SuperCANGAROO

Symposium on Future Projects in Cosmic Ray Physics,
June 26-28, 2003 @ICRR

Masaki Mori
ICRR, University of Tokyo
On behalf of the CANGAROO team

CANGAROO team (as of April 2003)

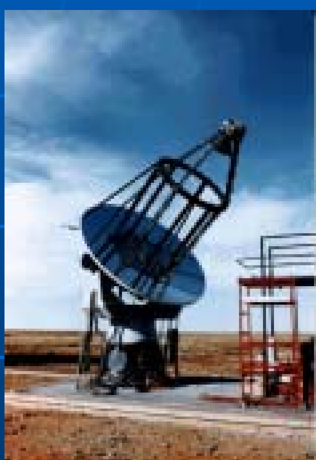
- University of Adelaide
- Australian National University
- Ibaraki University
- Ibaraki Prefectural University
- Kanagawa University
- Konan University
- Kyoto University
- Nagoya University
- National Astronomical Observatory of Japan
- Osaka city University
- Institute of Physical and Chemical Research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

CANGAROO history

CANGAROO-II
7m (1999)

upgraded

CANGAROO-III
T1 10m (2000)



CANGAROO-I
3.8m (1992)

CANGAROO-III
T1,T2,T3 (2002)

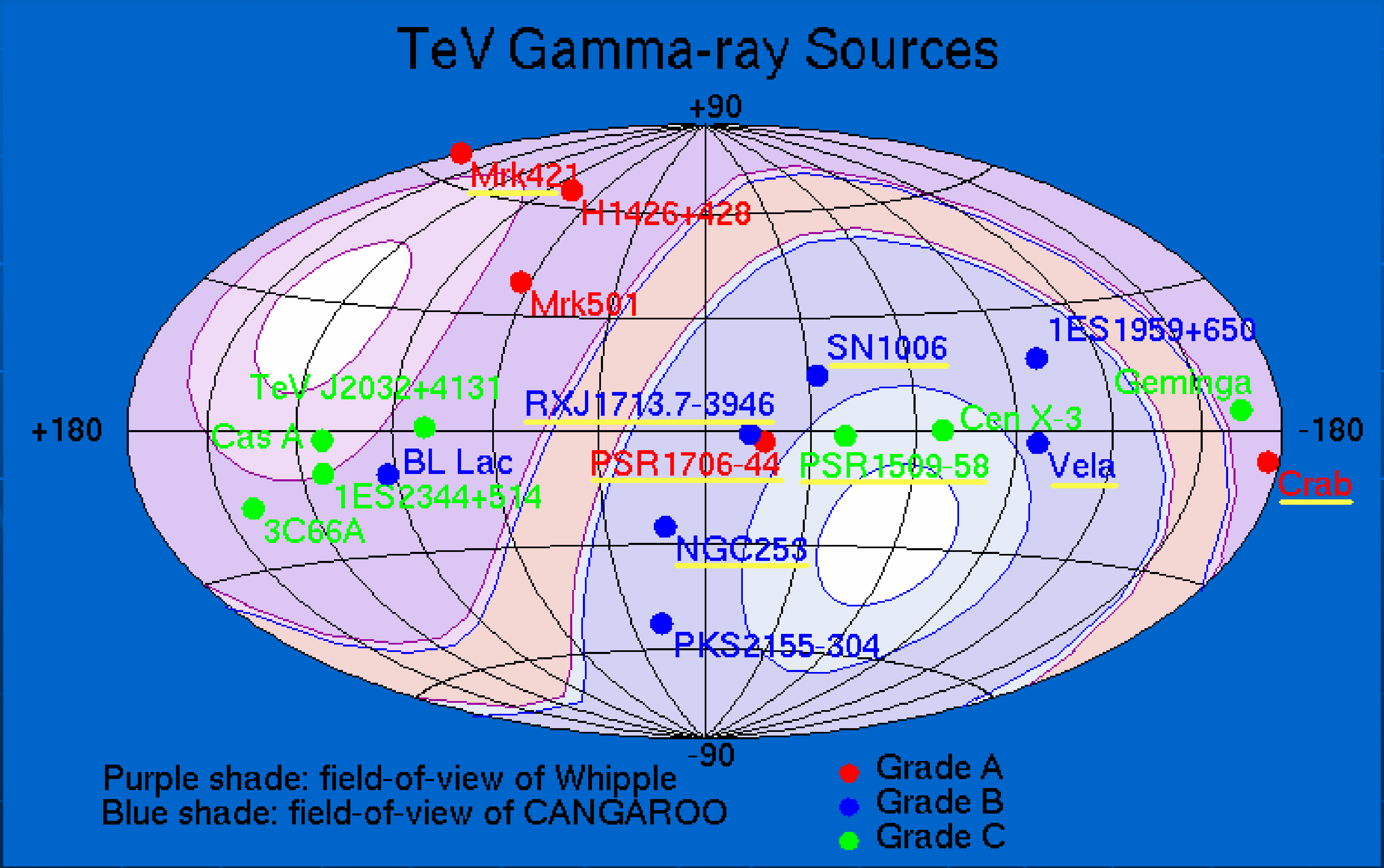
CANGAROO-III
(2003)

