Suzaku Observations of SNR RX J1713.7–3946 in the Energy Range from 0.4 keV up to 40 keV

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12/12/2007 Suzaku X-ray Universe @ Catamaran Hotel, San Diego
SNR RX J1713.7-3946

- Distance: 1 kpc
- Age: 1600 yr

- Non-thermal X-ray emission dominates
- Bright & Large (d ≈ 1°)
- Studied well also in TeV gamma-rays with H.E.S.S.

Best Object for Study of Particle Acceleration

Cutoff? Morphology of Dim Parts? → Suzaku
XIS Data (0.4–12 keV)

1–5 keV

Power-law type spectra (No line features)

Γ = 2.2–2.7

Consistent with previous studies by ASCA, Chandra and XMM-Newton
Cutoff around 10 keV

Spectrum of SW rim

Simple Power Law

\[
\frac{dN}{d\varepsilon} \propto \varepsilon^{-\Gamma}
\]

Power Law with an Exponential Cutoff

\[
\frac{dN}{d\varepsilon} \propto \varepsilon^{-\Gamma} \exp \left[ - \left( \frac{\varepsilon}{\varepsilon_c} \right) \right]
\]

Spectral steepening even below 10 keV
HXD: Spectra above 10 keV

Detected up to \( \approx 40 \) keV from all pointings

Dim part

Bright part

Total

Bgd

Bgd sub
HXD: Spectral Fitting

power-law fit \( \rightarrow \Gamma \approx 3.2 \)

significantly larger than those in soft X-ray band
Wide-Band Spectrum
From 0.4 keV to 40 keV

Detection up to 40 keV → Clear spectral cutoff
Cutoff Energy

Cutoff Energy $\rightarrow$

Acceleration rate = Synchrotron loss rate

Zirakashvili & Aharonian (2007)

Predict rapid cutoff which agrees with Suzaku spectrum

$$\varepsilon_0 = 0.55 \left( \frac{v_s}{3000 \text{ km s}^{-1}} \right)^2 \eta^{-1} \text{ keV} \quad (\eta \geq 1)$$

Chandra Image


$$\varepsilon_0 = 0.67 \pm 0.02 \text{ keV}$$

Suzaku Spectrum

$$v_s < 4500 \text{ km s}^{-1}$$

$$\eta \approx 1$$

Almost the Bohm limit

Very Efficient Acceleration
Magnetic Field
Uchiyama et al. (2007) Nature

Year-scale Variability detected with Chandra → Acceleration & Cooling in year-scale → High Magnetic Field: 1 mG
Multi-Wavelength Spectrum

\[ B = 200 \, \mu G, \ t_0 = 1000 \, \text{yr}, \ s = 2.0 \ (\text{for } e^- \text{ and } p) \]

\[ W_e = 3.1 \times 10^{46} \, \text{erg}, \ nW_p = 2.7 \times 10^{50} \, \text{erg cm}^{-3} \]
keV Image vs TeV Image

Color: Suzaku XIS (1–5 keV)
Contour: H.E.S.S.

Similar morphology also in the dim parts
(Low BGD and large effective area of Suzaku XIS)

Compare flux for the each square region
keV Image vs TeV Image

Tight Correlation

Homogeneous matter distribution? (Inconsistent with NANTEN)
Synchrotron emission correlate with matter distribution?

“keV” excess

Large e/p ratio? Recent acceleration at the bright spots?
**Toy Model**

**Injection Rate**

\[
\frac{dE}{dt} / \left( \frac{dE}{dt} \right)_{t=0}
\]

- **Bright spots**: Increase in electron/proton injection rate in the last 10 years
- **The other spots**: Constant injection rate during the age of the remnant

- Lifetime of electrons emitting 5 keV X-rays
- Lifetime of electrons emitting 2 keV X-rays
- Lifetime of protons emitting TeV gamma-rays
Toy Model vs Observation

**Toy model**

**Observation**
Conclusions

- We observed RX J1713.7–3946 with Suzaku
- We have detected hard X-rays up to 40 keV from RX J1713.7–3946, for the first time
- We have clearly detected cutoff structure around 10 keV
- Cutoff energy indicates very efficient acceleration (almost in the theoretical limit)
- Multi-wavelength spectrum can be well modeled with hadronic scenario.
- Tight keV-TeV correlation & “keV excess” in the bright spots
- Upcoming GLAST will play an important roll in determining the gamma-ray spectrum
Suzaku Observation of RX J1713.7–3946

Covers about 2/3 of the remnant

<table>
<thead>
<tr>
<th>Pointing ID</th>
<th>Exposure [ks] XIS / HXD</th>
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<tr>
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<td>18 / 22</td>
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<td>9</td>
<td>16 / 15</td>
</tr>
<tr>
<td>10</td>
<td>15 / 15</td>
</tr>
</tbody>
</table>
keV Image vs TeV Image

Color: Suzaku (1–5 keV)
Contour: H.E.S.S.

Similar morphology also in the dim parts
Spatial Variation

Input soft X-ray image to MC simulator
Compare detected flux between obs. and sim.

Hard X-ray emission seems to follow the brightness distribution of soft X-rays

Systematic Error ≈ 20%
1. Suzaku Data (Super-Exponential)
3. Exponential Cutoff
Multi-Wavelength Spectrum

$B = 14 \, \mu G, \, t_0 = 1000 \, yr, \, s = 2.0$

$W_e = 1.4 \times 10^{47} \, \text{erg}$
keV Image vs TeV Image

F_{keV} vs F_{TeV}

Map of F_{keV} - F_{TeV}

Tight Correlation & “keV excess” at the bright spots
Hadronic Model

H.E.S.S. data requires

\[ W_p \approx 10^{50} \left( \frac{D}{1 \text{ kpc}} \right)^2 \left( \frac{n}{1 \text{ cm}^{-3}} \right)^{-1} \text{ erg} \]

A matter density of \( > 0.2 \text{ cm}^{-3} \) is needed, assuming...

- The typical kinetic energy released by a supernova of \( 10^{51} \text{ erg} \)

- The conversion efficiency to the high energy protons of < 50%
Upper Limit on Thermal Emission

\[
EM = \frac{1}{4\pi D^2} \int n_e n_H \, dV
\]

Normalization of thermal component

\[
n = 1 \left( \frac{EM}{10^{14} \text{ cm}^{-5}} \right)^{1/2} \left( \frac{D}{1 \text{ kpc}} \right)^{-1/2} \text{ cm}^{-3}
\]

Matter density of \( n > 0.2 \text{ cm}^{-3} \)

↓

The electron temperature of 0.1 keV or lower

Efficient acceleration with gas heating suppressed?
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\[ \downarrow \]

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