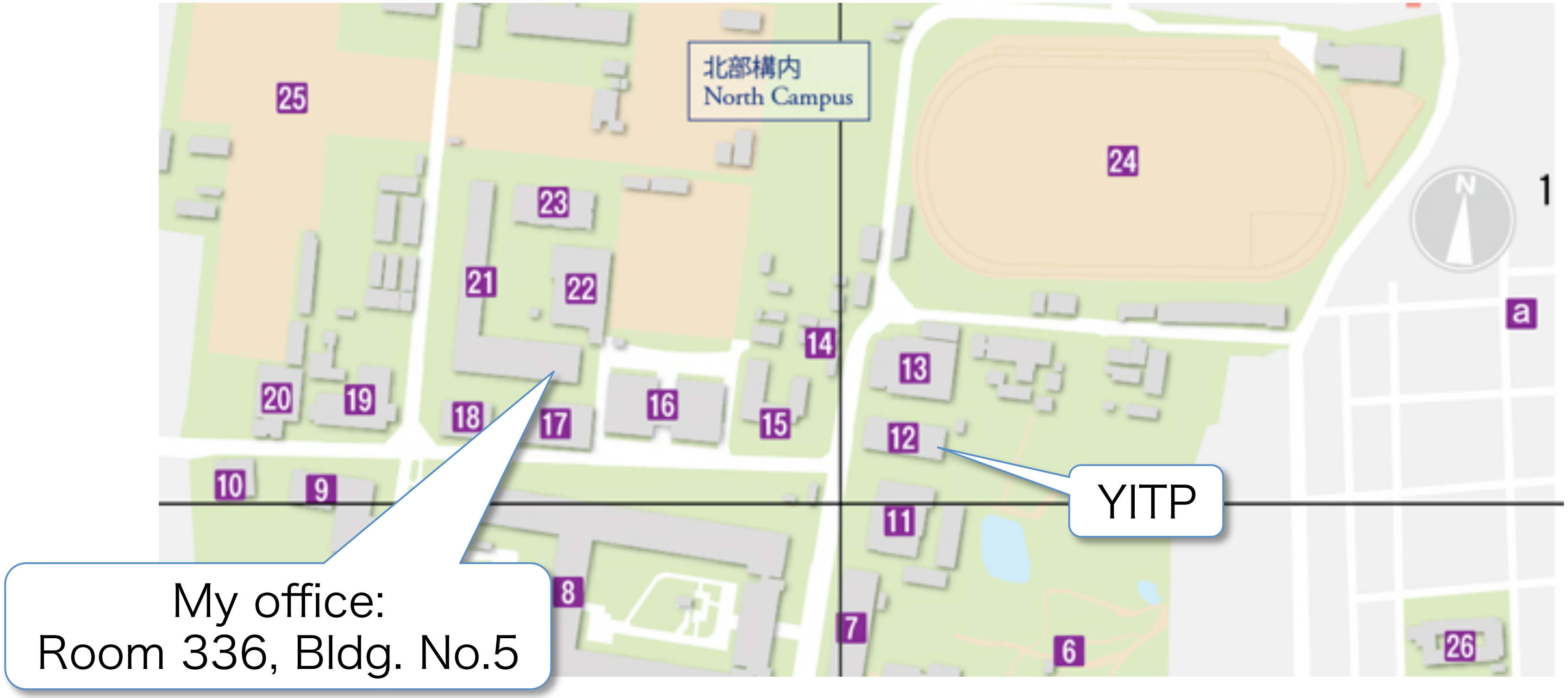
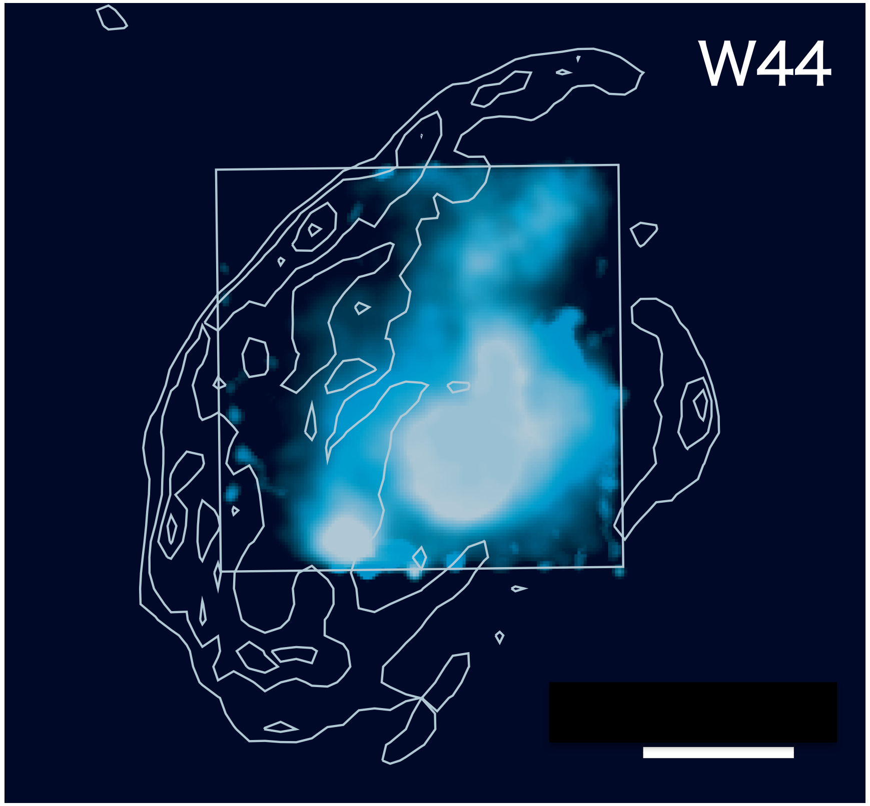
X-ray Observations of Supernova Remnants



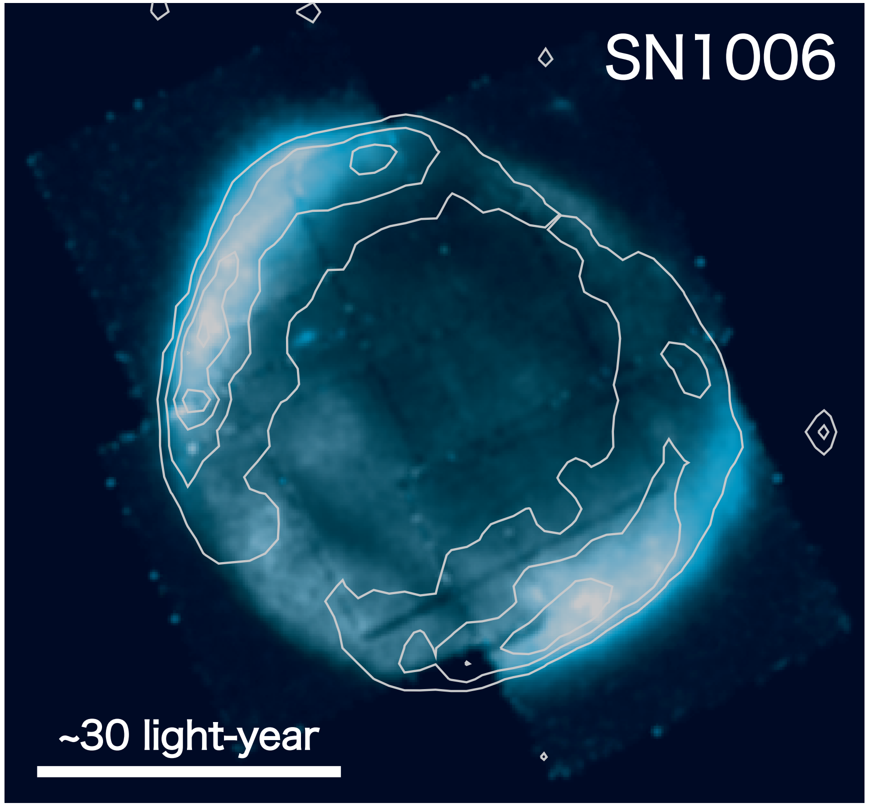
Hiroyuki Uchida（Kyoto University）

Conference on SNe, YITP, Kyoto, 1 November 2013

Motivation



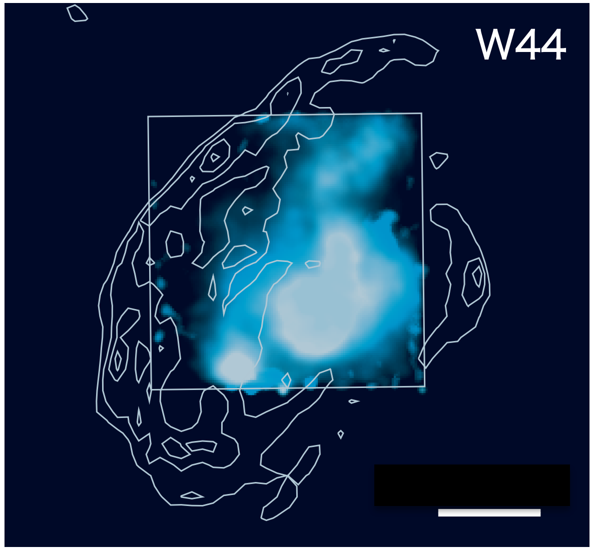
Mixed-morphology SNR

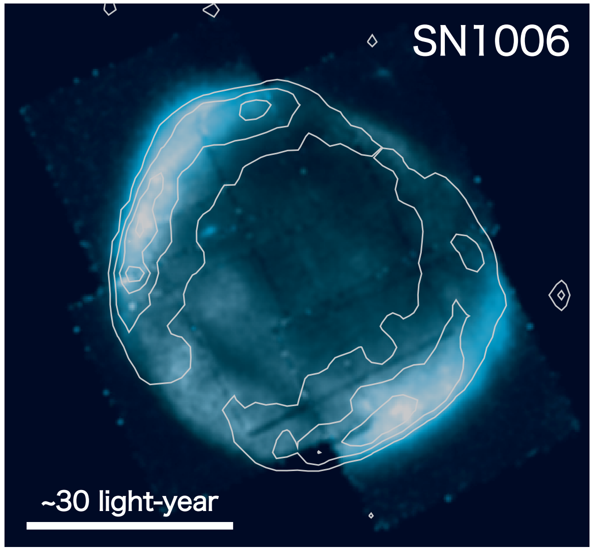


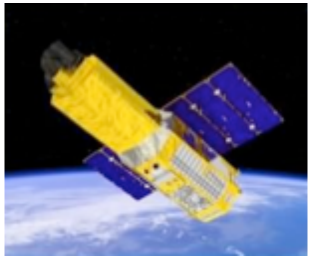
Shell-like SNR

Why do these SNRs have quite different morphologies?
How can we trace the histories from SNe to SNRs?

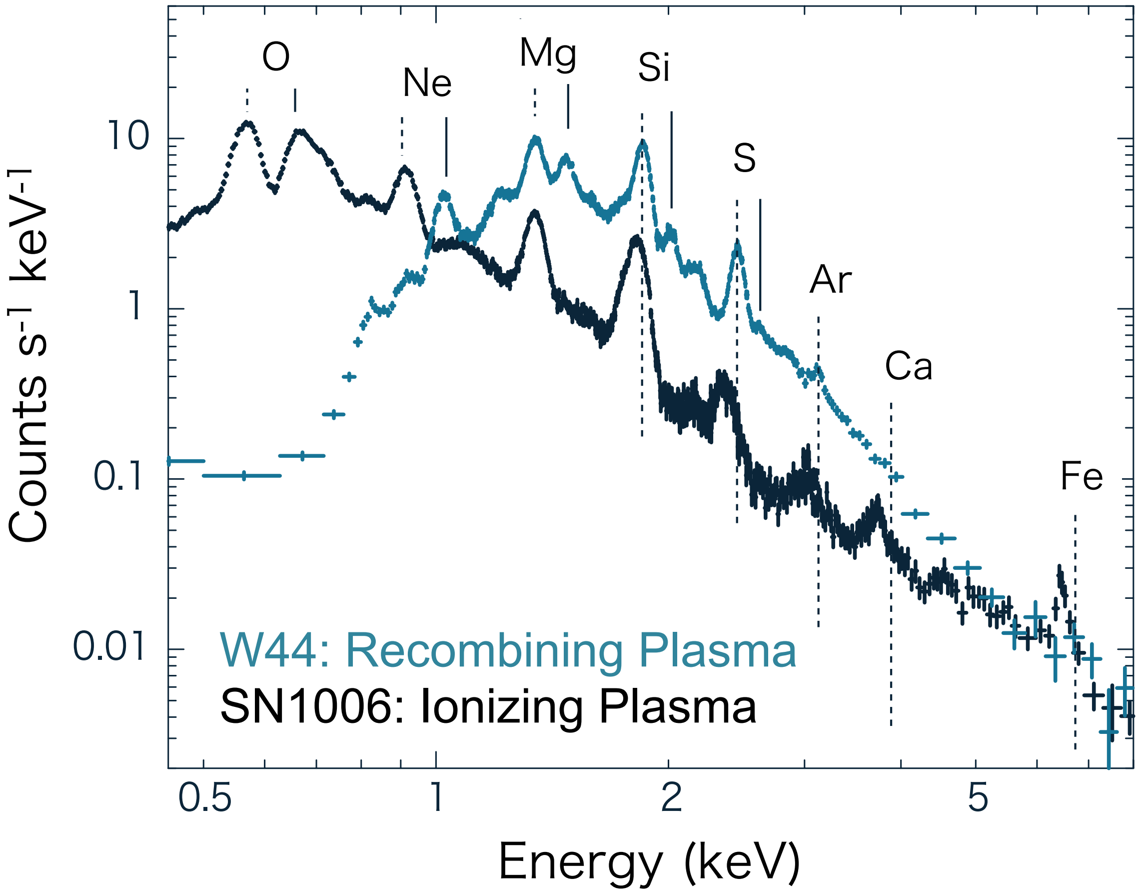
Different Spectra for Different Types of SNRs



