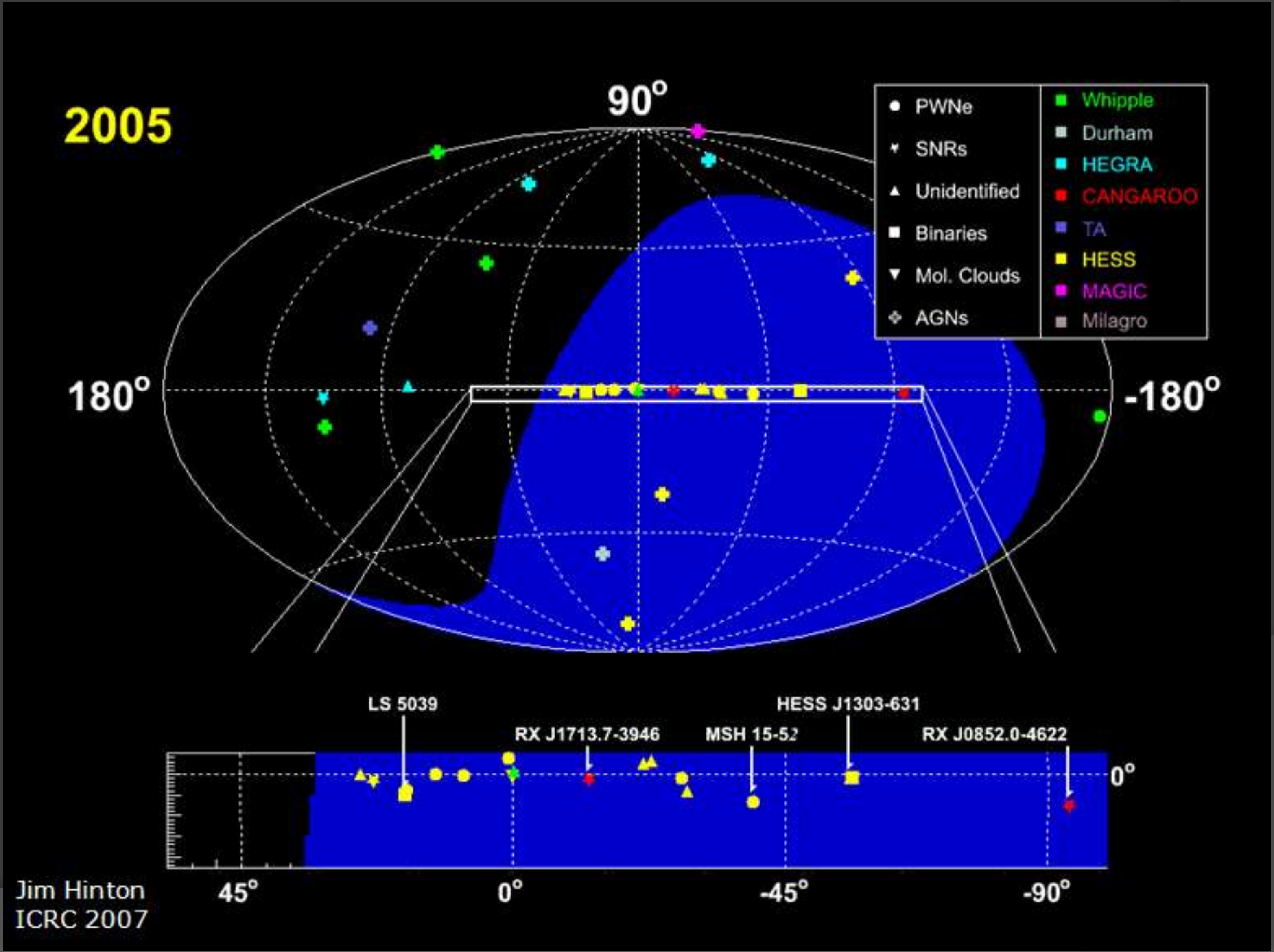
森　正樹

高エネルギーガンマ線・宇宙線

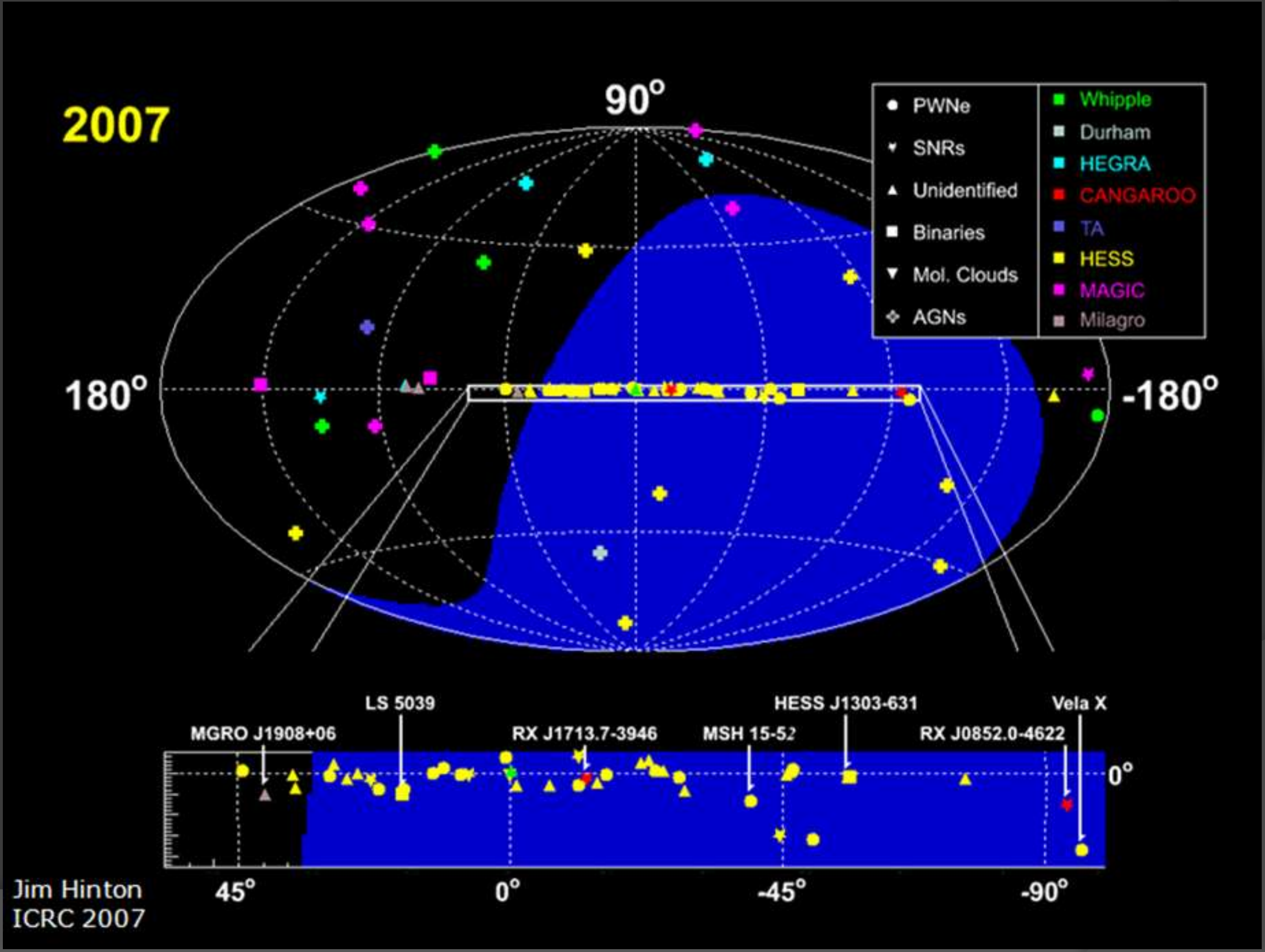
2006年時点での現状報告：http://www.icrr.u-tokyo.ac.jp/icrr-study/icrr-study.htm

2008年11月21日　ICRR勉強会

TeV skymap


2005
90°
180°
-180°
PWNe
SNRs
Unidentified
Binaries
Mol. Clouds
AGNs
Whipple
Durham
HEGRA
CANGAROO
TA
HESS
MAGIC
Milagro
LS 5039
RX J1713.7-3946
MSH 15-52
HESS J1303-631
RX J0852.0-4622
0°
45°
0°
-45°
-90°
Jim Hinton
ICRC 2007

TeV skymap



2007
90°
180°
-180°
PWNe
SNRs
Unidentified
Binaries
Mol. Clouds
AGNs
Whipple
Durham
HEGRA
CANGAROO
TA
HESS
MAGIC
Milagro
LS 5039
HESS J1303-631
Vela X
MGRO J1908+06
RX J1713.7-3946
MSH 15-52
RX J0852.0-4622
0°
45°
0°
-45°
-90°
Jim Hinton
ICRC 2007

R.Ong, rapporteur talk, ICRC2005

TeV sources classified (2005)

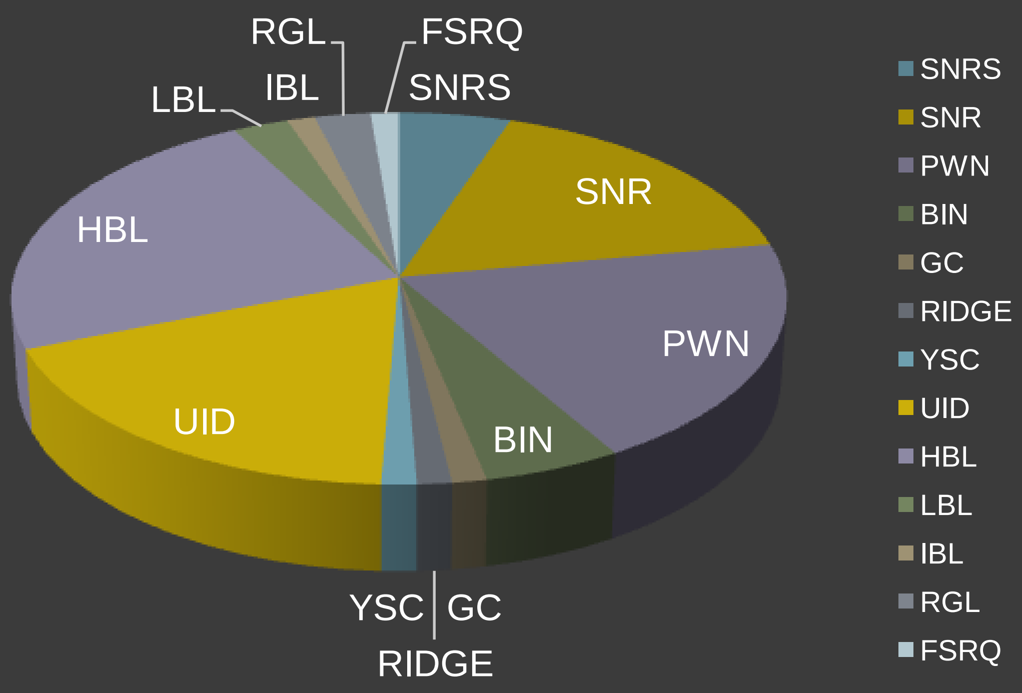
Source Type*	2003	2005
Pulsar Wind Nebula (e.g. Crab, MSH 15-52 …)	1	6
Supernova Remnants (e.g. Cas-A, RXJ 1713 …)	2	6
Binary Pulsar (B1259-63)	0	1
Micro-quasar (LS 5039)	0	1
Diffuse (Cygnus region)	0	1
AGN (e.g. Mkn 421, PKS 2155 …)	7	11
Unidentified	2	6
TOTAL	**12**	**32**

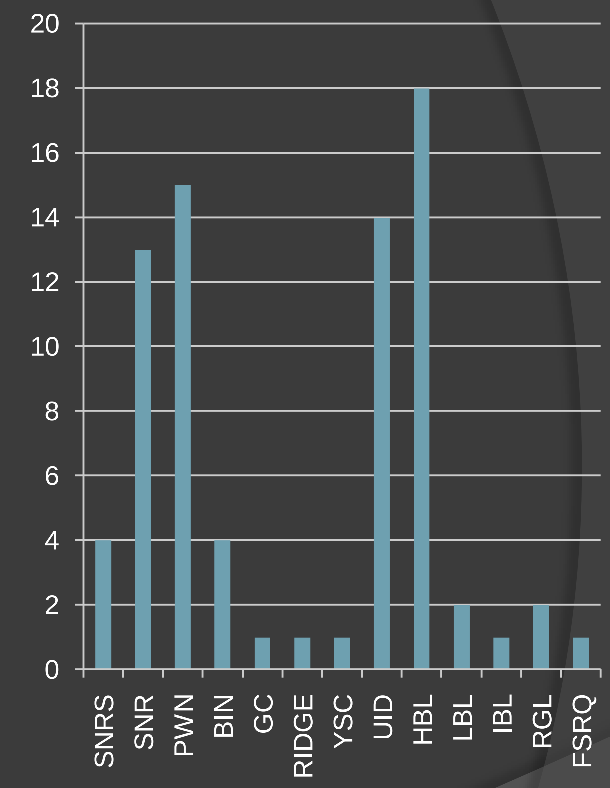
* Includes likely associations of HESS unid sources.

→ **Explosion in the number of VHE sources.**

Classified by M. Mori, as of Nov. 2008

TeV sources classified (2008)





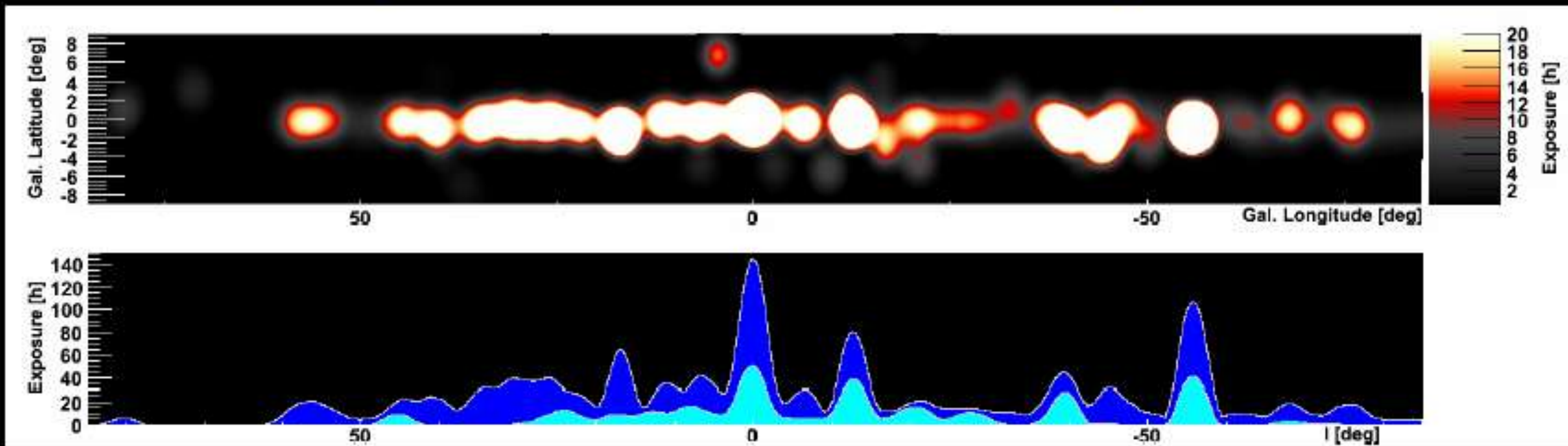
Total 77 sources

* Borders for SNR/PWN/UnID are vague…

H.E.S.S extended Galactic plane survey

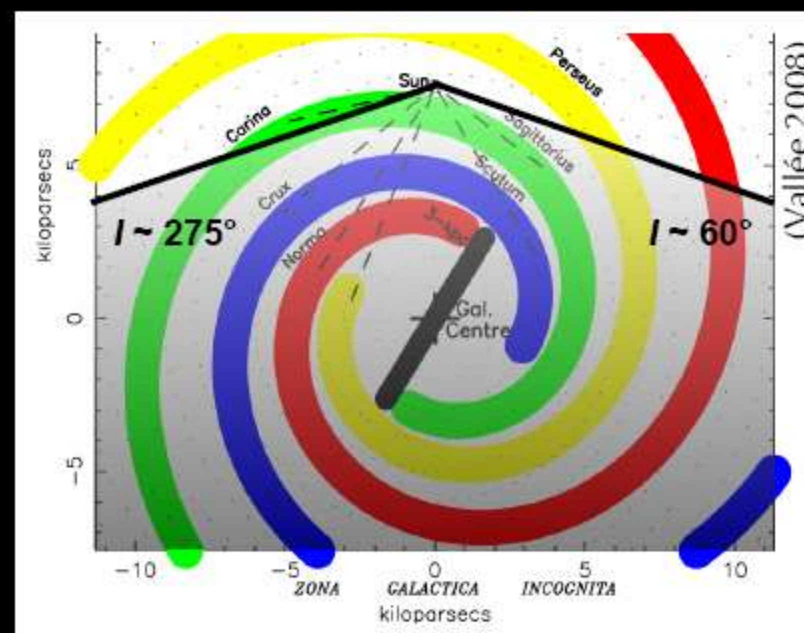
Chaves, Gamma2008, Heidelberg

Acceptance-corrected Exposure

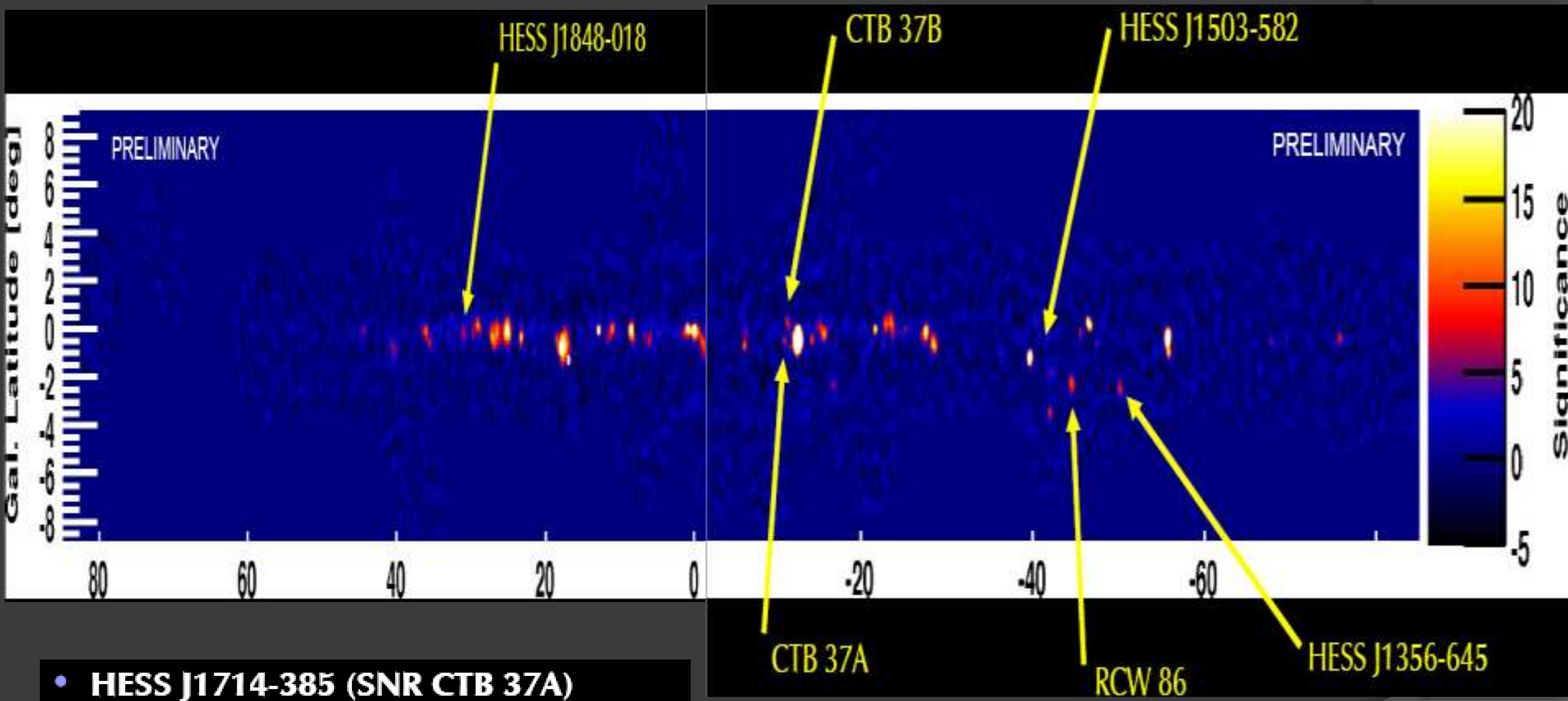


Extended H.E.S.S. GPS

- **-85° < *l* < 60°**
- -3° < *b* < 3°
- Scan mode: **400** h
- Detected **50+ Galactic sources** of VHE gamma-rays
- ICRC 2007, DPG 2008, Gamma08

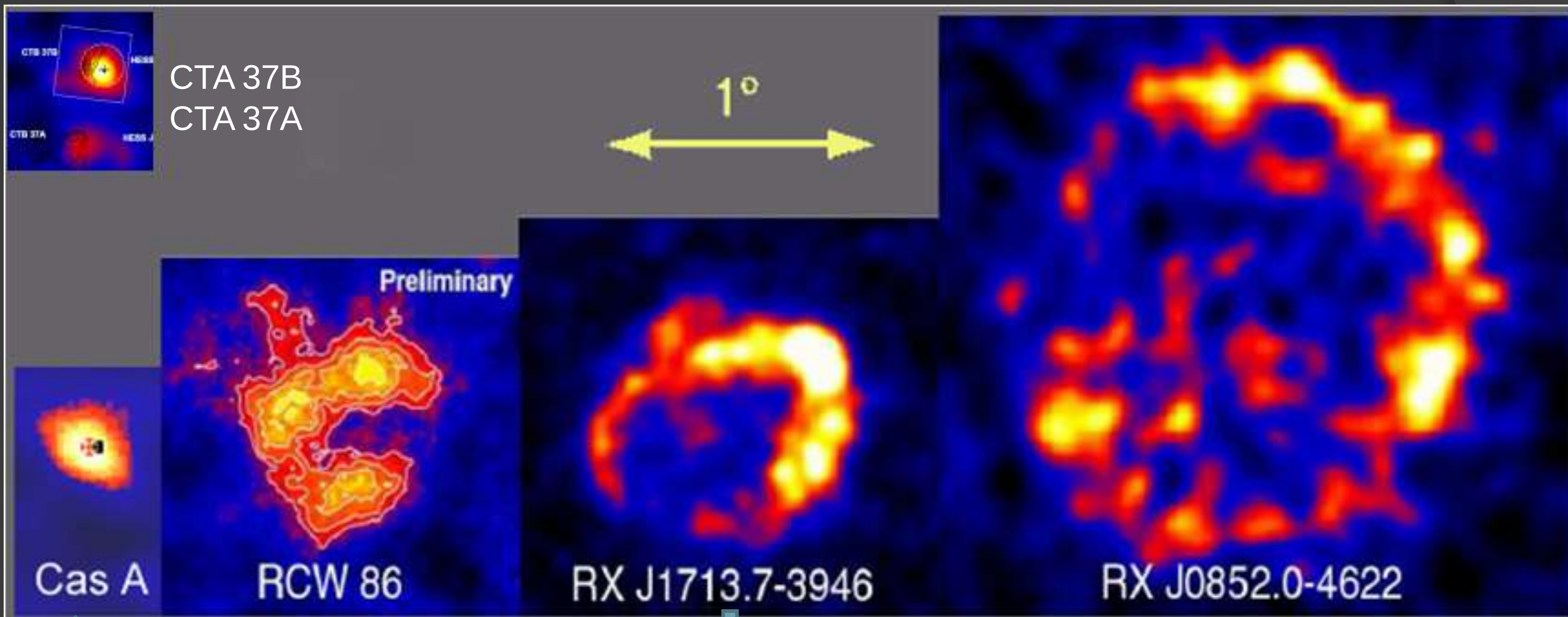


H.E.S.S. GPS significance map



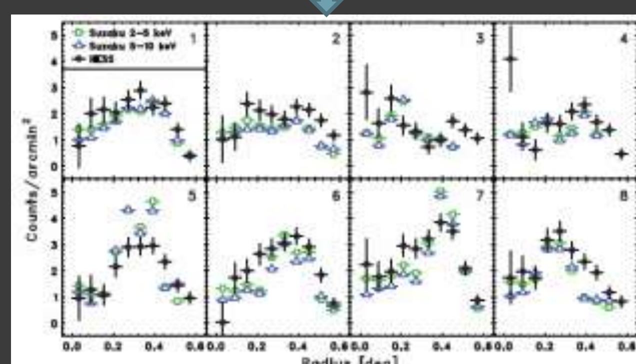
- HESS J1714-385 (SNR CTB 37A)
- HESS J1713-381 (SNR CTB 37B)
- HESS J1442-623 (SNR RCW 86)
- HESS J1356-654 (Offset PWN)
- HESS J1503-582 (FVW?)
- HESS J1848-018 (SFR W 43, WR 121a?)
- HESS J1849-000 (PWN)

TeVで見るシェル状SNR



Comparable to PSF (0.09°)

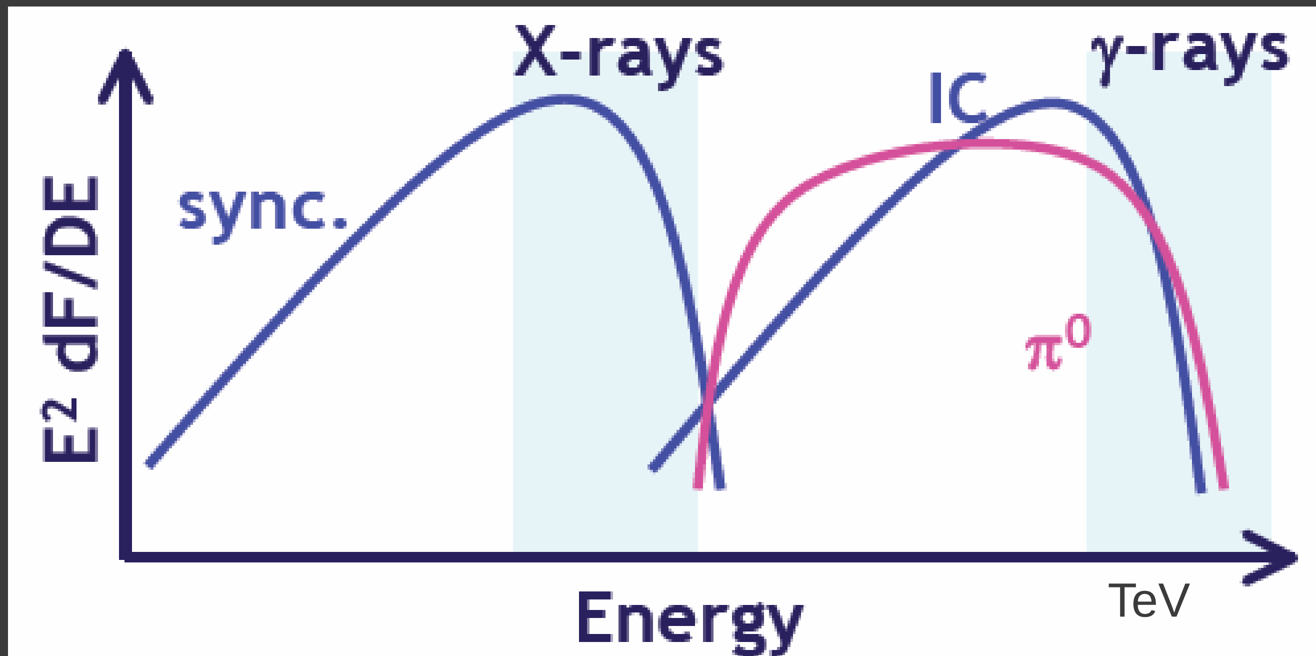
J. Albert et al., A&A 474, 934 (2007)



T.Tanaka, PhD thesis, 2007

Good keV-TeV Correlation!

加速粒子とスペクトル



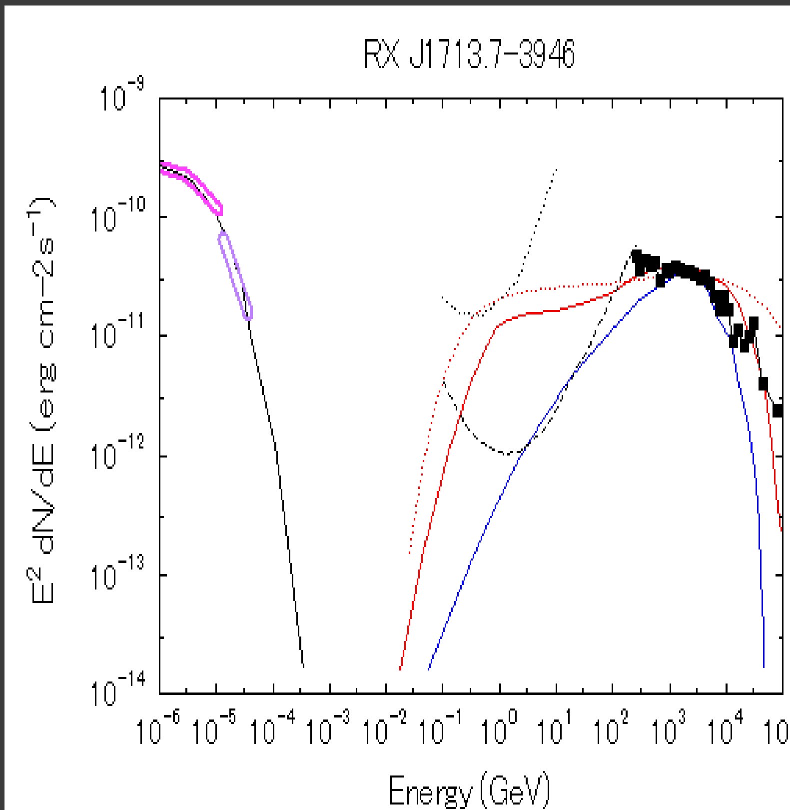
©A.Bamba

p/e ratio problem

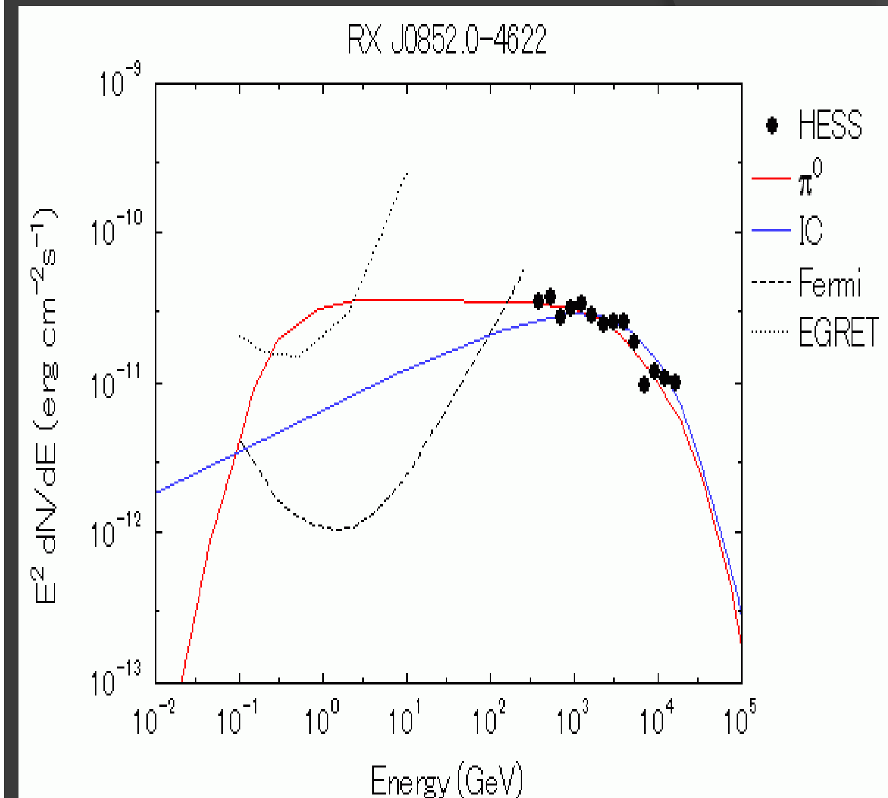
- Proton → Π^0 decay → Flat spectrum above 100MeV
- Electron → Synchrotron X-rays → Inverse Compton gamma-rays

Berezhko and Völk: arXiv:0810.0988 Aharonian et al.,ApJ 661, 236 (2007)

広域スペクトルとFermiの観測



Fermi (1yr)



- 電子モデルでも陽子モデルでもTeV領域は説明可能！
- Fermiの1年の観測で電子モデルなら決着（？）

Funk et al., ApJ 679, 1299 (2007)

RX J1713.7-3946とFermi

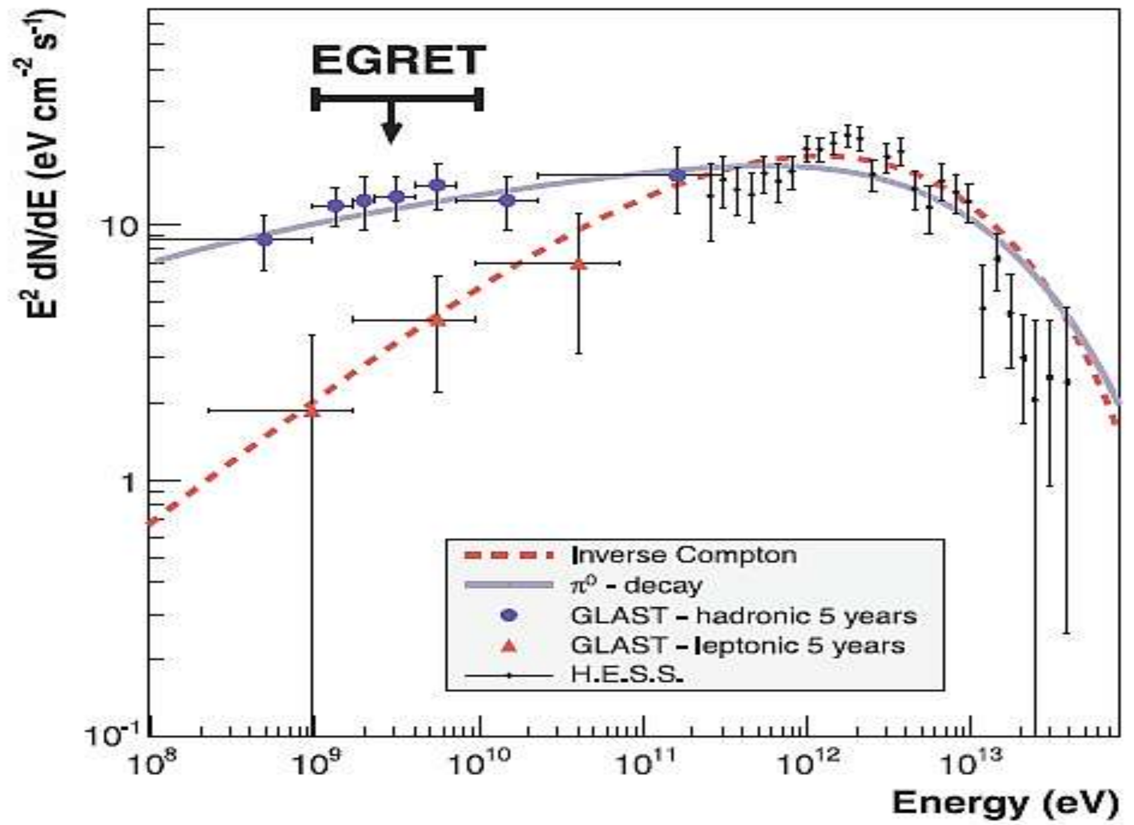
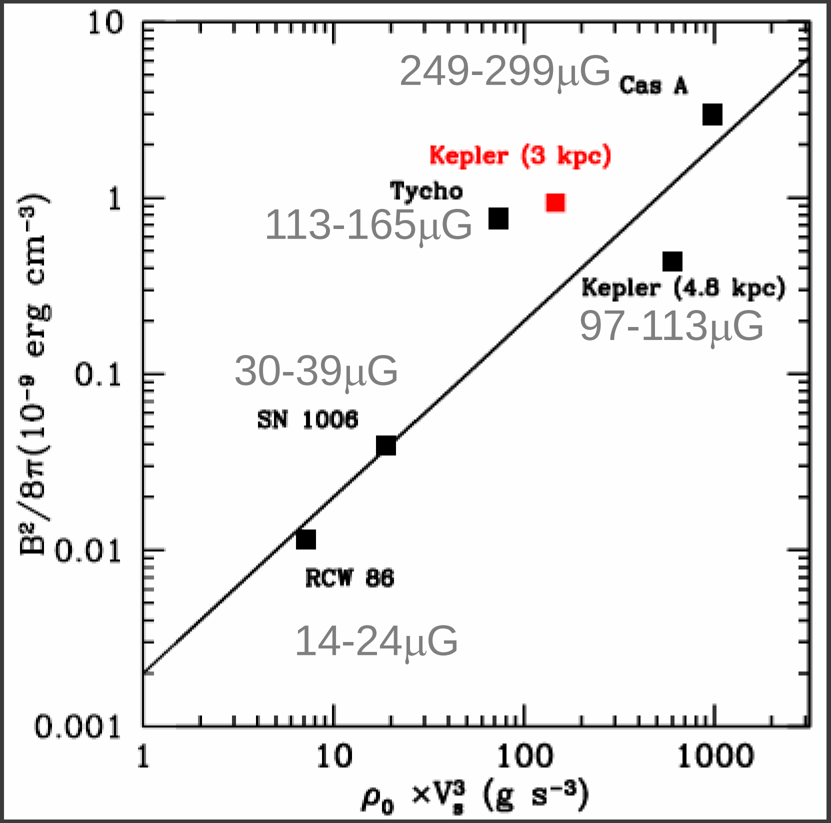


FIG. 11.—High-energy SED for the SNR RX J1713.7−3946. The black data points show measurements with H.E.S.S., whereas the blue circles and red triangles show simulated *GLAST* data, assuming two different models (leptonic and hadronic) for the γ-ray emission (*dashed red and solid blue lines, respectively*). This simulation uses the current best estimate of the LAT performance and illustrate that in principle the *GLAST* LAT should be able to detect this prominent shell-type SNR in a 5 yr observation or faster, depending on the emission mechanism. This figure has been reproduced from Funk et al. (2007b).

