XMM-Newton Workshop 2016: The Next Decade
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NANTEN
Submillimeter Observatory

Detailed studies of shock-cloud interaction toward the young supernova remnants

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■ Young SNRs are though to be primary accelerators of Galactic CRs

- □ Fast shock speed ~3,000–10,000 km s^{-1} (e.g., Uchiyama+07; Winkler+14)
- □ Bright in TeV gamma-rays and synchrotron X-rays (e.g., Aharonian+07)
- □ Age- or escape-limited phase (e.g., Ohira+12)

■ Interstellar gas

- □ Molecular clouds: dense neutral gas of H_2 (2.6 mm CO)
  → density ~10^3 cm^{-3} or higher, T_k ~10–20 K
- □ Atomic clouds: diffuse neutral gas of H (21 cm HI)
  → density ~1–100 cm^{-3}, T_k ~30–100 K

Dynamical interaction between the SNR' shocks and interstellar gas plays an essential role in producing the high-energy radiation & CRs

Origin of the synchrotron X-rays

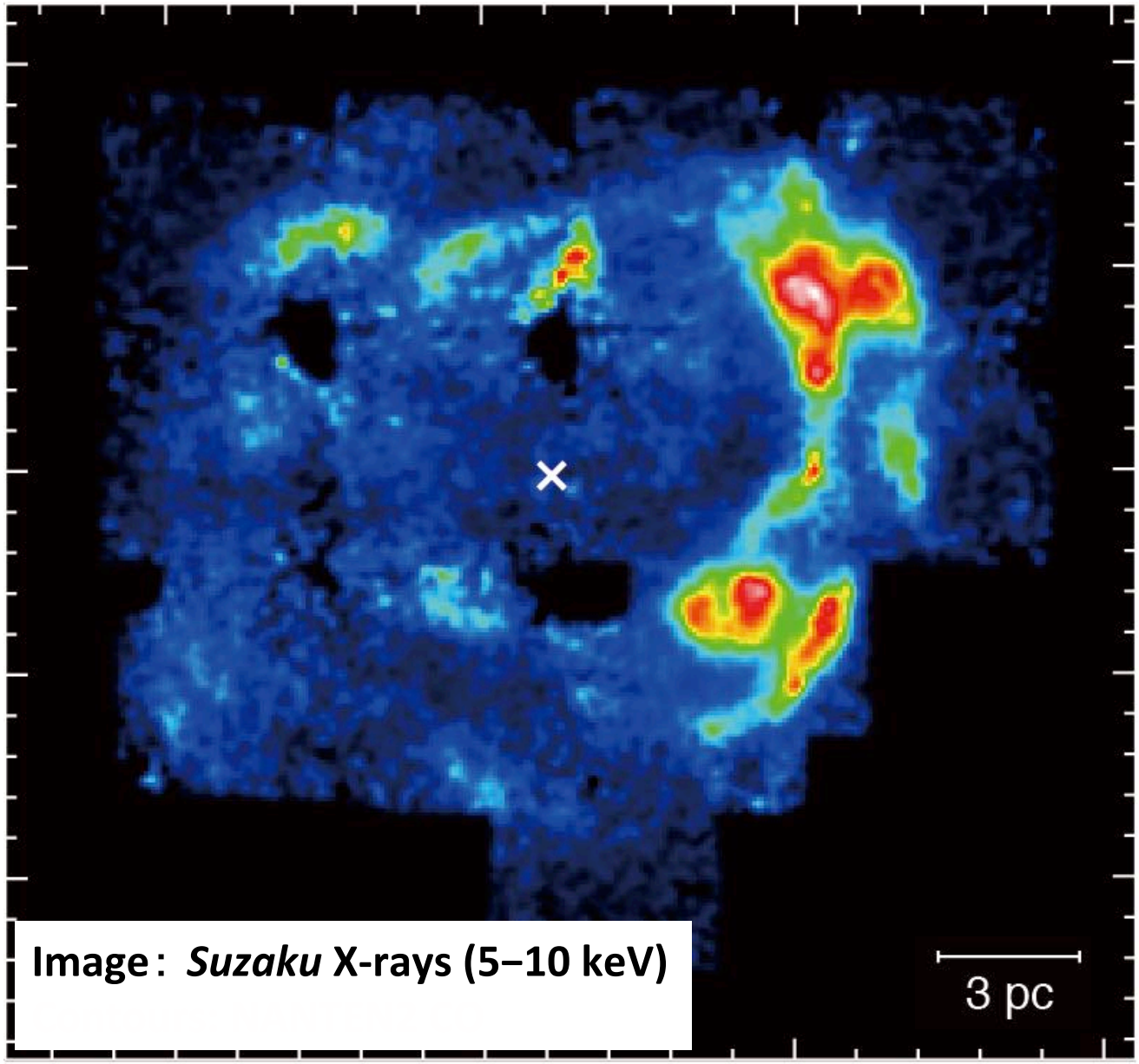


Image : *Suzaku* X-rays (5–10 keV)

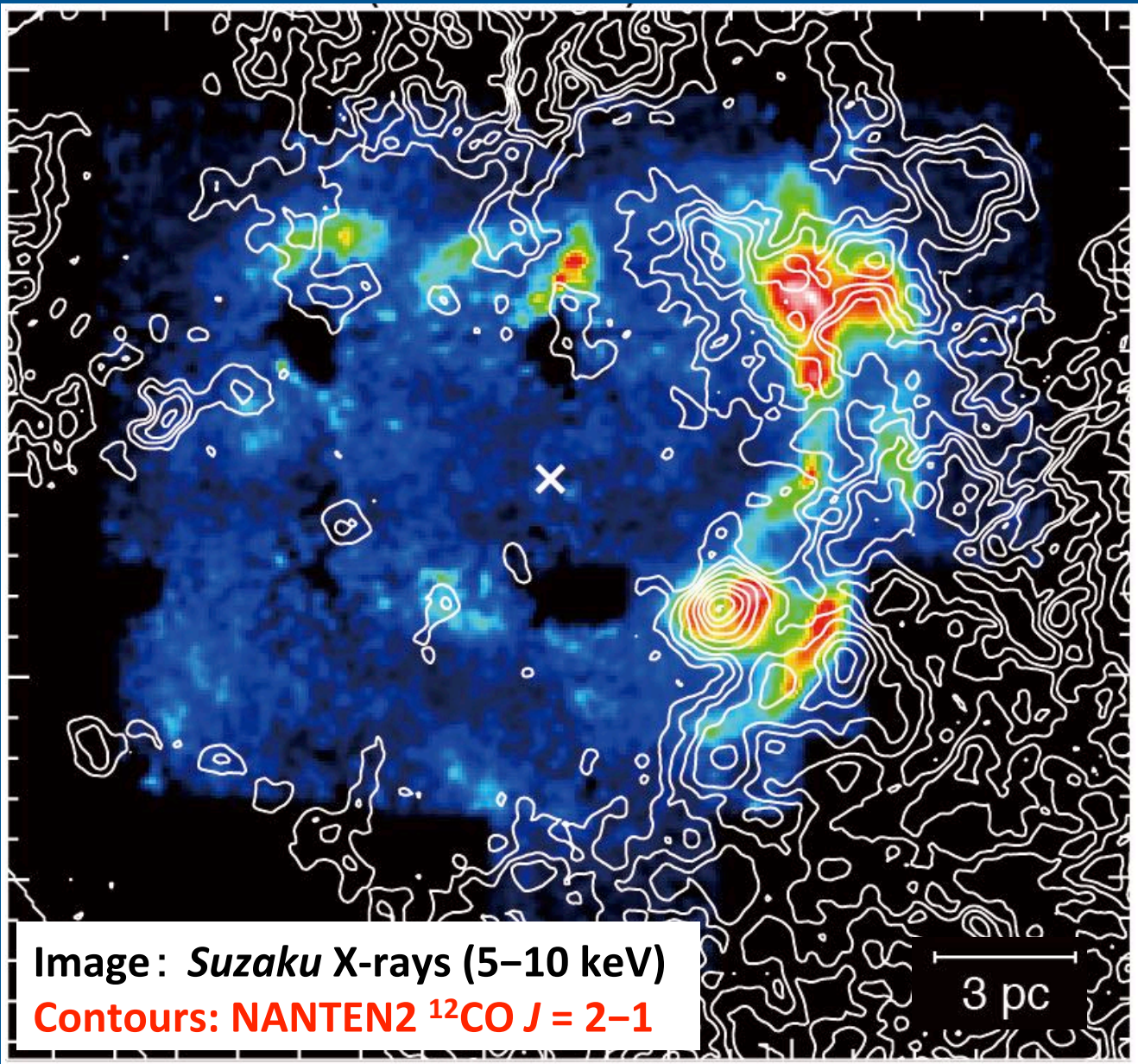
Sano+10, ApJ, 724, 59
Sano+13, ApJ, 778, 59