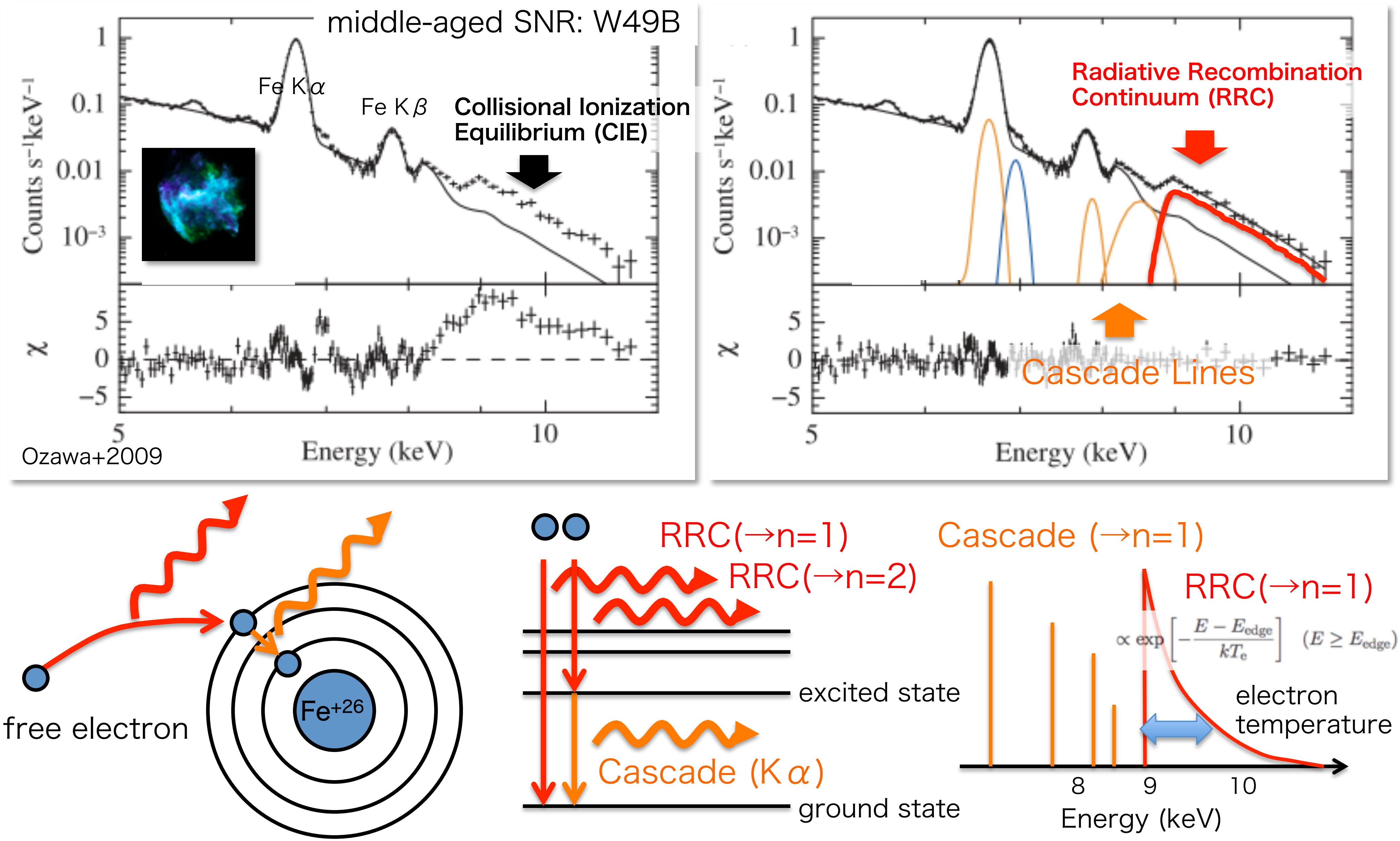




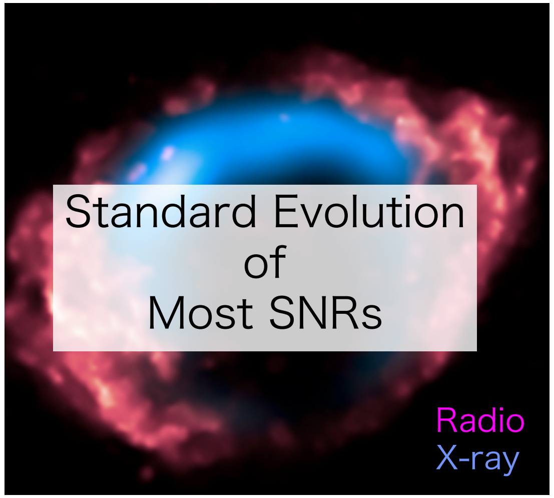
Suzaku XIS
high energy-resolution, low background
suitable for extended sources

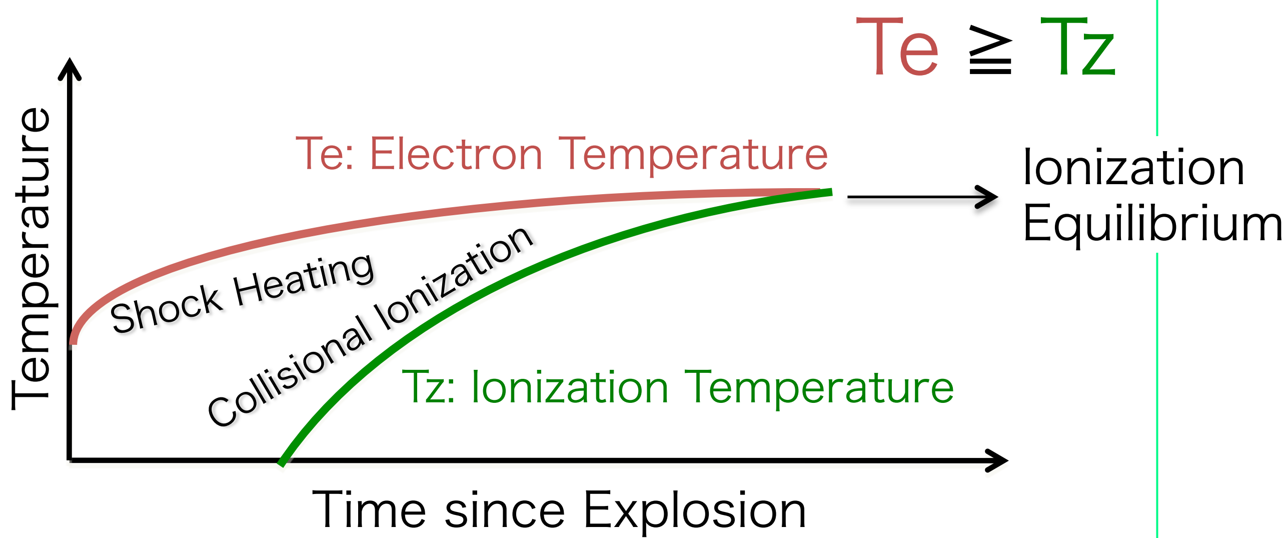


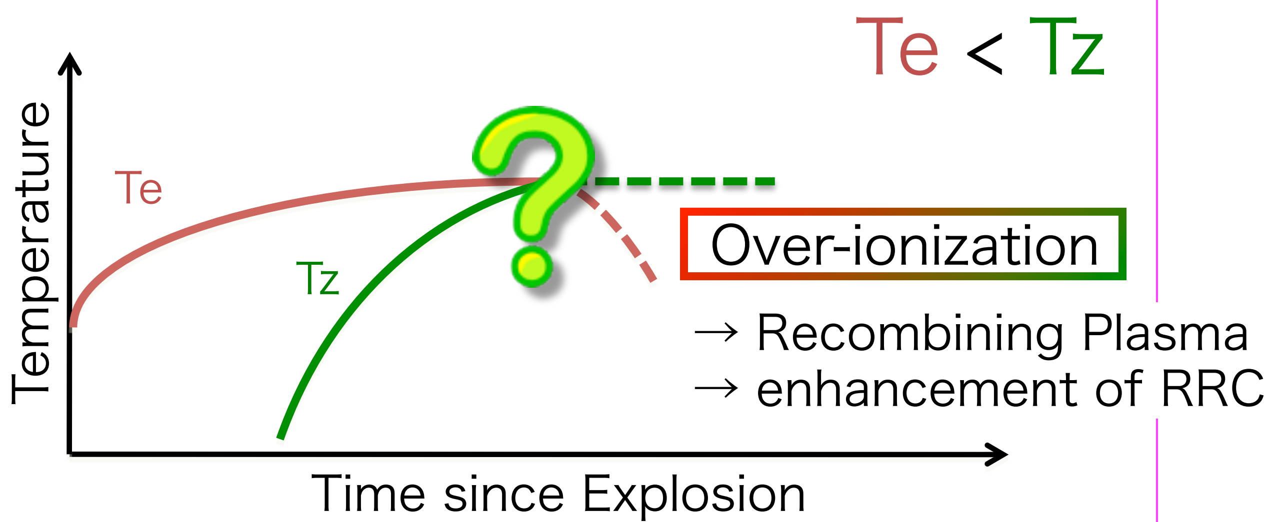
New Type of SNR Spectra Discovered with Suzaku



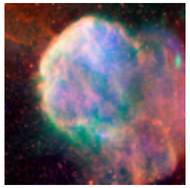
Two Different Types of SNR Evolutions



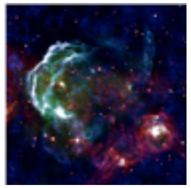




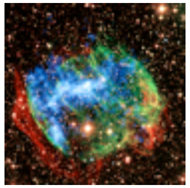
Recombining plasmas found only from mixed-morphology SNRs



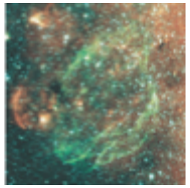
IC443
Yamaguchi et al. 2009
(discovery, suggesting a rarefaction scenario)



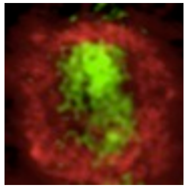
W28
Sawada & Koyama 2012 (multi-Tz)



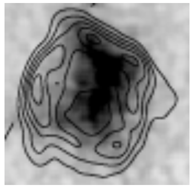
W49B
Ozawa et al. 2009
(discovery)



W44
Uchida et al. 2012b
(spatial analysis, NEIJ)



G359.1-0.5
Ohnishi et al. 2011
(prominent RRC)



G346.6-0.2
Yamauchi et al. 2013

⋮

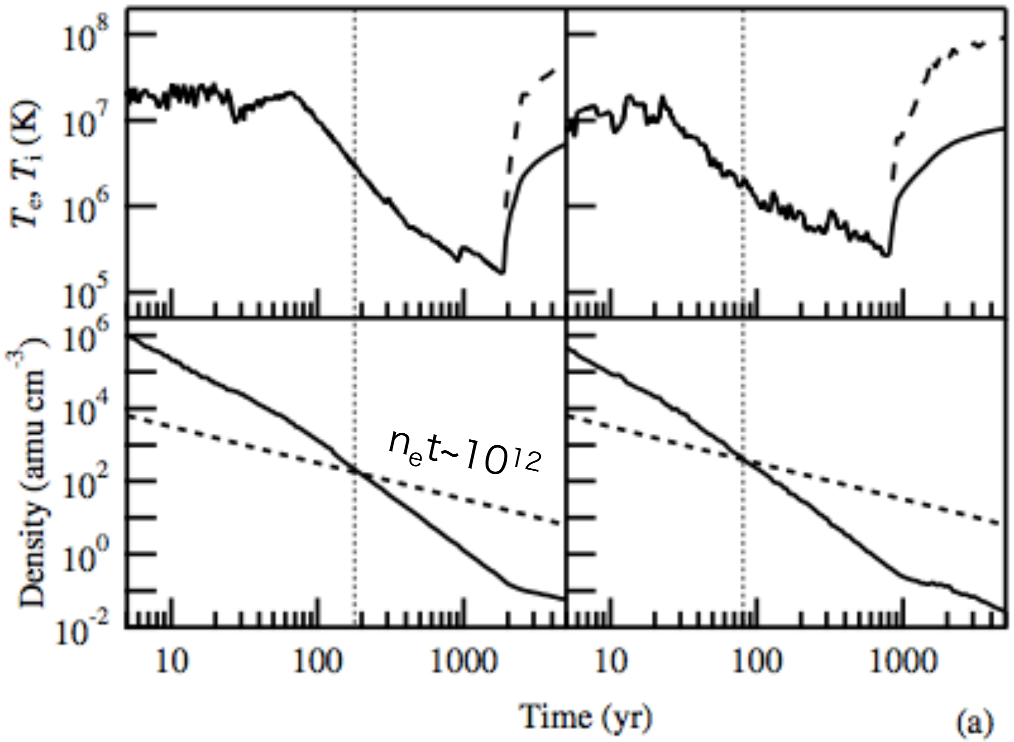
Mixed-morphology SNR

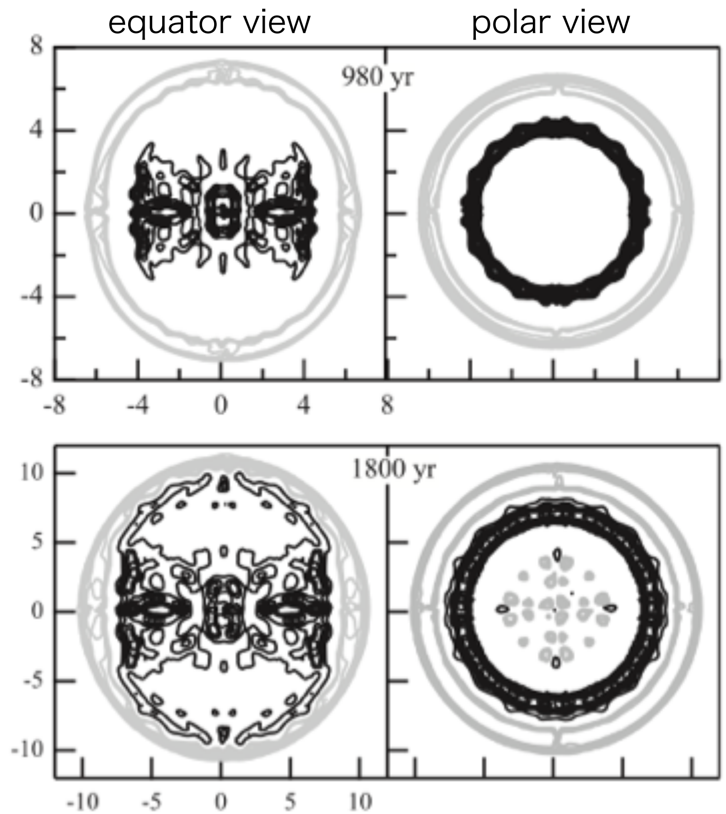
- shell-like (asymmetric) morphology in the radio band and centrally peaked thermal emission in the X-ray band (Rho et al. 1998).
- The morphology is associated with the origin of RP.

