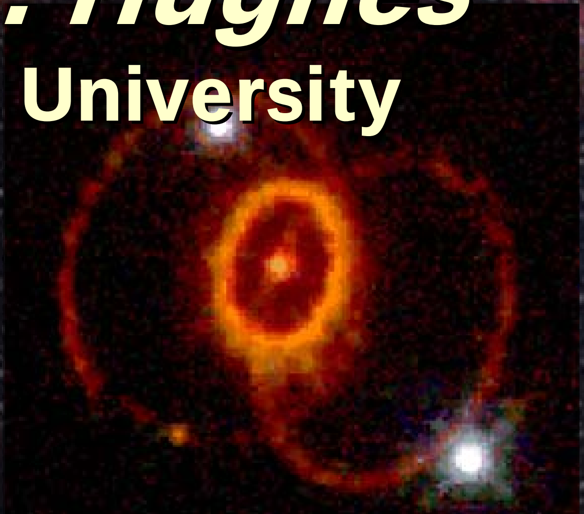
Production and Distribution of the Elements

John P. Hughes

Rutgers University



Panel Charge and Membership

Supernovae and their Remnants
Heavy metal/dust production
Shock Physics

Chair: Jack Hughes (Rutgers University)

Carlos Badenes (Princeton)
David Burrows (PSU)
Tracey Delaney (MIT)
Fiona Harrison (Caltech)
Martin Laming (NRL)
Julia Lee (Harvard)

Sangwook Park (PSU)
Dan Patnaude (SAO)
Dave Pooley (Wisconsin)
Stephen Reynolds (NCSU)
Pat Slane (SAO)
Alicia Soderberg (Princeton)

Key Topic I

Nucleosynthesis and Explosion Mechanisms in Supernovae through Studies of Supernova Remnants

Core Collapse SNe

- ~ 3/4 of all SNe
- M(progenitor) > 8 solar masses
- Predominant producers of O, Ne, Mg
- Leave compact remnants
- Gaseous remnants highly structured and asymmetric
- Precise explosion mechanism unknown

Thermonuclear SNe

- ~ 1/4 of all SNe
- White dwarfs that grow to near the Chandrasehkar mass
- Predominant producers of Fe
- Gaseous remnants relatively symmetric
- Progenitor systems and precise explosion mechanism unknown

Key Topic I

Nucleosynthesis and Explosion Mechanisms in Supernovae through Studies of Supernova Remnants

Why X-rays?

- Uniquely illuminate the composition and dynamics of the shocked ejecta and ambient medium – no other wave band offers as comprehensive a view
- SNRs offer a 3-D view of the entire ejecta – impossible to obtain on any individual SN, for which we sample a single line-of-sight

Why IXO?

- Current CCD "spectroscopy" is more akin to BVRI imaging than true optical spectroscopy
- Temperature and ionization diagnostics based on line ratios
- Radial velocities and line broadening
- Access to SNRs in M31 and M33

