Recent Status of CANGAROO-III

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The 3rd International Workshop for Comprehensive Study of the High Energy Universe
-Toward Very High Energy Particle Astronomy –
Mar. 20-22, 2003, ICRR, Univ. of Tokyo

CANGAROO team

- University of Adelaide
- Australian National University
- Ibaraki University
- Ibaraki Prefectural University
- Kanagawa University
- Konan University
- Kyoto University
- Nagoya University
- National Astronomical Observatory of Japan
- Osaka City University
- Institute of Physical and Chemical Research
- Shinshu University
- Institute for Space and Aeronautical Science
- Tokai University
- Tokyo Institute of Technology
- ICRR, University of Tokyo
- Yamagata University
- Yamanashi Gakuin University

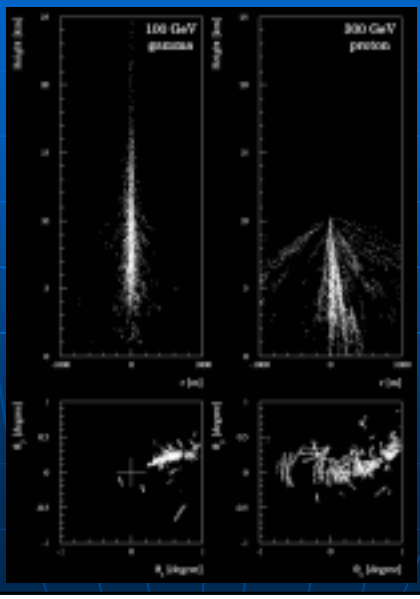
Imaging Cherenkov Telescope (1)

Gamma-ray:

Electromagnetic shower

⇓

Sharp Cherenkov image



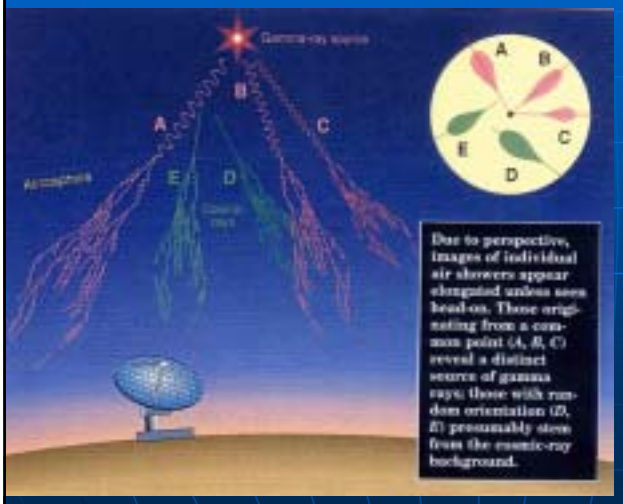
Proton:

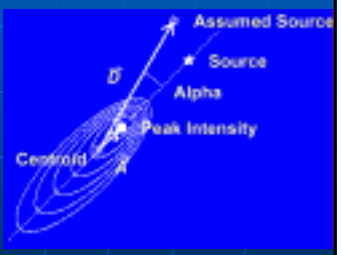
Nuclear shower

⇓

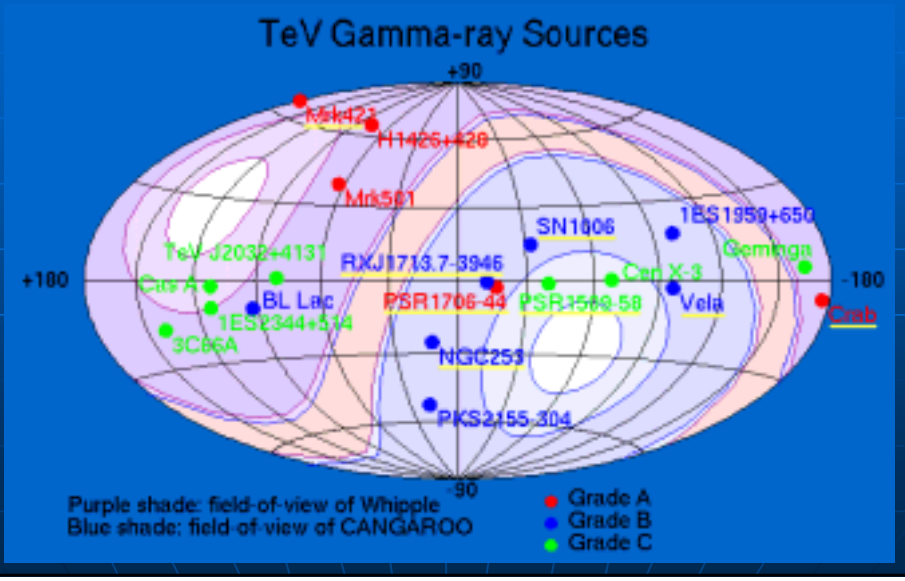
Diffuse Cherenkov image

Imaging Cherenkov Telescope (2)





TeV gamma-ray sky in 2002



Brief history of CANGAROO

- 1987: SN1987A explosion
- 1990: 3.8m telescope moved
- 1990: ICRR-Adelaide Physics agreement
- 1992: Start obs. of 3.8m tel.
- 1995: PSR 1706-44 result published
- 1998: SNR1006 result published
- 1999: 7m telescope completed
- 2000: Upgrade to 10m telescope
- 2001: U.Tokyo-U.Adelaide agreement
- 2002: Second and third 10m tel.

CANGAROO-I 3.8m telescope

- Ex. Lunar ranging telescope
- 3.8m, F/1.0
- PSF: 0.16° (FWHM)
- Alt-azimuth mount
- 256ch PMT camera (0.12° pixel)
- Timing and pulse height electronics

(1992-1999)

CANGAROO-I results

	Signal	Publish
SNR/Pulsar Crab	○	ApJL'94
SNR SN1006	○	ApJL'98
SNR RX J1713.7-3946	○	A&AL'00
SNR W28	↓	A&A'00
Pulsar PSR 1706-44	○	ApJL'95
Pulsar Vela	○	ApJL'97
Pulsar PSR 1509-58	Δ	ApJ'00
Pulsar PSR 1055-52	↓	(Ph.D.'97)
AGNs: PKS0521-365, EXO0423.4-0840, PKS2005-489, PKS2316-423	↓	A&A'98
Blazars: PKS0548-322, PKS2005-489 and PKS2155-304	↓	A&A'99
Radio galaxy Cen A	↓	(Proc.'99)

Signal: ○ detected, ↓ upper limit, Δ marginal

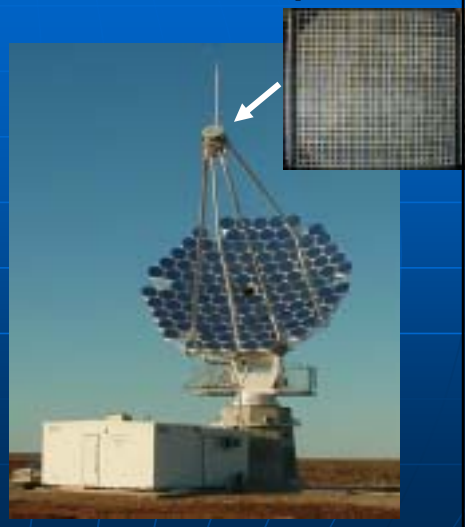
CANGAROO 7m telescope

- Completed in 1999
- 60 x 80cm CFRP mirror segments
- Focal length 8m
- 512ch imaging camera
- Timing and charge (TOT) electronics

(March 1999)