J. Vink, astro-ph/0601131

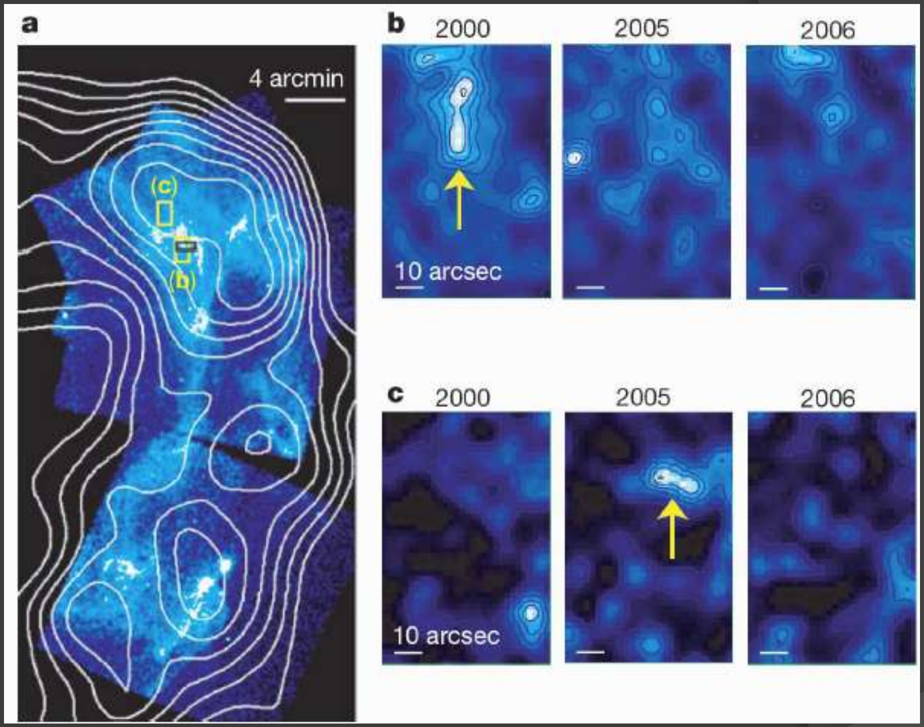
Y. Uchiyama et al., Nature 449, 576 (2007)

SNRの磁場



SNR	Dist kpc	V_s km s^{-1}	n_0 cm^{-3}	width $''$	B_{loss} μG	B_{diff} μG
Cas A	3.4	5200	3	0.5	249	299
Kepler	4.8	5300	0.35	1.5	97	113
Tycho	2.4	4500	0.3	2	113	165
SN1006	2.2	4300	0.1	20	30	39
RCW86	2.5	3500	0.1	45	24	14

RX J1713.7-3946 by Chandra

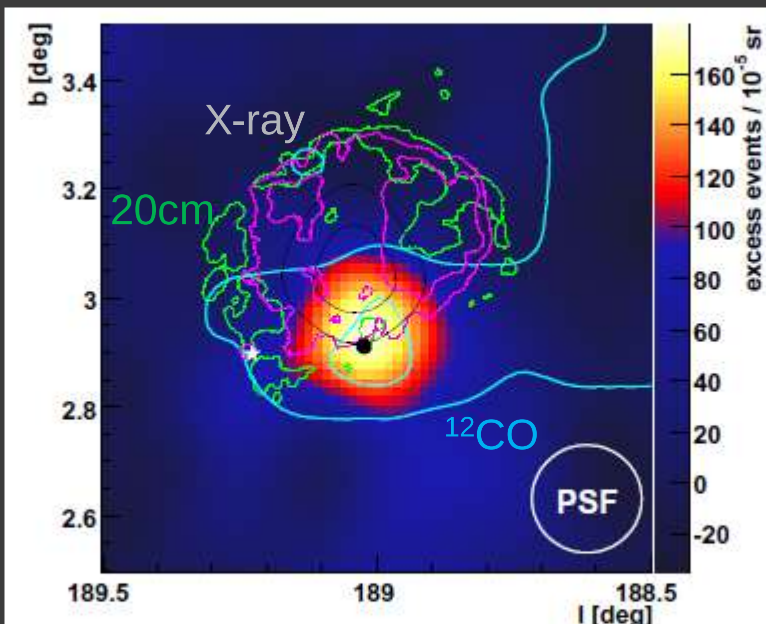


Variation in ~1yr time scale
→ Need > 1mG ! (locally)
→Protons produce TeV gamma-rays!?

Counter arguments: Y.Butt et al. , arXiv:0801.4954

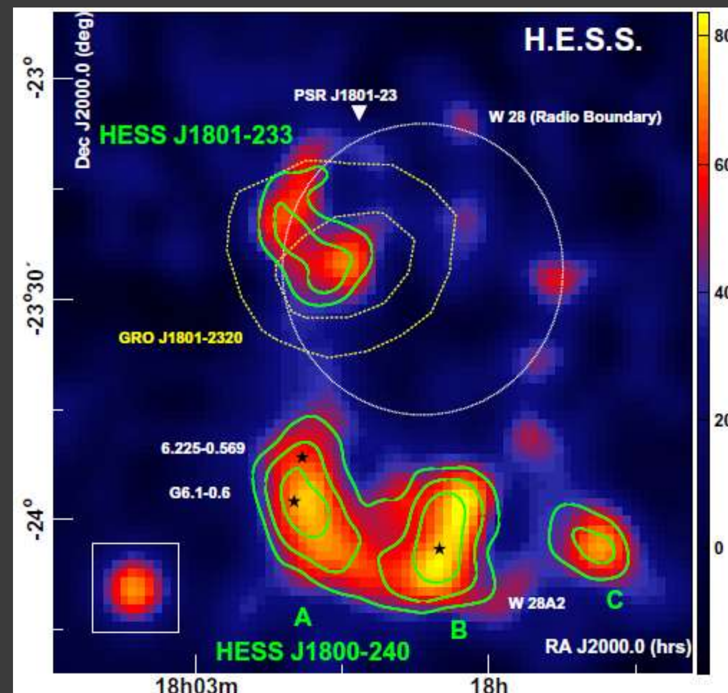
SNRと分子雲との相互作用？

IC443

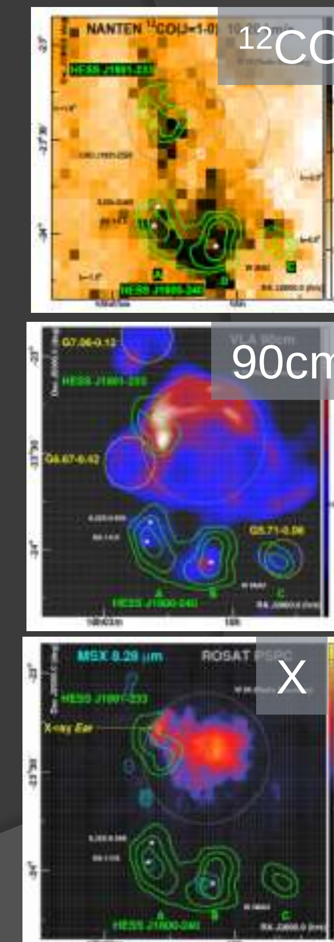


[MAGIC, Albert et al. , ApJ 664, L87,2007]

W28



[H.E.S.S., Aharonian et al. , A&A, in press]



標的のあるところでガンマ線放射

陽子加速の証拠か？

宇宙線と超新星残骸

- Energeticsから超新星残骸は宇宙線の加速源として有力とされてきた。(Ginzburg 1953; Hayakawa 1956)
  - 銀河の宇宙線power
    - 0.5 eV/cm^3, V~10^{67}cm^3, τ~3×10^{14}s ⇒ W_{CR} ~3×10^{40}erg/s
  - 超新星残骸のpower
    - 10M$_\odot$ SNR expanding at 5×10^{8}cm/s /century ⇒ W_{SN} ~3×10^{42}erg/s
  - 超新星残骸のpowerの~1 %で宇宙線を賄える!
    (Cf.Stanev, “High Energy Cosmic Rays”, 2004)
  - 衝撃波加速理論からE^{-2}のスペクトルが期待される
- 最高加速エネルギーの問題: up to “knee”?
  - Shockがejecta相当の質量を掃くまで加速が起こる
  - Lagage & Cesarsky (A&A 118, 223, 1983)
    - E_{max}=3×10^4 Z GeV/n
  - Correction for expansion velocity: (Stanev, “High Energy Cosmic Rays”, 2004)
    - E_{max}=2.4×10^5 Z GeV/n
  - Berezhko (Astropart. Physics 5, 367, 1996)
    - E_{max}=10^5 Z GeV/n

Berezhko&Völk, ApJ 661, L75 (2007)

Galactic cosmic ray spectrum

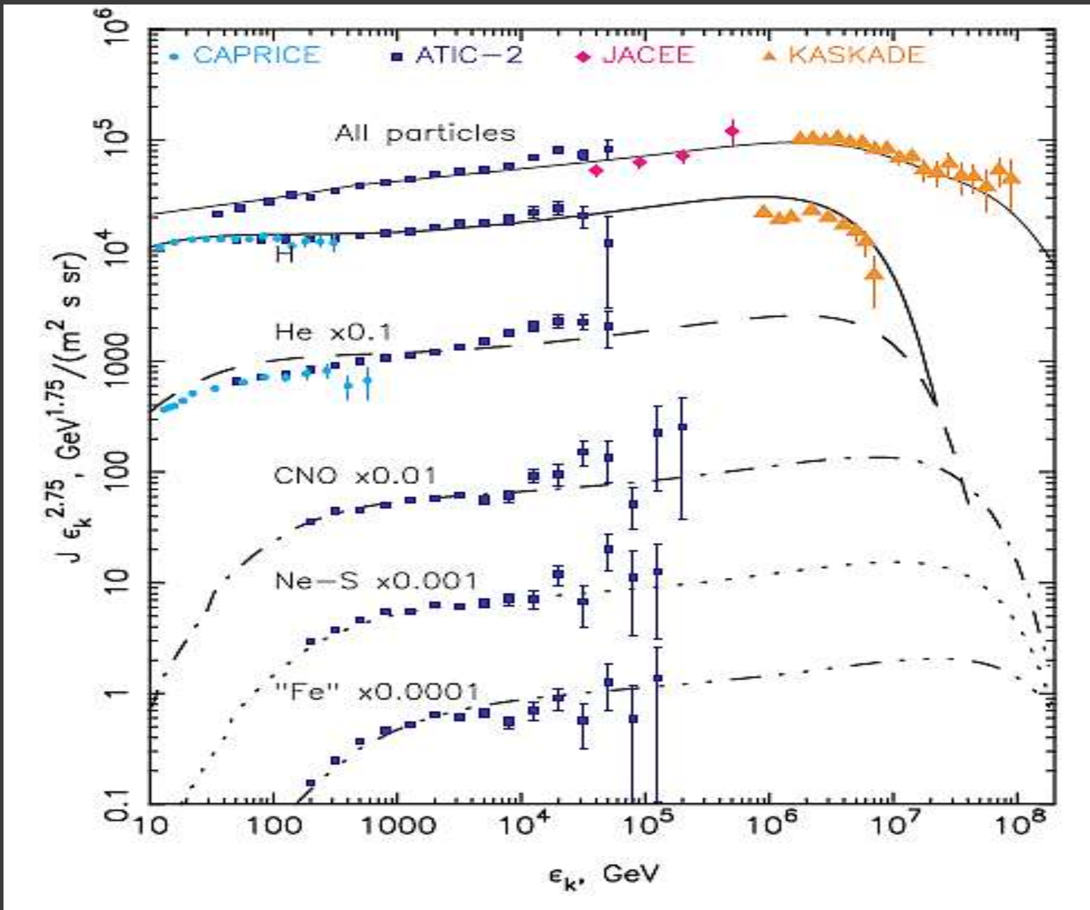


FIG. 1.—GCR intensities at the solar system as a function of particle kinetic energy. Curves represent the CR spectra calculated for a proton injection rate $\eta = 10^{-4}$, ion-to-proton ratios that provide a fit for the data at $\epsilon_k = 1$ TeV, and for $\mu = 0.75$. Experimental data obtained in the CAPRICE (Boezio et al. 2003), ATIC-2 (Panov et al. 2006), JACEE (Asakimori et al. 1998), and KASCADE (Antoni et al. 2005) experiments are shown as well.

Prediction by a model incorporating SNR evolution, injection and acceleration.

$J(E_k) \propto \tau_{esc} N(E_k)$

$\tau_{esc} \propto R^{-0.75}$

$R = pc/Ze$

E_p^{max} ~ several 10^6GeV
(several PeV)
"Pevatron" needed!

Berezhko&Völk, ApJ 661, L75 (2007)

All-particle CR spectrum

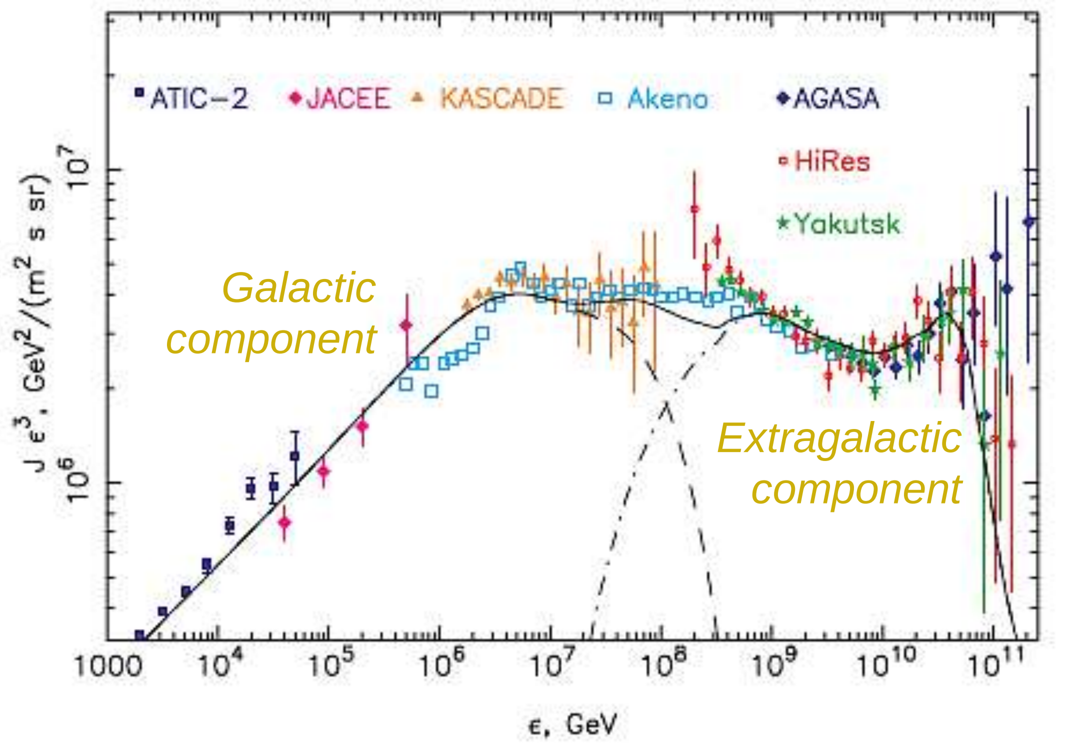
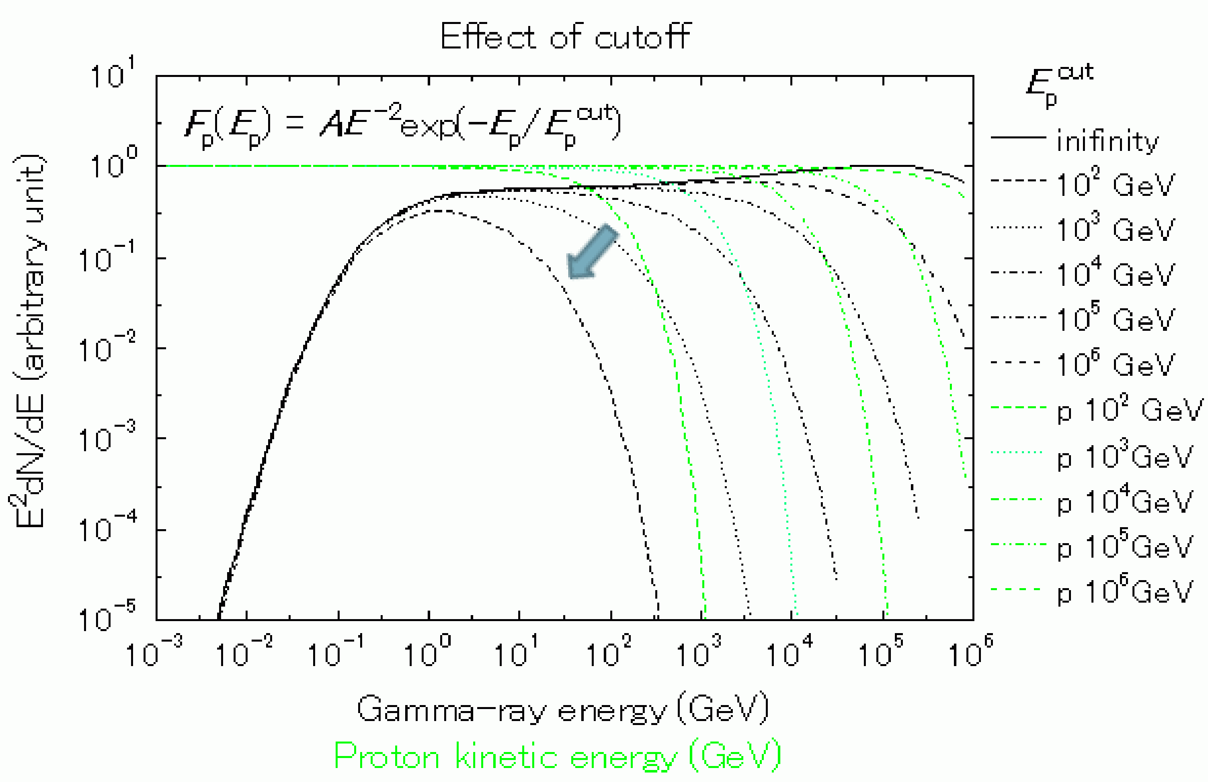


FIG. 2.—All-particle GCR intensity as a function of total particle energy. The dashed line represents the Galactic component, which is the all-particle spectrum from Fig. 1. The dash-dotted line represents the assumed extragalactic component. Experimental data obtained in the ATIC-2, JACEE, KASCADE, Akeno-AGASA (Takeda et al. 2003), HiRes (Abbasi et al. 2005), and Yakutsk (Egorova et al. 2004) experiments are shown as well.

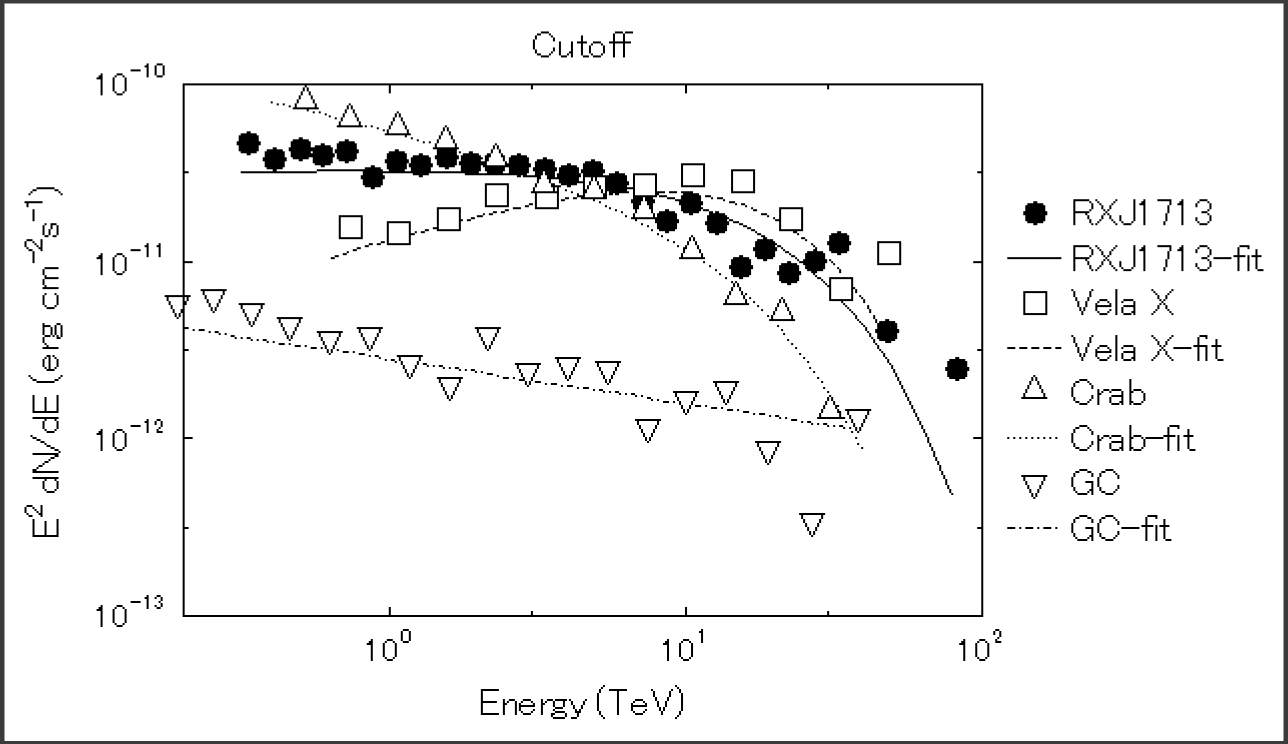
スペクトルのカットオフ

$p + p \rightarrow n\pi^0 + X,\ \pi^0 \rightarrow 2\gamma$



ガンマ線スペクトルのカットオフは、親粒子のスペクトルのカットオフより～1/10低いところに来る。

ガンマ線天体のスペクトル(>10TeV)



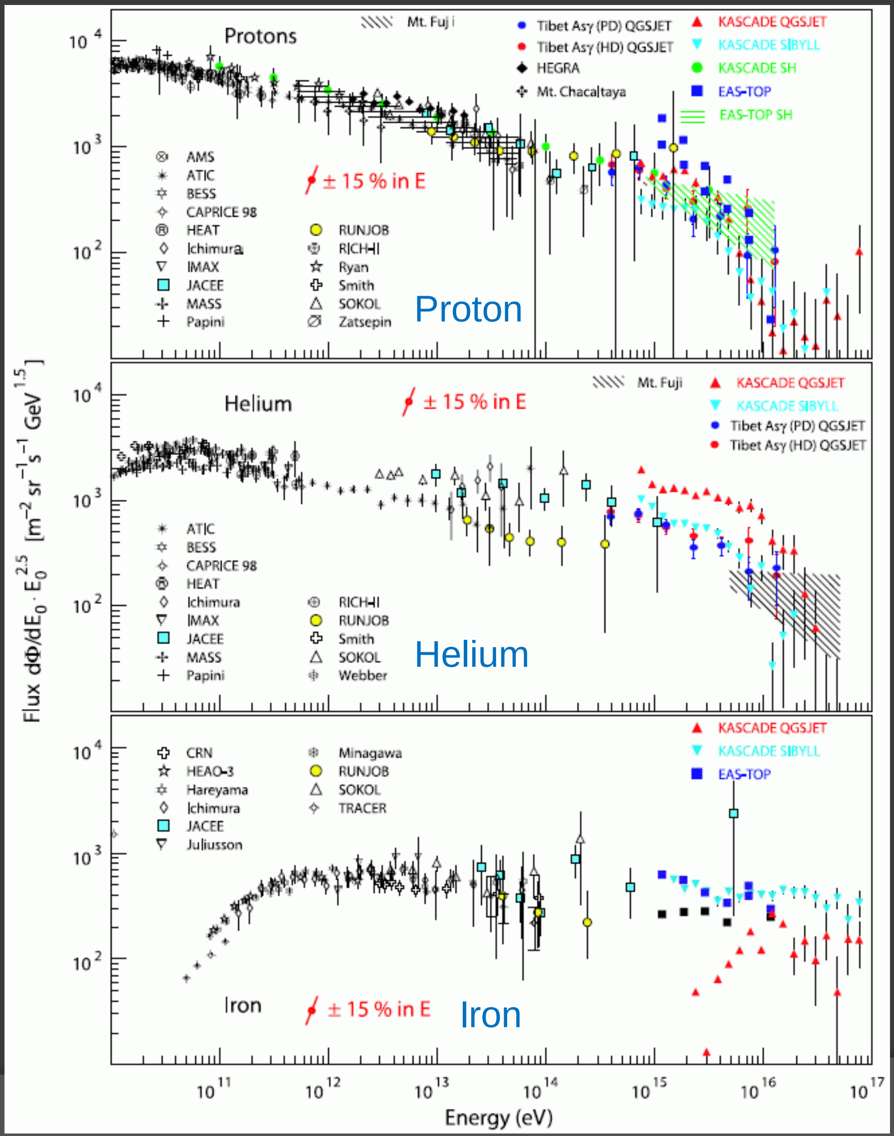
フラックスの大きい天体では、13-18 TeV程度でcutoffが見られる。
（フラックスの小さな天体では統計でリミットされている。）

親粒子は200TeV程度で加速限界に達している。

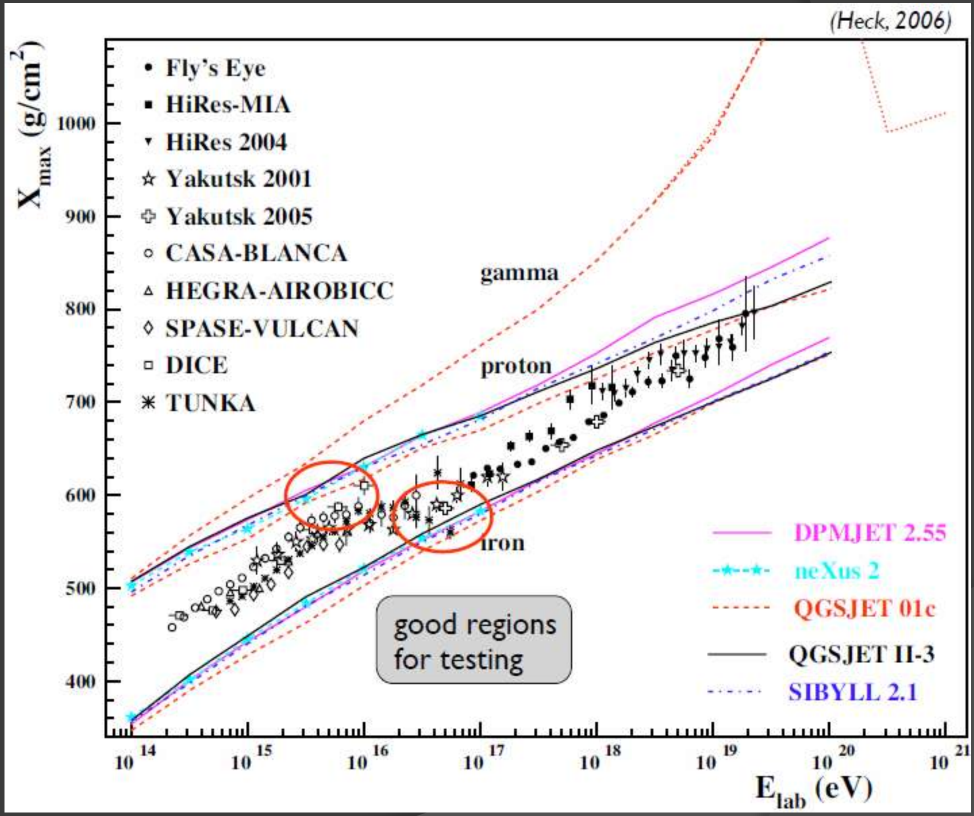
数100TeV以上まで加速が起こる天体(“Pevatron”)はまだ見つかっていない！（Kneeまで加速できる天体は未発見！）