White Paper Example

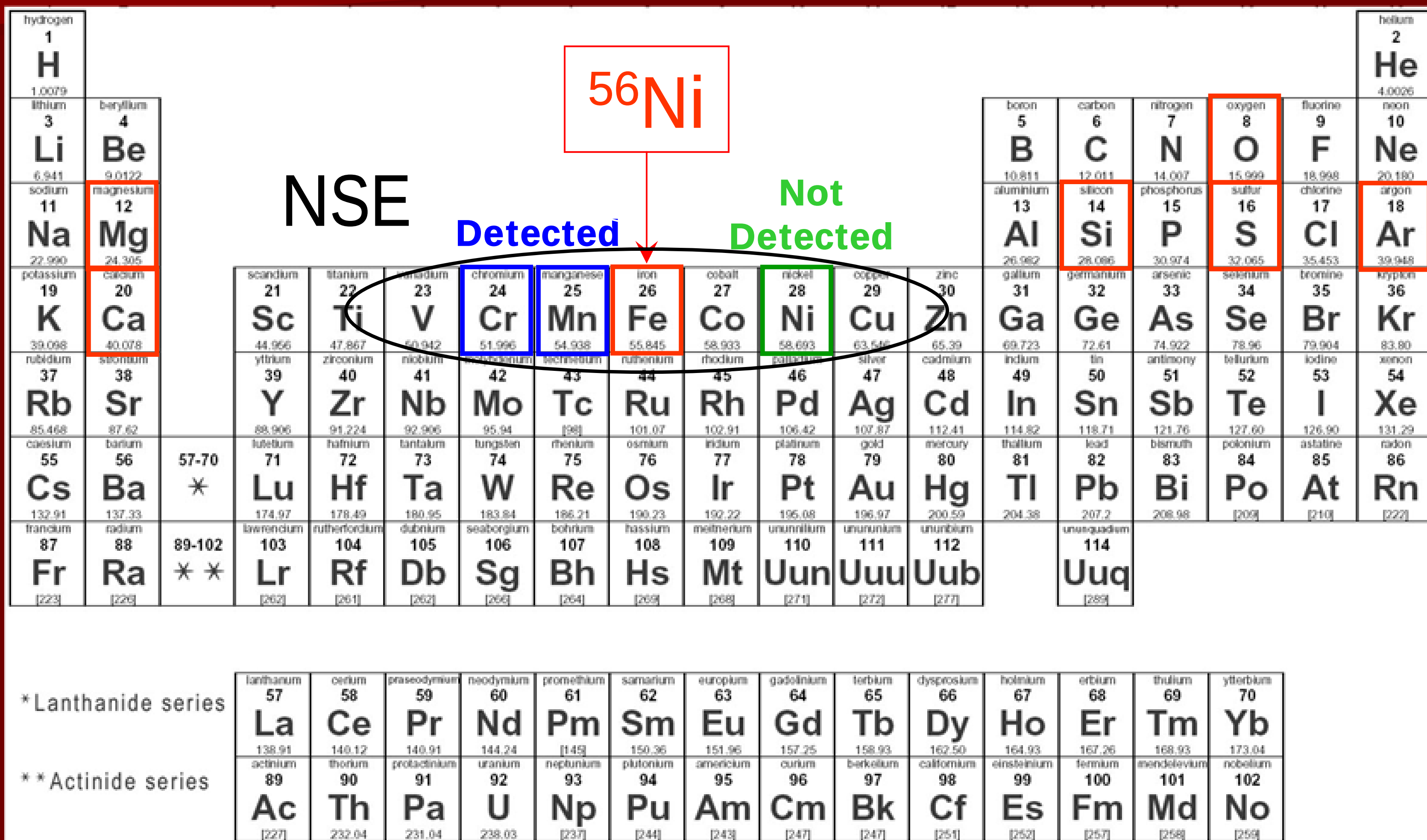
Nucleosynthesis of trace Fe-group elements in Remnants of Type Ia Supernovae

Motivation

- Explosion process (ignition, burning, etc.) in SN Ia longstanding unsolved problem
- SN optical light comes from radioactive decay of Fe-group elements – relevant to light curve width relation
- Roughly ½ of all the Fe in the Universe comes from this process

