TeV Gamma Rays from Synchrotron X-ray SNR

Kyoto University Department of Physics

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(CANGAROO Collaboration)

- Introduction
- TeV Gamma Ray emissions in celestial objects
- Results of CANGAROO

The Universe viewed in Gamma-Rays@ ICRR. 2002, Sep.

CANGAROO collaboration

Collaboration of Australia and Nippon for a Gamma Ray Observatory in the Outback

Site: South Australia, Woomera

31 ° 06' S, 136 ° 47' E

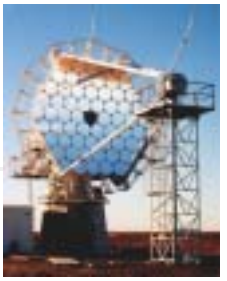
160m a.s.l.

- Institute for Cosmic Ray Research, U. Tokyo
- University of Adelaide
- Australian National University
- Ibaraki University
- Ibaraki Prefectural University of Health Science
- Institute of Space and Astronautical Science
- Kanagawa University
- Konan University
- Kyoto University
- National Astronomical Observatory of Japan
- Osaka City University
- STE Laboratory, Nagoya University
- Tokai University
- Tokyo Institute of Technology
- Yamagata University
- Yamanashi Gakuin University

The first 10m telescope

	10m telescope
Focal length	8m Parabola
80cm CFRP mirrors	114 (57m^2)
Number of PMTs	552 (1/2“) FOV ~ 3° (4°)
Electronics	TDC & ADC
Point image size	0.20° (FWHM) (<0.15°)

1999 7mϕ



1992 3.8mϕ (1.2TeV)

10m Reflector & Imaging camera

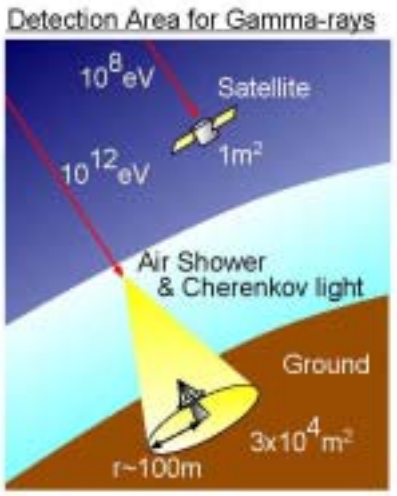
3° FOV, 0.115° pixel × 552 (R4124UV) + Light guide

~3°

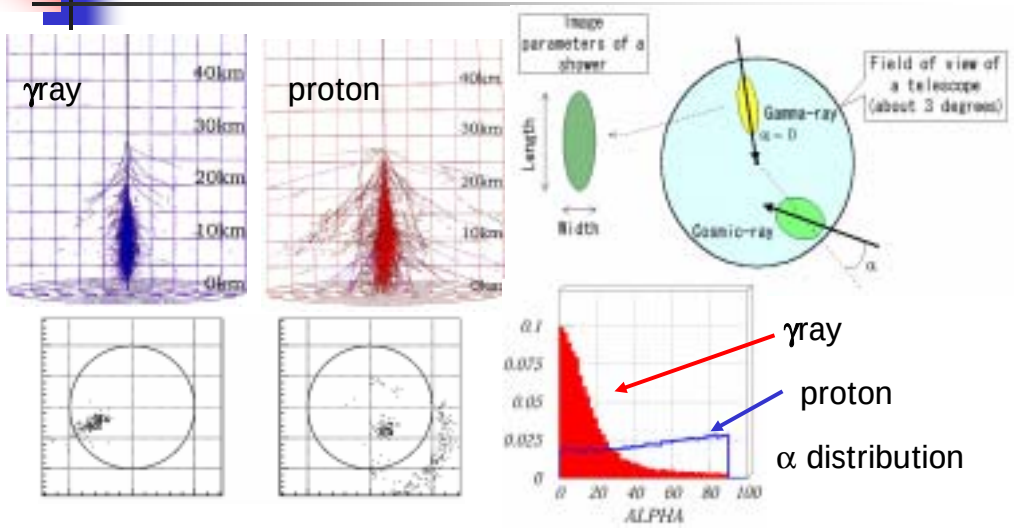
114 CFRP 80cmϕ mirrors

Satellite vs Ground-based gamma-ray telescope

Base	Satellite	Ground
Gamma-ray detection	Direct (pair creation)	Indirect (atmospheric Cherenkov)
Energy	< 30 GeV (-> 100 GeV)	>300 GeV (-> 50 GeV)
Pros	High S/N Large FOV	Large area Good $\Delta\theta$
Cons	Small area High cost	Low S/N (CR bkgd.) *(but imaging overcomes this!)* Small FOV



