CANGAROO実験

森 正樹 for the CANGAROO-III team

Woomera, Australia

2004 March

T2　　　　T4　　T3　　T1

日豪共同による解像型大気チェレンコフ望遠鏡アレイによる超高エネルギーガンマ線天体の観測。【COEプログラムは平成15年度で終了。平成16年度からは宇宙線研究所共同利用・科研費基盤（A)などで観測・維持を行っている。】

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
- Australia Telescope National Facility
- Tokai University
- ICRR, University of Tokyo
- Yamagata University
- Yamanashi Gakuin University
- Hiroshima University

望遠鏡の基本仕様

- 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

100m

©Google

T4

T1

T2

T3
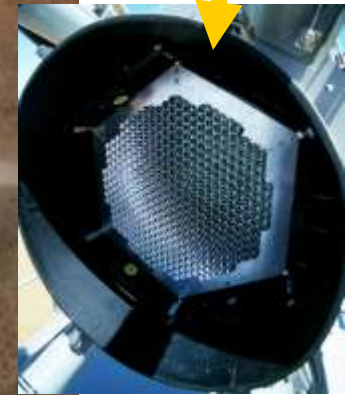
チェレンコフ光のステレオ観測
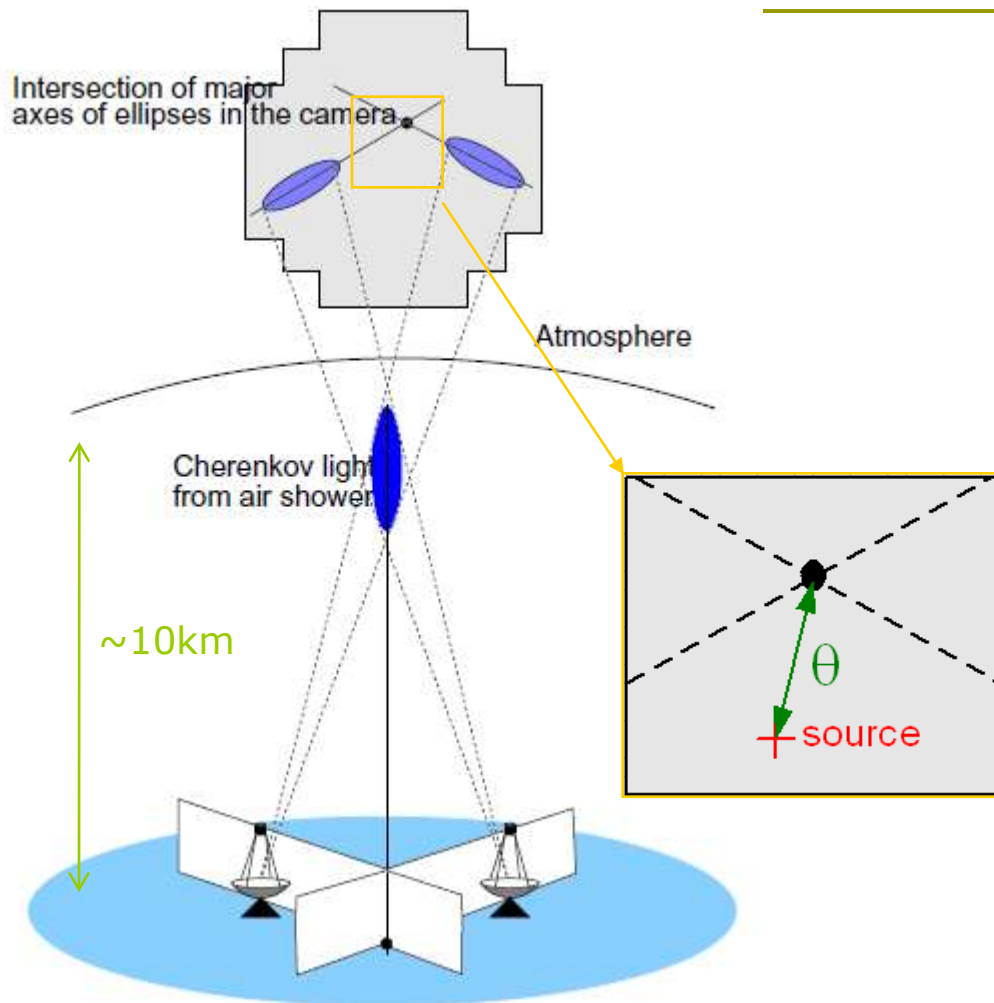
Angular resolution

0.25deg → 0.1 deg

Energy resolution

30% → 15%

Better S/N (no local muons)

© S.Funk, 2005
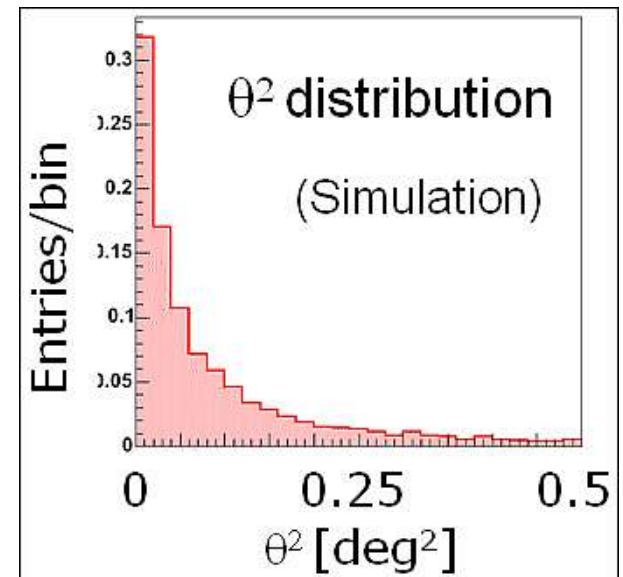
最近の状況

- 発表論文
  1. "CANGAROO-III Observations of the supernova remnant RX J0852.0-4622", Enomoto, R. et al, ApJ 652, 1268 (2006)
  2. "Erratum: Detection of diffuse TeV gamma-ray emission from the nearby starburst galaxy NGC 253", Itoh, C. et al., Astron. Astrophys., 462, 67-71 (2007)
  3. "CANGAROO-III Search for Gamma Rays from Centaurus A and the ω Centauri Region", Kabuki, S. et al., ApJ 668, 968-973 (2007)
  4. "CANGAROO-III Search for Gamma Rays from SN 1987A and the Surrounding Field", Enomoto, R. et al., ApJ 671, 1939 (2007)
  5. "CANGAROO-III Observations of the 2006 Outburst of PKS2155-304", Sakamoto, Y. et al., ApJ, *accepted*
  6. "Observation of an extended VHE gamma-ray emission from MSH15-52 with CANGAROO-III", Namamori, T. et al., *submitted*
  - 第30回宇宙線国際会議(2007)： 7編の論文を発表
- 作業など
  - 2006 Nov/Dec 望遠鏡保守、小型反射鏡の洗浄
  - 2007 Nov 望遠鏡保守
  - 宇宙線ミューオンデータの取得（利得較正）

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観測天体

観測期間	天体	観測時間*
Dec 2006	SN1987A	45 hr
Jan 2007	Vela	36
Feb 2007	Vela	55
Mar 2007	Vela, HESS J1616-508	47
Apr 2007	Vela, PSR 1706-44	32
May 2007	PSR 1706-44	51
Jun 2007	PSR 1706-44, PSR 1259-63	60
Jul 2007	PSR 1259-63, RX J1713.7-3946	48
Aug 2007	(軍の演習のため観測中止)	
Sep 2007	RX J1713.7-3946, MGRO J1908+06, dSph	41
Oct 2007	MGRO J1908+06, dSph	75
Nov 2007	dSph, A3376	49

Crab nebula
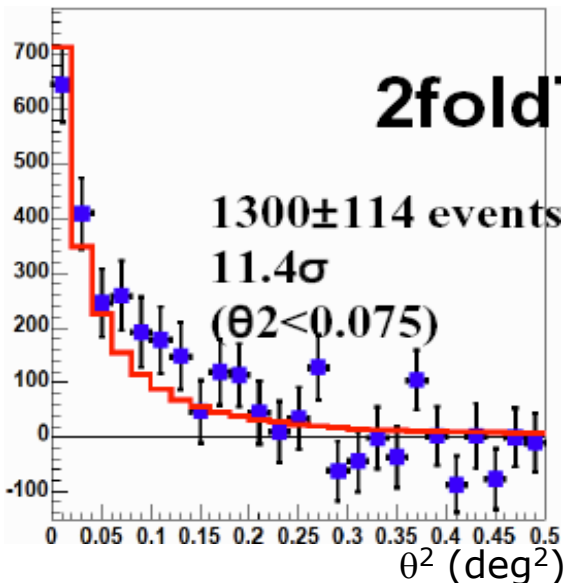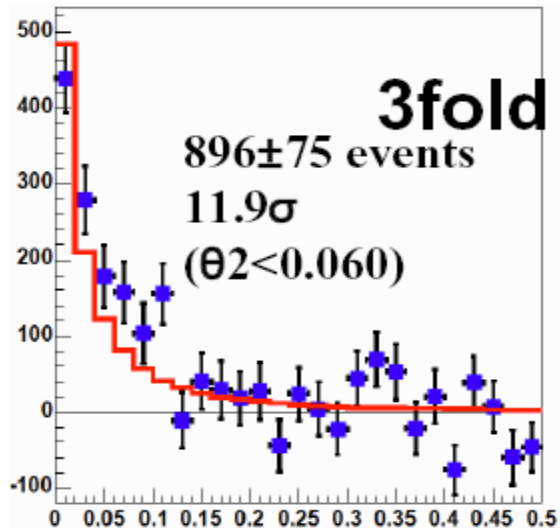
- 2005 Nov/Dec
- Large zenith angle (>55deg)
- 40hr (wobble)