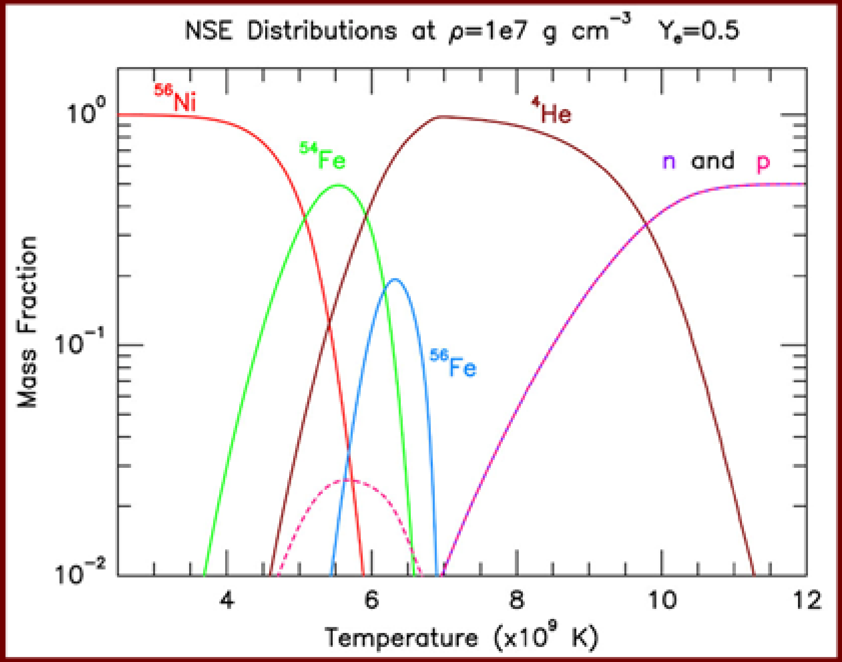
Fe-peak Elements

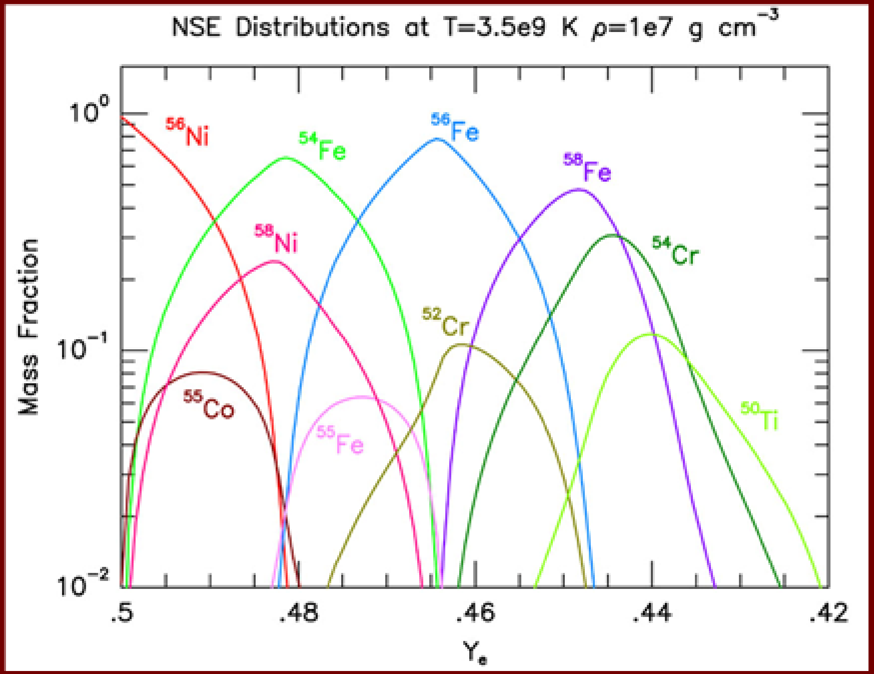
In SNe Ia nucleosynthesis is the explosion: C-O burns at high P and T to nuclear statistical equilibrium (NSE)



NSE

Nucleosynthesis in nuclear statistical equilibrium (NSE) depends on temperature, density, and Y_e (neutron excess)