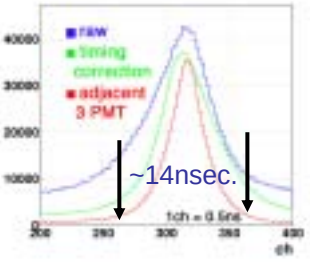
Imaging Cherenkov technique

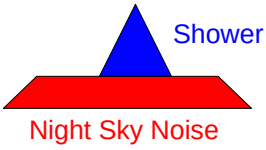


Imaging camera

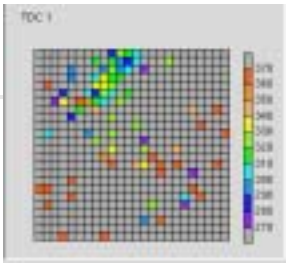
Timing Distributions of PMTs

3° FOV, 0.115° PMTs ✕ 552
Light guide

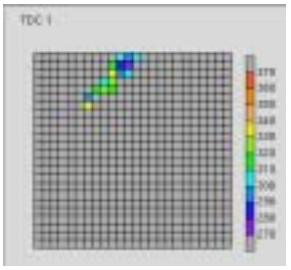




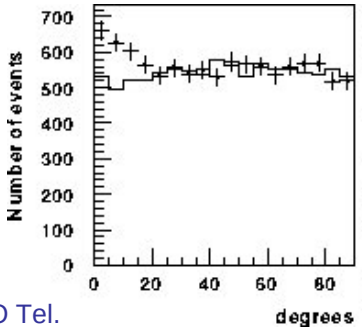
Raw data

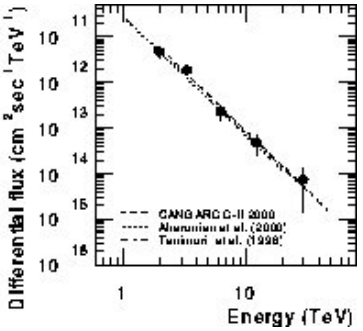


After Noise reduction



Observation of Crab nebula



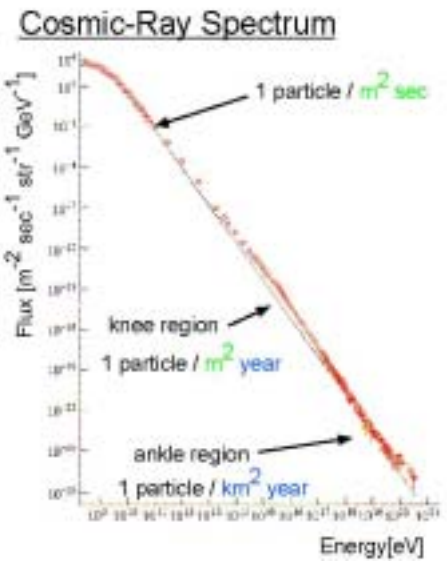


10mCANGAROO Tel.
10hrs, Observation
5.9σ

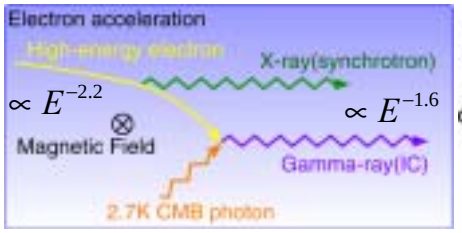
2TeV ~ 20TeV

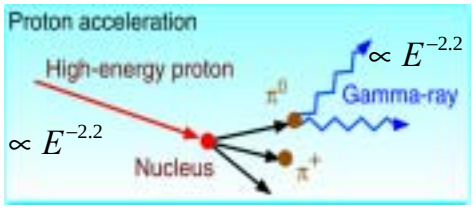
Origin of Cosmic Rays (Galactic)

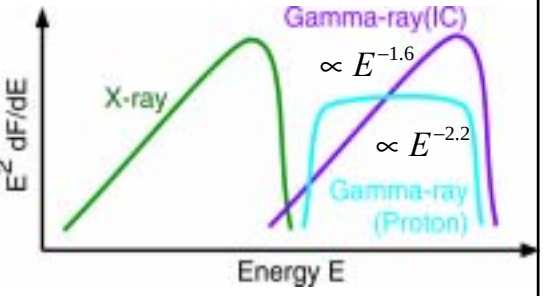
- **Energetics of Cosmic Rays(<10^{16} eV)**
  Required Energy Supply
  ~10^{40} erg/s
  ($\tau \sim 10^{6\sim7}$ yrs, $\rho_{CR} \sim 1$ eV/cm)
  Unique Candidate → SNR
  E_{max} <~10^{15} eV
- **Extra Galactic Origin (>10^{18} eV)**
  E_{max}~10^{20} eV
- **Spectrum Index -2.5 ~ -3.0**
  Shock Acceleration
- **Ion Acceleration Mainly Proton**
- Widely believed, but little observational evidences
  (Whipple No detection from 6SNR)



Process of TeV Gamma-Ray Emission







$$\left(\frac{dE}{dt}\right)_{\text{I.C.}} = \frac{4}{3}\sigma_{\text{T}}\, c\, \gamma_{\text{max}}^{2}\, \text{U}_{\text{photon}}$$

$$\left(\frac{dE}{dt}\right)_{\text{Sync}} = \frac{4}{3}\sigma_{\text{T}}\, c\gamma_{\text{max}}^{2}\, \frac{B^2}{2}$$

Mechanism of TEV Gamma Emission

- π^0 decay induced by Proton scattering

  Index of Gamma ray spectrum similar to that of progenitor proton

  (~2.2 for Shock Acceleration)

