CANGAROO

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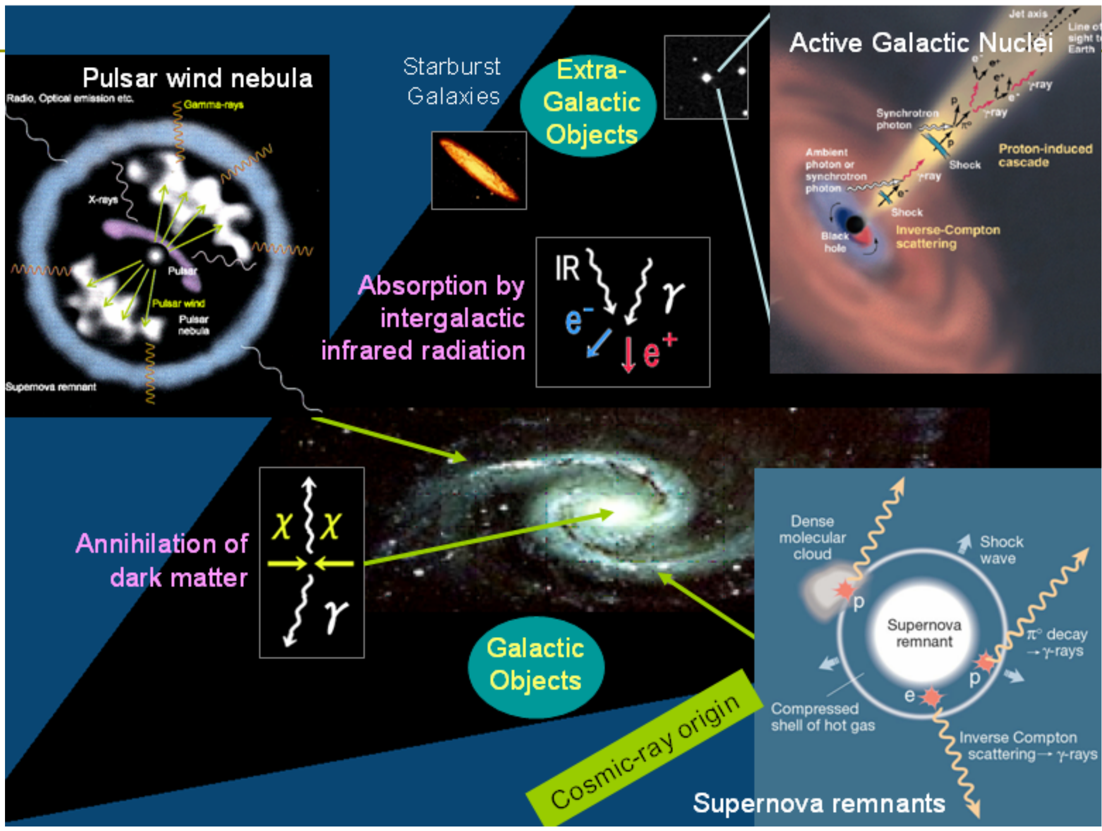
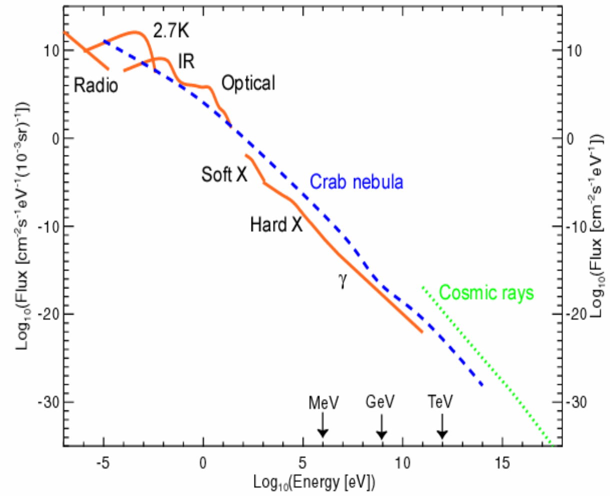
Gamma-rays probe the non-thermal Universe



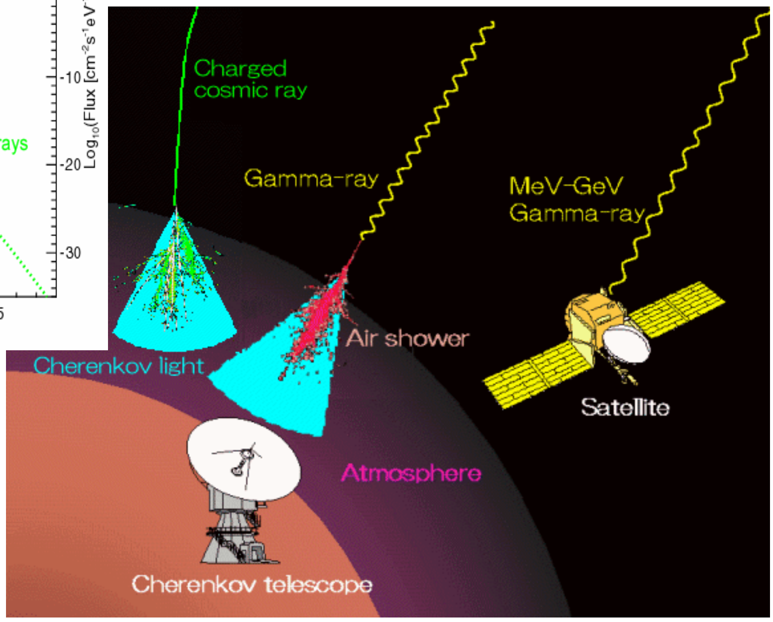
We have to rely on ground-based observation at TeV energy photons



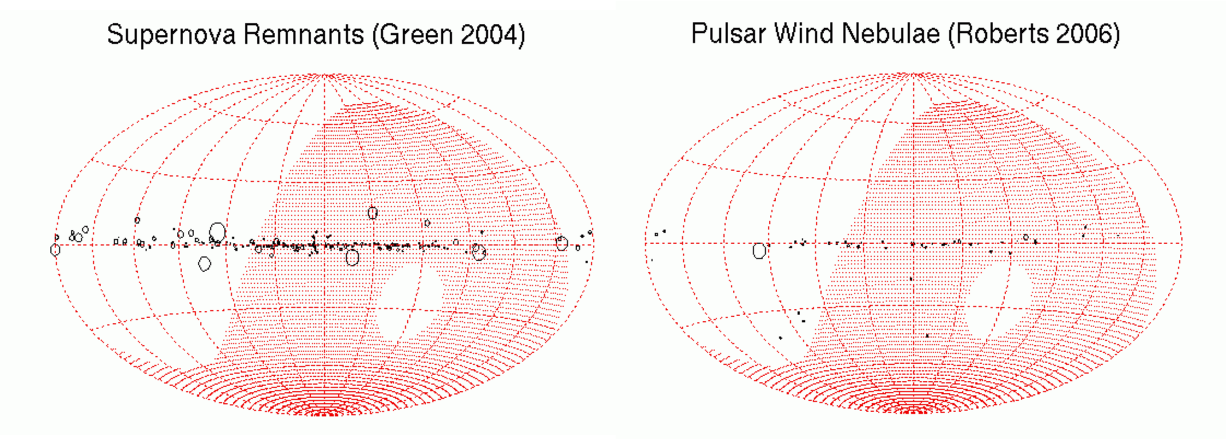
Diffuse photon spectrum

$A \sim 10^4 m^2$ $\sim 1\ m^2$

$\Omega \sim 10^{-2} sr$ $\sim \pi\ sr$



Southern sky objects



(Hatched: observable from Woomera)

We placed first priorities on Galactic objects, i.e. supernova remnants and pulsar wind nebulae, since the beginning of the CANGAROO project, as the first imaging Cherenkov telescope observatory in the southern hemisphere.

CANGAROO team

- University of Adelaide
- Australian National University
- Ibaraki University
- Ibaraki Prefectural University
- Konan University
- Kyoto University
- STE Lab, Nagoya University
- National Astronomical Observatory of Japan
- Kitasato University
- Shinshu University
- Australia Telescope National Facility
- Tokai University
- ICRR, University of Tokyo
- Yamagata University
- Yamanashi Gakuin University
- Hiroshima University

Brief history of CANGAROO

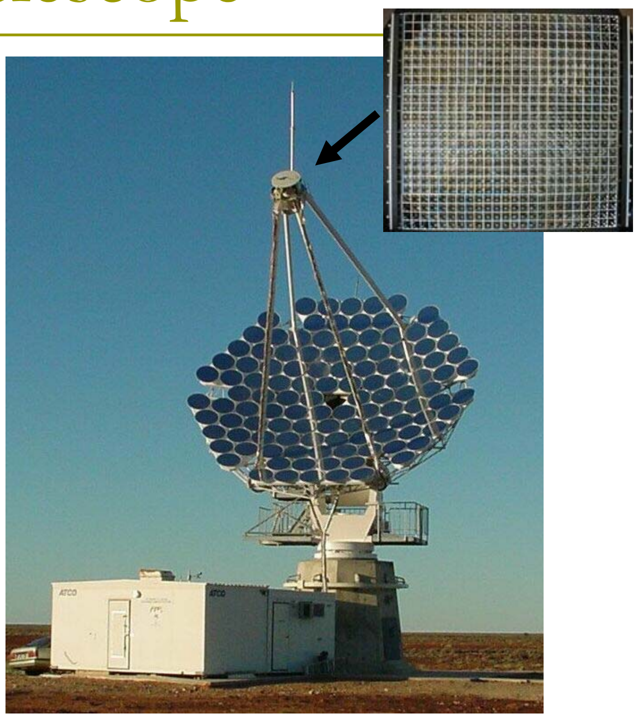
- 1987: SN1987A
- 1990: 3.8m telescope
- 1990: ICRR-Adelaide Physics agreement
- 1992: Start obs. of 3.8m tel.
- 1999: 7m telescope
- 2000: Upgrade to 10m
- 2001: U.Tokyo-U.Adelaide agreement
- 2002: Second and third 10m tel.
- 2004: Four telescope system

CANGAROO-I (3.8mϕ)

CANGAROO-II (10mϕ)

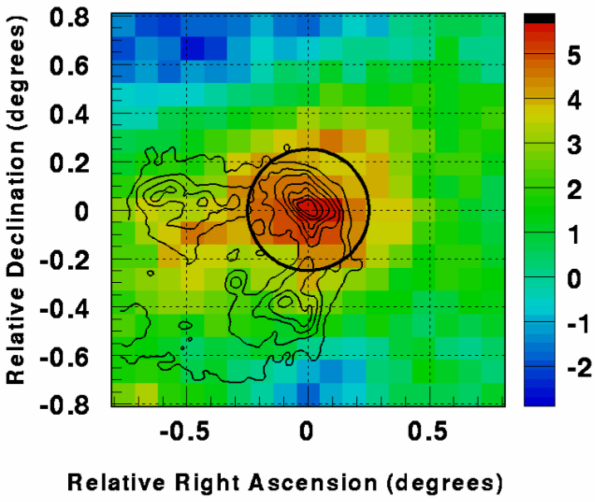
CANGAROO-II telescope

- Upgraded in 2000 from 7m telescope completed in 1999
- 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