GCR spectrum/composition uncertainty

Kampert, astro-ph/0611884

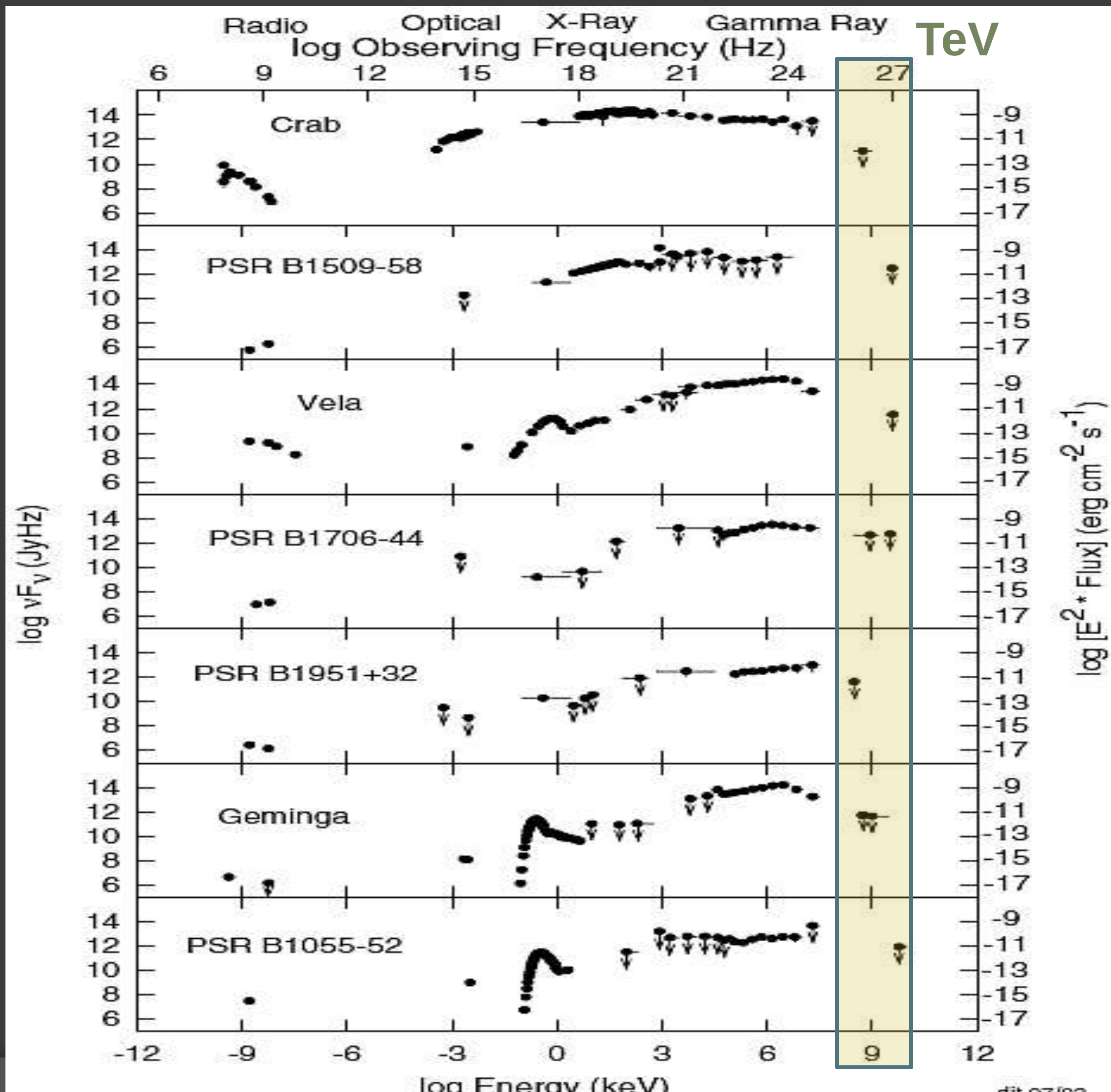


Engel, Rapporteur talk, ICRC 2007

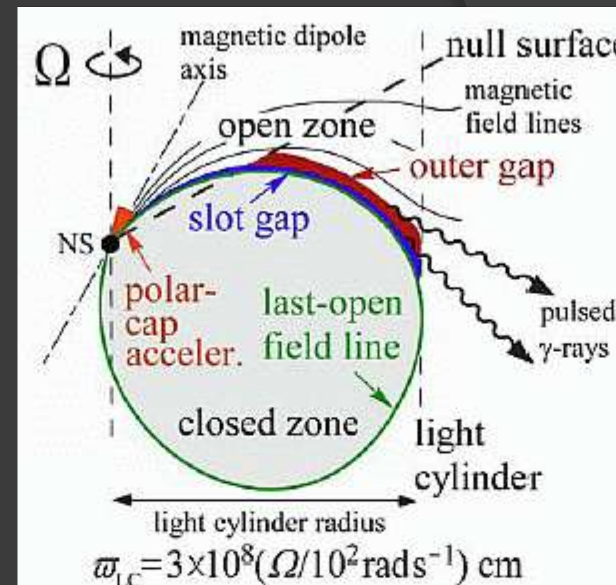


Thompson, Rep.Prog.Phys.71 116901 (2008)

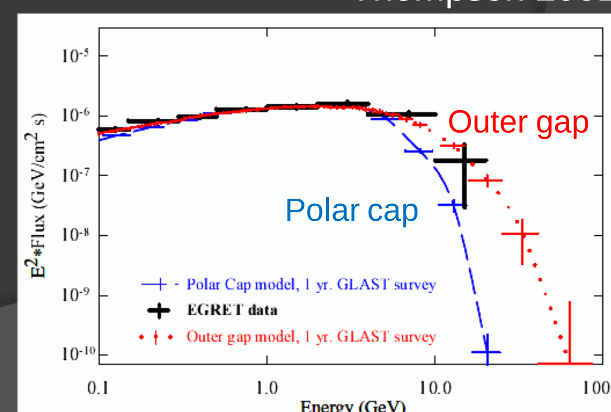
EGRET gamma-ray pulsars



Hirotani 2008

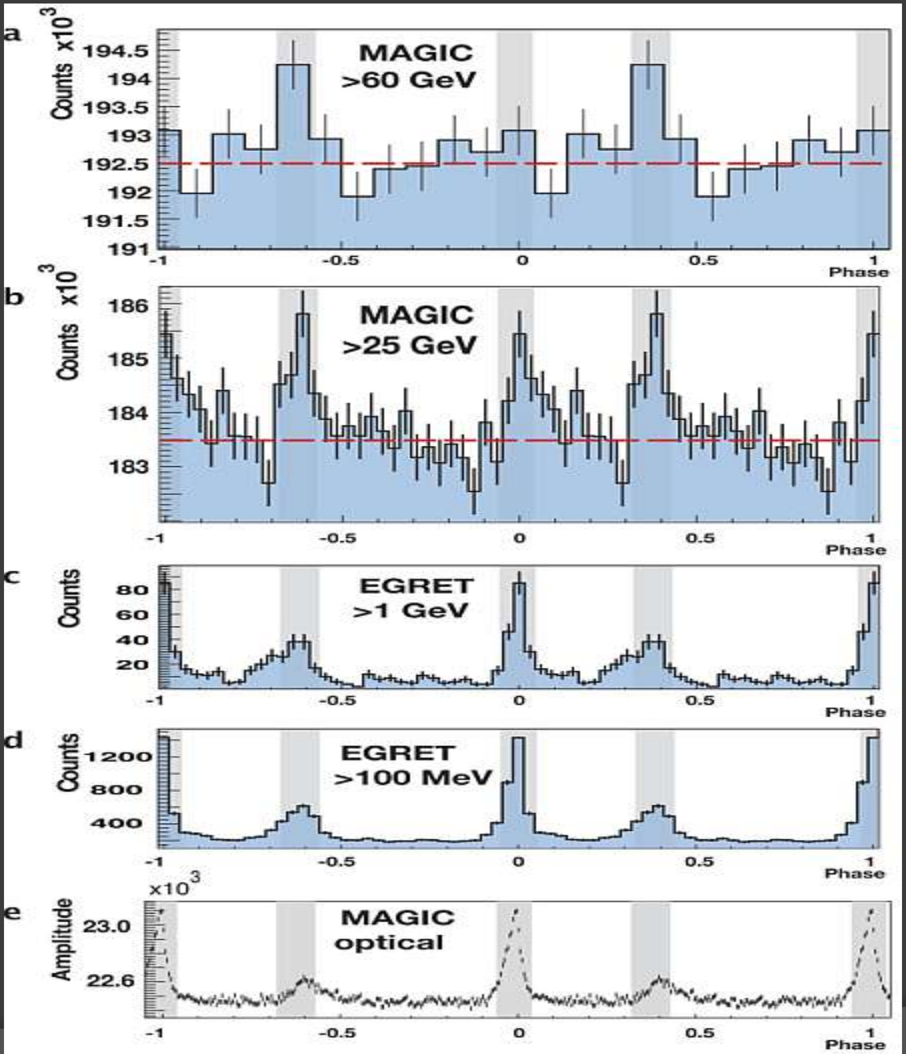


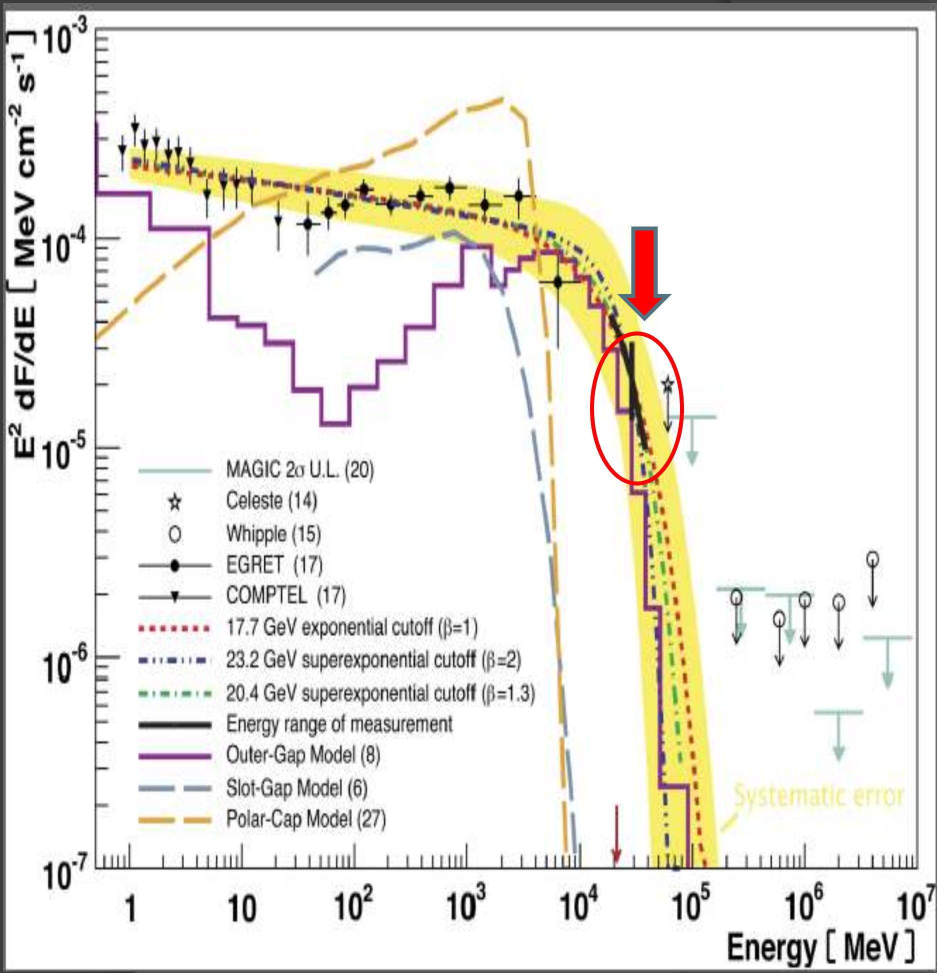
Thompson 2001



Aliu et al., Science Express, 16 Oct 2008

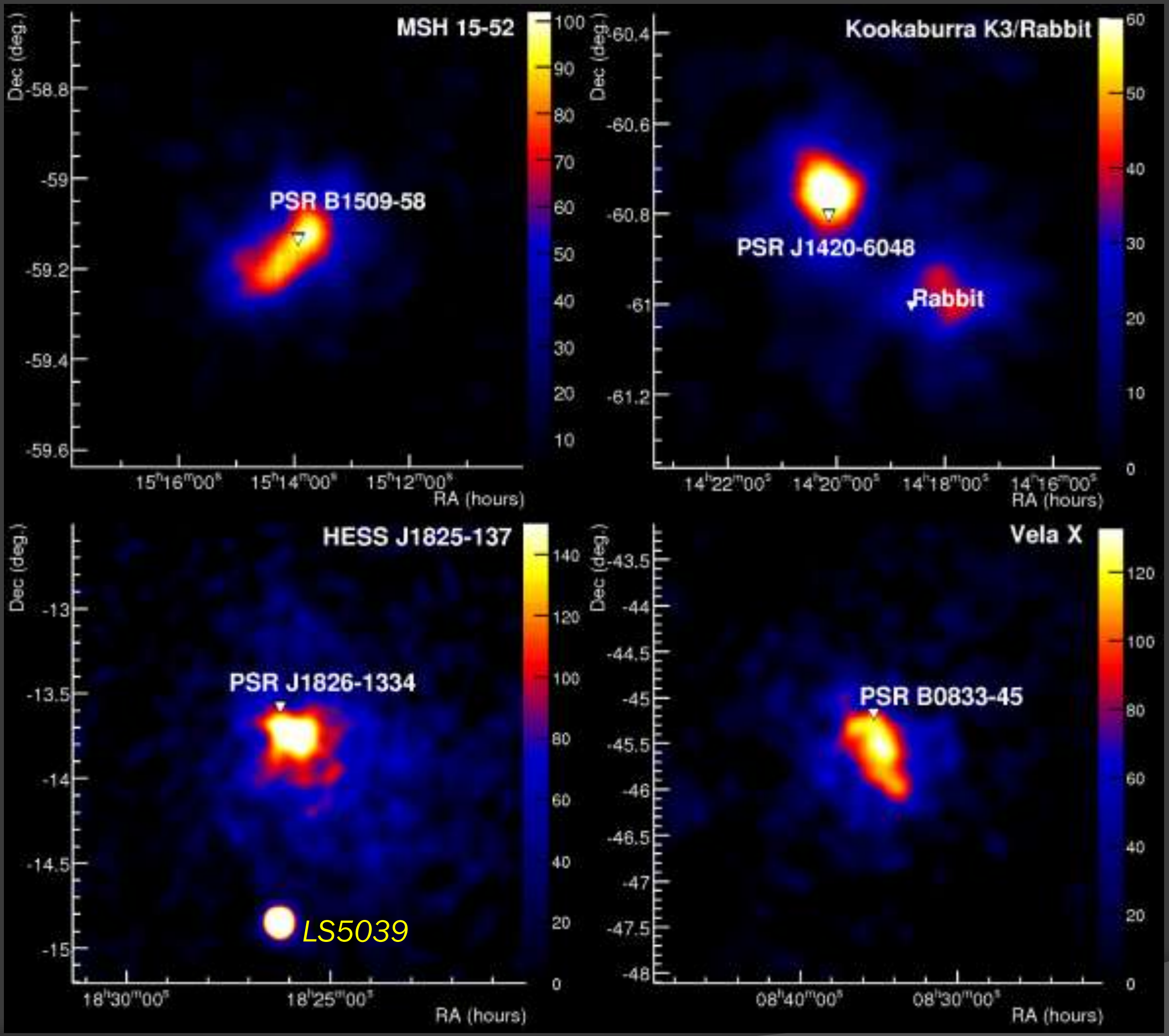
Crab pulsar by MAGIC





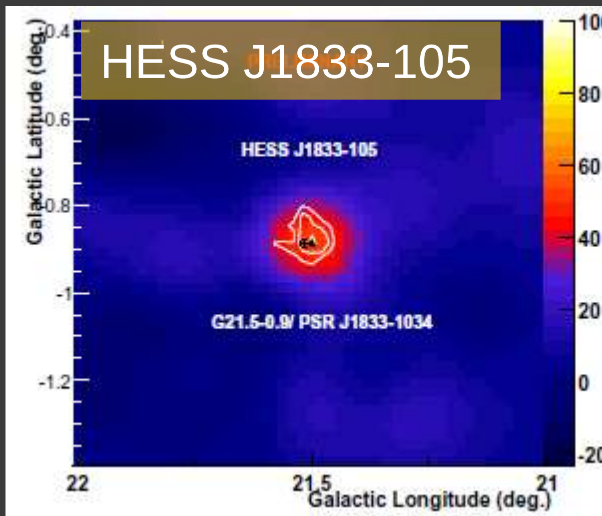
First pulsar detected by Cherenkov telescope!

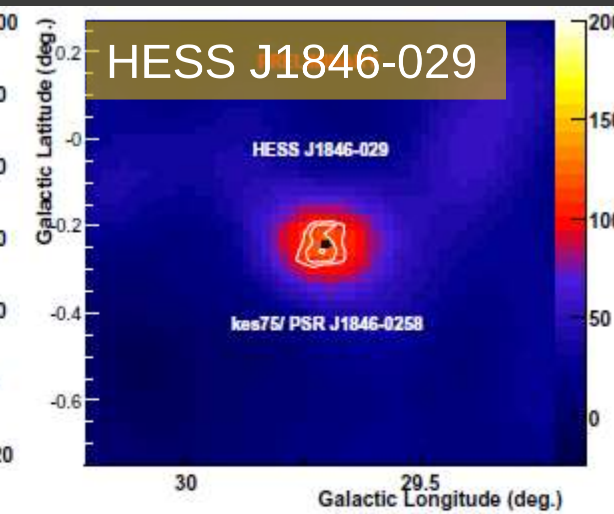
パルサー星雲 (Pulsar Wind Nebula)



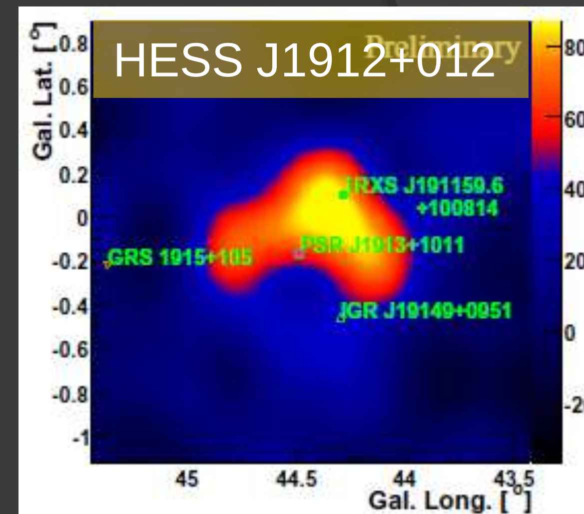
- Major group in Galactic TeV sources
  - 18/71 by Hinton (2007ICRC)
  - Associated with relatively young ($<10^5$ years) and large spin-down pulsars
- Extended *O*(10pc), displaced from pulsars
- Gamma-rays via inverse Compton by electrons?

パルサー星雲(続)

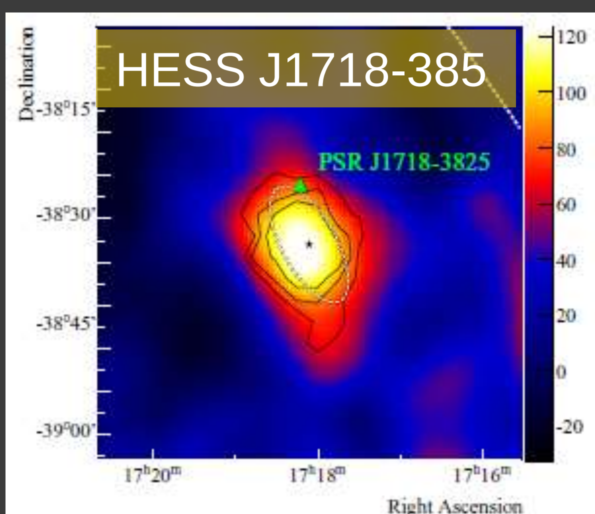




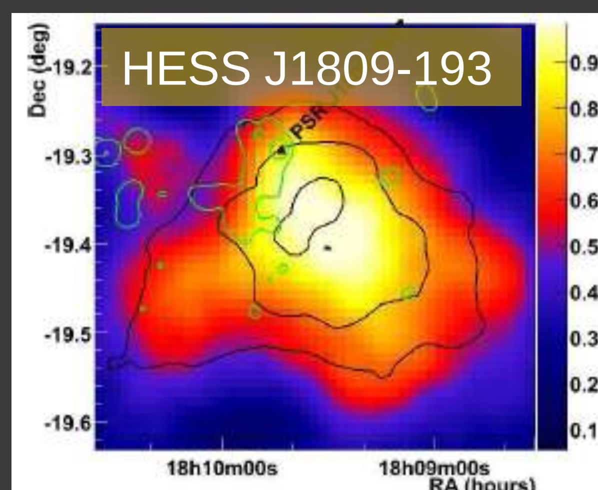
Djannati-Atai et al., ICRC2007



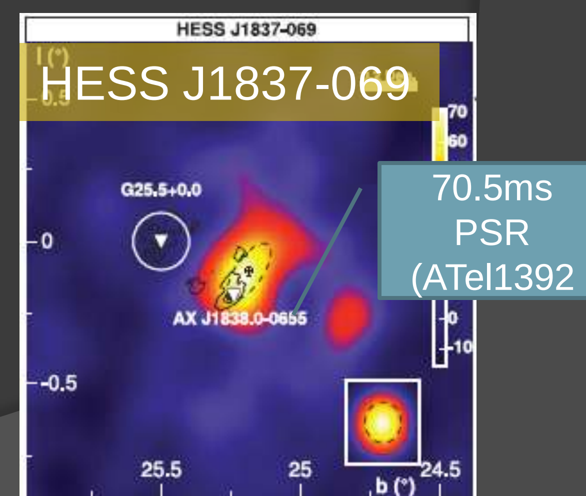
Hoppe et al., ICRC2007



Carrigan et al., ICRC2007



Komin et al., ICRC2007



Aharonian et al. ApJ 777 (2007)

S. Funk, paper 390, 30th ICRC (Merida), 2007

パルサー星雲とスピンダウン光度

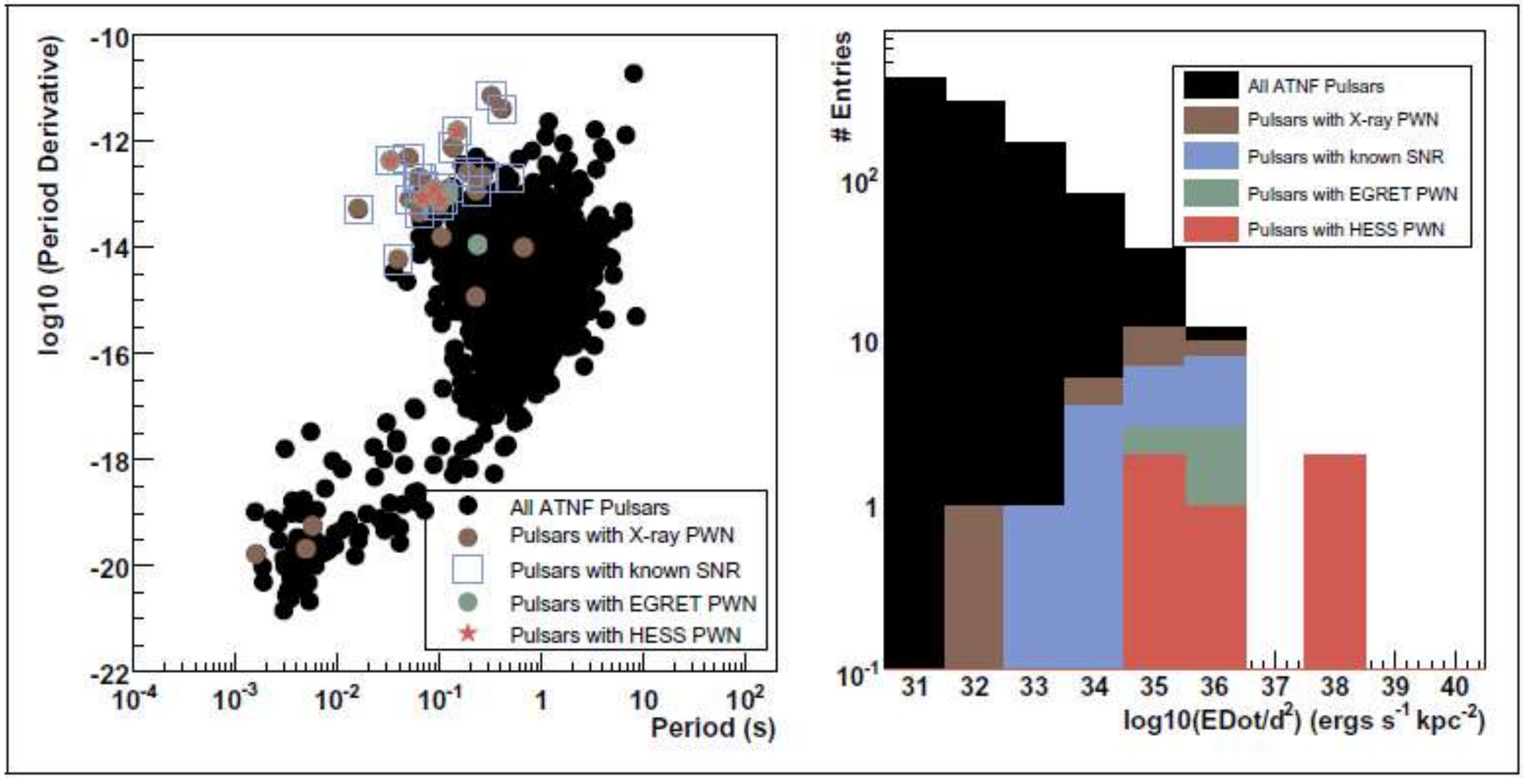
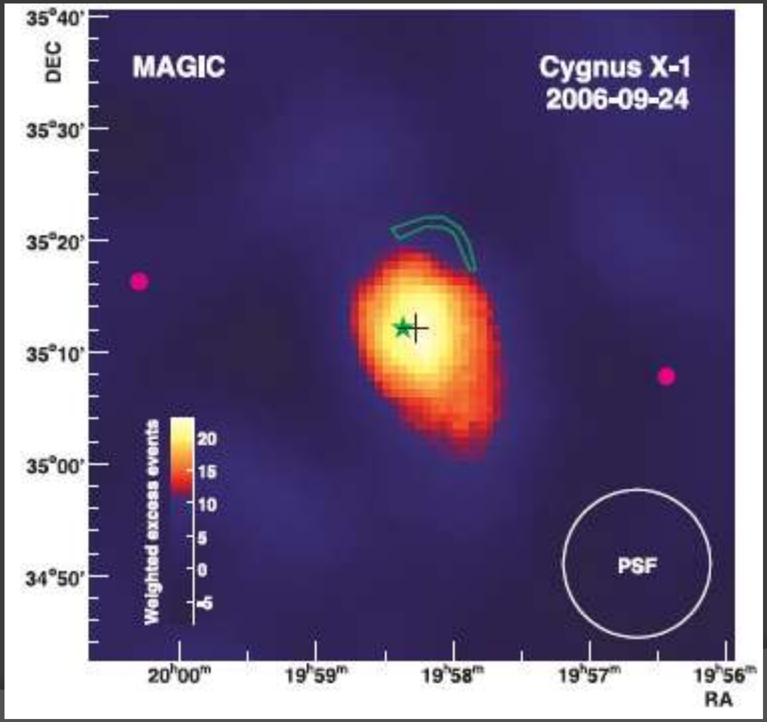
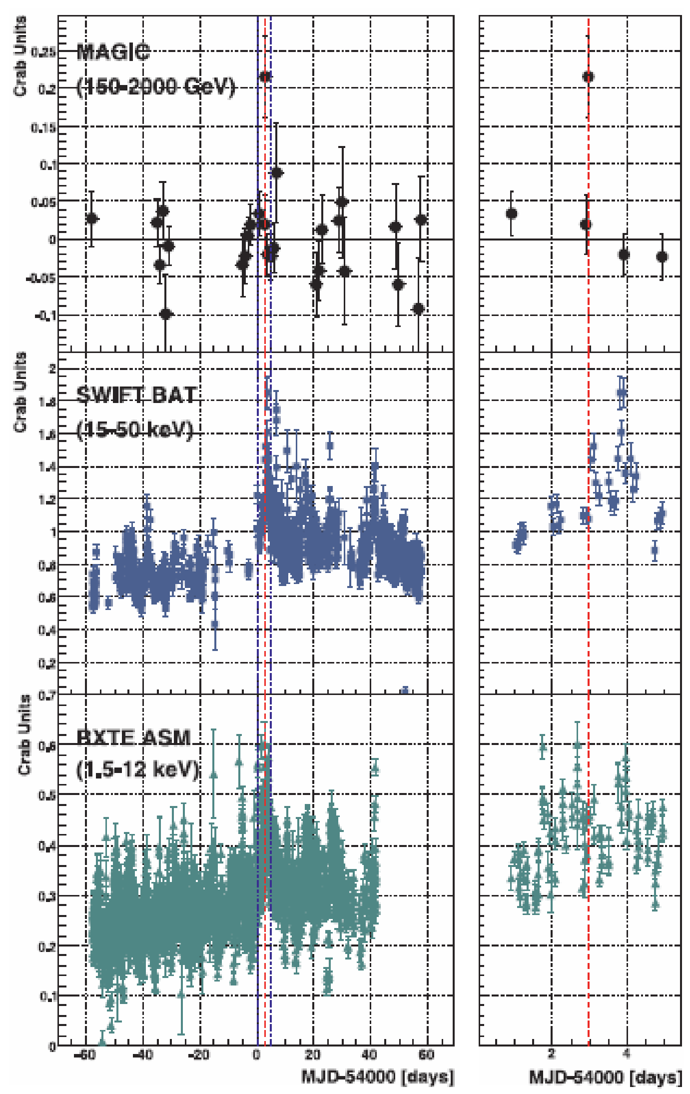


Figure 3: **Top:** $P - \dot{P}$ diagram for pulsars: all ATNF pulsars (black), with detected X-ray PWN (brown), with a known corresponding SNR (blue), potentially associated to an EGRET source (green), associated to a H.E.S.S. VHE PWN (red). **Bottom:** Energy output for the selections used at the top.

X線連星Cyg X-1

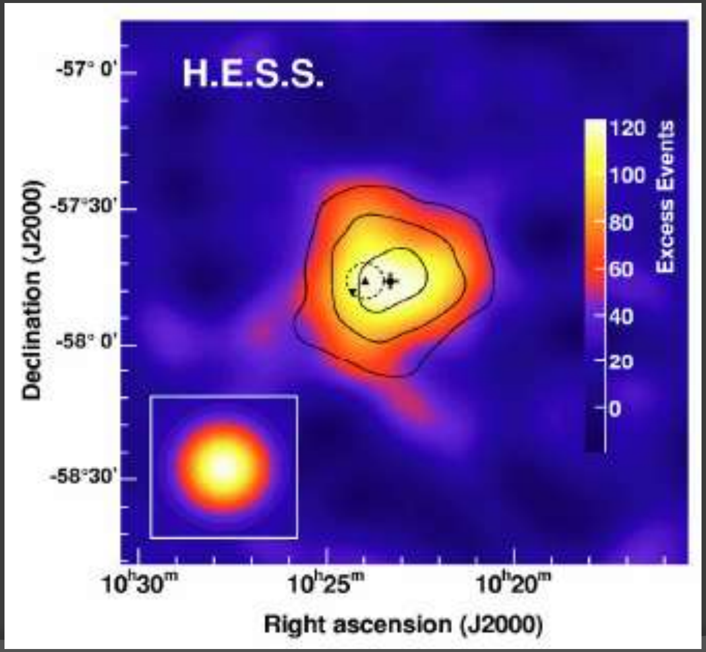
- Black hole binary: M_{BH}~21$M_\odot$, $M_\star$~30$M_\odot$
- Relativistic jet v>0.6c: “microquasar”
- MAGIC 40hr obs.
- 4.9σ seen in one 79 min. time slice
- Estimated significance: 4.1σ after correction for statistical trials

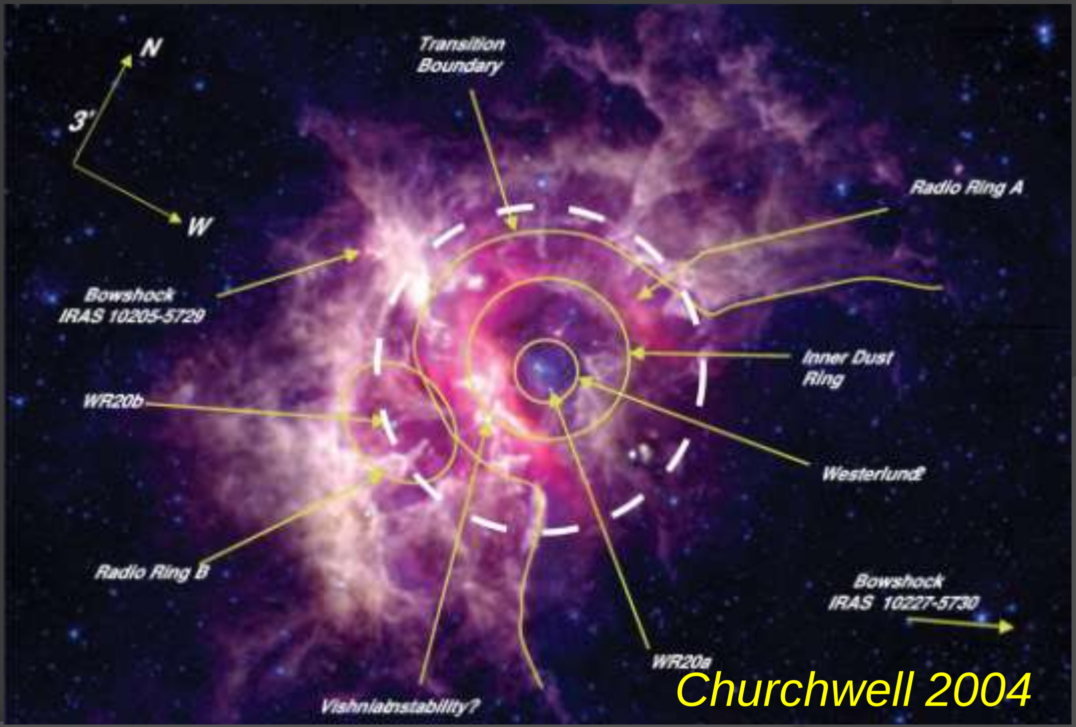




Westerlund 2星団

- Young open stellar cluster
  - Dozen O-stars
  - Two Wolf-Rayet stars (~80$M_\odot$ each)!
- Extended gamma-ray emission covering (but offset from) Westerlund 2 by HESS
- Due to collective effects of stellar winds in the cluster?
- A new source class?

