The TeV Gamma Ray Universe

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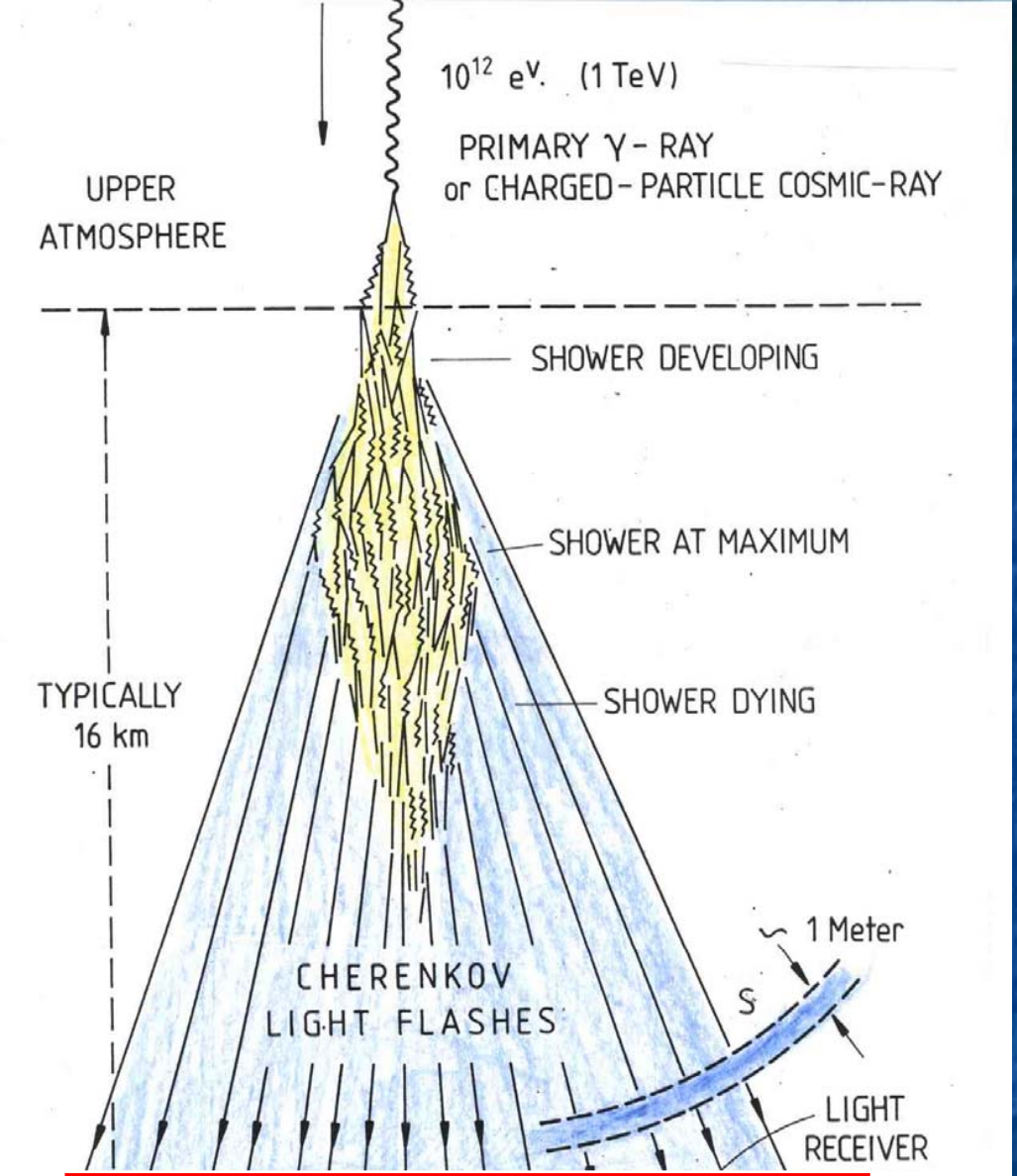
Center for Astrophysics



Collection Area = Size of Football

Atmospheric Cherenkov Gamma-ray Technique

Ground-based but Indirect

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*

Elegant:

Weak flux of Optical Photons

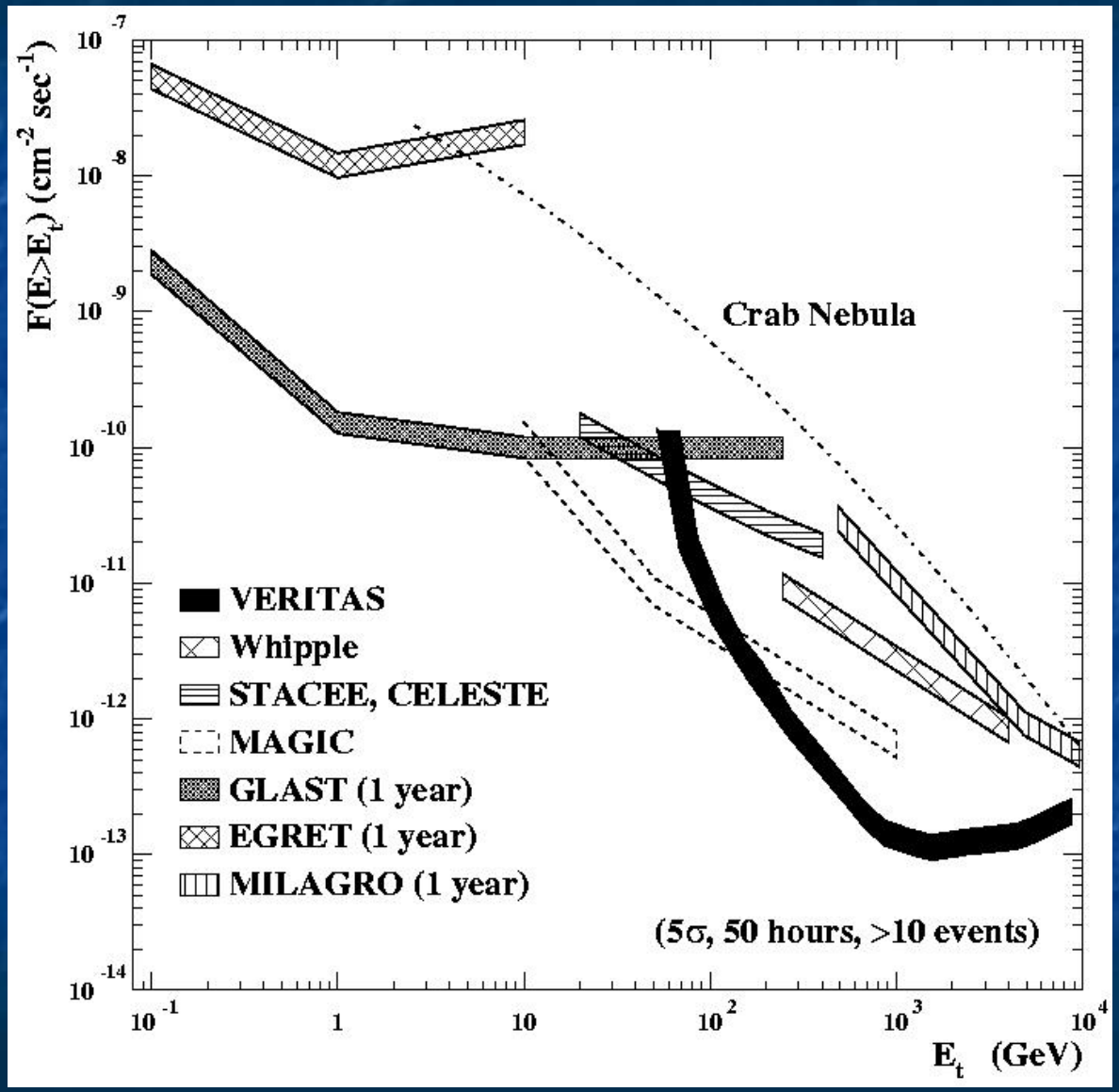
Economic:

Light detector Technology

Efficient:

Nature

Integral Flux Sensitivity



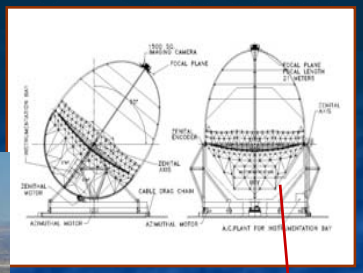
INTEGRAL SENSITIVITY:

Existing and Future Observatories

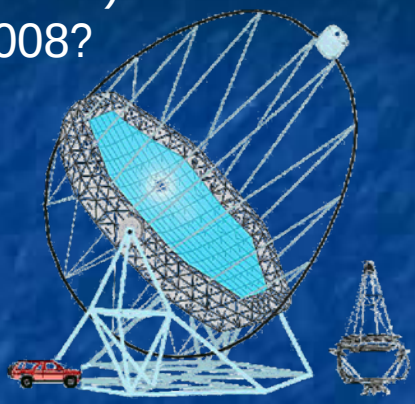
Exposure:
50 hours (pointed)
I year (allsky)

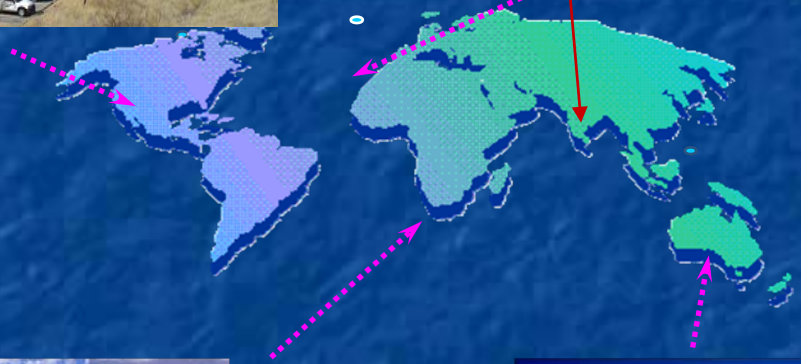
What have we got to work with at higher energies?

The Big 5 TeV IACT Observatories



MACE (India)
2 tel. 2008?





VERITAS, (Arizona)
4 tel. 2007

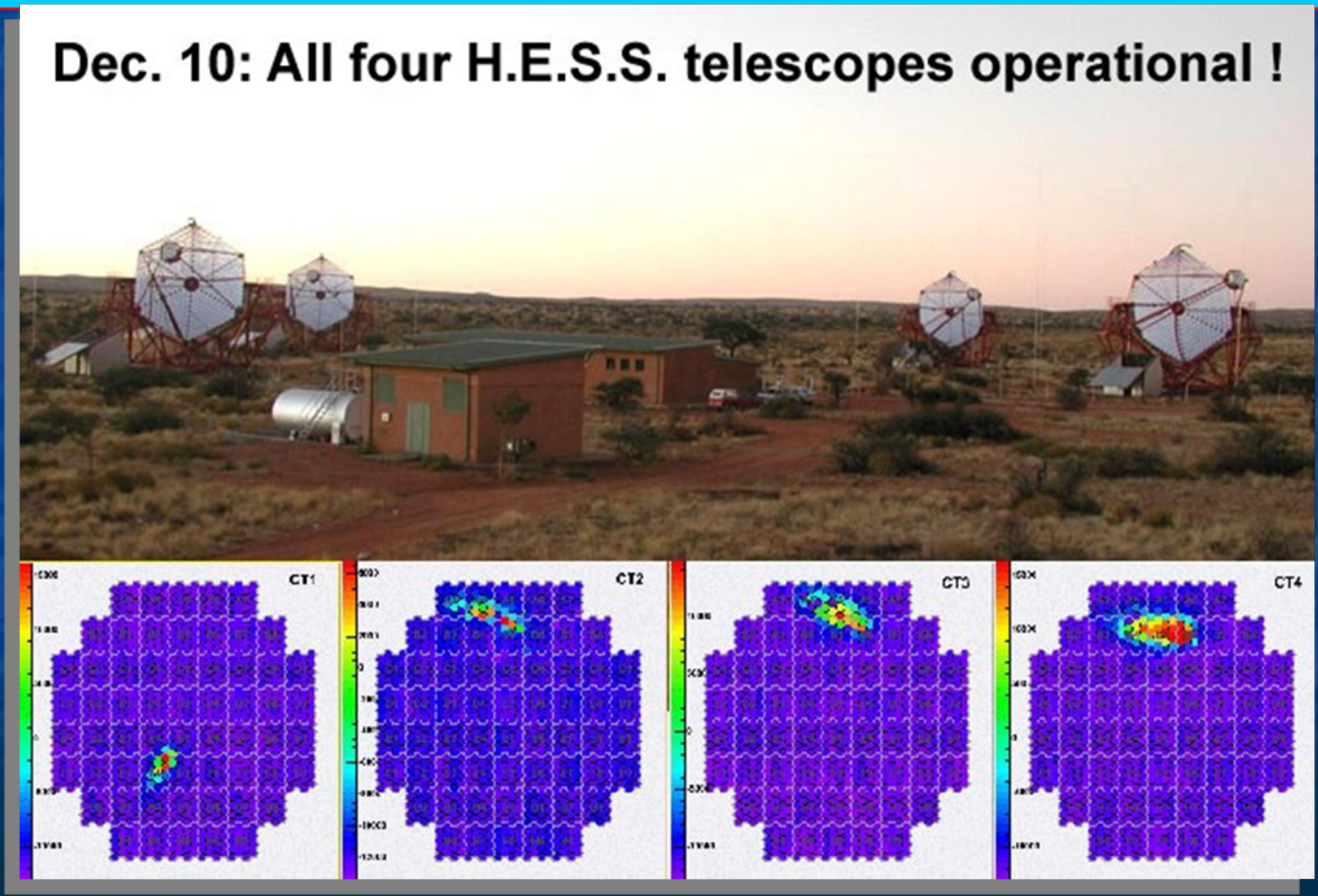
MAGIC (La Palma),
1 tel., 2004
2 tel., 2008

HESS, (Namibia) 4 tel., 2003
5 tel., 2009

CANGAROO III, 3 tel., 2006
(Australia)

HESS

European Collaboration; M.P.I (Heidelberg)
4 x 13 m Telescopes
Completed in Dec. 2003; located in NAMIBIA



CANGAROO III

- Four telescope system
  - 10m diameter
  - 100m spacing
- 427 pixel camera
  - 0.17º spacing
- Woomera, S. Australia (31ºS 138ºE 160m a.s.l.)
- 3 telescopes in operation with full sensitivity

MAGIC

Largest Telescope

17 m aperture

- Carbon fibre support frame
- Area=239m^2
- 577 pixel camera

- La Palma (28ºN 17ºW, 2300m a.s.l.

VERITAS 2007

Instrument:

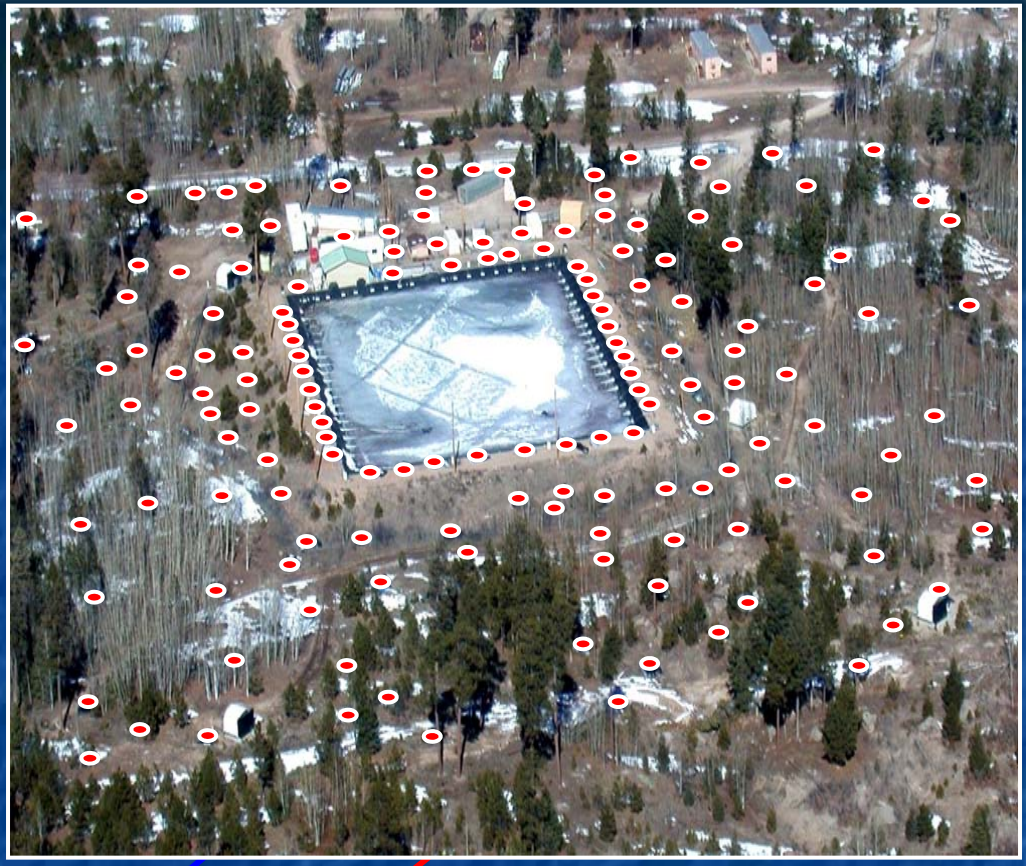
- Four 12-m telescopes
- 500-pixel cameras (3.5˚ FoV)
- FLWO, Mt. Hopkins, Az (1268 m)
- Completed Spring, 2007

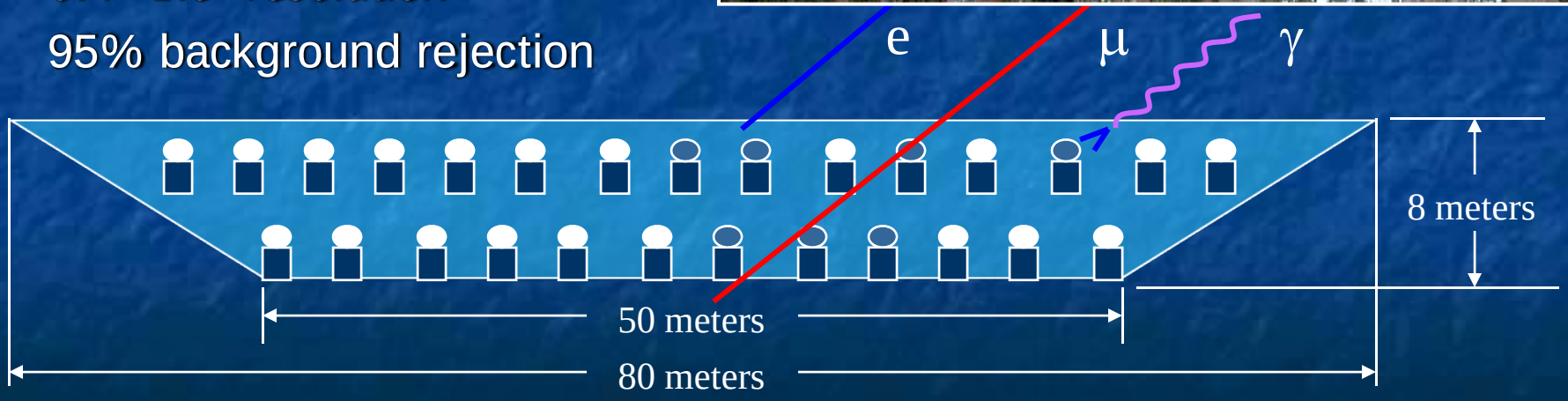
Specifications:

- Energy threshold ~ 150 GeV
- Source location < 0.05˚
- Energy resolution ~ 10-20 %

Milagro

- Water Cherenkov Detector
- 2600m asl
- 898 detectors
  - 450(t)/273(b) in pond
  - 175 water tanks
- 4000 m^2 / 4.0×10^4 m^2
- 2-20 TeV median energy
- 1700 Hz trigger rate
- 0.4^o-1.0^o resolution
- 95% background rejection





What do we know now about the TeV sky?

The TeV Sky – 2007

Diverse Categories of TeV Gamma-ray sources:

GALACTIC

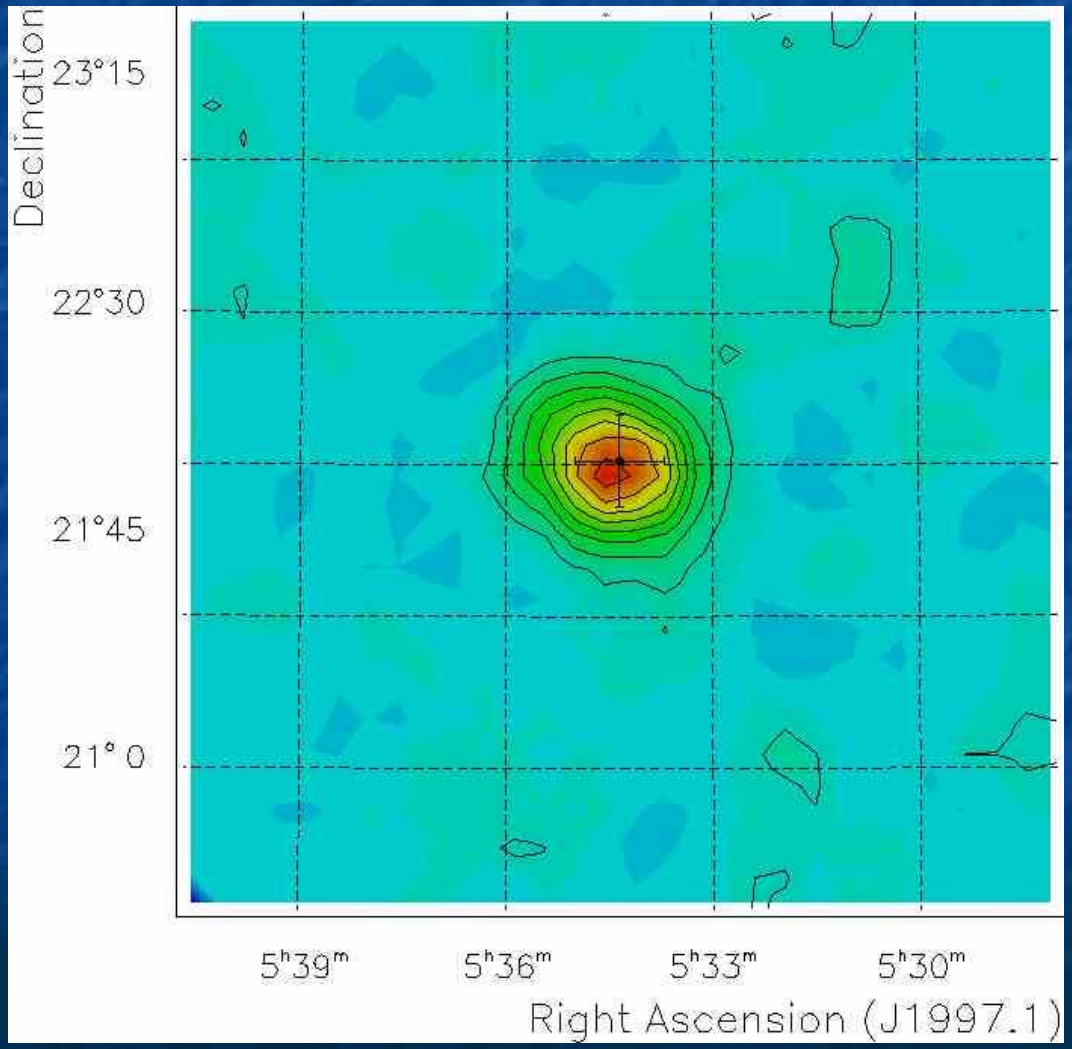
- Pulsar Wind Nebulae (18)
- SNR (7)
- Binaries (4)
- Diffuse Sources (2)
- Dark Sources (21)

EXTRAGALACTIC

- AGN (19)

Raporteur at 30th ICRC in Merida, Mexico in July, 2007 reported 71 TeV sources in all.....but not all independently confirmed