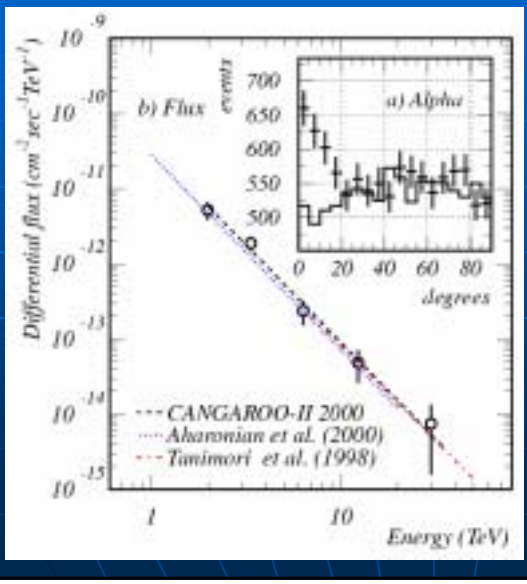
CANGAROO 10m telescope

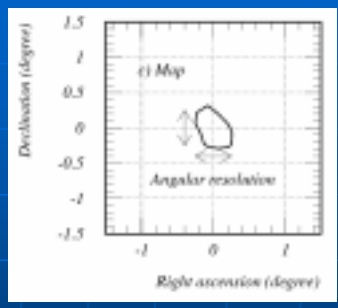
- Upgraded in 2000
- 114 x 80cm CFRP mirror segments *(first plastic-base mirror in the world!)*
- Focal length 8m
- Alt-azimuth mount
- 552ch imaging camera
- Charge and timing electronics



(March 2000)

Crab nebula





"Standard candle" is observed as it should be
– Our telescope is working properly!

C. Itoh, Ph.D. thesis 2003

CANGAROO-II observations

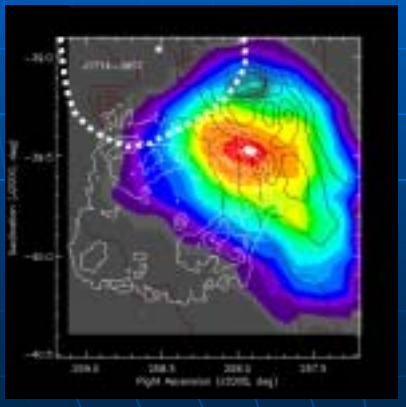
	Signal	Publish
SNR/Pulsar Crab	○	
SNR RX J1713.7-3946	○	○ (Nature'02)
SNR SN1006	○	Δ
SNR SN1987A	↓	Δ
SNR RX J0852-4622	Δ	
SNR RCW86	Δ	
Pulsar PSR 1706-44	○	Δ
Pulsar Vela	Δ	
Pulsar PSR 1259-63/SS2833	↓	Δ
AGN Mrk421	○	○ (ApJL'02)
AGN PKS2155-304, PKS2005-489	↓	Δ
Starburst galaxy NGC253	○	○ (AApL'02)
Galactic Center/Sgr A*	Δ	
Galactic jet object SS433	Δ	
EGRET unID 3EG J1234-1318	Δ	
Galaxy Small Magellanic Cloud	Δ	

Signal: ○ detected, ↓ upper limit, Δ under analysis

Publish: ○ published, Δ in preparation

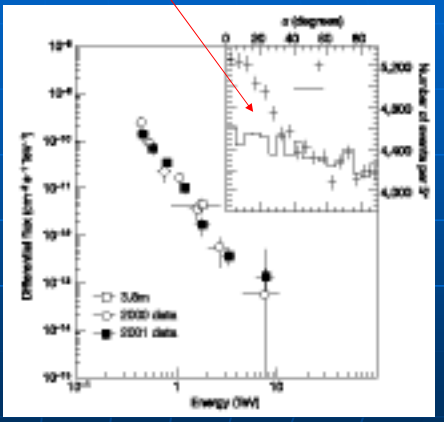
SNR RX J1713.7-3946

- SNR detected by X-ray satellite
- Non-thermal emission



Significance map

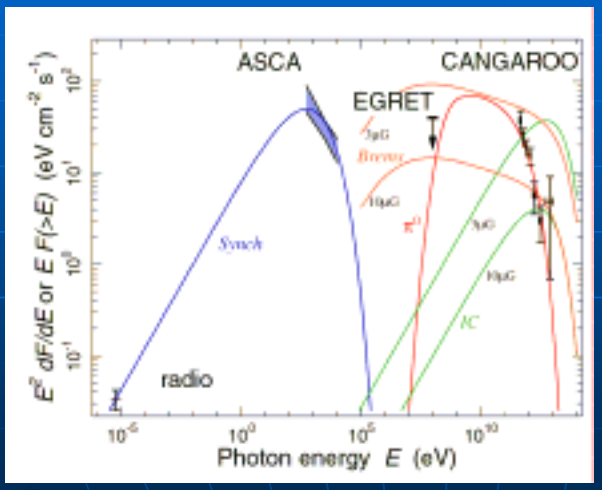
Gamma-ray signal = (ON) – (OFF)



Energy spectrum

Enomoto et al. Nature 2002

SNR RX J1713.7-3946: emission from protons?