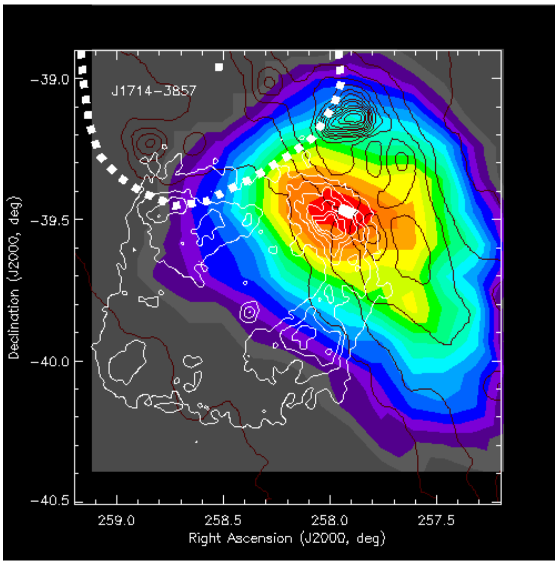


(March 2000)

SNR RX J1713.7-3946/G347.3-0.5

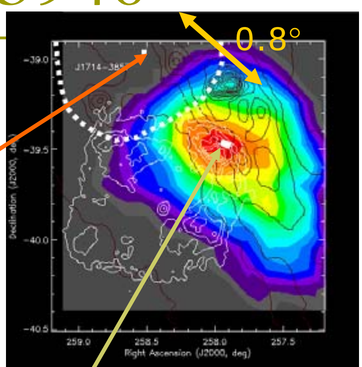


CANGAROO-I (Muraishi et al., A&A 354, L57, 2000)



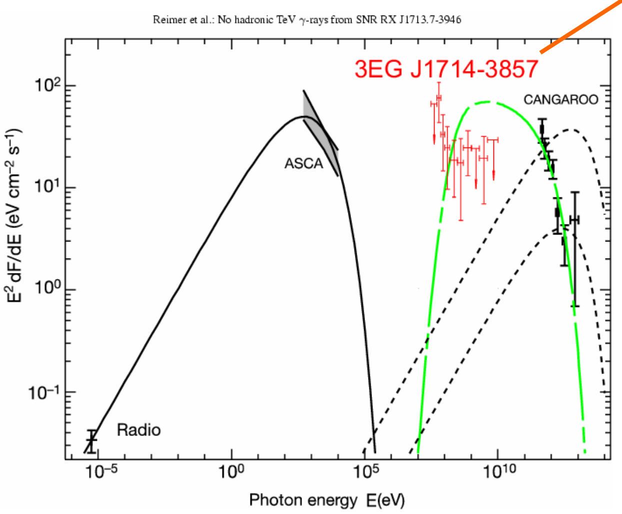
CANGAROO-II (Enomoto et al., Nature 416, 8232002)

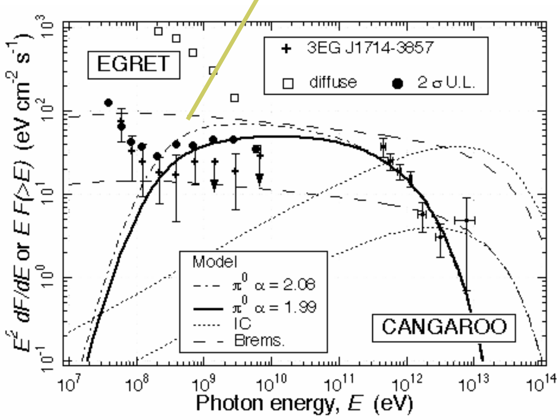
Spectrum of RX J1713.7-3946



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

Butt et al., Nature 418 (2002) 489





H.E.S.S.: Aharonian et al., A&A 449, 223 (2006)

Electrons or protons?

RX J1713.7-3946

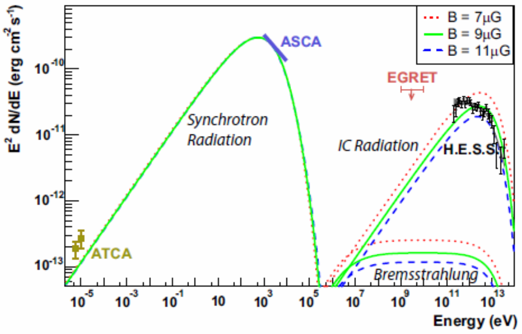


Fig. 19. Broadband SED of RX J1713.7−3946. The ATCA radio data and ASCA X-ray data (Hiraga 2005) for the whole SNR are indicated, along with the H.E.S.S. measurement and the EGRET upper limit. Note that the radio flux was determined in Lazendic et al. (2004) for the northwest part of the shell only and was scaled up by a factor of two here to account for the whole SNR. The synchrotron and IC spectra were modelled assuming a source distance of 1 kpc, an age T of 1000 years, a density n of 1 cm^{-3}, and a production rate of relativistic electrons by the acceleration mechanism in the form of a power law of index $\alpha = 2$ and an exponential cutoff of $E_0 = 100$ TeV. Shown are three curves for three values of the mean magnetic field: 7 μG, 9 μG, and 11 μG, to demonstrate the required range of the B field strength for this scenario. The electron luminosity is adopted such that the observed X-ray flux level is well matched. For the three magnetic field values the luminosity L_e is $L_e = 1.77 \times 10^{37}$ erg s^{-1} (7 μG), $L_e = 1.14 \times 10^{37}$ erg s^{-1} (9 μG), and $L_e = 0.81 \times 10^{37}$ erg s^{-1} (11 μG).

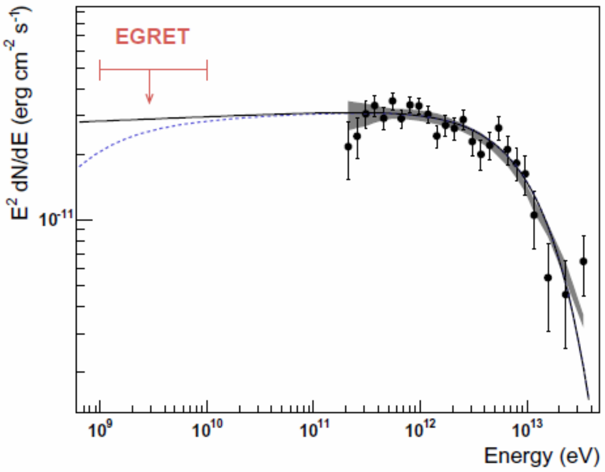


Fig. 20. H.E.S.S. data points plotted in an energy flux diagram. They shaded grey band is the systematic error band for this measurement (see Sect. 3.2). The black curve is the best fit of a power law with exponential cutoff to the data, extrapolated to lower energies. The dashed blue curves is the same function, but it takes the π^0 kinematics into account. The EGRET upper limit from 1 GeV to 10 GeV is plotted as red arrow.

⇒ Protons favored (?)

Galactic Center/Sgr A*

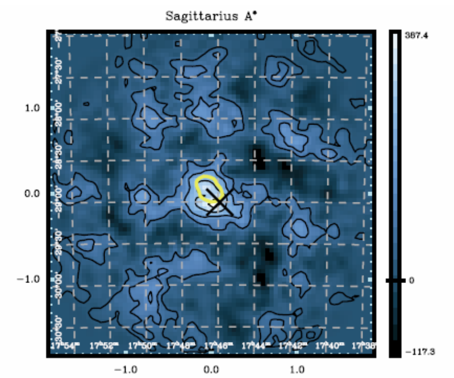
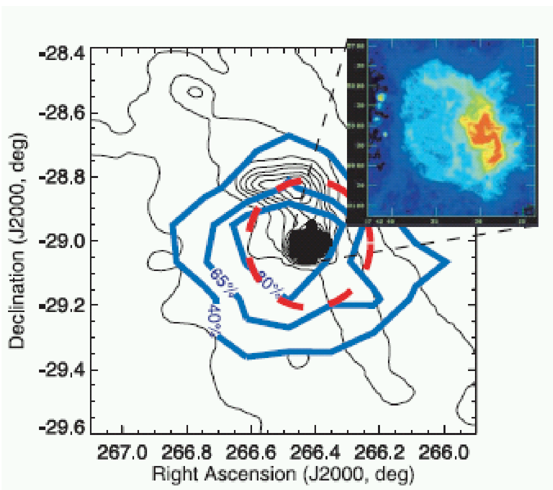
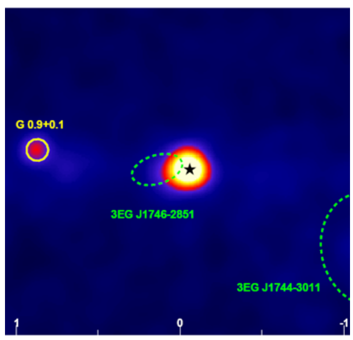


FIG. 1.—Gamma-ray image of the region around Sgr A*. The image is of excess counts with overlaid significance contours (1 σ per contour). The axes are labeled in degrees from the assumed camera center. The true center position of the camera, which is not exactly at (0, 0) because of flexing of the telescope at low elevation, is marked with a cross. The dashed lines are the R.A. and decl. contours at this position. Also shown (as a light contour) is the 99% confidence region for the EGRET observations (Hooper & Dingus 2002).

Whipple: Kosack et al., ApJ 608, L97 (2004)



CANGAROO-II (Tsuchiya et al., ApJ 606, L115, 2004)



HESS: Aharonian et al., A&A 425, L13 (2004)

Sgr A* spectrum

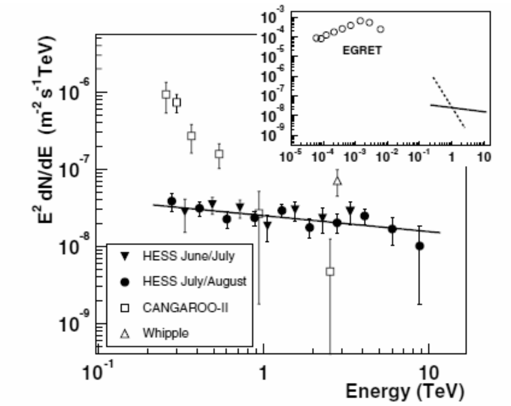


Fig. 4. Energy spectrum $E^2 dN/dE$ of γ-rays from the Galactic Centre. Full circles: HESS "July/August 2003" data set. Full triangles: HESS "June/July 2003" data set. The line indicates a power-law fit to the "July/August" spectrum. Open squares: CANGAROO-II spectrum from Summer 2001 and 2002 (Tsuchiya et al. 2004). Open triangle: Whipple flux from 1995 through 2003 (Kosack et al. 2004), converted to a differential flux at the peak detection energy assuming a Crab-like spectrum. The inset shows the EGRET flux from 1991 to 1996 (Mayer-Hasselwander et al. 1998) (circles) compared to fits to the CANGAROO-II (dashed line) and HESS (solid line) spectra. Due to the poor angular resolution of EGRET (1°) the flux shown may include other sources.

Aharonian et al., A&A 425, L13 (2004)

Dark matter annihilation signal??