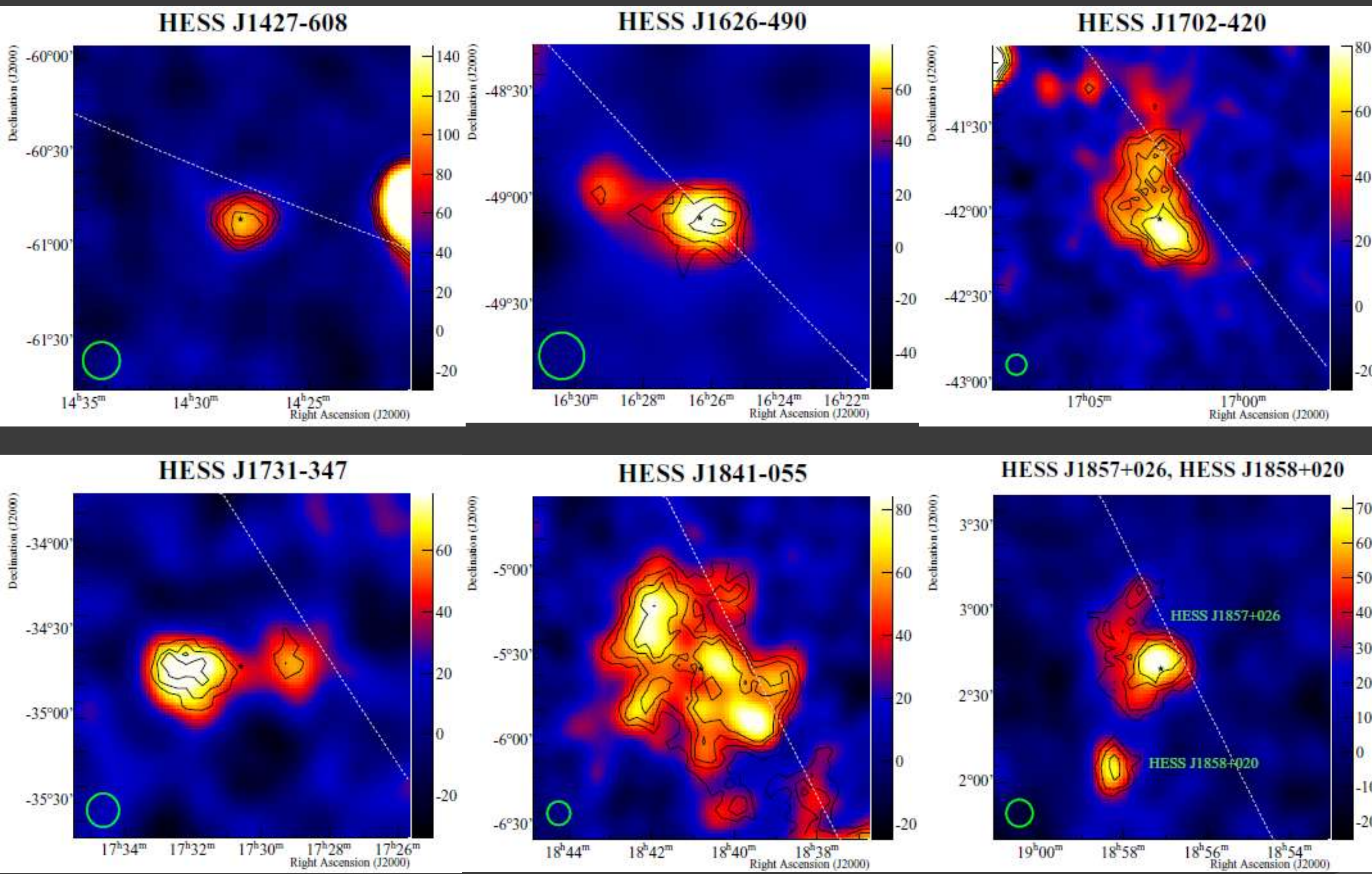




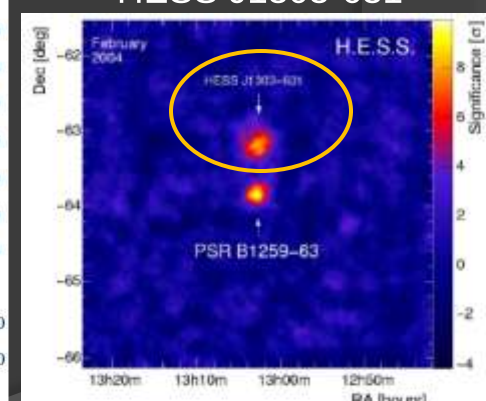
Churchwell 2004

F. Aharonian et al., A&A 477, 353 (2008)

HESS未同定天体



HESS J1303-631



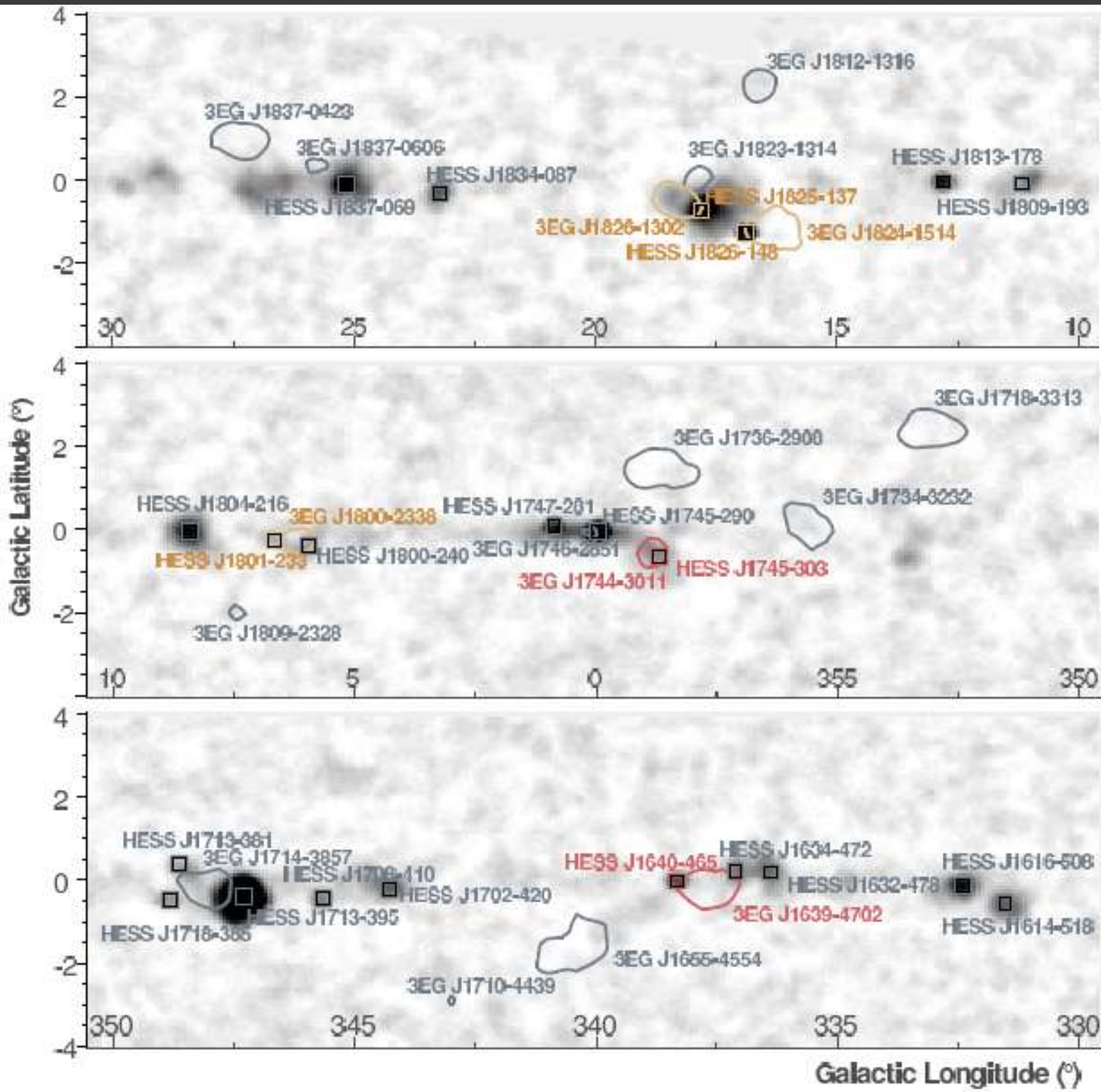
F. Aharonian et al., A&A 442, 1 (2005)

Two types:

1) No compelling counterparts
2) Dark in other wavelengths

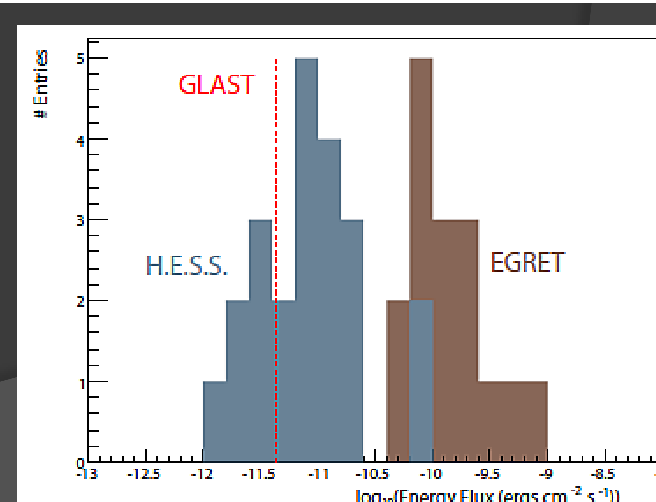
Funk et al., ApJ 679, 1299 (2008)

TeV-GeVの相関



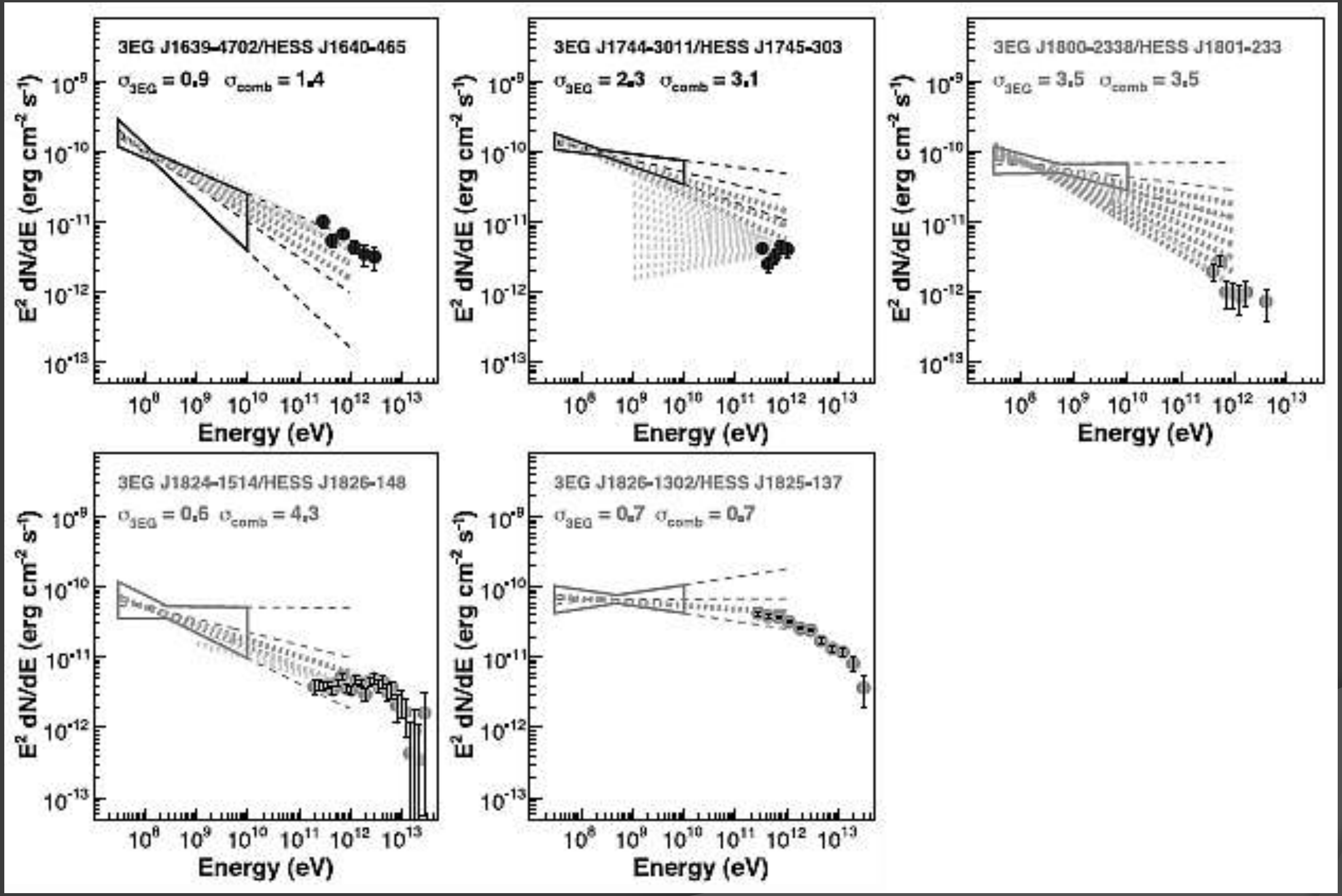
Coincident sources

EGRET source	VHE γ-ray source	Potential Counterpart
	Within the H.E.S.S. GPS	
3EG J1639–4702	HESS J1640–465	G338.3–0.0 (SNR/PWN)
3EG J1744–3011	HESS J1745–303	
3EG J1800–2338	HESS J1801–233	W28 (SNR)
3EG J1826–1302	HESS J1825–137	G18.0–0.7 (PWN)
3EG J1824–1514	HESS J1826–148	LS 5039 (Binary)
	Outside the H.E.S.S. GPS	
3EG J0241+6103	MAGIC J0240+613	LSI +61 303 (Binary)
3EG J0617+2238	MAGIC J0616+225	IC443 (SNR/PWN)
3EG J0634+0521	HESS J0632+058	Monoceros
3EG J1420–6038	HESS J1420–607	Kookaburra (PWN)



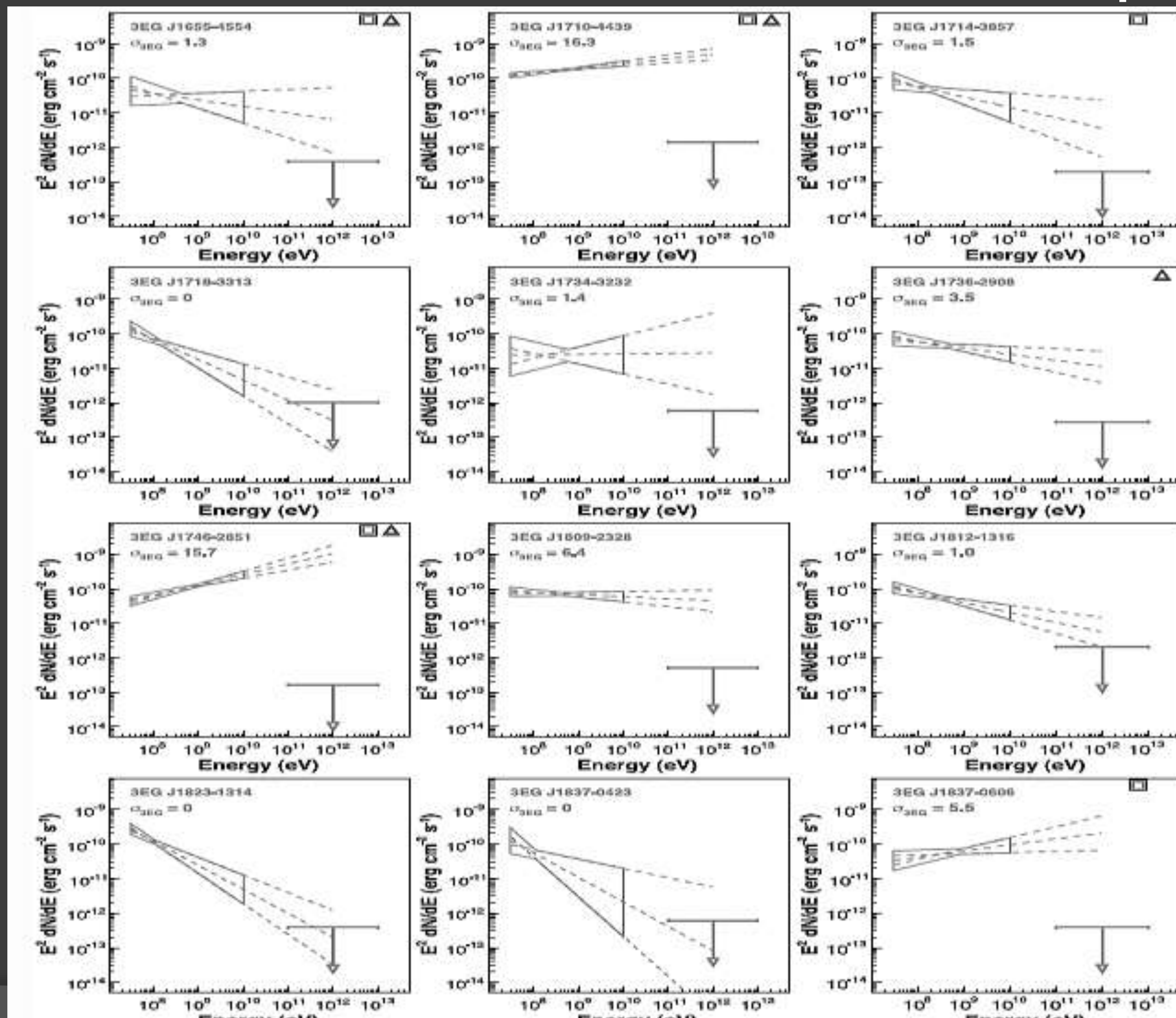
Funk et al., ApJ 679, 1299 (2008)

TeV-GeV spectral matching
(1) coincident sources



Funk et al., ApJ 679, 1299 (2008)

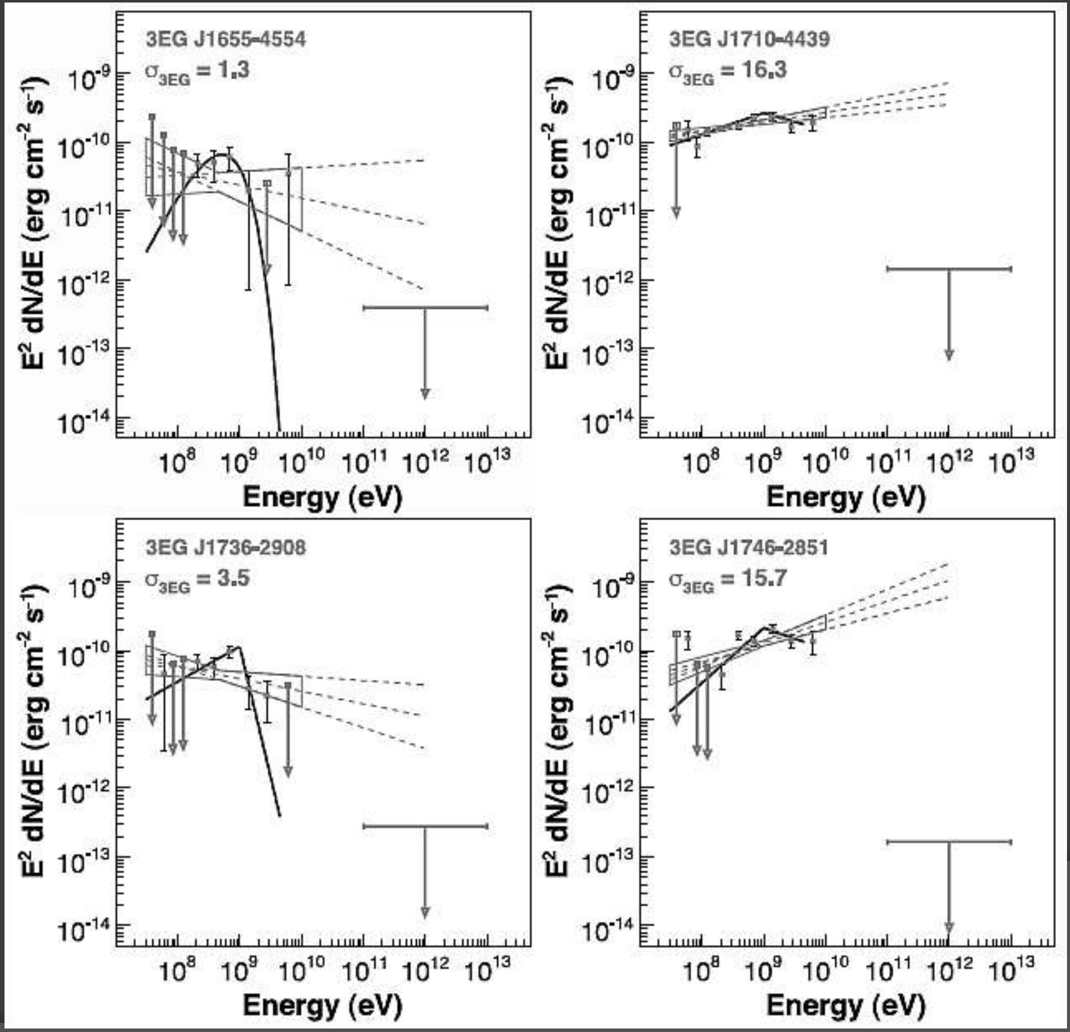
TeV-GeV spectral matching
(2) GeV source with no TeV counterpart



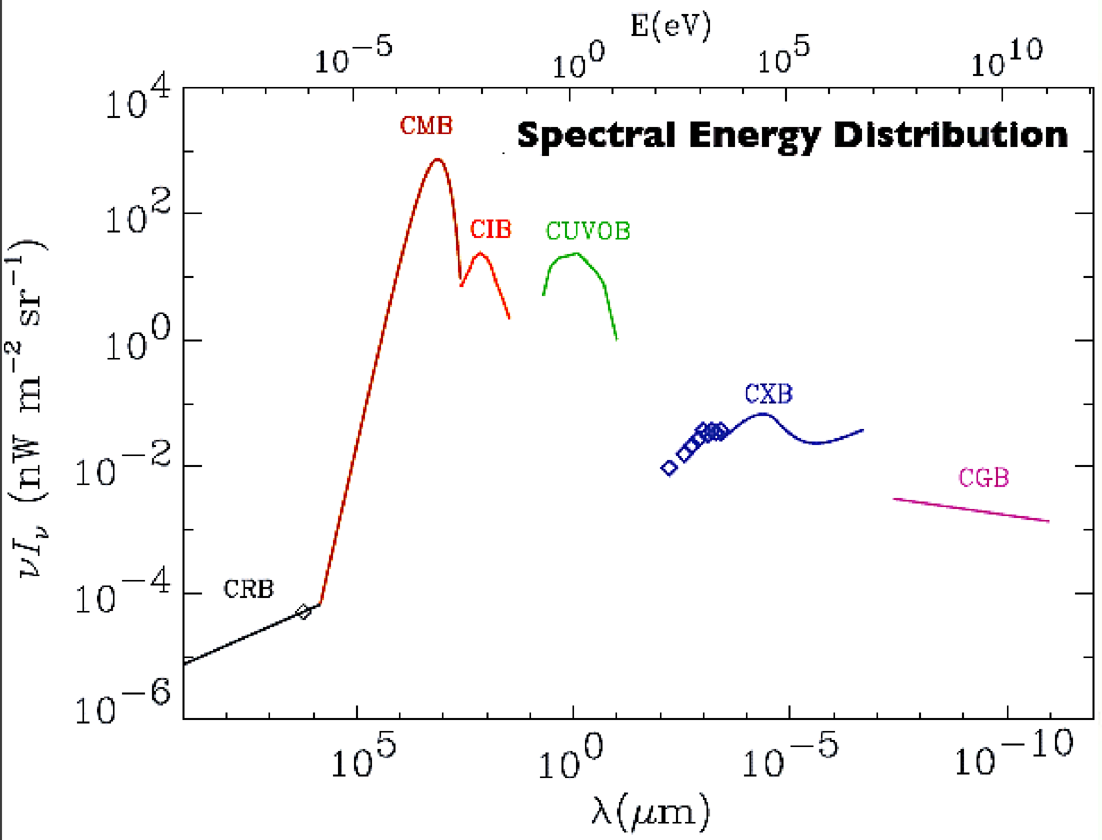
Funk et al., ApJ 679, 1299 (2008)

TeV-GeV spectral matching

(3) GeV source showing bending with no TeV counterpart

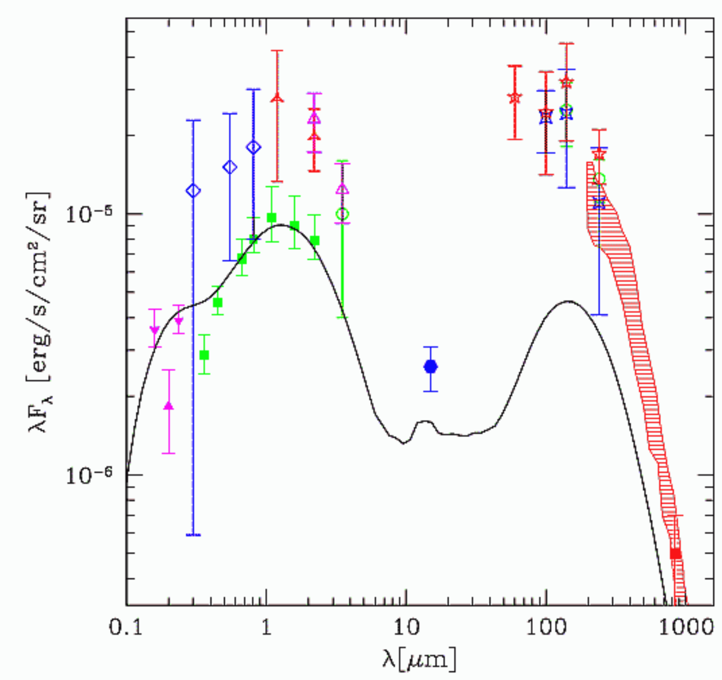


宇宙の背景放射



Raue & Mazin, arXiv:0802.0129

背景赤外線放射

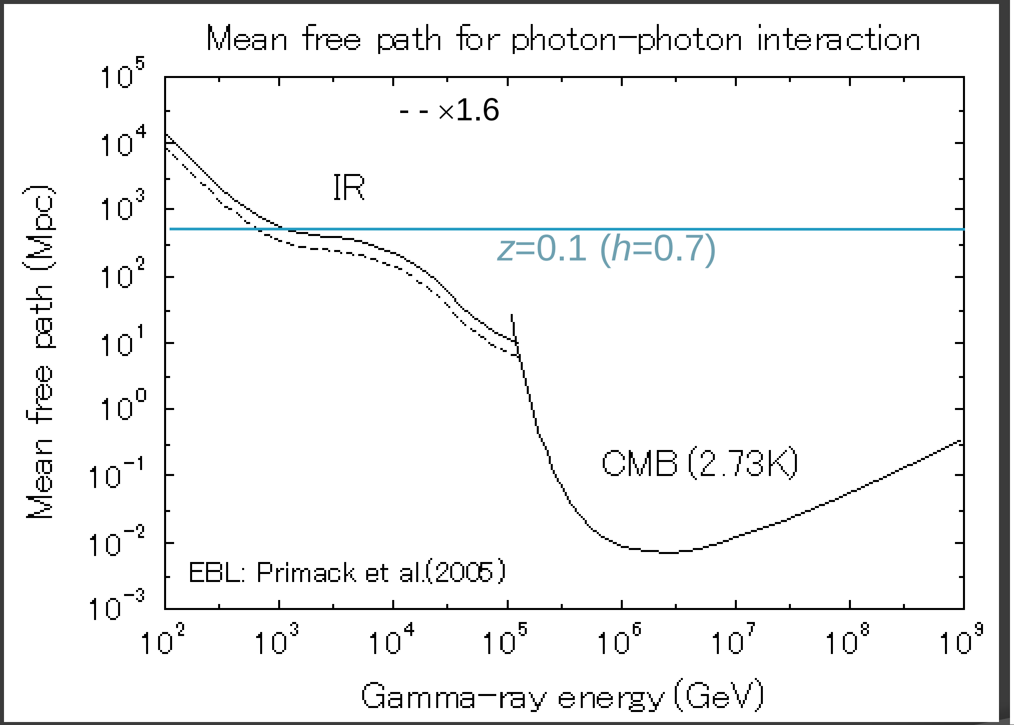


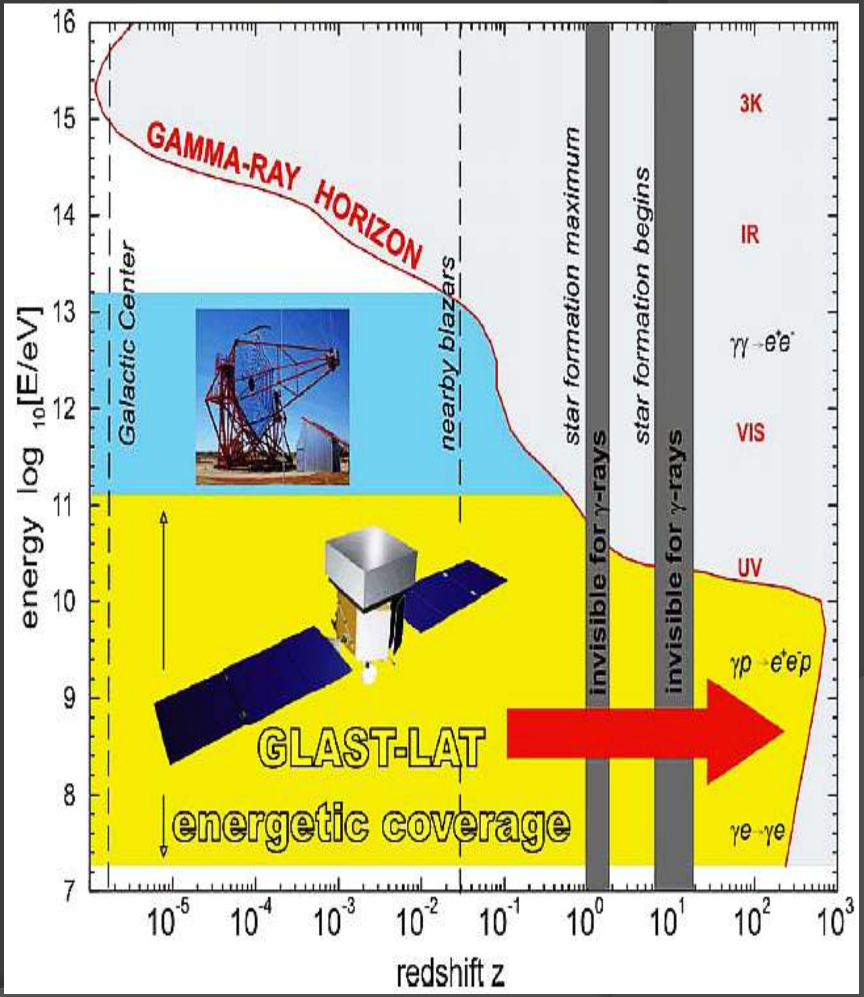
Primack et al., AIP Conf.745, 23 (2005)

Gamma-ray horizon

$$\gamma_{HE} + \gamma_{bkgd} \rightarrow e^{+} + e^{-}$$

Peak: $\lambda_{bkgd} \approx 1.5\ (E/1\ \mathrm{TeV})\ \mu\mathrm{m}$





O.Reimer, KIPAC Nov.2007

Interstellar radiation field

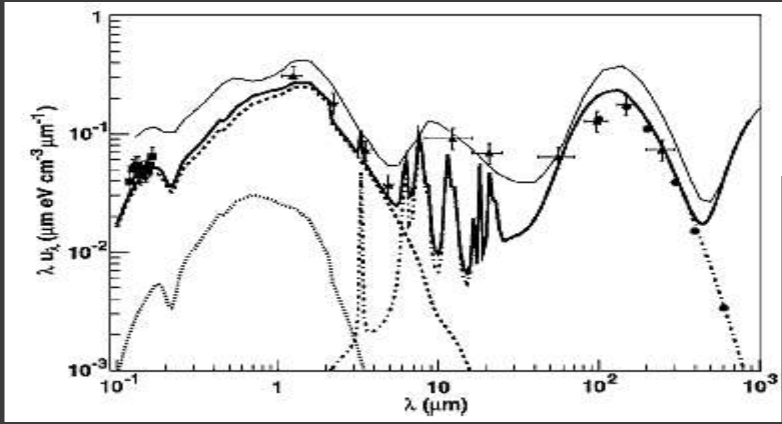
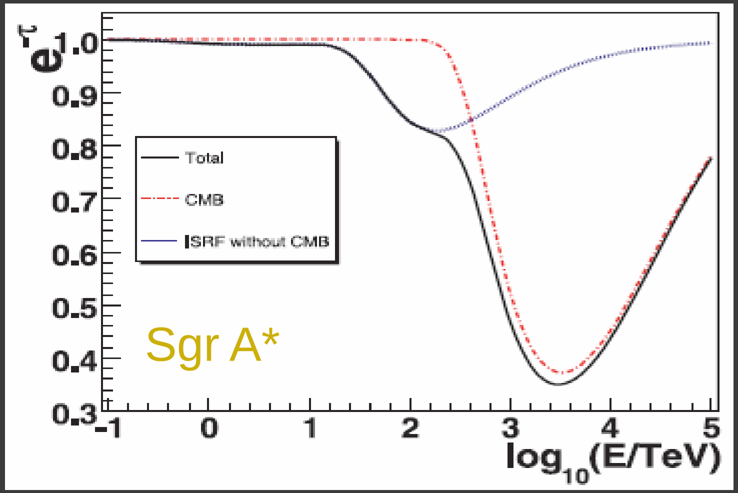


FIG. 1.—Interstellar radiation field energy density. *Top*: Local interstellar radiation field. *Thick solid line*, total radiation field including CMB; *thick dashed line*, contribution by stars; *thick dotted line*, scattered light; *thick dot-dashed line*, infrared; *thin solid line*, local ISRF from Strong et al. (2000). Data: *Squares*, *Apollo* (Henry et al. 1980); *triangles*, DIRBE (Arendt et al. 1998); *circles*, FIRAS (Finkbeiner et al. 1999). *Bottom*: Interstellar total ra-

Moskalenko et al., ApJ 460, L155 (2006)



Zhang et al., A&A 449, 641 (2006)

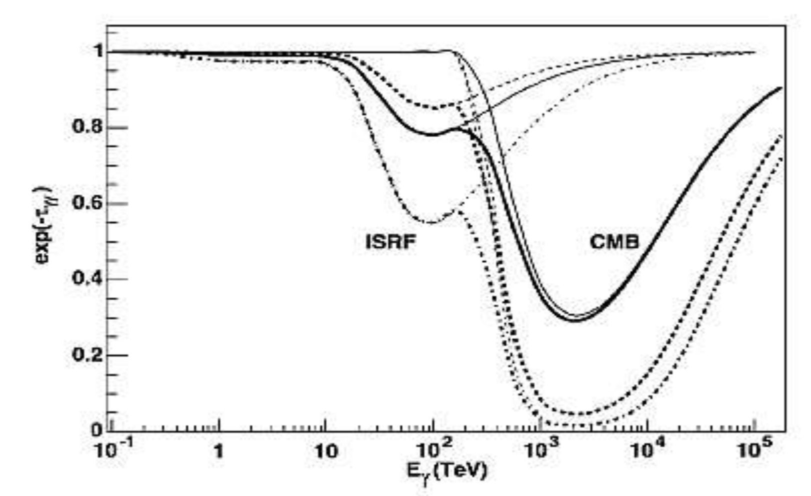


FIG. 3.—Transmittance of VHE γ-rays as a function of γ-ray energy. *Solid lines*, $(R, z, \alpha) = (0$ kpc, 0 kpc, $0°)$ ($L = 8.5$ kpc); *dashed lines*, $(R, z, \alpha) =$ (20 kpc, 0 kpc, $90°$) ($L = 21.8$ kpc); *dash-dotted lines*, $(R, z, \alpha) =$ (20 kpc, 0 kpc, $180°$) ($L = 28.5$ kpc). Thick lines give the total transmittance curve including the ISRF and CMB. The leftmost thin lines give the transmittance for the ISRF only, and the rightmost thin lines that for the CMB only.

