Results from CANGAROO:

Southern Sky(Galactic Objects)

1.Introduction
2.SNR & Cosmic Ray Origin
3.Another Results

Toru Tanimori (Kyoto Univ.)
For the CANGAROO Collaboration

7, Aug, 2003@SLAC Topical Conference

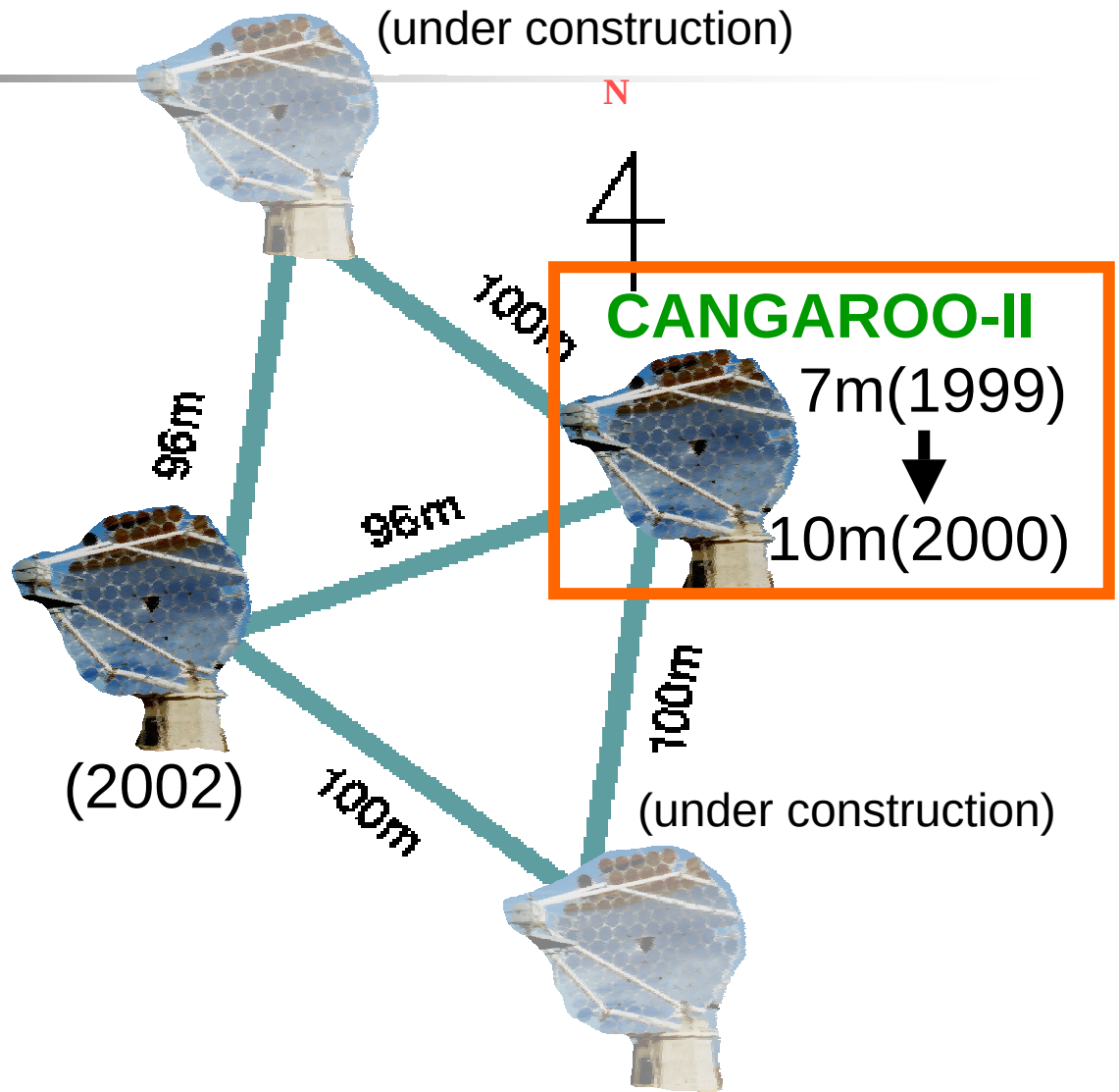
CANGAROO-III project

Array of four 10m imaging atmospheric Cherenkov telescopes to detect

gamma-rays E>200GeV

in Woomera, South Australia

31 ° 06‘**S,** 136 ° 47’**E**, 160m a.s.l



CANGAROO collaboration

CANGAROO III

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

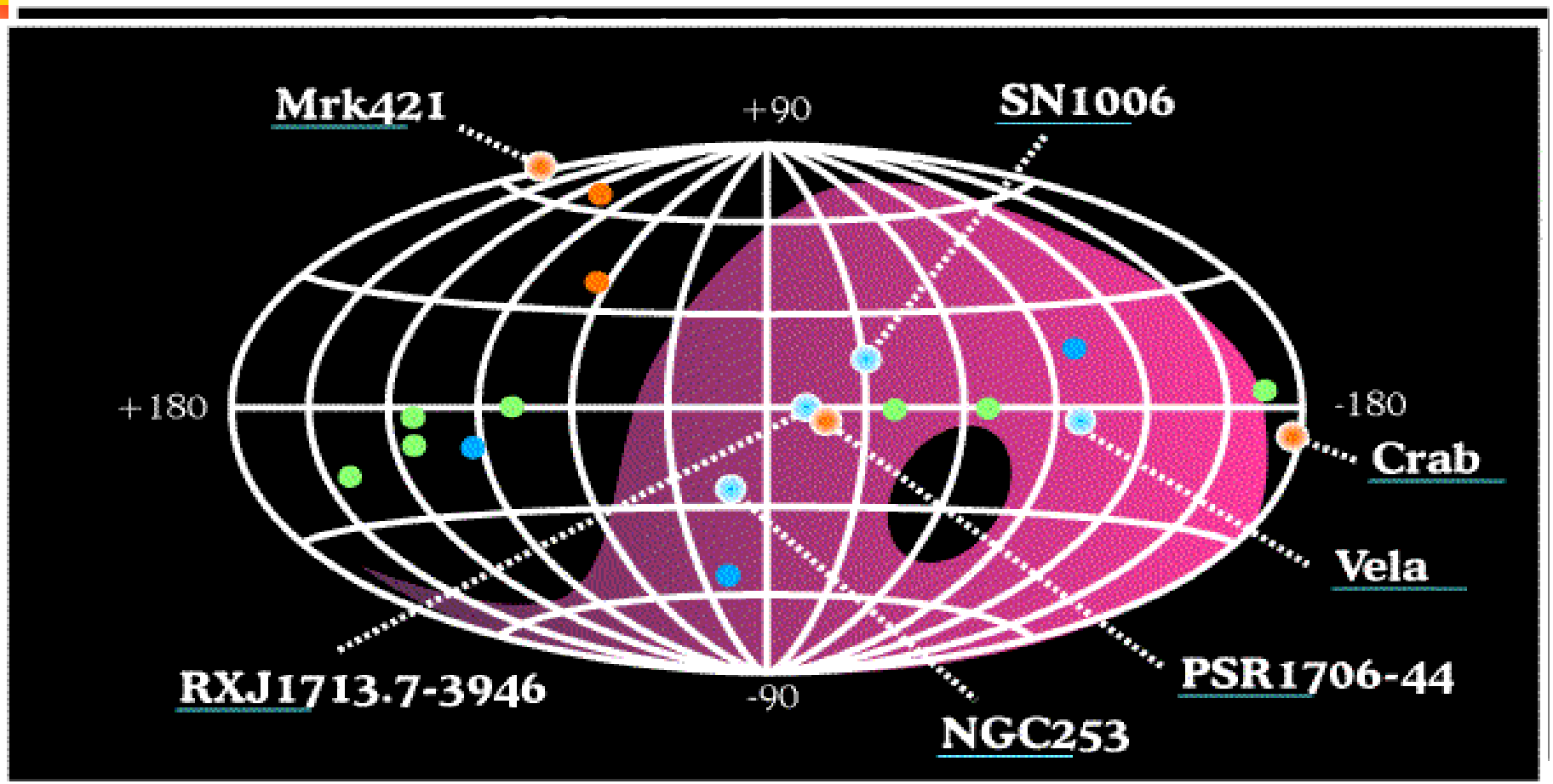
- University of Adelaide
- Australian National University
- Ibaraki University
- Ibaraki Prefectural University
- Kanagawa University
- Konan University
- Kyoto University
- Nagoya University
- National Astronomical Observatory of Japan
- The University of Tokyo,ICRR
- Shinshu University
- Institute for Space and Aeronautical Science
- 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°)

1992 3.8mϕ (1.2TeV)

TeV gamma-ray sky ~ 2003



- Grade A
- Grade B
- Grade C

Red: Grade A

Blue: Grade B

Black: Grade C

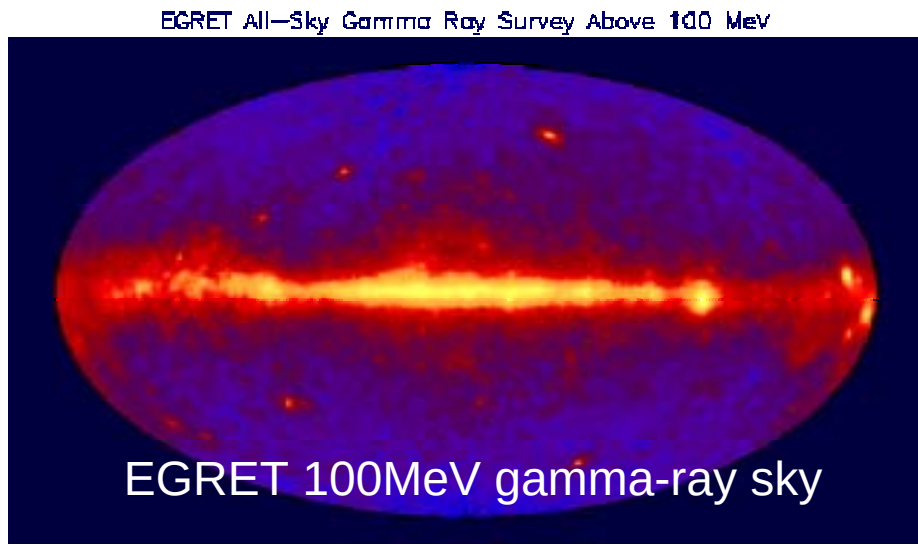
TeV sources

CANGAROO Detected

3 Pulsar nebulae	Crab Vela PSR 1706-44
8 Blazars	Mrk 421 Mrk501 1ES2344+514 PKS2155-304 3C66A BL Lac 1H1426+428 1ES1959+650
3 Supernova remnants	SN1006 → Grade A (ICRC2003) RX J1713.7-3946 Cas.A
1 X-ray Binary	Cen X-3
galaxies	NGC253, M87

Galactic Targets in CANGAROO

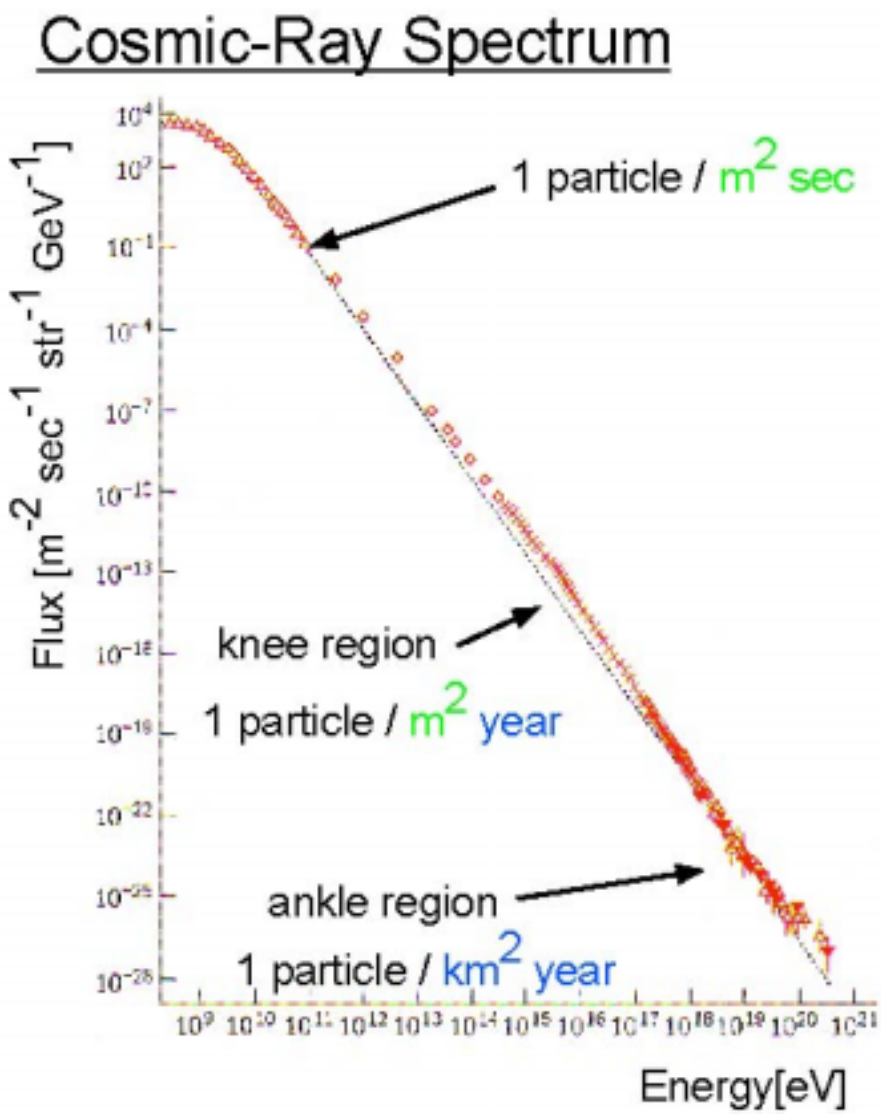
- SNR: e(Synch.+IC) or proton? SN006, RX J1713-3946, RCW86, RX J0852-4622,
- Pulsar/nebula: Non-pulsed, Young pulsar + synchrotron nebula IC with 2.7K or SSC by $e^{\pm}$
  Crab, PSR1706, Vela Pulsar, PSR1509, PSR1259, PSRJ1420(EGRET UN ID)
- **Others:** SS433, Galactic Center
- **proton acceleration??**



