

CANGAROO実験

森 正樹 for the CANGAROO-III team



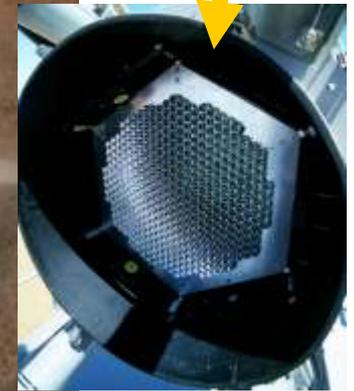
日豪共同による解像型大気チェレンコフ望遠鏡アレイによる超高エネルギーガンマ線天体の観測。【COEプログラムは平成15年度で終了。平成16年度からは宇宙線研究所共同利用・科研費基盤(A)などで観測・維持を行っている。】

CANGAROO Team

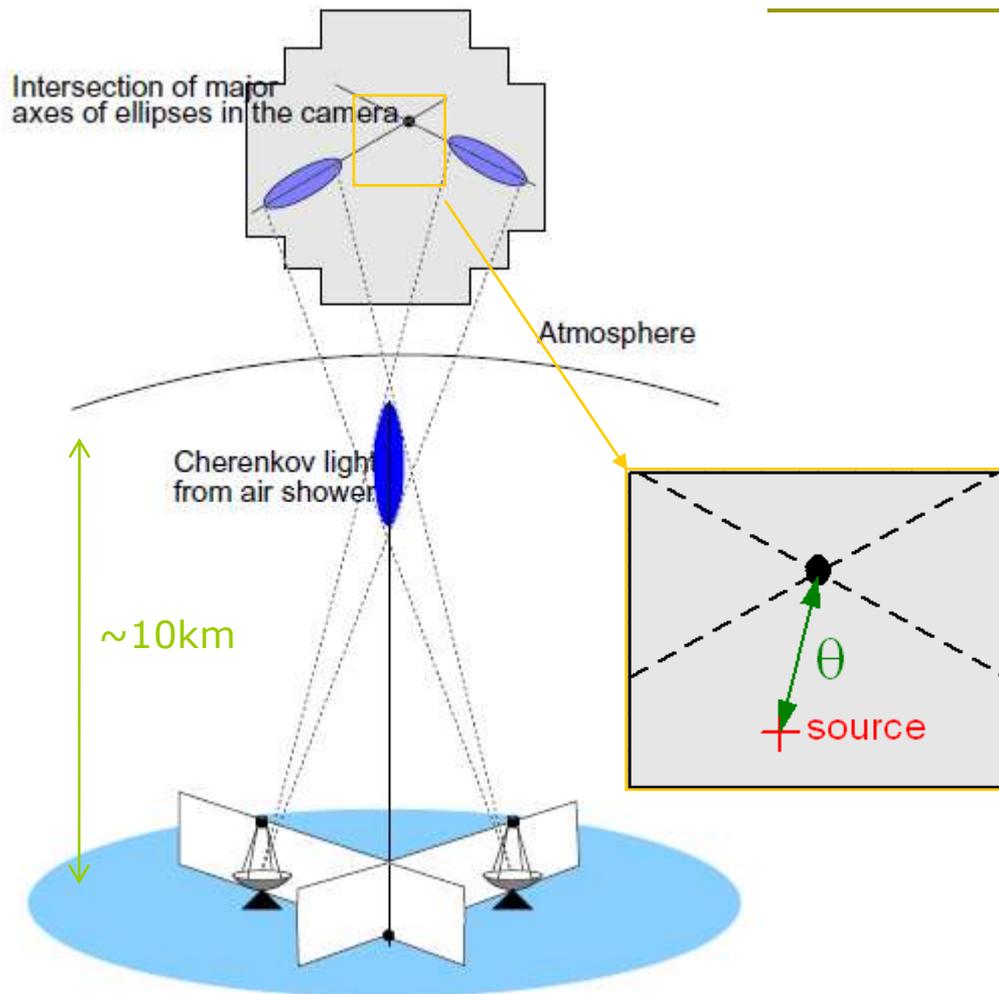
- University of Adelaide 
- Australian National University 
- Ibaraki University 
- Ibaraki Prefectural University 
- Konan University 
- Kyoto University 
- STE Lab, Nagoya University 
- National Astronomical Observatory of Japan 
- Kitasato University 
- Australia Telescope National Facility 
- Tokai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

望遠鏡の基本仕様

- Location:
 - $31^{\circ}06'S$, $136^{\circ}47'E$
 - 160m a.s.l.
- Telescope:
 - $114 \times 80\text{cm}\phi$ FRP mirrors (57m², Al surface)
 - 8m focal length
 - Alt-azimuth mount
- Camera:
 - T1: 552ch (2.7° FOV)
 - T2, T3, T4: 427ch (4° FOV)
- Electronics:
 - TDC+ADC



チェレンコフ光のステレオ観測



© S.Funk, 2005

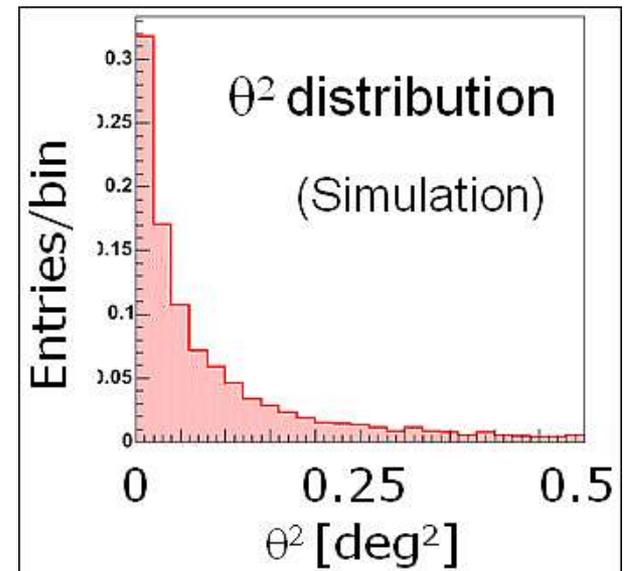
Angular resolution

$0.25\text{deg} \rightarrow 0.1\text{ deg}$

Energy resolution

$30\% \rightarrow 15\%$

Better S/N (no local muons)



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
- 宇宙線ミュオンデータの取得(利得較正)

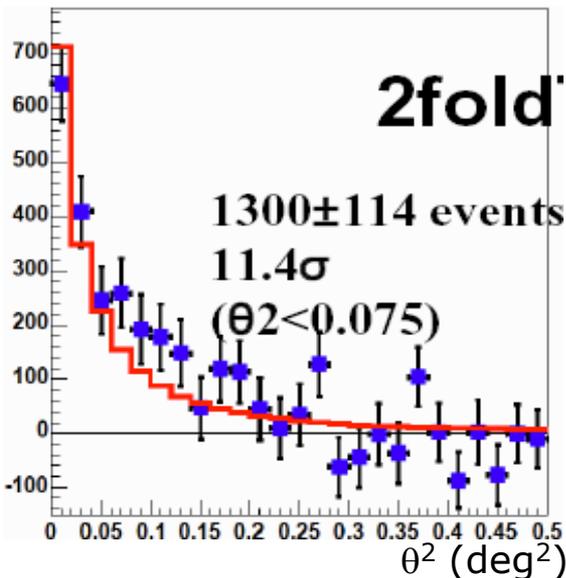
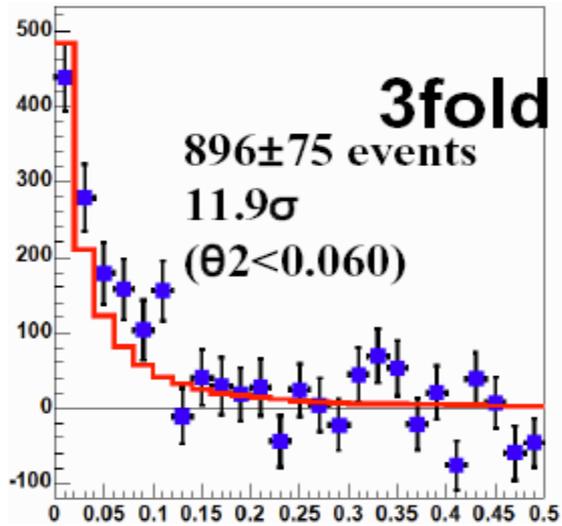


観測天体

*Performance run含む

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 ($>55\text{deg}$)
- 40hr (wobble)

