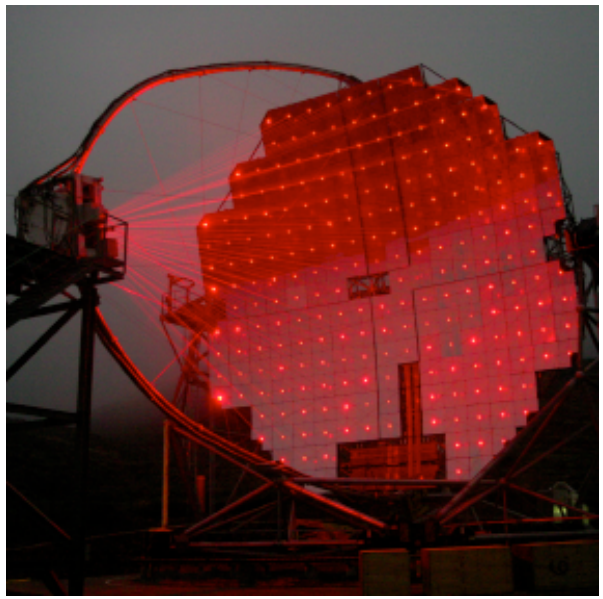
The MAGIC Telescope: Project status and source observations

David Paneque for the MAGIC collaboration



(Courtesy of R.Wagner)

Astronomical picture of the day (16/10/04)

OUTLINE

1- IACTs for doing gamma-ray astronomy

2- The MAGIC Telescope, a technological challenge

3- Project status and source observations

4- Conclusion

1 - Imaging Atmospheric Cherenkov Telescopes (*IACT*) as ground-based instruments for making gamma-ray astronomy

1.0 - Introduction to IACTs and Gamma-Ray astronomy

➢ **Imaging Atmospheric Cherenkov Telescopes (IACTs) are instruments for performing gamma-ray astronomy**

IACTs* aim to provide experimental basis for the understanding of the *Non-thermal Universe

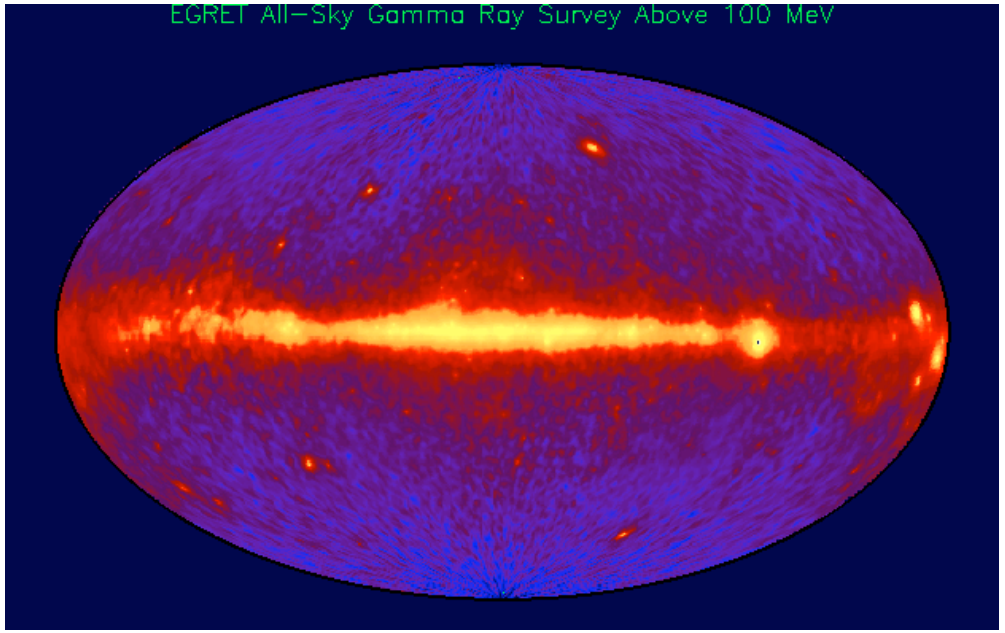
Acceleration, propagation and interaction of high energy particles can produce gamma rays

Hadronic high-energy particles → $\pi^0 \rightarrow \gamma\gamma$, $\pi^\pm \rightarrow \mu^\pm \nu$

Leptonic high-energy particles → *Bremsstrahlung*, *Synchrotron*, *Inverse Compton*

Gamma rays are secondary products of the cosmic accelerators

EGRET All-Sky Gamma-Ray Survey E > 100 MeV



Gamma rays are mostly produced by the interaction of *cosmic rays* with the interstellar gas of the *Milky Way*

Information brought by the gamma quanta:

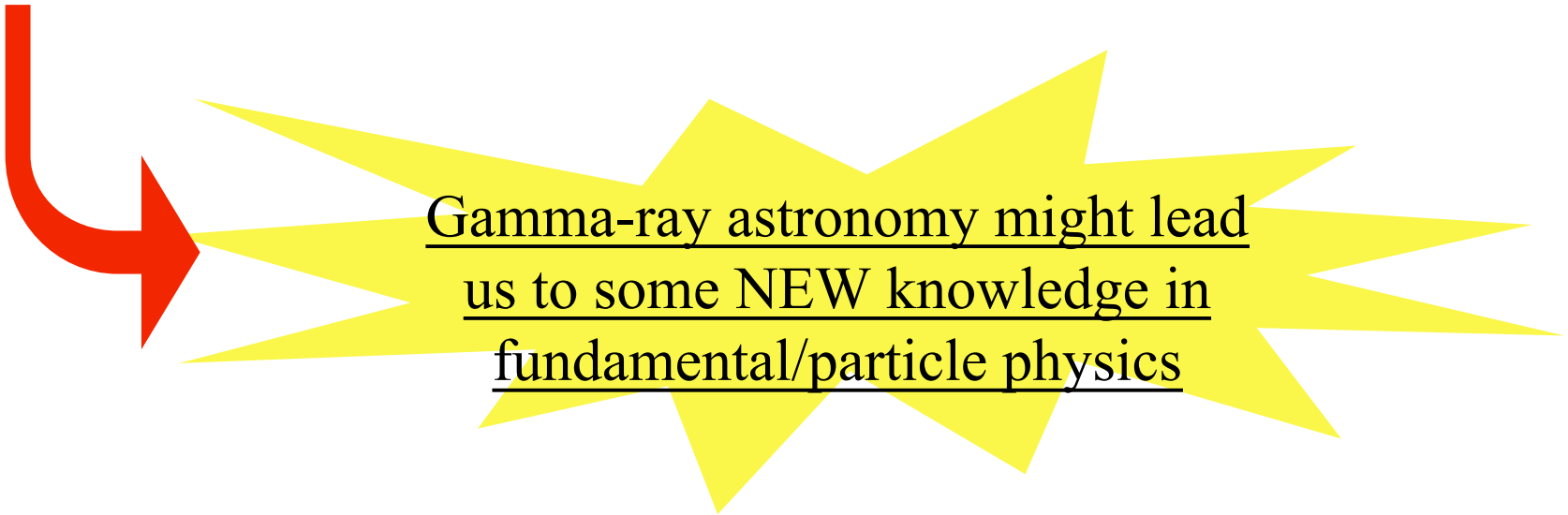
1 - Location of the high energy particles
2 - Lower limit to the energy of the high energy particles
3 - Time information

Gamma ray astronomy opens a new window to explore the Non-thermal Universe

Rather young discipline

with satellite-borne experiments: *70s*
with ground-based experiments: *90s*

Attention: using this novel tool might have side effects



Tycho Brahe: observations of planetary motion

→ **Johannes Kepler**: laws of planetary motion

→ **Isaac Newton**: **Gravitation (1665)**

Balmer series of hydrogen involved spectroscopic observations of violet and ultraviolet lines of hydrogen in *white dwarf stars*

→ **Niels Bohr**: **atomic structure (1913)** **Nobel Prize (1923)**

Hulse and **Taylor** discovered a *binary pulsar system (1974)*

→ **Gravitational radiation loss predicted by General Theory of Relativity** **Nobel Prize (1993)**

History shows *outstanding achievements in the knowledge of physics* due to the observation of the Universe

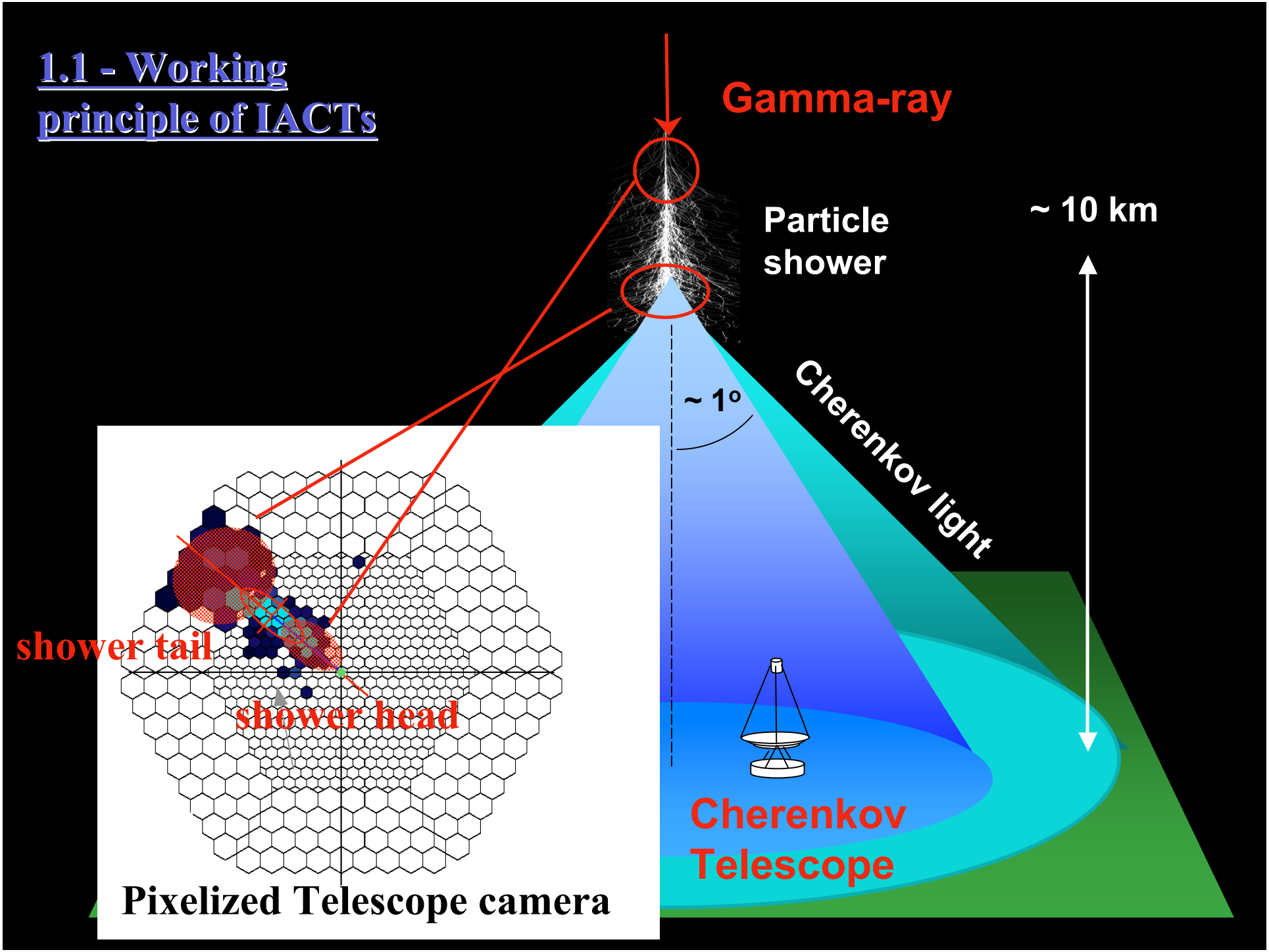
Recipe:

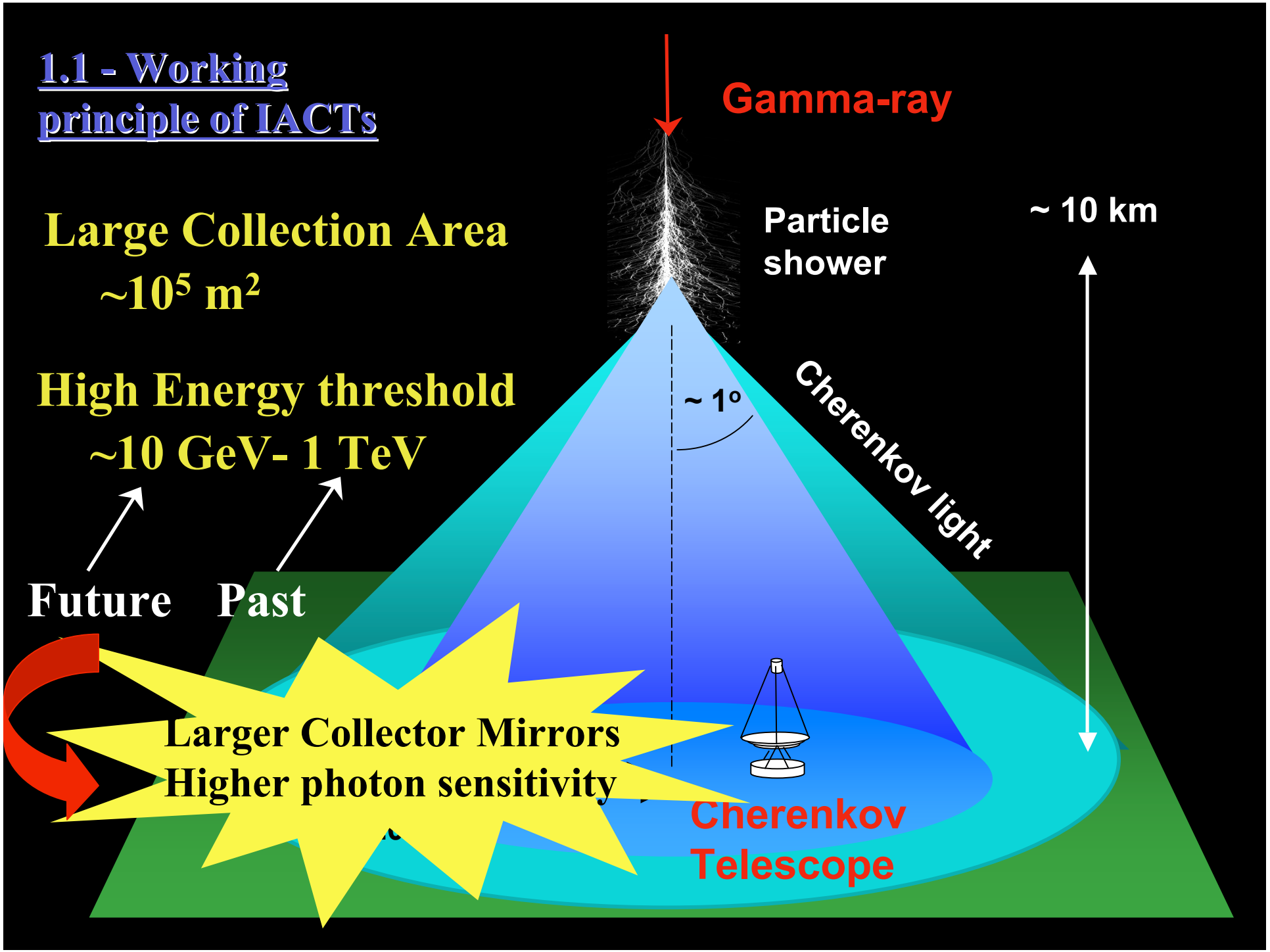
- ***Observation of physical environments not reproducible on Earth-based laboratories***
- ***New perspective provided by a novel instrument***
- ***!!!!!!!! GOOD LUCK !!!!!!***

