CANGAROO Project for High-Energy Gamma-ray Astrophysics

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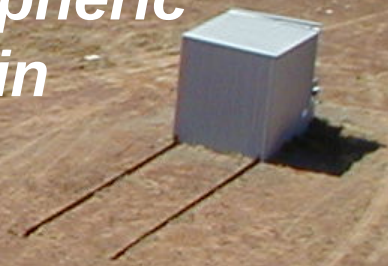
“CANGAROO”

=

Collaboration of **A**ustralia and **N**ippon for a
GAmma **R**ay **O**bservatory in the **O**utback

Observation of high-energy gamma-rays from celestial objects with imaging atmospheric Cherenkov telescopes in Woomera, Australia

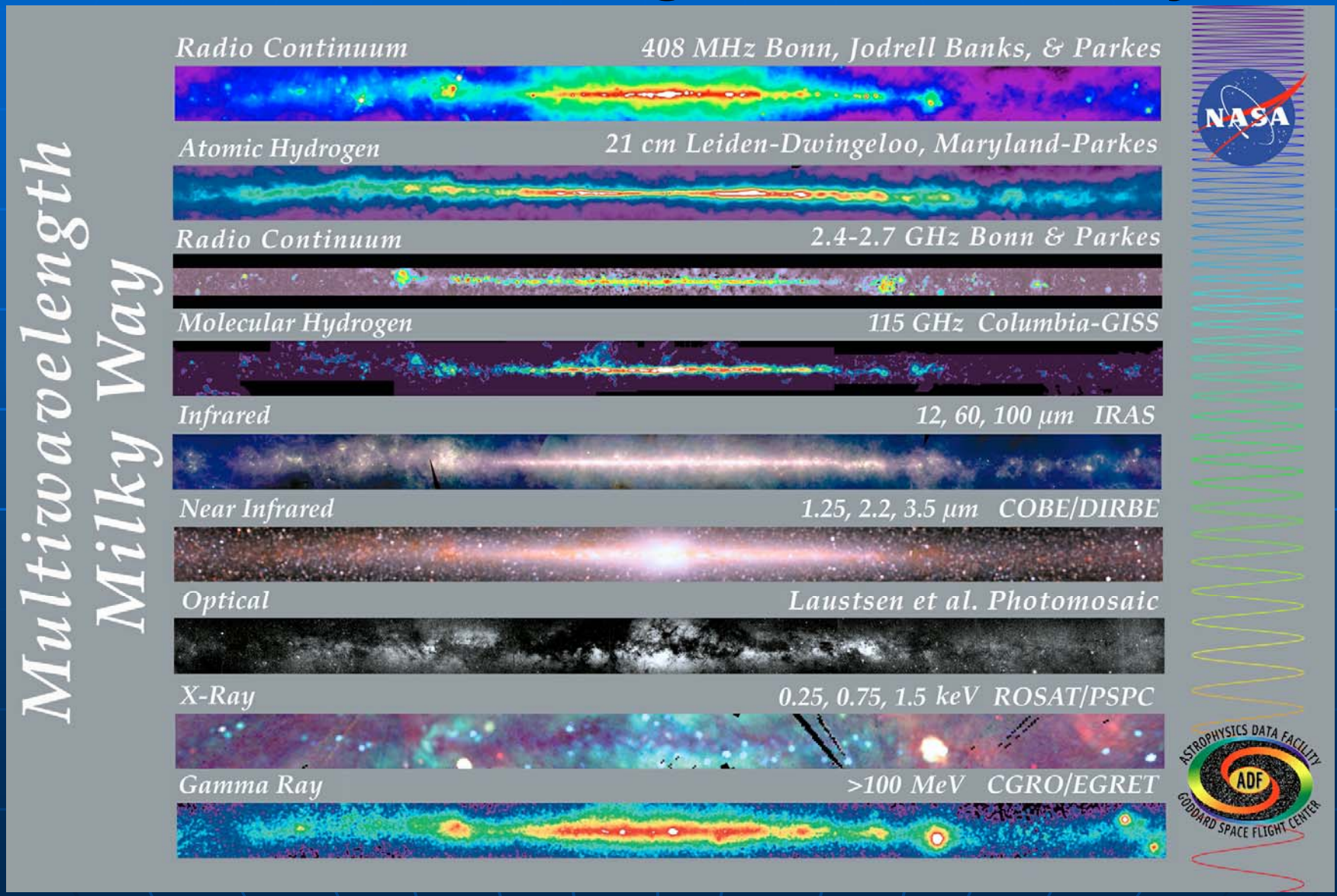


Woomera, South Australia

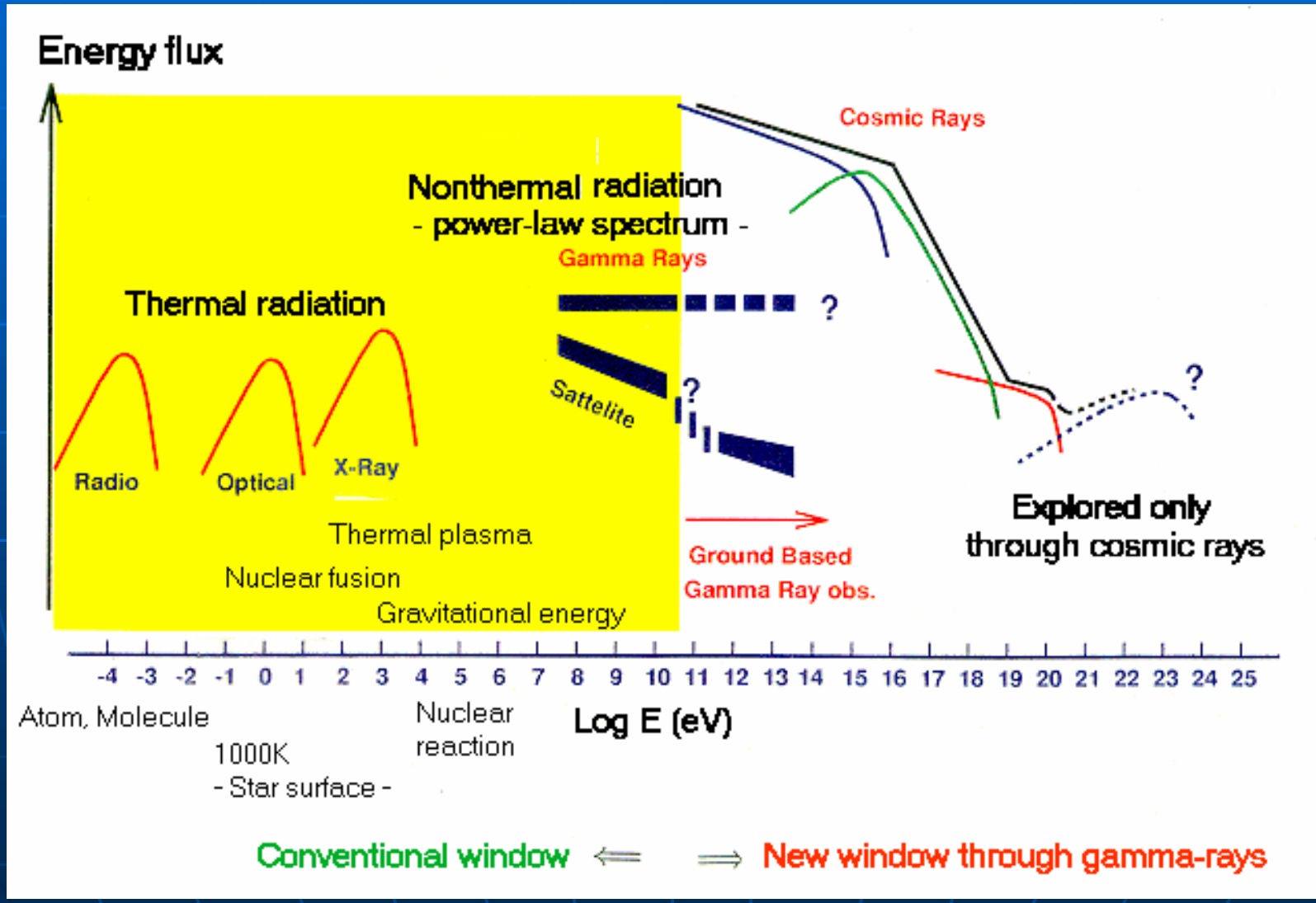
CANGAROO team

- University of Adelaide
- Australian National University
- Ibaraki University
- Ibaraki Prefectual 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 Tehnology
- Yamagata University
- Yamanashi Gakuin University

Multiwavelength astronomy

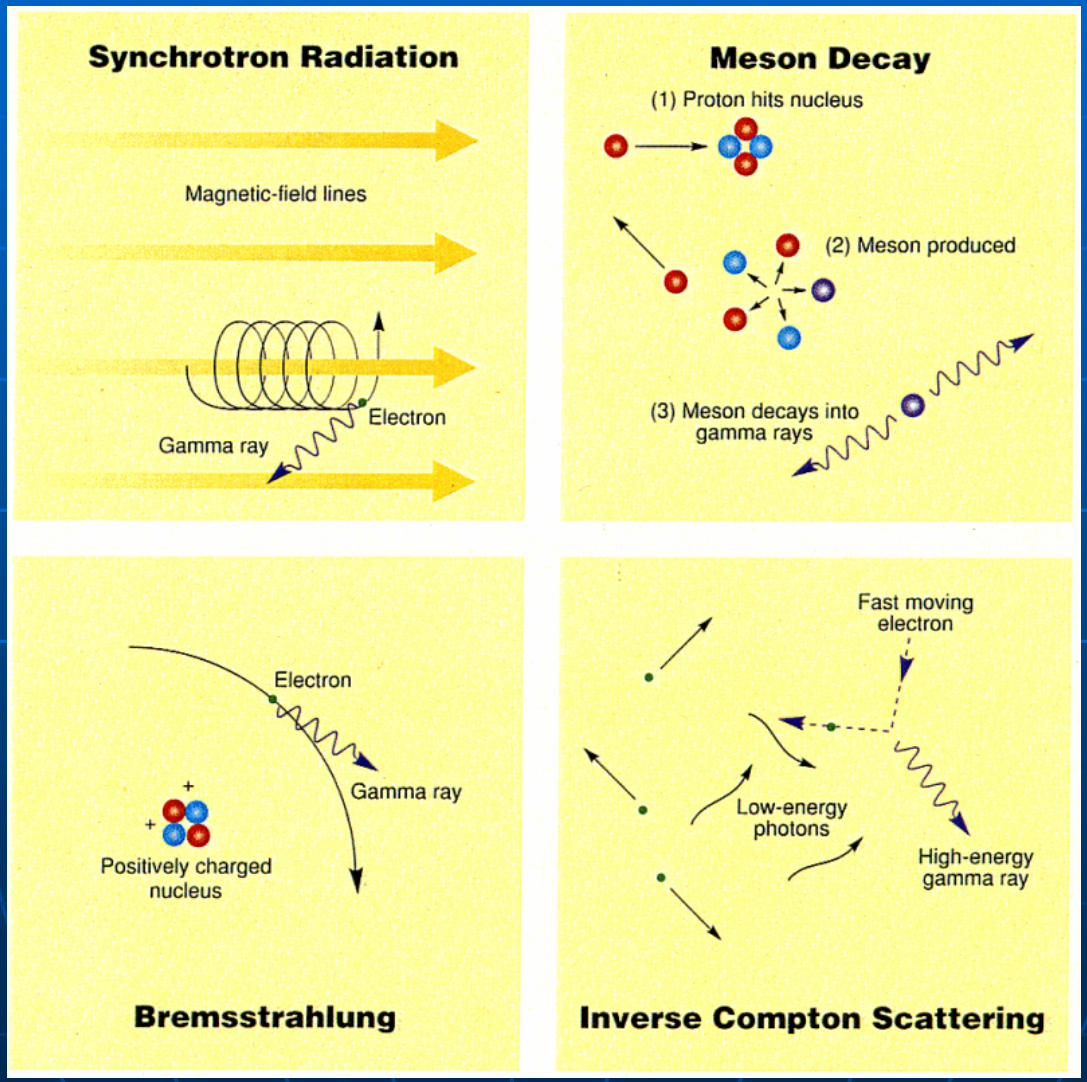


New window on Universe



Gamma-ray emission: *non-thermal*

High energy electron + magnetic field



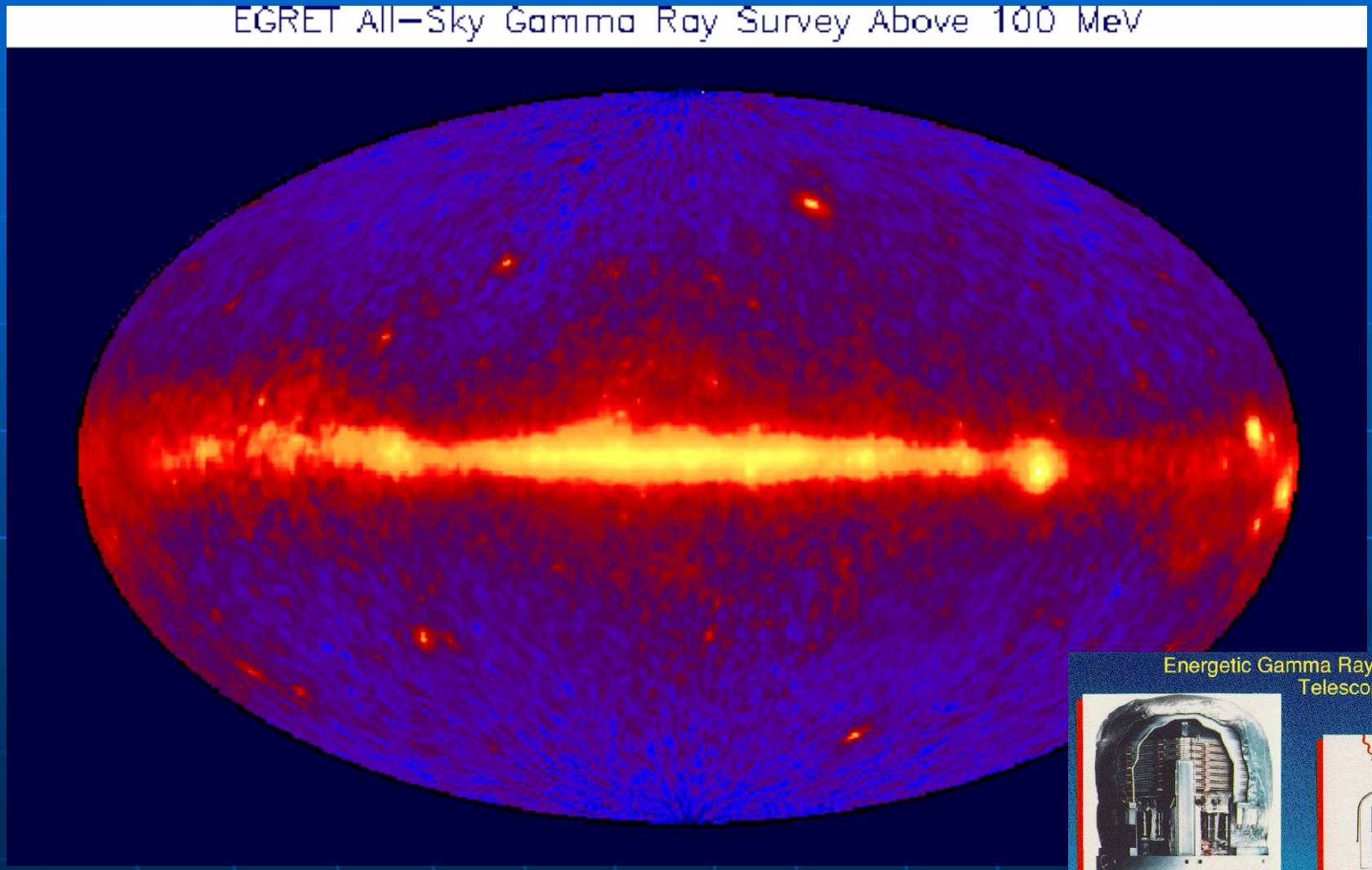
High energy proton + matter

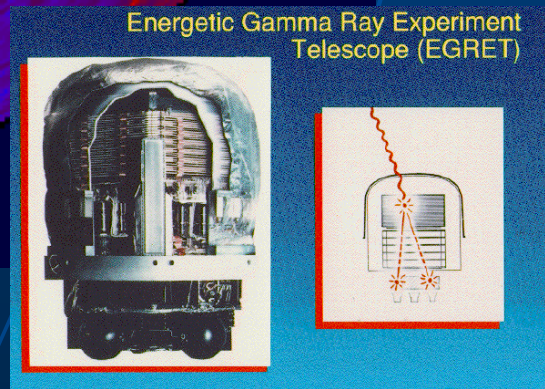
High energy electron + atomic electric field

