

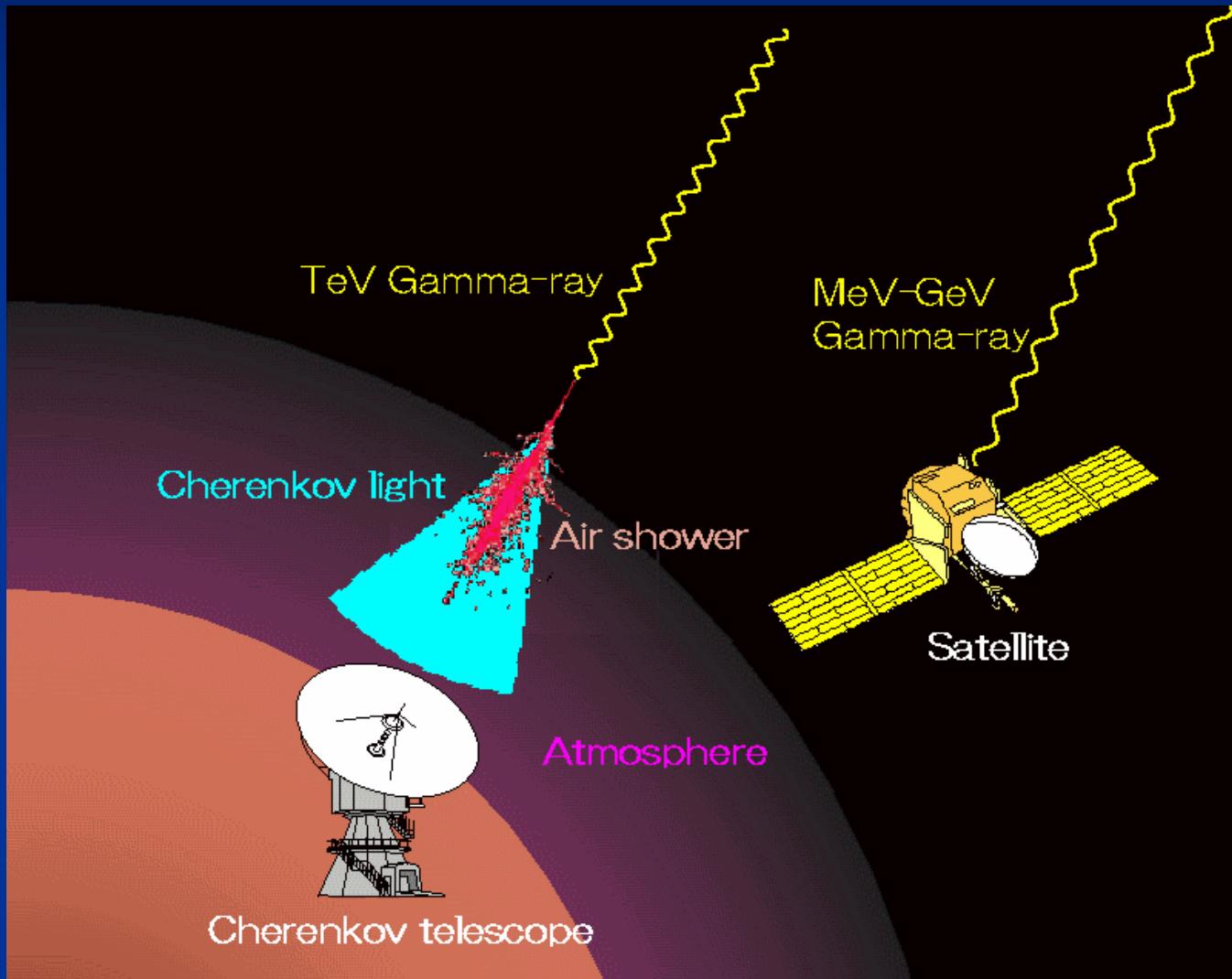
Recent Topics from Very High Energy Gamma-ray Astrophysics

Masaki Mori

Institute for Cosmic Ray Research
University of Tokyo

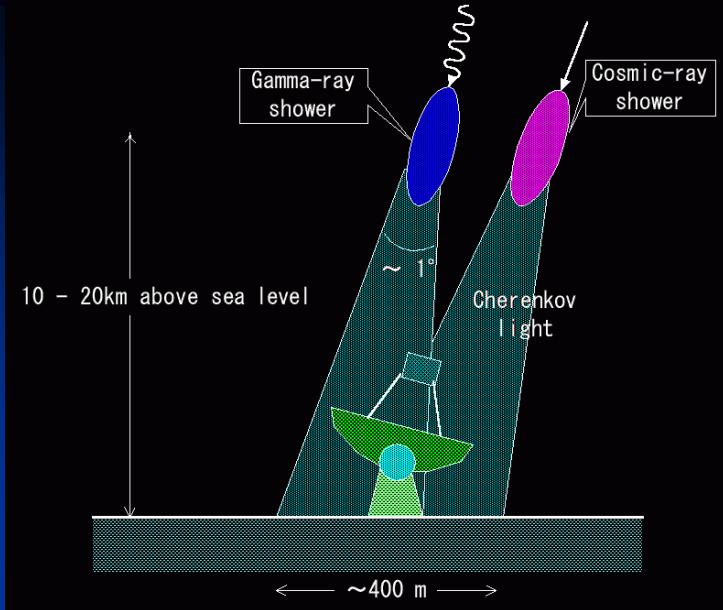
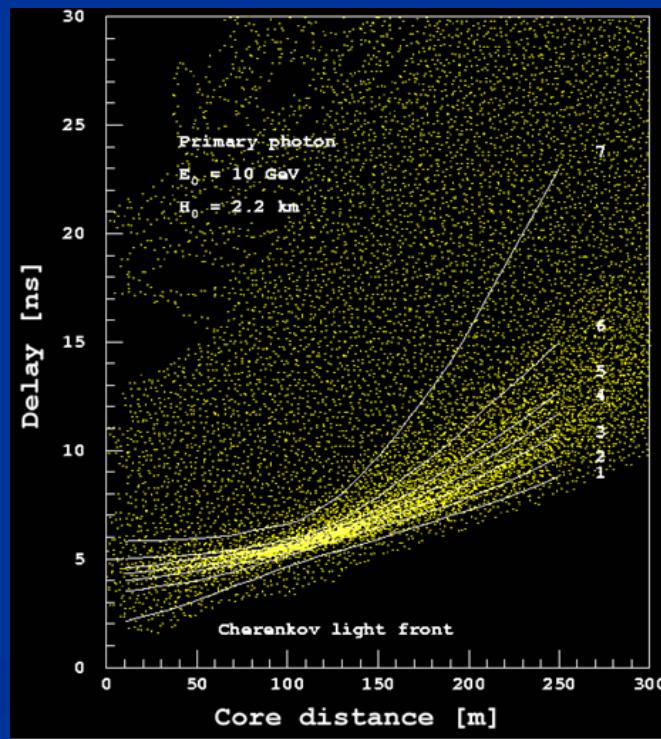
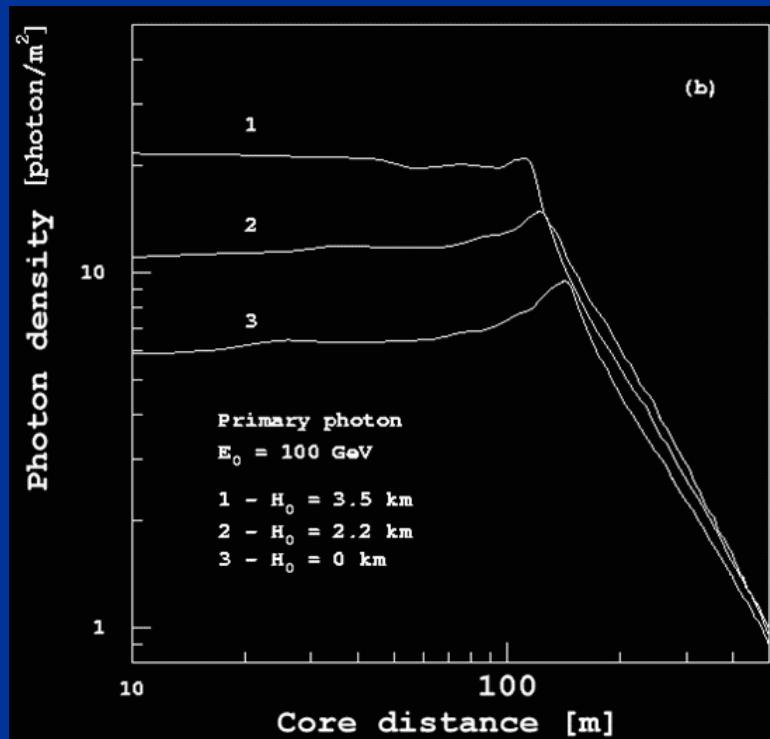
The 6th RESCEU International Symposium, Nov. 4-7, 2003, Sanjo Hall, Univ. Tokyo

Detection of gamma-rays (1)



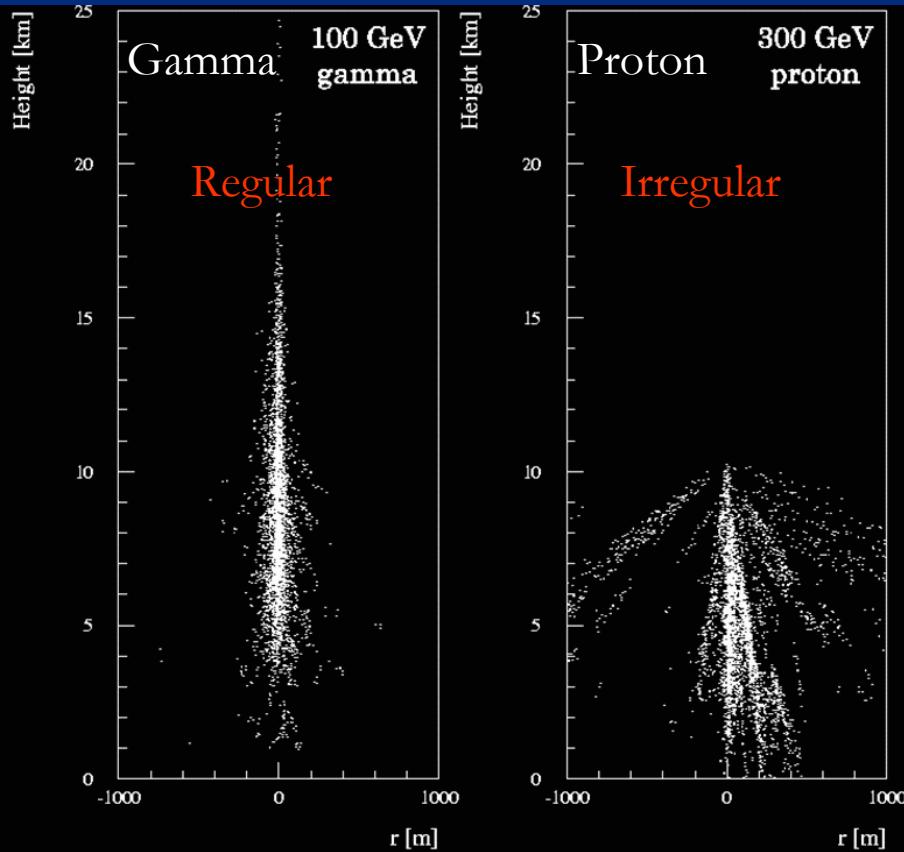
Atmospheric Cherenkov telescopes

Cherenkov light from gamma-ray showers
Lateral distribution \wp *Timing distribution*

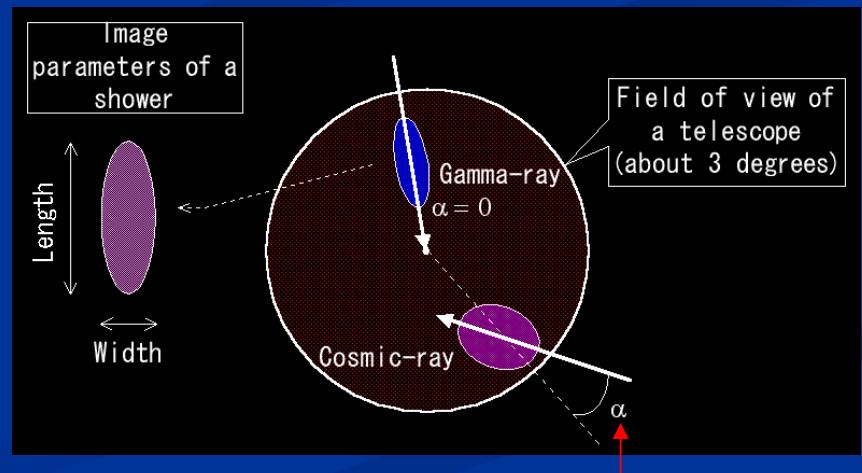
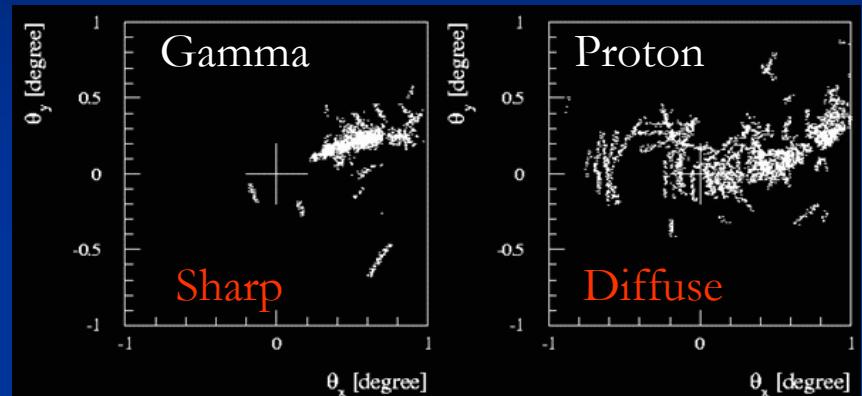


Imaging Cherenkov Telescopes

Shower profile

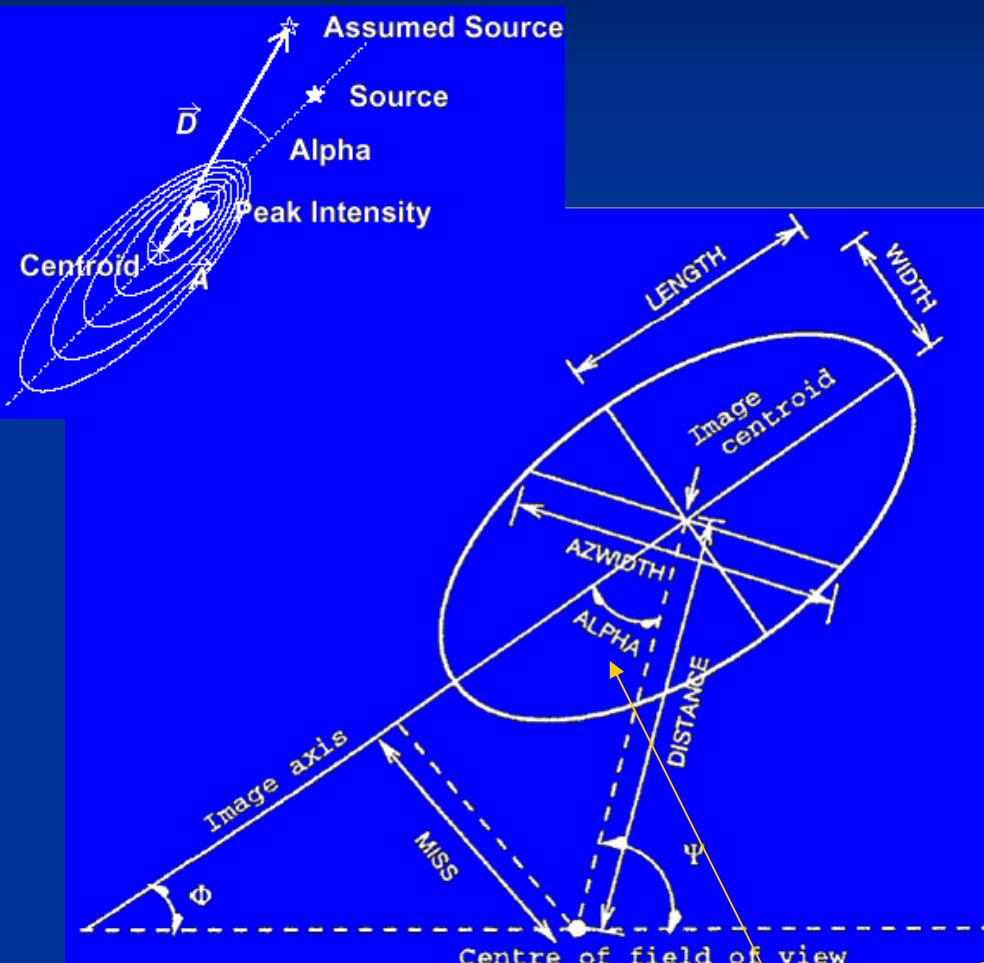


Focal plane image

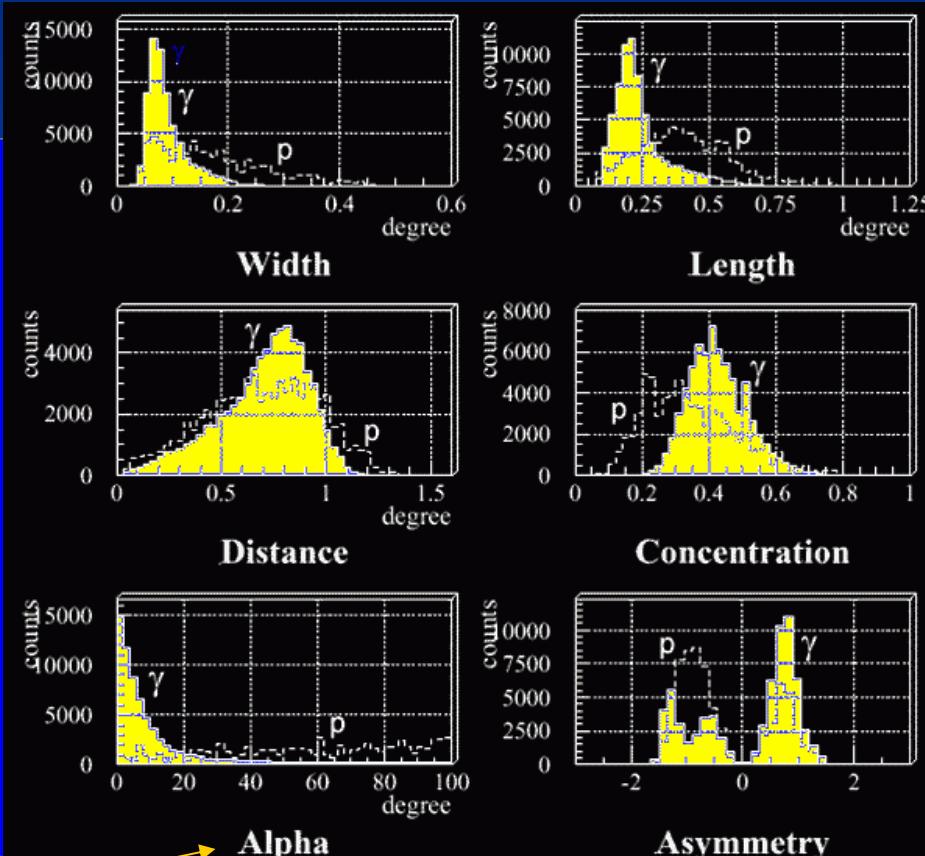


α (image orientation angle)

