High energy aspects of SNRs

10 years old 10 years old 4 years old

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Cosmic Rays

high E particles in the universe

$u_{CR} \sim 1\text{eV/cc}$

c.f. CMB 0.3 eV/cc
  - stellar light < 0.3 eV/cc
  - magnetic field 0.3 eV/cc
  - turbulence 0.3 eV/cc
  - thermal energy 0.01 eV/cc

Essential component in our Galaxy

$\Gamma = 2.7$

knee = $10^{15.5}\text{eV}$

$\Gamma = 3.1$

Who and how to accelerate is still unknown after 100 years from the discovery

(Cronin 1999)
How to search for cosmic ray accelerators?

X-ray: synchrotron from e
thermal emission

Gamma-ray: IC emission from e
emission from pi-on
(nonthermal brems: next talk)

Combination of X-ray and gamma-ray is important!
Observational clues of CR acceleration at SNRs

synchrotron X-ray

SN1006
Discovered by ASCA (Koyama+95)

TeV gamma-ray

RXJ1713-3946
Discovered by HESS (Aharonian+04)

Shocks of SNRs accelerate cosmic rays!
Remaining problems in the 20\textsuperscript{th} century
(Contents of this talk)

1. Estimating acceleration efficiency
   How efficiently can shocks accelerate cosmic rays?
   Can SNRs be the main contributor of CR acceleration?

2. Estimating Maximum energy
   Can we expect the $E_{\text{max}}$ of accelerated particles?
   Is it larger/smaller than the knee energy?

3. Can we discover proton accelerators?
   The main goal of cosmic ray physics in 100 years.
   Not yet, but we are finding some clue.
   It should be the golden age now
   to study cosmic rays!
1. Estimating acceleration efficiency
1. Acceleration is really efficient??

before Chandra/XMM
No observational information on the acc. efficiency
many theories used “test particle”
ignoring energy of accelerated particles

Chandra/XMM
Discovery of very thin filaments with synchrotron X-rays!!

thin = small gyro radius
small diffusion

-> amplified and turbulent B
  efficient acceleration

Bamba+03
Young SNRs have thin filaments with sync. X-rays

thin filaments are common in young SNRs. Efficient acceleration might be common.

(Bamba+05)
Direct evidence of rapid acceleration??

year-scale time variability of filaments in RXJ1713-3946

synchrotron loss ~ 1yr -> $B \geq 1\text{mG}$ !!
acc. time-scale ~ 1yr -> very very efficient !!

How about total emission?

Only a few % of emission is time variable

Is the acc. efficient in total ??

(Uchiyama+07)
Very low $kT$ plasma behind the shock

Helder+09: NE rim of RCW86
measured shock velocity using Chandra observations
\[ \rightarrow v_{\text{shock}} \sim 6000 \text{ km/s} \]
\[ \rightarrow \text{expected temperature: } 40-70 \text{ keV} \]
measured $kT$ with H-alpha observations
\[ \rightarrow kT = 2.3 \text{ keV} \]

“disappeared E”
to the acceleration?

\textbf{efficiency:}\n\[ > 50 \% !! \]

\textbf{1st conclusion:}\nSeveral observations imply very efficient acceleration
2. Estimating Maximum energy
How to search for efficient acceleration?

Synchrotron X-rays have cut-off.

Electron distribution

\[ N(E) \]

exp. \[ E \]

\[ E_{\text{max}} \]

electron distribution

emission from an e

Sync. emission

\[ \Gamma \]

\[ B \]

\[ E_{\text{max}}^2 \]

cutoff energy \( \sim B E_{\text{max}}^2 \) (Reynolds 1998)

\[ B: \text{magnetic field} \quad E_{\text{max}}: \text{the maxmimum } E \text{ of e} \]

good statistics in wide band is essential
Suzaku observations of SNRs

Suzaku has sensitivity in wide band and detected synchrotron X-rays from several SNRs.

SN1006 (Bamba et al. 2008)

CTB37B (Nakamura et al. 2009)
cut-off energy determined by Suzaku

RXJ1713-3946: cut-off $\approx 8.9$ keV (Uchiyama+07)

SN1006: cut-off $\approx 0.25$ keV

CTB37B: cut-off $> 16$ keV

Suzaku detected cut-off of sync. X-rays cut-off $\approx 0.2 - 10$ keV

2nd conclusion:

$E_{\text{max}} \approx 10-100$ TeV

$E_{\text{max}}$ for p should be higher
3. Possible proton accelerators
How to search for p accelerators?

X-ray obs. cannot see protons.
Gamma-ray obs. cannot distinguish e and p.

We need both observations.
Do we have sources with only TeV gamma-rays?
In a young SNR case: RX J1713-3946

Complete maps in X-ray and TeV bands.

TeV and X-ray flux have some correlation.

some special region? -> B amplification?

(Tanaka+09)

simple correlation? -> sync. from uniform B?