High energy electron + photon field

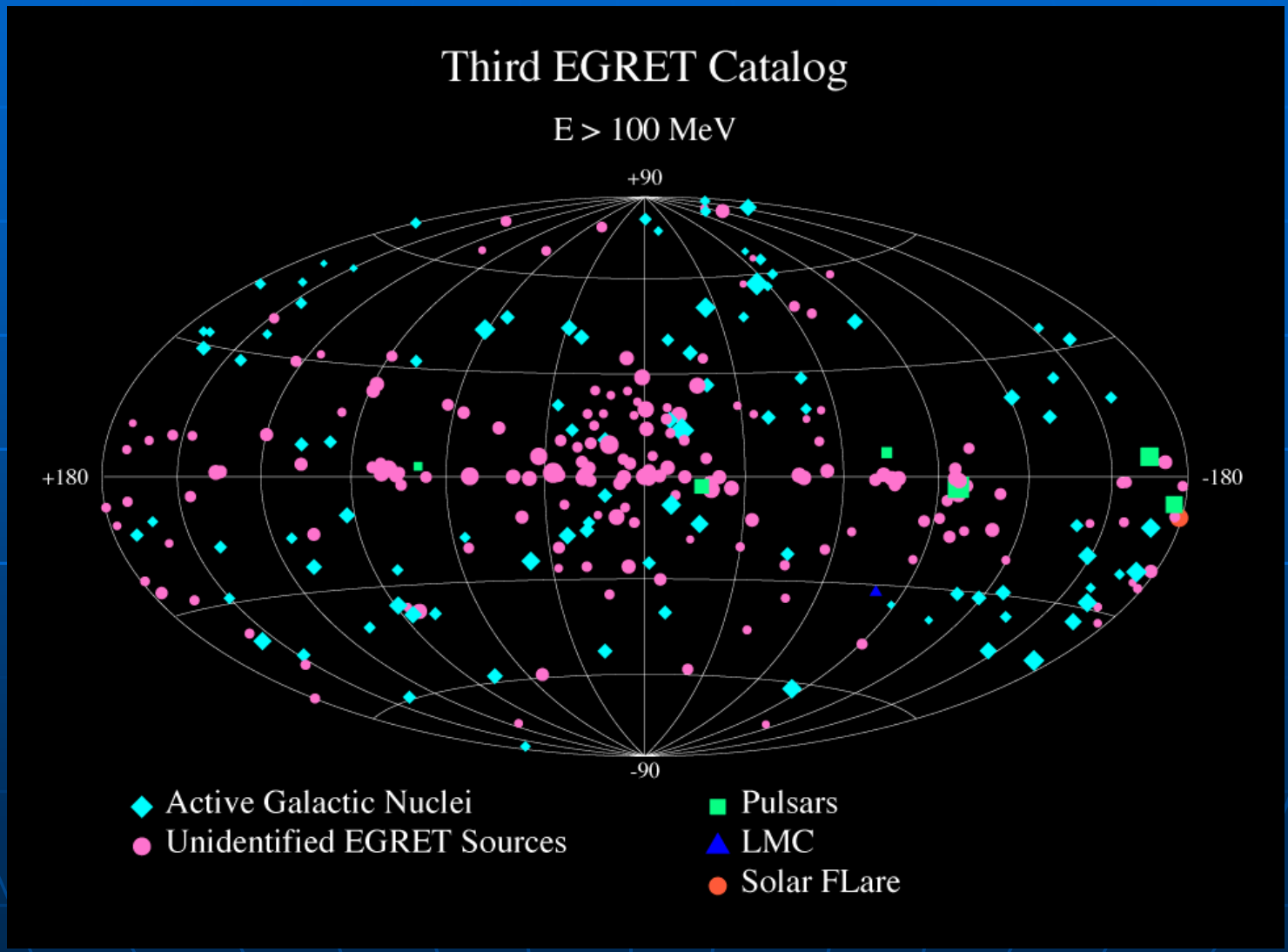
High energy particles ⇐ particle acceleration process

Gamma-ray sky (1)





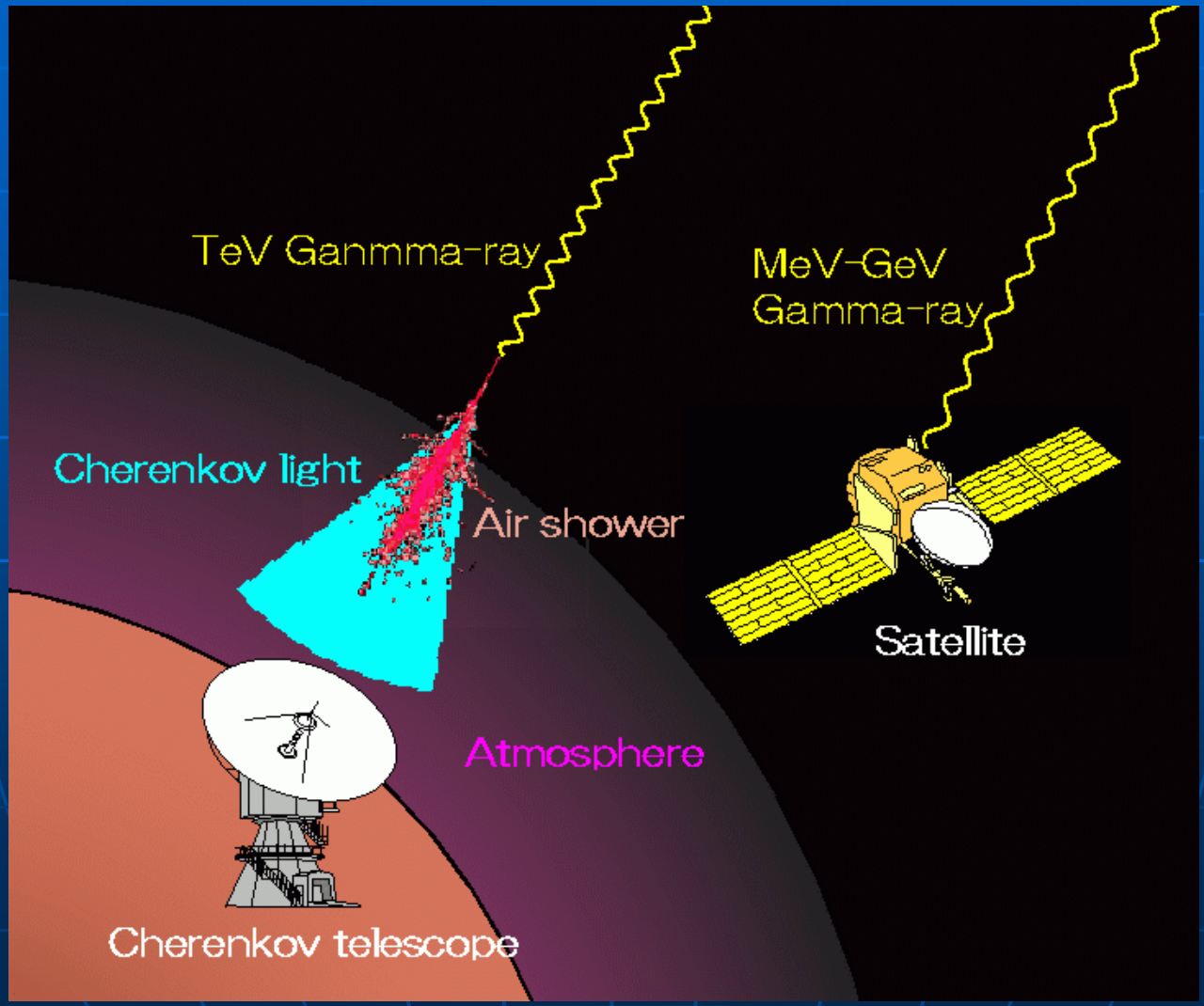
Gamma-ray sky (2)



EGRET point source summary

Pulsars	5
AGN (mostly blazars)	66 27 (marginal)
Radio galaxy (Cen A)	1 (marginal)
Unidentified (Some may be SNRs)	170
Large Magellanic Cloud	1
Solar flare	1
Total	*271*

Detection of gamma-rays



Cherenkov telescope

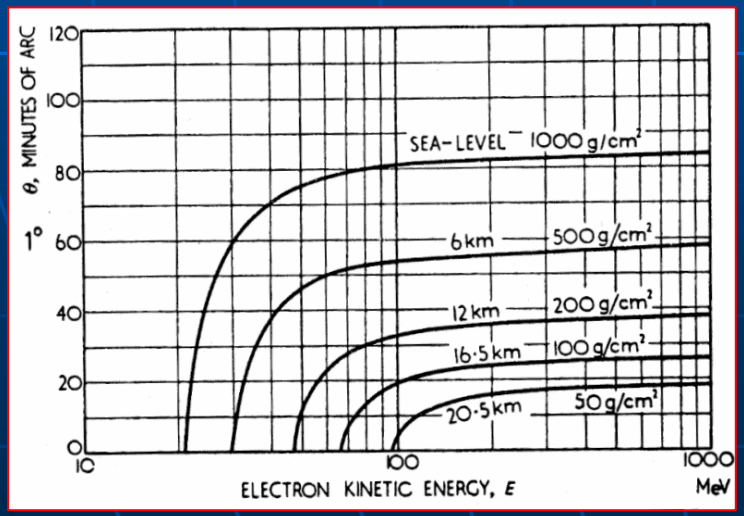
- Cherenkov angle

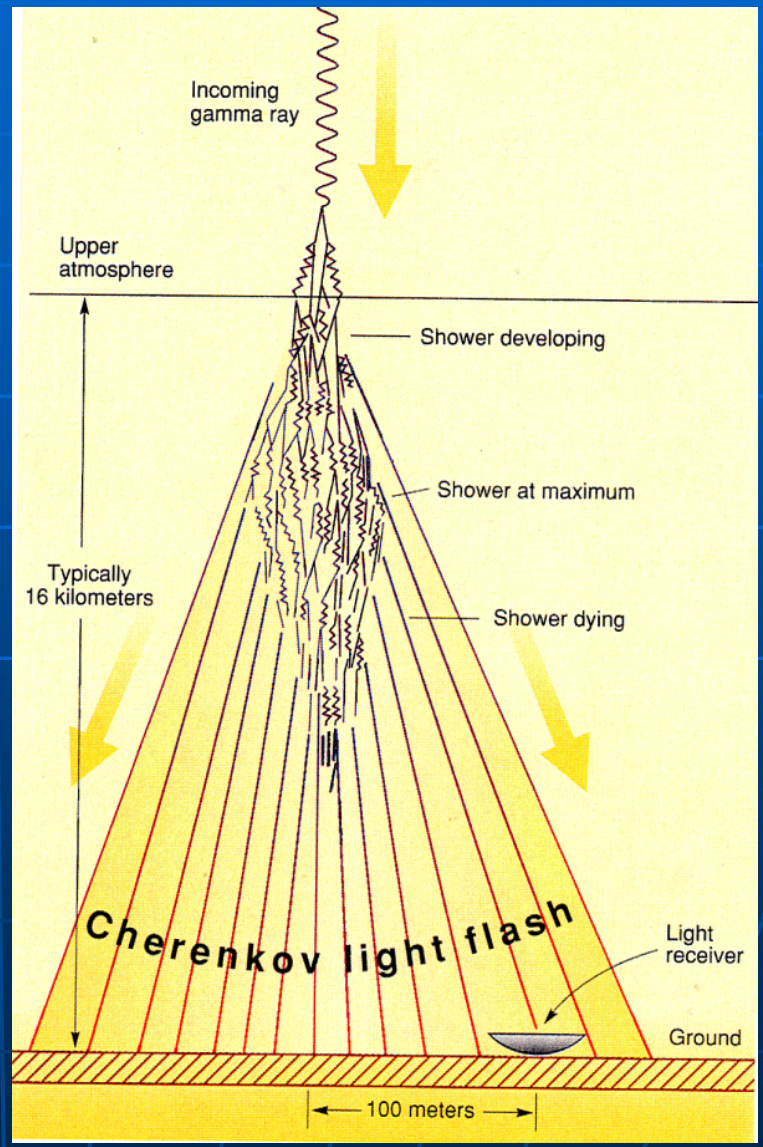
  $\cos\theta = 1/n\beta$

  $\beta = v/c$

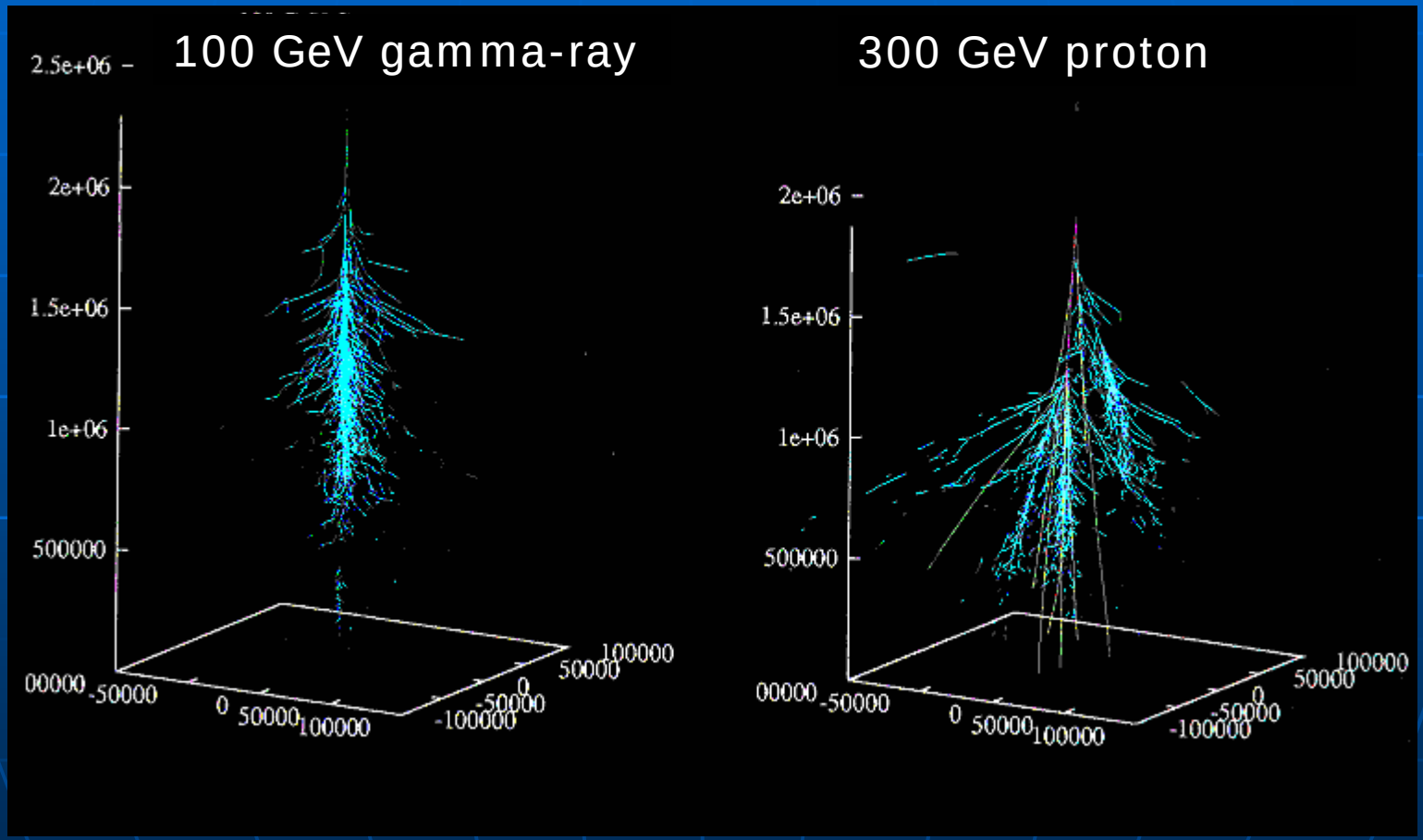
  $n = 1.0003$ (1atm)

  $\Rightarrow \theta = 1.3^{o}$

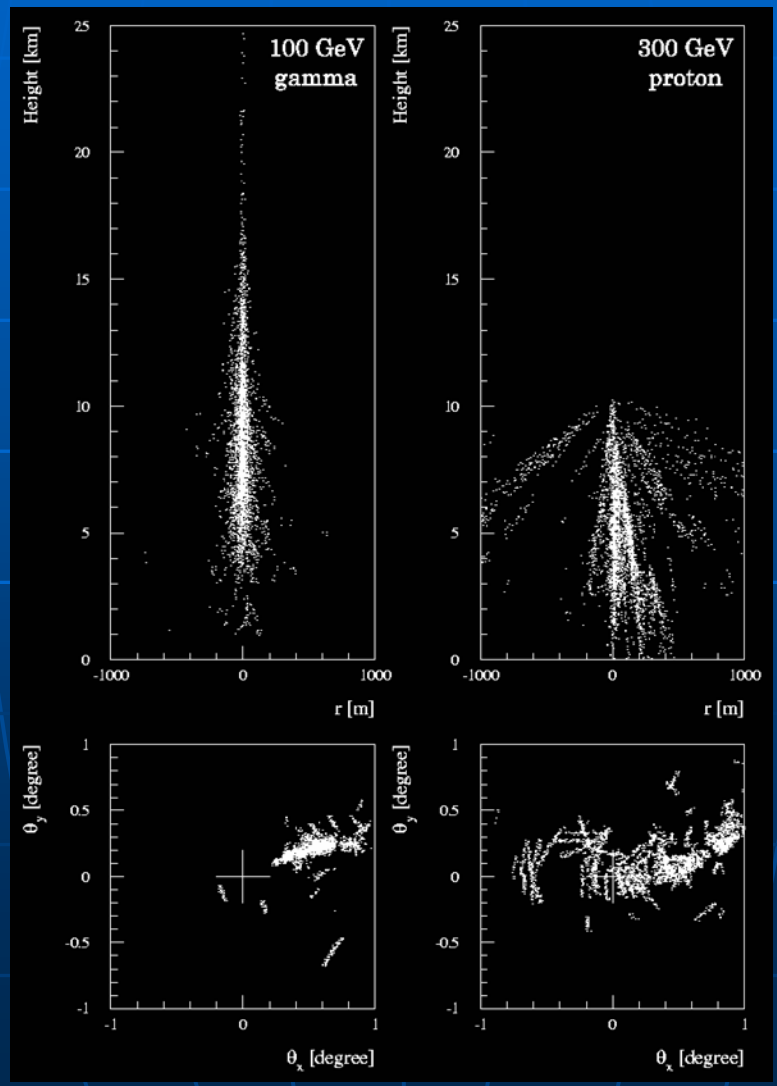




Discrimination of cosmic-ray background (1)



Discrimination of cosmic-ray background (2)



Gamma-ray:

Electromagnetic shower

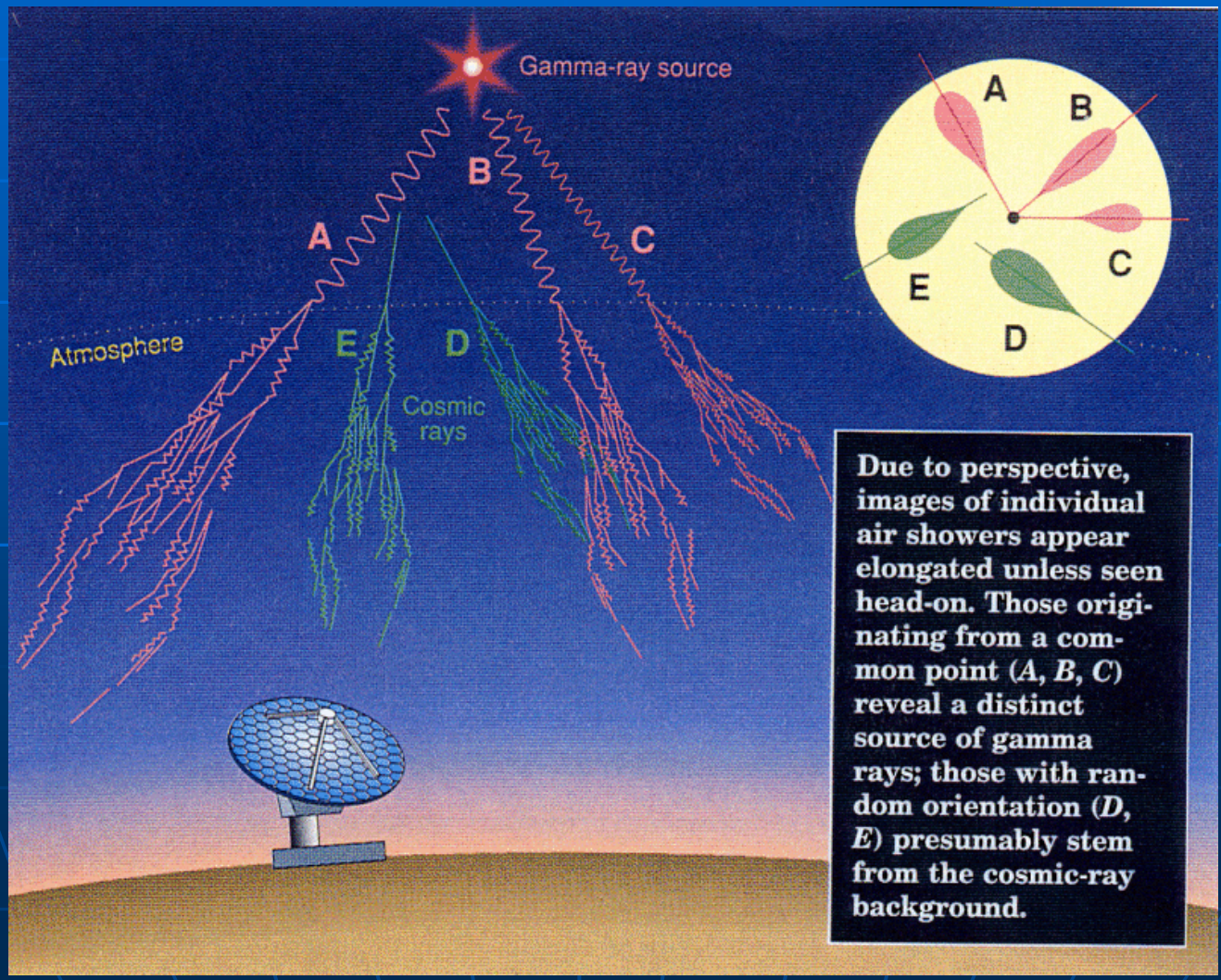
⇒ Sharp image

Proton:

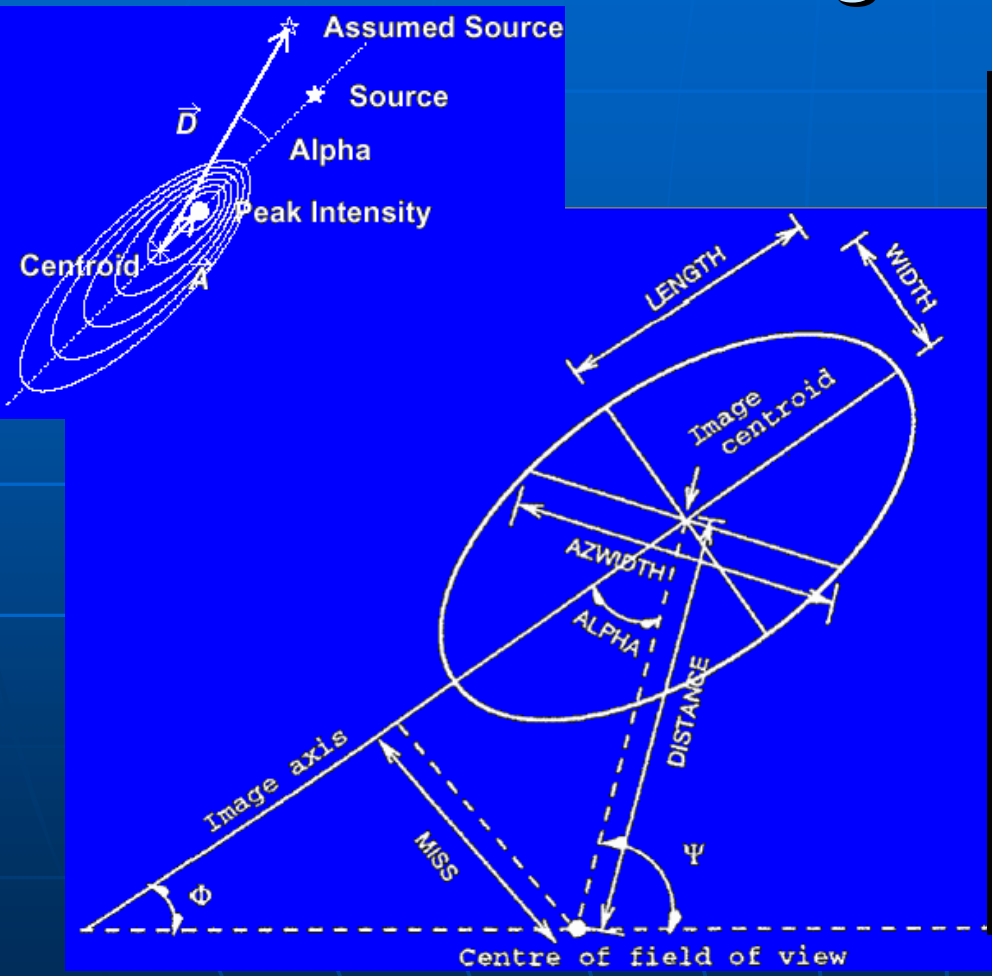
Nuclear shower

⇒ Diffuse image

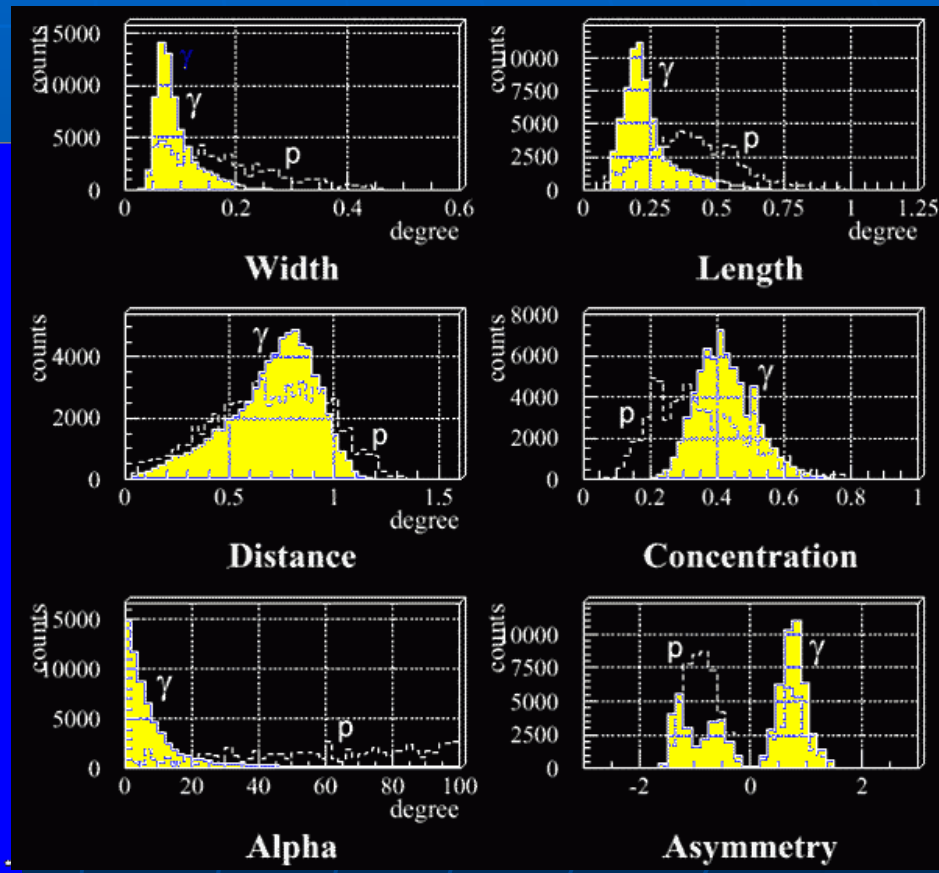
Discrimination of cosmic-ray background (3)



Discrimination of cosmic-ray background (4)



D.J. Fegan, J.Phys.G, 1997

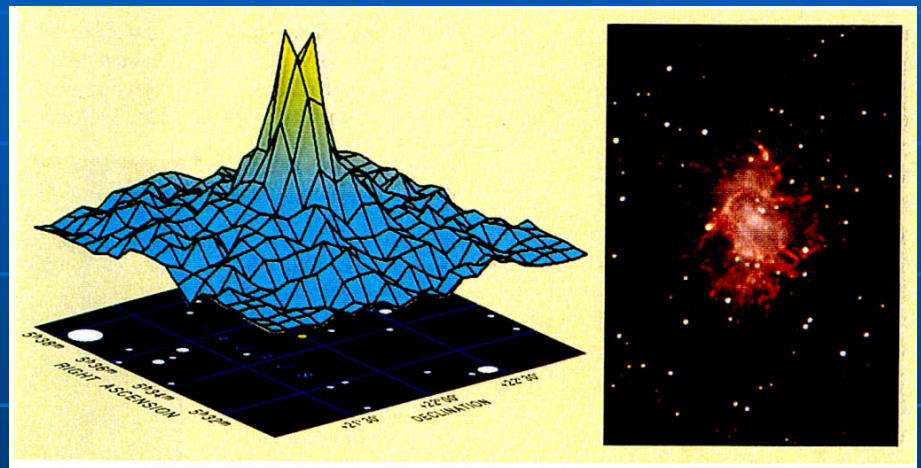


(Simulation)

The first TeV source: Crab Nebula

Whipple 10m telescope

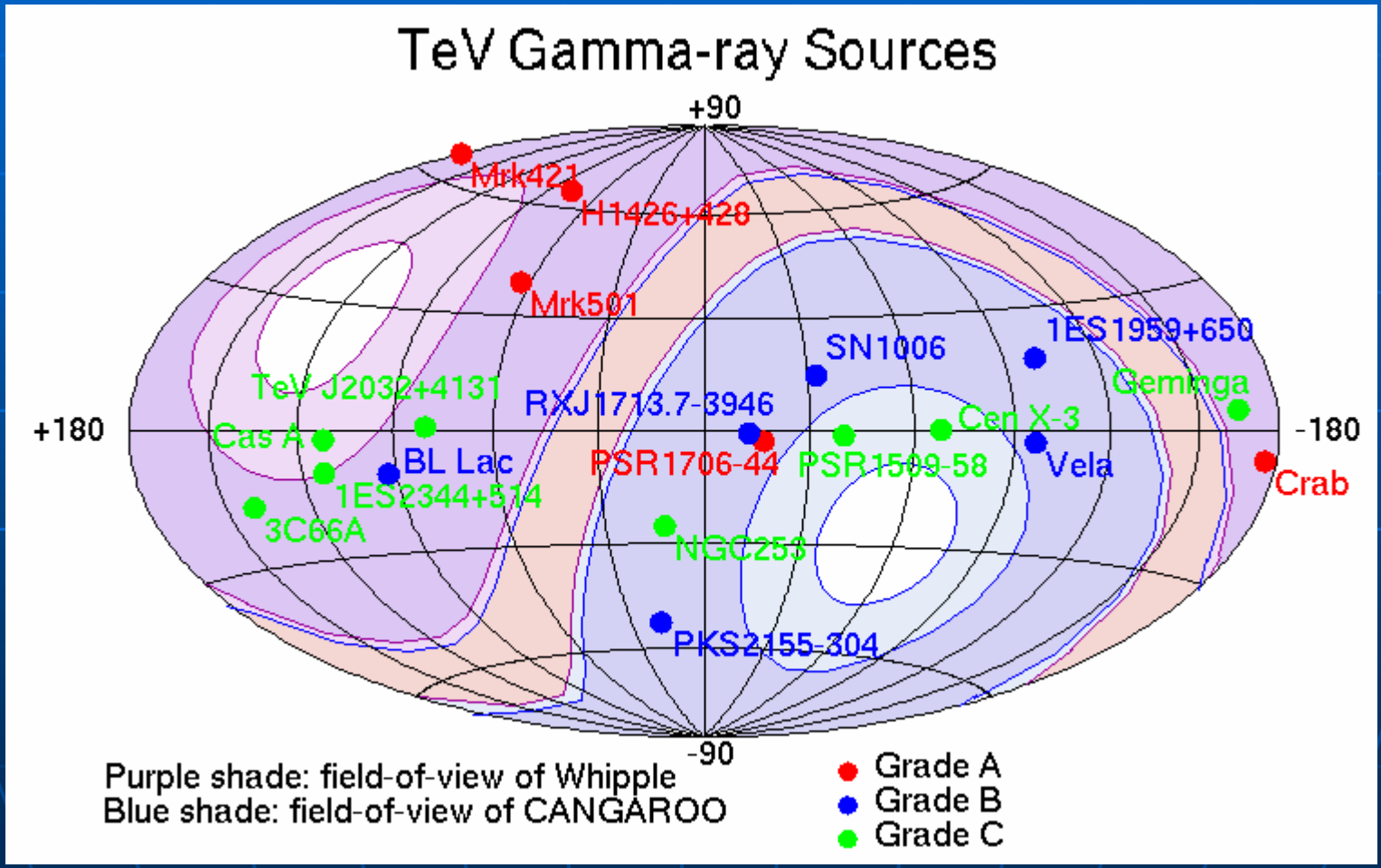
(Arizona, USA)



In 1986 the familiar Crab Nebula provided Whipple Observatory astronomers with their first point-source TeV detection. Each count in this Whipple TeV "image" of the Crab represents the intersection of coincident, elliptical images like those depicted on page 24. The image's large angular extent is an artifact of the telescope's limited resolution. Courtesy John Quinn. *Inset:* This three-color visible-light composite of the Crab was obtained on California's Mount Pinos by Bill and Sally Fletcher.

Weekes et al. ApJ 1989

TeV gamma-ray sky in 2002



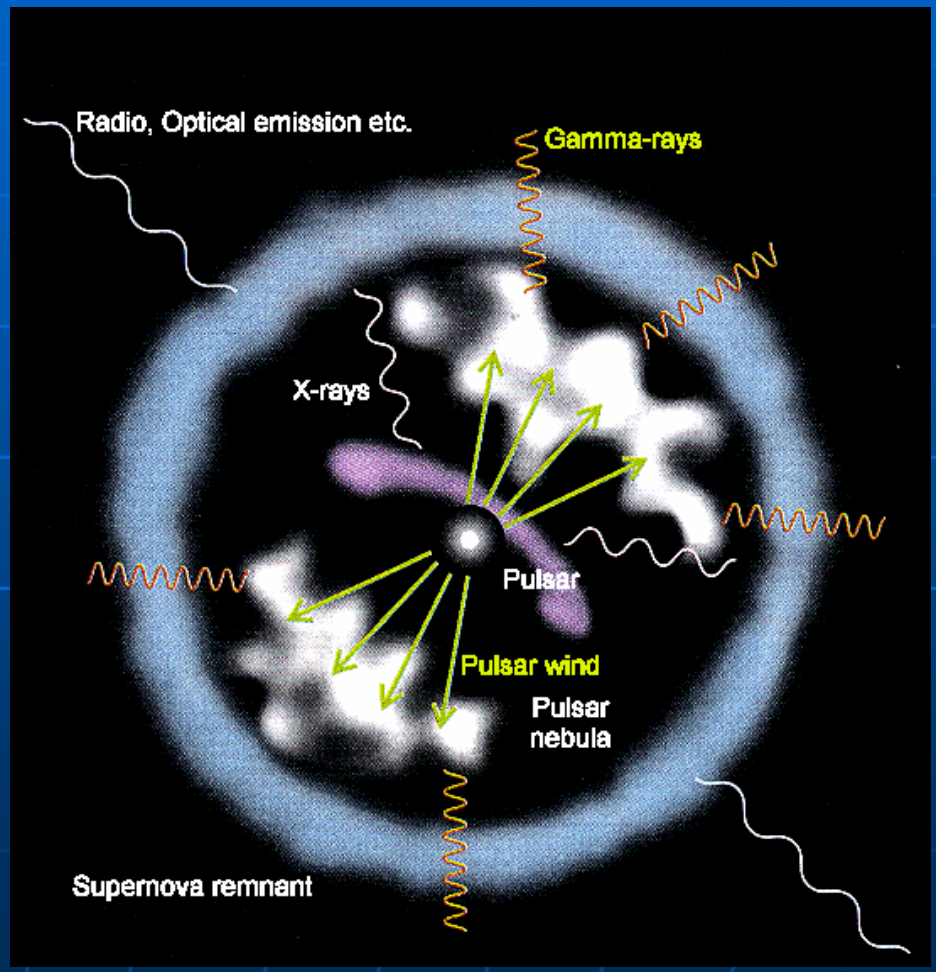
TeV sources

4 Pulsar nebulae	Crab Vela PSR 1706-44 PSR1509-58
8 Blazars	Mrk 421 Mrk501 1ES2344+514 PKS2155-304 3C66A BL Lac 1H1426+428 1ES1959+65
3 Supernova remnants	SN1006 Cas A RX J1713.7-3946
1 X-ray Binary	Cen X-3
1 Starburst galaxy	NGC253