CANGAROO results

- "Search for TeV gamma-rays from SN1987A in 2001"
  Enomoto, R. et al., Astrophysical Journal (Letters), 591, L25-L28 (2003)
- "Evidence for TeV gamma-ray emission from the nearby starburst galaxy NGC 253"
  Itoh, C. et al., Astronomy and Astrophysics, 402, 443-455 (2003)
- "Detection of diffuse TeV gamma-ray emission from the nearby starburst galaxy NGC253"
  Itoh, C. et al., Astronomy and Astrophysics 396, L1-L4 (2002)
- "Development of an atmospheric Cherenkov imaging camera for the CANGAROO-III experiment"
  Kabuki, S. et al., Nucl. Instr. Meth. A500, 318-336 (2003)
- "Observation of gamma-rays greater than 10 TeV from Markarian 421
  Okumura, K. et al., Astrophys. J. Lett. 579, L9-L12 (2002)
- "The Acceleration of Cosmic-ray Protons in the Supernova Remnant RX J1713.7-3946"
  Enomoto, R. et al., Nature, 416, 823-826 (2002)
- "Design Study of CANGAROO-III, stereoscopic imaging atmosphereic Cherenkov Telescopes for Sub-TeV Gamma-ray Detection"
  Enomoto, R. et al., Astropart. Phys. 16, 235-244 (2002)
- "The Optical Reflector System for the CANGAROO-II Imaging Atmospheric Cherenkov Telescope"
  Kawachi, A. et al., Astropart. Phys. 14, 261-269 (2001)
- "Observations of the Supernova Remnant W28 at TeV Energies"
  Rowell, G.P. et al., Astron. Astrophys. 359, 337-346 (2000)
- "Very High-Energy Gamma-Ray Observations of PSR B1509-58 with the CANGAROO 3.8m Telescope"
  Sako, T. et al., Astrophys. J. 537, 422-428 (2000)
- "Evidence for TeV Gamma-ray Emission from the Shell Type SNR RXJ1713.7-3946"
  Muraishi, H. et al., Astron. Astrophys., 354, L57-L61 (2000)
- "TeV Gamma-ray Observations of Three X-ray Selected BL Lacs"
  Roberts, M.D. et al., Astron. Astrophys., 343, 691-696 (1999)
- "TeV Gamma-ray Observations of Southern BL-Lacs with the CANGAROO 3.8m Telescope"
  Roberts, M.D. et al., Astron. Astrophys., 337, 25-30 (1998)
- "Discovery of TeV Gamma Rays from SN 1006: Further Evidence for the Supernova Remnant Origin of Cosmic Rays"
  Tanimori, T. et al., Astrophys. J. Lett., 497, L25-L28 and Plate L2 (1998)
- "Detection of Gamma Rays of up tp 50 TeV from the Crab Nebula"
  Tanimori, T. et al., Astrophys. J. Lett., 492, L33-36 (1998)
- "Very High Energy Gamma Rays from the Vela Pulsar Direction"
  Yoshikoshi, T. et al., Astrophys. J. Lett., 487, L65-68 (1997)
- "Very High Energy Gamma Rays from PSR1706-44"
  Kifune, T. et al., Astrophys. J. Lett., 438, L91-94 (1995)
- "Observation of 7 TeV Gamma Rays from the Crab using the Large Zenith Angle Air Cherenkov Imaging Technique"
  Tanimori, T. et al., Astrophys. J. Lett., 429, L61-64 (1994)
- "First Test Data from the CANGAROO Project for Stereo Cherenkov Imaging"
  Edwards, P.G. et al., Astronomical Soc. of Australia Proc., v10:4, p.287 (1993)
- "3.8m Imaging Cherenkov Telescope for the TeV Gamma-ray Astronomy Collaboration between Japan and Australia"
  Hara, T. et al., Nucl. Instr. and Meth., A332, pp.300-309 (1993)

21 papers in refereed journals

TeV gamma-ray sky 2002



Gamma-ray astrophysics in the 10 GeV region

- Origin of cosmic rays
  - Gamma-rays pin-point accelerators
  - Galactic and extragalactic sources
- High-energy astrophysics
  - More distant AGNs; time variability study
  - Highest energy end of pulsar emission / pulsar nebula
  - Gamma-ray bursts (in FOV and afterglow)
- Astroparticle physics
  - Dark matter annihilation
- And there should be *surprises*…

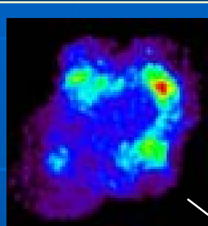
SNR origin of cosmic rays

- Theoretical preference:
  - (Good) Pros:
    - Energetics $(dE/dt)_{SN} \sim 10\ (dE/dt)_{CR}$
    - Diffusive shock acceleration $\rightarrow$ p^{-2} spectrum
  - (Weak?) Cons:
    - Maximum energy < PeV ~ E_{knee}

- Experimental situation:
  - We already have some evidence…
  - How many "gamma-ray SNRs"?
    - Systematic survey of galactic plane
  - Hadronic or leptonic?
    - Wide-band energy spectrum

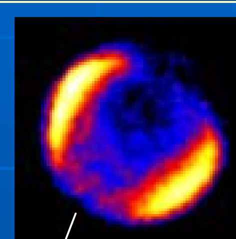
Systematic survey of SNRs

RX J1713.7-3946 (CANGAROO)



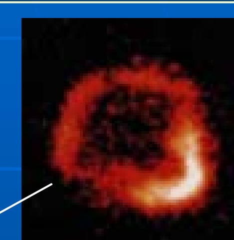
ASCA

SN1006 (CANGAROO)

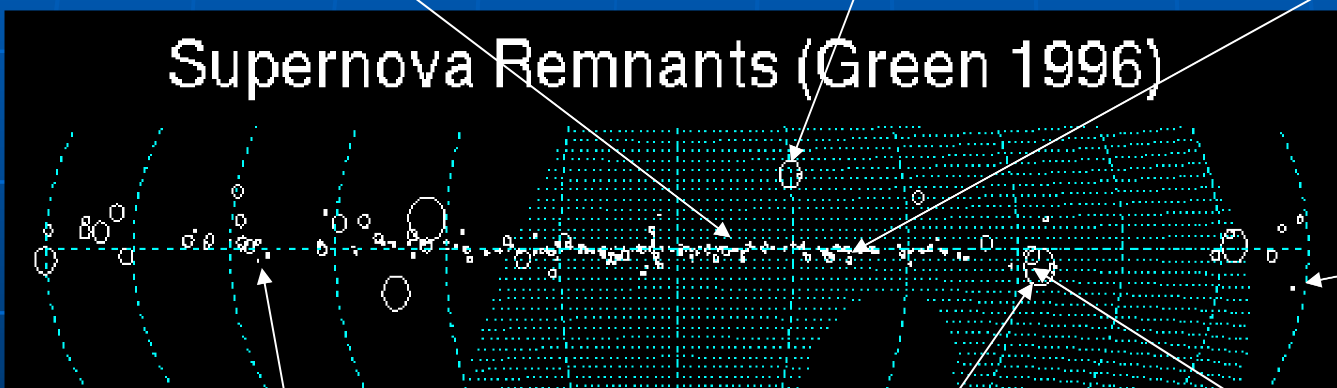


ASCA

RCW86 (CANGAROO under analysis)

