MAGIC
Major Atmospheric Gamma Imaging Cerenkov Telescope

Observation of VHE Gamma Ray Sources with the MAGIC telescope

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MAGIC collaboration

Outline:

Gamma Ray Astronomy

- Physics goals
- Air Cherenkov technique

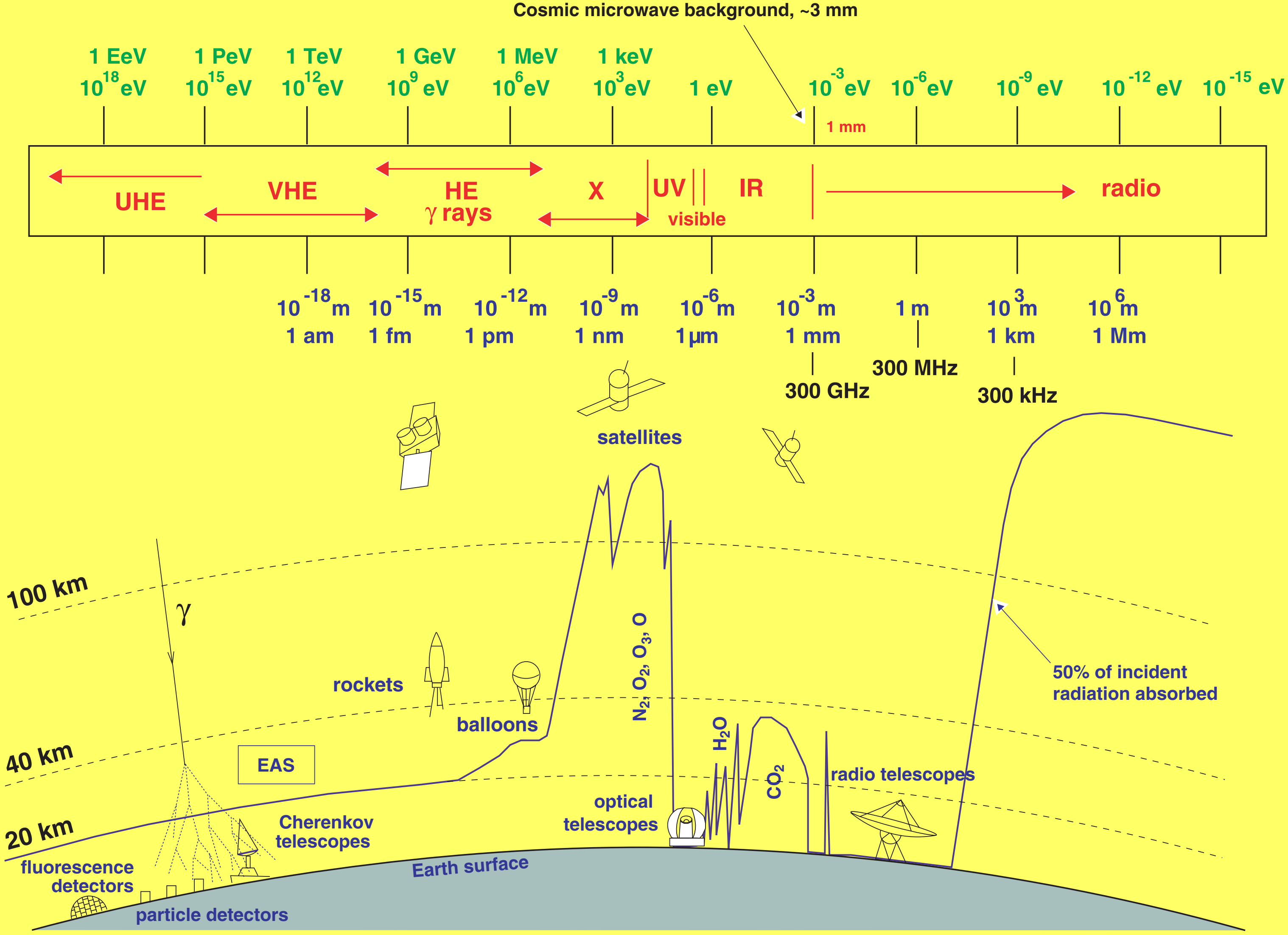
The MAGIC telescope

- key technologic elements
- Performance of telescope & analysis
- Results

The future: MAGIC II

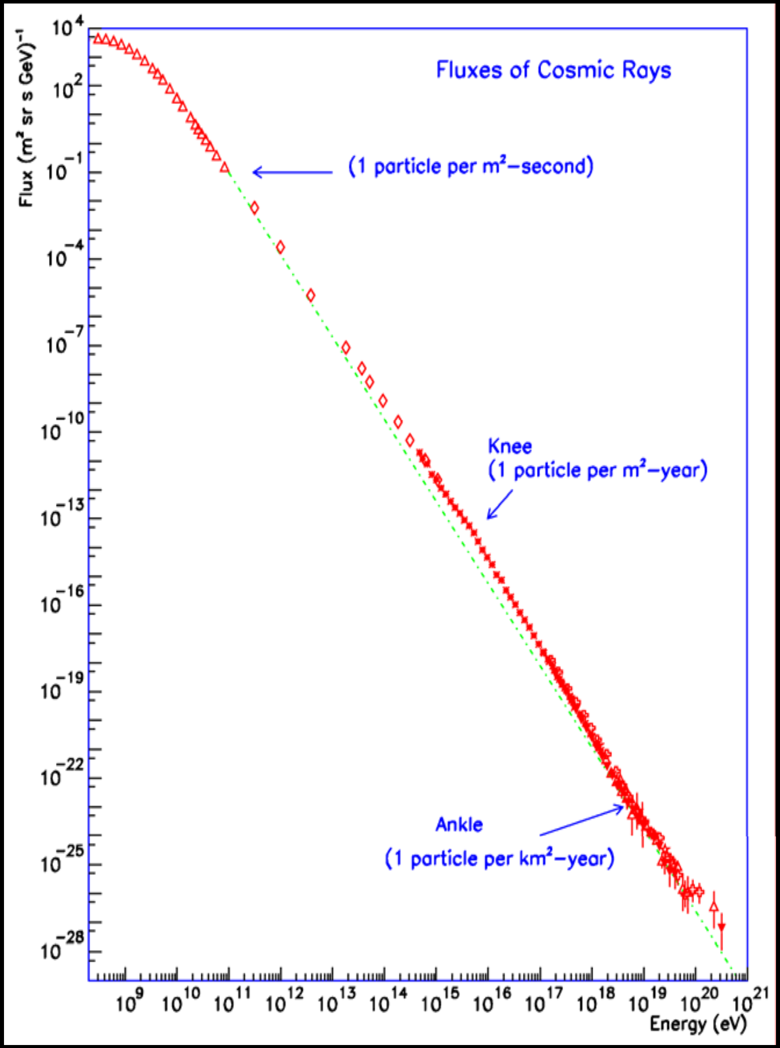
- motivation & technological challenges

Multiwavelength Astronomy



Cosmic Radiation

original motivation for search
for TeV gamma radiation

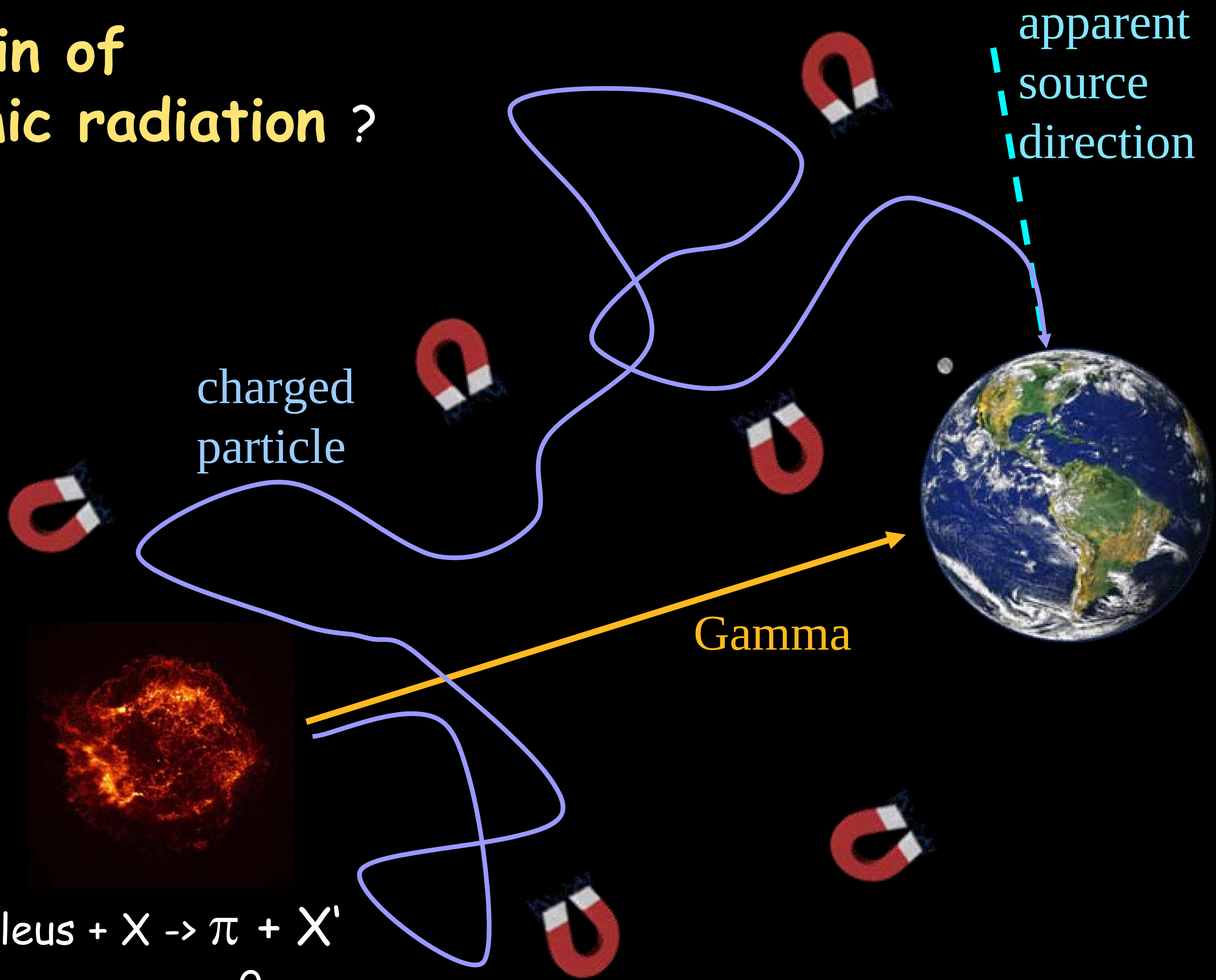


discovered 1912
by Victor Hess

composition:
-mainly protons

energy spectrum
-power law ($\sim E^{-2.7}$) over
very large energy range

Origin of cosmic radiation ?

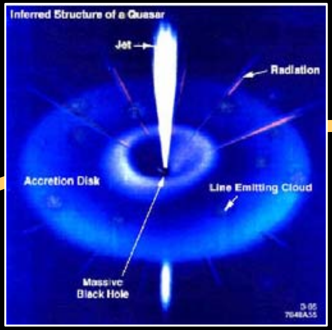


nucleus + X -> π + X'