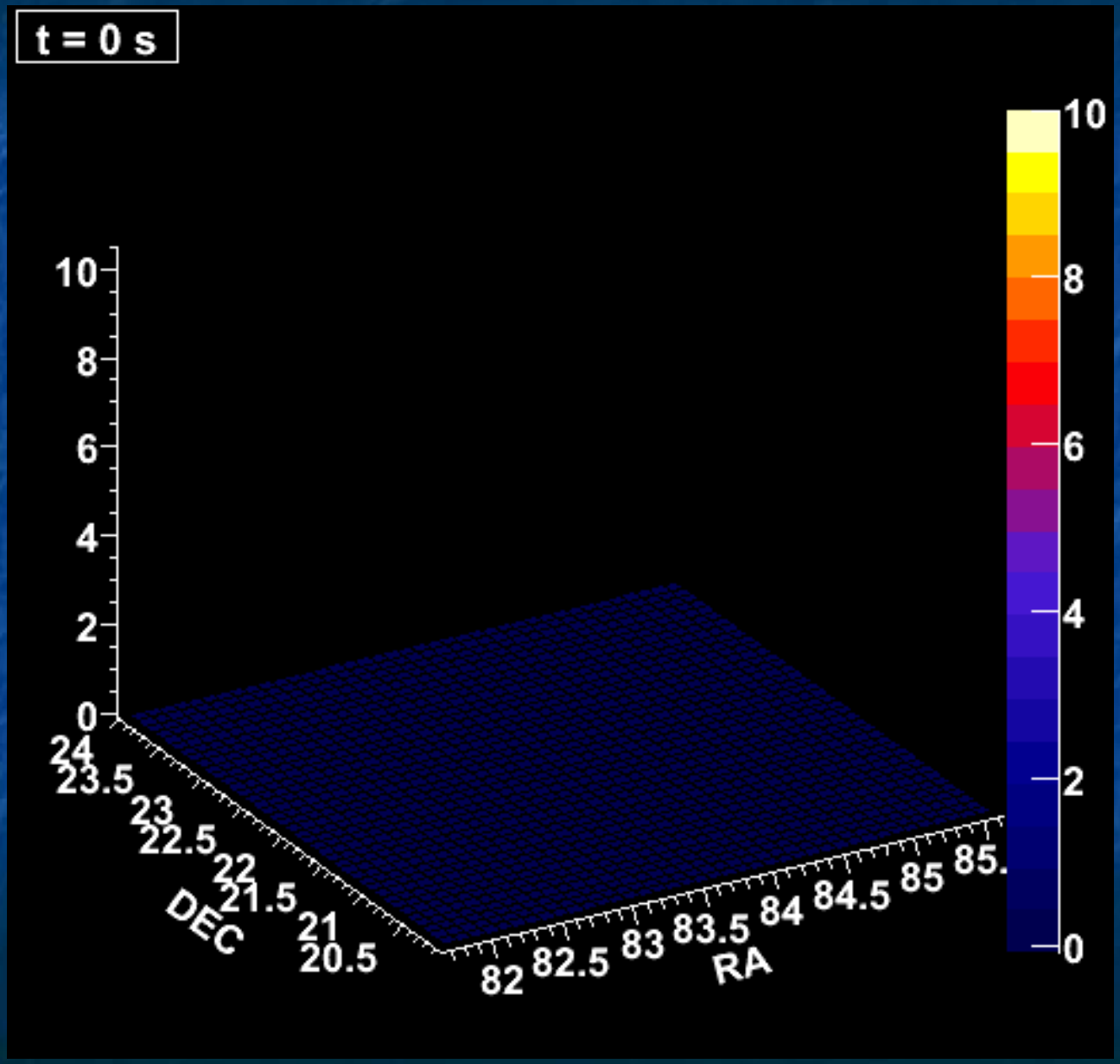
The Crab Nebula: the Strongest Gamma Ray Source



Established in 1986
Strongest Steady Source
Standard candle

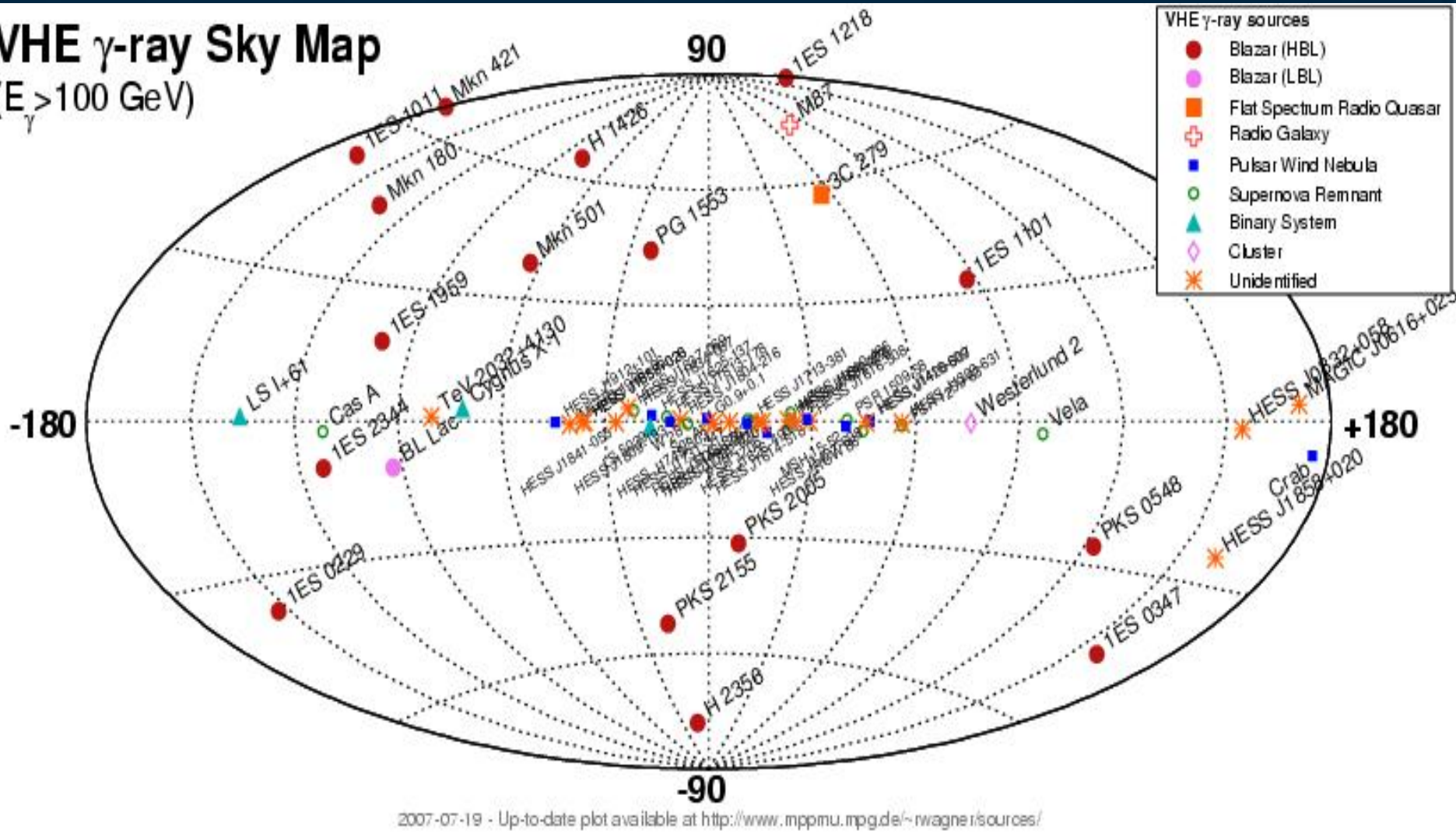
Supernova 1054 A.D.

Crab Signal as seen in VERITAS in real time



VERITAS:
31 sigma in one hour of data taking

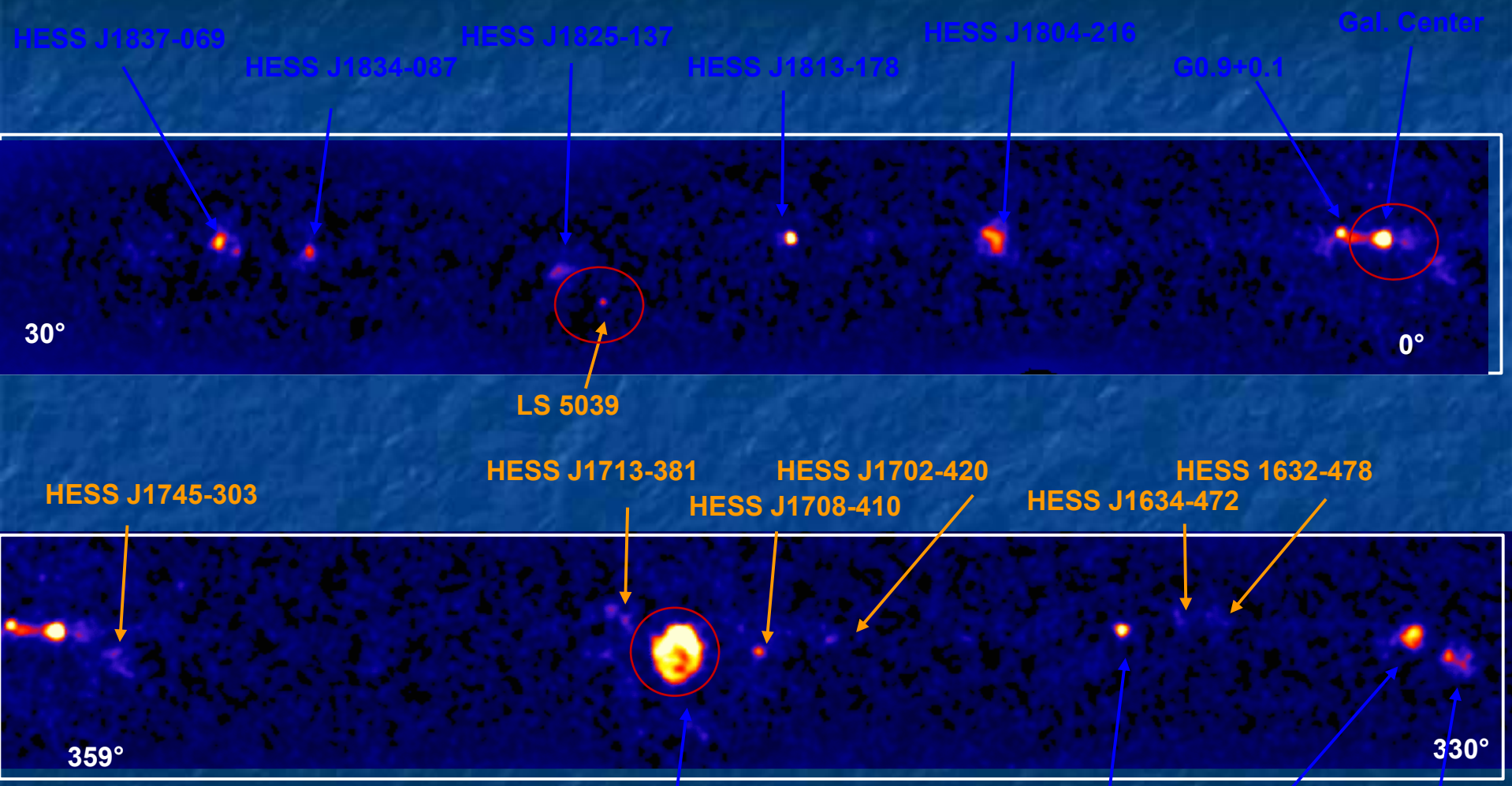
MAGIC:
19 sigma in an hour; 0.4 Hz!



http://xxx.mppmu.mpg.de/~rwagner/sources/index.html

http://tevcat.uchicago.edu (sources in refereed journals only)

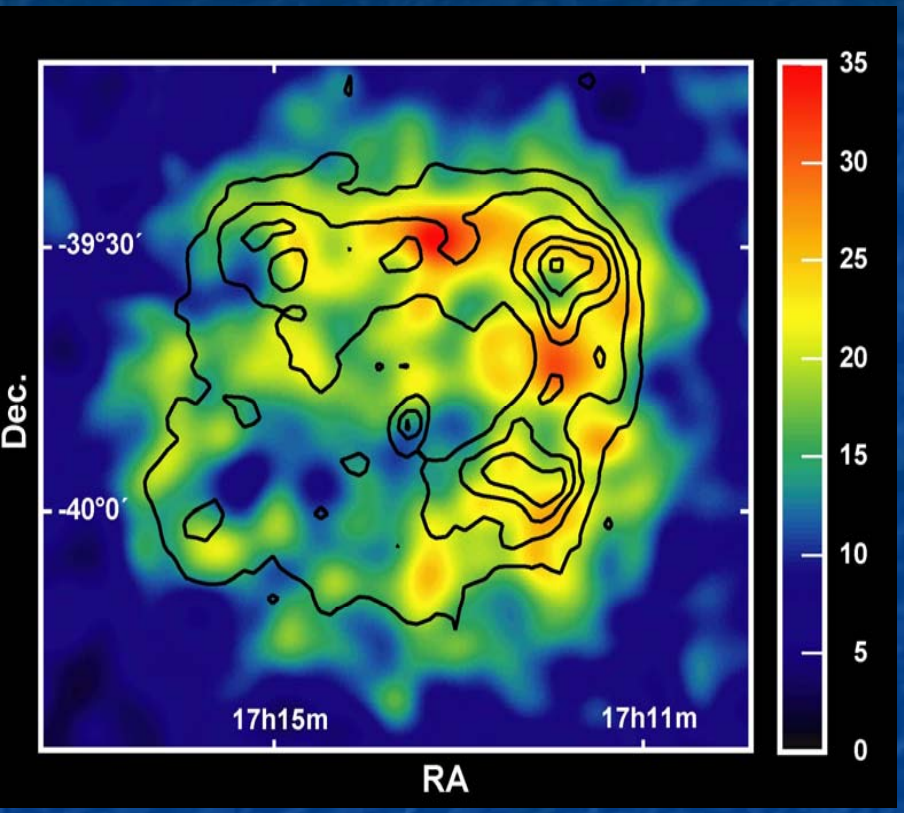
HESS Survey of Inner Galaxy



Sources > 6 sigma (9 new, 11 total)

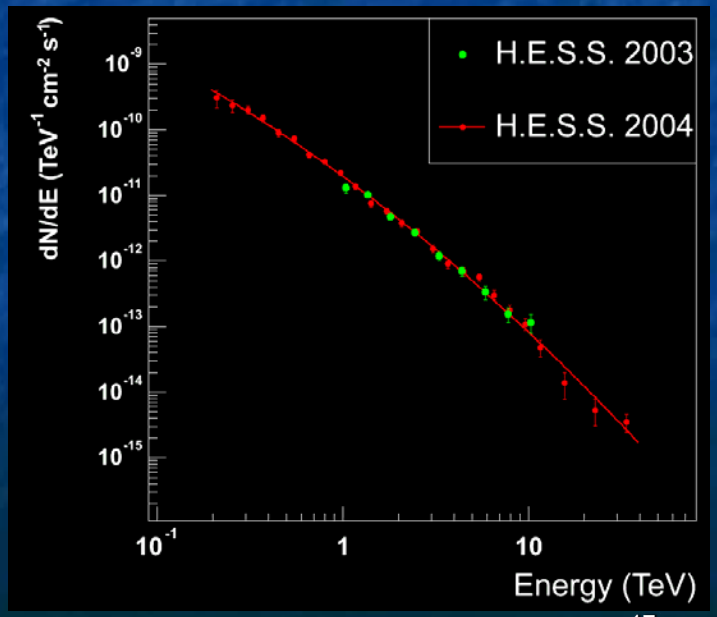
Sources > 4 sigma (7 new)

RX J1713-394



HESS Gamma: color
ASCA X-ray: Lines

CANGAROO detection ~7σ.
Shell Supernova Remnant
HESS confirmation ~ 40σ.
Extended Bright Source
Close Correlation with X-rays
Spectrum
Cosmic Ray Source?



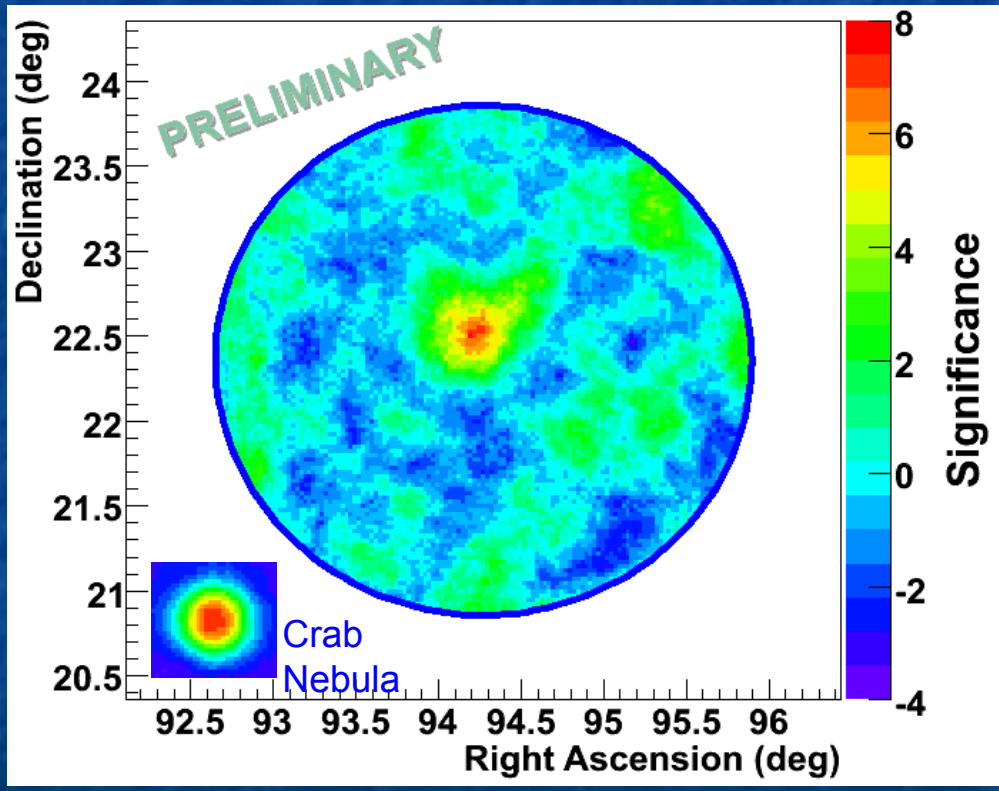
Hard spectrum $\Gamma \sim 2$
Not a simple power-law.

SNR: source of cosmic rays?

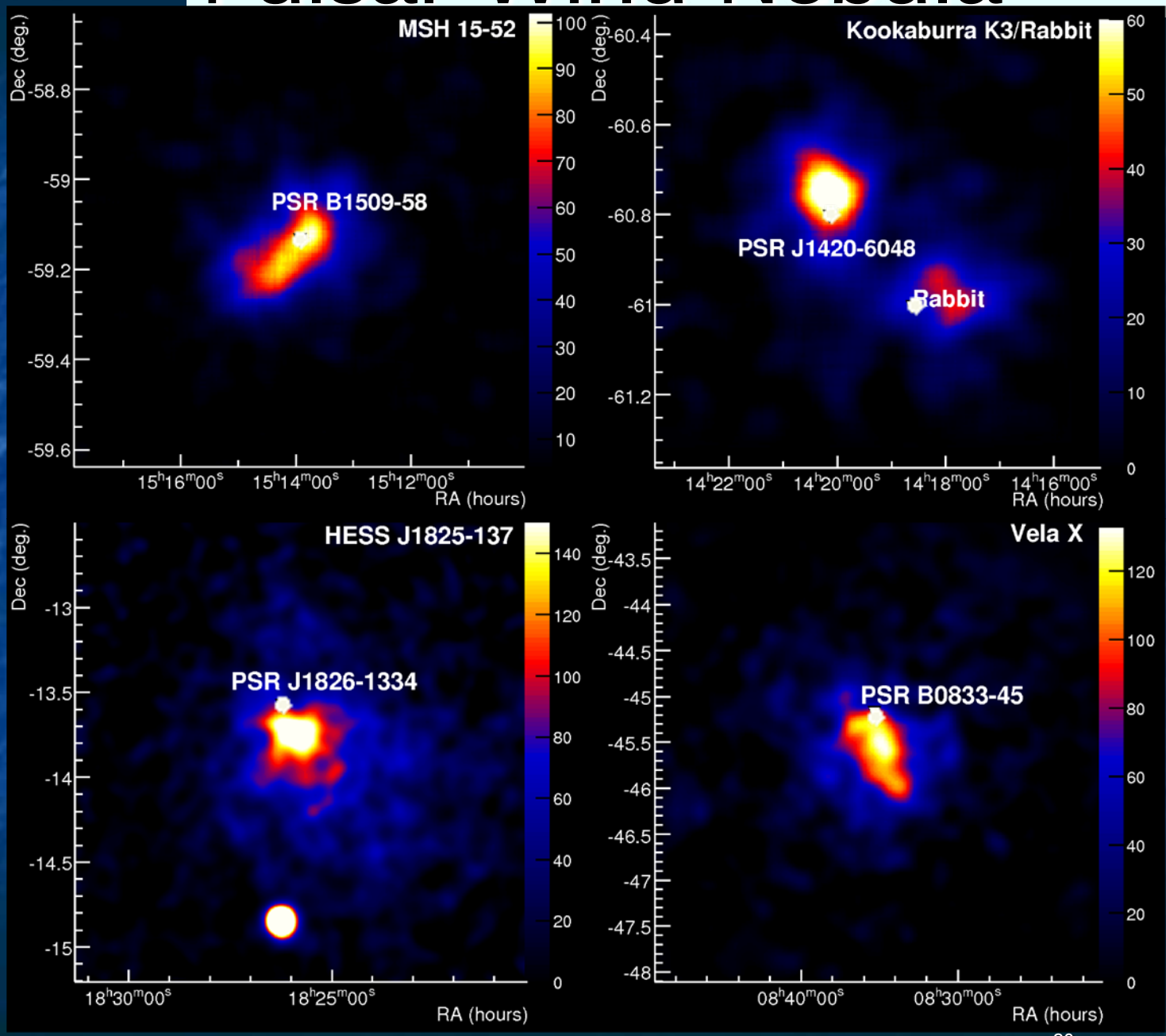
- Interpretation still ambiguous
- Originally assumed that TeV astronomy would provide the answers
- Cosmic electrons muddy the waters
- Need clear correlation with molecular clouds

IC 443

- VERITAS:
- 7.1 sigma in 16 hours
- F(E>200 GeV)
  ~ 3% Crab
- MAGIC:
- 5.7 sigma in 29 hours



Pulsar Wind Nebula



18 detected by HESS.