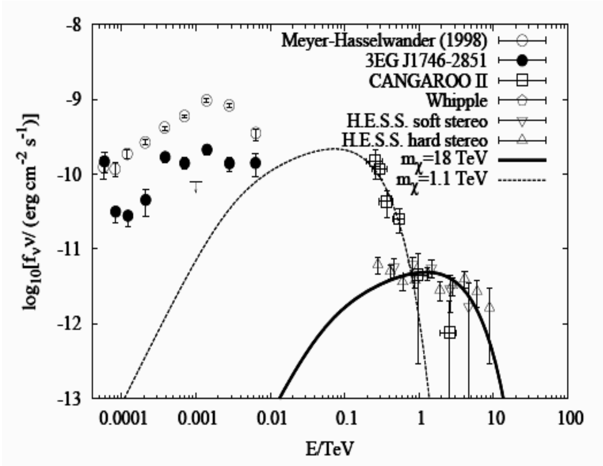
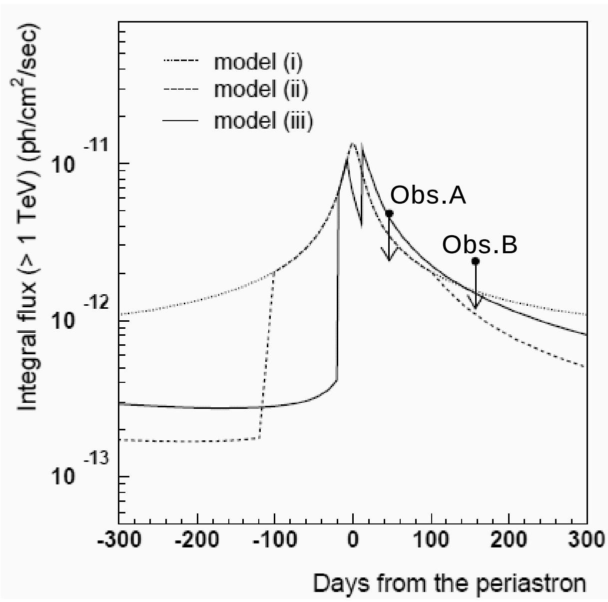


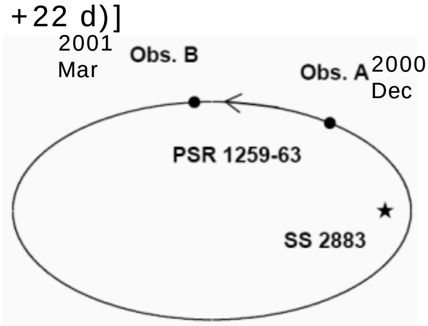
Fig. 2. A summary of data and best-fit models for WIMP annihilation from the Galactic center: H.E.S.S. (open triangles), CANGAROO (open boxes), EGRET (solid and open circles), 10m Whipple telescope of the VERITAS collaboration (solid diamond).

Horns, Phys.Lett. B607 (2005) 225

PSR 1259-63/SS2883

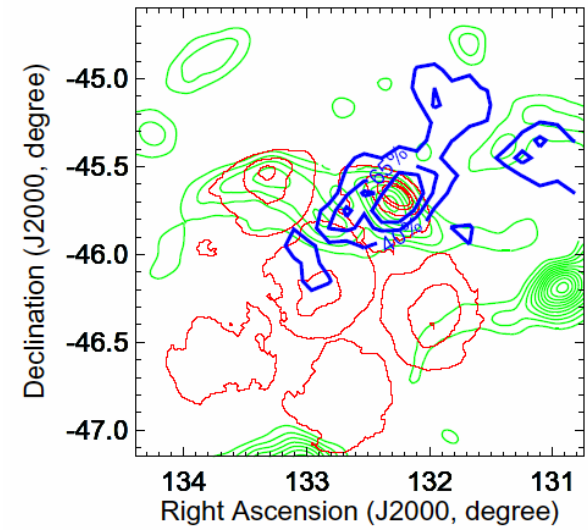


(i) aligned disc to the orbital plane and interaction throughout the orbit
(ii) mis-aligned disc and interaction in the ~200-day period around periastron (τ), during which the radio emission is depolarized
(iii) mis-aligned disc and interaction in two short periods, [(τ -18 d) ~(τ ~ -8d)] and [(τ +12 d) ~ (τ +22 d)]



CANGAROO-II: Kawachi et al., ApJ, 607(2004) 949

SNR RX J0852.0-4622



CANGAROO-II: Katagiri et al., ApJ, 619, (2005) L163

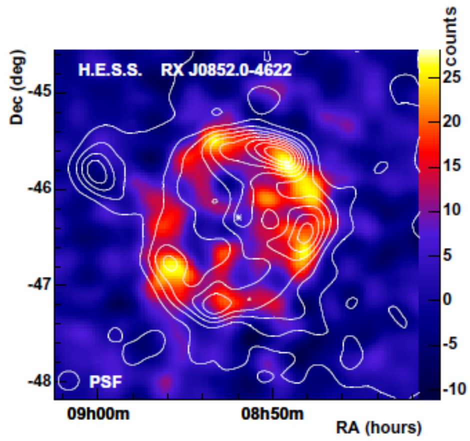
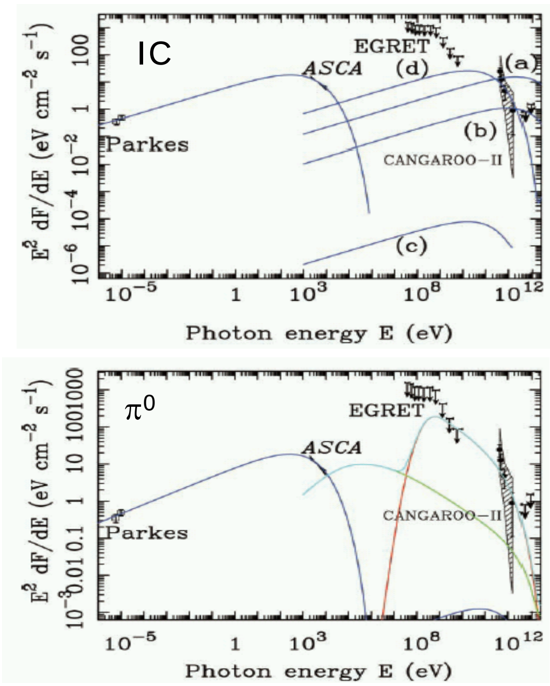


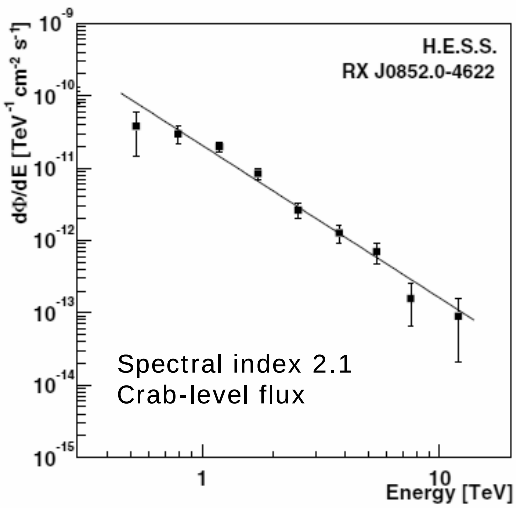
Fig. 2. Count map of γ-rays from the direction of RX J0852.0−4622 after background subtraction. The data are smoothed with a Gaussian (σ = 0.1°) representing the angular resolution of the instrument. The point spread function (PSF) is indicated by a circle. γ-ray features smaller than the PSF should not be considered as real. The lines denote equidistant contours of smoothed (σ = 0.1°) X-ray data from the ROSAT All Sky Survey, with energies restricted to above 1.3 keV. The position of the neutron star candidate AX J0851.9−4617.4 is marked with an asterisk. The axes show J2000.0 equatorial co-ordinates.

H.E.S.S.: Aharonian et al., AA 437, L7 (2005)

RX J0852.0-04622 spectrum



CANGAROO-II: Katagiri et al., ApJ, 619, (2005) L163



H.E.S.S.: Aharonian et al., AA 437, L7 (2005)

CANGAROO-II results: summary

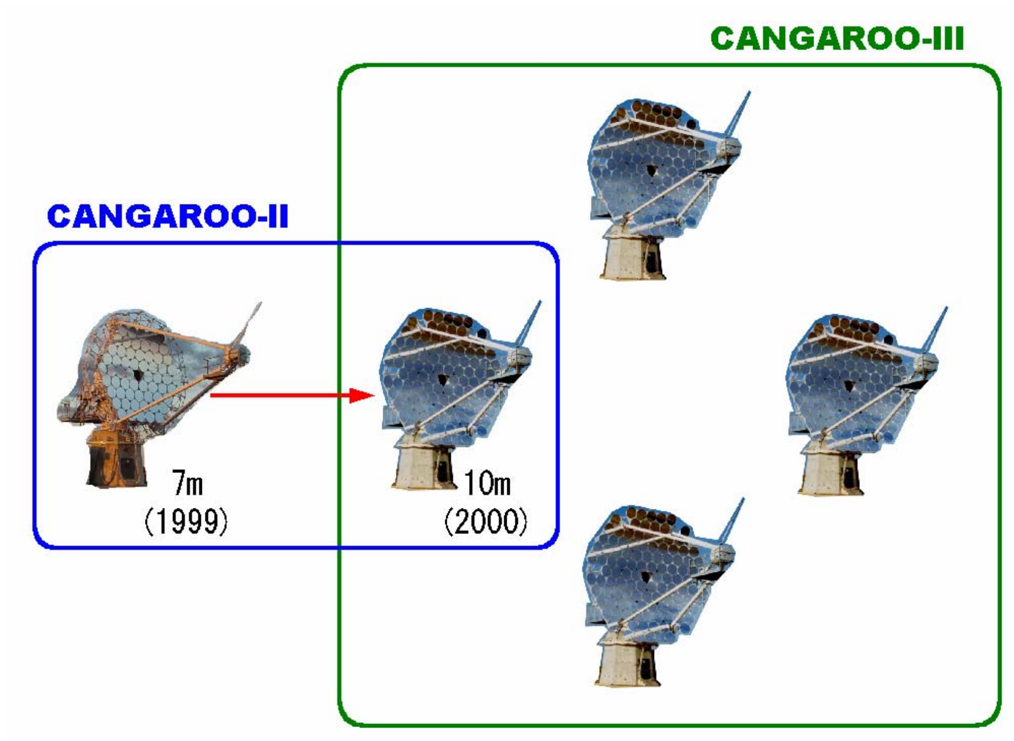
	Signal	Publish	H.E.S.S.
SNR RX J1713.7-3946	○	Nature' 02	○
Blazar Mrk421	○	ApJL'02	○
Starburst galaxy NGC253	○	A&AL'03	↓
SNR SN1987A	↓	ApJL'03	↓
Galactic Center	○	ApJL'04	○
Pulsar binary PSR 1259-63/SS2883	↓	ApJ'04	○v
SNR RX J0852.0-4622 (Vela Jr.)	○	ApJL'05	○