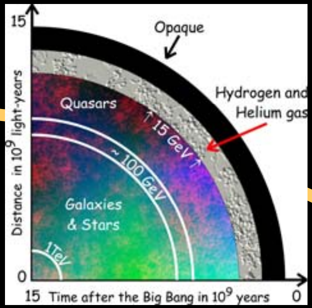
$\pi^0 \rightarrow \gamma\gamma$

Physics Motivation for MAGIC

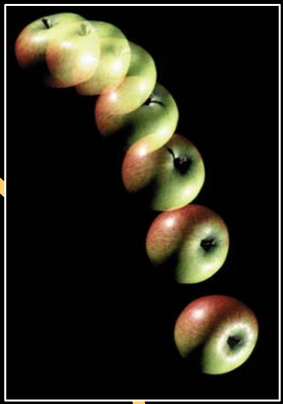
Pulsars



AGNs

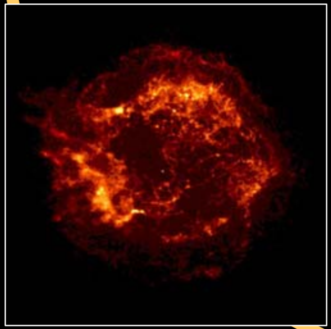


Cosmological
γ-Ray Horizon

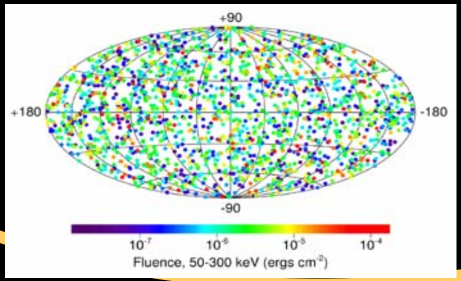


Quantum Gravity

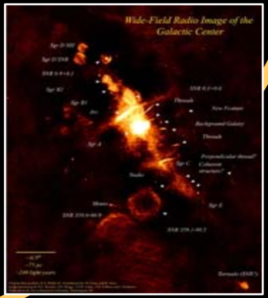
Origin of
Cosmic Rays



SNRs



GRBs

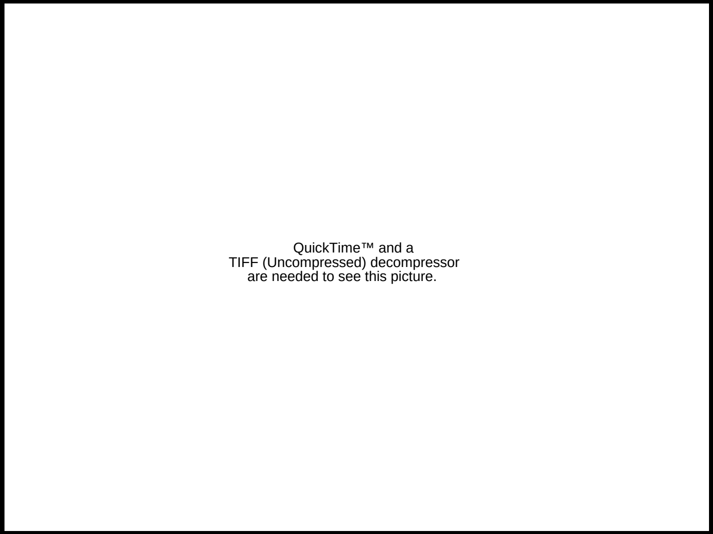


Dark Matter

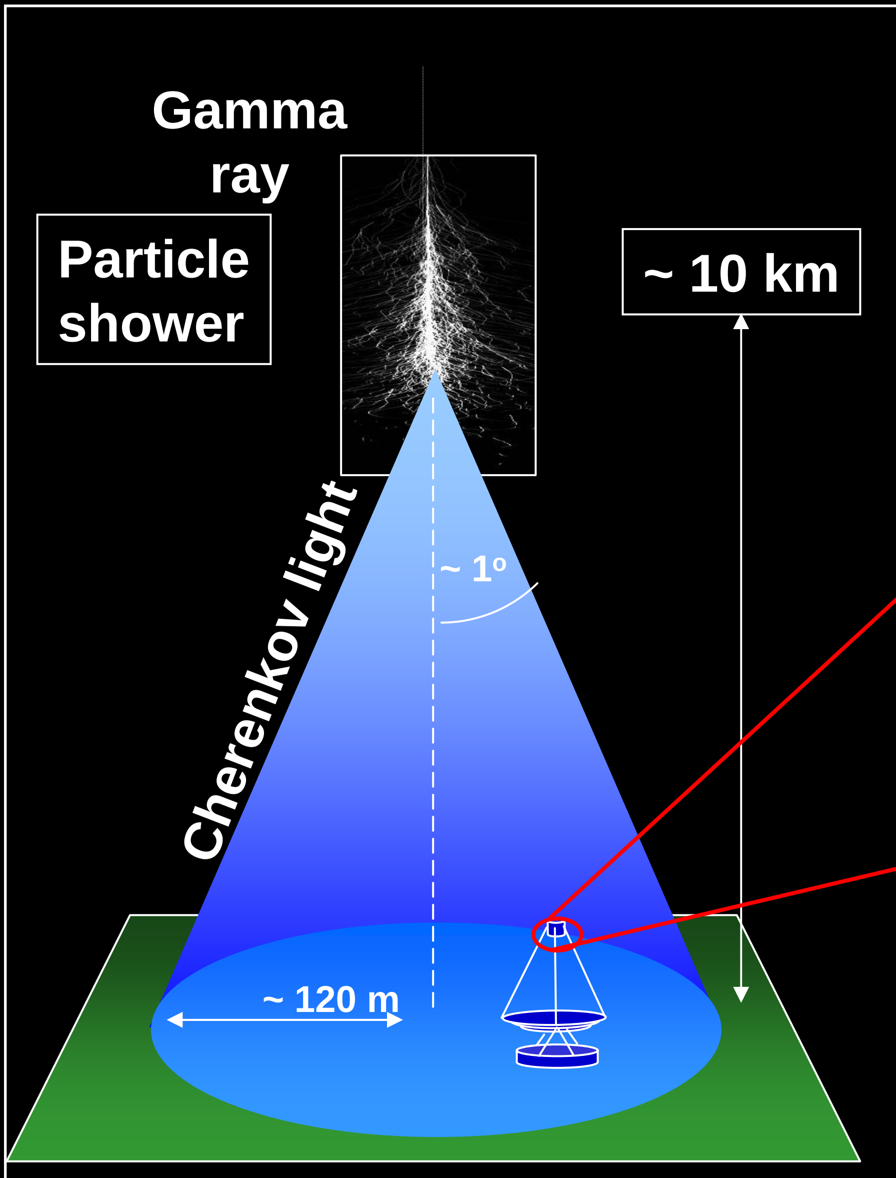
TeV Gamma-rays (10^{12}eV)

High energy γ-ray astronomy:

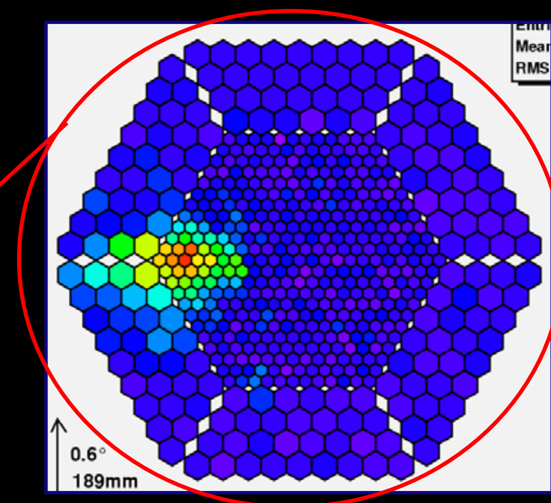
- youngest astronomic discipline
- First significant measurement of TeV γ-ray emission from Crab Nebula by Whipple telescope in 1989



Imaging Air Cherenkov Telescopes



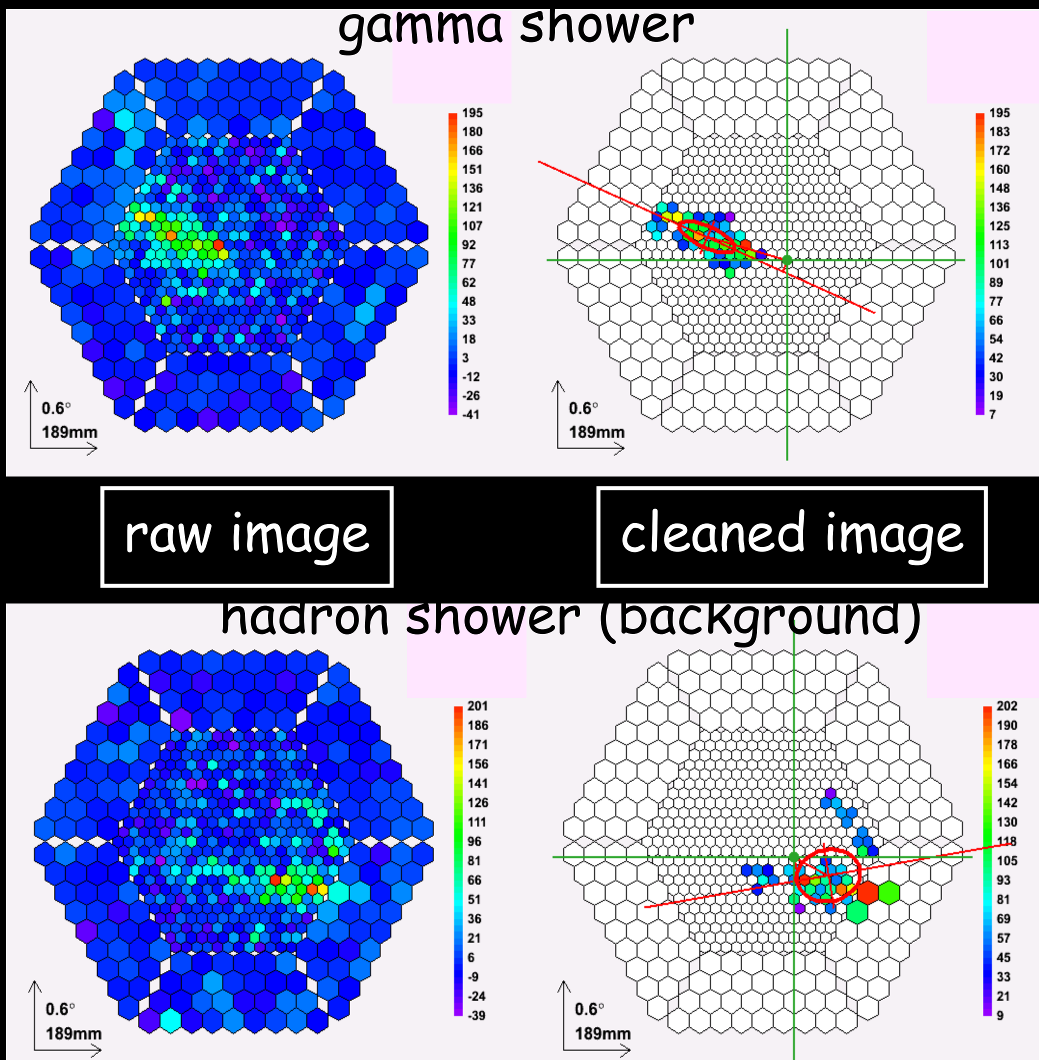
Cherenkov light Image of particle shower in telescope camera



Intensity => Energy
Orientation => Arrival direction
Shape => Primary particle

P.Majumdar, 24th August, IIA, India

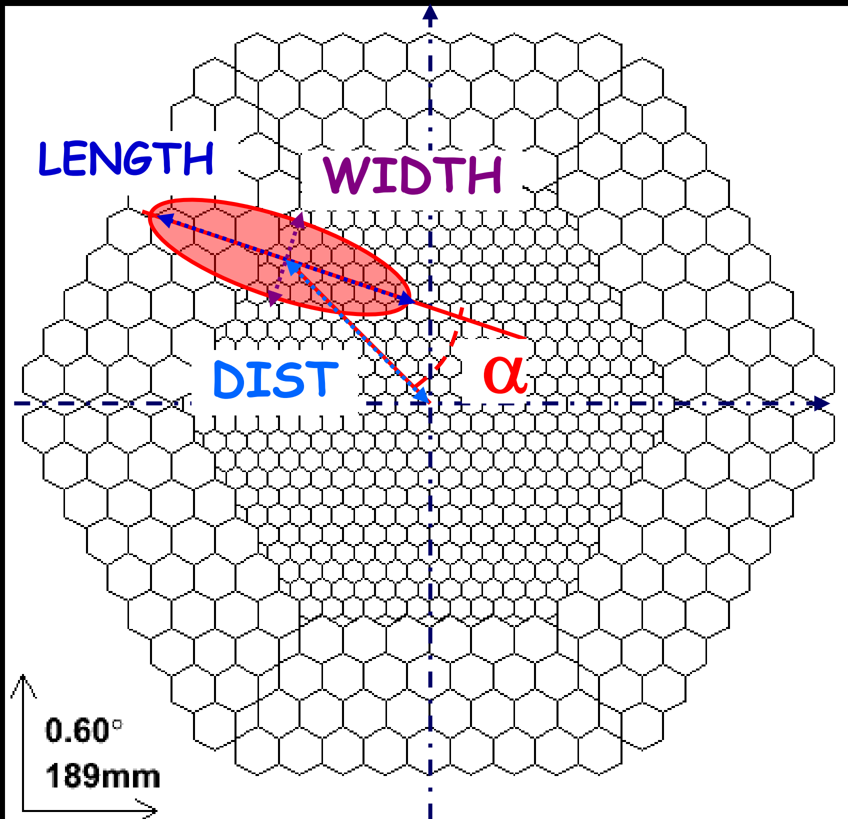
Background Rejection

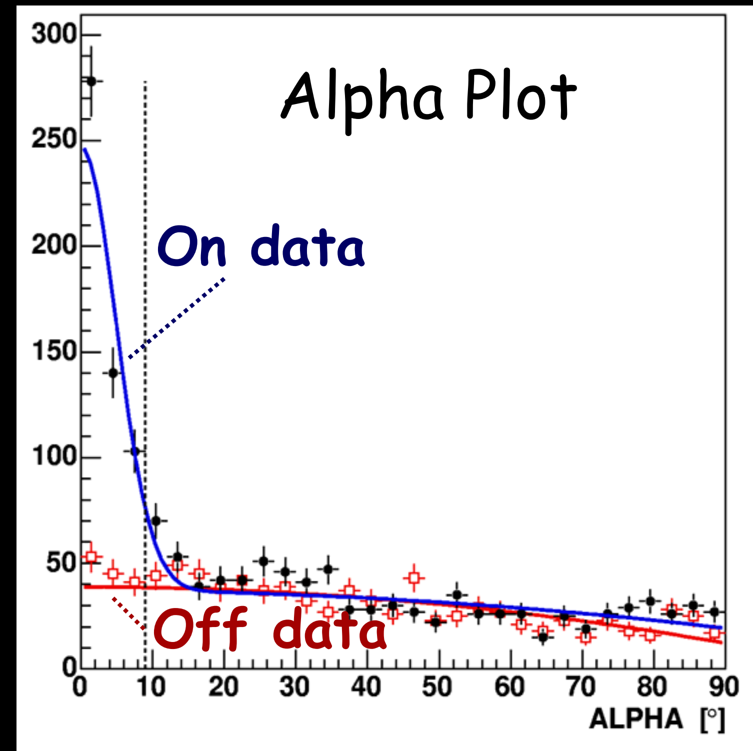


Main Background:

- Cosmic Ray (hadron) showers
- >10^4 times more numerous than γ-ray showers
- Reject based on shower shape

Standard "Hillas" Analysis



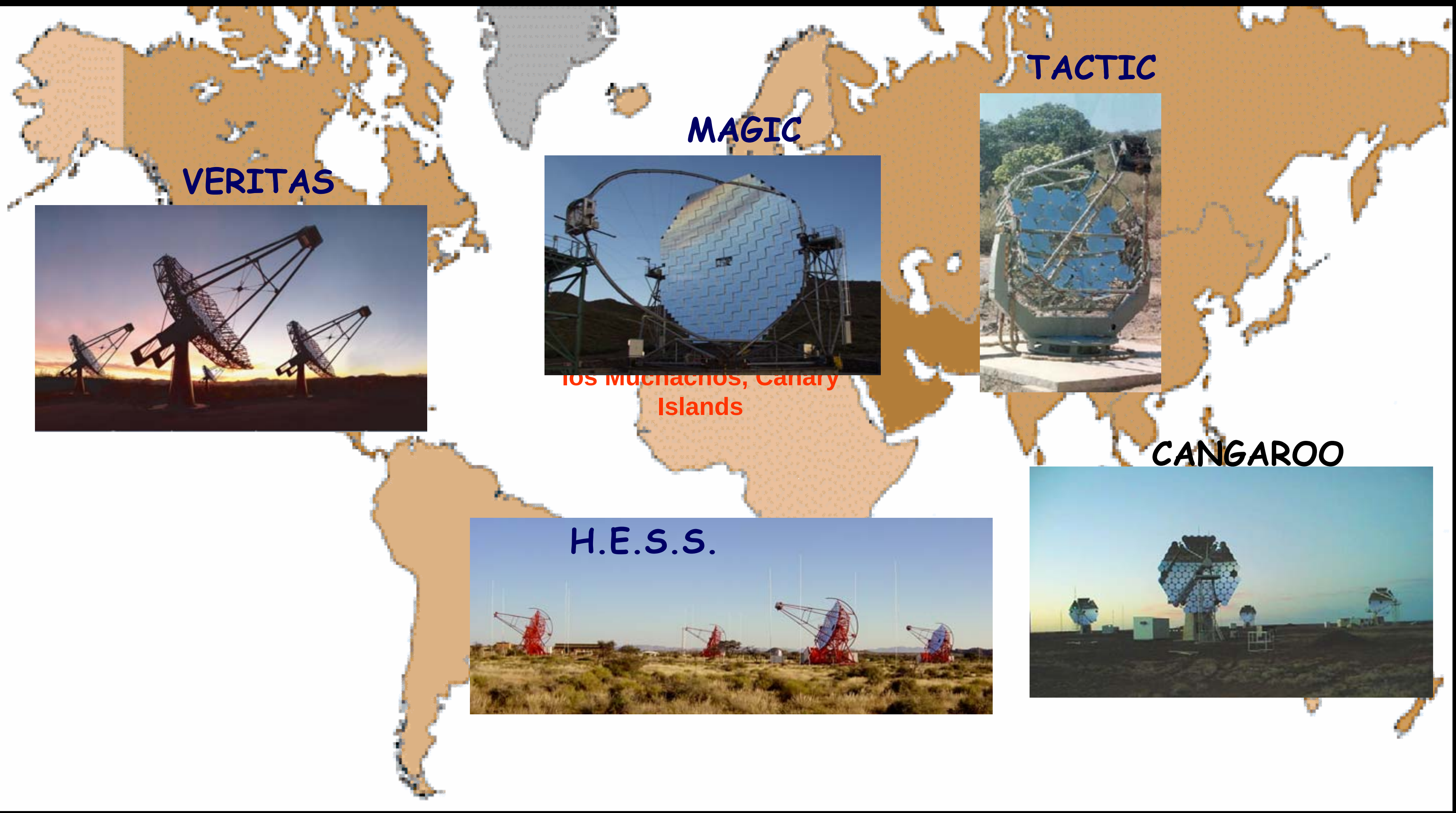


Background rejection with multidimensional cuts on Hillas parameters:
Length, Width, Dist, Alpha

Hadron background:
- isotropic
- flat Alpha distribution

Gammas:
- excess in source direction

Current generation IACTs

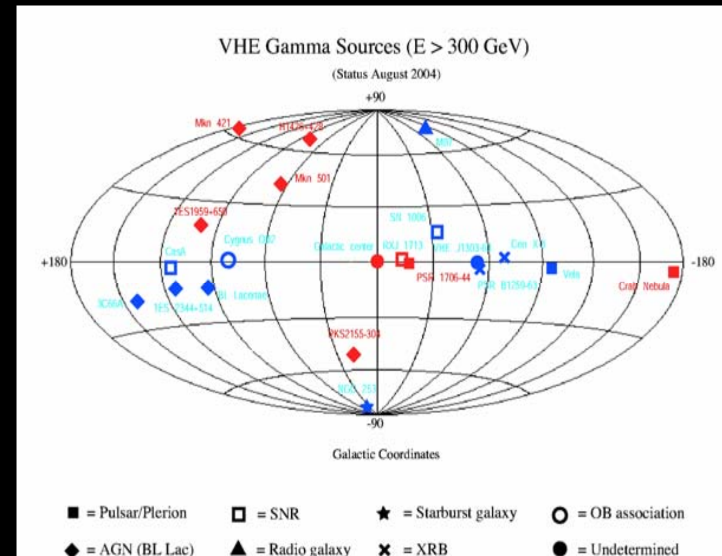


Success of Cherenkov Telescopes (E > 300 GeV)

Discovery of several (o(10)) TeV γ-ray sources (upto 2003-2004)

- galactic sources
  (shell type SNR, Plerions)
- extra-galactic sources (AGNs)

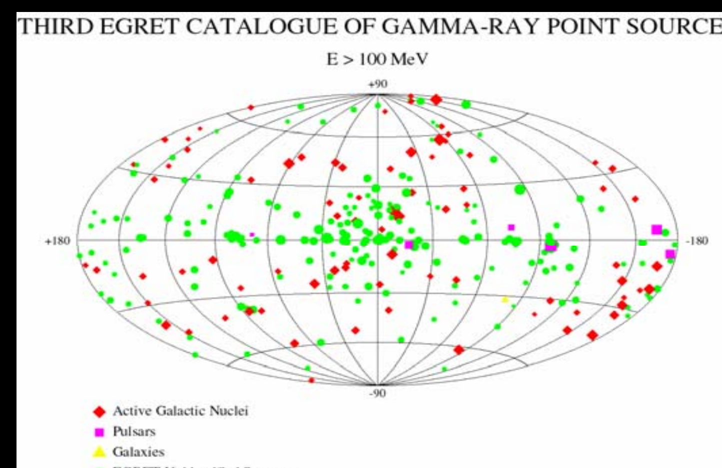
Cosmic Ray origin not resolved (?)



But ...

Where are all the sources seen by EGRET ?

- effective area ~ 1 m^2
- E < 10 GeV,
- 271 sources (171 unidentified)

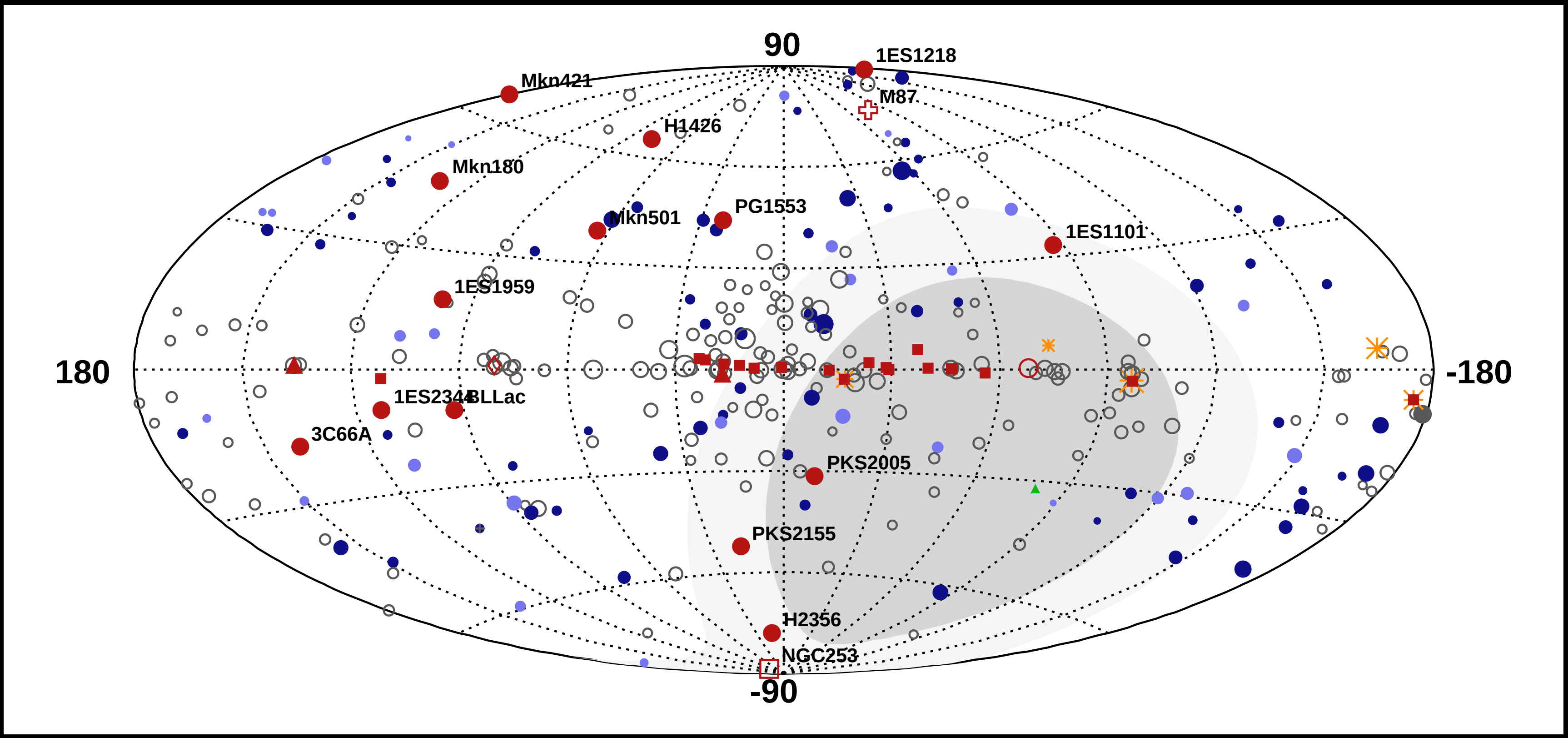


The unexplored spectrum gap

- Strong cutoff in γ-spectrum for 10 Gev < E < 300 GeV
- The energy range between E ~ 10GeV (satellites) and E ~ 100 GeV (IACTs) is still unexplored