γ-ray sources tend to be

- extended
- displaced from pulsar

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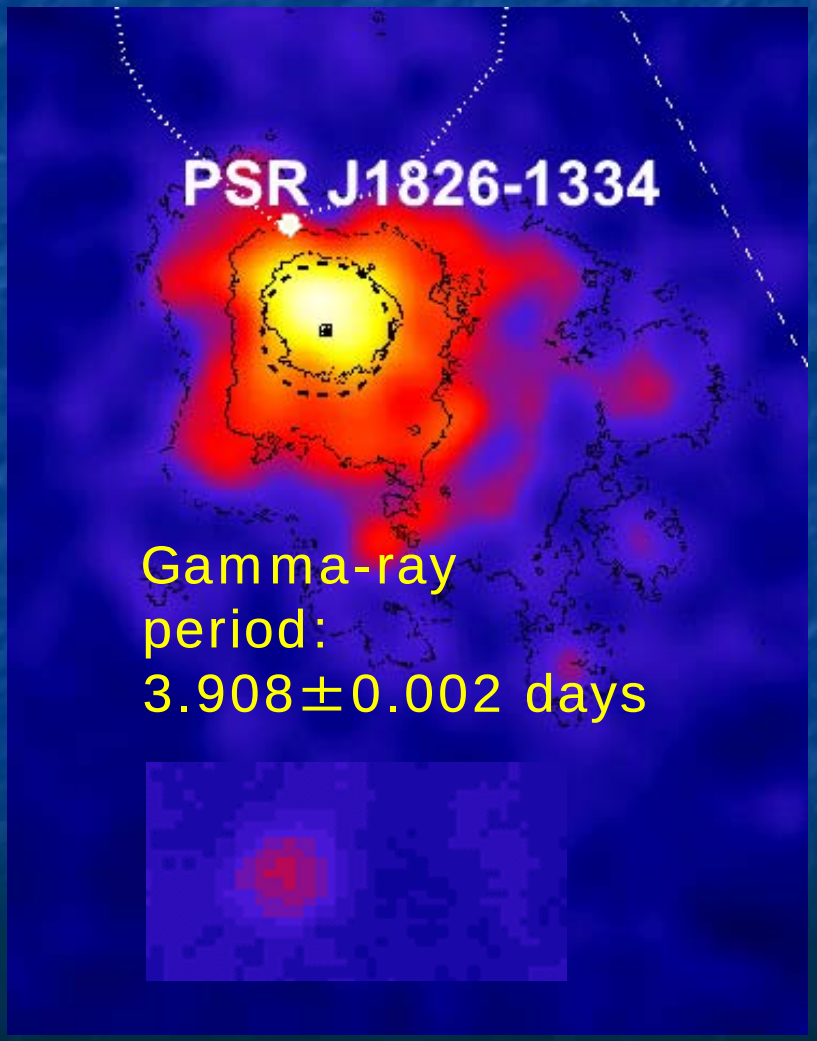
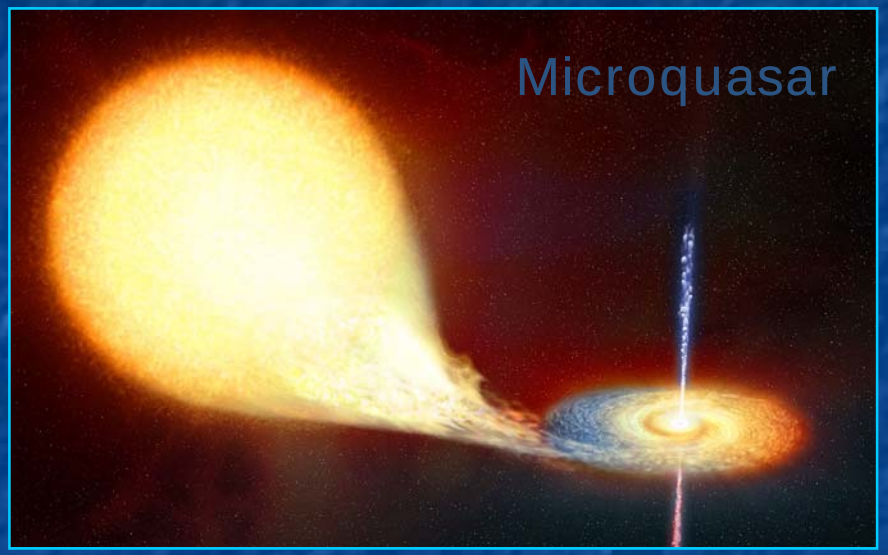
Pulsar Wind Nebula

- Associated with young pulsars (< 100,000 years old)
- Inverse Compton scattering of 1-100 TeV electrons
- 70% of pulsars with Edot/d^2 > 10^35 erg/s/(kpc)^2 are detected
- 1% of spin down energy goes into TeV gamma rays

Binaries and Microquasars





LS 5039

- 4 (?) $M_\odot$ object in eccentric 3.906-day orbit around 20-30 $M_\odot$ star
- closest approach ~10^{12} cm or ~2 stellar radii

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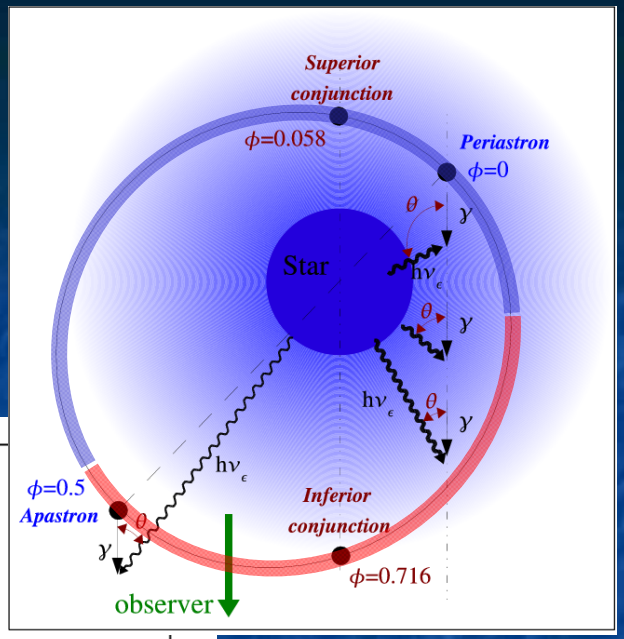
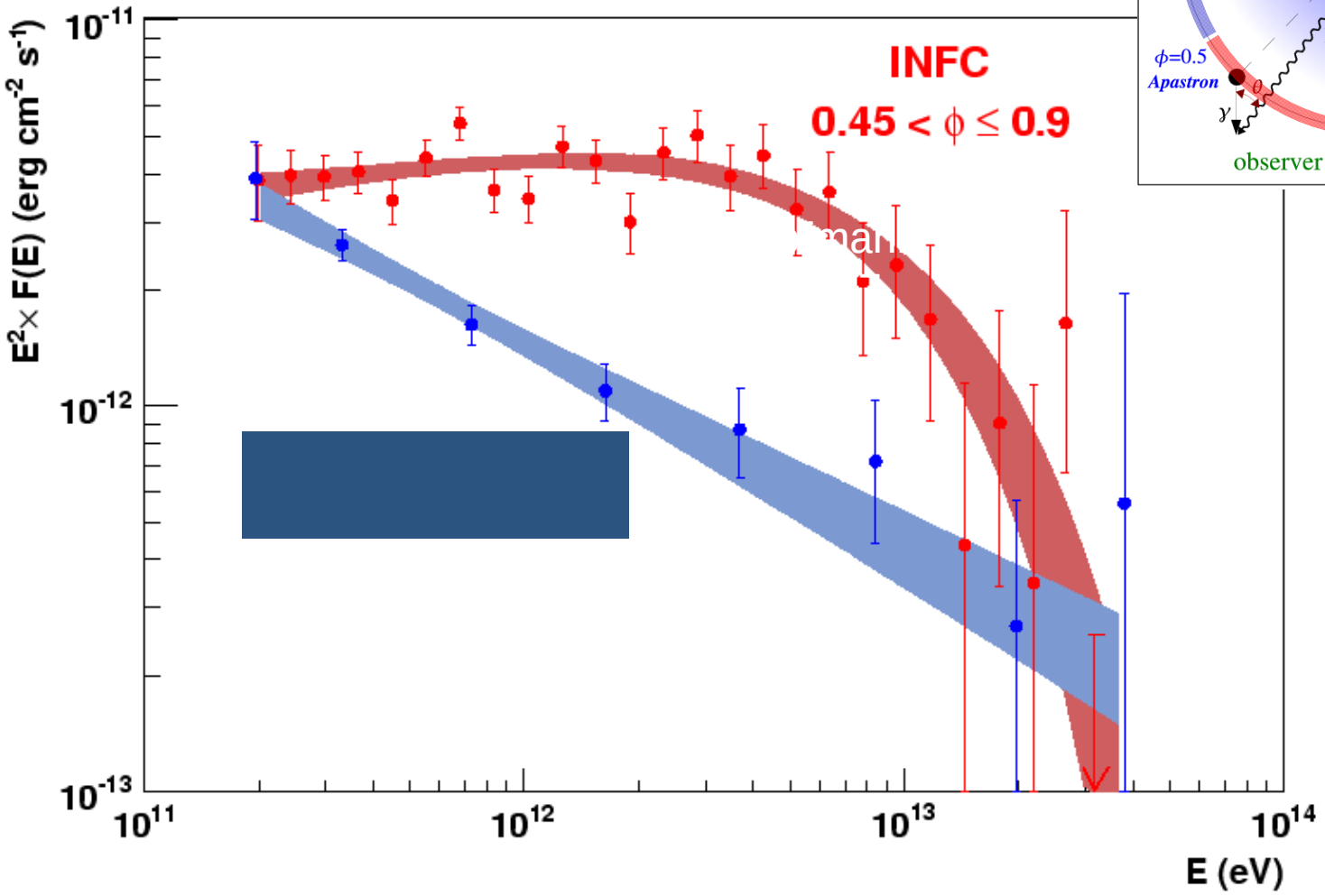
Spectral variation





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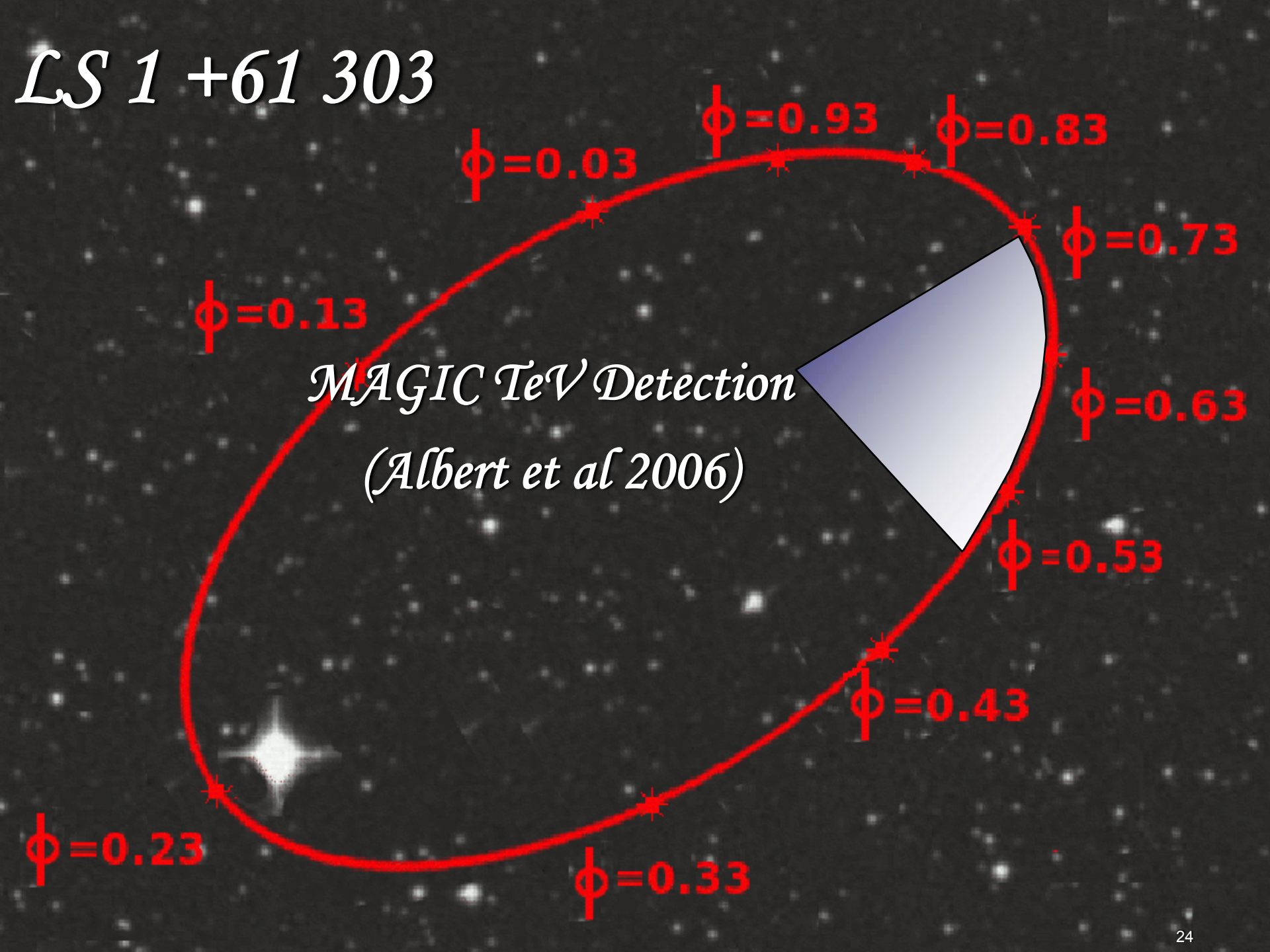
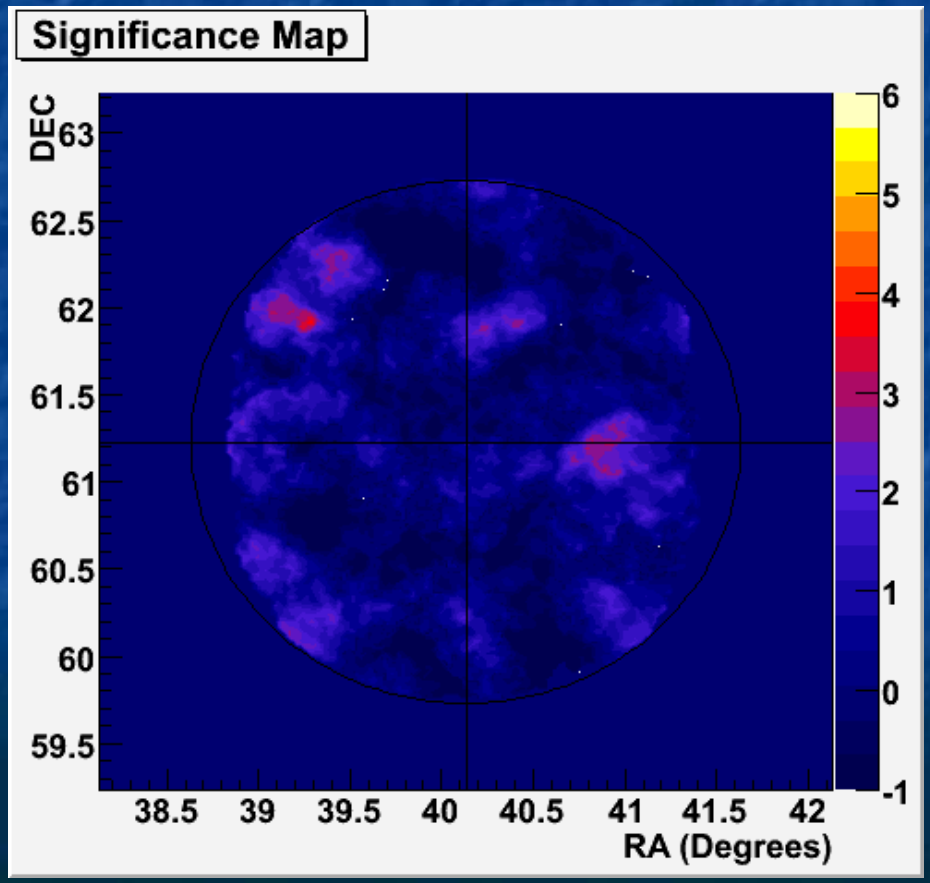
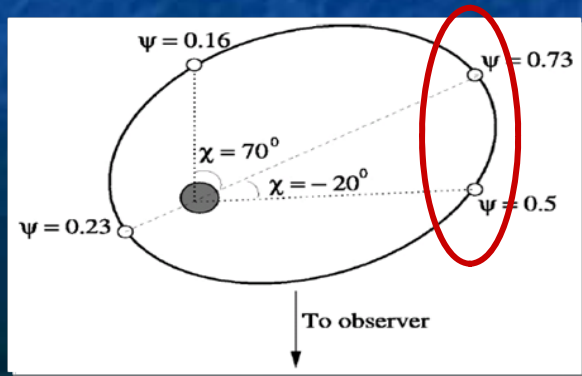
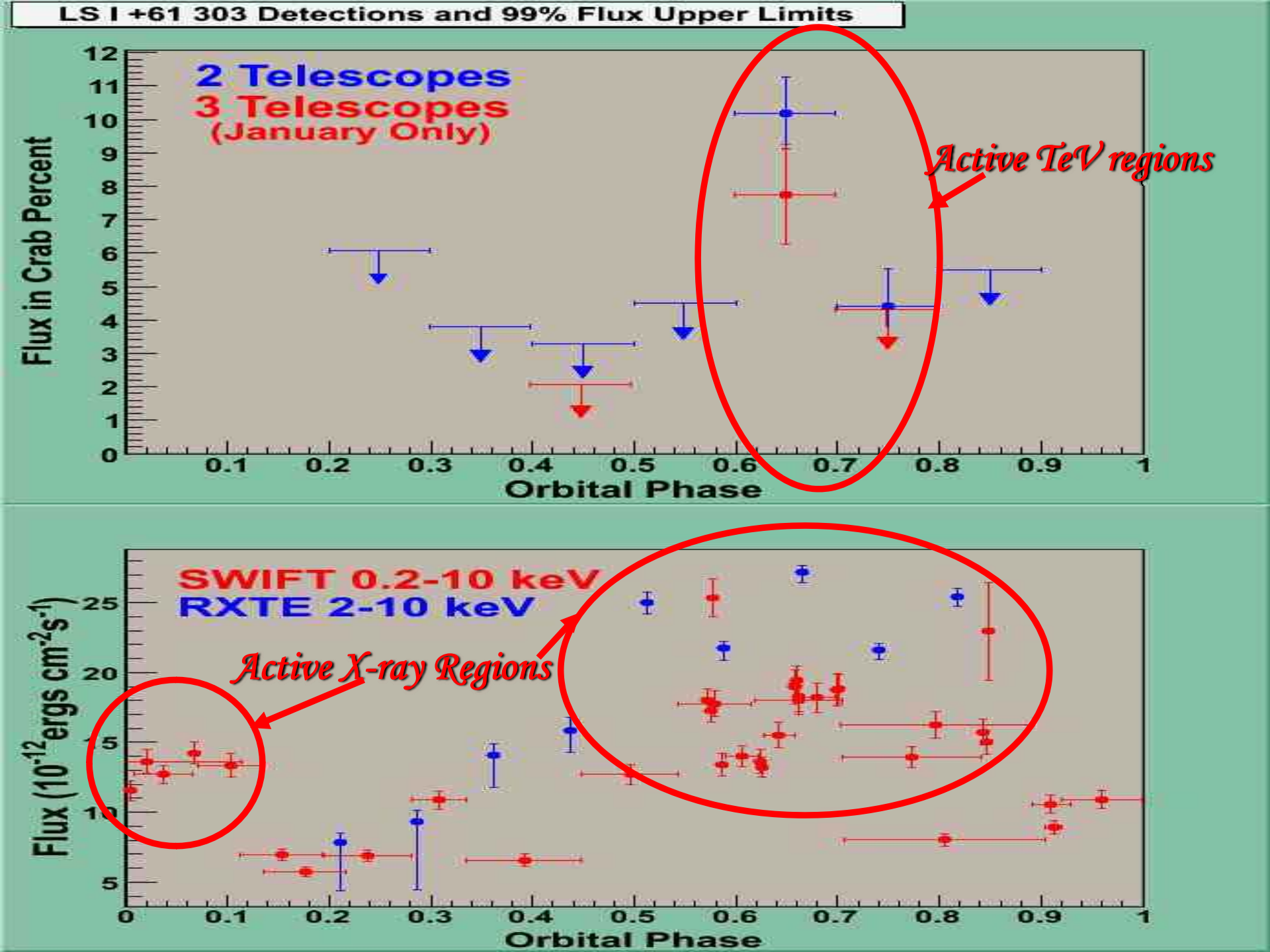

LS 1 +61 303
ϕ=0.93
ϕ=0.83
ϕ=0.03
ϕ=0.73
ϕ=0.13
MAGIC TeV Detection
(Albert et al 2006)
ϕ=0.63
ϕ=0.53
ϕ=0.43
ϕ=0.23
ϕ=0.33

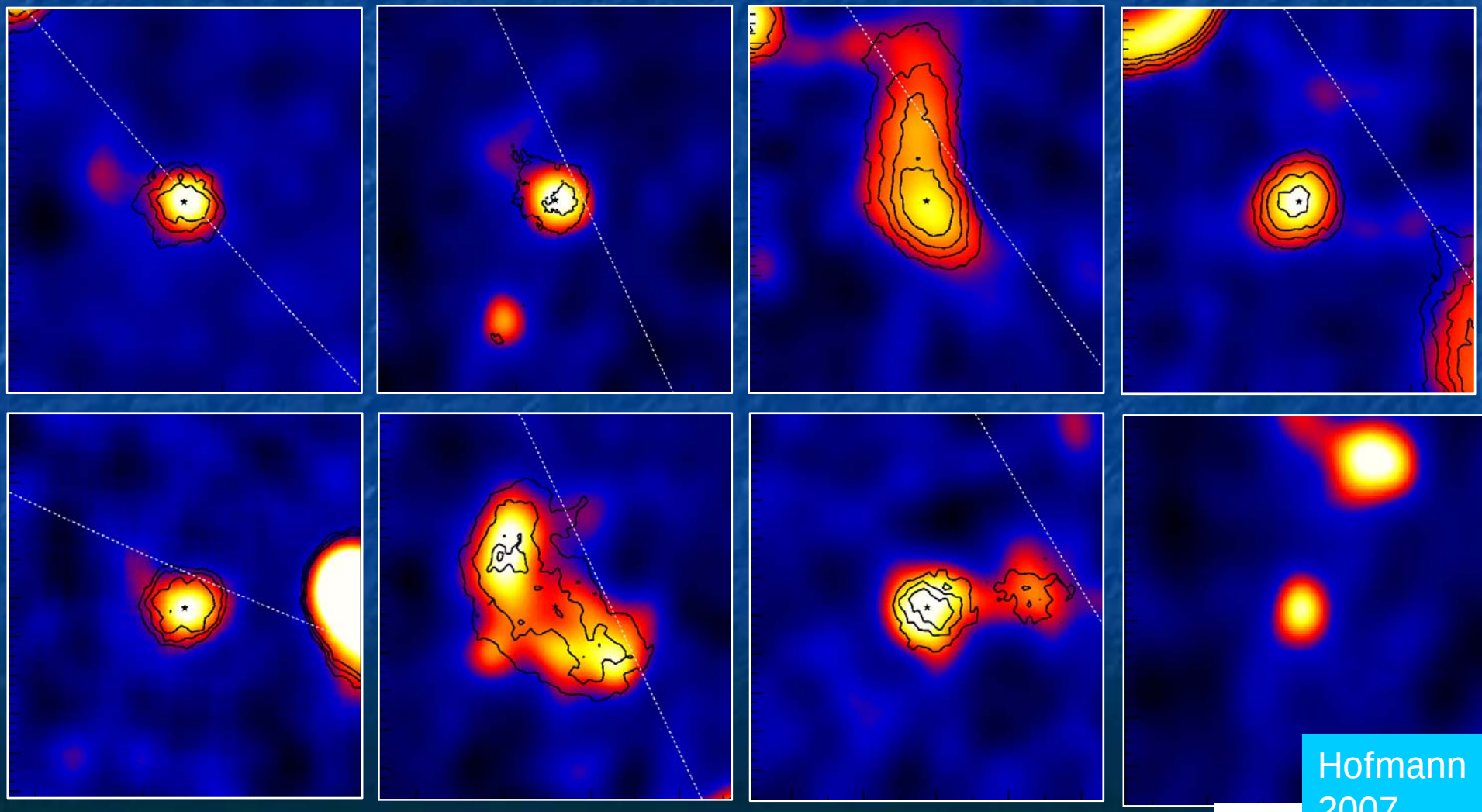
VERITAS:
40.8 hr of data:
Oct. '06 – Jan. '07
Two/three telescopes
Significance = +8.6 σ
Mean rate = 0.24 +/- 0.03 γ/min






LS I +61 303 Detections and 99% Flux Upper Limits
2 Telescopes
3 Telescopes
(January Only)
Active TeV regions
Flux in Crab Percent
Orbital Phase
SWIFT 0.2-10 keV
RXTE 2-10 keV
Active X-ray Regions
Flux (10^{-12} ergs cm^{-2}s^{-1})
Orbital Phase

... “Dark” Sources: Objects which only shine in gamma rays !