Hard to explain by emission from electrons (Brems, IC)

⇒Emission from protons (π^0)?

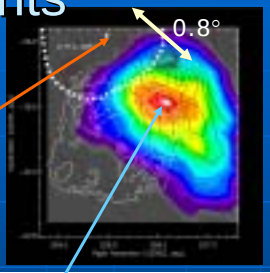
⇒ Cosmic ray origin?

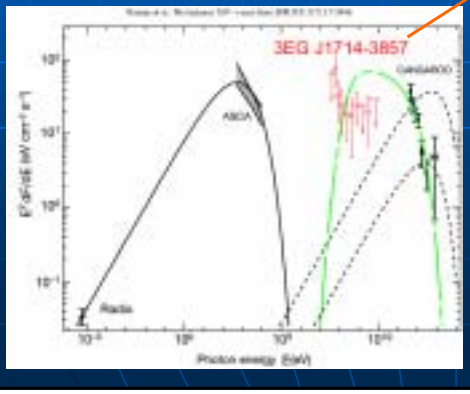
Enomoto et al. Nature 2002

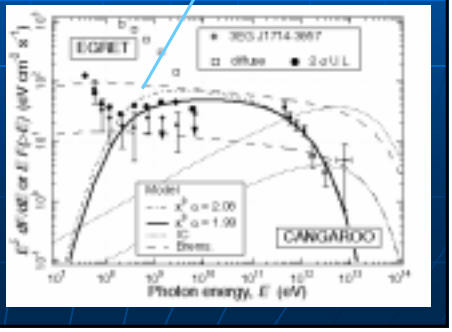
SNR RX J1713.7-3946: counter arguments

Reimer & Pohl, A&A 390 (2002) L43

Butt et al., Nature 418 (2002) 489



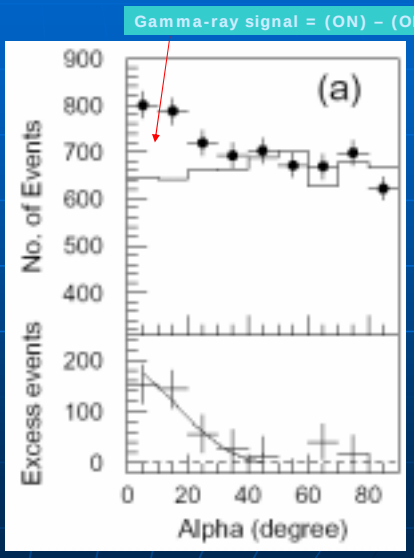




Markarian 421

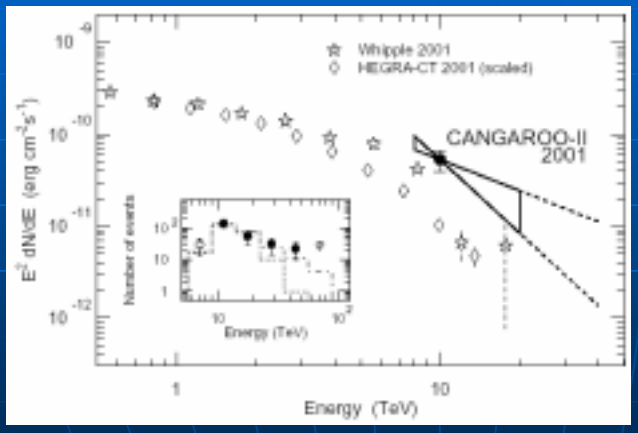
- The first TeV blazar in the northern sky
- z=0.031 (~130Mpc)
- Flare in 2001
- Large zenith angle observation from Woomera: higher energy
- Intergalactic absorption by IR: No 10TeV photons?

Optical image



Okumura et al. ApJL 2002

Mrk 421: hint for cosmology?



Emission above 10 TeV detected

⇒ Fewer IR photons?