Gamma ray astronomy fulfils the first 2 conditions

One never knows about the third one…

1.1 - Working principle of IACTs

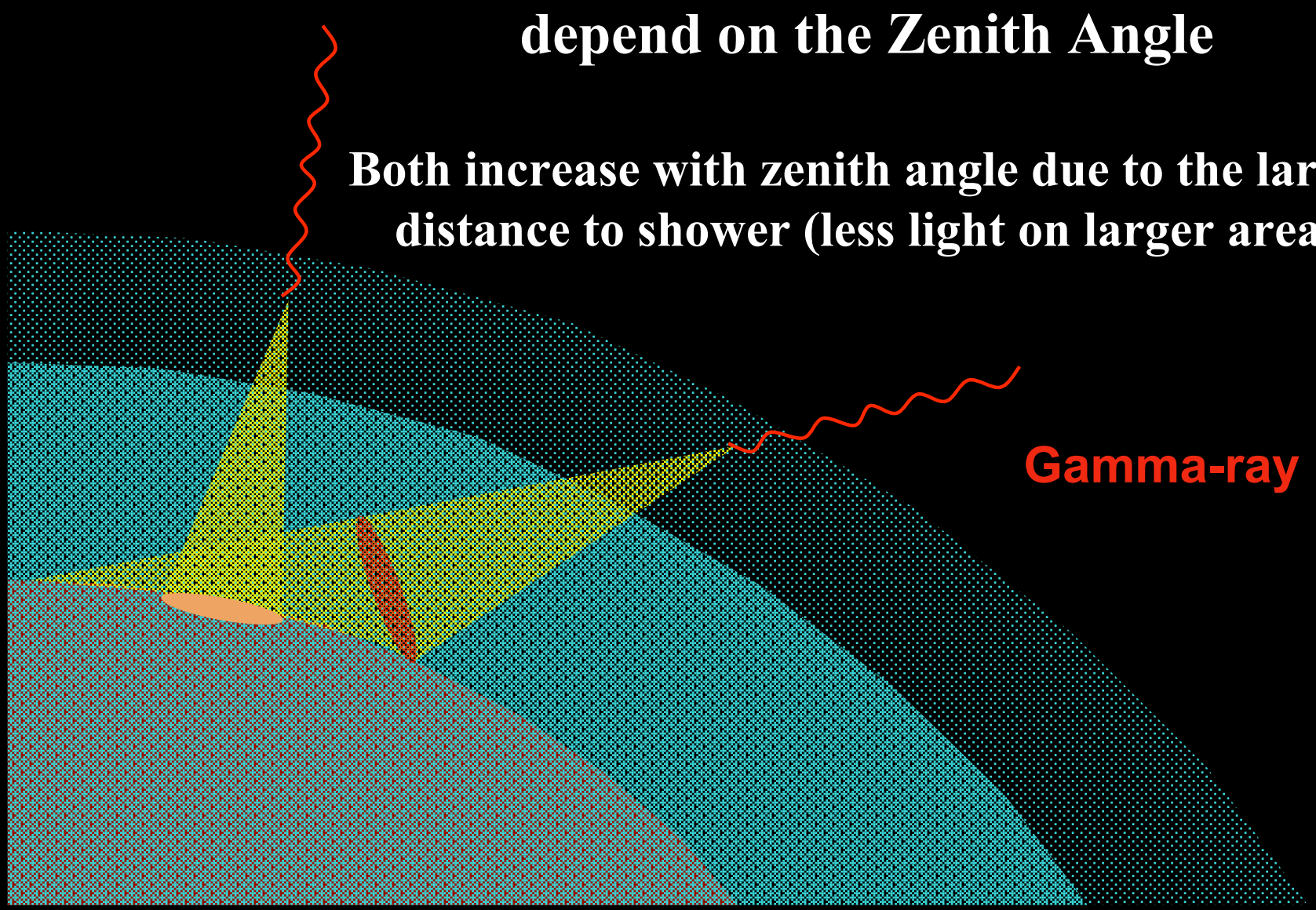



1.1 - Working principle of IACTs
Gamma-ray
Large Collection Area
~10^5 m^2
Particle shower
~ 10 km
High Energy threshold
~10 GeV- 1 TeV
~ 1°
Cherenkov light
Future
Past
Larger Collector Mirrors
Higher photon sensitivity
Cherenkov Telescope

Gamma-ray

Collection Area and Energy Threshold depend on the Zenith Angle

Both increase with zenith angle due to the larger distance to shower (less light on larger area)

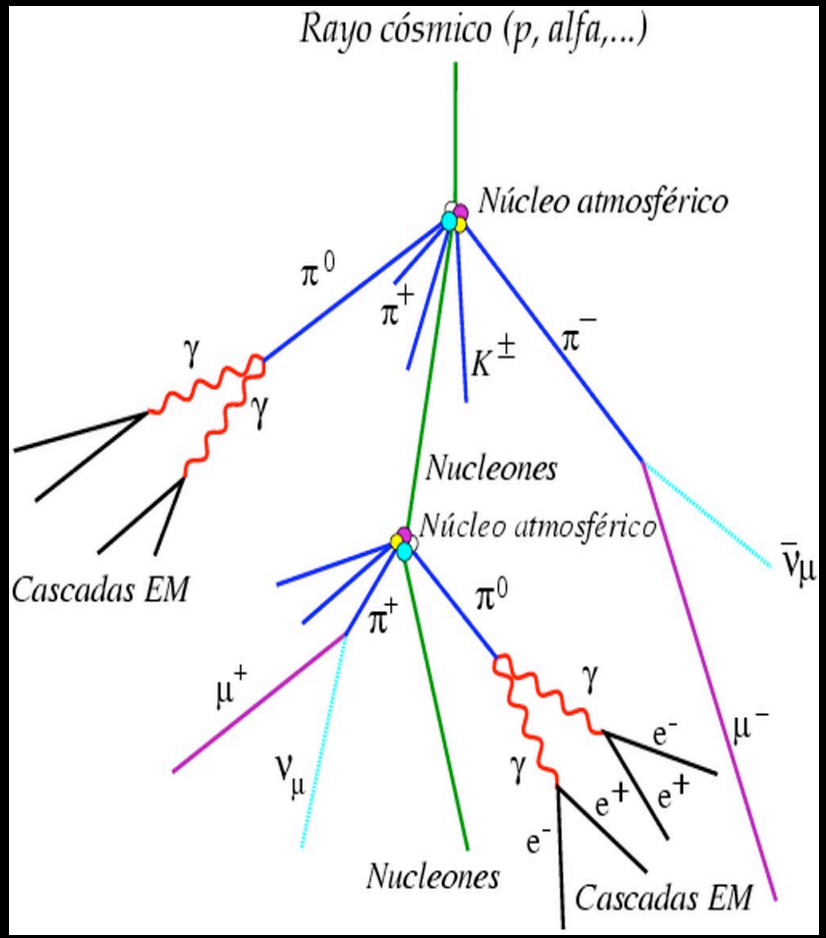


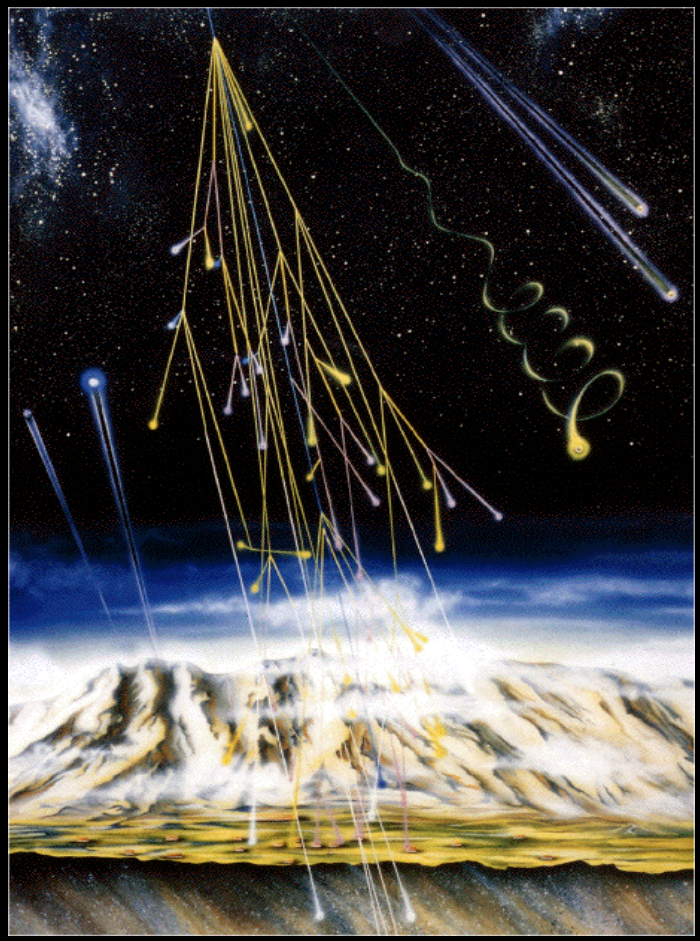
Gamma-ray

Drawback of IACTs: Strong background

Cosmic nuclei also initiate air showers producing Cherenkov light

Hadrons are about 10^4 more numerous than Gammas



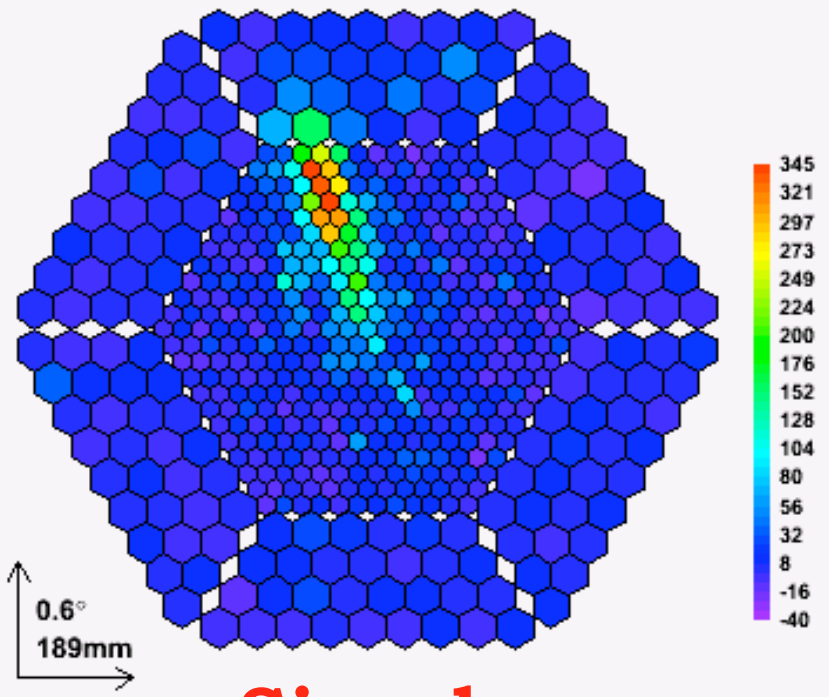


1.2 - Analysis method to select and reconstruct the gamma-rays

◆ **Analysis based on the classical Hillas parameters to perform a quantitative description of the shower images**

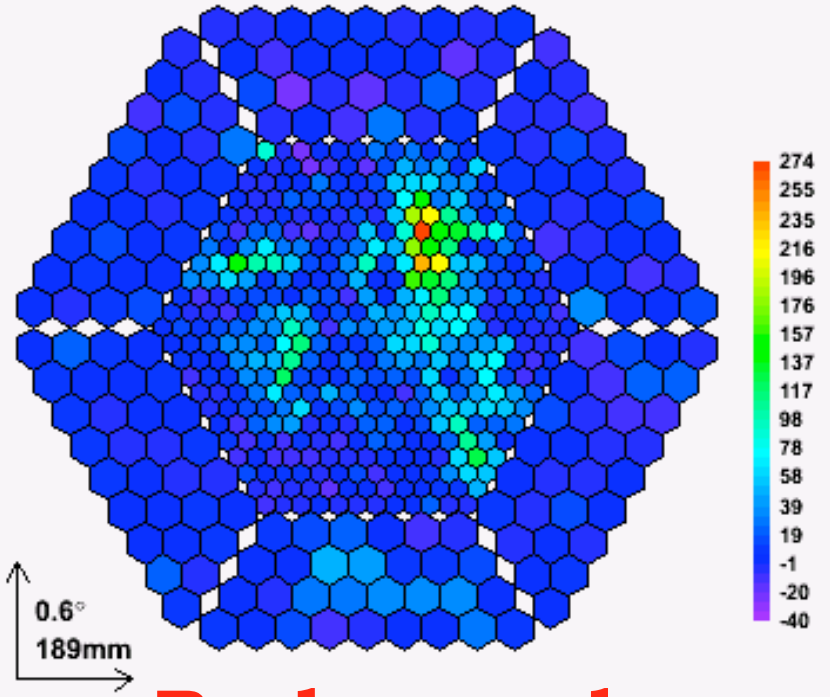
(Hillas, 19th ICRC, vol. 3, 445-448, 1985)

Gamma-like image



Signal

Hadron-like image



Background

Hadrons are 10^4 more numerous than Gammas
Efficient selection cuts in Hillas parameters are required

1.2 - Analysis method to select and reconstruct the gamma-rays

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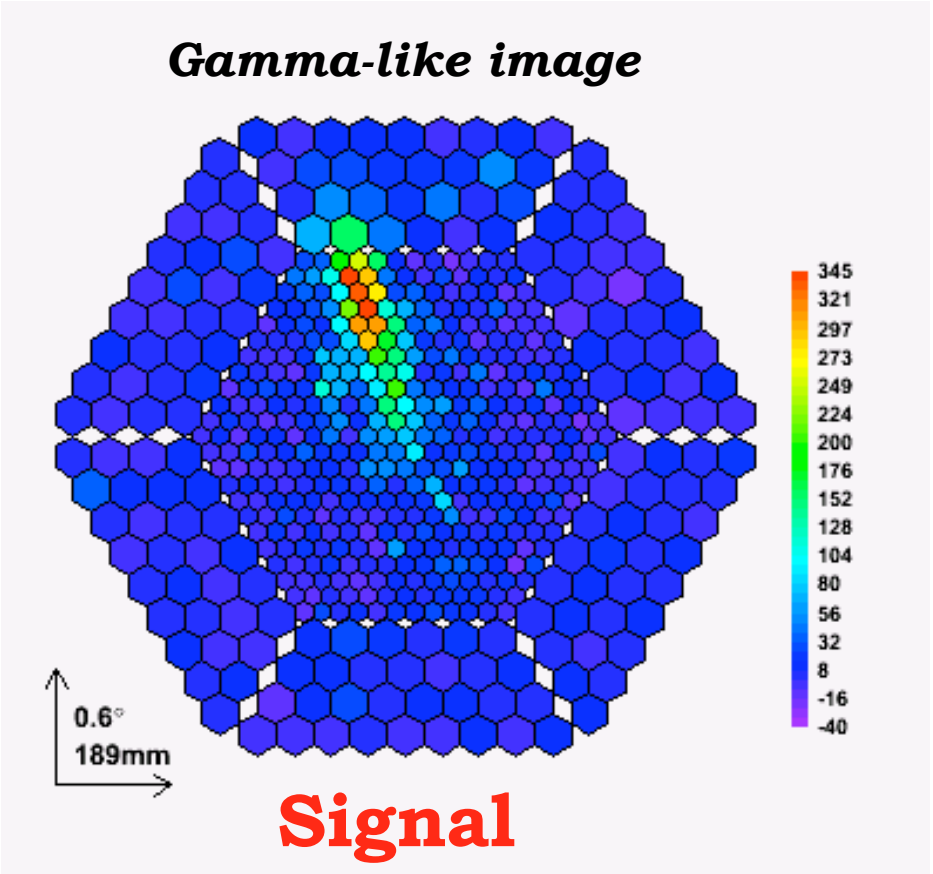


Shape of image → **Nature of primary particle**

Orientation of image → **Incoming direction of primary particle** ***and bkg rejection***

Intensity of image → **Energy of primary particle**

Hadrons are 10^4 more numerous than Gammas
Efficient selection cuts in Hillas parameters are required