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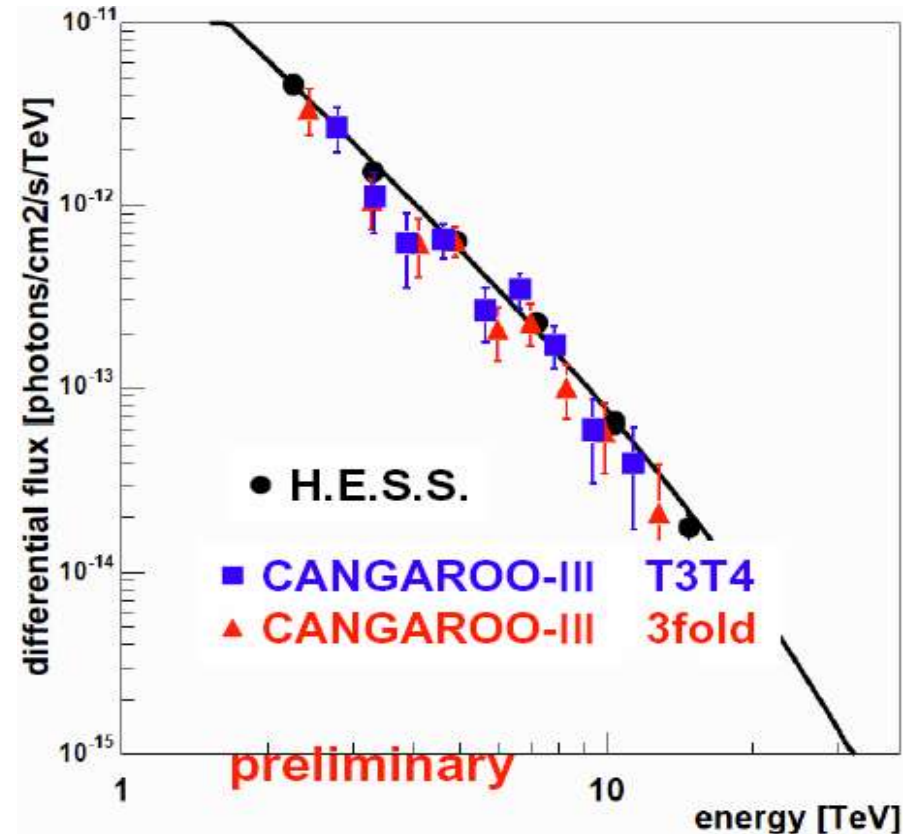
Image moments: data vs MC

Width
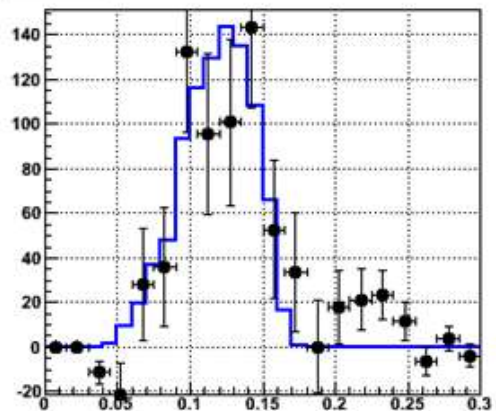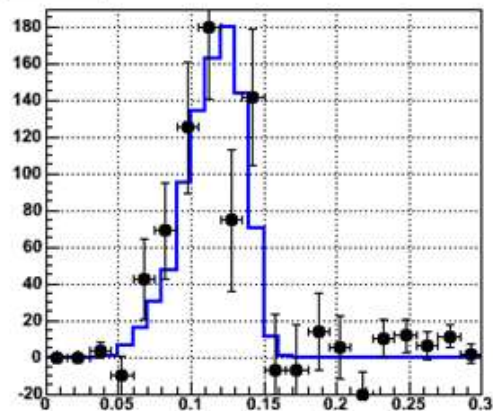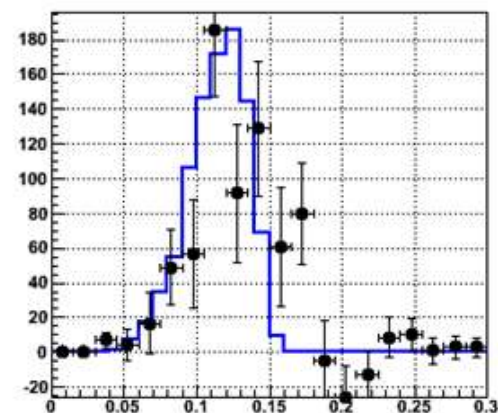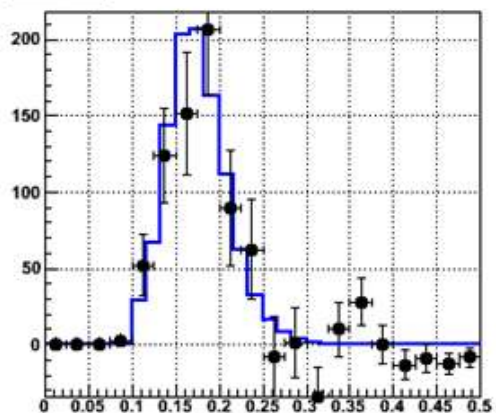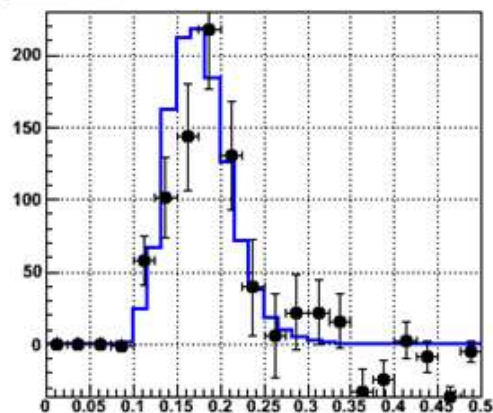
Length
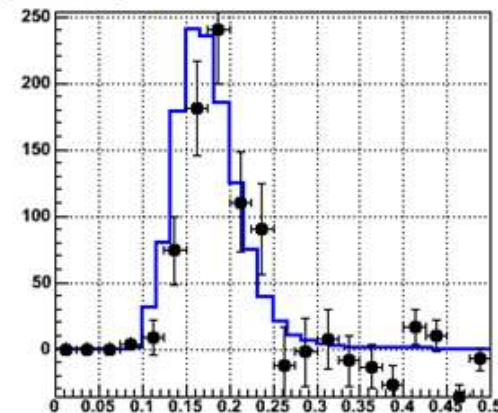
Data (γ-like, Crab): points, histogram: γ MC

活動銀河核PKS2155-304のフレア

- 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 [8 hour difference in Time-zone!]
- Analyzed by independent teams (ICRR, Tokai, Kyoto)

CANGAROO-III
Jul/Aug 2006

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PKS2155-304:　日変化

PKS 2155: nightly light curve
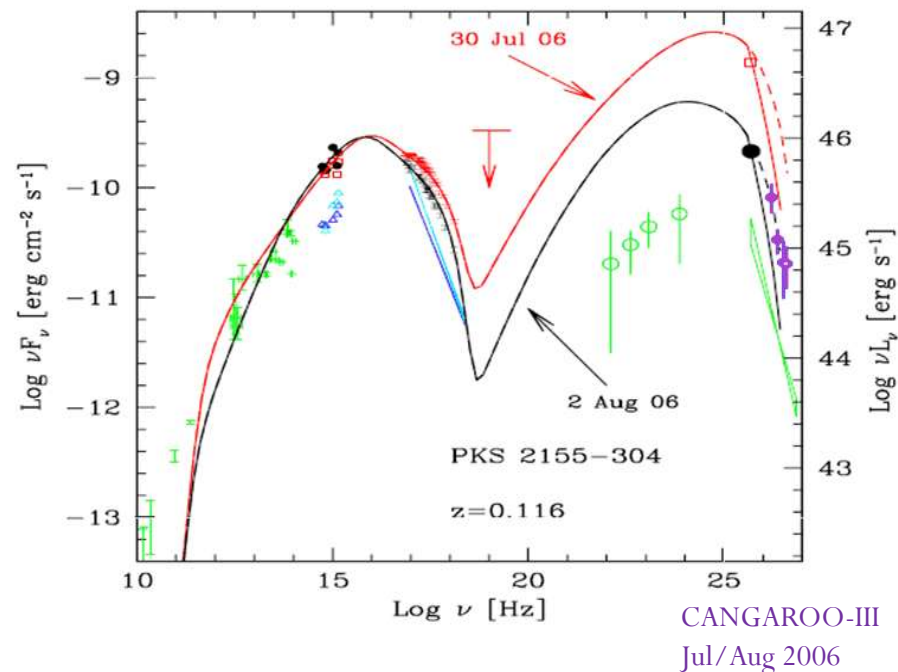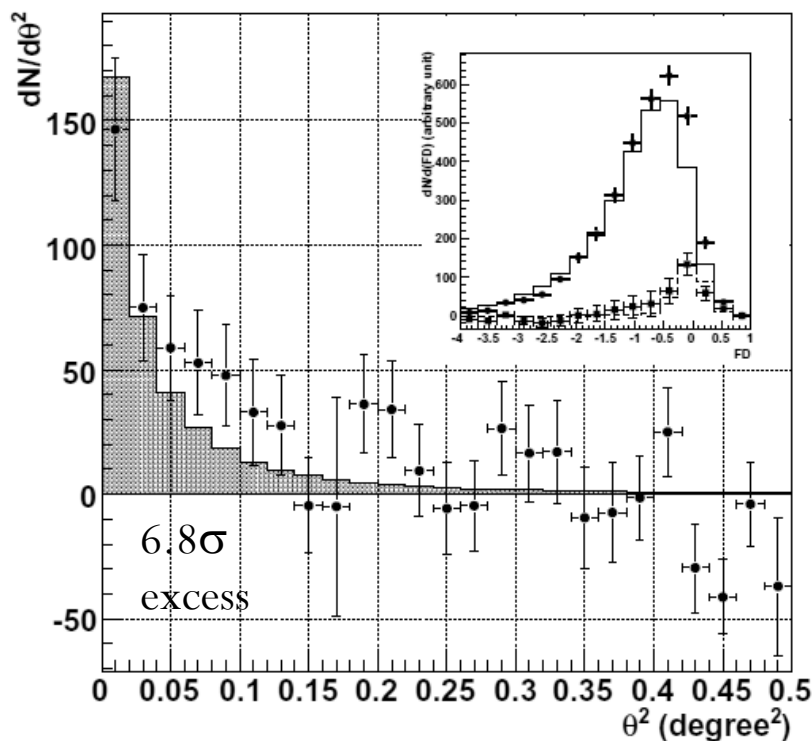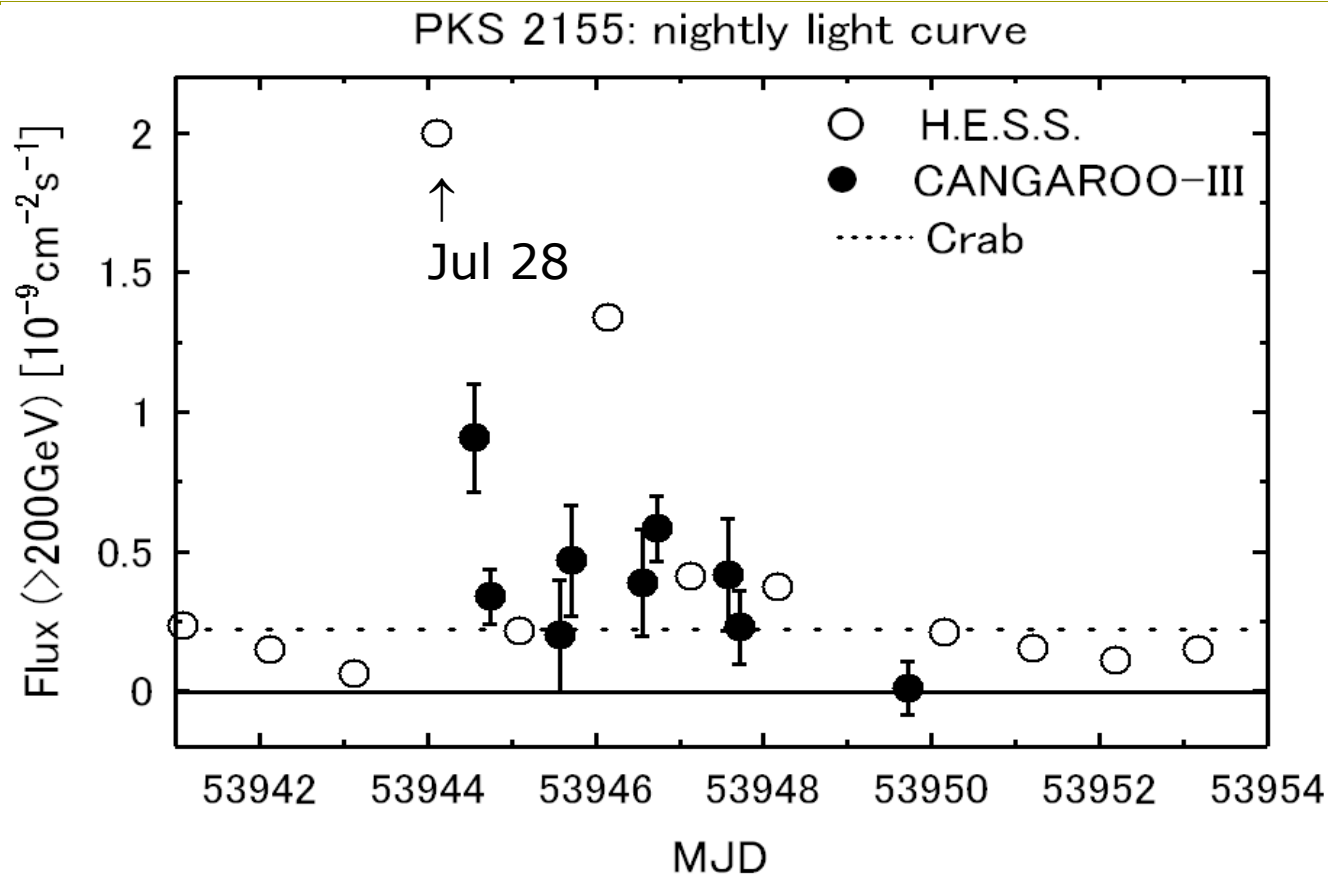
φ(CANGAROO) - φ(H.E.S.S.) = 120° = 8hr