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Tibet Result Air Shower Array: Extended Source in Cygnus

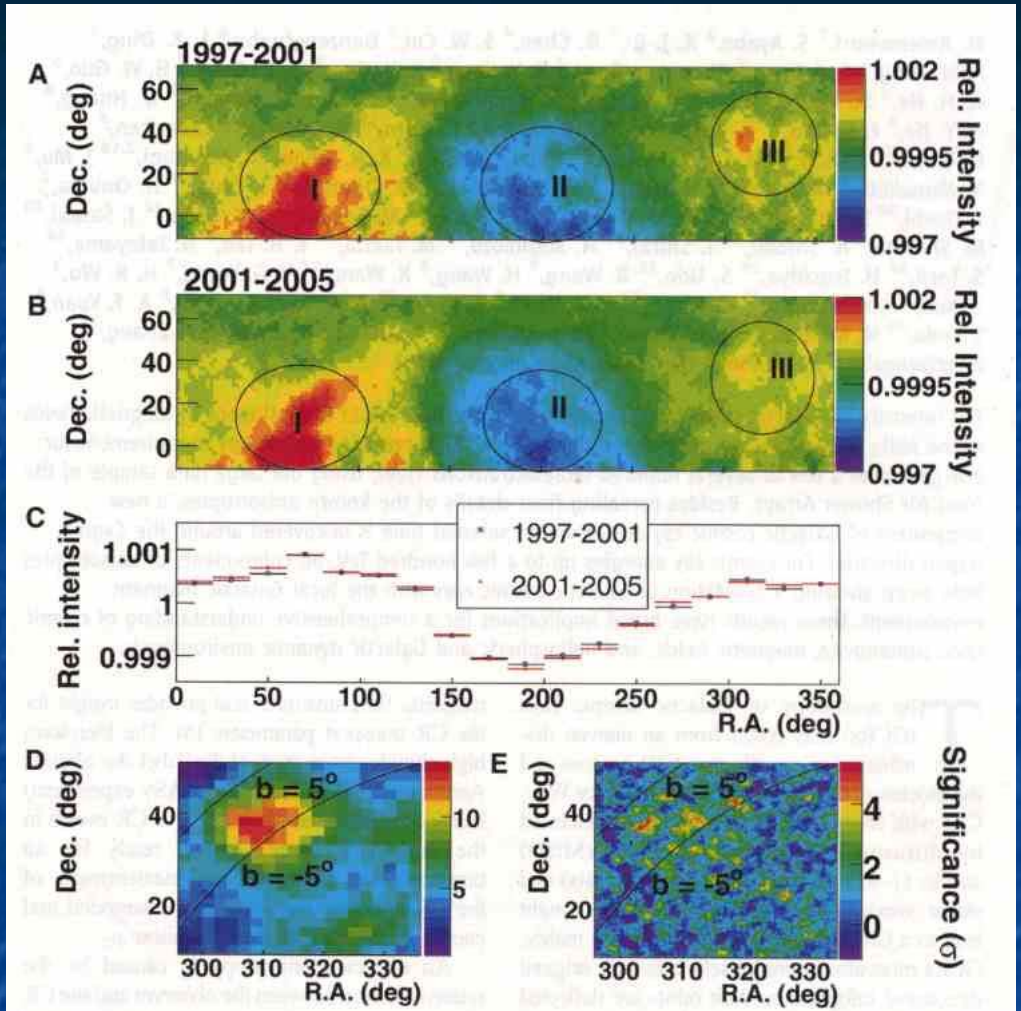
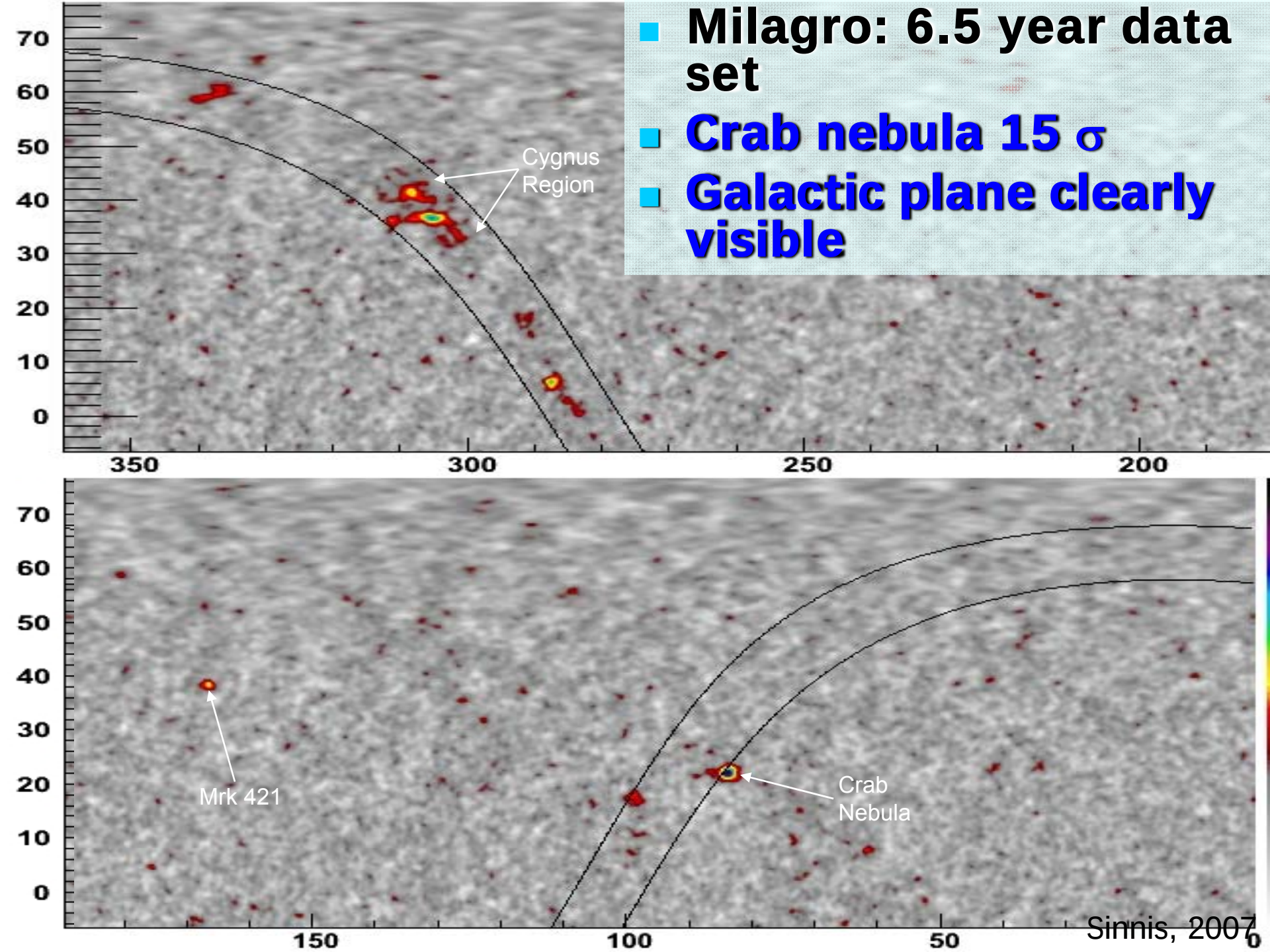
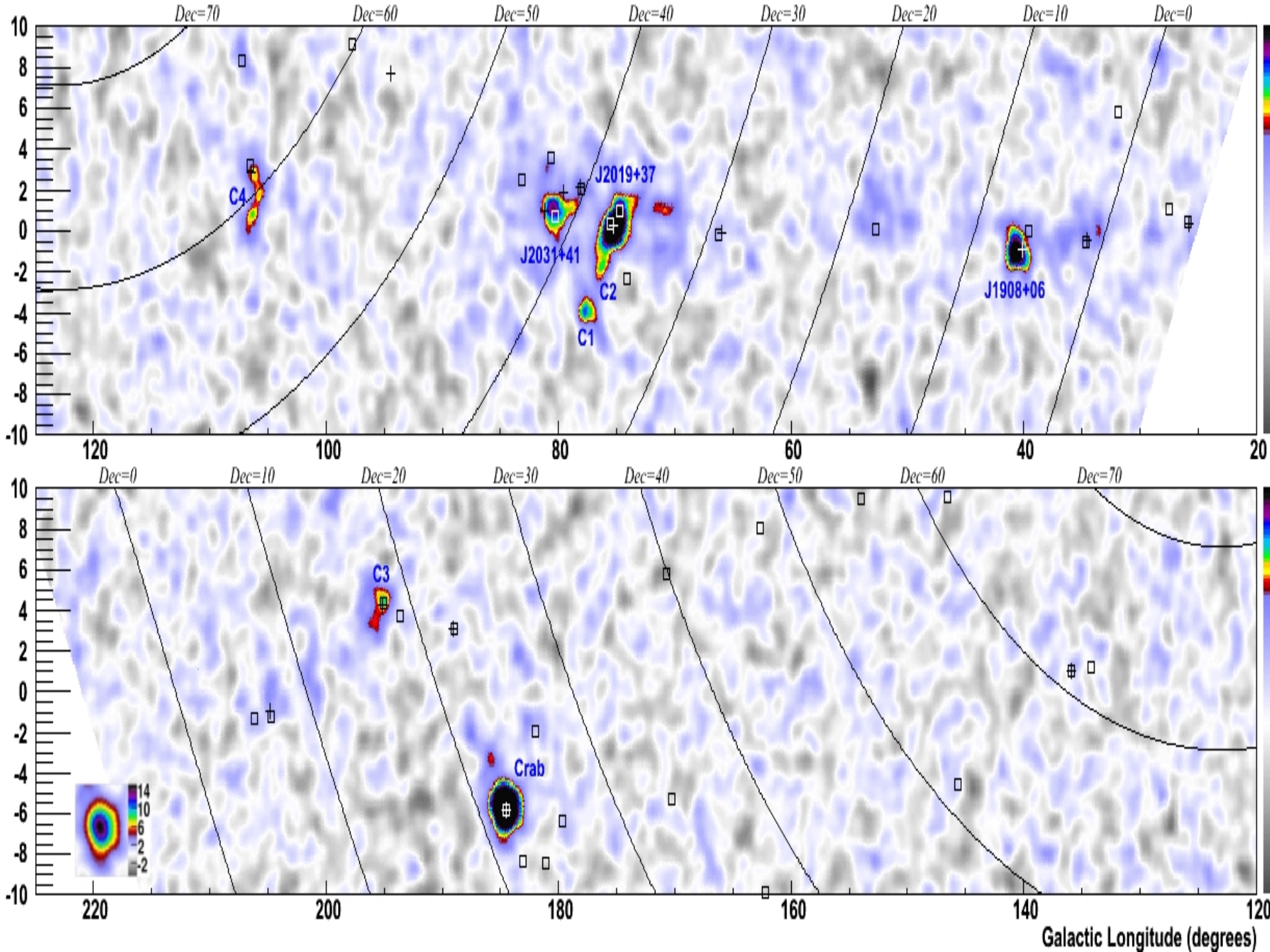
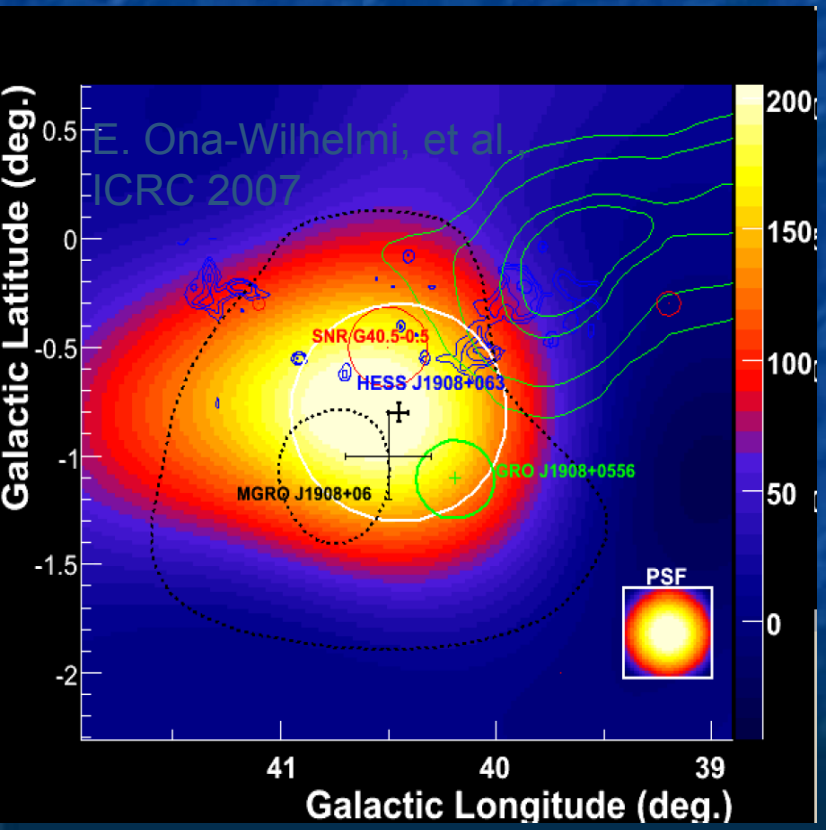


Fig. 1. Celestial CR intensity map for Tibet ASγ data taken from **(A)** 1997 to 2001 and **(B)** 2001 to 2005 (*40*). The vertical color bin width is 2.5×10^{-4} for the relative intensity in both (A) and (B). The circled regions labeled by I, II, and III are the tail-in component, the loss-cone component (*12*, *13*), and the newly found anisotropy component around the Cygnus region (~38°N Dec and ~309° R.A.), respectively. **(C)** The 1D projection of the 2D maps in R.A. for comparison. **(D)** and **(E)** show significance maps of the Cygnus region [pixels in radius of 0.9° and sampled over a square grid of side width 0.25° for (E)] for data from 1997 to 2005. The vertical color bin widths are 0.69 SD and 0.42 SD for significance in (D) and (E), respectively. Two thin curves in (D) and (E) stand for the Galactic parallel $b = \pm 5°$. Small-scale anisotropies (E) superposed onto the large-scale anisotropy hint at the extended gamma-ray emission.


Milagro: 6.5 year data set
Crab nebula 15 σ
Galactic plane clearly visible
Cygnus Region
Mrk 421
Crab Nebula
Sinnis, 2007

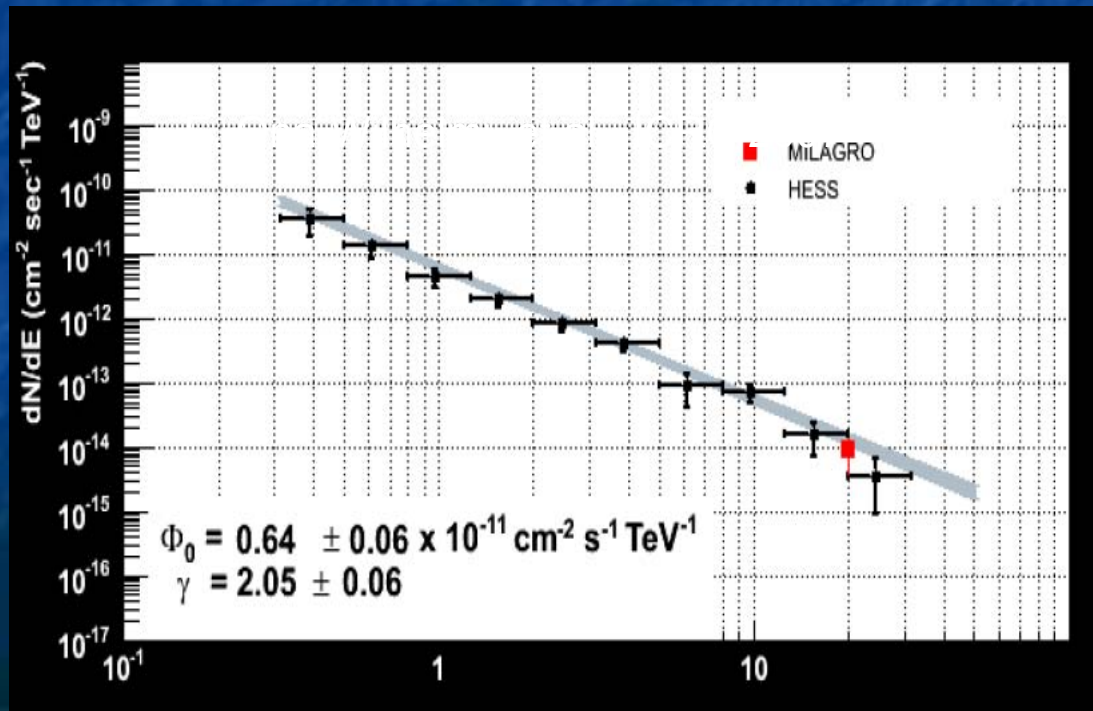

Dec=70
Dec=60
Dec=50
Dec=40
Dec=30
Dec=20
Dec=10
Dec=0
C4
J2019+37
J2031+41
C2
C1
J1908+06
C3
Crab
14
10
6
2
-2
10
8
6
4
2
0
-2
-4
-6
-8
-10
120
100
80
60
40
20
220
200
180
160
140
Galactic Longitude (degrees)

- Milagro has discovered 3 new sources & 4 candidate sources in the Galaxy.
- 5/7 of these TeV sources have GeV counterparts (only 13 GeV counterparts in this region - excluding Crab)
  - Probability = 3×10^{-6}

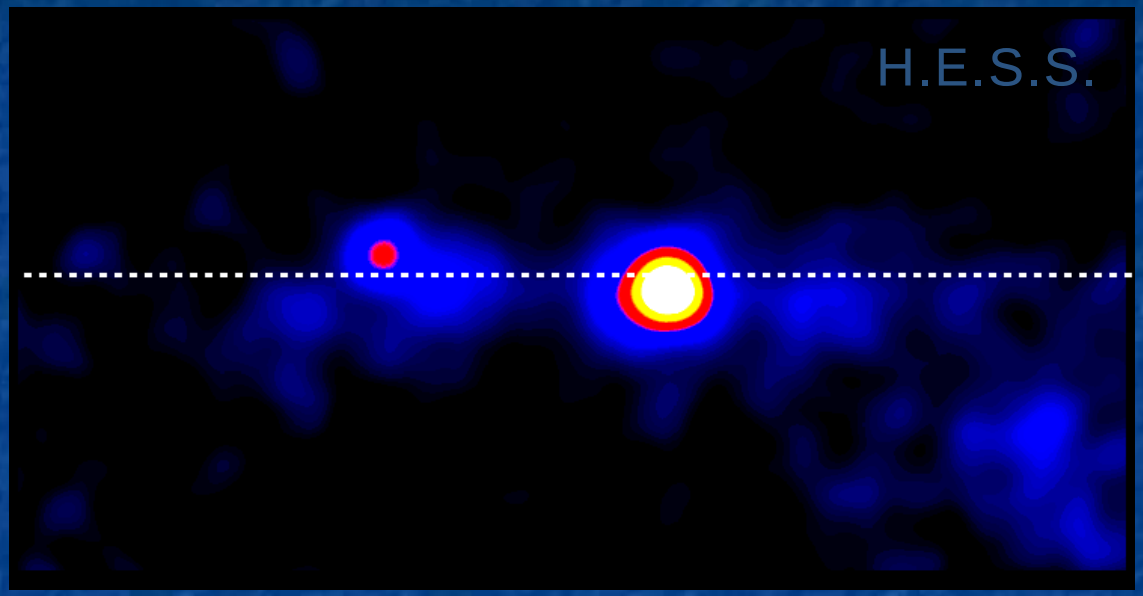


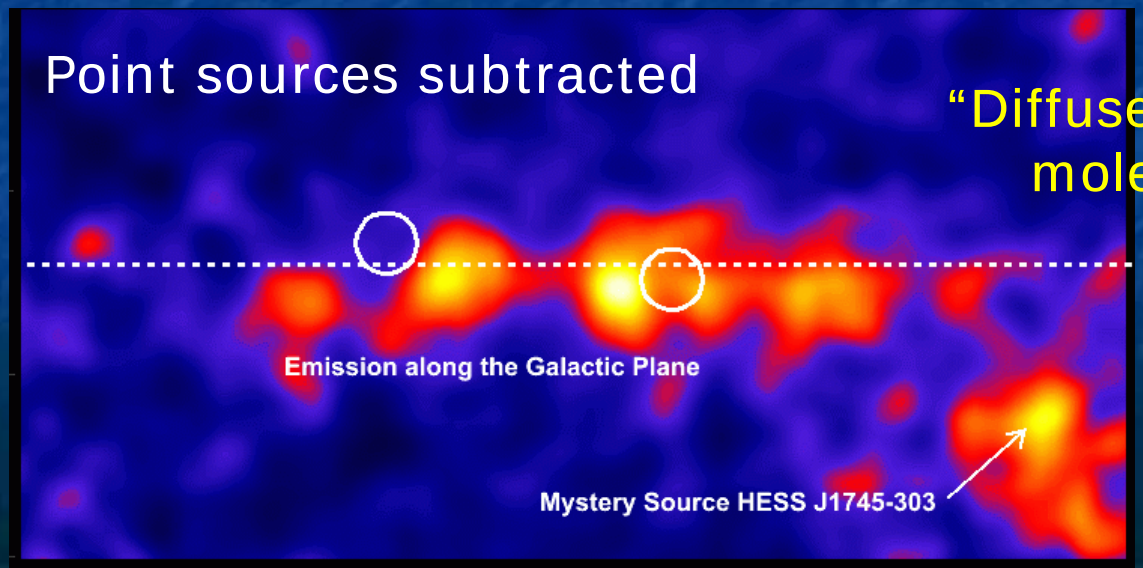
Sinnis, 2007

Confirmation of MGRO J1908+06 by HESS



The Center of our Galaxy





"Diffuse" γ-rays tracing molecular clouds

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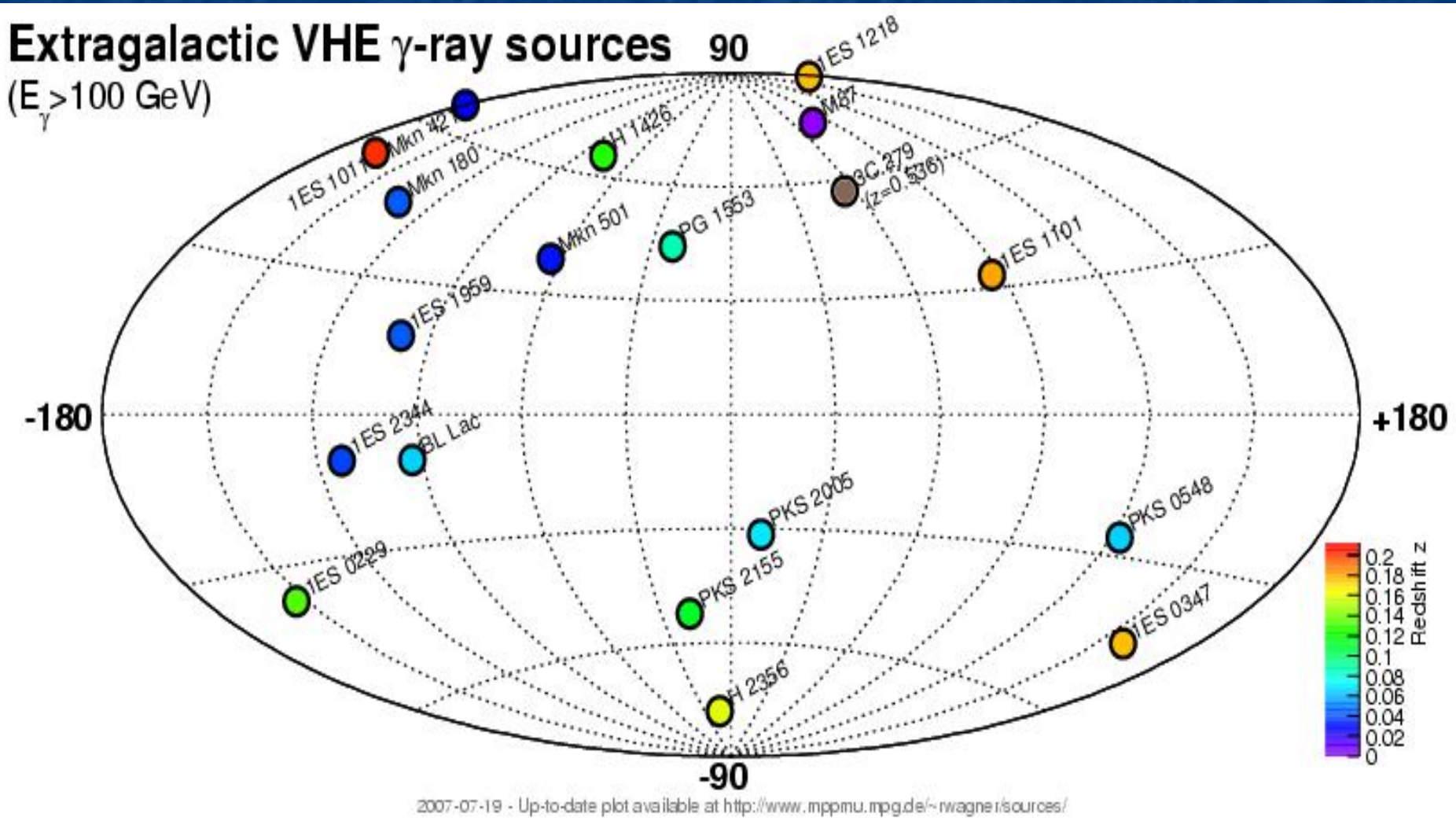
Galactic TeV Sources

- Many types of source
- Many sources
- TeV Galactic Particle Acceleration is Ubiquitous
- But if SNRs are the origin of the Galactic Cosmic Radiation, why are they not the dominant TeV source population?