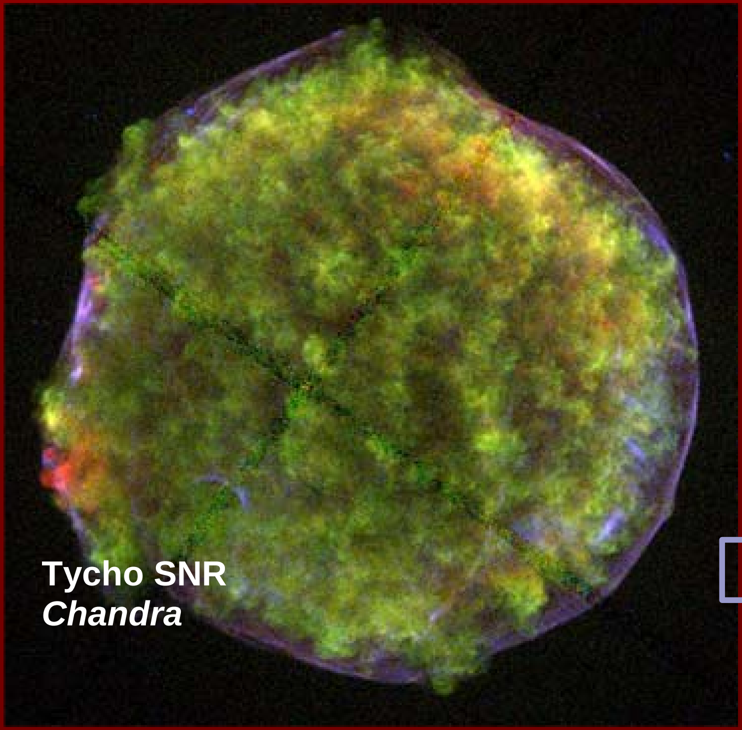


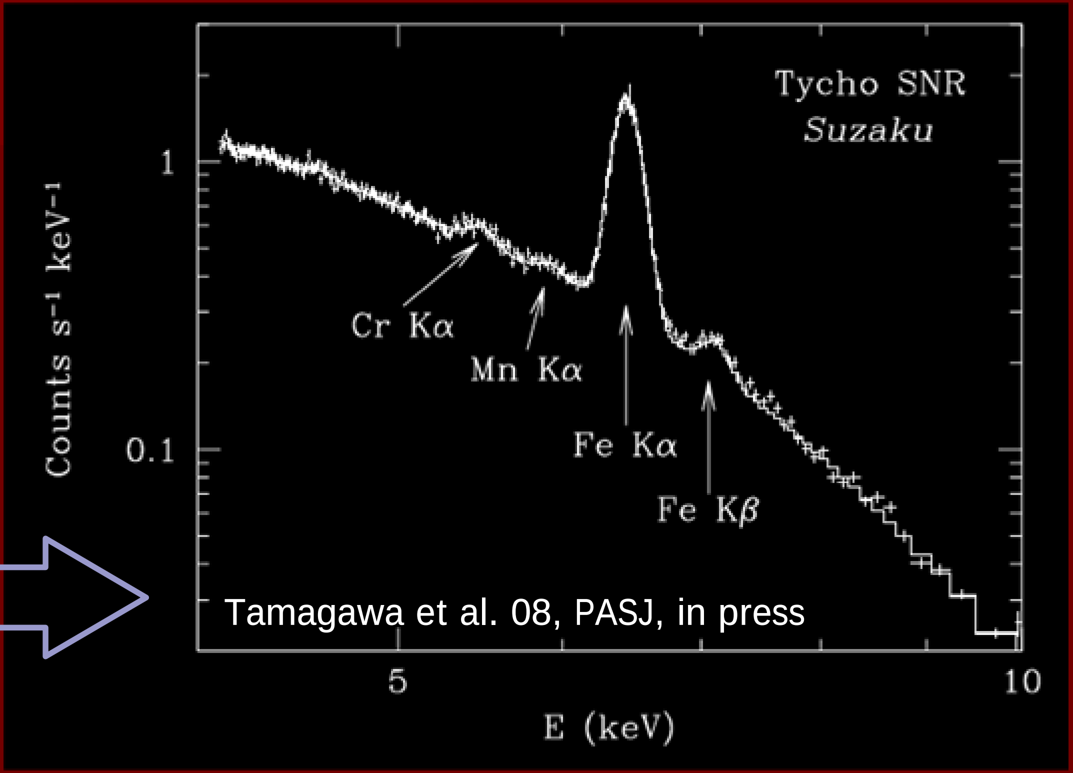


From Frank Timmes

Increasing neutron excess

Suzaku integrated spectrum of Tycho





Suzaku detection of Cr (>10σ) and Mn (>7σ) Kα emission lines from Tycho SNR ejecta

Tycho believed to be SN Type Ia, to be confirmed shortly with light echo spectroscopy

Mn/Cr as a Metallicity Tracer

- Metallicity is an important constraint on the age of a progenitor system.