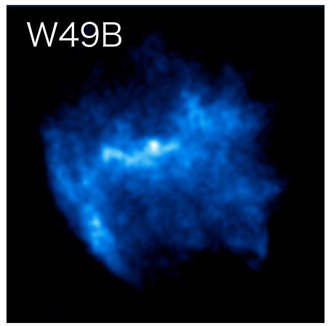
3D Hydrodynamical Simulation

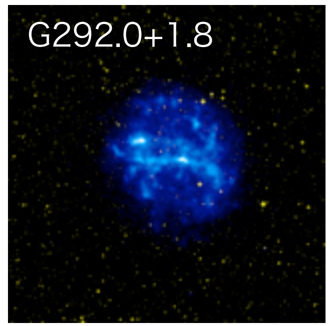
- Simulation of rarefaction had predicted recombining plasma (Itoh & Masai 1987).
- Advanced simulation; Shimizu+2012.
- Disk-like CSM (e.g., Be stars) well explains "belt-like" structure such as W49B (also maybe G292.0+1.8).

Shimizu+2012



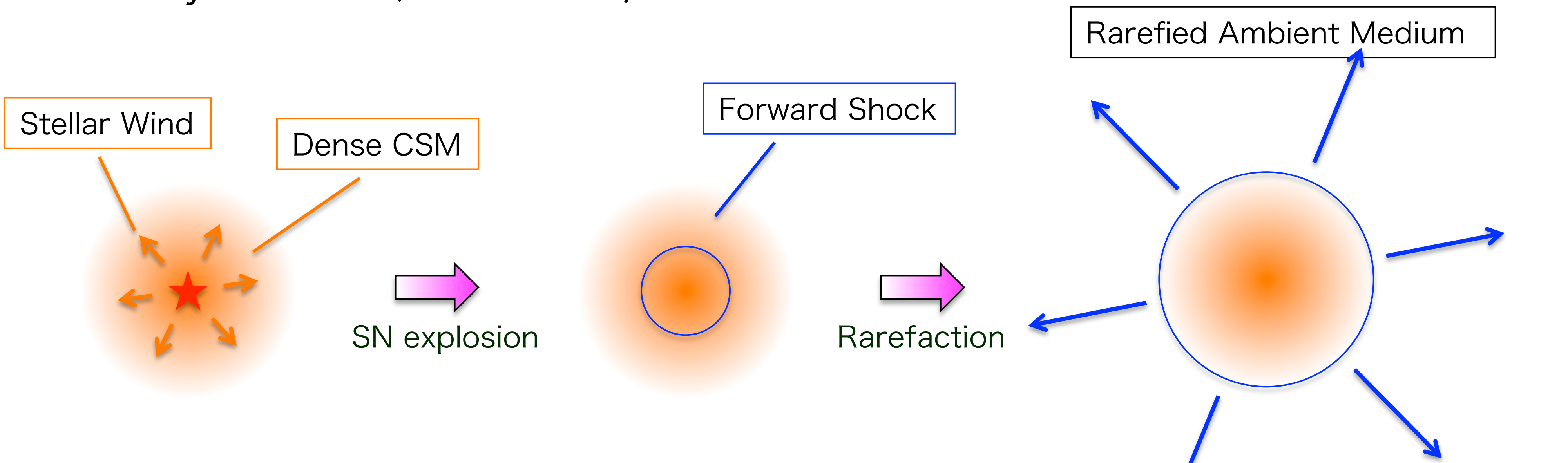






A possible scenario leading to over-ionization: Rarefaction

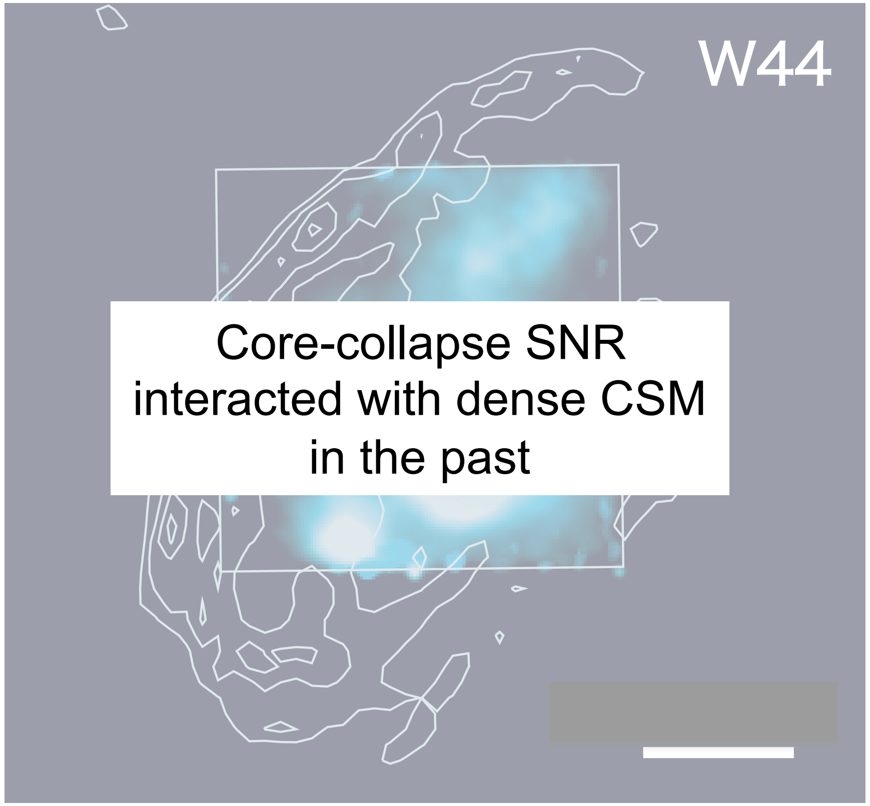
- “Rarefaction scenario is plausible” (Yamaguchi+2009; Sawada & Koyama 2012; HU+2012b)



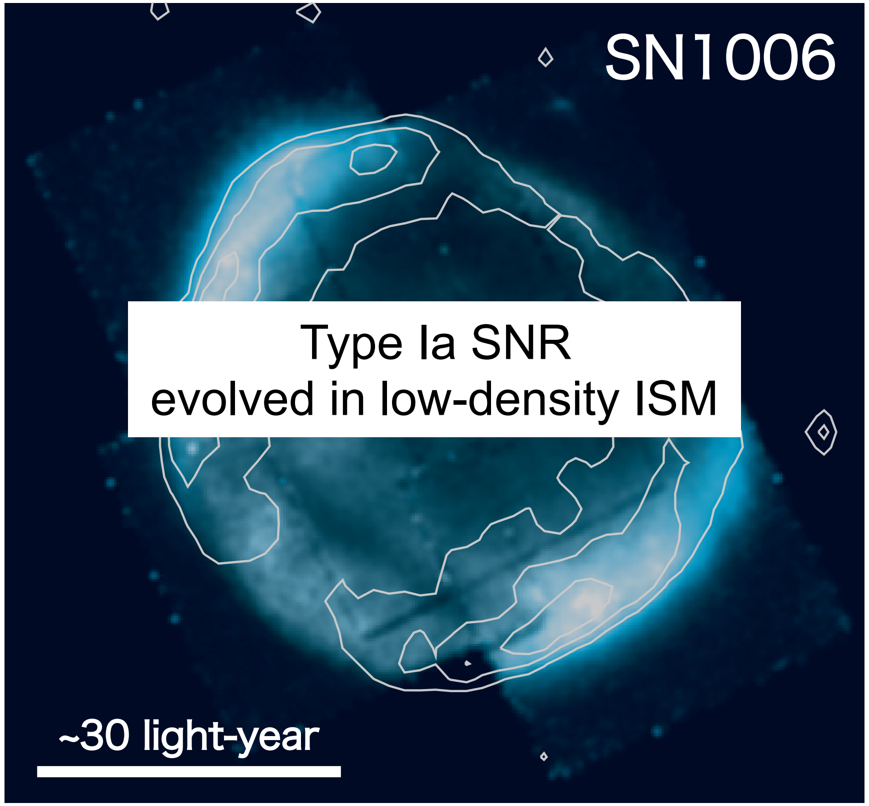
1. Before SNe, stellar wind forms dense CSM around the progenitor.
2. After SNe, forward shock propagates into dense CSM.
3. Due to a large $n_e t$, the ejecta rapidly comes to the collisional ionization equilibrium (Te=Tz).
4. When the forward shock runs over the dense CSM, the plasma rapidly expands into a rarefied ambient medium.
5. The electron temperature decreases adiabatically, hence Te<Tz.

Dense CSM is required: Type IIn SNe origin? → Future work

Motivation



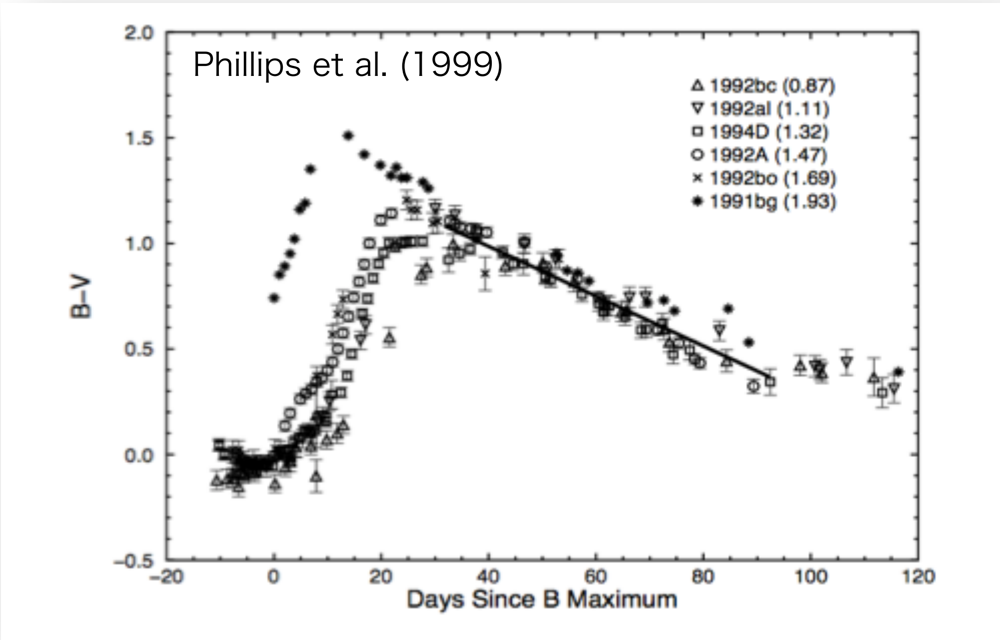
Mixed-morphology SNR

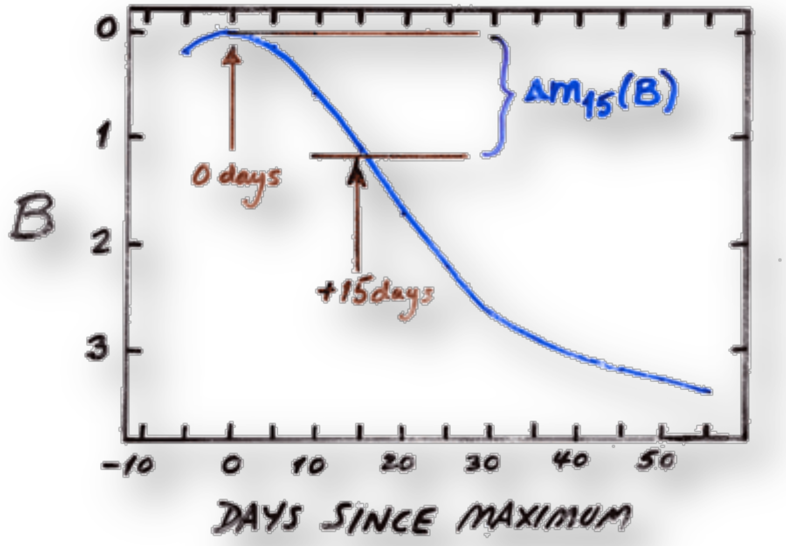


Shell-like SNR

As for SN1006, it is easier to date back to the time of explosion, and thus to get to its explosion mechanism itself.

“Phillips relation” (Phillips et al. 1993, 1999)





- Relationship between the peak luminosity and the speed of luminosity evolution after maximum light $\Delta m_{15}(B)$ (Phillips et al. 1993)

Magnitude of a Type Ia SN:

$$m_0 = [m_{obs} - A_m(\mathrm{Gal})] - K_m - A_m(\mathrm{host})$$

observation value

Galactic extinction

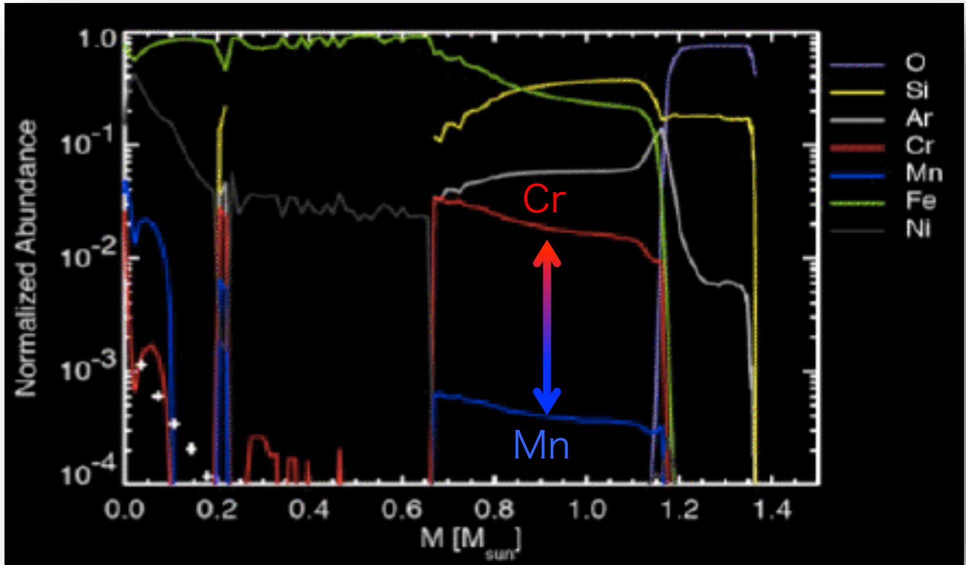
red shift

host galaxy extinction

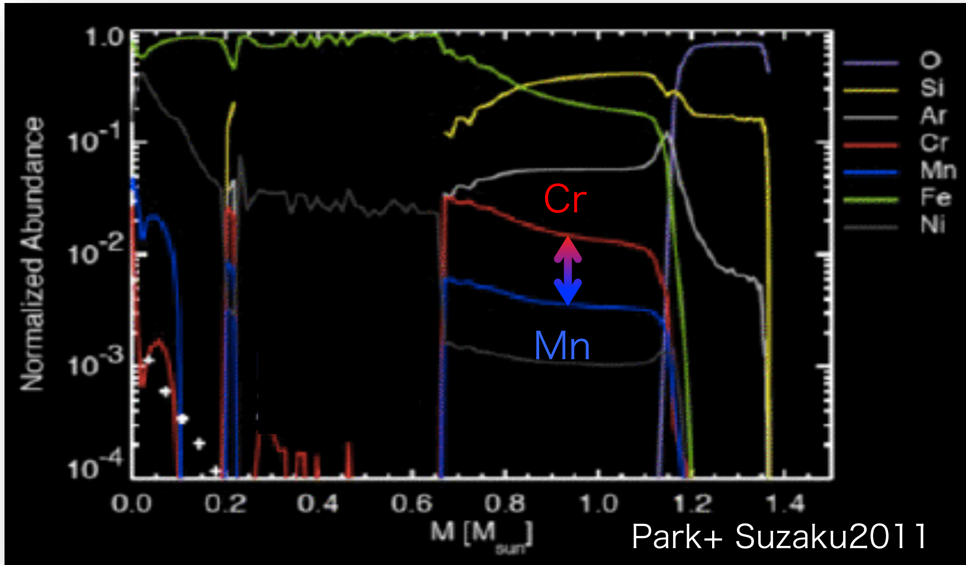
Why do Type Ia SNe have diversity?