EGRET 100MeV gamma-ray sky

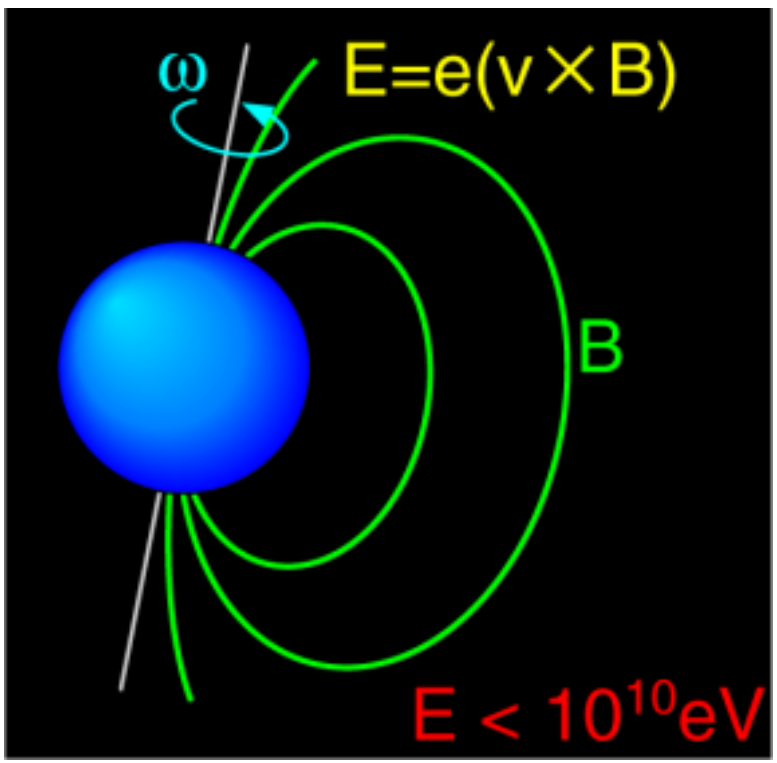
Origin of Cosmic Rays (Galactic)

- **Energetics of Cosmic Rays(<10^{16} eV)**
  Required Energy Supply
  ~10^{40} erg/s
  (τ ~ $10^{6\sim7}$ yrs, ρ_{CR} ~ 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)

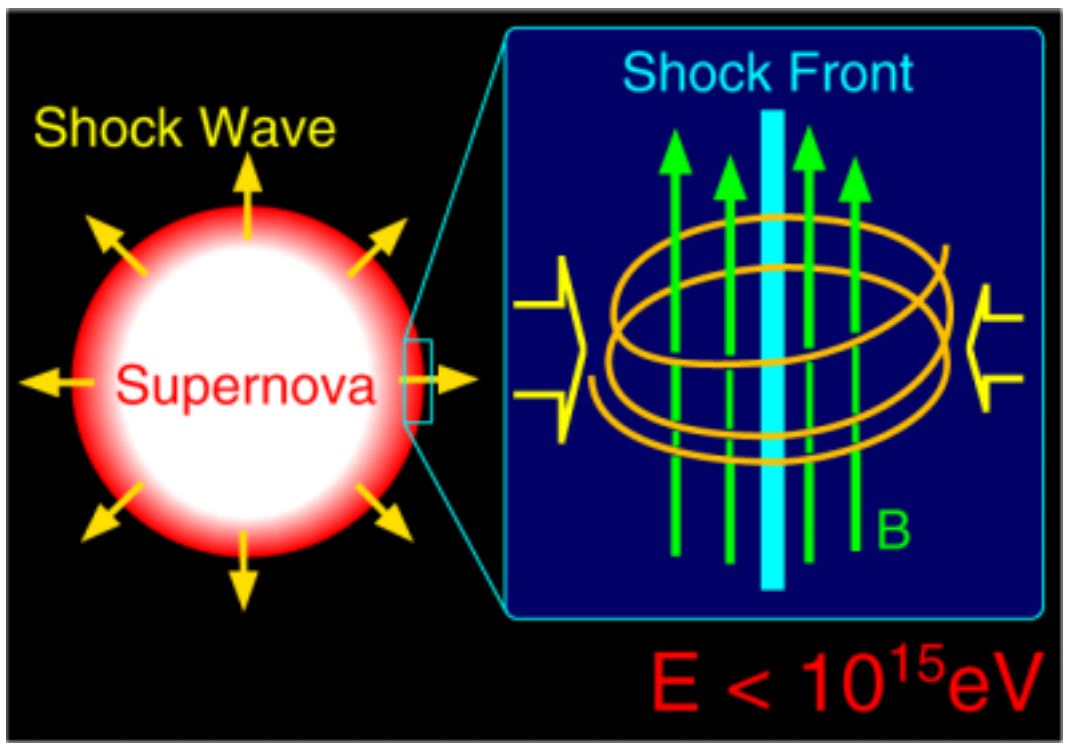


Cosmic Accelerators

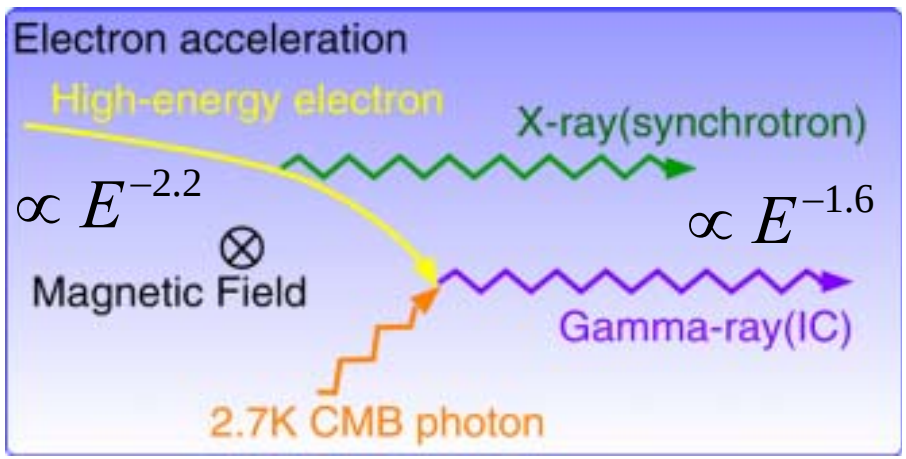
High Electrostatic field (one shot)

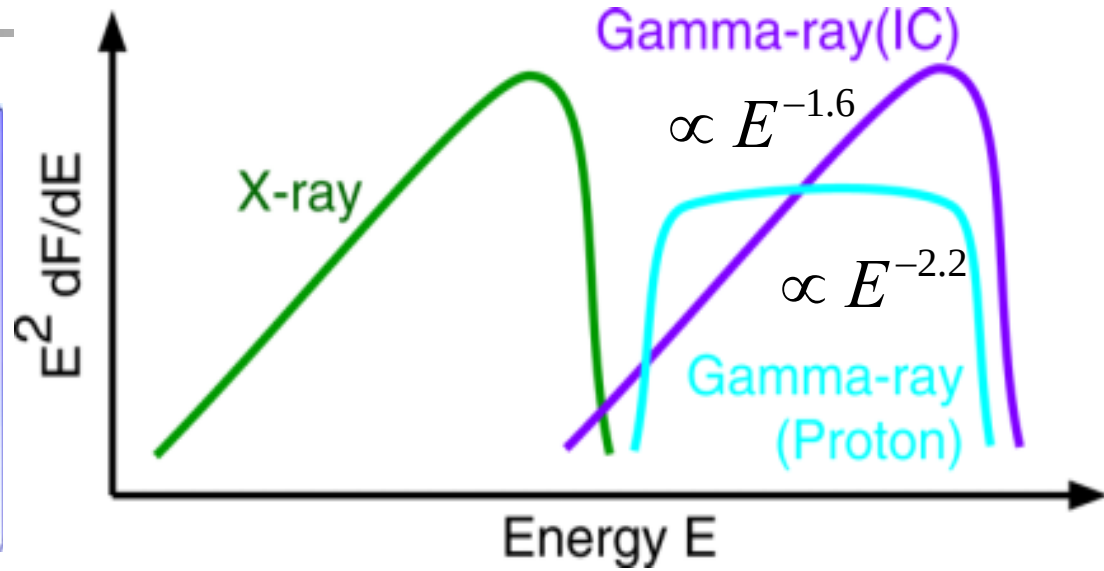


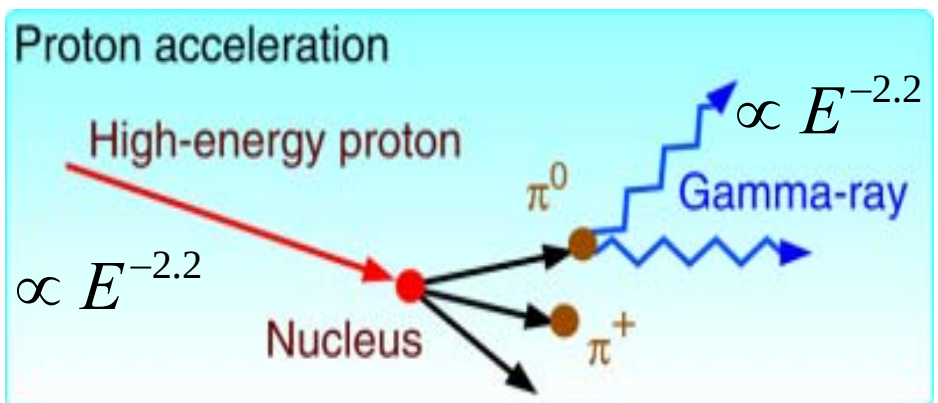
Shock Acceleration (1st order)



Process of TeV Gamma-Ray Emission







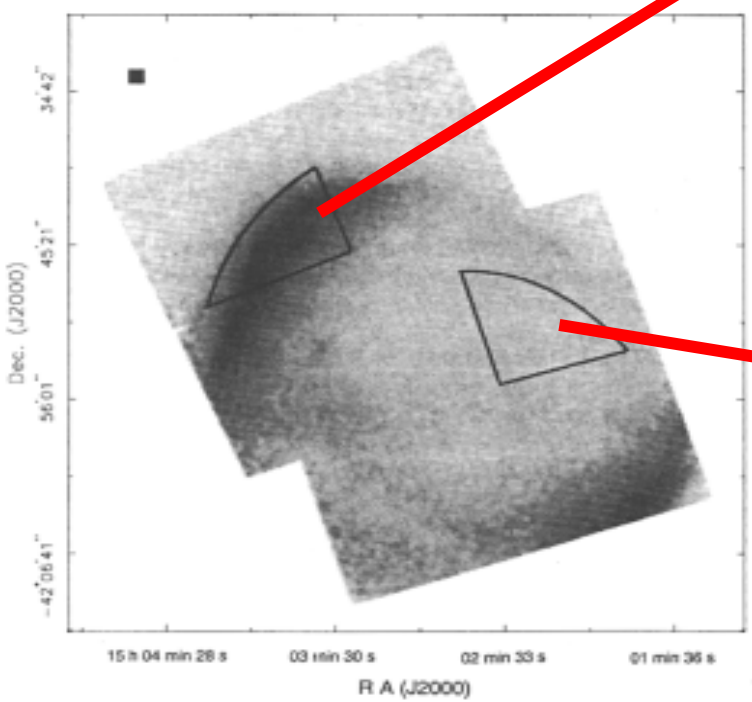
$$\left(\frac{dE}{dt}\right)_{\mathrm{I.C.}} = \frac{4}{3}\sigma_{\mathrm{T}}\, c\, \gamma_{\max}^{2}\, \mathrm{U}_{\mathrm{photon}}$$