  Low energy cut off (70MeV)

- Inverse Compton Scattering of H.E. electrons with $h\upsilon$

  +Synchrotron (Radio to X-ray)

  Flatter spectra than those of progenitor electrons (~1.6)

- Bremsstrahlung

  In high density region

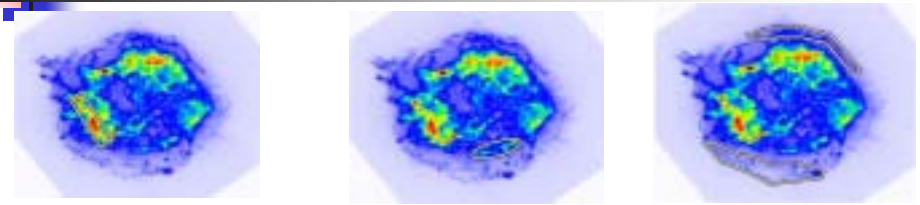
  (~2.2 for Shock Acceleration)

  + thermal X-ray emission

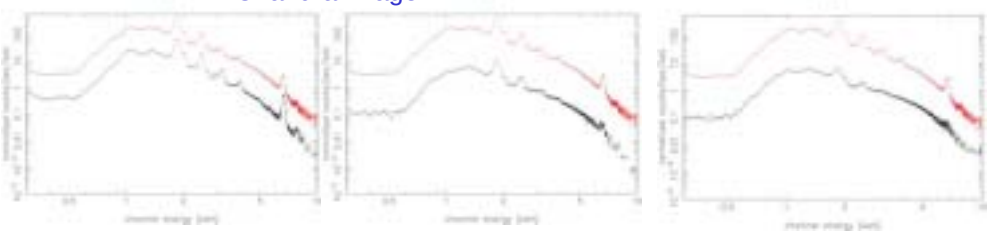
  + emission line (neutral Iron 6.4keV)

X-ray Spectrum (Bremsstrahlung)

Emission Line X-ray (6.4 keV)
From neutral Iron



Chandra Image



Cas.A 3.4kpc. 5.9'×5.9'

•Supernova remnant: Cas A (HEGRA)

Goret et al. 26th ICRC OG2.2.18, 1999

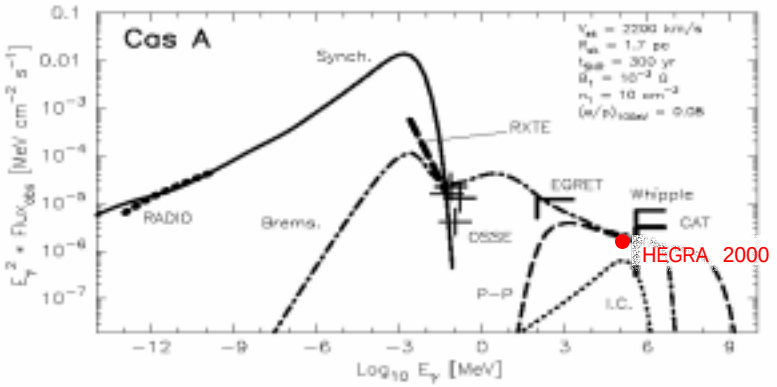
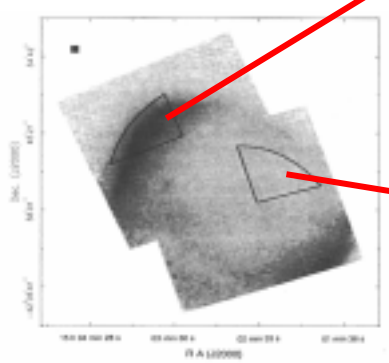


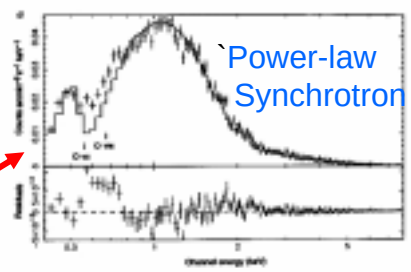
Figure 2: *Predictions of the nonlinear diffusive shock-acceleration model from radio to TeV γ-rays as compared to observations (see Ellison et al. (1999) for details and references therein). The present result is shown together with the Whipple upper limit of Lessard (1999).*

Observation by ASCA/SIS

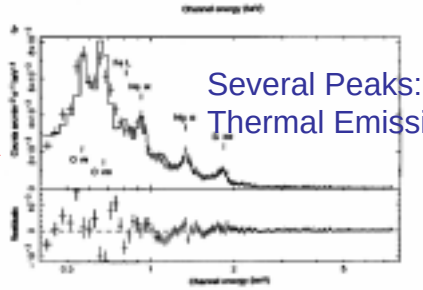
Koyama et al.1995

- Dominant Power law from NE rim
- Pointed out the possibility TeV Gamma-Ray Emission





Power-law
Synchrotron Rad.