RX J1713.7–3946

- Age: ~1,600 yr
- Distance: ~1 kpc
- Size: ~19 pc
- Core-collapse SNR
- Bright in TeV γ- & non-thermal X-rays
- CO cavity + cold HI

- However, it is not known how the X-ray local peaks are formed?

Origin of the synchrotron X-rays



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- Synchrotron X-rays are well spatially correlated with CO in a pc scale

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Sano+10, ApJ, 724, 59
Sano+13, ApJ, 778, 59

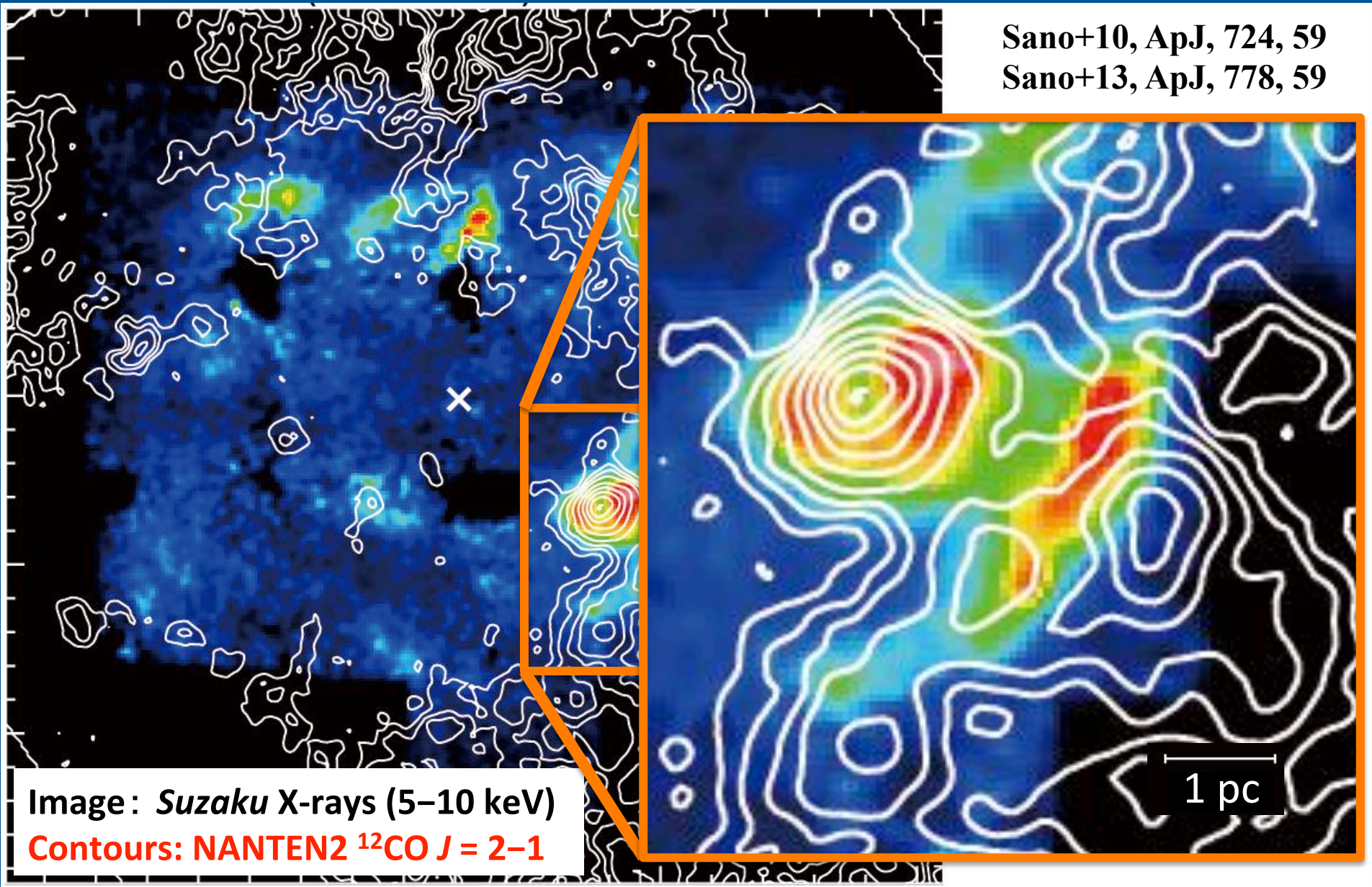

Image : *Suzaku* X-rays (5–10 keV)
