XMM-NEWTON 2019 SCIENCE WORKSHOP @ MADRID

Spatially Resolved Spectroscopy of the Supernova Remnant N63A in the Large Magellanic Cloud

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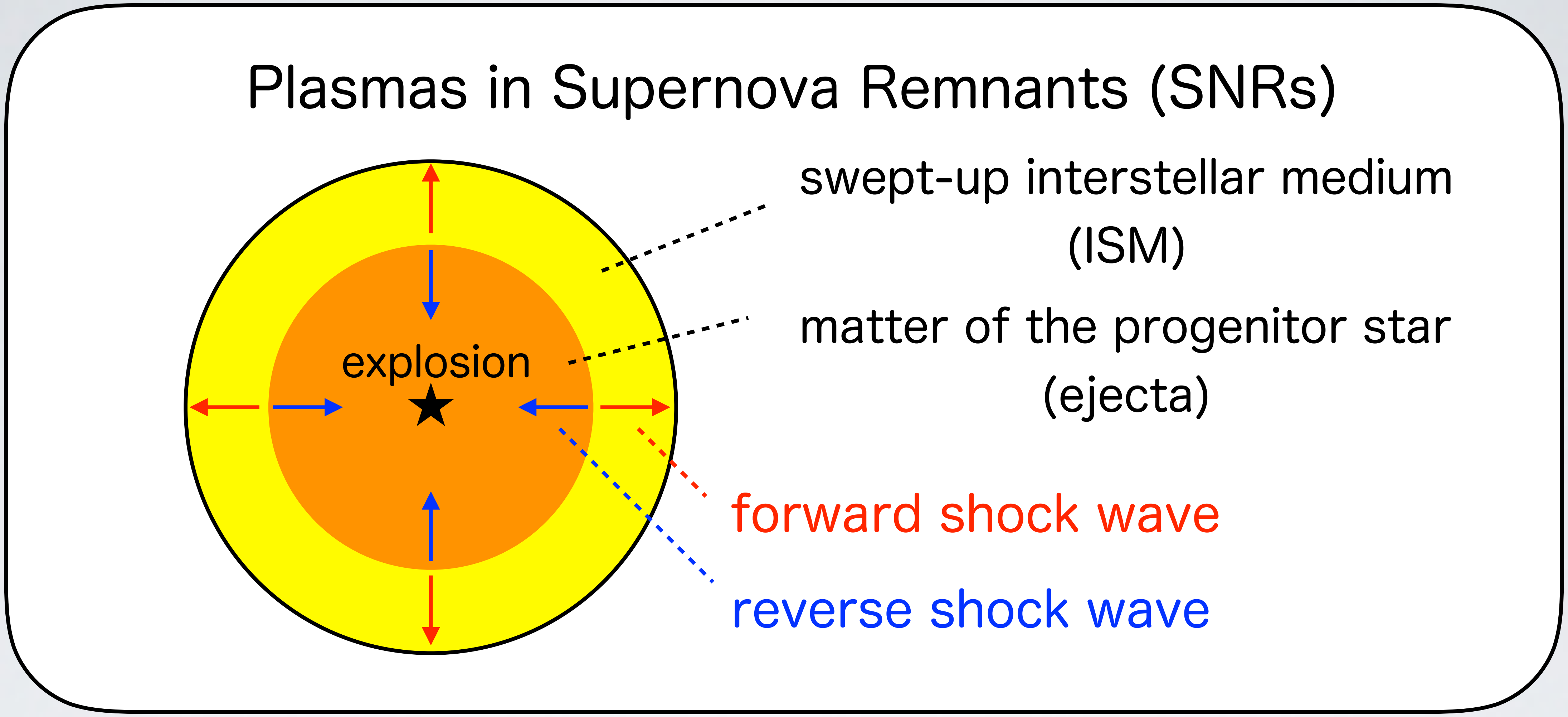
H. Sano, H. Matsumura et al. 2018, ApJ, 873

Plasma evolution in SNRs


Plasmas in Supernova Remnants (SNRs)

swept-up interstellar medium (ISM)

matter of the progenitor star (ejecta)

forward shock wave

reverse shock wave

SNR plasma evolution depends heavily on surrounding ISM.

In many SNRs, surrounding ISM is not uniform.

→ Spatially resolved spectroscopy of plasmas
High-resolved ISM morphology

SNRs in the Large Magellanic Cloud

In Galactic SNRs, previous X-ray studies revealed
unique ionization state of plasmas interacting with dense ISM.

e.g.,
- reverse shock decelerated (RCW 86; Yamaguchi+ 06)
- recombining plasma (G166.0+4.3, IC 443; Matsumura+17ab)

Gaseous environment is different for each SNR.

→ We need to have a large sample

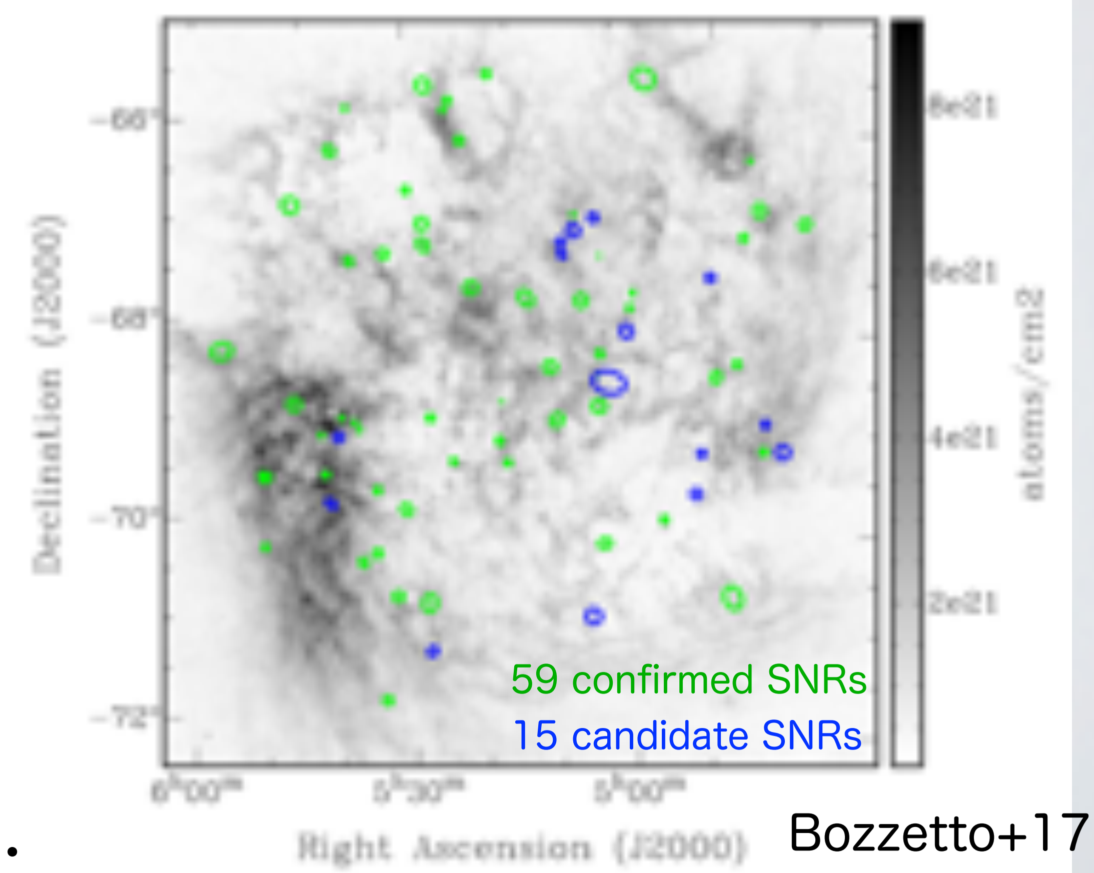
→ We focus on extragalactic SNRs

SNRs in the Large Magellanic Cloud (LMC)

74 SNRs (Bozzetto+ 17)
Distance ~ 50 kpc
Angular Size $\lesssim$ a few 10''

We used Chandra (~0.5'') and ALMA (~1'')
for X-ray and CO observations.