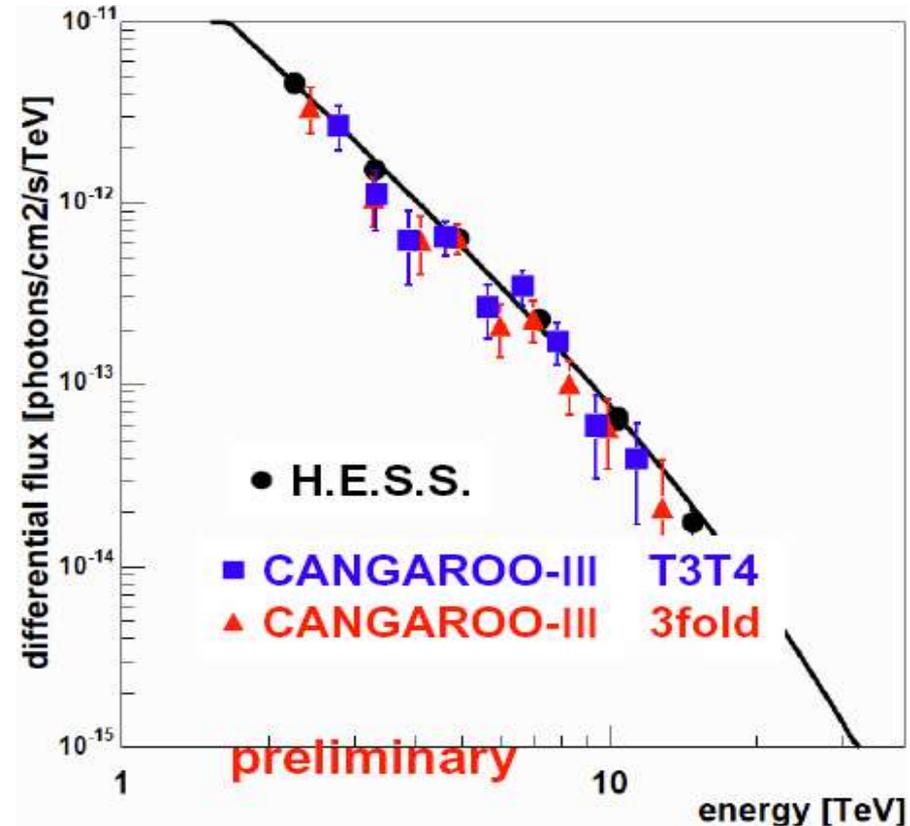
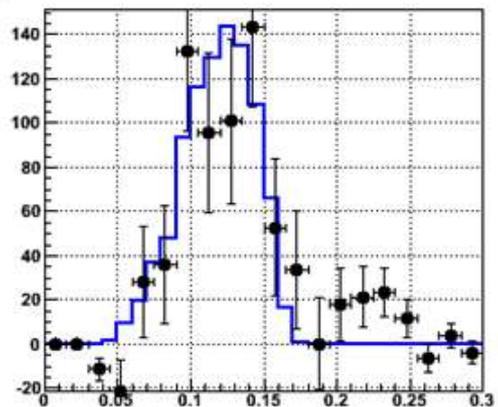


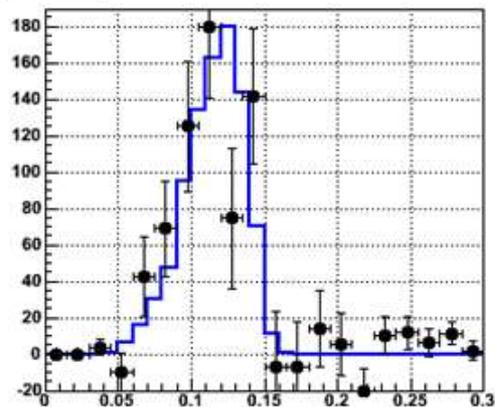
Image moments: data vs MC

Width

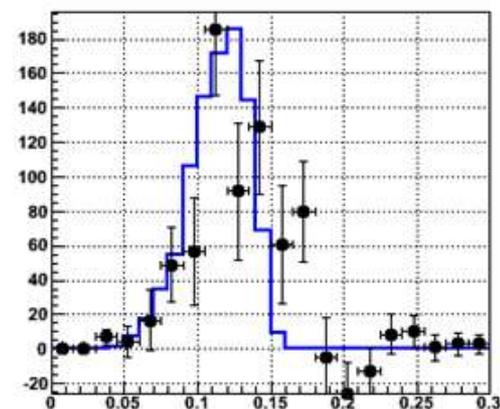
T2 width



T3 width

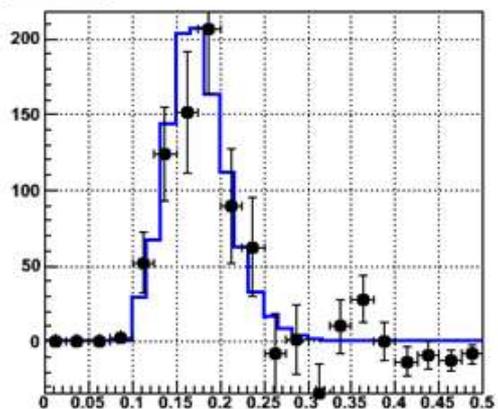


T4 width

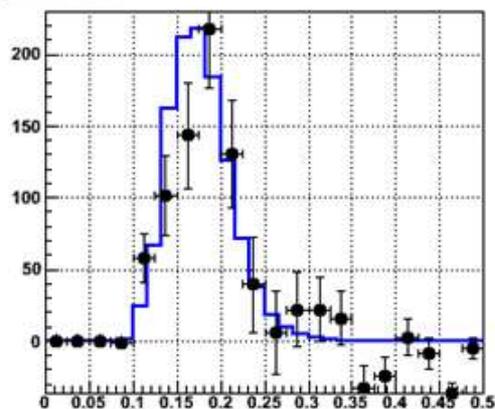


Length

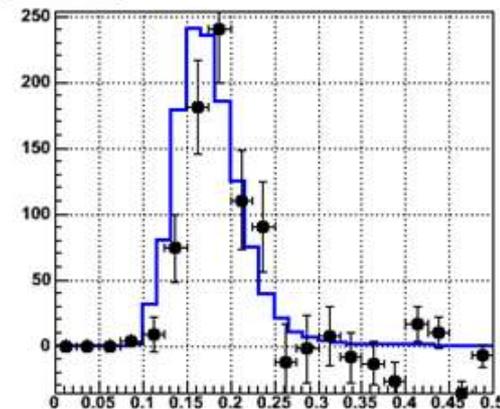
T2 length



T3 length



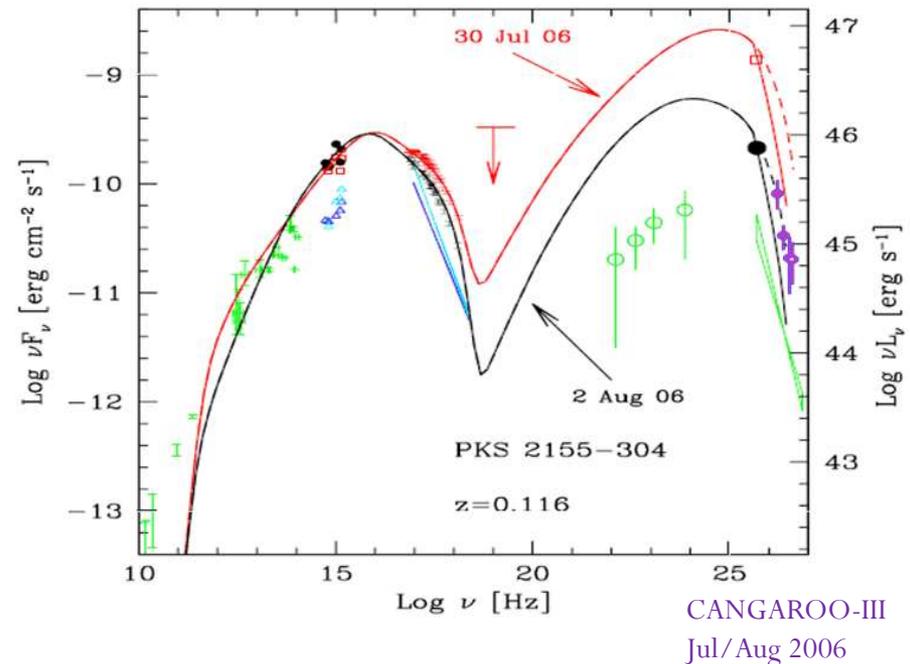
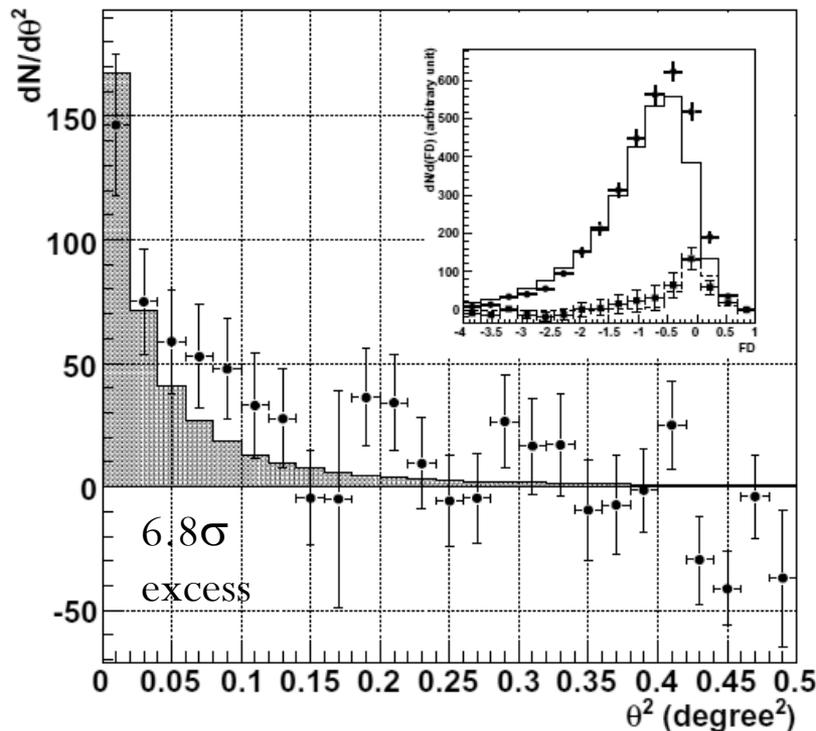
T4 length