(Acero+-09)
Radial profiles

XMM 1-2 keV
XMM 2-4.5 keV
HESS

(Acero+09)

The X-ray emission seems to come more from the inside of the SNR than in gamma-rays

X-rays: synchrotron from the shock ??
gamma-rays: via pi-0 decay

on the shock-molecular cloud interaction ?

X-ray gamma-ray

still contravatial ...
TeV-bright and X-ray faint sources?

HESS discovered a lot of new sources on the Galactic plane. Some are diffuse Galactic sources. HESS J1616-508

On the Galactic plane, they should be accelerators. However, they have no CP! They are not known PSRs, PWNe, known SNRs, known SF regions.

Are they really “dark”? What are their origin? X-ray follow-ups are essential.

“TeV unID sources” “dark particle accelerators” (Aharonian+06)
Suzaku follow-ups of several TeV unID sources

**HESSJ 1616-508** *(Matsumoto+07)*

**HESS J1702-420** *(Fujinaga+ in prep.)*

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**upper-limit !**

\[ \frac{F_{\text{TeV}}}{F_X} > 55 \]

**HESS J1804-216** *(Bamba+07)*

**TeV 2032+4130** *(Murakami+ poster)*

detected: \[ \frac{F_{\text{TeV}}}{F_X} \approx 10 \]

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Real dark particle accelerators? Origin is still unknown
Suzaku XIS image of HESS J1745-303 (1)

SNRs G359.0-0.9, G359.1-0.5 (Bamba+ 2000)

No X-ray!

Only thermal

6 arcmin

0.5-2.0 keV (Suzaku) contour: HESS

nearby sources

(Bamba+09)
Suzaku XIS image of HESS J1745-303 (2)

No X-ray!

2.0-8.0 keV (Suzaku) contour: HESS

(Bamba+09)
Suzaku XIS image of HESS J1745-303 (3)

neutral (cold) iron line (Suzaku)
contour: HESS

excess!

6 arcmin

total int.: 1.1e-5 ph cm^{-2}s^{-1}

(Bamba+09)
Origin of neutral iron emission line?
“X-ray reflection nebula”

X-ray source -> scattered in MC -> strong emission line from cold iron

X-ray irradiator:
past active GC SMBH itself!
(Koyama+ 2007)
It was very bright 300 years ago.

HESS J1745-303 coincides with MC.

(SgrB2: Murakami+ 2002)
(Bamba+09)
SNR + MC = HESS J1745-303 as a proton accelerator?

Our scenario

old SNR
G359.1-0.5

- The SNR G359.1-0.5 is old enough to lose sync. X-rays. (Bamba+00)
- This SNR collides with MC. It has OH mesars.
- Protons emit gamma-rays via pi-0 decay.
- Only TeV gamma-rays are observed.
  They should bright in GeV gamma-rays!
  -> Fermi !!! (Bamba+09)
Fermi detected TeV unIDs!

Fermi bright source catalog (Abdo+09)

9 of 205 sources coincide with TeV sources

4% of the Fermi bright sources!!

- HESS J1023-575
- HESS J1418-609
- HESS J1616-508 dark with Suzaku
- HESS J1741-302 unknown
- HESS J1804-216 dark with Suzaku
- HESS J1813-178 PWN
- HESS J1834-087 PWN
- HESS J1923+141
- TeV J2032+4230 unknown

Two dark accelerators are bright in GeV
HESS J1616-508 case

Huge gap!

Suzaku
(Matsumoto+07)

HESS
(Aharonian+06)
HESS J1804-216 case

Huge gap!

Fermi (Abdo+09) (same $\Gamma$ to TeV)

Suzaku (Bamba+07)

HESS (Aharonian+06)
Origin of the gap?

Proton accelerators??
  large GeV bump -> pion decay !?
  long awaited answer!
  photon index is too soft (2.3-2.7)
  -> it is very difficult for CRs
  due to the softening during propagation ...

X-ray emitters are already moved/disappeared?
  X-rays are from more energetic electrons
  than GeV/TeV gamma-rays -> shorter time scale!
  PWN/pulsars?
  Difficult to prove it ...

  Anyhow, making the energy gap of observations
  smaller is crucial
Hard X-rays will cover (partly) the gap

Huge gap!

(INTEGRAL/MAXI)
ASTRO-H
NuStar
(Simbol-X)

3rd conclusion:
hard X-rays might catch new clues to these exciting sources.
Summary

- Chandra revealed us that SNRs accelerate CRs very efficiently.

- Suzaku showed us that the $E_{\text{max}}$ is $\sim 10$-100 TeV. Protons should be accelerated more.

- Wide-band images with XMM/Suzaku show us some clue of p acceleration.

- Several TeV unID sources could be p accelerators.

- The most interesting sources are much brighter in higher energies.
  We are waiting for New high-E mission, ASTRO-H, NuStar, and more!