Signal: ○ detected, ↓ upper limit, v: variable

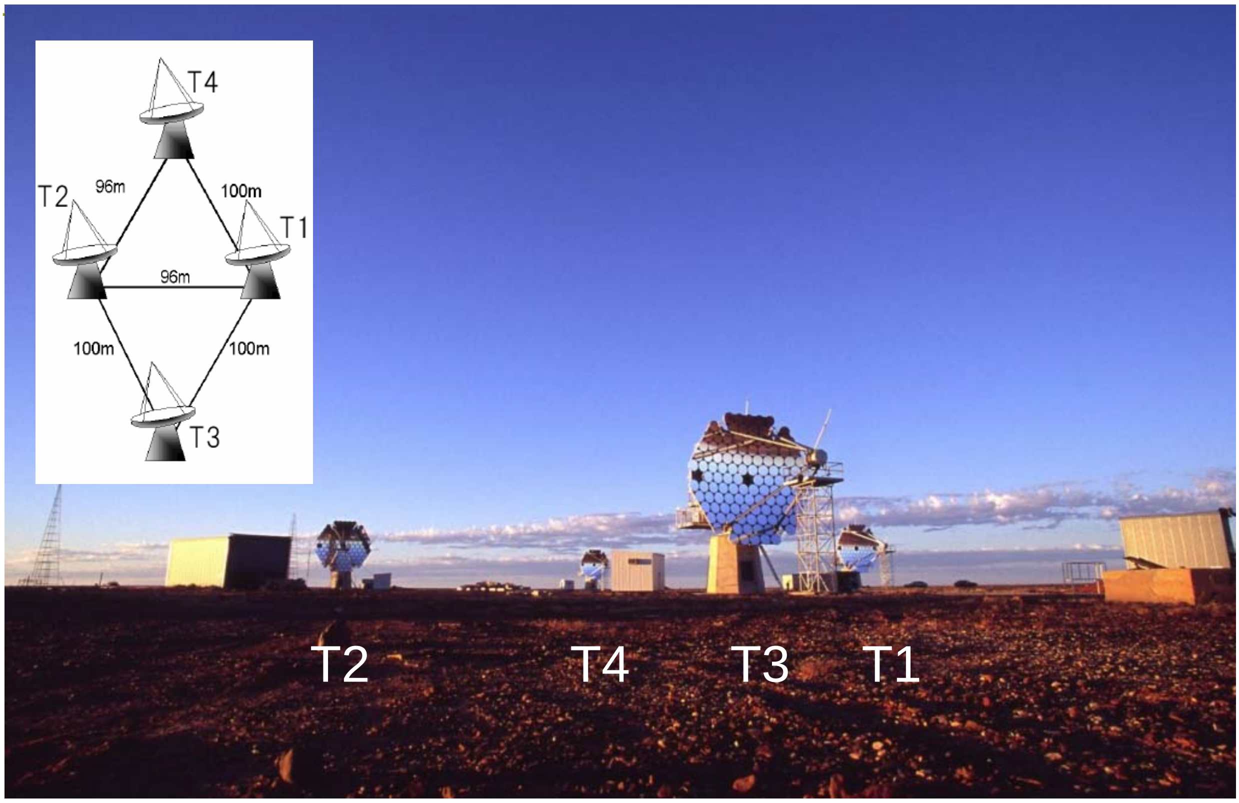
However, spectral indices differ significantly...

→ Re-observations with CANGAROO-III stereo system

CANGAROO-II & -III



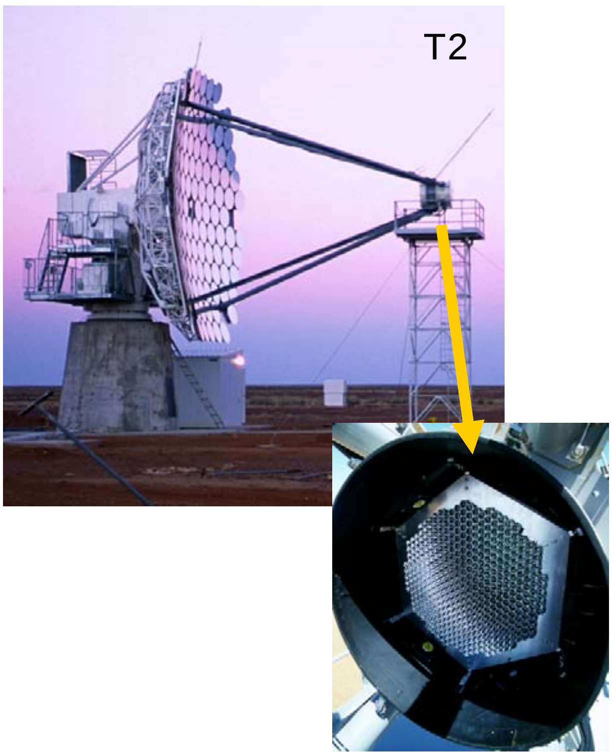
CANGAROO-III: 2004 March



Enomoto et al., Proc. ICRC 2003

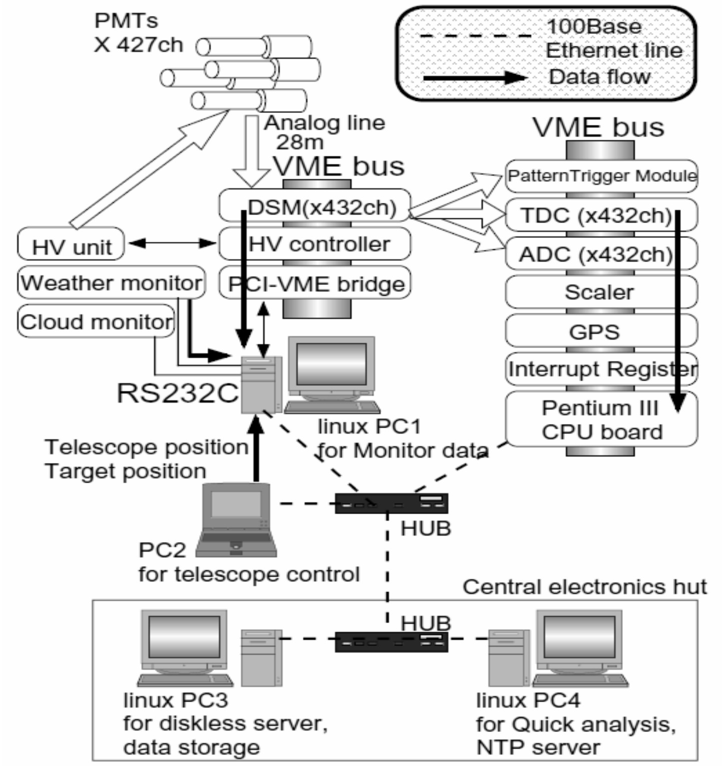
Basic specifications of telescopes

- Location:
  - 31°06’S, 136°47’E
  - 160m a.s.l.
- Telescope:
  - 114× 80cmϕ FRP mirrors ($57m^2$, Al surface)
  - 8m focal length
  - Alt-azimuth mount
- Camera:
  - T1: 552ch (2.7° FOV)
  - T2,T3,T4: 427ch (4° FOV)
- Electronics:
  - TDC+ADC

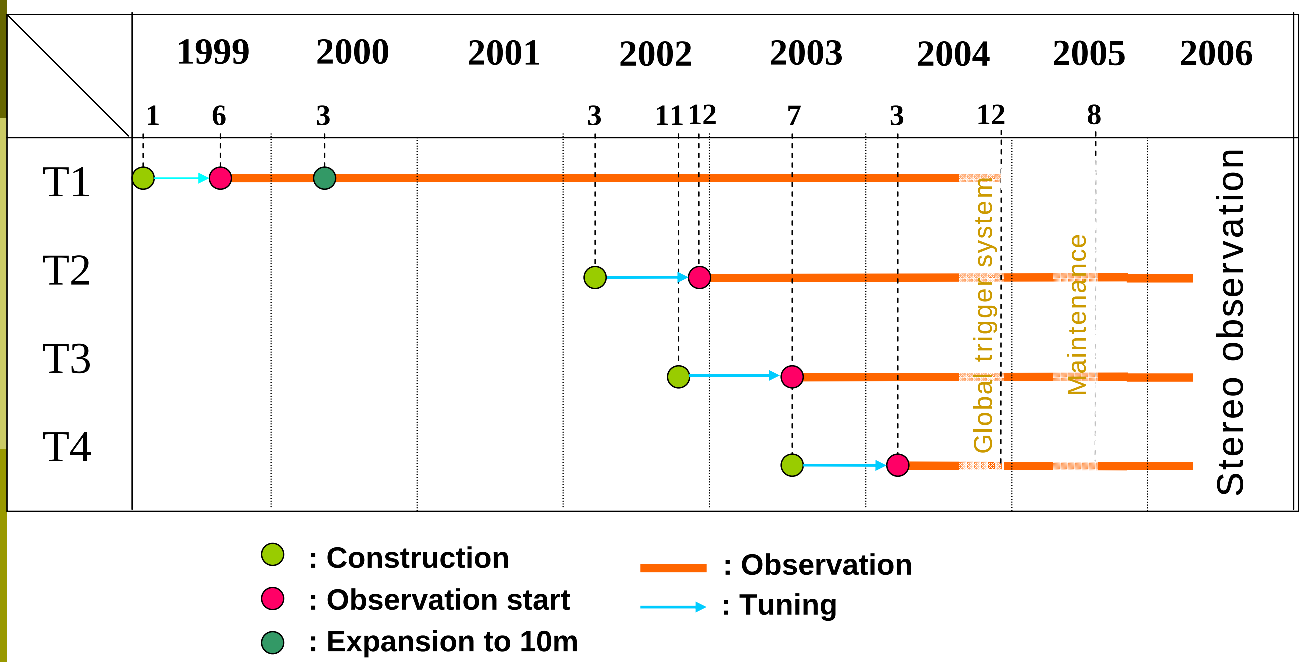


Kubo et al., Proc. ICRC 2003

CANGAROO-III electronics



History of CANGAROO-III

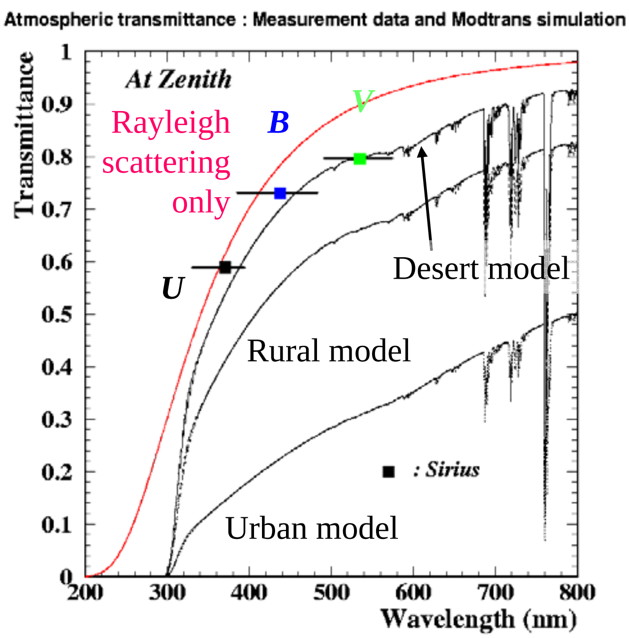


Monte Carlo simulation

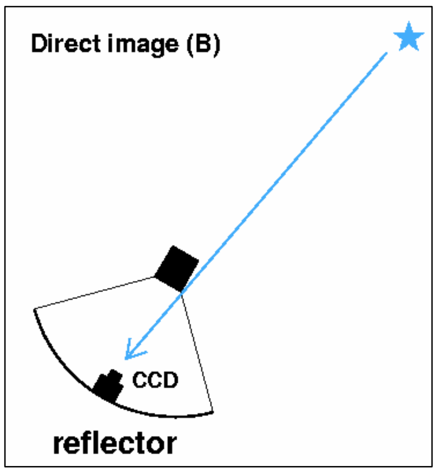
- GEANT 3.21 base
  - 80 layers for atmosphere (12.9g/cm^2 each)
    - (<10% change even if more layers were used)
  - Particle transport down to 20MeV
  - Proprietary code to generate Cherenkov photons
    - Only photons coming to telescopes are tracked
  - Geomagnetic field of 0.520G (vert.) / 0.253G (hor., 6.8°E of S)
  - Rayleigh scattering 2970g/cm^2(λ/400nm)^4
    - (+Mie scattering ~10% effect)
  - Detector parameters: reflectivity, point spread function, light guide efficiency, PMT Q.E., etc.
  - Night sky background