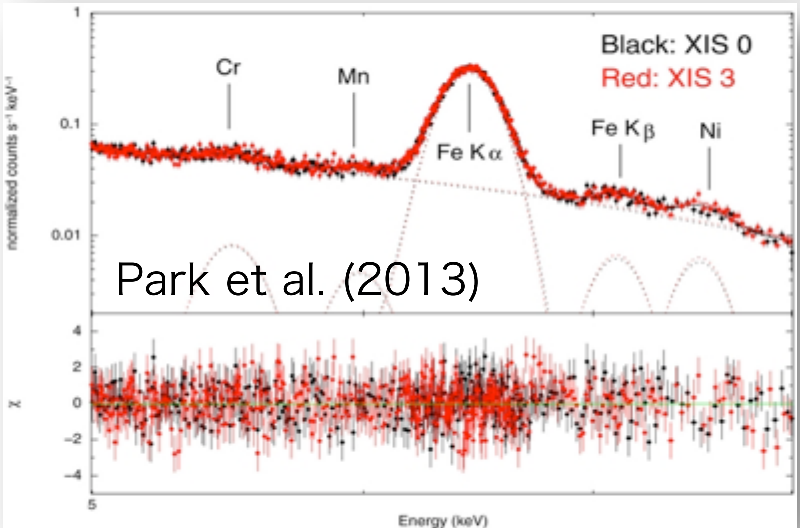
Mn/Cr = Good Tracer of Metallicity of the Progenitor

$Z=2\times10^{-4}$



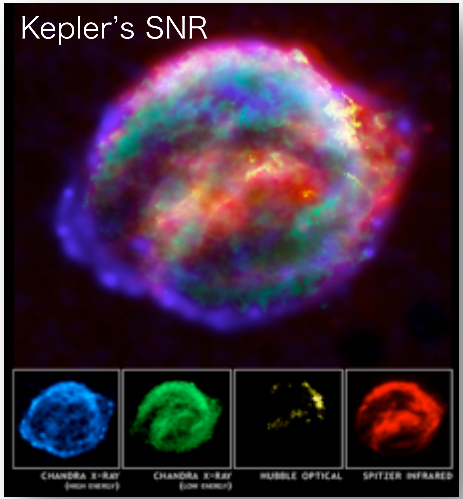
$Z=9\times10^{-3}$



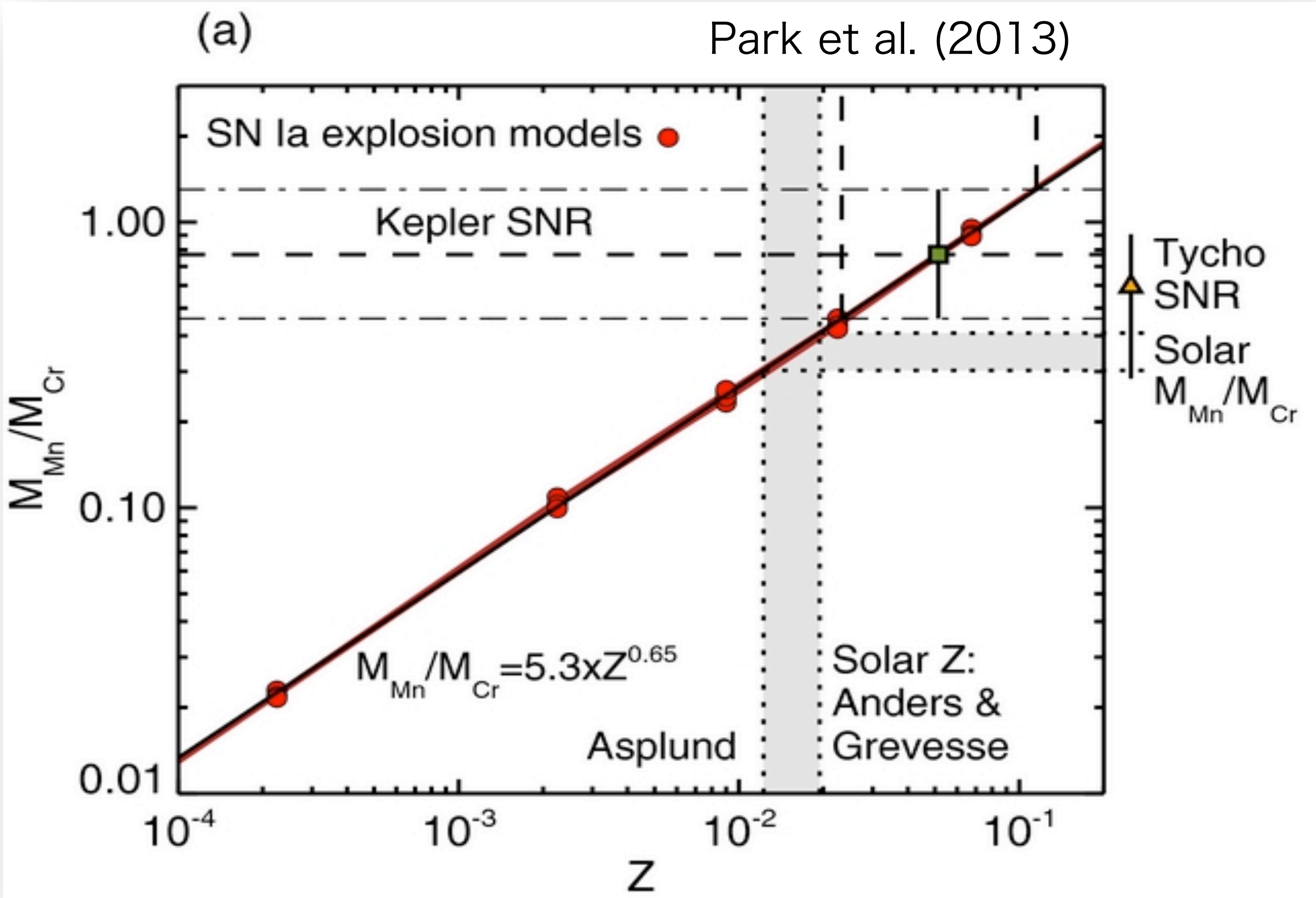


- ^{55}Co (p=27, n=28) → ^{55}Mn (p=25, n=30): Neutron-excess element.
- He-burning: ^{14}N → ^{18}F → ^{18}O → ^{22}Ne (p=10, n=12; p<n).
- End products of CNO cycle: ^{14}N.
- Total yield of ^{14}N depends on initial metallicity of the progenitor.
- Hence ^{55}Mn/^{52}Cr is sensitive to metallicity of the progenitor

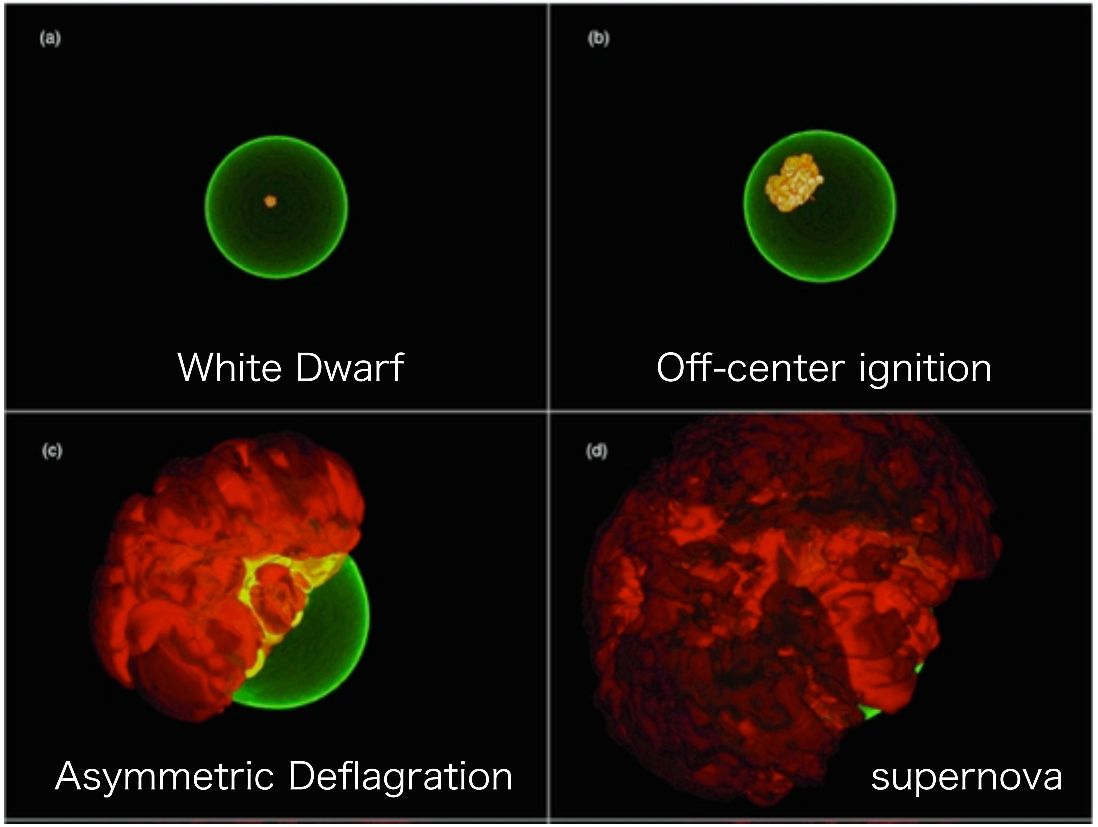
“Super-solar Metallicity”: SN 1604 (Park et al. 2013)



- Deep observation for Kepler SNR with Suzaku (660-690ks)
- Metallicity of the progenitor is significantly higher than the solar metallicity: $Z \sim 3Z_{\odot}$
- Suggesting a fainter Type Ia SN than that of normal luminosity?
- Can we observe light echo in the future?



Example of Theoretical Simulations for Asymmetric Type Ia Explosion

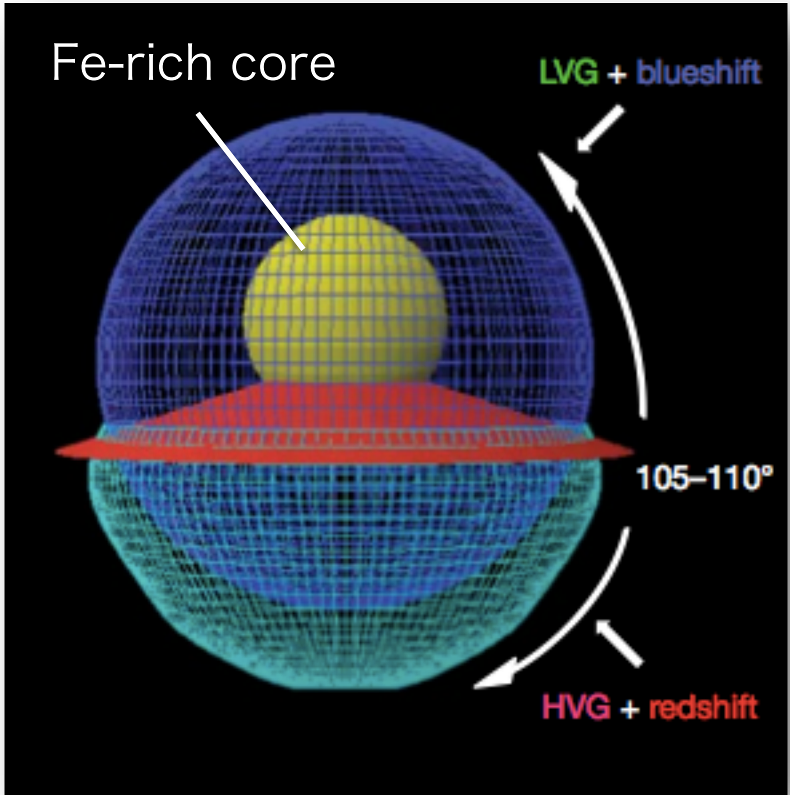


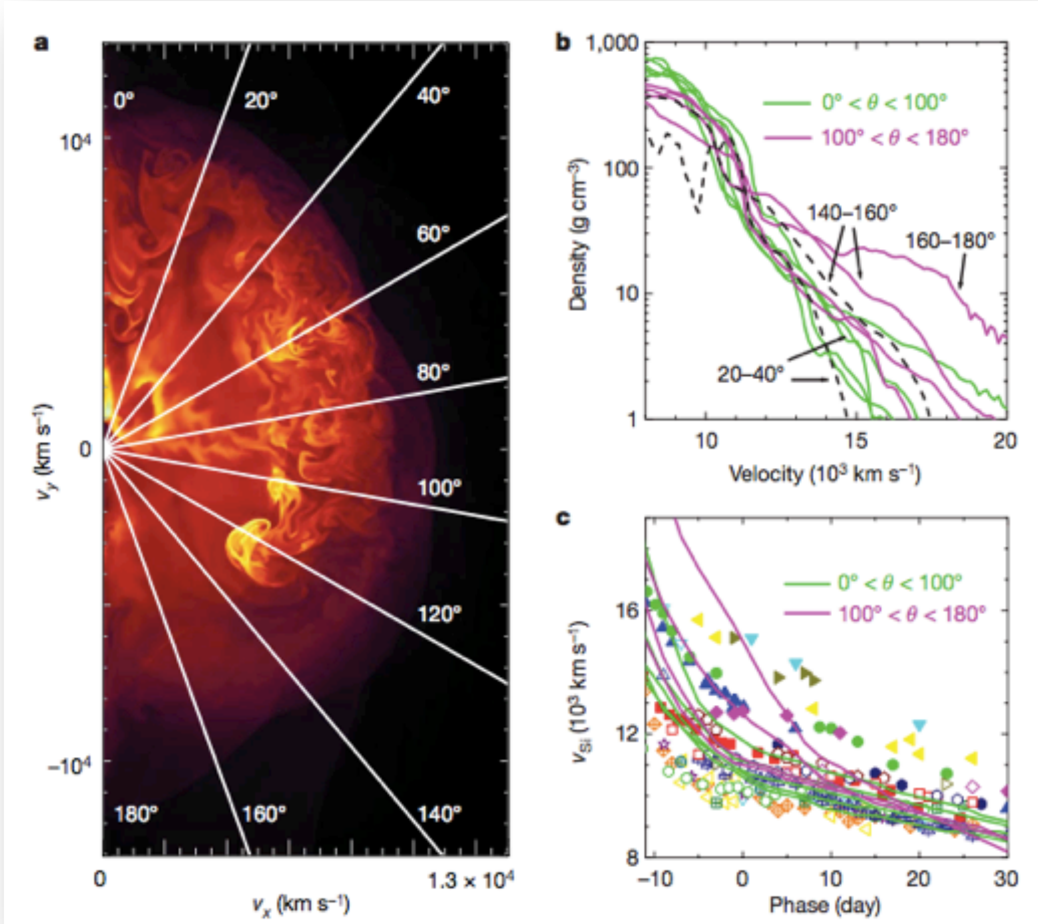
Jordan IV + 2012

3D simulations have indicated that “asymmetry” is essential for Type Ia SNe.