◆ **Several methods can be used to obtain a set of selection cuts**

Classic

Static cuts

Dynamical cuts

Scaled cuts

New

Linear discriminant analysis

Neural Networks

Random Forest

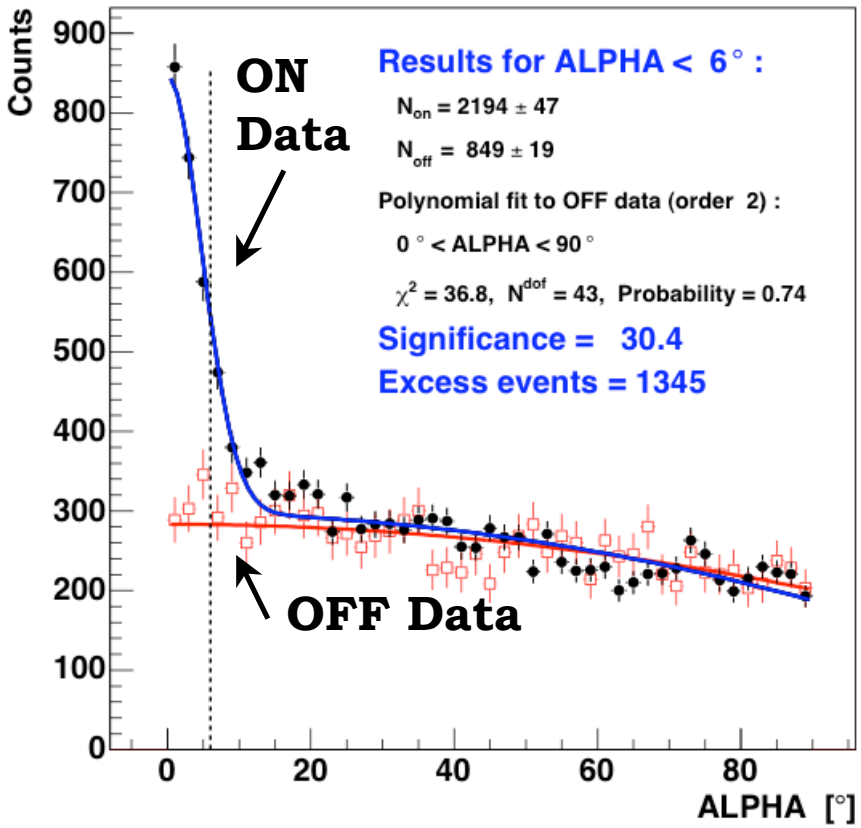
3D-Model (only for stereo)

Semi-analytical models

Currently used in MAGIC data analysis

Some MAGIC people working on that

Le Bohec et al, NIM A 416 (1998) *It does not use the Hillas parameters*



◆ **Signal shows up in the distribution of the ALPHA parameter after the selection cuts (*ALPHA plot*)**

MAGIC Mkn421 data from 14-15/02/2004

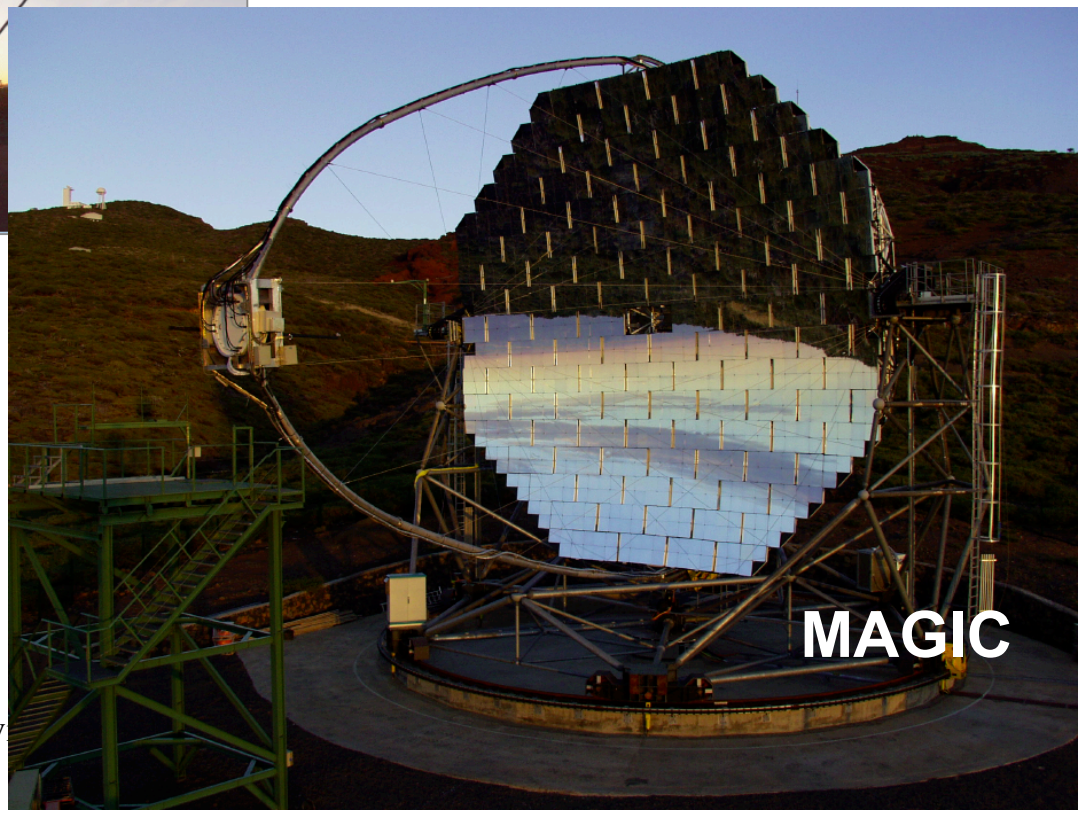
(105 minutes ON observation)

1.3 - The new generation of IACTs

SOUTHERN HEMISPHERE

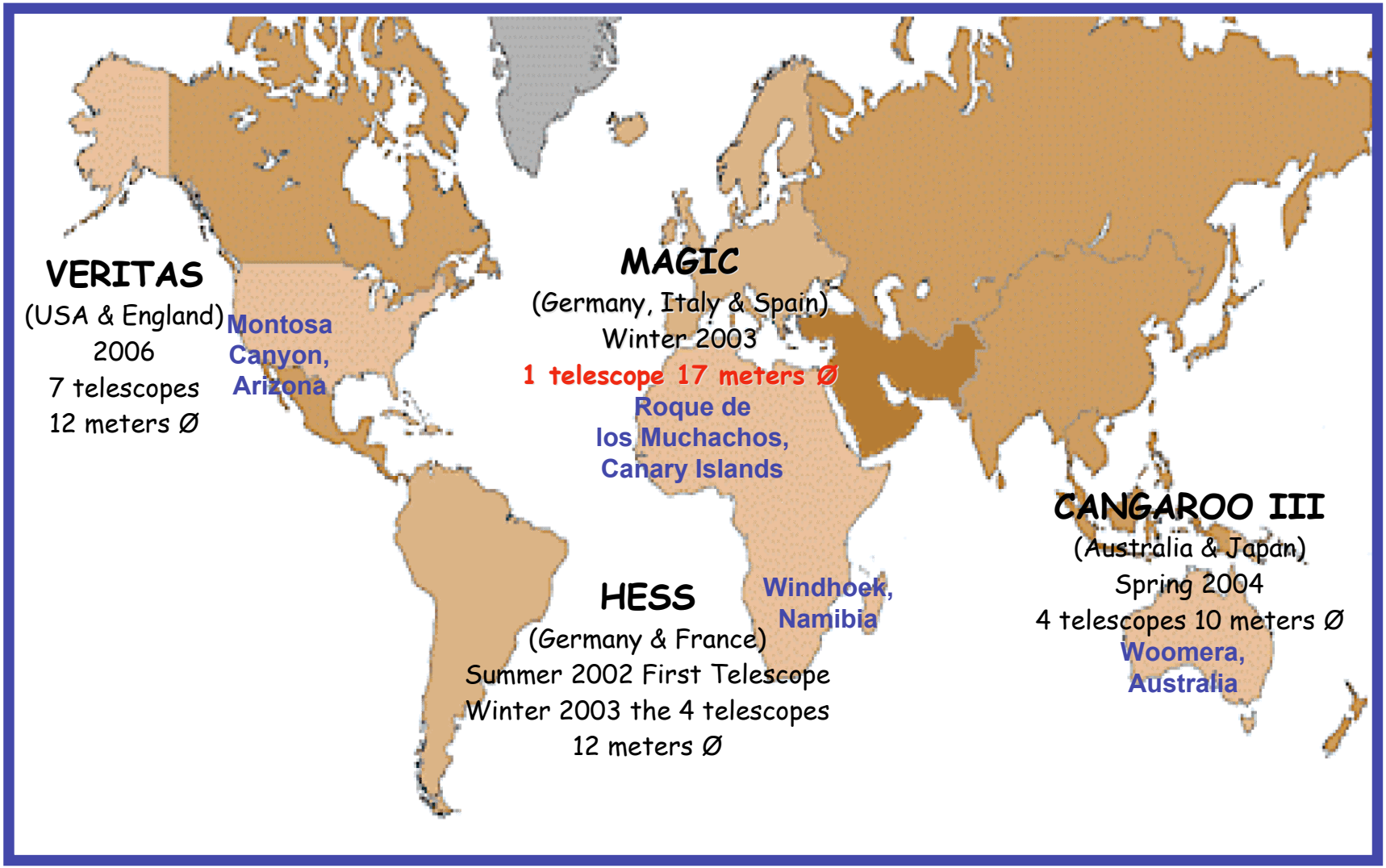
1.3 - The new generation of IACTs

NORTHERN HEMISPHERE



1.3 - The new generation of IACTs

"THE BIG 4"



1.3 - The new generation of IACTs

Location of these 4 observatories is perfect to follow up of sources. Specially important for *transient* sources (*AGN, GRB*).

Do not miss details of a source flare

Observe sources simultaneously at *low zenith angle* (low energy threshold) and *large zenith angles* (high energy events with good statistics)

Perform simultaneous *multiwavelength* observations. Correlation of TeV and GeV gamma-rays with x-rays, optical and radio.

Joint observations with the GLAST Satellite are particularly important due to the overlapping energy region (*30-300 GeV*). Exploit *performance differences* between IACTs and satellite-based detectors. Coordinated actions are required:

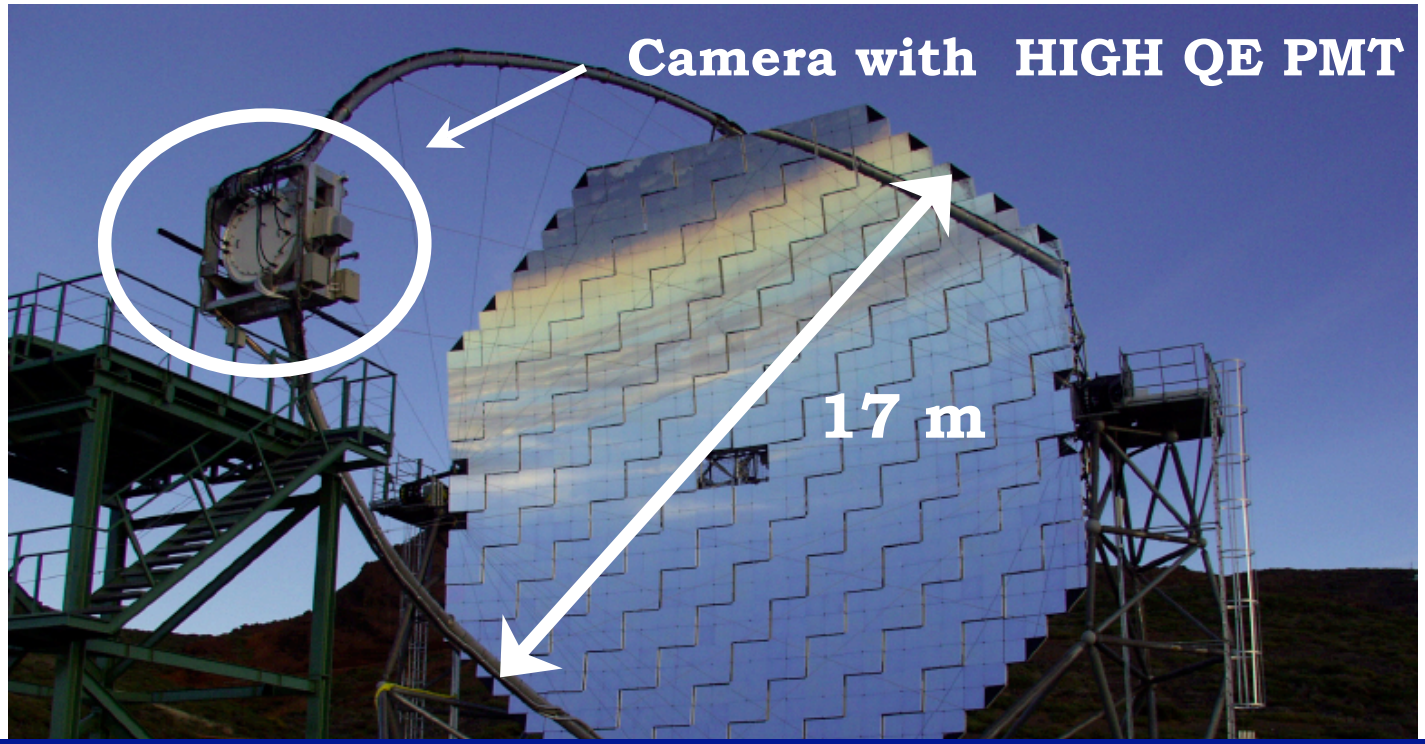
GLAST GeV-TeV Symposium (September 2004, SLAC)

2 - The MAGIC Telescope, a technological challenge

2.1 - Motivation for building MAGIC

- **Largest** Imaging Atmospheric Cherenkov Telescope (***IACT***) world-wide
- **Lowest energy threshold**; -ray astronomy in the range **30 GeV-30 TeV**

30-300 GeV was still unexplored



Collaboration: > 100 physicists, 18 institutes, 11 countries:

Barcelona IFAE, Barcelona UAB, HU Berlin, Crimean Observatory, U.C. Davis, U. Dortmund, U. Lodz, UCM Madrid, INR Moscow, MPI München, INFN/ U. Padua, INFN/ U. Siena, Sofia, Tuorla Observatory, Yerevan Phys. Institute, INFN/ U. Udine, U. Würzburg, ETH Zürich

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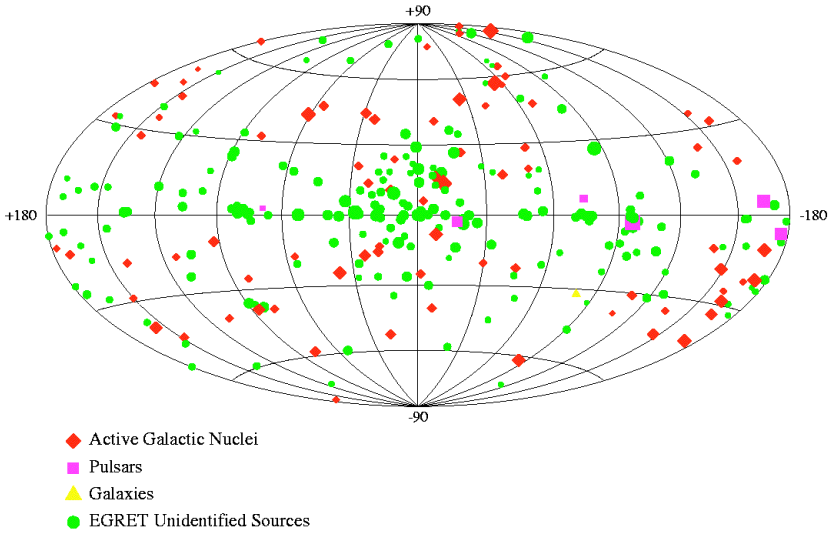
30-300 GeV was still unexplored