R. Kiuchi et al., Energy Budget in the High Energy Universe, Kashiwa, Feb. 2006

Atmospheric transmission measurement



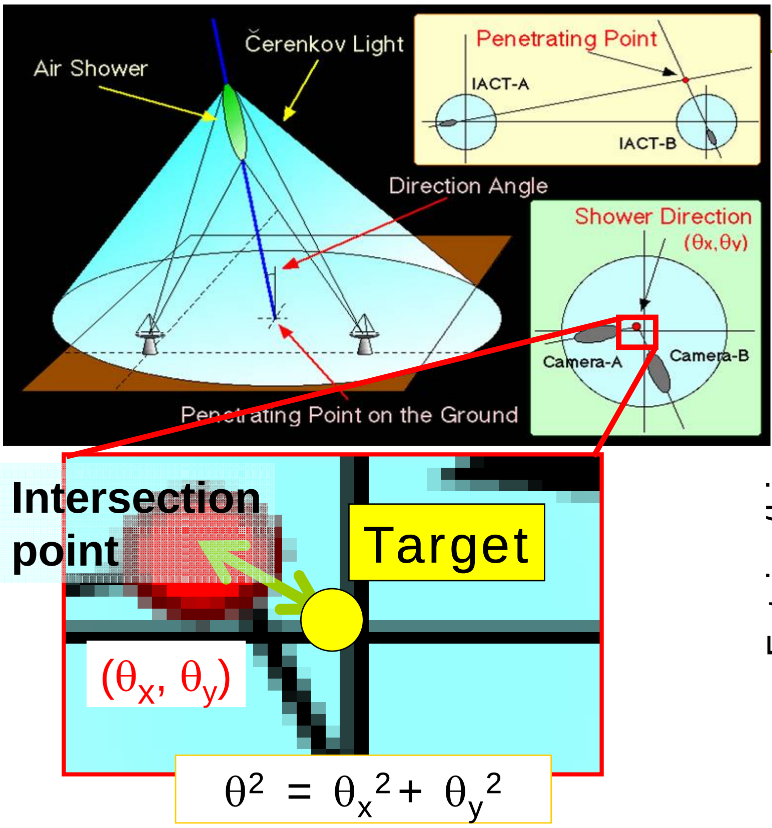
Take star images at various zenith angles with a cooled CCD camera



Data compatible with "Desert model" of MODTRAN4

Systematic errors under study

Stereo observation



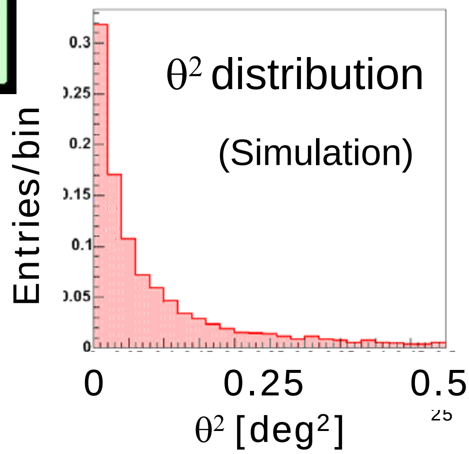
Angular resolution

0.25deg → 0.1 deg

Energy resolution

30% → 15%

Better S/N (no local muons)

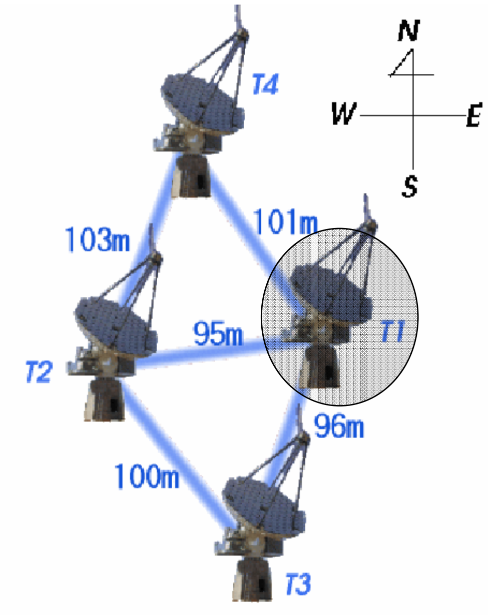


Analysis of stereo observation

- Inconsistency with H.E.S.S results on some sources
  ⇒ New observations with CANGAROO III
  Efforts for advanced analysis procedures
- Measure more optical parameters
  - CCD measurements of spotsizes and stars
- Use muons for calibration
  - Tune Monte Carlo simulation
- Use the Crab as the standard candle
  - Flux obtained with Monte Carlo simulation is compared with those reported by other groups
- Independent teams within the collaboration are working:
  - Results, especially detections, are double-checked

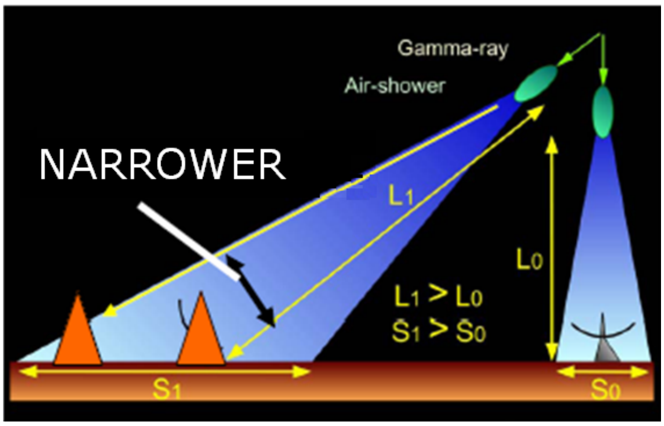
Unfortunate situation for the Crab

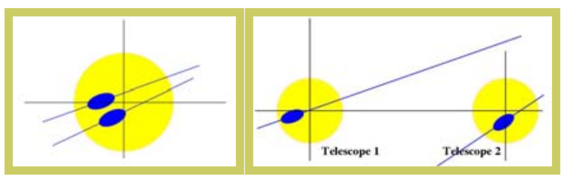
Showers from the Crab



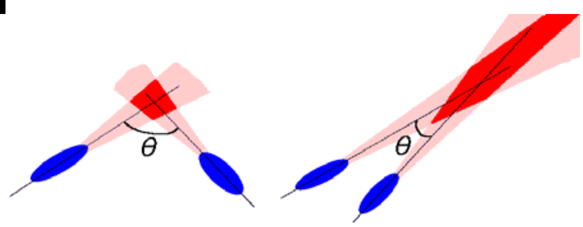
- The oldest T1 has higher energy threshold and bad efficiency for stereo observation
- Only T2/T3/T4 are used for stereo analysis
- Stereo baseline becomes short for the Crab observation at large zenith angles

Large zenith angle observation of the Crab





Far core
→small angle
→bad accuracy



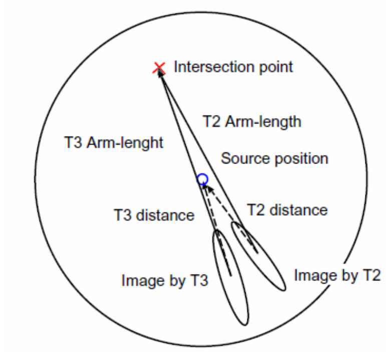
Higher energy threshold ~1TeV

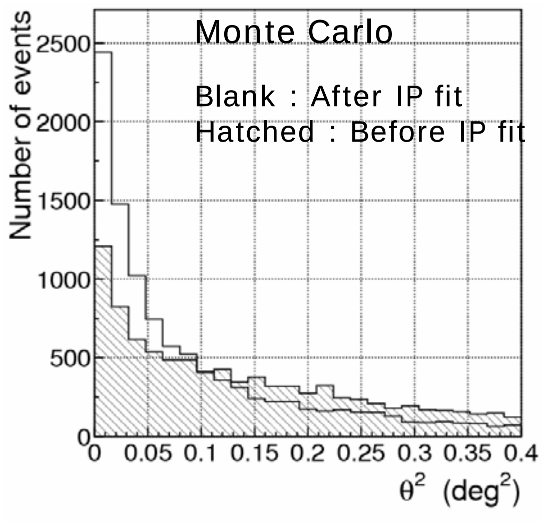
Bad intersection accuracy

IP constraint fit

$$\chi^2 \equiv \sum_{\text{Telescopes}} \left[\left(\frac{\text{Width}(x,y)}{\sigma_w} \right)^2 + \left(\frac{\text{Armlength}(x,y) - \langle \text{Armlength} \rangle}{\sigma_{ARM}} \right)^2 \right]$$

Search intersection point (IP) by minimizing χ^2 so that width along shower axis to be minimum and armlength to be near the expected value (<Armlength>=0.75, Mesh size 0.025°)





γ/h separation by Fisher discriminant

- Linear combination of image parameters (x_i)

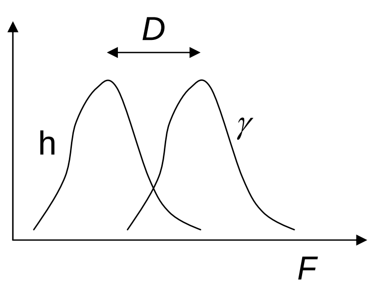
$$F \equiv \sum_i \alpha_i x_i$$

- Difference between signal (γ) and background (h)

$$D \equiv \langle F_\gamma \rangle - \langle F_h \rangle$$

- Determine α_i which maximize separation (solvable using correlation matrix)

$$S \equiv \langle D \rangle^2 / \langle (D - \langle D \rangle)^2 \rangle$$



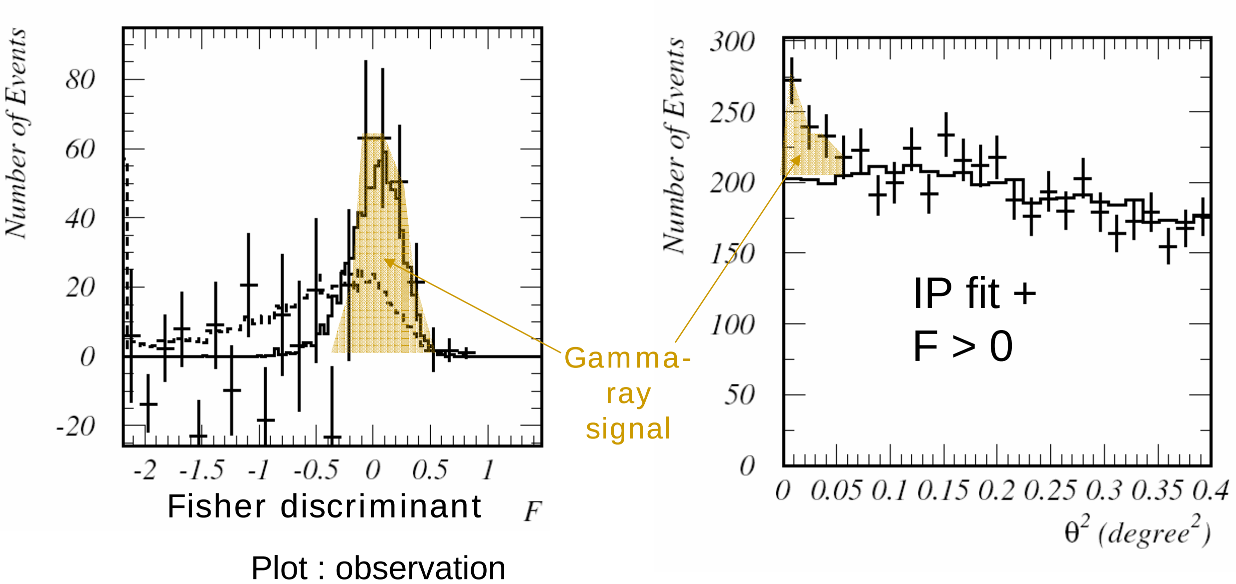
- With calculated α_i for a known source, the (appropriately normalized) combination *F* could be the "Fisher discriminant" for other sources.