Note 1: CANGAROO points were scaled from those above 620 GeV by $E^{-3.3}$ spectrum.

Note 2: X-axis of HESS data are NOT official [from M. Raue, INTEGRAL Workshop, Rome, Oct. 2006]

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パルサー星雲MSH15-52

MSH15-52 / RCW89
PSR 1509-58 ($\dot{E}=2\times10^{37}$erg/s)
Pulsar wind nebula

CANGAROO-III: Extended emission (total excess 582±77)

2D Gaussian fit results (before smoothing)

rotation angle
  j = 29.8 ± 1.9deg

intrinsic standard deviations
  $\sigma_{x'}$ = 0.07 ± 0.07 deg
  $\sigma_{y'}$ = 0.21 ± 0.08 deg
    consistent with H.E.S.S.

MSH15-52: 陽子起源モデル

νF$_ν$ [eV cm^{-2} s^{-1}]

- △ H.E.S.S.
- ▲ CANGAROO-III
- ✠ EGRET
- ◇ COMPTEL
- — π^0 decay
- ···· pulsed component

EGRET [Pulsed + Unpulsed, Kuiper+ 99]

Energy [eV]

Proton spectrum:

$$f_p(p) = f_0 \frac{V}{4\pi d^2} p^{-\alpha} \exp(-\frac{p}{p_{max}})$$

Fit with TeV data:

$\alpha = 2.16 \pm 0.05$

$p_{max} = 530 \pm 399\,\mathrm{TeV/c}$

$E_{tot} = 3.2\times10^{51}\,\mathrm{erg}$

@5.2kpc, 1.0 H/cc

c.f.

$$\int_0^\tau \dot{E}_{rot}\,dt \sim 10^{48}\,\mathrm{erg}$$

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MSH15-52: 電子起源モデル

- BeppoSAX/MECS data for soft X-ray
- INTEGRAL/IBIS data for hard X-ray

(du Plessis+ 95, Gaensler+ 02, Mineo+ 00, Forot+ 06, Kuiper+ 99, Aharonian+ 05)

Electron spectrum:

$$f_e(E_e) = f_0 \frac{V}{4\pi d^2} \frac{(\frac{E_e}{E_{br}})^{-\gamma_1}}{1 + (\frac{E_e}{E_{br}})^{\gamma_2-\gamma_1}} \exp(-\frac{E_e}{E_{max}})$$
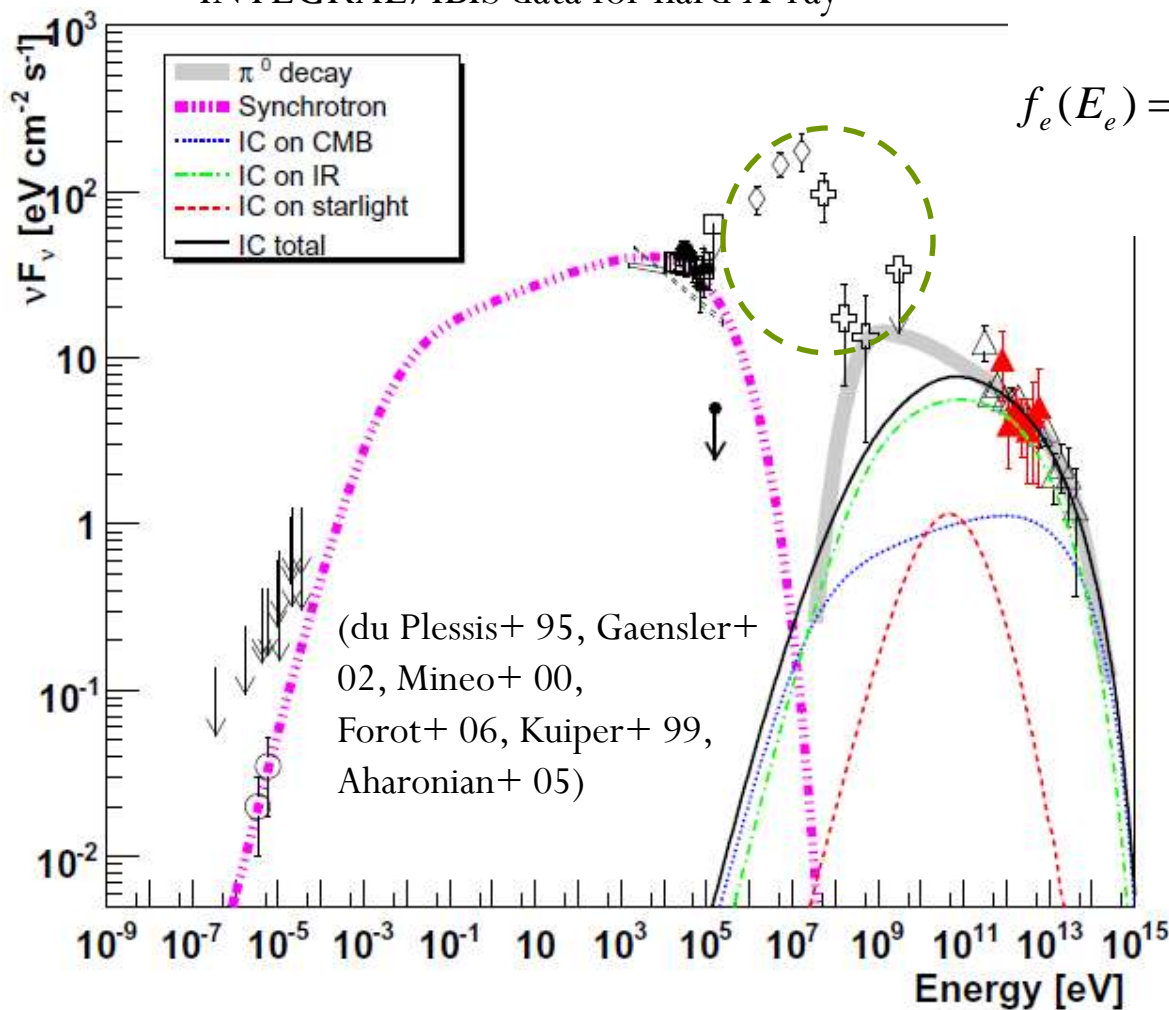
- *Broken power law*
- "Eye-fit"
- B=17μG (Aharonian+ '05)
- Starlight 1.4 eV cm^{-3}
- IR necessary (parameter)
- E_{tot}=7×10^{48} erg
- E_{br} does not match the characteristic age (if t = 1700yr, sync. break @ 0.2keV)

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SNR RX J1713.7-3946

Preliminary

0.4225

θ^2 [deg^2] (from shell center)

Region for flux estimation
(same as H.E.S.S.)