Moskalenko et al., ApJ 460, L155 (2006)

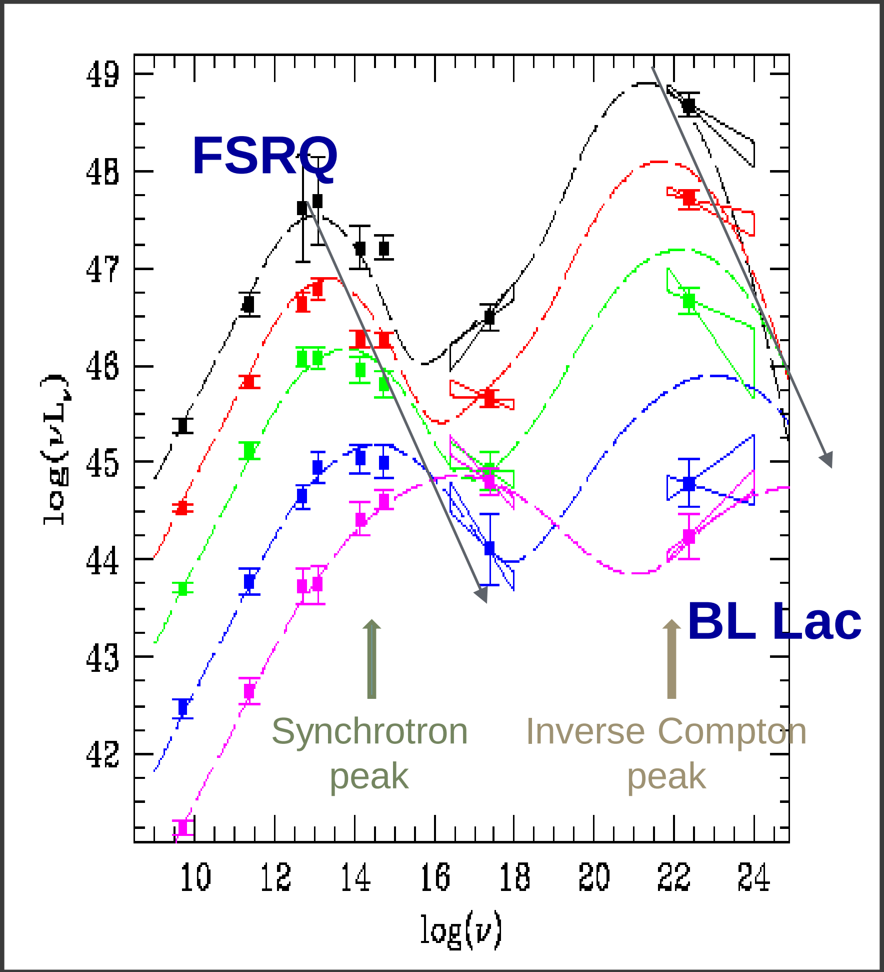
Some attenuation at >50TeV!
(depending on location)

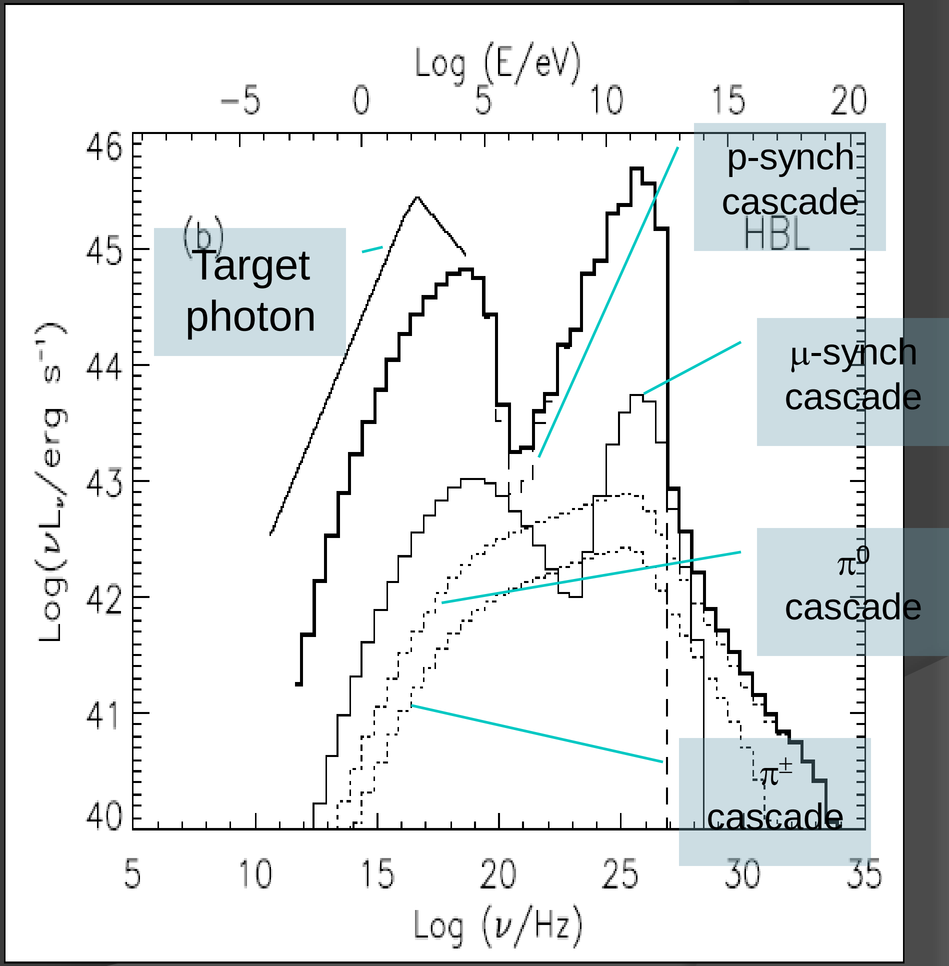
Extragalactic TeV sources

No.	Object	z	Class	Discovered
1	M87	0.004	Radio	HEGRA,2003
2	**3C66B**	**0.021**	**Radio**	**HESS, 2008**
3	Mrk421	0.031	HBL	Whipple,1992
4	Mrk501	0.034	HBL	Whipple,1996
5	1ES 2344+514	0.044	HBL	Whipple,1998
6	**Mrk180**	**0.046**	**HBL**	**MAGIC,2006**
7	1ES 1959+650	0.047	HBL	7TA,1999
8	**BL Lac**	**0.069**	**LBL**	**MAGIC,2007**
9	**PKS 0548-322**	**0.069**	**HBL**	**HESS,2007**
10	PKS 2005-489	0.071	HBL	HESS,2005
11	**RGB J0152+017**	**0.08**	**HBL**	**HESS, 2007**
12	**W Com**	**0.102**	**IBL**	**VERITAS, 2008**
13	PKS 2155-304	0.116	HBL	Durham,1999
14	H 1426+428	0.129	HBL	Whipple, 2002
15	**1ES 0806+524**	**0.138**	**HBL**	**VERITAS, 2008**
16	**1ES 0229+428**	**0.140**	**HBL**	**HESS,2007**
17	**H2356-309**	**0.165**	**HBL**	**HESS,2006**
18	1ES 1218+304	0.182	HBL	MAGIC,2006
19	1ES 1101-232	0.186	HBL	HESS,2006
20	**1ES 0347-121**	**0.188**	**HBL**	**HESS,2007**
21	**1ES 1011+496**	**0.212**	**HBL**	**MAGIC,2007**
22	**PG 1553+113**	**>0.25**	**HBL**	**HESS,2006**
23	**S5 0716+714**	**0.33?**	**Blazar**	**MAGIC, 2008**
24	**3C279**	**0.536**	**FSRQ**	**MAGIC,2007**

13 new sources since 2006

AGNの放射機構





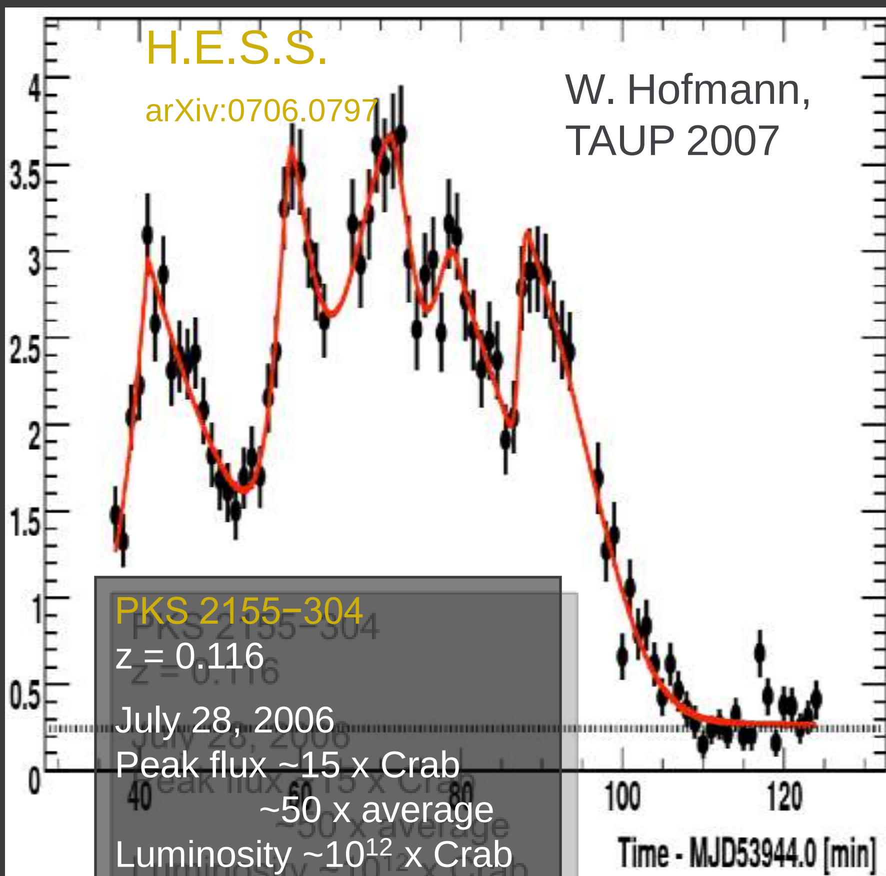
Electron model

Fossati et al. 1998

Proton model

Muecke et al. APh 18, 2003

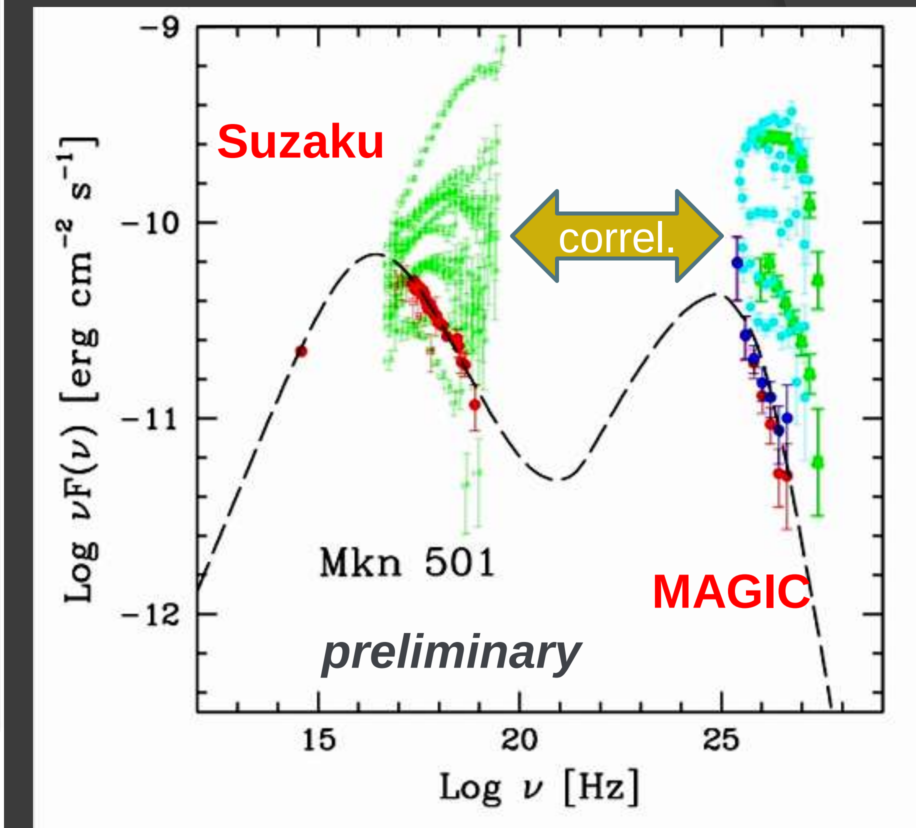
速い時間変動



PKS 2155−304
z = 0.116

July 28, 2006
Peak flux ~15 x Crab
~50 x average
Luminosity ~10^{12} x Crab
Doubling times
67, 116, 173, 178 ±50 s

$R_{BH}/c \sim 1...2 \cdot 10^4$ s

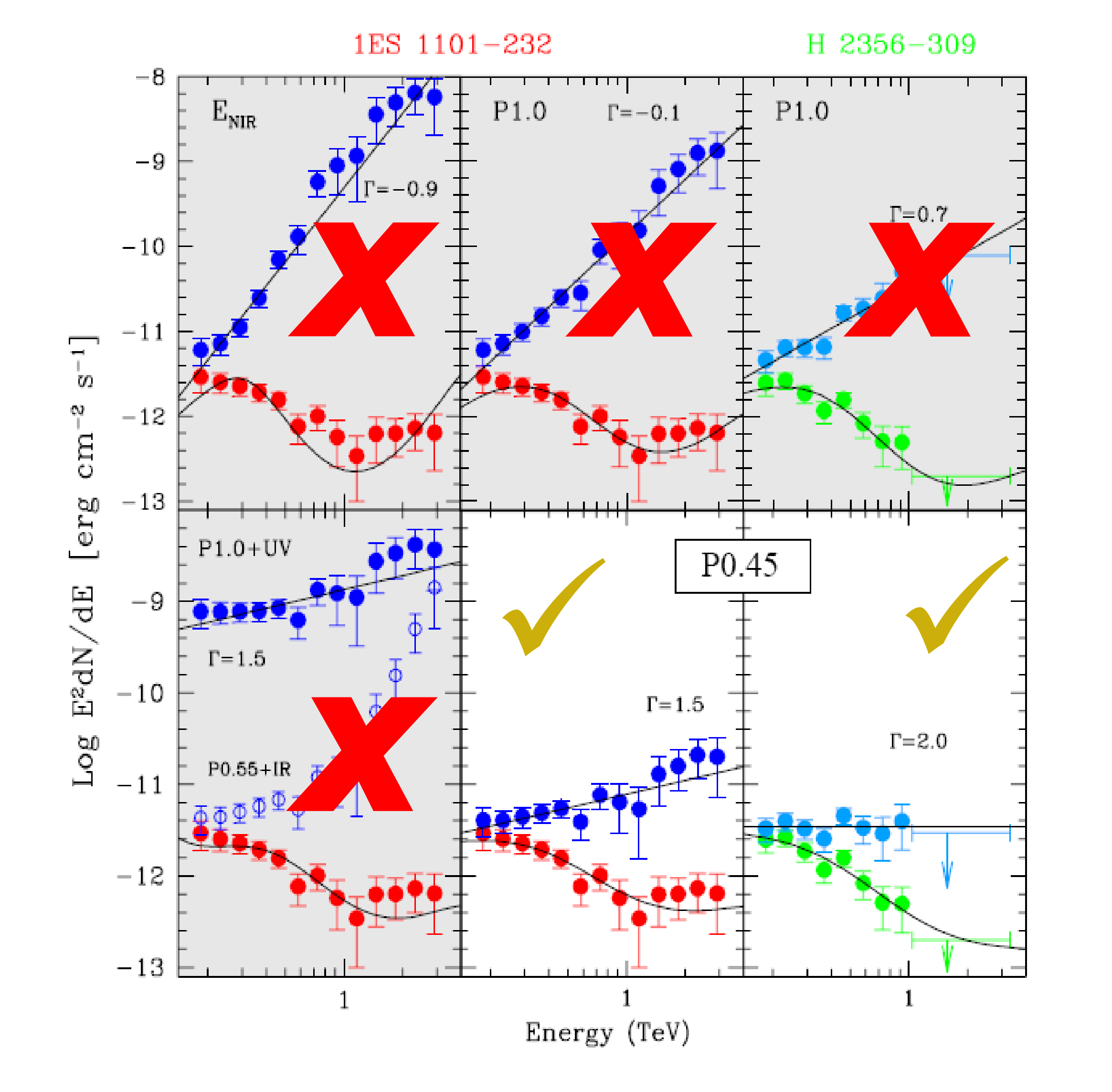


M. Hayashida, ICRC 2007

Fast variation ↔ Acceleration site & mechanism

H.E.S.S.: Aharonian et al., Nature 440, 1018 (2006)

ソーススペクトルに戻す

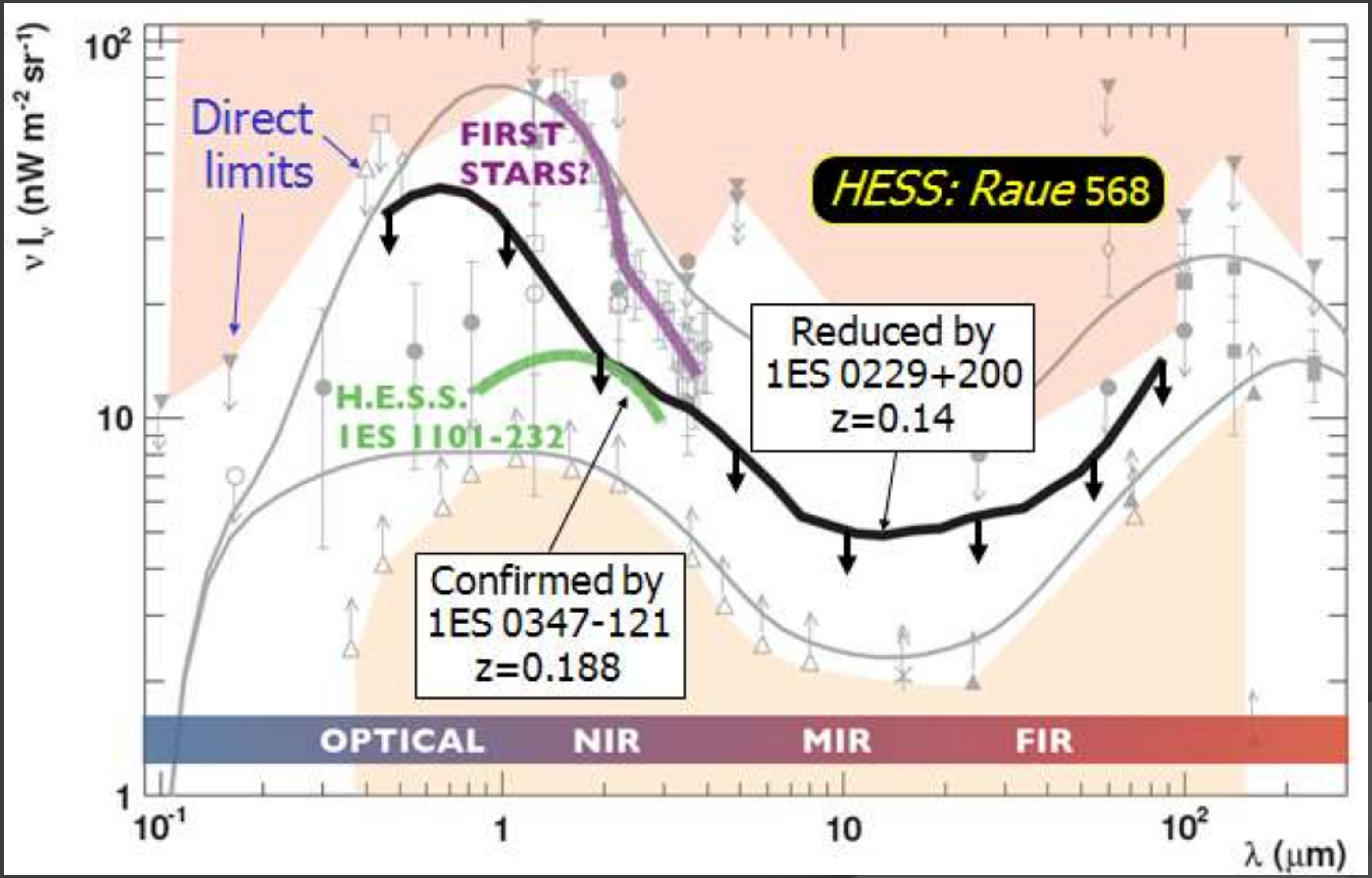


Source spectrum is unknown!

Assume not harder than $E^{-1.5}$

Some models can be rejected

背景赤外線量のTeV観測による制限



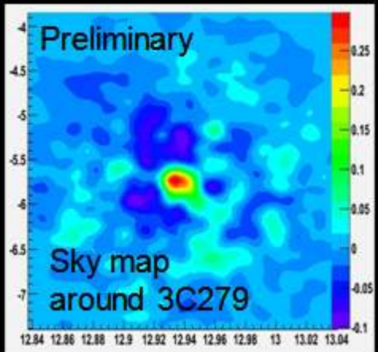
Upper limits: fluctuation/direct measurements
Lower limits: source counts

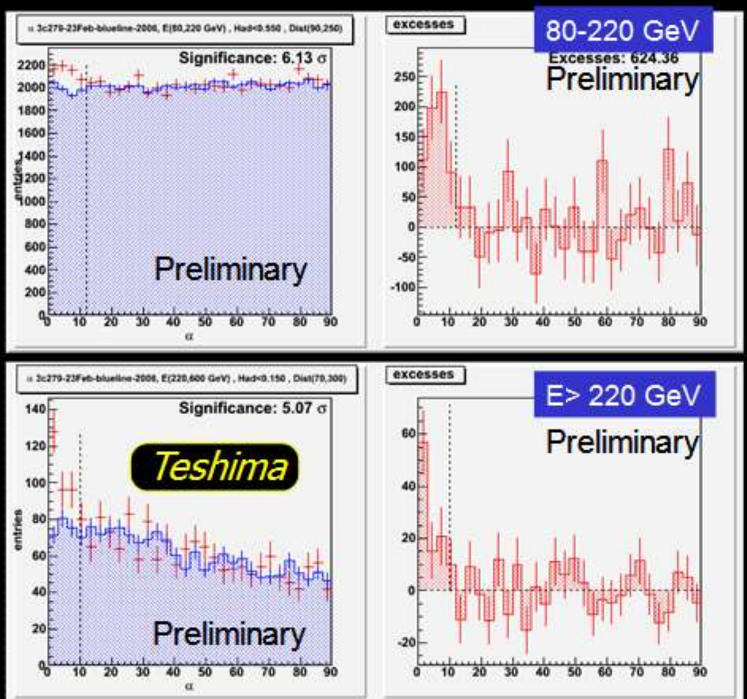
Albert et al., Science 320, 1752 (2008)

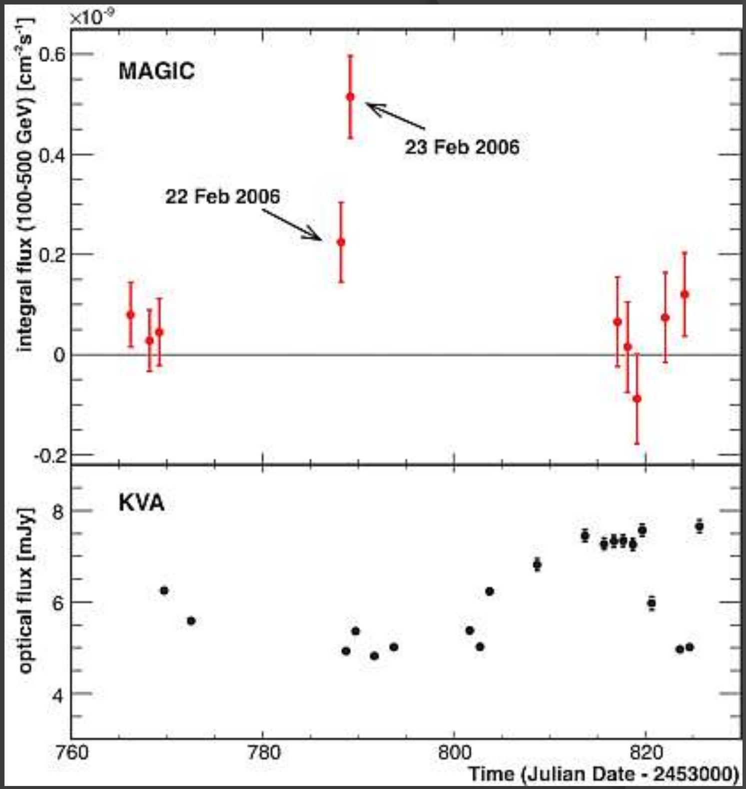
3C279 at z=0.538

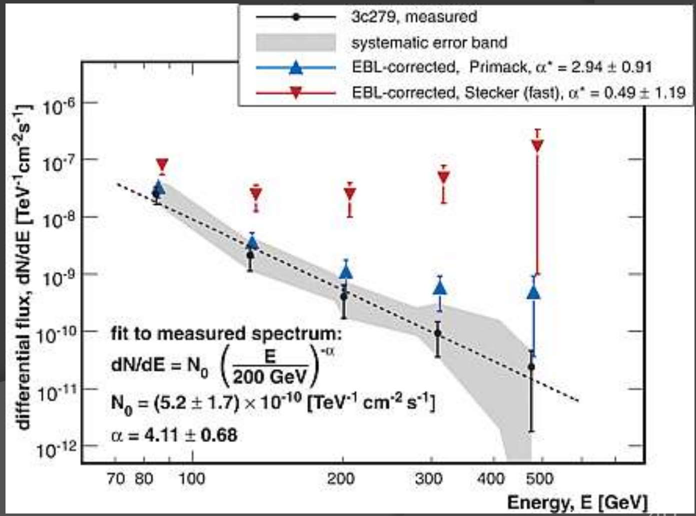
3C 279: One night, 23rd Feb 2006

- 6.1 σ in low Energy band
  - Post-trails?
- 5.1 σ >220 GeV
  - Surprising!



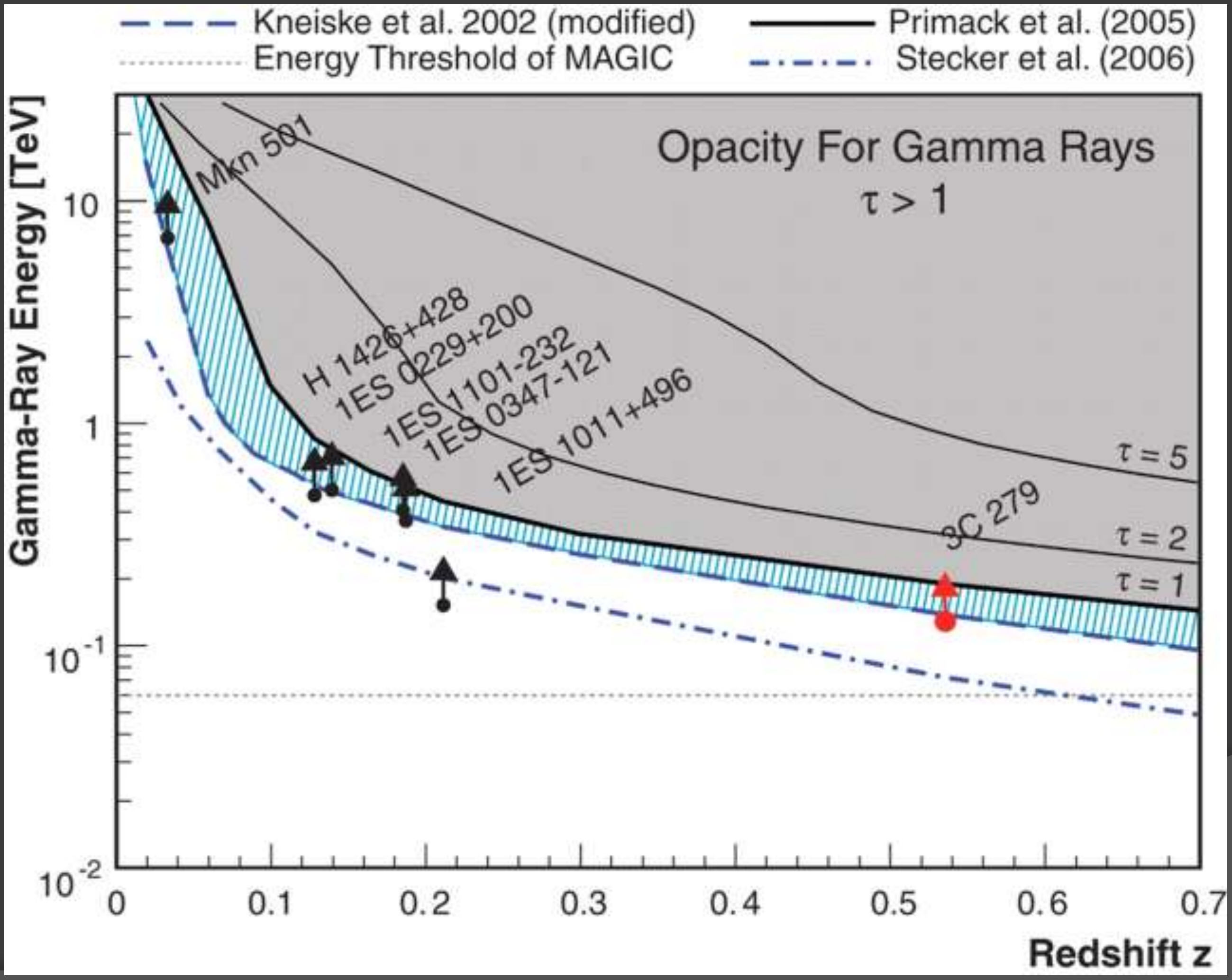






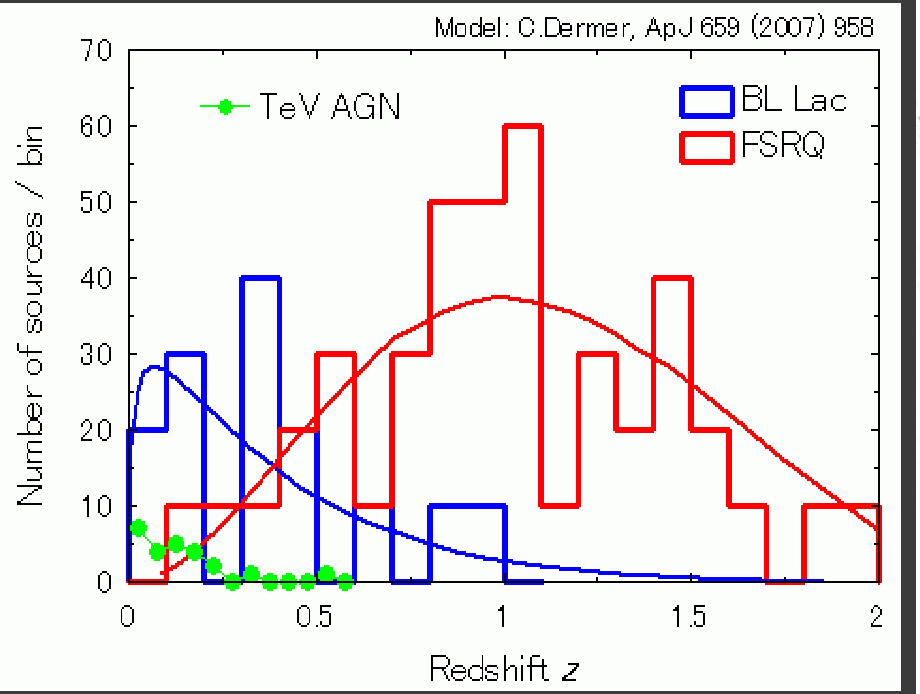
Albert et al., Science 320, 1752 (2008)

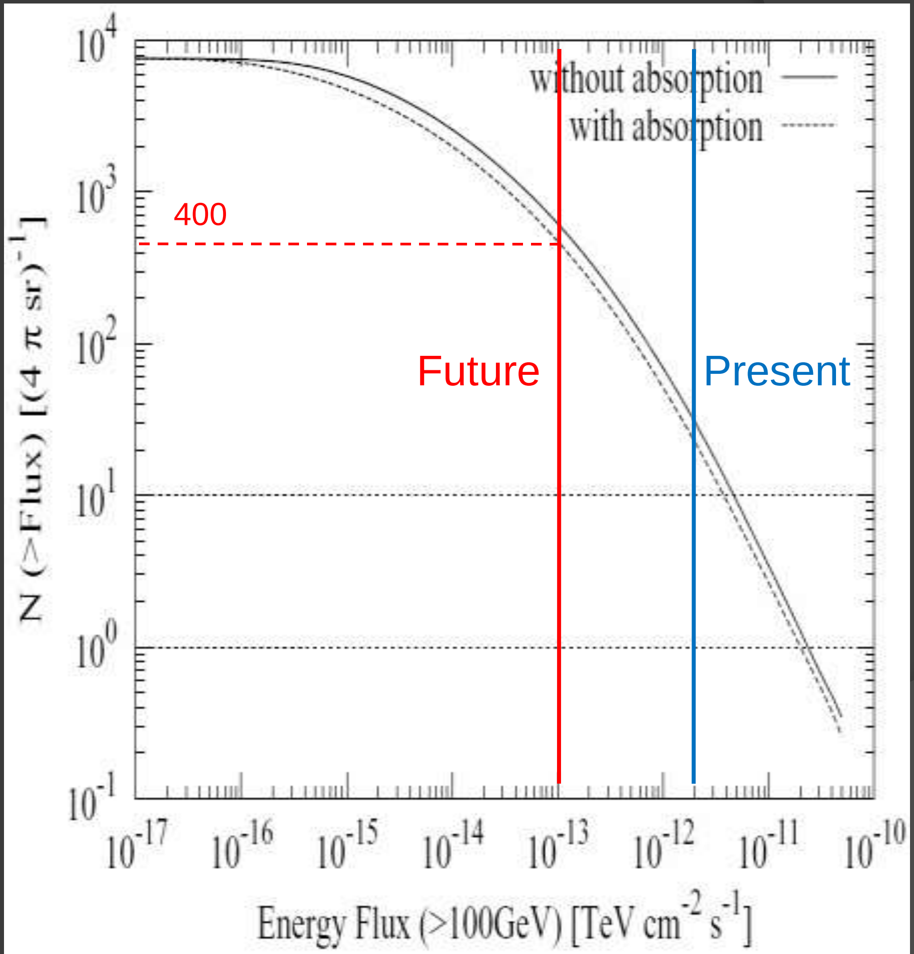
Gamma-ray horizon tested



Blazar distribution model

Inoue&Totani, arXiv:0810.3580 / private comm.





