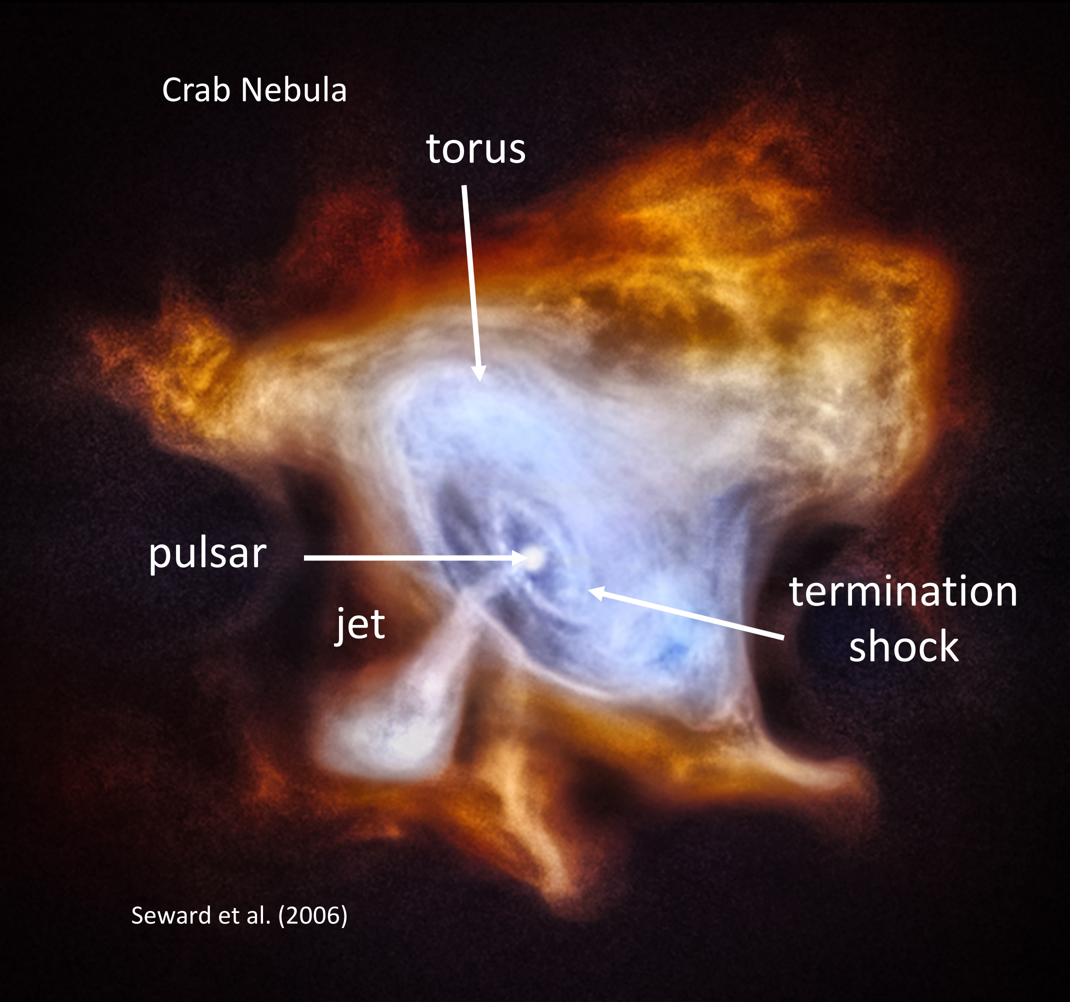
Unraveling the Structure of Cas A

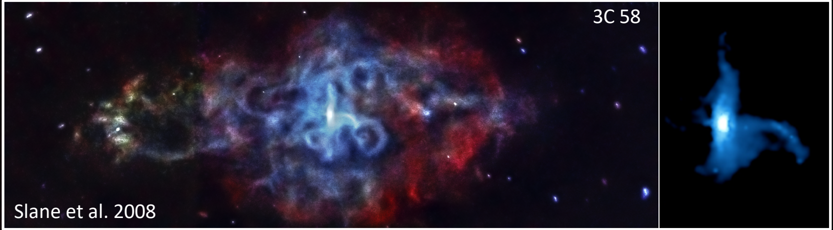


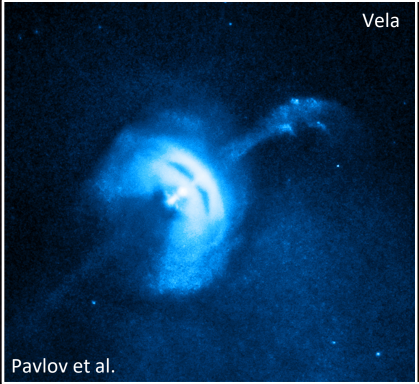


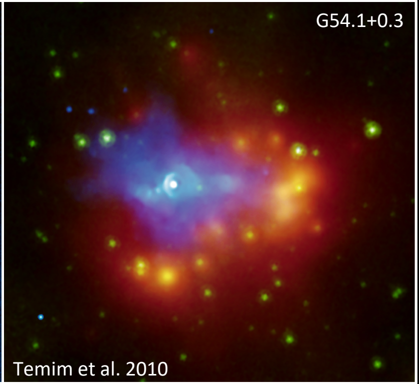
Delaney et al. (2010)
Milisavljevic & Fesen (2013)
Milisavljevic & Fesen (2015