0.65deg

Preliminary   1deg circle   PSF
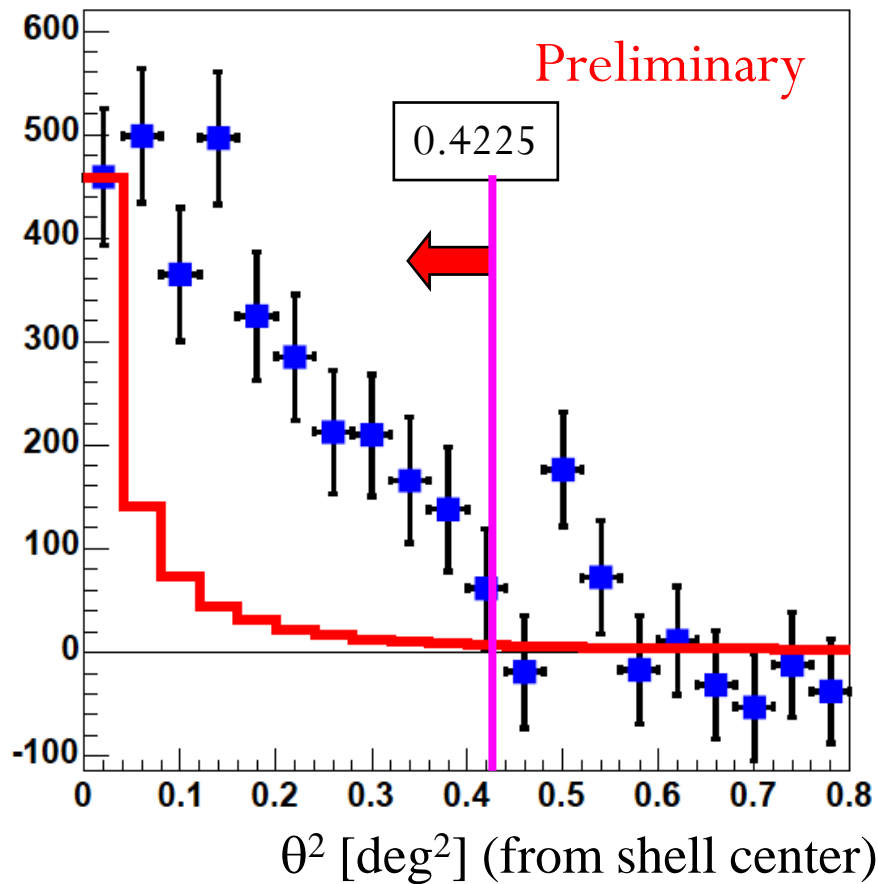
Contour : H.E.S.S.

3154 ±194 events

16.1σ (excess region θ<0.65)
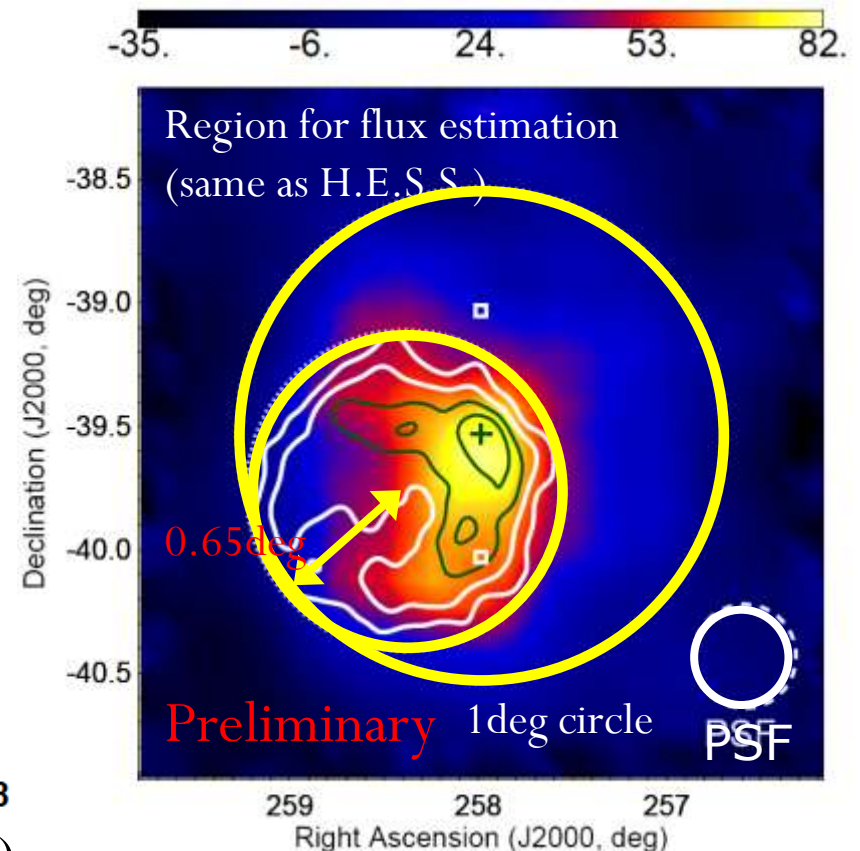
• >~1TeV

• Extended compared to PSF

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SNR RX J1713.7-3946: spectrum
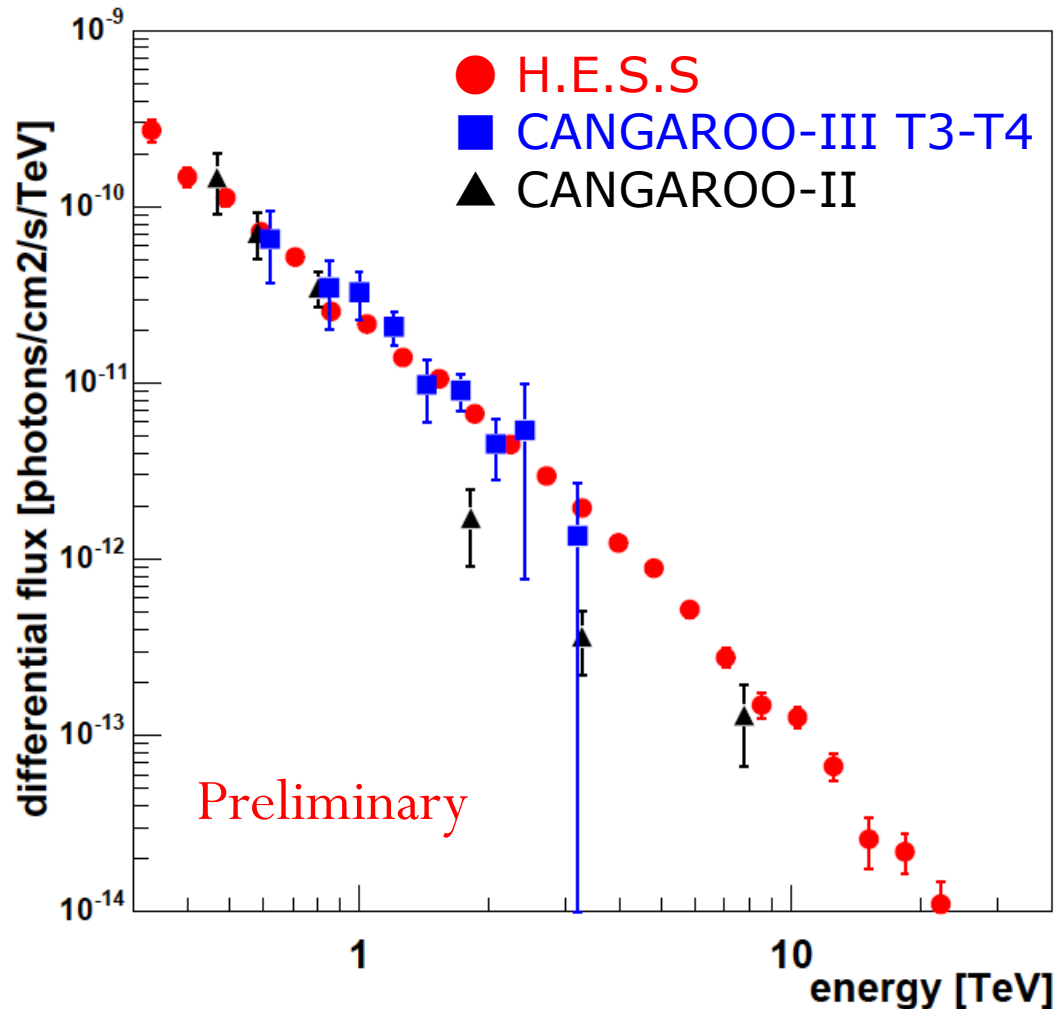
$$\propto E^{-2.26\pm0.3}$$

Consistent with H.E.S.S.

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Kepler's SNR (G4.5+6.8)

- 2005 April, 874min
- Two-fold (T3-T4)
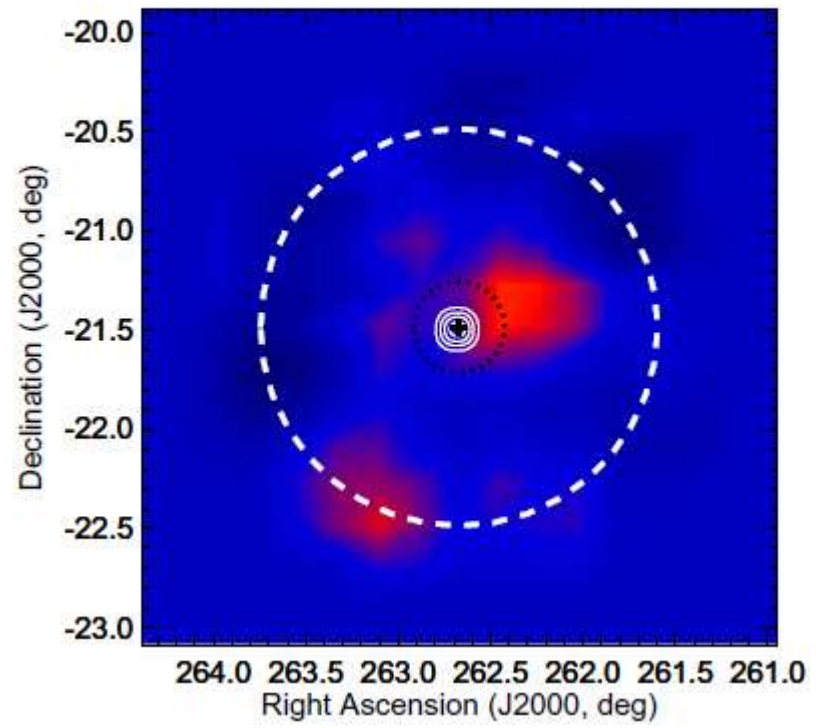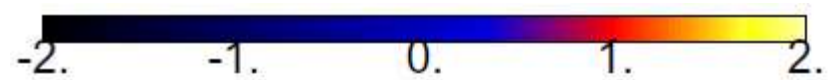
FIG. 3.— Significance map. The dotted-black circle is the point-spread function. The dashed-white circle is the fiducial region (1° radius). The thin-white contour is a radio measurement at 4850MHz(SkyView 2007).