HI peak temp. map in the LMC



Bozzetto+17

X-ray and CO emissions of LMC SNRs

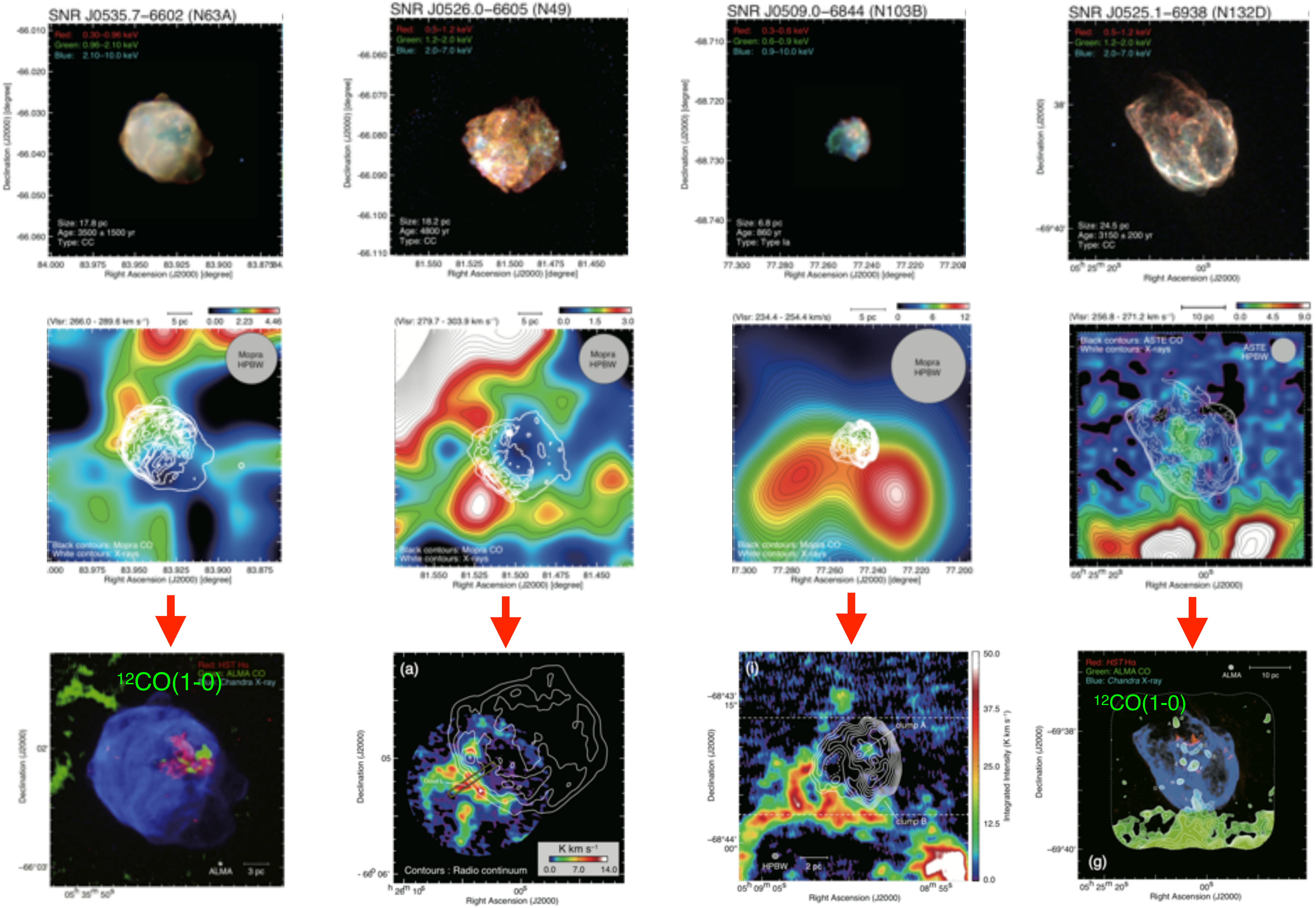
Sano+17ab,18,19, Yamane+18

N63A | N49 | N103B | N132D

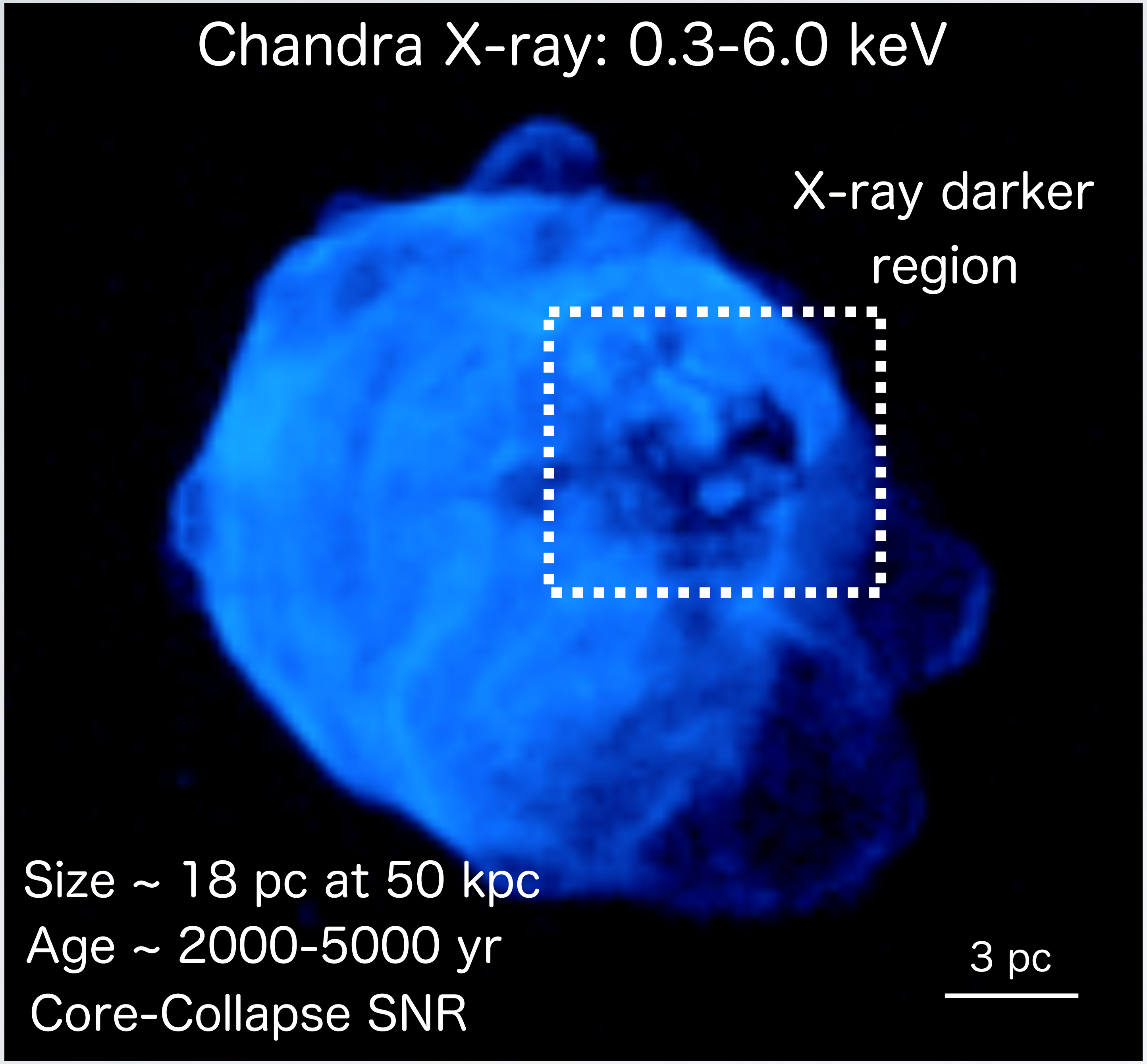
X-ray (Chandra)