TeVの観測からわかったこと

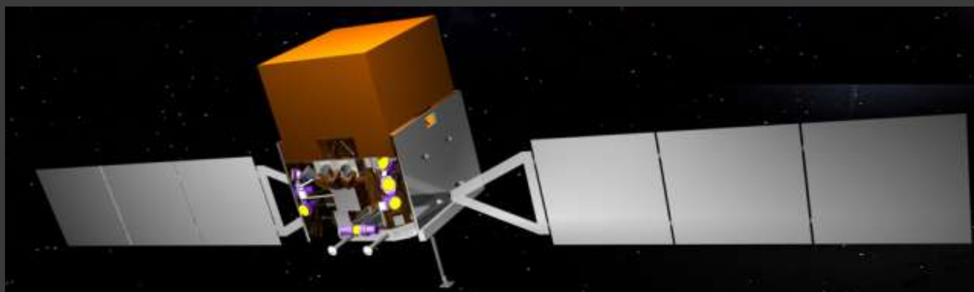
- 超新星残骸にはTeVガンマ線源がある。スペクトルは~E^{-2}で~20TeVまで伸びている。
- TeV天体は銀河中心、パルサー星雲、X線連星、OB association、マイクロクェーサーなど最初の期待よりずっと多彩である。
- TeVでしか検出されていない未同定天体がある。
- Crab pulsarからのパルス放射は数十GeVまで延びている。
- 活動銀河核には激しい時間変動のTeVガンマ線源がある。電子起源がもっともらしい。
- 背景赤外線密度はnumber countから見積もられた下限程度に低い。
- 電波銀河にもTeVガンマ線源がある。

まだわからないこと

- 超新星残骸で加速されているのは陽子か電子か？
- 超新星残骸での加速限界はどこか？宇宙線のKneeとはつながるのか？
- 超新星残骸と分子雲の相互作用は見えているのか？
- 銀河中心からのガンマ線の起源は何か？
- パルサーでの加速限界は？
- パルサー星雲での加速・放射機構はどう働くのか?
- TeV未同定天体とは何か？
- 活動銀河核の放射は電子起源でよいのか？ジェットにおける粒子加速機構はどう働くのか？
- 背景赤外線の量は本当に少ないのか？

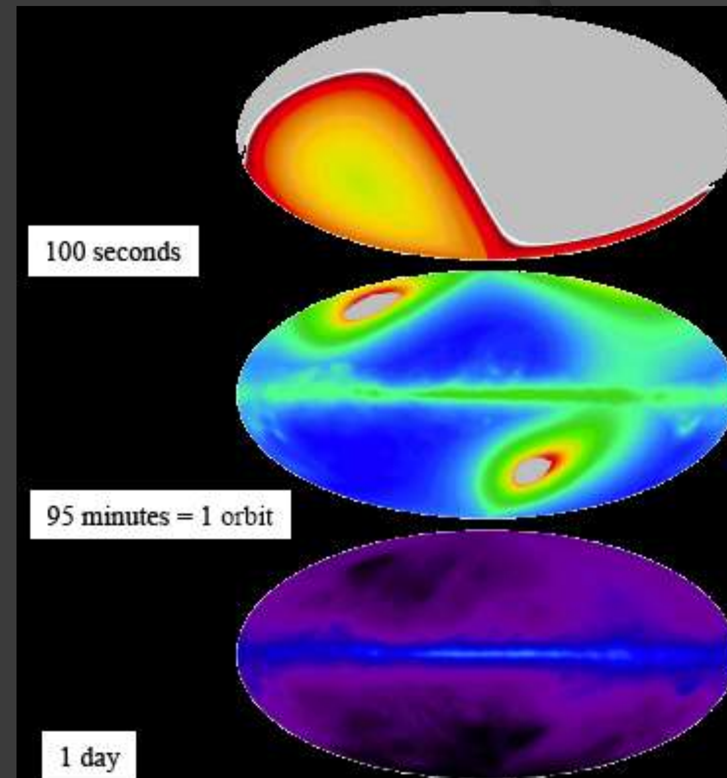
http://fermi.gsfc.nasa.gov/

Fermi Gamma-ray Space Telescope

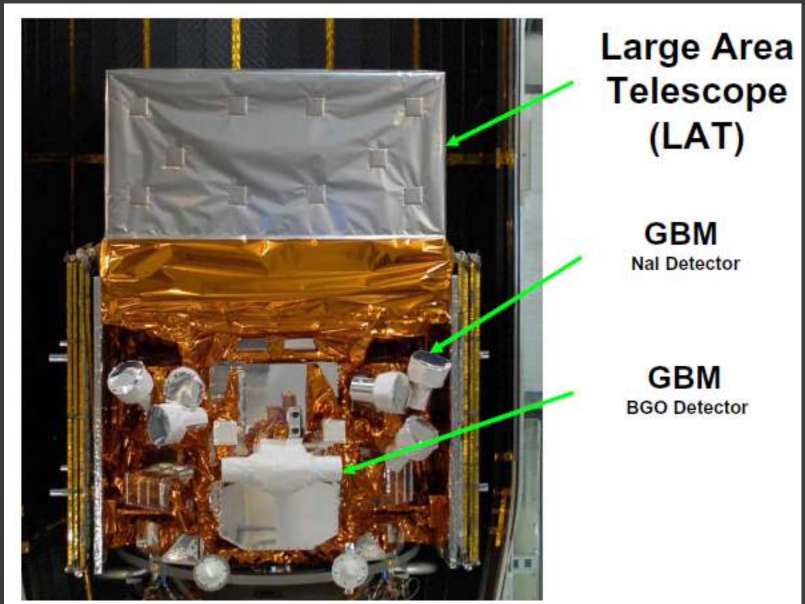


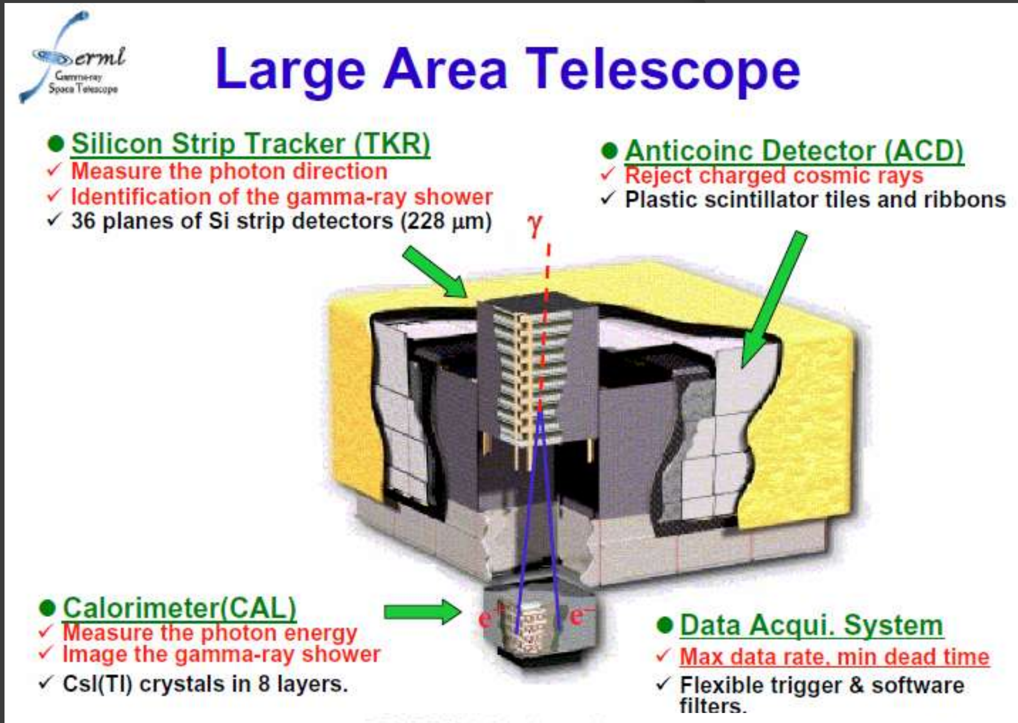
2008年6月11日
打上成功

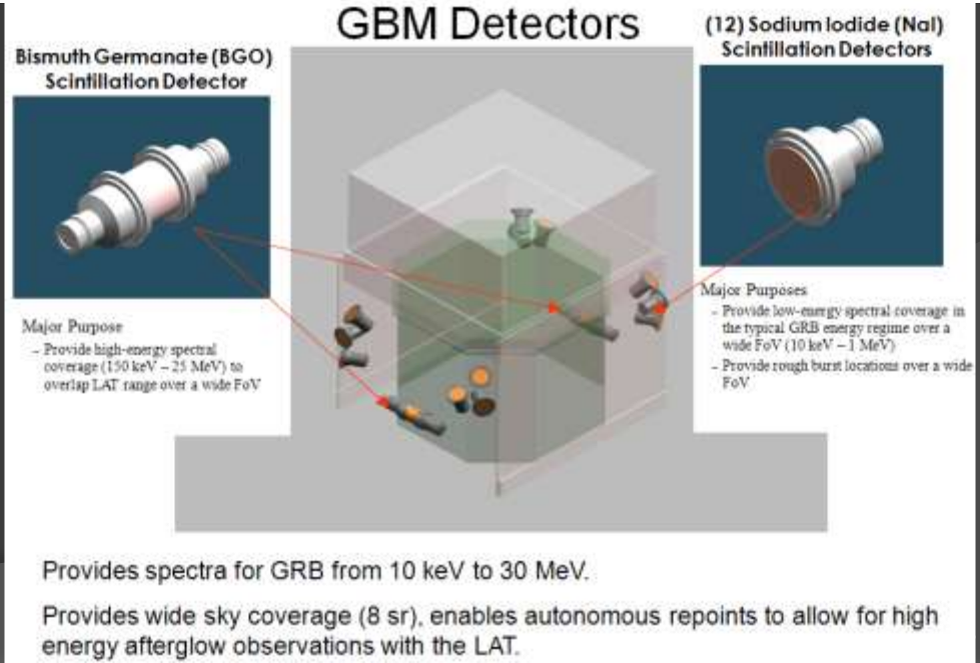
	GLAST/LAT	EGRET
Energy Range	20 MeV ... 300 GeV	30 MeV ... 10+ GeV
Energy Resolution	0.1	0.1
Effective Area	9000 cm^2	1500 cm^2
Field of View	2.2 sr.	0.5 sr.
Angular Resolution	3.5 @ 100 MeV 0.1@10 GeV	5.8@100 MeV 0.5@10 GeV
Sensitivity (>100 MeV)	3×10^{-9} cm^{-2} s^{-1}	$\sim10^{-7}$ cm^{-2} s^{-1}
Deadtime	27 μs	100ms



Fermi





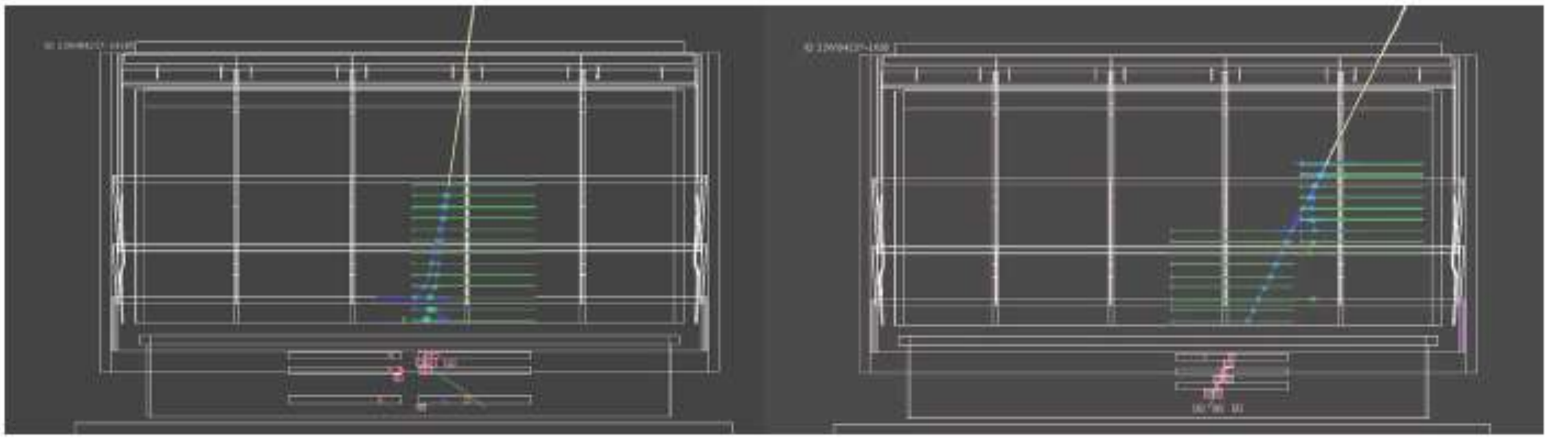


T.Kamae, RESCEU symposium, Nov.2008

J.McEnery, 4th NHEGE, Elba, Italy, 2006

Fermi LAT event sample

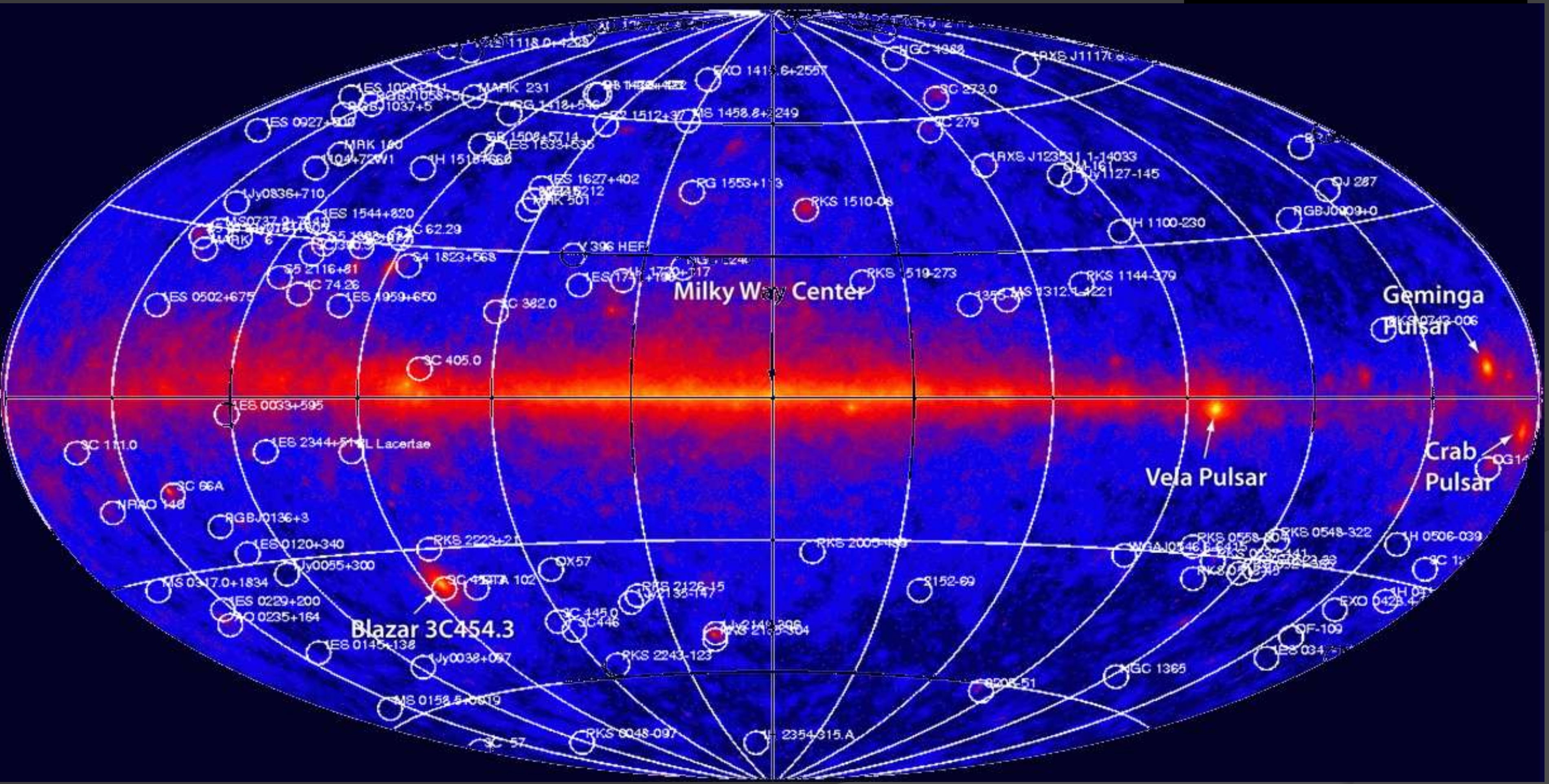
Event Reconstruction on Ground



- **Pulse heights** at all TKR Si strips, CAL CsI logs and ACD tiles/ribbons with signals are recorded with **time stamps (dt~25us).**
- Candidate gamma-ray events are **reconstructed on ground** (see Figs).
- Charged particle cosmic-ray events are also sampled and recorded for monitoring and calibration purpose.

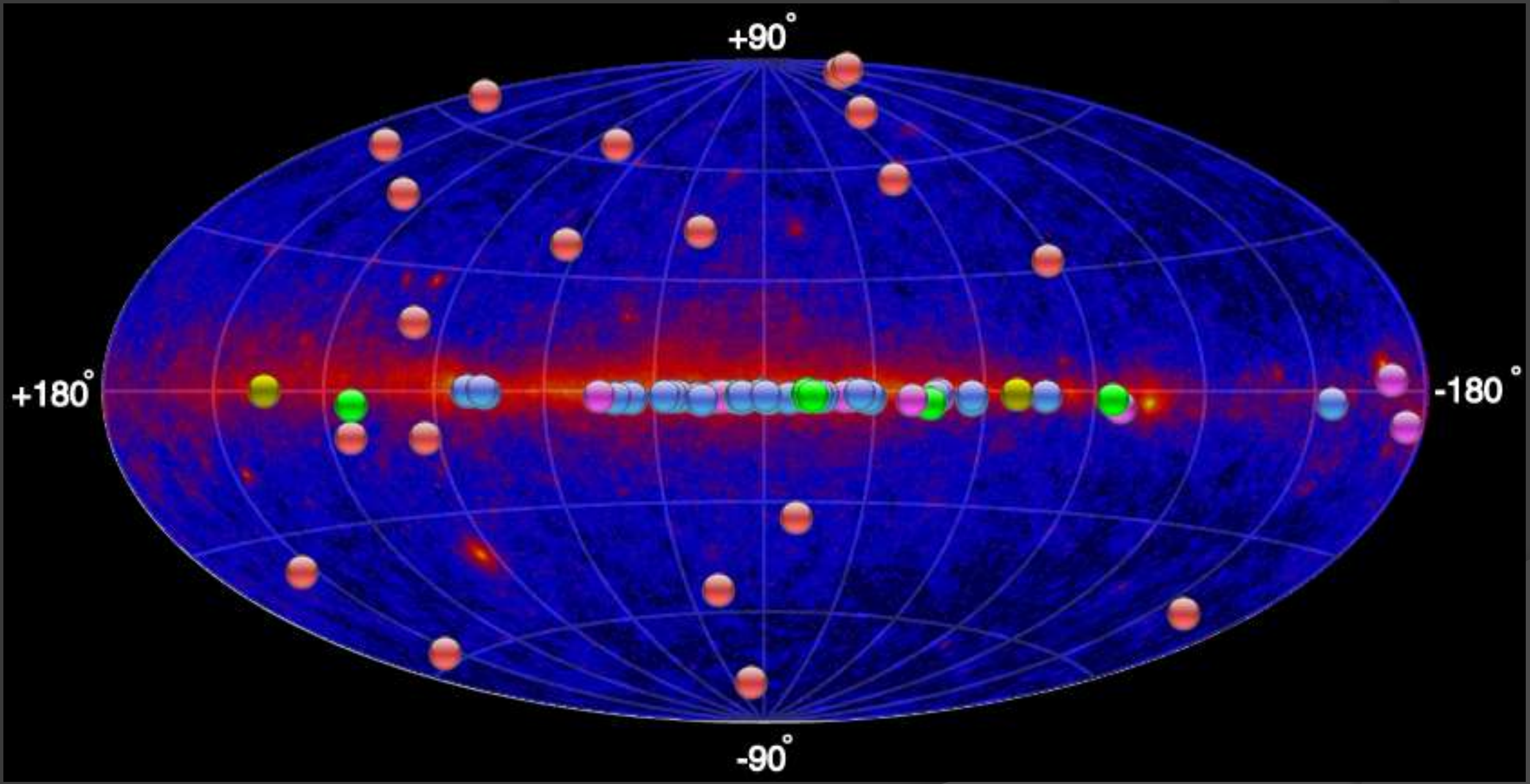
Fermi Firstlight skymap

With AGN catalog

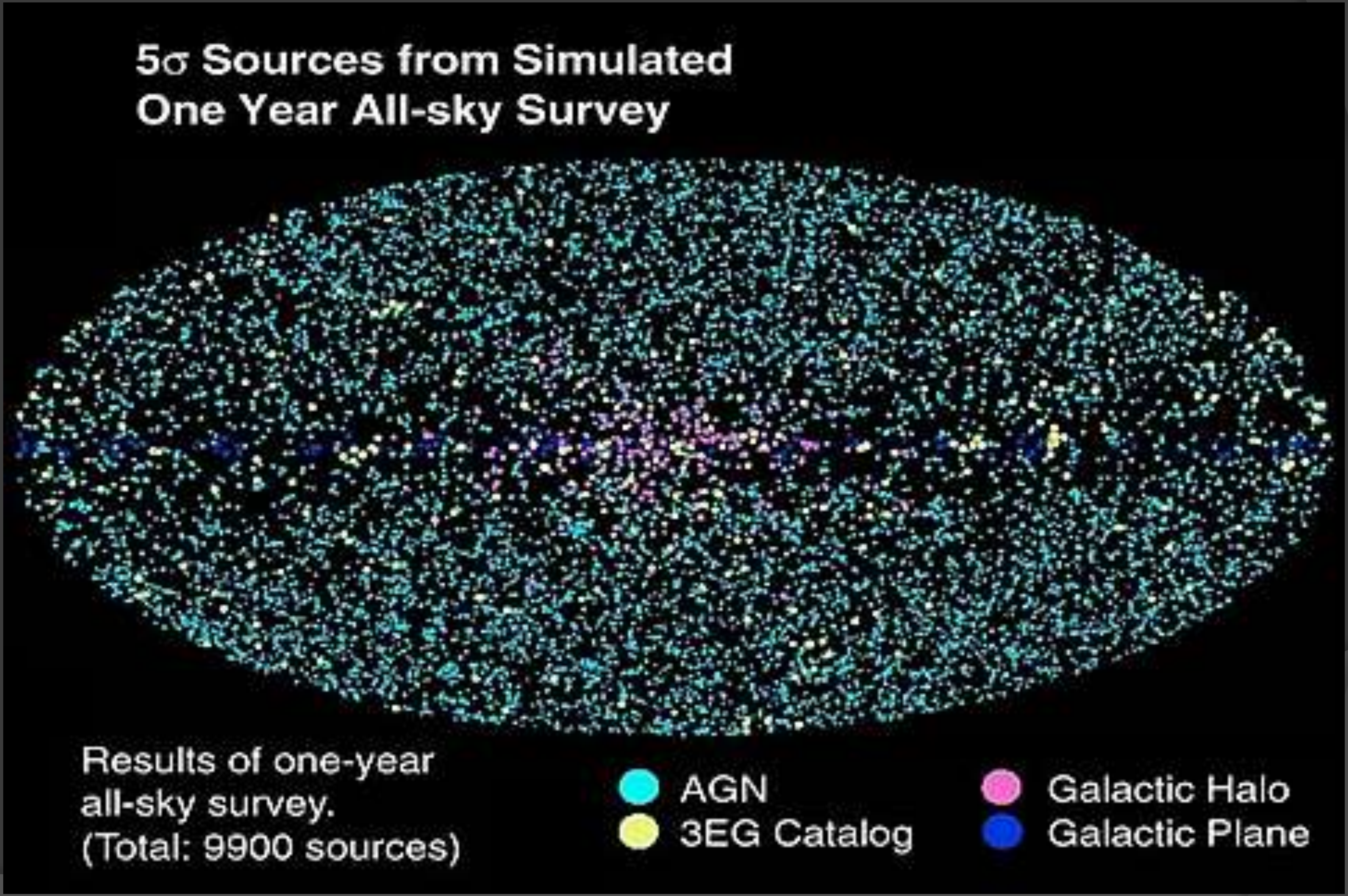


http://tevcat.uchicago.edu/

Firstlight map & TeV sources



Simulated Fermi skymap



Baltz et al., arXiv:0806.2911

Fermi sensitivity for dark matter

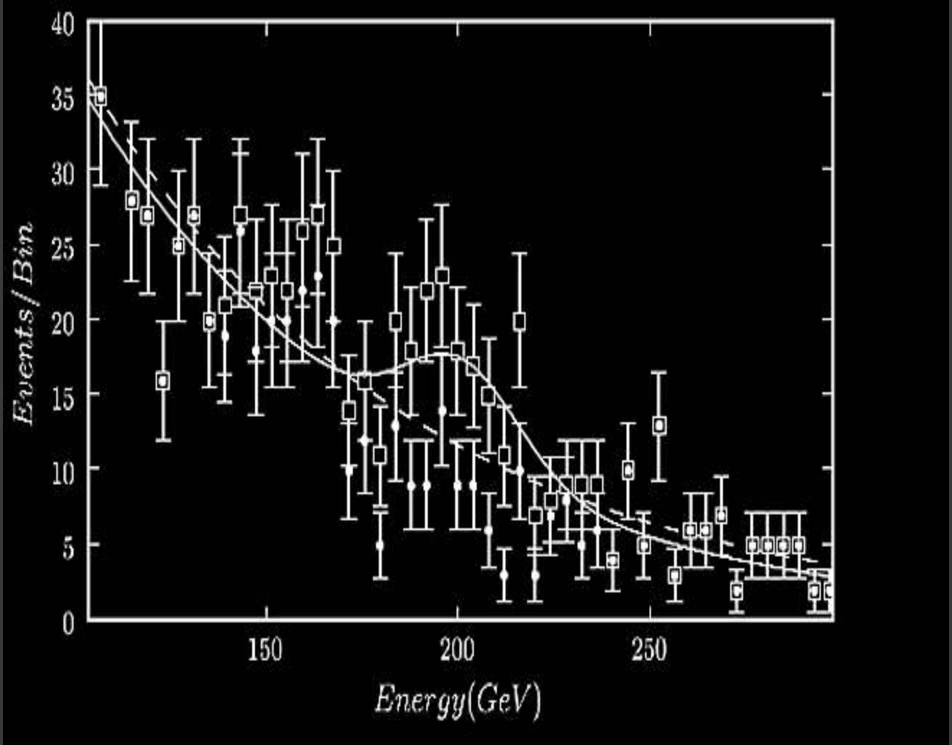


Figure 20. "Optimized" diffuse background and a 5σ signal at 200 GeV. The black dots and open squares correspond to the diffuse background and the diffuse background plus MC signal, respectively. Full and dotted lines correspond to the signal plus background fit to $\phi2$ and $\phi1+\phi2$, respectively. $< \Delta\chi^2 >=25.0$ for this run.

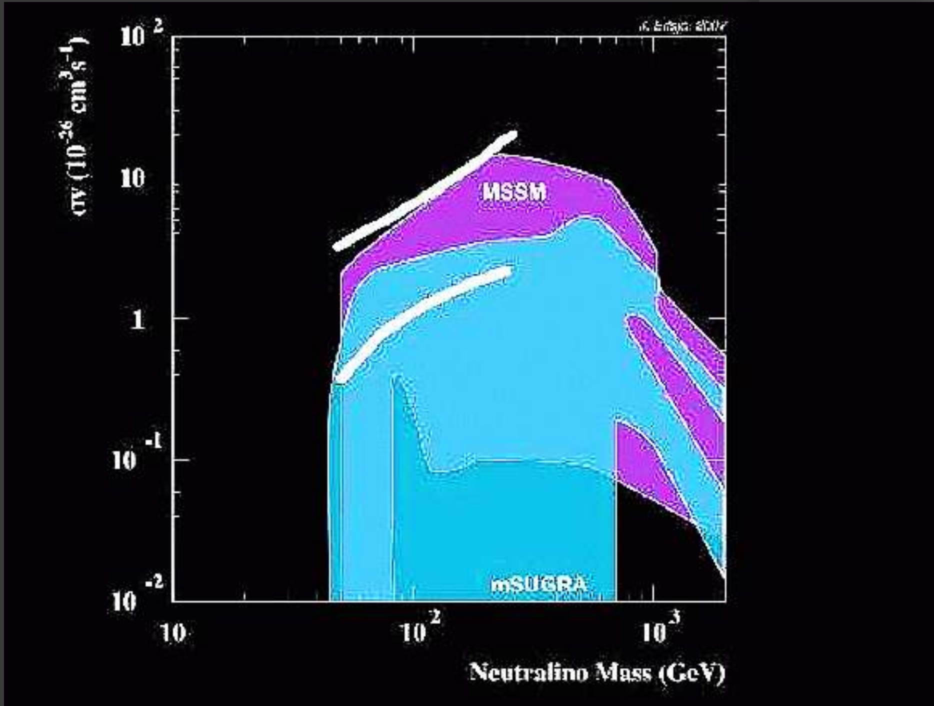
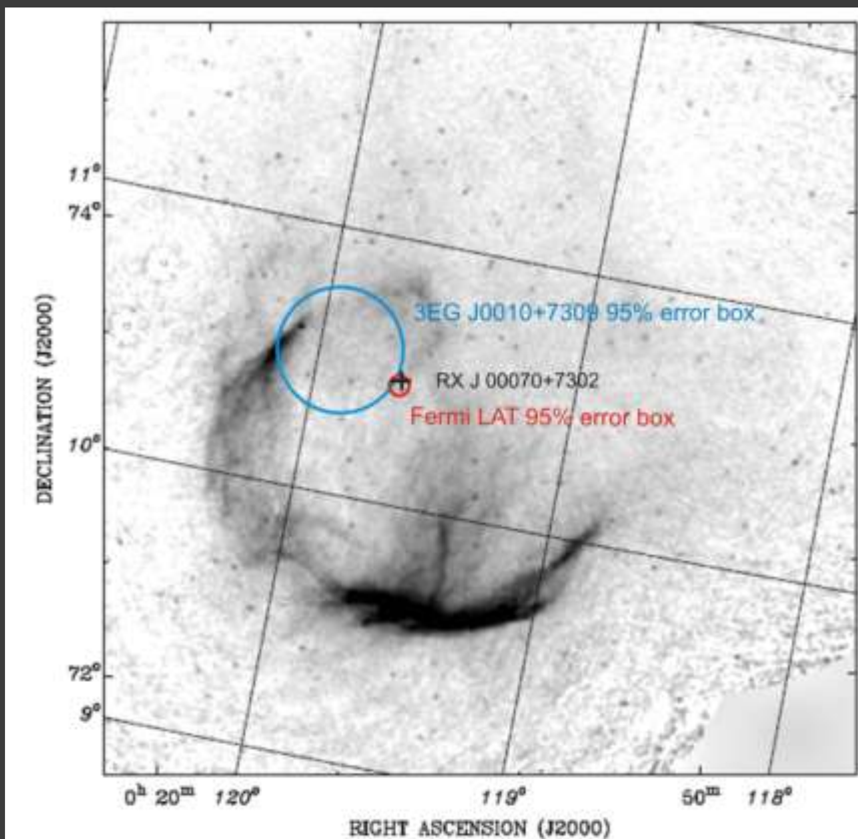
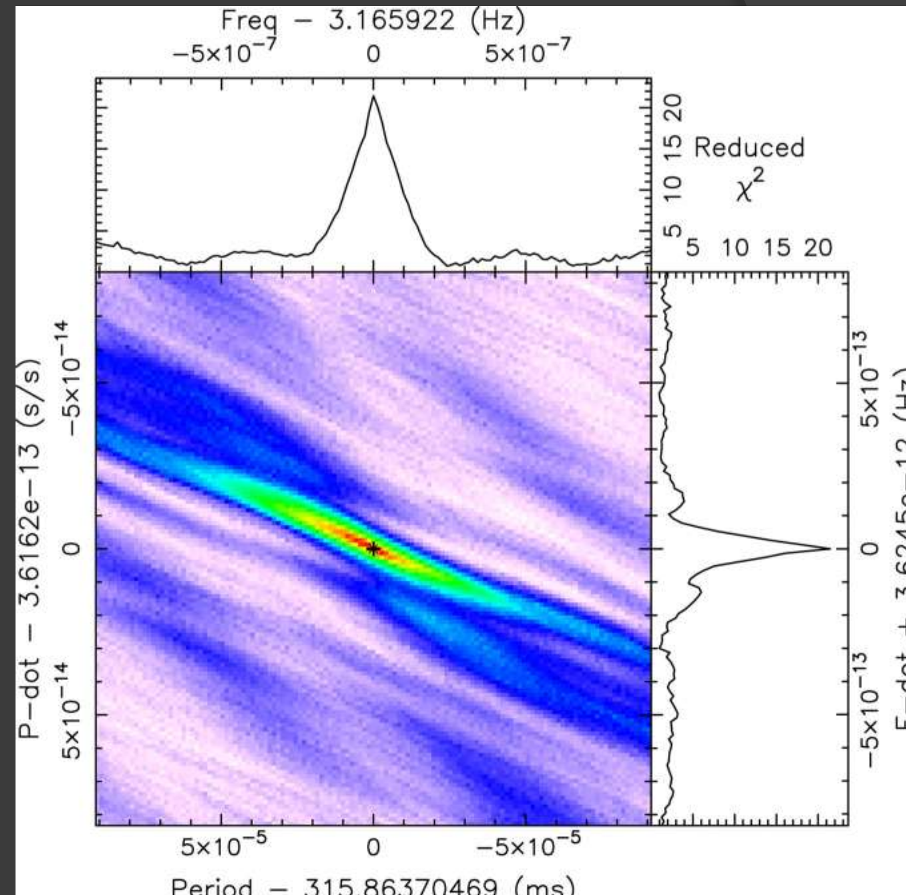


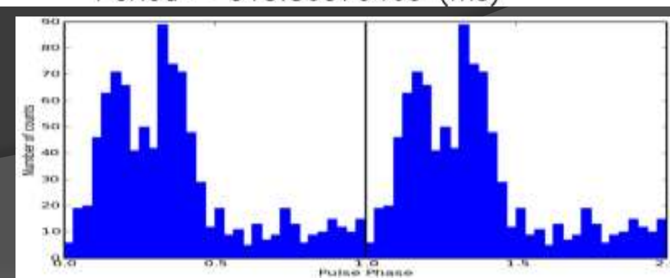
Figure 25. MSSM and mSUGRA models in the $< \sigma v >, m_{WIMP}$ plane. The models included in these regions are consistent with accelerator constrains and WMAP data. The lines represent the 5 σ sensitivity from the GC (upper) and the 5 σ sensitivity from a Galactic halo analysis (lower) corresponding to the best and worst sensitivities estimated in this paper for a NFW profile.