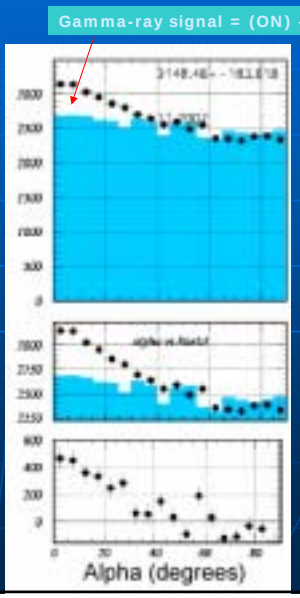
⇒ Cosmology: galaxy formation

Okumura et al. ApJL 2002

Starburst galaxy NGC 253

- Nearby spiral galaxy (2.4Mpc)
- Starburst activity ⇔frequent SNe

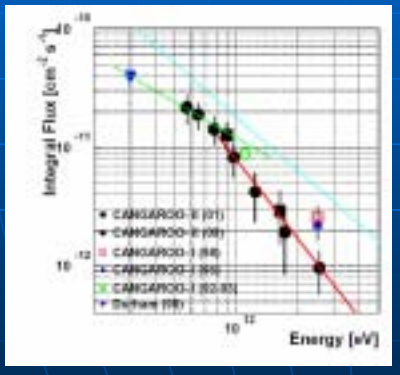
Optical image



Itoh et al. A&AL 2002

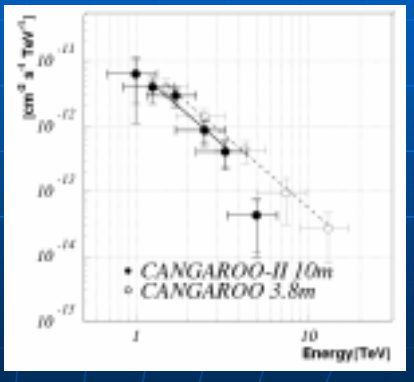
CANGAROO-I sources revisited

- PSR 1706-44



J. Kushida, Ph.D. thesis

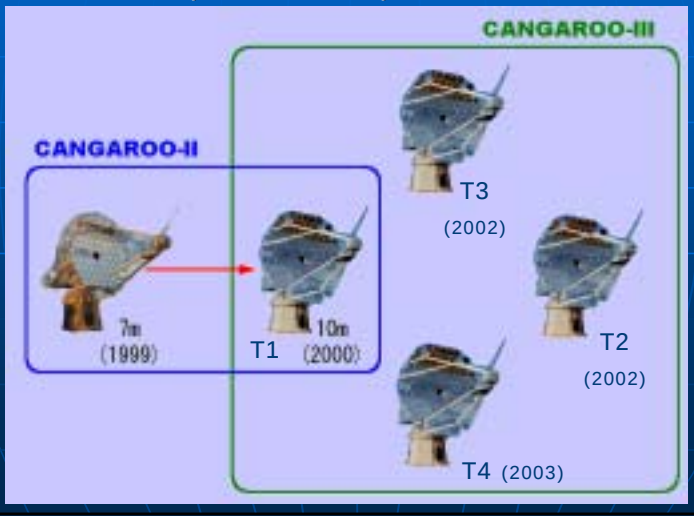
- SN1006 NE rim



S. Hara, Ph.D. thesis

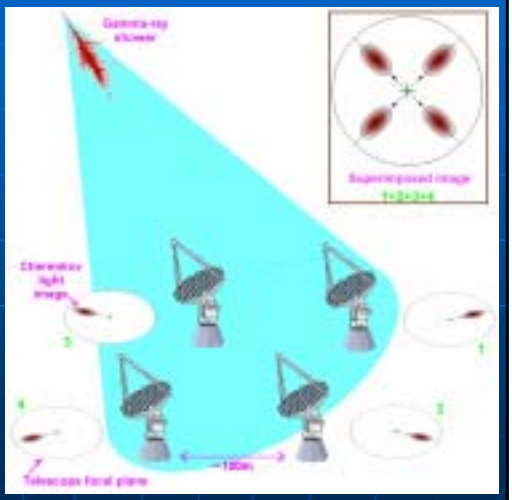
CANGAROO-III project

- 4 x 10m telescopes to be completed in 2003



Merit of stereo observation

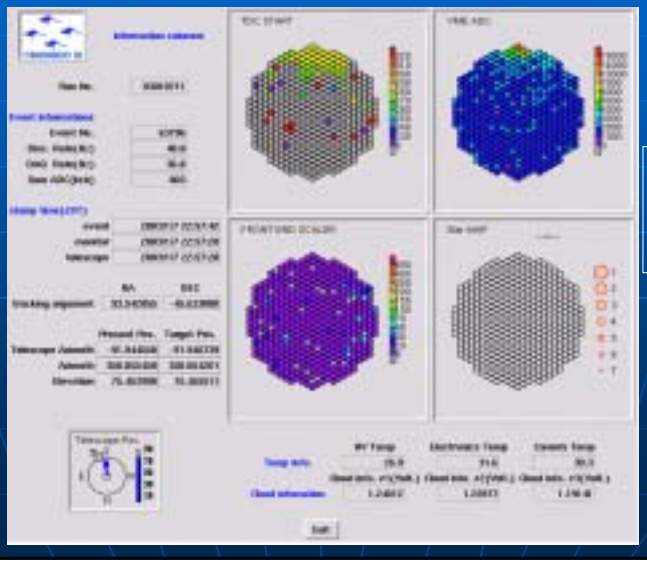
- Cherenkov shower pool: ~300mϕ