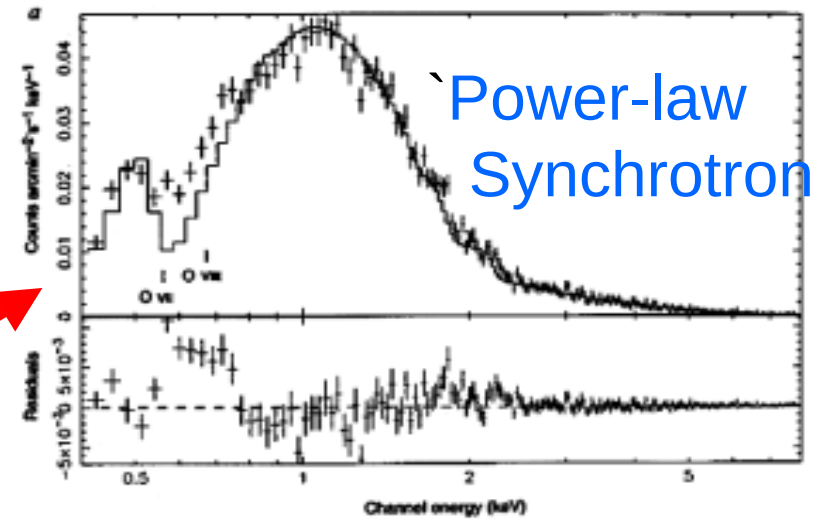
$$\left(\frac{dE}{dt}\right)_{\mathrm{Sync}} = \frac{4}{3}\sigma_{\mathrm{T}}\, c\, \gamma_{\max}^{2}\, \frac{B^2}{2}$$

Observation by ASCA/SIS

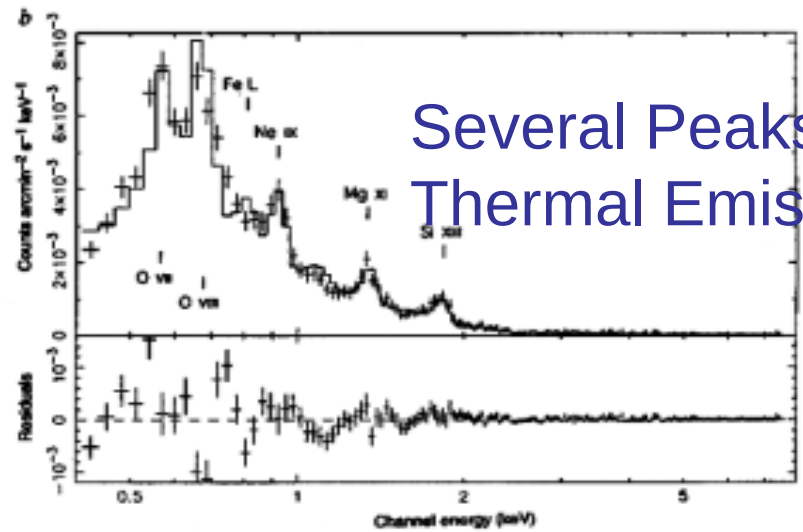
Koyama et al.1995

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



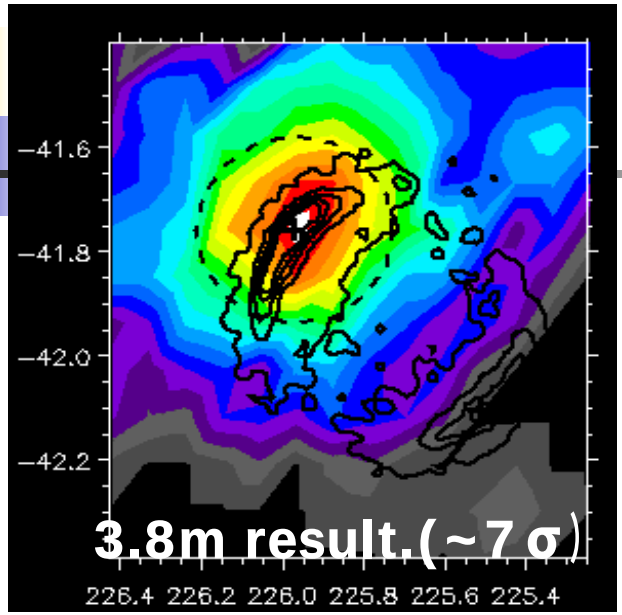


`Power-law Synchrotron Rad.

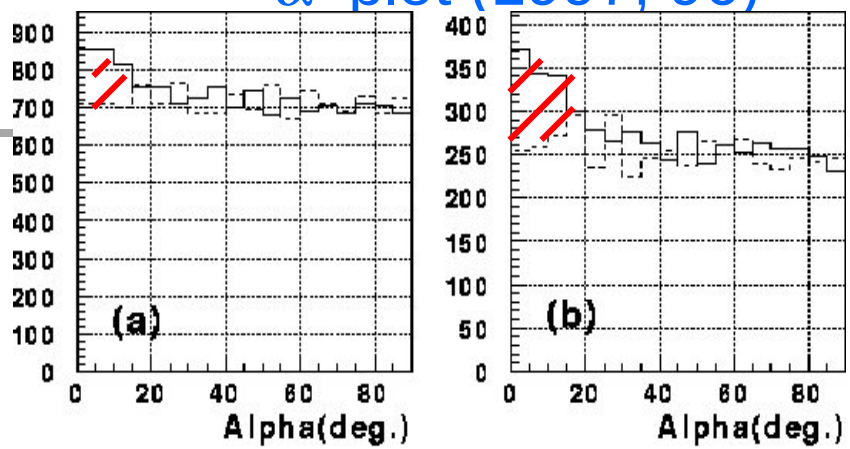


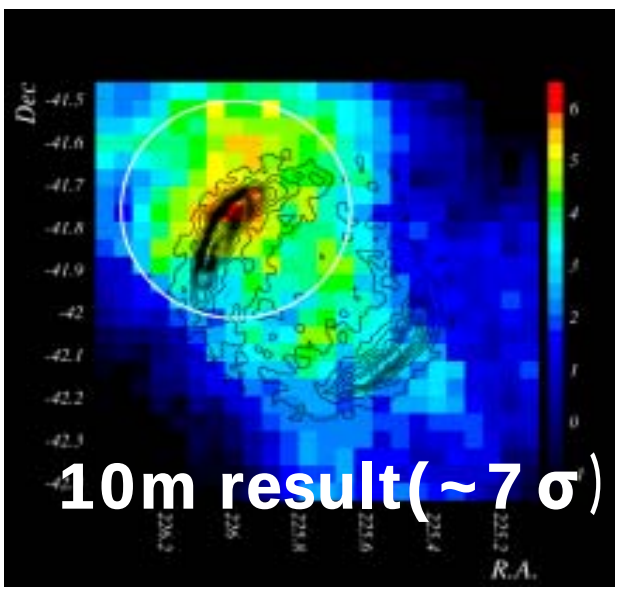
Several Peaks: Thermal Emission

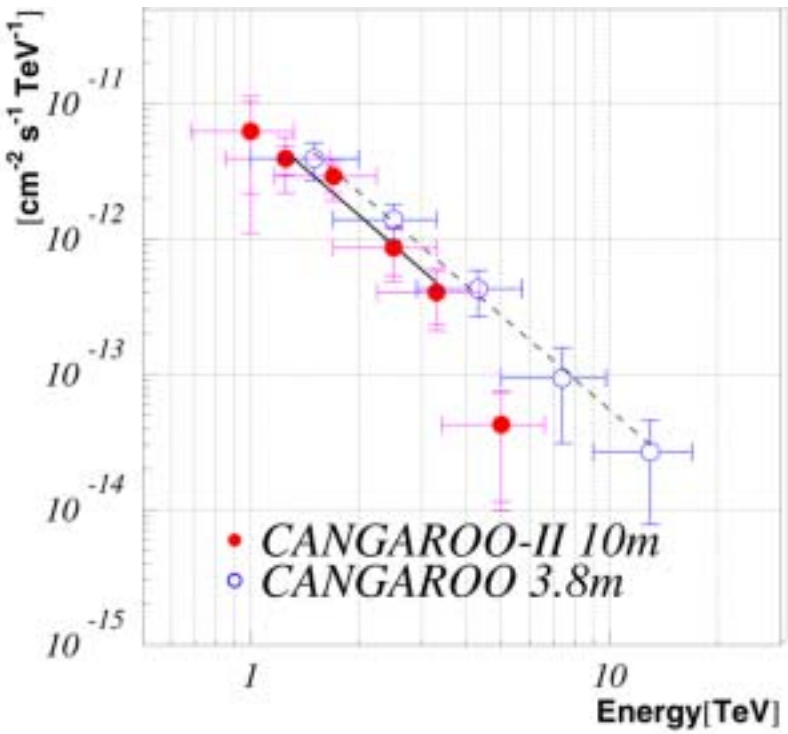
TeV Gamma Rays from SN1006



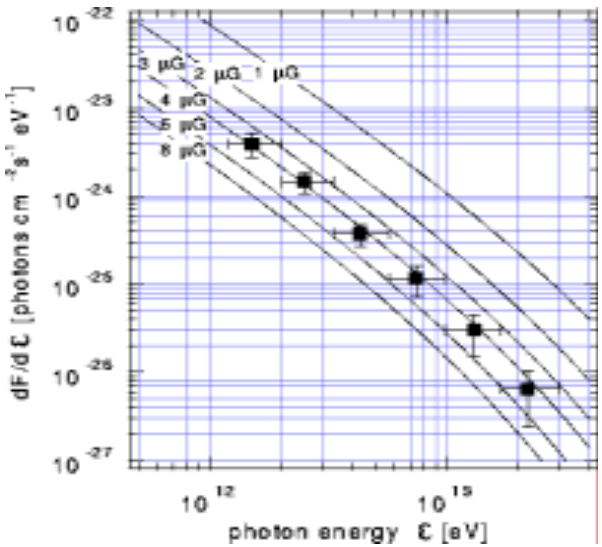
α–plot (1997, 96)