Contours: NANTEN2 ^{12}CO J = 2–1

- Synchrotron X-rays are enhanced around CO clumps in a sub-pc scale

Origin of the synchrotron X-rays

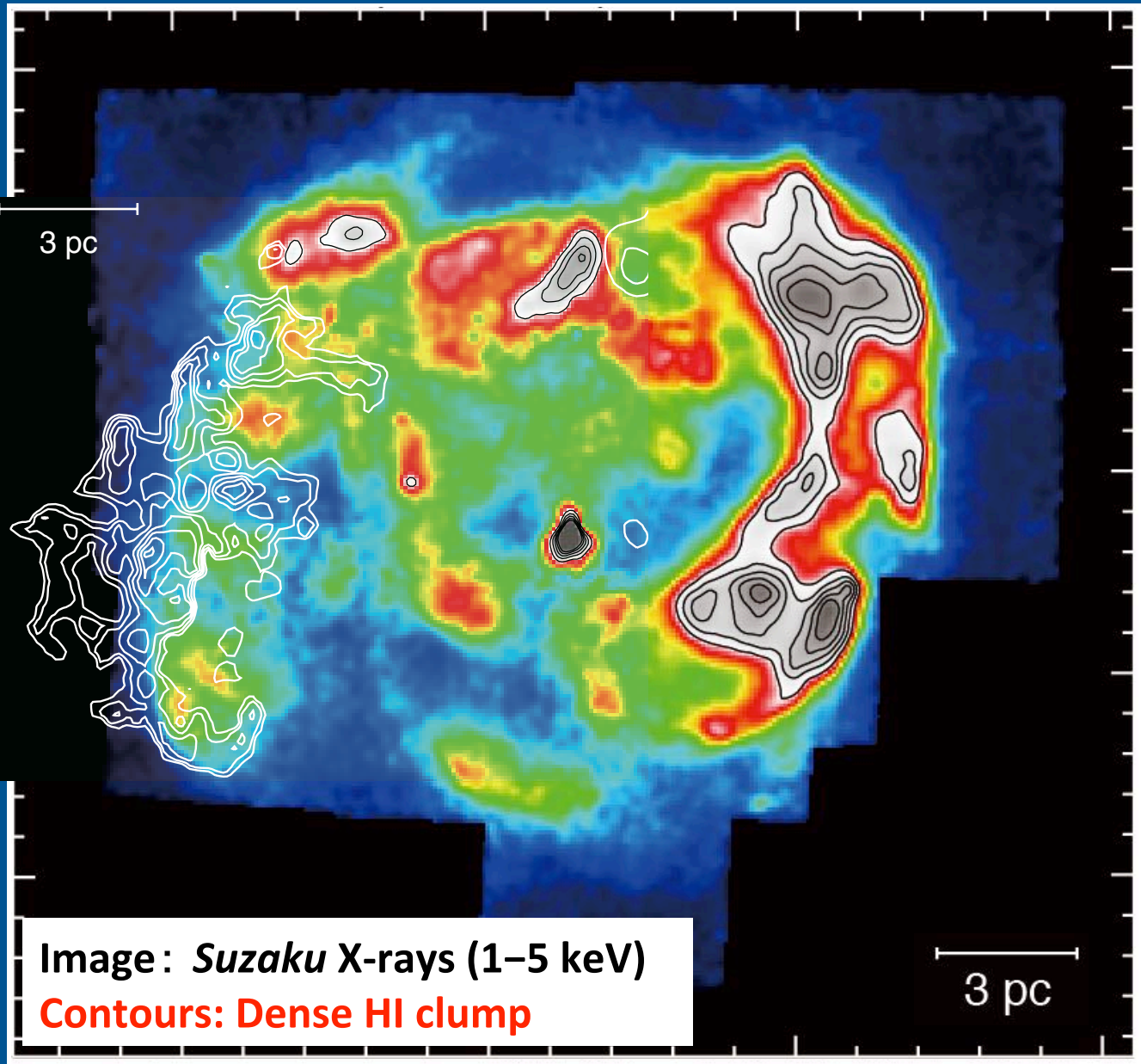

Image : *Suzaku* X-rays (1–5 keV)
Contours: Dense HI clump

Sano+10, ApJ, 724, 59
Sano+13, ApJ, 778, 59

RX J1713.7–3946

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■ Synchrotron X-rays are enhanced around the cold HI clump

Origin of the synchrotron X-rays

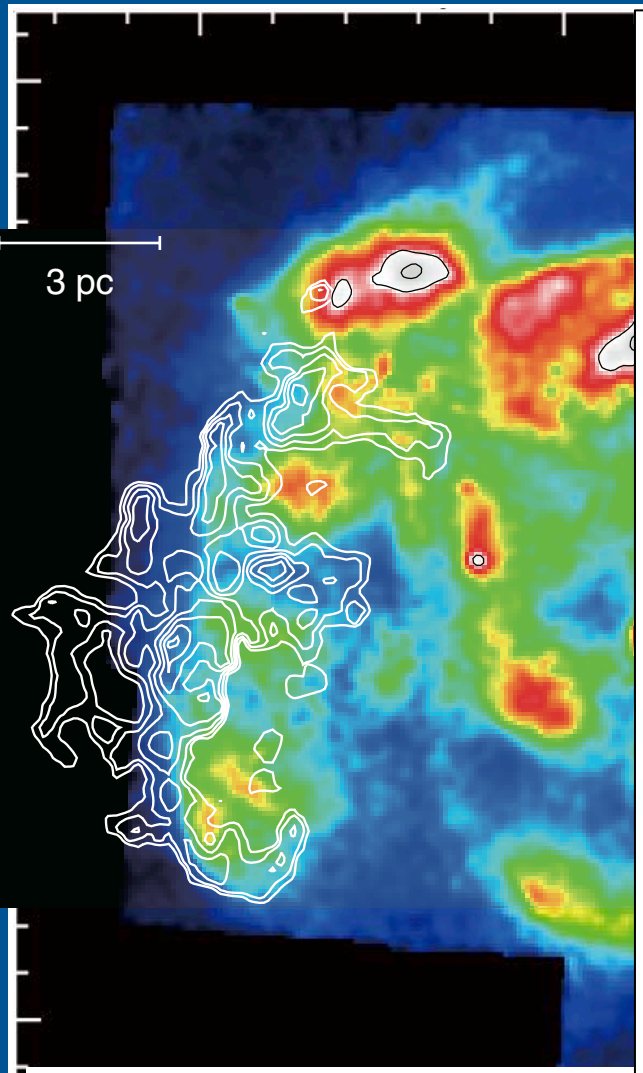
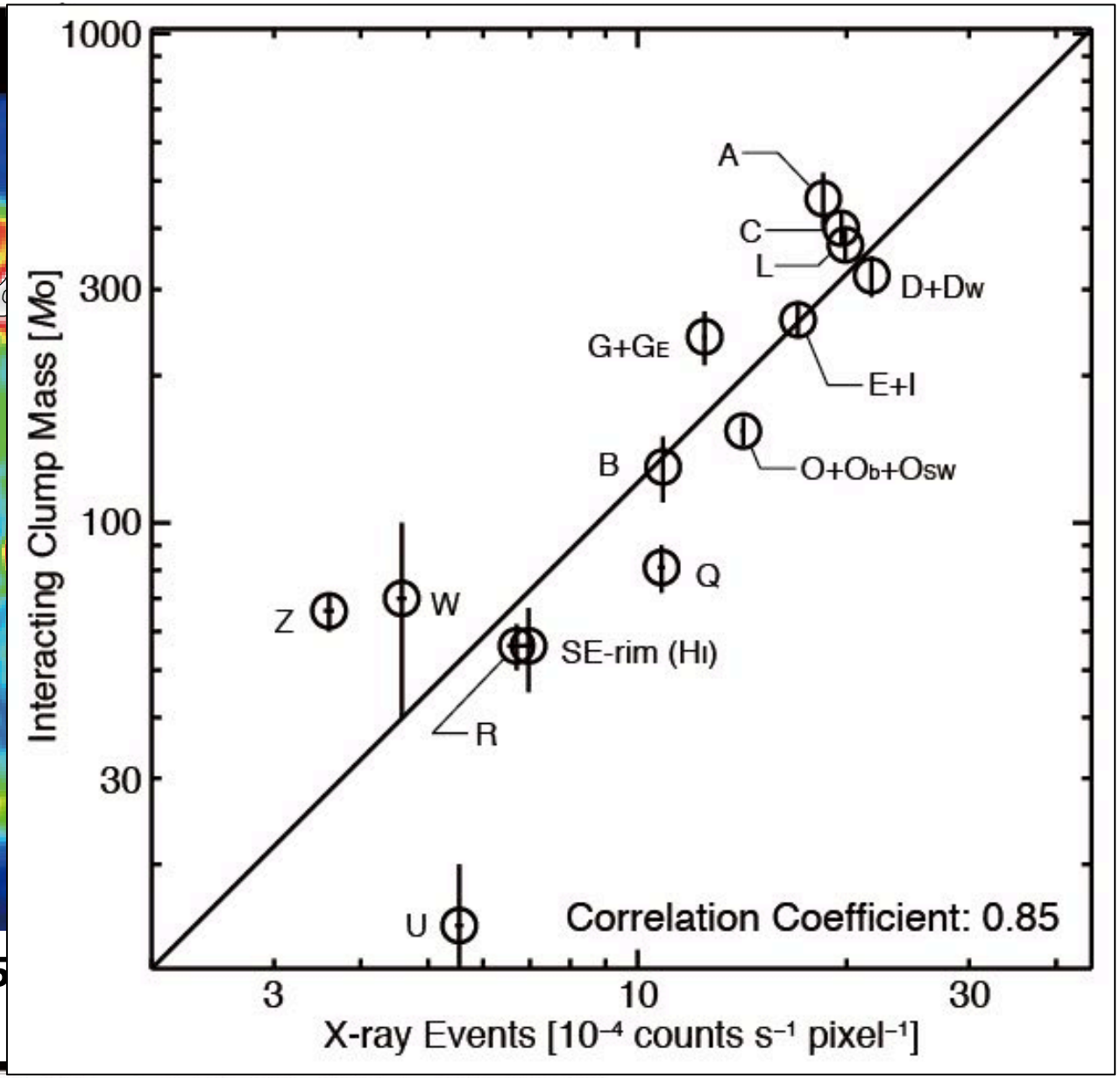