Extragalactic Sources: 19 to date



Catalog of TeV AGN c. 2007

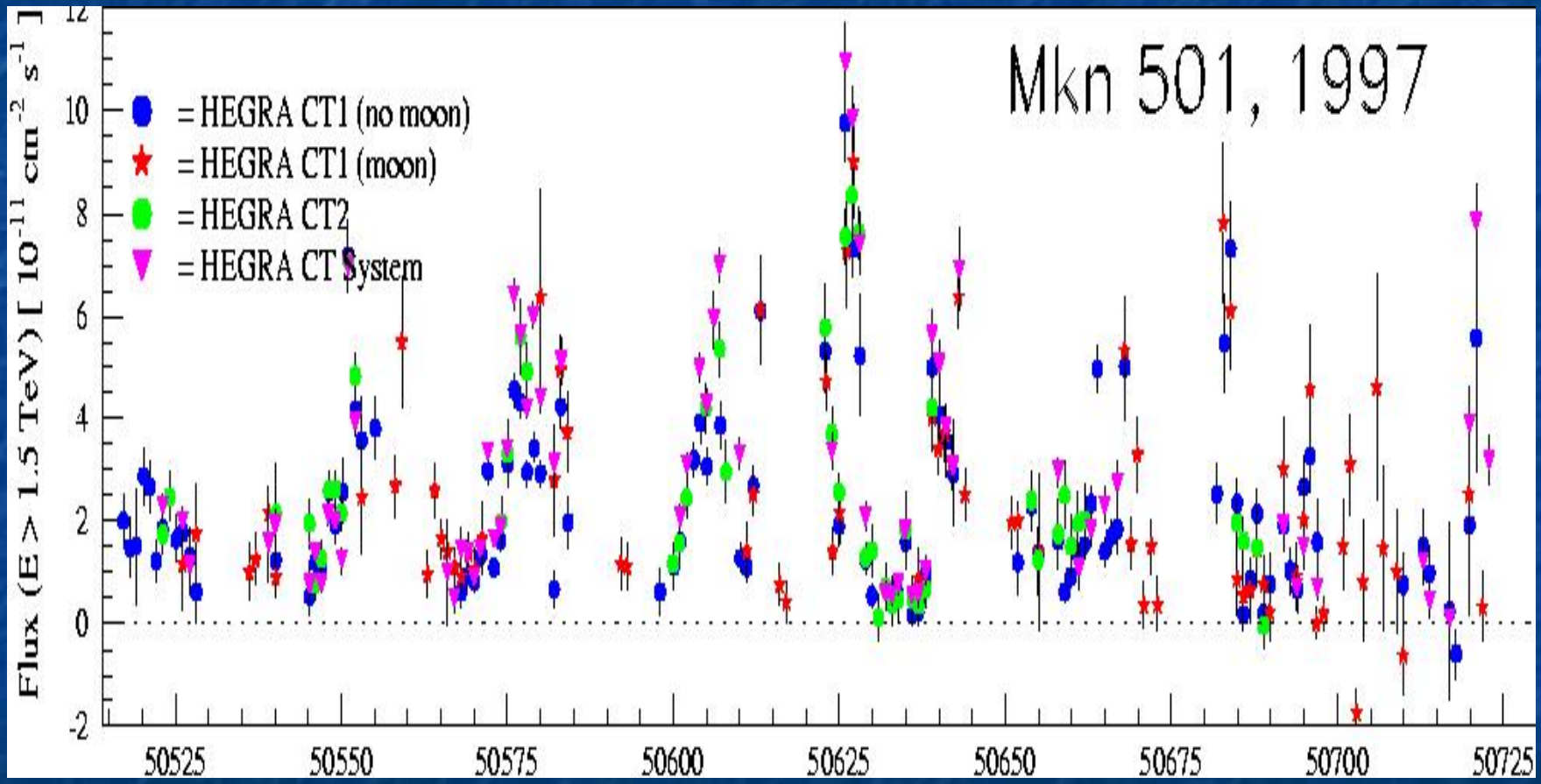
Name	z	Class	Discovery
M87	0.04	RG	HEGRA (Aharonian 2003)
Markarian 421	0.031	HBL	Whipple (Punch, 1992)
Markarian 501	0.034	HBL	Whipple (Quinn, 1996)
1ES 2344+514	0.044	HBL	Whipple (Catanese, 1998)
Markarian 180	0.045	HBL	MAGIC (Albert, 2006
1ES 1959+650	0.048	HBL	T. A. (Nishiyama, 2000)
PKS 548-322	0.067	HBL	HESS(Aharonian, 2007)
BL Lac	0.069	LBL	MAGIC (Albert, 2007)
PKS 2005-489	0.071	HBL	HESS (Aharonian, 2005)
PKS 2155-304	0.117	HBL	Durham (Chadwick, 1999)
H 1426+428	0.129	HBL	Whipple (Horan, 2002)
1ES0229+200	0.139	HBL	HESS (Aharonian, 2007)
H 2356-309	0.165	HBL	HESS (Aharonian 2006)
1ES 1218+304	0.182	HBL	MAGIC (Albert 2006)
1ES 1101-232	0.186	HBL	HESS (Aharonian 2005)
1ES 0347-121	0.188	HBL	HESS (Aharonian, 2007)
1ES1011+496	0.212	HBL	MAGIC (Albert 2007)
PG 1553+113	?????	HBL	HESS (Aharonian 2006)

Markarian 501

(HEGRA)

Days-

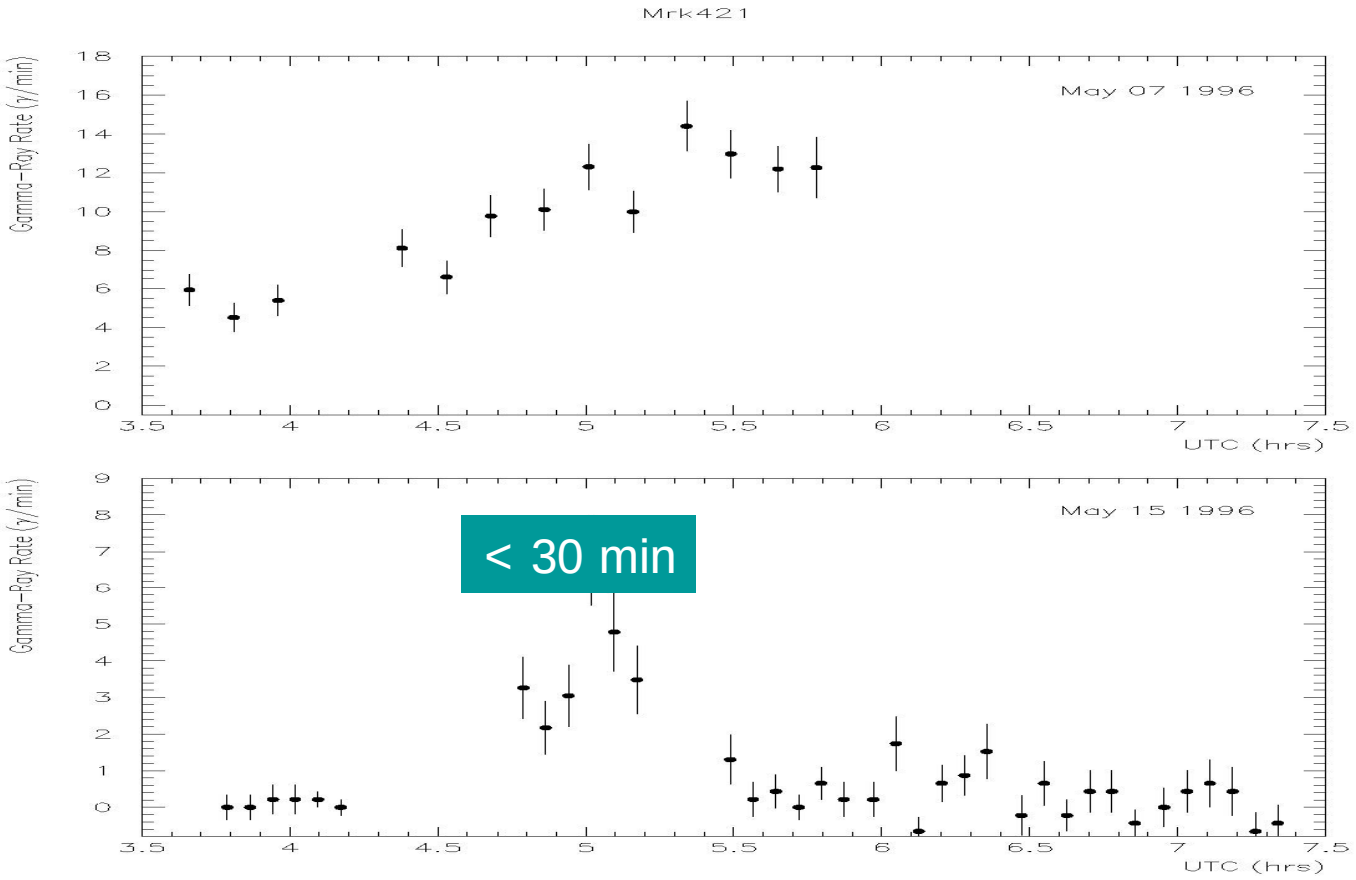
months



Six Months

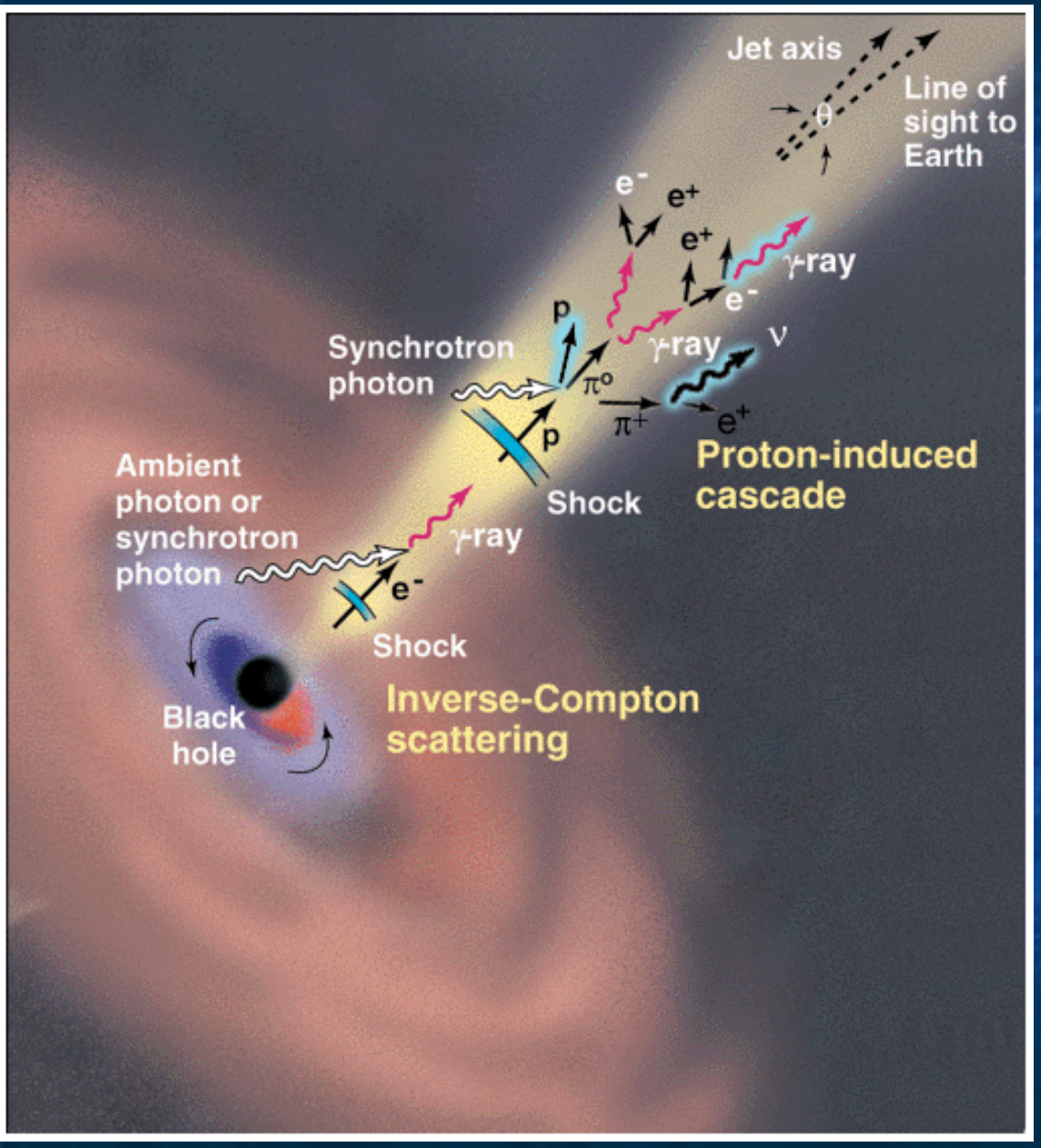
Variations Seen on Many Time-scales

Markarian 421
Whipple Observatory
Hours – minutes



Crab x 4

AGN Jet Emission Mechanisms



Cosmic Cannon:
Looking down the Barrel of the Cannon

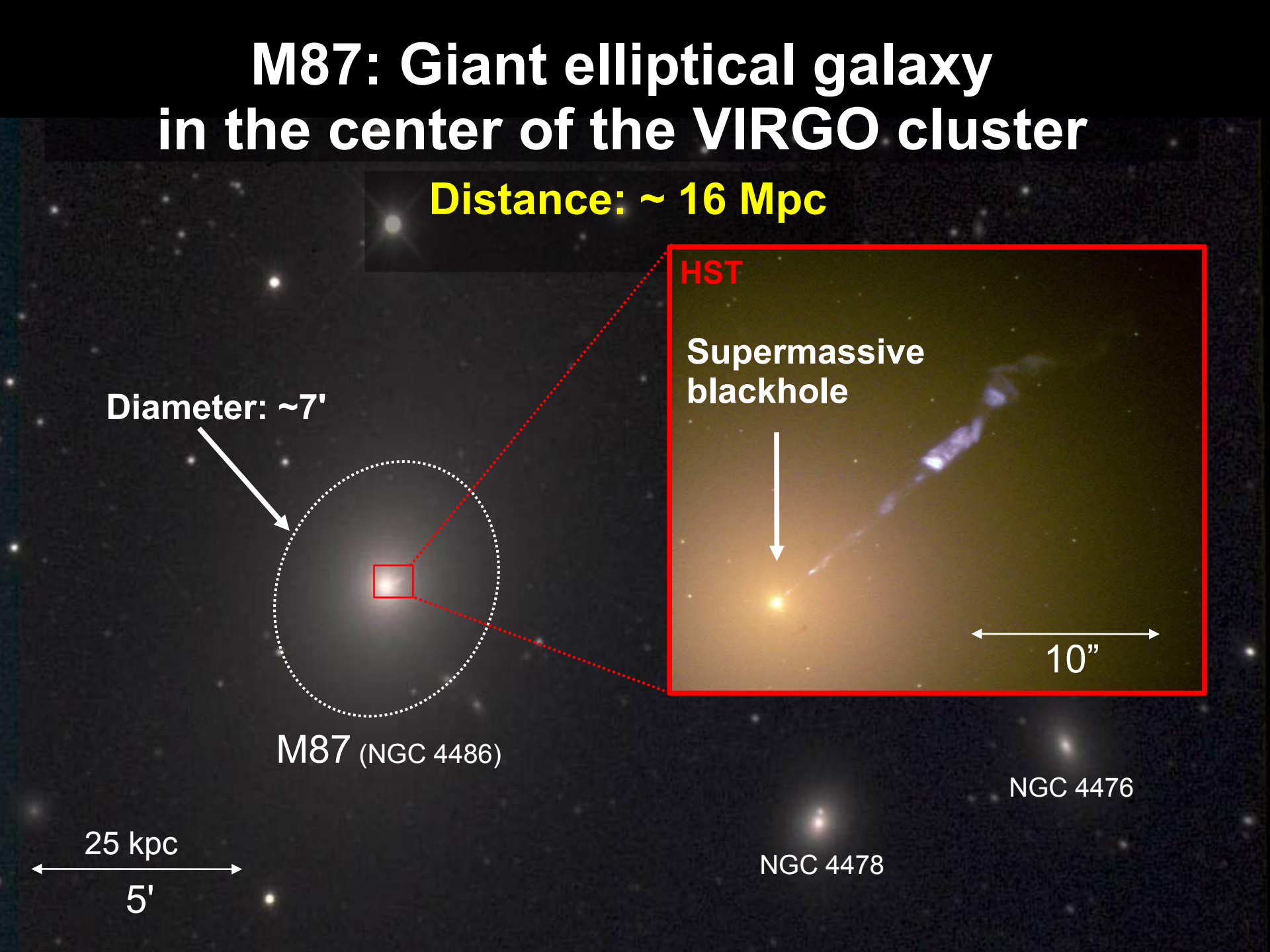
Electron Progenitors:
- Synchrotron Self Compton
- External Compton

Proton Progenitors:
- Proton Cascades
- Proton Synchrotron

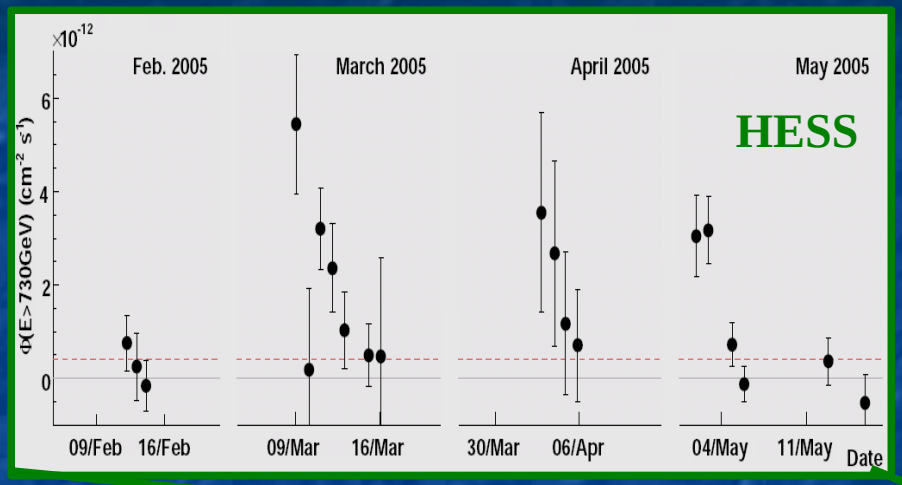
(Buckley, Science, 1998)

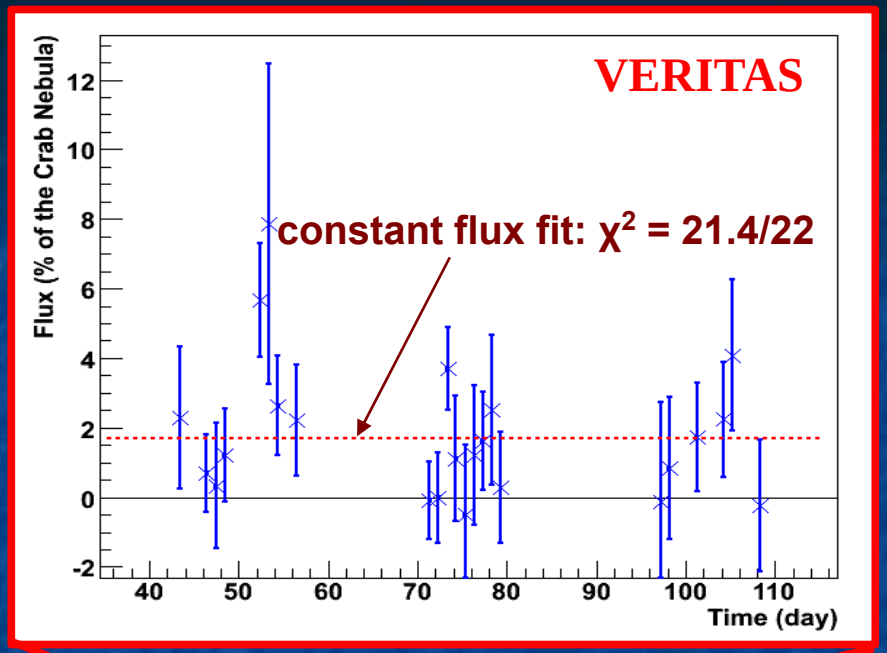
M87: Giant elliptical galaxy in the center of the VIRGO cluster

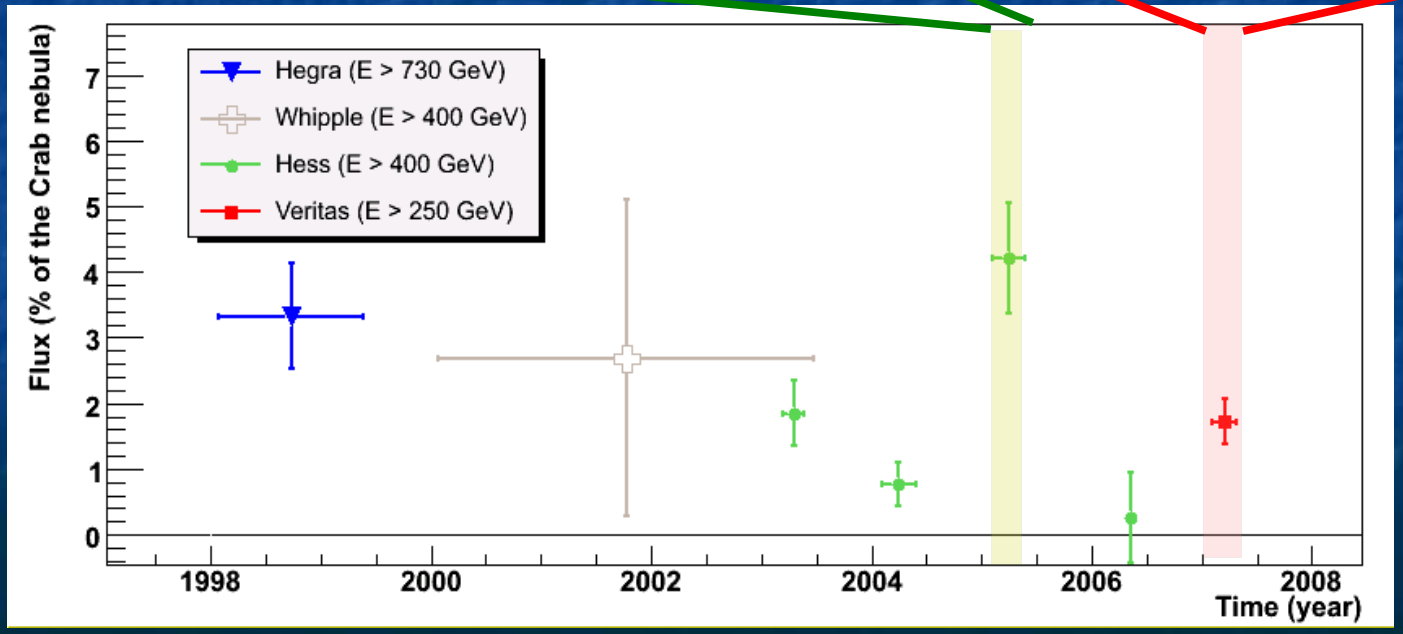
Distance: ~ 16 Mpc



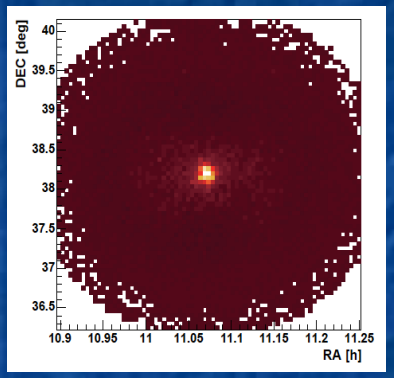
TeV Variability of M87



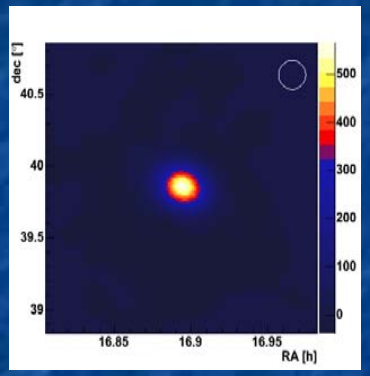




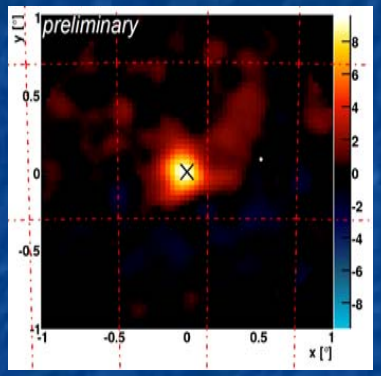
Extra-galactic sources: MAGIC



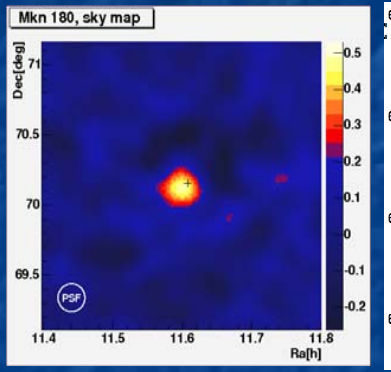
Mrk421 (0.031)