=> Push down E_{thr} of IACTs

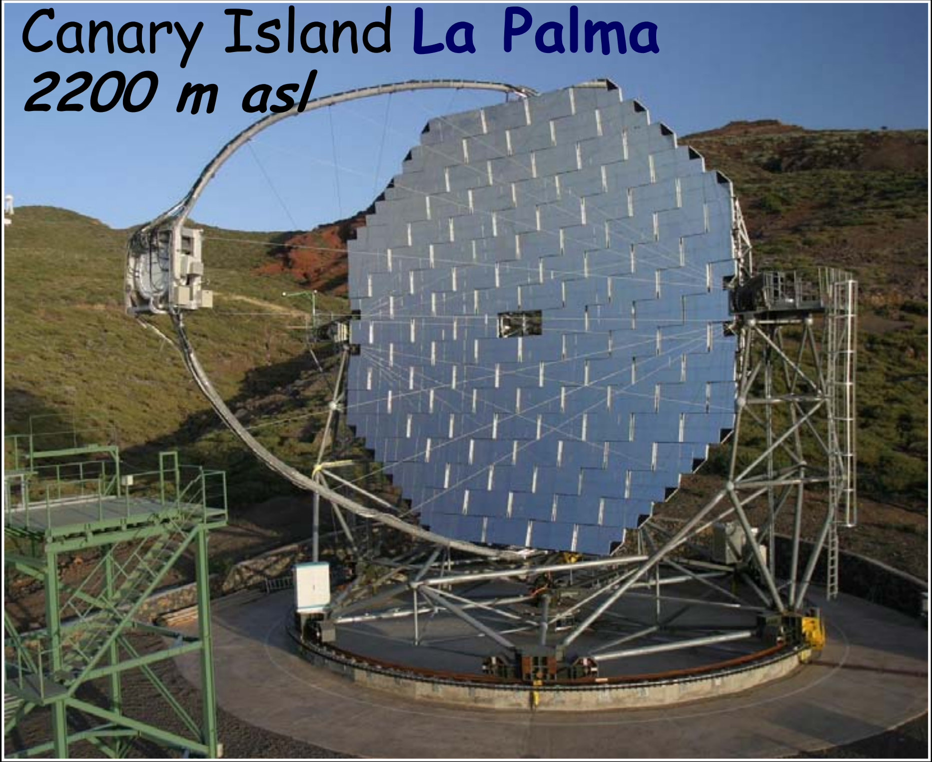
Present Status of VHE sources



- Many new galactic and extragalactic sources being discovered with current generation telescopes

The MAGIC telescope

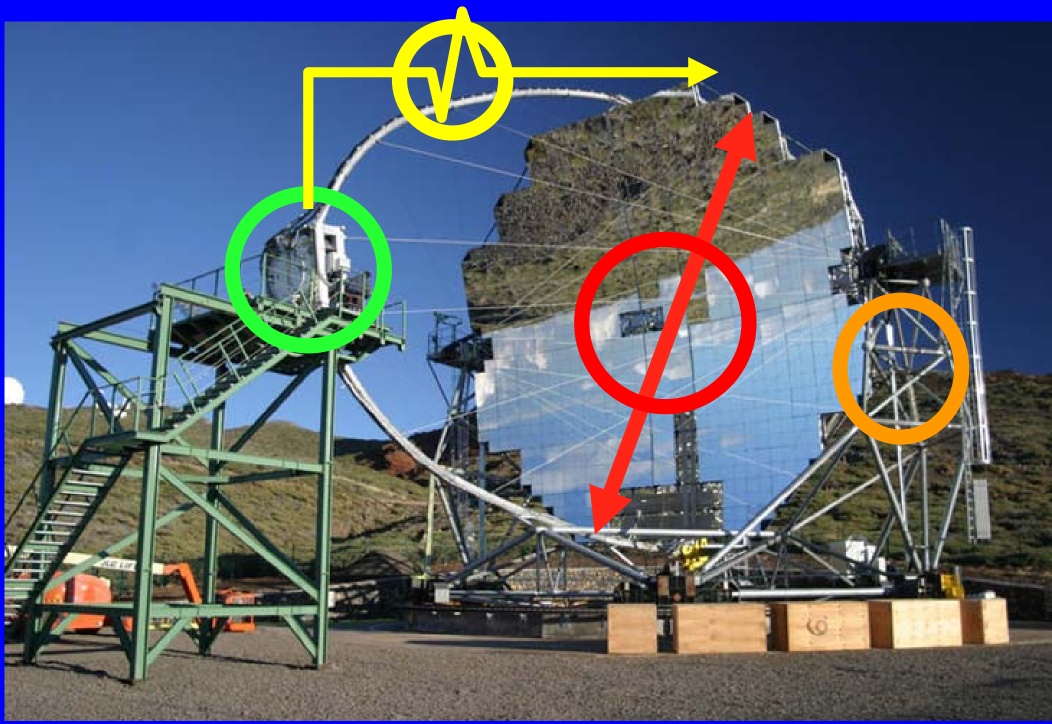
- **Largest Imaging Air Cherenkov Telescope** for γ-ray astronomy (17 m mirror dish)
  - low energy trigger threshold E_γ = 50-60 GeV
  - fast repositioning t_R<30 sec



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

MAGIC: a pioneering telescope
The key parameters of the MAGIC telescope:

- 17 m ∅ reflector (240 m^2)
- carbon fibre frame
- Active mirror control
- 577 pixel, ~3.5° camera
- Analogue optical signal transport via fibres
- 3-level trigger system
- Ultra-fast readout
- Trigger threshold 50 GeV



Energy Res. 20% (30%) @ 1 TeV (100 GeV)

Sensitivity: 2.5 % Crab/50 hrs 5 sigma

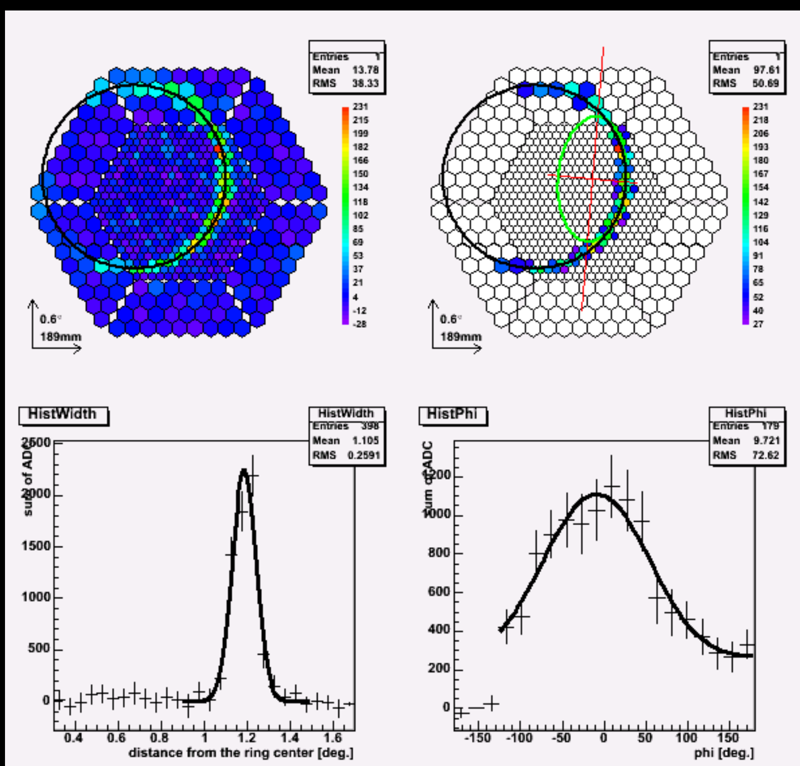
Status of MAGIC

- October 2003: Inauguration
- until August 2004: Commissioning
- July 2004: Installation of last Mirrors
- September 2004:
  Start of regular data-taking
  - data-taking efficiency gradually improving, reaching 80-90% in January 2005 (nice weather)
- February 2005:
  - weather is not always nice
- Data taking smooth in 2006
- Completed Cycle 1 data taking

Calibration

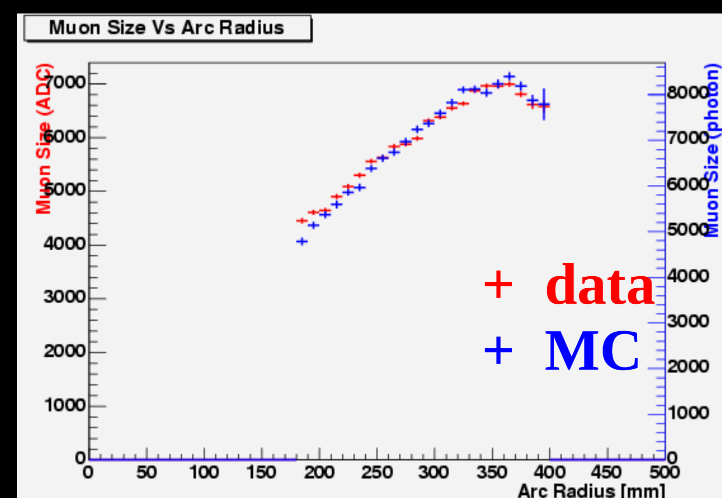
Standard calibration

- light pulses illuminating camera uniformly
- allows calibration in PEs

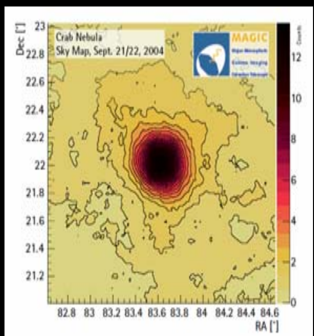


Muon calibration

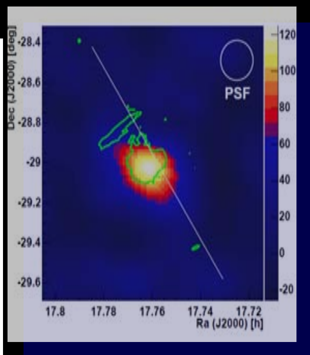
- select set of clean muons hitting mirror dish (2.3 Hz)
- comparison of measured and expected muon signal
- allows **absolute calibration** of **photon collection efficiency** of detector (mirror + PMTs + ..)



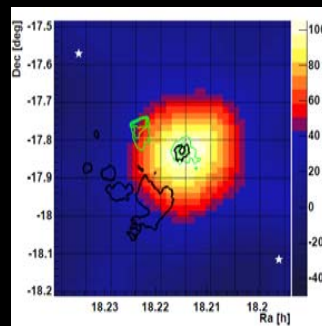
MAGIC HIGHLIGHTS



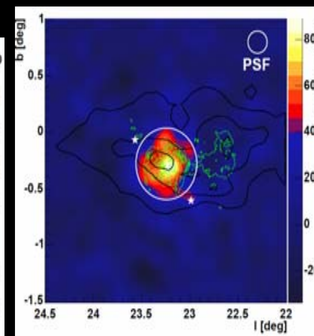
Crab Nebula
SZA & LZA



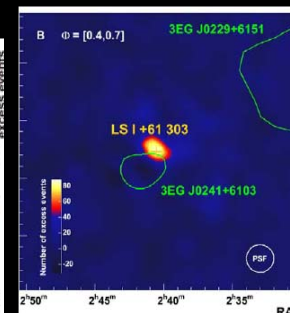
Galactic Center



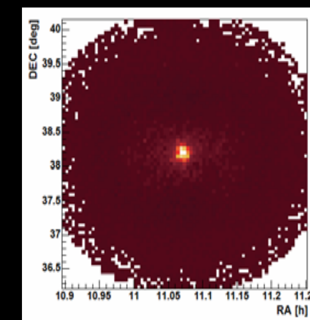
HESS J1813



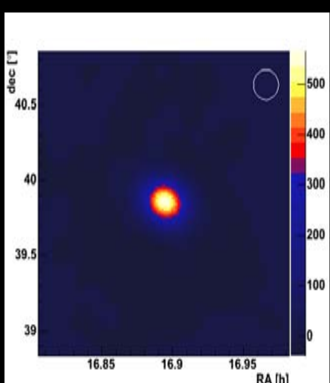
HESS J1834



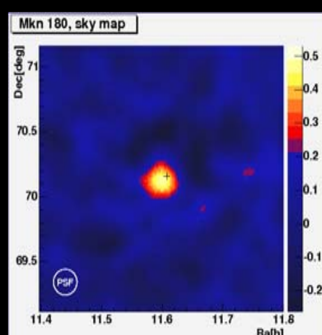
LSI+61 303
Micro-Quasar
New Source



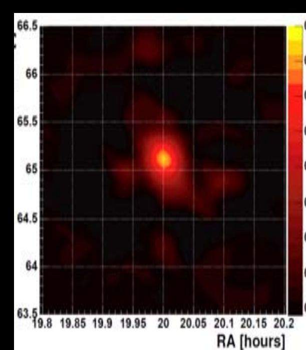
Mrk421 (0.031)



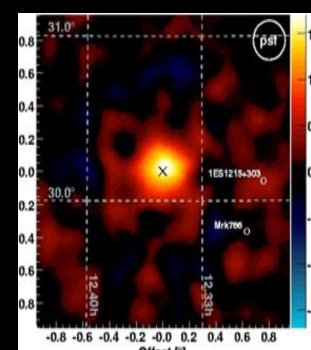
Mrk501 (z=0.034)



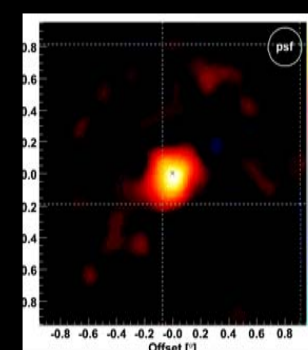
Mrk180 (0.045)
New source



1ES1959 (0.047)