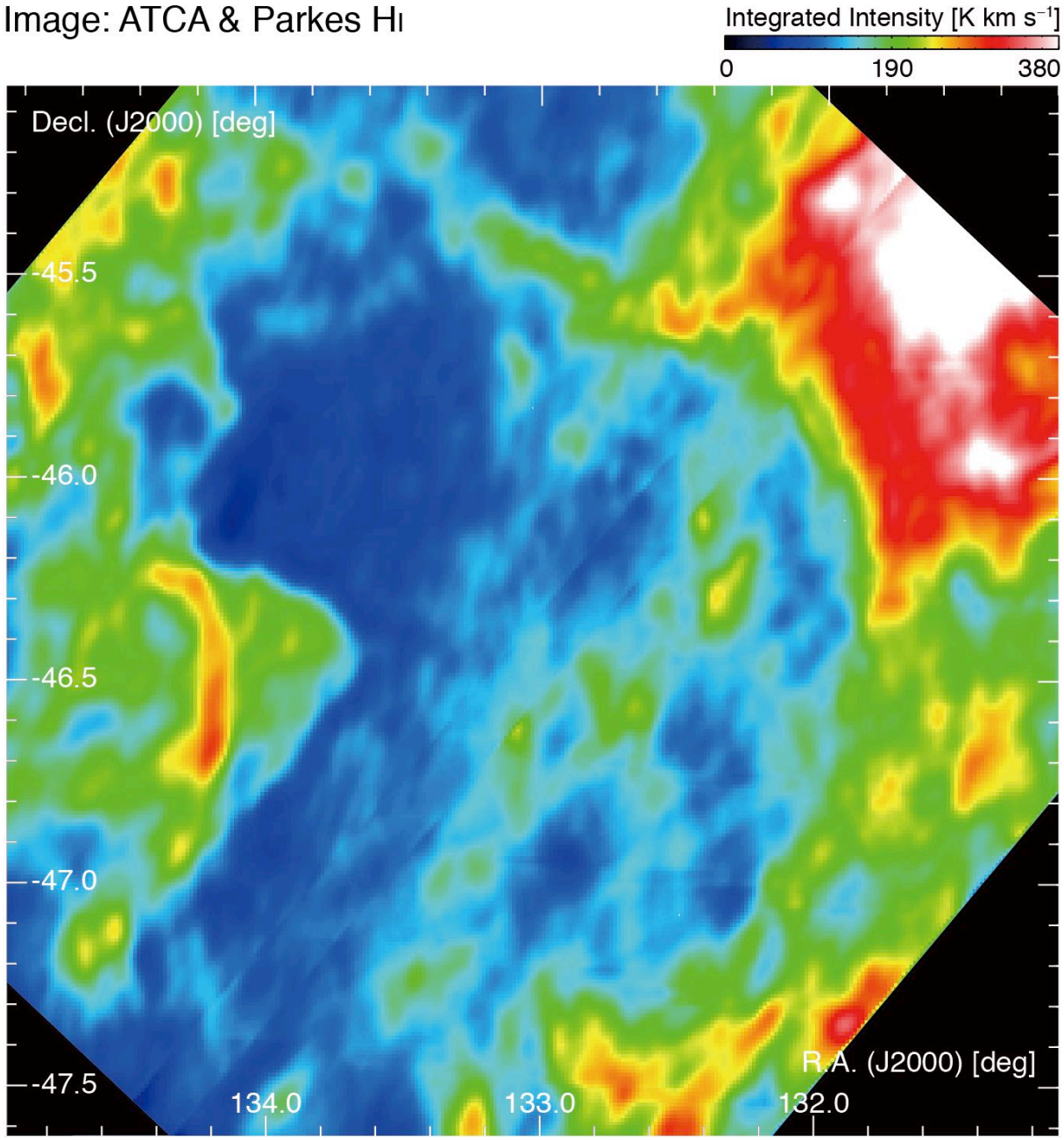
Image : *Suzaku* X-rays (1–5

Contours: Dense HI clump



- X-ray intensities are well correlated with the total interacting gas masses

Shock-cloud interaction in RX J0852.0–4622

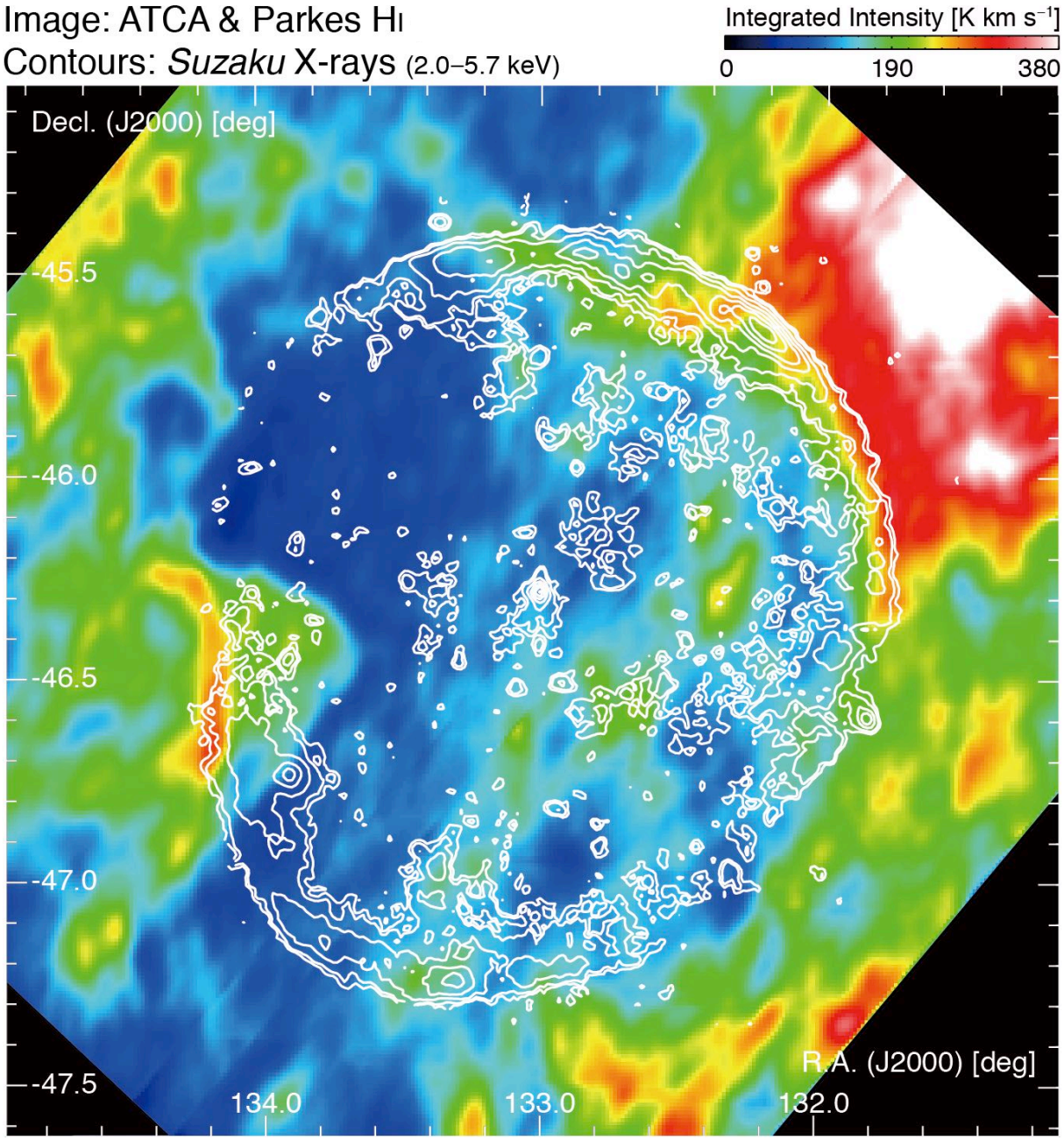


RX J0852.0–4622 (Vela Jr.)