Supportive Evidence from SN observations and Simulations

Maeda et al. 2010: “An asymmetric explosion as the origin of spectral evolution diversity in type Ia supernovae”

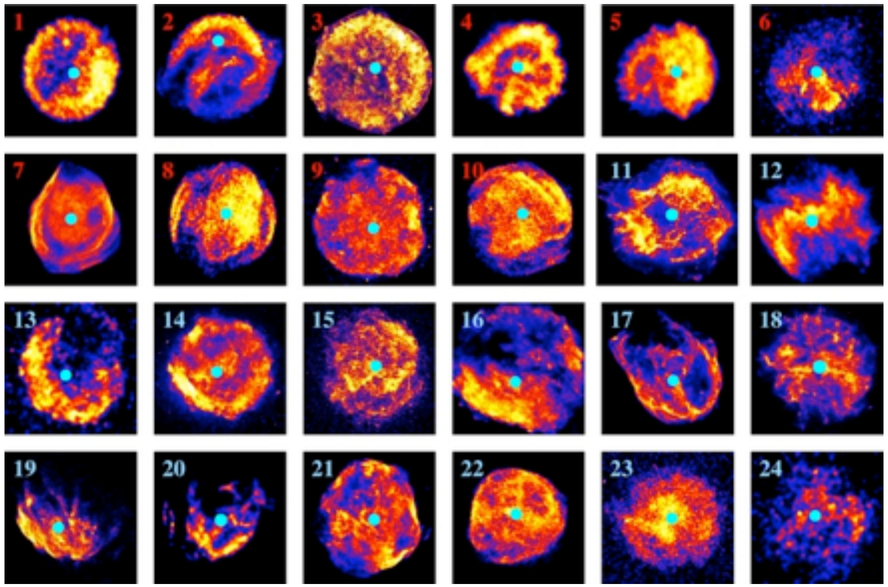


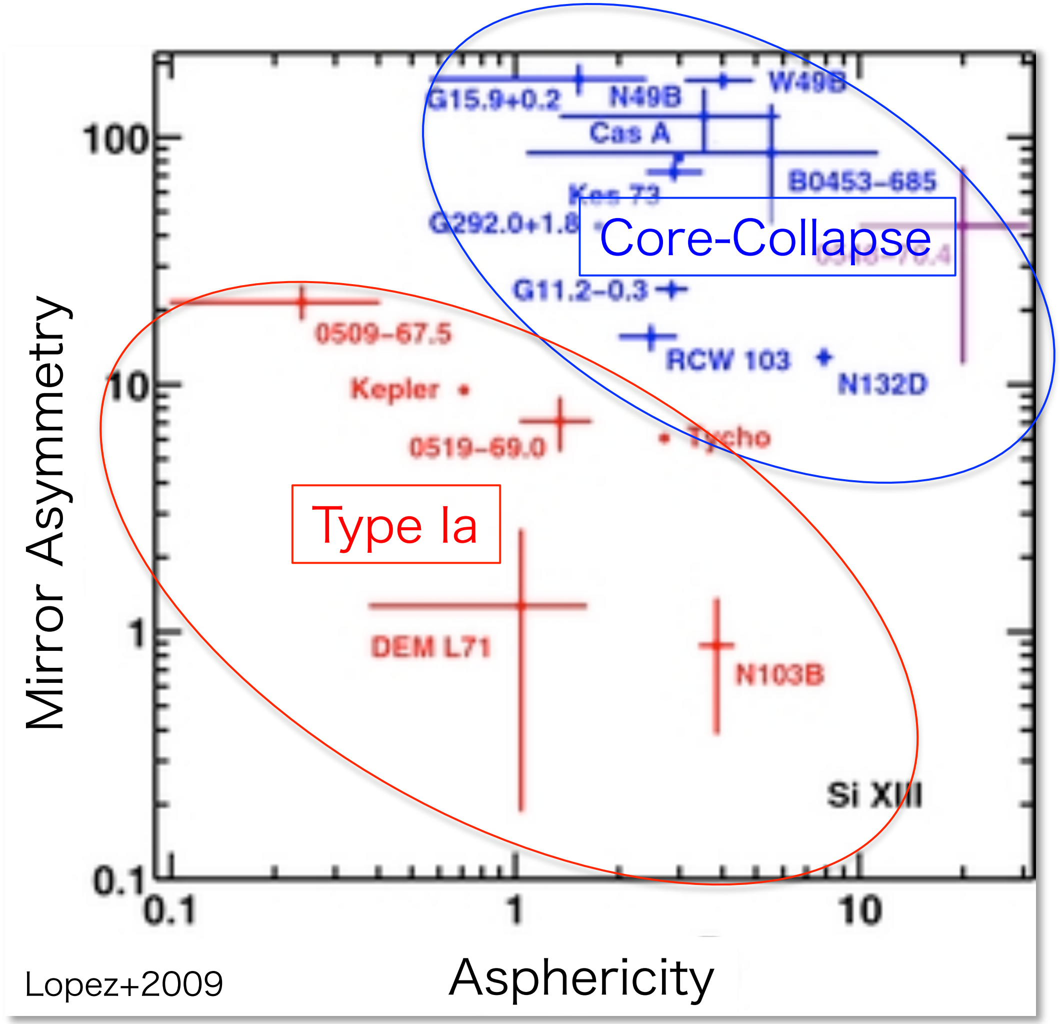


The asymmetric explosion is common for extragalactic Type Ia SNe.

If so, clear evidence should also be found from nearby SNRs.

“Asymmetry” of Shell Structure or SNRs

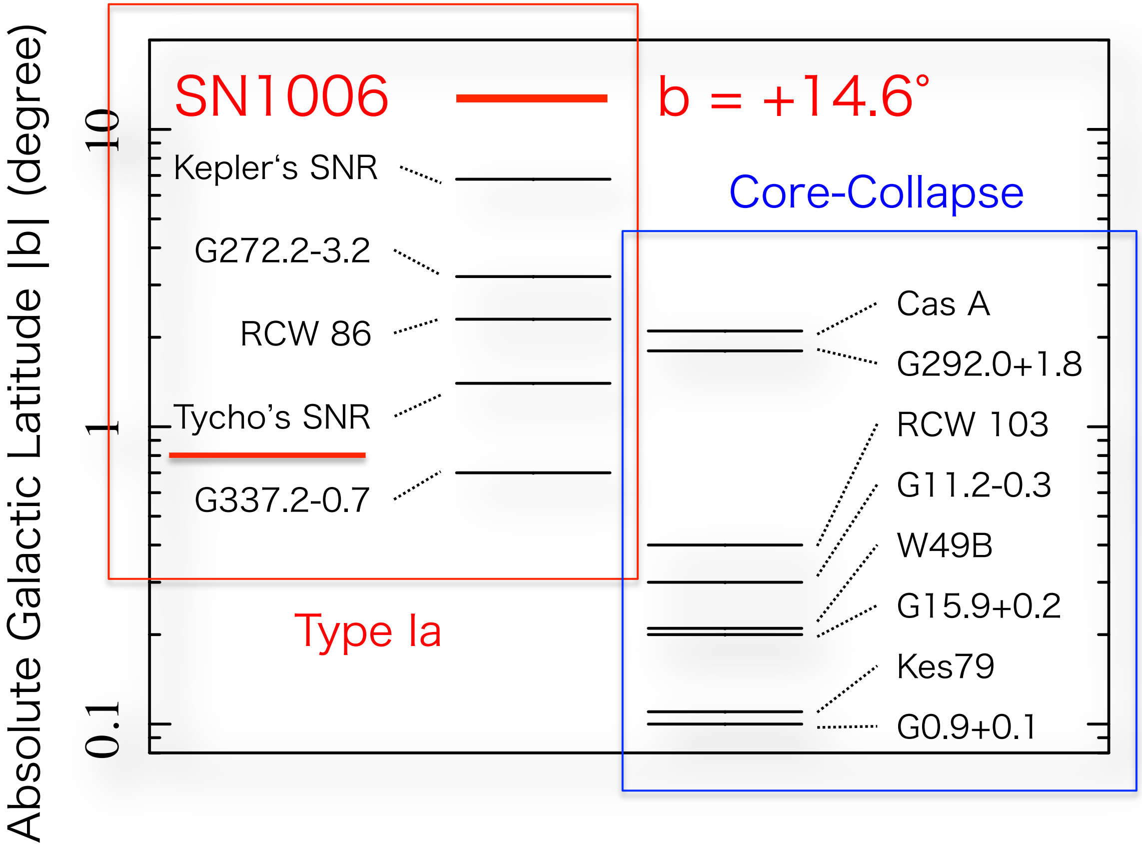


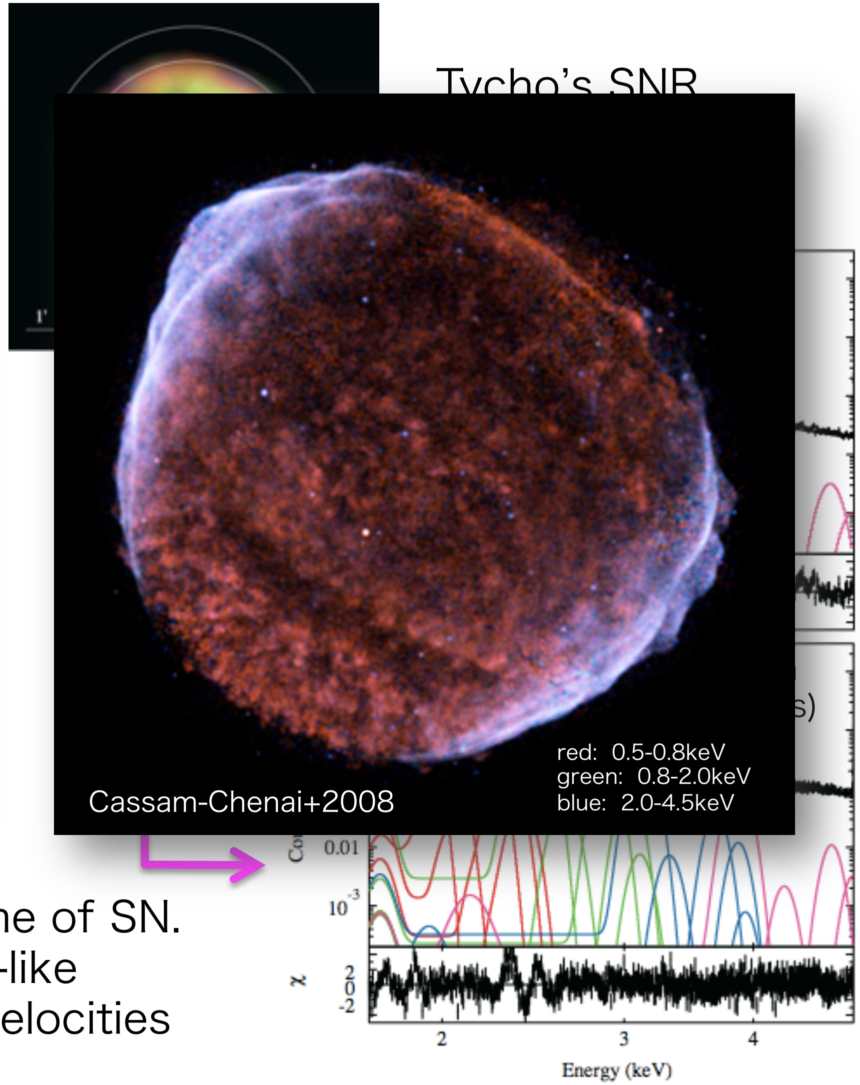


- Core-collapse SNRs are easy to be distorted by dense circumstellar gas.
- Type Ia SNRs have more “round” shape (Lopez+2009).

Horizontal axis: asphericity
Vertical axis: mirror asymmetry

Ejecta Distribution in Type Ia SNRs





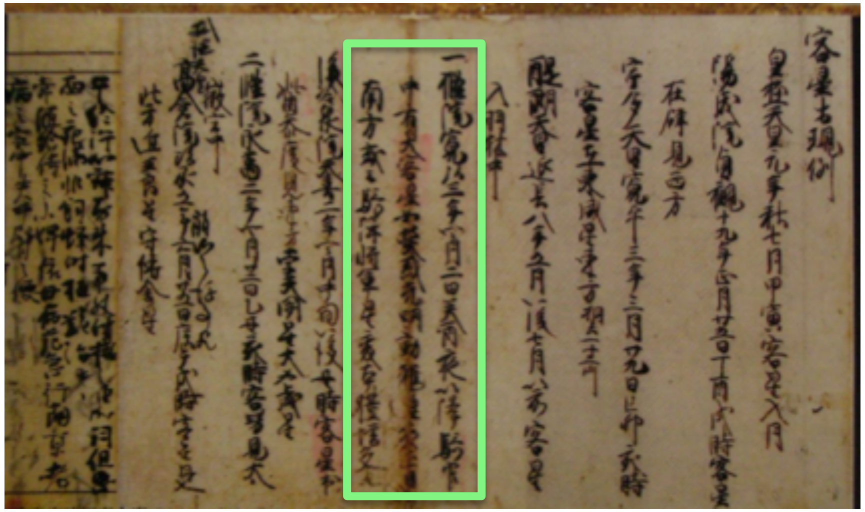
- Low ambient density = Easier to go back to the time of SN.