1ES1218 (z=0.18)
New Source



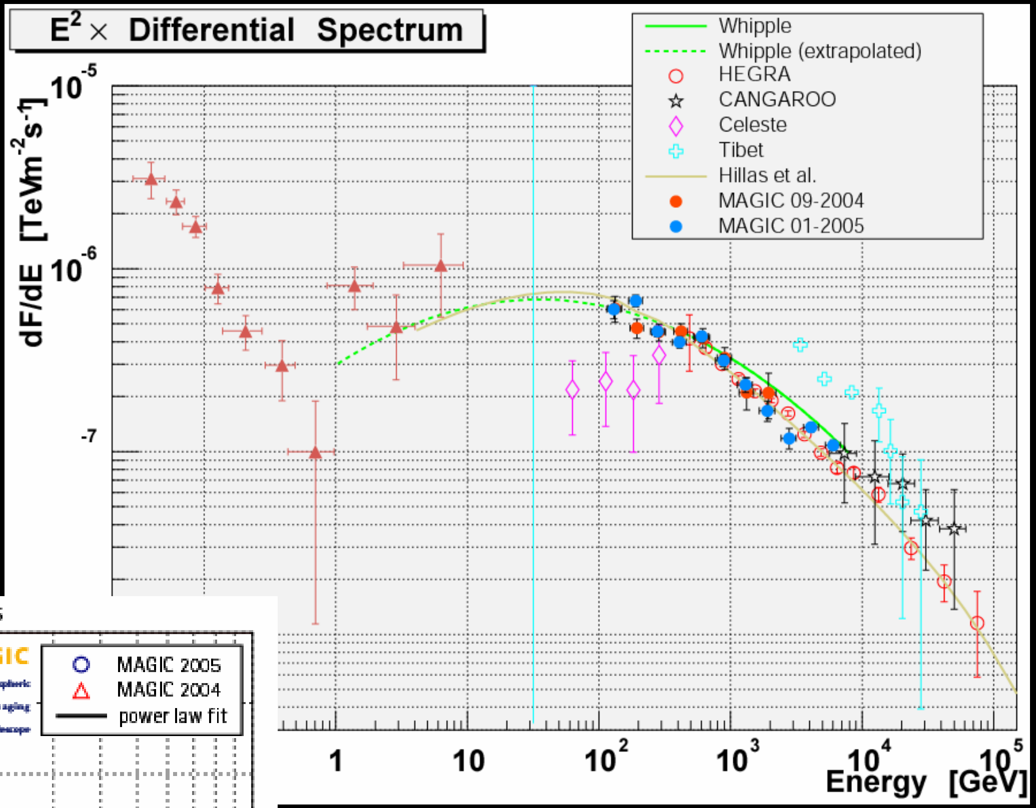
PG 1553 (Z>0.25)
New source

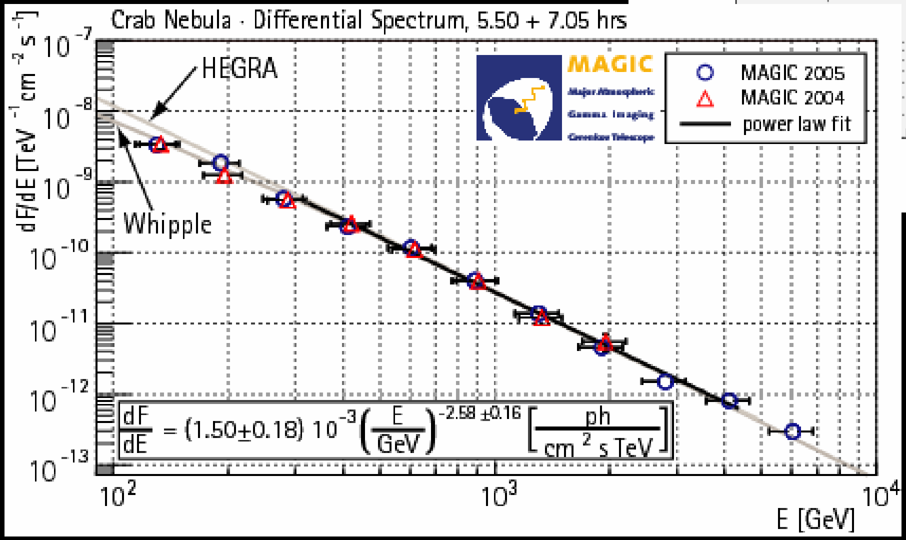
P.Majumdar, 24th August, IIA, India

Crab Nebula SED

Crab Nebula used as a
Calibration source

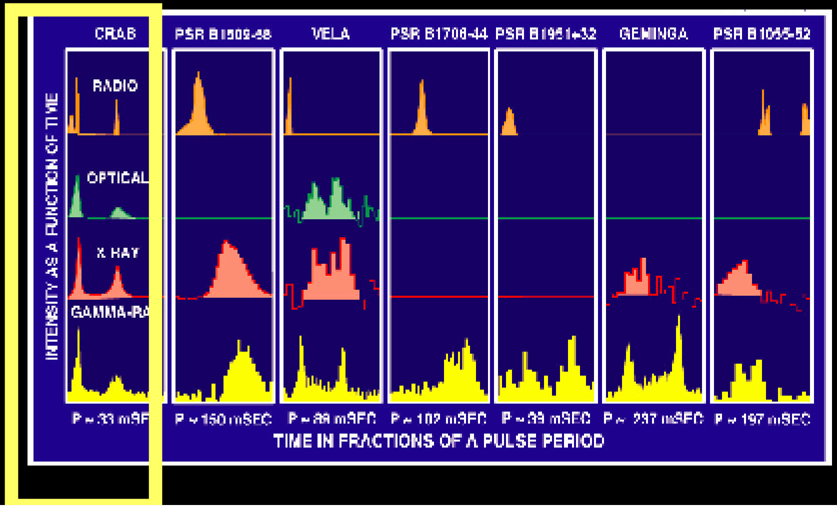
Sensitivity
2.5% Crab in 50 hours/5sigma