- ☐ Age: ~2,000 yr
- ☐ Distance: ~750 pc
- ☐ Size: ~25 pc
- ☐ Core-collapse SNR
- ☐ Bright in non-thermal X-rays & TeV γ-rays
- ☐ HI/CO wind bubble

Fukui+2016 in prep.
Sano+2016 in prep.

Shock-cloud interaction in RX J0852.0–4622



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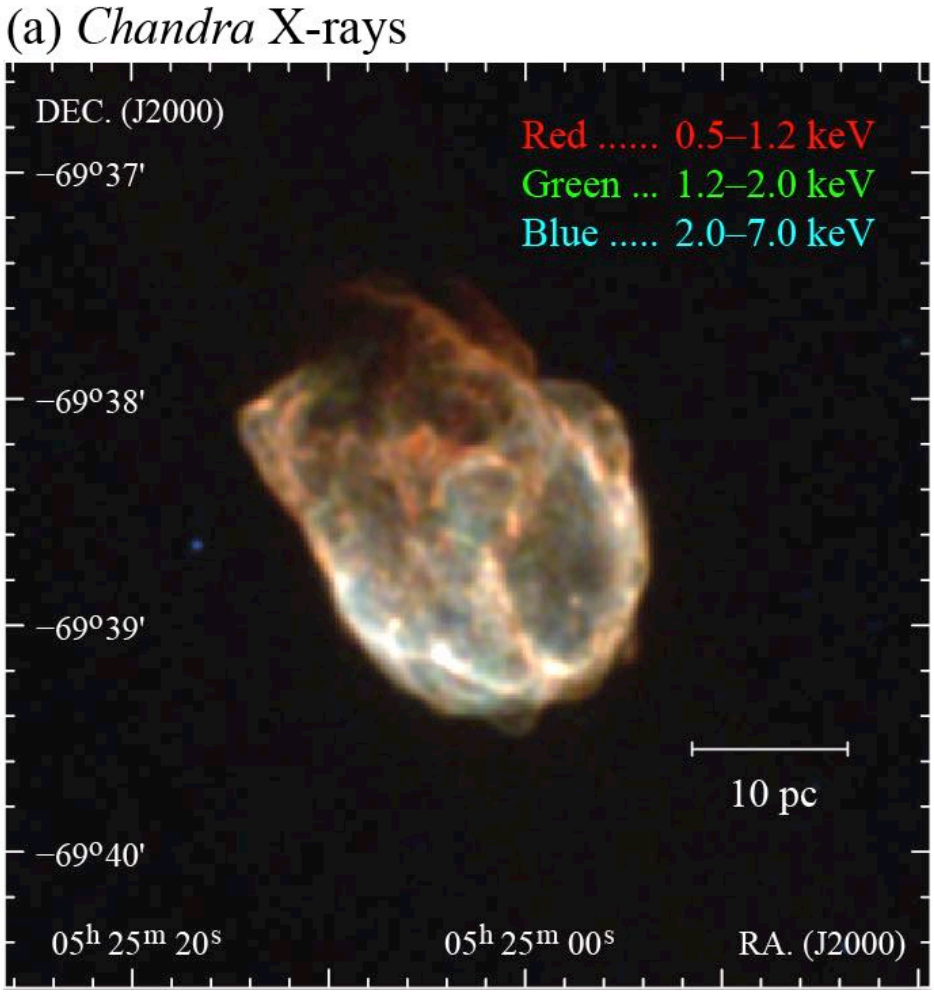
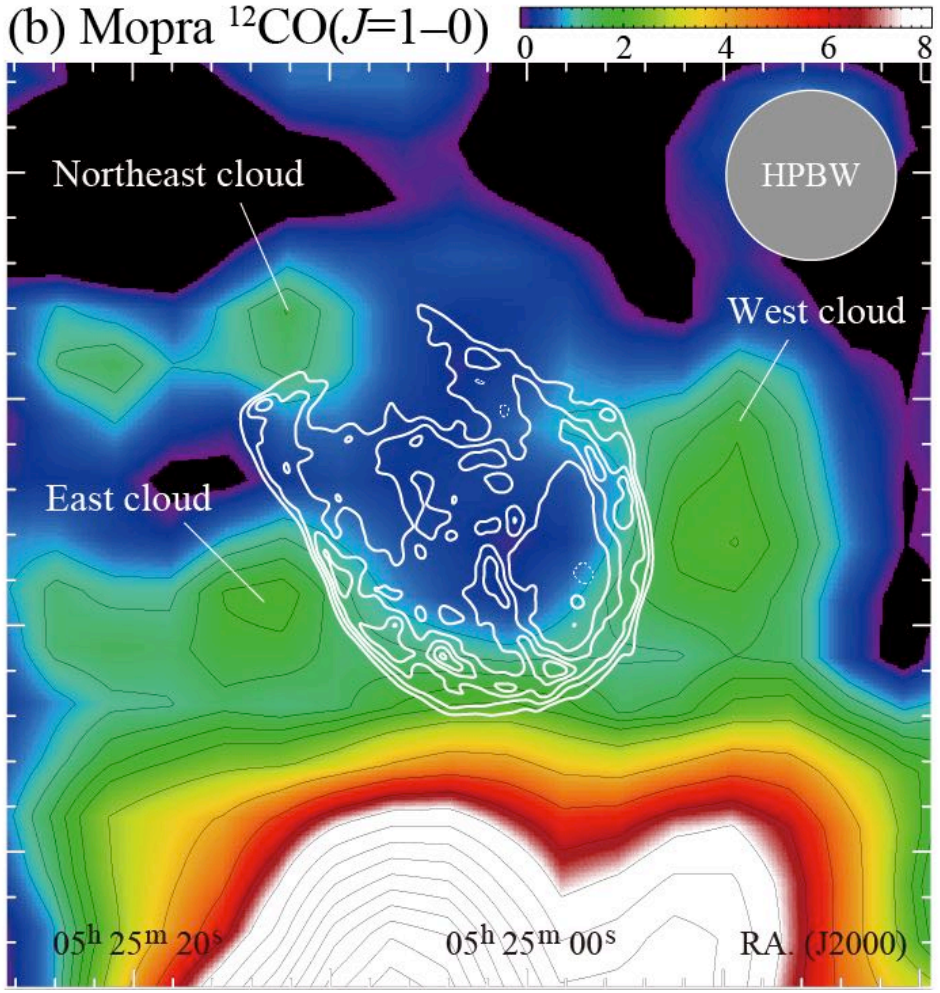
Shock-cloud interaction in N132D