No significant emission
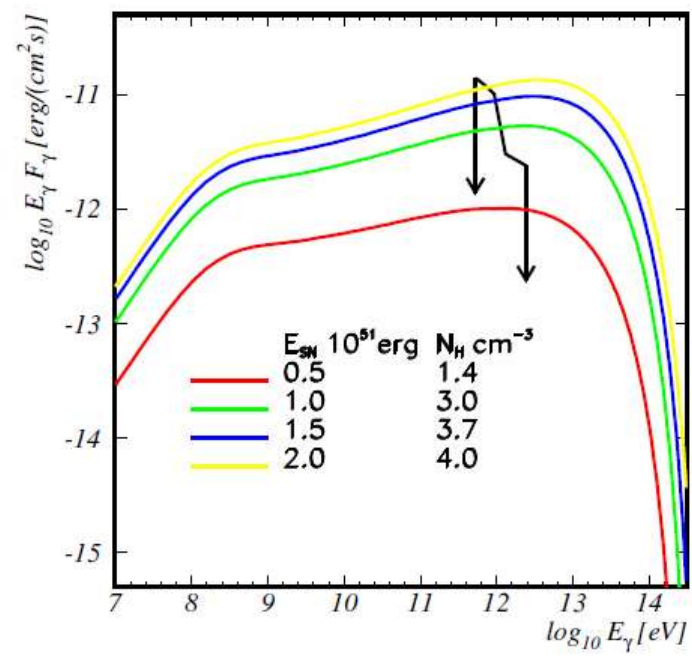
FIG. 4.— Spectral energy distributions. The black curve with arrows at both ends are the upper limits obtained by this observation. The colored curves are the theoretical predictions, which are as same as Fig. 3 of Berezhko et al (2006).

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H.E.S.S. unID: J1804-216

□ May-July 2006, 3-fold, ~75 h, wobble
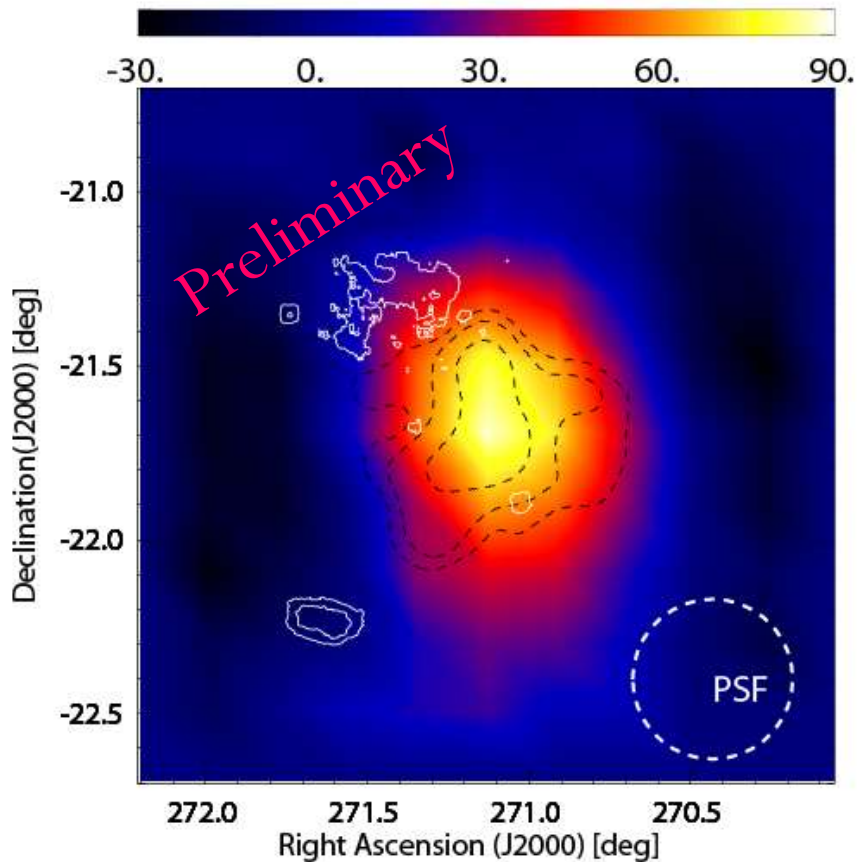
Black contour : HESS
White contour : ROSAT
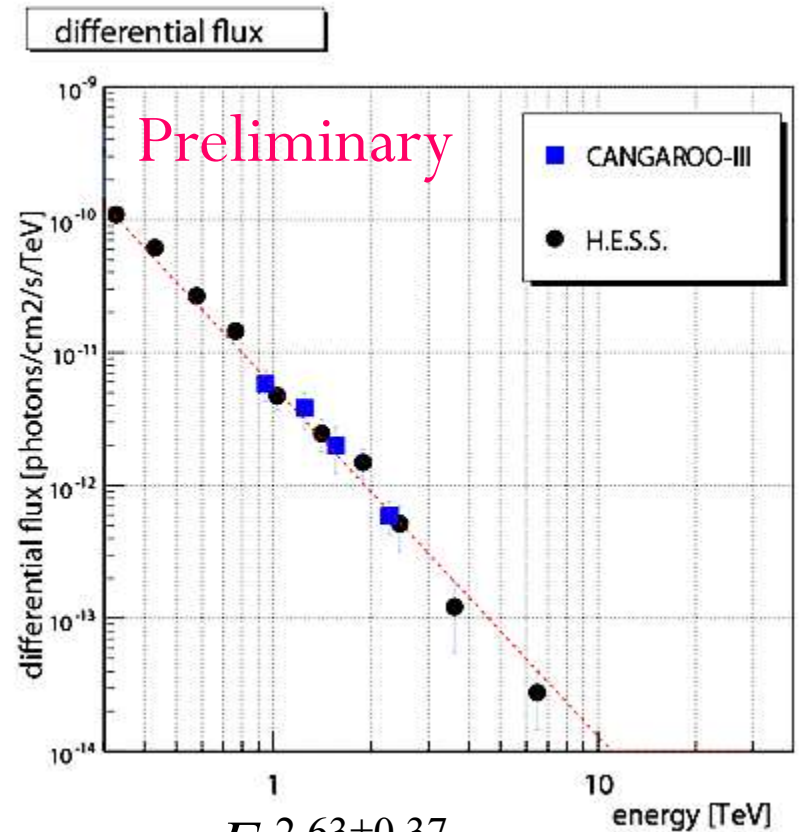
$$\propto E^{-2.63\pm0.37}$$

(Cf. H.E.S.S. $E^{-2.72\pm0.06}$)
24% Crab (> 200GeV)

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H.E.S.S. unID: J1303-631

☐ Feb/May 2006, 3-fold, ~34 h, wobble (R.A.)
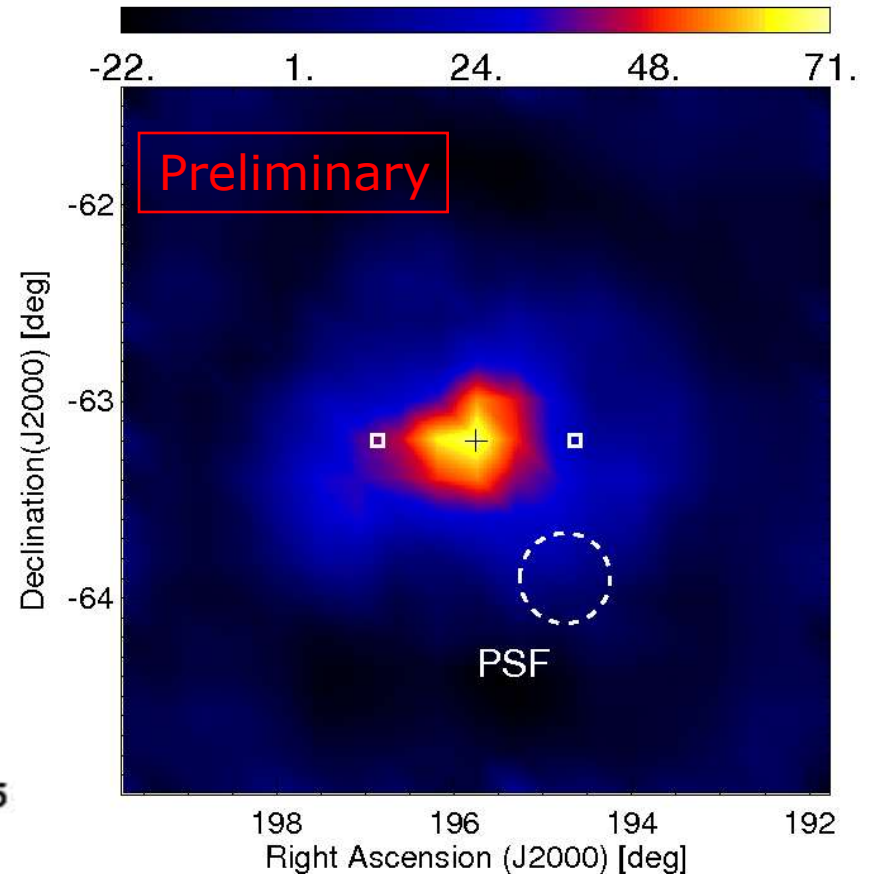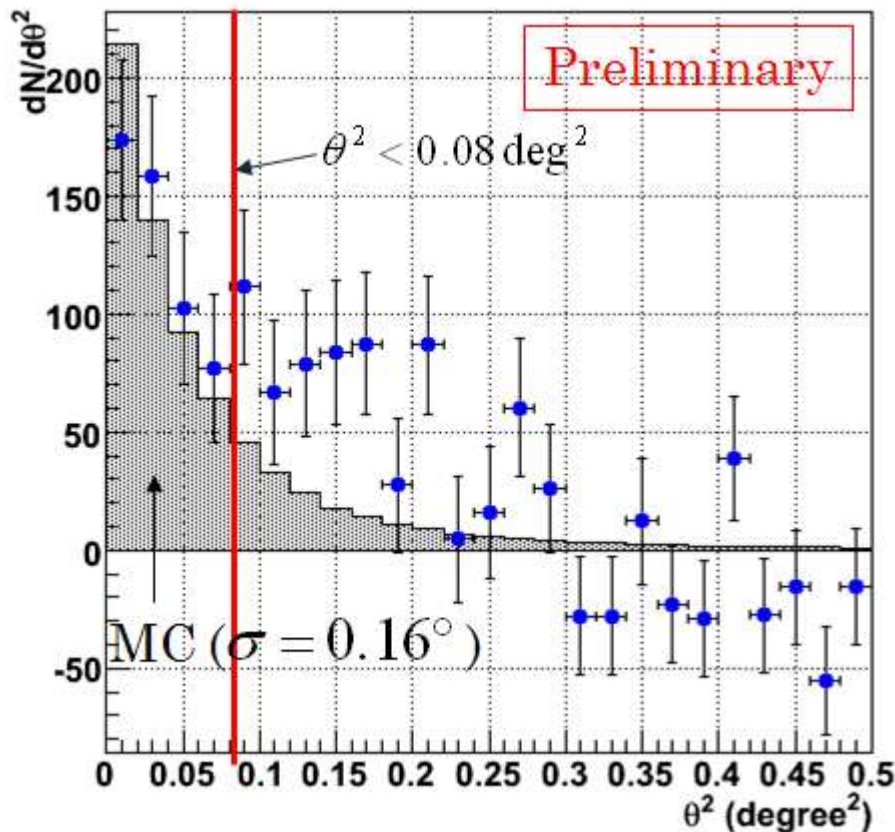
電波銀河Cen Aと球状星団ω Cen