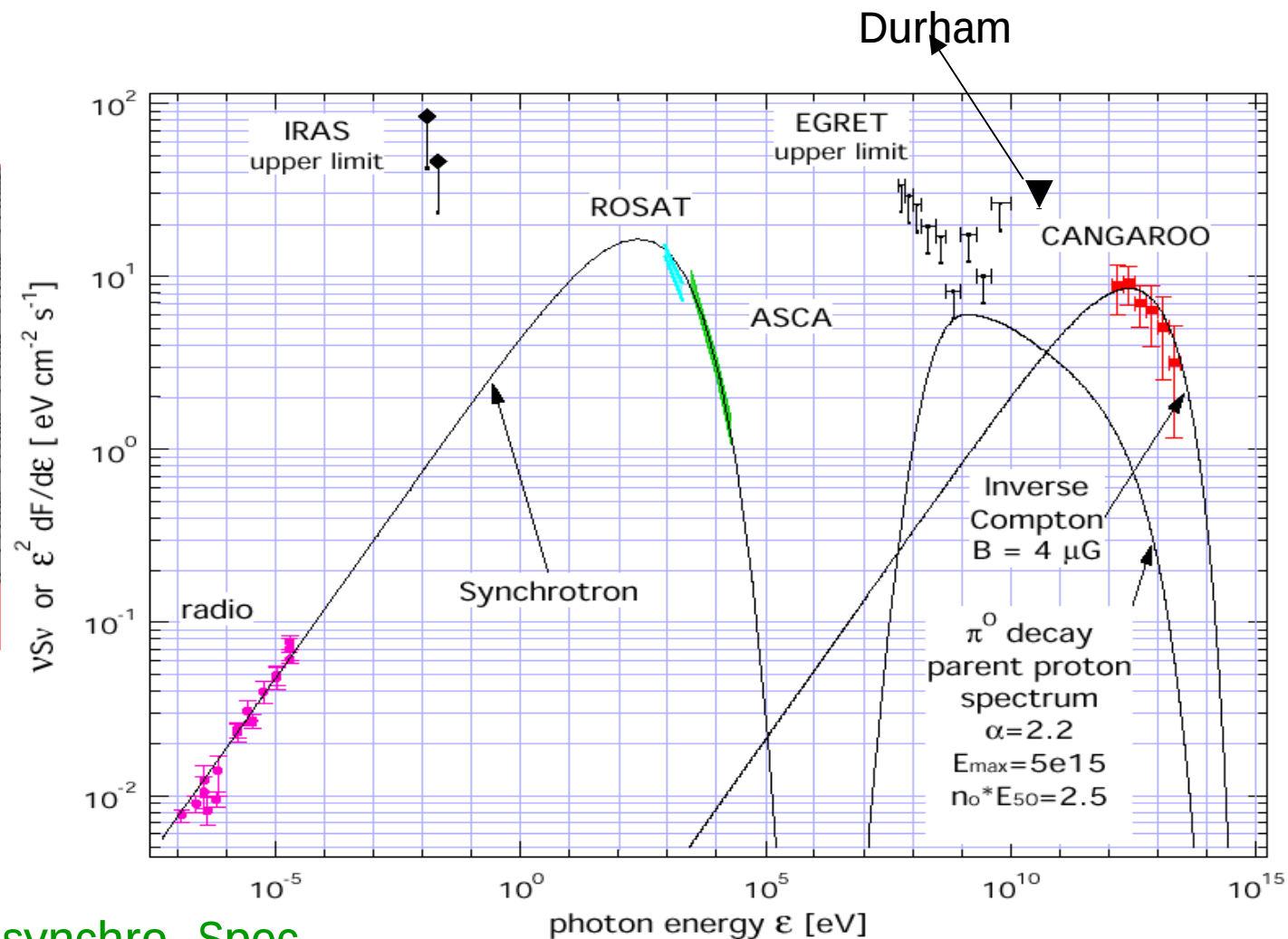




Multi band Spectrum & Fitting



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

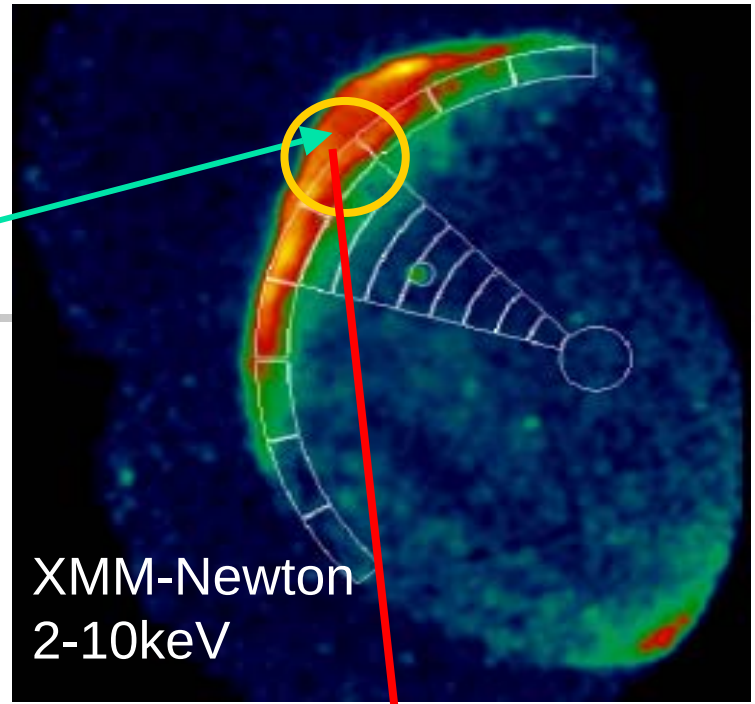


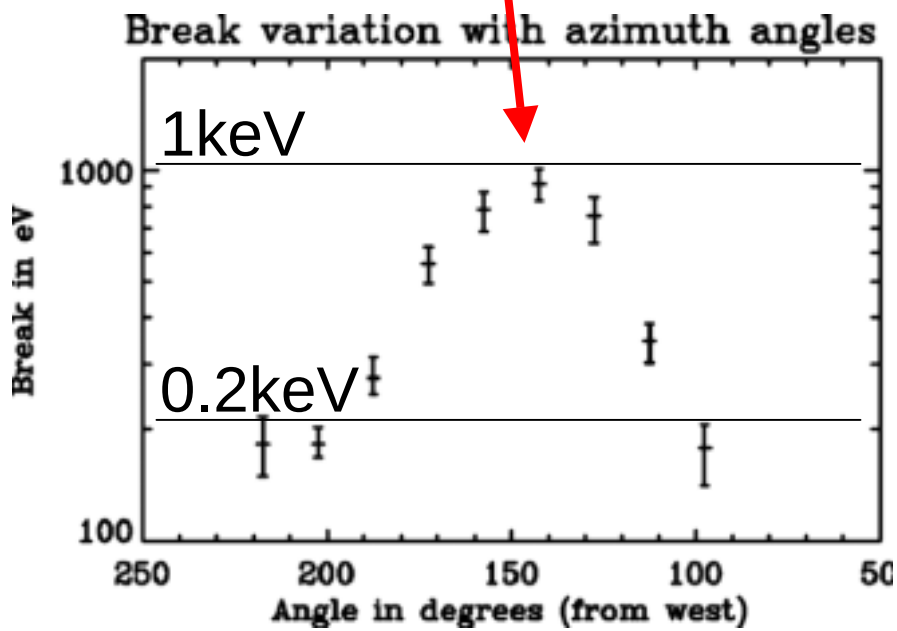
$$\left(\frac{E_{max}}{TeV}\right)\sqrt{\frac{B}{\mu G}} = 101$$ ← synchro. Spec.

Naito et al. Astron. Nach. 320, 1999

Recent X-ray Observation

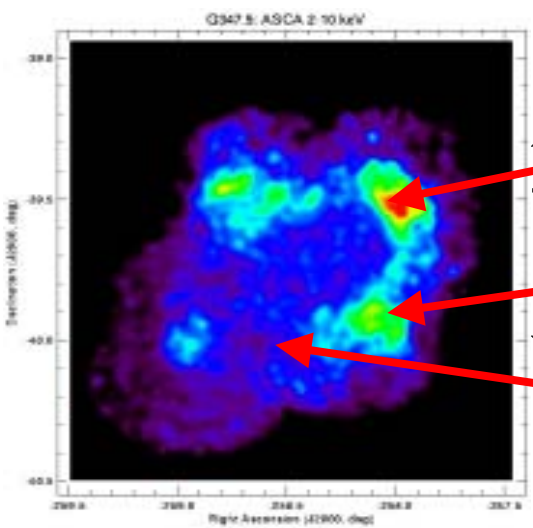
TeV γ Emission Region



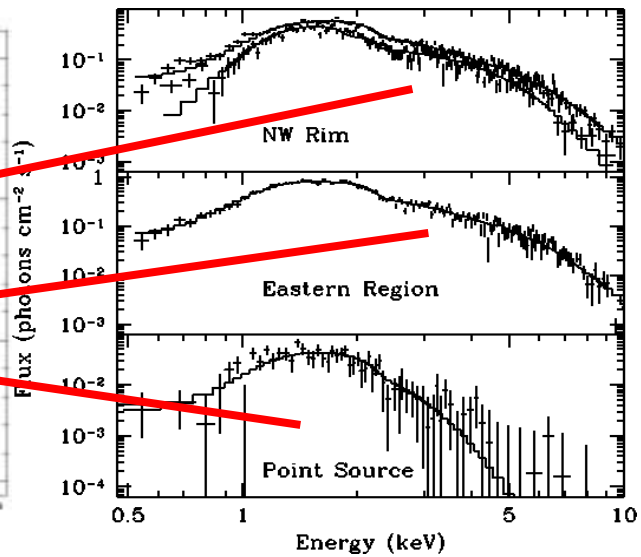


X-ray & Gamma-Ray Observations of RXJ1713.7-3946

Synch. X-ray Emission(ASCA)

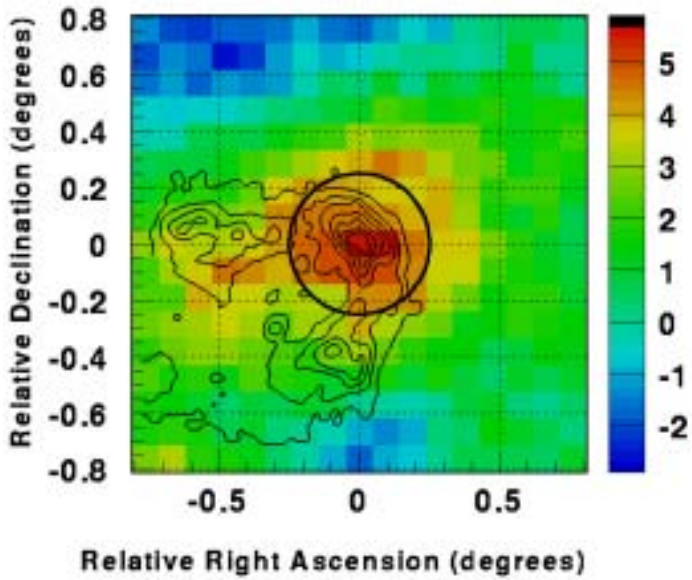


Tomida, Ph.D., 1999



Slane et al, ApJ, 525,1999

TeV-Gamma 3.8m Tele.



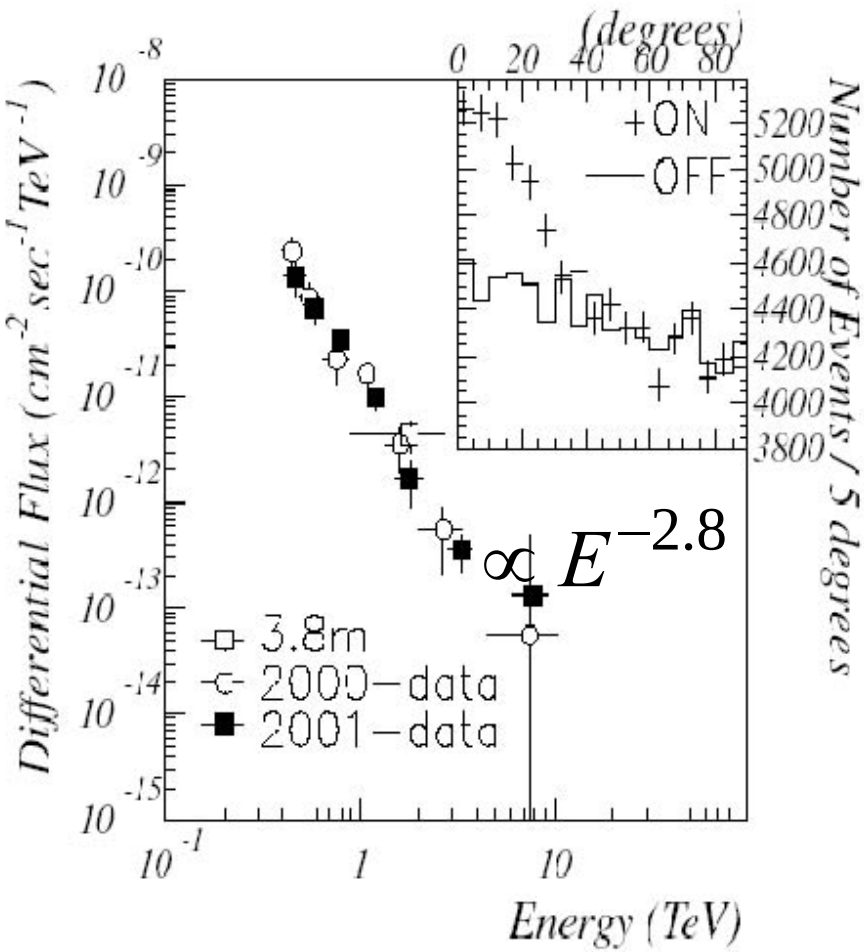
Muraishi et al., A&Ap 354, 2000

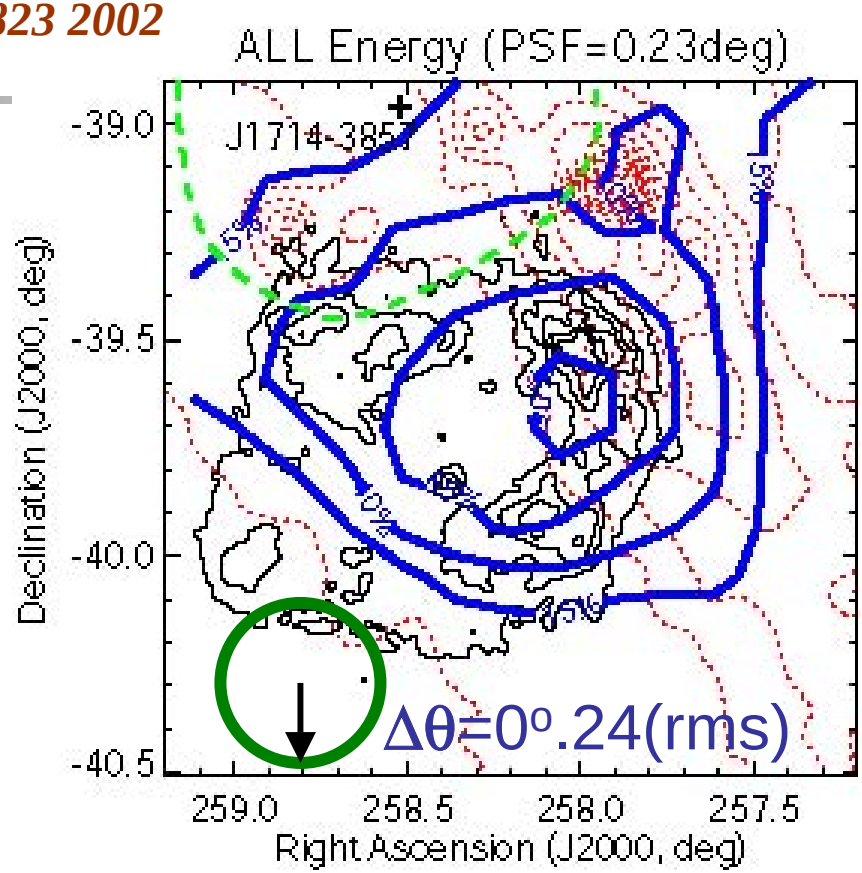
$E\gamma > \sim 1.5\text{TeV}\ (E^{-2.5})$

Distance ~1kpc or 6kpc ?