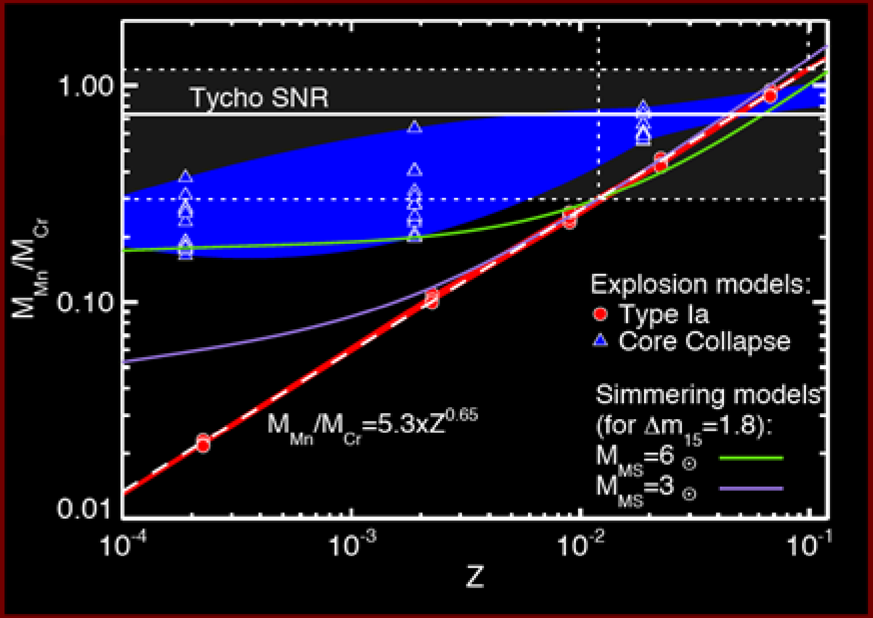
Processes during the Progenitor's Evolution:

- During the progenitor's MS hydrogen burning through the CNO cycle an excess abundance of ^{14}N develops
- This gets converted to ^{22}Ne during hydrostatic He-burning, which increases the neutron excess of the WD material
- Timmes et al. (2003) have shown that there is a linear relationship between the neutron excess and the original metallicity of the progenitor
- The neutron excess determines the relative proportion of Fe-group elements produced at NSE.

Mn/Cr as a Metallicity Tracer

Processes during the SN explosion

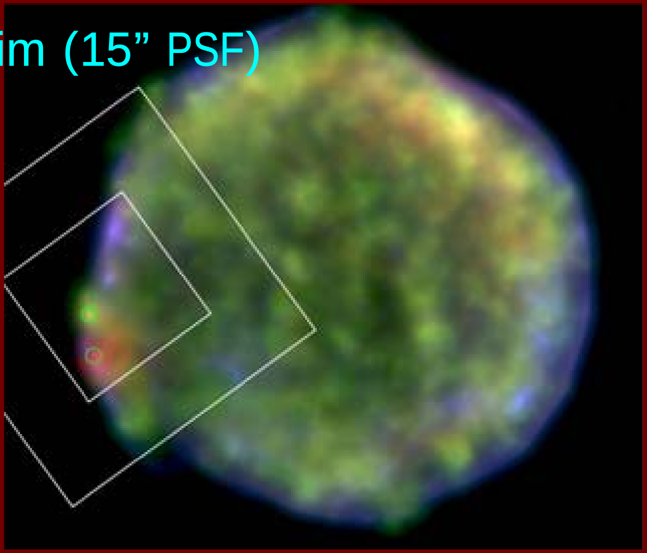
- Model SNIa explosions using different neutron excesses and various classes of explosions (delayed detonations, etc.)
- Complexities due to gravitational settling of elements and pre-explosion simmering of WD
- For the progenitor of Tycho's SN, this yields a supersolar metallicity
  - $Z = 0.048\ (-0.036,\ +0.051)$
  - Large uncertainty, but definitely not subsolar