□ 3-fold, 2004 Mar/Apr, 639/601min (ON), 587/429min (OFF)

Significance map
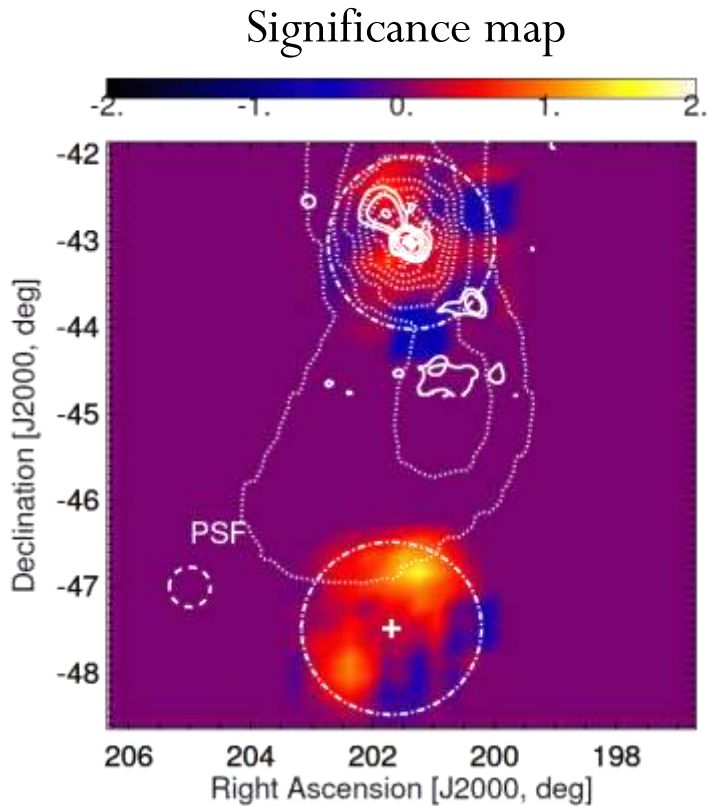
Upper limits of the CDM density
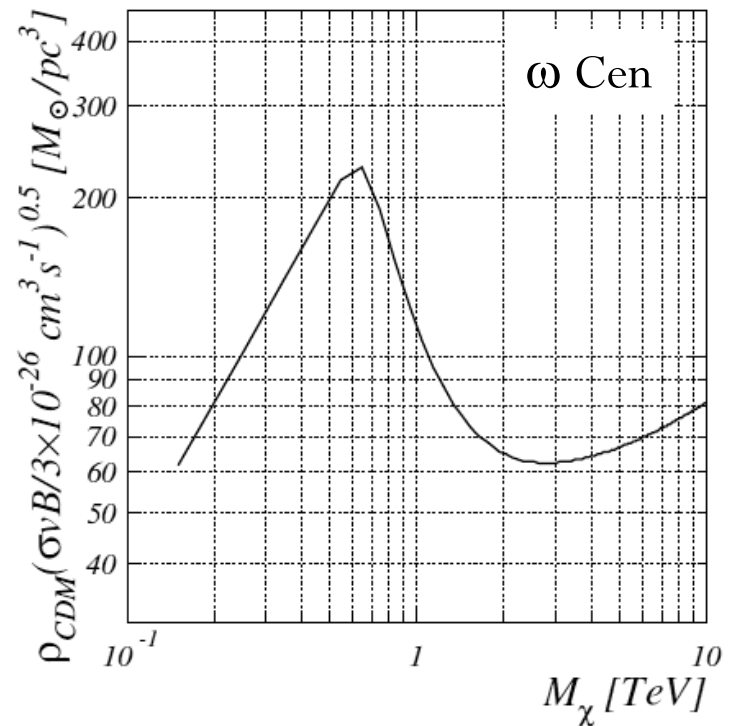
Solid: 4850MHz radio (inner lobes and middle lobe)
Dotted: 408MHz radio (outer lobes)

No significant emission

CDM density $<100 M_\odot pc^{-3}$: less than its gravitational mass!

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超新星1987Aとその周辺

- 3-fold, 2004 Nov: 632min, 2006 Dec: 1316min

Excess count map (2004 data)

Spectral energy distribution
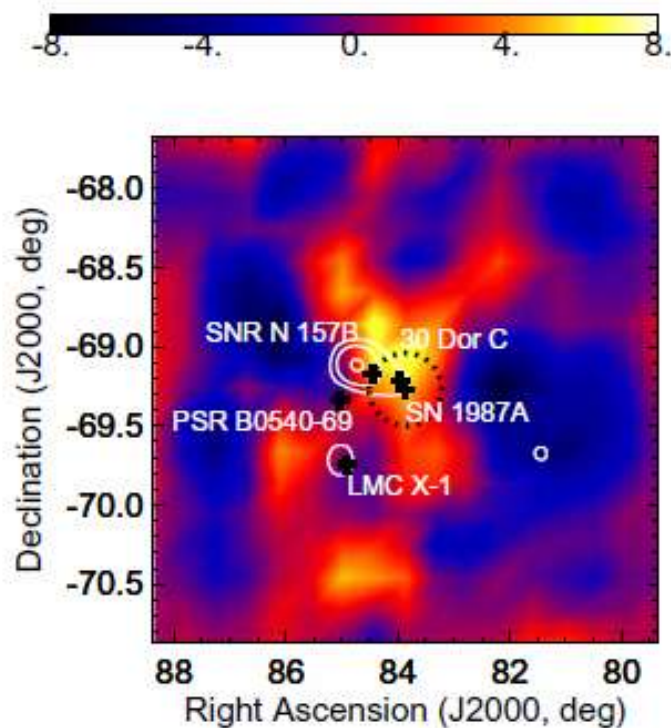
Contour: 4850MHz radio PMN survey data

No significant emission
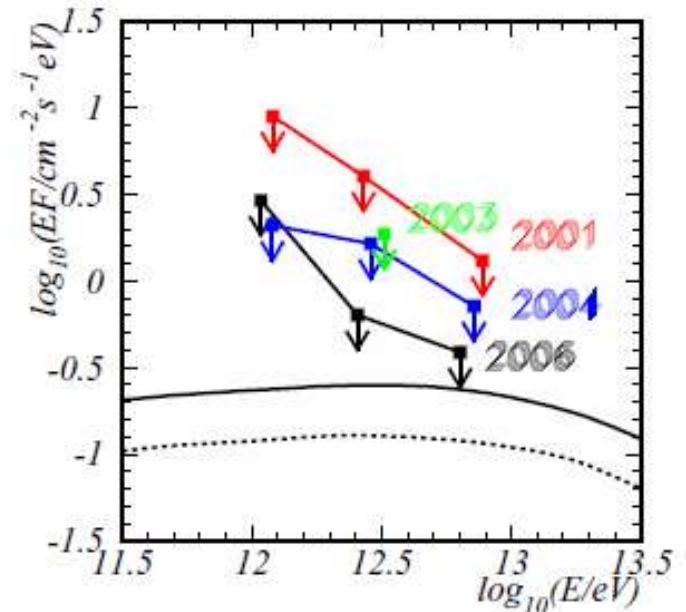
The solid and dashed curves are the predictions of the gamma-ray flux 8249 and 7300 days after the supernova, respectively [Berezhko & Ksenofontov (2006)]