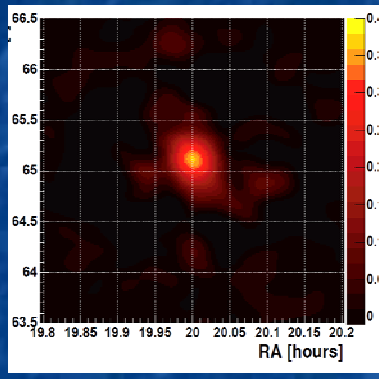
Mrk501 (z=0.034)
Very fast flare



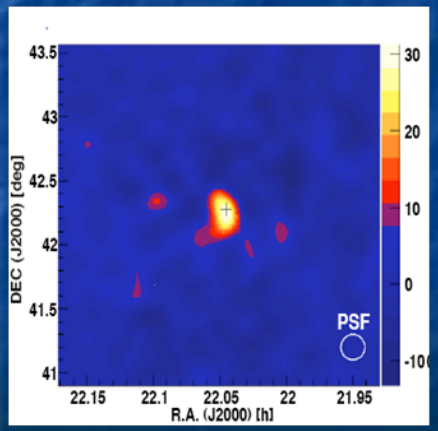
1ES2344 (z=0.044)



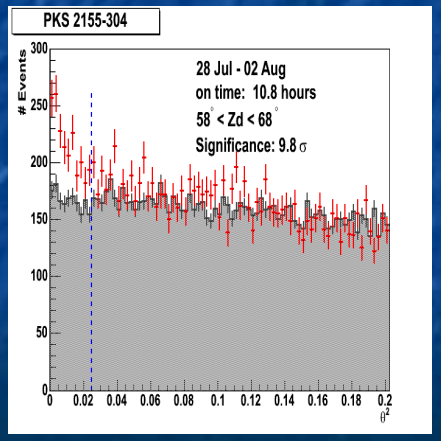
Mrk180 (0.045)
MAGIC discovery



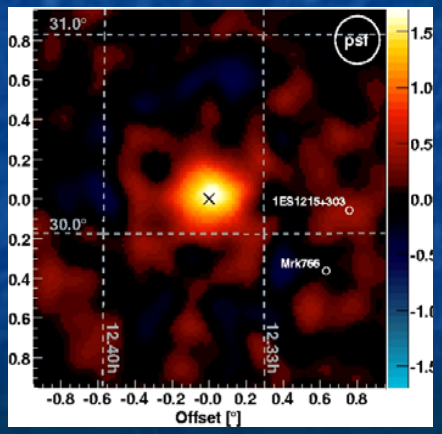
1ES1959 (0.047)



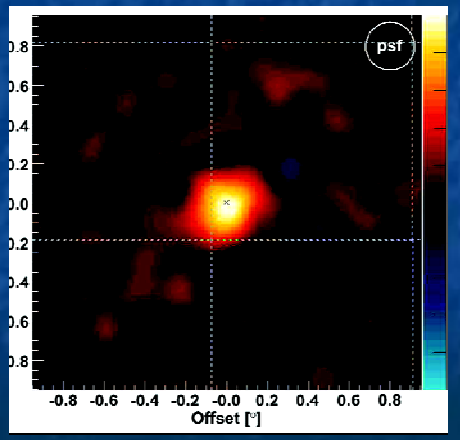
BL-Lacertae (0.069)
MAGIC discovery



PKS2155 (0.116)



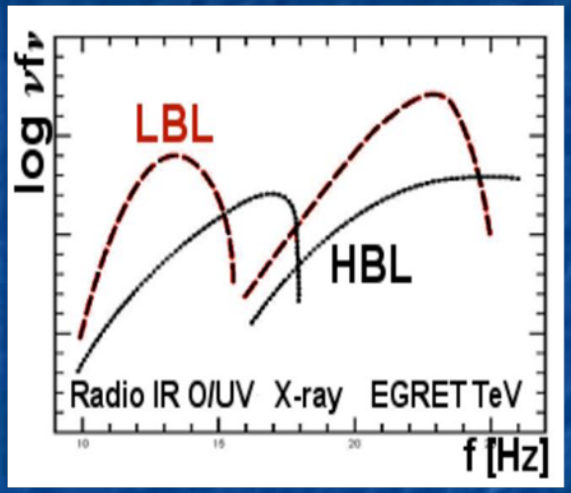
1ES1218 (0.18)
MAGIC discovery



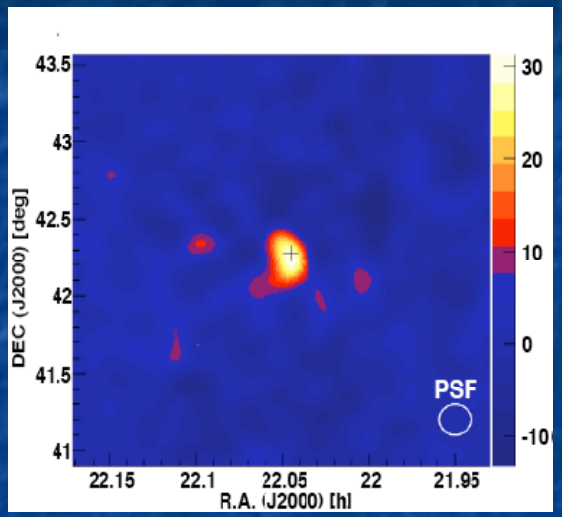
PG 1553 (Z>0.25)
MAGIC discovery

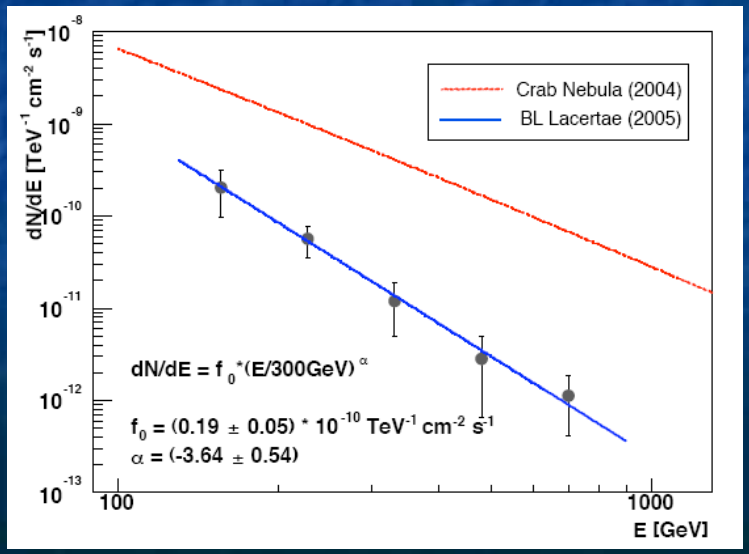
Teshima 2007

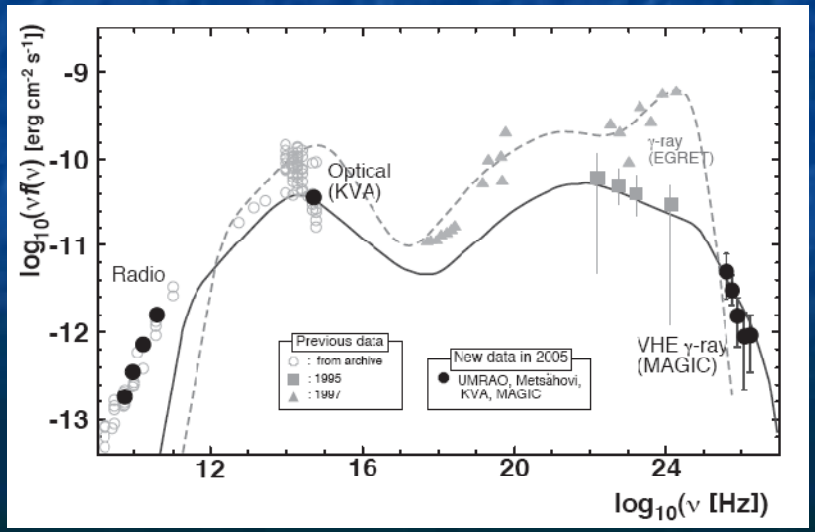
New Source, BL Lacertae (New class LBL, z=0.069)



5.1σ





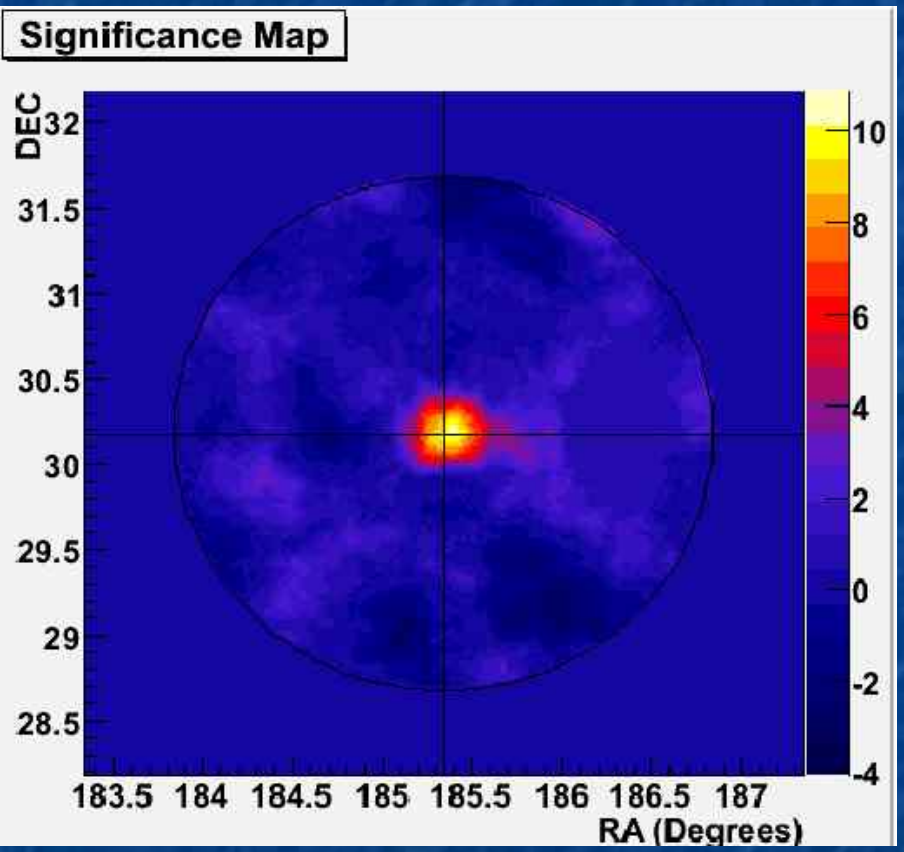


~ 3%Crab

Very steep Spectrum

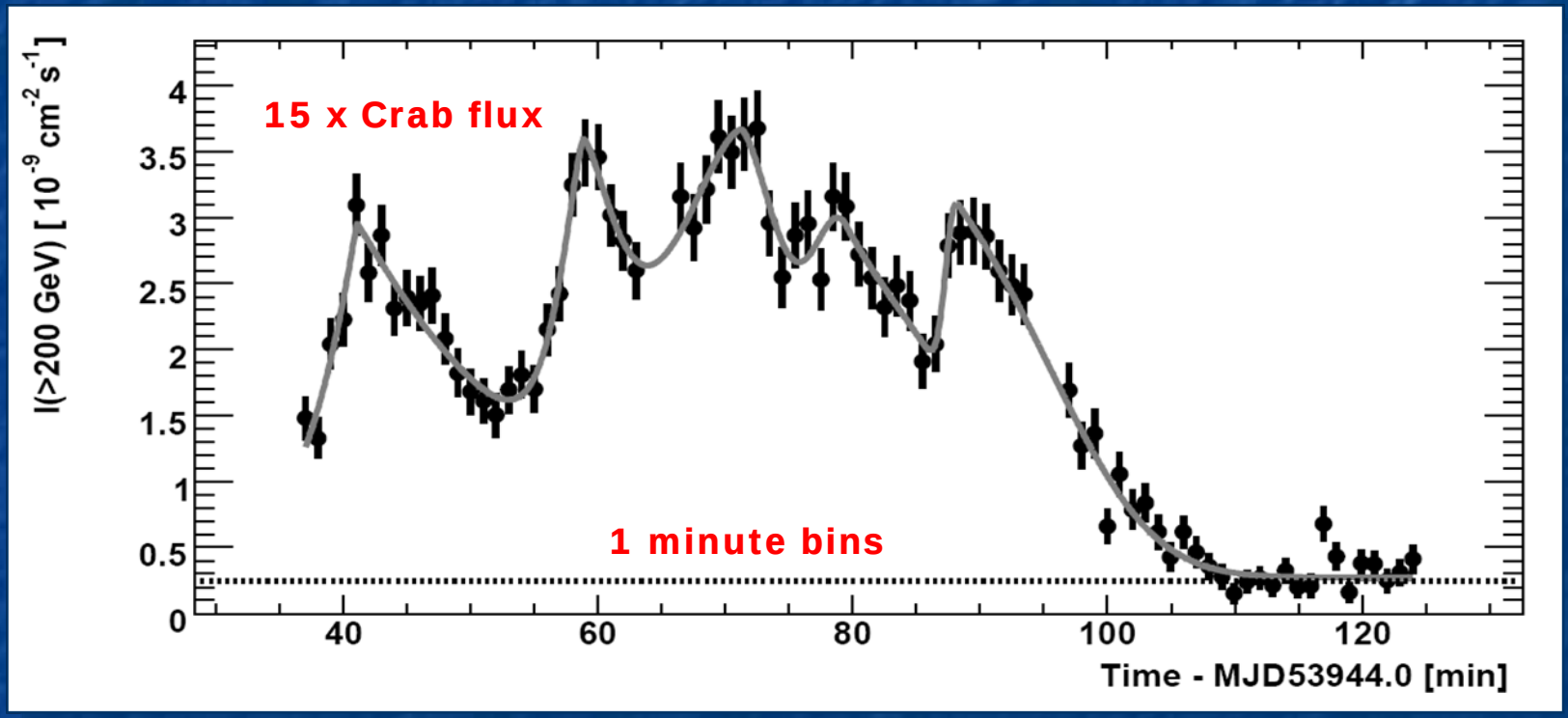
Teshima 2007

AGN: 1ES1218+30.4



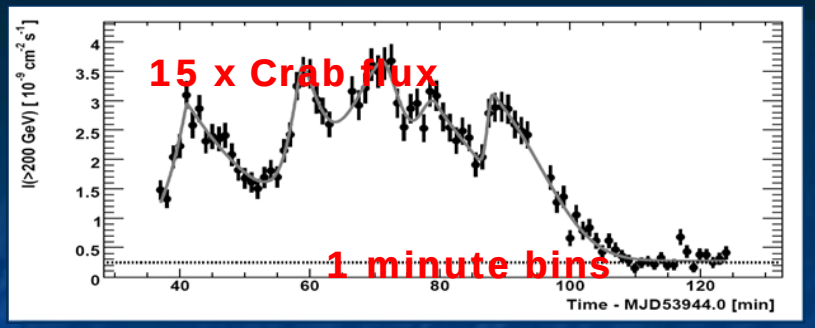
- z=0.182 => one of most distant TeV blazars
- MAGIC 8.2 hr, 6.4σ, E>120 GeV
- VERITAS: 29 hours
- January-March, 2007
- Three telescopes
- 13.2σ, 0.47 $\pm$ 0.04 γ/min

Remarkable Outburst seen by HESS from PKS 2155-304



- Aharonian et al. ApJ 664 L71

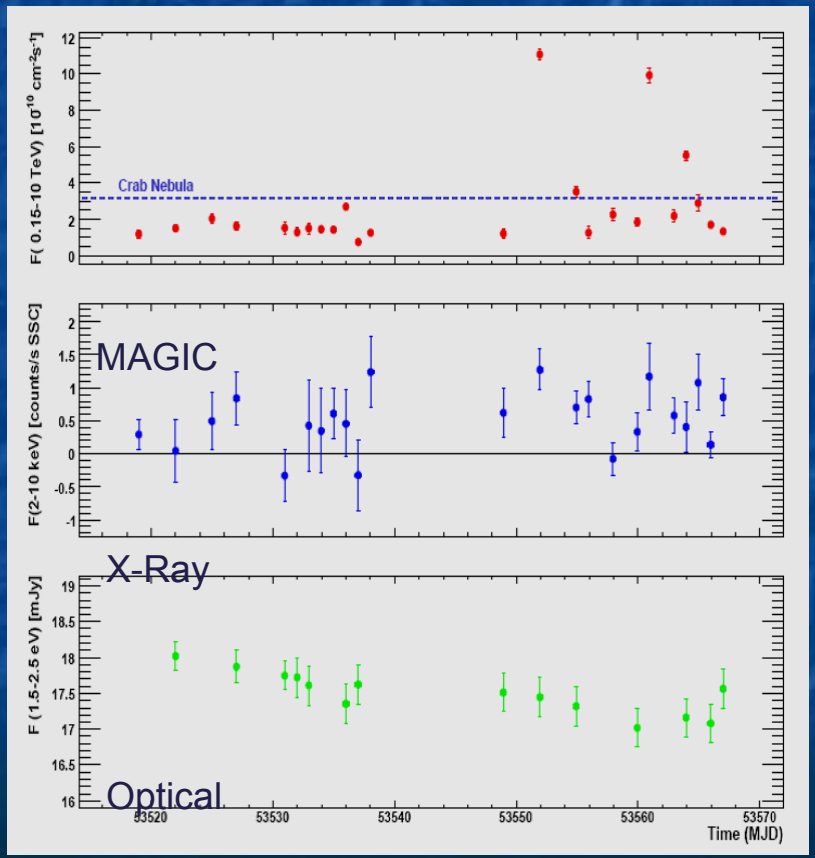
PKS 2155-304



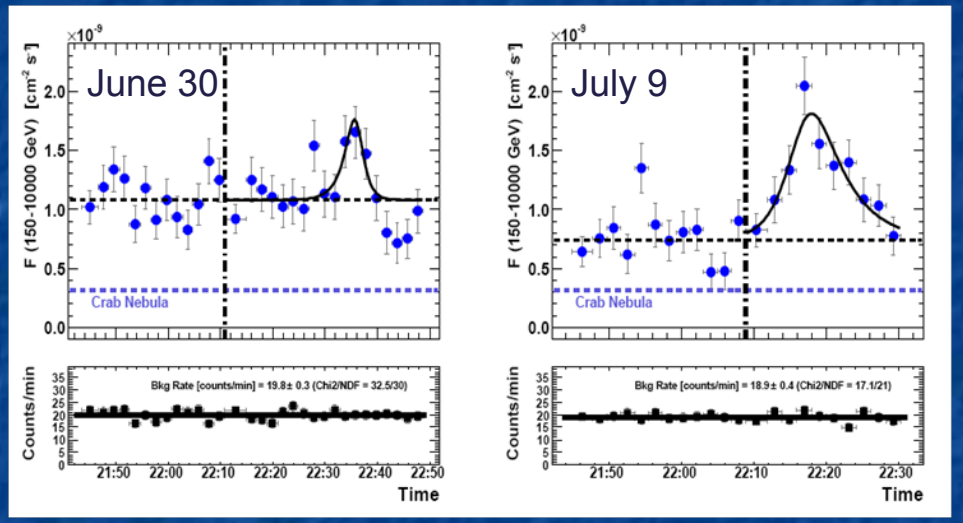
- Serendipity
- Known source: z = 0.112
- Monitoring....active in July, 2006
- Normal level ~ 15% of Crab
- Five flares: 3 minute rise times
- Black hole > 2x10^9 solar masses
- Doppler factor → 100
- No change in spectrum during flares
- Multi-wavelength data to come
- Most remarkable TeV observation yet!