CO (Mopra/ASTE)

CO (ALMA)

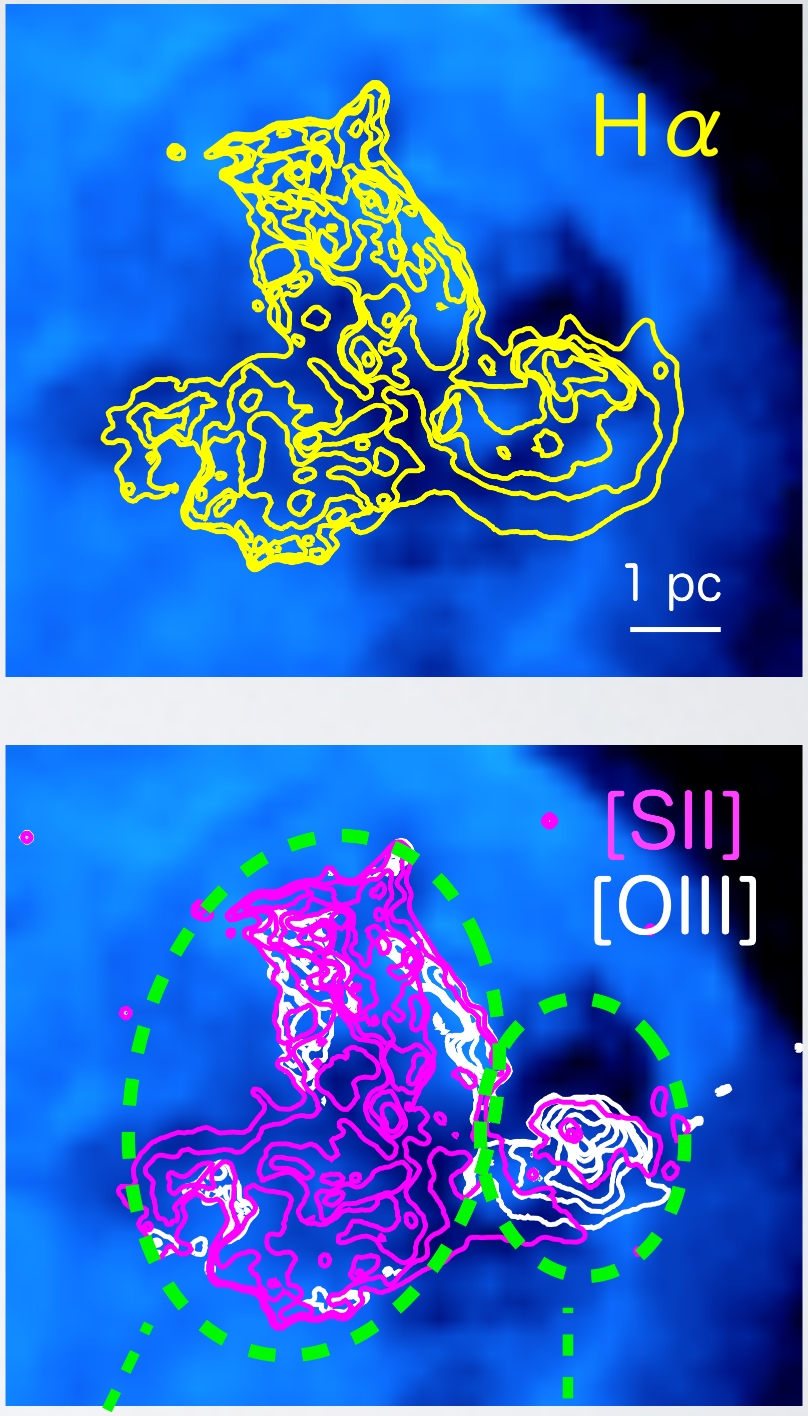


Supernova Remnant N63A


Chandra X-ray: 0.3-6.0 keV

X-ray darker region

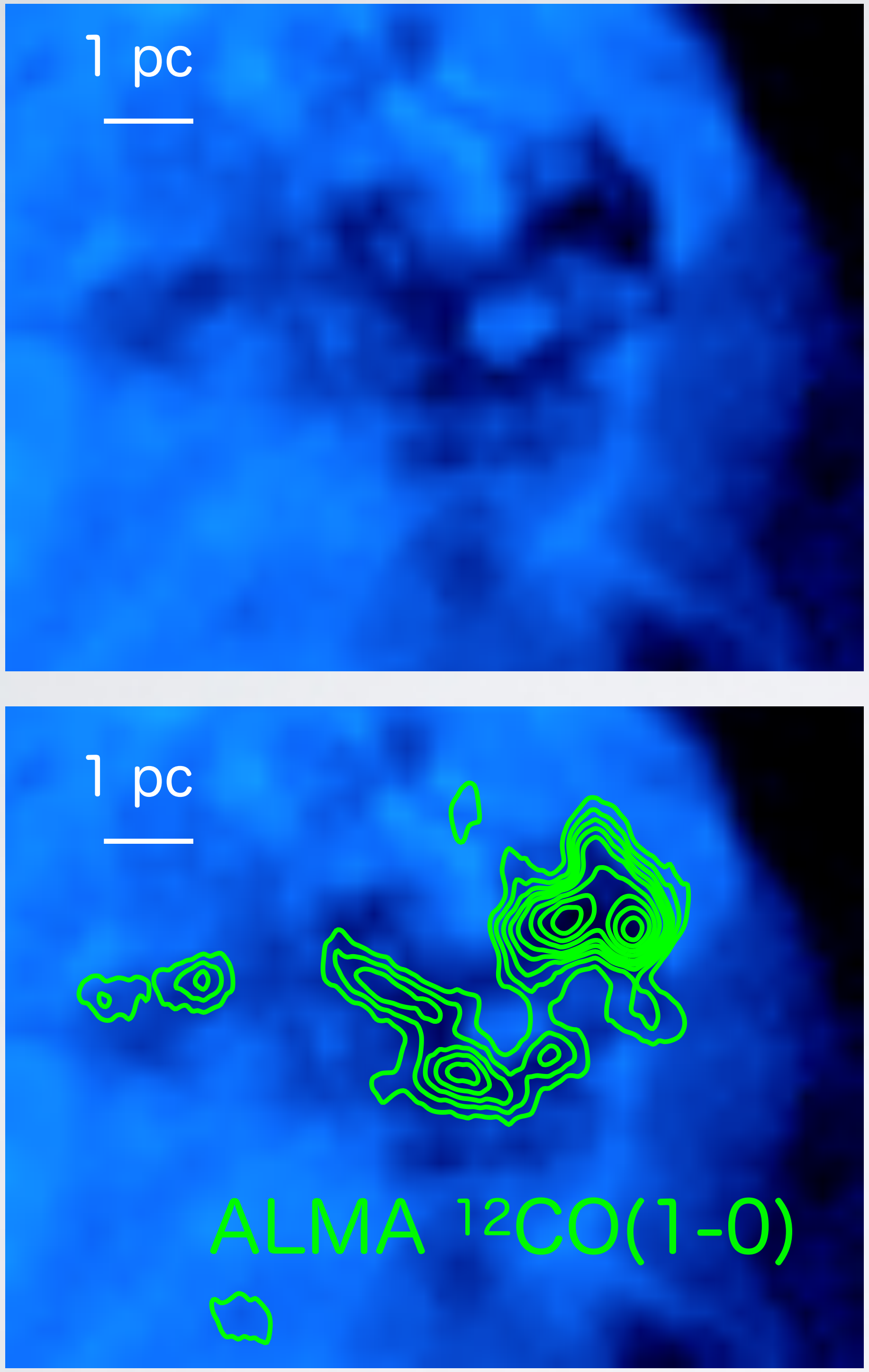
Size ~ 18 pc at 50 kpc
Age ~ 2000-5000 yr
Core-Collapse SNR