- We use *widths* and *lengths* of multiple telescopes for image parameters (x_i).

R.A. Fisher, Annals of Eugenics, 7 (1936) 179

R.Enomoto et al., ApJ 638, 397 (2006)

Crab signal



Plot : observation
Solid : MC gamma
Dashed : background

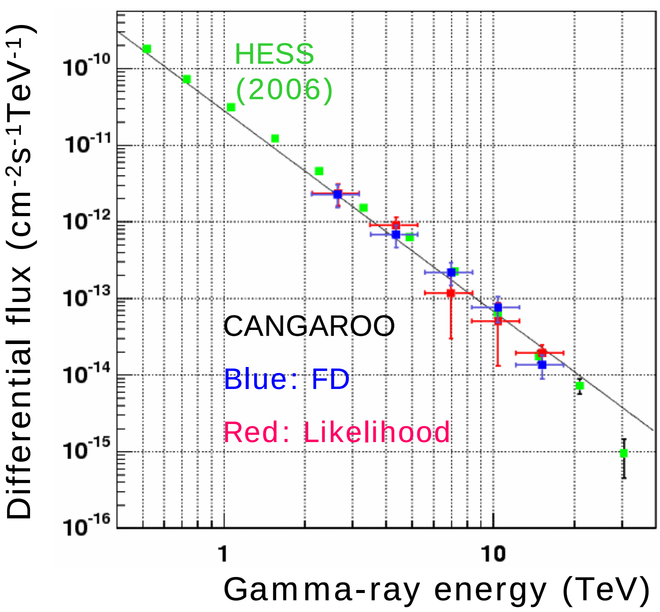
203 excess events
5.8 sigma

- T2 & T3
- 890 min (Dec.2003)

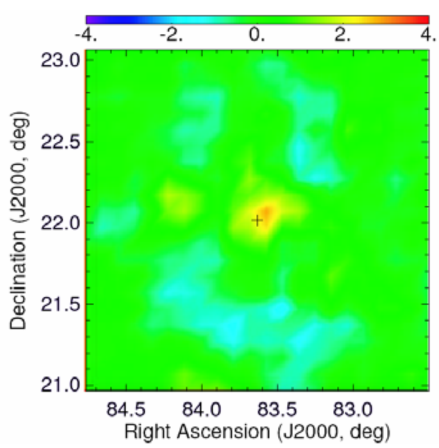
R.Enomoto et al., ApJ 638, 397 (2006)

Crab spectrum

S.Watanabe, Ph.D. thesis (2006)



Excess event map



Angular resolution ~ 0.23 deg

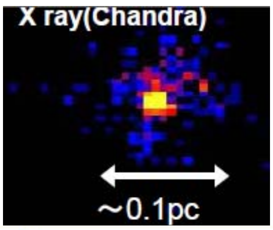
CANGAROO-I claims vs. H.E.S.S.

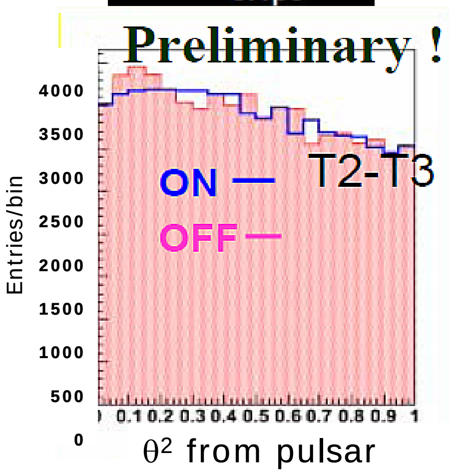
- CANGAROO-I claims
  - Pulsar PSR1706-44 : 0.57Crab (~8σ, >1 TeV)
    [Kifune et al. ApJ 431, L195, 1995]
    - Cf. H.E.S.S. upper limit: 0.024Crab (>0.5TeV)
      [Aharonian et al. A&A 432, L9, 2005]
  - SNR SN1006 : 0.81Crab (5.3σ, >3 TeV) [1996]
    0.62Crab (7.7σ, >1.7TeV) [1997]
    [Tanimori et al. ApJ 497, L25, 1998]
    - Cf. H.E.S.S. upper limit: 0.046Crab (>1.7TeV)
      [Aharonian et al. A&A 437, 135, 2005]
  - Vela pulsar : 0.73Crab (5.8σ, >2.5TeV) at 0.13°SE
    [Yoshikoshi et al. ApJ 487, L65, 1997]
    - Cf. H.E.S.S. Vela X (extended): 0.75Crab (>1TeV)
      [Aharonian et al., A&A 448, L43, 2006]

* Fluxes are given in unit of the Crab integral flux at 1TeV

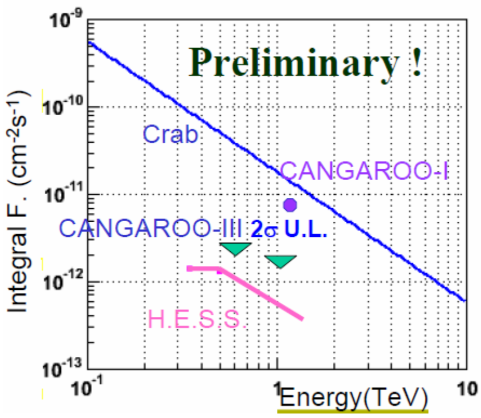
T.Tanimori et al., ICRC2005

PSR 1706-44





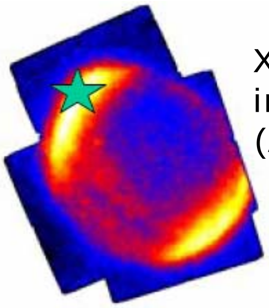
- Pulsar pointing (2004 May)
- Stereo (T2, T3 & T4 long ON/OFF)
- 1,625 min. ON, 1,738 min. OFF
- T2 & T3 results on square cut
- Independent analysis (Fisher disc.)



⇒ To be checked with our latest analysis methods

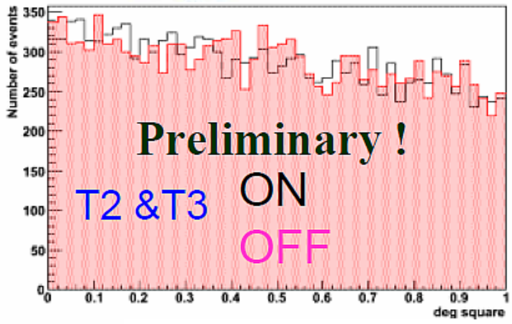
T.Tanimori et al., ICRC2005

SN1006 (G327.6+14.6)

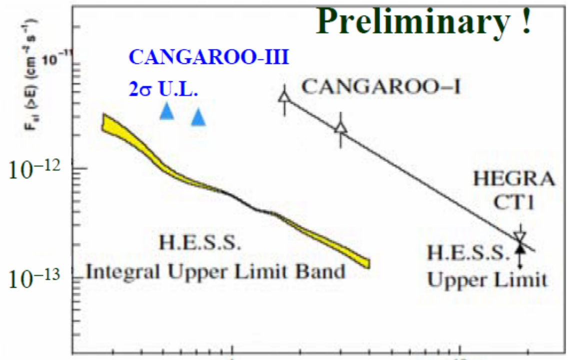


X-ray image (ASCA)

- •NE-rim pointing (2004 May)
- •Stereo (T2, T3 & T4 long ON/OFF)
- •1,625 min. ON, 1,738 min. OFF
- •T2 & T3 results on likelihood
- •Independent analysis (Fisher disc.)



θ^2 from NE rim



Gamma-ray energy (TeV)

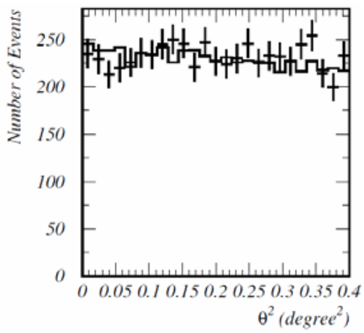
⇒ To be checked with our latest analysis methods

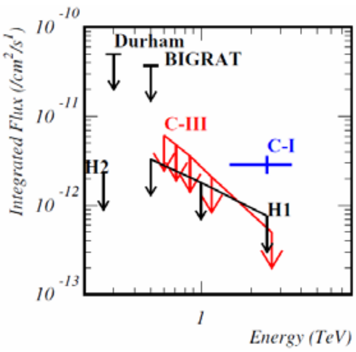
R.Enomoto et al., ApJ 638, 397 (2006)

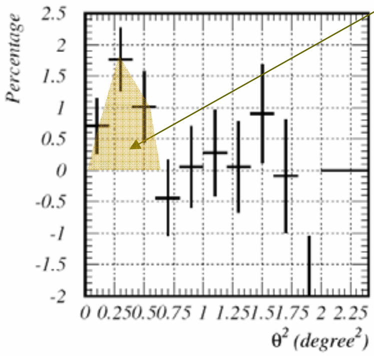
Vela pulsar/nebula

Pulsar position

- •Pulsar pointing (2004 Jan/Feb)
- •Stereo (T2 & T3 wobble), 1,311 min.
- •Fisher discriminant