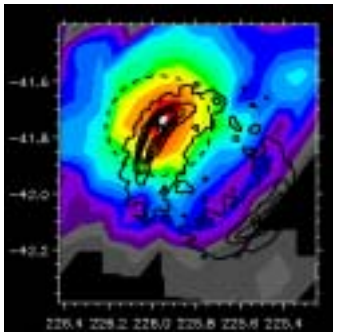
Several Peaks:
Thermal Emission

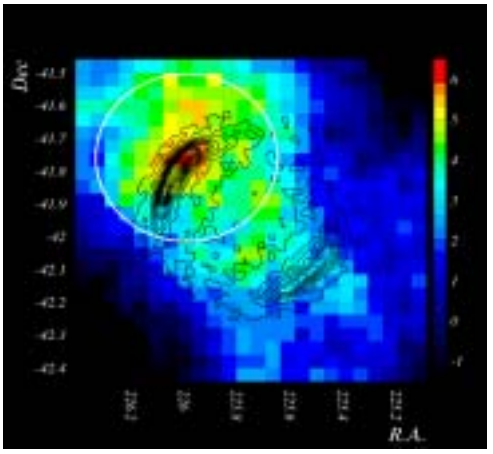
Significance map

10m result (~7σ)

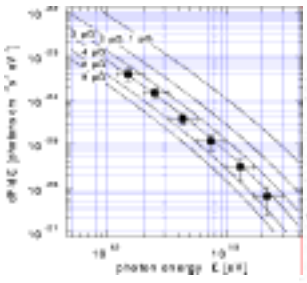
PSF ~0.25 deg radius.

3.8m result. (~7σ)



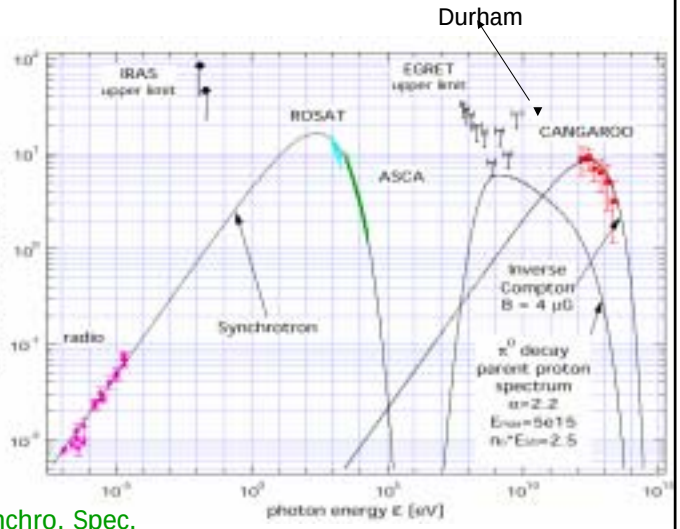


Multi band Spectrum & Fitting



- S = -2.2
- B ~ 4 μG
- E_{max} ~50TeV

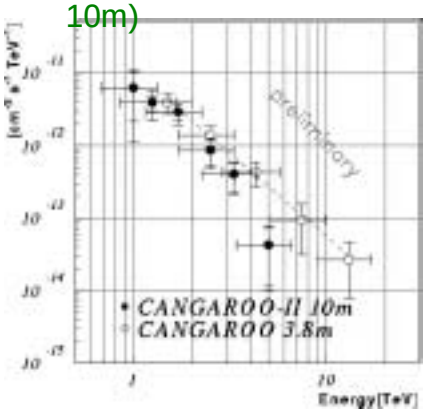
$$\left(\frac{E_{\max}}{TeV}\right)\sqrt{\frac{B}{\mu G}} = 101$$ ← synchro. Spec.



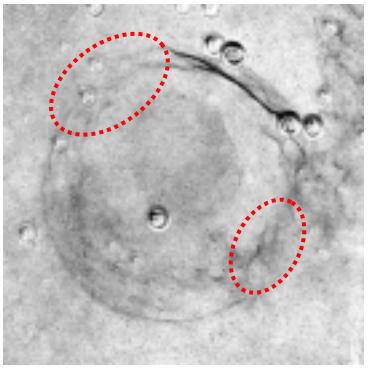
Naito et al. Astron. Nach. 320, 1999

SN1006 (electron acceleration)

Differential flux(3.8m + 10m)