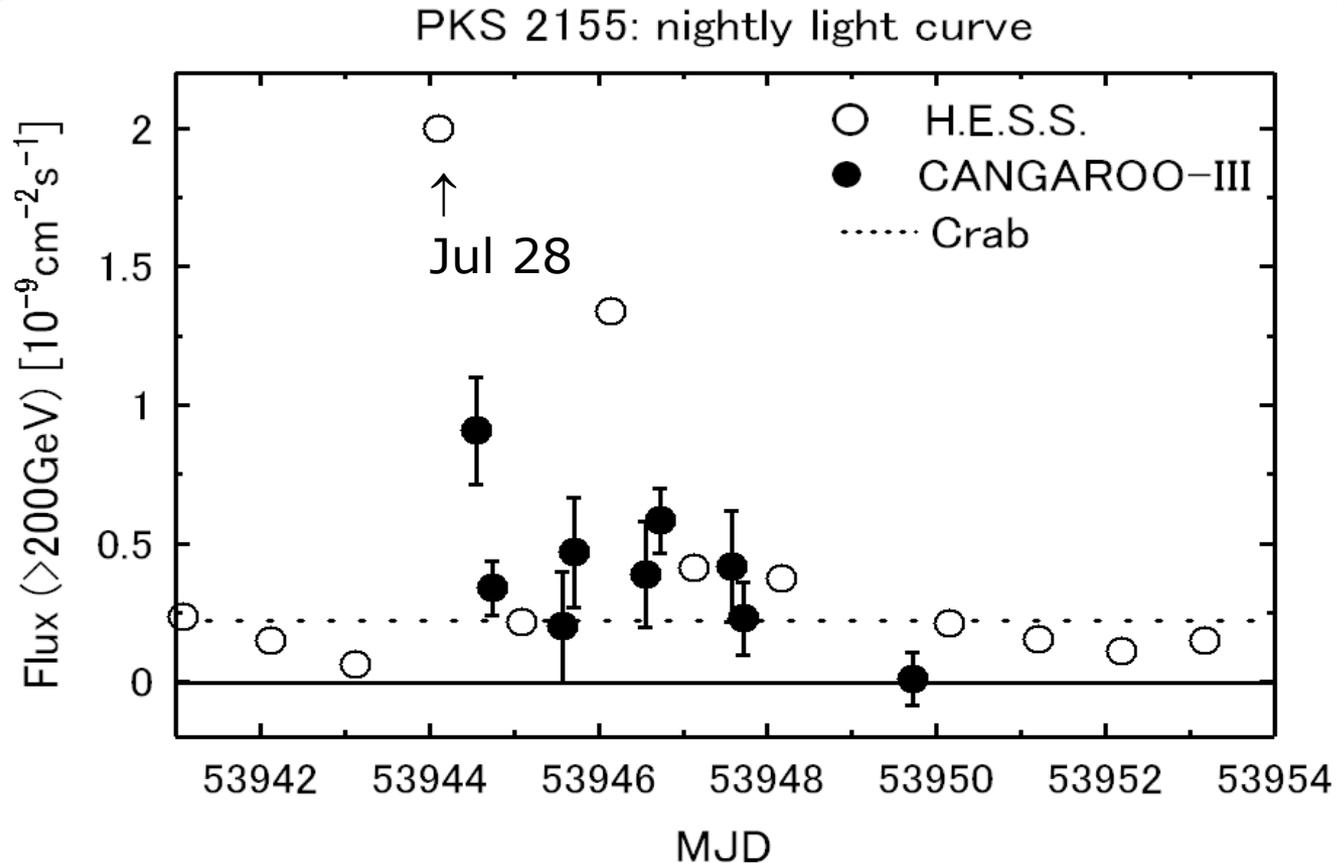
Data (γ -like, Crab): points, [histogram](#): γ MC

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)



PKS2155-304: 日変化



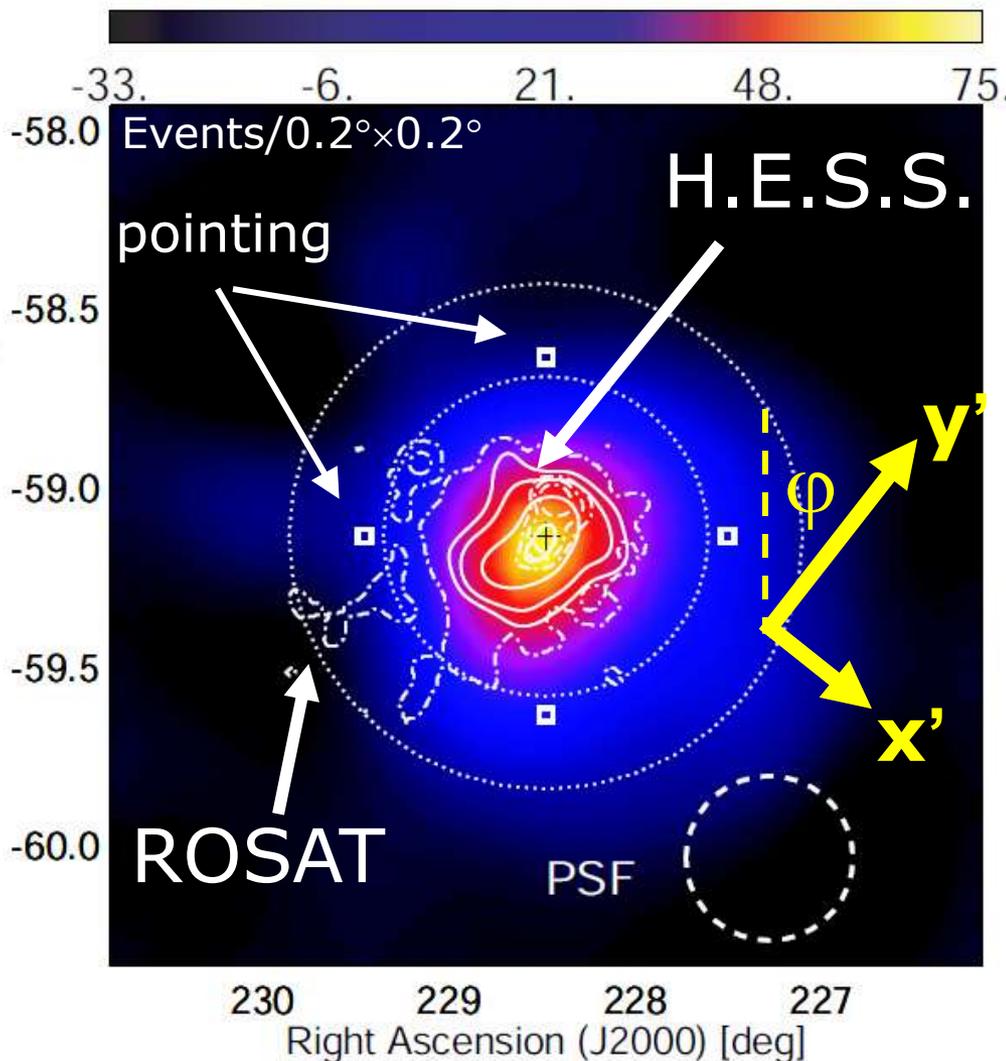
$$\phi(\text{CANGAROO}) - \phi(\text{H.E.S.S.}) = 120^\circ = 8\text{hr}$$

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

10

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

パルサー星雲MSH15-52



MSH15-52 / RCW89

PSR 1509-58 ($\dot{E}=2\times 10^{37}$ erg/s)