- Stereo $\Rightarrow$ Info. on distance to showers
- Better angular resolution $\Delta\theta$=0.2°$\rightarrow$0.05°
- Better energy resolution ΔE/E=30%$\rightarrow$15%



10m telescope No.2

- Completed in 2002
- Improved FRP mirror segments
- Focal length 8m
- 427ch imaging camera
- Faster electronics (charge and timing)
- Pattern trigger under testing

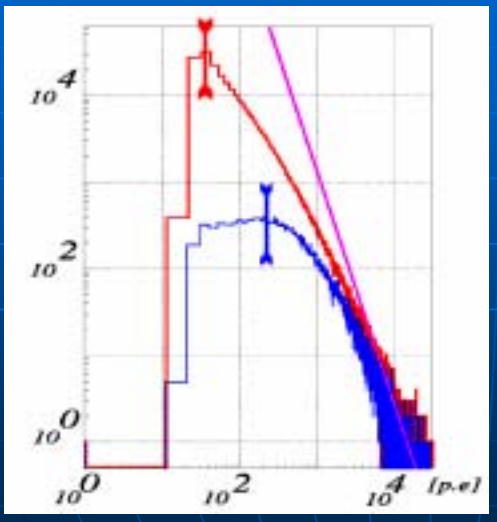
T2 event samples



TDC ADC

Scaler Star

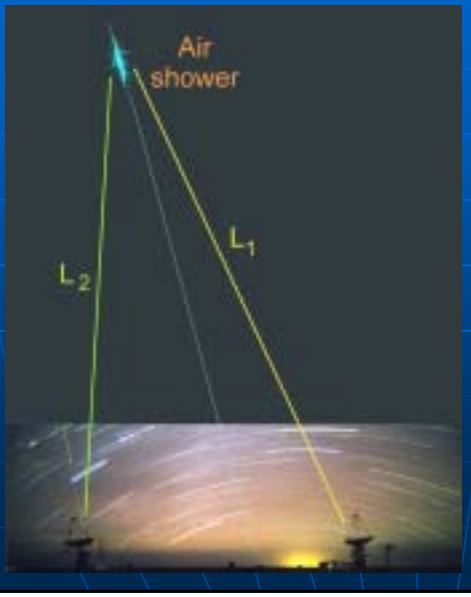
T1 vs T2: p.e. distribution

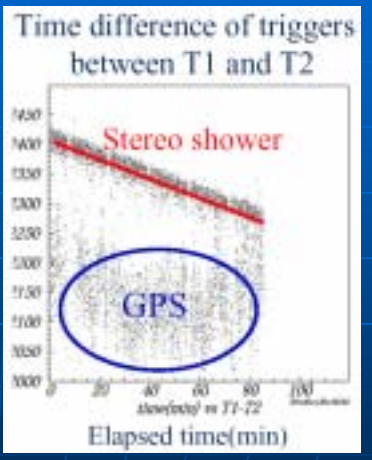


Red: P.E. spectrum of T2
Blue: P.E. spectrum of T2 for events triggered by T1
Pink: Power law: $(P.E.)^{-2.7}$