Mrk501 Flares on June 30 and July 9 in 2005

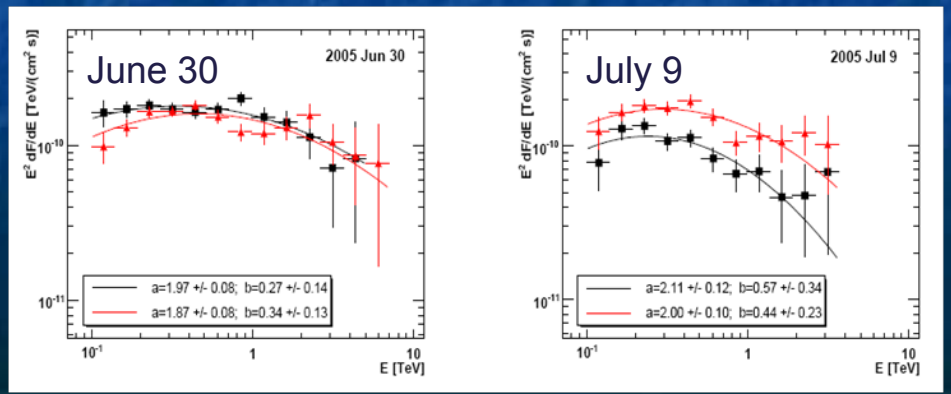
Light curve in May-July 2005



Intra-night light curve in 2mins bin

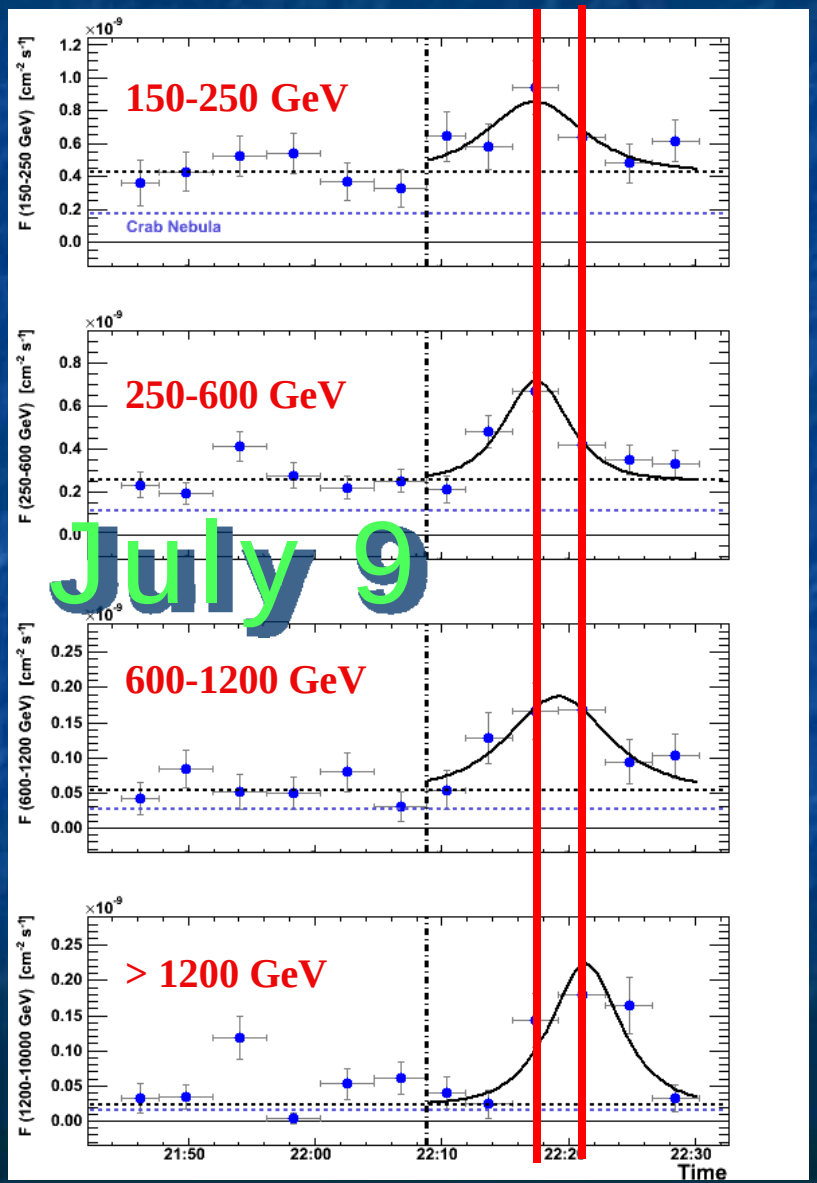


Energy Spectra in pre-burst state and burst state



Teshima
2007

Mrk501 MAGIC observation (2005 July 9)
Time lag for higher energies?



4min bin

This time lag may be explained by the particle acceleration process.

Mrk501 BH ~ 10^9Msolar ➔ Rsh/c ~10^4sec

Order of 100sec time variation requires extreme jet / blob emission of Γ-factor of 100. Perhaps new explanation is necessary.

Albert et al. (2007) ApJ in press
xxx.lanl.gov/abs/astro-ph/070208

****

"Probing Quantum Gravity using Photons from a Mkn 501 flare.." ~
Albert et al. (2007) Phys. Rev. Lettr.
arXiv:0708.2889
Quantum Gravity Mass ~ 0.4x10^18 GeV

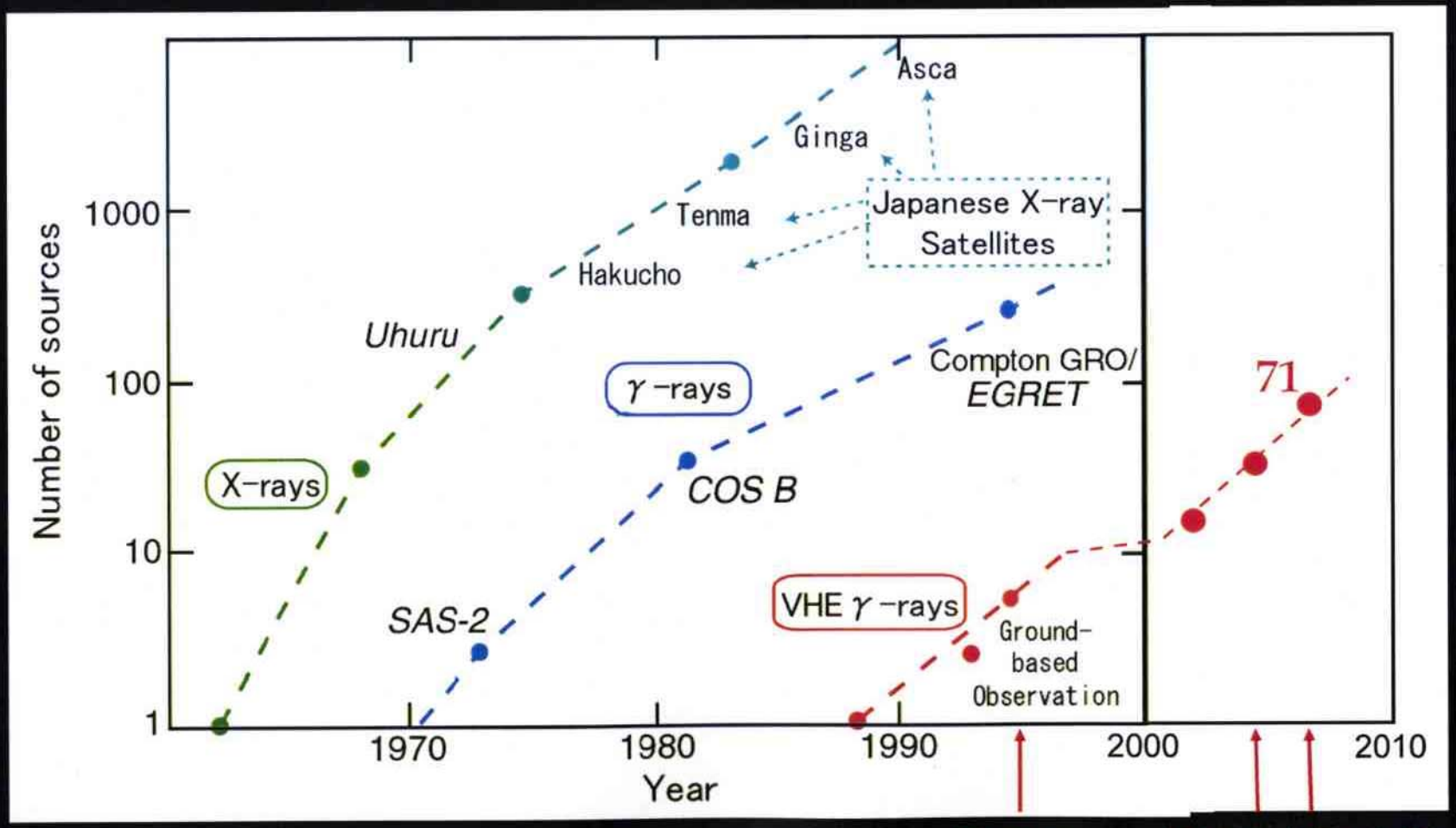
Teshima 2007

TeV Sources not seen (yet!)

- Pulsars
- GRBs
- Dark Matter
- Clusters of Galaxies
- Starburst Galaxies
- Diffuse Background
- UHE point sources
- Neutrino Dark Sources
- Primordial Black Holes

KIFUNE PLOT

Growth in number of sources with time



Source count versus year
[T. Kifune]

Hinton, 2007

But the number of sources is no longer what is important

- We now have the capability to explore these objects in exquisite detail
  - Angular resolution
  - Energy spectrum
  - Time variability

What can we do with present instruments?

Energy Range

- IACT's: 100 GeV - 50 TeV
- Milagro/Tibet/ARGO: 10 - 100 TeV

Flux Range (Crabs):

Source Strengths
1% to 1500%

Angular Size of Sources:

3 min of arc to 3 degrees

Distances to sources:

552 light-years
to 1 billion light-years

Time Variations

- Minutes to months

Gamma-ray Spectrum

- 10 to 15 % Resolution

What do we want to know?

U.S. “White Paper” on TeV Gamma-ray Astronomy

Commissioned by Division of Astrophysics, American Physical Society 2006
Almost completed

Sections:

- Galactic Diffuse Sources
- Galactic Compact Objects
- Extragalactic Sources
- Dark Matter
- Gamma Ray Bursts
- Technical/Roadmap

Science Matrix:

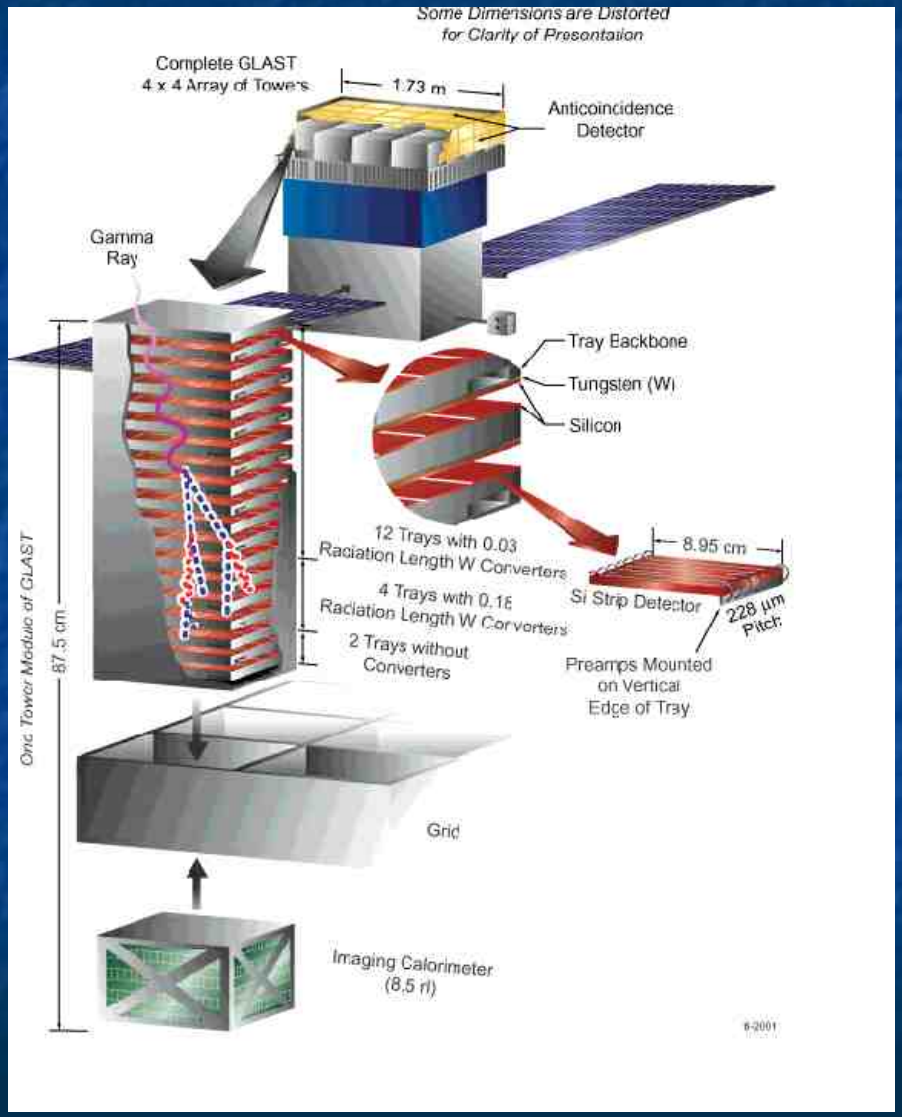
	Sensitivity > 50 GeV	Sensitivity > 200 GeV	Sensitivity > 10 TeV	Angular Resolution	Field of view
AGNs	++	+++	++	o	o
GRBs	+++	+	+	o	+++
EBL	+	+++	+++	o	o
nearby,e.g, radio galaxies	+	+++	+++	+++	o
SNRs	+	+++	+++	+++	o
Unid. in Gal. Plane	?	+++	+++	+++	+
Pulsars	+++	+	o	+	o
Dark Matter	+	+++	+++	+++	?
Gal. Transients	+	++	+	++	+++

What is comes next…near term?

What's is in the immediate future?

- Exploitation of existing Observatories
- Improved Facilities
  - GLAST (AGILE)
  - MAGIC-2
  - HESS-5
  - Milagro/Tibet/ARGO

Future of GeV Gamma-ray Astronomy

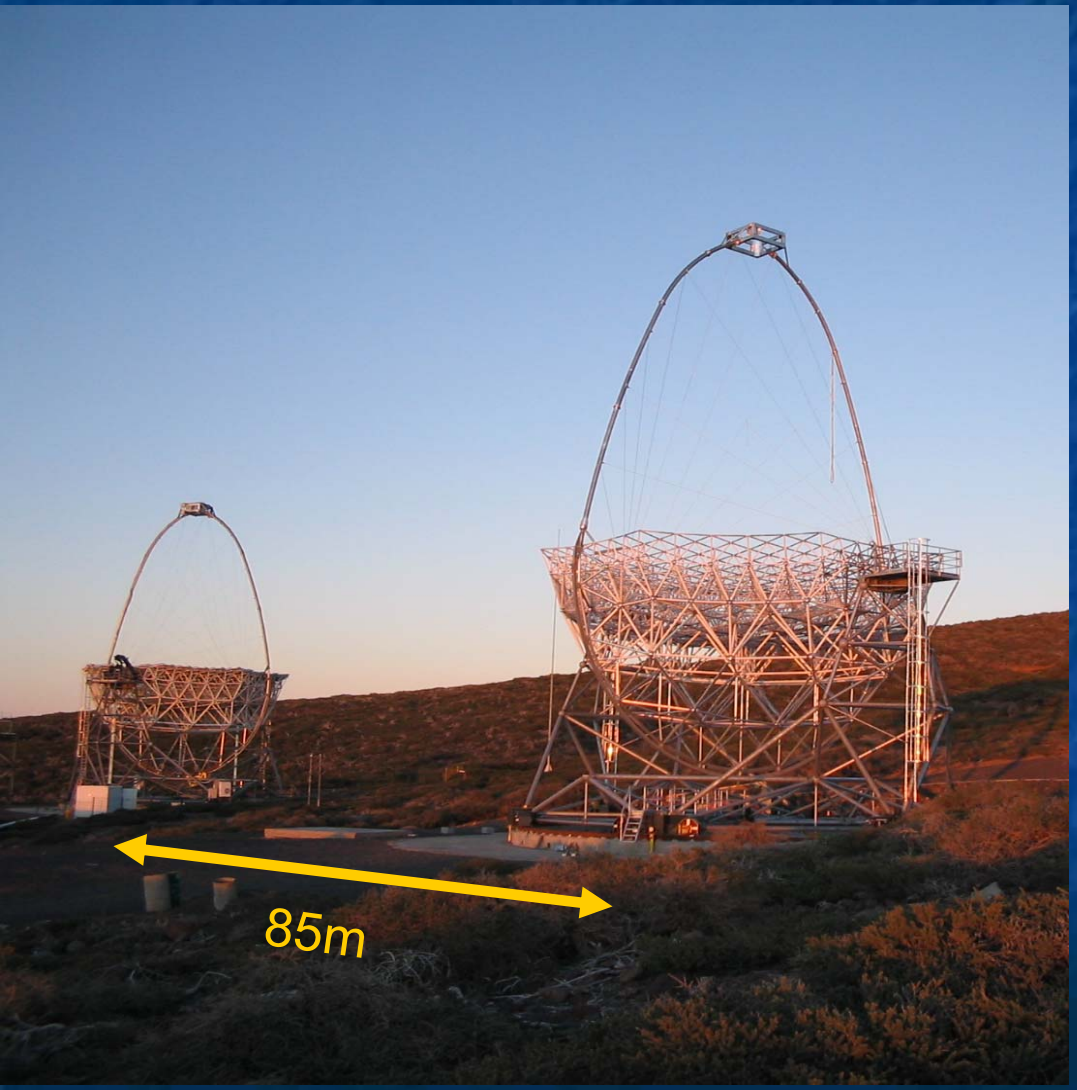


GLAST:
the Next Generation Gamma-ray Space Telescope: 2008-2013

GLAST has a factor 10-20 improvement in flux sensitivity compared to EGRET
It extends to higher energies (300 GeV)

Also smaller version: AGILE (launched in 2007)

MAGIC 2008



New technologies to lower the threshold energy

17m diameter world largest cherenkov tel.
0.1° High resolution camera
Analogue signal fiber transmission

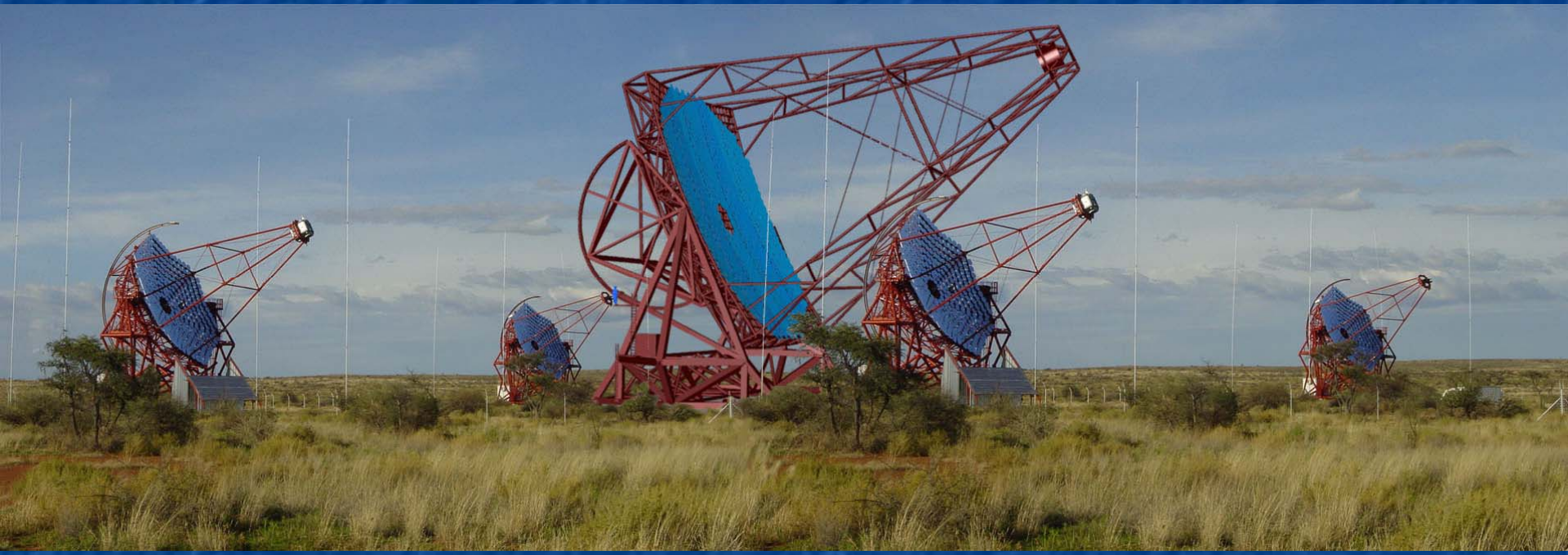
Current MAGIC-I Performance

Fast rotation for GRB < 40secs
Trigger threshold ~50GeV
Sensitivity ~2% of Crab (50hrs)
Angular resolution ~0.1 degrees
Energy Resolution 20-30%

MAGIC-II is under construction and will be completed in the fall of the next year

Improve sensitivity by a factor of three
Effectively lower the threshold energy

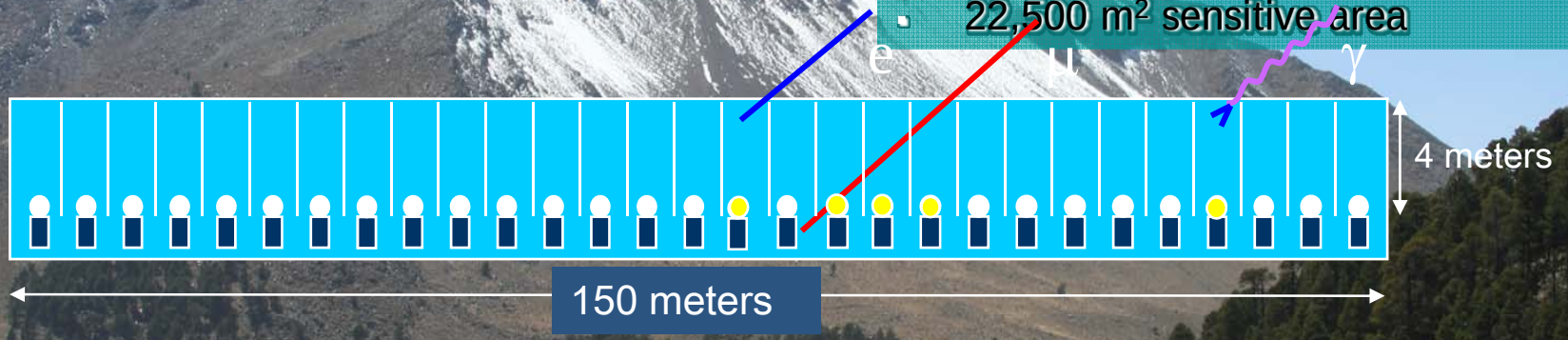
HESS 2009



Addition of 28 m aperture Telescope at center of array
Lower Energy Threshold
2009?

HAWC: High Altitude Water Cherenkov

- Build pond at extreme altitude
  - Sierra Negra, Mexico 4100m
- Incorporate new design
  - Optical isolation between PMTs
  - Larger PMT spacing
  - Single PMT layer (4m deep)
- Reuse Milagro PMTs and electronics
- 22,500 m² sensitive area



Milagro has been closed down ....but HAWC is not yet funded

~$6M for complete detector
~10-15x sensitivity of Milagro
Crab Nebula in 1 day (4 hours) [Milagro 3-4 months]
4x Crab flux in 15 minutes
GRBs to z < 0.8 (now 0.4)

Sinnis, 2007

What is comes next...long term?

Development of GeV-TeV Gamma-ray Astronomy

- First Generation Systems 1960 – 1985
  - Weak or no discrimination
  - Lebedev, Glencullen, Whipple, Narrabri, Crimea, Ooty

New Technology

- Second Generation Systems 1985 – 2003
  - Atmospheric Cherenkov Imaging Telescopes
  - Whipple, Crimea, CAT, HEGRA, Durham, CANGAROO

……

Increase in Scale

- Third Generation Systems 2003 – 2012
  - Arrays of Large ACITs
  - MAGIC-2, HESS-5, CANGAROO-III, VERITAS-4

New Technology?

- Fourth Generation Systems 2012 -
  - TBD

TeV Sources
Zero
~ 12
> 100
1000?

Next Generation IACTs

- No clear successor to GLAST in space
- IACTs can be improved by scaling up number and quality of telescopes
- But can we increase the sensitivity by a factor of 10 without increasing the cost by a factor of 100
- But no major breakthrough in technology as yet that would reduce cost

New Technology for IACTs?