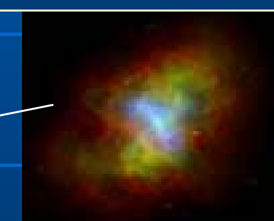


ROSAT



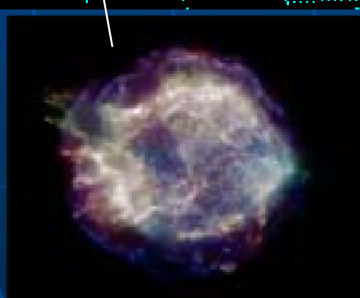
Crab nebula

("Standard candle")



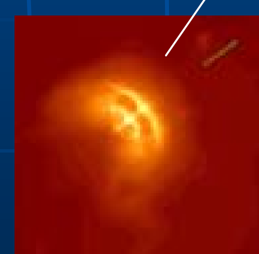
Chandra

• optical



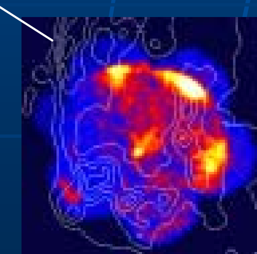
Chandra

Cas A (HEGRA)



Chandra

Vela (CANGAROO)

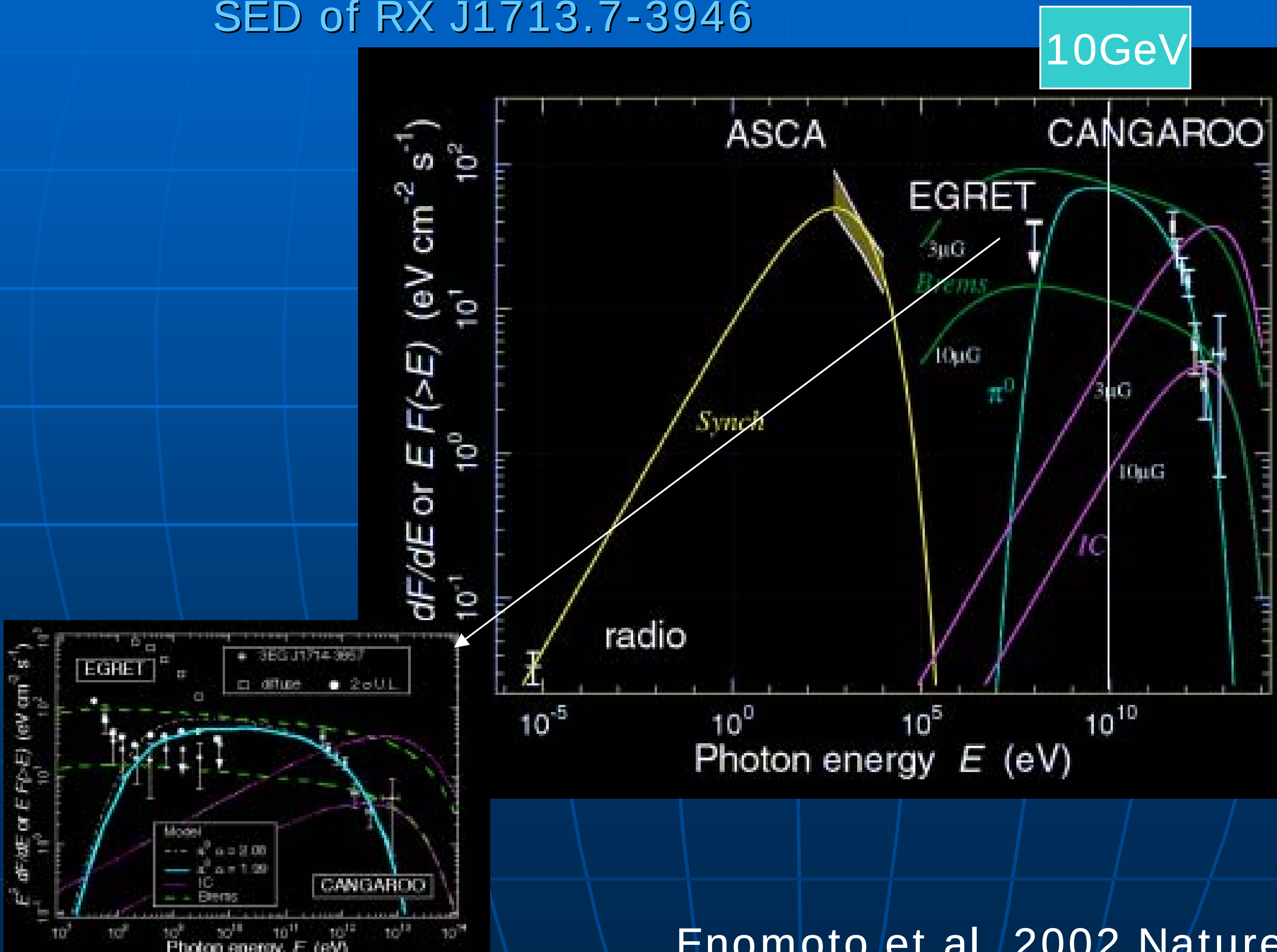


ROSAT

RX J0852-46 (CANGAROO under analysis)

Wide-band study of SNR spectrum

SED of RX J1713.7-3946



Spectral shape

↓

Leptonic:

[IC, Brems]

or/and

Hadronic:

[π^0]