Imaging analysis



Distribution of imaging parameters



(Simulation)

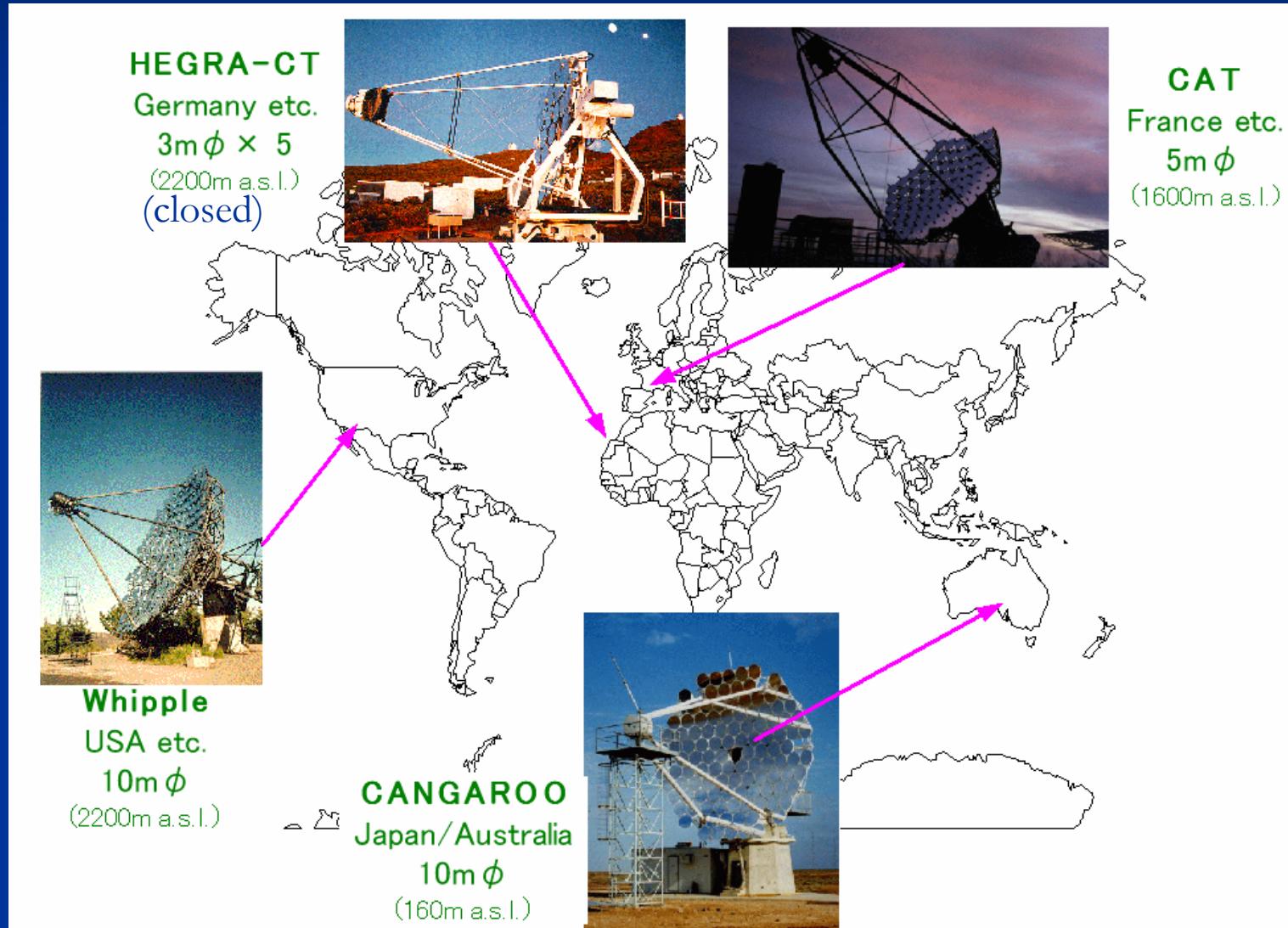
D.J. Fegan, J.Phys.G, 1997

α (image orientation angle)

Detection of gamma-rays (2)

Base	Satellite	Ground
Gamma-ray detection	Direct (pair creation)	Indirect (atmospheric Cherenkov)
Energy	< 30 GeV $(\rightarrow 100 \text{ GeV})$	>100 GeV $(\rightarrow 50 \text{ GeV})$
Pros	High S/N Large FOV	Large area Good $\Delta\theta$
Cons	Small area High cost	Low S/N (CR bkgd.) <i>(but imaging overcomes this!)</i> Small FOV

Imaging Cherenkov telescopes in operation



Galactic sources: basics

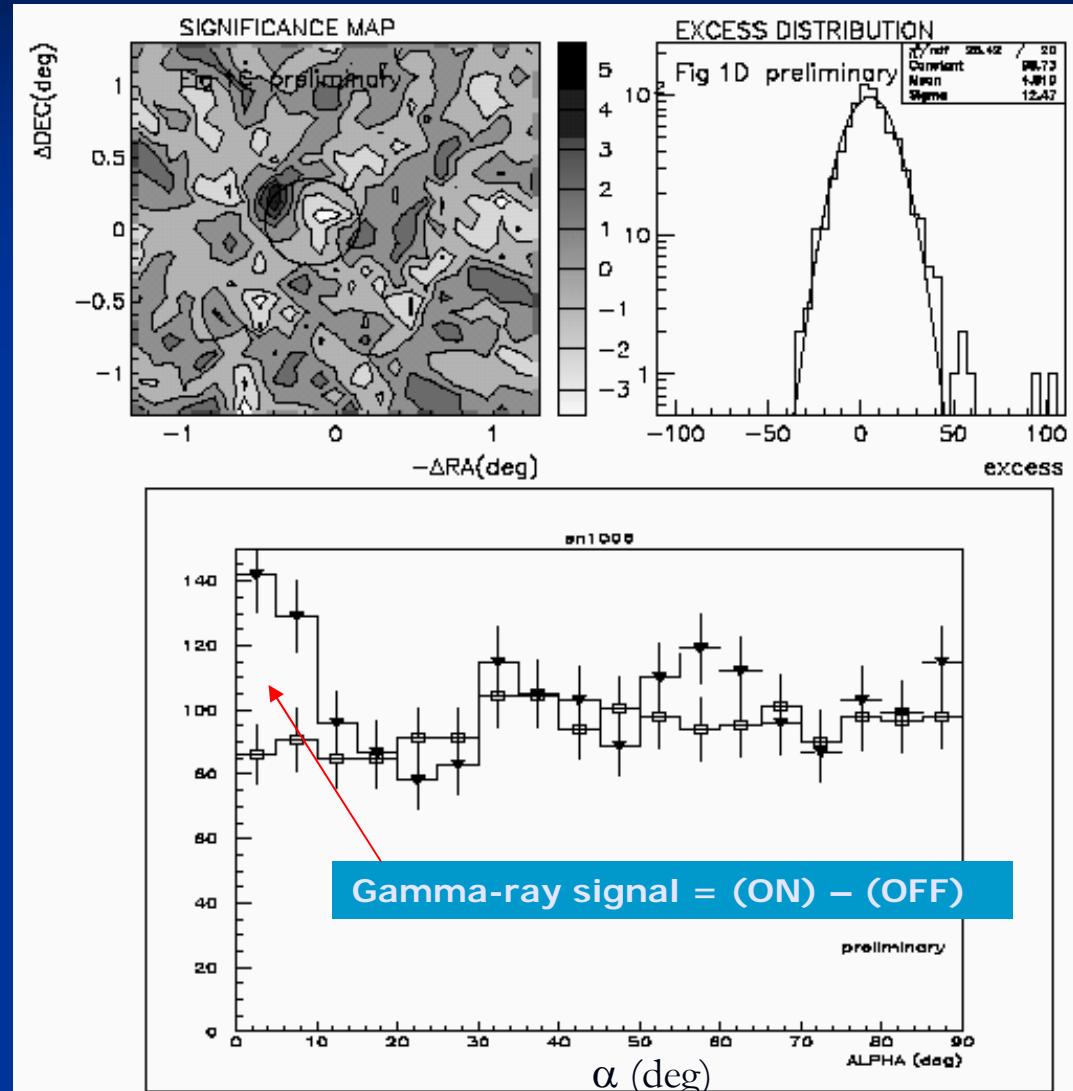
- Supernova remnants = Origin of CR?
 - Energetics – OK
 - Maximum energy – Up to “Knee region”
 - How much of them?
 - Some evidences, which can be ascribed to HE electrons:
where are HE protons?
- Pulsar and pulsar wind nebula (plerions)
 - Crab – “The standard candle”
 - Up to a few 10GeV: pulsed+unpulsed
 - Above: unpulsed only
 - - Unpulsed: SSC (Synchrotron-Self-Compton) model
 - - Where is the cutoff?
 - - (Pulsar emission models)
 - Others? Vela, PSR1706-44,...

“Known” galactic sources

- Crab “The standard candle”
 - Well established (many observations since 1989)
- Pulsar PSR 1706-44
 - CANGAROO 1995
- Vela pulsar
 - CANGAROO 1997
- Supernova remnant SN1006
 - CANGAROO 1998, HEGRA CT1 2003
- Supernova remnant RX J1713.7-3946
 - CANGAROO 2000, 2002
- Supernova remnant Cas A
 - HEGRA CT system 2001

SN1006: HEGRA CT1

- HEGRA CT1
- 219hrs
- $>18\text{TeV}$
- 5σ excess
- Position within 0.1° of CANGAROO hotspot



SN1006: H.E.S.S.

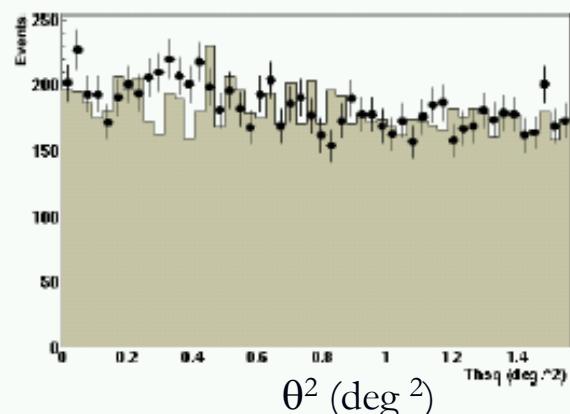
CT3 Observations:

4.5 hrs livetime
14 On/Off pairs
after quality selection

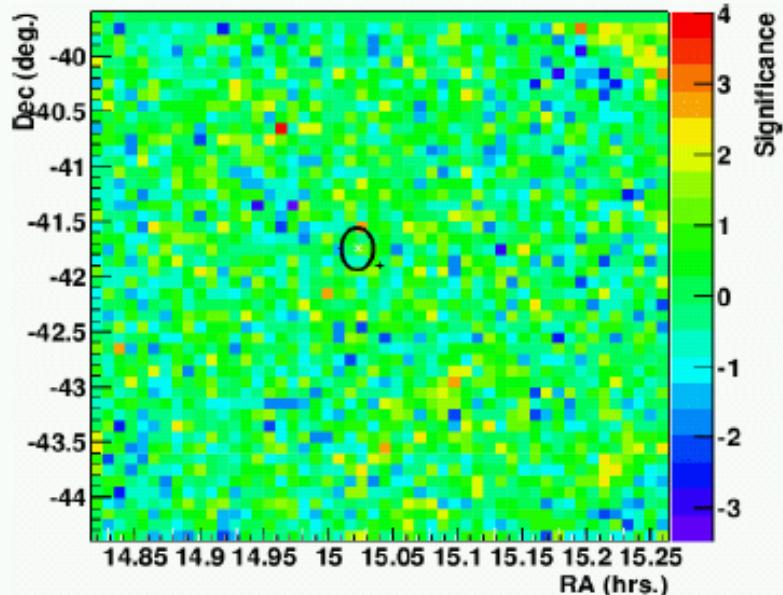
2-D excess:

1.0 σ

Background after cuts
0.96 min. $^{-1}$



SN 1006 CT3



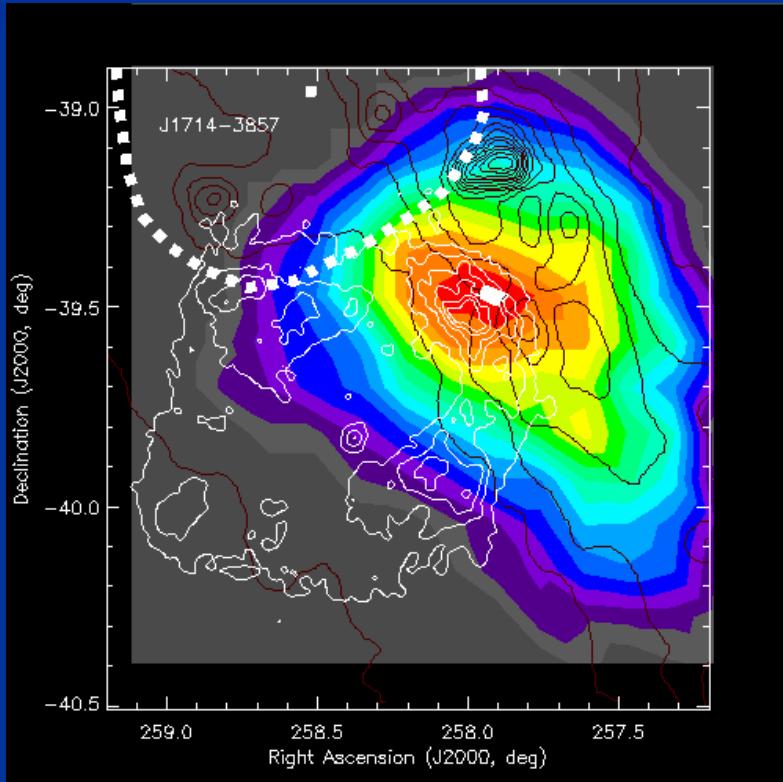
Cangaroo hotspot marked by circle

Excess as function of distance from
Cangaroo hotspot

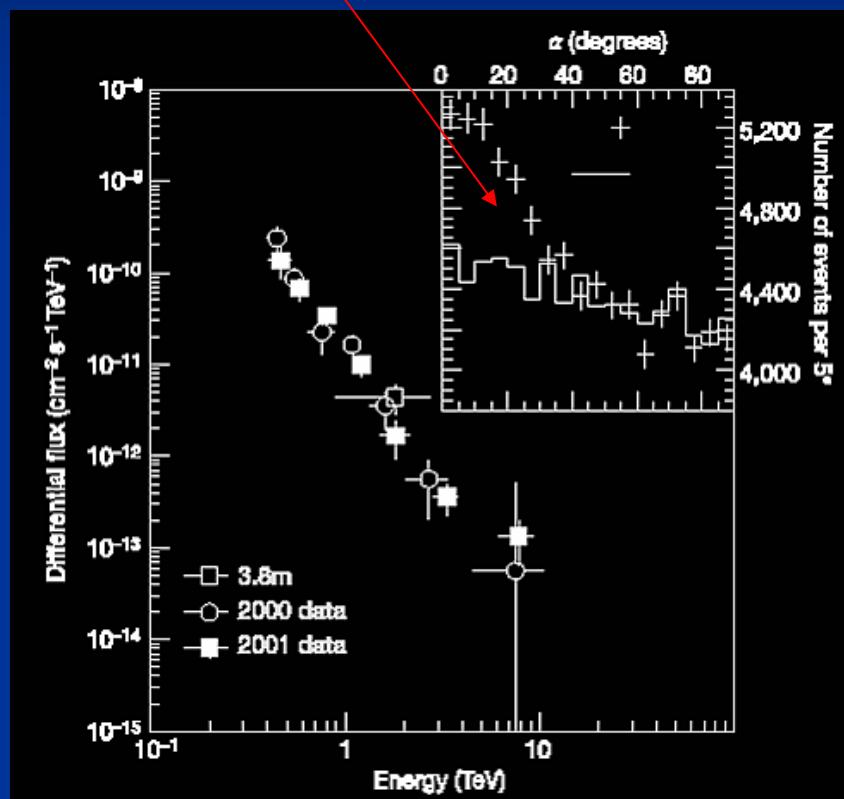
SNR RX J1713.7-3946 (1)