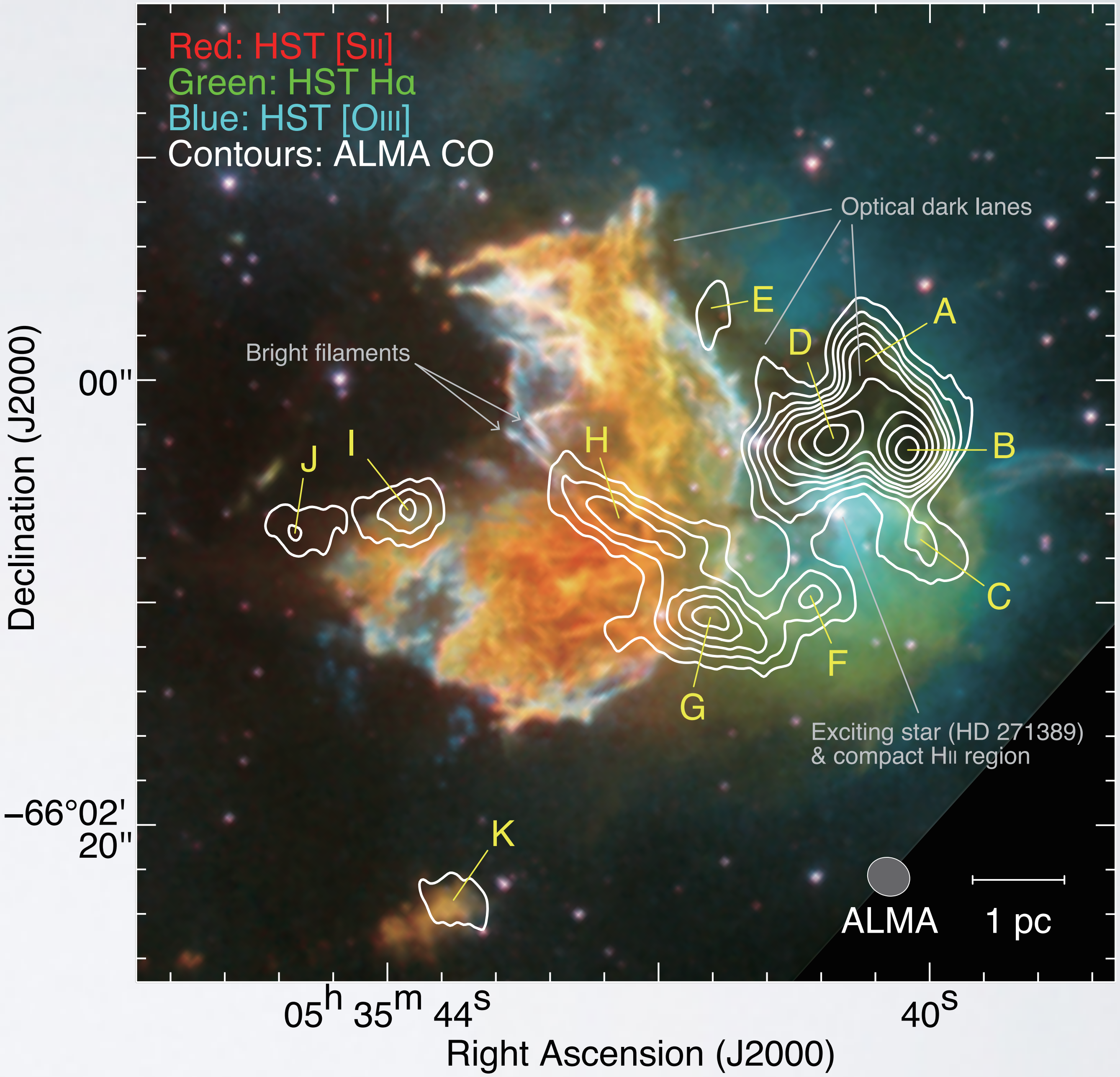
shock-ionized lobe

photoionized lobe

Molecular Clouds in N63A

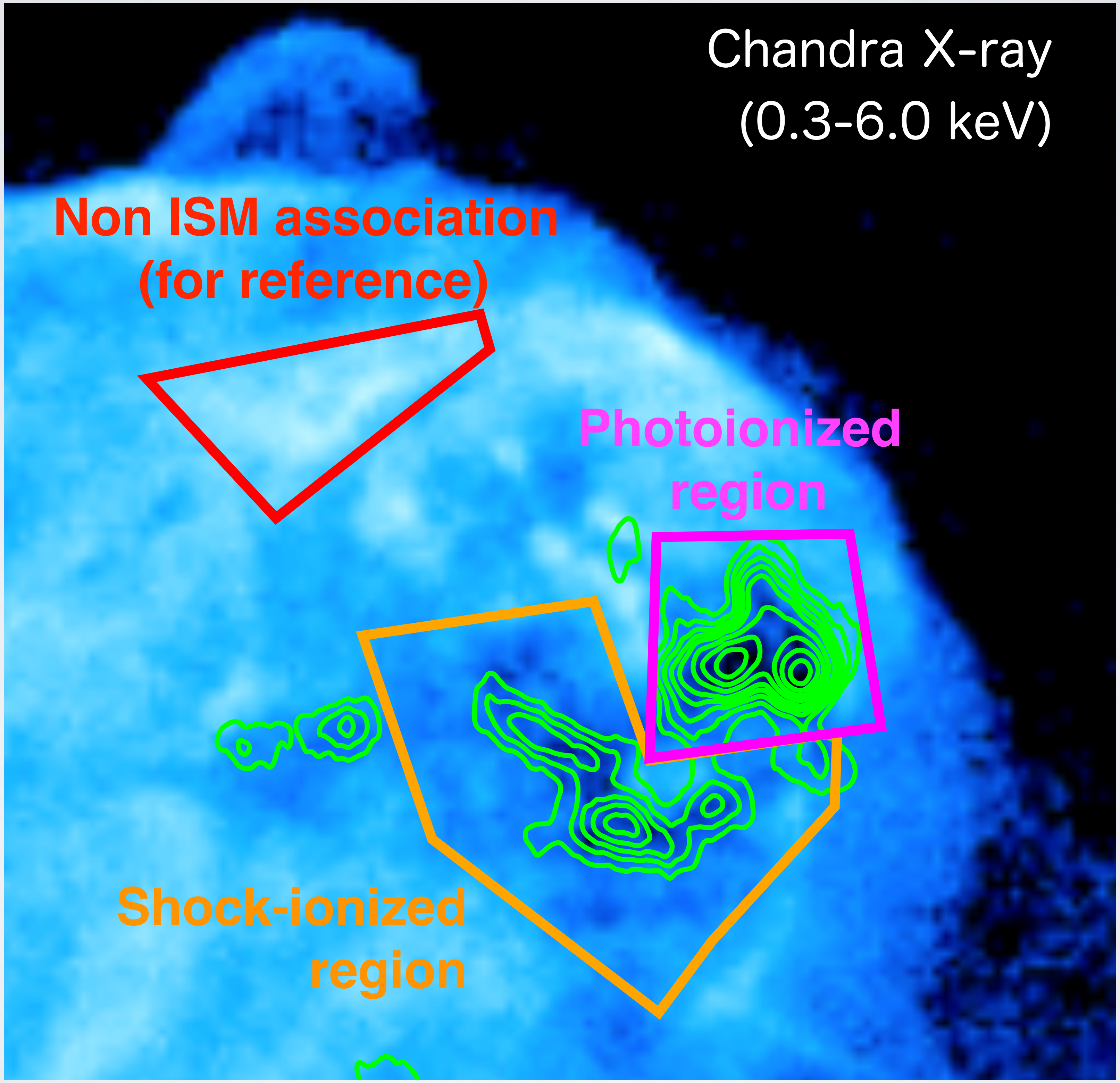


perfect matching