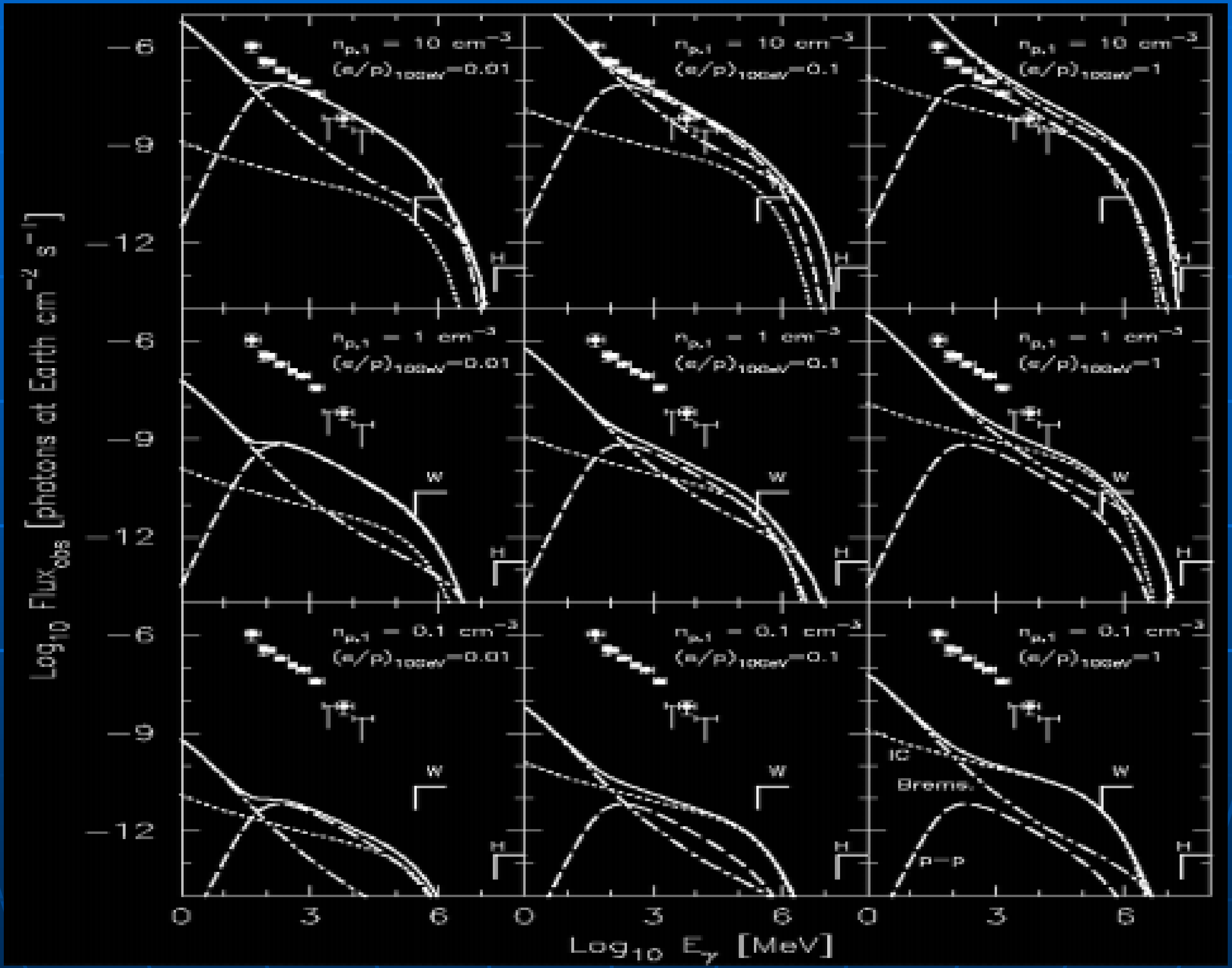
Enomoto et al. 2002 Nature 416, 823

SNR emission models

n=10 cm^{-3}

n=1 cm^{-3}

n=0.1 cm^{-3}



Dot: IC

Dash: π^0

Dot-dash:brems

(Data: EGRET IC443)

e/p = 0.01 0.1 1

Baring et al. 1999 ApJ 513, 311

Other than SNRs

- Galactic sources
  - Galactic jet sources
    - X-ray binaries (Cen X-3*1,...)
    - Microquasars (SS433,...),...
  - Wolf-Rayet stars
    - High velocity winds, CR abundance
- Extragalactic sources
  - Starburst galaxies
    - NGC 253*2, M82, ...
  - Radio galaxies
    - M87*3, Cen A,...
  - Clusters of galaxies
    - Coma,...
    - Gamma-ray clusters

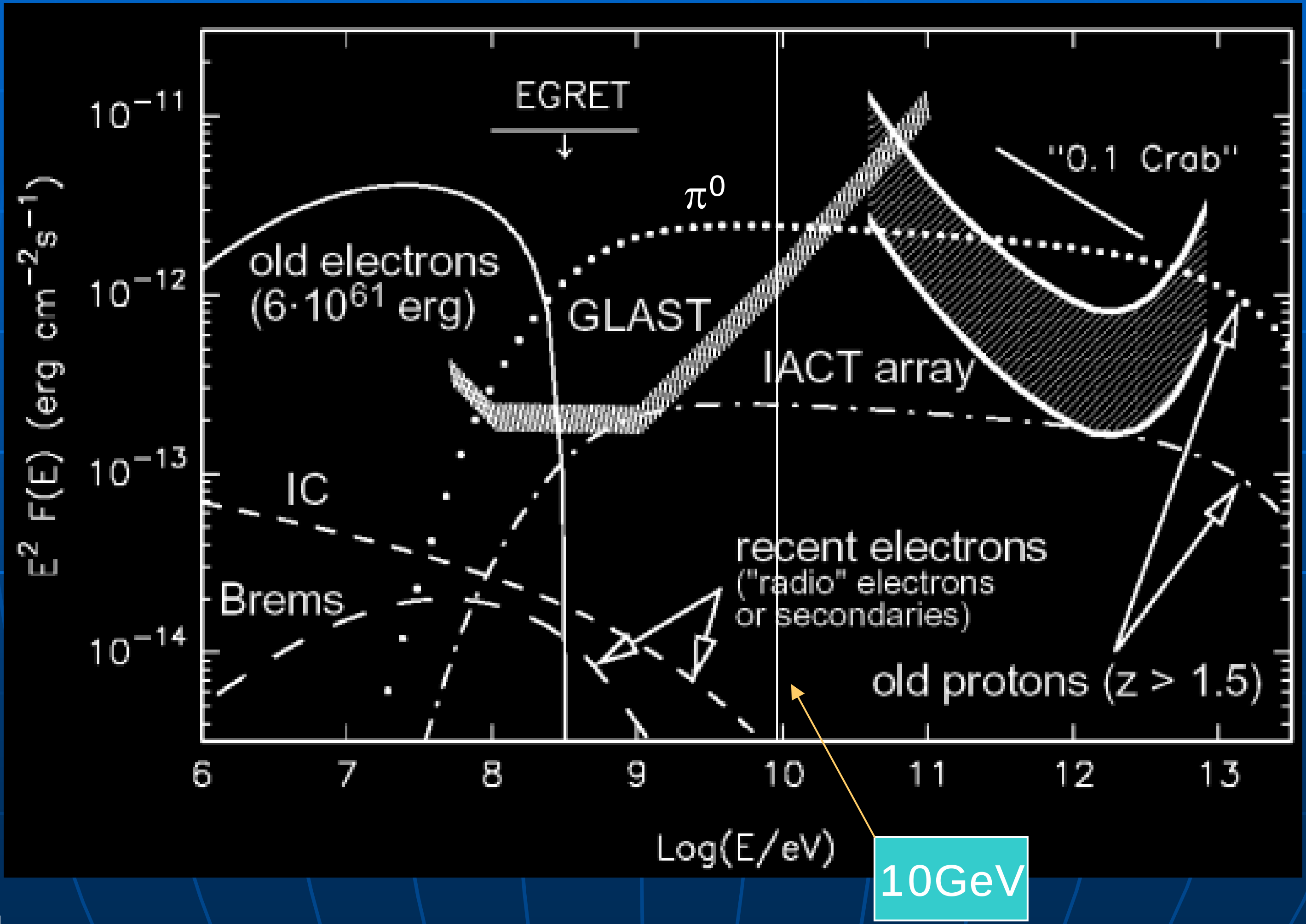
      Totani and Kitayama 2000 ApJ 545, 572