Pulsar wind nebula

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

2D Gaussian fit results (before
smoothing)

rotation angle

$$j = 29.8 \pm 1.9 \text{ deg}$$

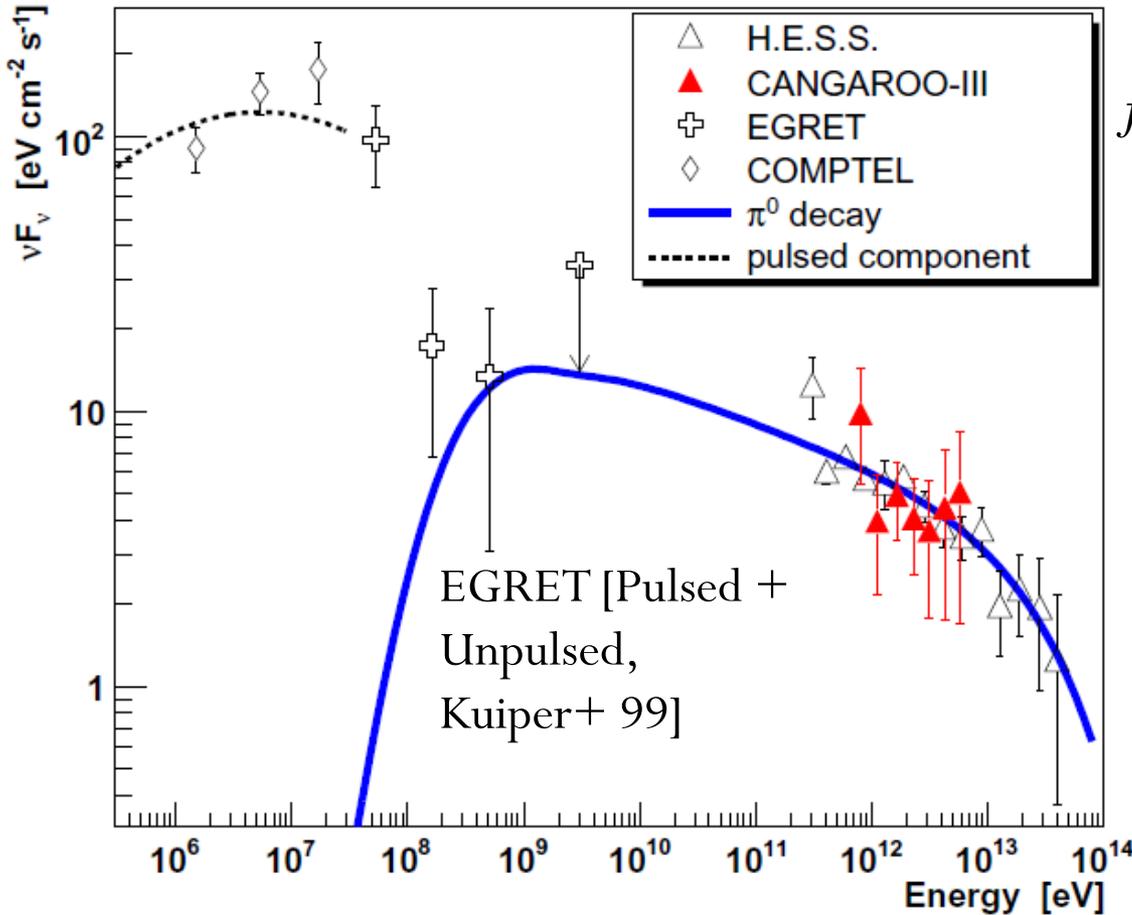
intrinsic standard deviations

$$\sigma_{x'} = 0.07 \pm 0.07 \text{ deg}$$

$$\sigma_{y'} = 0.21 \pm 0.08 \text{ deg}$$

consistent with H.E.S.S.

MSH15-52: 陽子起源モデル



Proton spectrum:

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

Fit with TeV data:

$$\alpha = 2.16 \pm 0.05$$

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

$$E_{\text{tot}} = 3.2 \times 10^{51} \text{ erg}$$

$$\text{@}5.2 \text{ kpc, } 1.0 \text{ H/cc}$$

c.f.

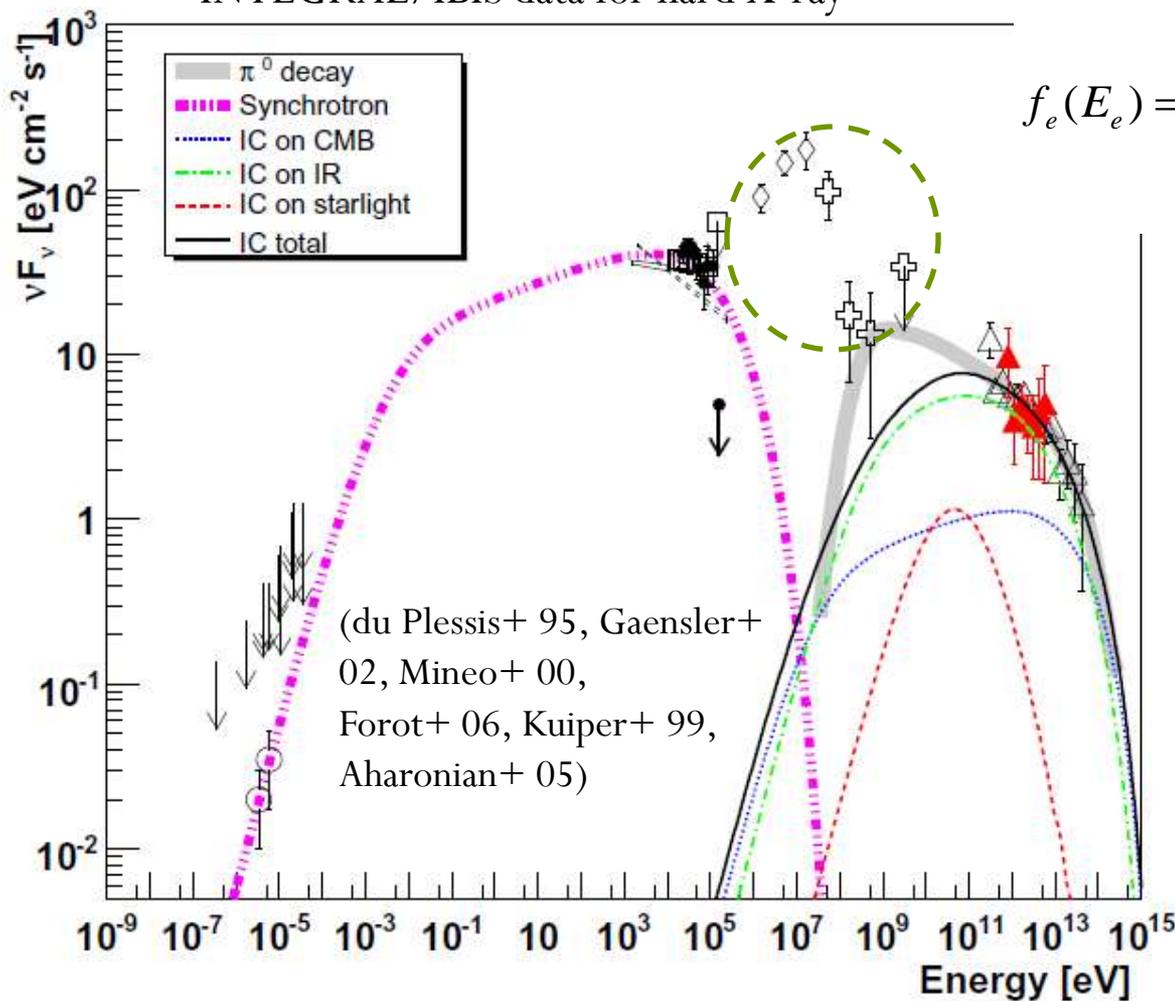
$$\int_0^\tau \dot{E}_{\text{rot}} dt \sim 10^{48} \text{ erg}$$

MSH15-52: 電子起源モデル

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

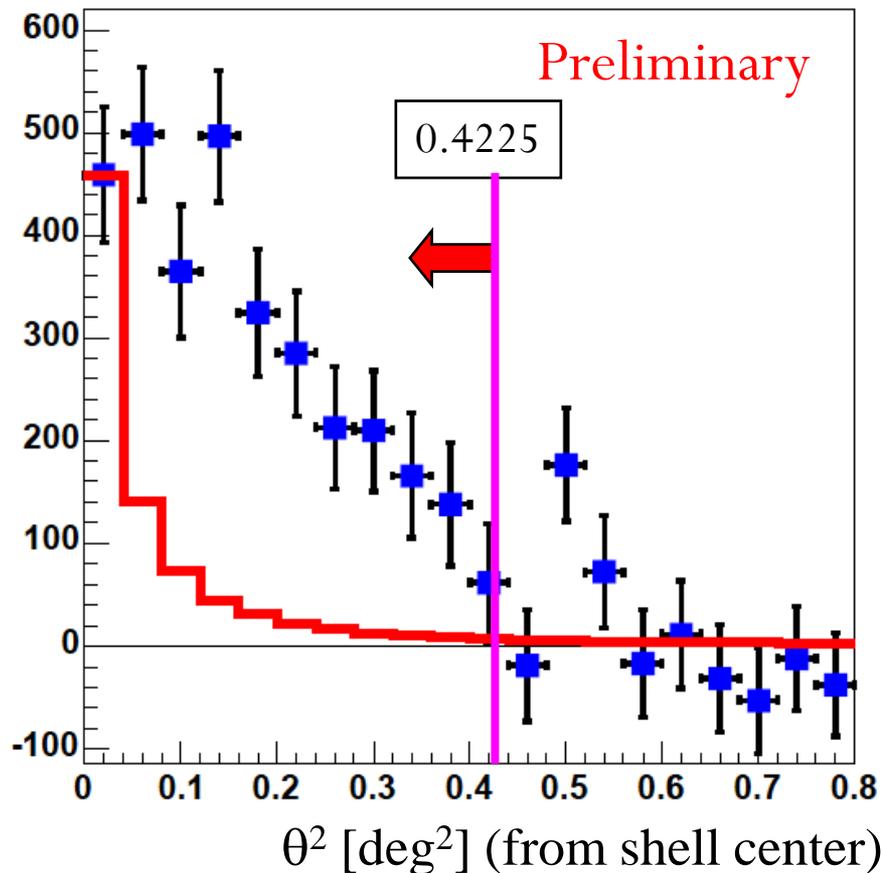
Electron spectrum:

$$f_e(E_e) = f_0 \frac{V}{4\pi d^2} \frac{\left(\frac{E_e}{E_{br}}\right)^{-\gamma_1}}{1 + \left(\frac{E_e}{E_{br}}\right)^{\gamma_2 - \gamma_1}} \exp\left(-\frac{E_e}{E_{max}}\right)$$