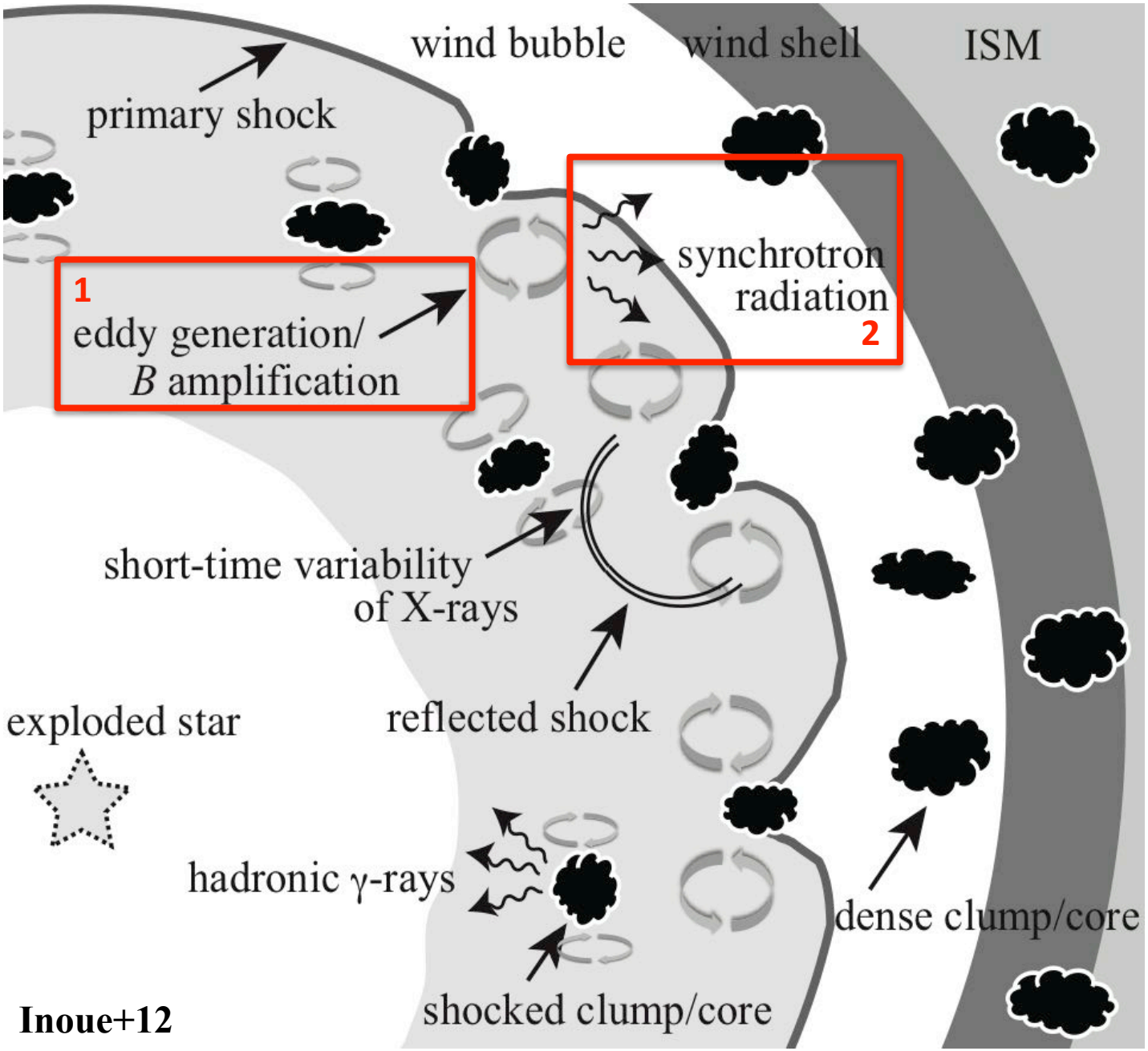


Magellanic SNR N132D

Sano+15a, ASPC, 499, 257

- ☐ Age: ~3,150 yr
- ☐ Size: ~25 pc
- ☐ Core-collapse
- ☐ Bright in thermal/non-thermal X-ray & TeV γ-ray
- ☐ Associated with the GMC?