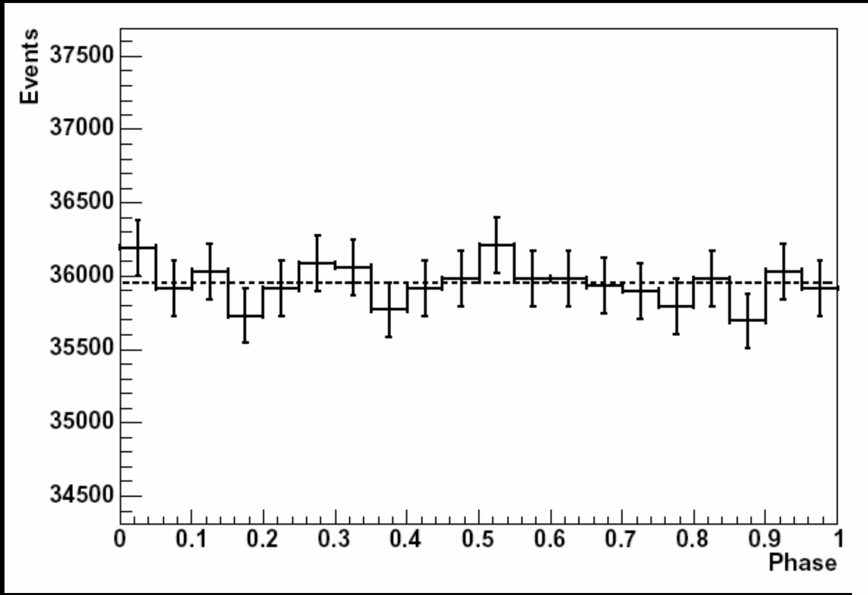


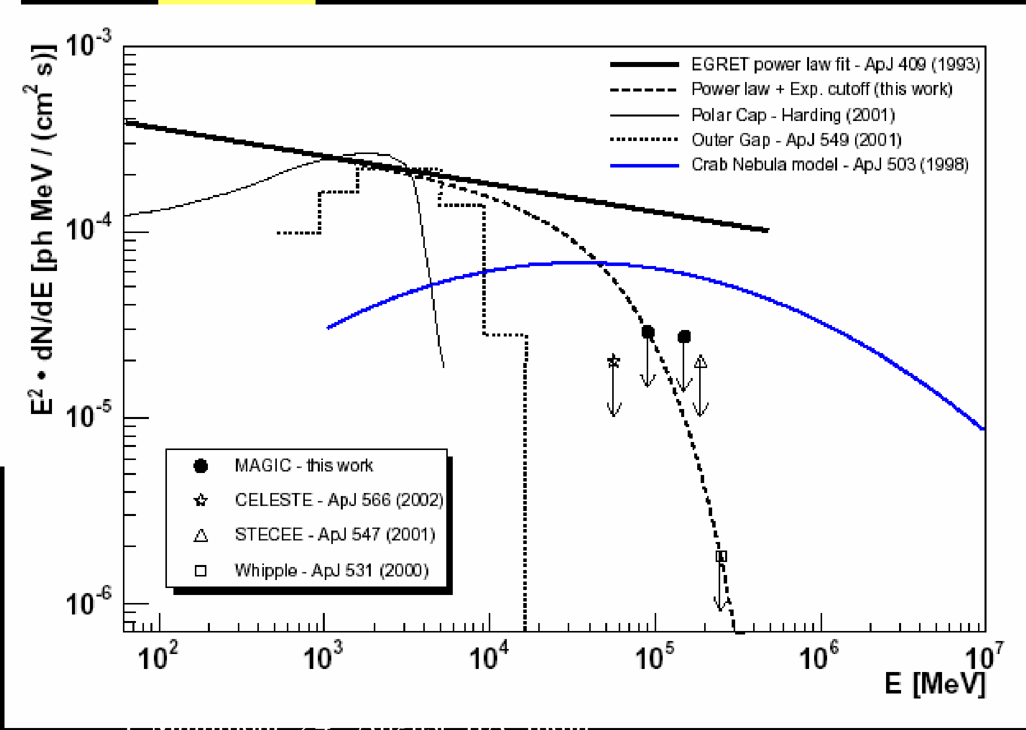


Search for Pulsations in VHE data

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





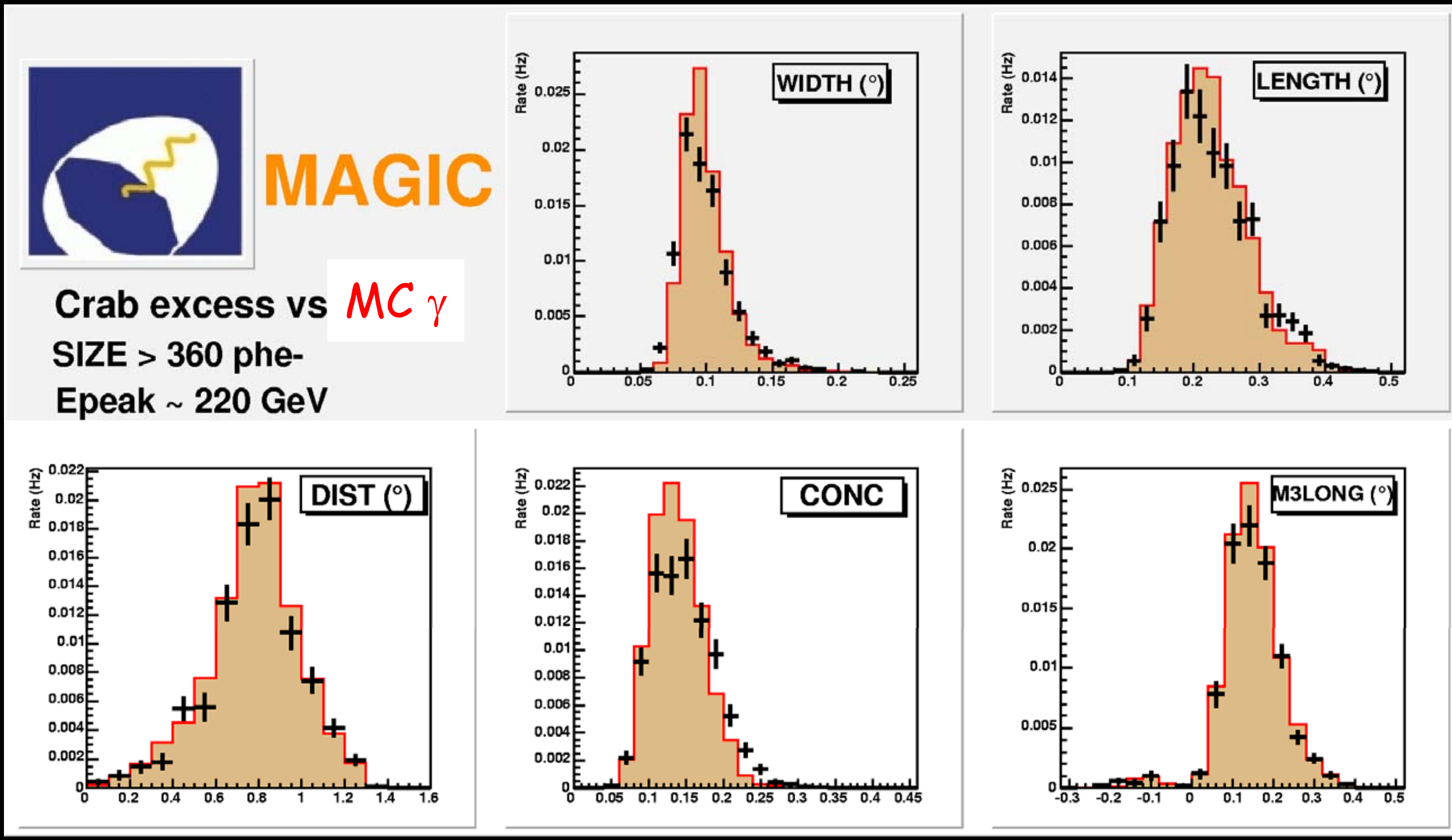


NO PULSATION DETECTED AT ENERGIES > 100 GeV

Limit to Exponential cut-off

E_{cut} < 60 GeV

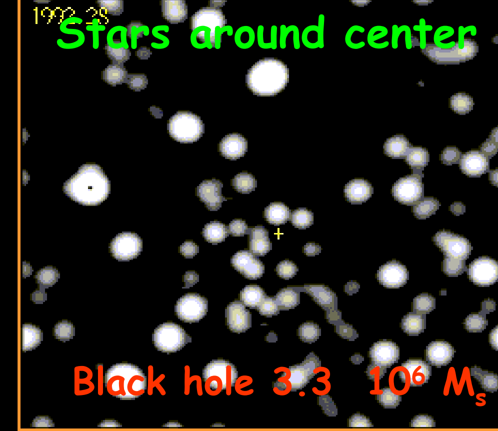
Monte Carlo: comparison with data

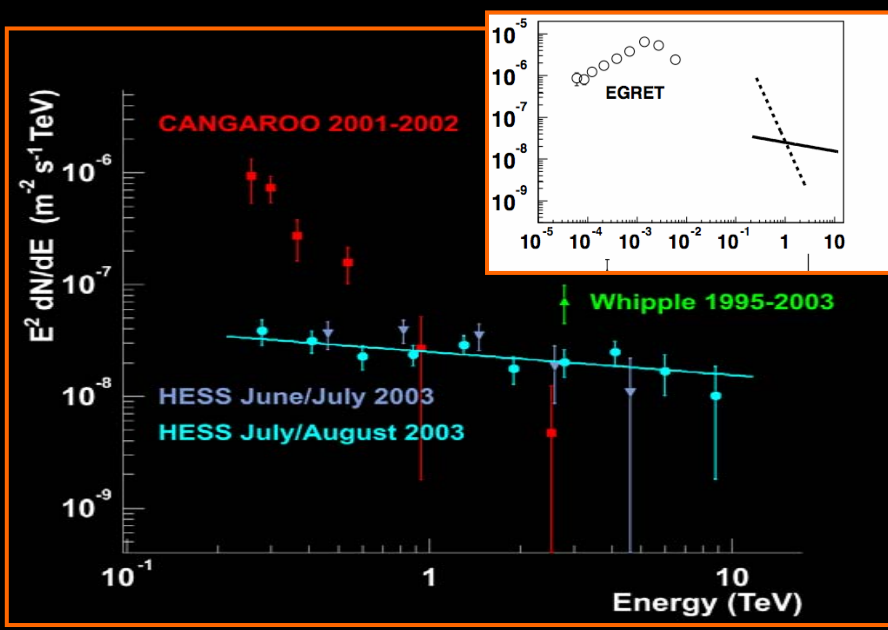


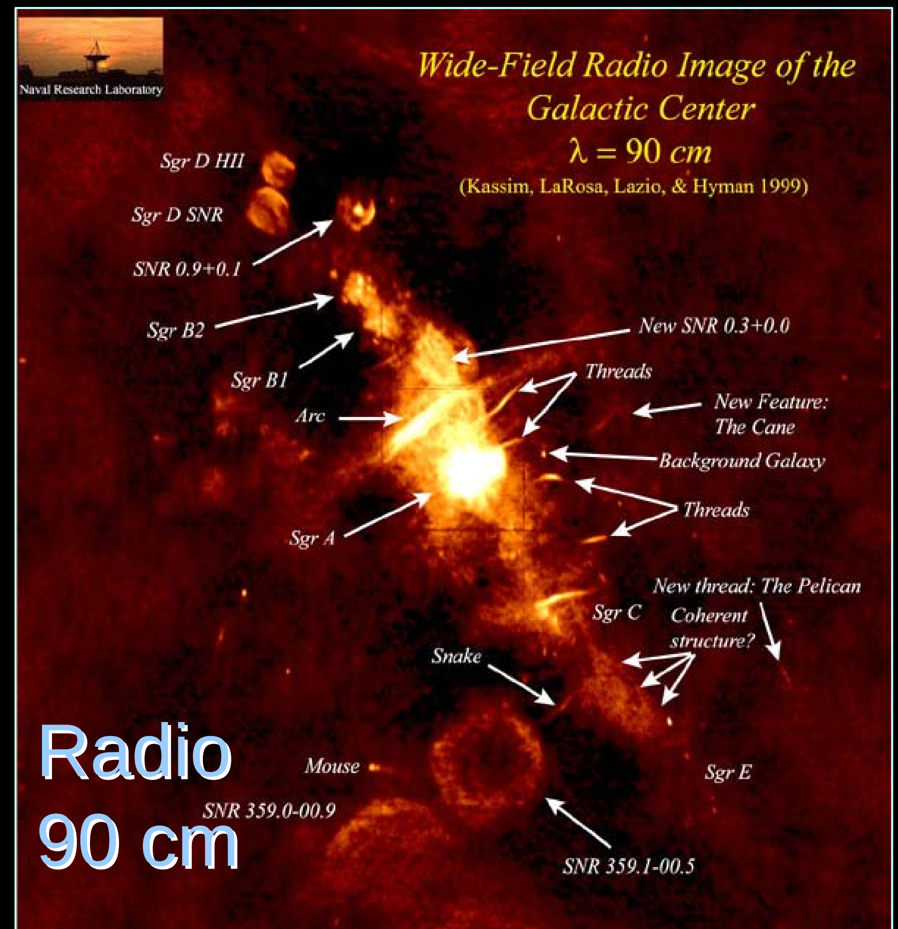
Data: ON (gammas+hadrons) - Off(hadrons)

Galactic Center

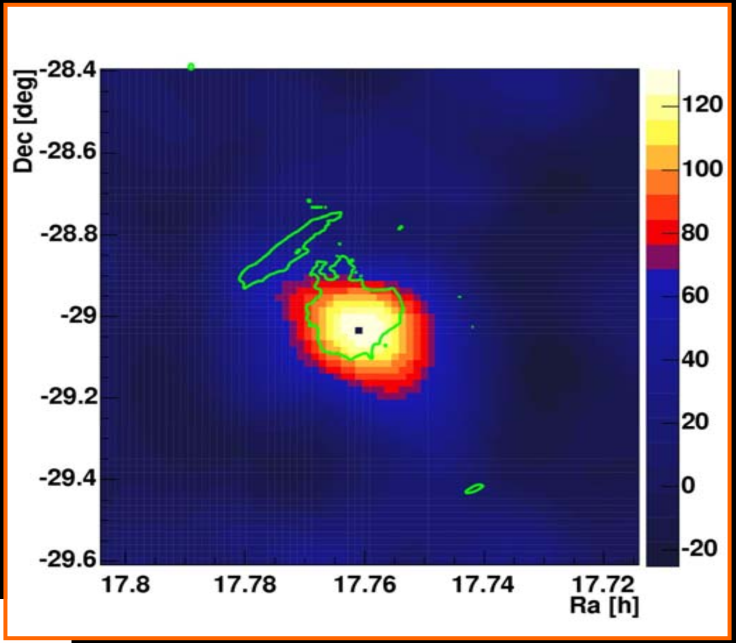
- Very turbulant region
- Central black hole 3.3 10^6 M_S
- fast X-ray flares (in hours)
- Several SNRs close
- Neutralino annihilation ?
- Controversial TeV spectrum

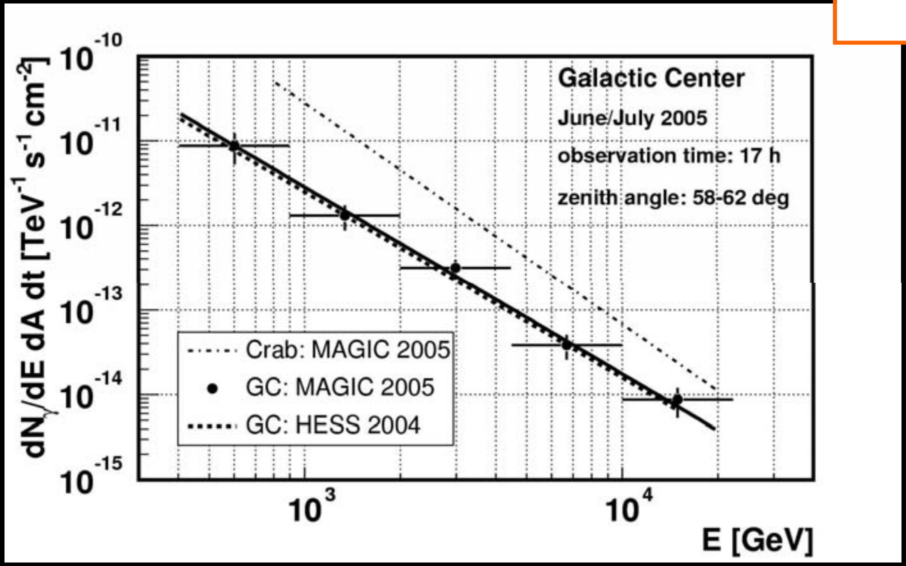




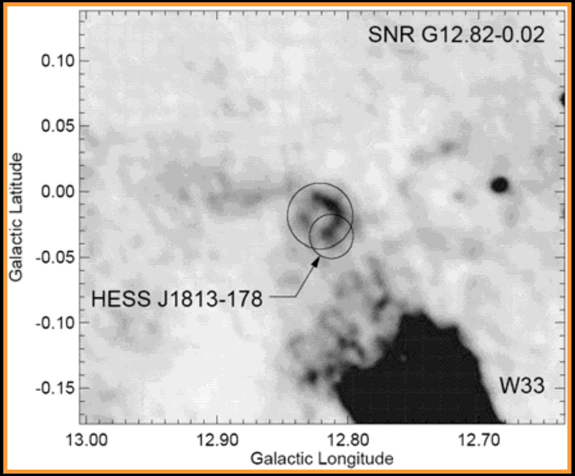


- Analysisthreshold ~400 GeV
- Spectral Index 2.2 ± 0.2
- No significant variability
- Morphology and spectrum under study: only neutralino anihilation unlikely (no cutoff in spectrum ➔ mn > 12 TeV)
- Zenithangle 58°-62°
- TeV gamma emission spatially consistent with Sgr A* and Sgr A East
- Compatible with point source





HESSJ 1813-178



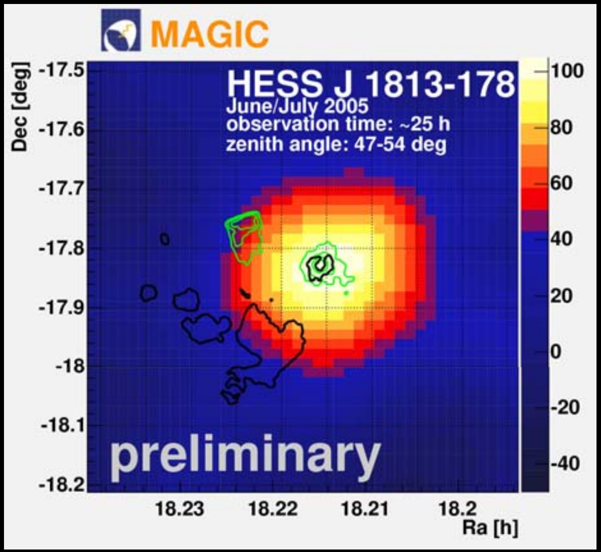
Section of shell spatially coincident with SNR G12.82-0.02