2.1.1 - Observations in this energy range are very valuable

Sources observed with EGRET

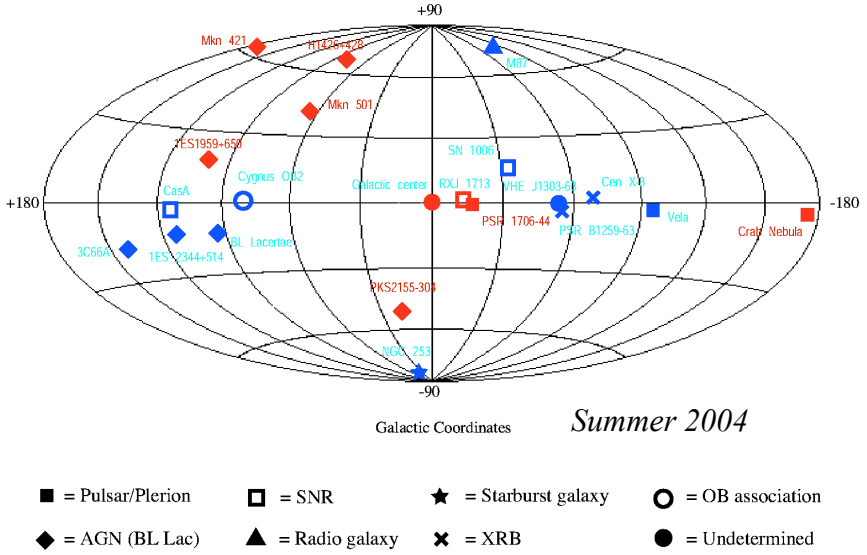
100 MeV < E ≤ 10 GeV



271 sources, from which
170 are still unidentified

Sources observed with *IACTs*

E > 300 GeV



21 sources; 9 established,
12 need further confirmation

Existence of strong cut-offs in the -spectra in the range 10-300 GeV

2.1 - Motivation for building MAGIC

- **Largest** Imaging Atmospheric Cherenkov Telescope (***IACT***) world-wide
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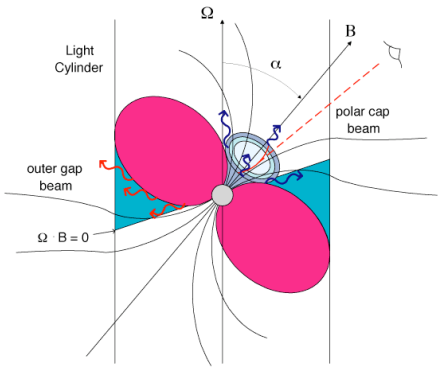
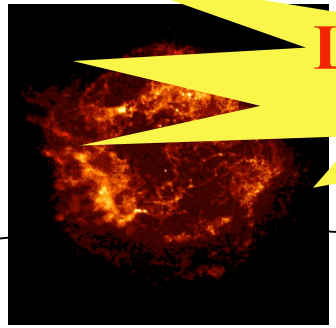
30-300 GeV was still unexplored

2.1.2 - Main astrophysical targets for the MAGIC Telescope

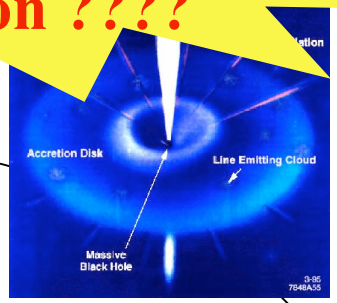


Pulsars



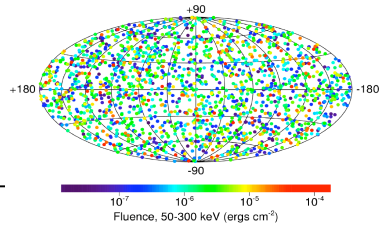
Supernova Remnants (SNR)

Leptonic or hadronic acceleration ????

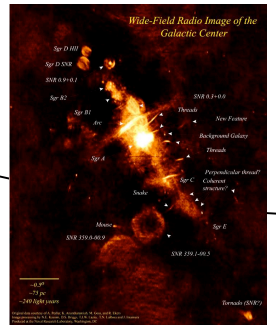


Active Galactic Nuclei (AGN)

Gamma Ray Bursts (GRBs)



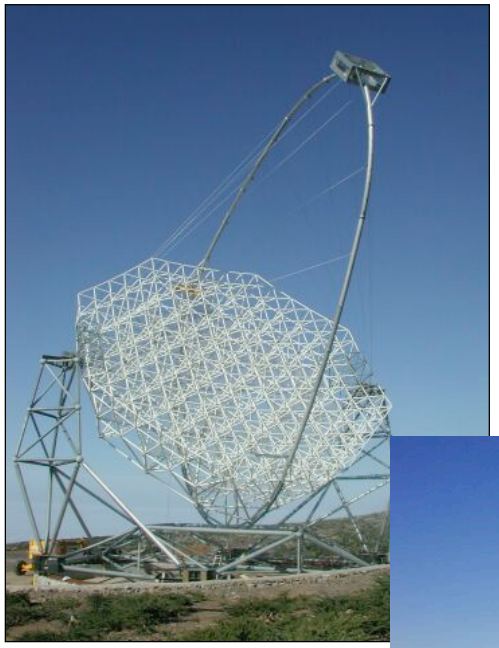
Annihilation of Dark Matter Particles

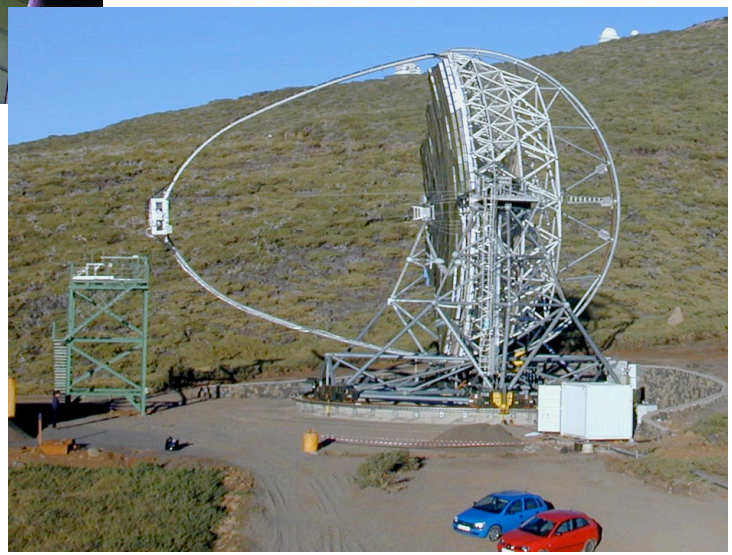


2.2 - Development of new technologies

2.2.1 - Carbon fiber tube frame with light-weight aluminium mirrors

Fast telescope repositioning (GRB search) requires low inertia





Single mirror weights 4 kg

Combined weight of frame and 964 mirrors is 17 tons

Repositioning to any sky direction in about 20 s

2.2 - Development of new technologies

2.2.2 - Development of an Active Mirror Control (AMC)

2.2.3 - Enhancement of the PMT sensitivity by a special coating

2.2.4 - Development of an optical system with large dynamic range to transmit the analogue PMT signals

2.2.5 - Trigger providing online background rejection

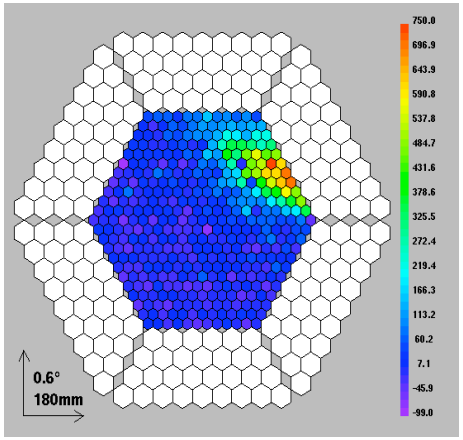
2.2.6 - Development of a DAQ with 8bits 300 MSample/s FADCs

3 - The MAGIC Project, status and source observations

3.1 - Recent history of the MAGIC Project

2000-2003 **Construction** of the MAGIC Telescope

10 Oct 2003 **Inauguration** of MAGIC



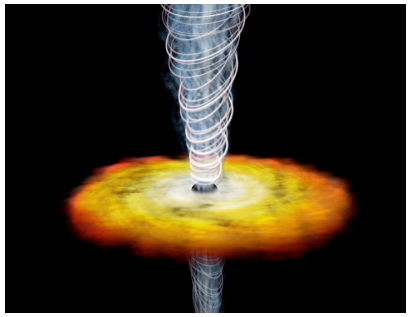
29 May 2003
First cosmics observed

Nov 2003-Sep 2004

Commissioning and first observations:

Crab, Mrk421 ...

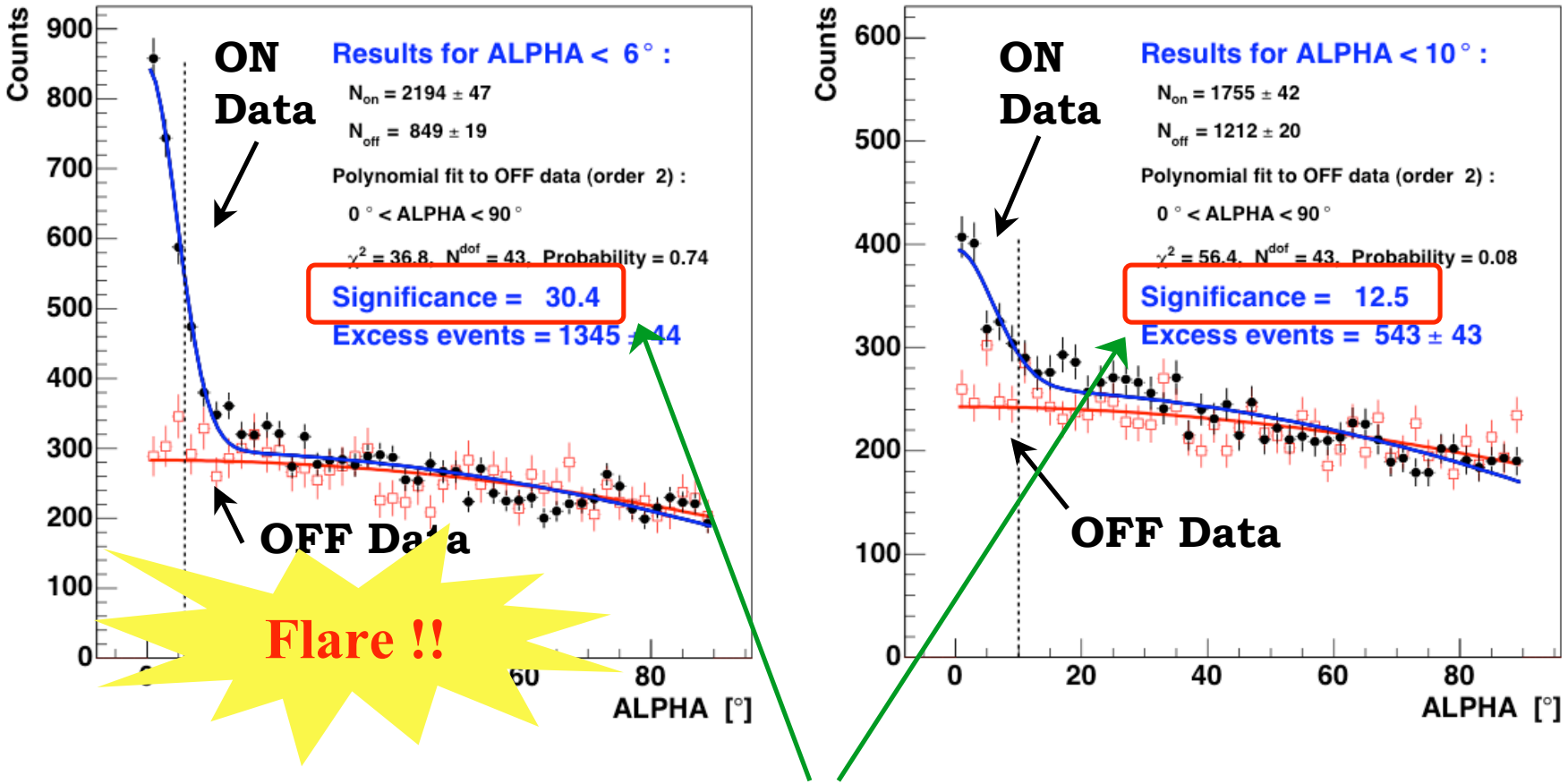
Mirror installation finished in July 2004



14-15 February 2004: First gamma-ray source detections

◆ Mkn421 (*z= 0.031*), 105 min ON time, mean zenith angle 20^0

◆ Crab Nebula, 85 min ON time, mean zenith angle 26^0



Despite the beginning of the telescope commissioning, the signals are very significant

(Only statistical errors considered)

3.2 - Status of the MAGIC Project

- **September 2004; MAGIC starts running smoothly, only few hardware interventions and some performance tests in November.**

Starting regular observation of several sources till January 2005

◆ Status after 2nd week of January 2005

People say that the weather is always good at La Palma…

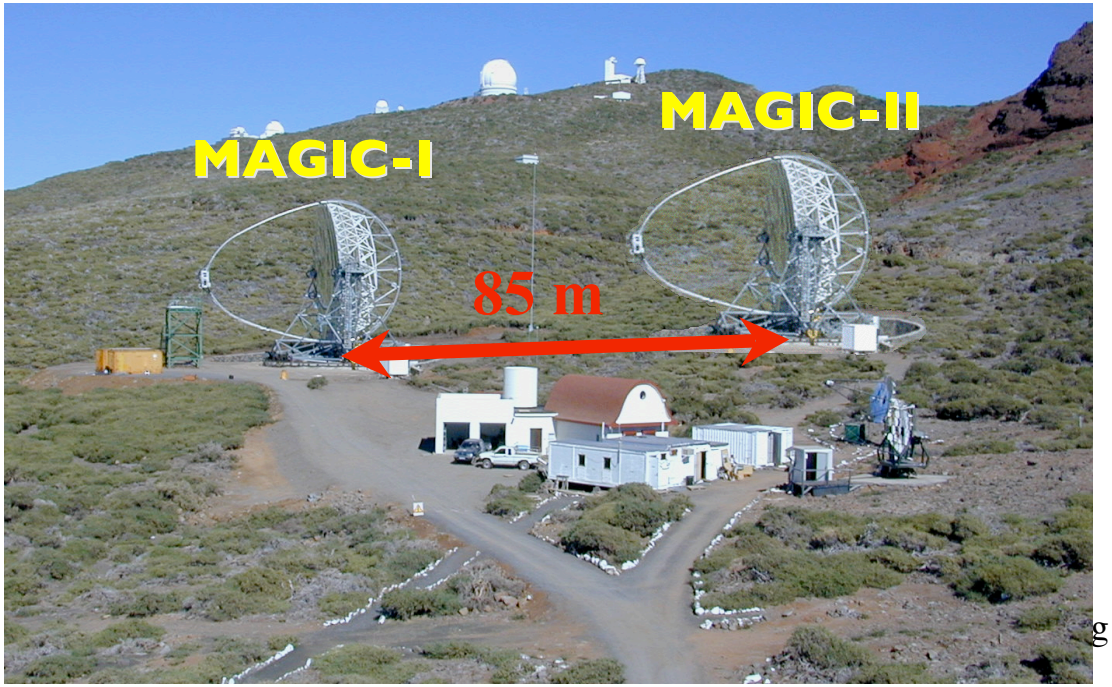
… this is not always true …

◆ **Status in February 2005**

… and it can always get worse …

3.2 - Status of the MAGIC Project

- **September 2004; MAGIC starts running smoothly, only few hardware interventions and some performance tests in November.**
  Starting regular observation of several sources till January 2005
- **No data taken from mid January till mid March**
- **Regular observations till now**
- **Construction of the second telescope started**



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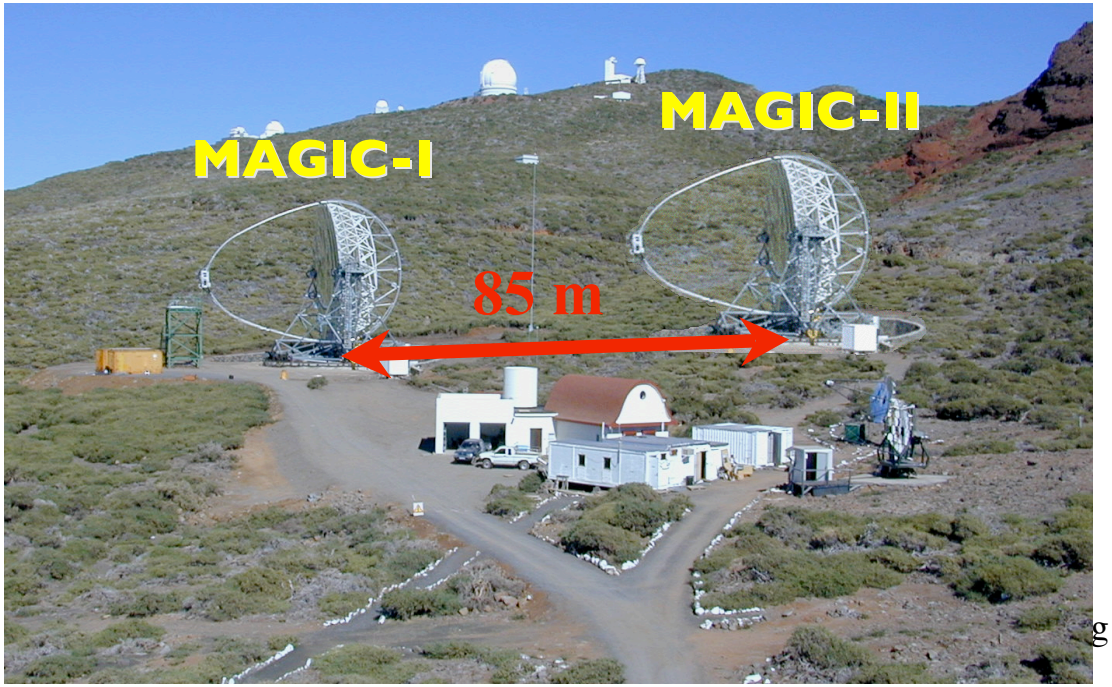


- Increase in sensitivity
- Better angular resolution
- Reduction of energy threshold
- Independent Obs. of two diff. Sources simultaneosly

Expected to be operational by beginning 2007

3.3 - Source observations

◆ **September 2004; MAGIC starts running smoothly, only few hardware interventions and some performance tests in November.**
Starting regular observation of several sources

CRAB NEBULA

➢ ONLY steady (VHE) source in the Northern sky. Very powerful object. Located only 2 kpc away.