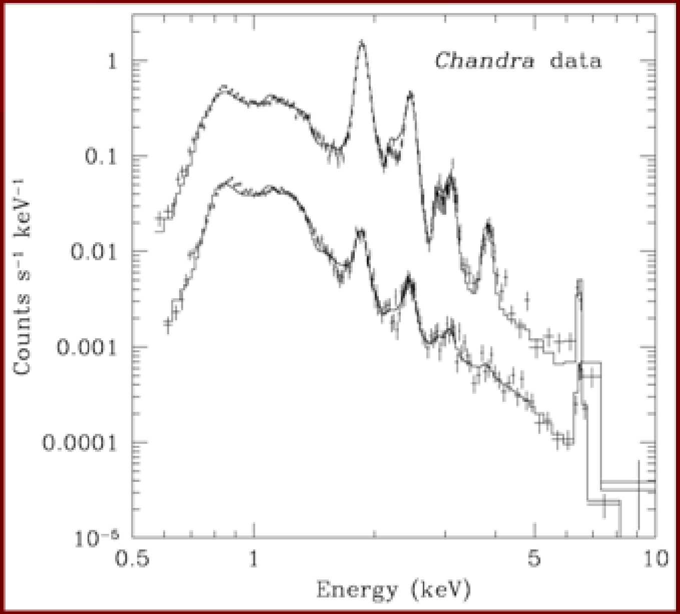


Badenes, Bravo, & JPH 2008, ApJL, 680, L33

- Mn/Cr also detected in W49B, while Cr is seen in Kepler and Cas A. IXO should allow detection in ~20 Galactic or Magellanic Cloud SNRs

Simulations

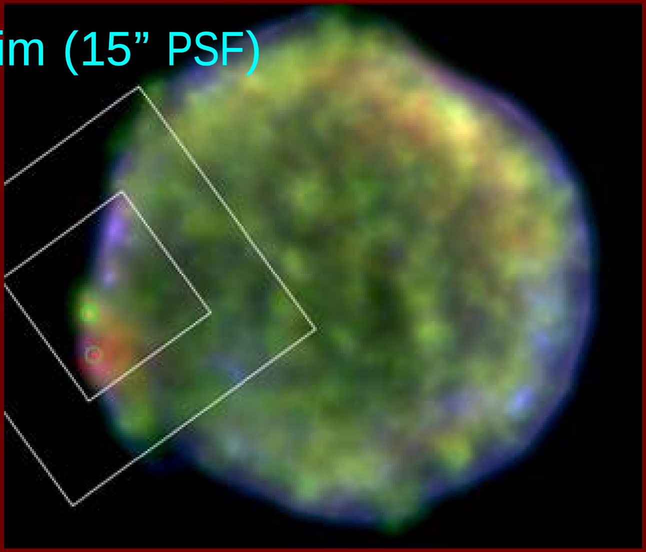


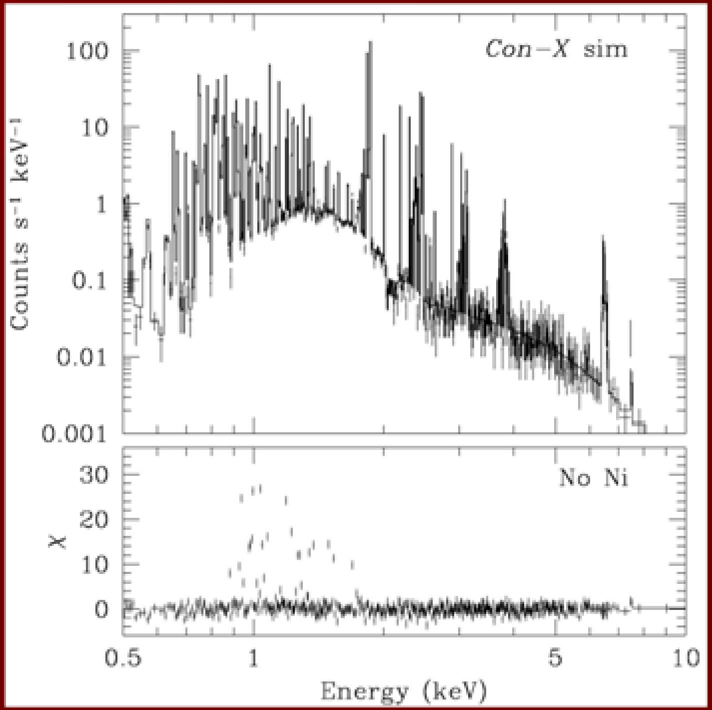


Well sampled spectra extracted from 15” diameter circle. Remnant size and characteristic knot size also well matched to 15” HPD

5” will be even better.