RX J1713-3946 Spectrum

Enomoto et al, Nature, 416, 823 2002



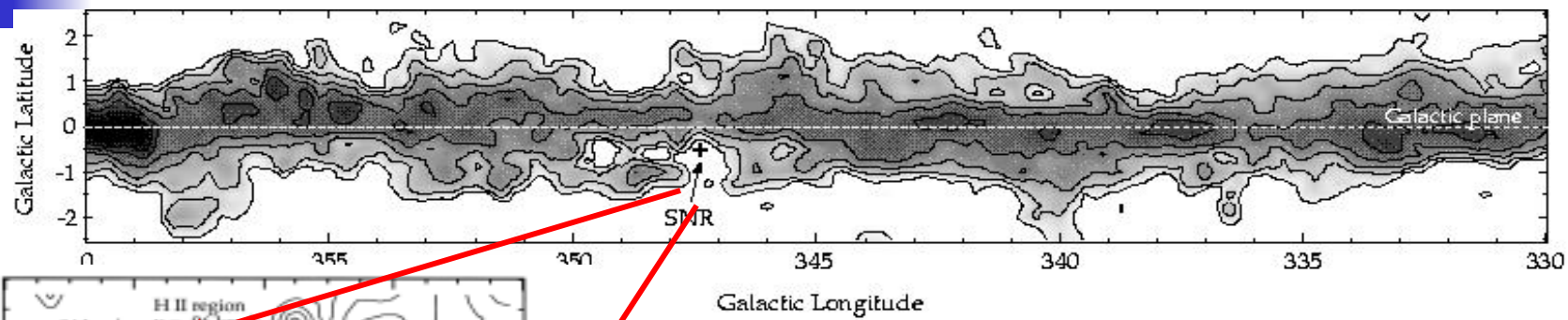


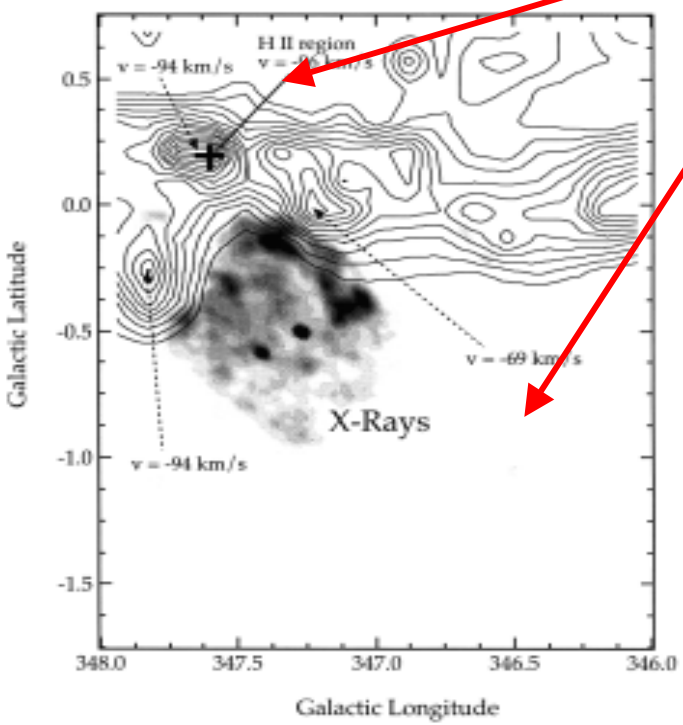
X-ray ..... Infra. Red

TeV γ

Proximity of RXJ1713.7-3946

Slane et al, ApJ, 525,1999



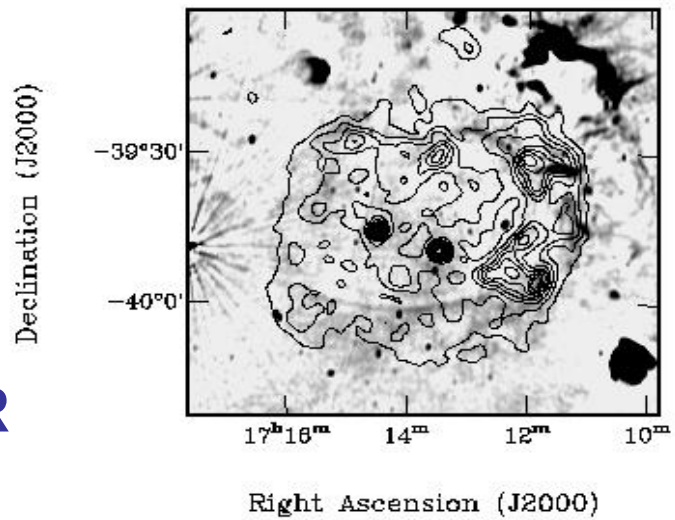


Galactic plane

CO Image

Dist. 2 or 6kpc

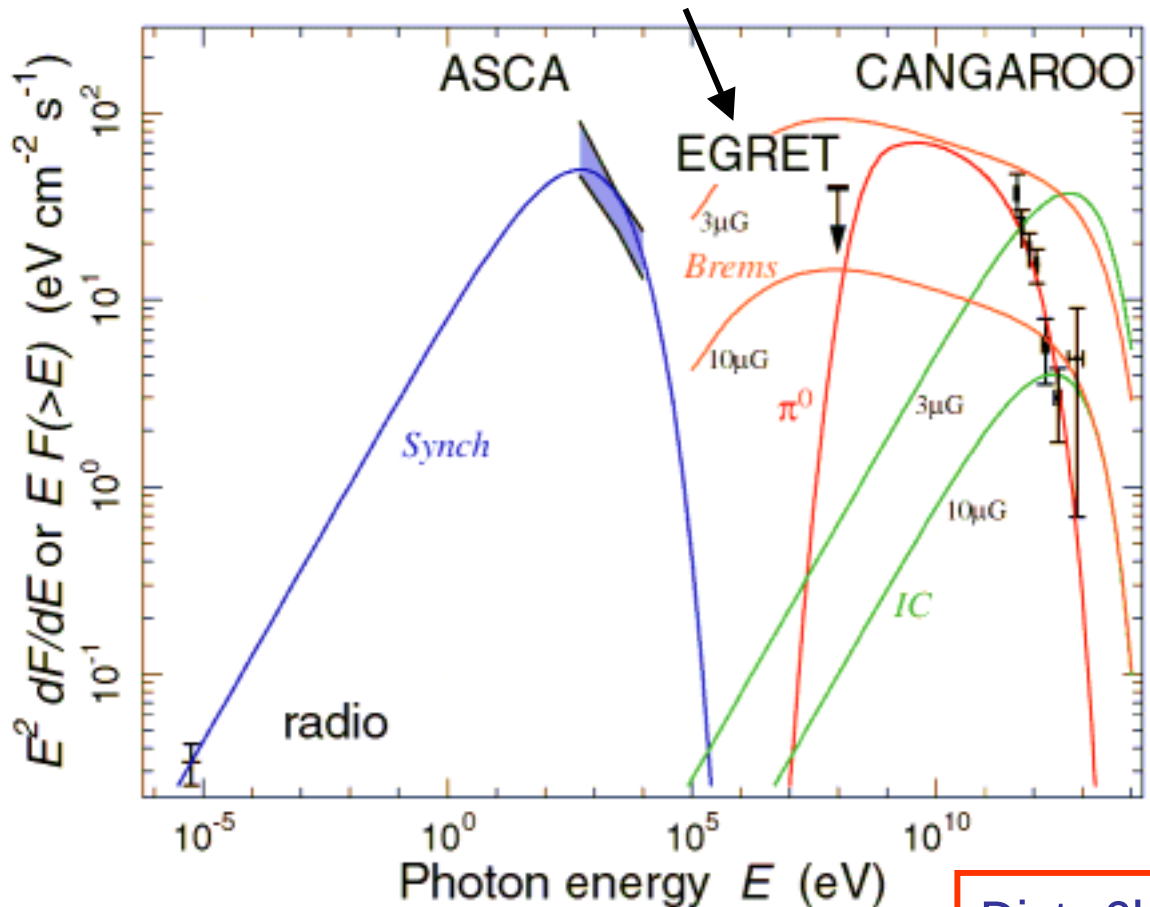
Density in SNR
<<1atom/cm^{-3}

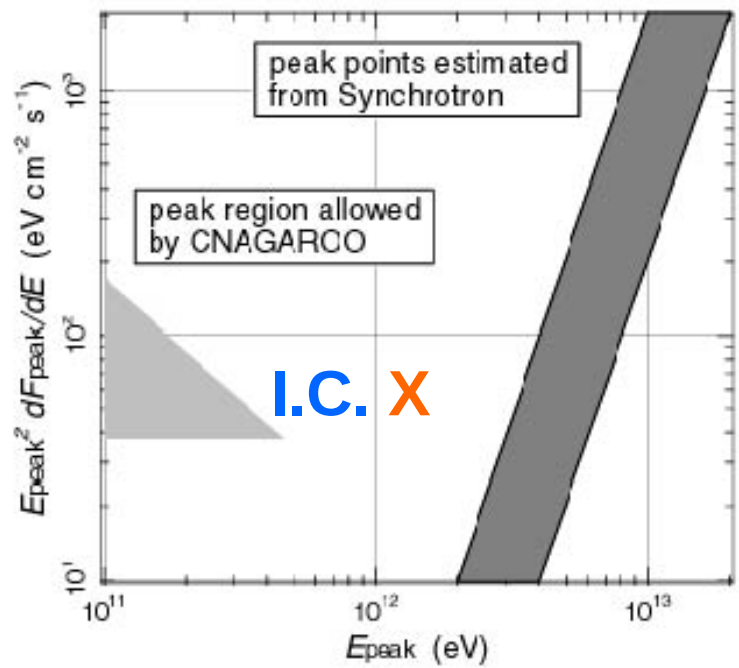


Radio Image @843MHz

Multi wavelength spectrum with Proton Model

Nature 416, 823 (2002)