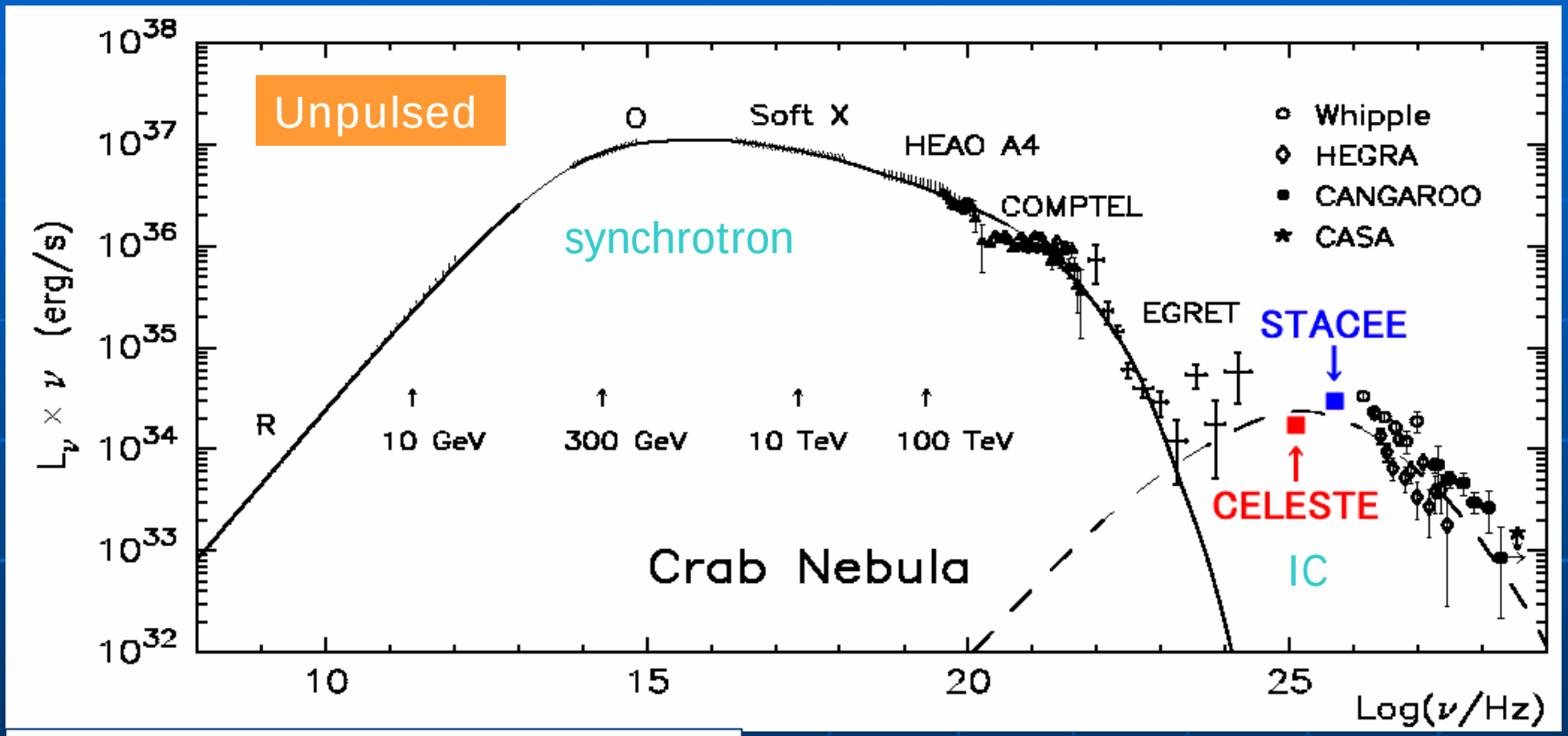
Pulsar nebulae

Crab (X-ray image)

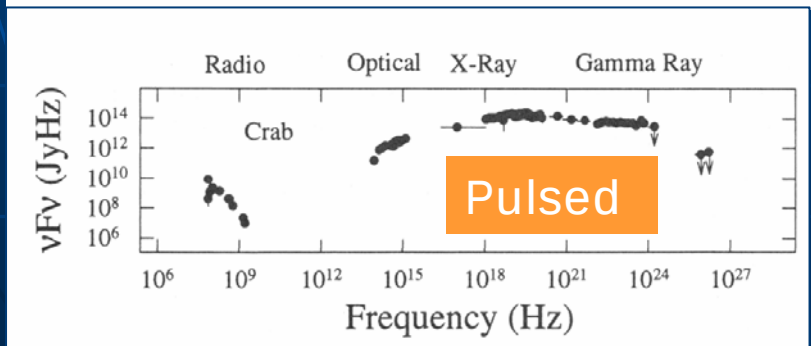
- Fast rotating magnetized pulsar = power generator
- E.M. energy ⇒ Pulsar wind out of light cylinder
- Shock wave in ambient medium ⇒ particle acceleration
- Gamma-rays by IC



Energy spectrum of Crab



Aharonian & Atoyan, astro-ph/9803091 / Heidelberg WS, 2000

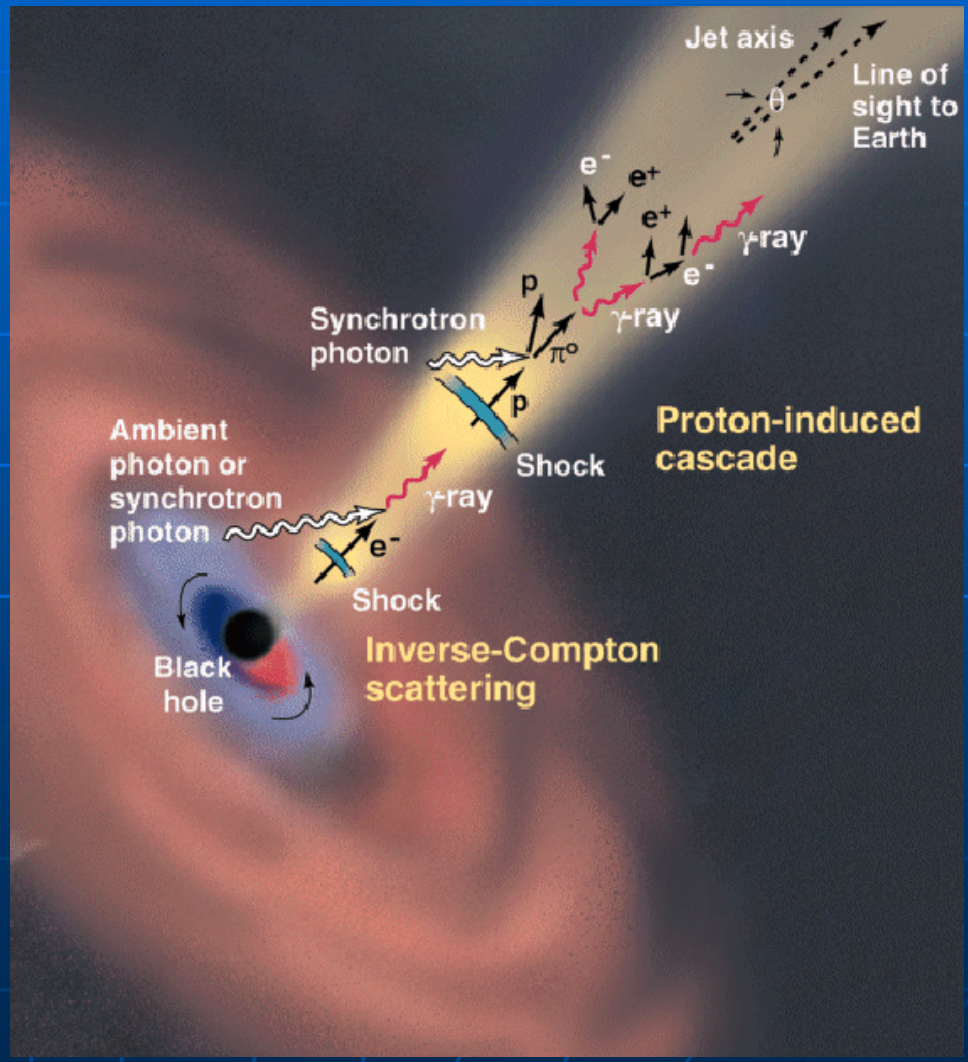


D.Thompson, 4th Compton Symp. 1997

Blazars

Mrk501 (optical image)

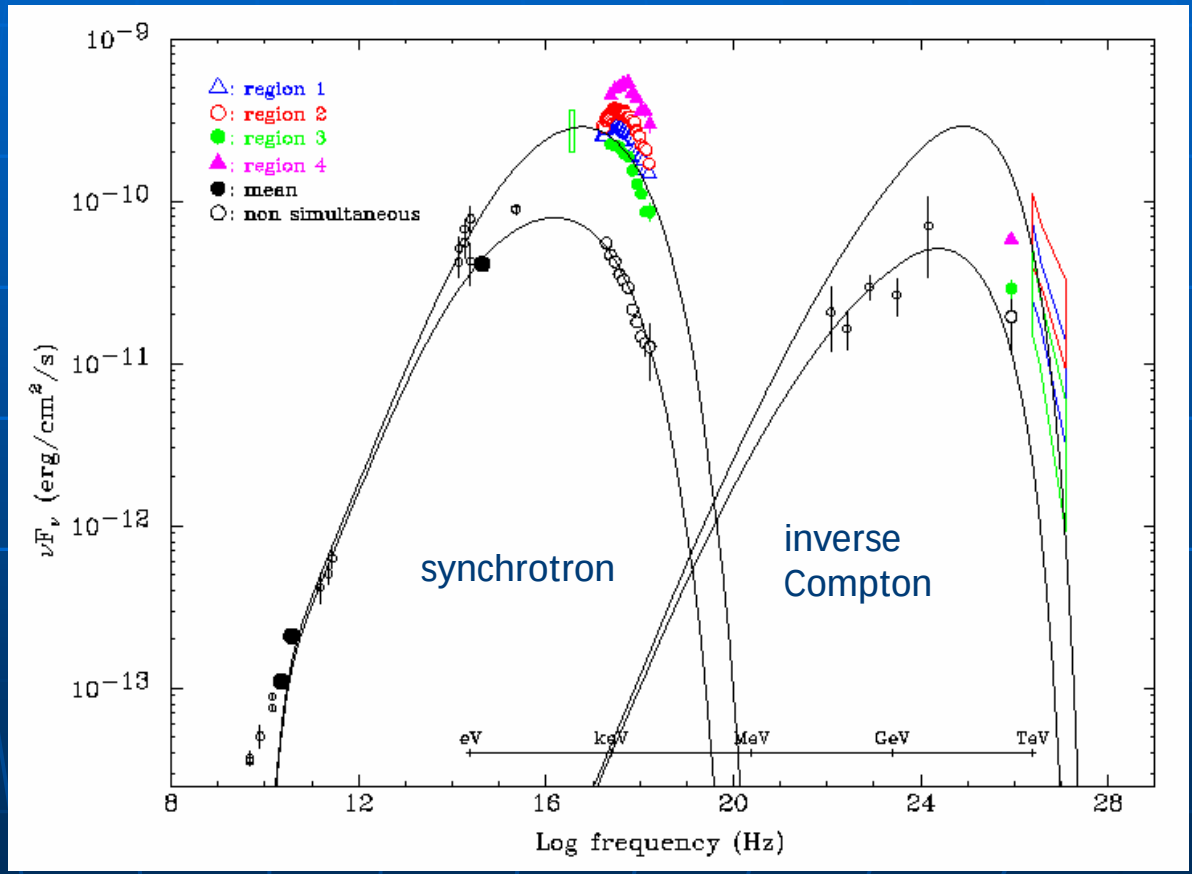
- Matter accretion to massive black hole ⇒ release of gravitational energy
- High speed jet ejection from B.H.
- Shock wave in jets ⇒ particle acceleration
- Gamma-rays from IC or proton-induced cascade



Blazar spectrum

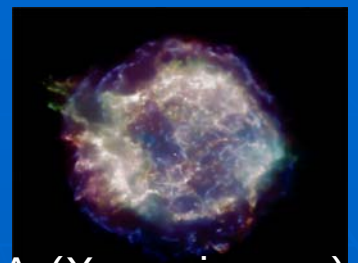
- Double-peaked structure = synchrotron + inverse Compton (Synchrotron Self Compton model)

Mrk421



Takahashi et al. ApJL 2000

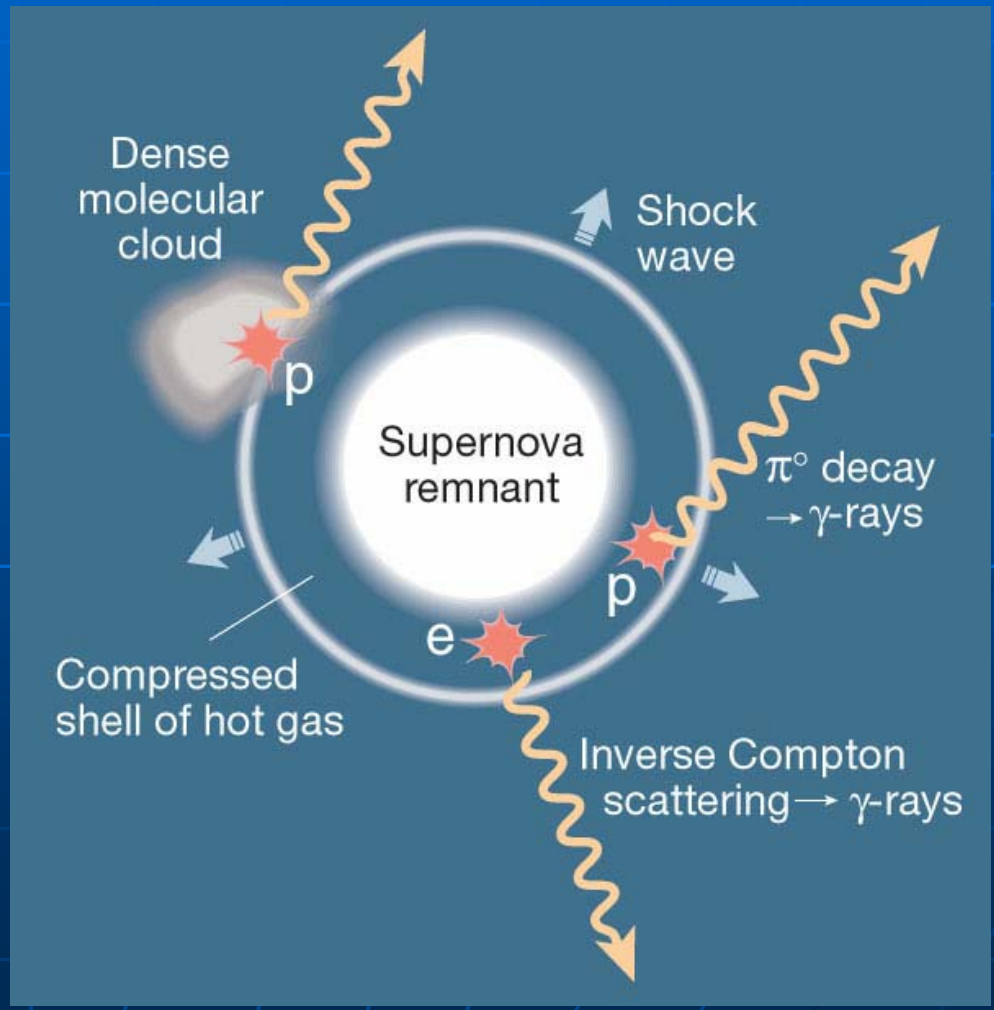
Supernova remnants



Cas A (X-ray image)

- Expanding blast wave from explosion
  $\Rightarrow$ shock wave
- Particles accelerated in shock wave
- Interaction with ambient medium
  - e + $\vec{B}$ (syncrotron)
  - e + Photons (IC)
  - p + Gas (π^0)

  $\Rightarrow$ Gamma-rays
- Cosmic ray origin? (energetics argument)

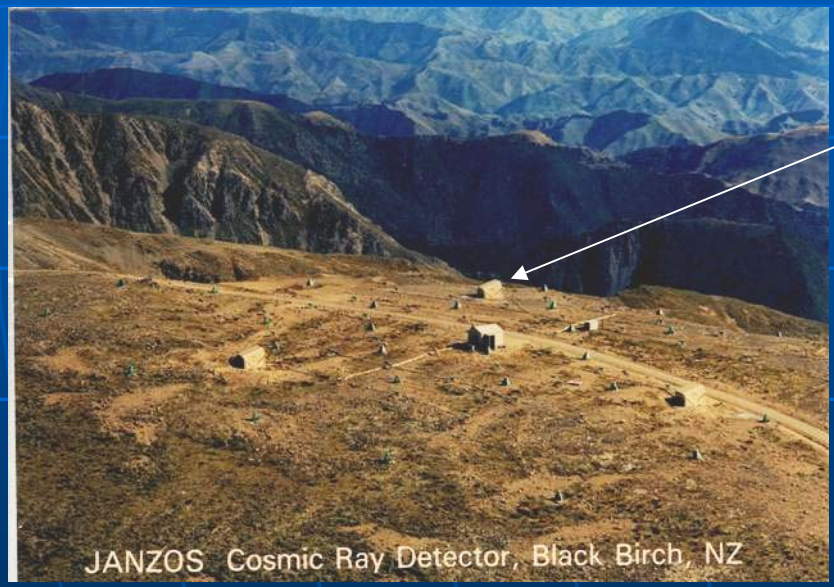


Brief history of CANGAROO

- 1987: SN1987A
- 1990: 3.8m telescope
- 1990: ICRR-Adelaide Physics agreement
- 1992: Start obs. of 3.8m tel.
- 1994: PSR 1706-44
- 1998: SNR1006
- 1999: 7m telescope
- 2000: Upgrade to 10m
- 2001: U.Tokyo-U.Adelaide agreement
- 2002: Second and third 10m tel.