Gamma-ray signal = (ON) – (OFF)

- Detected in X-rays
- Non-thermal X-ray spectrum

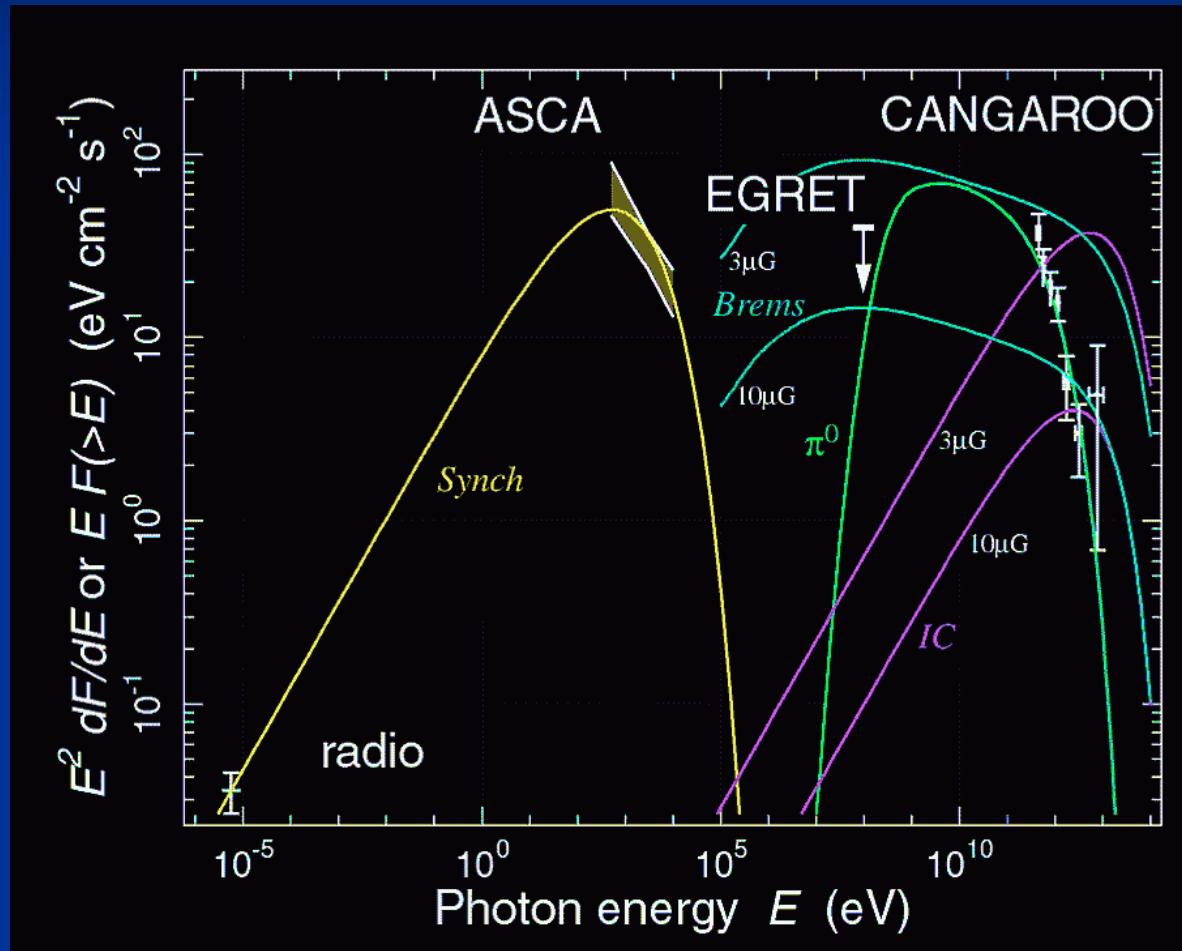


Significance map



Energy spectrum

SNR RX J1713.7-3946 (2)



Hard to explain by
emission from electrons
(Brems, IC)

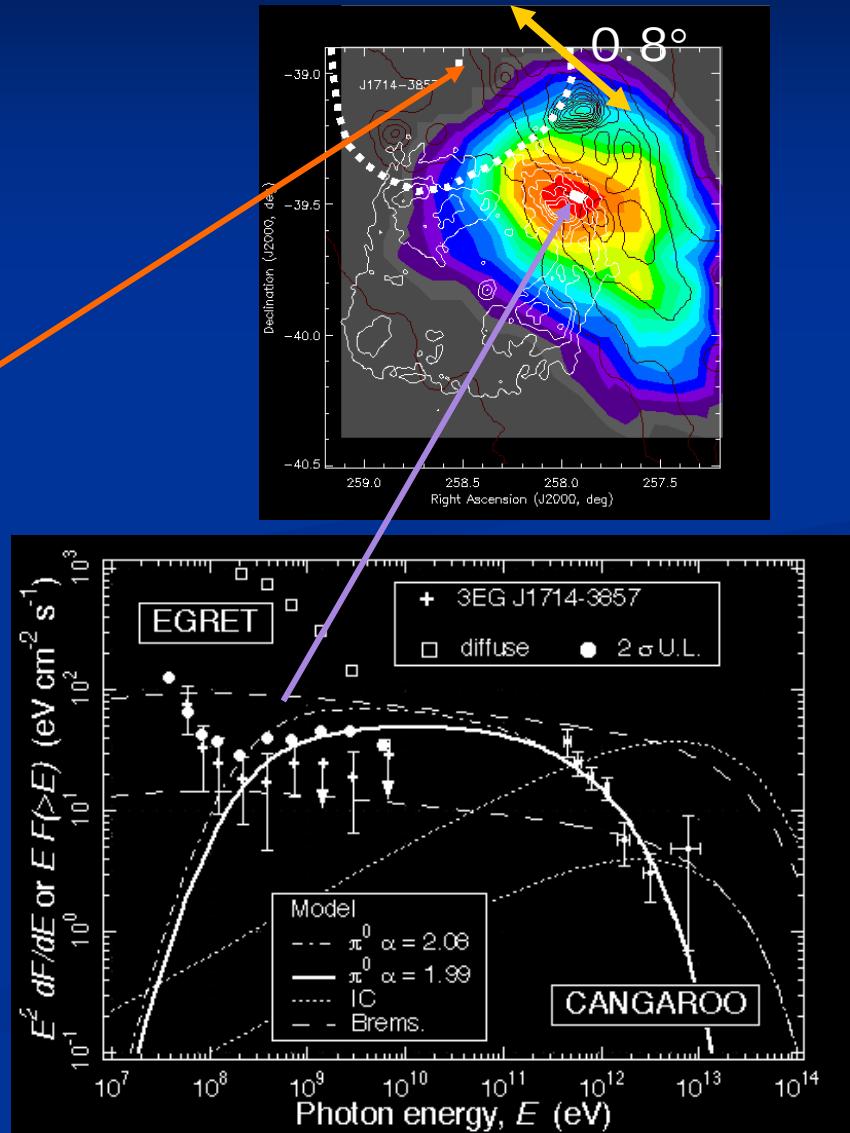
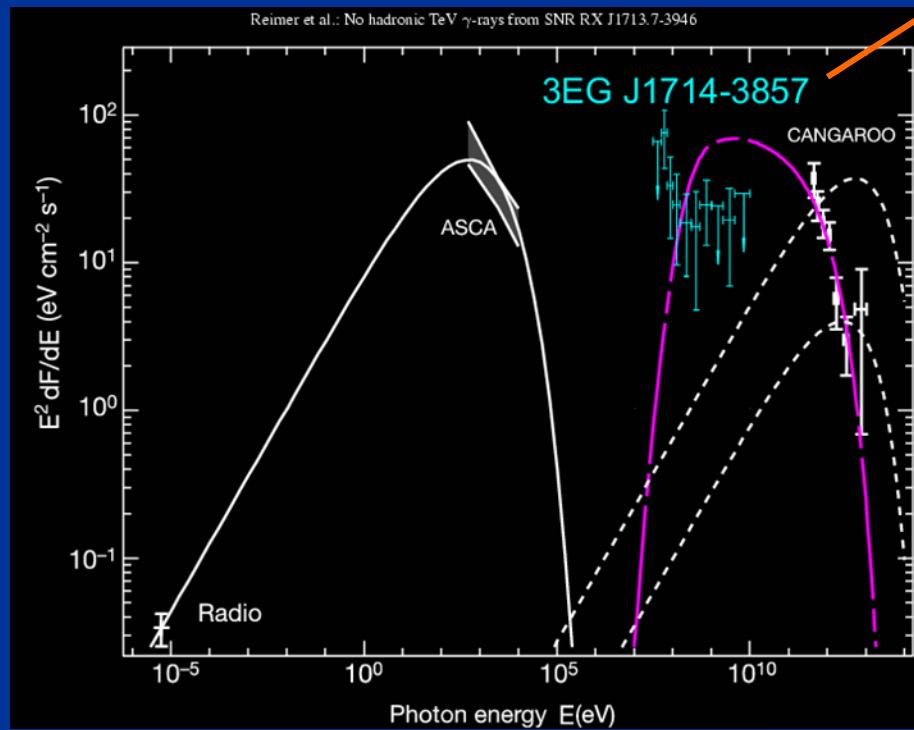
⇒ Emission from
protons (π^0)?

⇒ Cosmic ray
origin?

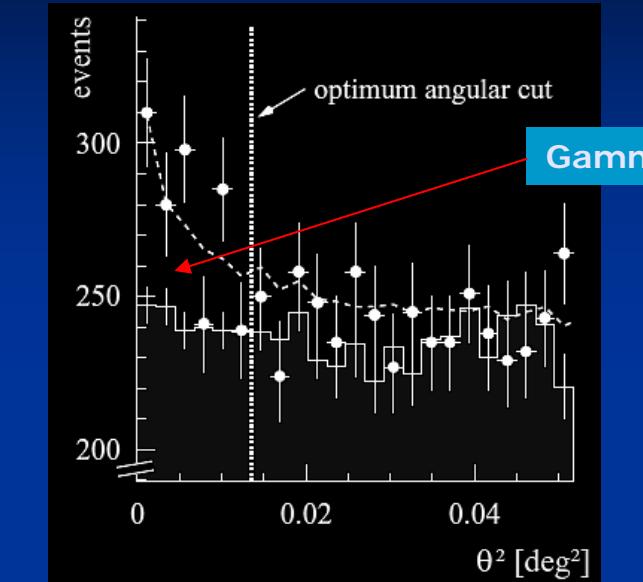
SNR RX J1713.7-3946 (3)

Counter arguments

- * Reimer & Pohl, A&A 390 (2002) L43
- * Butt et al., Nature 418 (2002) 489

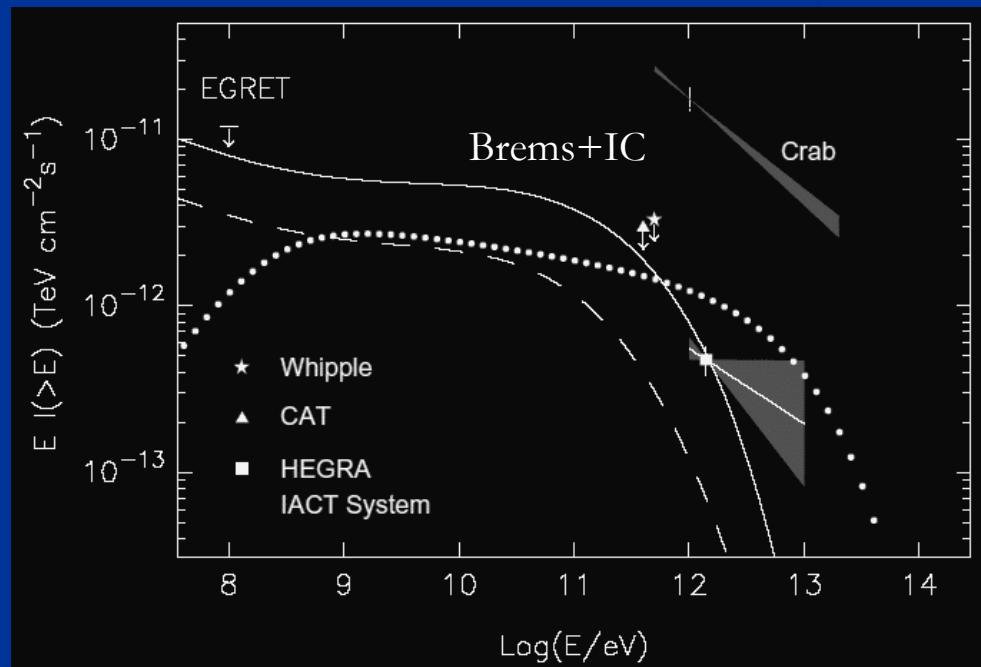
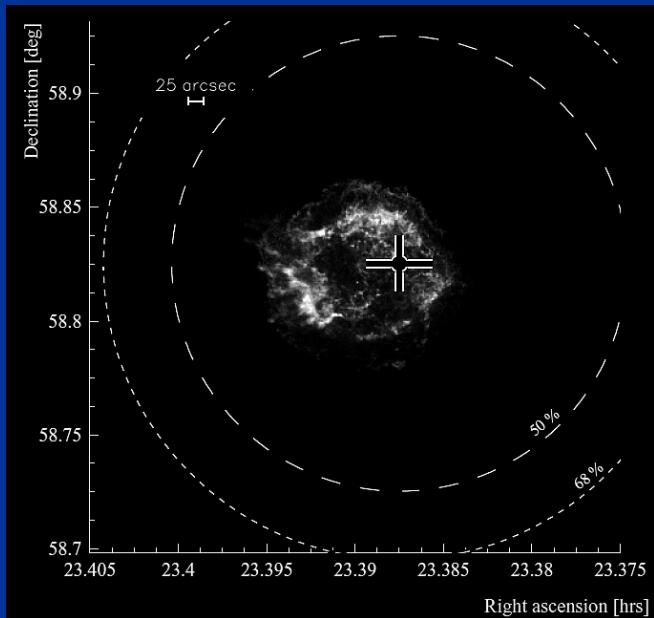


SNR Cas A



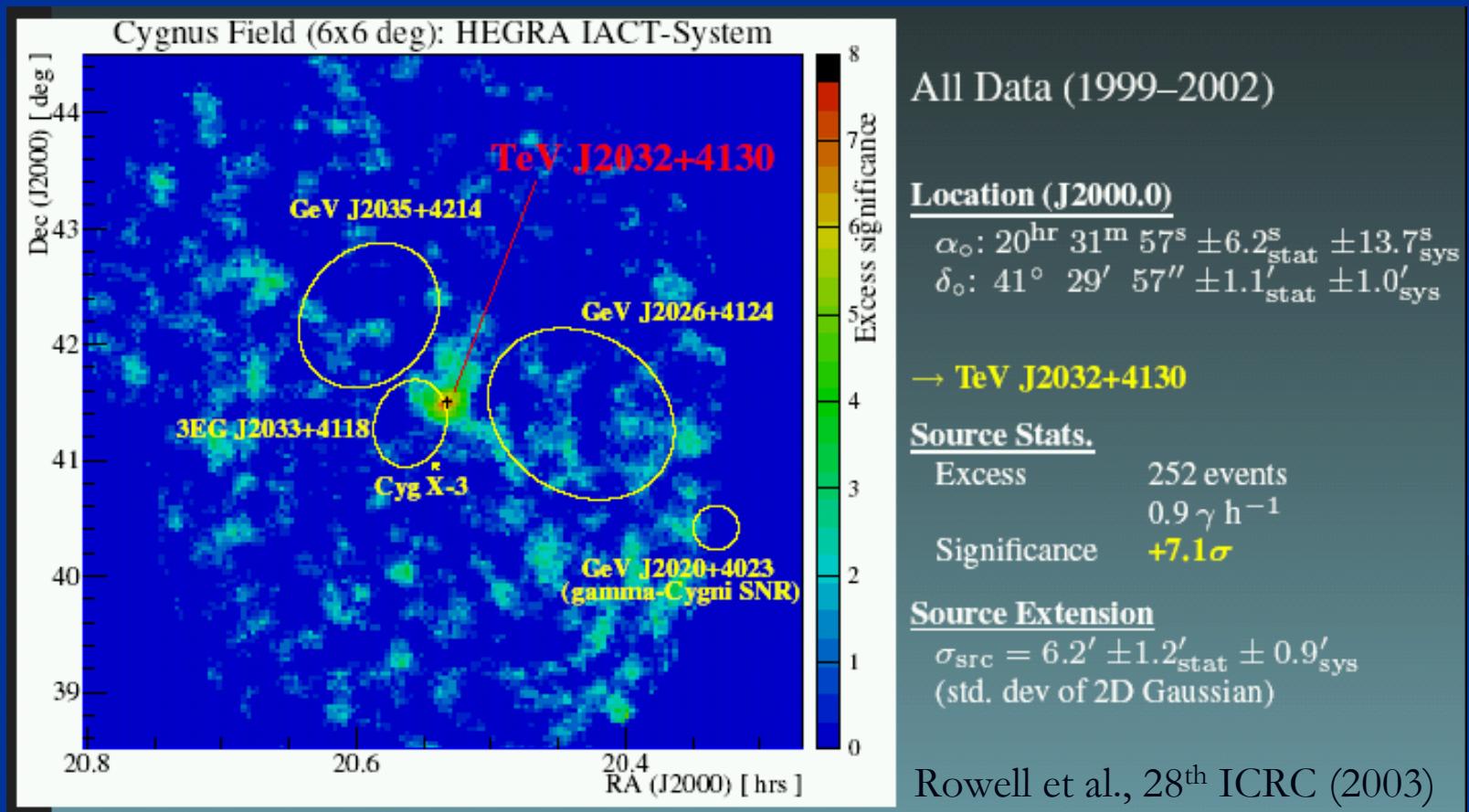
HEGRA-CT system (stereo)