Tycho's SNR (Hayato+2010): Discovery of the "Onion-like Structure" of ejecta. "Si and S ejecta have higher velocities (~3500 km s^{-1}) than Fe ejecta (~3000 km s^{-1})."

- SN1006: located at the highest Galactic latitude. → Good for approaching the explosion mechanism of a Type Ia SN.

A thousand years ago SN1006 was observed in Kyoto

藤原定家（1162-1241）
Fujiwara no Teika



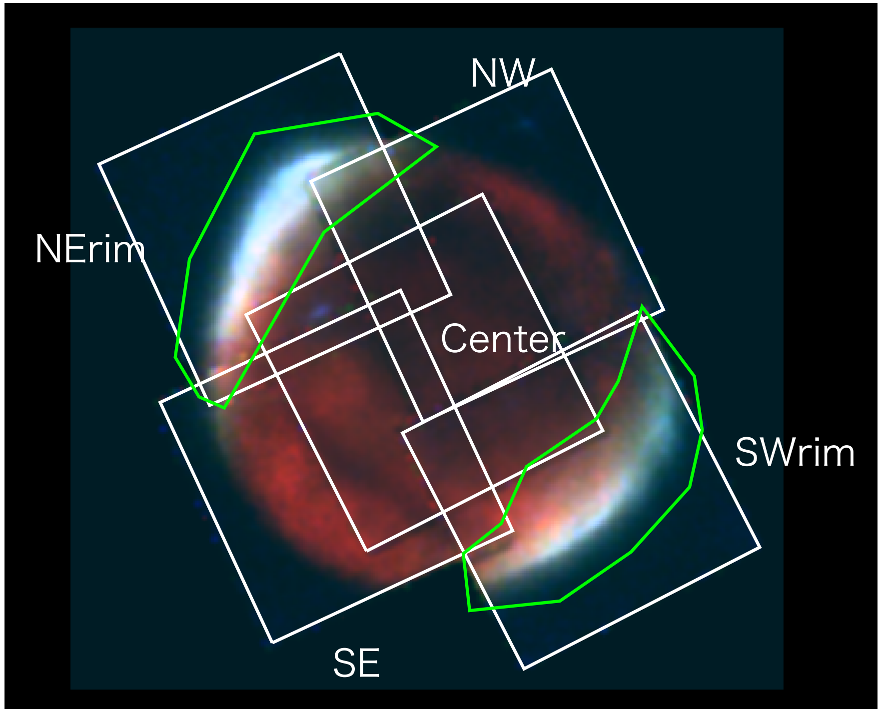
- In his diary ”Meigetsuki (明月記)”
  - 「一條院 寛弘三年 四月二日 癸酉 夜以降 騎官中有大客星」
  - 「如螢惑 光明動耀 連夜正見南方 或云」

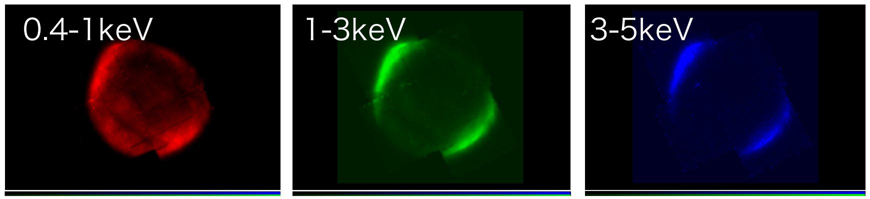
“A large guest star (Supernova) appeared within the Kikan (Lupus) constellation.”

“It was very bright like Mars, and visible in the southern sky every night. “

No obscuring dense dust along the line of sight:
SN1006 located at high Galactic latitude

“Millenium” Long-time Observation of SN1006 with Suzaku





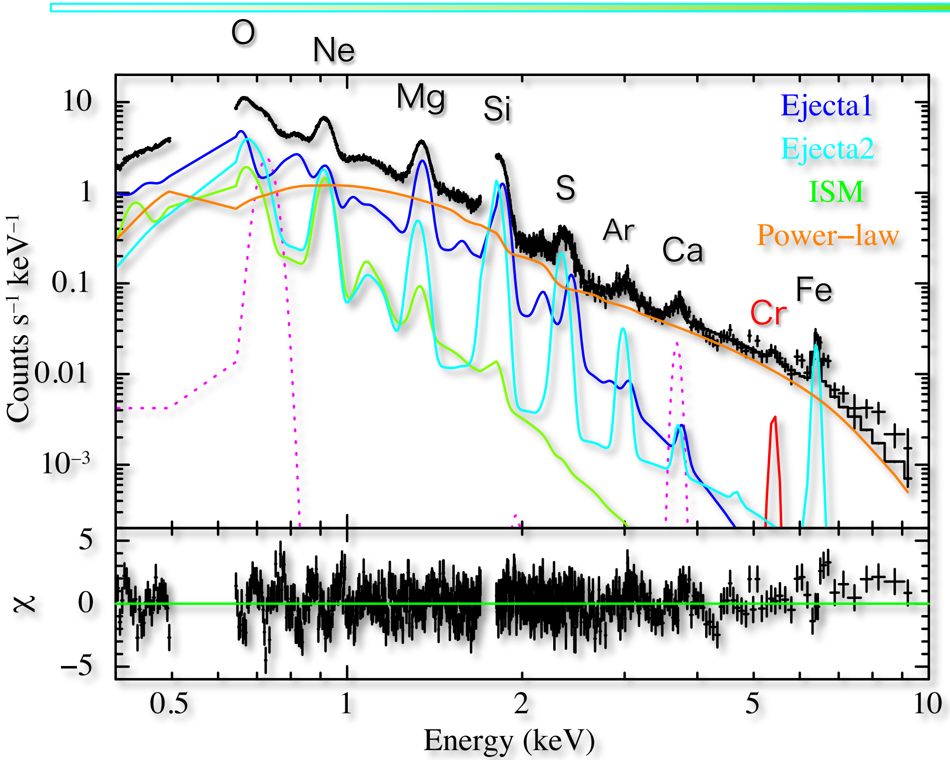
- Located on relatively high galactic latitude (b = 14.6 deg).
- The ambient density is extremely low.
  - $n_H \sim 0.03\ cm^{-3}$ at NE (Yamaguchi +2008)
  - $n_H \sim 0.085\ cm^{-3}$ at SE (Katsuda +2009)
- Fairly uniform circumstellar matter (Dubner+2002).
- Various line emissions from heated ejecta (Yamaguchi+2009).

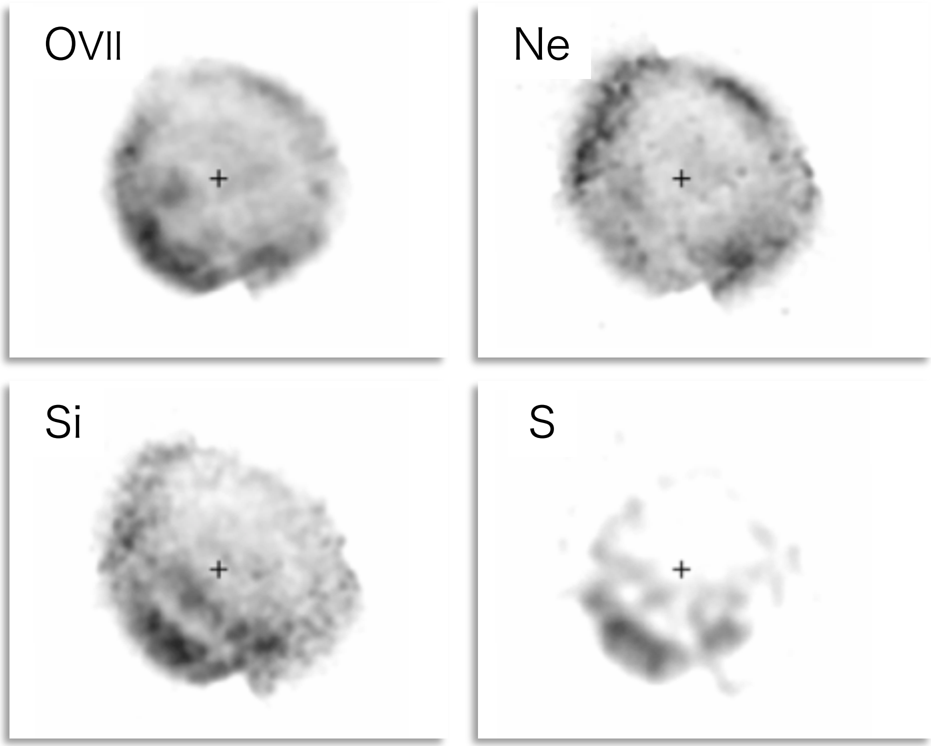
- SN1006 is a textbook sample for investigating the origin of Type Ia SNe.

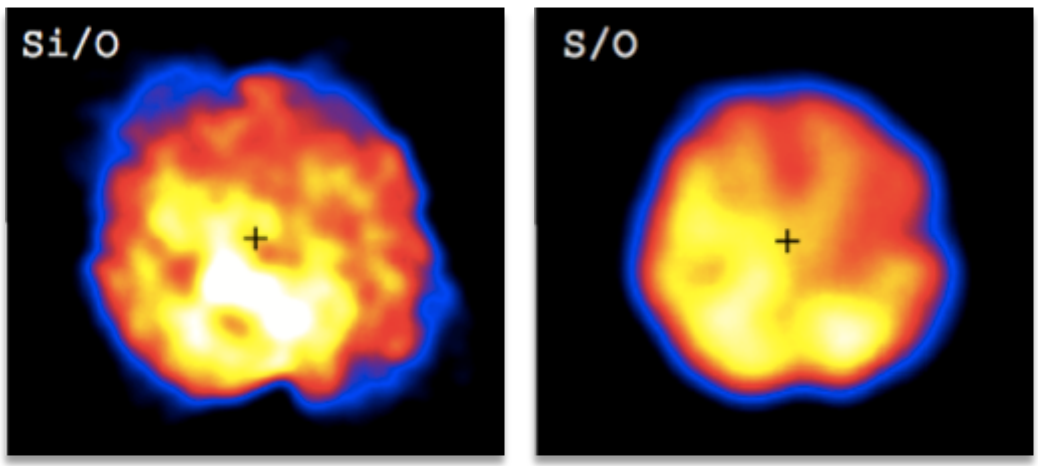
- A total of ~400-ks observations (↓200ks for Center region) with Suzaku.

Object	Obs ID	RA NOM	DEC NOM	Exp. Time	Date
SN1006 Center	502046010	225.7	-41.9	211.7 ks	20090314

Spectral Analysis and Equivalent Width Maps

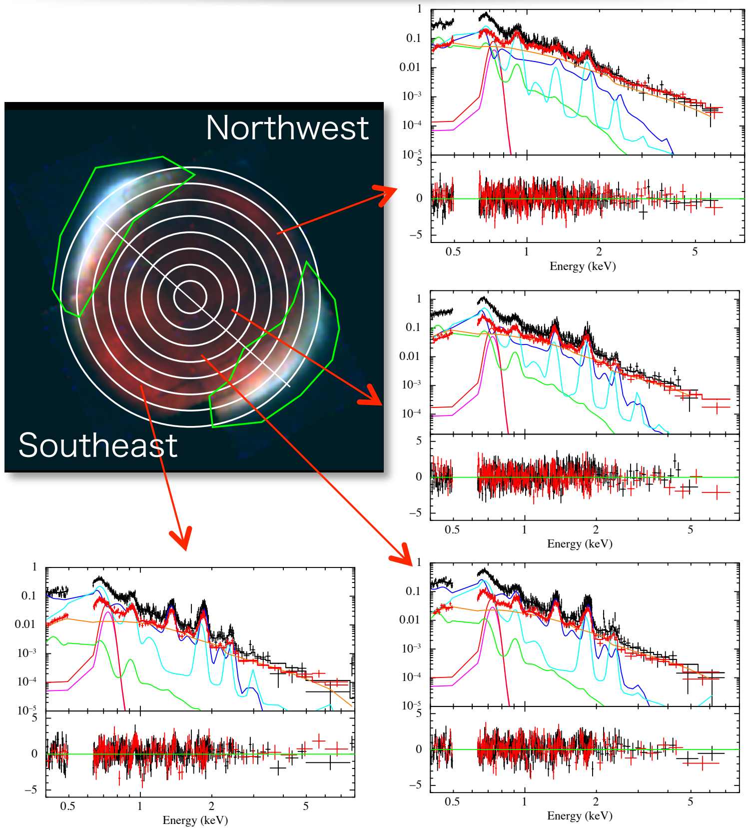


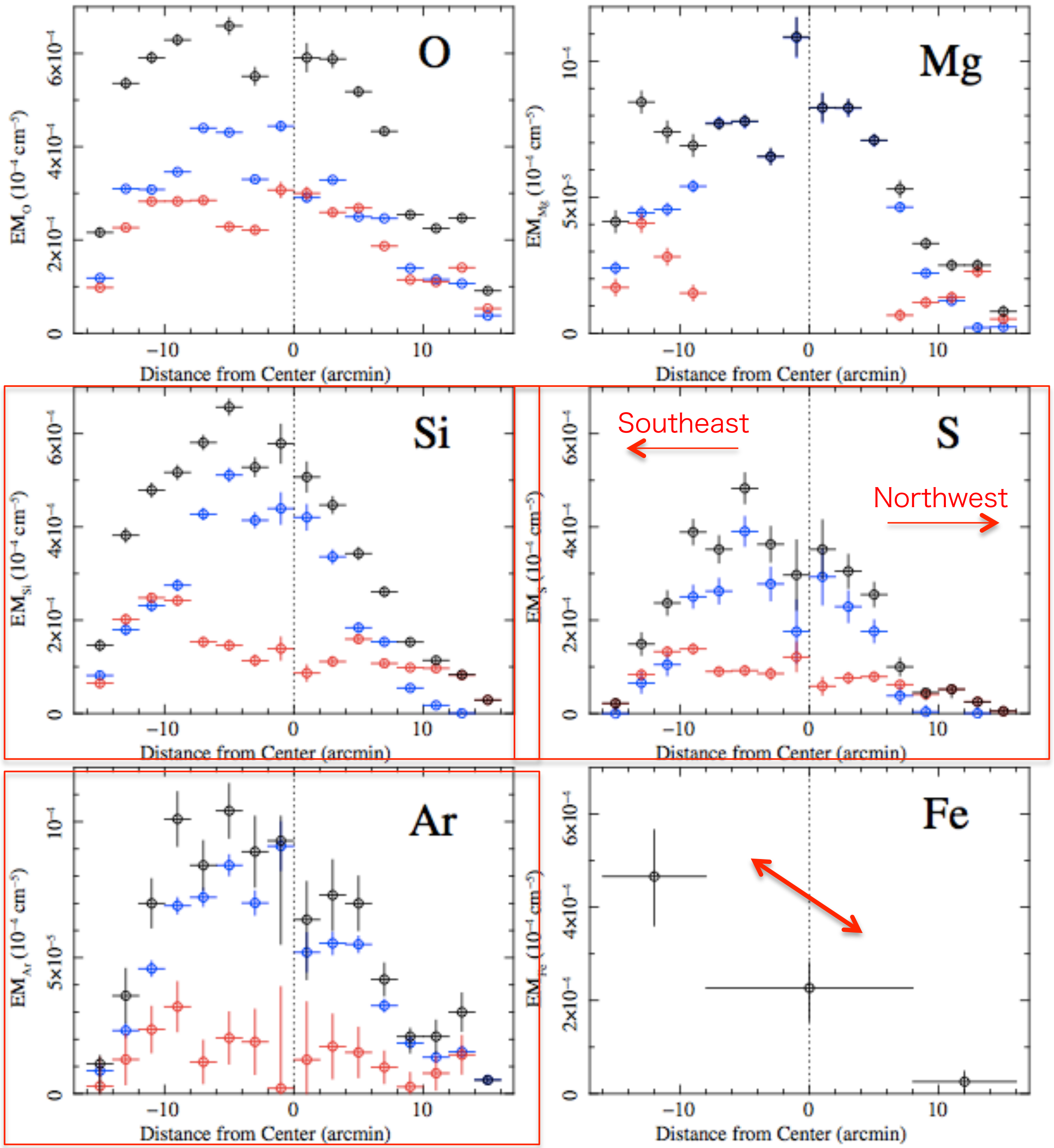




- Best-fit model: two-component ejecta with different ionization timescales plus power-law and ISM components.
- Si and S are displaced toward southeast. Shift velocity is estimated to be ~3000 km/s