T2 Energy threshold << T1

Stereo observation



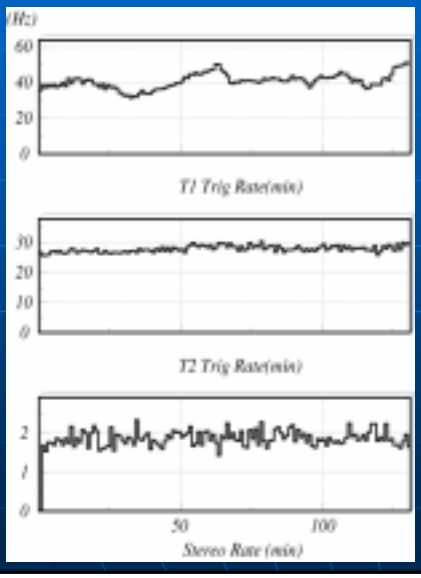


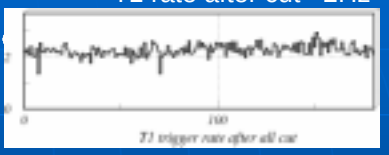
$\Delta t = (L_1 - L_2)/c \propto \cos A \cos h$

GPS: 1pps

Trigger rate

T1 rate after cut ~2Hz





T1: trigger rate ~ 40Hz
T2: trigger rate ~ 30Hz

Coincidence ~ 2Hz

The Stereo trigger rate is limited by T1.

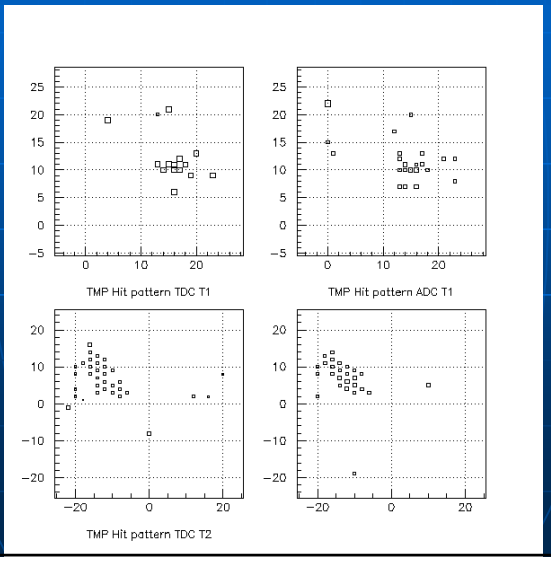
Stereo sample

T1 TDC

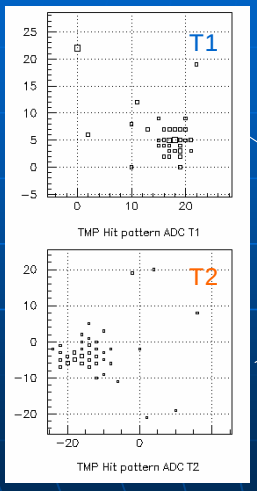
T1 ADC

T2 TDC

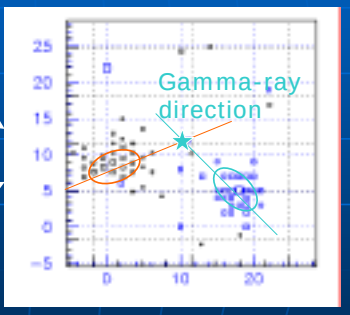
T2 ADC



Stereo reconstruction



overlay



(This is just an illustrative example.)