JANZOS project in New Zealand

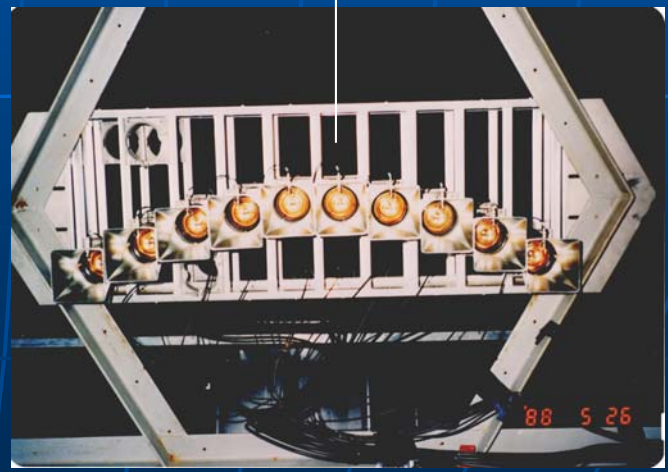
Japan Australia New Zealand
Observation of Supernova 1987A



Shower particle detector array

+

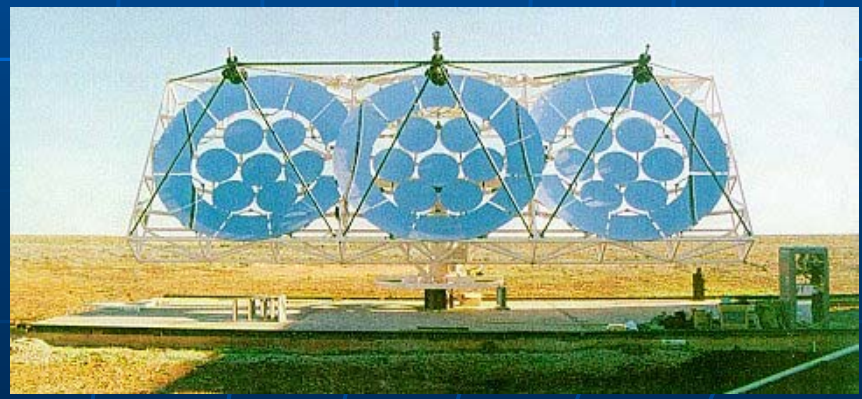
Three Fixed Cherenkov telescopes



Why Woomera?

- NZ: too wet, not many clear nights
- Woomera:
  - Former rocket range and prohibited area...infra-structure and support
  - Adeldaide group was operating BIGRAT

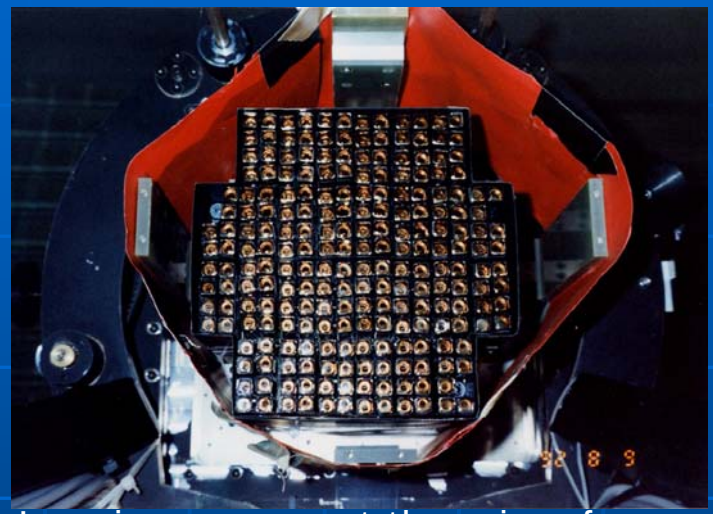
ELDO rocket Launch site in ’60s



BIGRAT

(BIcentinnial Gamma RAy Telescope)

3.8m telescope: ex. Lunar ranging

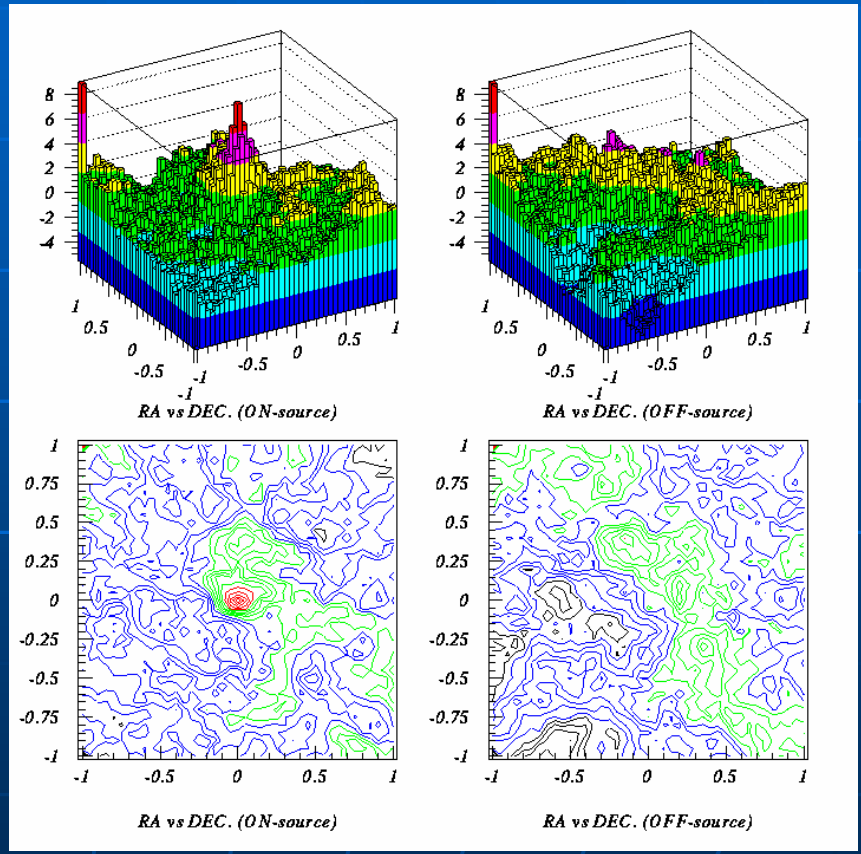


Imaging camera at the prime focus

Tadashi Kifune & John Patterson

PSR 1706-44: the first southern TeV object

- 102ms pulsar
- Age: 17,000 yr
- GeV gamma-ray source (pulsed)
- TeV emission confirmed by Durham group and CANGAROO 7/10m
- Emission mechanism: still unclear



Significance map near PSR:

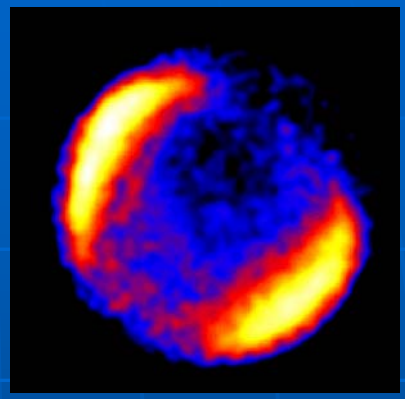
(Left: ON, Right: OFF)

Kifune et al. ApJL 1995

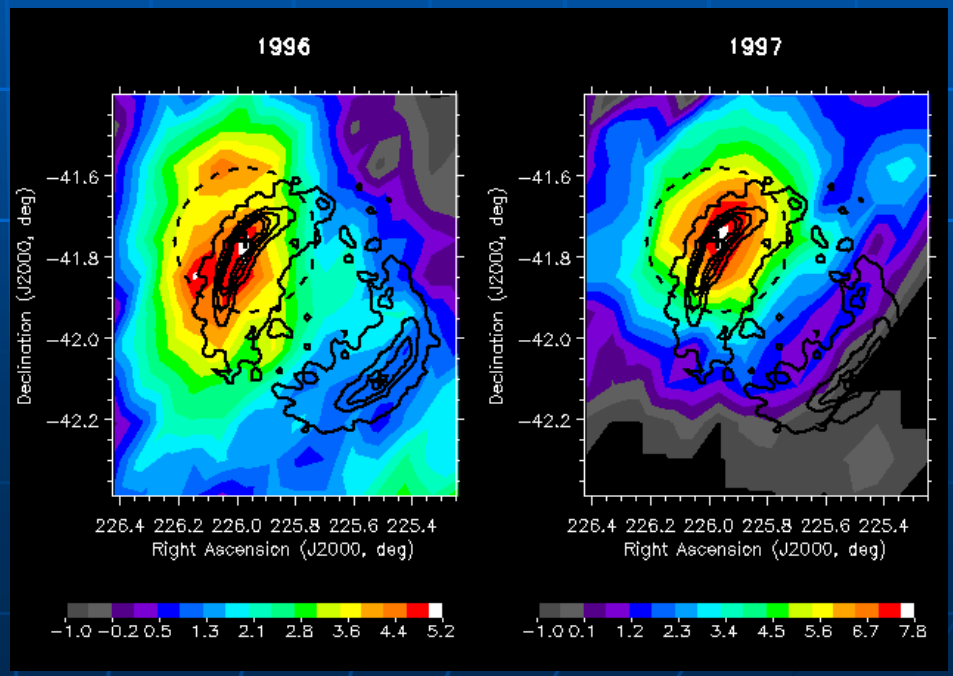
Supernova remnant 1006 (1)

- Historical SNR recorded in 1006
- Nonthermal X-rays detected by ASCA (Koyama et al. 1995) ⇒ *Synchrotron* emission by high energy electrons
- Inverse Compton emission expected and detected by CANGAROO!

Tanimori et al. ApJL 1998

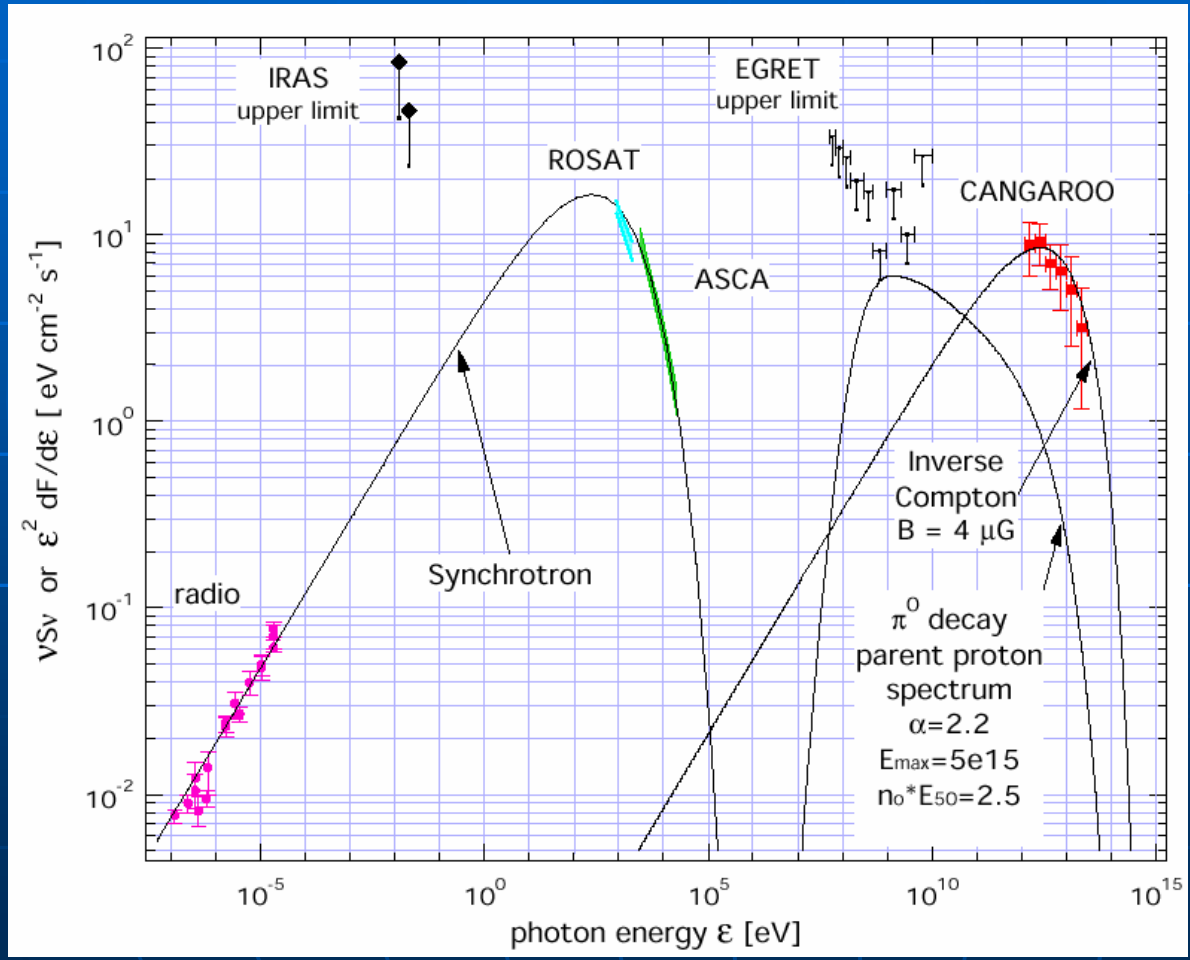


ASCA X-ray image



CANGAROO Significance map

Supernova remnant 1006 (2)

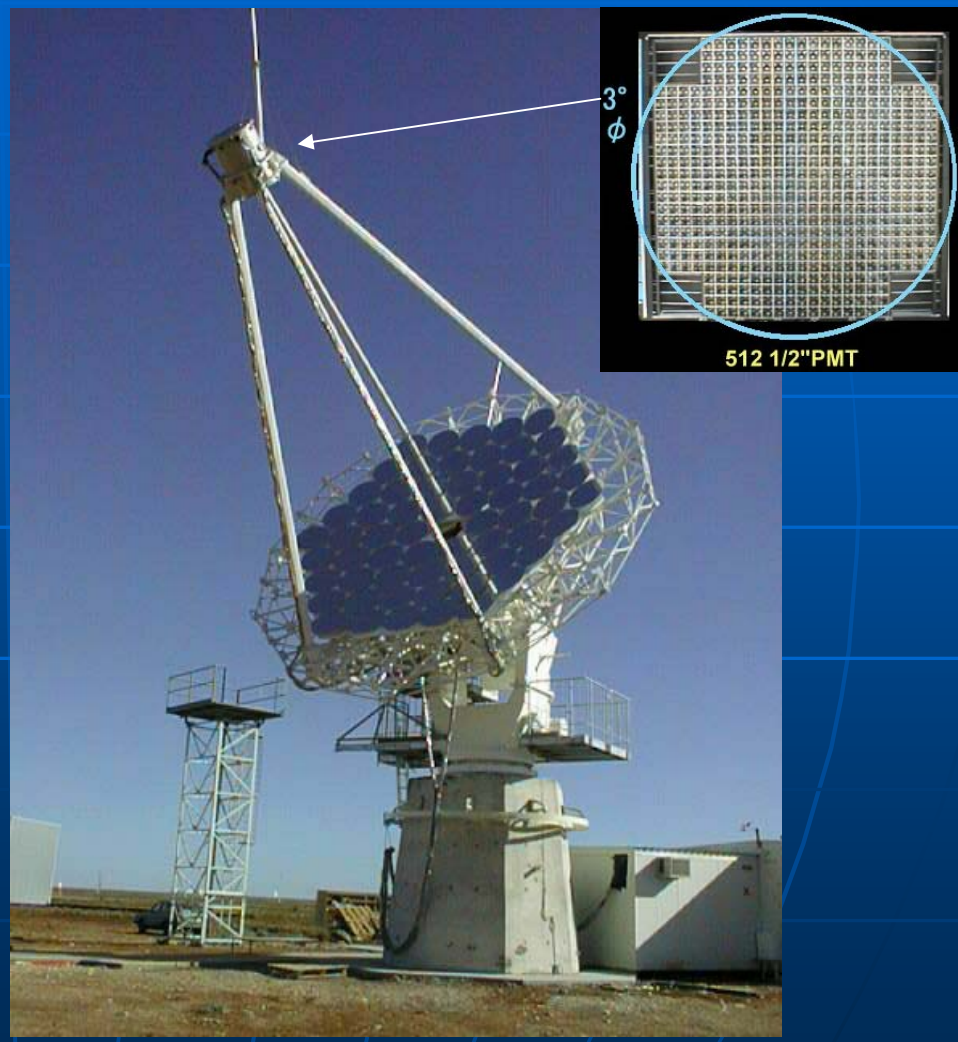


Well fit by inverse Compton emission from electrons

⇒ SNR as a high-energy accelerator!