Abdo et al., Science Express, 16 Oct 2008

First paper: pulsar in SNR CTB 1







τ_c~10^4yr ≈ SNR age

Some initial results

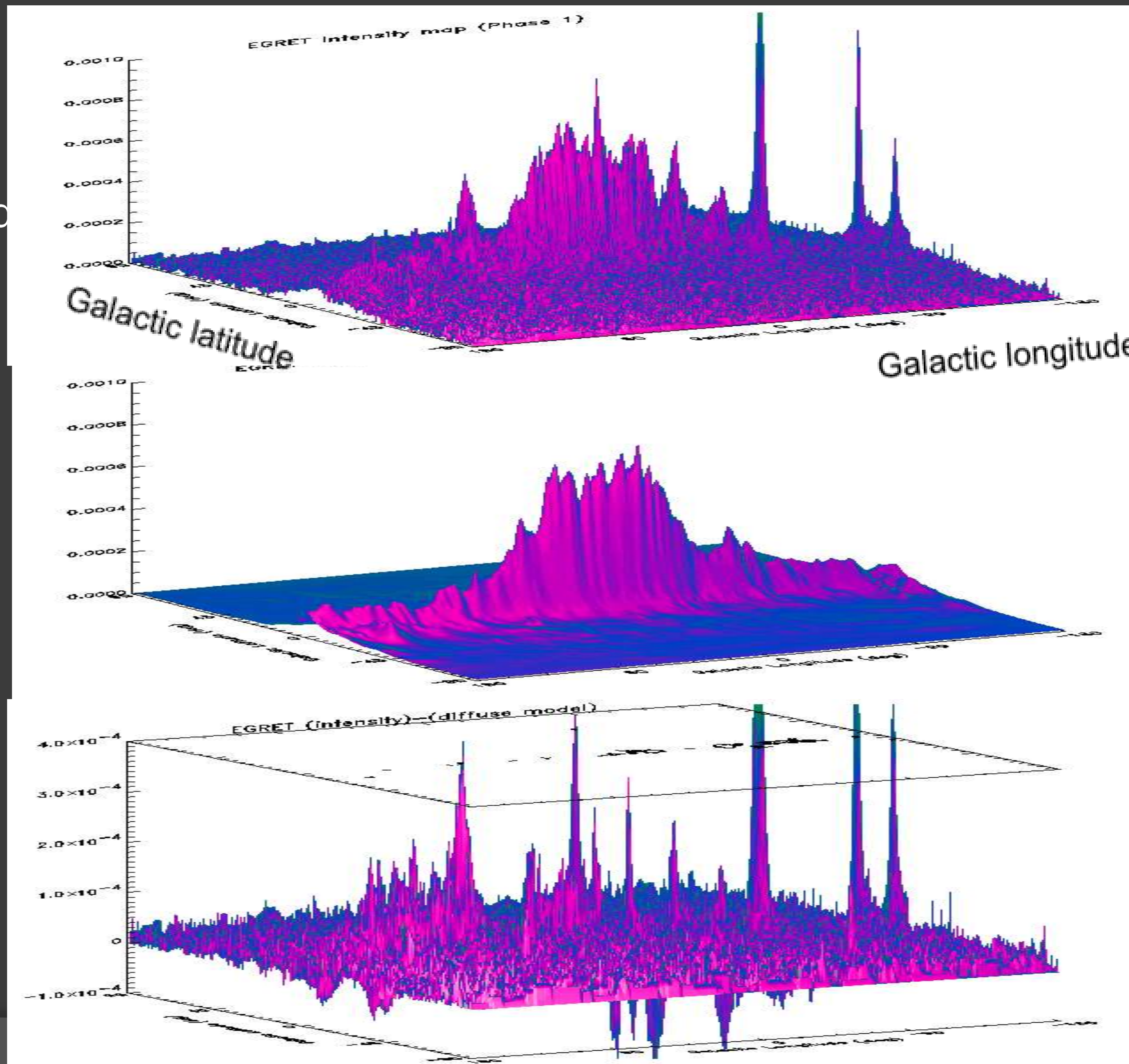
- 銀河系内天体
  - パルサー：SNR CTA1, Light curve (Crab, Geminga), Glitch in PSR1706-44
  - 分子雲：Orion A
  - 連星：LSI +61 303
  - 太陽、月
- 銀河系外天体
  - 10個のAGNのフレア
  - 3個のGRB (080825C, 080916C, 081024B)

Point sources = Observed intensity – Diffuse model

EGRET observed intensity

Diffuse model

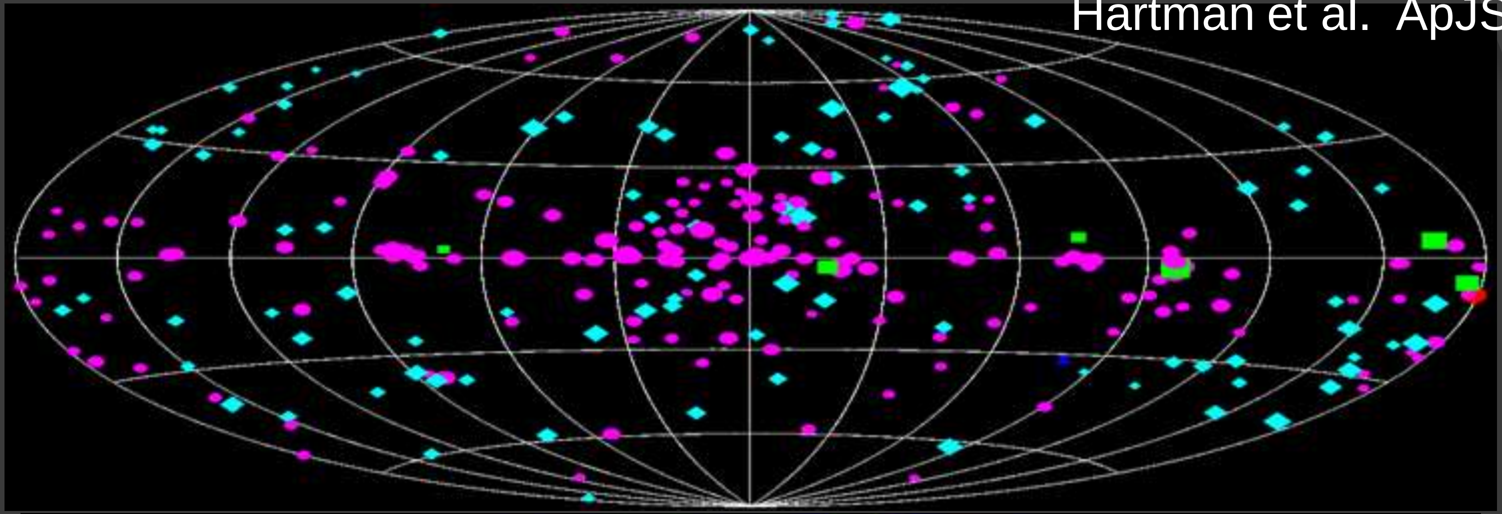
Intensity – model



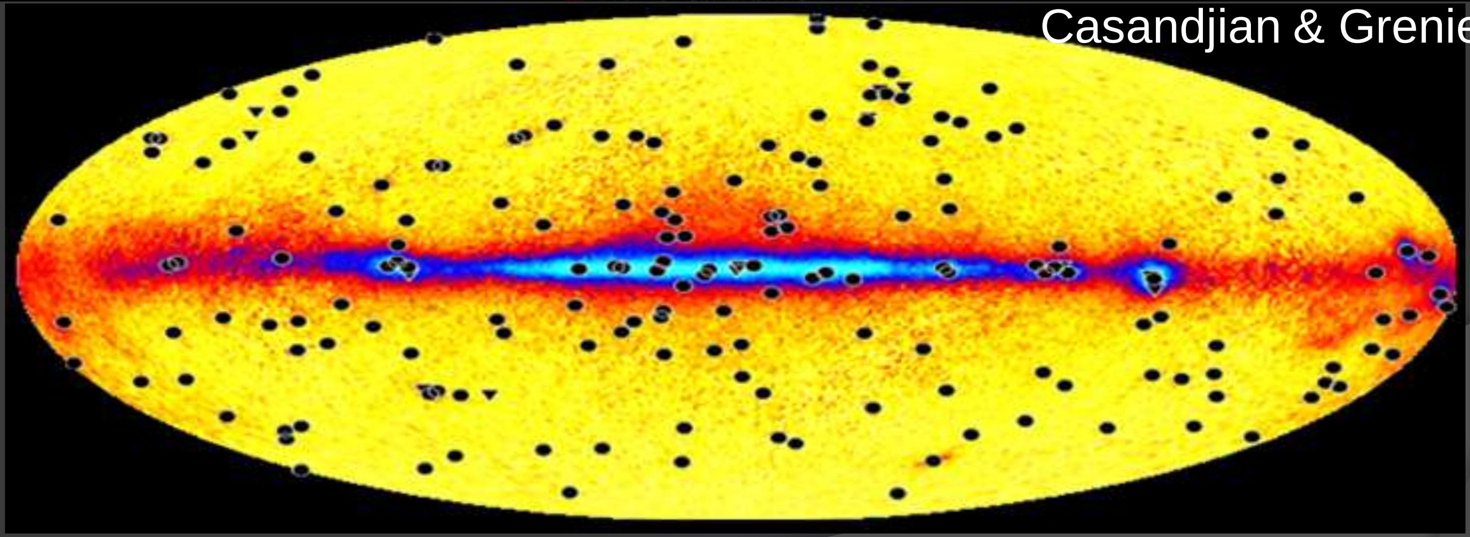
Depends on diffuse model!

A revised EGRET catalog

Hartman et al. ApJS 1999

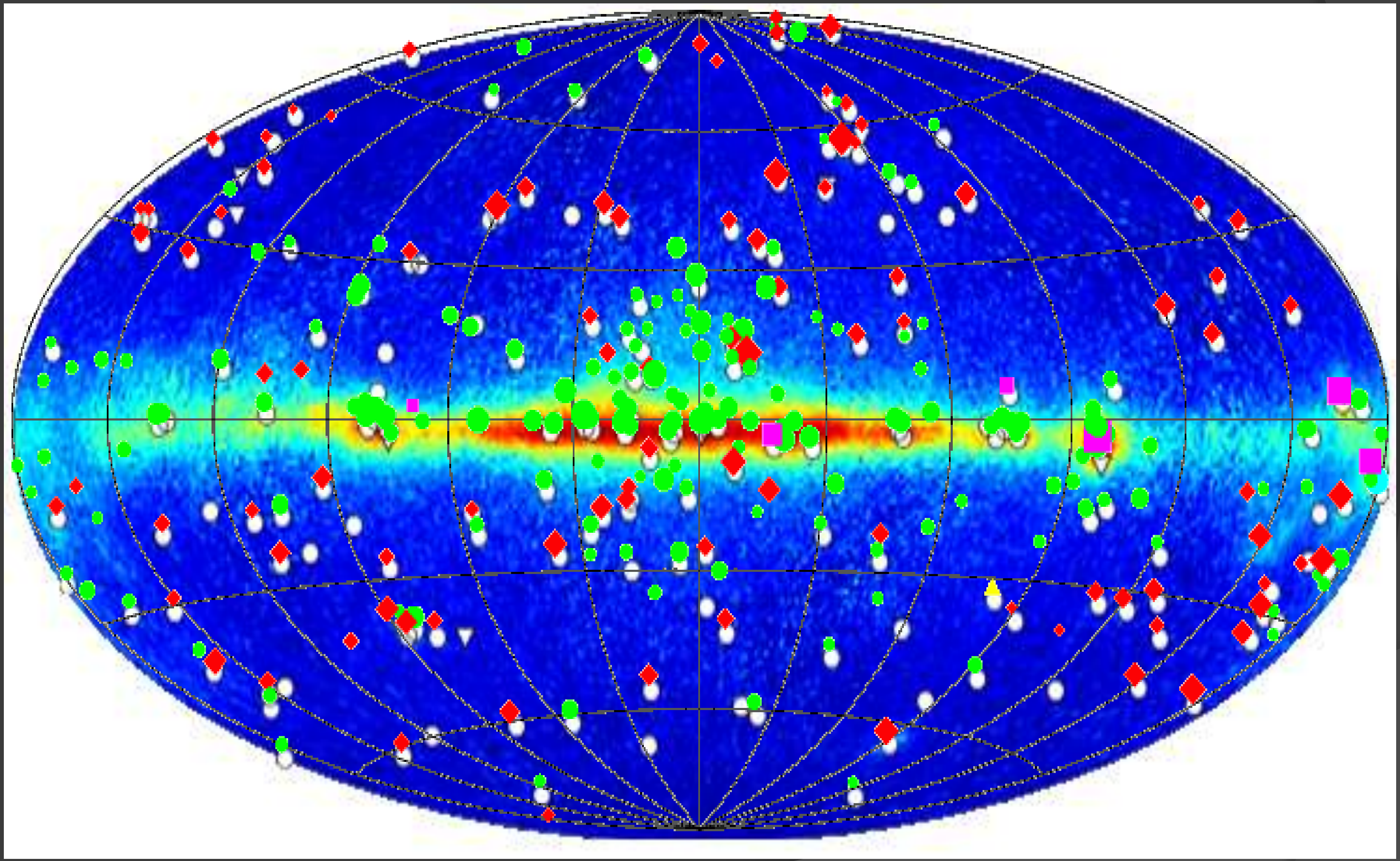


Casandjian & Grenier 2008



→Galactic diffuse gamma-rayモデルが系統誤差！

3rdカタログとRevisedカタログの比較



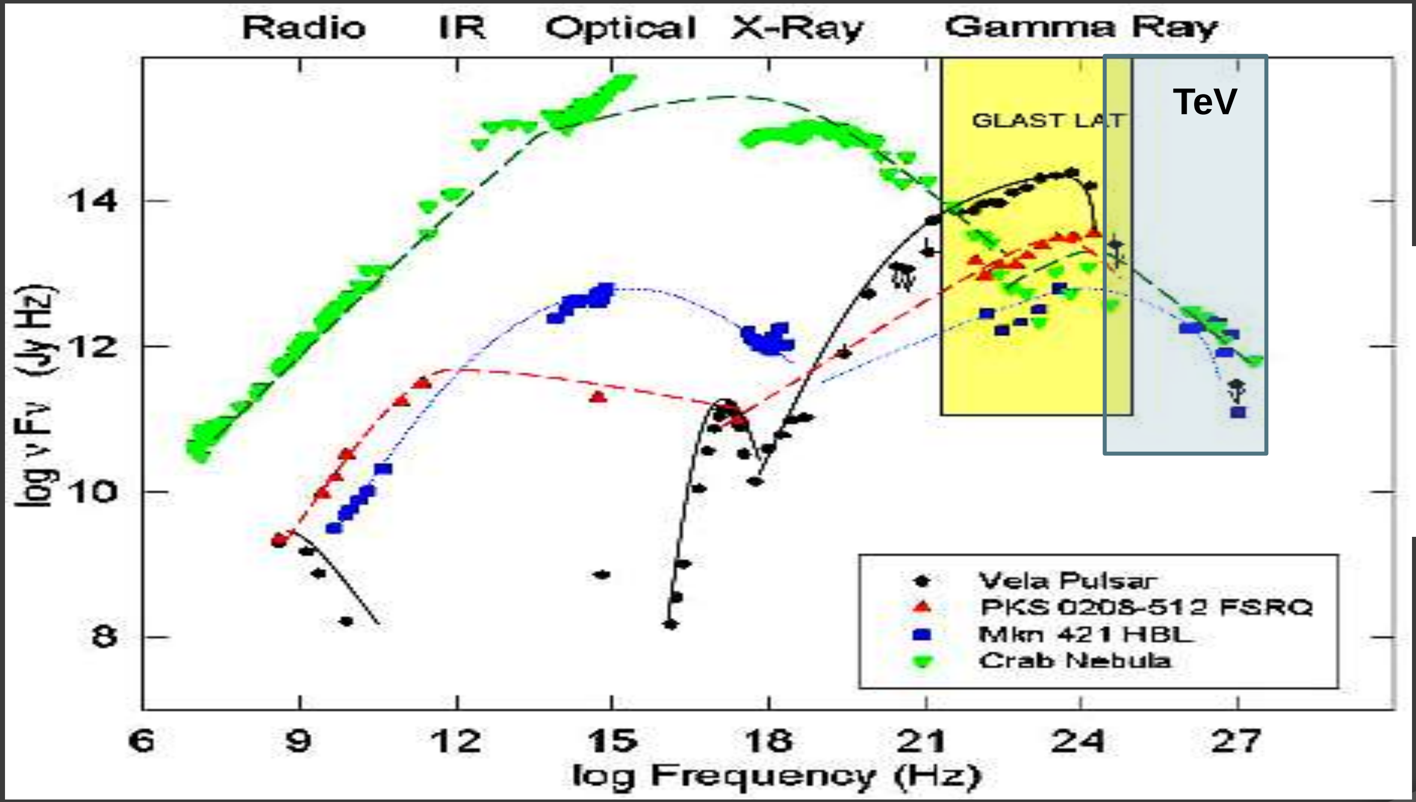
(Small offset to avoid complete overlapping)

Thompson, Rep.Prog.Phys. 71, 116901 (2008)

EGRETからの宿題

- 銀河拡散ガンマ線の正体は？（特にGeV excessの原因）
- 銀河放射はcold dark gasやdark matterの手がかりを含むのか?
- パルサーにおける粒子加速はどこで起こっているのか？
- 電波で暗いガンマ線パルサーはどのくらいあるのか?
- どのような連星系がガンマ線源になるのか?
- 他に銀河系のどのような天体がガンマ線源なのか?
- Blazarの多波長観測や時間変動からジェットの性質がどこまでわかるか?
- 他の銀河の観測で宇宙線や物質密度の情報が得られるのか?
- 他に系外のどのような天体がガンマ線源なのか?
- 系外背景ガンマ線放射は多数の天体の集まりで説明できるのか、他の説明があるのか?
- ガンマ線バーストの多くに高エネルギー放射が伴うのか?
- 太陽フレアからの高エネルギーガンマ線の測定は太陽活動の解明につながるのか?
- ガンマ線の天空に新しい驚きはまだあるのか？

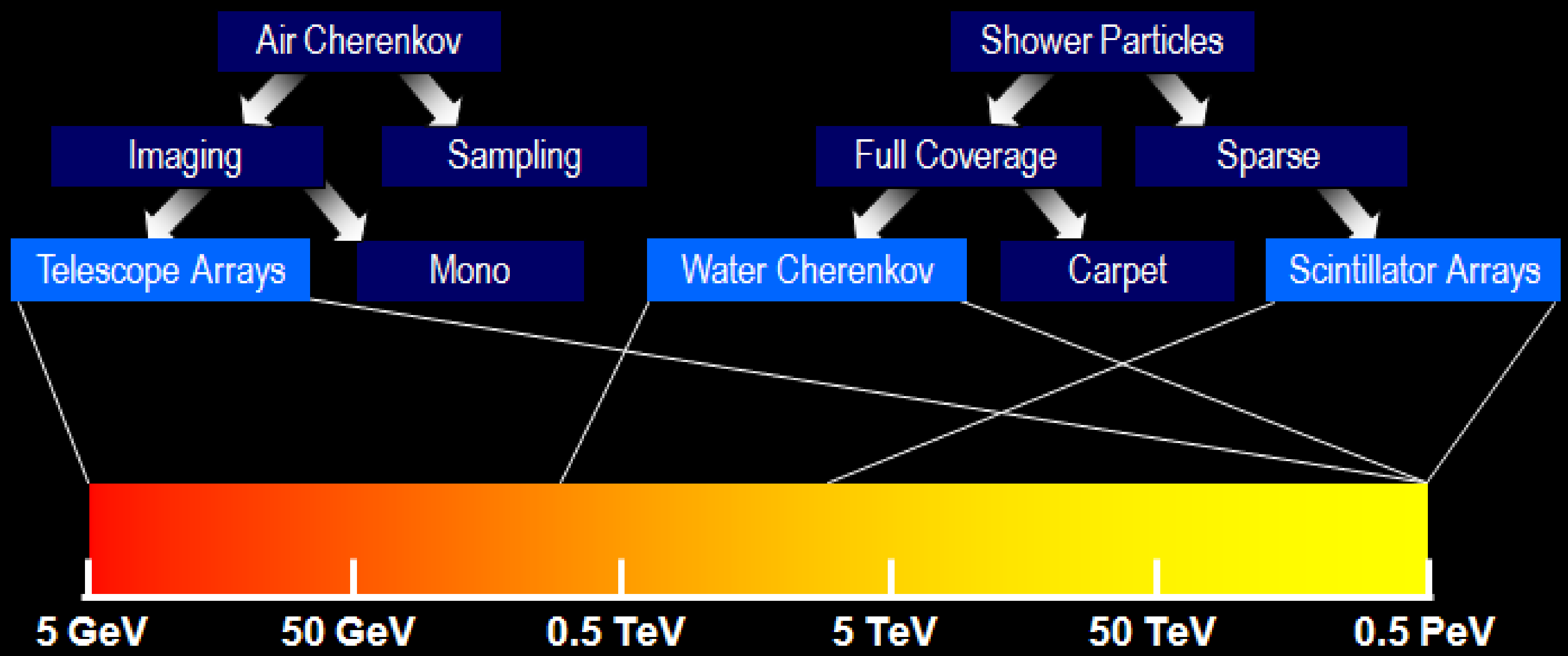
多波長観測



パルサー
FSRQ
HBL
かに星雲

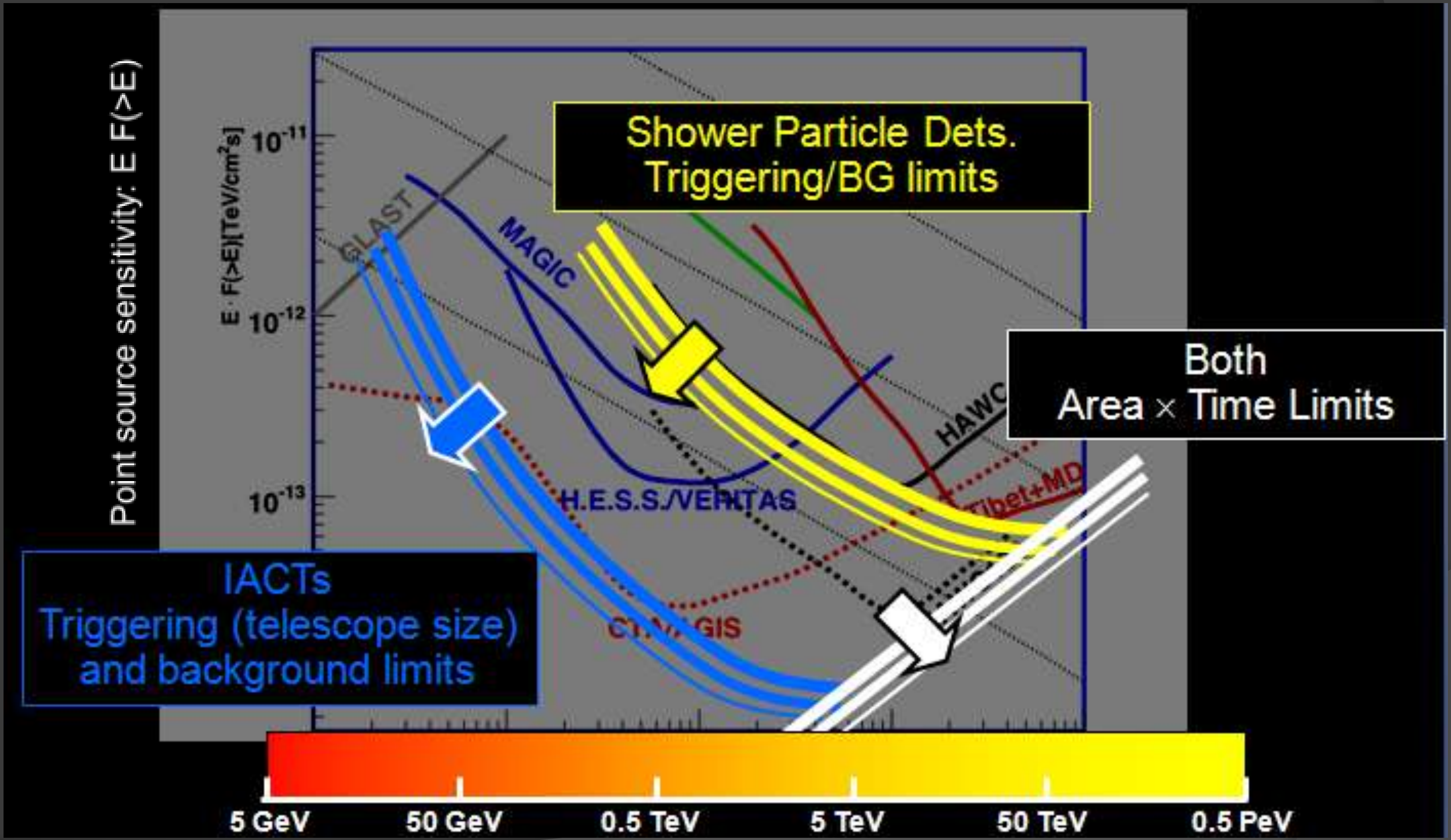
非熱的放射 ⇔ 粒子の加速 ⇔ 広帯域の放射

Techniques

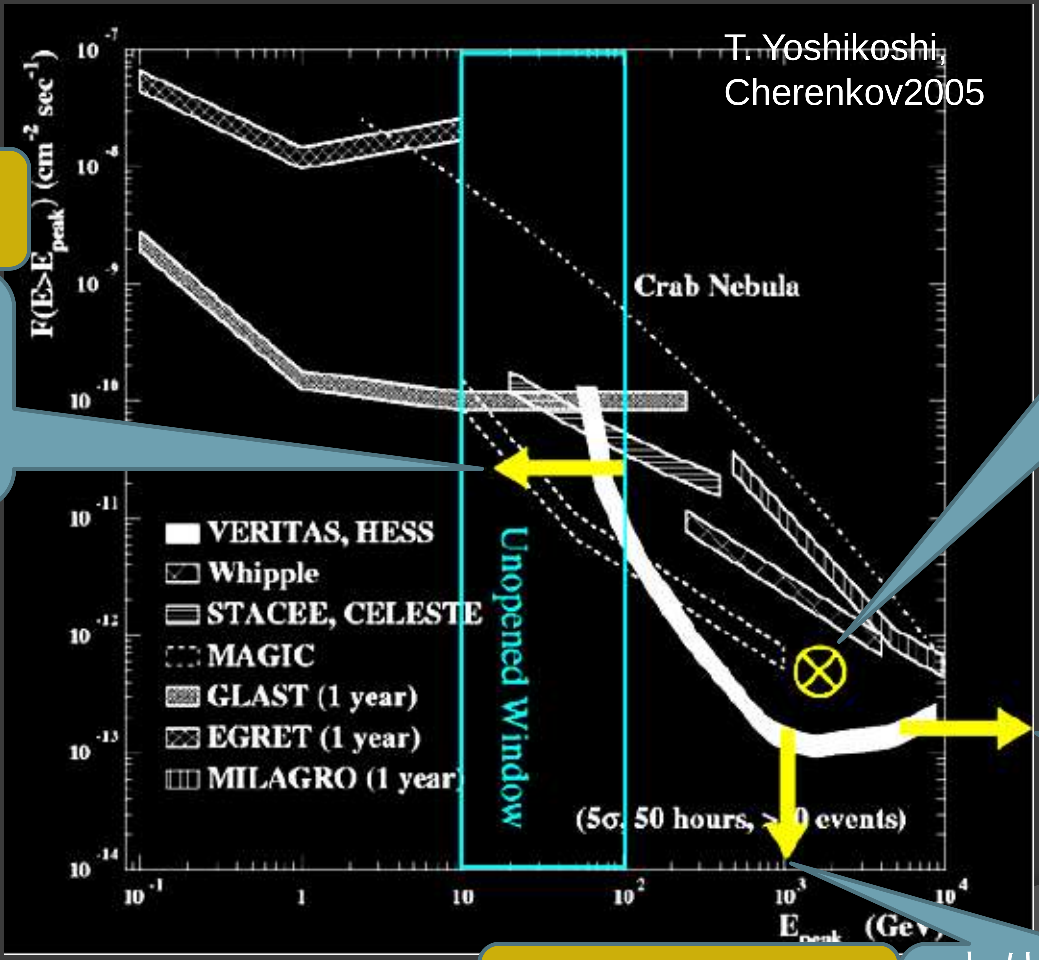


- Many different approaches have been tried
  - Not all have stood the test of time
  - Major projects planned using three of them

Limitations to sensitivity



これからの方向性



広視野へ

•より広いSurvey
•未知のガンマ線天体？
•時間変動天体

低エネルギーへ

•衛星観測とのGAPを埋める
•より遠くの系外天体

高エネルギーへ

•加速限界を探る
•宇宙線の起源

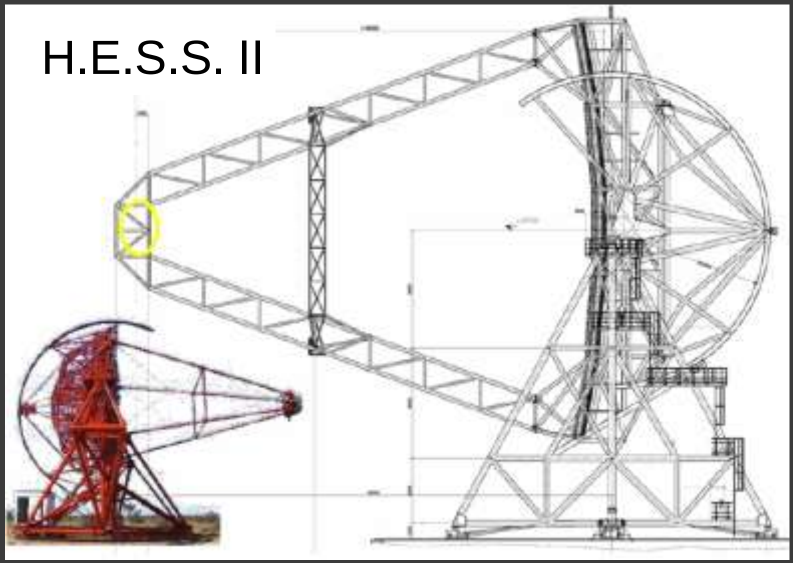
高感度へ

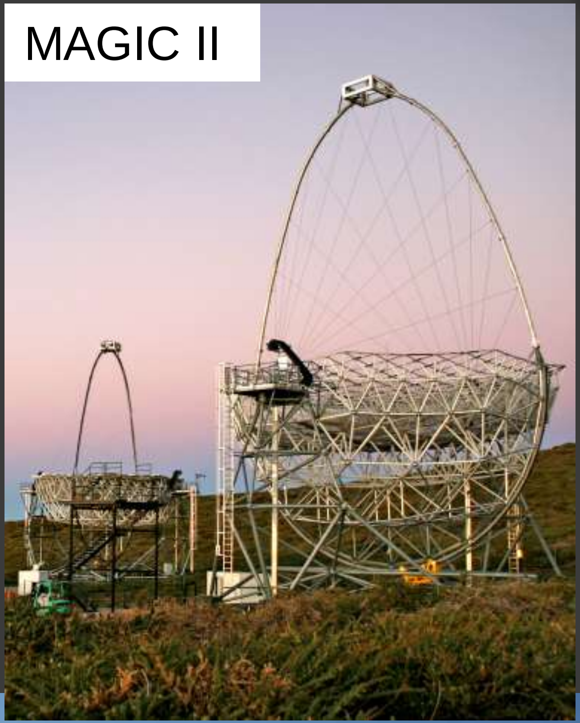
•より深いSurvey
•未知のガンマ線天体？

Instrument concepts

- **But the point-source sensitivity curve is not the whole story - what kind of instruments do we want?**
  - **A precision TeV instrument** CTA/AGIS
    - **Excellent (<< 0.1°) angular resolution and background suppression**
  - **An "all sky monitor"** HAWC/Tibet MD
    - **Very large FoV and duty cycle – sufficient area to be sensitive on ~day timescales**
  - **~10 GeV timing explorer** 5@5?
    - **Low Threshold! (will be systematics dominated for long exposures)**
  - **100 TeV instrument** Tibet MD/TenTen
    - **Size. Reasonable (~0.1°) angular resolution**
  - **A broad energy range observatory** CTA/AGIS
    - **Coverage 30 GeV – 100 TeV with good sensitivity on one site**