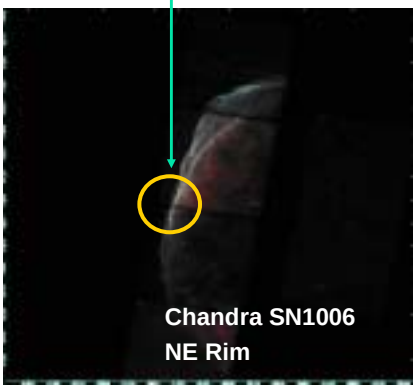
Optical (H_α) Image

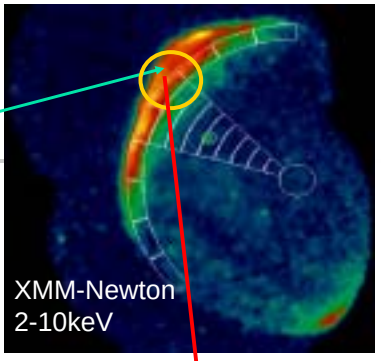


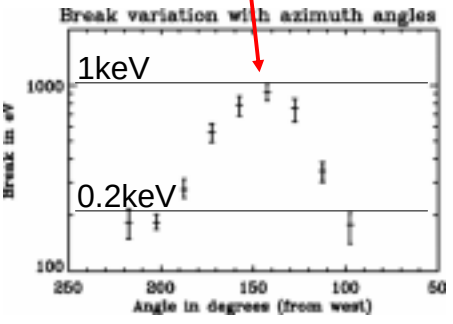
Winkler et al. astro-ph/0208415

Recent X-ray Observation

TeV γ Emission Region



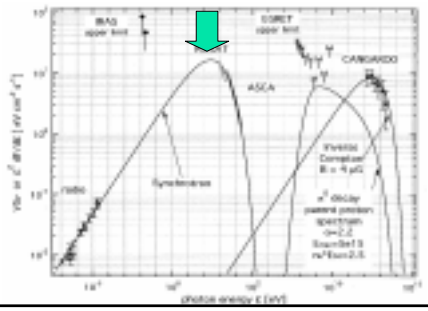




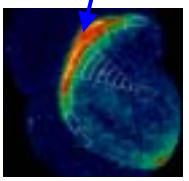
Observation by XMM

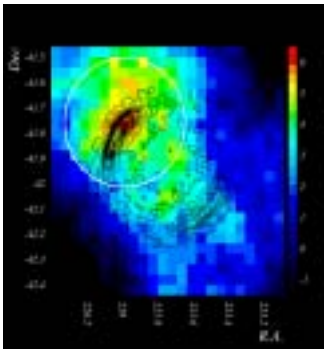
- Strong Correlation between TeV γ and Synchrotron X

1keV

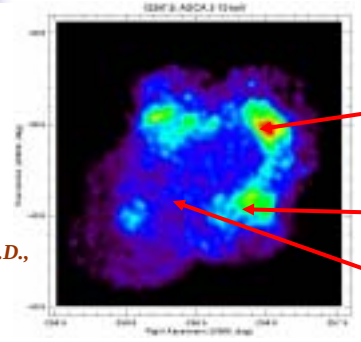


Maximum Cut-off Energy Point





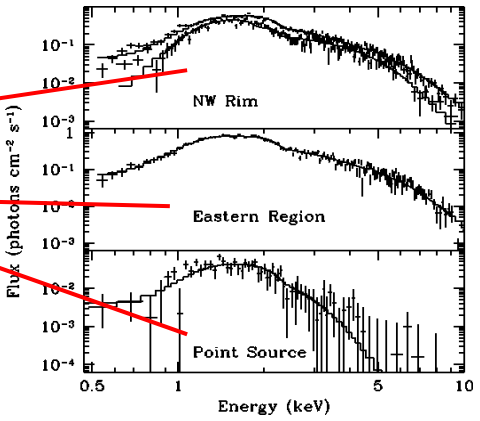
ASCA X-ray Observation of RXJ1713.7-3946



Tomida, Ph.D., 1999

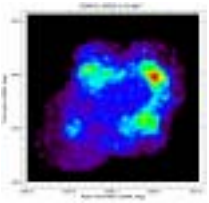
Synch. X-ray Emission(ASCA)

Distance ~1kpc or 6kpc ?



Slane et al, ApJ, 525,1999

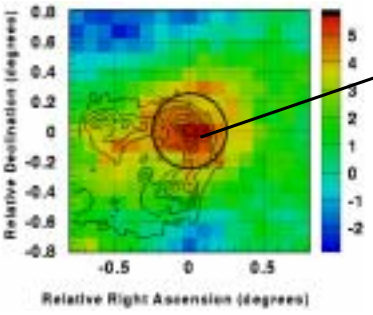
TeV gamma rays from RXJ1713



RXJ1713.7-3946

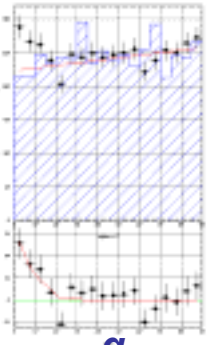
Synch. X-ray Emission(ASCA)

Tomida, Ph.D., 1999



TeV-Gamma 3.8m Tele.

Muraishi et al., A&Ap 354, 2000

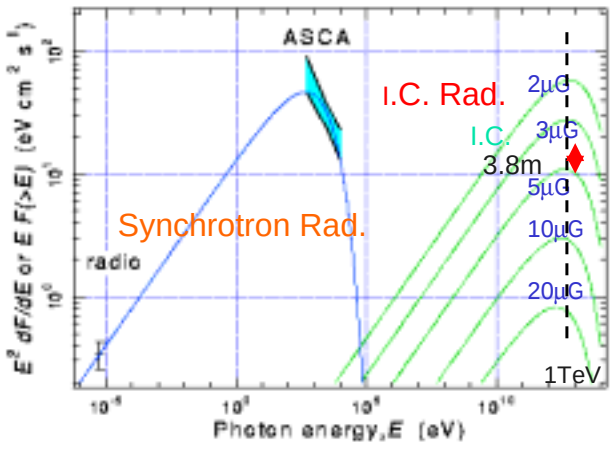


7m Tele. 1999 (16hours)