*1 Durham, ApJ 1998

*2 CANGAROO, AA 2002&2003

*3 HEGRA, AA 2003

Coma cluster

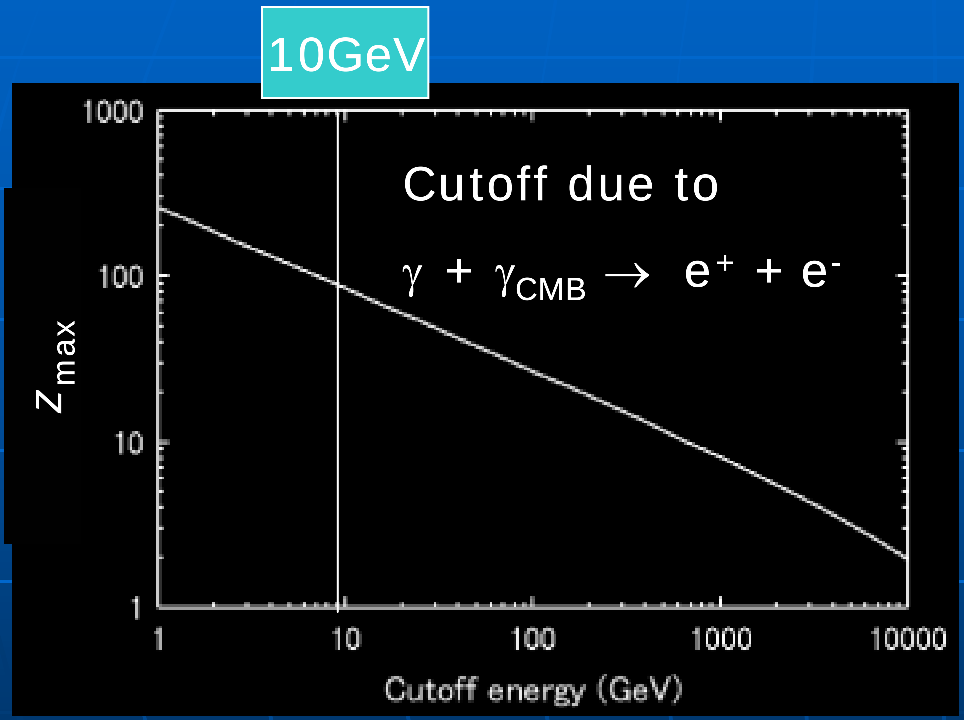


$B = 1\mu G$

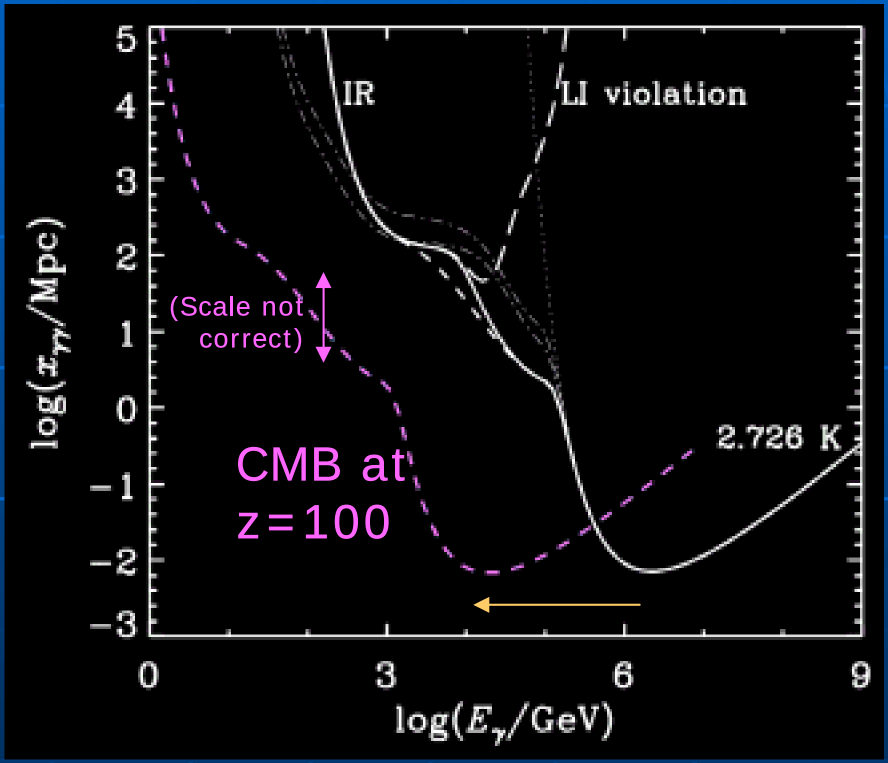
$W_p = 3x10^{62}/3x10^{61}$ ergs

Atoyan and Voelk 2000 ApJ 535, 45

Cosmological gamma-ray horizon



Fazio & Stecker 1970 Nature 226, 135



10 GeV gamma-rays can explore the Universe up to z=100!

10 GeV Cherenkov telescopes

- Collect photons 20 times more!
- Hadron showers increase but fainter
- Electrons, indistinguishable from gamma-rays, remain background
  - Limit sensitivities for diffuse sources
  - Cf. Rigidity cutoff: 6-9GV@Woomera
- Higher altitude option to be closer to showers
  - Image broadens a little and Cherenkov disk brighter near center