232 hrs



New entry: TeV J2032+4130

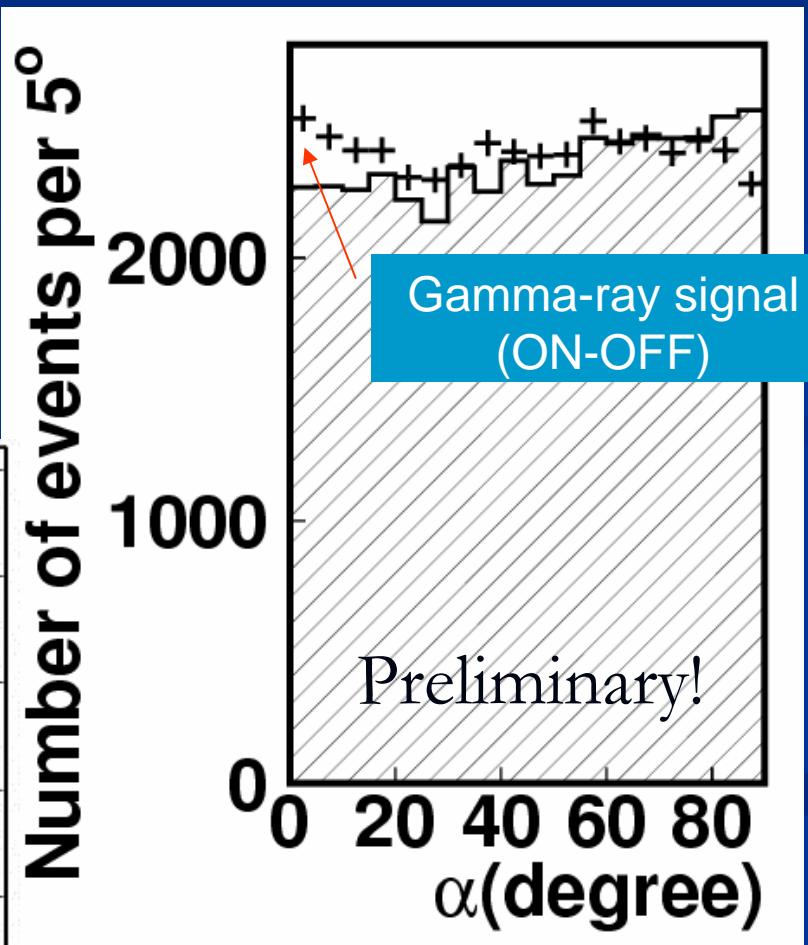
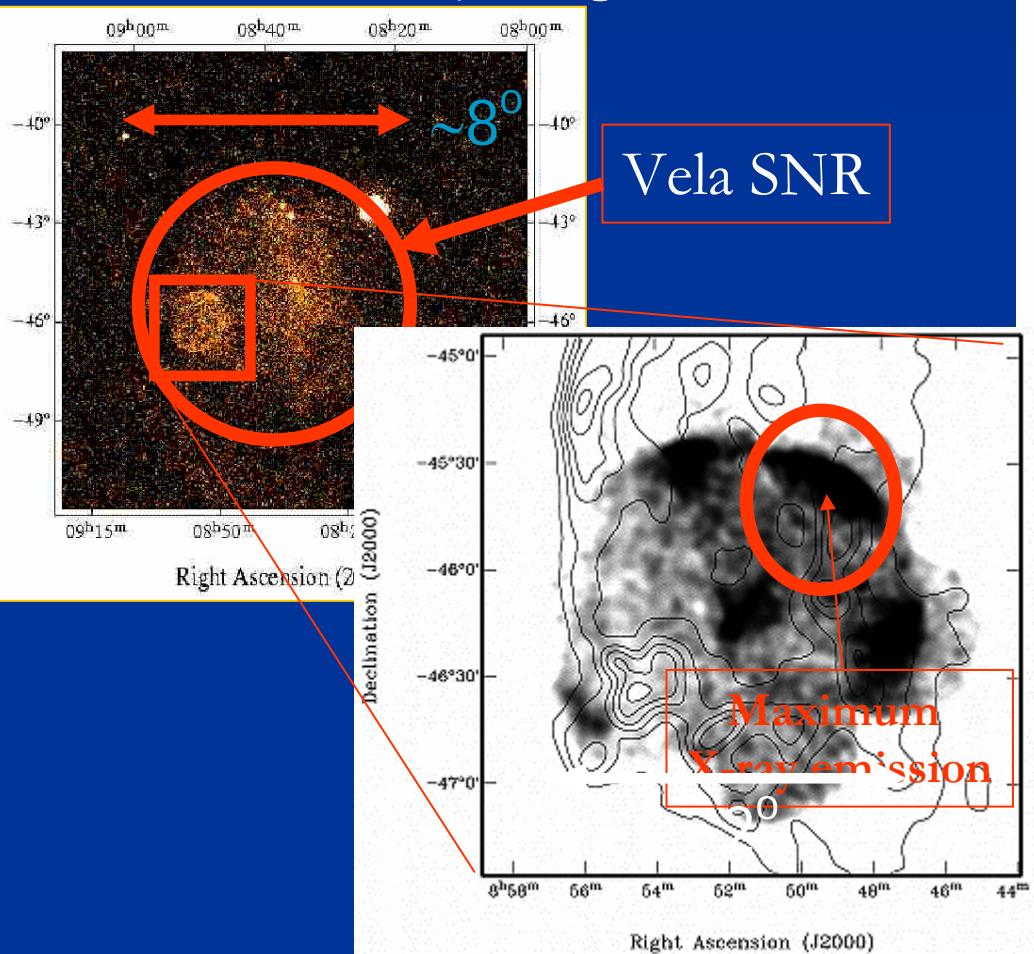
- Unidentified TeV source TeV J2032+4130
 - Very hard spectrum $E^{-1.9}$
 - No counterpart in radio or X-rays



New entry: SNR RX J0852.0-4622

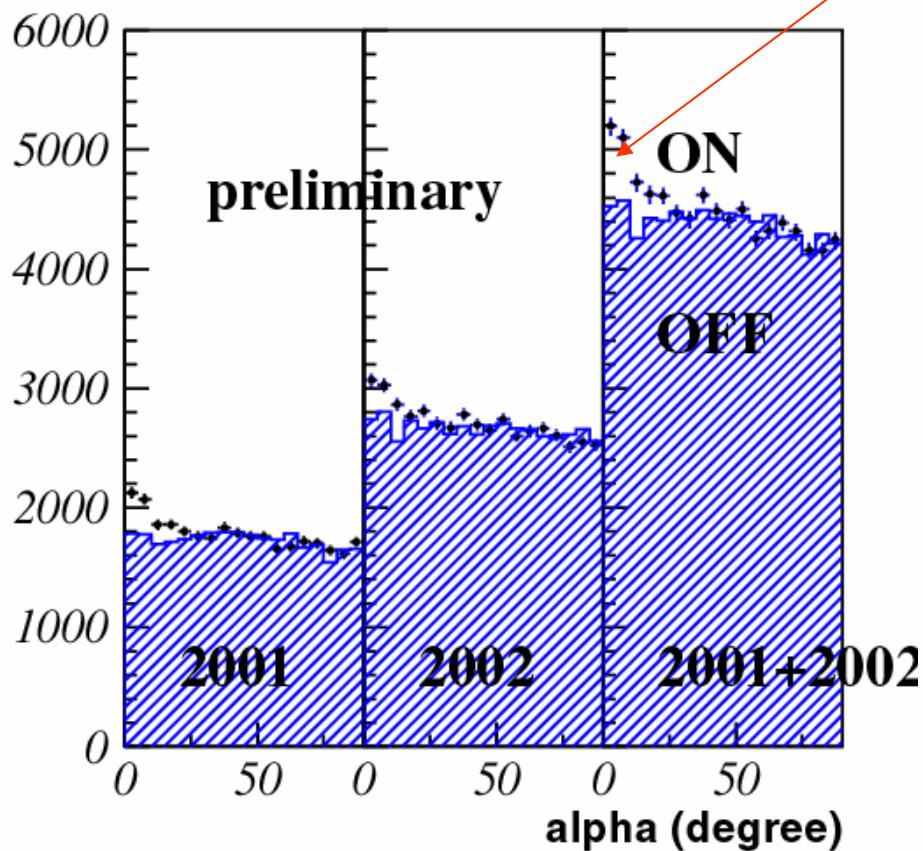
- CANGAROO 10m result

ROSAT X-ray image

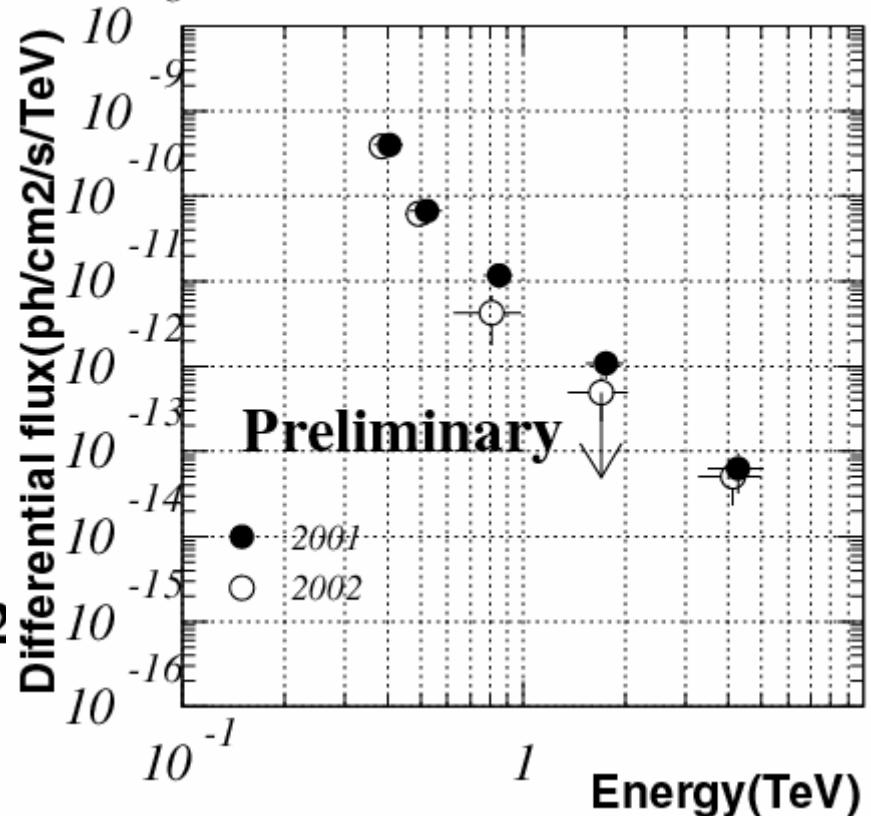


New entry: Galactic center

■ CANGAROO 10m result



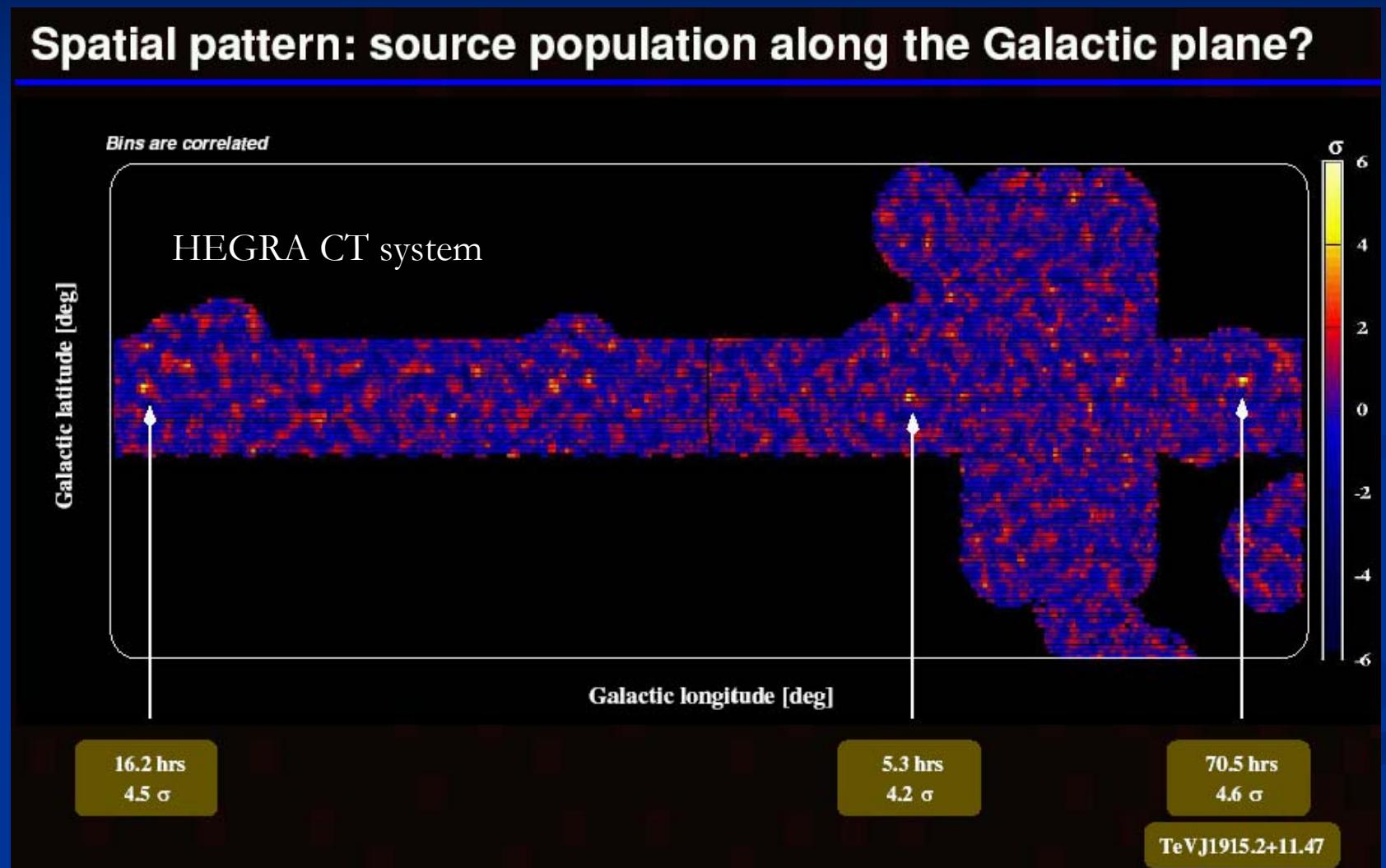
Gamma-ray signal
(ON-OFF)



Tsuchiya et al., 28th ICRC (2003)

Galactic plane survey

Spatial pattern: source population along the Galactic plane?