Eγ > ~1TeV ($E^{-2.5}$)

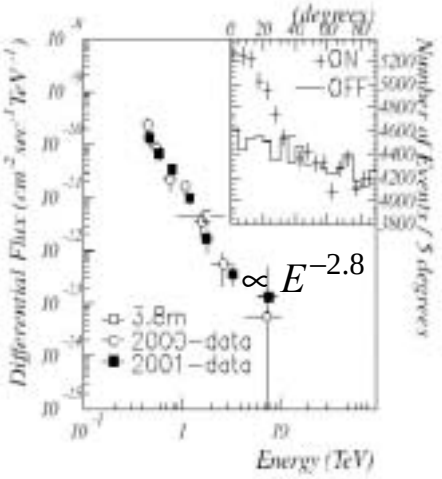
Multi wavelength Spectrum of synchrotron-I.C Model (RJX1713)

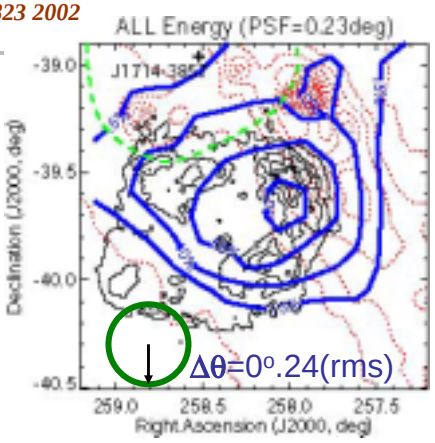
Naito et al 2001(CANGAROO)



RX J1713-3946 Spectrum

Enomoto et al, Nature, 416, 823 2002



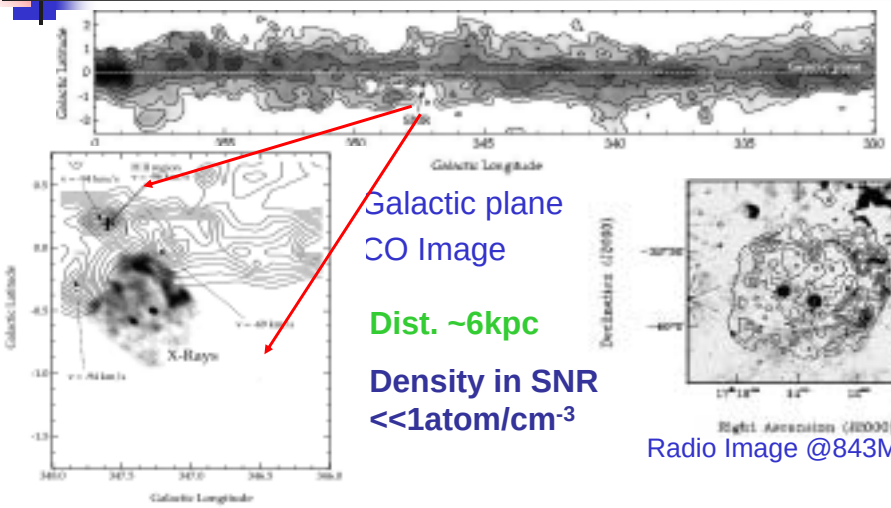


X-ray ..... Infra. Red

TeV γ

Proximity of RXJ1713.7-3946

Slane et al, ApJ, 525,1999



Galactic plane CO Image

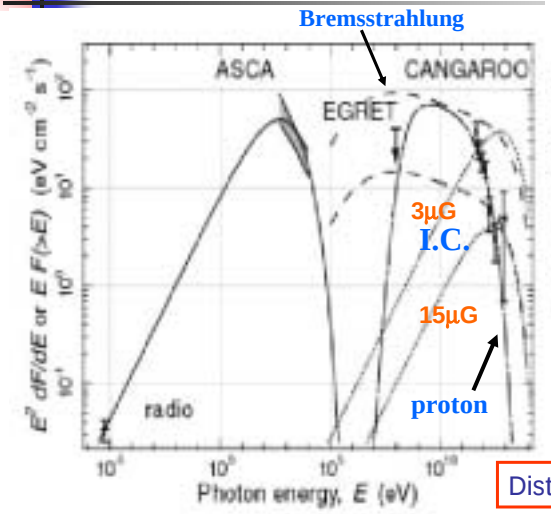
Dist. ~6kpc

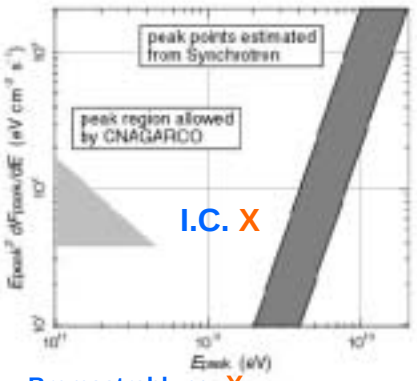
Density in SNR <<1atom/cm^{-3}

Radio Image @843MHz

Multi wavelength spectrum with Proton Model

Nature 416, 823 (2002)