Radial Profiles of Ejecta Elements

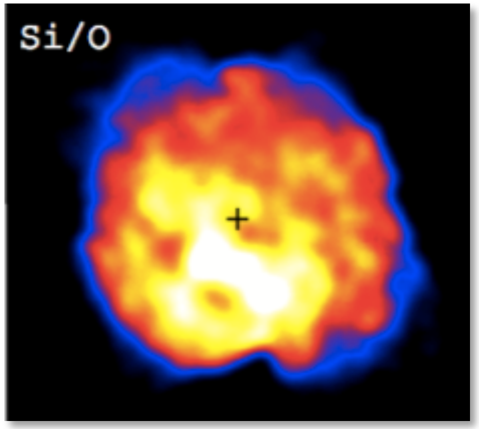




- Si, S, and Ar (yields from incomplete Si-burning layer) are displaced from northwest to southeast.
- Fe distribution is also asymmetric.
- Heavy elements distribute asymmetry.

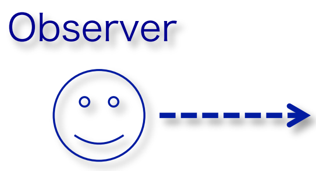
“3D” View of the Ejecta in SN1006

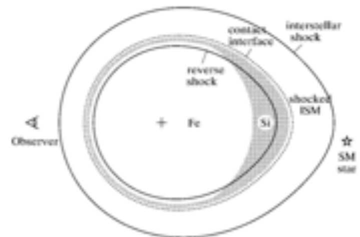
Frontal View



Our result shows a clear asymmetry of heavy elements (HU+2013).

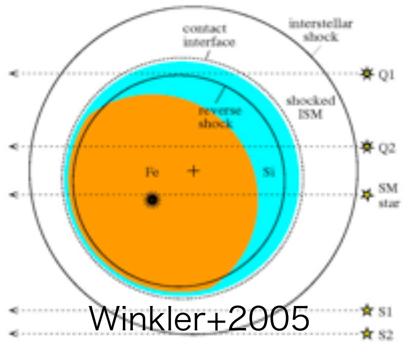
Side View



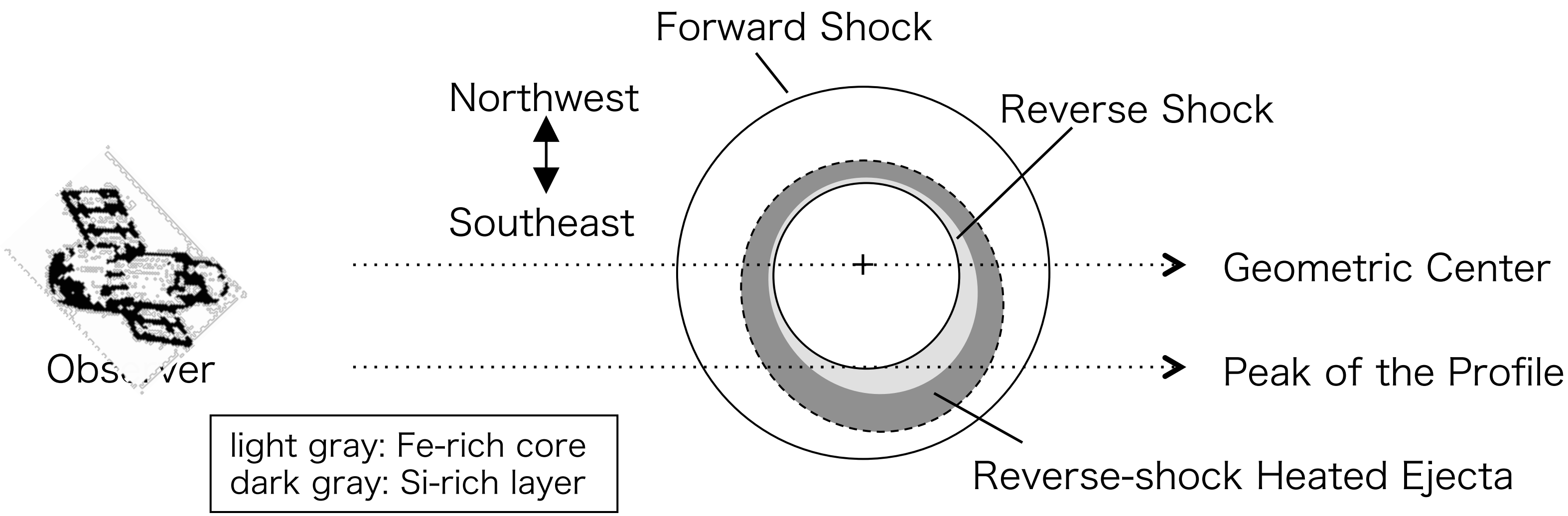


Hamilton+1997

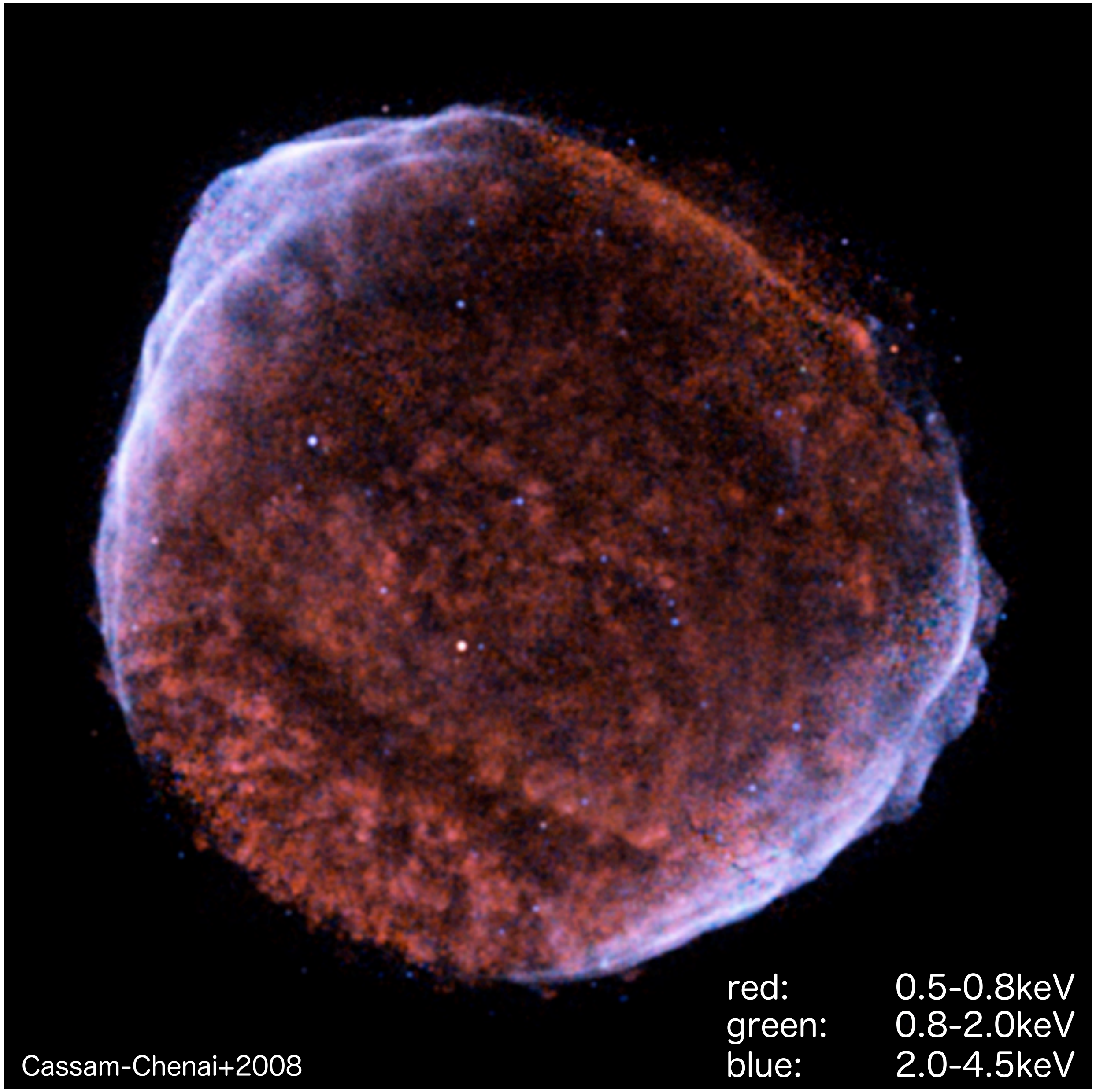
Several Observations of background stars suggest the line-of-sight asymmetry of Fe based on a Doppler shift of absorption lines of FeII.



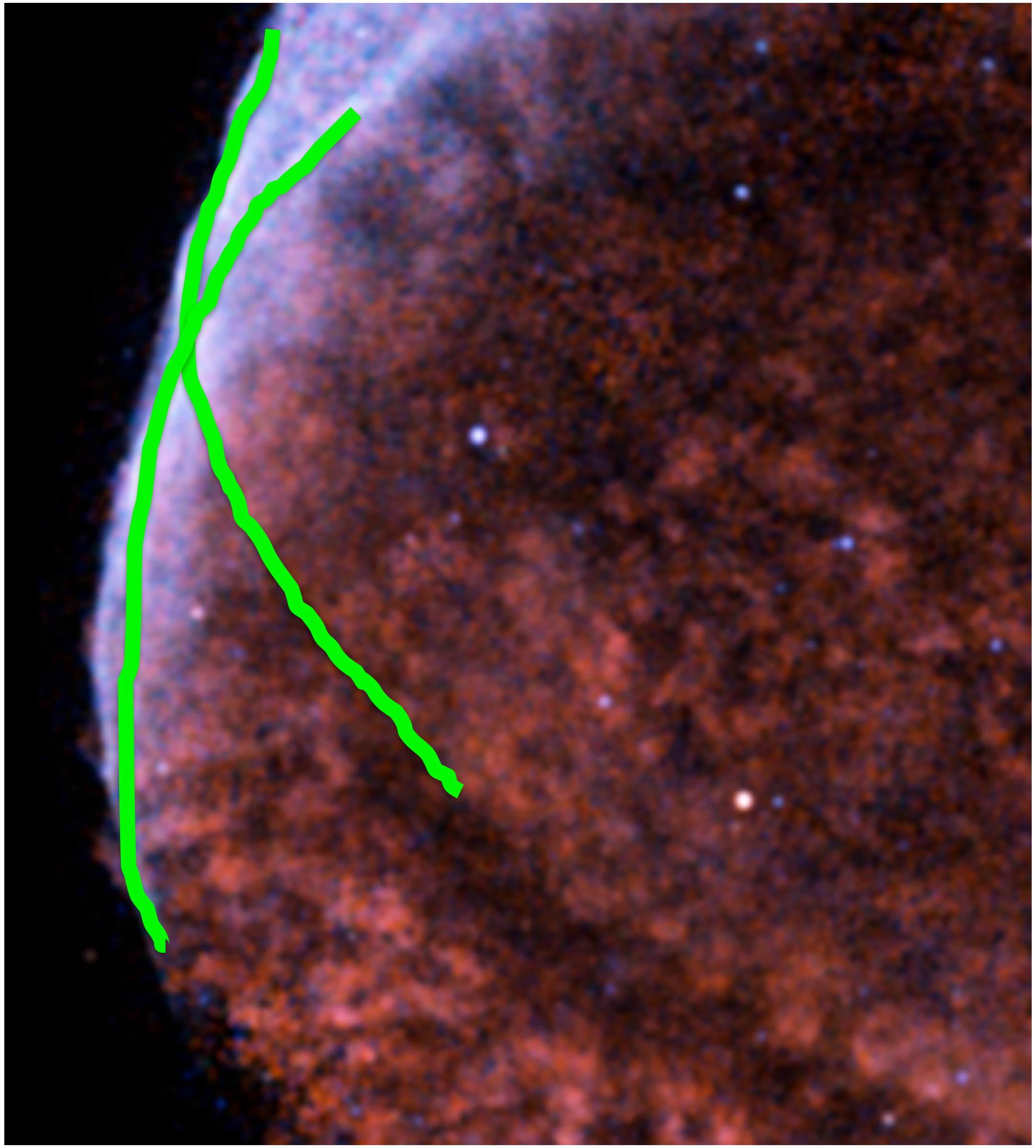
Winkler+2005



Is the ambient density of SN1006 "Uniform"?