CANGAROO-II: 7m telescope

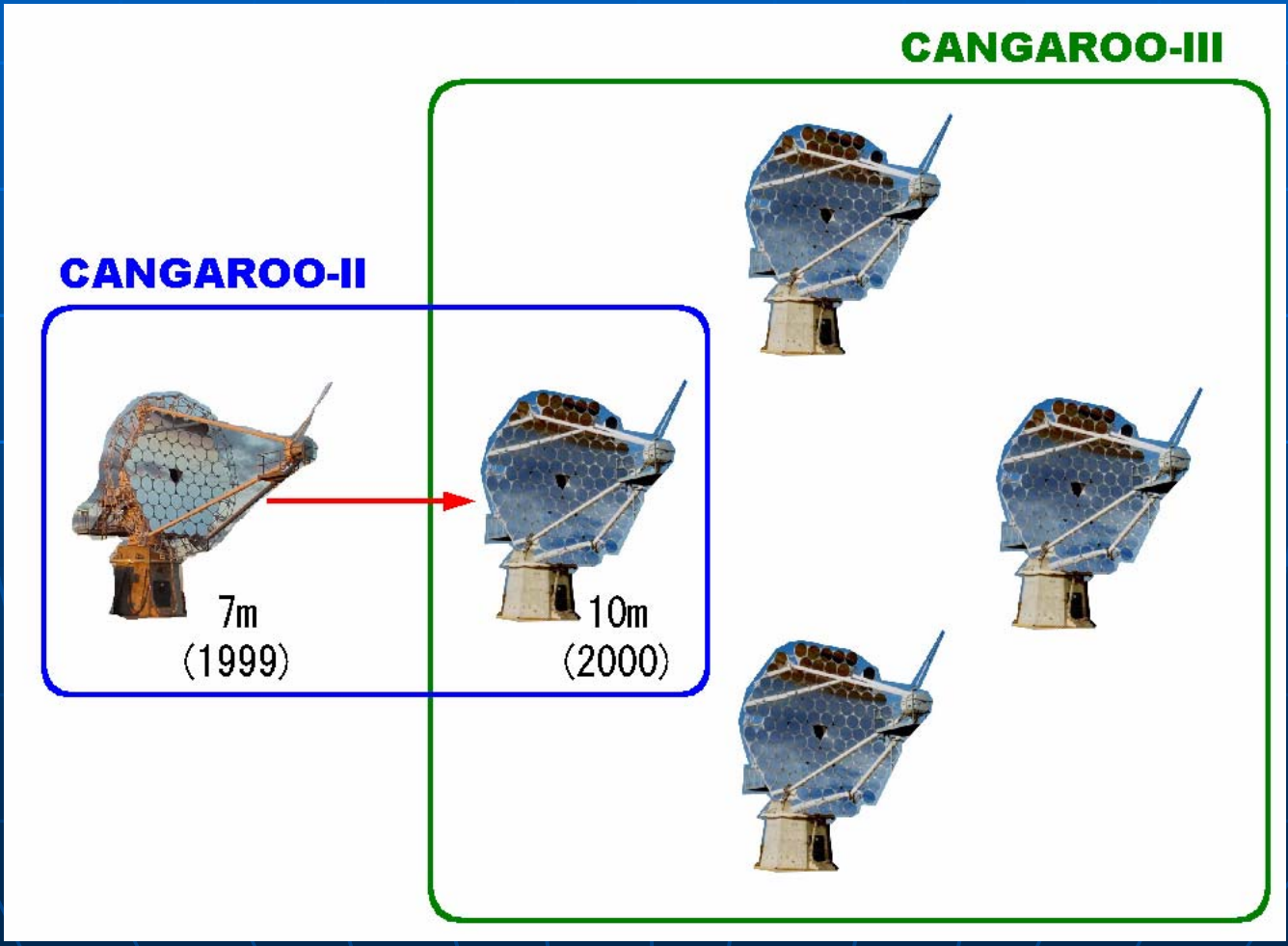
- Completed in 1999
- 60 x 80cm CFRP mirror segments
- Focal length 8m
- 512ch imaging camera
- Fast electronics (charge and timing)



(March 1999)

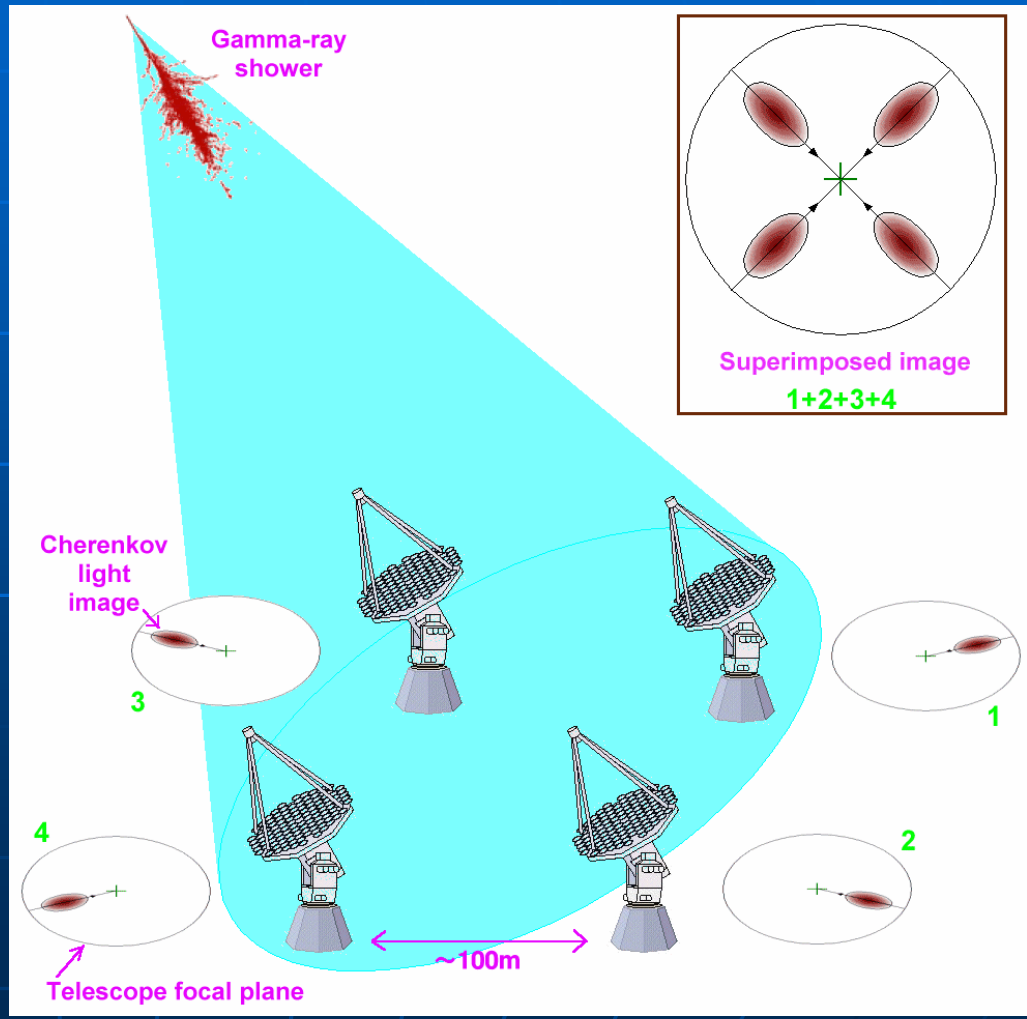
CANGAROO-III: Stereo imaging

- 4 x 10m telescopes to be completed in 2003

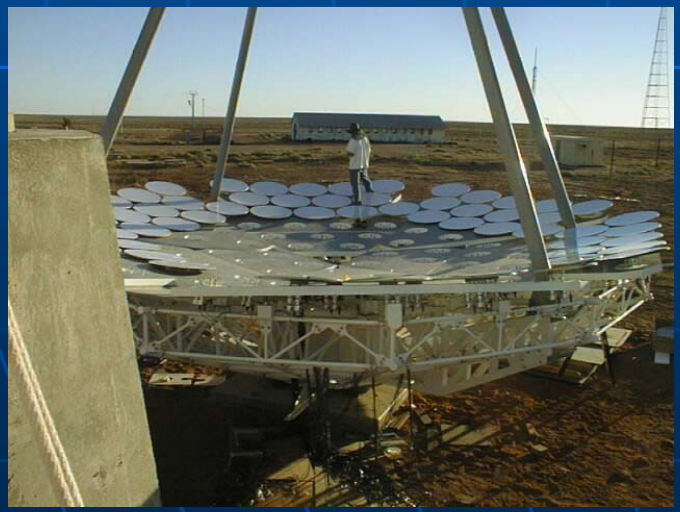


Stereo imaging of Cherenkov light

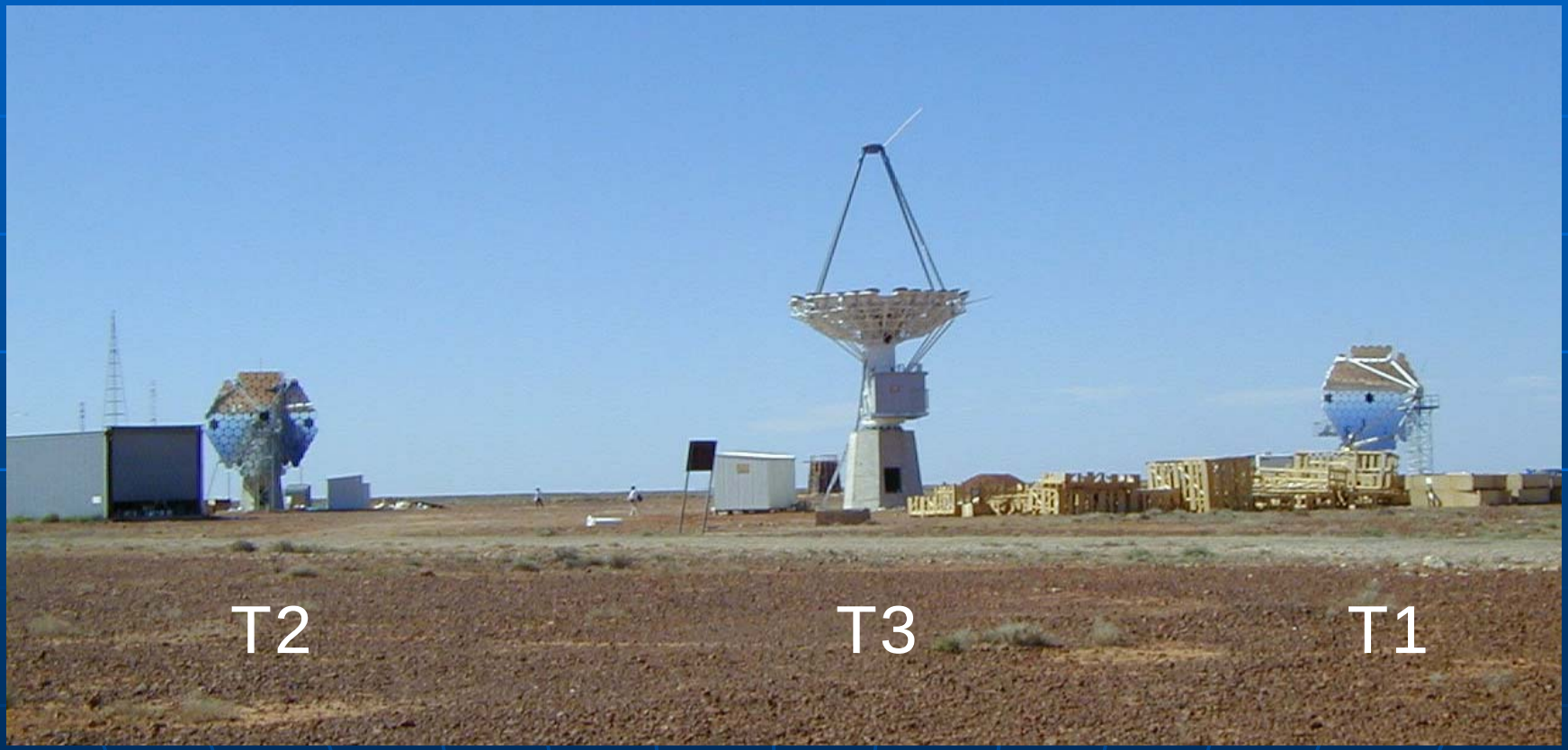
- Cherenkov shower pool: ~300mϕ
- Stereo ⇒ Info. on distance to showers
- Better angular resolution
- Better energy resolution



Construction of 2nd 10m telescope in 2002



Present status: Three 10m telescopes in Woomera



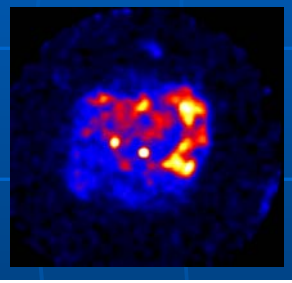
Started operation in Dec. 2002

Assembled in Dec. 2002

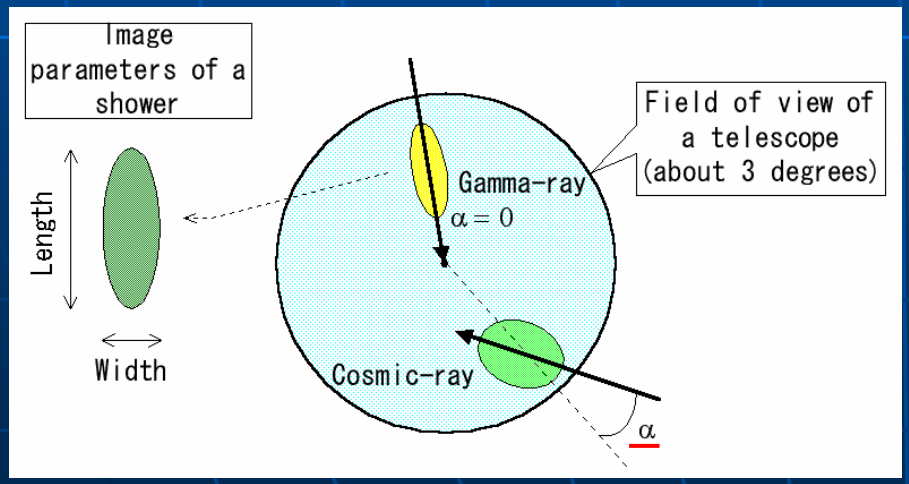
In operation since 2000

SNR RX J1713.7-3946

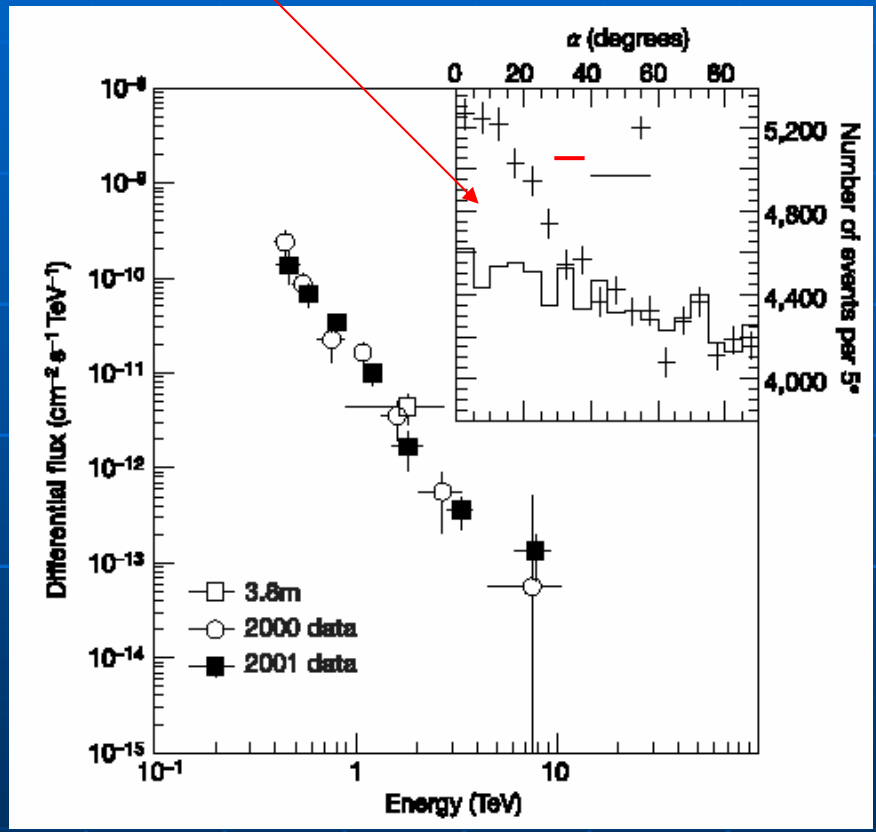
- SNR detected by X-ray satellite
- Non-thermal emission



X-ray image



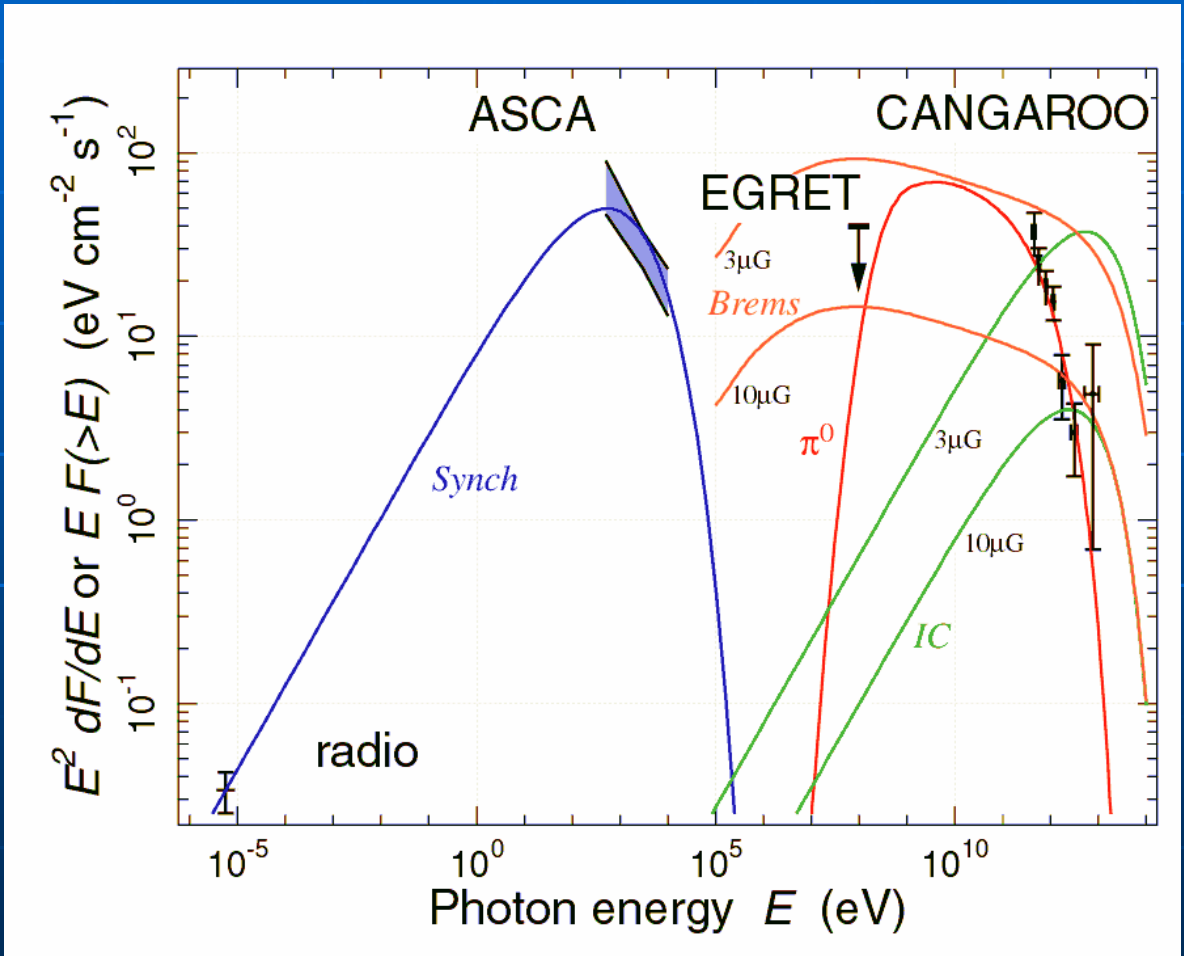
Gamma-ray signal = (OFF) – (ON)



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)?