→ Test case for developing methods of ENERGY and FLUX calibration

➢ Remnant of the SN 1054. Plerion type…

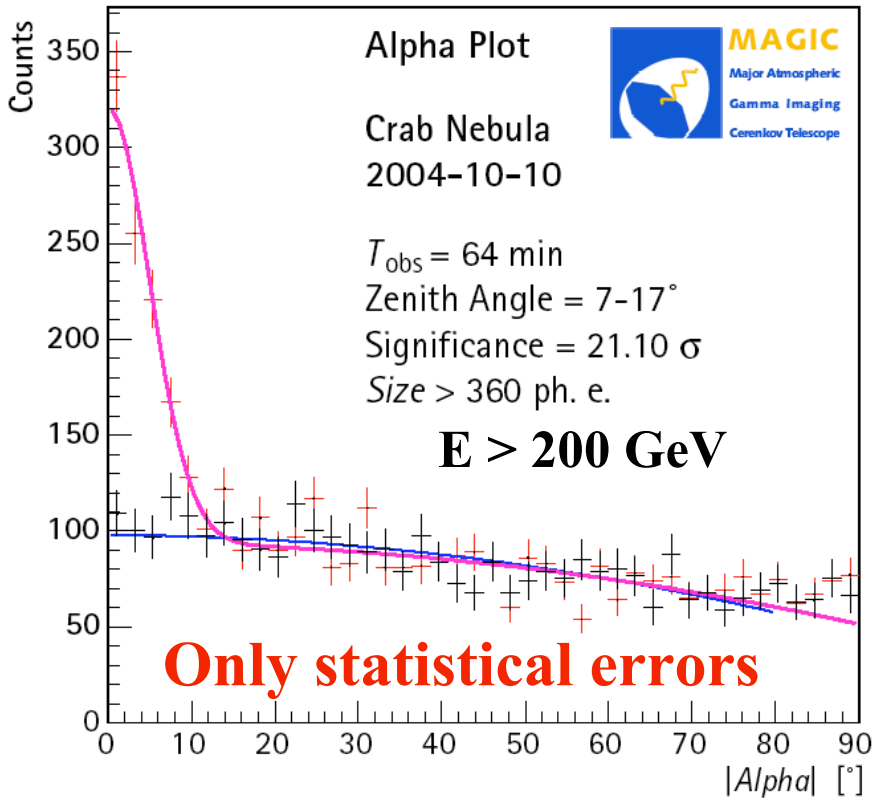
➢ FIRST significant *VHE* gamma ray detection; 1989 (WHIPPLE)
50 h. of ON observation to get a 9 sigmas detection

Very young astronomic discipline

3.3 - Source observations

CRAB NEBULA

***Wagner et al*, 29th ICRC, August 2005**



CRAB detected in relatively short times with high significance

With this analysis

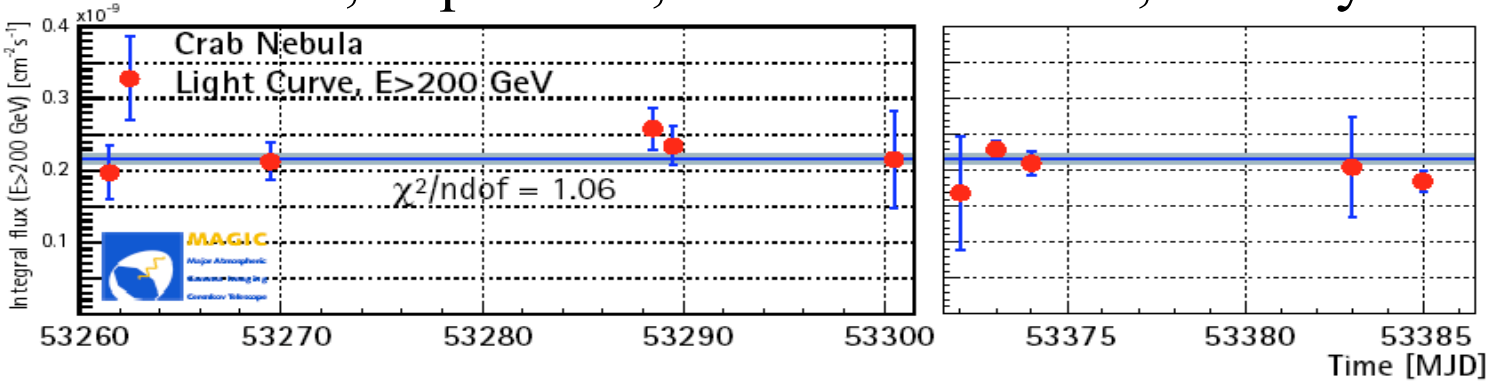
$$21\sigma \cdot \sqrt{time(h)}$$

(5 sigmas for Crab in 3 minutes)

(Only statistical errors are considered)

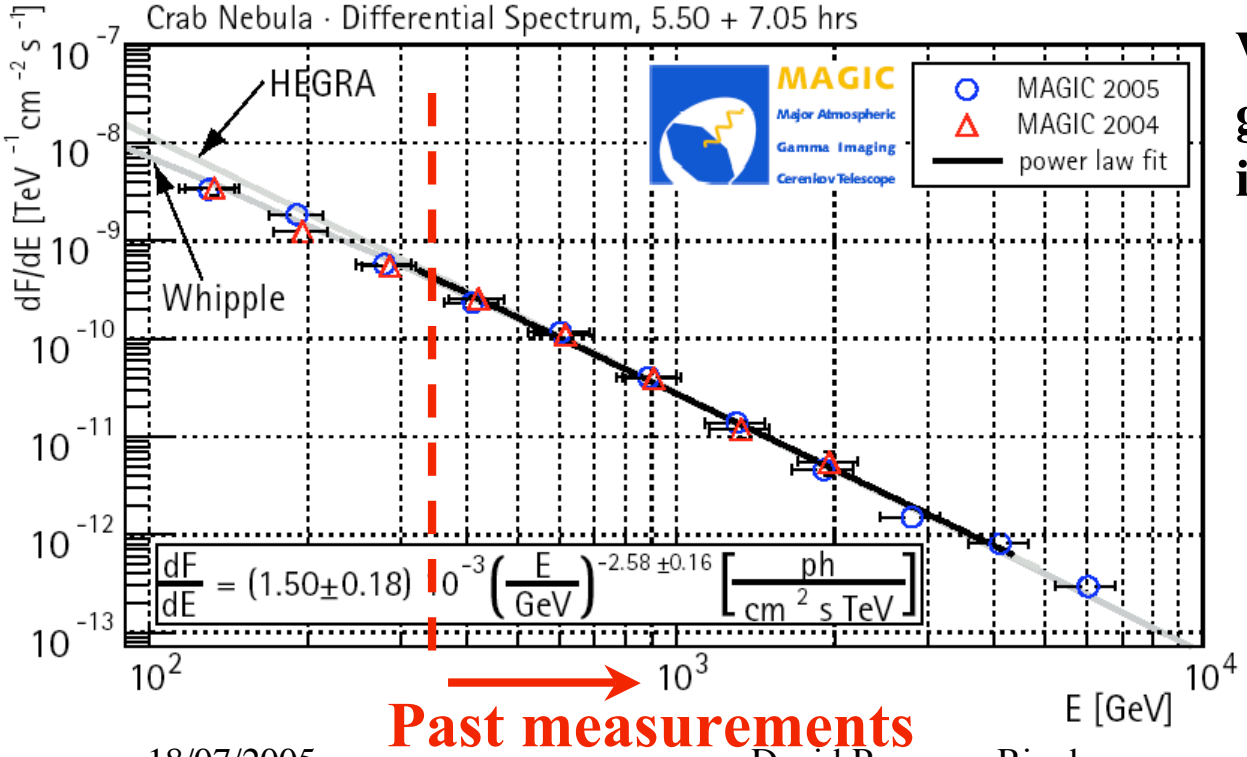
Observation time: 1 h.
Mean Zenith Angle: 12^0

2004; September, October **2005**; January



Light Curve

No points below 100 GeV for the time being…



Past measurements

With the *standard analysis*, g/h separation < 100 GeV is not very efficient

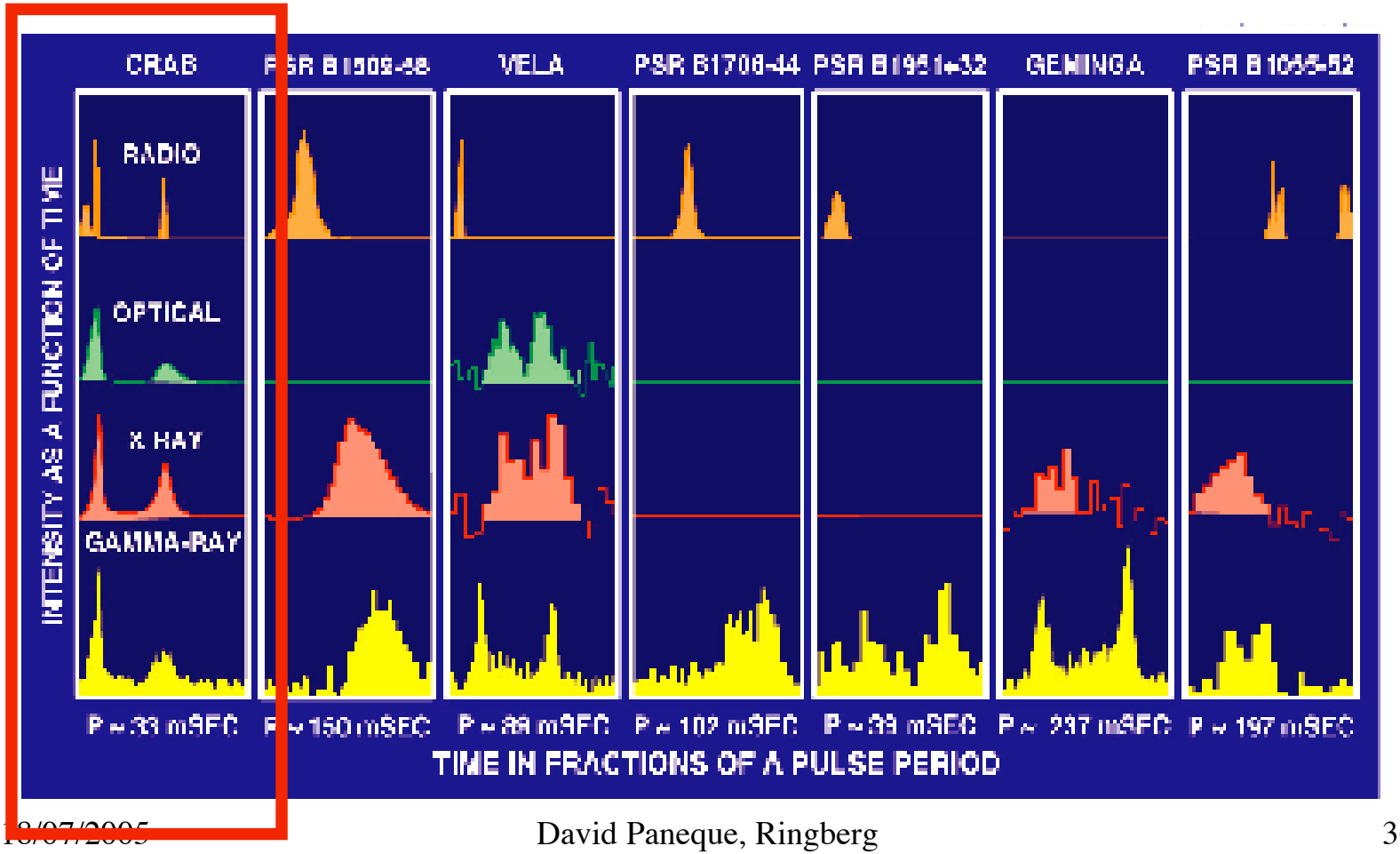
Work ongoing to refine analysis methods

New Image Cleaning
Island treatment
Use of time information
Semianalitical models
…

3.3 - Source observations

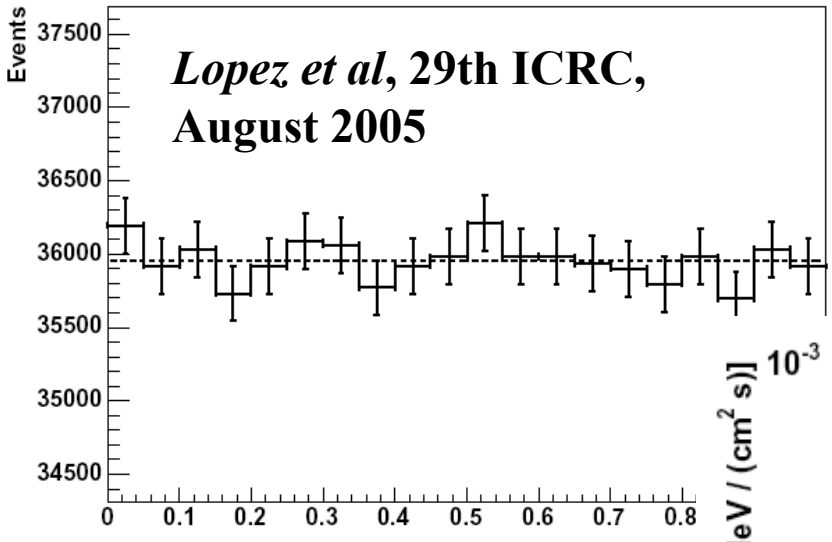
CRAB PULSAR

- Most energetic pulsar ($L_m = 5 \bullet 10^{38}$ erg s^{-1})
- Only pulsar whose pulsed emission phase is the same in all wavelengths.