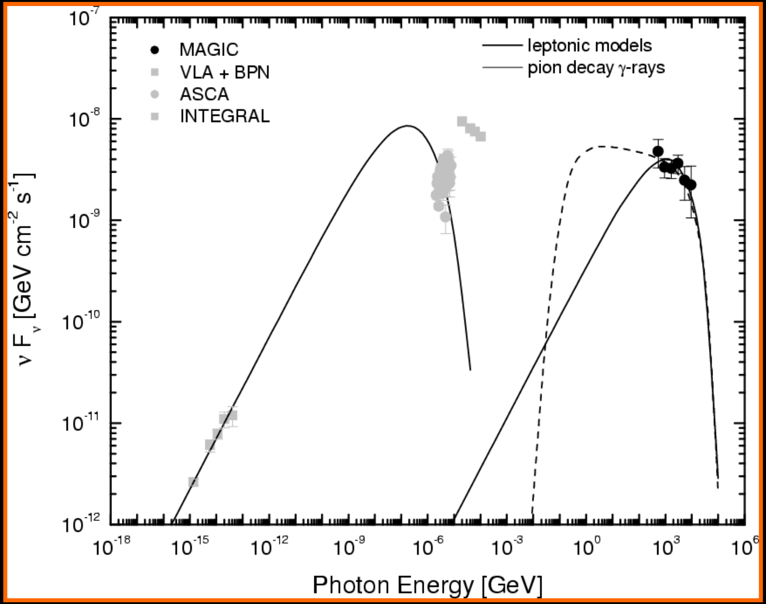
Zenithangle: 47°-54°

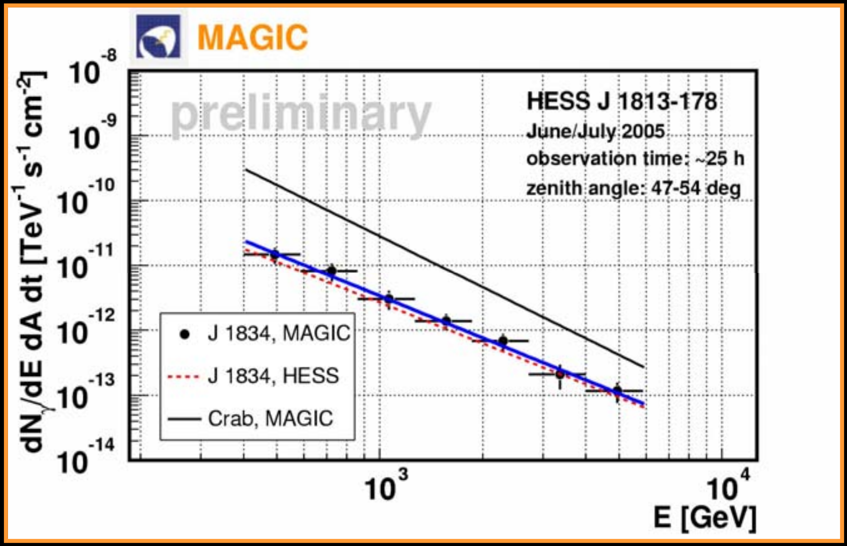
Threshold: 400 GeV

Index 2.15 ± 0.3

Hadronic Acceleration ?

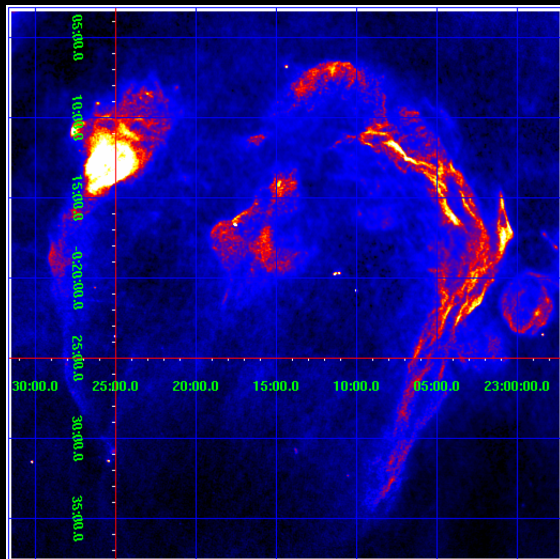




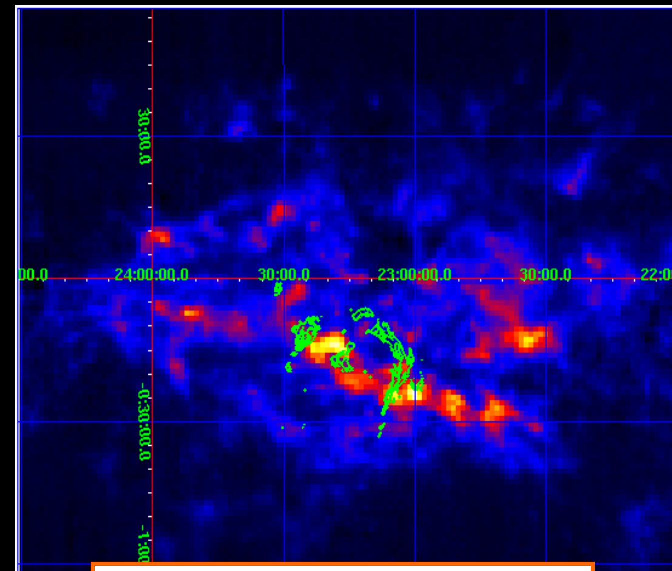


HESS1834-087

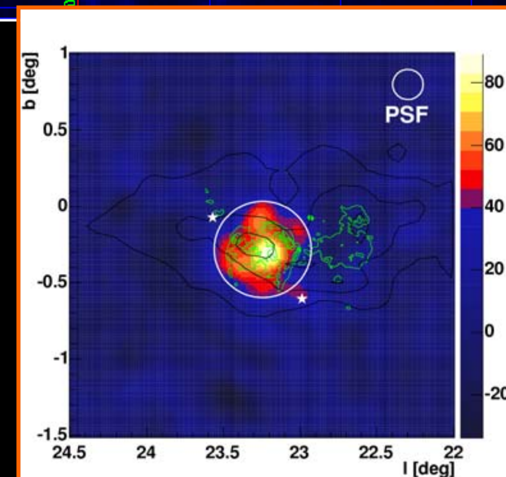
VLA: 20 cm radio



Molecular clouds: ^{13}CO data



Coincident with
SNR G 23.3-0.3 (W41)
Source clearly extended
Index -2.5 ± 0.2 ➔ steep
➔ Indication for interaction with dense cloud
➔ Hadronic acceleration ?



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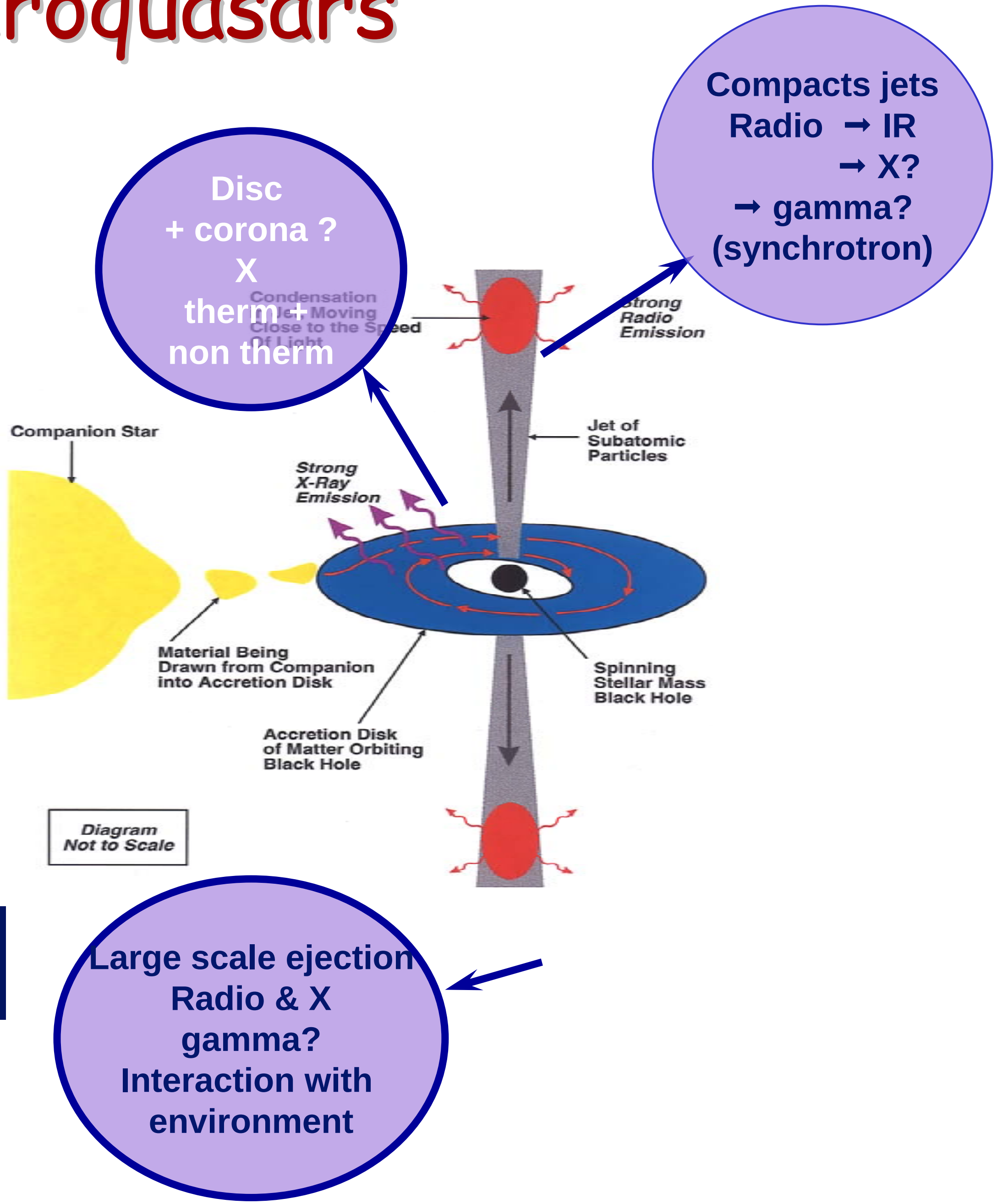
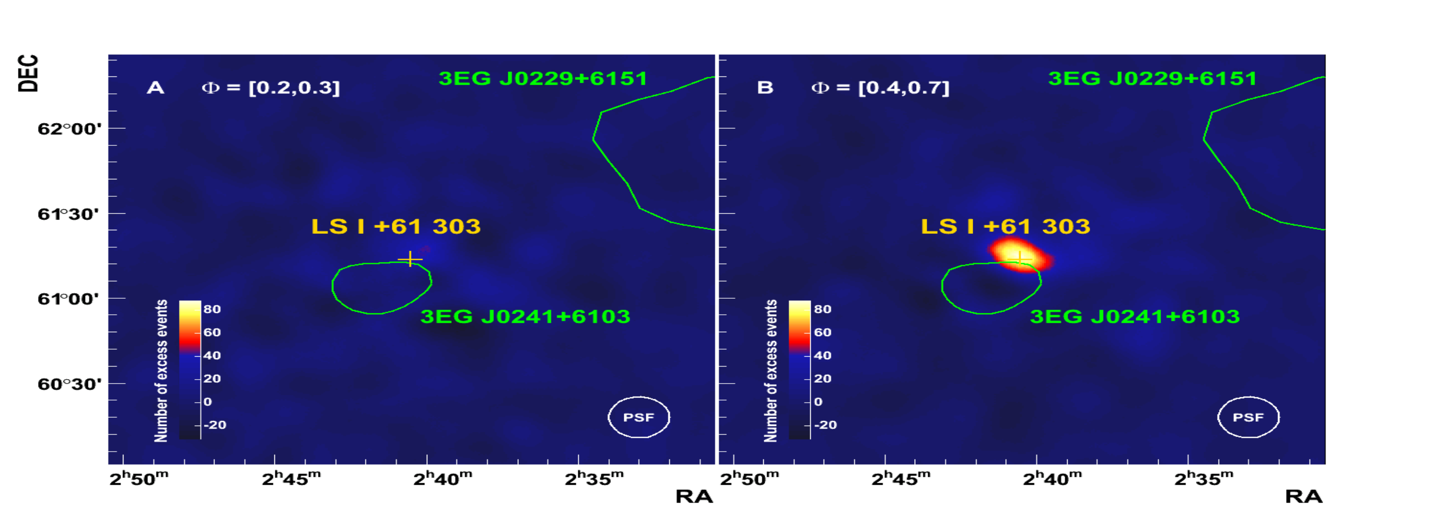
Microquasars

- **Microquasars:**
  - Binary systems displaying relativistic radio jets
  - Compact object Neutron Star or a Black Hole
  - Laboratories of jet physics
  - Possible contributors to galactic cosmic rays