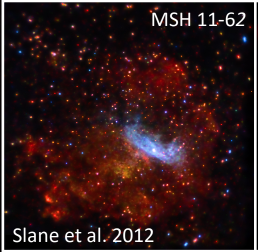
Pulsars and Their Winds

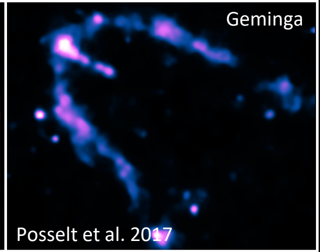




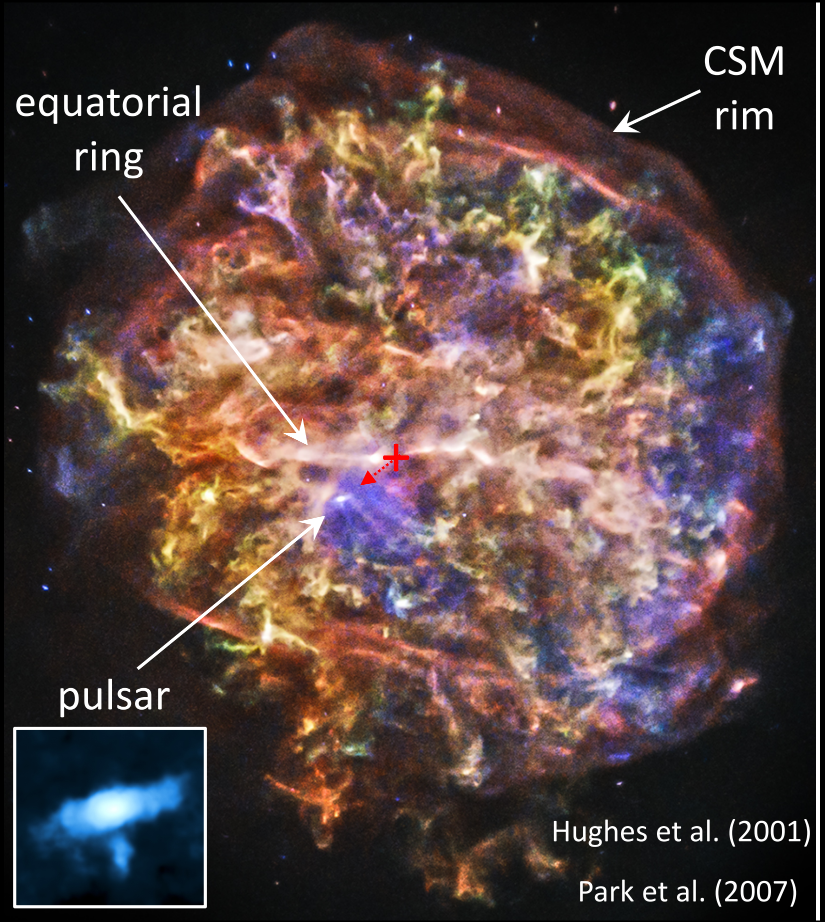