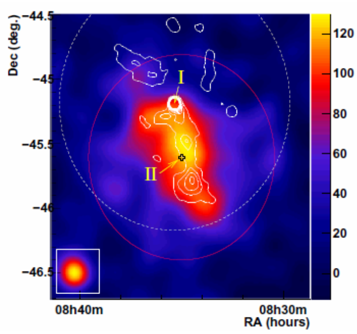






θ^2 from Vela X center

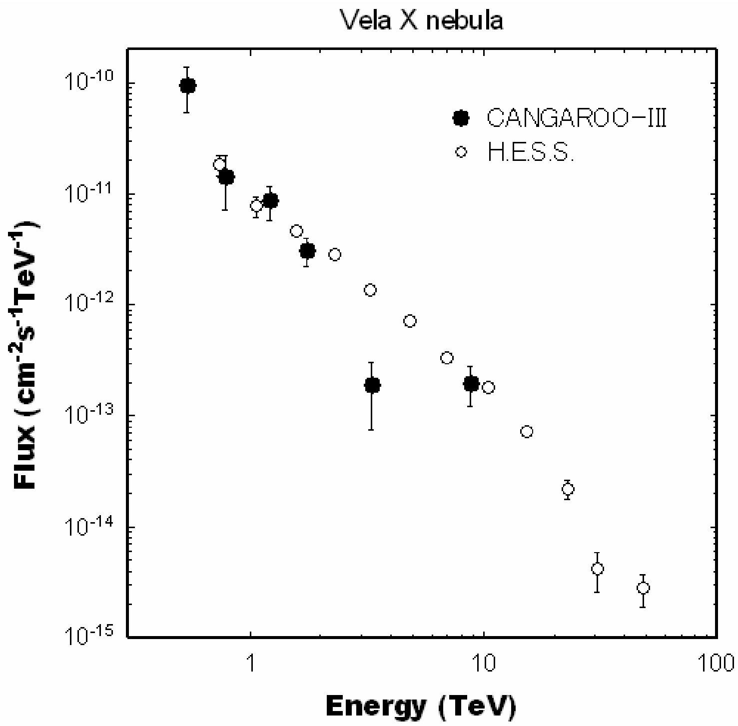
Vela X nebula



H.E.S.S., AA 448, L43 (2006)

R.Enomoto et al., ApJ 638, 397 (2006)

Vela X nebula: spectrum



$\theta^2 < 0.6$ deg^2

Excess 561±114

H.E.S.S.:
Aharonian et al.,
AA 448, L43 (2006)
$\propto E^{-1.45}\exp(-E/13.8\mathrm{TeV})$

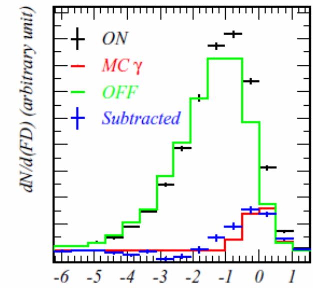
CANGAROO-II claims vs. H.E.S.S.

- CANGAROO-II claims
  - SNR RX J1713.7-3946: 0.51Crab, $E^{-2.84\pm0.15\,\pm0.20}$ (11σ, >0.5 TeV)
    [Enomoto et al., Nature 416, 823, 2002]
    - Cf. H.E.S.S. flux: 0.83Crab, $E^{-2.19\ \pm0.09\pm0.15}$
      [Aharonian et al. Nature 432, 75, 2004]
  - NGC253: 0.15Crab (11σ, >0.5 TeV)
    [Ito et al., A&A 402, 443, 2003]
    - Cf. H.E.S.S. upper limit: 0.05Crab
      [Aharonian et al. A&A 442, 177, 2005]
  - Galactic center: $E^{-4.6(+1.2-5.0)}$
    [Tsuchiya et al., ApJ 606, L115, 2004]
    - Cf. H.E.S.S. spectrum: $E^{-2.2\ \pm0.09\pm0.15}$
      [Aharonian et al. A&A 425, L13, 2004]
  - SNR RX J0852.0-4622 : $E^{-4.6(+1.7-4.4)}$
    [Katagiri et al., ApJ, 619, L163, 2005]
    - Cf. H.E.S.S. spectrum: $E^{-2.1\ \pm0.1\pm0.2}$
      [Aharonian et al. A&A 437, L7, 2005]

⇒ To be checked with CANGAROO-III stereo data

R. Enomoto et al, ApJ, in press

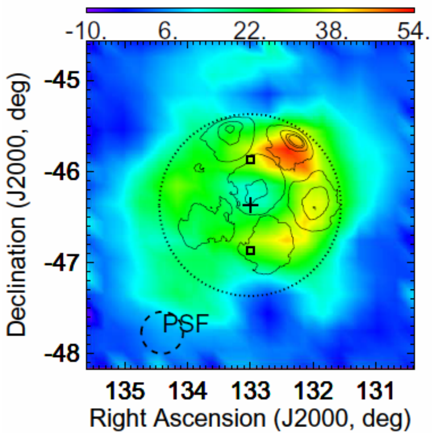
SNR RX J0852.0-4622

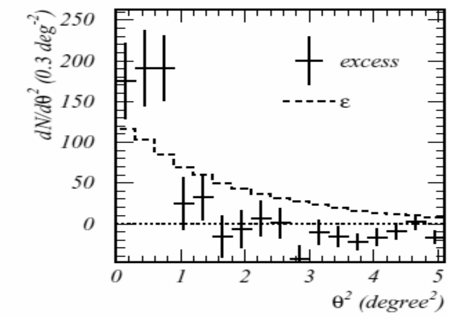


Fisher discriminant

- Distance ~1 kpc
  (NANTEN: Moriguchi et al. ApJ 2005)
- Stereo (T2 & T3 &T4 wobble)
- 1,129 min. ON, 1,081 min OFF
  (2005 Jan/Feb)
- Independent analysis (ICRR, Kyoto)

Excess event map





θ^2 from SNR center

R. Enomoto et al, ApJ, in press

SNR RX J0852.0-4622: spectrum

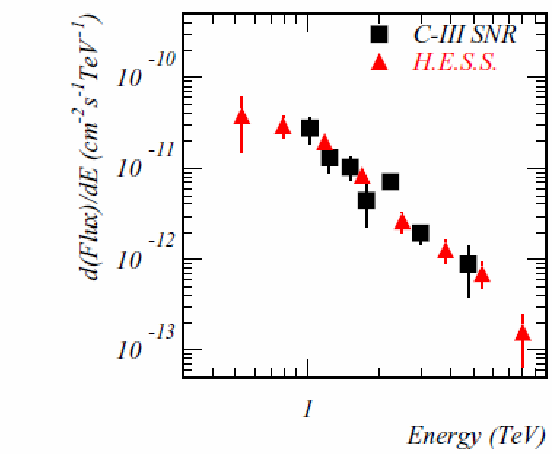
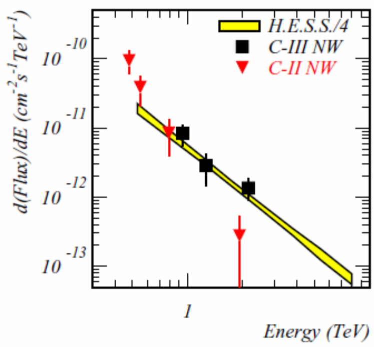


FIG. 7.— Differential energy spectra; the red points by H.E.S.S. are for the whole remnant and the black points from these CANGAROO-III observations are also for the whole remnant. The error bars are statistical.

$$\frac{dF}{dE} = [2.5 \pm 0.6(stat.) \pm 0.6(sys.)] \times 10^{-11} \cdot \left(\frac{E}{1\ \mathrm{TeV}}\right)^{2.2\pm0.3(stat.)\pm0.3(sys.)} [\mathrm{cm^{-2}s^{-1}TeV^{-1}}]$$

Comparison with C-II



C.Itoh et al., A&A erratum, in press

Starburst galaxy NGC253

- 3-fold, 2004 Oct, 1179min (ON), 753min (OFF)

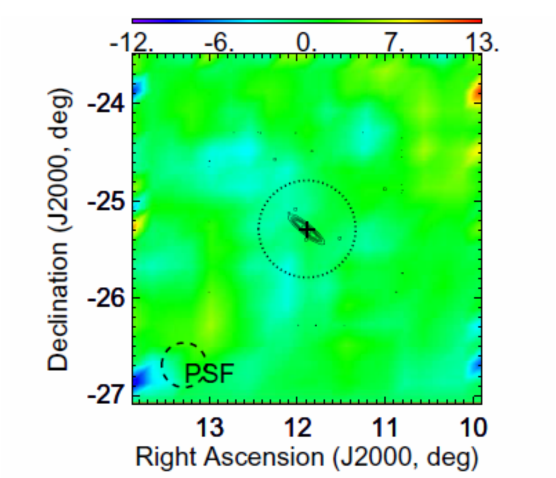


Fig. 3. Excess count map. The rainbow map is the excess count. The black contour is DSS2 (second version of Digital Sky Survey) data. The dotted circle is 0.5 degree radius. The point spread function is shown in left-below corner (the dashed line).

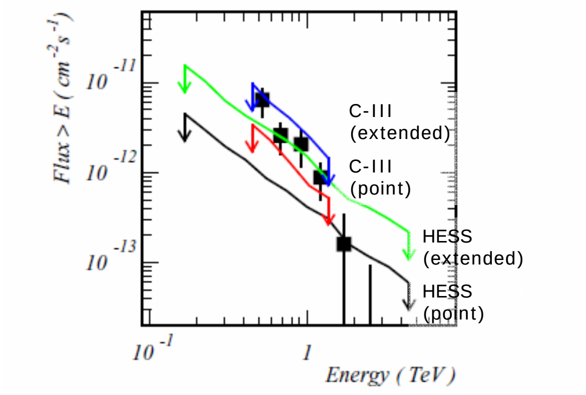


Fig. 4. Integral fluxes. The points with error bars are the CANGAROO-II's ones (see text for the detail). The black curve is 99% upper limit (UL) by H.E.S.S. for point source assumption. The green is that for 0.5 degree diffuse source. The red is 2σ UL for this observation for point source assumption and the blue for 0.5 degree diffuse.

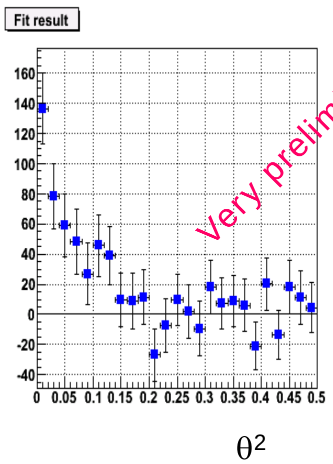
C.Itoh et al., A&A erratum, in press

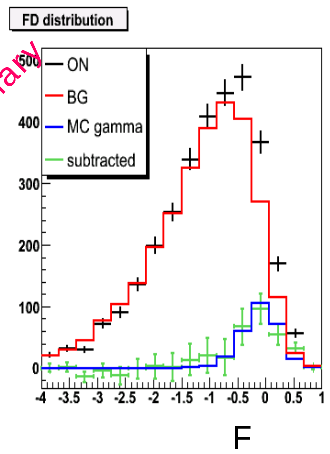
Problems in CANGAROO-II analysis

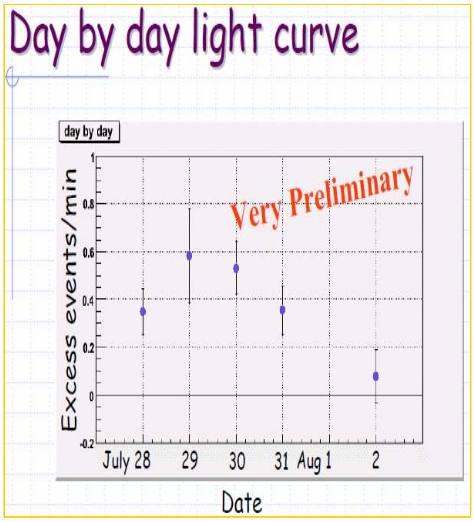
- Treatment of “hot” channels
  - In the case of NGC253
    - Hot “box” scan for recovering flatness were carried out (“box” is a unit of sixteen (four by four) neighbored PMTs)
    - further scan inside these sixteen channel were done and finally find the field-deforming pixels.
    - Excess reduced to 700 (4σ) from 2000 (11σ) without above procedures.
  - Different procedure for RX J1713.7-3946, Galactic center, RX J0852.0-4622
    - Bright stars were in the field-of-view for these observations.
    - RX J1713.7-3946: we removed hot pixels due to small discharges triggered by the bright star passages.
    - Galactic center and RX J0852.0-4622: we selected them based on the χ^2 calculated by the pixel-hit rate and deviation of each ADC spectrum from the average one.