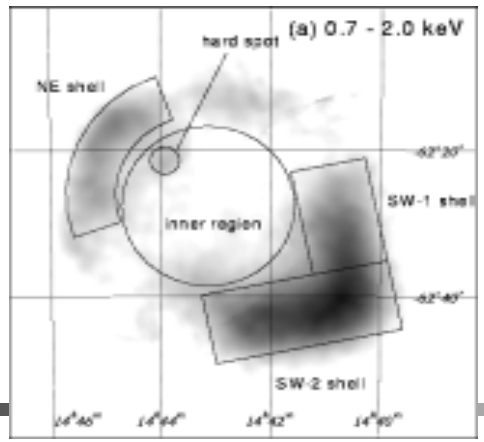
Bremsstrahlung X from X-ray spectrum

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

X-ray Synchrotron SNR

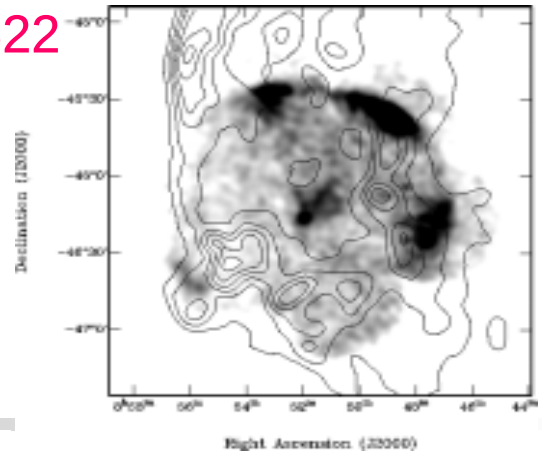
RCW86

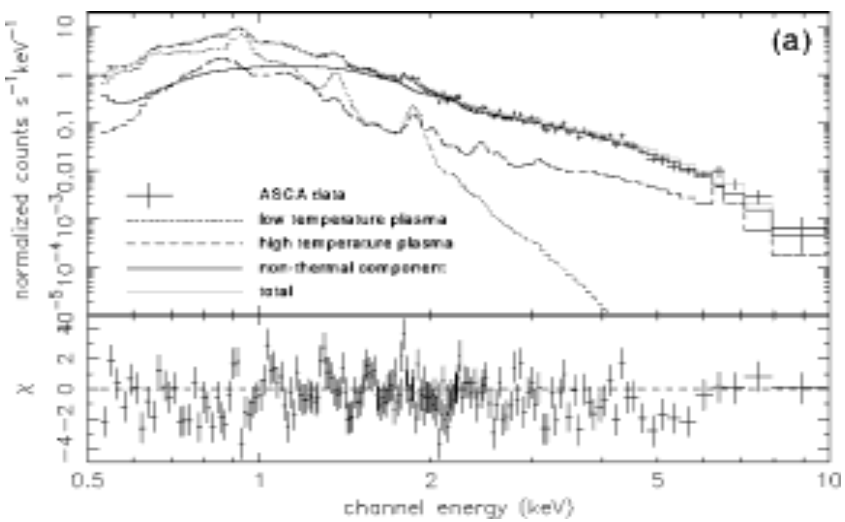
Dist. a few Kpc
Type II

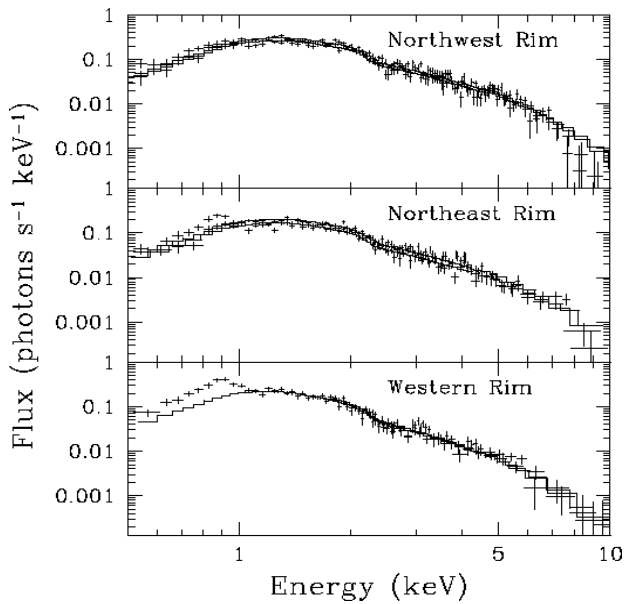


RX J0852-4622

Dist >1kpc?





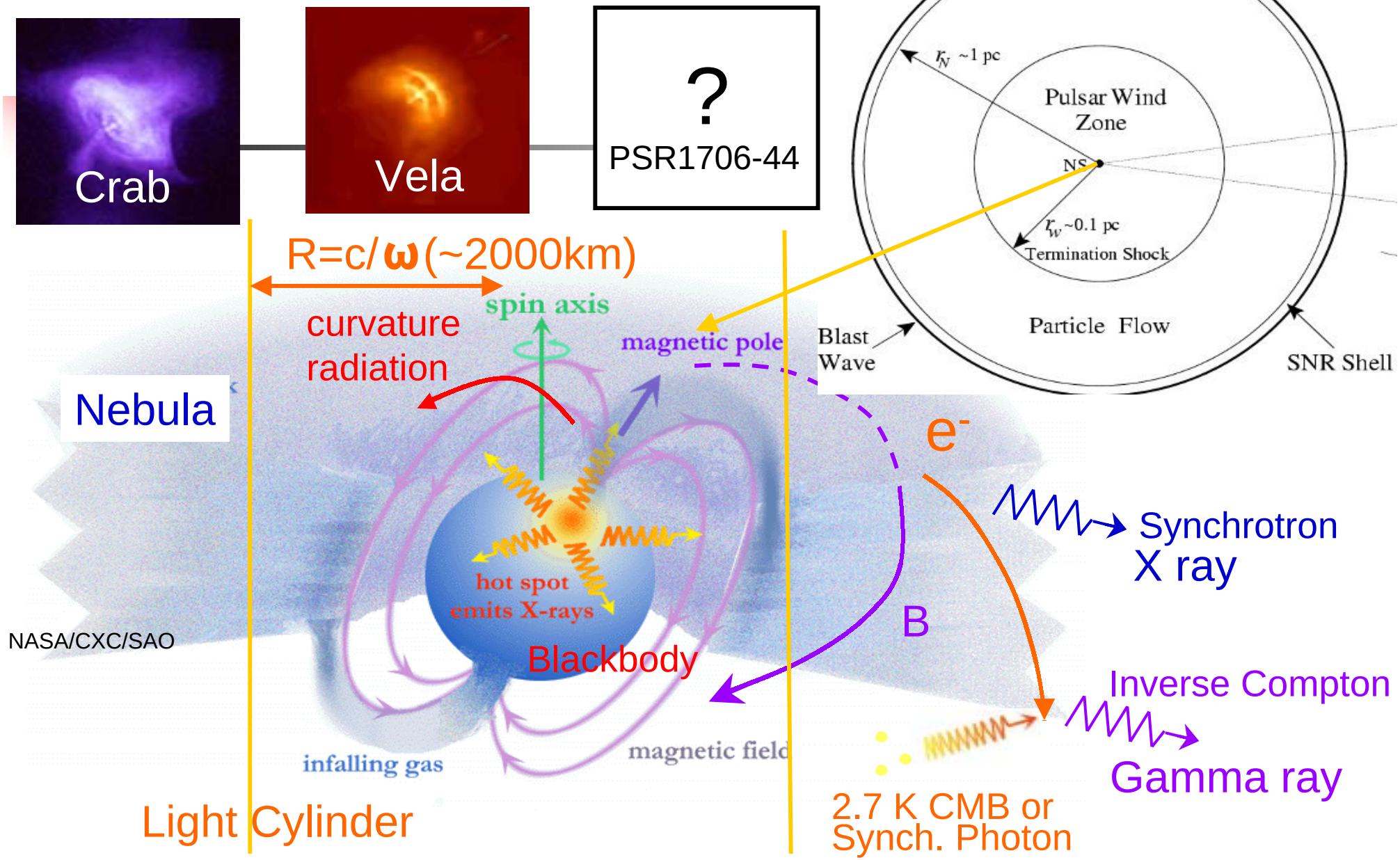


Bamba et al. 2000

ASCA Results

Slane et al. 2001

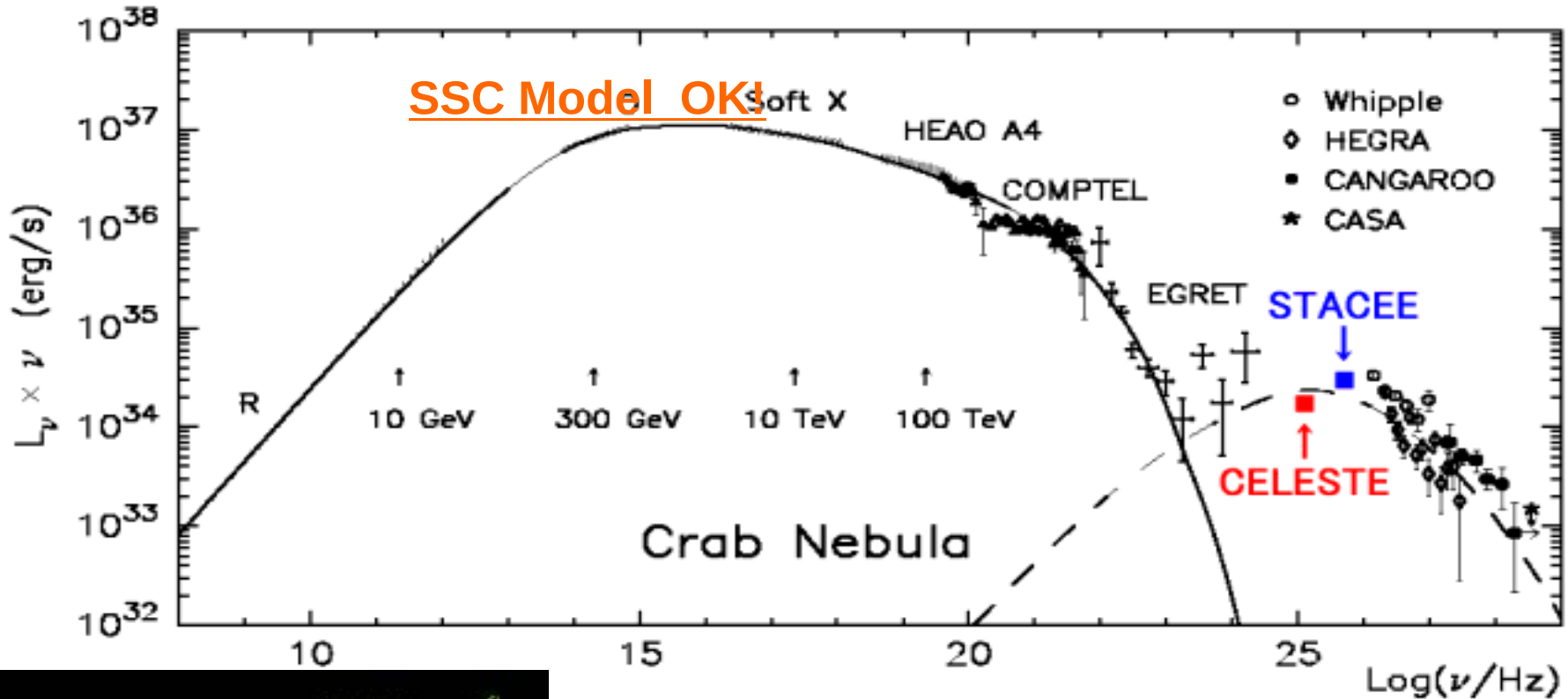
Pulsar-Nebulae

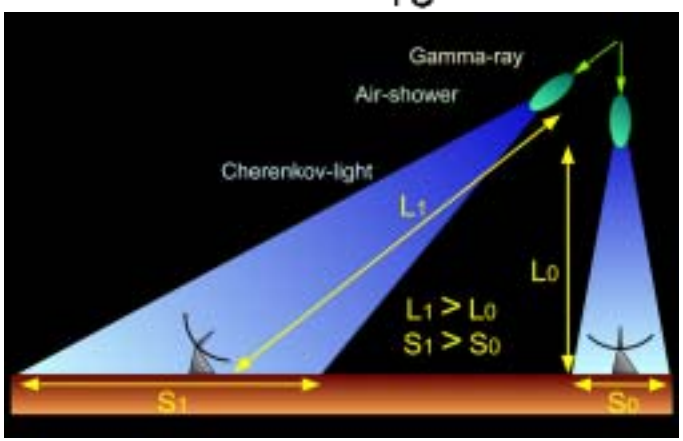


NASA/CXC/SAO

Crab nebula(unpulsed)

Aharonian & Atoyan, astro-ph/9803091

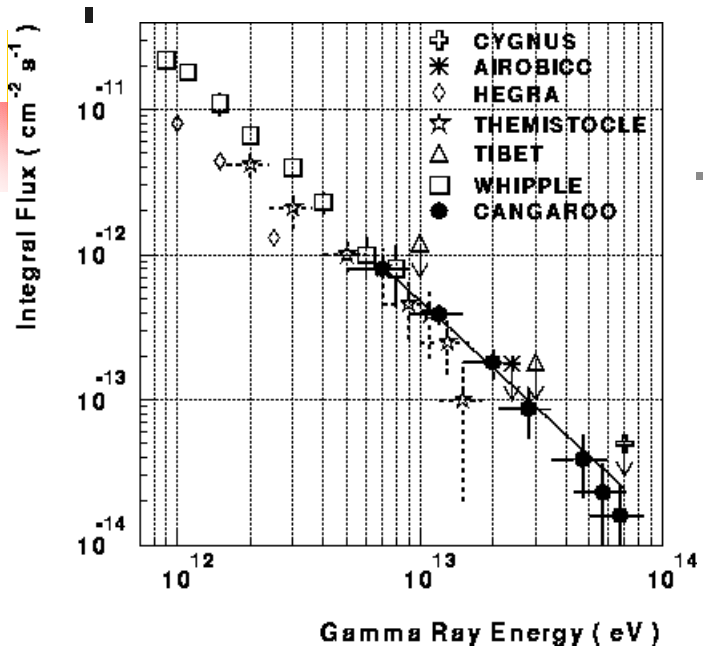




Max. of acceleration energy ?