CO emissions



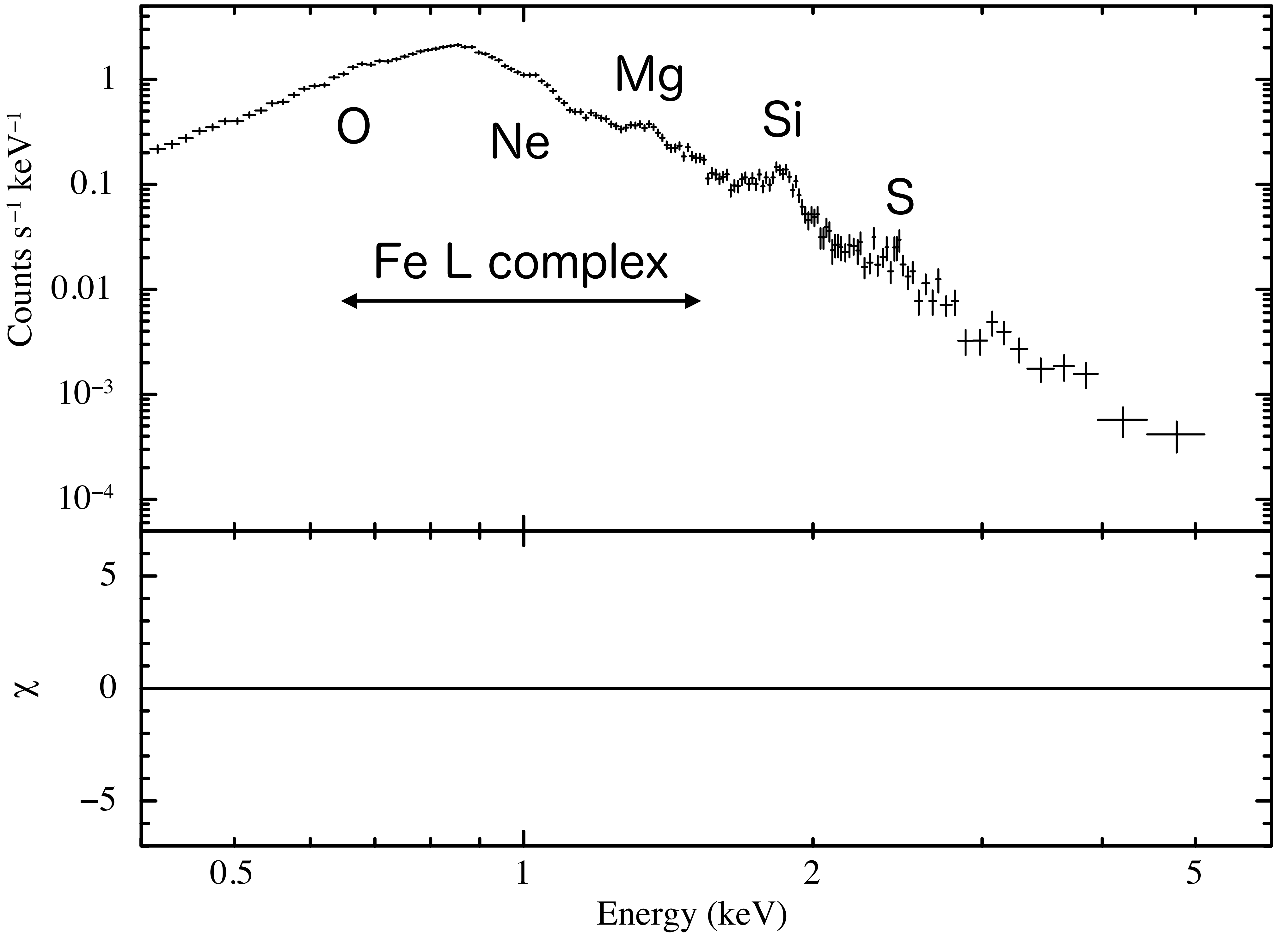
Clouds A, B, & D: in front of the optical nebula
Clouds F, G, & H: embedded within the lobes