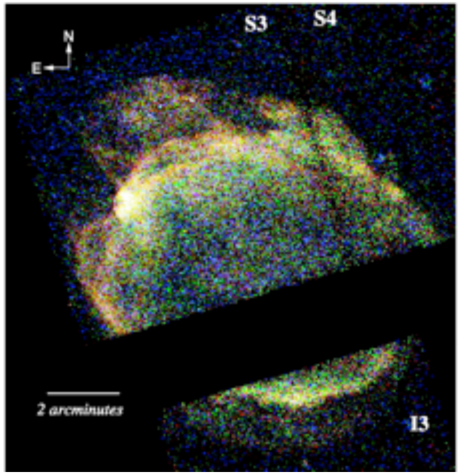


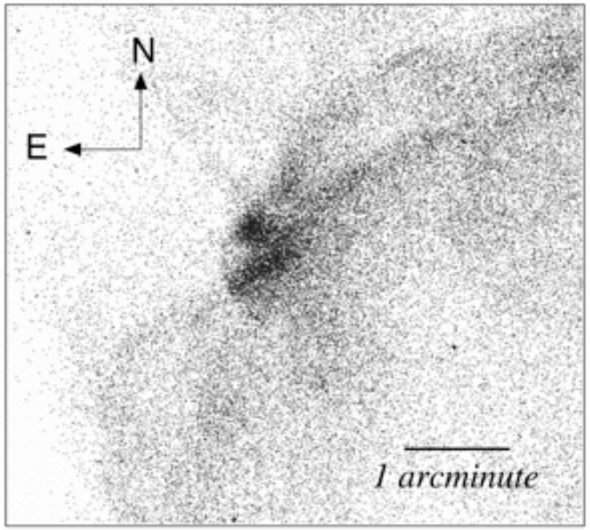
Is the ambient density of SN1006 “Uniform”?

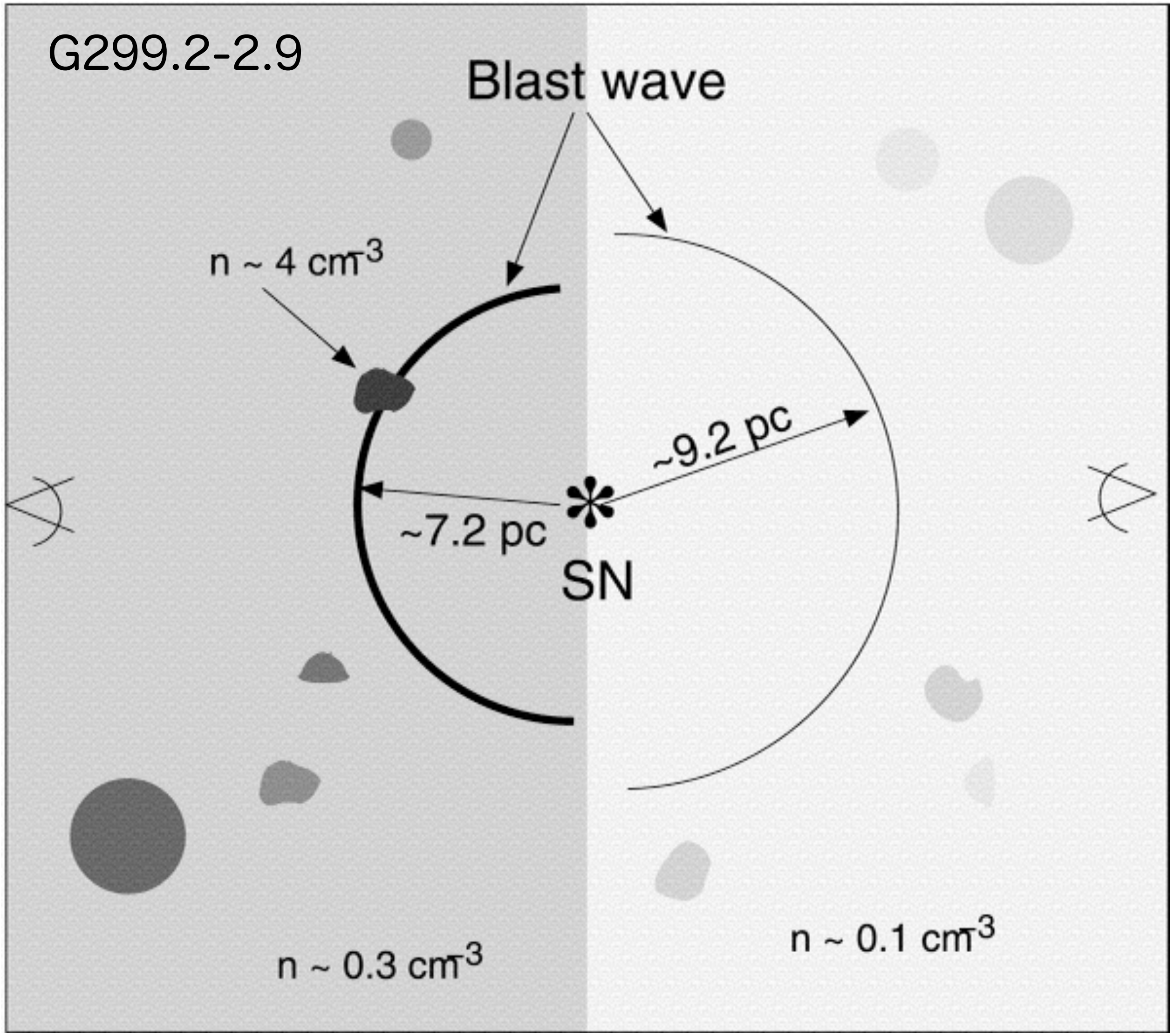


Line-of-sight Density Gradient (G299.2-2.9)

Park+2007

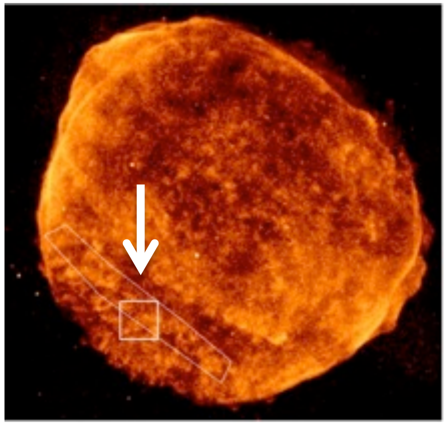


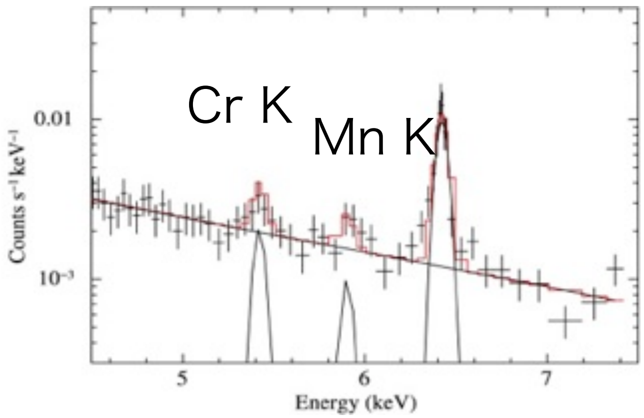


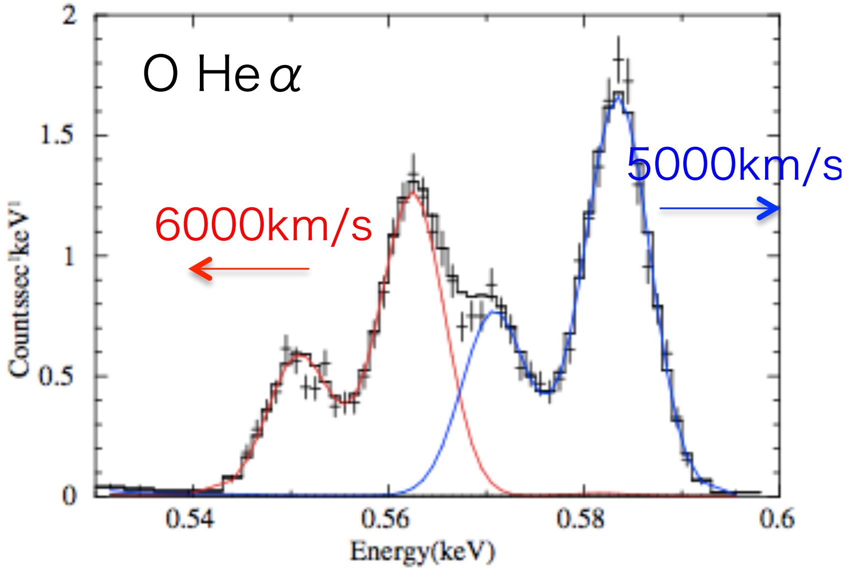


SN1006 shows similar double-shell structure, also has density gradient?

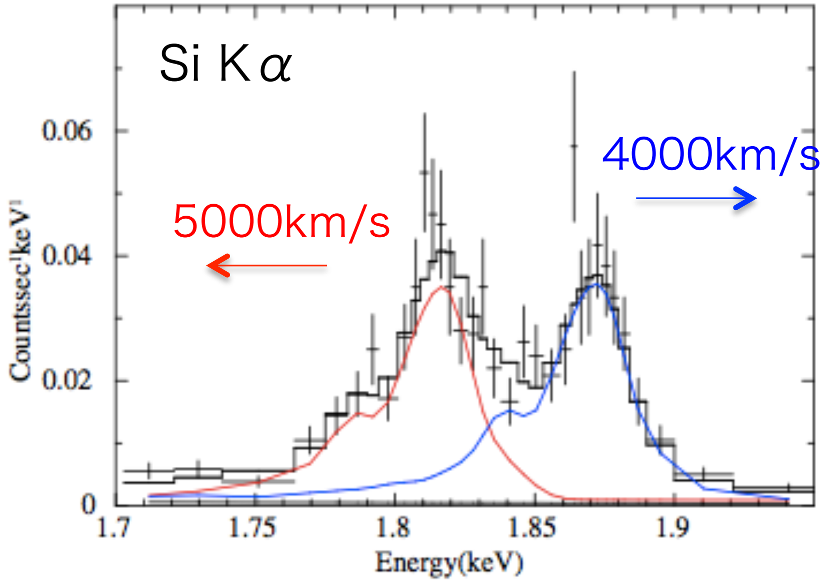
Astro-H SXS Simulations for SN1006



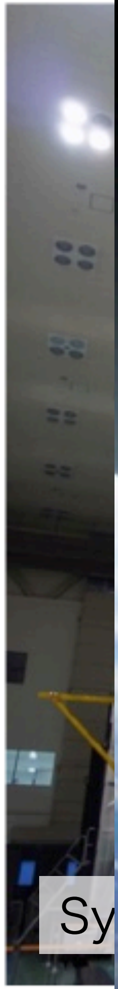


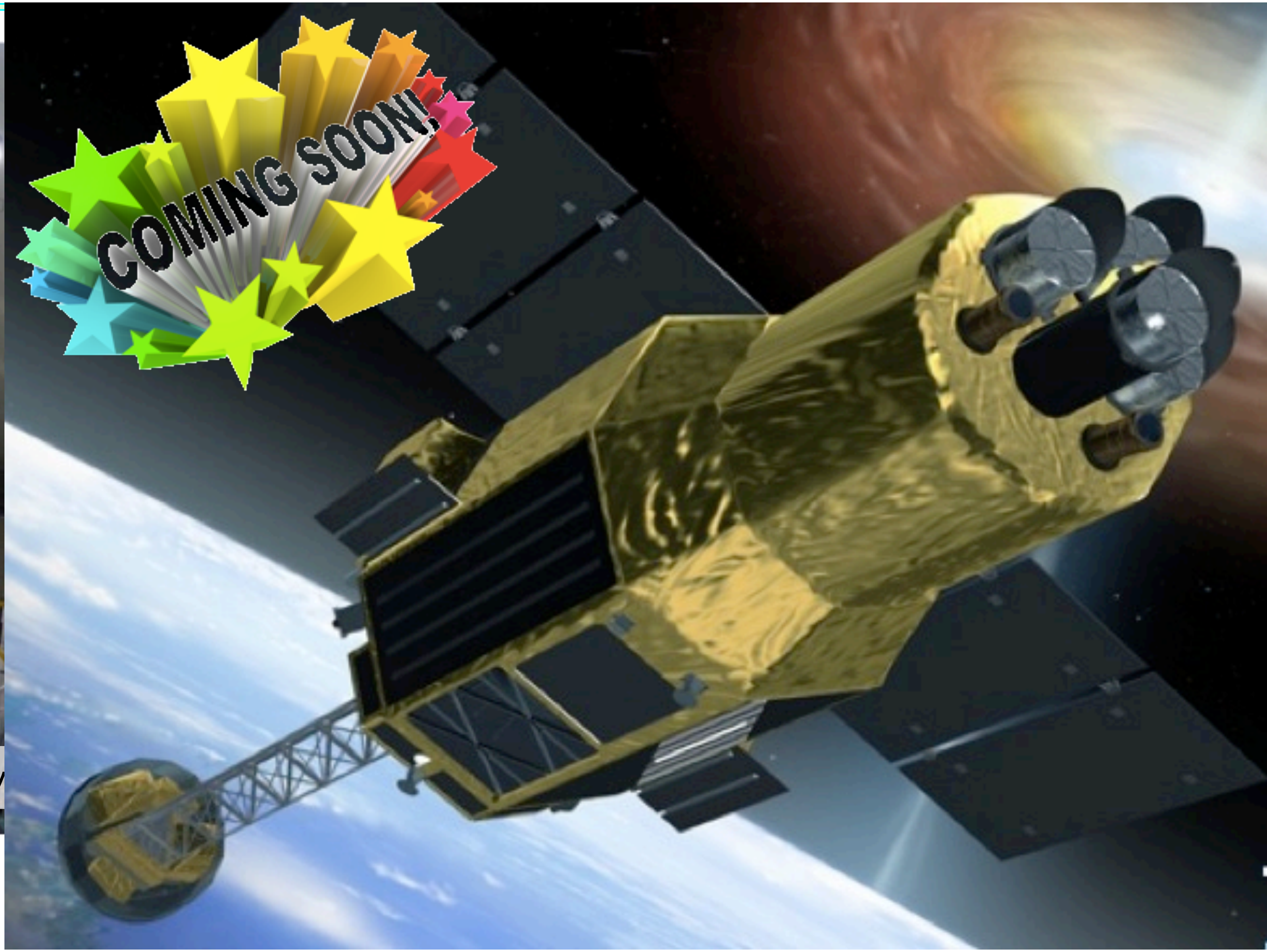


- Simulated SXS observations (200ks) of a pointing the interior of SN1006.
- First estimation of Mn/Cr.
- Measuring line-of-sight expansion velocity of some elements.
- ASTRO-H will provide new knowledge concerning structures of SNRs and SNe.



Current Status of ASTRO-H





ASTRO-H will be launched in 2015!