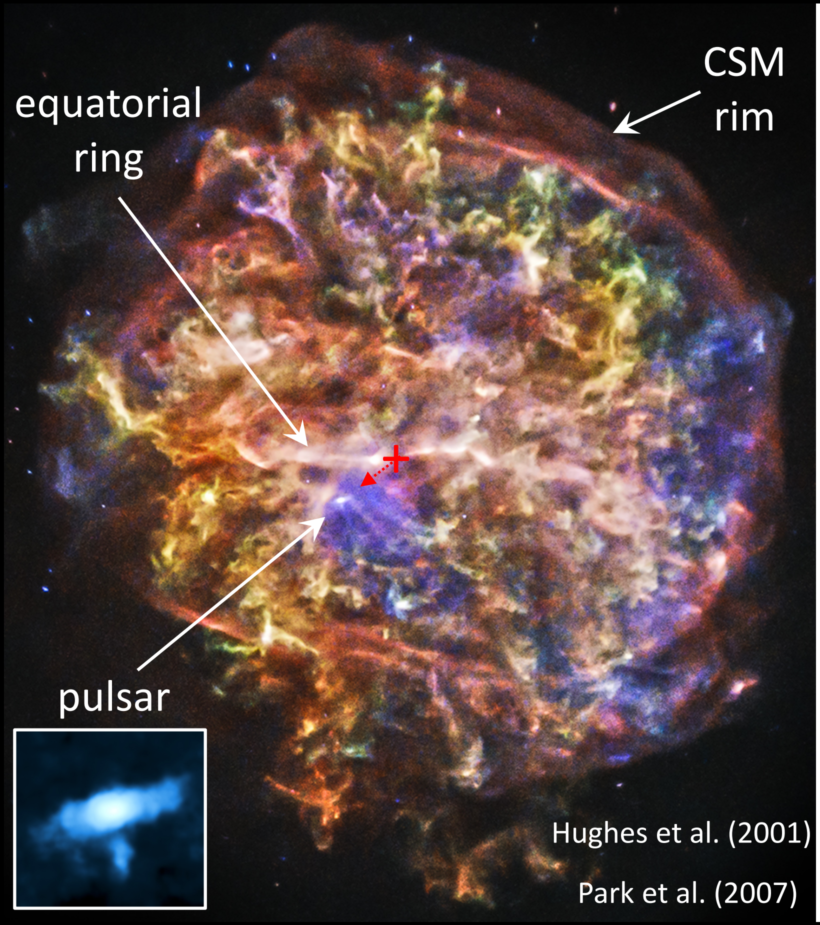


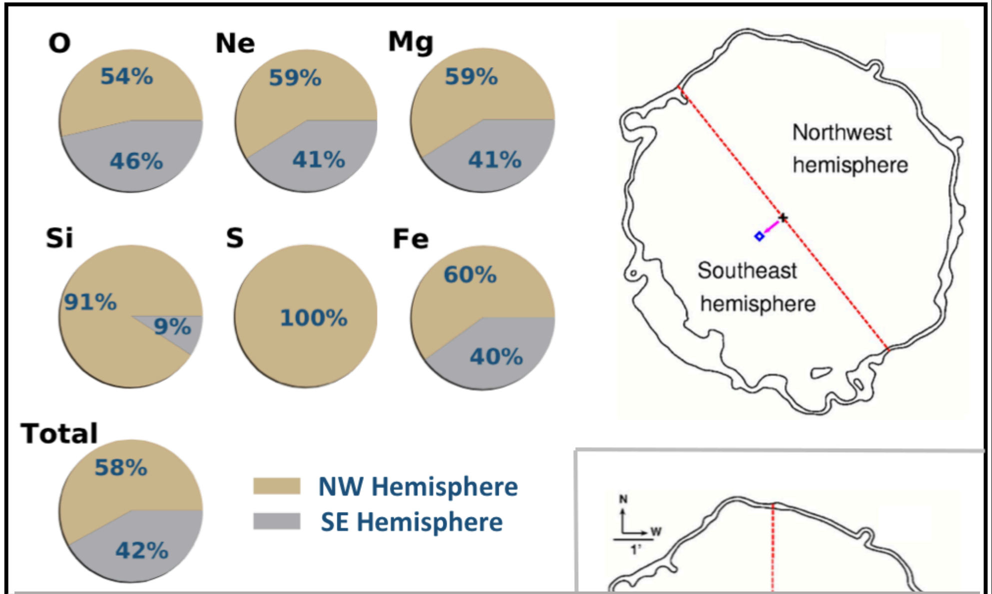


Explosion Dynamics in G292.0+1.8



Explosion Dynamics in G292.0+1.8





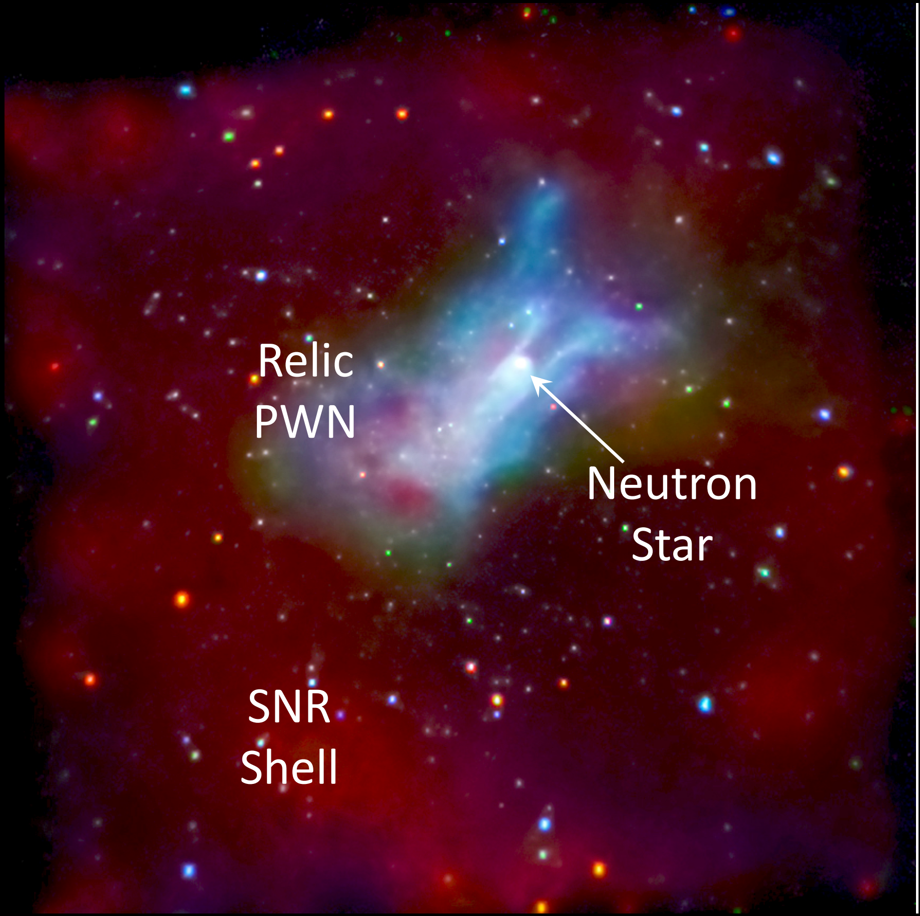