Region Selection for X-ray Analysis



X-ray Spectral Analysis with Chandra

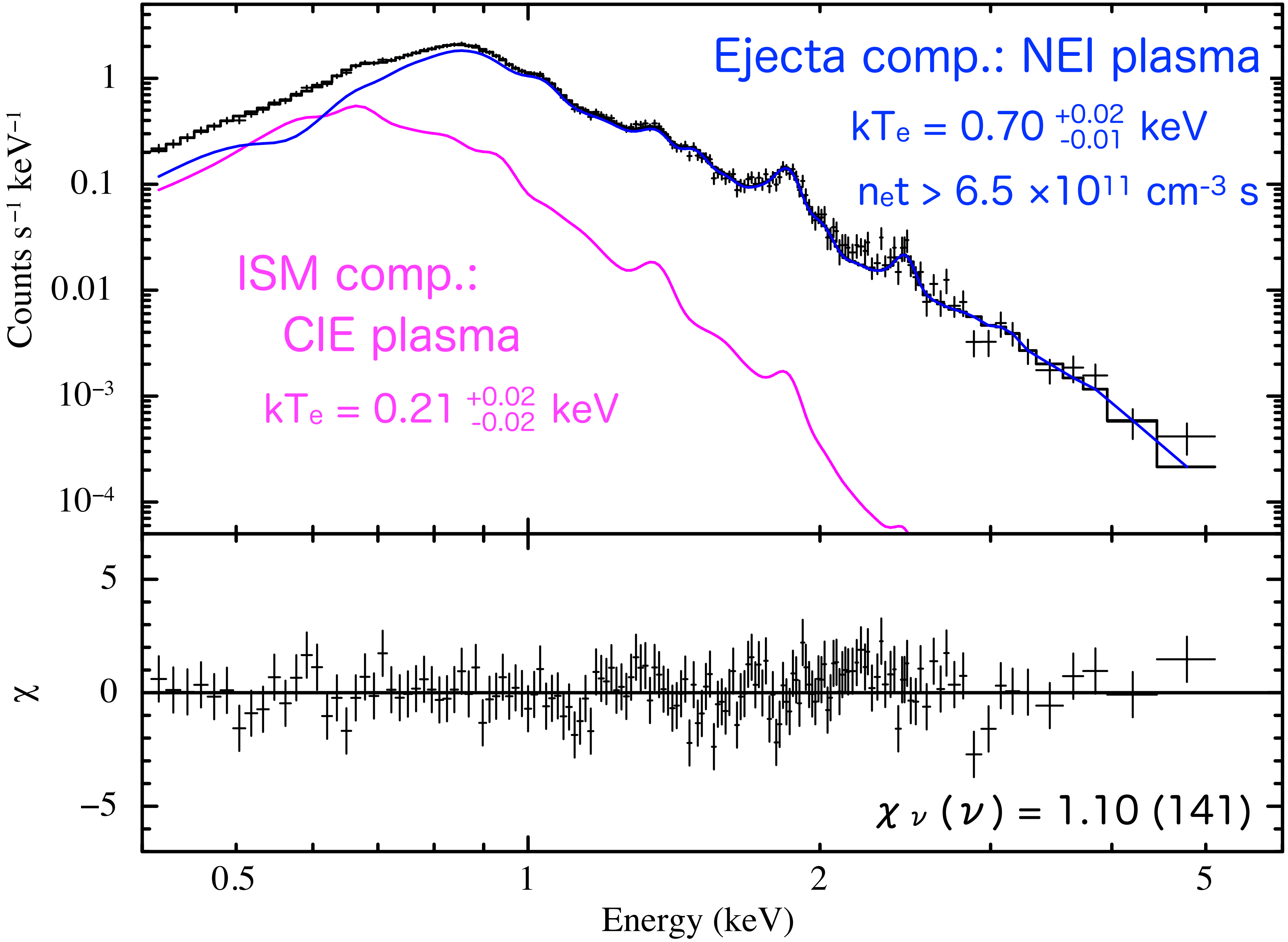
Non ISM association region



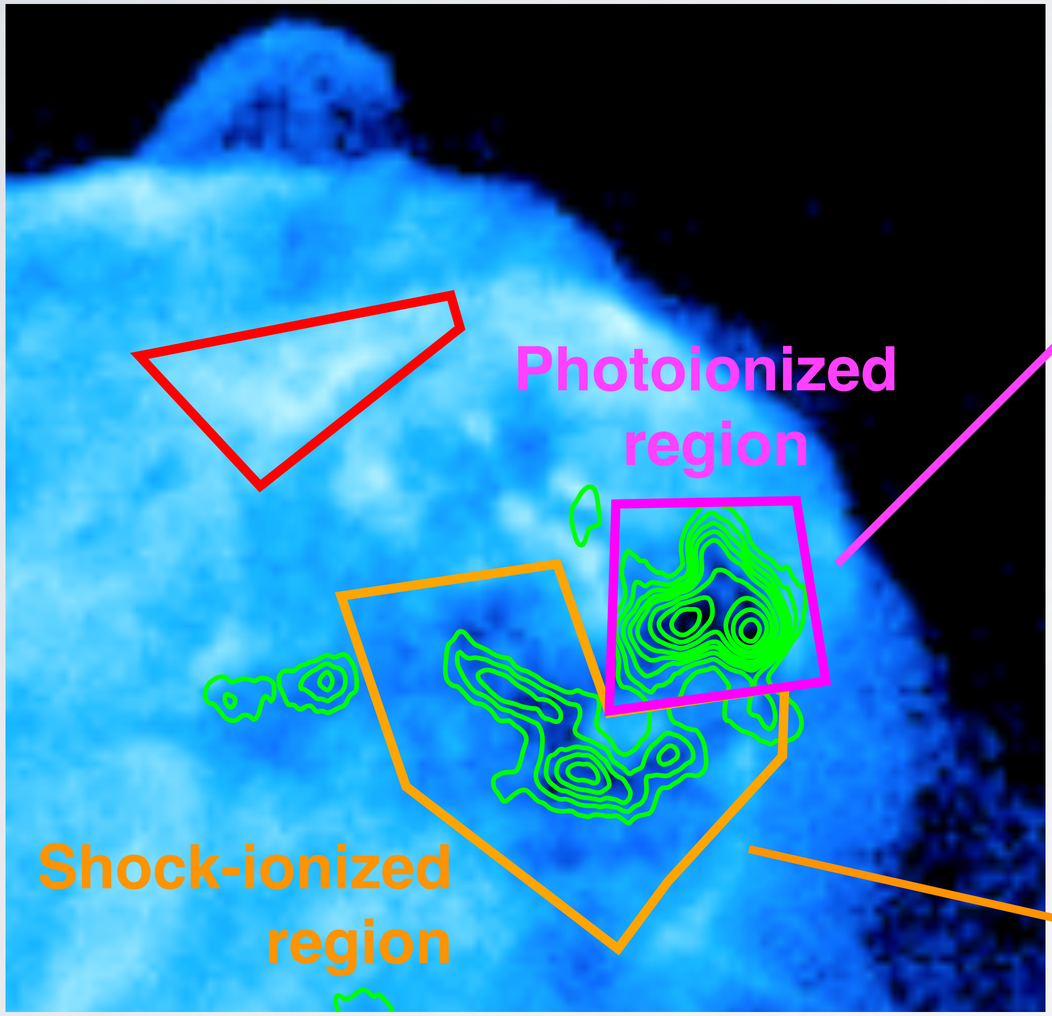
X-ray Spectral Analysis with Chandra

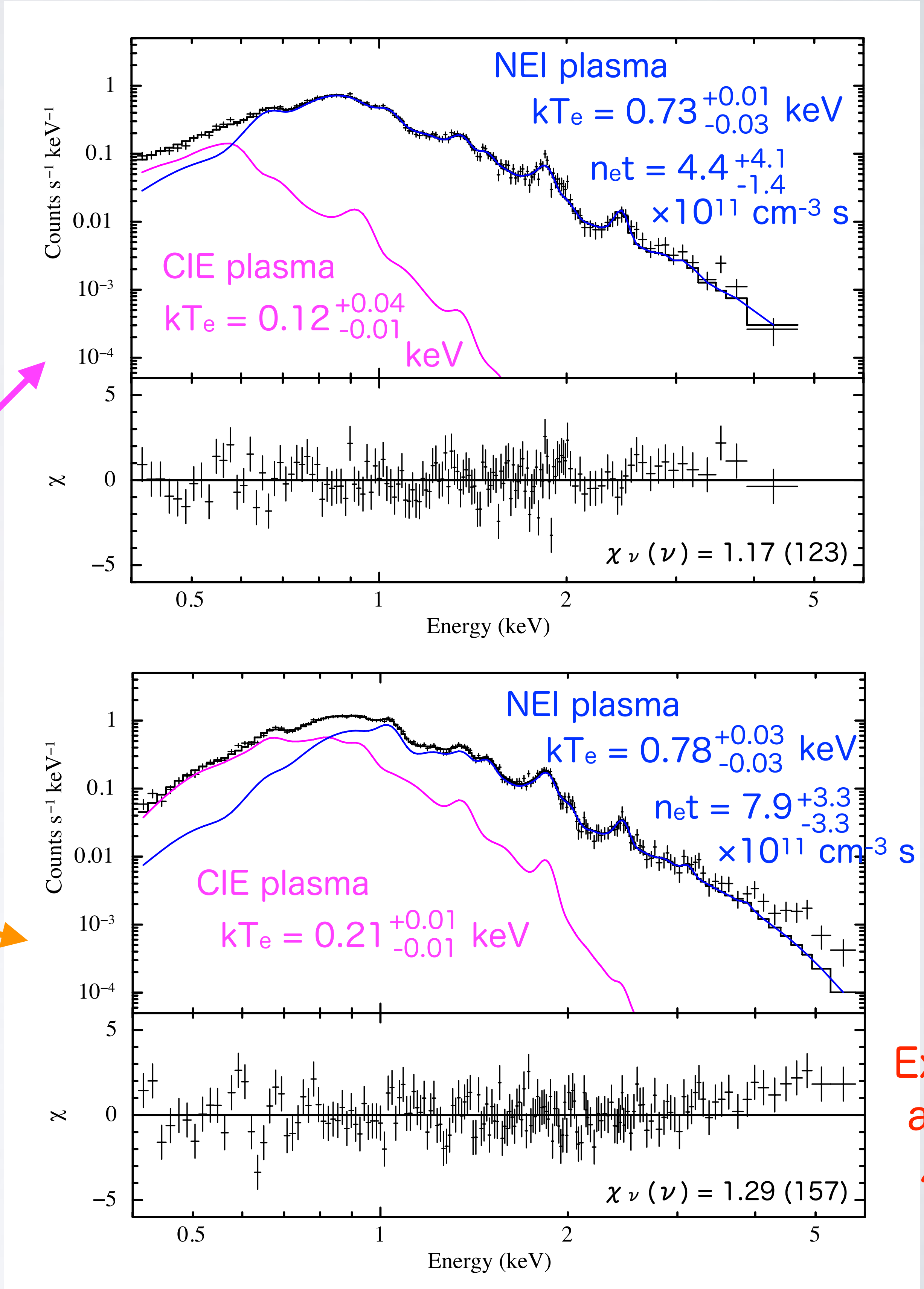
Non ISM association region

CIE: collisional ionization equilibrium
NEI: non-equilibrium ionization



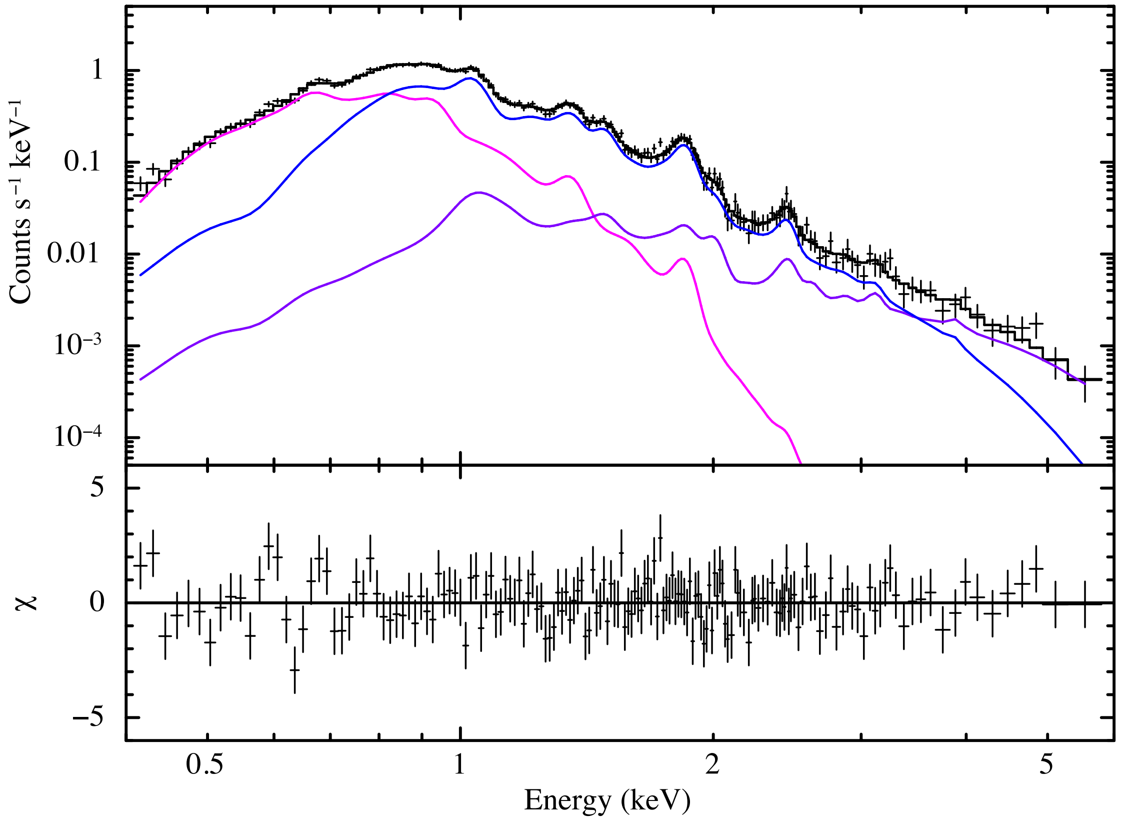
X-ray Spectral Analysis with Chandra