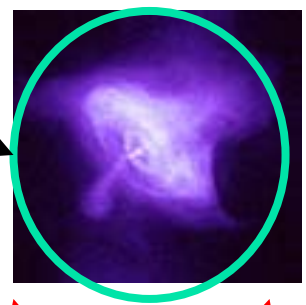
~20 TeV or >100 TeV

Observation of Crab nebula (Highest Energy)



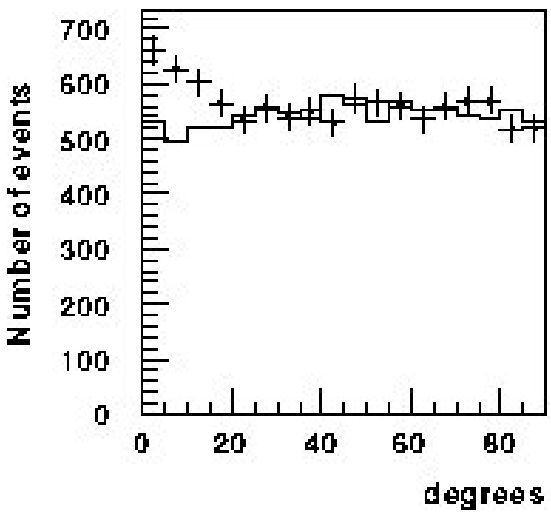
3.8m Tel. (70TeV)

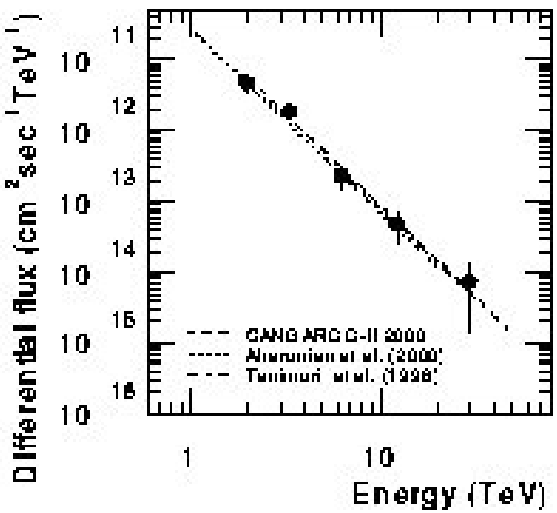
0.°1



10mCANGAROO Tel.
10hrs, Observation
5.9σ

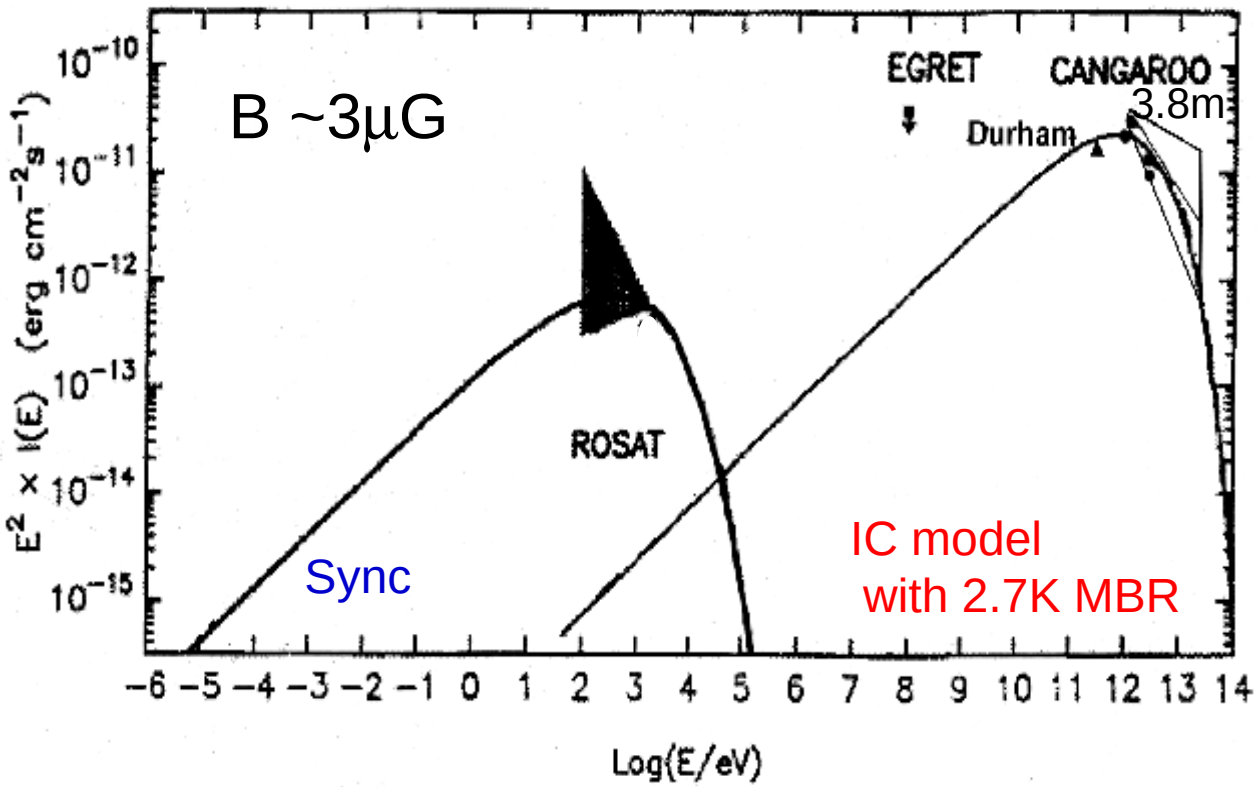
2TeV ~ 20TeV





Multi-wavelength Model (PSR1706)

PSR1706-44 unpulsed spectrum, from Nebula



Aharonian,Atoyan and Kifune et al(1997)

<Model>

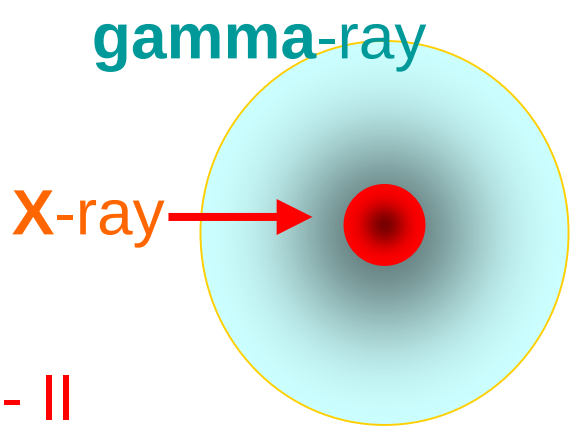
Different size of Emission regions

X-ray :r_x < 30 arcsec

B=20μG

Gamma-ray:r_γ < 0.˚1

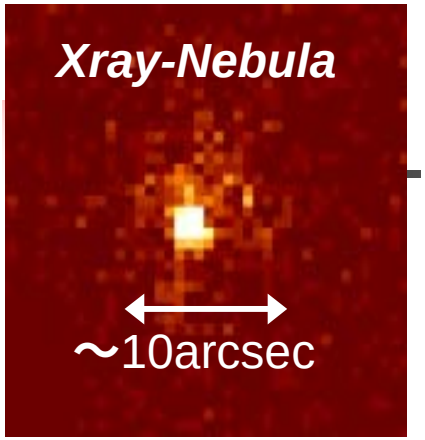
B=3μG

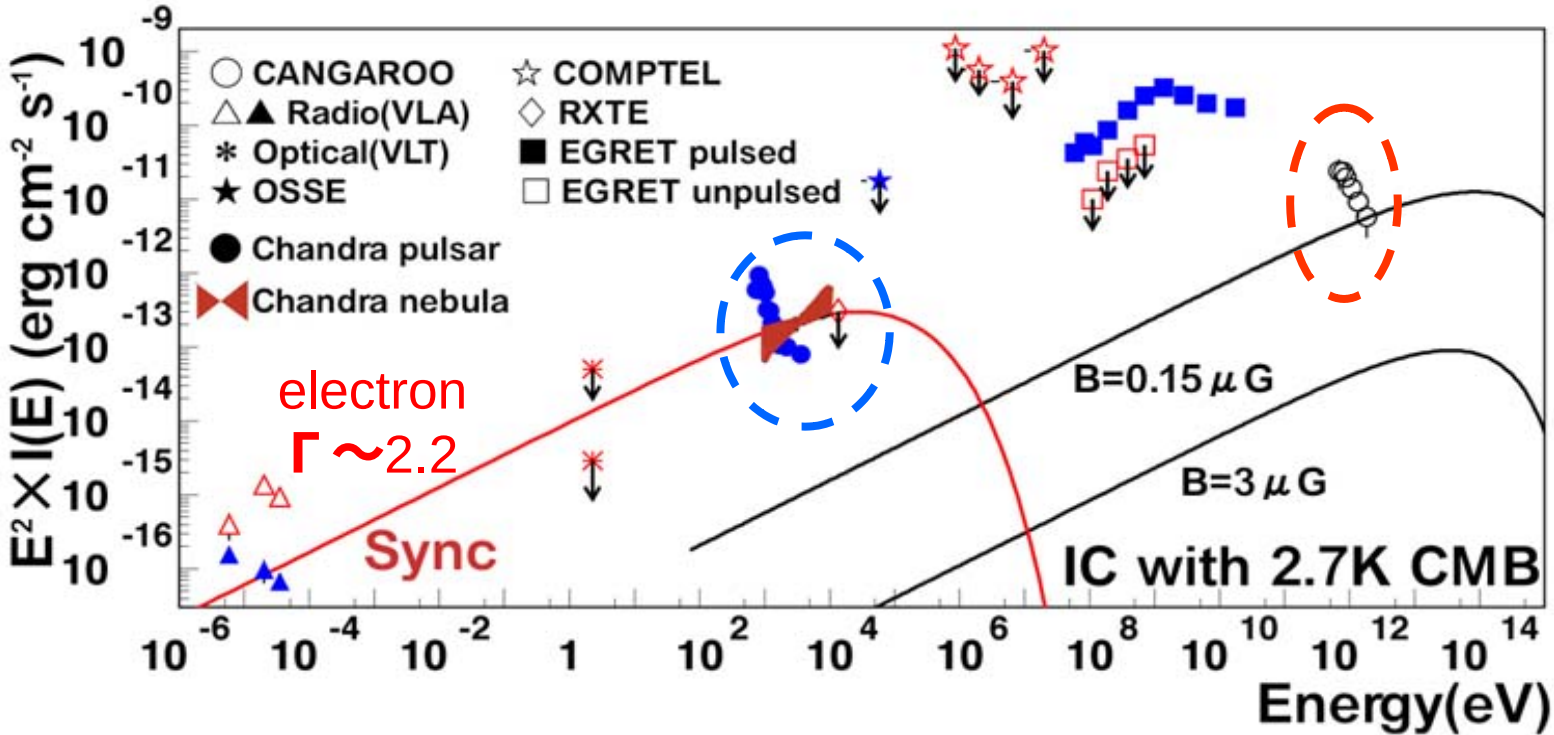


X ray : Spatial resolution → Chandra

Gamma ray: Energy range → CANGAROO - II

Multi-wavelength Spectrum of PSR 1706





Synch. IC. Model ??

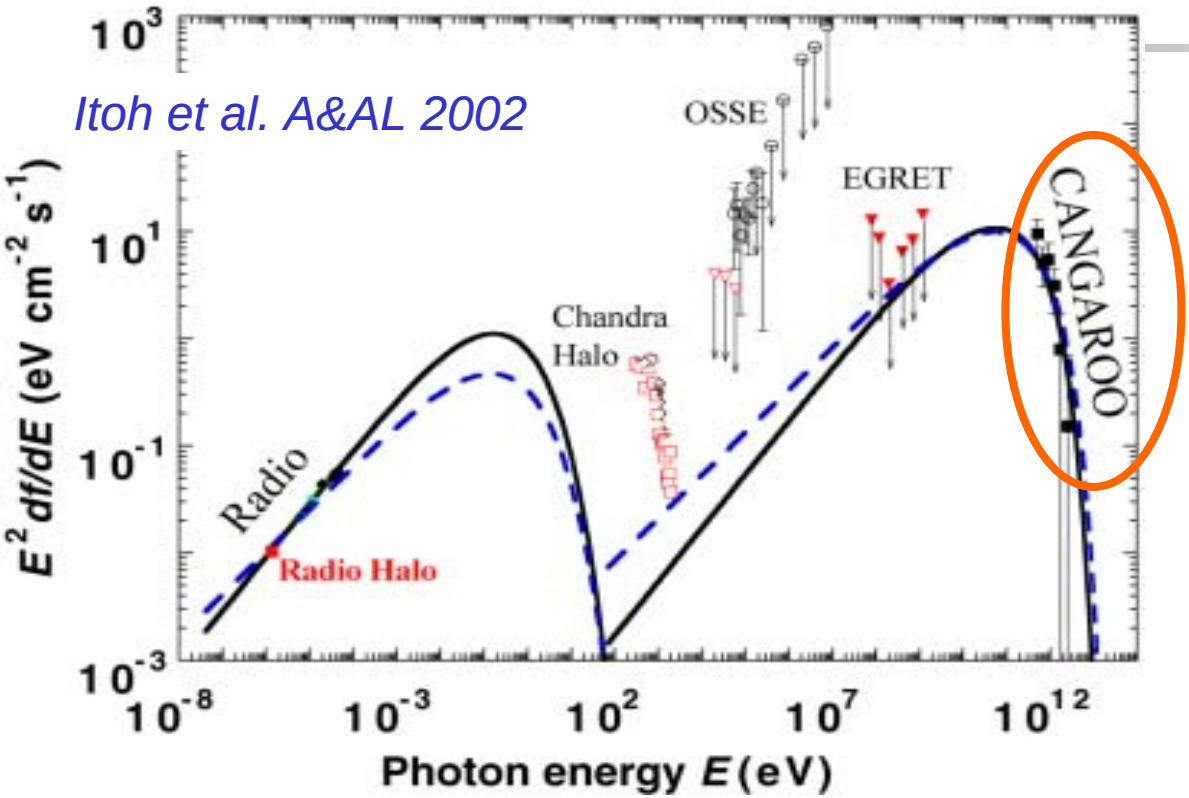
TeV flux: 10 ×X ray flux

Synchrotron cut off > 10keV

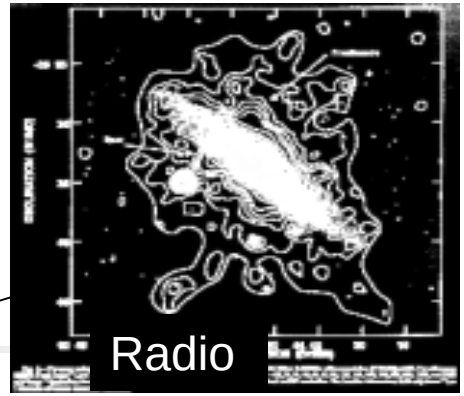
B~ 1mG & E_e ~20TeV OR B~ 20μG & E_e ~400 TeV