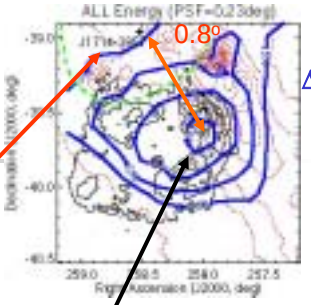
Bremsstrahlung X from X-ray spectrum

Dist. 6kpc ->~10 times of the Crab

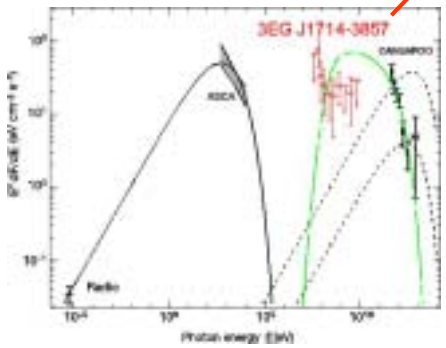
Counterarguments

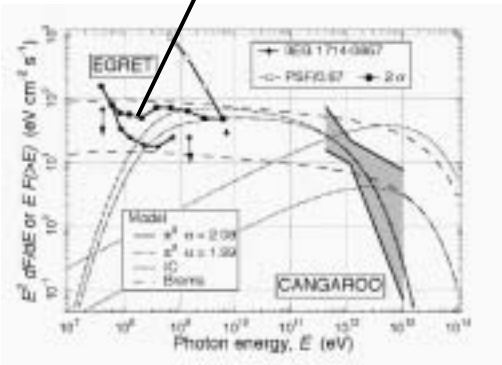
O.Reimer & M.Pohl A&A, 390, L43, 2002

M.Butt et al., Nature 418, 489, 2002

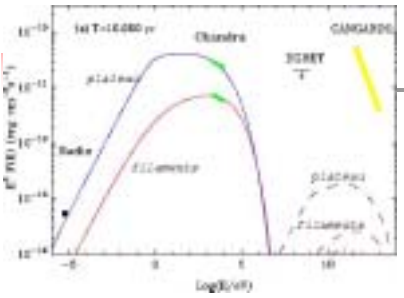


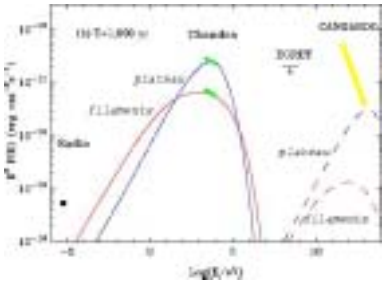
$\Delta\theta=0^{o}.24$





Counterarguments(cont.)

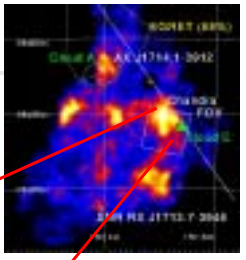




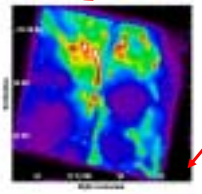
Uchiyama et al A&A 2002

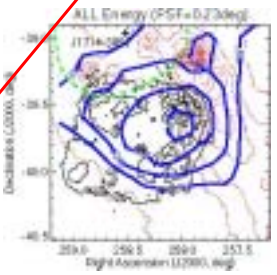
Chandra data

Consistent with ASCA spectrum



(ASCA)



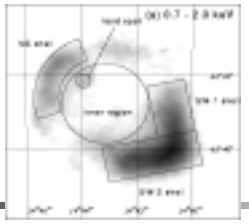


X-ray Synchrotron SNR

RCW86

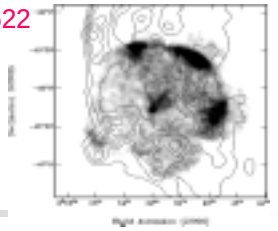
Dist. a few Kpc

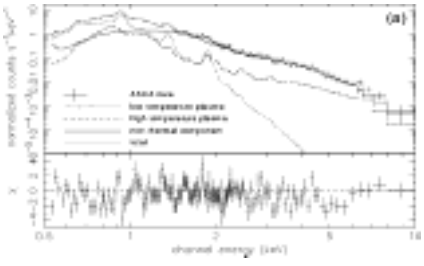
Type II

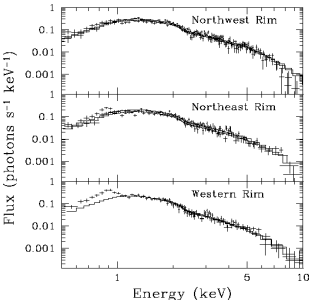


RX J0852-4622

Dist >1kpc?