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銀河団A3667とA4038
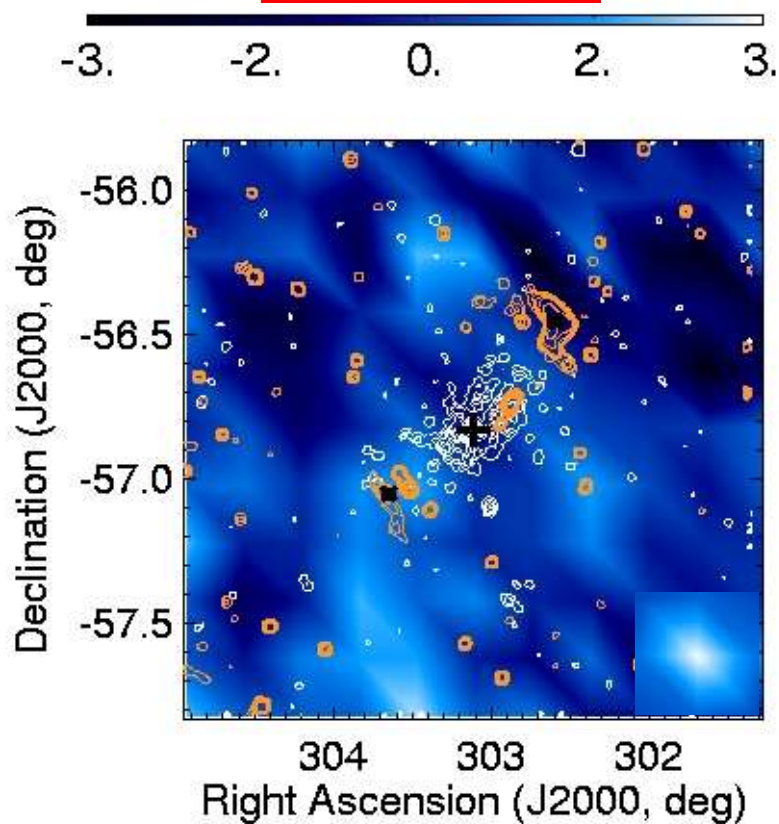
Orange contour : MOSAT (radio)

White contour : ROSAT (X-ray)
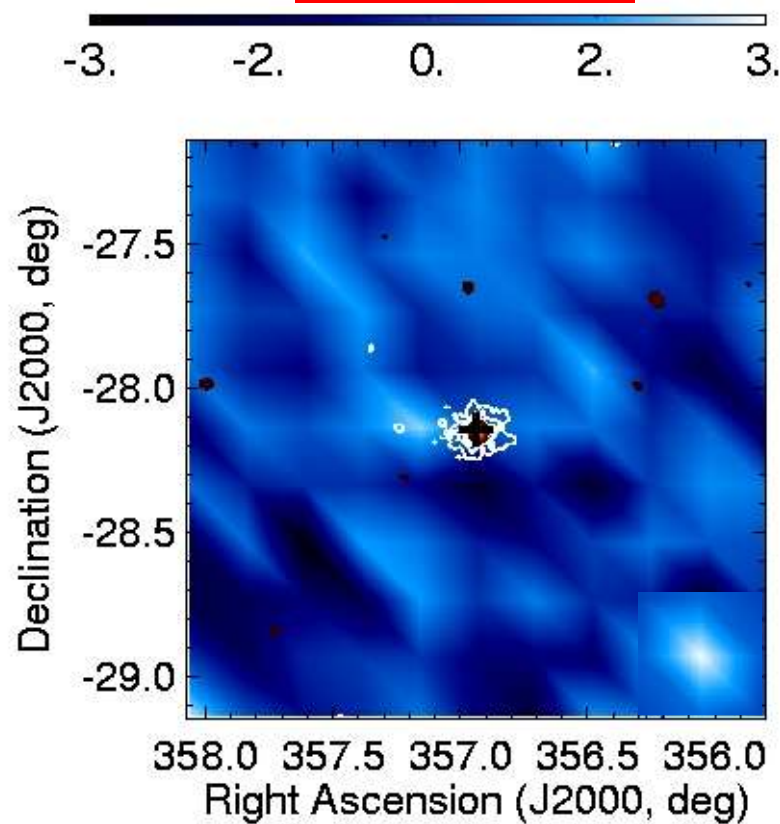
Orange contour : VLA (radio)

White contour : ROSAT

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銀河団: モデルと上限値

Abell 3667, NW radio region
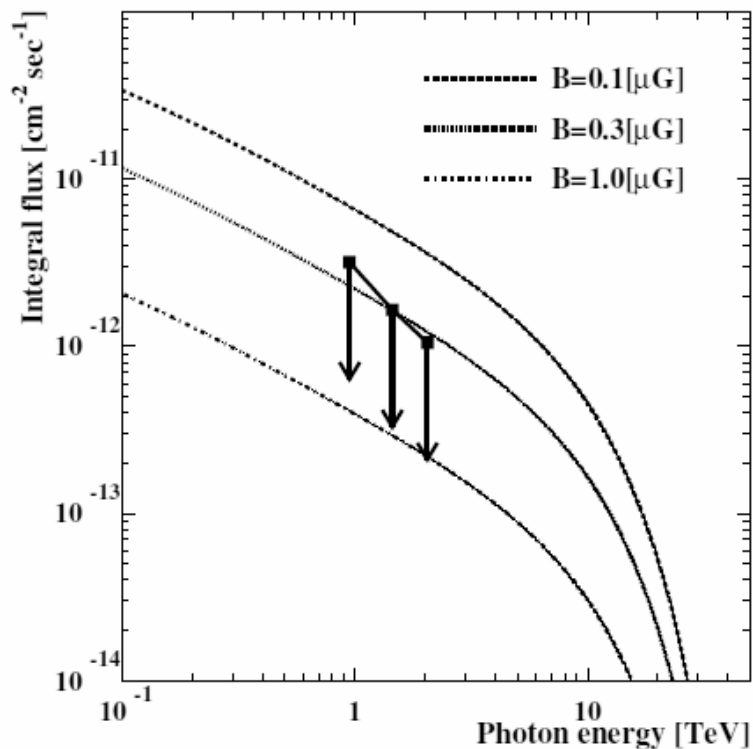
Model: Inoue et al. (2005)

[pγ process]

Abell 4038, central region
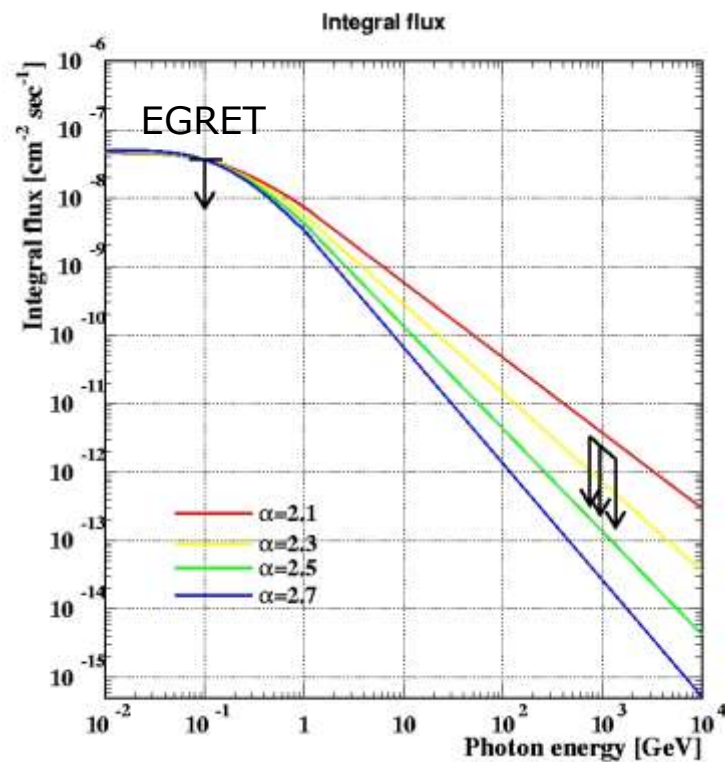
Model: Pfrommer and Ensslin (2004)

[pp process]

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活動状況

- シフト（新月前後1週間ずつ、3名）
  - ICRR　11回、京都大　5回、東海大　9回、茨城大　5回、山形大　2回、Adelaide大　1回
- 他の予算
  - 科研費　基盤Aほか、JSPS日豪、ICRR校費
- 修士論文
  - 京都大　1件、東海大　1件
- 博士論文
  - 2007年春　0件

平成19年度ICRR共同利用

研究代表者	校費（千円）	旅費（千円）
森（ICRR）	500	1,720
榎本（ICRR）	3,000	400
谷森（京都大）	200	500
西嶋（東海大）	200	800
内藤（山梨学院大）	100	200
河内（東海大）	200	300
櫛田（東海大）	0	500
大石（ICRR）	60	250
計	4,260	4,670

旅費
　海外：3,000
　　（オーストラリア）
　国内：1,670
　　（2回のグループ
　　ミーティング）
校費
　測定器、PC周辺
　機器、望遠鏡保
　守、PMTなど

研究会経費　250千円：吉田（茨城大）、開催予定

Summary

- 望遠鏡3台によるステレオ観測を継続的に行っている。（1号機は視野が狭く老朽化のため休止中：鏡・カメラ・回路の更新が必要）

- パルサー星雲MSH15-52、超新星残骸RX J1713.7-3946、活動銀河PKS2155-304からのガンマ線の検出に成功。HESS unID J1804-216/J1303-631からの10%Crabレベルの観測も実現。

- 活動銀河Cen A・球状星団ωCen、超新星残骸SN1987A、Keplerの超新星残骸、銀河団A3667・A4038からのガンマ線放射には上限値を与えた。

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 pulsar	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., 652, 1268–1276 (2006)

[4] "Erratum: Detection of diffuse TeV gamma-ray emission from the nearby starburst galaxy NGC 253"

Itoh, C. et al., Astron. Astrophys., 462, 67–71 (2007)

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イメージモーメント
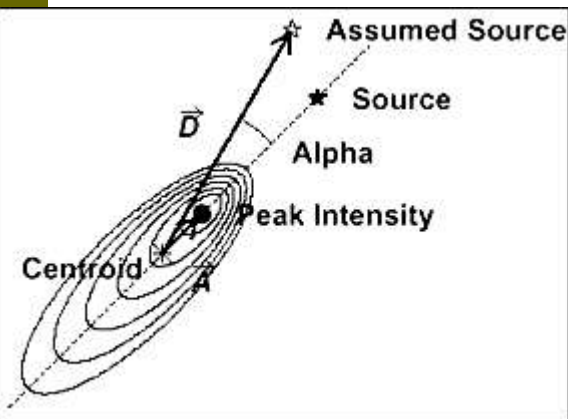
Distribution of imaging parameters (Simulation)

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

櫛田淳子、東工大修士論文、2000

"Image parameters": A.M. Hillas, 1983 ICRC

α (image orientation angle)