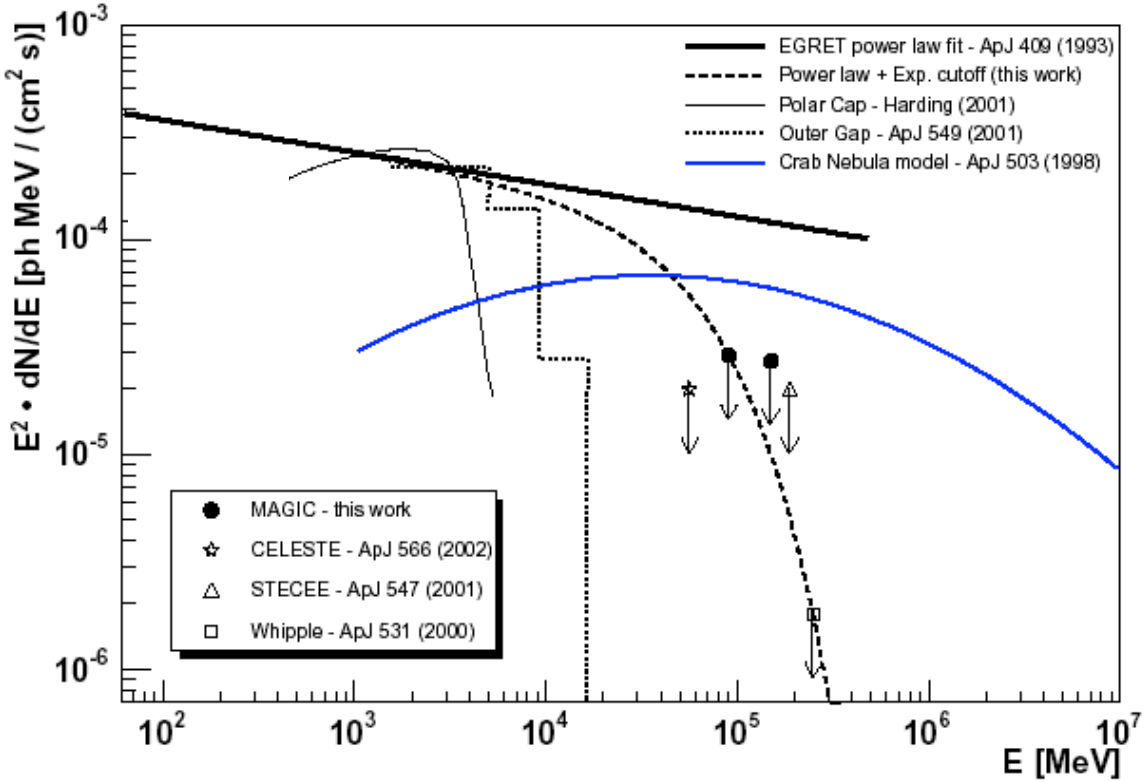


3.3 - Source observations

CRAB PULSAR



NO PULSATION DETECTED AT ENERGIES > 100 GeV



Limit to Exponential cut-off

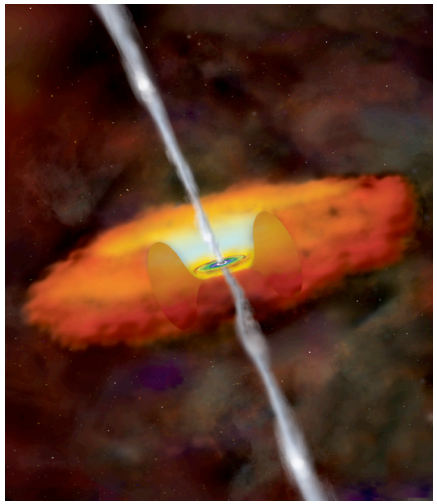
$E_{cut} < 60$ GeV

Agreement with CELESTE

3.3 - Source observations

MARKARIAN 421

Elliptical galaxy
Active Galactic Nucleus (*AGN*)
z = 0.031
RA =11h04m
Dec = +38.2°



- First detected in VHE gamma rays in 1992 by WHIPPLE.
  First extragalactic detection in VHE gamma rays

- Highly variable source (doubling flux in 15 minutes) with high correlations between gamma rays and x-rays

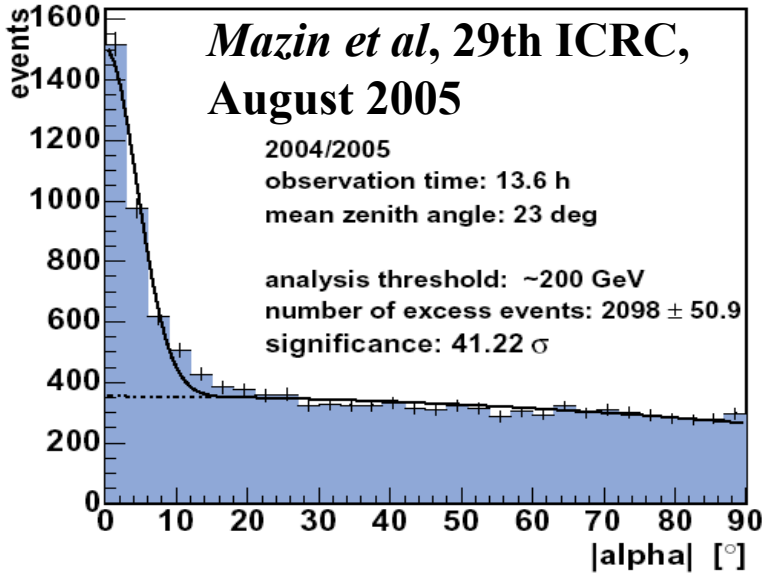
- *Super-massive black hole* surrounded by an accretion disk
- Jets of highly energetic particles pointing towards the Earth (***Blazar***)

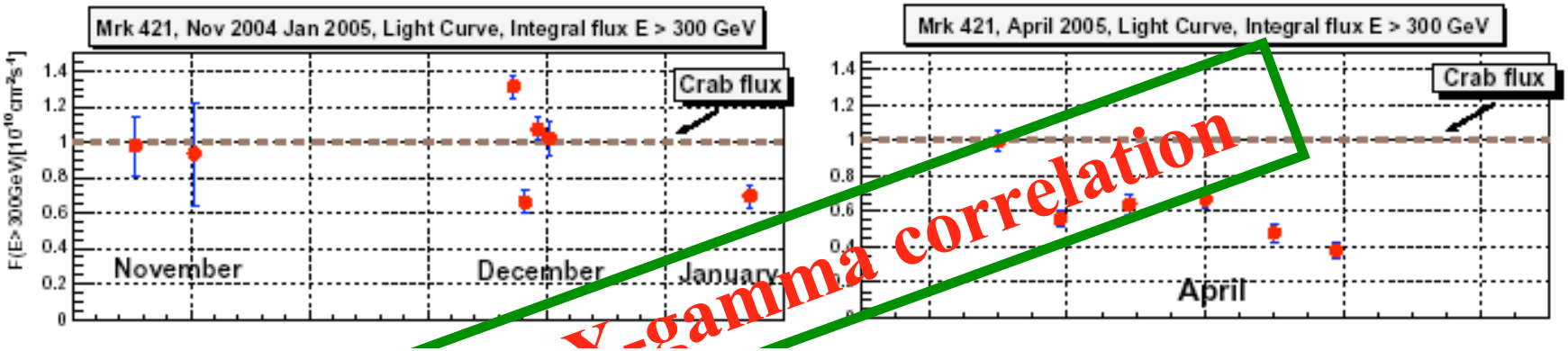
- Preferred model for the gamma ray emission; Inverse Compton

3.3 - Source observations

Almost 14 hours of observation (2004, 2005)

Flaring state in December 2004

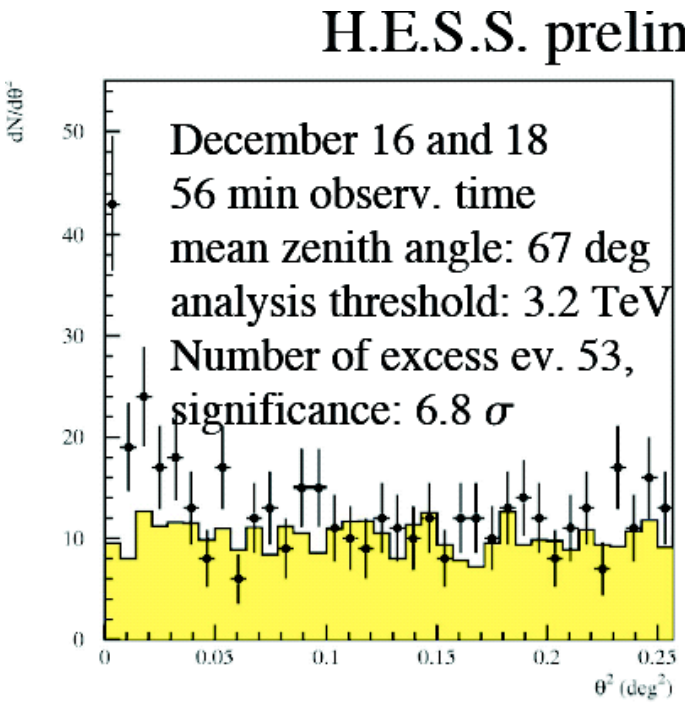


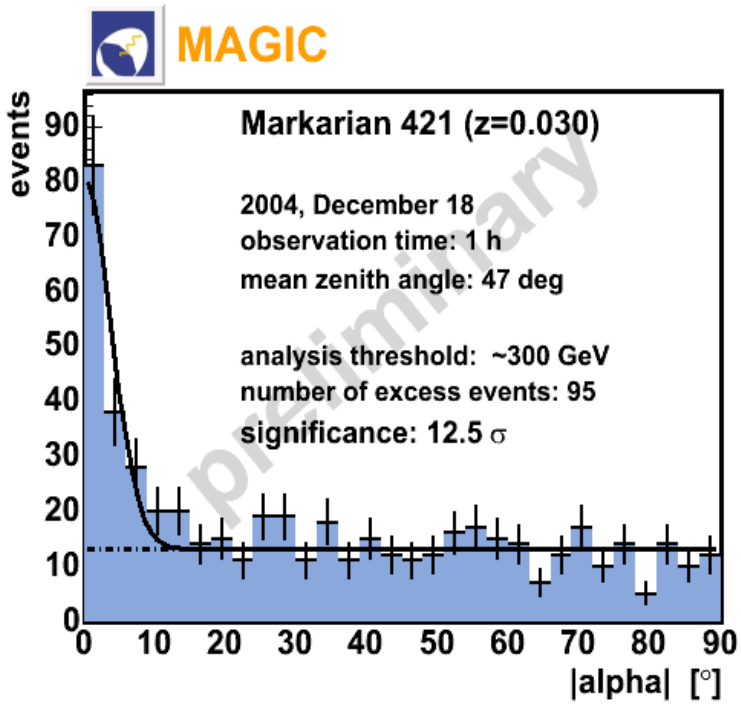


◆ **December 2004; first simultaneous observations with HESS**

December 14th, RXTE found Mkn421 flaring in X-rays

Coordinated action was perform within days (Detected Flux about 1 Crab)





Importance of simultaneous obs.

Cross calibration

Larger Energy range coverage

3.3 - Source observations

1ES1959

Elliptical galaxy

Active Galactic Nucleus (*AGN*)

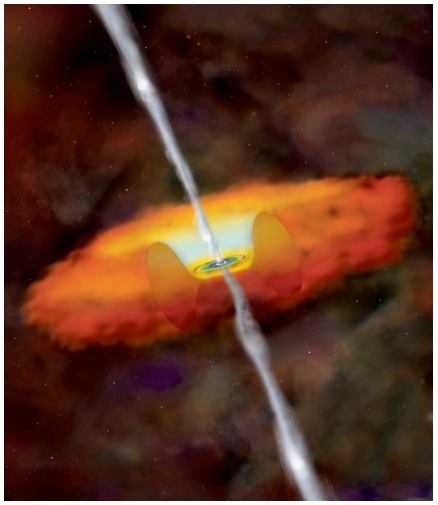
z = 0.047

RA =20h00m

Dec = +65.1°

Observability at la Palma:

May-October 35°-54°



- 1998: First □detection: Seven Telescope Array in Utah
- Confirmed in 2002 by WIPPLE and HEGRA (CT1 and System)
- Most interesting aspect: orphan flare in June 2002.

Correlation with position of a UHECR from HiRes

(Gorbunov 2004, astro-ph/0406654)

Candidate source for the neutrino community

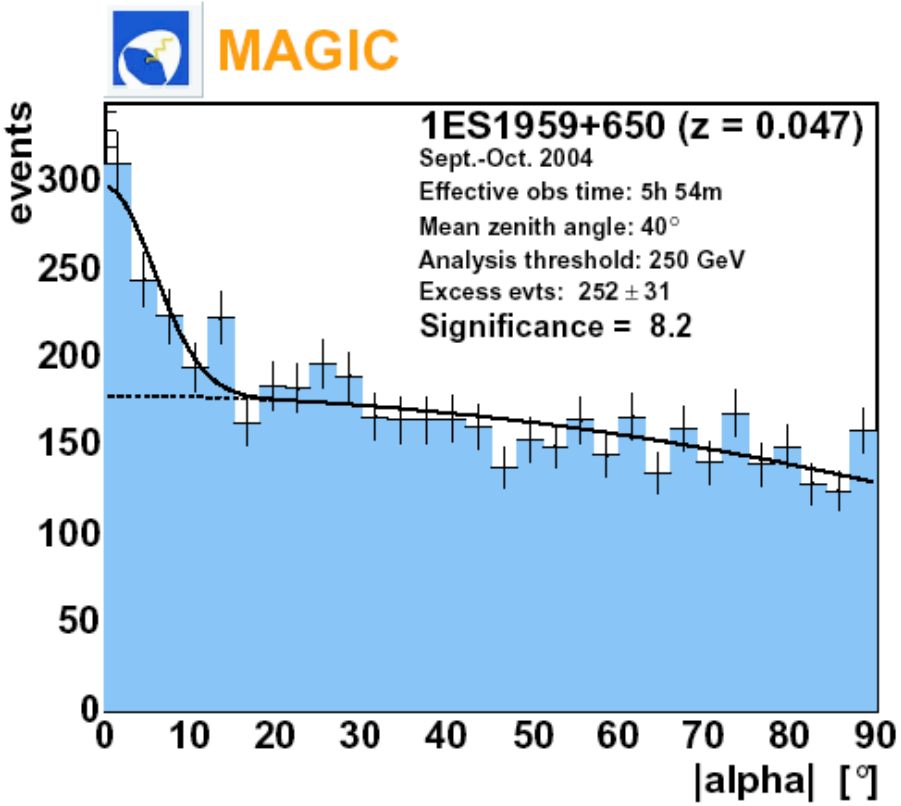
(Excess indication found in AMANDA)

- Intermediate distance between the closest observed TeV AGNs

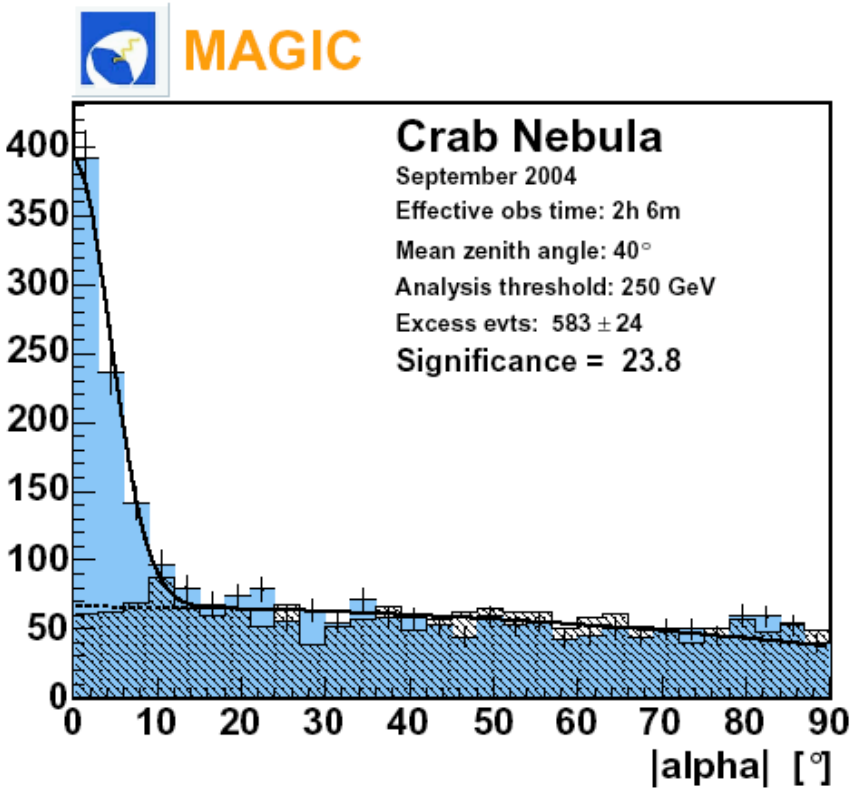
(Mkn421, Mkn501) and the most distant ones (1ES2155 and H1426)