Cherenkov photon yield

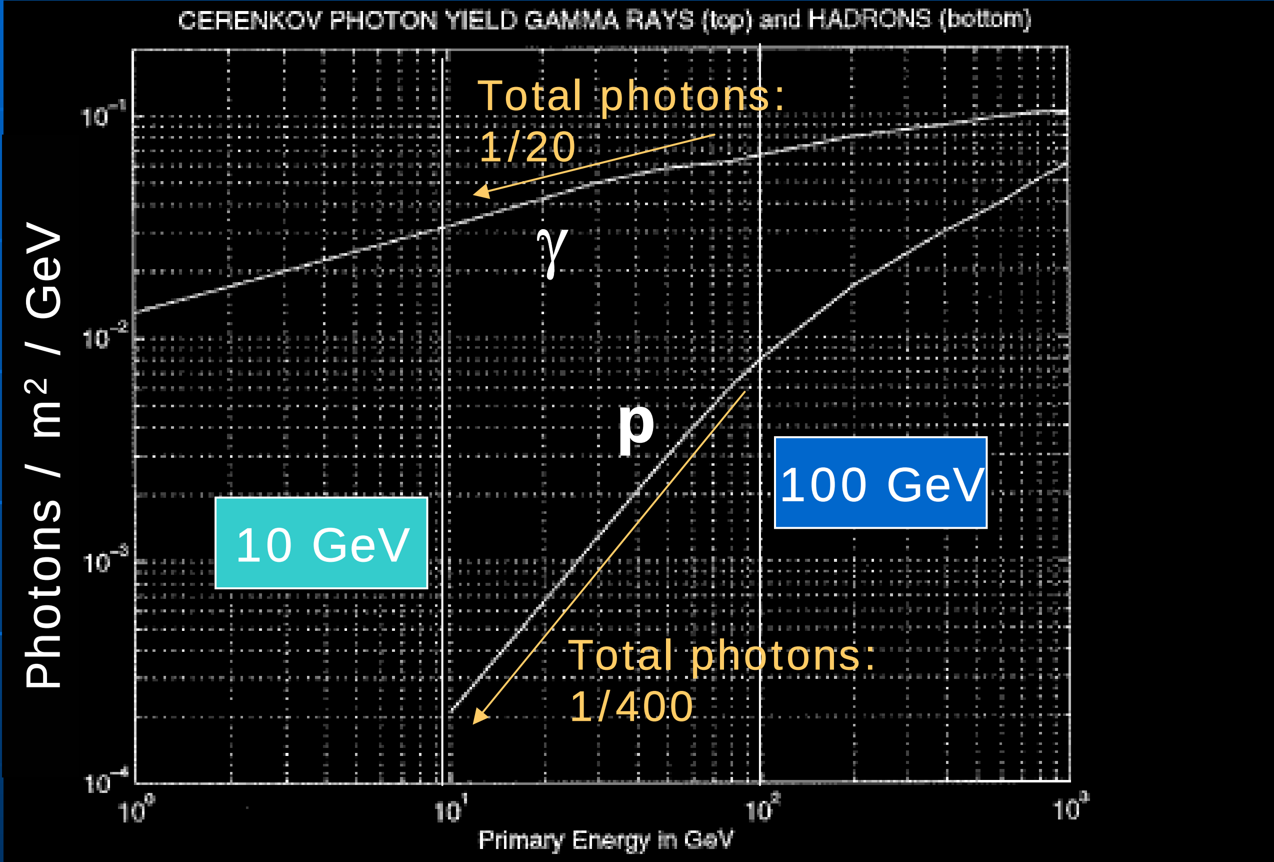
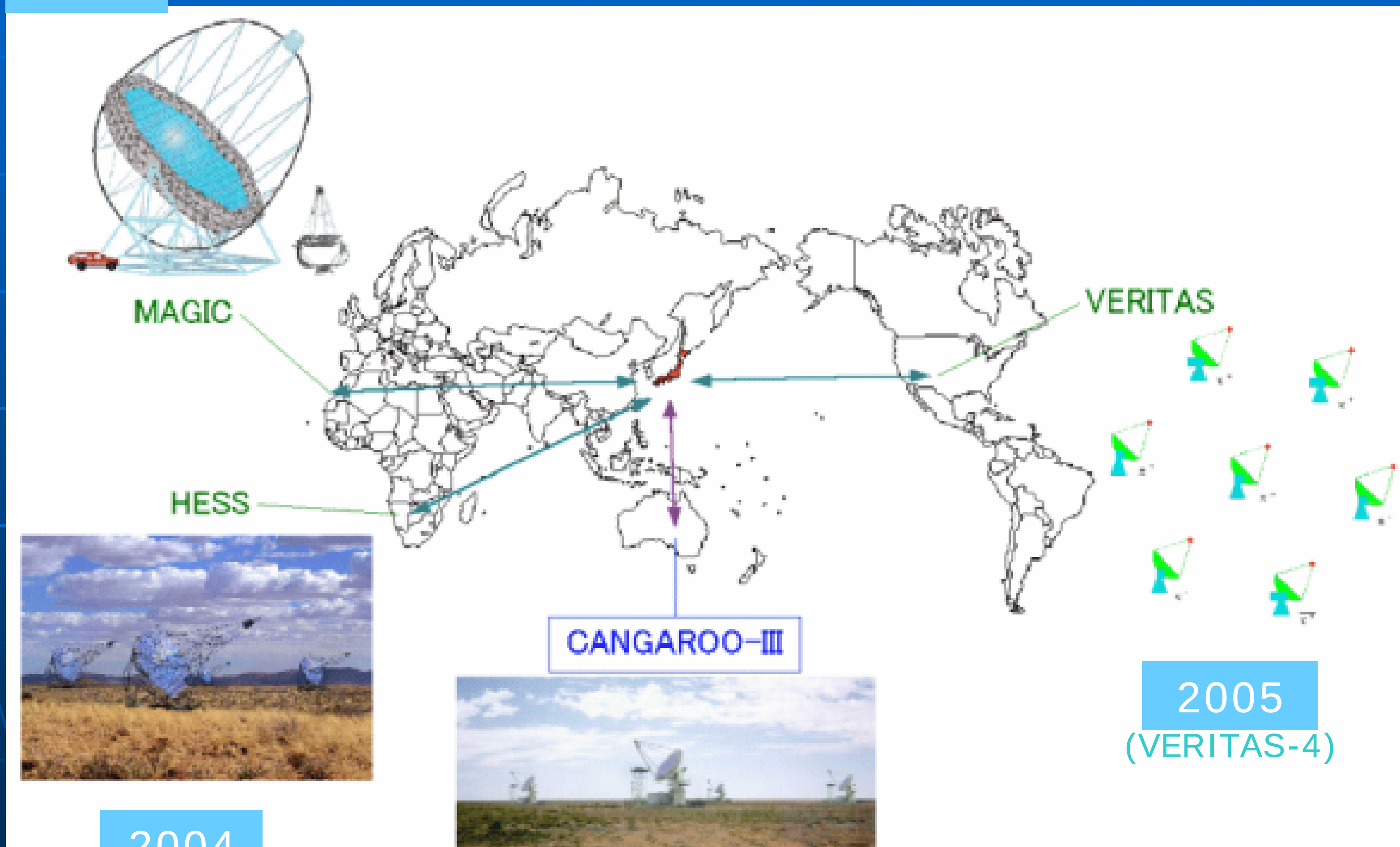