"Alpha": A.V.Plyasheshnikov and G.F.Bignami, N.C. 1985

イメージパラメータによるγ/h識別

- Whipple
  - "Supercut" (square cut) [Punch et al., Nature, 1992]
- CANGAROO-II
  - Likelihood [Enomoto et al. ICRC, 5, 2477, 2001]
- CANGAROO-III
  - Fisher discriminant [Enomoto et al. ApJ 638, 397, 2006]
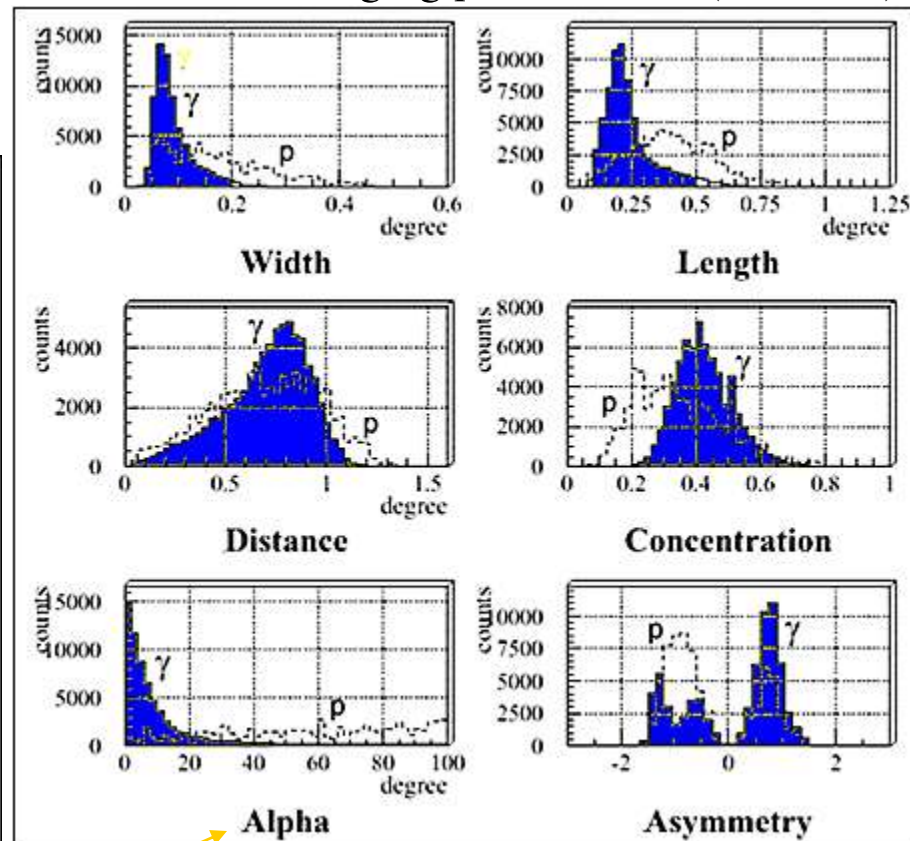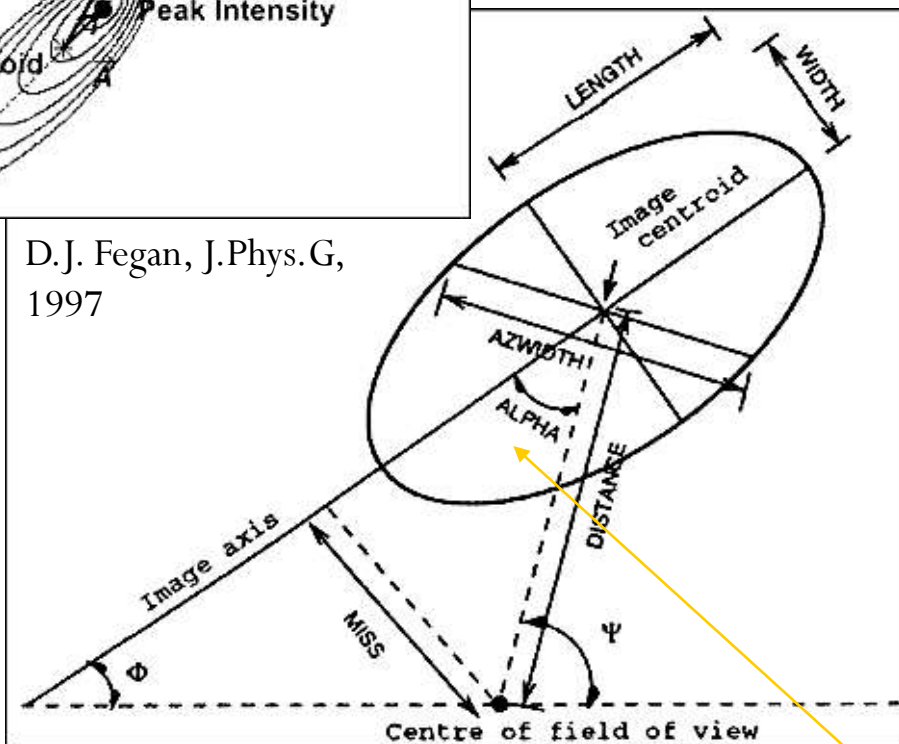- H.E.S.S.
  - Mean scaled width/length [M. de Naurois, Proc. Conf. Towards a Network of Atmospheric Cherenkov Detectors VII, Palaiseau, France, 2005, p. 163-172]
  - Model / 3D model [M. de Naurois / M. Lemoine-Goumard, ibid., p. 149-162]
- MAGIC
  - Random forest [Mase, Ph.D. thesis, 2006 / J. Albert et al., arXiv:0705.3244]
- VERITAS
  - Mean scaled width/length [M. K. Daniel et al., 30th ICRC, 2007]
  - Multi-parameter likelihood [Krawczynski et al., Astropart. Phys. 25, 380, 2006]

Fisher discriminant

- Linear combination of image parameters (x_i)

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

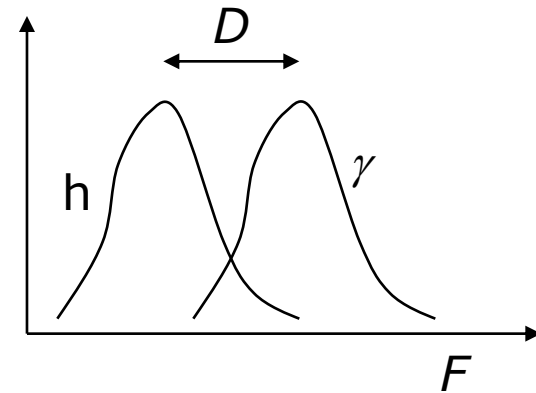- Difference between signal (γ) and background (h)

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

- 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).

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Data handling and analysis

- Data are stored on local HDD and copied to mobile HDD, then carried to Japan monthly (~70GB/month).
    - On-site storage: 750GB
    - Online-analysis system is still underway…
    - Woomera site – only dial-up connection is available (64 kbps)
    - Recently 512 kbps ADSL line is connected to observer's flat (at last).
- Data are archived on ICRR storage (79TB HDD+225TB tape) and accessed by each institution.
- Analysis (and MC simulation) is carried out by mainly ICRR computer farm (700 CPUs).
- ICRR computer system will be upgraded in January 2008 (1 PB, 1000 CPUs).

【既報】

爆発的星形成銀河NGC253
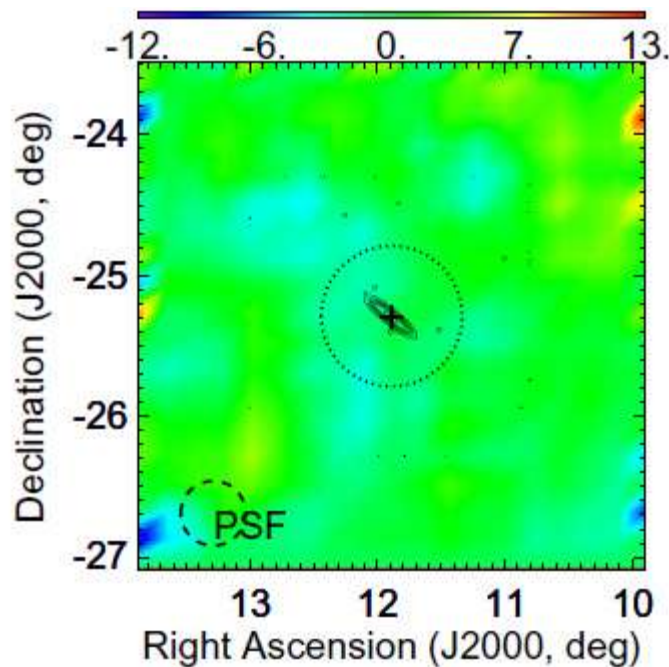
- 3-fold, 2004 Oct, 1179min (ON), 753min (OFF)

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).
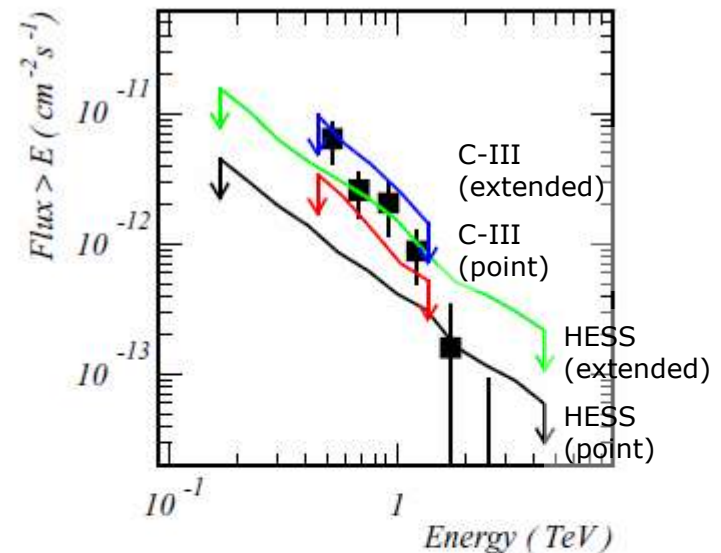

Fig. 4. Integral fluxes. The points with error bars are the CANGAROO-II's ones (see text for the detail). The black curve is 99% upper limit (UL) by H.E.S.S. for point source assumption. The green is that for 0.5 degree diffuse source. The red is 2σ UL for this observation for point source assumption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

No significant emission

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