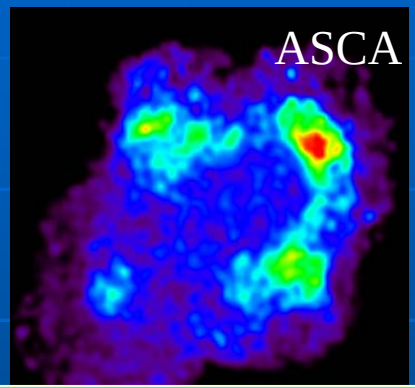
⇒ Cosmic ray origin?

Enomoto et al. Nature 2002

Systematic study of SNRs

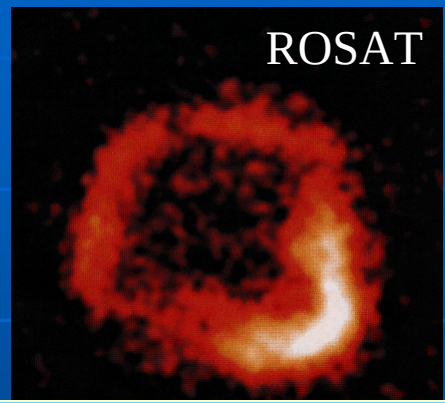
Crab nebula

（"Standard candle"）



RX J1713.7-3946

（CANGAROO）



RCW86

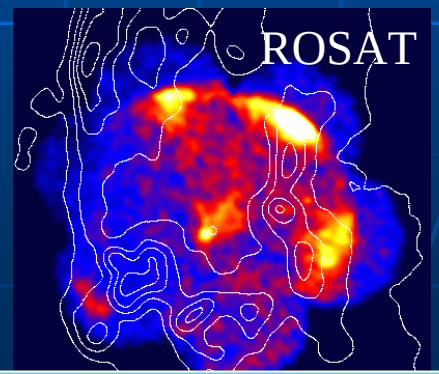
（CANGAROO under analysis）

Vela

（CANGAROO）

Cas A

（HEGRA）



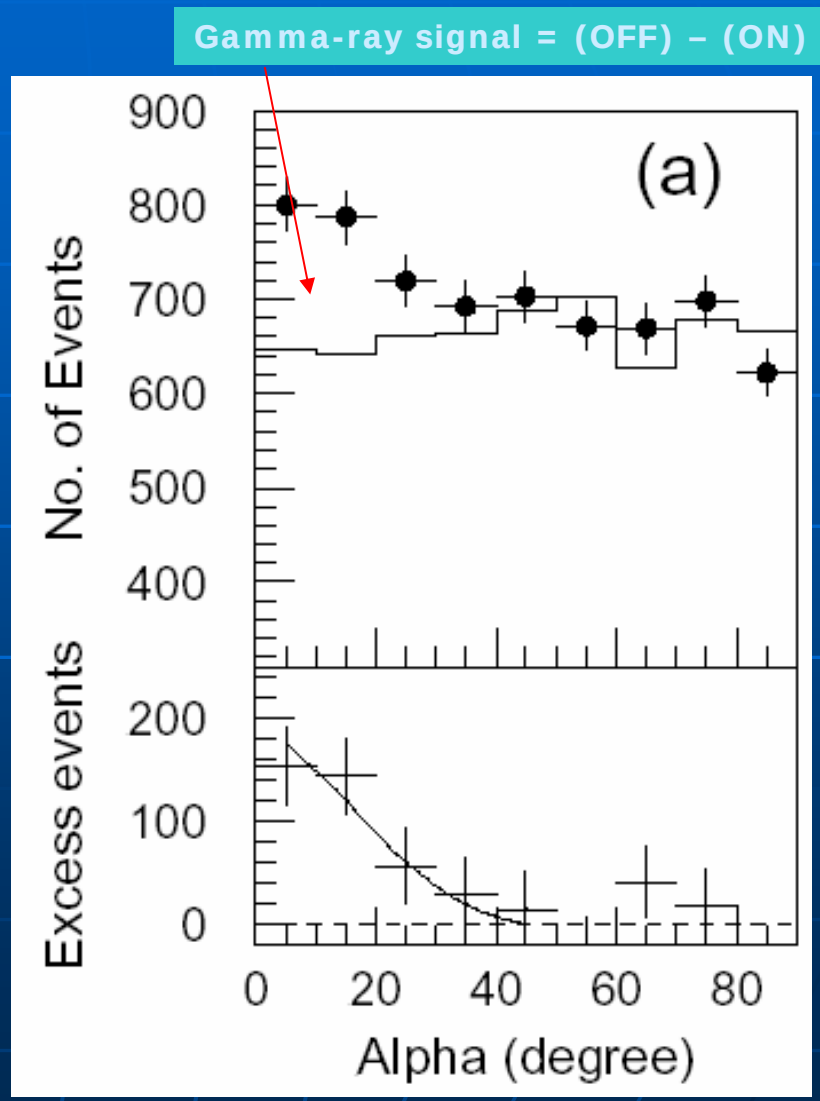
RX J0852-46

（CANGAROO under analysis）

Blazar: Markarian 421

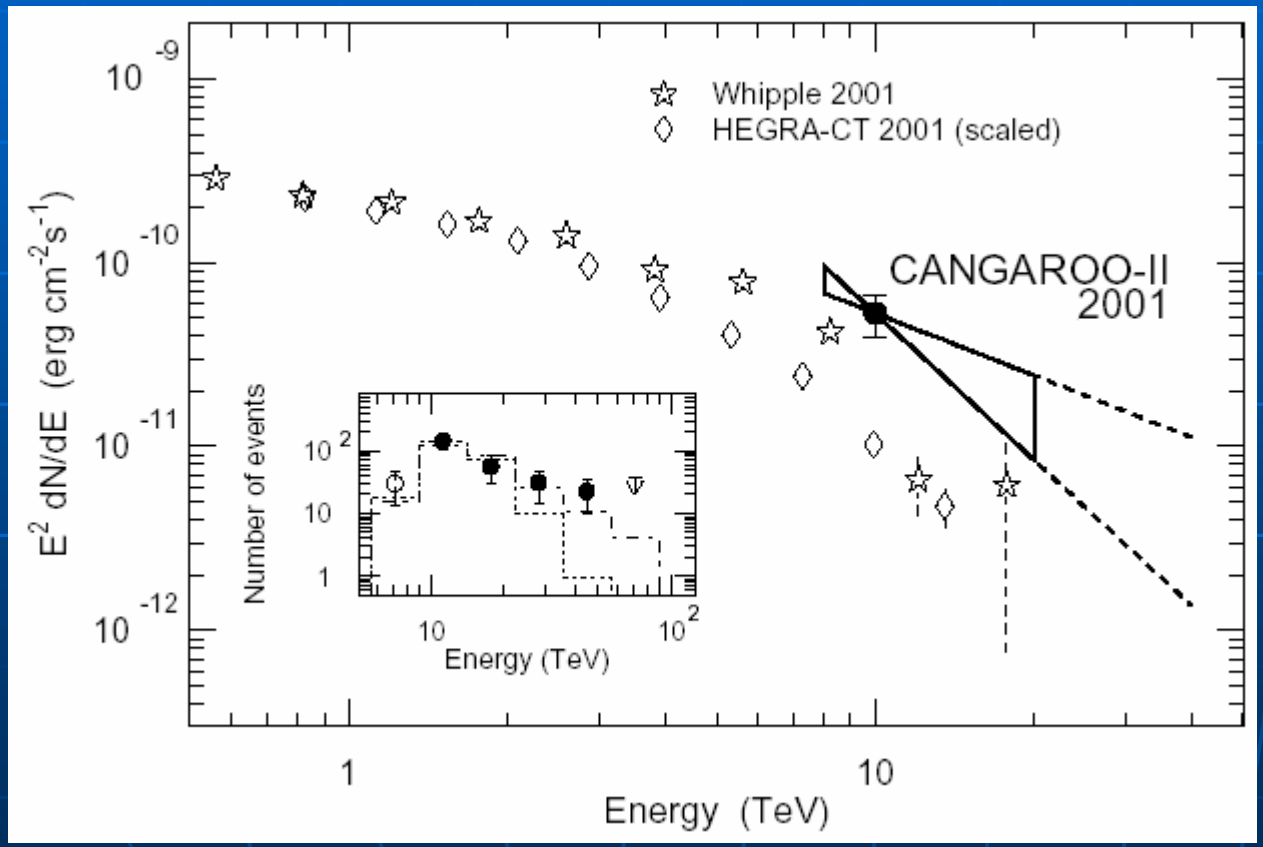
- The first TeV AGN in the northern sky
- z=0.031 (~130Mpc)
- Flare in 2001
- Large zenith angle observation from Woomera: higher energy
- Intergalactic absorption by IR: No 10TeV photons?

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

TeV gamma-ray absorption by IR background

$$\gamma_{TeV} + \gamma_{IR} \rightarrow e^+ + e^-$$

Summary of extragalactic background light measurements

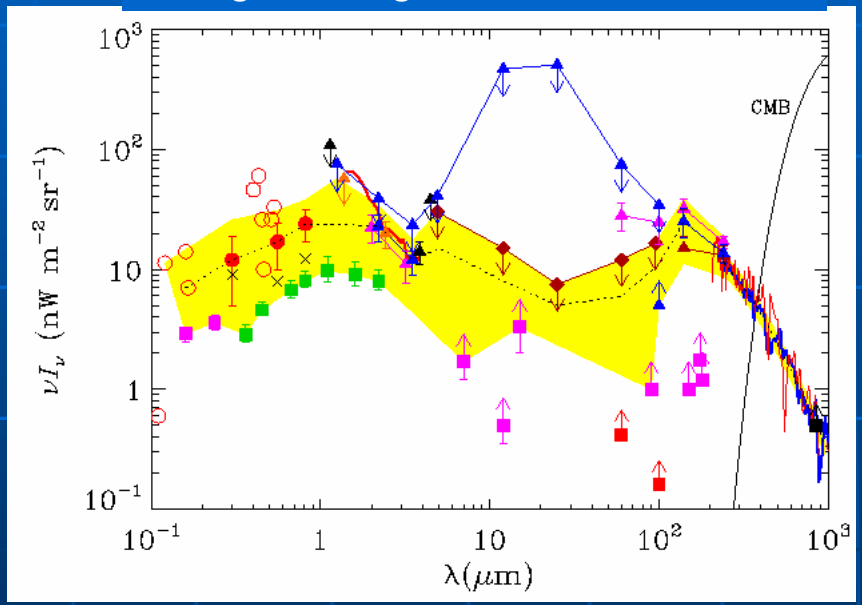


Figure 5. Summary of extragalactic background light (EBL) measurements and limits. Error bars for detections are 1σ. Square symbols show lower limits obtained by integrating the light of detected sources. X's show 2σ lower limits on integrated resolved sources from Bernstein (1999). Diamonds show upper limits from fluctuation measurements. All other symbols show absolute background measurements (1σ error bars) or limits (2σ). The shaded region represents current observational limits for the EBL spectrum, and the dotted line shows nominal values (see § 3.10 for discussion). The black line (CMB) shows the cosmic microwave background radiation.

Hauser and Dwek astro-ph/0105539

Mean free path for e^+e^- pair production

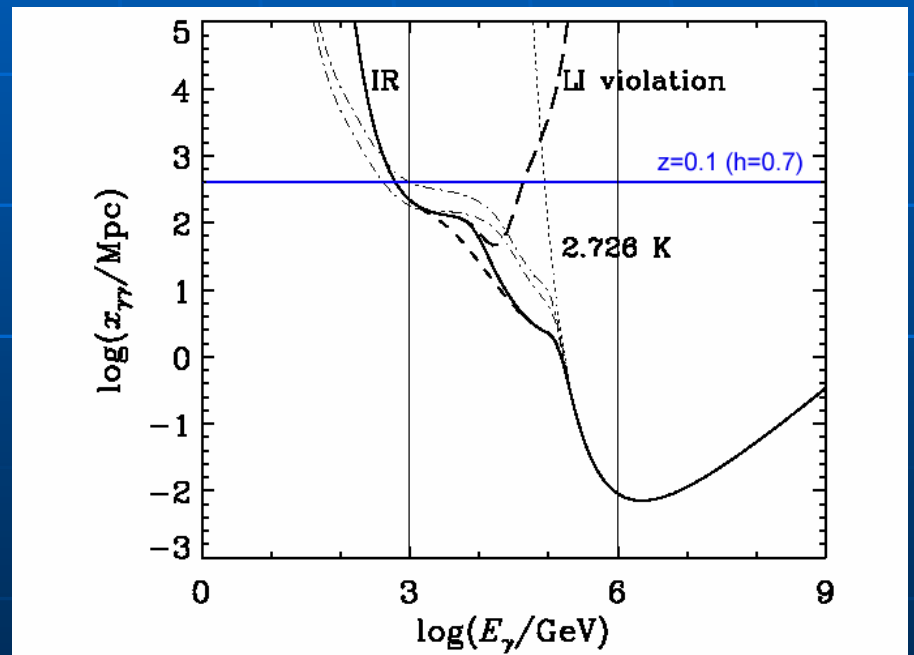


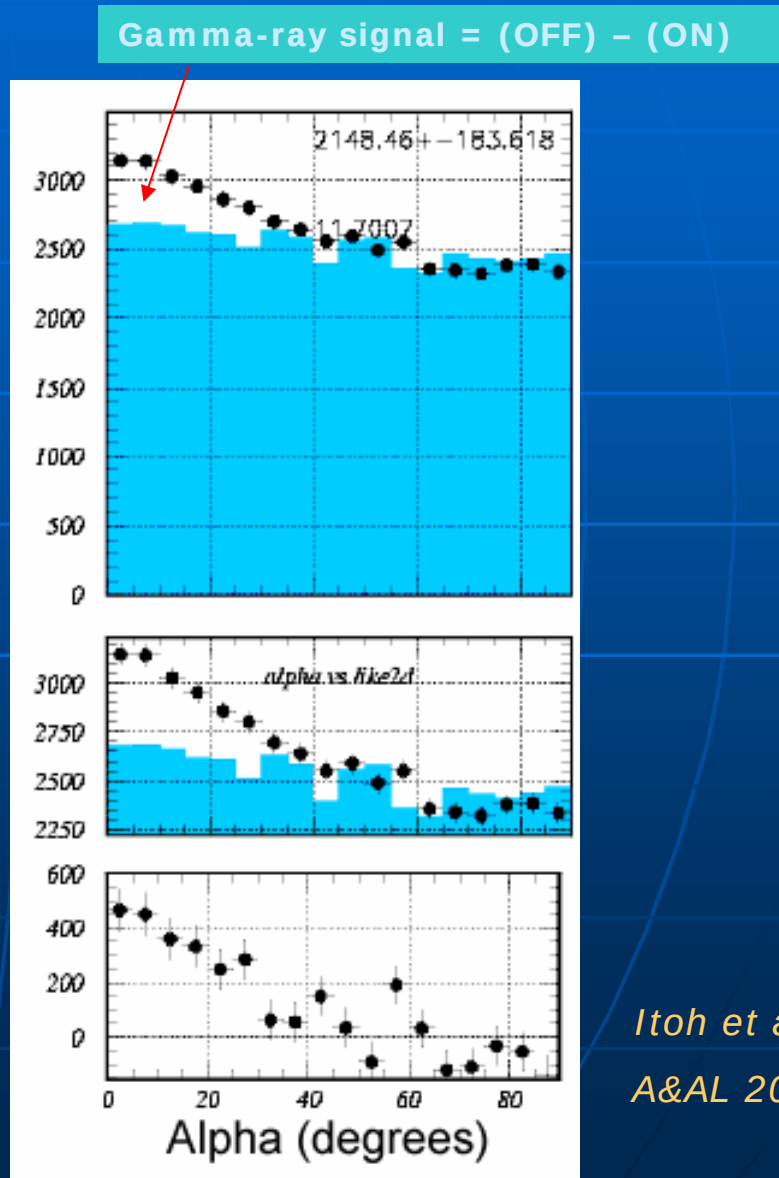
Figure 2: Mean free path for photon-photon pair production in the infrared–microwave background radiation. The curves correspond to those in Fig. 1 except that the effect of Lorentz Invariance violation discussed in Section 4 is shown by the long dashed curve.