建設中／完成



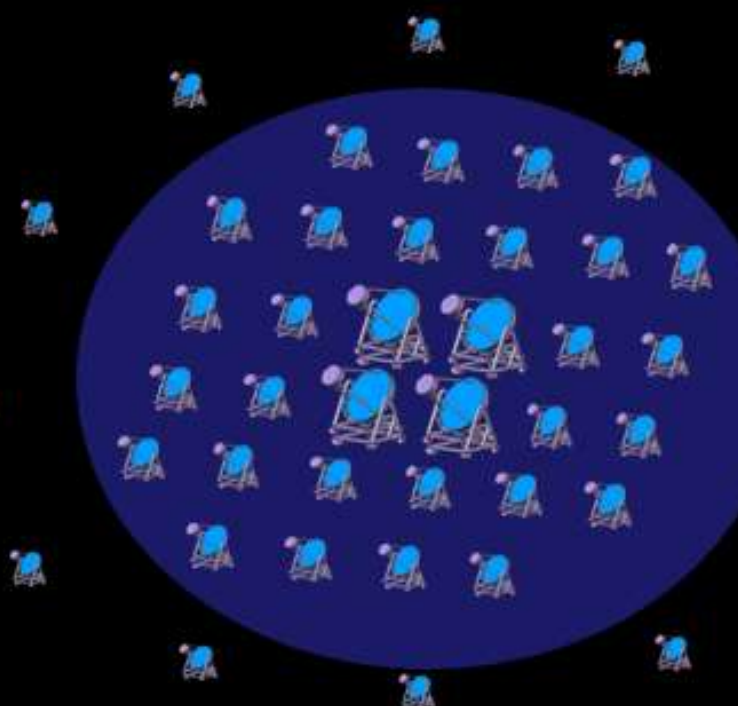


2009完成予定

2008.9完成

CTA (Cherenkov Telescope Array)

- **Concept**
  - An IACT array *observatory*
  - an order of magnitude more sensitive than HESS: 1 mCrab
  - wide energy coverage: from a few tens of GeV up to the 100 TeV range, baseline design achieves this with a mixture of telescope sizes & spacings
  - sites in the South and North
- **Consortium**
  - Largely European
  - HESS + MAGIC + many others
  - 15 countries currently involved



~150 M€ price tag

AGIS (Advanced Gamma-ray Imaging System)

- US led ~100 M$ project at concept stage
- Goals are very similar to those of CTA
- One idea is wide field of view + fine pixellation = *secondary optics* (and ~100 GeV performance)
- Baseline is a 1 km^2 array, ~50 telescopes

Multi-TeV IACT ("TenTen")

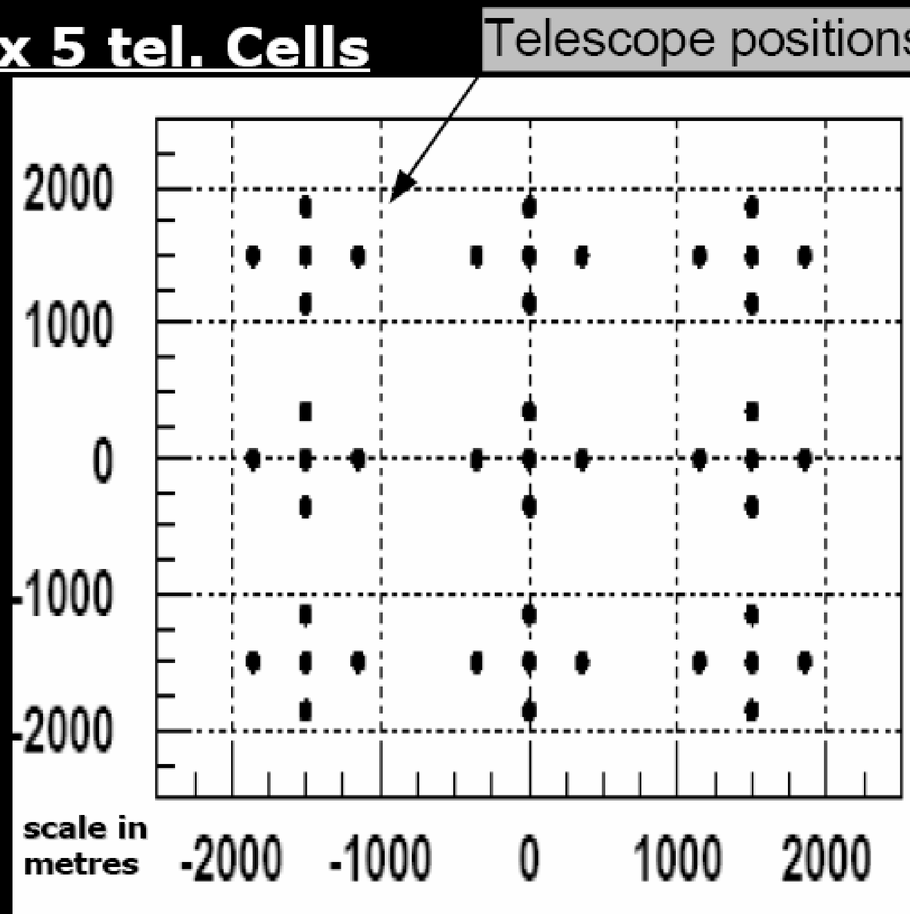
Example Array: 9 x 5 tel. Cells

- 45 telescopes
- cell L = 500m
- intercell spacing
  = 1500m
- 6pe,3pix trigger
  8,4 cleaning

msw < 1.05
msl < 1.2

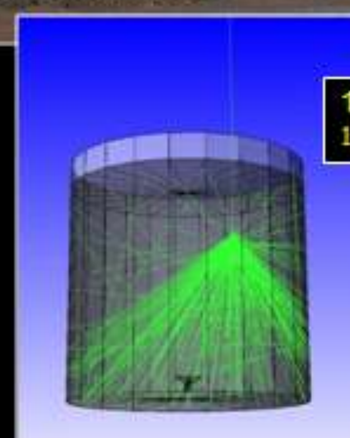
msnp < 1.1
alg3 direction reco.

- 0.2 km
- 1.8 km
- 100ns time buffer

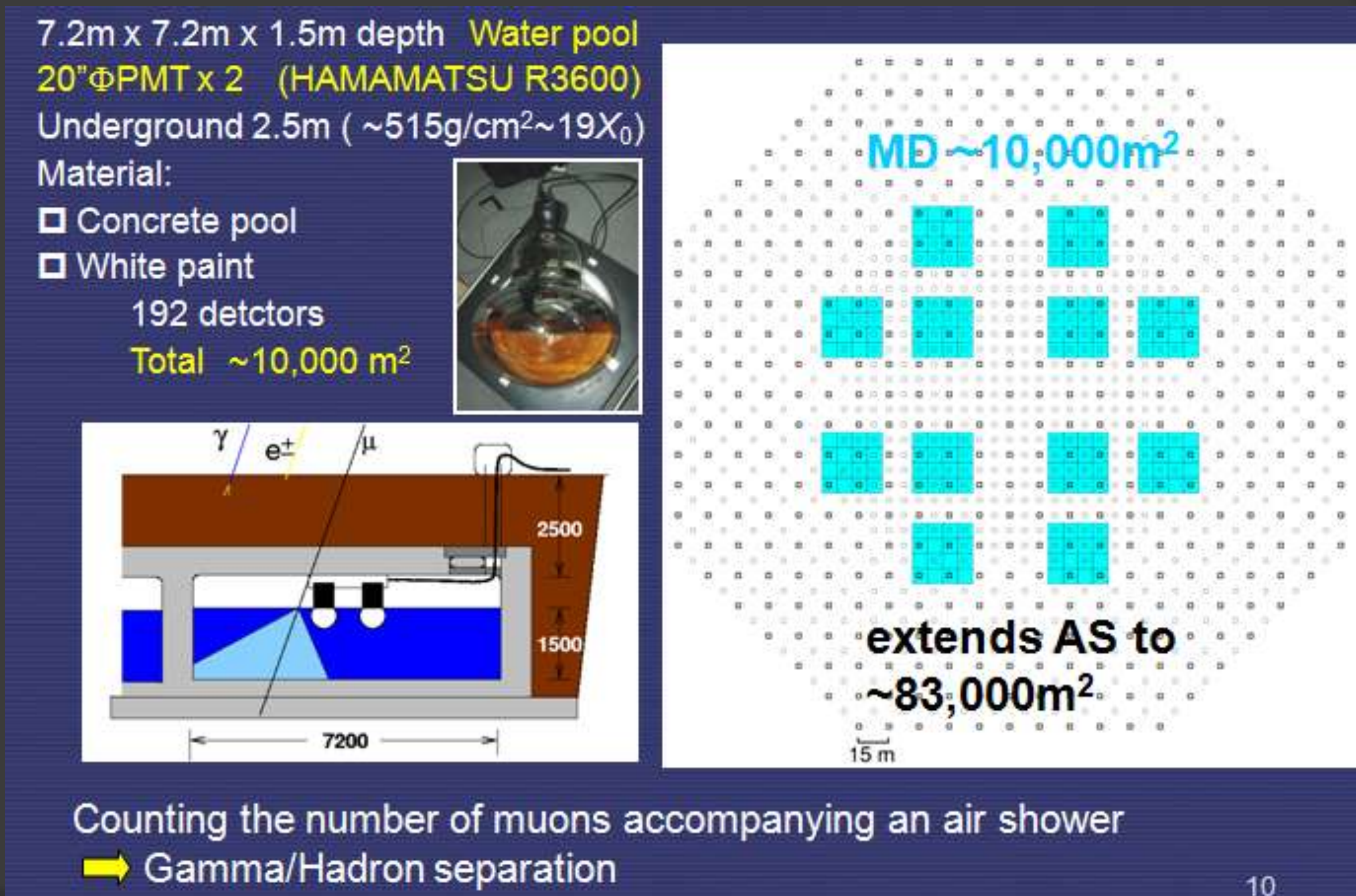


HAWC

- High altitude Water Cherenkov detector
- Array of water tanks
  - 900 tanks each 4.3 m high and 5 m diameter 1 PMT at bottom
  - 150 m x 150 m array
  - 75% ground coverage
- Site: Sierra Negra, Mexico, alt: 4100 m lat: +19°
  - cf MILAGRO 2630 m alt, lat: +36° (5000 m^2 pond)

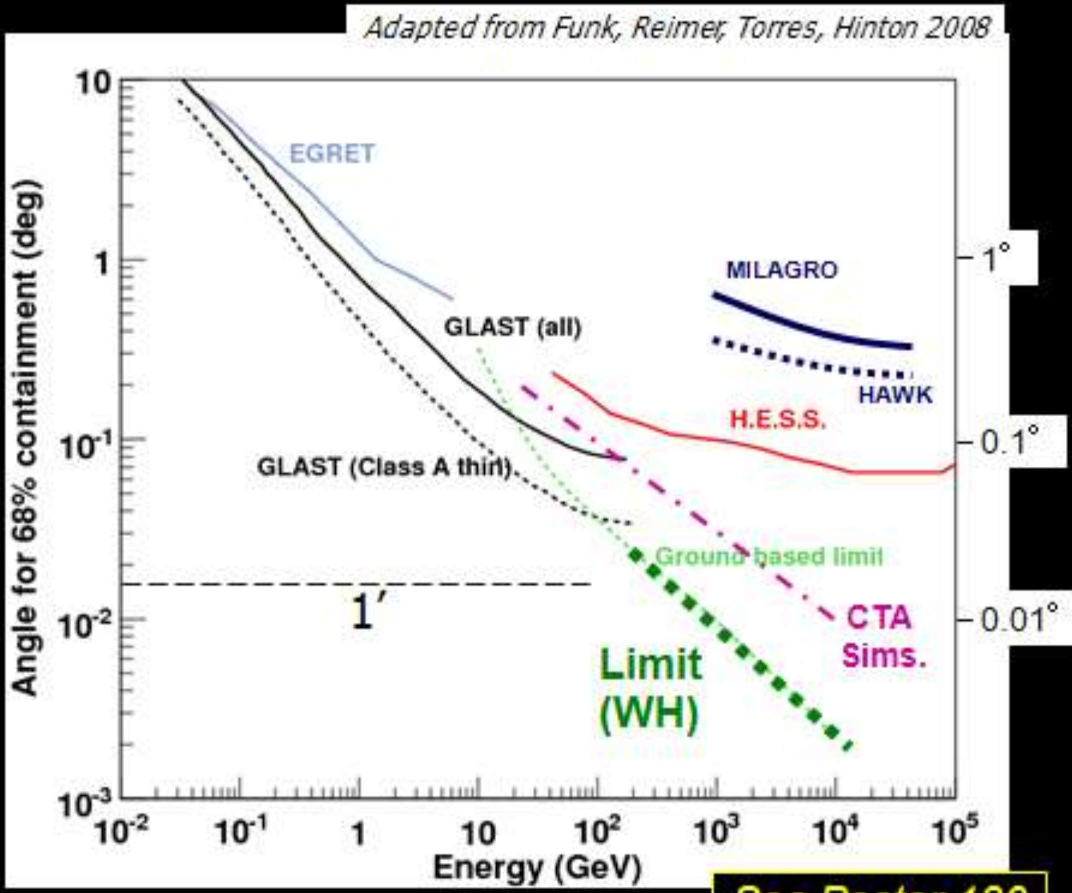


Tibet Muon Detector (MD) array



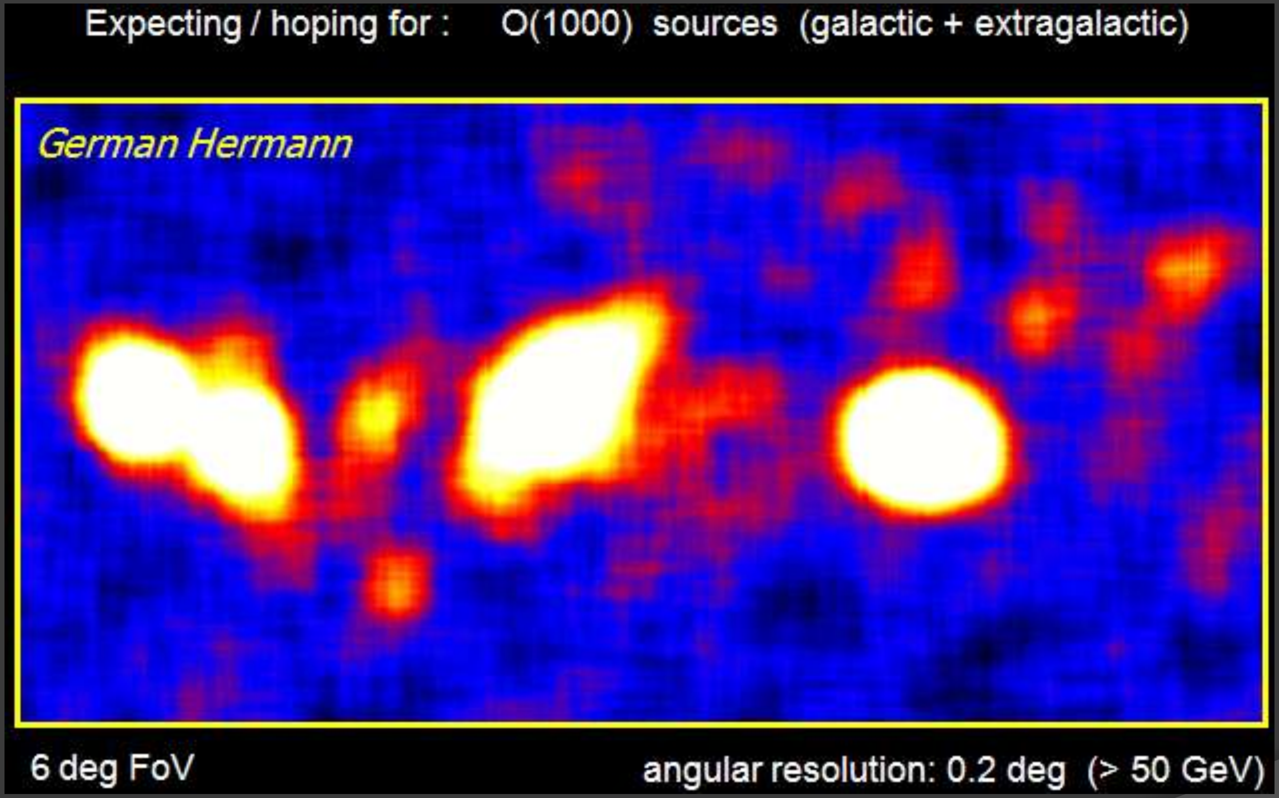
Angular resolution

- At a few TeV we can reach **2 orders of magnitude** better ang. resolution than GLAST at ~1 GeV using IACTs
- Resolution → Science
  - source IDs, resolved systems…

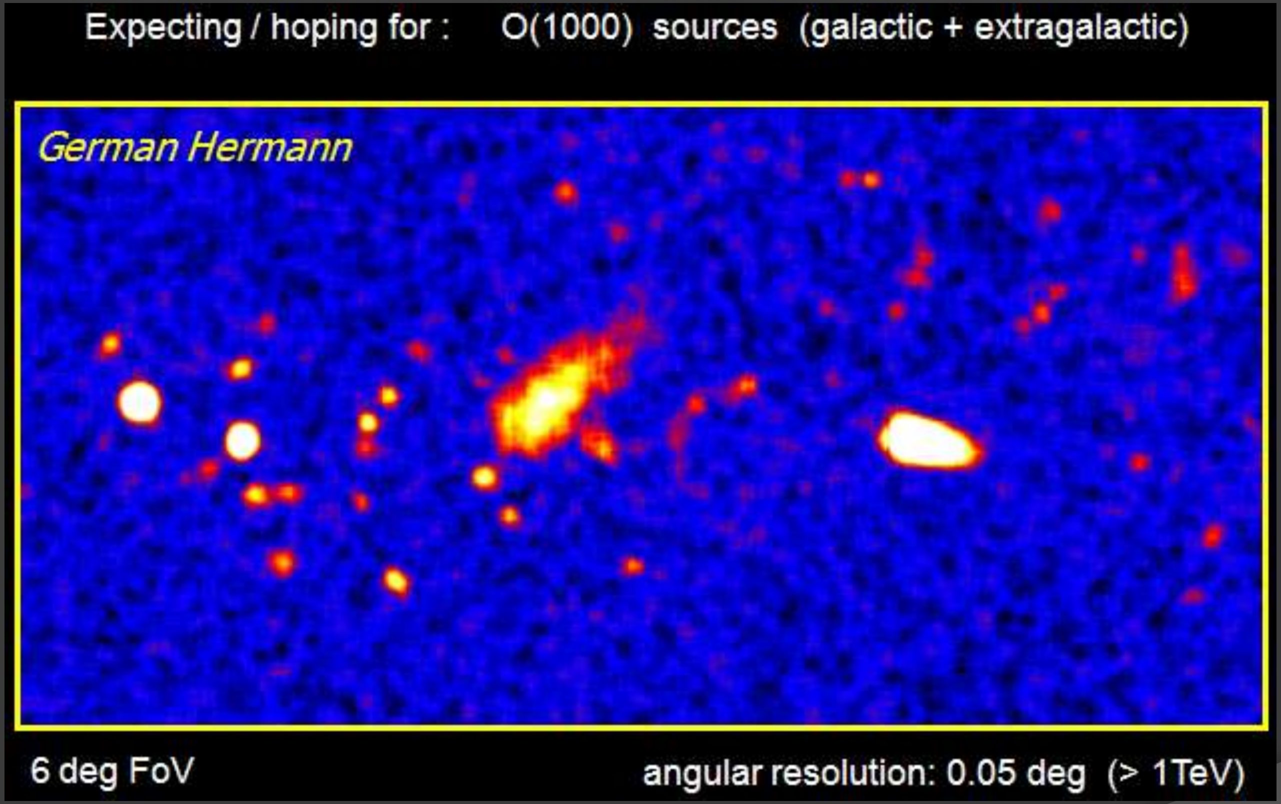


See Poster 130

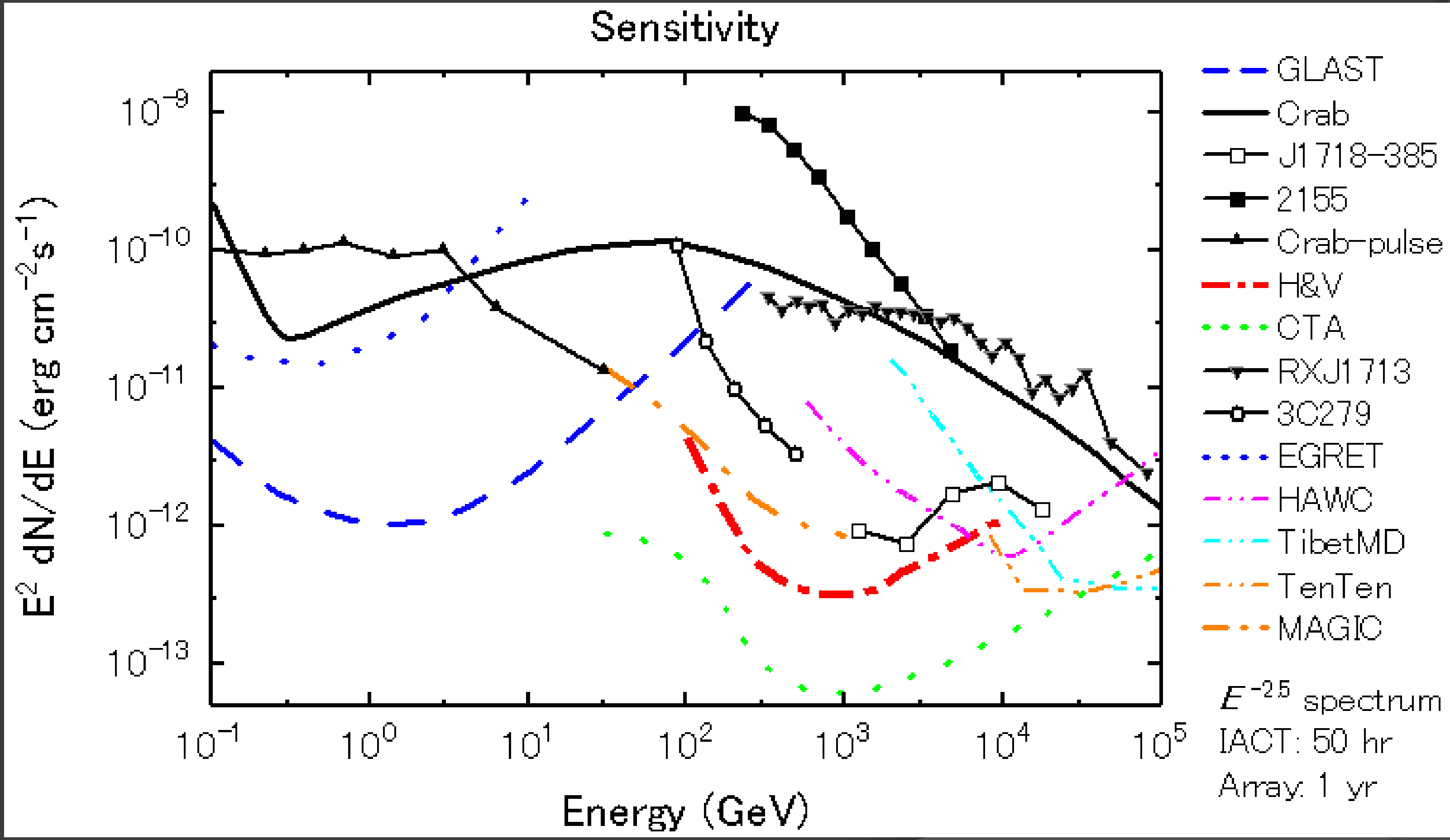
Angular resolution



Angular resolution



Expected sensitivity



Revised 24-DEC-2008

Positron excess by PAMELA

Adriani et al., arXiv:0810.4995

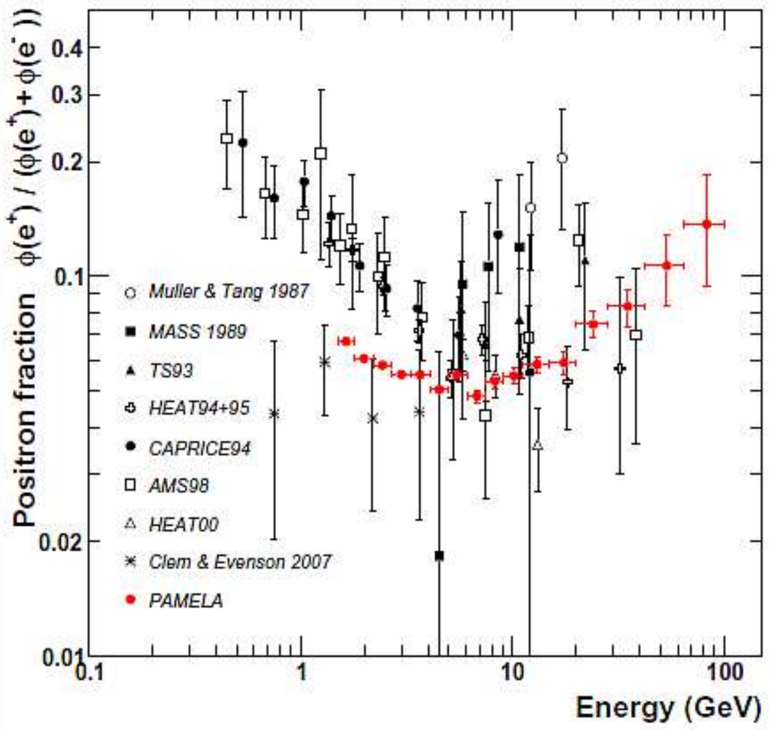


FIG. 3: PAMELA positron fraction with other experimental data. The positron fraction measured by the PAMELA experiment compared with other recent experimental data[24, 29, 30, 31, 32, 33, 34, 35]. One standard deviation error bars are shown. If not visible, they lie inside the data points.

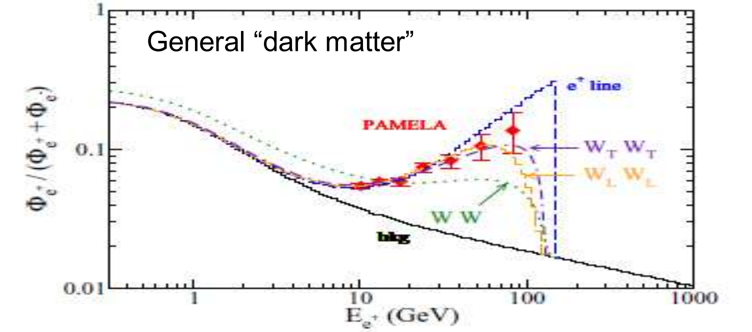


FIG. 1: Annihilations of DM directly into e^+e^- give the e^+ line at about $M_{DM} = 150$ GeV. The secondary positron spectrum from decays into $e^+\nu$ of longitudinal (transverse) W bosons is labeled $W_L W_L$ ($W_T W_T$); the soft component of the spectra are neglected for illustration. Including the soft component (with spin-correlations neglected) results in a much softer spectrum labelled WW that does not fit the PAMELA data above 10 GeV. The solid curve is the expected background. The Med set of propagation parameters is used with a cored isothermal profile for the DM halo.

Barger et al., arXiv:0809.0162

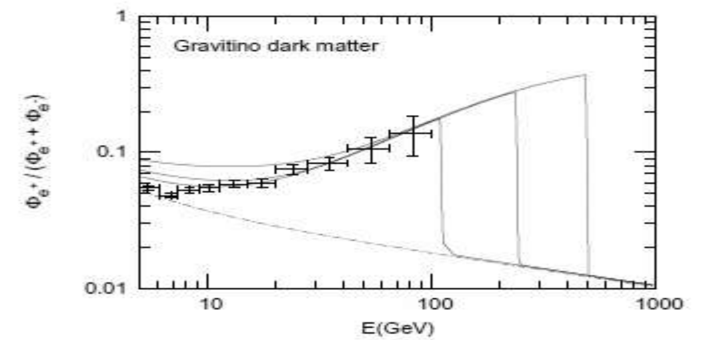


FIG. 2: Positron fractions for the gravitino dark matter case. Gravitino is assumed to decay only into the first generation lepton (plus gauge or Higgs boson). We take $m_{3/2} = 250$ GeV, 500 GeV, and 1 TeV (from left to right), and $\tau_{3/2} = 8.5 \times 10^{26}$ sec $\times (m_{3/2}/100\text{ GeV})^{-1}$. The MED propagation model is used.

Dark matter? Pulsar? Microquasars?...

Ishiwata et al., arXiv:0811.0250

Electron peak by ATIC/BETS

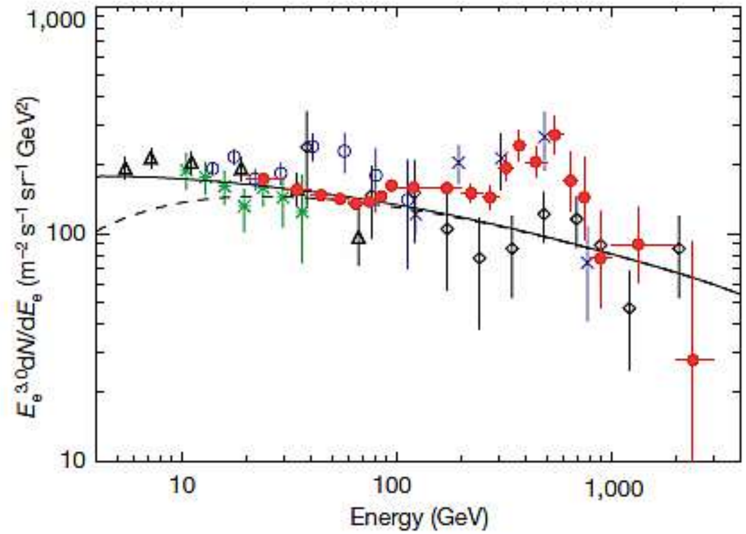


Figure 3 | ATIC results showing agreement with previous data at lower energy and with the imaging calorimeter PPB-BETS at higher energy. The electron differential energy spectrum measured by ATIC (scaled by E^3) at the top of the atmosphere (red filled circles) is compared with previous observations from the Alpha Magnetic Spectrometer AMS (green stars)[31], HEAT (open black triangles)[30], BETS (open blue circles)[32], PPB-BETS (blue crosses)[16] and emulsion chambers (black open diamonds)[4,8,9], with uncertainties of one standard deviation. The GALPROP code calculates a power-law spectral index of −3.2 in the low-energy region (solid curve)[14]. (The dashed curve is the solar modulated electron spectrum and shows that modulation is unimportant above ~20 GeV.) From several hundred to ~800 GeV, ATIC observes an 'enhancement' in the electron intensity over the GALPROP curve. Above 800 GeV, the ATIC data returns to the solid line. The PPB-BETS data also seem to indicate an enhancement and, as discussed in Supplementary Information section 3, within the uncertainties the emulsion chamber results are not in conflict with the ATIC data.

Chang et al., Nature 456, 352 (2008)

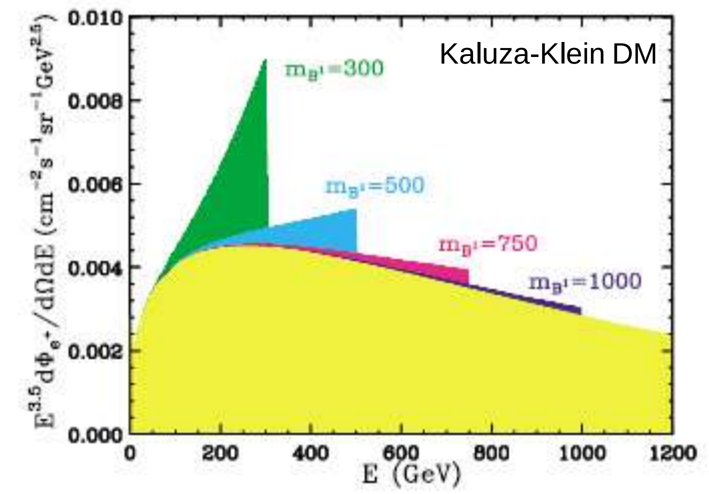


FIG. 2 (color online). Predicted positron signals above background (light shaded area, yellow) as a function of positron energy for $m_{B^1} = m_{e^1_R} = m_{e^1_L} = 300, 500, 750,$ and 1000 GeV.

Cheng et al., PRL 89, 211301 (2002)

Summary

- High energy window of the Universe is now open!
  - Additional 2-3 decades of the photon spectrum
  - Wider variety of sources than expected
    $\rightarrow$ *Cosmic accelerators are ubiquitous!*
  - Much work left to understand their physics
  - Also: cosmology, fundamental physics
    (Hints for dark matter???)
- Still lacking understanding their nature…
  - Need more sensitivity / lower energy / higher energy!
  - Huge scale detectors are planned.

End