Excess
above
4 keV

Hard Excess in the Shock-ionized Region



(Model 1) $\chi_\nu(\nu)$ = 1.04 (154)

Hard comp.: NEI plasma

$kT_e > 1.80$ keV,

$n_e t = 1.0^{+1.4}_{-0.6} \times 10^{11}$ cm^{-3} s

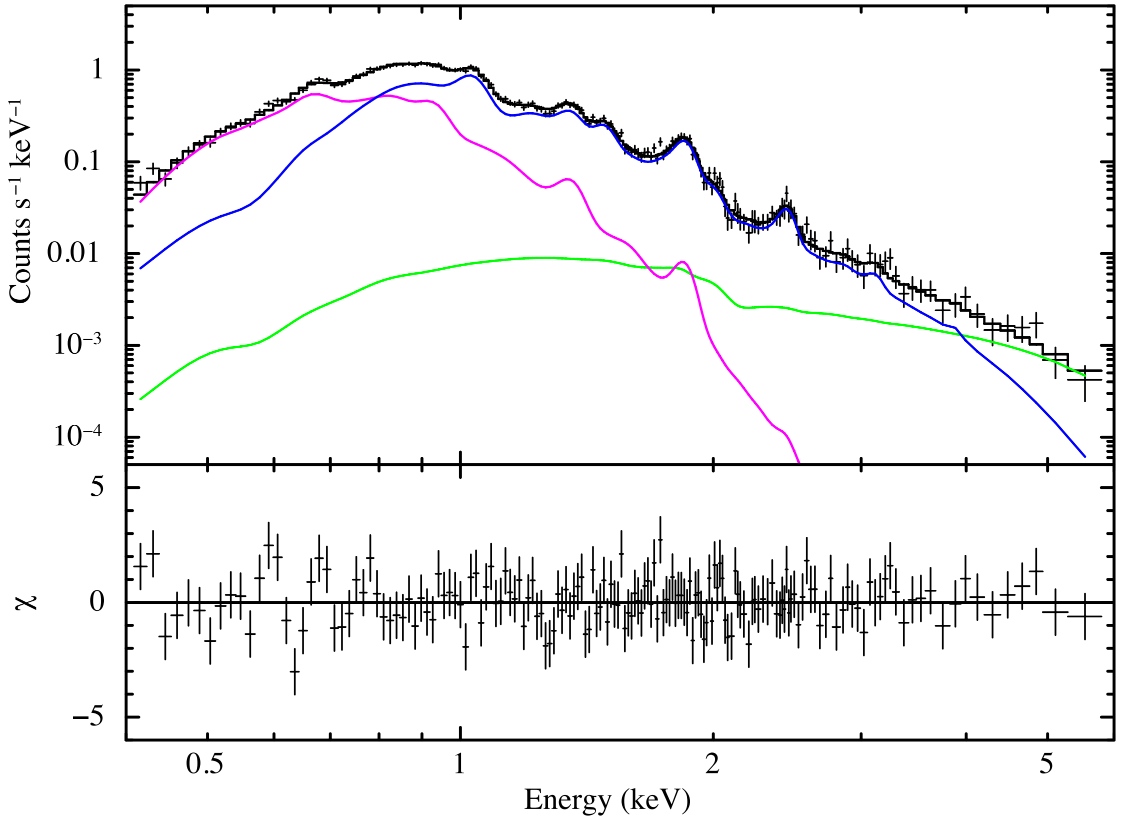
Ejecta comp.: NEI plasma

$kT_e = 0.70 \pm 0.04$ keV

$n_e t > 6.1 \times 10^{11}$ cm^{-3} s

ISM comp.: CIE plasma

$kT_e = 0.20 \pm 0.01$ keV



(Model 2) $\chi_\nu(\nu)$ = 1.06 (156)