Figure 9. Efficiency of production of Cerenkov light for both γ-rays and hadrons. The Cerenkov photon yield as a function of primary energy for γ-rays (upper curve) and hadrons (lower curve). For γ-rays the Cerenkov yield remains nearly proportional to energy down to about 20 GeV. For hadrons, a significant cut-off occurs about 100 GeV.

Fegan 1997 JPG 23, 1013

The “Big Four”


2004
MAGIC
VERITAS
HESS
CANGAROO-III
2005
(VERITAS-4)
2004
2003

Next generation projects

- **5@5**
  - Max Planck Inst. for Nuclear Physics
  - $50 m^2$ mirror area
  - 5 telescopes (4 in 100m grid and 1 at center) at 5000m a.s.l.
  - 3.2° camera, 721 pixels
  - 5 GeV threshold

Aharonian et al. 2001 APh 15, 335

- **ECO-1000**
  - Max Planck Inst. for Physics
  - $35 m\phi$, $1000 m^2$ mirror area
  - <5° camera, >2000 pixels
  - 5 GeV threshold

Merck et al. ICRC2003

SuperCANGAROO

- "Strawman" design parameters
  - <10 GeV energy threthold
    → *10 times more area x 2 times QE*
  - 30mϕ, f=30m (F/1.0), parabola
  - Field-of-view ~10° ← survey mode
  - Short barrel preferred to keep long focal length → new optical design necessary
  - 0.1° -class pixel camera with advanced photon sensors
  - Stereo observation is essential

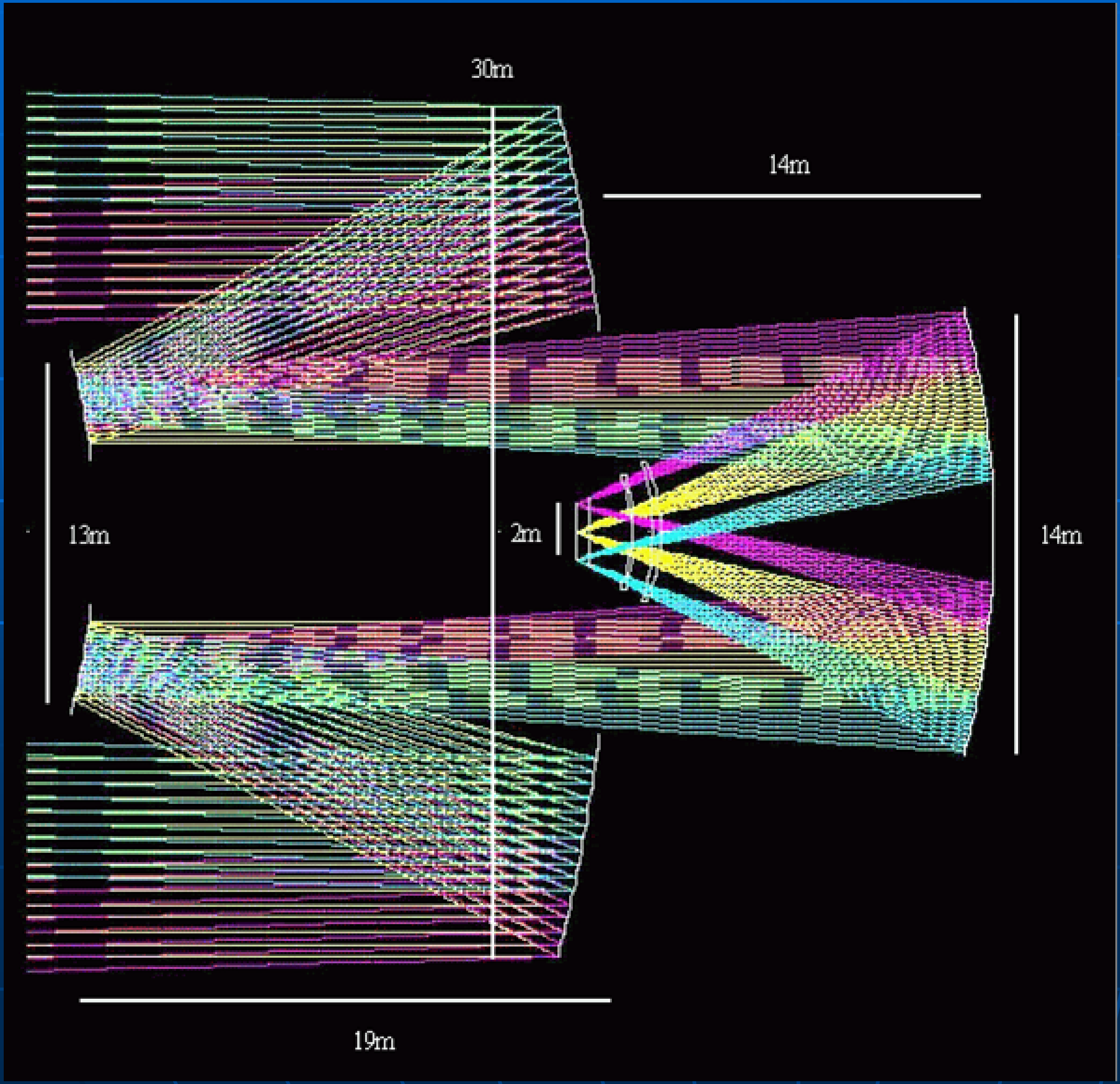
3 mirror wide-field optical design: an example