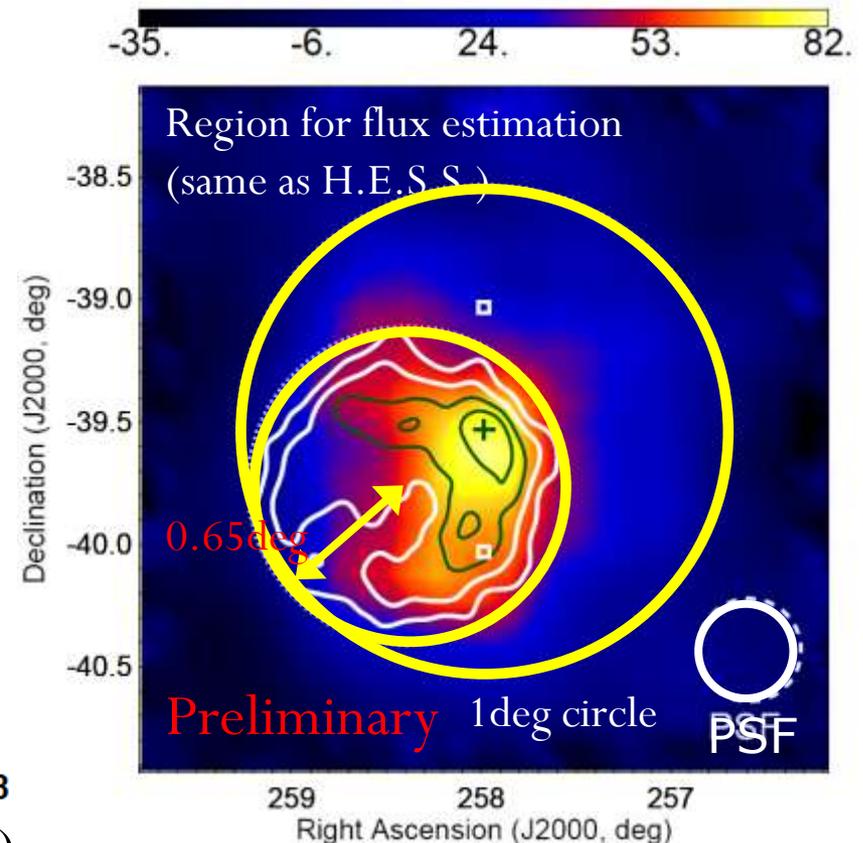
- *Broken power law*
- “Eye-fit”
- $B=17\mu\text{G}$ (Aharonian+ ‘05)
- Starlight 1.4 eV cm^{-3}
- IR necessary (parameter)
- $E_{tot}=7\times 10^{48} \text{ erg}$
- E_{br} does not match the characteristic age (if $t = 1700\text{yr}$, sync. break @ 0.2keV)

SNR RX J1713.7-3946



3154 \pm 194 events

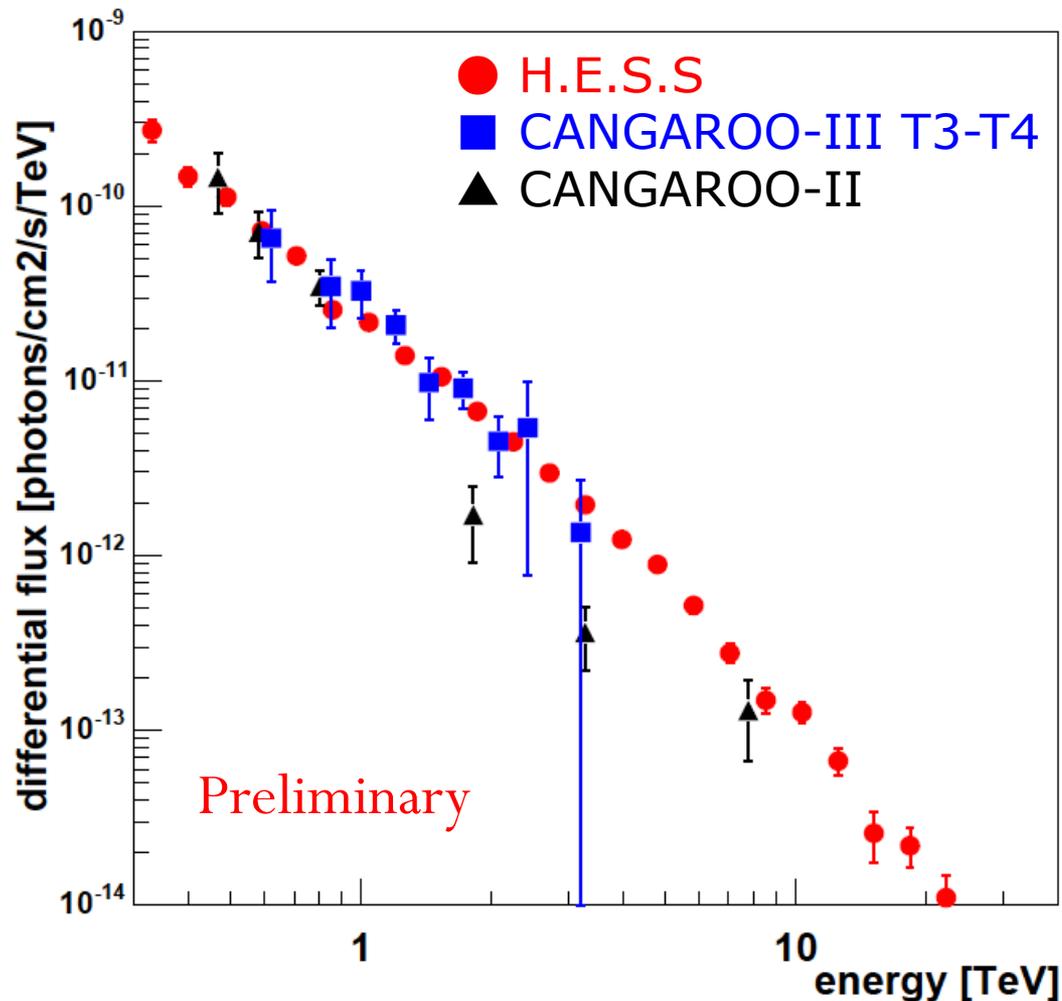
16.1 σ (excess region $\theta < 0.65$)



Contour : H.E.S.S.

- $> \sim 1$ TeV
- Extended compared to PSF

SNR RX J1713.7-3946: spectrum



$$\propto E^{-2.26 \pm 0.3}$$

Consistent with H.E.S.S.

Kepler's SNR (G4.5+6.8)

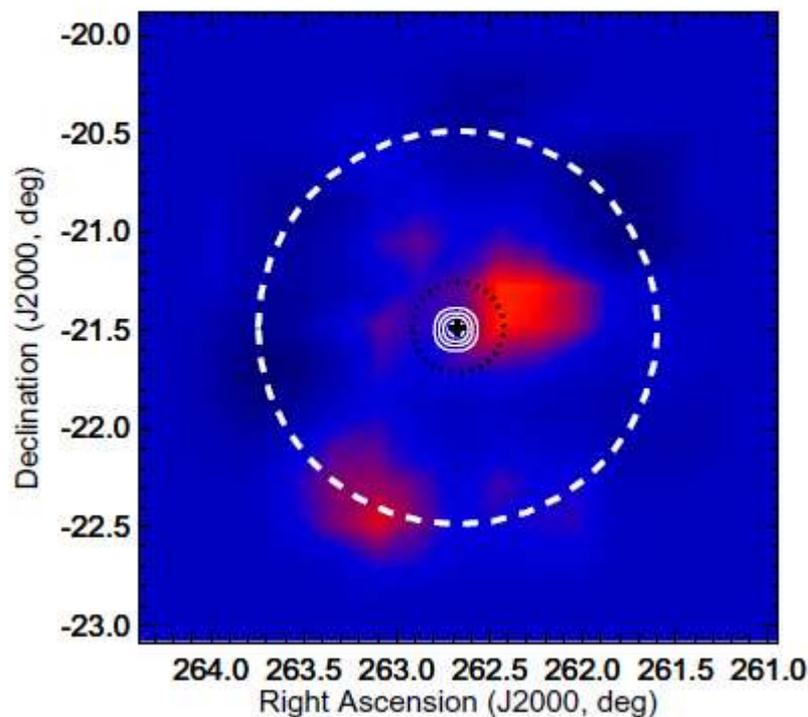


FIG. 3.— Significance map. The dotted-black circle is the point-spread function. The dashed-white circle is the fiducial region (1° radius). The thin-white contour is a radio measurement at 4850MHz(SkyView 2007).