Simulations





Simulated Con-X spectrum derived from Chandra fits. Detection (3σ) of Cr Kα takes 70 ks, Mn Kα takes 220 ks

Can map on 15” arcsec scales

L lines easier to detect (Ni residuals)

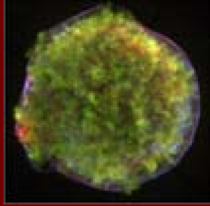
Key Topic II

The Physics of Shocks

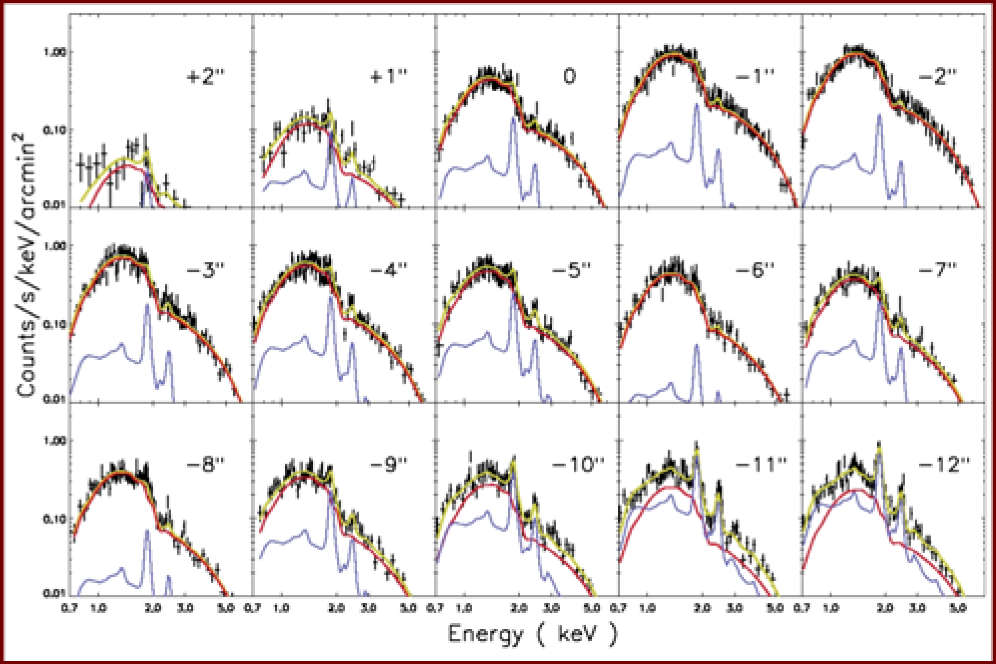
Basic Questions

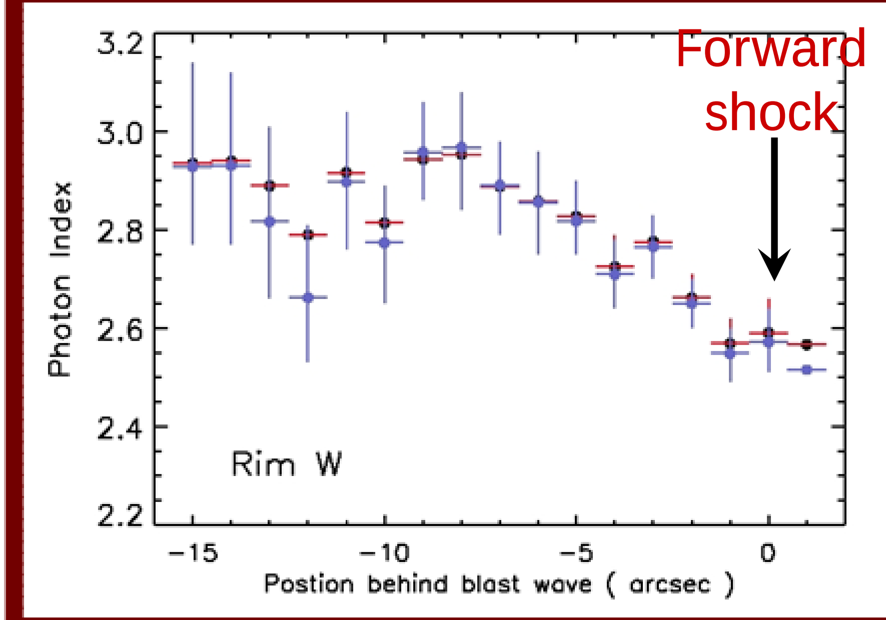
- How do strong shocks in astrophysics accelerate cosmic rays, heat electrons, and amplify magnetic field?
- How do the thermal and nonthermal properties of strong shocks interact?

