X-ray Diagnostics of Acceleration Efficiency of Cosmic Rays on the SNR Shock Fronts

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Abstract

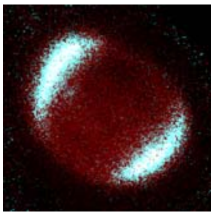
Since the discovery of cosmic rays, their origin is one of the biggest problems in astrophysics. Now, the acceleration mechanism and efficiency of electrons are well studied using synchrotron X-rays; the shells of supernova remnants accelerate electrons so efficiently. However, it still remains as a mystery for the main component of cosmic rays, protons. The temperature of downstream plasma of the shock front is determined by Rankine-Hugoniot relation. When there is no acceleration, the energy budget of the downstream plasma is about 20% of the kinetic energy of shocks. On the other hand, if protons accelerate so efficiently, they get energy from the shocks, and as a result, the downstream plasma cannot heat up. Therefore, the precise determination of the plasma parameters is critical for the cosmic ray study on the shock.

X-ray carolimeters can determine the precise plasma parameters such as temperature, density, ionization states, and so on. In this paper, we perform how to determine the energy budget into accelerated protons with X-ray calorimeters onboard NeXT mission.

1. Introduction

X-ray observations of SN 1006 always establishes milestones !

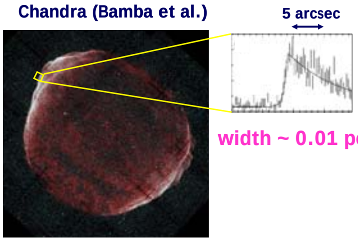
ASCA (1995 Koyama et al.)



Synchrotron X-rays from NE and SW shells of SN1006

shells of SNRs are electron acc. sites!

Chandra (Bamba et al.)



width ~ 0.01 pc!

Sync. X-rays concentrate on very thin filaments

Electron acc. efficiency is extremely high!

Now we know that electrons are accelerated on shells of SNRs so efficiently.
However,
How about protons ?

2. Idea

from Rankine-Hugoniot relation

$$kT_d \frac{2(\gamma-1)}{(\gamma+1)^2} mv_s^2 = \begin{cases} \sim 0.19\, E_{shock} & \text{(no acc.)} \\ < 0.19\, E_{shock} & \text{(efficient acc.)} \end{cases}$$

Efficient acceleration cools down the downstream plasma.

kinetic E of shocks → thermal E of downstream plasma
kinetic E of shocks → E of accelerated particles
kinetic E of shocks → kinetic E of shocks

3. Tools

X-ray calorimeter onboard NeXT → thermal E of plasma

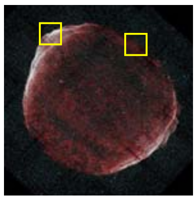
Hα observations
Proper motion with Chandra → kinetic E of shocks
(2290 km/s; Ghavamian et al. 2002)

\+ Rankine-Hugoniot relation

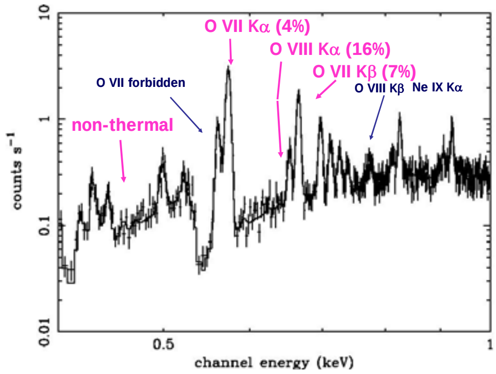
E of accelerated particles

With the NeXT calorimeter, we can determine the energy budget of accelerated particles for the first time !

4. NeXT observatiosn of SN 1006



FOV of X-ray calorimeter (NE and NW rim)



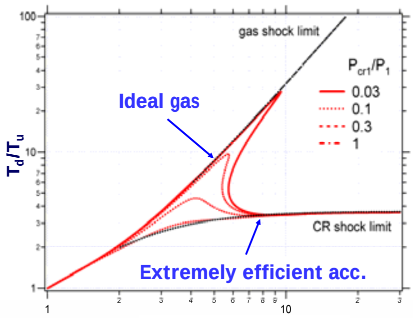
80 ks observation of NE rim with NeXT carolimeter

With 80 ks observations, we can determine the intensity and broadening of lines with good accuracy.

5. Recipe for the estimation

1. Determine kT_e, kT_i, and n_et
   - He-like O Kα, He-like O Kβ → kT_e (30% acc.)
   - H-like O Kα, He-like O Kα → kT_i (10% acc.)
   - → n_et (11% acc.)
2. Measure the difference of kT_e and n_et between NE and NW regions (15% acc.)
3. The age MUST be same
   → Determine the difference of compression ratio (15% acc.)
4. Determine the shock velocity (with Hα and Chandra observations; 3% acc.)

Mach number vs. compression ratio



Courtesy of T. Terasawa
cf. Axford et al. 1982
Boulares et al. 1988

With realistic observation time, NeXT will reveal us the acceleration efficiency of protons.

References

Axford, W.I. et al. 1982, A&A, 111, 327
Bamba, A. et al. 2003, ApJ, 589, 827
Boulares, A. et al. 1988, ApJ, 333, 198
Koyama, K. et al. 1995, Nature, 378, 255
Mewe, R. et al. 1085, A&AS, 62, 197