Disentangle source features from absorption in EBL

3.3 - Source observations



Tonello et al, 29th ICRC, August 2005

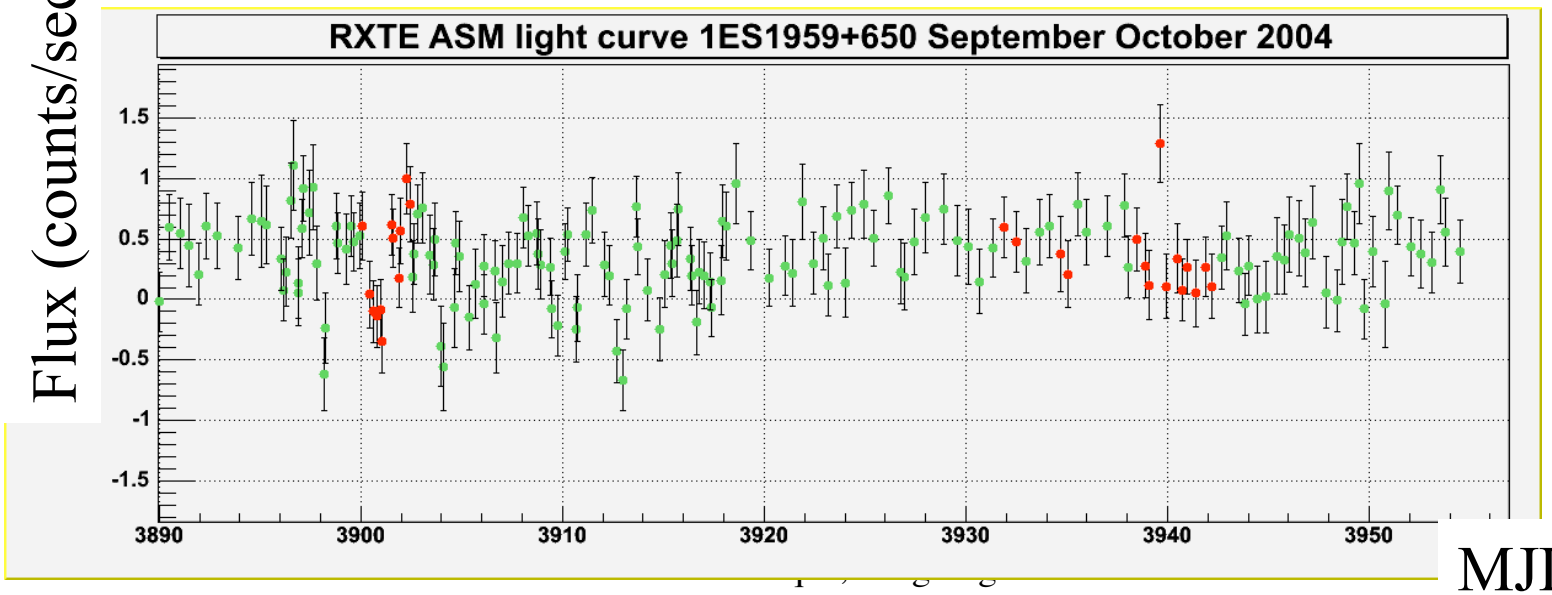


To be compared/normalized with Crab observations at medium/large zenith angle

No significant time variation of gamma-ray activity

Days	Obs time	Significance	Excess	Rate (phot/min)
September 6,7	121 min	3.6	42.8 ± 11.8	0.35 ± 0.09
October 7,10,15	110 min	4.0	49.5 ± 12.3	0.45 ±0.11
October 16, 17	137 min	5.0	64.0 ± 12.8	0.46 ± 0.09

No significant time variation in the X-ray activity



3.3 - Source observations

1ES1959 flux is about 15% the Crab (at those zenith angles)

HEGRA System
Results (2000-2001):
94 h obs. Time.
Energy threshold: 2TeV
Significance 5.2 □
□= 3.2 ±0.2

MAGIC
Results (2004):
6 h obs. Time.
Energy threshold: 250 GeV
Significance 8.2 □
□= To be determined

Spectrum is certainly softer than that of Crab.
Compatible with HEGRA flux measurements

New instruments show significant performance improvement

3.3 - Source observations

MARKARIAN 501

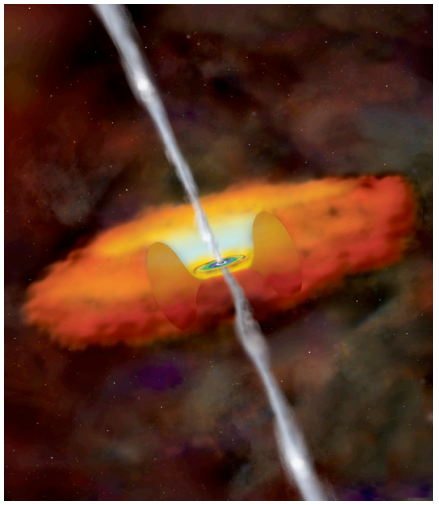
Elliptical galaxy

Active Galactic Nucleus (*AGN*)

z = 0.034

RA =16h54m

Dec = +39.8°



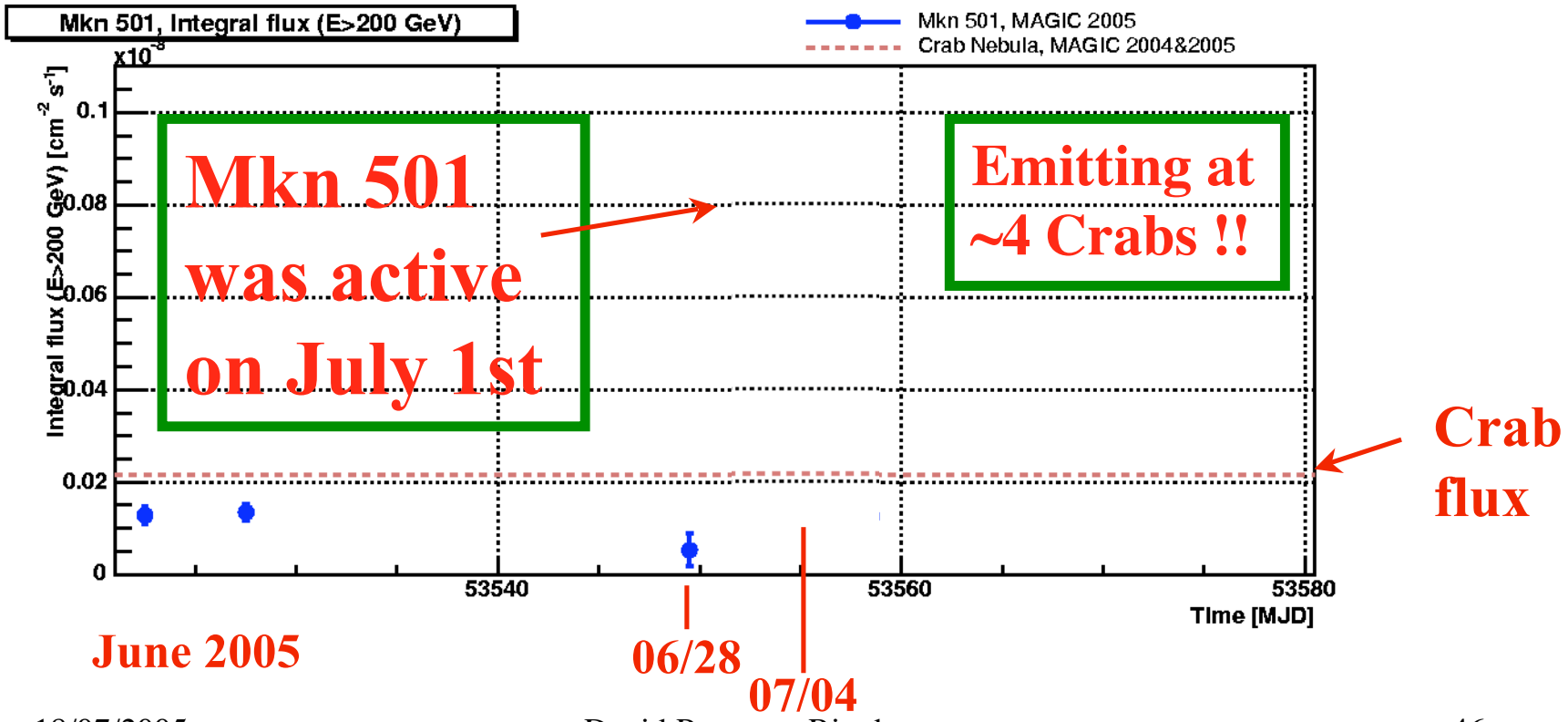
- First detected in VHE gamma rays in 1996 by WHIPPLE and HEGRA CT1.
  Second extragalactic detection in VHE gamma rays
  147 h. of ON observation; 5.2 sigmas detection with CT1 (quiescent state)
- Variable source with high correlations between gamma rays and x-rays
  (*Huge flare in 1997, up to 10 Crabs*)
- Super-massive black hole surrounded by an accretion disk
- Jets of highly energetic particles pointing towards the Earth (***Blazar***)

- Preferred model for the gamma ray emission; Inverse Compton

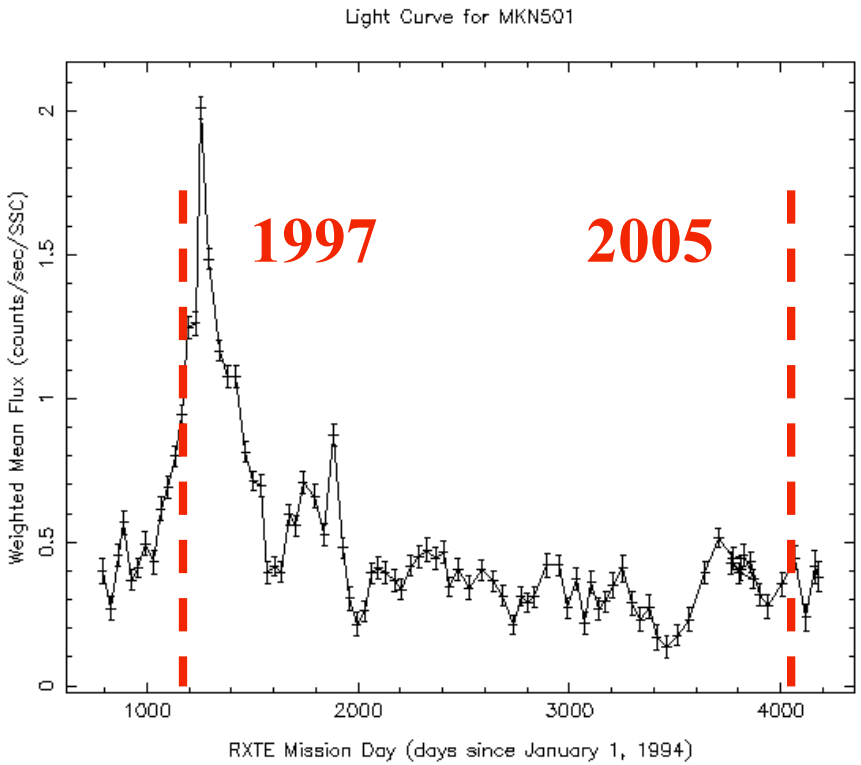
Mkn 501 was observed with MAGIC in June and July 2005

- Source found mostly in quiescent state (0.3-0.5 Crabs above 200 GeV). Not all data analyzed yet…

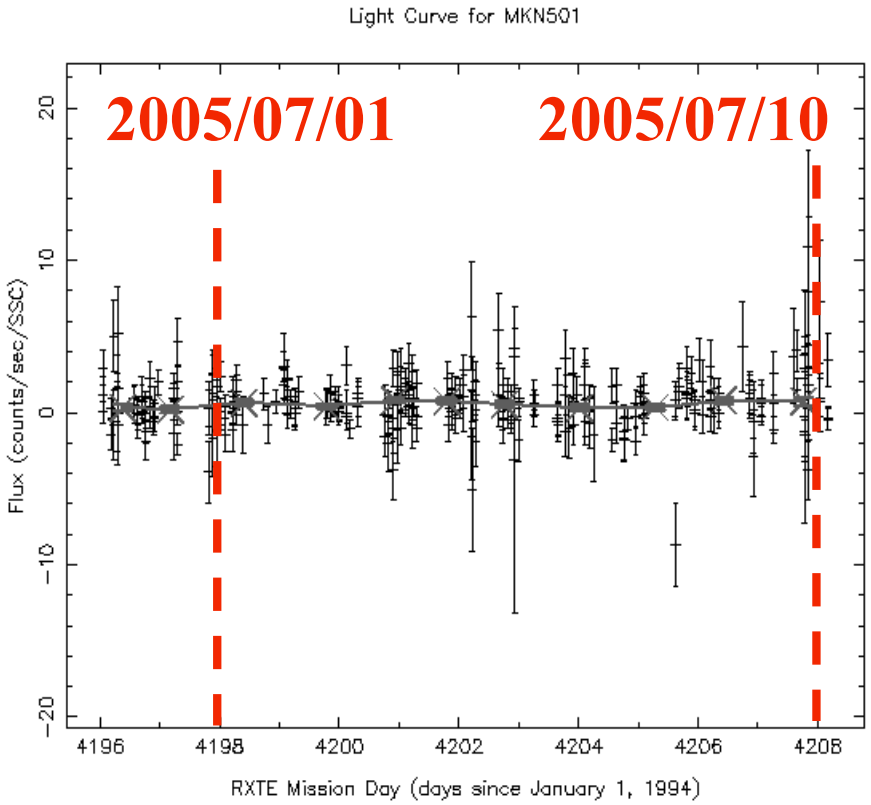
- Signal above 5 sigmas in only 1/2 hour (for 30% Crab) !!!!



X-rays measured by ASM since 1994
(average over 700 obs.)



X-rays measured by ASM
during last 2 weeks



- Source was not found active by the ASM detector
  Is it an ORPHAN flare ??????

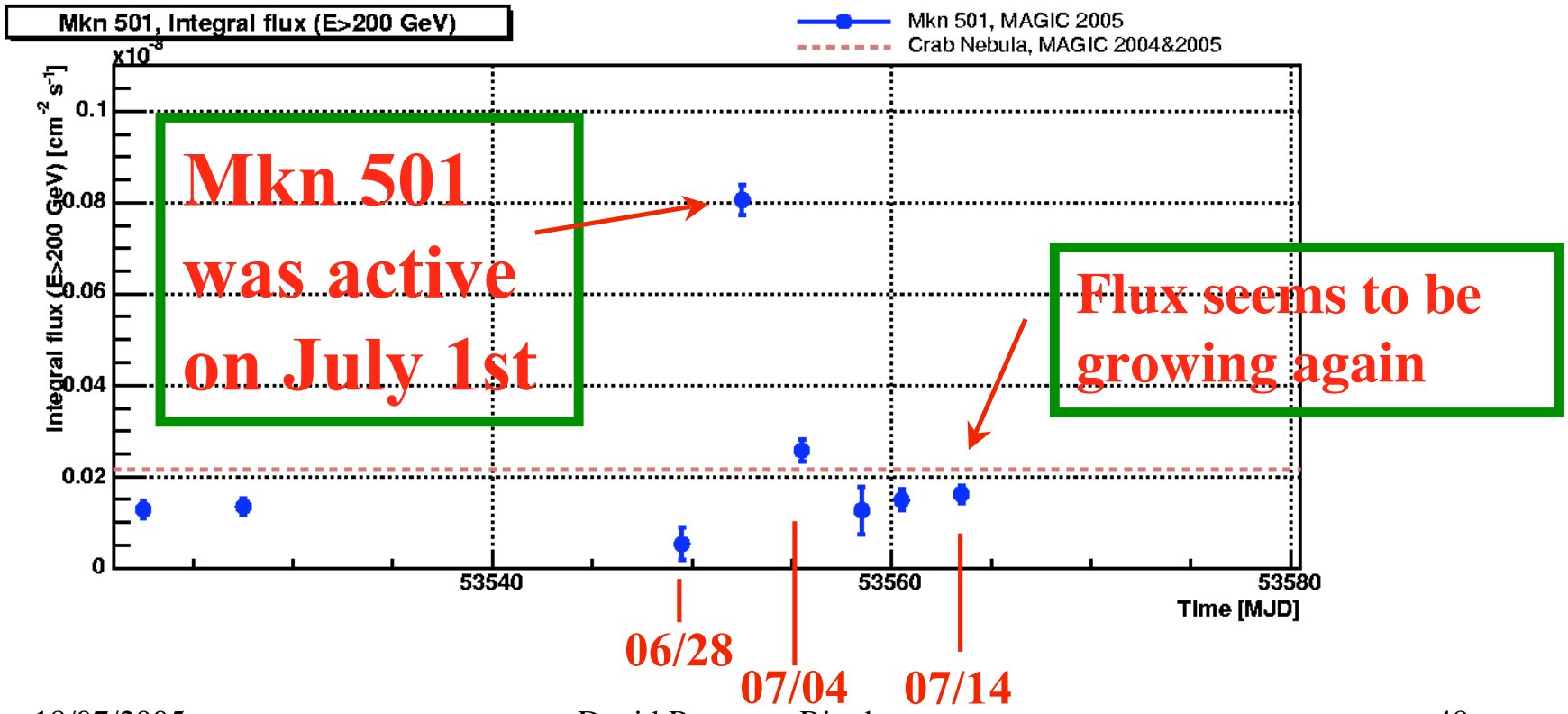
We need to check other wavelengths… still work to be done…