Extragalactic sources: basics

- Active galactic nuclei
 - Blazars
 - Wide-band spectrum – nonthermal
 - Quasars – LBL (RBL) – HBL (XBL) sequence
 - Leptonic models
 - SSC or EC (External Compton)
 - Hadronic models
 - Proton-initiated cascades
 - Radio galaxy,...
- Gamma-ray absorption by EBL (Extragalactic Background Radiation)
 - Infrared photon field: uncertain
- Center of galaxies
 - Accumulation of dark matter??
- Extragalactic background radiation

“Known” extragalactic sources

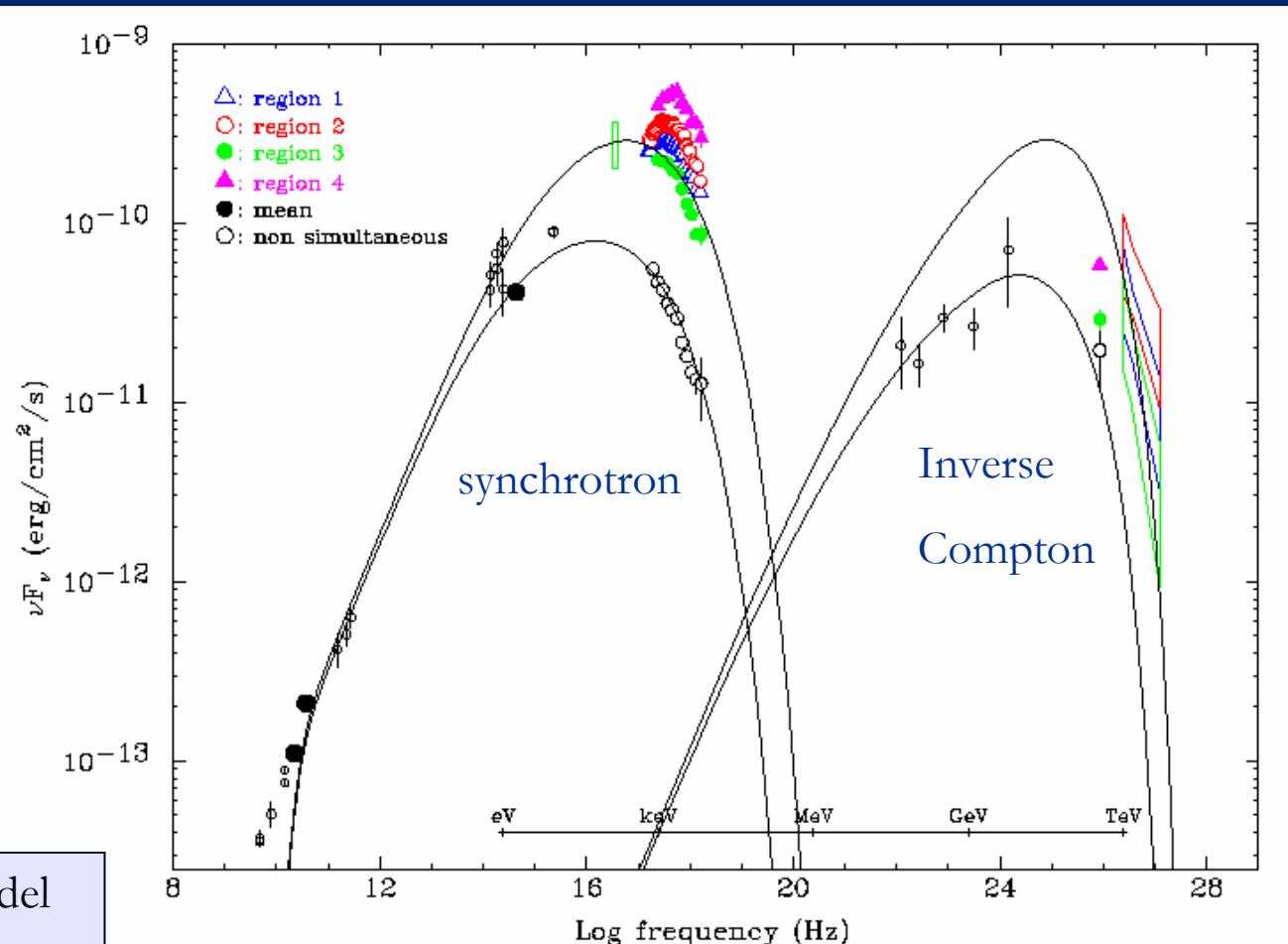
- Mrk421 ($z=0.031$)
 - First detection in 1992 [Punch et al. Nature 1992]
 - Flares in 1994, 1996, 2001, 2002-3
- Mrk501 ($z=0.034$)
 - First detection in 1995 [Quinn et al. ApJ 1996]
 - Large flares in 1997
- 1H1426+428 ($z=0.129$)
 - First detection in 2001 [Horan et al. 5th Compton 2001]
 - Flares in 2001

Mrk421 spectrum

- Synchrotron + inverse Compton model works well
→ e^\pm origin (SSC: Synchrotron Self Compton)
- Proton model still viable

One-zone SSC model

$$\delta = 14, B = 0.14 \text{ G}$$



Takahashi et al. ApJ 542, 2000

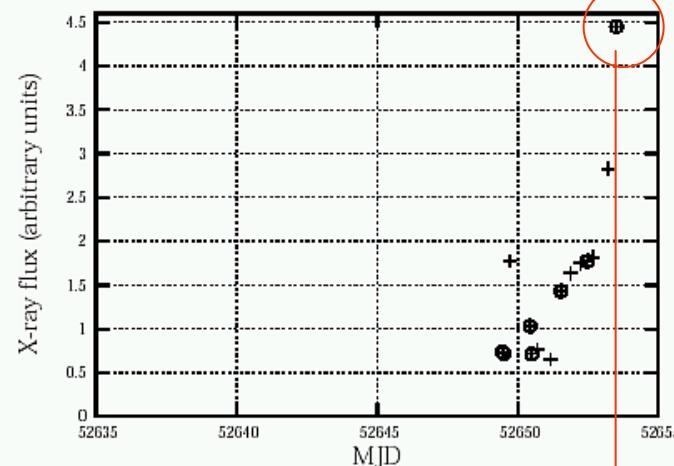
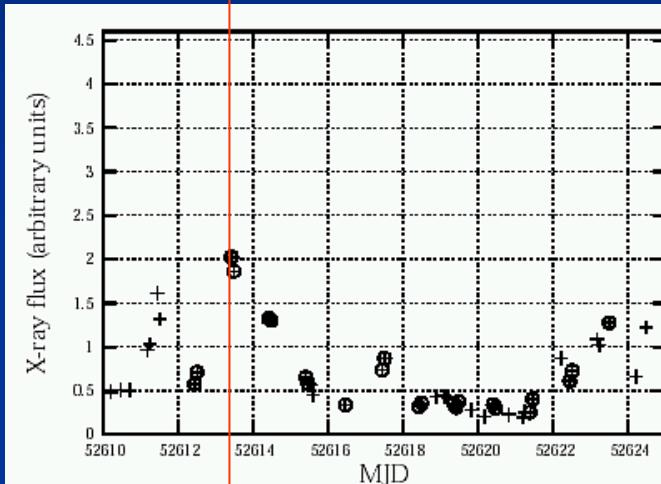
Mrk421: Whipple Flare Dec02-Jan03

“Orphan” X-ray flare

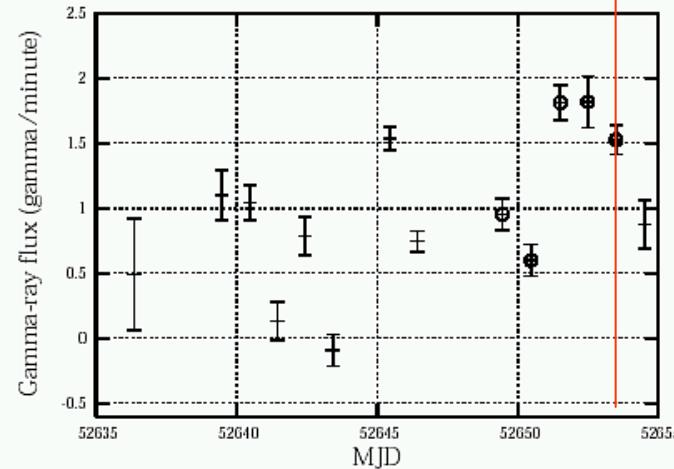
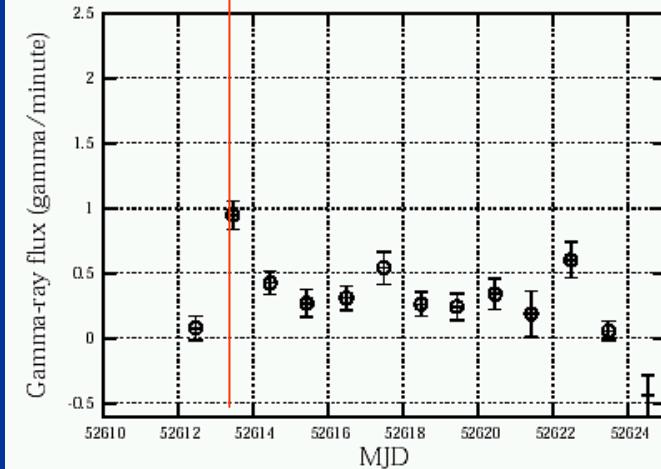
Correlated flare

Correlation is not simple!

X-ray

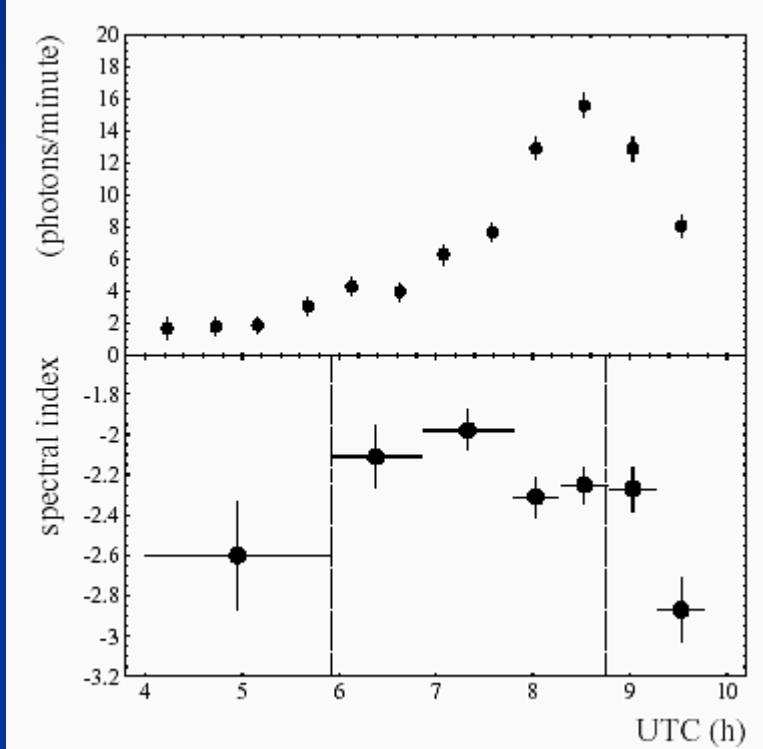


γ -ray

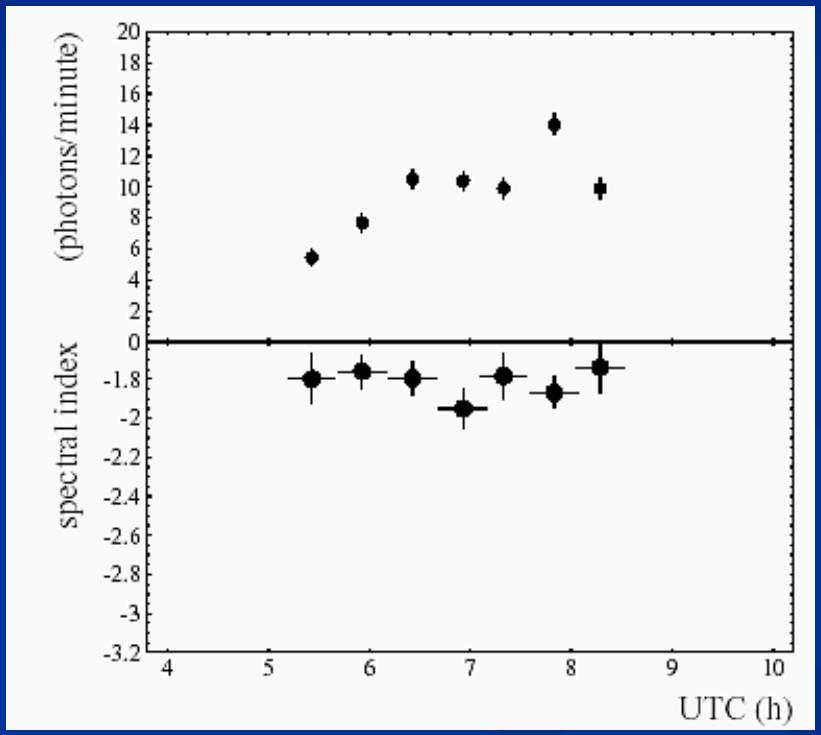


Mrk421: Whipple Hourly variability

Mar 19, 2001



Mar 25, 2001



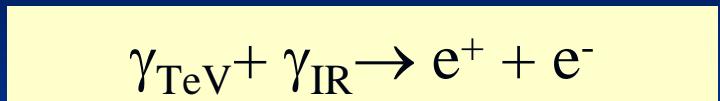
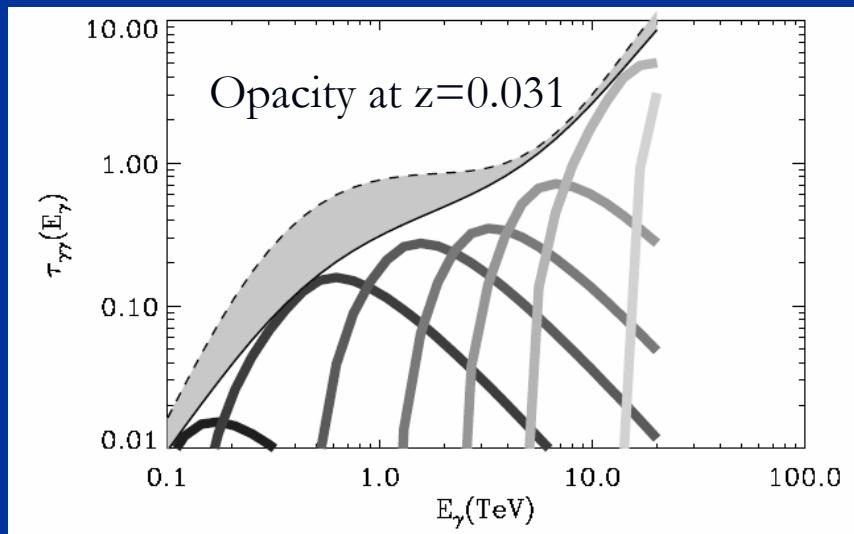
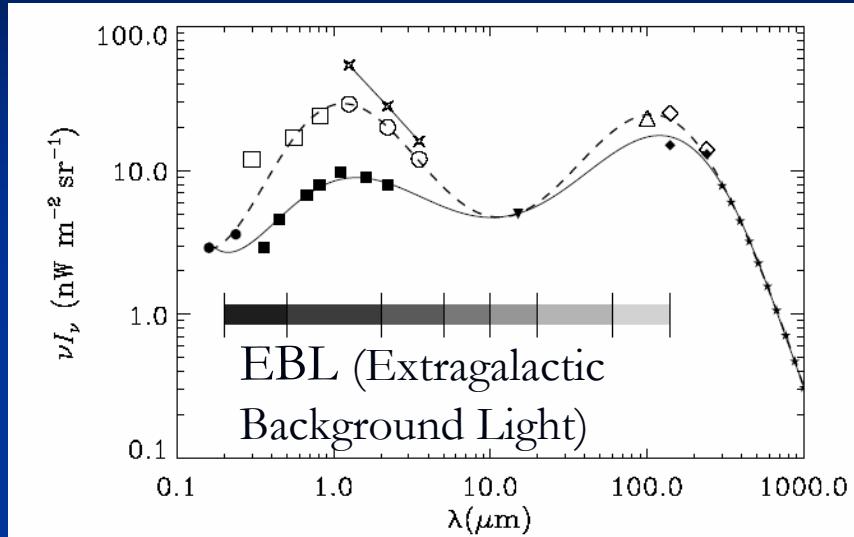
Harder for stronger

↔

Constant slope

Why this difference?