Hard comp.: Power Law

$\Gamma = 1.7 \pm 1.5$

$F_{1\text{-}10\mathrm{keV}} = 1.8 \times 10^{13}$ erg s^{-1} cm^{-2}

Ejecta comp.: NEI plasma

$kT_e = 0.71 \pm 0.04$ keV

$n_e t = 3.3 \pm 3.9$ cm^{-3} s

ISM comp.: CIE plasma

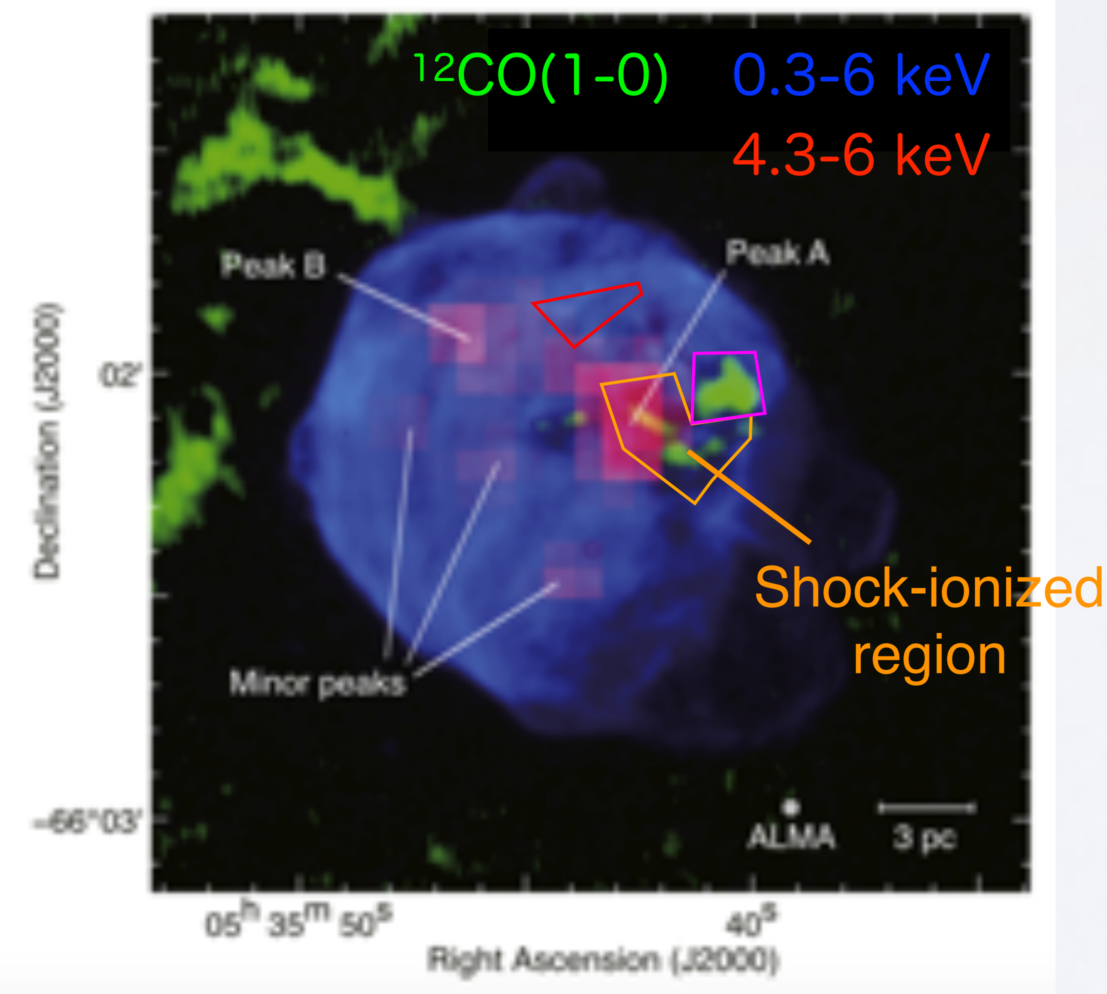
$kT_e = 0.20 \pm 0.01$ keV

Origin of the Hard Component (Case 1)

Hard comp.: NEI plasma

$kT_e > 1.80$ keV,

$n_et = 1.0^{+1.4}_{-0.6} \times 10^{11}\ \mathrm{cm^{-3}\ s}$



Our idea :

In this region, the supernova shock may strongly interact with clumpy and dense molecular clouds, developing multiple reflected shock structures to heat the gas up to high temperatures (similar simulation to RCW 86).

The elapsed time since the dense cloud was heated

$n_et \rightarrow$ t ~ 1300 yr < age = 2000-5000 yr

The plasma likely has been heated recently

The spatial extent of the hard-X-rays is very similar to that of the shock-ionized optical lobe, indicating that the hard X-rays possibly have the same origin as the shock-ionized optical lobe.

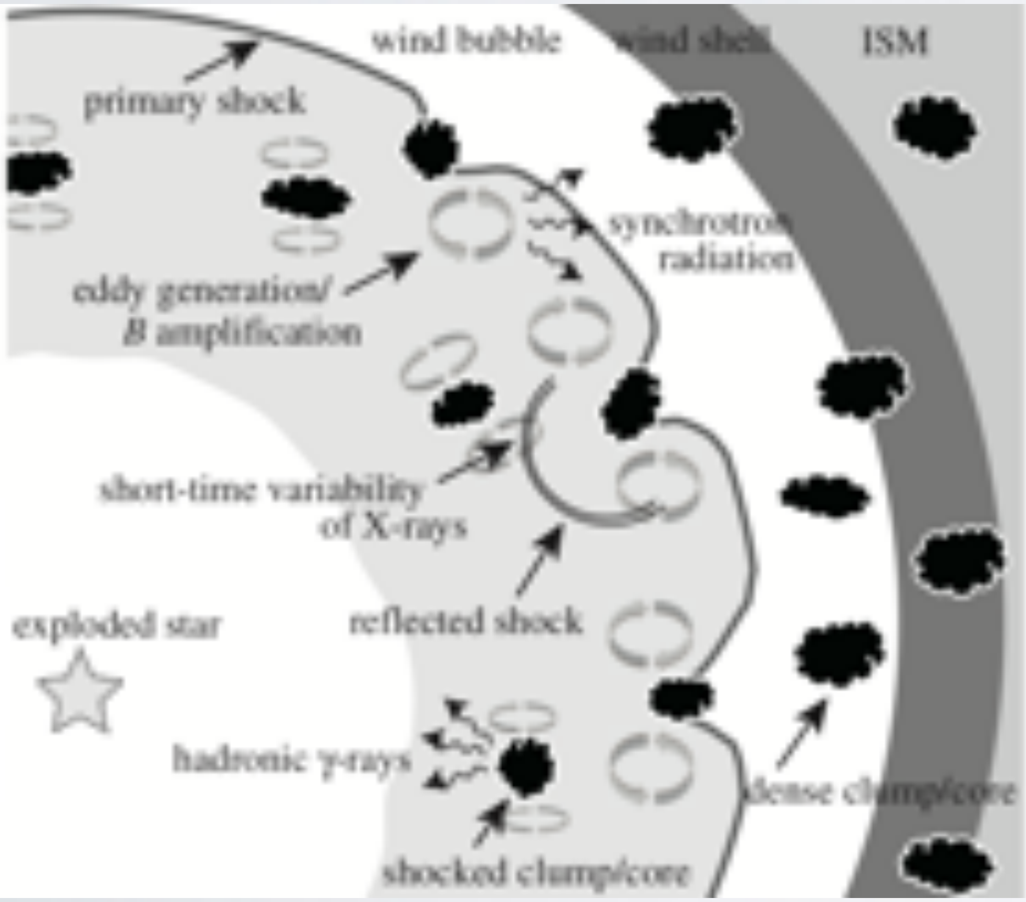
Origin of the Hard Component (Case 2)

Hard comp.: Power Law

$\Gamma = 1.7 \pm 1.5$

$F_{1\text{-}10\mathrm{keV}} = 1.8 \times 10^{13}\ \mathrm{erg\ s^{-1}\ cm^{-2}}$

MHD simulation (Inoue+12)



Our idea;

Owing to interactions between the shock and inhomogeneous gas distribution (dense gas clump ~10^{3} cm^{-3} in low-density environment ~10^{-2} cm^{-3}), the magnetic field strength is significantly enhanced up to ~1 mG via the strong turbulent motion around the dense gas clumps. Then, we observe bright synchrotron X-rays around the molecular clouds.
(similar simulation to RX J1713.7–3946)

Both the cases;

- multiple reflected shock (case1)
- magnetic filed amplification (case2)

are caused by the shock-cloud interaction.

Spacial resolved analysis is useful to understand the interaction of SNRs and local ISM.

Summary

- We start project of ALMA observations for LMC SNRs to understand the shock-cloud interaction. High-resolved spectroscopy with Chandra can be revealed ionizing states of plasmas where the interaction occurs.
- In the shock-ionized region of N63A, we found hard X-ray excess above 4 keV which was reproduced by the high-temperature NEI plasma or power-low models.
- To explain the hard X-rays, we propose two hypotheses; multiple reflected shock and magnetic filed amplification. Both the cases are caused by the SNR-cloud interaction.