That's getting exciting …

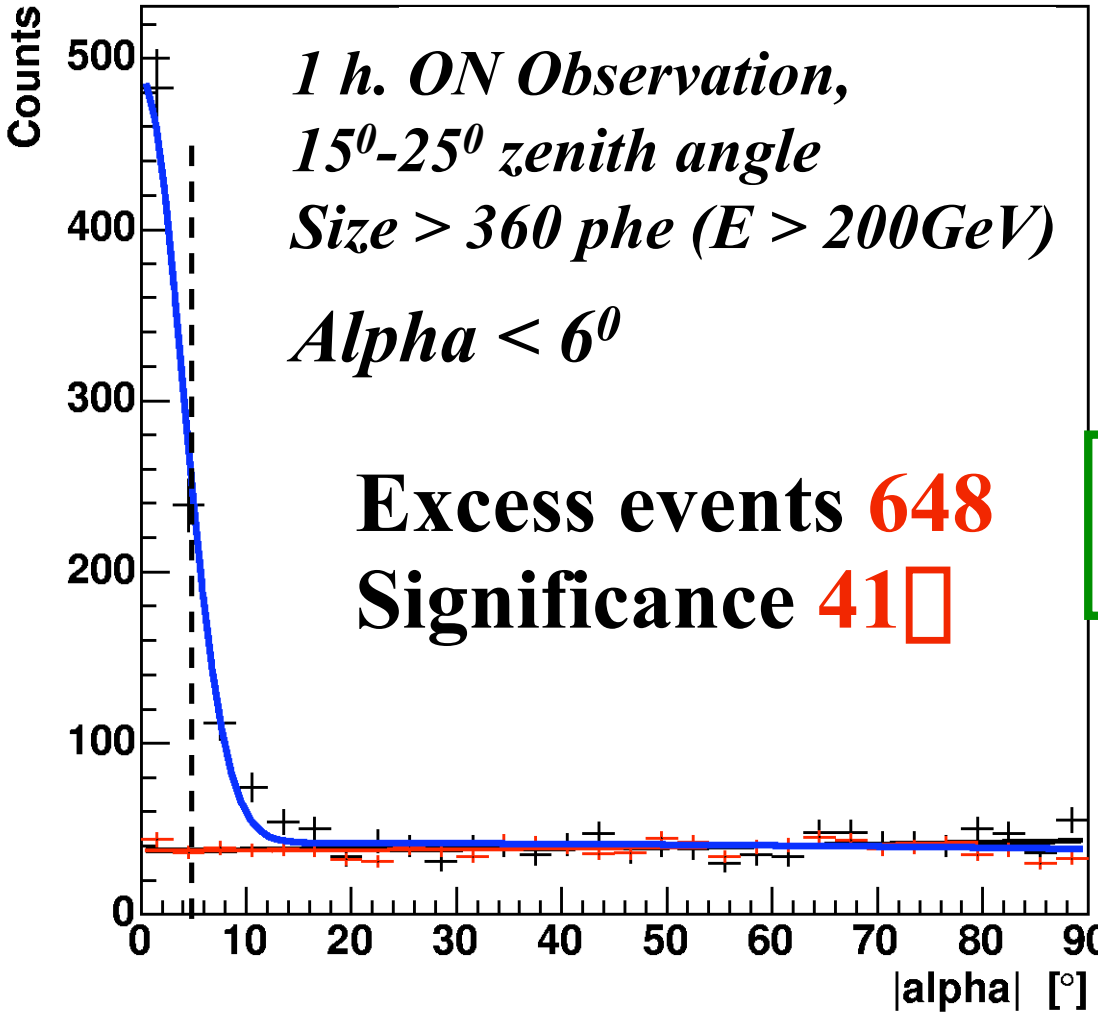
Mkn 501 was observed with MAGIC in May, June and July 2005

- Source found mostly in quiescent state (0.3-0.5 Crabs above 200 GeV). Not all data analyzed yet…

- Signal above 5 sigmas in only 1/2 hour (for 30% Crab) !!!!



Alpha plot for data taken on July 1st



High purity in the extracted gamma signal

Excellent for comparisons *Data - Monte Carlo*

Improvement of our analysis techniques

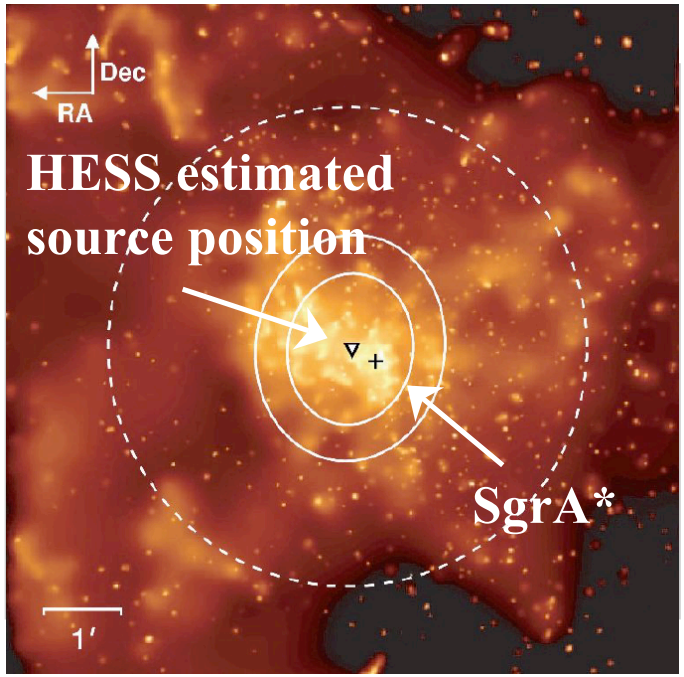
GALACTIC CENTER

Quite some excitement due to the latest detections in this region

CANGAROO II, Jul 2001, Jul-Aug 2003, *(Tsuchiya et al,2004)*
67 h, about **9 sigmas**

WHIPPLE/VERITAS, 1995-2003, *(Koshack et al,2004)*
26 h, about **4 sigmas,** (*Large Zenith Angle*)

HESS, Jun-Jul and Jul-Aug 2003, (1 and 2 telescopes) *(Publication under preparation…)*
5 h and 12 h, about **6 and 9 sigmas**



Latest detections disfavours hypothetical neutralino annihilation coming from SgtA*

But nothing is conclusive yet

This is an exciting summer target for all IACTs

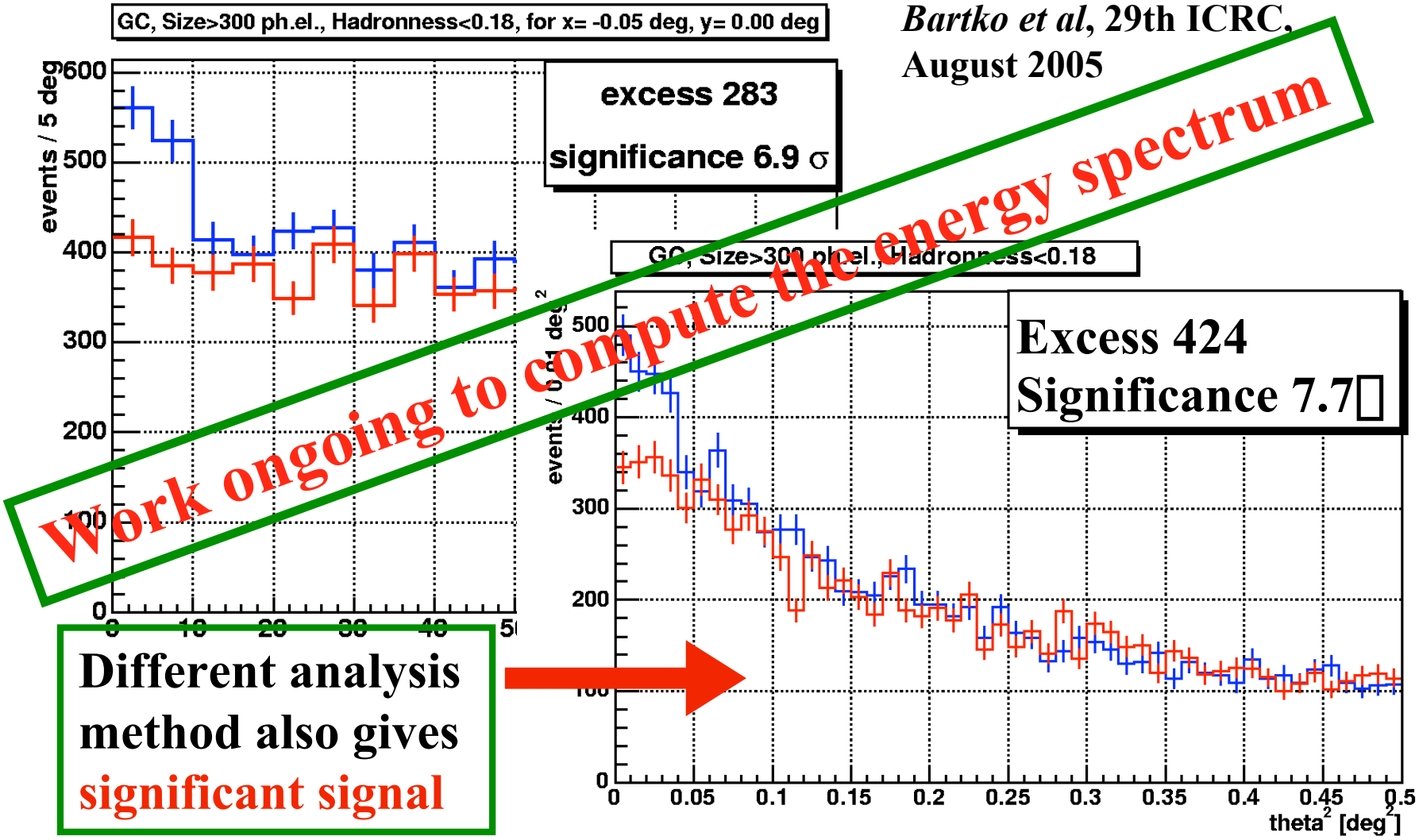
Chandra image with the estimated HESS position for the detected TeV emission (triangle). The two ellipses are the 68% and 95% confidence regions for the source position. SgrA is marked with a cross*

GALACTIC CENTER WITH MAGIC

14 h. ON Observation, about 60 degrees zenith angle

(Data taken on June-July 2005)

Bartko et al, 29th ICRC, August 2005

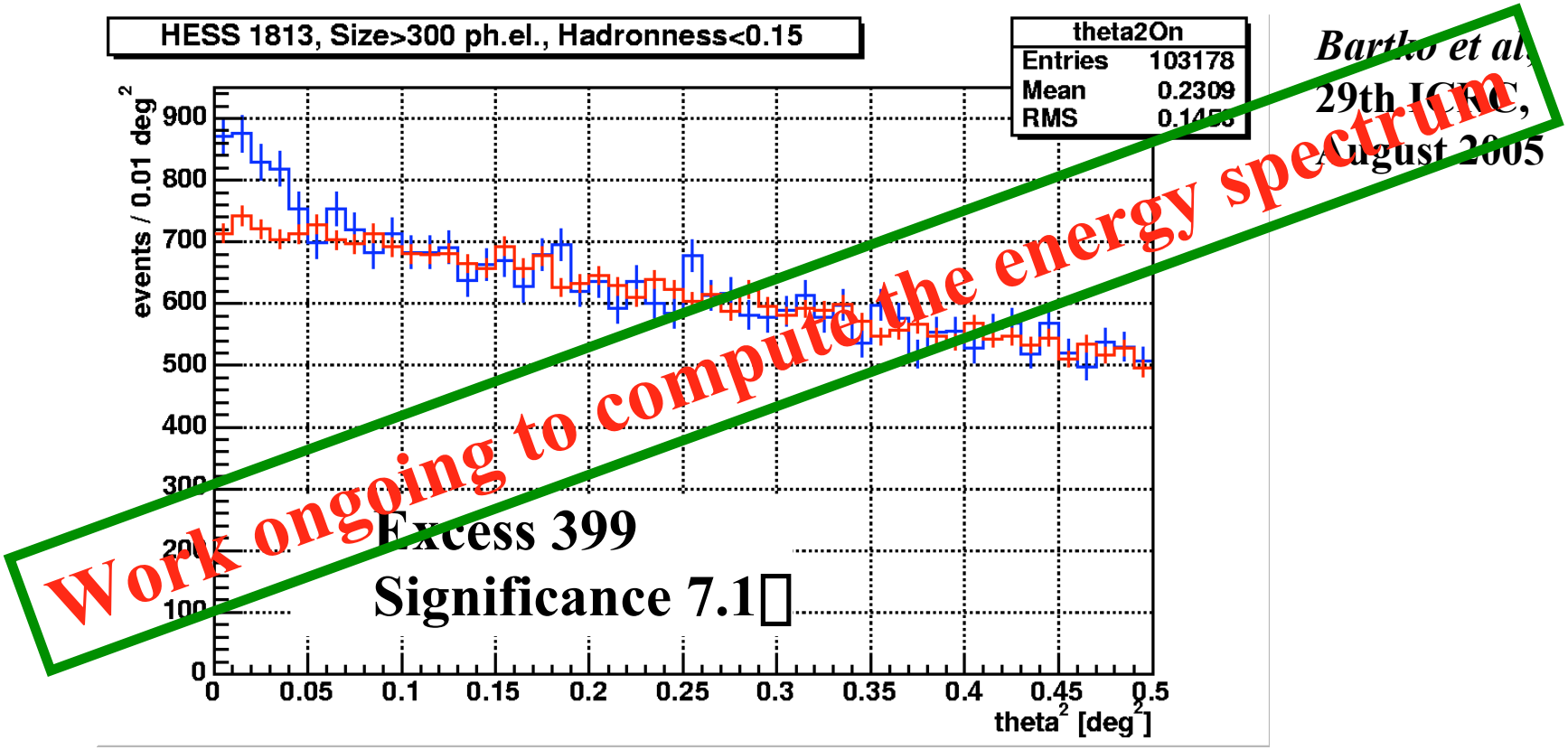


HESS 1813 -178

High energy galactic source discovered recently by HESS
Aharonian et al, Science 307 (2005) 1938-1942

20 h. Wobble mode Observation; about 50 degrees zenith angle

(Data taken on June-July 2005)



4 - CONCLUSIONS

Construction of MAGIC was a technological challenge

MAGIC is operating regularly since September 2004.
Clear gamma-source detections have been performed.
Reasonable understanding of the telescope performance achieved.

Signals down to 100 GeV have been detected with high significance and reliability

Work ongoing to:

1) *Increase sensitivity at low energies*
2) *Reduce further the analysis energy threshold*

4 - CONCLUSIONS

The Universe in gamma-rays is more fascinating than expected.

Latest excitements (in addition to the above mentioned)…

Binary pulsar system PSR 1259 / SS2883; new type of TeV gamma-source

Unidentified TeV sources; TeV J2032 (*HEGRA*), TeV J1303 (*HESS*)

Starburst galaxy NGC 253 (CANGAROO); new type of TeV gamma-source

Radio galaxy M87 (HEGRA)

Increasing number (*already 6*) of TeV Blazars detected with high statistics

Galactic scan in gamma rays (HESS); 8 new sources

MAGIC, as the other *new generation of IACTs* that aim for low energy thresholds and high sensitivity, will bring key data for understanding the "non-thermal Universe"

The real voyage, is not to travel to new landscapes, but to see with new eyes…

Marcel Proust *(1871-1922)*