See posters:

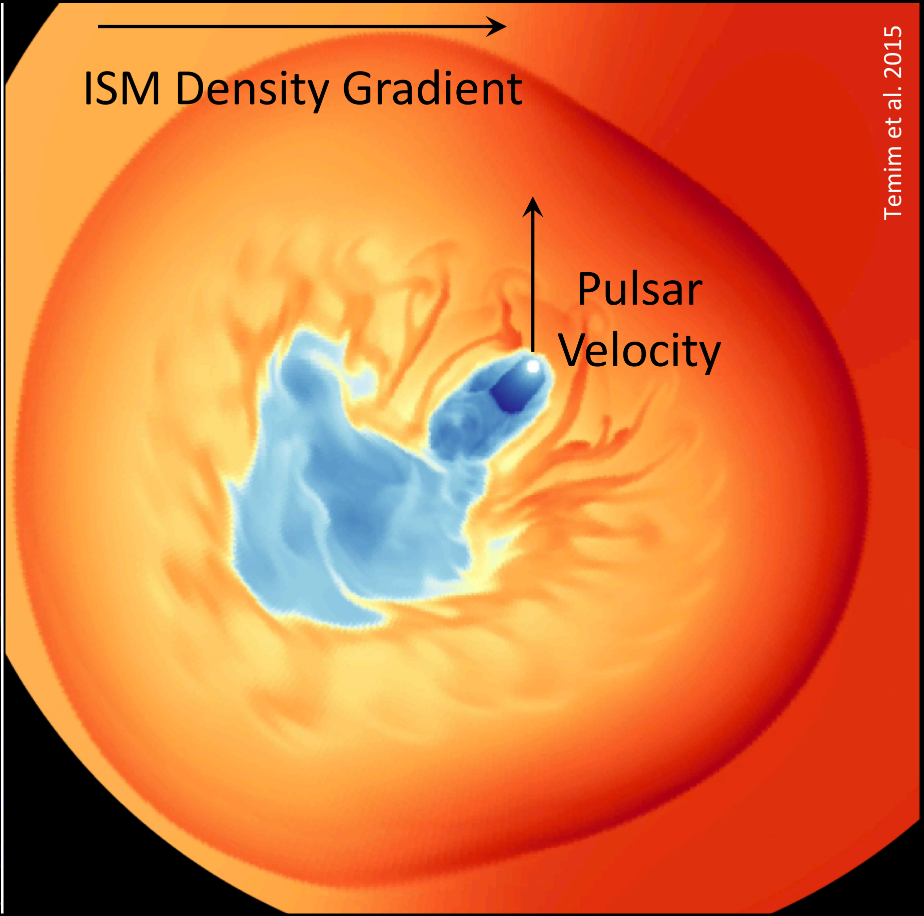
P19 Kazimierz Borkowski (NC State) "Fast Expansion of Young, Ejecta-Dominated SNRs G292.0+1.8 and RCW 89"