Present status: Three 10m telescopes in Woomera

Started operation in Dec. 2002

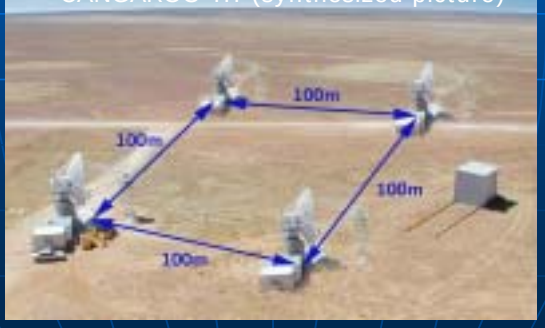
Assembled in Dec. 2002

In operation since 2000

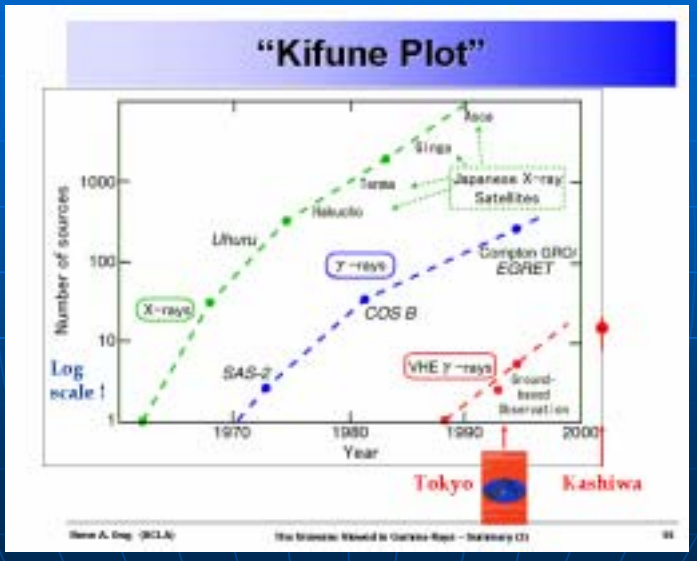
Next several years

- Systematic study of SNRs
- Survey of the galactic plane
- International/multiwavelength coordination

CANGAROO-III (synthesized picture)



Number of sources vs. year



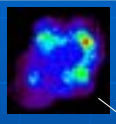
©R. Ong, 2002, "The Universe viewed in Gamma-rays", Kashiwa, 2002 Sep

Summary

- CANGAROO is a pioneer of imaging Cherenkov observation of gamma-rays in the southern hemisphere since 1992.
- TeV objects, mainly Galactic ones including non-thermal SNRs, have been discovered with 3.8m and 10m telescopes.
- Stereo observation started in 2002 and we can explore TeV gamma-ray sky with higher sensitivities.

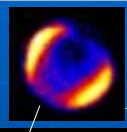
Systematic study of SNRs

RX J1713.7-3946 (CANGAROO)



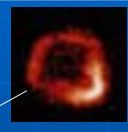
ASCA

SN1006 (CANGAROO)



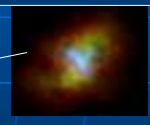
ASCA

RCW86 (CANGAROO under analysis)

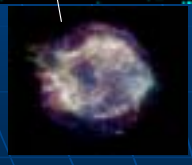


ROSAT

Crab nebula
("Standard candle")

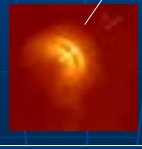


Chandra
optical



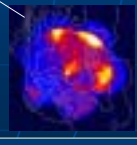
Chandra

Cas A (HEGRA)



Chandra

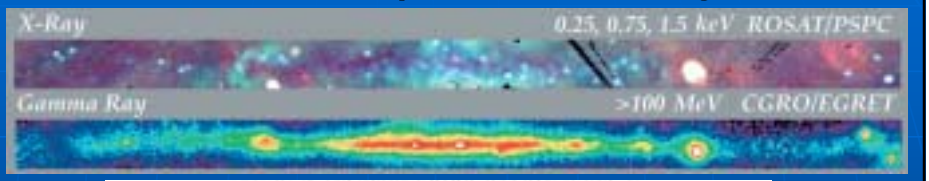
Vela (CANGAROO)

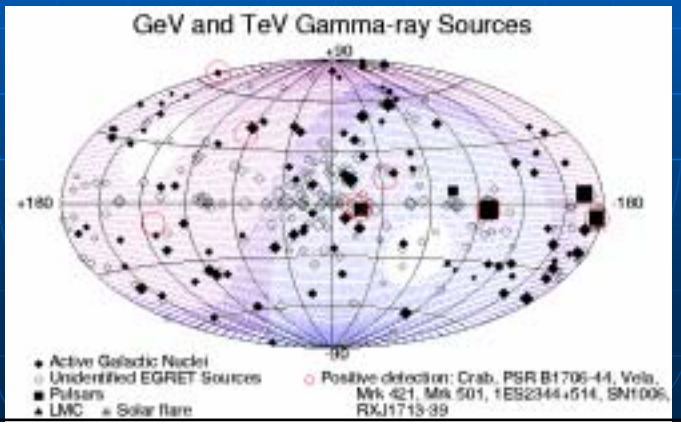


ROSAT

RX J0852-46 (CANGAROO under analysis)

Galactic plane survey





International coordination

- Continuous observation of time variable objects (ex. Blazars)
- Multiwavelength campaign