Results from *Chandra*



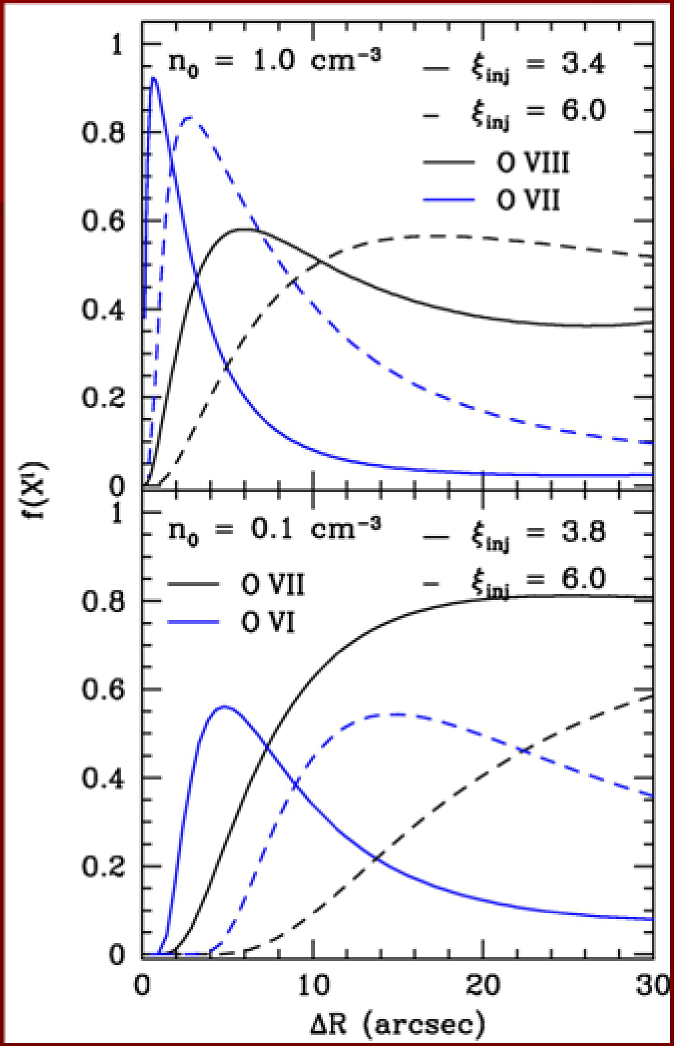
- Spectral analysis of forward shock in Tycho shows spectral softening of featureless rims
  (Cassam-Chenai, JPH, Ballet, Decourchelle 2007)
  - Observationally robust (seen at several locations)





Chandra ACIS spectra

CR-Accelerating Shocks



Patnaude, Ellison, & Slane 2008

- Calculation of ionization states of Oxygen for blast waves with (solid) and without (dashed) efficient particle acceleration
  - Models match distance, age, etc. of Tycho
- Synchrotron emission typically dominates – need IXO spectral resolution to dig out these lines.
- Will be a challenging measurement even at 5” resolution (impossible at 15”)

Usefulness of IXO improved performance

Angular Resolution – most useful overall

Field of View – for calorimeter very useful; for CCD not so much

Collecting Area – useful for M33/M31 SNR studies

Hard X-ray data – very useful if PSF matched to that of soft X-ray telescope