Shock-cloud Interaction: schematic view

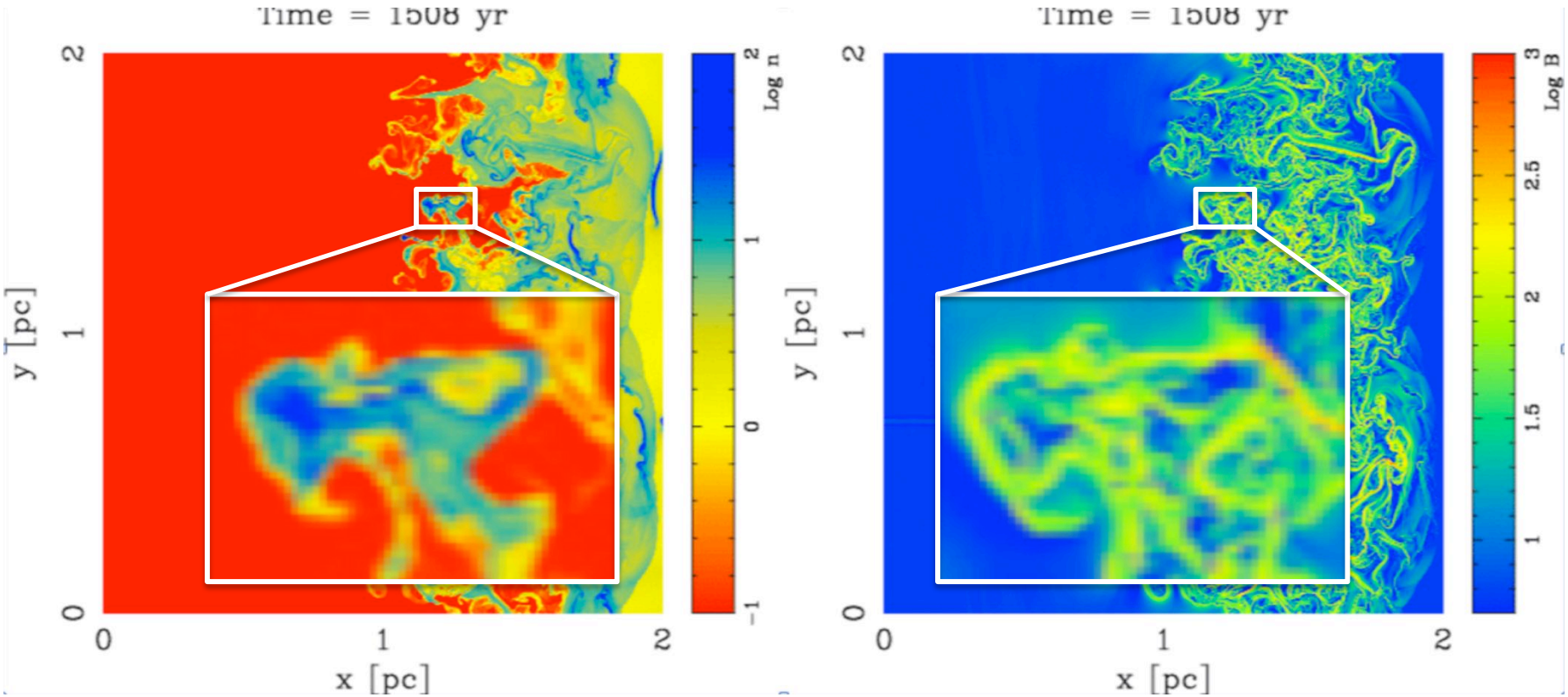


Inoue+12

Shock-cloud Interaction: MHD simulation

Gas density

B Field strength

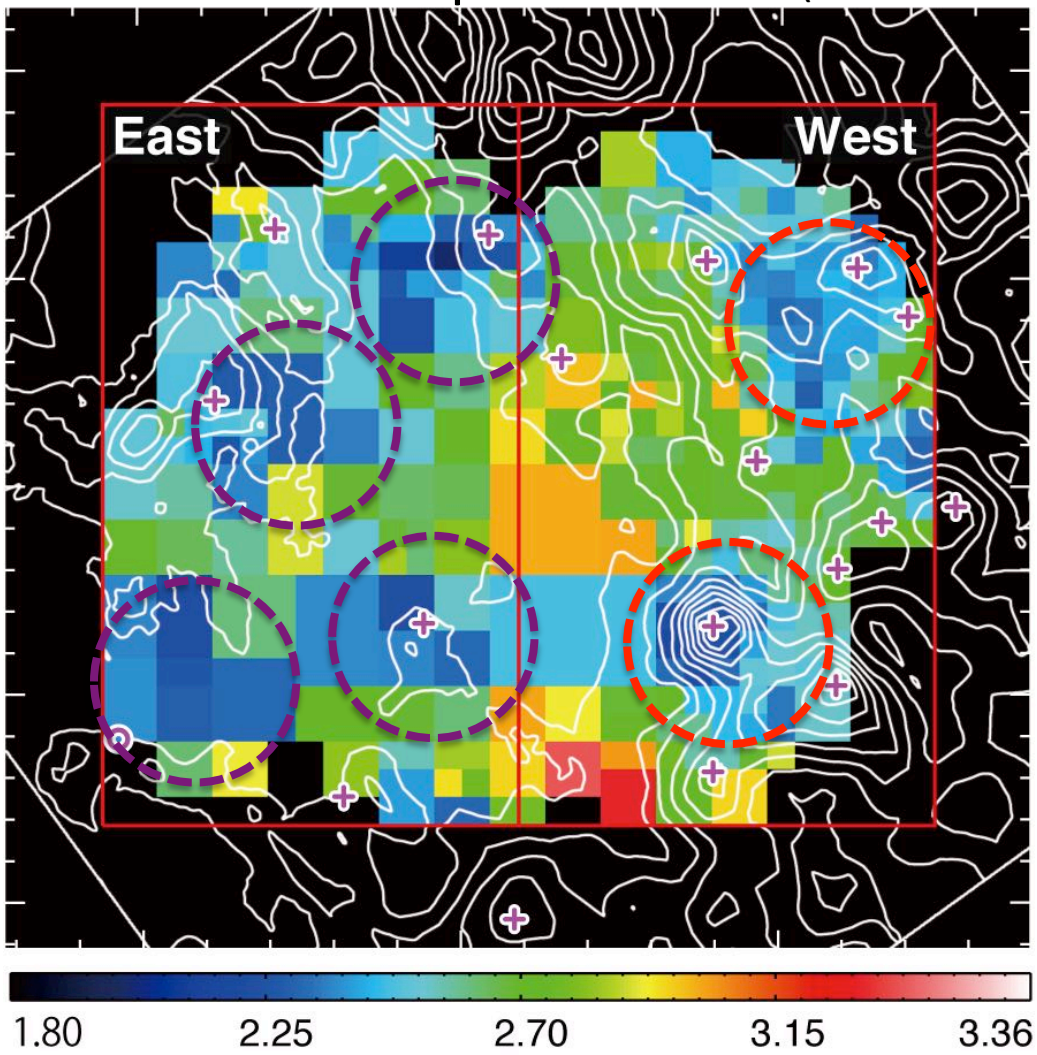


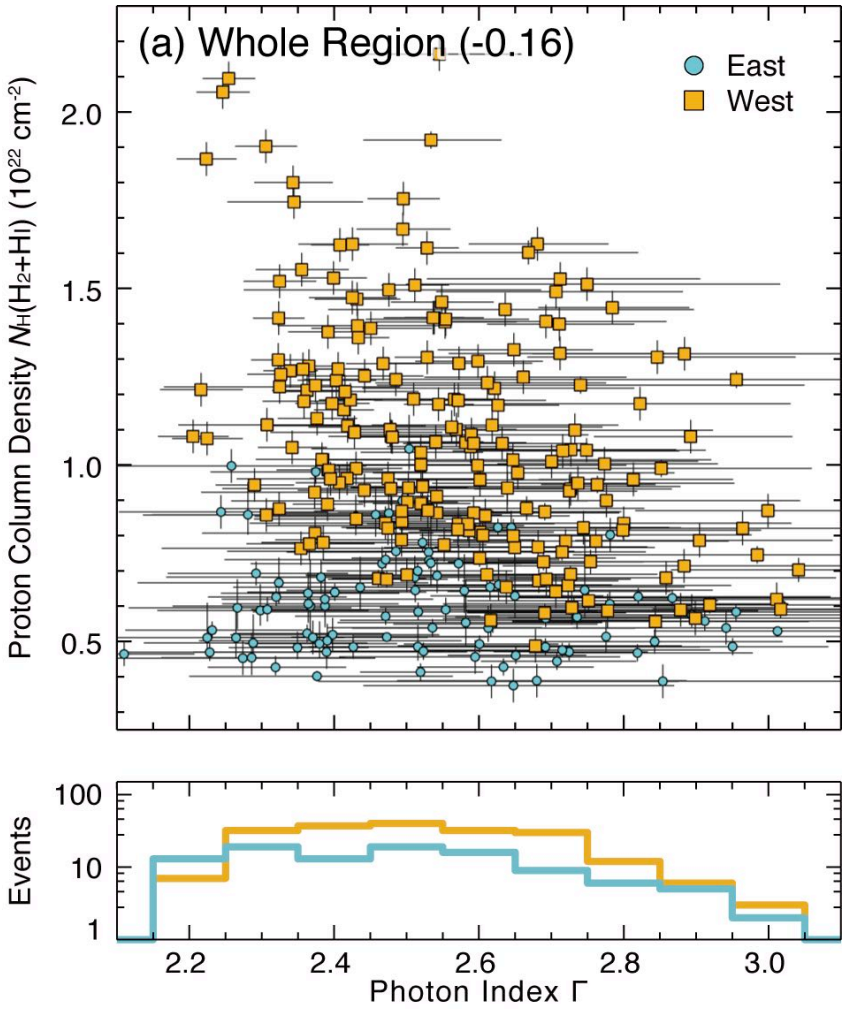
Inoue+09; 12

- *B* field are amplified around the CO-like clump
- Maximum *B* field strength reaches ~1 mG
  （Averaged *B* field strength in down stream of ~100 μG）

Interpretation of the synchrotron X-ray spectra

Photon index map of RXJ1713 (Contours: total gas)





Sano+15b, ApJ, 799, 175

- Photon indexes became small (< 2.4) toward both gas rich/poor regions

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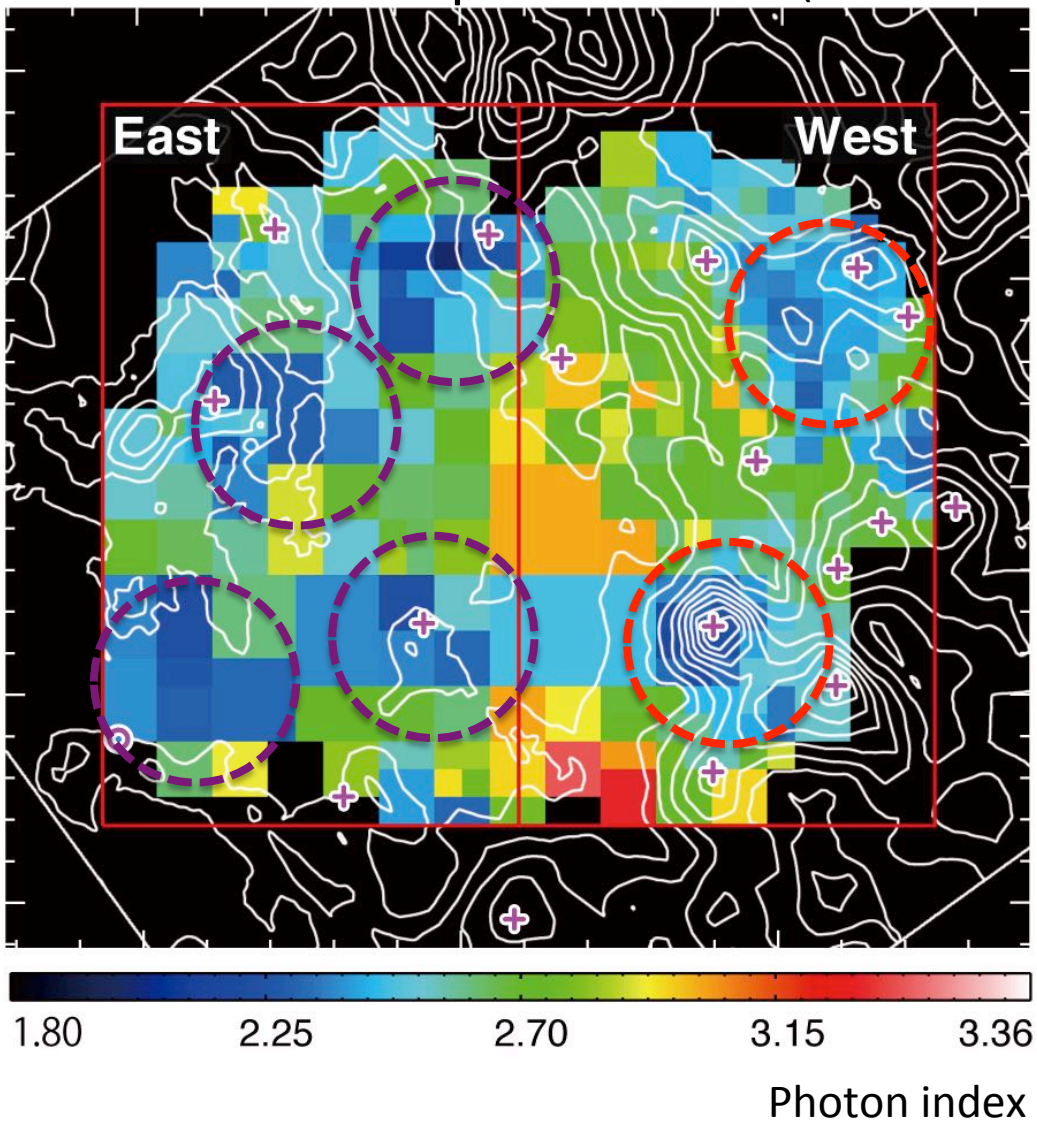