No significant emission

- 2005 April, 874min
- Two-fold (T3-T4)

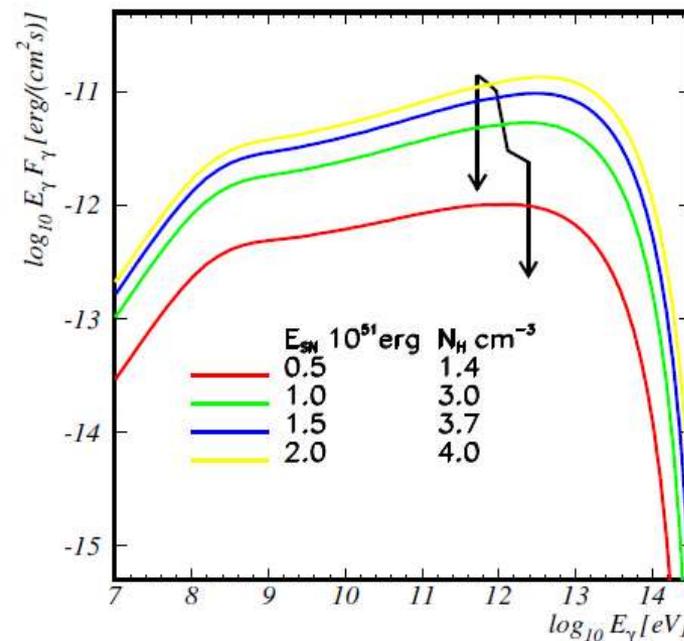
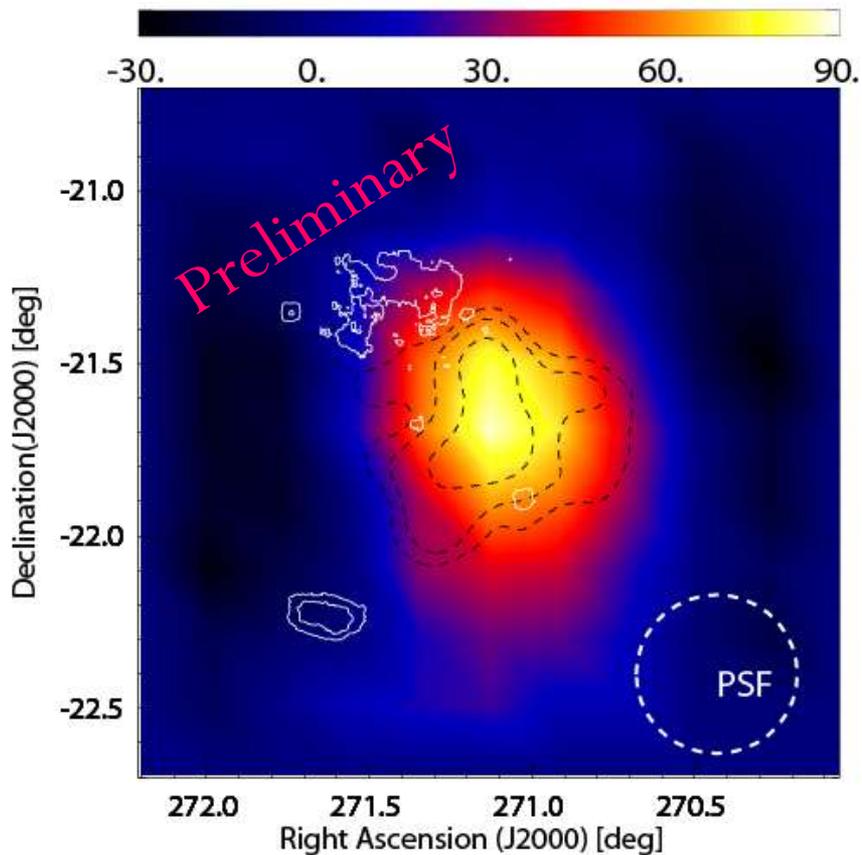


FIG. 4.— Spectral energy distributions. The black curve with arrows at both ends are the upper limits obtained by this observation. The colored curves are the theoretical predictions, which are as same as Fig. 3 of Berezhko et al (2006).