P25 Tyler Holland-Ashford (Ohio) "Using Chandra to Quantify Ejecta Asymmetries in SNRs and Compare NS Kicks"

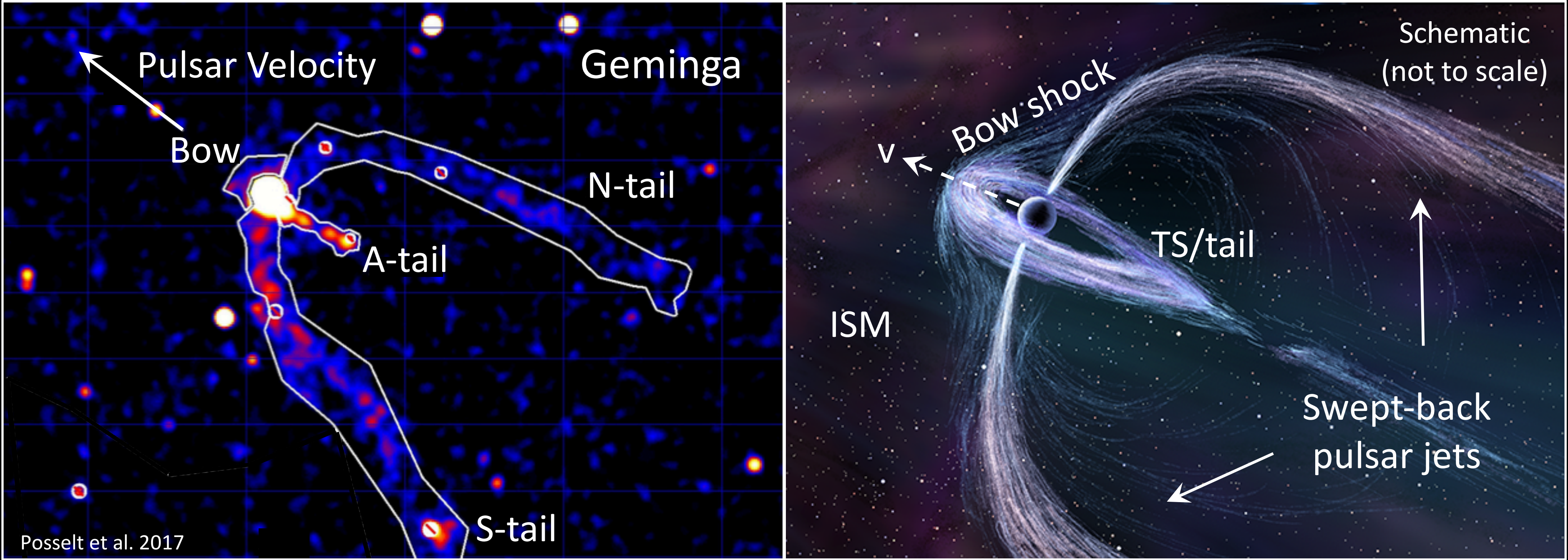
Bhalerao et al. (2019)