TeV gamma-ray absorption on EBL (1)



Mean free path for e^+e^- pair production

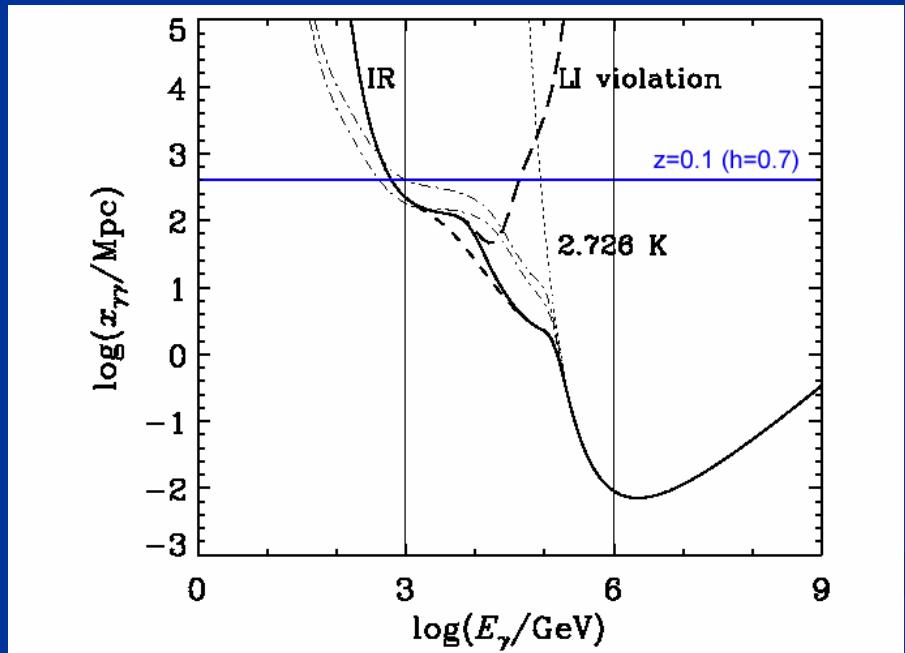
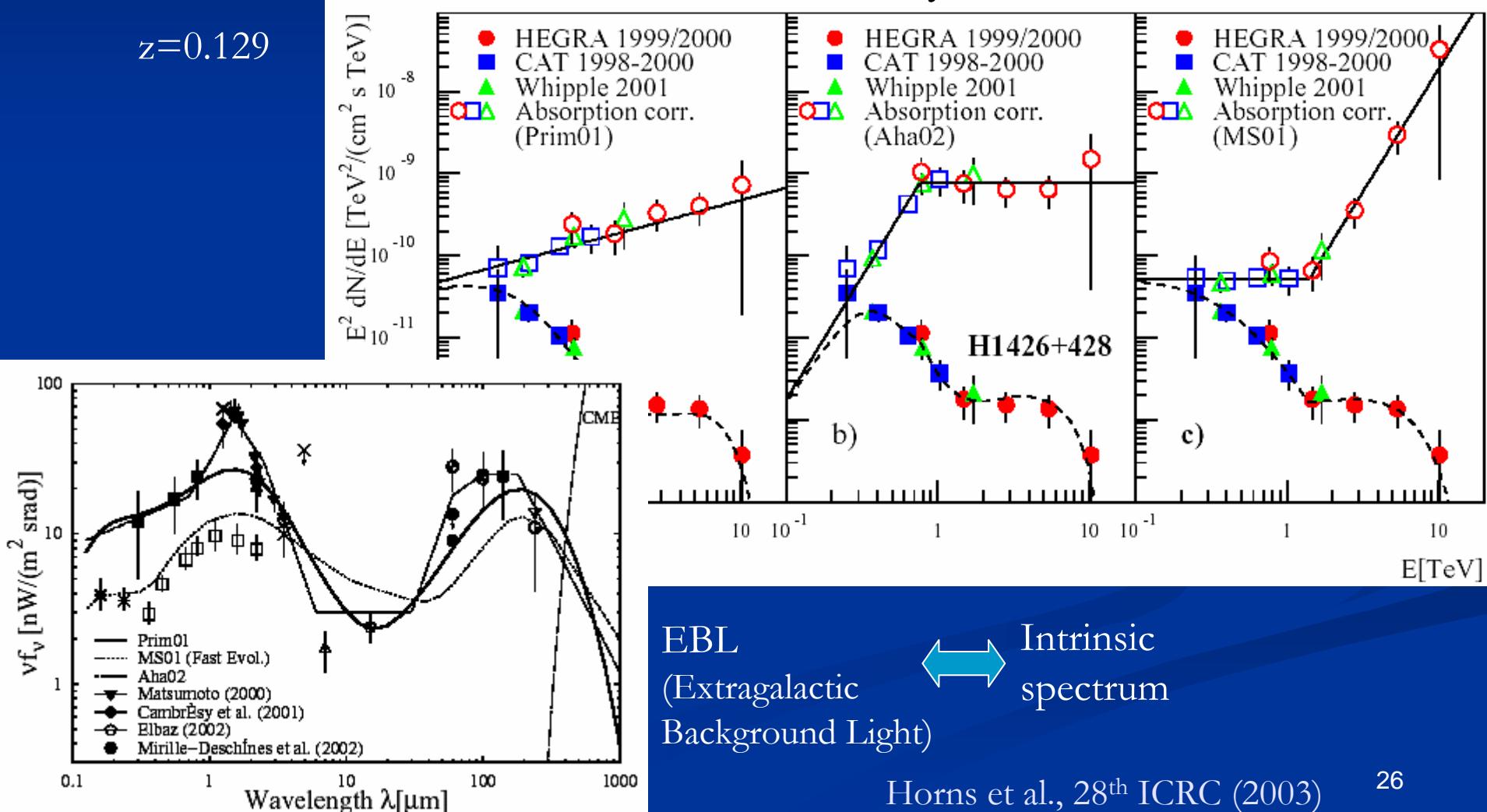


Figure 2: Mean free path for photon-photon pair production in the infrared-microwave background radiation. The curves correspond to those in Fig. 1 except that the effect of Lorentz Invariance violation discussed in Section 4 is shown by the long dashed curve.

TeV gamma-ray absorption on EBL (2)

■ H1426+428: HEGRA CT system

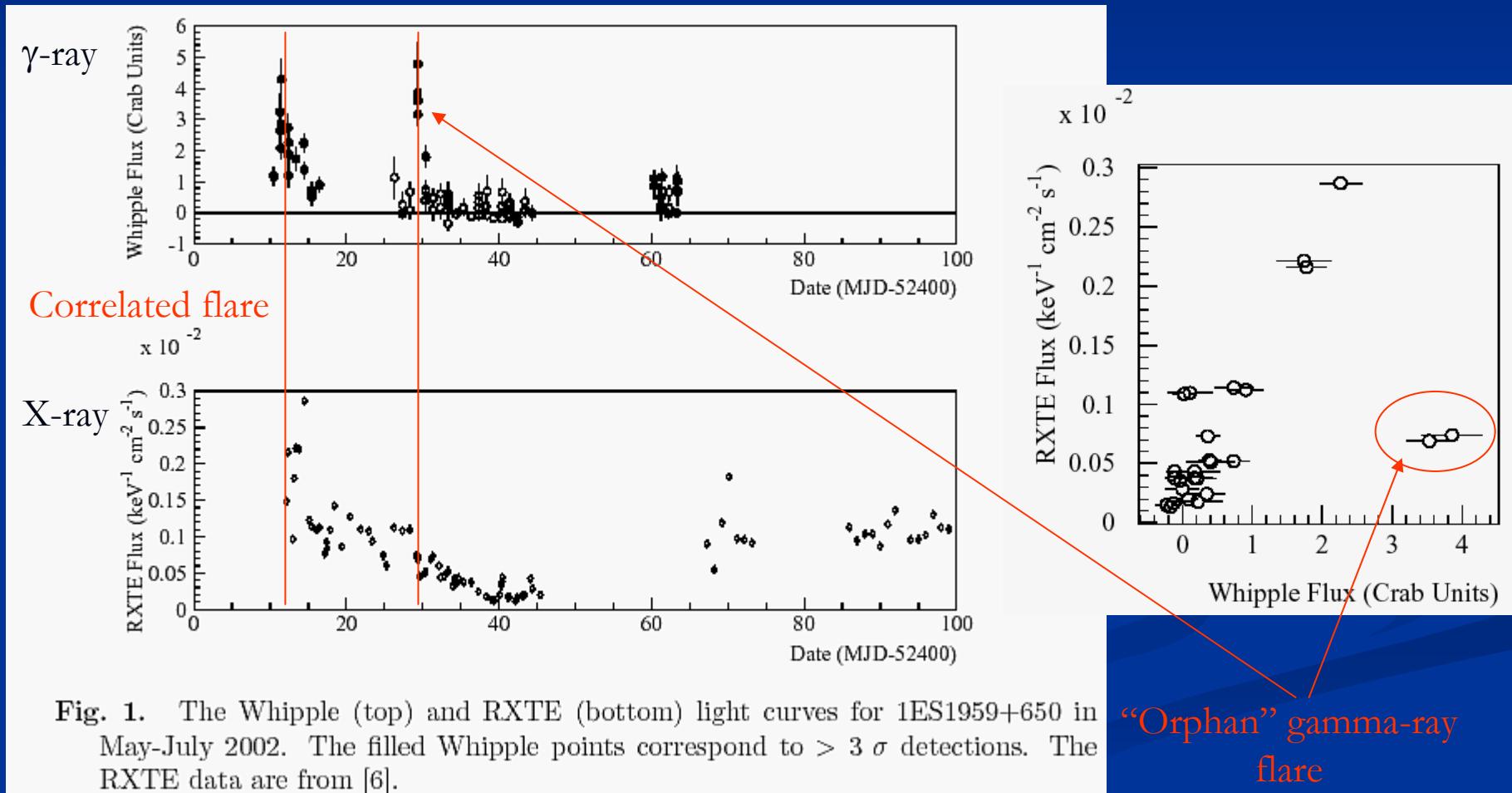
$z=0.129$



Confirmed extragalactic sources

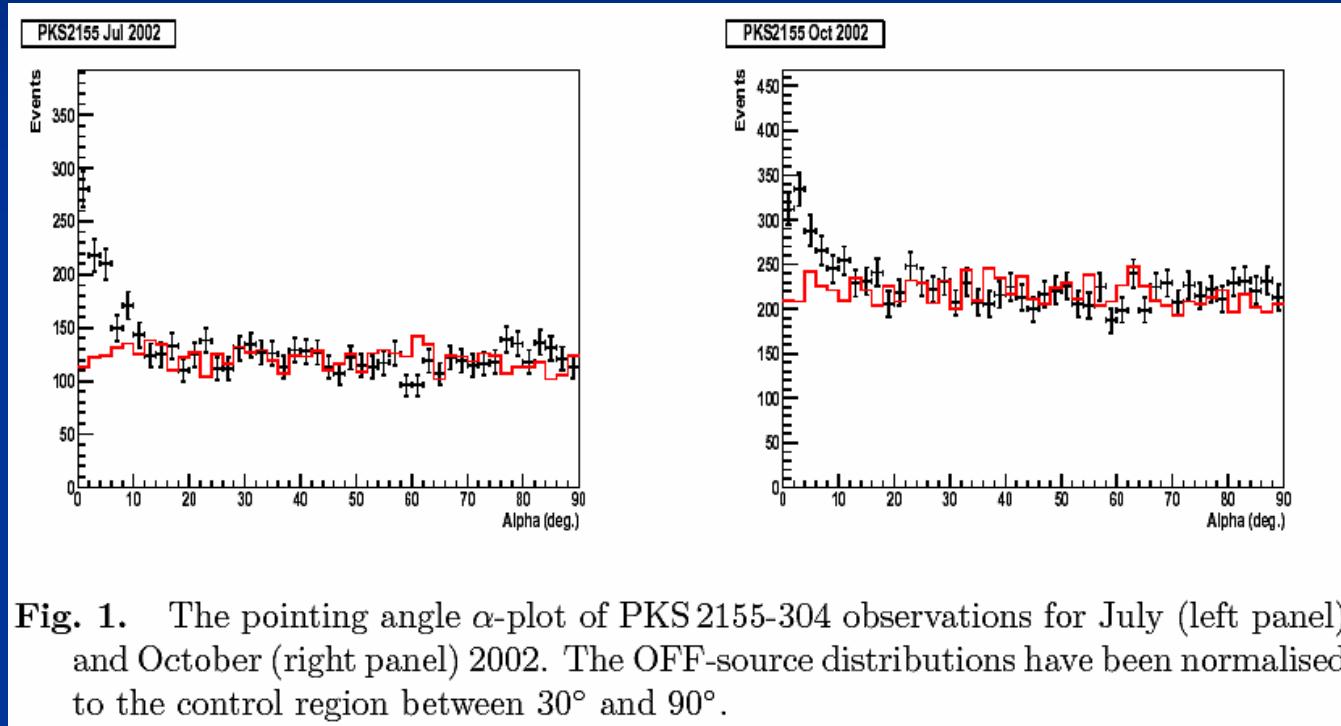
- 1ES1959+650 (Blazar, z=0.048)
 - Utah 7TA detection [Nishiyama et al. 1999ICRC] 3.9σ
 - Large Flare in 2002
 - HEGRA CT system [Aharonian et al. 2003A&A]
 - HEGRA CT1 [Tonello et al. 28th ICRC 2003]
 - Whipple [Holder 2619]
- 1ES2344+514 (Blazar, z=0.044)
 - Whipple detection [Catanese et al. 1998ApJ]
 - HEGRA CT system [Tluczykont et al. 28th ICRC 2003] 4.4σ
- PKS2155-304 (Blazar, z=0.116)
 - Durham Mark6 detection [Chadwick et al. 1999ApJ]
 - CANGAROO [Nakase et al. 28th ICRC 2003] upper limit, 2000-2001
 - H.E.S.S. [Djannati-Atai et al., 28th ICRC 2003] detection $>6\sigma$, 2002

1ES1959+650: Whipple May-July 2002



PKS 2155-304

- H.E.S.S. (single telescope)



PKS2155	T_{live} (h)	Non	Noff	Excess	γ/min	Significance
Jul 2002	2.2 h	1029	625	404	3.1	9.9 σ
Oct 2002	4.7	1444	1107	337	1.2	6.6 σ

New entry: NGC253 (1)

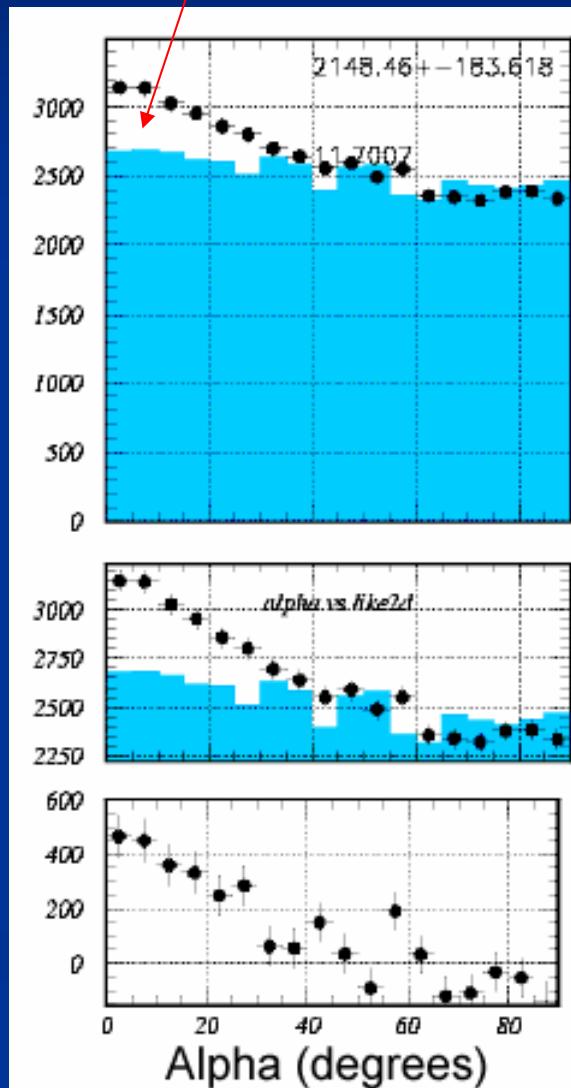
- Nearby spiral galaxy (2.4Mpc)
- Starburst activity
 \Leftrightarrow frequent SNe



Optical
image

AAT '23

Gamma-ray signal = (ON) – (OFF)

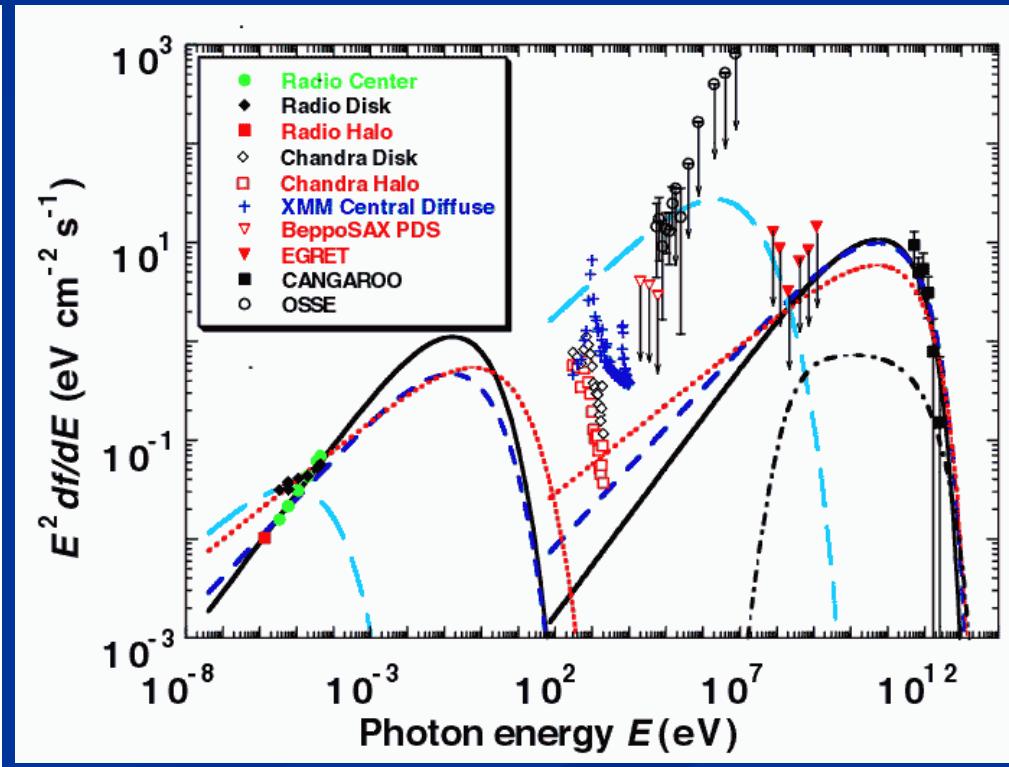
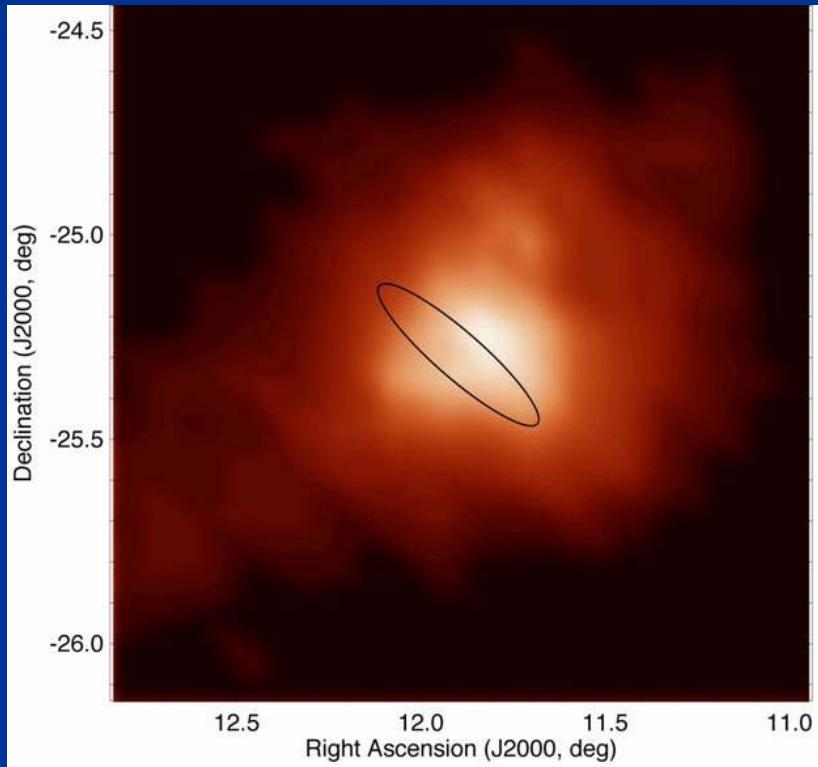


Itoh et al.