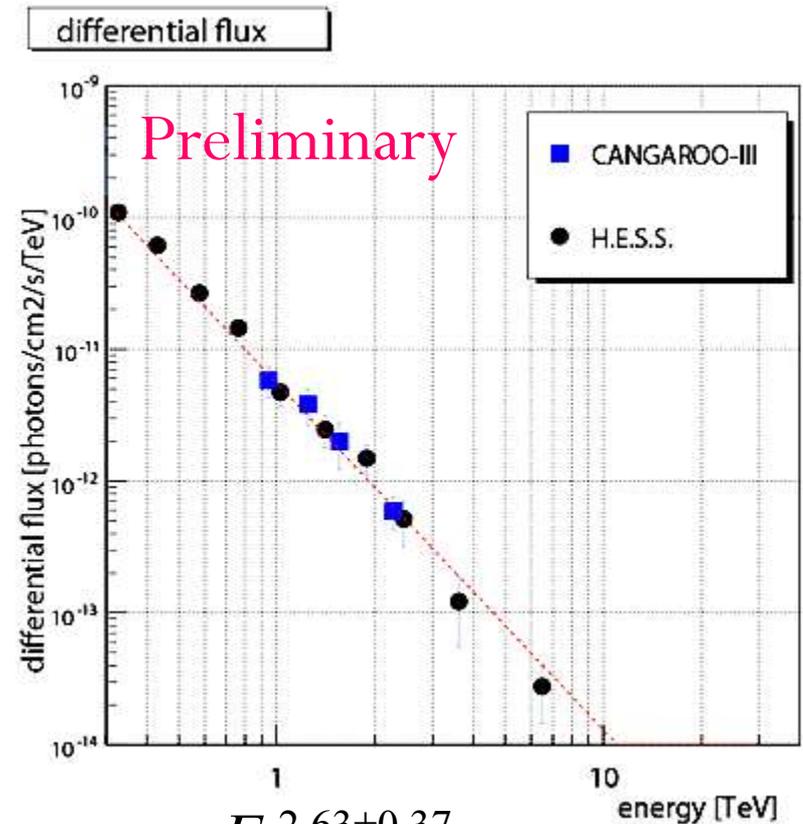
H.E.S.S. unID: J1804-216

- May-July 2006, 3-fold, ~75 h, wobble



Black contour : HESS

White contour : ROSAT

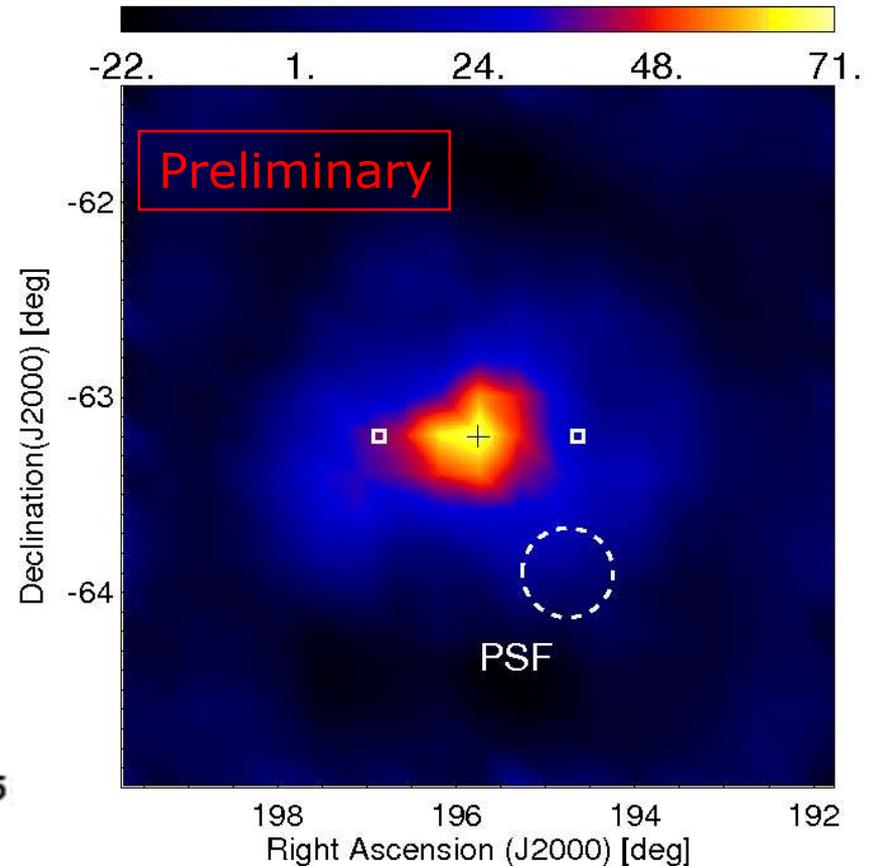
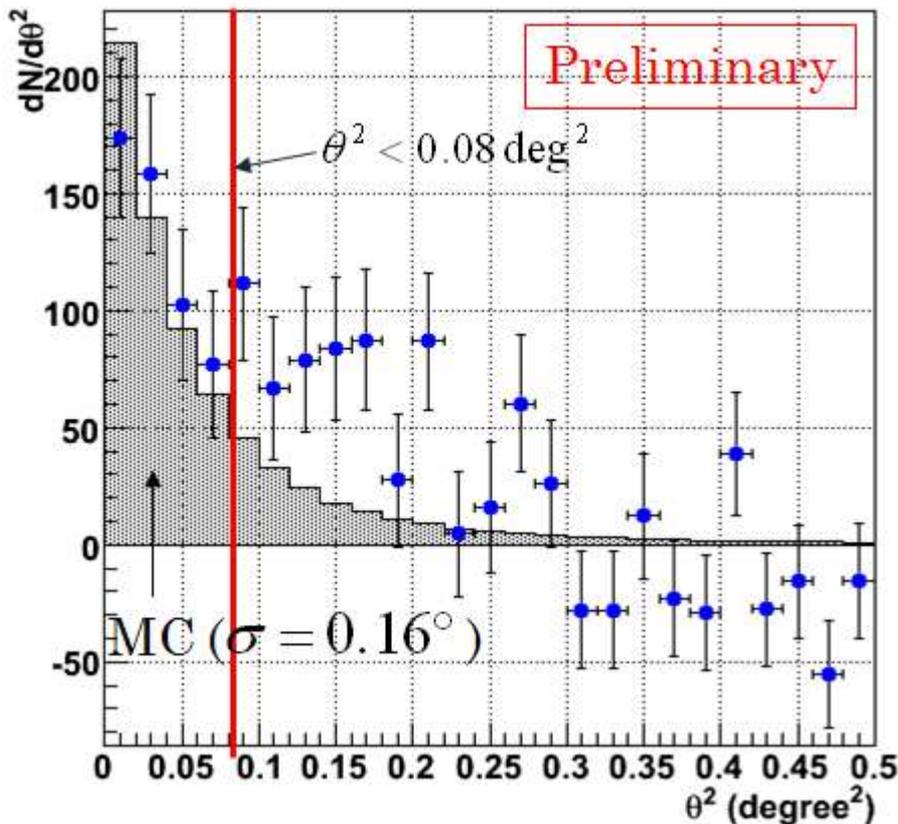


$$\propto E^{-2.63 \pm 0.37}$$

(Cf. H.E.S.S. $E^{-2.72 \pm 0.06}$)
24% Crab ($> 200\text{GeV}$)

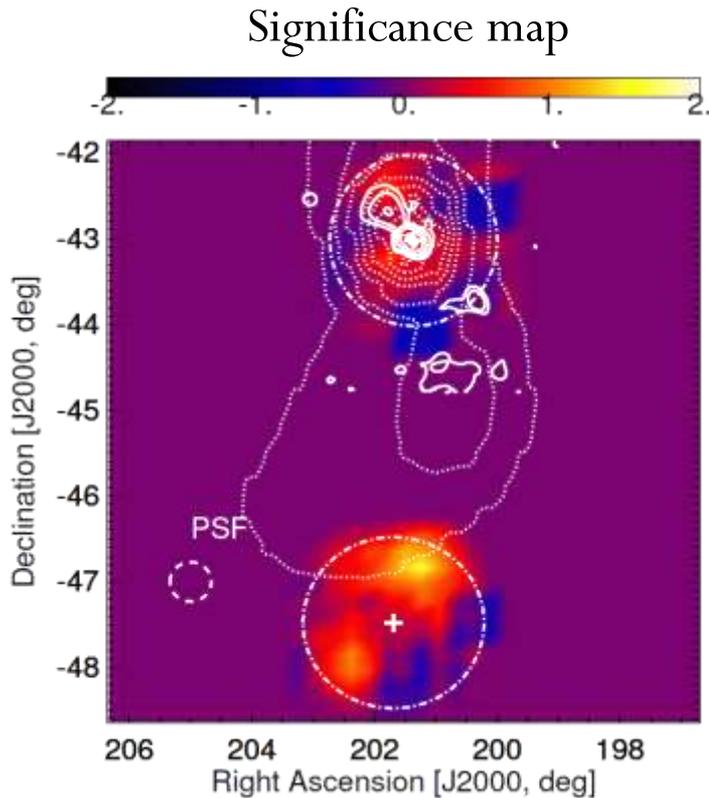
H.E.S.S. unID: J1303-631

- Feb/May 2006, 3-fold, ~ 34 h, wobble (R.A.)

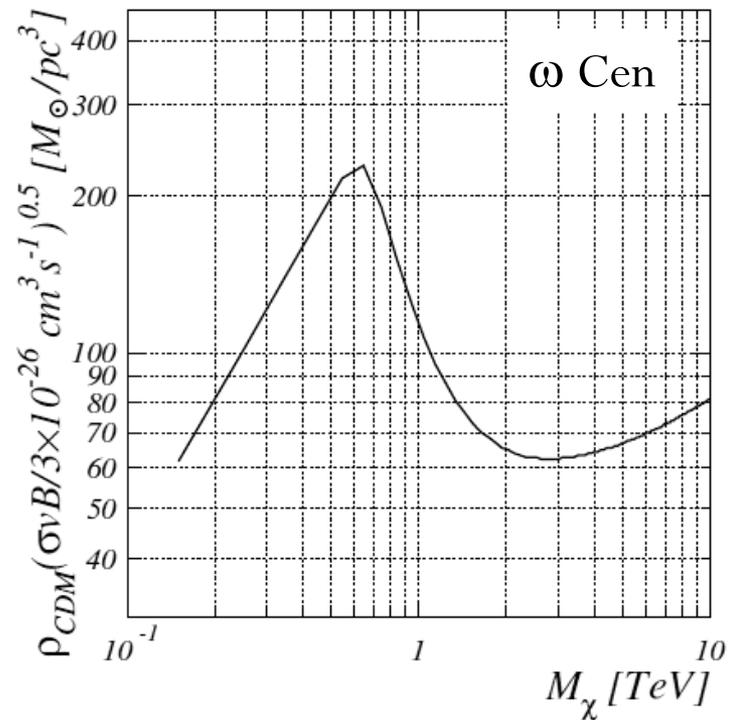


電波銀河 Cen A と球状星団 ω Cen

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



Upper limits of the CDM density



Solid: 4850MHz radio (inner lobes and middle lobe)

Dotted: 408MHz radio (outer lobes)

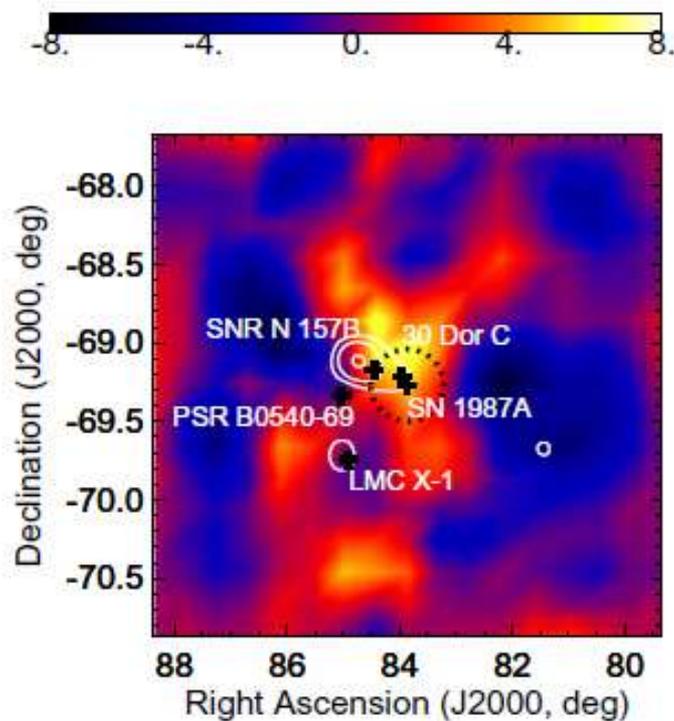
No significant emission

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

超新星1987Aとその周辺

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

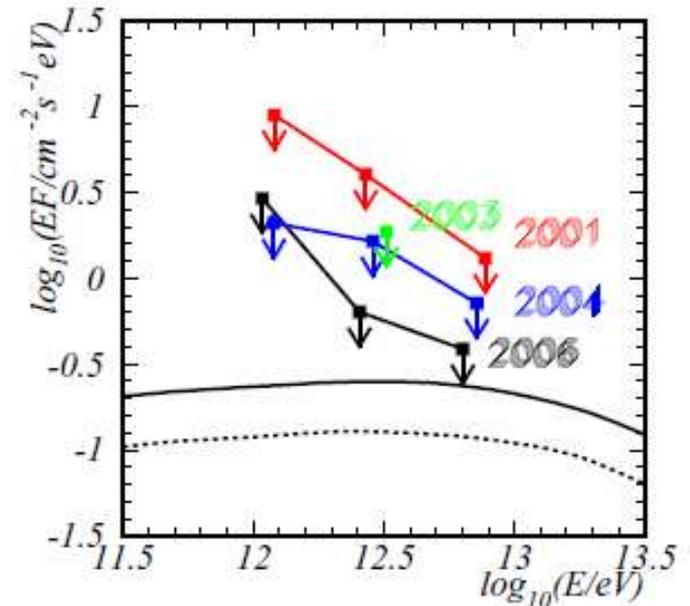
Excess count map (2004 data)