G327.1-1.1: Evolution of PWNe in SNRs





Bowshock PWNe: Geminga



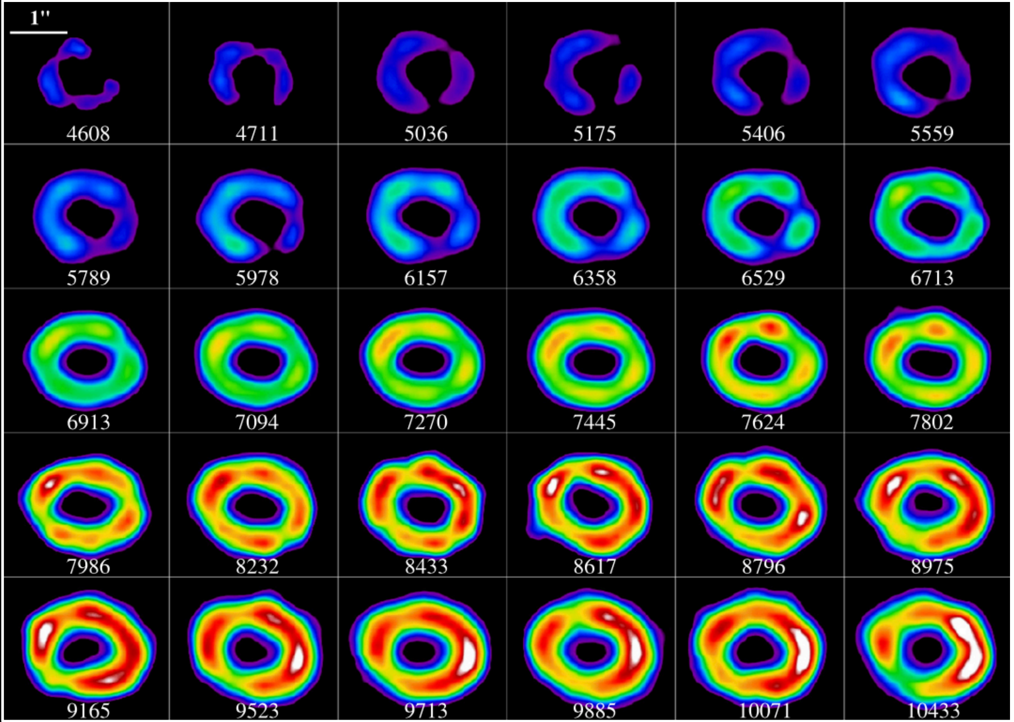
See posters:

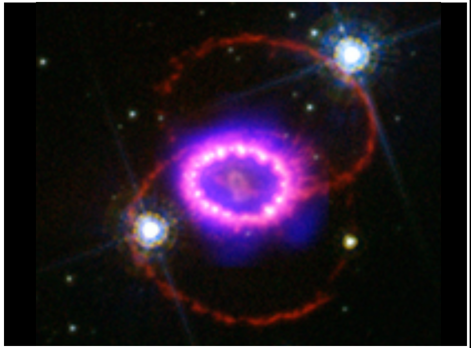
P55 Martijn de Vries (KIPAC, Stanford) CXO Reveals Swept-back Jets in the PSR J1709-4429 PWN

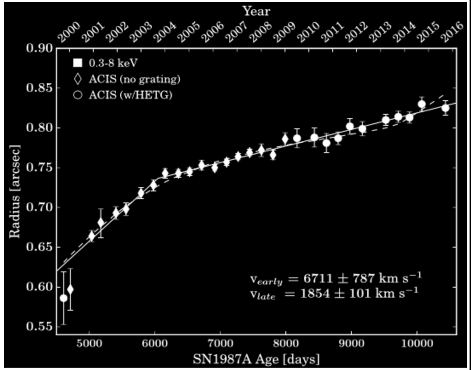
P56 Noel Klingler (PSU) Multi-Scale Structure of the Variable Pulsar Wind Nebula Powered by PSR J1809-1917

P57 Oleg Kargaltsev (GWU) Chandra observations of supersonic pulsar wind nebulae

Evolution of SN 1987A







Frank et al. 2016

- Chandra monitoring tracks interaction with equatorial ring and transition
- Recent models indicate shock has exited equatorial ring.

See poster:

P15 Aravind Pazhayath Ravi (UT Arlington) “High Resolution Spectroscopic Study of the X-ray Remnant of SN 1987A”

Summary

- Chandra's unique capabilities have revolutionized our understanding of supernova remnants and pulsar wind nebulae.

- Spectroscopy studies have provided a new understanding of ejecta properties, and provided the opportunity to constrain progenitor models and SNR evolution.

- Expansion measurements provide direct input for shock models. Combined with Doppler measurements, 3D views of SNRs become possible.

- High resolution studies reveal sites of cosmic ray acceleration in SNRs.

- Identification of compact neutron stars provide constraints on explosion dynamics and on overall neutron star demographics.

- High angular resolution reveals structure of pulsar winds and geometry of pulsar systems.