Flare of Blazar PKS 2155-304

- Nearby high-frequency BL Lac (z=0.117)
- TeV flare report by H.E.S.S. in July-Aug 2006 (ATel#867)
- 1,053 min (wobble), 3-fold
- Analyzed by independent teams (ICRR, Tokai, Kyoto)







Summary table: update

Table 1: Summary of TeV source status claimed by CANGAROO compared with H.E.S.S. results.

Object	C-I	C-II	C-III	H.E.S.S.
Crab	Yes	Yes	Yes [2]	Yes
PSR 1706-44	Yes	†	U.L. [1]	U.L.
Vela pular	Yes (0.13° offset)	N/A	U.L. [2]	U.L.
Vela X	N/A	N/A	Yes [2]	Yes
SN1006	Yes	†	U.L. [1]	U.L.
RX J1713.7-3946	Yes	Yes	under analysis	Yes
PSR 1509-58	Yes	N/A	under analysis	Yes (MSH15-52)
Mrk 421	N/A	Yes	N/A	Yes
NGC 253	N/A	Yes	U.L.[4]	U.L.
Galactic center	N/A	Yes	under analysis	Yes
RX J0852.0-4622	N/A	Yes	Yes [3]	Yes

'C-I' means CANGAROO-I, etc. 'Yes': detection, 'U.L.': upper limit, 'N/A': not available. † means the result is not published yet.

[1] "Status of the CANGAROO-III Project"
T. Tanimori et al., 29th International Cosmic Ray Conference, Pune, India (August 3-10, 2005), published in Proceedings (Tata Institute of Fundamental Research, Mumbai, India, 2006) Vol.4, pp.215-218

[2] "A Search for sub-TeV Gamma-rays from the Vela Pulsar Region with CANGAROO-III"
Enomoto, R. et al., Astrophys. J., 638, 397-408 (2006)

[3] "CANGAROO-III Observations of the supernova remnant RX J0852.0−4622"
Enomoto, R. et al., Astrophys. J., in press (2006)

[4] "Erratum: Detection of diffuse TeV gamma-ray emission from the nearby starburst galaxy NGC 253"
Itoh, C. et al., Astron. Astrophys., in press (2006)

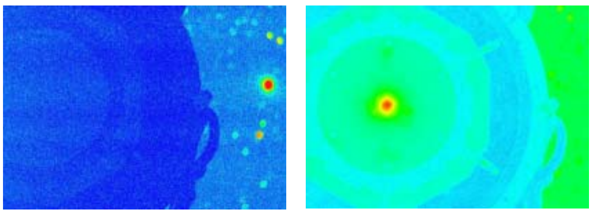
Up and coming sources…

- MSH 15-52
  - Pulsar wind nebula (PSR 1509-58)
  - H.E.S.S. : 25% Crab, extended (~6'x2')
  - Observation: 40hr in 2005, 90hr in 2006
- HESS J1804-216
  - G8.7-0.1(SNR) / PSR J1803-2137
  - H.E.S.S. : 25% Crab, extended (~12')
  - Observation: 90hr in 2006
- HESS J1303-631
  - Unidentified
  - H.E.S.S. : 17% Crab, extended (~10')
  - Observation: 70hr in 2006
- And more…

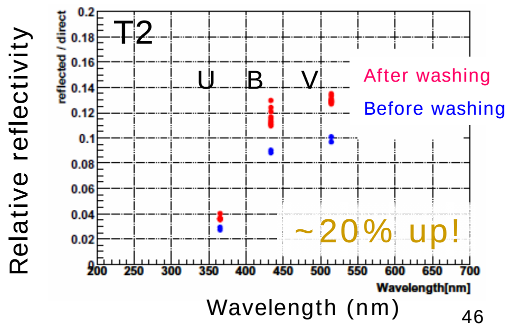
Maintenance works in 2005 Sep/Oct

- Intensive works…
  - Washing mirrors
  - Mirror realignment
  - Optical measurement
  - Electronics tuning
  - Muon data for calibration
  - Etc.

Reflectivity measurement using star images



Direct star images Reflected image of stars



(R. Kiuchi et al., in "Energy budget in the High Energy Universe", Kashiwa, Feb. 2006)

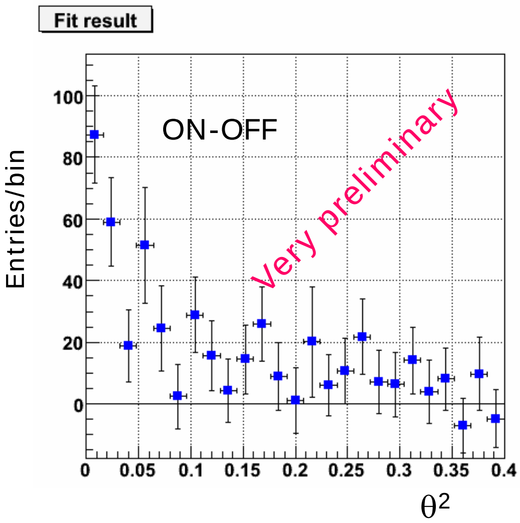
Crab observation after the maintenance

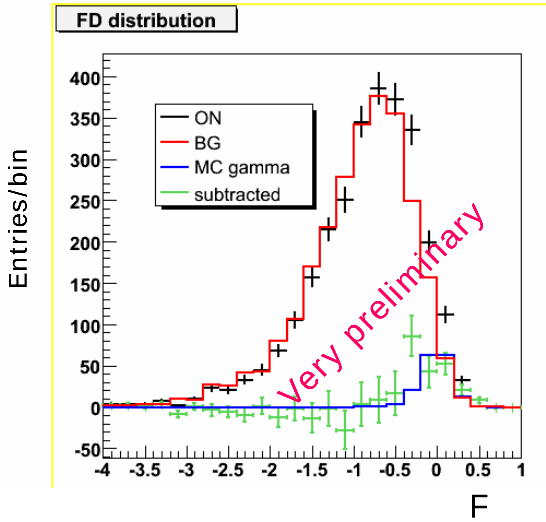
•Stereo (T2 & T3 & T4)

•Nov/Dec 2005, ~950 min. (wobble)

•Fisher discriminant

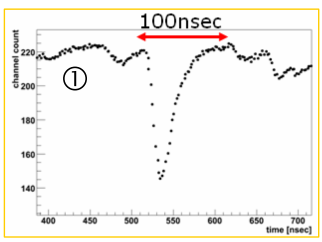
By T.Nakamori

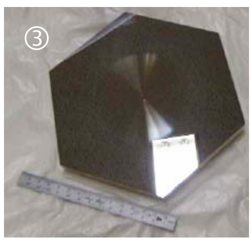




Joint-use projects related to CANGAROO

- Independent analysis teams
- Target meetings, domestic workshops
  - Lead by Ibaraki, Yamanashi Gakuin
- R&D works
  - Electronics: FADC①, capacitor array [Kyoto]
  - Cloud monitor [Tokai]②
  - Metal mirrors [Tokai]③





Near future: upgrade of CANGAROO-III

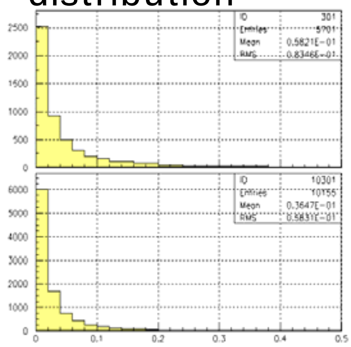
- Upgrade of mirrors (FRP process limited spotsize.)
- Upgrade of T1 camera & electronics

[Requesting budget]

Expected sensitivity after upgrade

(Monte Carlo simulation assuming 1'-spotsize mirrors)

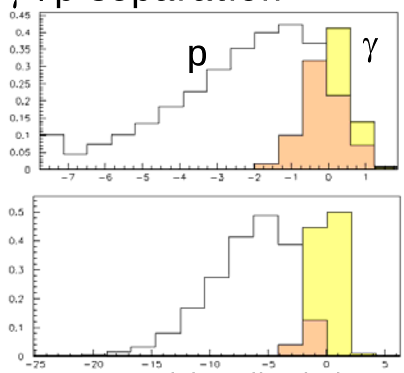
θ^2 distribution



Present

Upgraded

γ /p separation

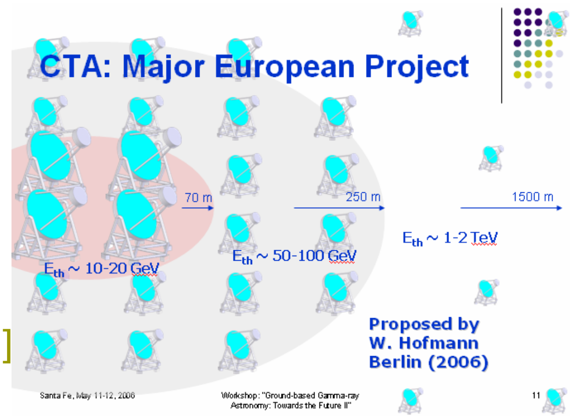


- RMS 0.083 $\rightarrow$ 0.058 degree^2
- ε 5400 $\rightarrow$ 11000 events
- Threshold 580 $\rightarrow$ 330 GeV

- 47 times better S/N!

Toward next generation telescopes

- Cherenkov technique is now established.
- More sensitive next-generation projects are awaited and should be fruitful!
- Large-scale telescope complex by international collaboration is inevitable.
  - R&D for large / wide-angle arrays
  - CTA (Cherenkov Telescope Array) [mix of graded array?]
  - TenTen, HE-Astro, GRATIS...



Konopelko, Santa Fe WS, May 2006

Summary

- CANGAROO-II 10m telescope produced pioneering results on SNR RX J1713.7-3946, Galactic center and SNR RX J0852.0-4622.
- CANGAROO-III atmospheric Cherenkov telescope system are observing sub-TeV gamma-rays since 2004 March in stereoscopic mode.
- Observations of SN1006 and PSR1706-44 were made by using CANGAROO-III telescopes. Preliminary analyses appear to show no significant signals, yielding upper limits lower than the CANGAROO-I fluxes obtained several years ago.
- Observation of Vela pulsar showed no gamma-ray signal, but there is a hint of signal in the Vela X nebula.
- SNR RX J0852.0-4622 was detected as an extended source, and the morphology seems to follow the X-ray emission profile.
- Starburst galaxy NGC 253 was observed with CANGAROO-III but the signal reported by CANGAROO-II was not confirmed.
- A flaring activity of a blazar PKS 2155-304 was detected in July-August 2006 showing rapid time variation.
- Analysis of stereo observations are now established, and application to other sources are underway.
- We are discussing possible collaboration toward a large-scale international Cherenkov observatory.