A&AL (2002)

New entry: NGC253 (2)

- Extended halo?



Significance map by CANGAROO

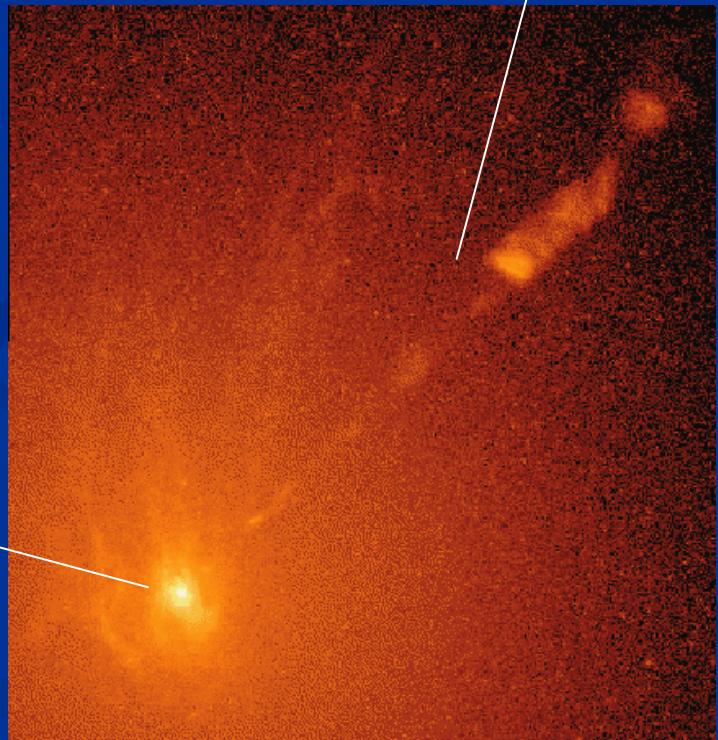
Itoh et al. ApJ (2003)

New entry: M87 (1)

■ M87 (Vir A, Giant radio galaxy, $z=0.00436$ or 16Mpc)

- HEGRA CT system detection
- Whipple upper limit

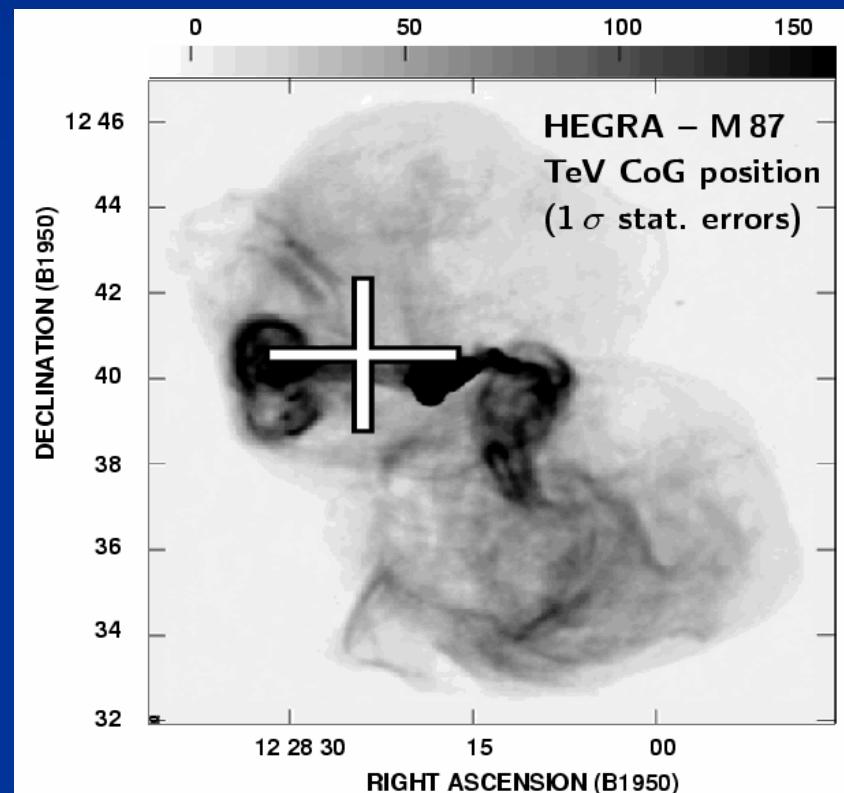
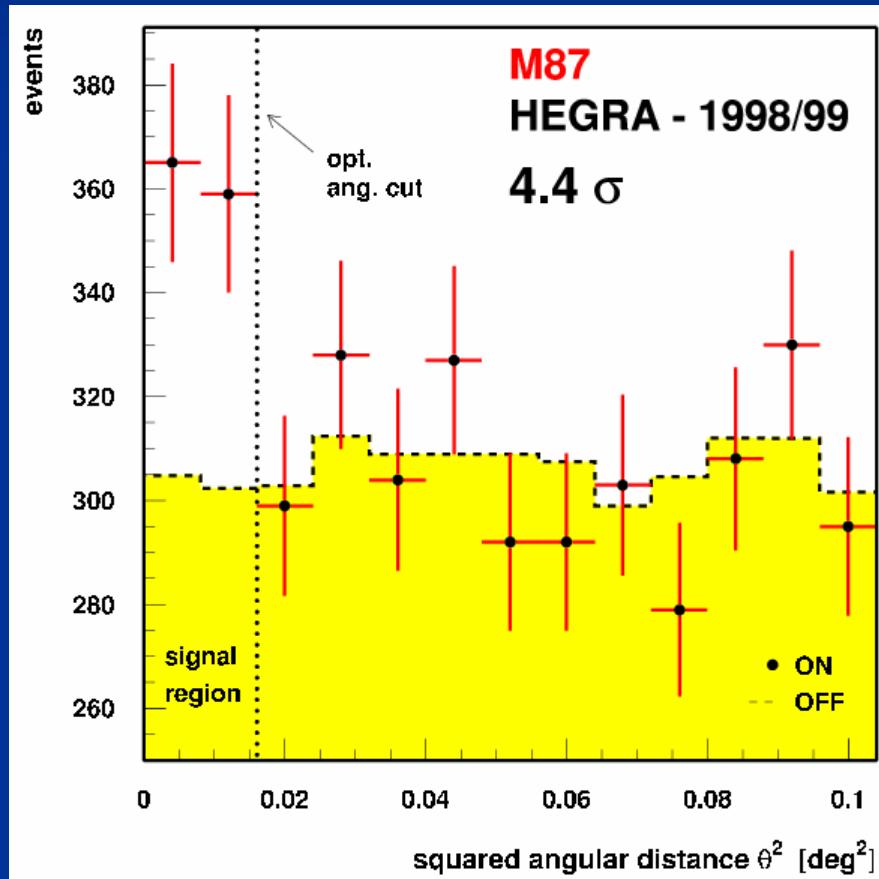
AGN
 $\sim 10^9 M_\odot$ B.H.



Optical image

New entry: M87 (2)

- M87: HEGRA CT system 1998-1999 4.4σ



New entry: M87 (3)

- M87: Whipple 2000-2001 2.4σ , 2002-2003 no excess

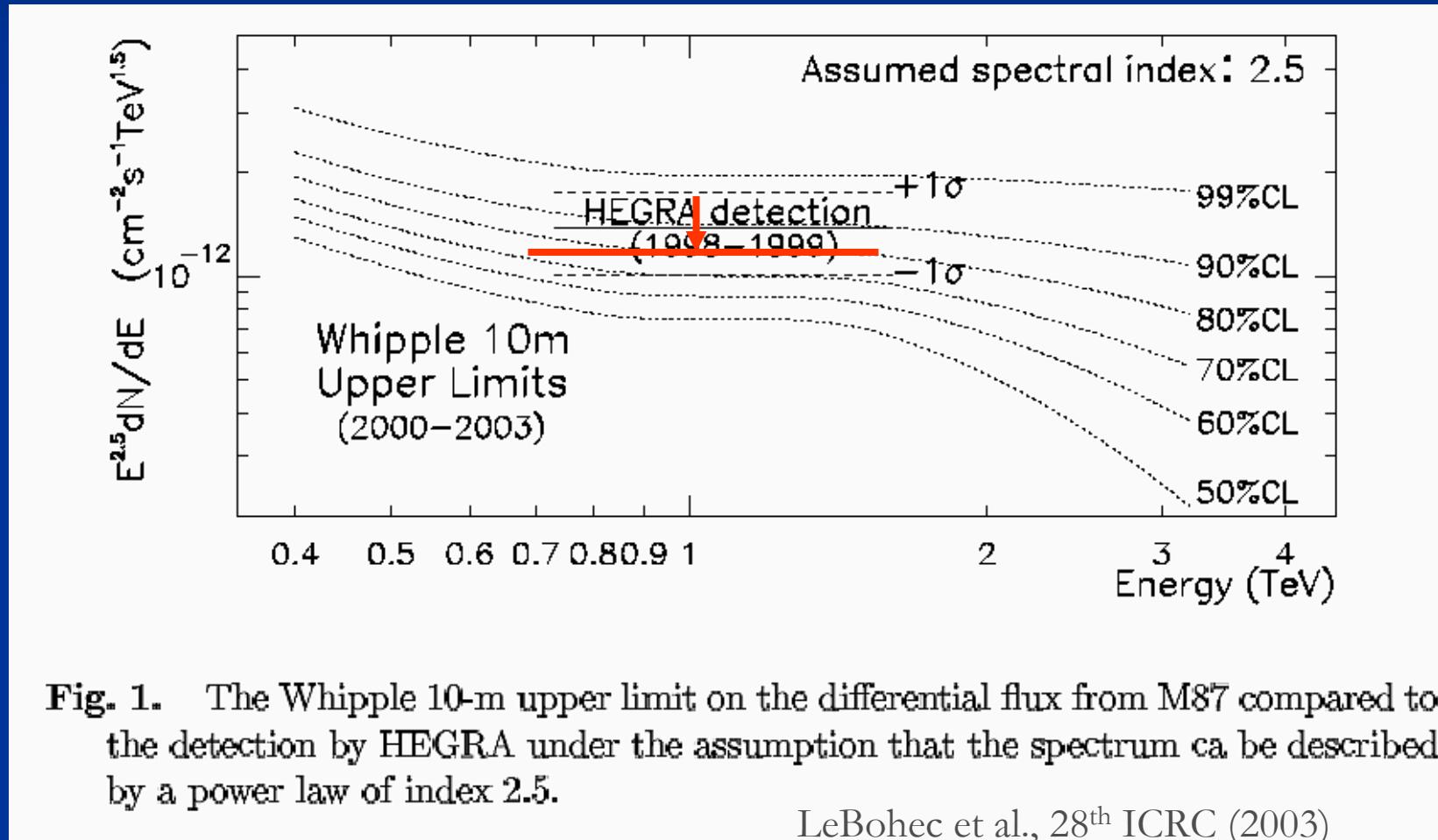
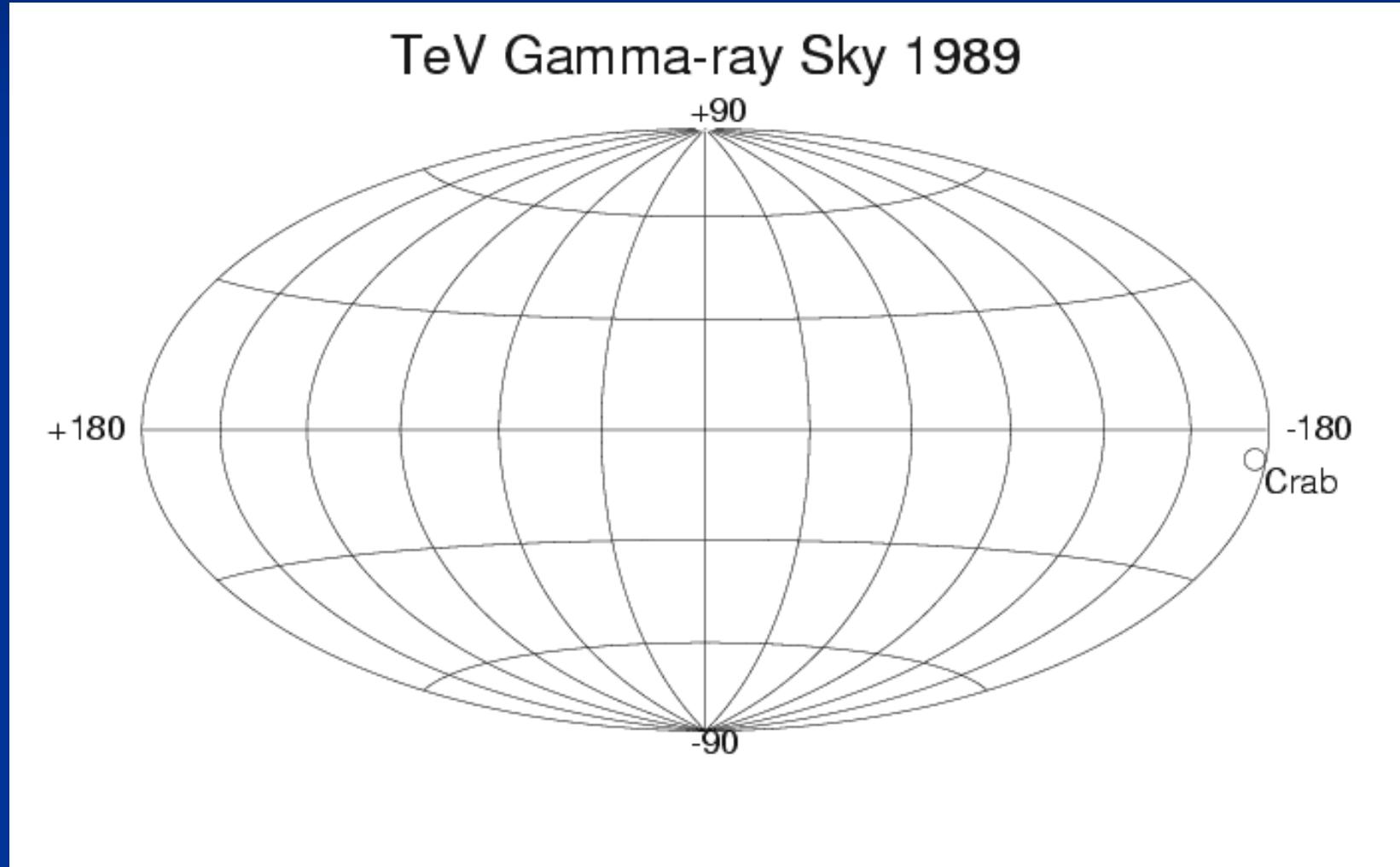
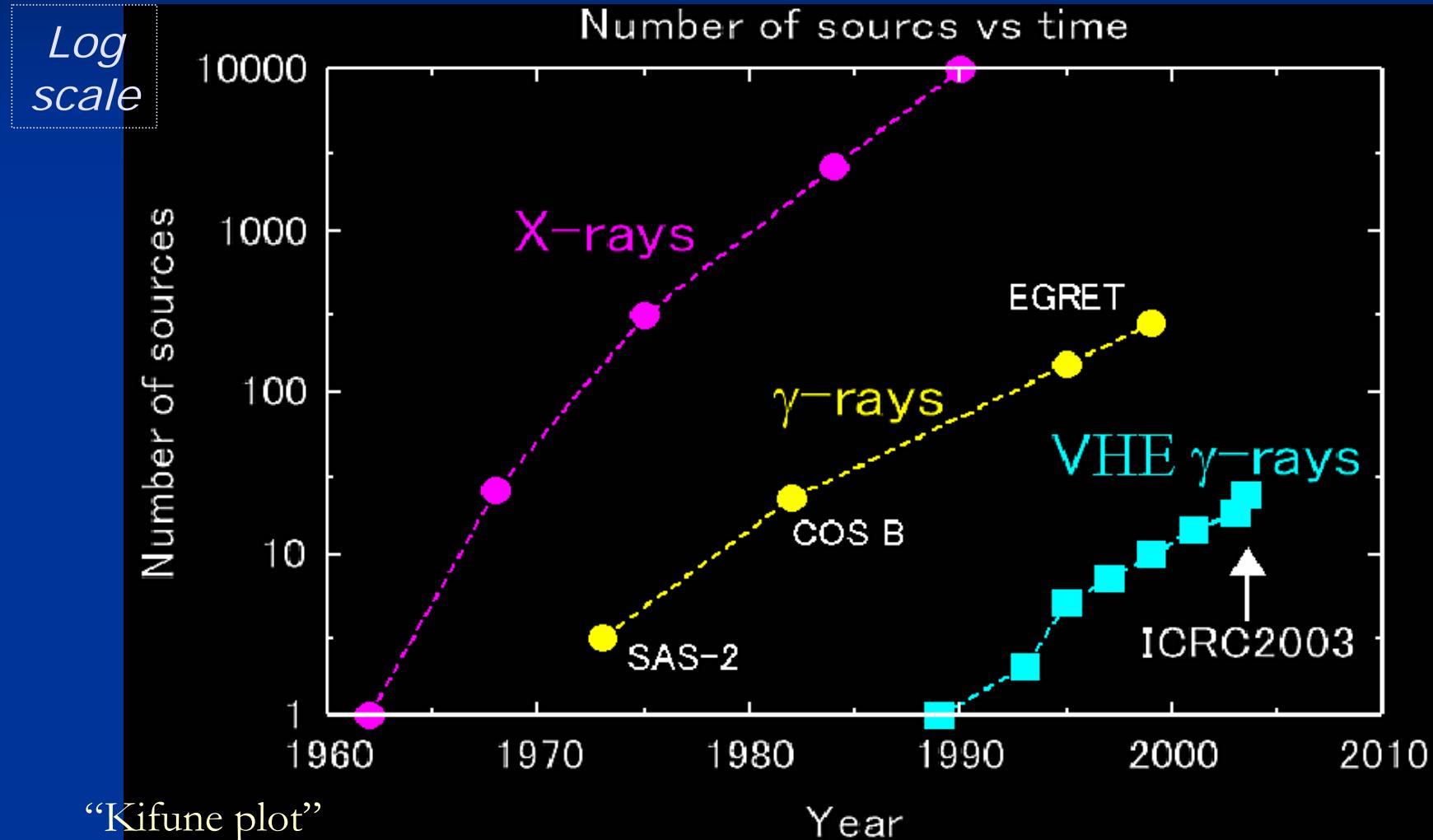