- Telescopes
  - Aperture
  - Mirrors
  - Optical accuracy/design
  - Number
  - Modularity
  - Robotic
- Cameras
  - Triggering/readout
    - Smart Triggering
    - ASICs
    - Multiplex FADCs
    - DAQ Readout
  - Photodetectors
    - PMTs
    - Image Intensifiiers
    - MAPMT
    - Hybrid PMTs
    - Microchannel Plates
    - Silicon PMT

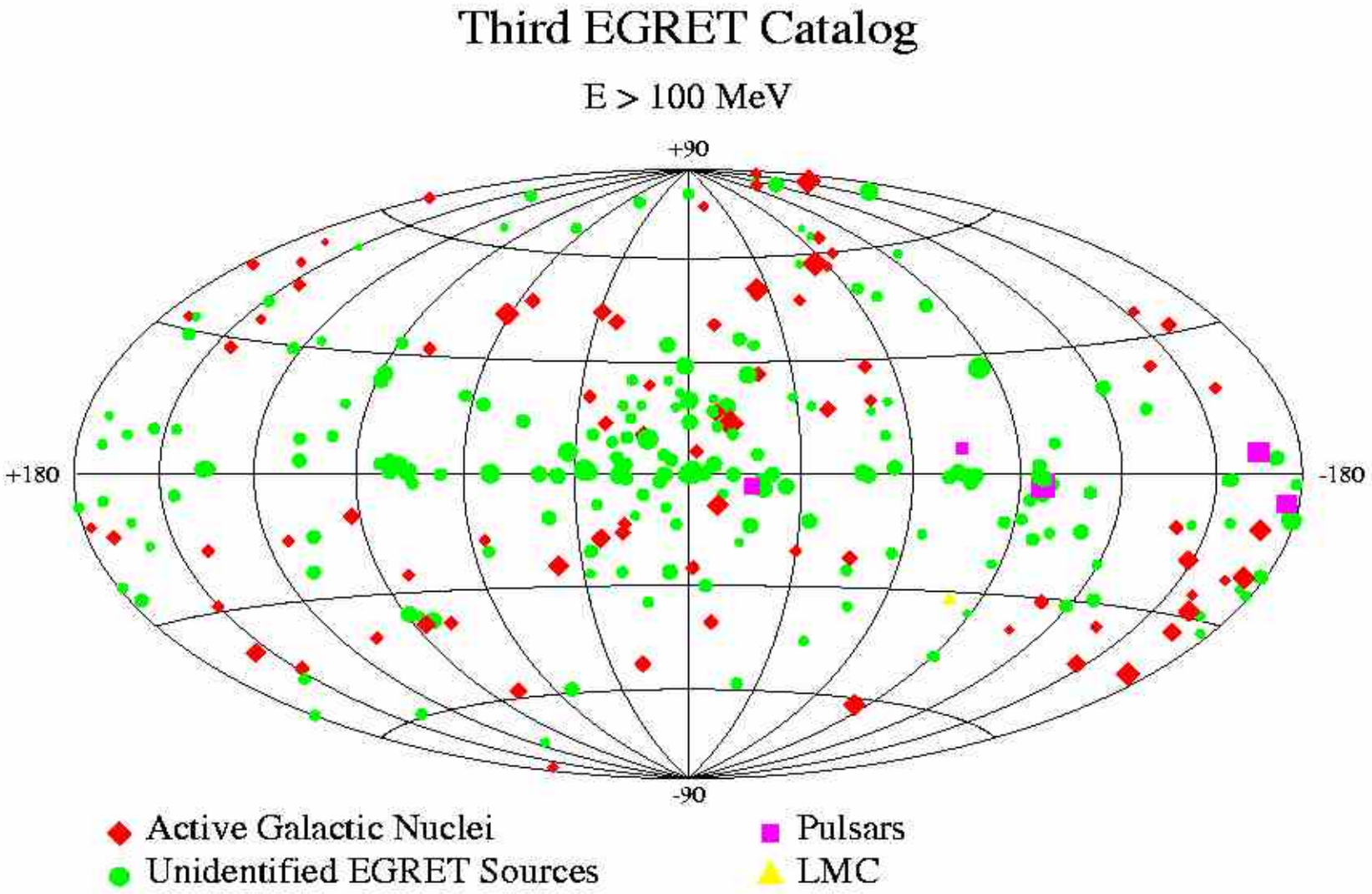
Next Generation IACTs

- Two New Collaborations forming:
  - AGIS (largely USA) ….Northern Hemisphere
  - CTA (largely European)….Southern and Northern Hemispheres
  - But…….
- Price Tag > $100,000,000
- Aim for energy threshold ~ 30 GeV
- Aim for 1km^2 collection area

Should there be only one observatory?

- Advantages of more than one:
  - Two hemispheres
  - Verification
  - Observatories
  - Specialization
  - Competition
  - Shared technology

EGRET's definitive map of the 100 MeV discrete sources

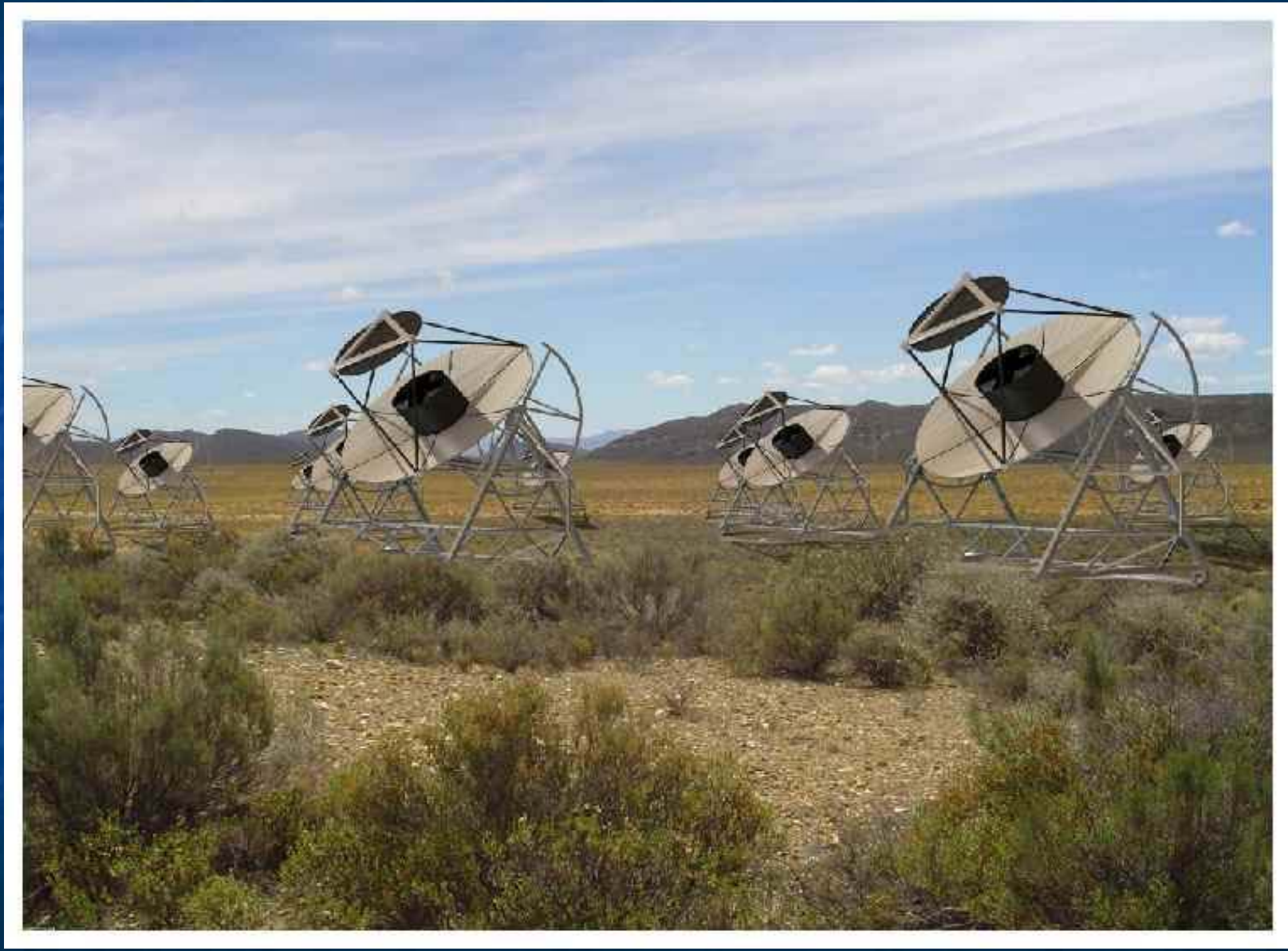


But as many as 120 of these sources may not be real!

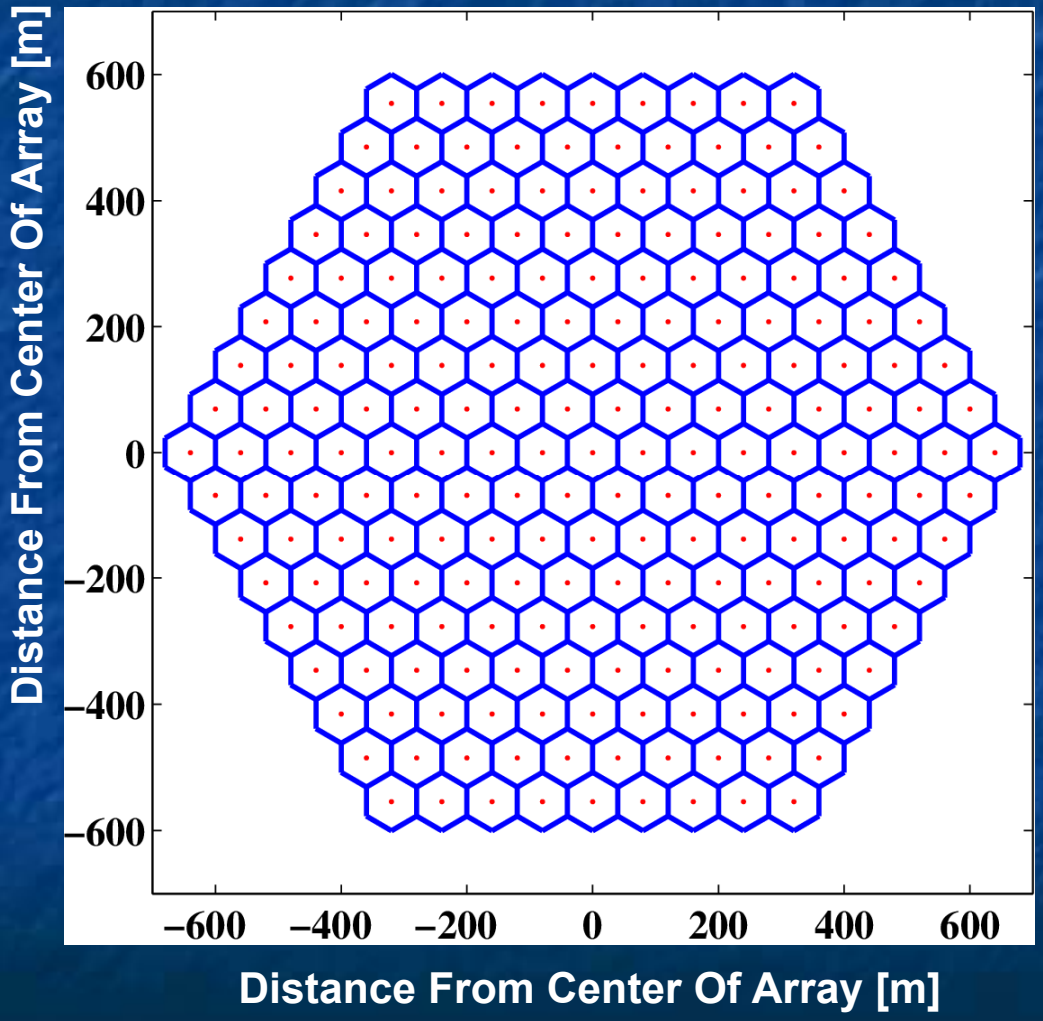
AGIS (Advanced Gamma-ray Imaging System): mission statement

- Design studies and hardware development
- 50 – 100 telescopes
- Sensitivity ten times that of VERITAS
- Energy Range: 40 GeV to 50 TeV
- Prototype ~ 8 m aperture
- New optical design: small camera scale
- Field of View: 7 – 10 degrees
- Cost envelope < $100M

AGIS



Possible configuration of 1km^2 array



Array

1. 217 telescopes
2. 8 hexagonal rings + 1
3. 80m separation

Telescope and Detector

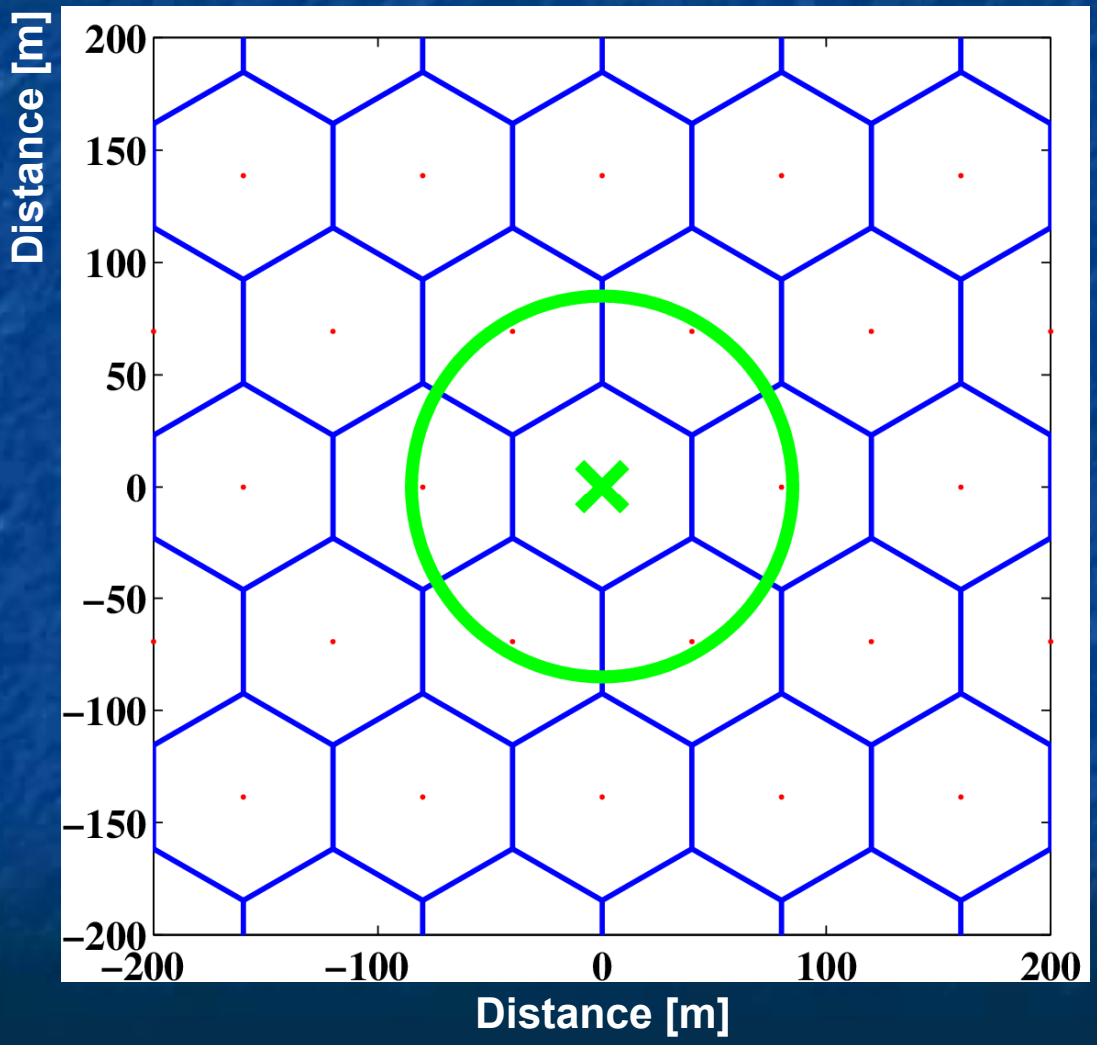
1. Ø=10m equivalent
2. QE = 0.25 (Bialkali)

Facts and Figures

1. Outer radius: 640m
2. Single cell area: 5543m^2
3. Total area: 1.06km^2

Fegan, Vassiliev 2007

Cell effect



Infinite Array Of Telescopes

1. 3500m ASL
   $\rightarrow R_{Cherenk} = 85m$
2. $D_{Scopes} = 80m$

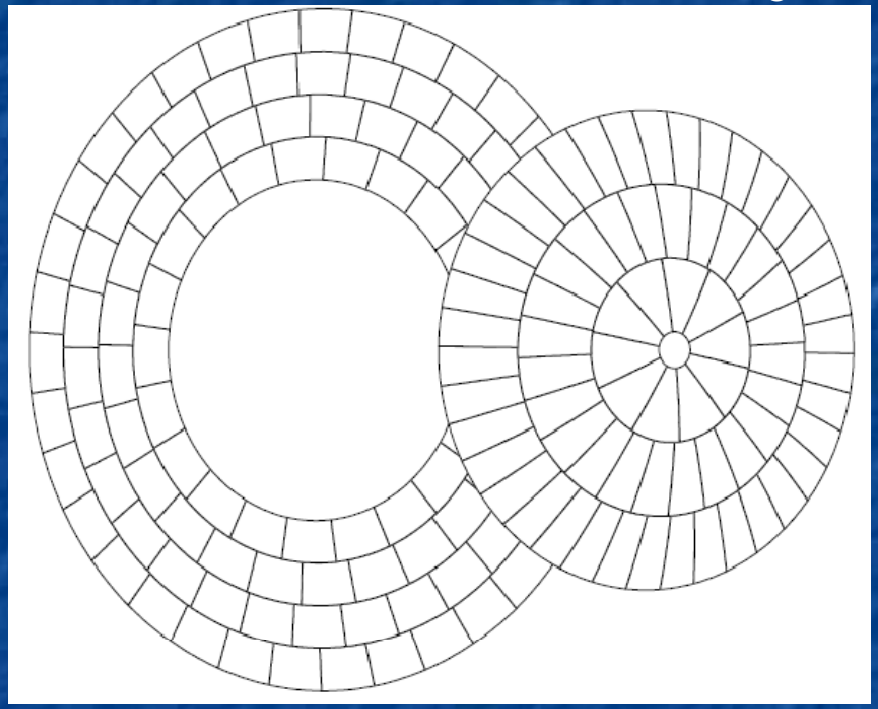
Geometry Dictates That

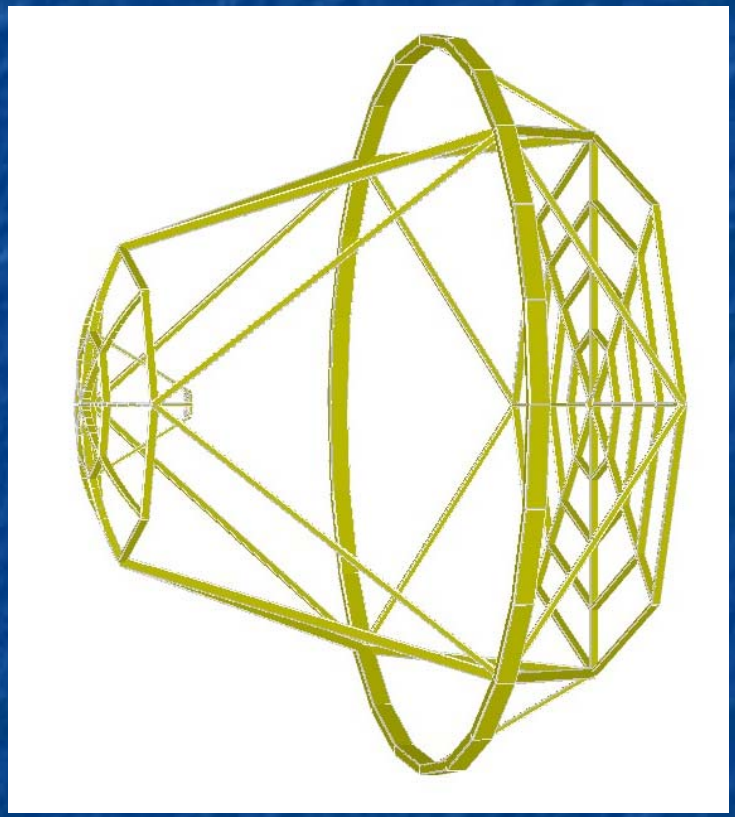
1. Impact point of every shower is in *some* cell
2. $B_{Max} = 47m$
3. At least 3 telescopes contained in Cherenkov light pool

Fegan, Vassiliev 2007

Possible optical design

Primary: 30+25+20 mirrors in each of 3 rings = 75 mirrors total





- **Required tolerance of optical system support and alignment is similar to radio telescopes in mm and sub-mm range, such as ALMA.**
- **An inexpensive mirror replication technology is required to mass produce non-spherical, off-axis optics.**

Fegan, Vassiliev 2007

http://www-conf.slac.stanford.edu/vhegra/

TOWARD THE FUTURE OF VERY HIGH ENERGY GAMMA-RAY ASTRONOMY SLAC

- Home
- Registration
- Agenda
- Participants
- Accommodations
- Travel and Directions
- Visa Information
- Social Events
- Past Meetings
- Contact

Toward The Future of Very High Energy Gamma-ray Astronomy

November 8-9, 2007
Stanford Linear Accelerator Center
Menlo Park, California
Location: Panofsky Auditorium

The goal of this workshop is to bring together an international group of scientists interested in the future of gamma-ray astronomy to define the direction and discuss R&D projects for the next generation observatories such as CTA, HAWC and AGIS. This is the 4th workshop in the series of this kind with previous workshops being held in Los Angeles, Santa Fe and Chicago. The focus of the meeting will be to summarise the scientific motivations for such instruments, drawing on the White Paper for the Division of Astrophysics of the American Physical Society. Particular emphasis in the discussion will be devoted to technical challenges, design parameters and projected sensitivities of such future observatories.

RECENT NEWS

- **Agenda has been updated.**

REGISTRATION

Registration is necessary to participate in the workshop. There is no registration fee for this workshop.

→ Register

ORGANIZING COMMITTEE:

Stefan Funk
Roger Blandford
Seth Digel
Eduardo do Couto e Silva
Greg Madejski
Olaf Reimer
Roger Romani
Hiro Tajima

ACCOMMODATIONS

A block of 40 rooms is reserved until Oct 7, 2007 at the **Stanford Guest House**. Please reserve your room early and mention that you are attending this workshop.

→ More Information

SLAC KIPAC

AGIS

CTA (Cherenkov Telescope Array)

- Concept: Hierarchy of telescopes
- Inner array of large (>25 m) telescopes
- Medium array of conventional (~10m) telescopes
- Large outer array of small (~5m) telescopes

- European (MAGIC/HESS/+) proposal to build a fourth generation IACT
- Design Proposal (E5M) submitted this summer to European funding agency
- Ranked highly but not funded
- Will seek national funding

CTA

Cherenkov Telescope Array

An advanced facility for ground-based gamma-ray astronomy

Home

Introduction

Working groups

Contact

Links

Internal

Getting in touch

CTA combines the European efforts in ground-based gamma-ray astronomy. Currently about 250-300 European physicists are directly involved in this field. Already now physicists from other areas, like particle and nuclear physics, radio, optical and X-ray astronomy and neutrino astrophysics actively contribute to the definition of CTA. We explicitly invite interested members of these communities to join CTA.

For further information about the project, or about possibilities to contribute to the definition of CTA please contact the co-coordinators

- German Hermann
- Thomas Schweizer

or the spokespersons of H.E.S.S. or MAGIC:

- Werner Hofmann
- Masahiro Teshima

Summary

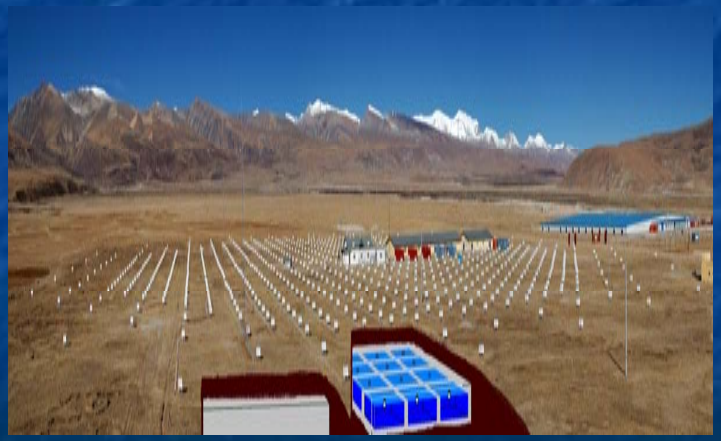
- The sky is full of TeV sources
- TeV emission is ubiquitous
- Much to be done with existing observatories
- Plans are afoot for next generation IACTs
- These are exciting times for TeV gamma-ray astronomers

Extra Slides

Future Synoptic TeV Telescopes

Tibet w/Muon Detectors
China-Japan collaboration
4300m asl (YBJ, Tibet)
Tibet w/buried water tanks
Emphasis 10-1000 TeV

ARGO
Complete summer 2007
Chinese-Italian collaboration
4300m asl (YBJ, Tibet)
RPC carpet
10-15σ /$\sqrt{}$year on Crab



HAWC
US-Mexico collaboration
>4100m asl (Tibet or Mexico)
Water Cherenkov
100 σ /$\sqrt{}$year on Crab

Sinnis, 2007