Contour: 4850MHz radio PMN survey data

No significant emission

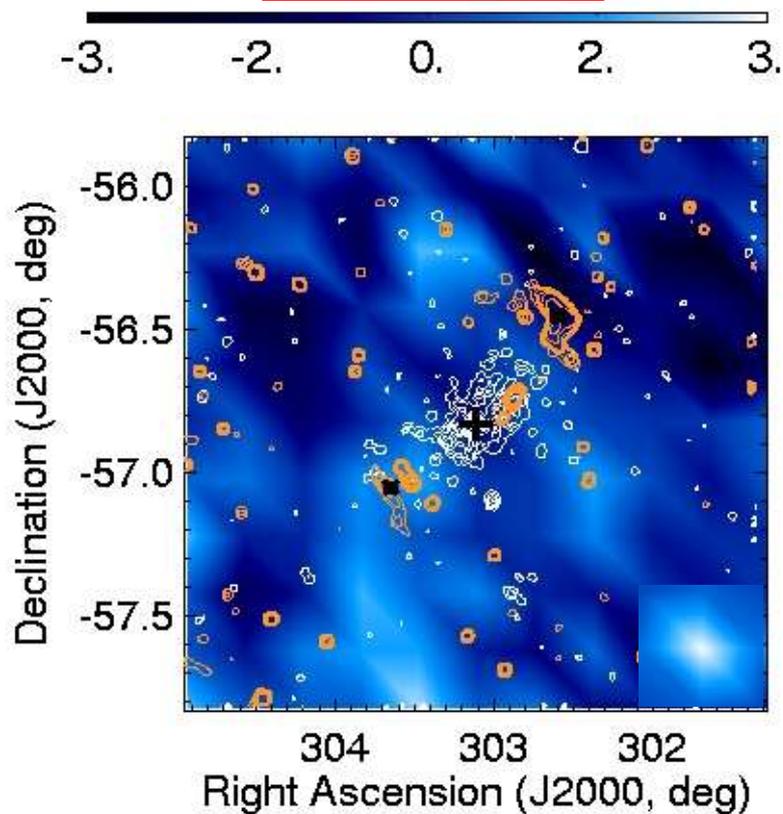
Spectral energy distribution



The solid and dashed curves are the predictions of the gamma-ray flux 8249 and 7300 days after the supernova, respectively [Berezhko & Ksenofontov (2006)]

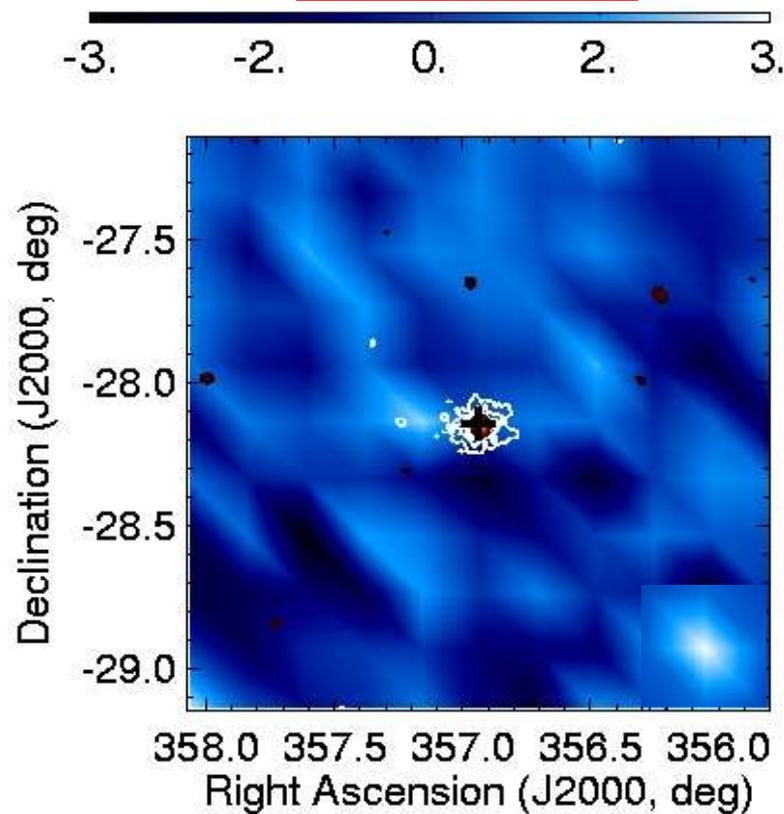
銀河団A3667とA4038

Abell 3667



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

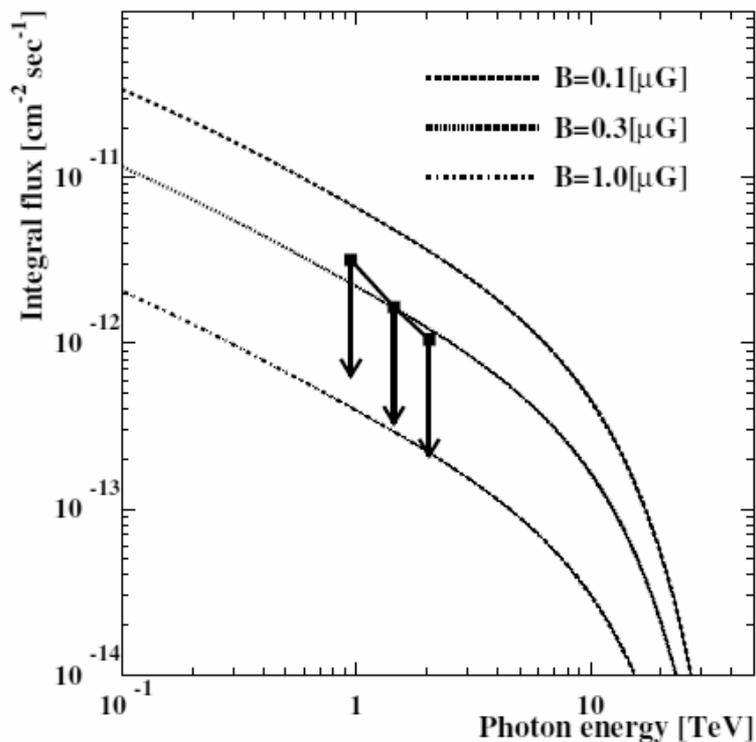
Abell 4038



Orange contour : VLA (radio)
White contour : ROSAT

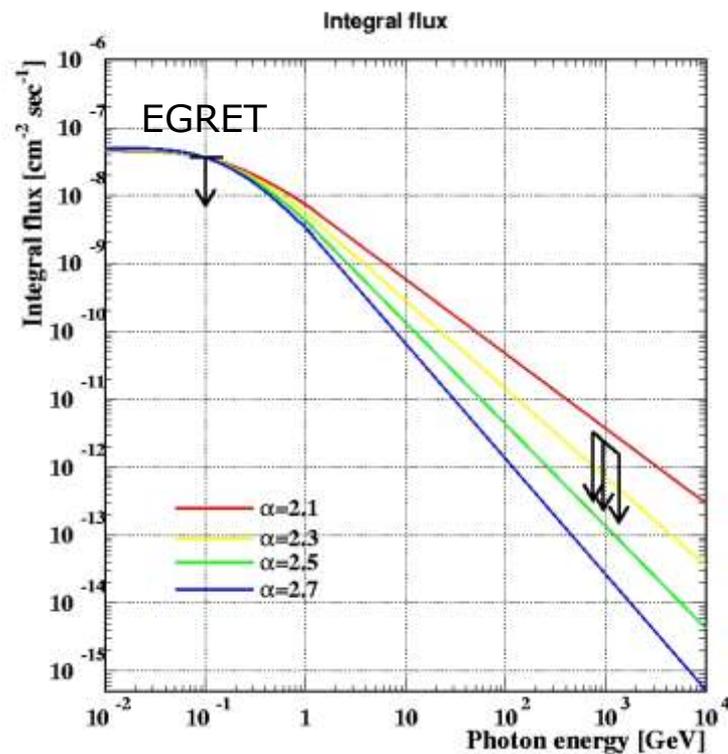
銀河団: モデルと上限値

Abell 3667, NW radio region



Model: Inoue et al. (2005)
[$p\gamma$ process]

Abell 4038, central region



Model: Pfrommer and Ensslin (2004)
[pp process]

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 ω Cen、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。