Fig. 1. The Whipple 10-m upper limit on the differential flux from M87 compared to the detection by HEGRA under the assumption that the spectrum can be described by a power law of index 2.5.

“Evolution” of the TeV gamma-ray sky

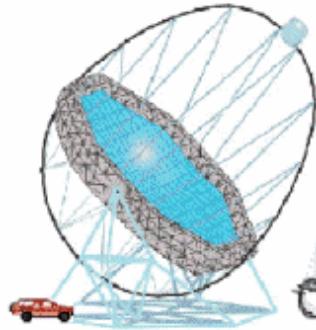


“Evolution” in number of objects

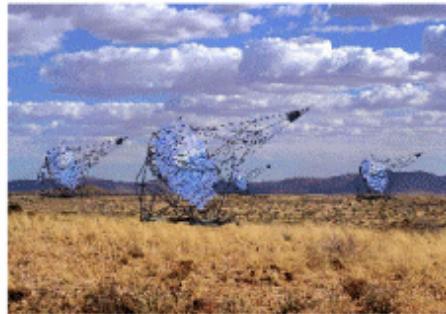


New Cherenkov telescopes

The “Big Four”



MAGIC



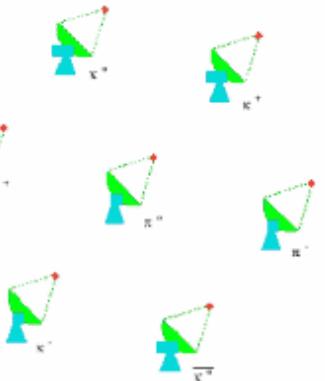
HESS



CANGAROO-III



VERITAS



CANGAROO-III: completion in 2003



Four 10m telescopes (3 completed) in Woomera, Australia

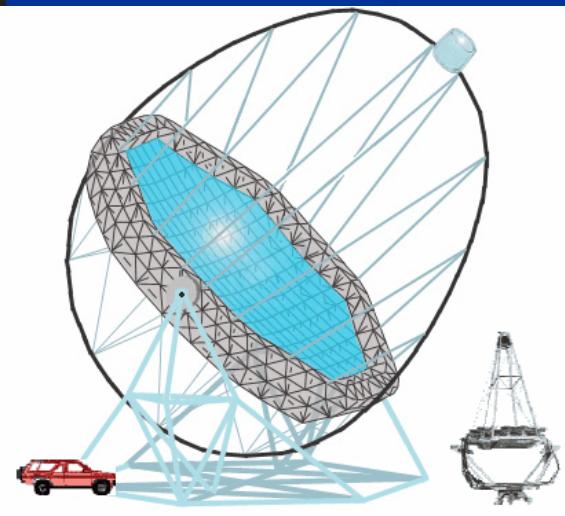
ICRR, Univ.Tokyo, Kyoto Univ., Univ. Adelaide etc.

H.E.S.S.: completion in 2004



Four 12m telescopes (2 completed) in Namibia, Africa
Max Planck Inst., Heidelberg, etc.

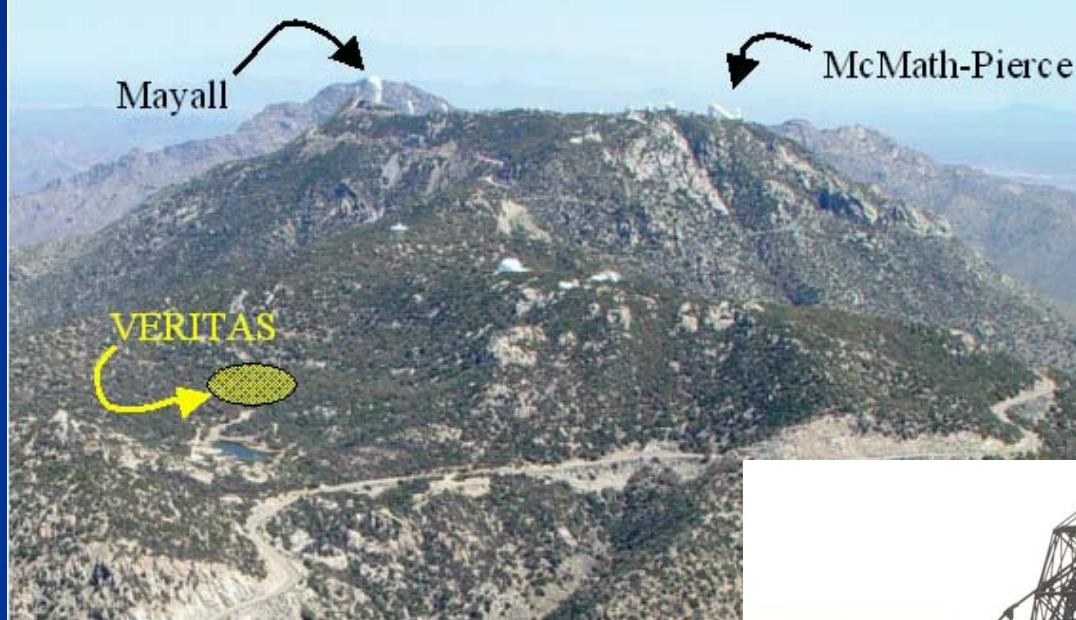
MAGIC: completion in 2003



One 17m telescope in Canary Island

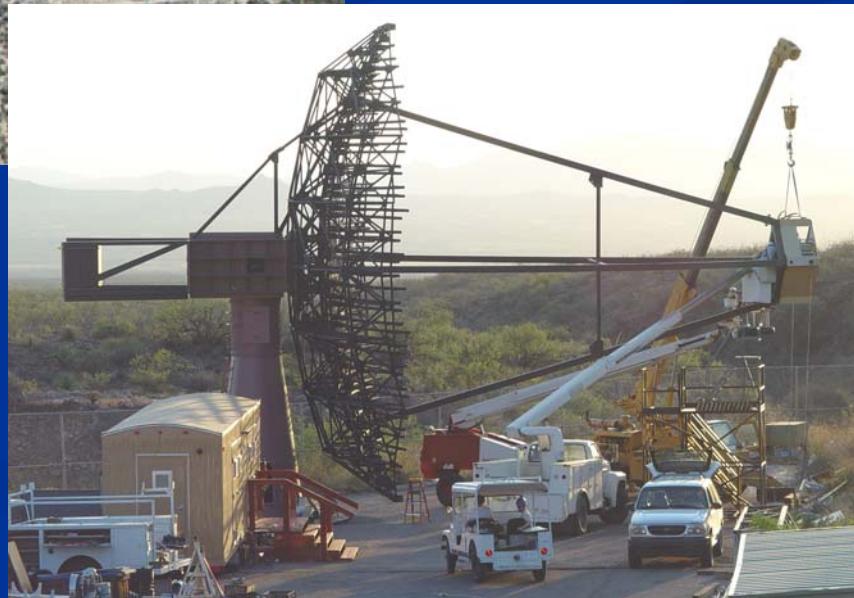
Max Planck Inst., Munich, etc.

VERITAS: VERITAS-4 by 2006, then -7



New site: Horseshoe canyon,
Kitt Peak

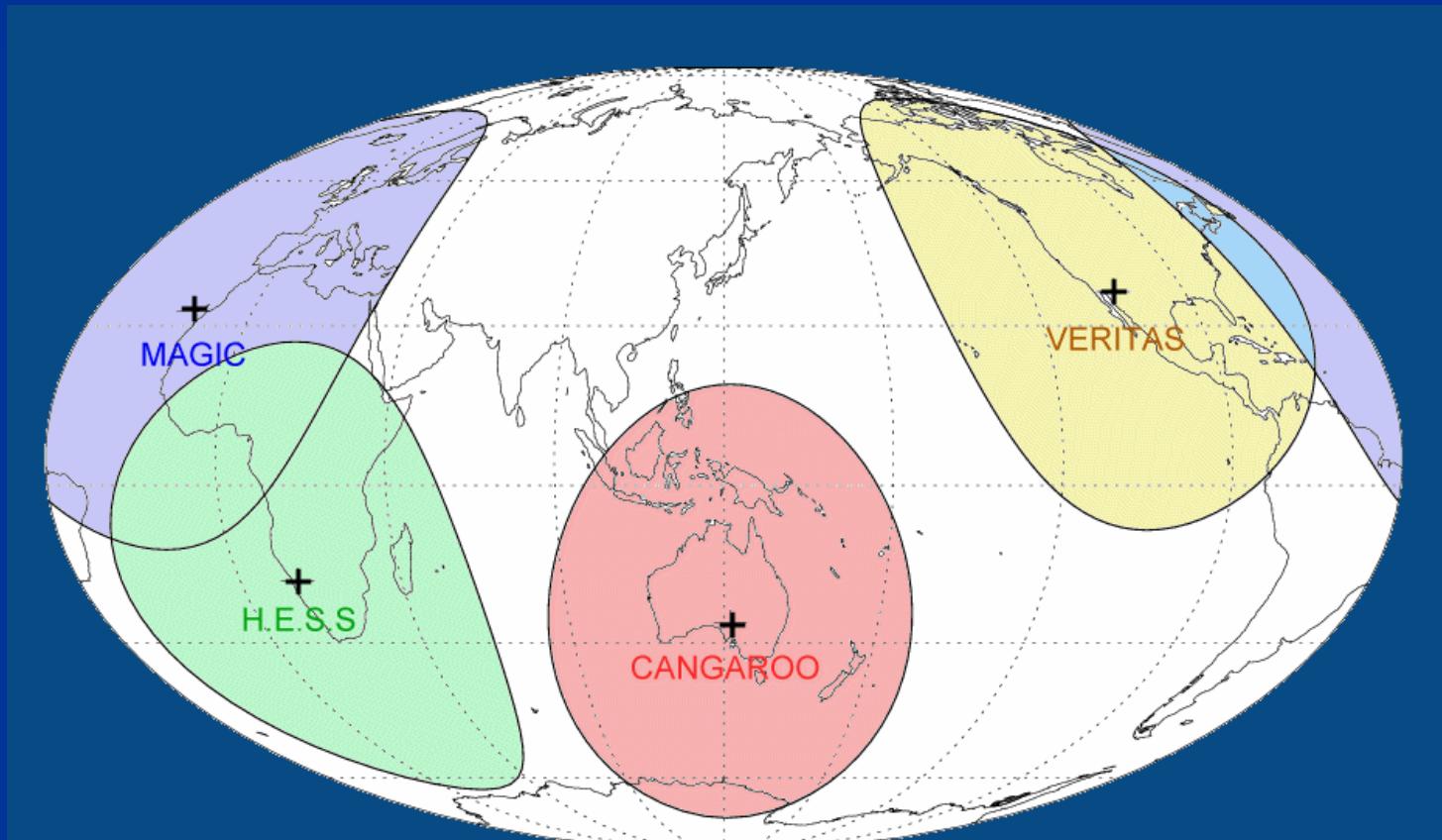
Prototype



Four 12m telescopes in Arizona
Smithsonian Inst. etc.

International coordination

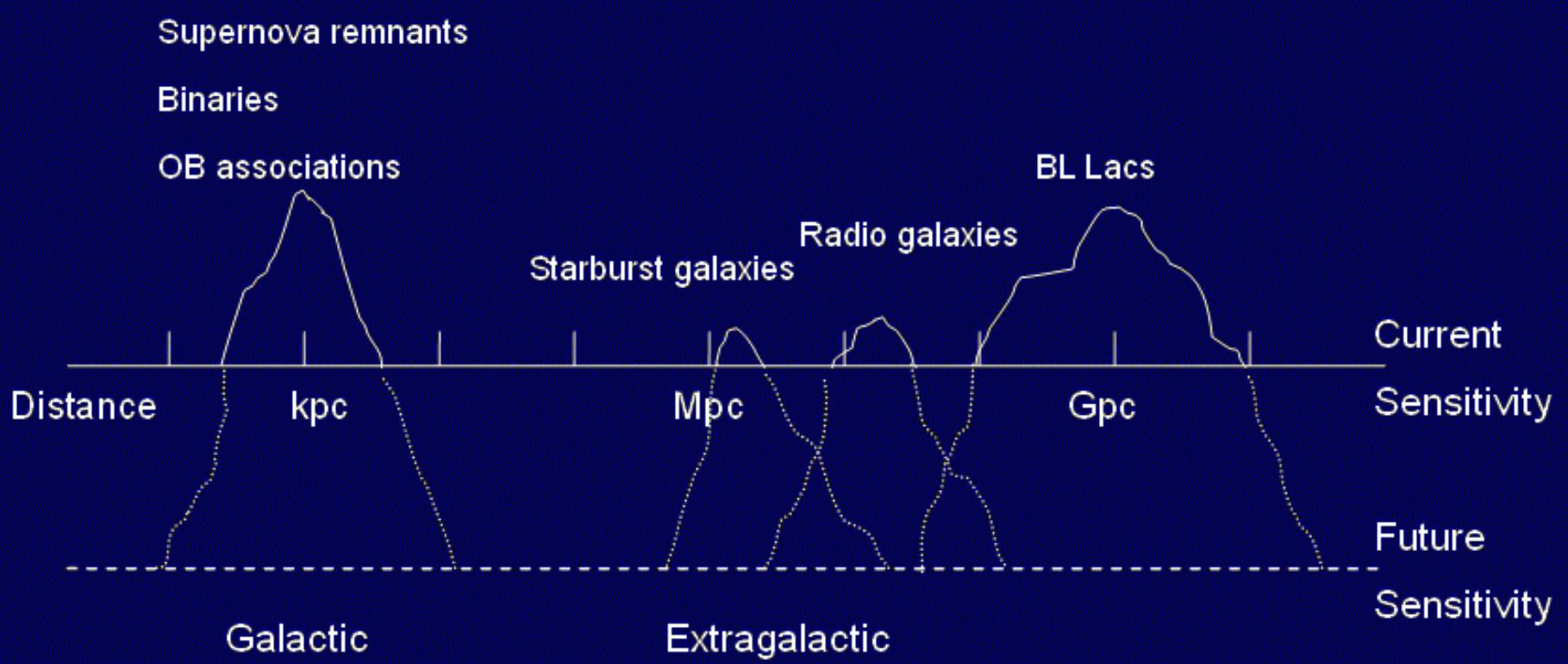
- Monitoring of time-variable objects (e.g. blazars)
- Multiwavelength observation campaign



Summary

- Very high energy sources may contain large varieties, including both galactic and extragalactic objects.
- TeV gamma-ray astronomy is becoming an indispensable field of astronomy.
- The “third generation” Cherenkov telescopes are about to increase sensitivity – **more fun!**

Tips of the Icebergs in the TeV Universe



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