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

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Young supernova remnants & Interstellar medium

- Young SNRs are thought to be primary accelerators of Galactic CRs
  - Fast shock speed $\sim 3,000$–$10,000$ 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 $\text{H}_2$ (2.6 mm CO)
    - density $\sim 10^3$ cm$^{-3}$ or higher, $T_k \sim 10$–$20$ K
  - Atomic clouds: diffuse neutral gas of H (21 cm $\text{H}_\text{I}$)
    - density $\sim 1$–$100$ cm$^{-3}$, $T_k \sim 30$–$100$ K

Dynamical interaction between the SNR’ shocks and interstellar gas plays an essential role in producing the high-energy radiation & CRs
However, it is not known how the X-ray local peaks are formed?

**RX J1713.7−3946**
- Age: \(~1,600\) yr
- Distance: \(~1\) kpc
- Size: \(~19\) pc
- Core-collapse SNR
- Bright in TeV \(\gamma\)- & non-thermal X-rays
- CO cavity + cold HI

Image: *Suzaku X-rays (5−10 keV)*
Synchrotron X-rays are well spatially correlated with CO in a pc scale.

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*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

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

Synchrotron X-rays are enhanced around the cold HI clump

Origin of the synchrotron X-rays

Image: *Suzaku* X-rays (1–5 keV)

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

Image: ATCA & Parkes HI

Fukui+2016 in prep.
Sano+2016 in prep.
Shock-cloud interaction in RX J0852.0–4622

Image: ATCA & Parkes HI
Contours: Suzaku X-rays (2.0–5.7 keV)

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Shock-cloud interaction in N132D

(a) Chandra X-rays

Red ..... 0.5–1.2 keV
Green ... 1.2–2.0 keV
Blue ..... 2.0–7.0 keV

(b) Mopra $^{12}$CO($J=1–0$)

Northeast cloud

West cloud

East cloud

Magellanic SNR N132D

- Age: $\sim$3,150 yr
- Size: $\sim$25 pc
- Core-collapse
- Bright in thermal/non-thermal X-ray & TeV $\gamma$-ray
- Associated with the GMC?

Sano+15a, ASPC, 499, 257
Shock-cloud Interaction: schematic view

1. eddy generation/
   $B$ amplification

2. synchrotron radiation

short-time variability of X-rays

exploded star

reflected shock

hadronic $\gamma$-rays

shocked clump/core

dense clump/core

Inoue+12
- B field are amplified around the CO-like clump
- Maximum B field strength reaches $\sim 1$ mG
  (Averaged B field strength in down stream of $\sim 100$ $\mu$G)
Photon indexes became small ($<2.4$) toward both gas rich/poor regions.
Interpretation of the synchrotron X-ray spectra

Photon index map of RXJ1713 (Contours: total gas)

- **East**
- **West**

\[ \varepsilon_0 \propto \nu_{sh}^2 \times \eta^{-1} \]

- **Small photon index** \(\rightarrow\) **large \(\varepsilon_0\)**

- **Gas rich/clumpy region**
  - small \(\nu_{sh}\) & \(\eta \sim 1\) \(\rightarrow\) **large \(\varepsilon_0\)**

- **Gas poor/diffuse region**
  - large \(\nu_{sh}\) & \(\eta > 1\) \(\rightarrow\) **large \(\varepsilon_0\)**

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

Recently, TeV gamma-ray emission from the We hereby investigate if a similar conclusion can be drawn from a superbubble (SB), which are large hot cavities carved by the combination alone. The photon index and X-ray intensity in 2 - 10 keV show some spatial variation in the west can be fitted with an absorbed non-thermal model (Fig.3)\cite{5}. The spectra in the east region of 30 Dor C can be described with a...

30 Dor C (Babazaki+)
Detailed study of X-ray spectra analysis
[Poster $\rightarrow$ H01]

RCW 86 (Fukui & Sano)
Detailed comparative study between the X-ray and gas thermal X-ray flux $\propto$ gas density
[Poster $\rightarrow$ H03]
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