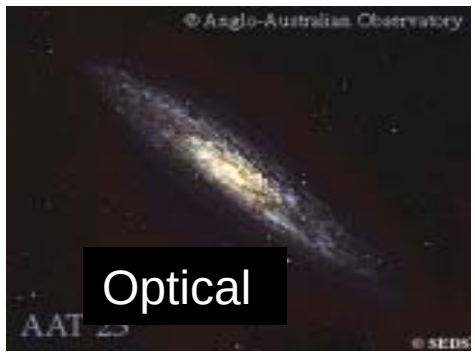
difficult to explain Sync-IC(2.7k CMB) model

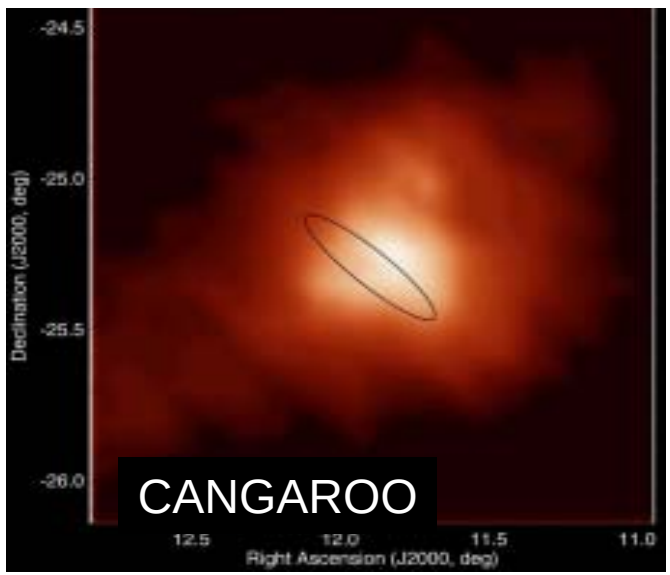
Starburst galaxy NGC 253



Non-thermal Radiation



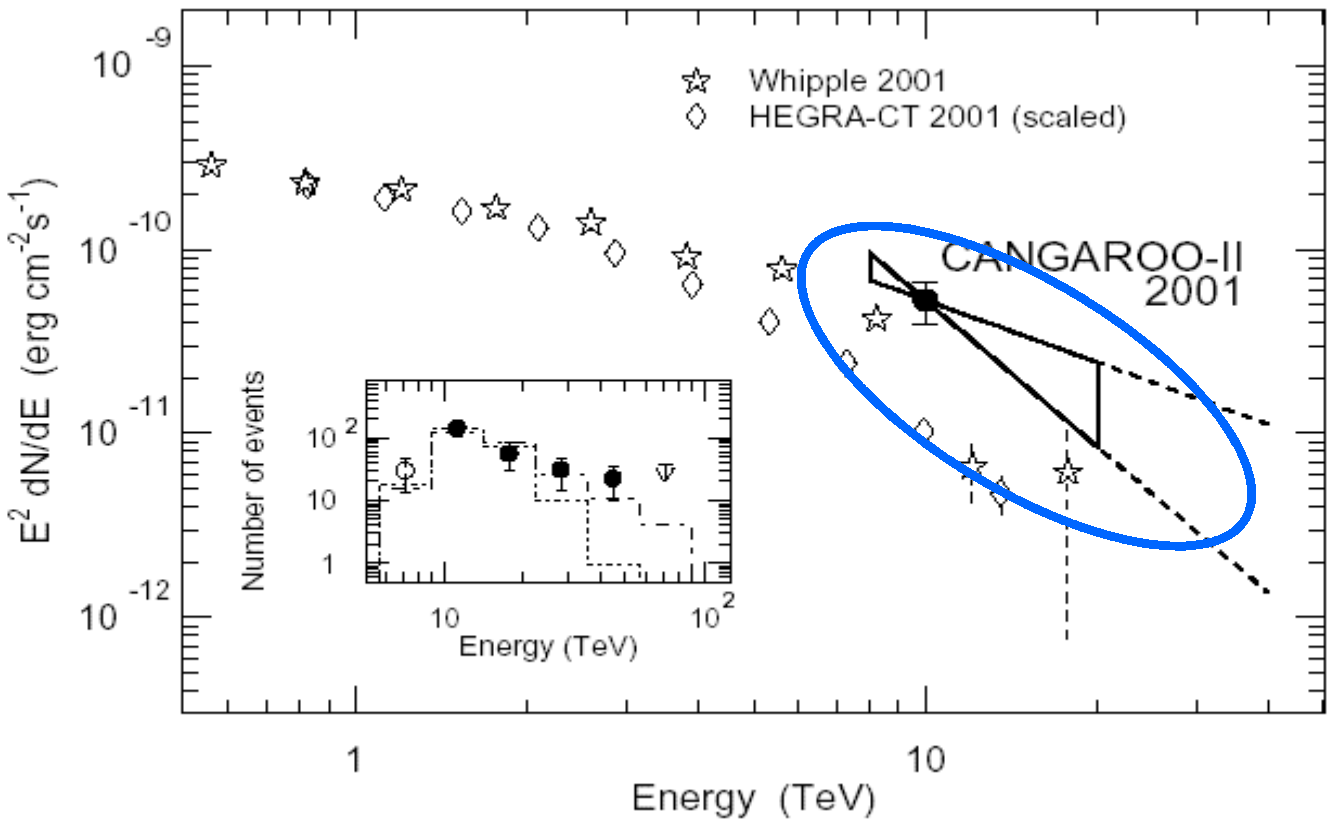




- New type TeV source
- Nearby spiral galaxy (2.4Mpc)
- Broad emission region.

Mrk 421: hint for cosmology?

Large Zenith Observation(~70º)



Emission above 10 TeV detected

⇒ Fewer IR photons?

⇒ Cosmology: galaxy formation

Okumura et al. ApJL 2002

CANGAROO III

Detected
Positive
Upper limit

Other Targets

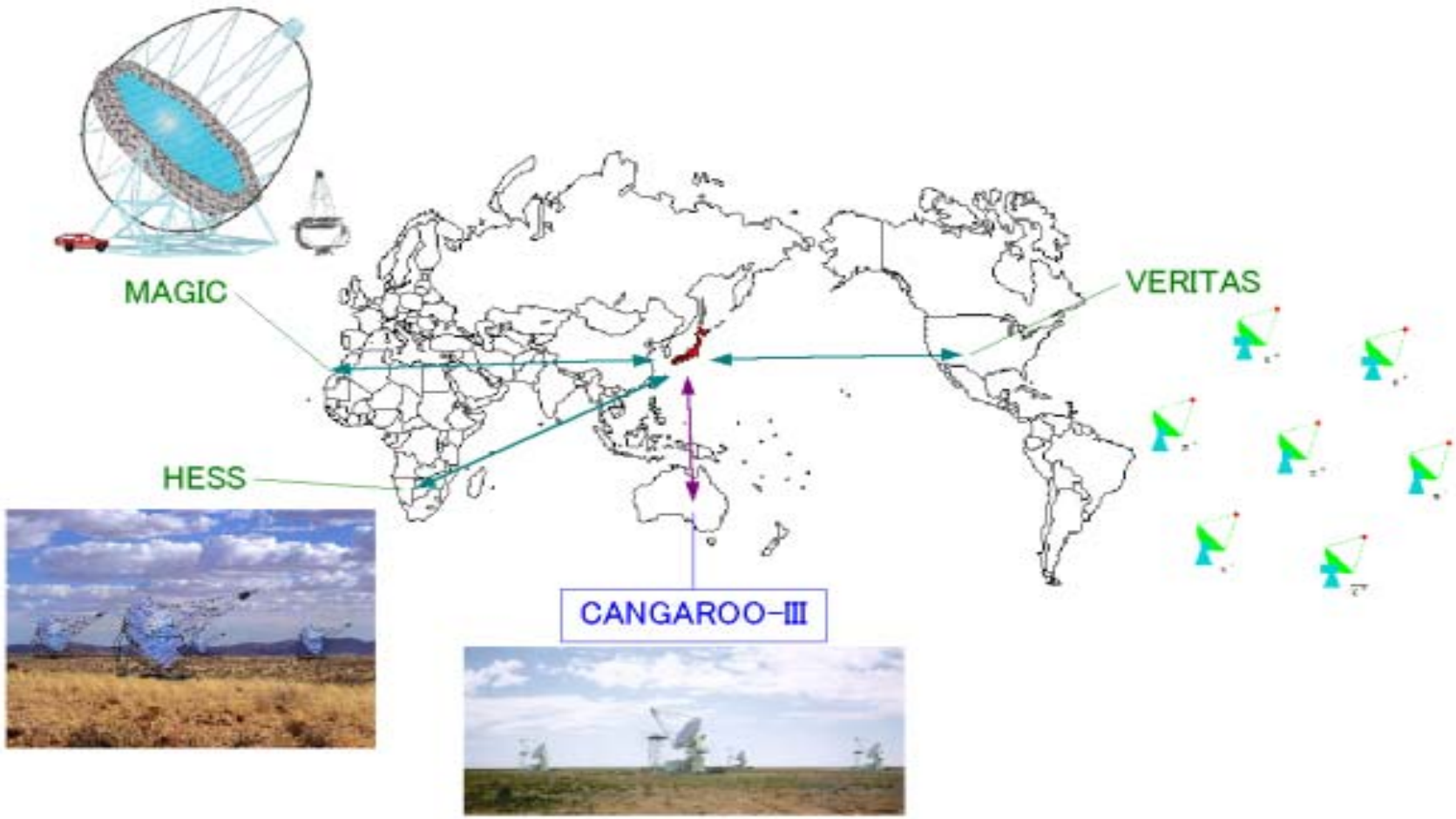
Status before ICRC2003

	Signal	Status
SNR RX J0852-4622	○	ICRC2003@Tsukuba
PSR 1259-63/SS2833	↓	Finished; In prep.
SNR RCW 86	○	ICRC2003@Tsukuba
PSR 1509-58		Under analysis
PSR J1420-6048		ICRC2003@Tsukuba
Vela pulsar		Under analysis
Galactic Center/Sgr A*	○	ICRC2003@Tsukuba
Galactic jet object SS433		ICRC2003@Tsukuba
SN 1987A	↓	Published
Galaxy The Small Magellanic Cloud		ICRC2003@Tsukuba
AGN PKS 2155-304, PKS 2005-489	↓	ICRC2003@Tsukuba
AGN PKS 0548-322	↓	ICRC2003@Tsukuba
EXO 055625-3838.6		Under analysis
EGRET un-ID 3EG J1234-1318		ICRC2003@Tsukuba

Present status of CANGAROOIII : Four 10m telescopes in Woomera

Dec/02 T1, T2 Stereo → Nov/03. Full Operation

On-going projects



Summary

- VHE Gamma-Ray Sources: Pulsar Nebula, SNR, Galaxy, AGN
- Almost All the Sources due to electrons: I.C. Gamma Rays

  Where is Proton?? Where is the origin of Cosmic Origin??

But,

- SNR: confirmed to accelerate particles up to ~100TeV*(SN1006)*
- One Convincing Candidate of Proton Acceleration Site; *RXJ1713.7-3946,* Another Candidate,

New topics

- Pulsar-Nebula, TeV gamma rays from Nebula ?
- New types of TeV gamma-ray sources; Galaxy…….