Protheroe et al. astro-ph/0005349

Starburst galaxy NGC 253

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

Optical image

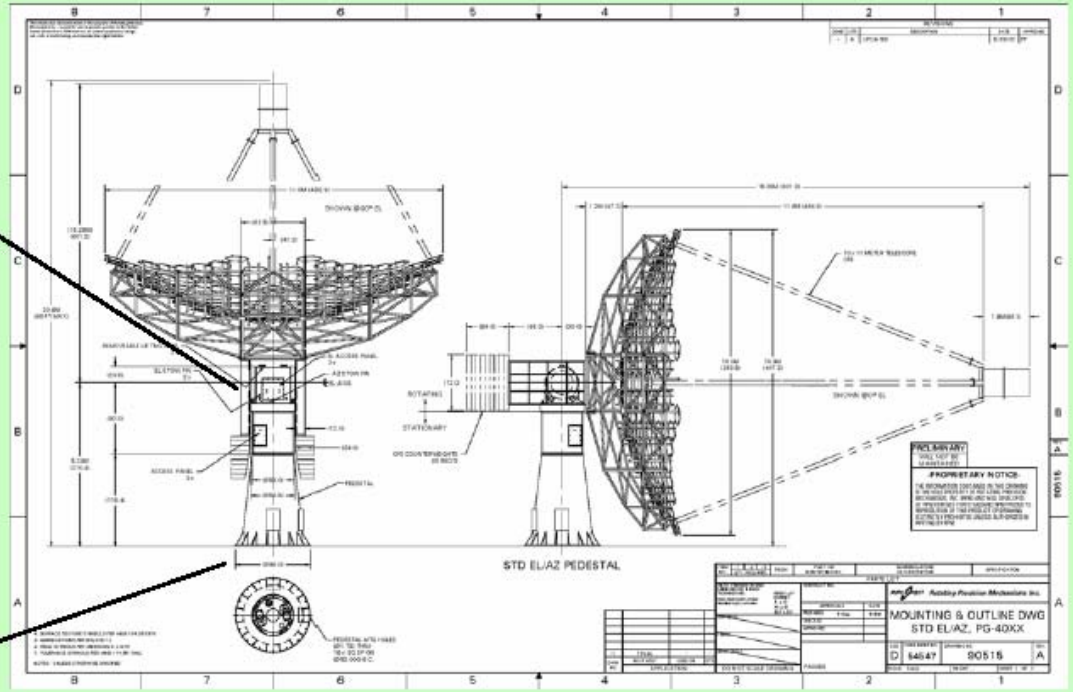


Itoh et al. A&AL 2002

Cherenkov telescopes in the world

TELESCOPE

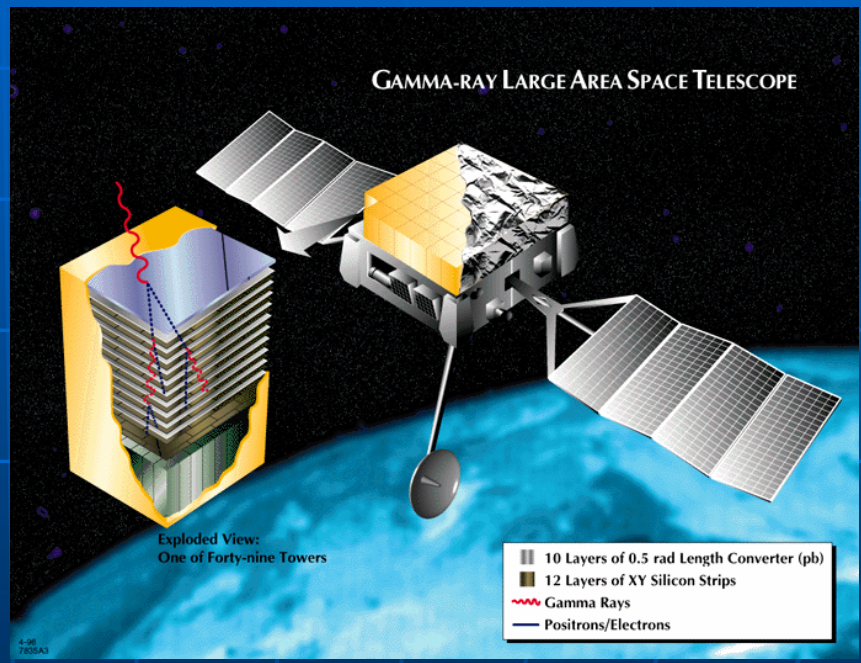
Pedestal



Overall Optical Support Structure
Accommodates 12m mirror

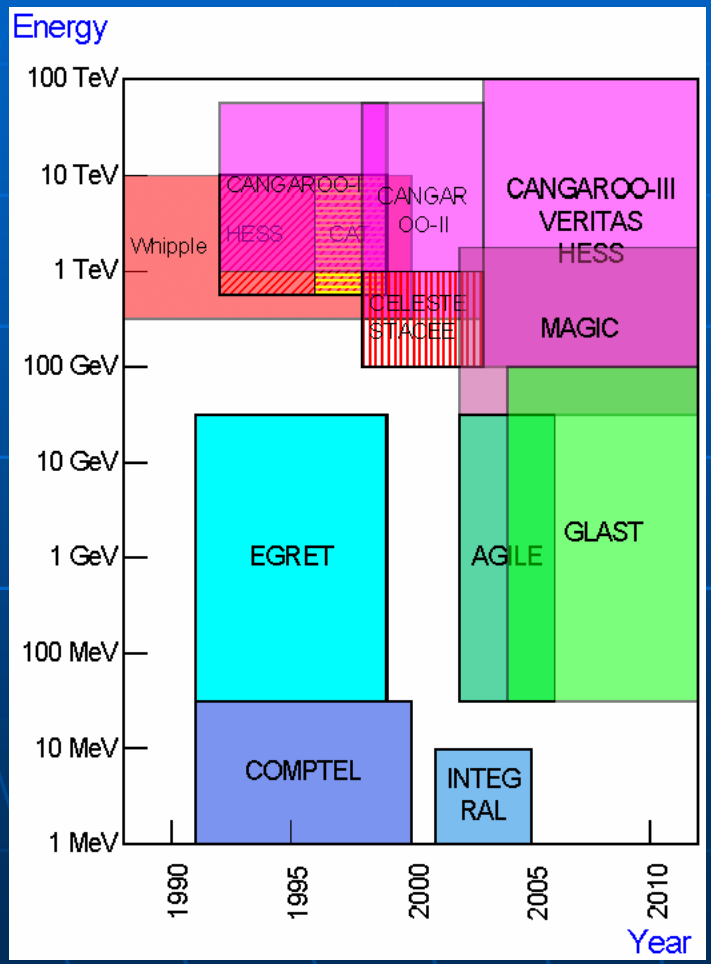
Satellites waiting for launch

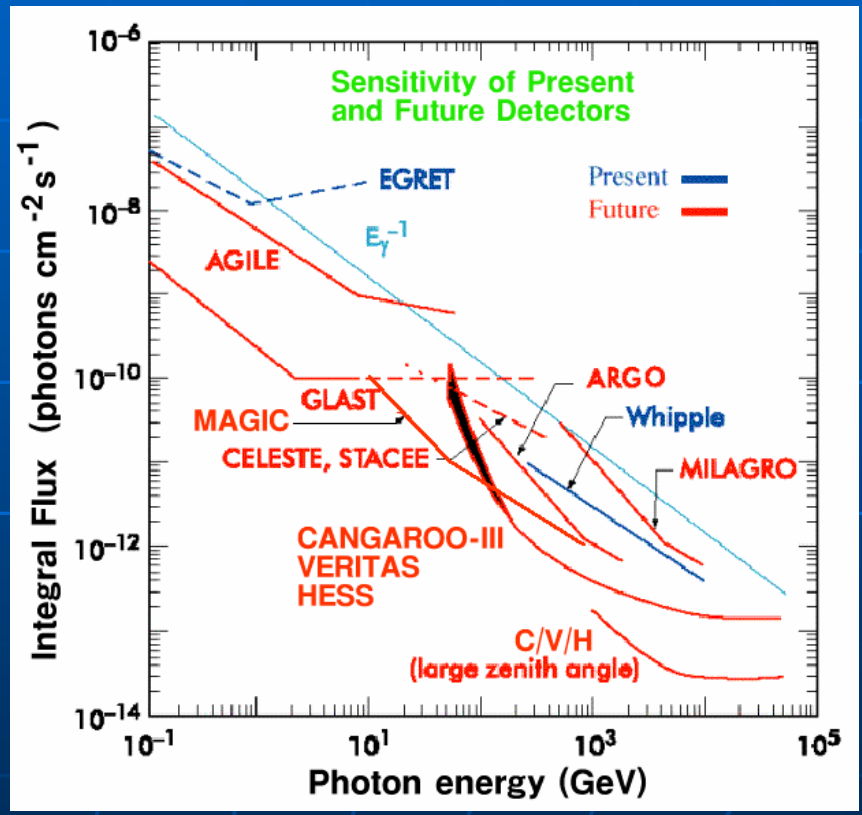
AGILE (ASI [Italy] 2003)



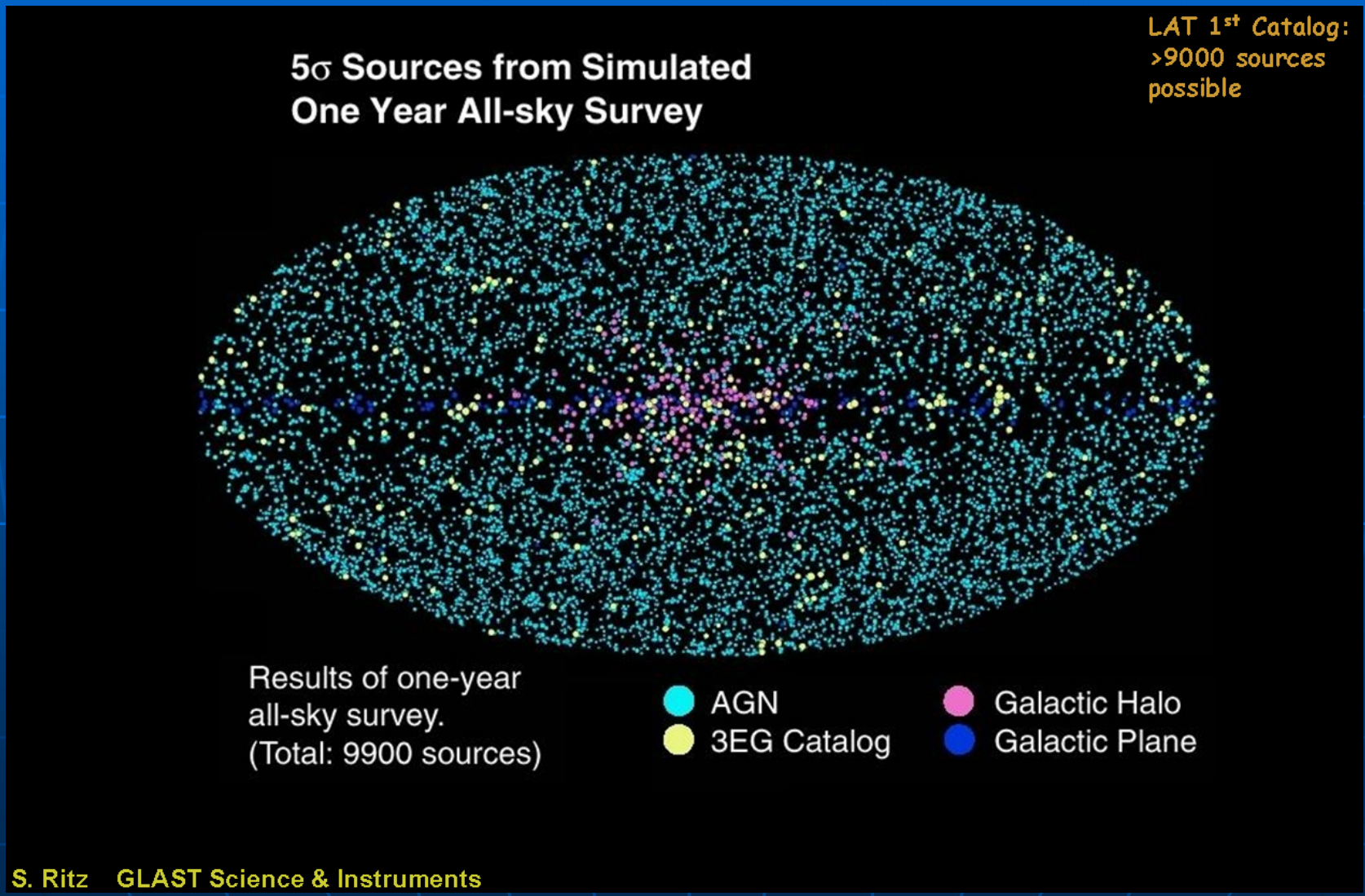
GLAST (NASA, 2006)

Near future

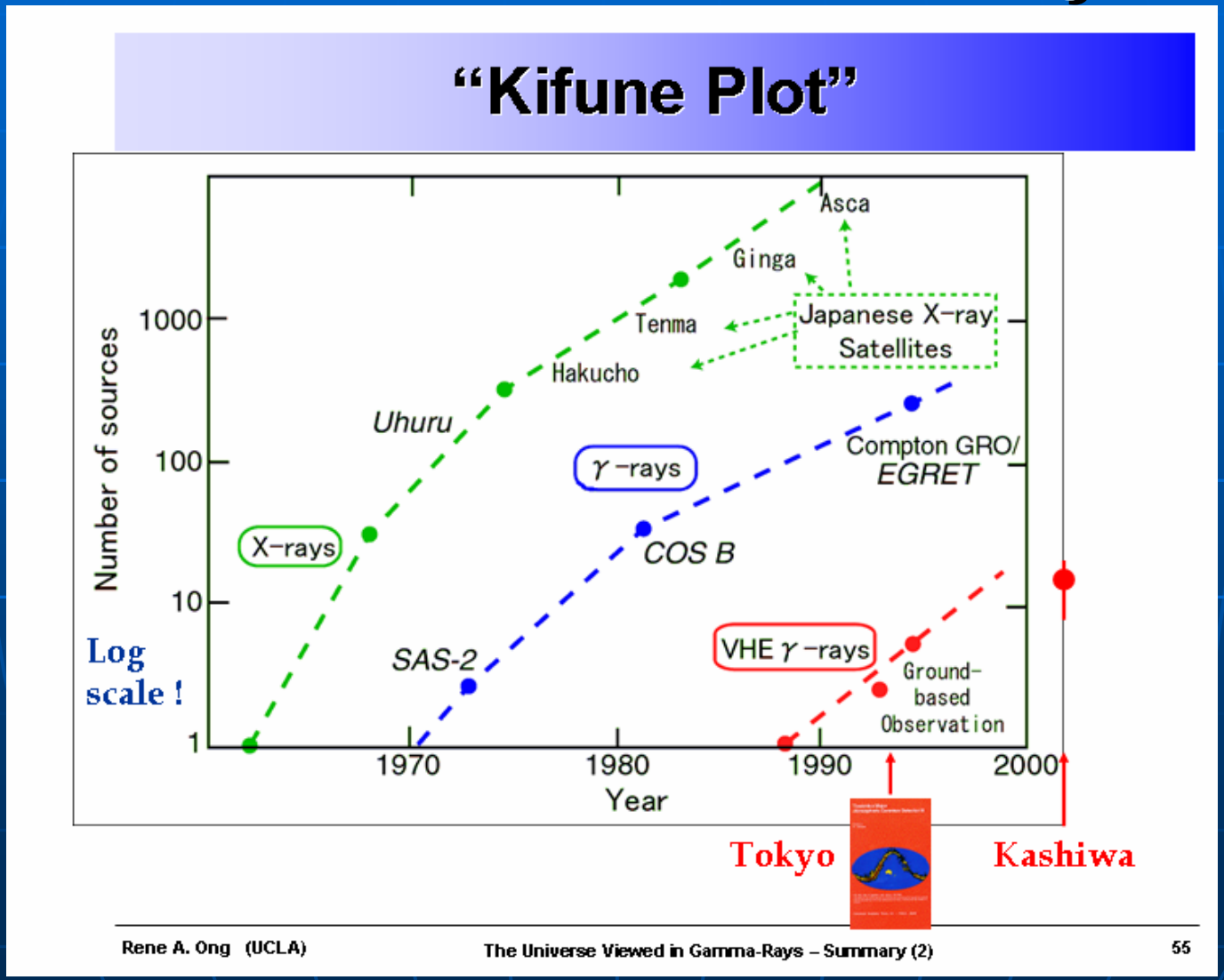

Energy
100 TeV
10 TeV
1 TeV
100 GeV
10 GeV
1 GeV
100 MeV
10 MeV
1 MeV
Whipple
CANGAROO-I
HESS
CAT
CANGAR
OO-II
CANGAROO-III
VERITAS
HESS
CELESTE
STACEE
MAGIC
EGRET
AGILE
GLAST
COMPTEL
INTEG
RAL
1990
1995
2000
2005
2010
Year


Sensitivity of Present
and Future Detectors
Present
Future
EGRET
E_γ^{-1}
AGILE
GLAST
MAGIC
CELESTE, STACEE
ARGO
Whipple
MILAGRO
CANGAROO-III
VERITAS
HESS
C/V/H
(large zenith angle)
Integral Flux (photons cm^{-2} s^{-1})
Photon energy (GeV)
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-1}
10^{1}
10^{3}
10^{5}

GeV Gamma-ray sky in 2007?



Number of sources vs. year



Summary

- Gamma-ray astronomy – last frontier of astronomy
- Gamma-rays are emitted by non-thermal particle acceleration process
- TeV astronomy emerged in late ’80s is rapidly growing
- CANGAROO is a pioneer of Southern TeV sky
- Non-thermal universe will be explored deeply in near future