$$\varepsilon_0 \propto v_{sh}^{\,2} \times \eta^{-1}$$

Role-off energy — Shock velocity — Gyro-factor

Small photon index → large ε_0

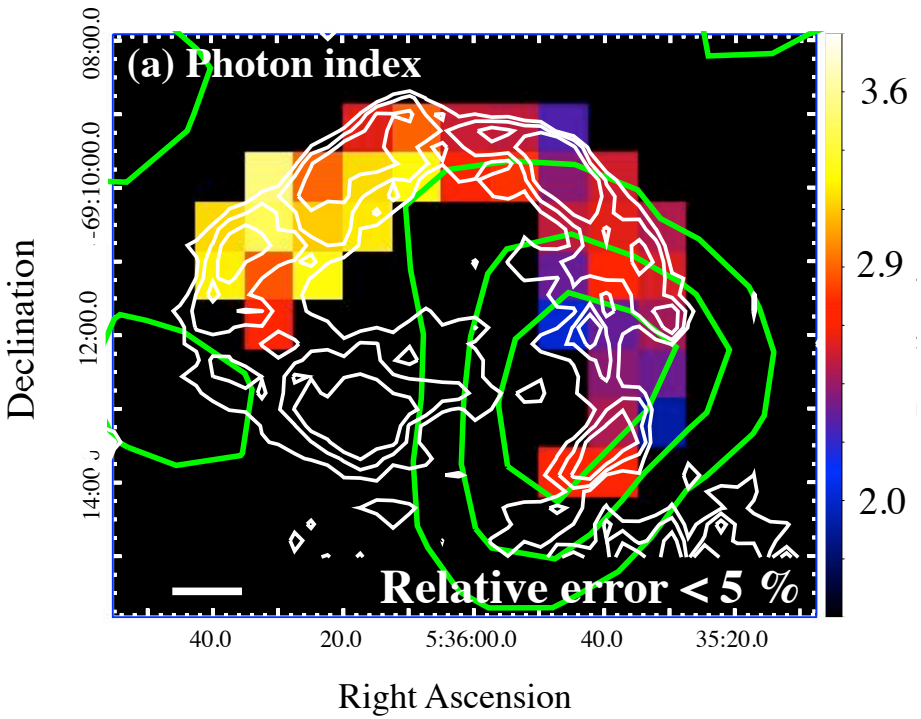
Gas rich/clumpy region
small v_{sh} & $\eta \sim 1$ → large ε_0

Gas poor/diffuse region
large v_{sh} & $\eta > 1$ → large ε_0

Sano+15b, ApJ, 799, 175

- Interstellar gas distribution may control the X-ray spectra!!

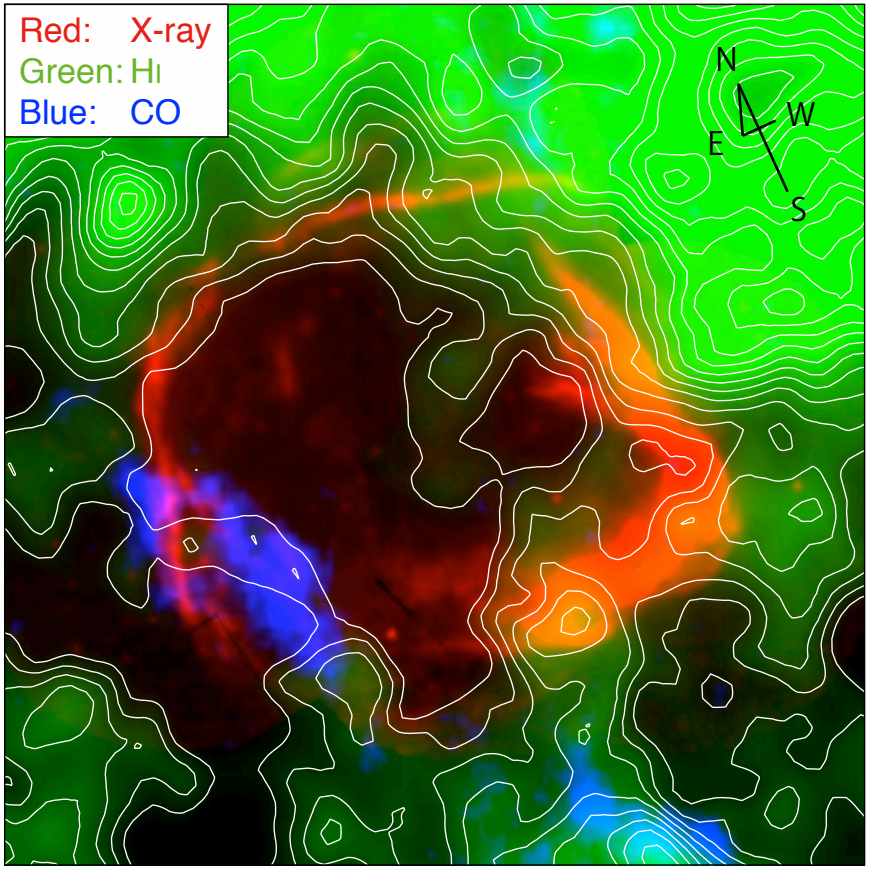
Comparative study using *XMM-newton* archival data 15/16



■ **30 Dor C (Babazaki+)**

Detailed study of X-ray spectra analysis

[Poster → H01]



■ **RCW 86 (Fukui & Sano)**

Detailed comparative study between the X-ray and gas

thermal X-ray flux ∝ gas density

[Poster → H03]

Summary

- **Young SNRs & interstellar gas**
  - Fast shocks & bright in the TeV γ-rays and synchrotron X-rays
  - Molecular cloud (> 1000 cm^{-3}), Atomic cloud (~1–100 cm^{-3})
- **Shock-cloud interaction in the young SNR RXJ1713**
  - Enhancement of the turbulence & *B* field around the gas clumps
  - Gas distribution may control the synchrotron X-ray spectra
- **Shock-cloud interaction toward the Galactic/Magellanic SNRs**
  - RXJ0852: X-rays are enhanced around the CO clumps & HI wall
  - N132D: CO cavity-like structure along with the X-ray shell

Interstellar gas (H + H_2) interacting with the SNR is important to understand the high-energy radiation & the origin of CR