LSST:

- Paul-Baker optics
- 6.9m effective aperture
- F/1.25
- 7sq.deg = 3°ϕ

http://www.lssto.org/lsst_home.html

LSST scaled to 30mϕ



For Cherenkov observation:

- No need for lenses
- Reflector can be segmented and mirrors can be plastic or metal-shaved to save weight

Camera can be located near the center-of-gravity:

- Smaller moment, faster movement
- No long signal cables

Large mount example: Lovell 76m

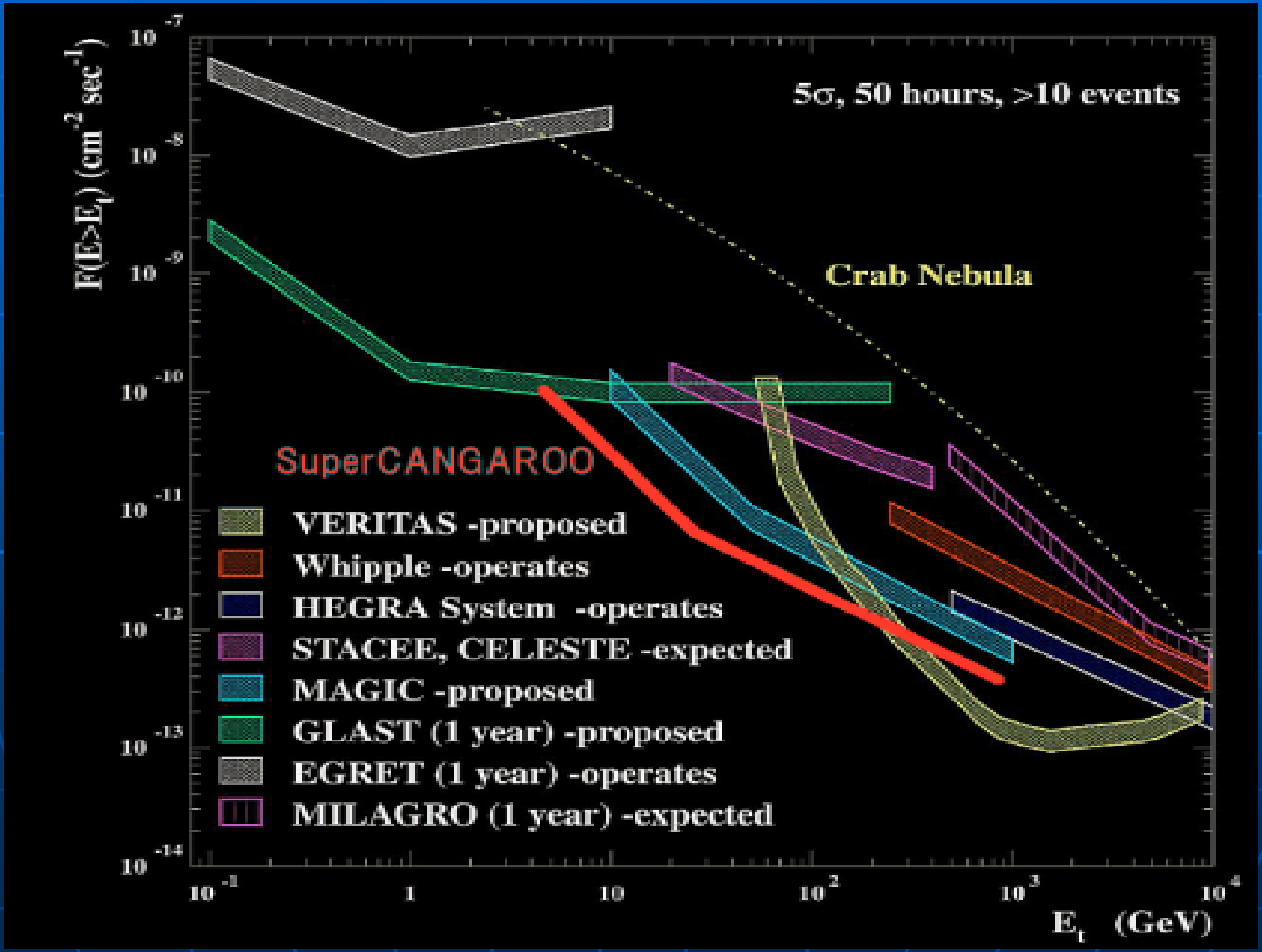
Jodrell Bank, UK

No counter weight !

2mϕ camera

- <0.1° pixel to reduce nightsky bkgd.
- $3m^2 \leftrightarrow$ 1500 x 2”ϕ ~ 6000 x 1” ϕ
- Photosensors:
  - High-QE PMT (GaAsP etc.)
  - Advanced sensors
- Electronics
  - Located next to the camera
  - GHz-class FADC

Sensitivity



(rough estimate)

Comparison with GLAST

	GLAST	**SuperCANGAROO**
Energy	20MeV-300GeV	10GeV-10TeV
Area	$>0.8 m^2$	$\sim 10^5 m^2$
FOV	>2.5sr	$\sim 2 \times 10^{-2}$ sr
Source location	0.5-5’	~3’ (stereo)
Sensitivity	$3 \times 10^{-9} cm^{-2} s^{-1}$ (>100MeV, 1yr)	$2 \times 10^{-9} cm^{-2} s^{-1}$ (50hr)
Life	>2yr	>5yr
Cost	300M$	30M$?? x N

Summary

- 10 GeV gamma-ray astrophysics:
  - Systematic study of cosmic ray origin & much more fun!
- Cherenkov observation vs satellites:
  - *Sensitive in shorter time* $\rightarrow$ deeper survey & shorter time variability study
- R&D items:
  - Larger reflector with shorter barrel, wide FOV, modest optical quality at moderate cost: a little challenge
  - Fast, high-QE optical sensors are desirable
- Site: Australia (higher is better, but cost performance?)