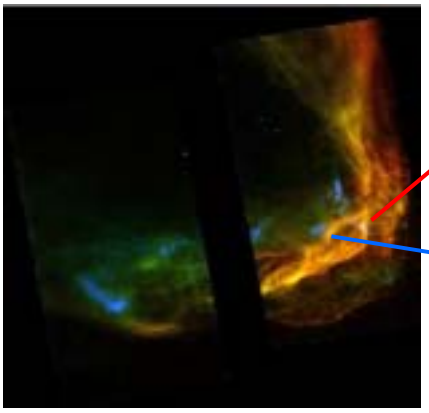
Bamba et al. 2000

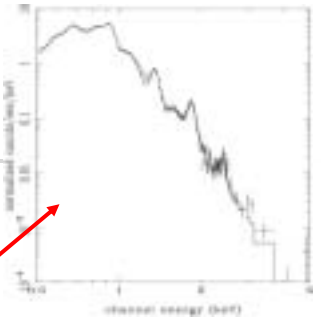
ASCA Results

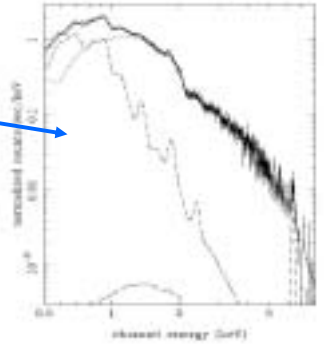
Slane et al. 2001

RCW86 Chandra Data

J.Rho et al., Astro-ph/0208013



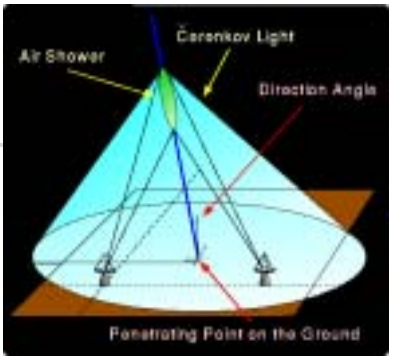


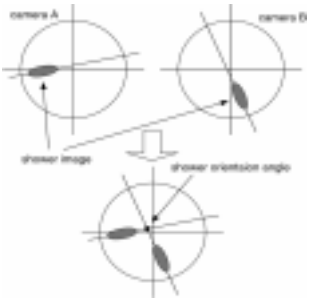


Red : 0.5-1 keV, Green :1-2 keV, Blue : 2-8 keV

CANGAROO-III (Stereo Observation)

- Array of four 10m telescopes(~2004)
- Full Imaging:
  Angular Res. ~0.1 deg.
- Energy Threshold: ~100GeV





Summary

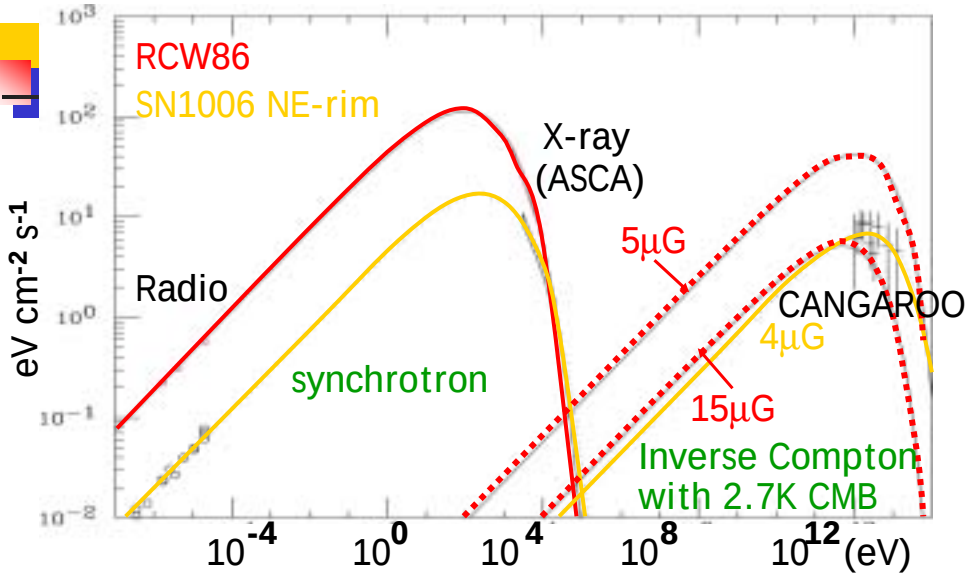
- VHE Gamma-Ray Sources: Pulsar/nebulae, SNR, AGN
- Almost Sources due to electrons: I.C. Gamma Rays

Where is Proton?? Where is Cosmic Origin??

But,

- Several SNRs presumably emit TeV gamma rays.
- *One Convincing Candidate of Proton Acceleration Site; RXJ1713-3934*
- *Another Synch.X-ray SNRs;* RCW86 *and* RX J0852-4622

Multi-Wave length Spectrum (RCW86)



Galactic Targets in CANGAROOII

- SNR: e(Synch.+IC) or proton? SN006, RX J1713-3946, RCW86, RX J0852-4622,
- Pulsar/nebula: Non-pulsed, Young pulsar + synchrotron nebula IC with 2.7K or SSC by $e^{\pm}$
  Crab, PSR1706, Vela Pulsar, PSR1509, PSR1259, PSRJ1420(EGRET UN ID)
- **Others:** SS433, Galactic Center
- **No source due to proton acceleration??**