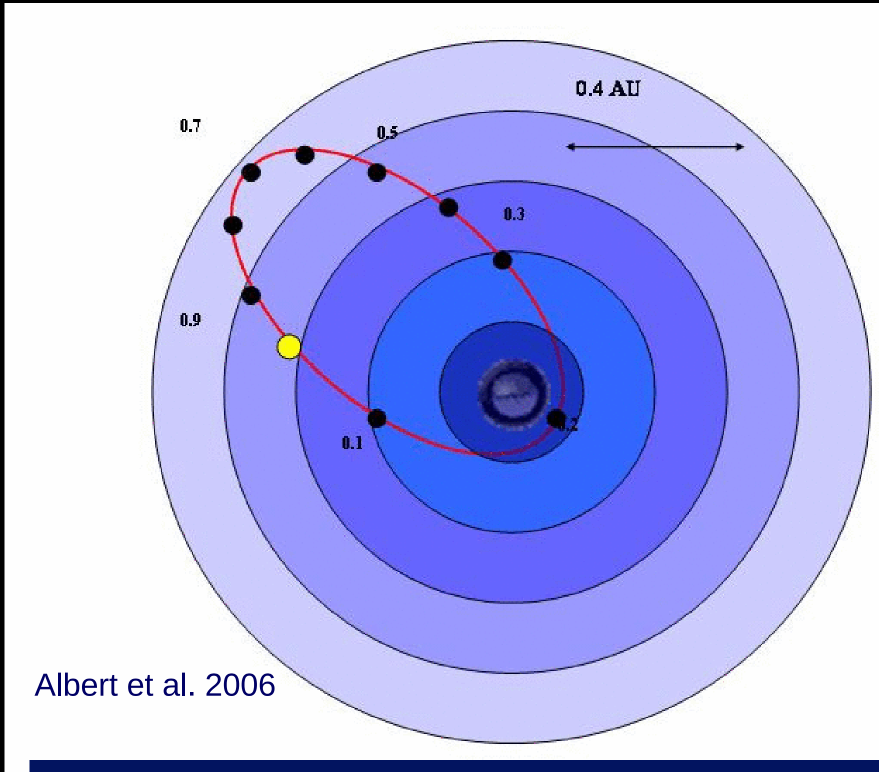
- **MAGIC** has observed LS I +61 303 for 54 hours from November 2005 to March 2006 (6 orbital cycles)



Albert et al. 2006, Science

- **A point-like source** (E>200GeV) detected with significance of ~9σ
- Position: RA=$2^h40^m34^s$, DEC=61°15' 25" [±0.4' (stat), ±2' (syst)] in agreement with LSI position ⇒ **identification of γ-ray source**
- The source is **quiet at periastron** passage and at relatively **high emission level** (16% Crab Nebula flux) at later phases [0.5-0.7]

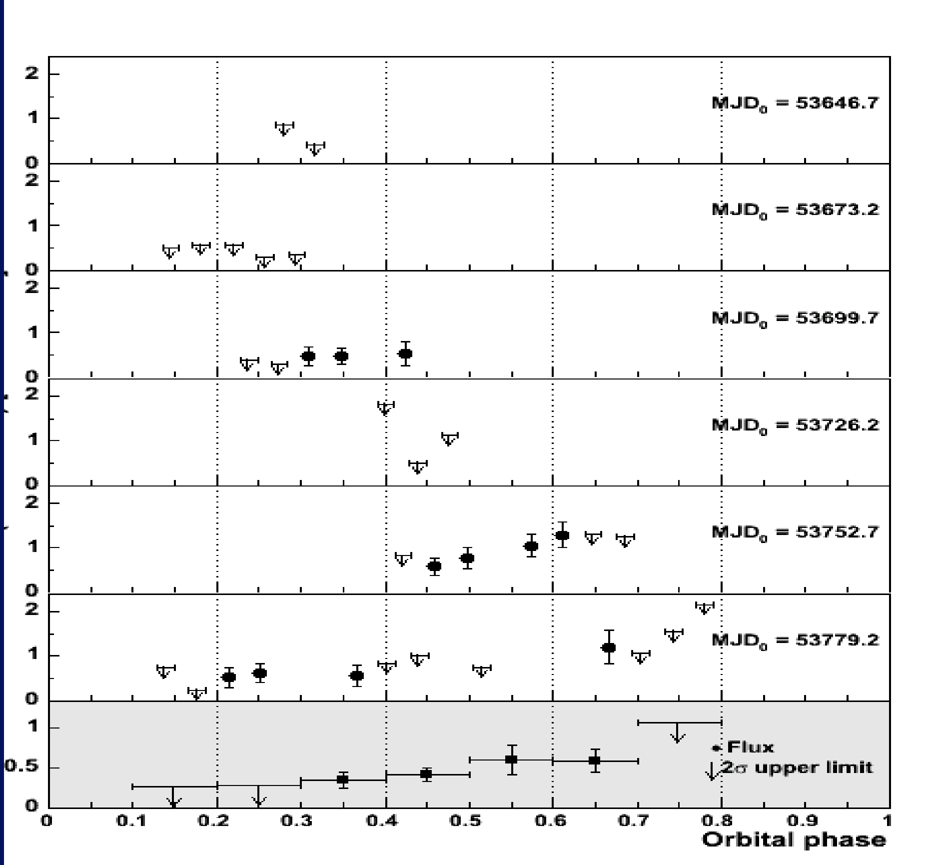
LS I +61 303: the film



- The average emission has a **maximum at phase 0.6**.
- Search for **intra-night flux variations** (observed in radio and x-rays) yields negative result
- **Marginal detections** occur at lower phases. We need more observation time at periastron passage
- Parts of the orbit not covered due to **similarities between orbital period (26.5 days) and Moon period**

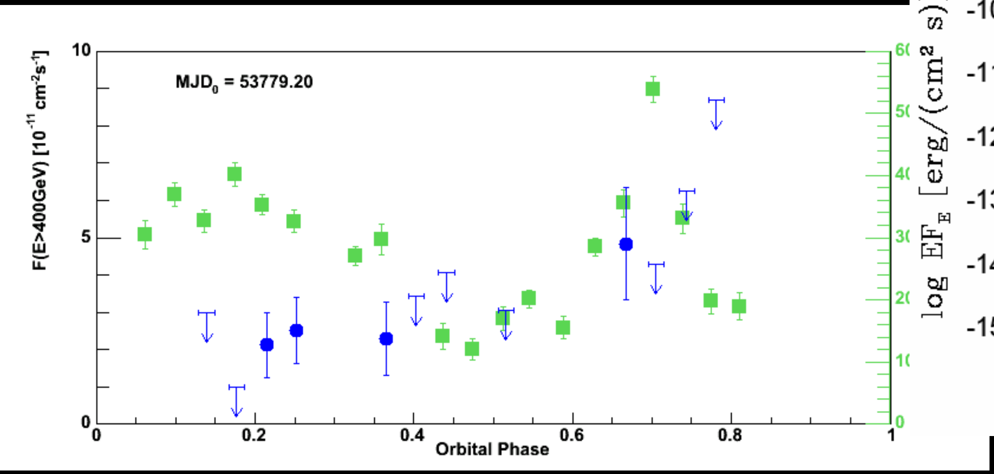
Flux variability

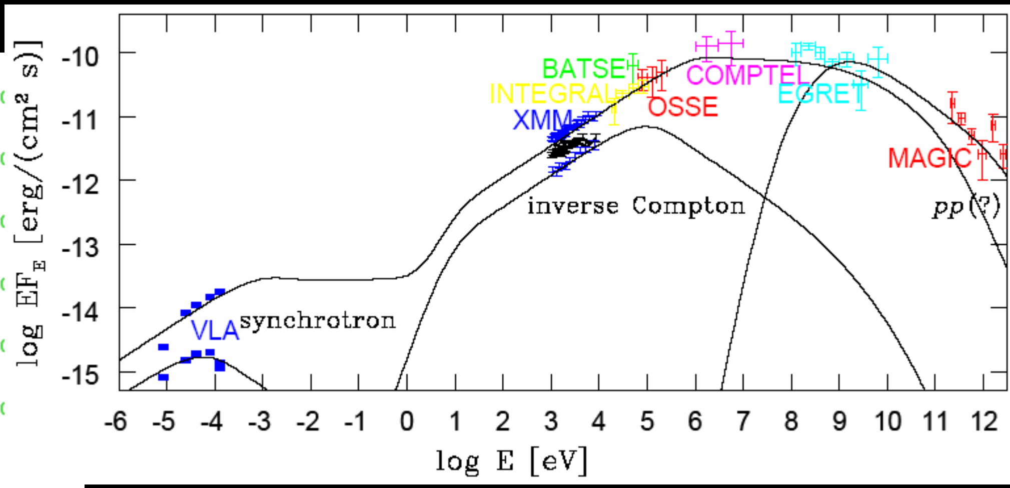
- **MAGIC** has observed LSI during 6 orbital cycles
- A **variable flux** (probability of statistical fluctuation 3×10^{-5}) detected
- **Marginal detections** at phases 0.2-0.4
- **Maximum flux** detected at phase 0.6-0.7 with a 16% of the Crab Nebula flux
- **Strong orbital modulation** ⇒ the emission is produced by the interplay of the two objects in the binary
- No emission at periastron, two maxima in consecutive cycles at similar phases ⇒ **hint of periodicity!**



Albert et al. 2006

Contemporaneous radio observations





Albert et al. 2006

- We perform **contemporaneous radio observations** (Ryle telescope 15GHz) during the last observed orbital cycle
- **Two maxima** are detected: just before periastron and higher at phase 0.7
- **TeV peak** observed before the radio ???
- The absence of a spectral feature between 10 and 100 keV *goes against* an accretion scenario !!!!

Extragalactic Objects

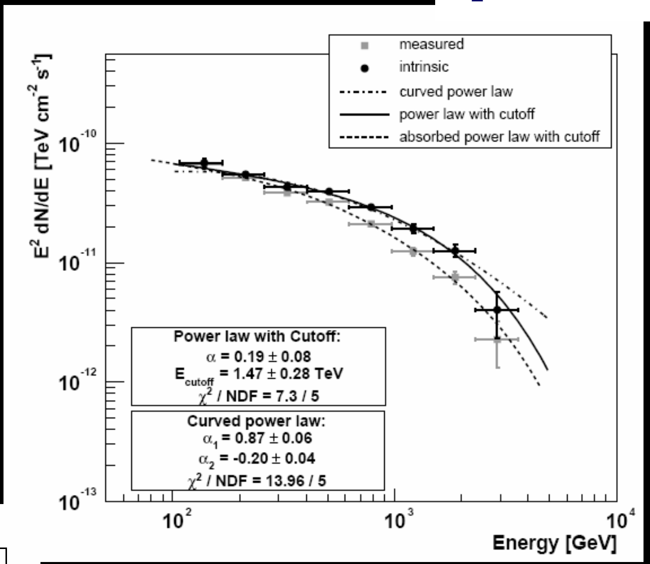
- Active Galactic Nuclei (AGN) and blazars
- MAGIC
  - Markarian 421, z=0.030
  - Markarian 501, z=0.034
  - Markarian 180, z=0.045
  - 1ES1959+650, z=0.047
  - 1ES1218+304, z=0.182
  - PG1553+113, z>0.09

redshift

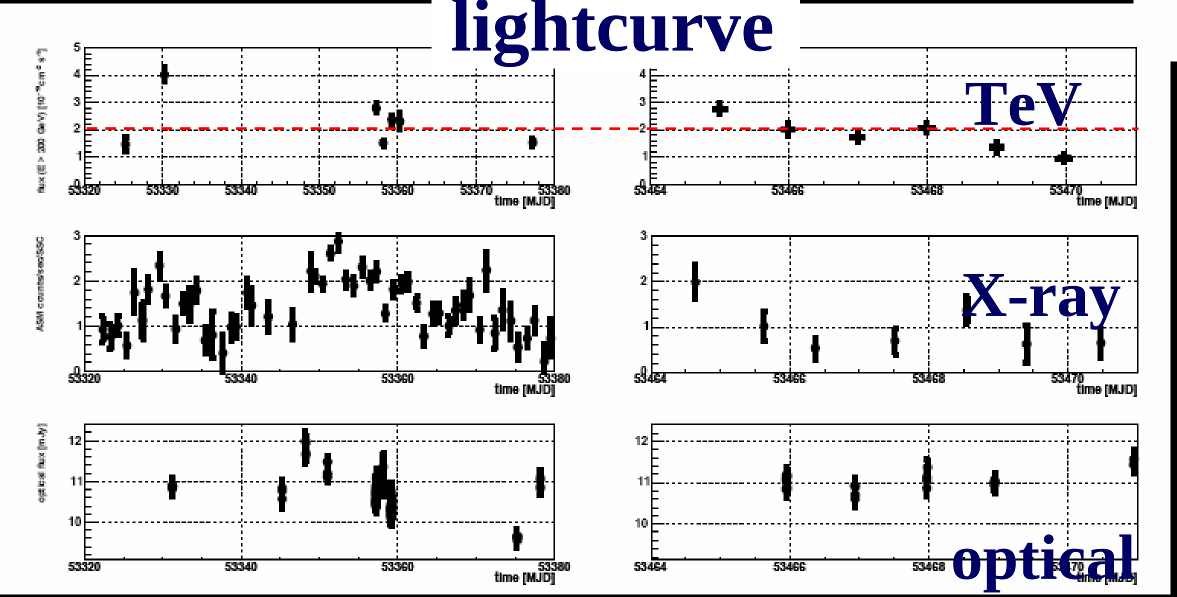
Mkn 421 (z=0.030)

- Dec 2004 – Apr 2005
- 25.6 h, over 7000 excess events
- Energy threshold: 150 GeV

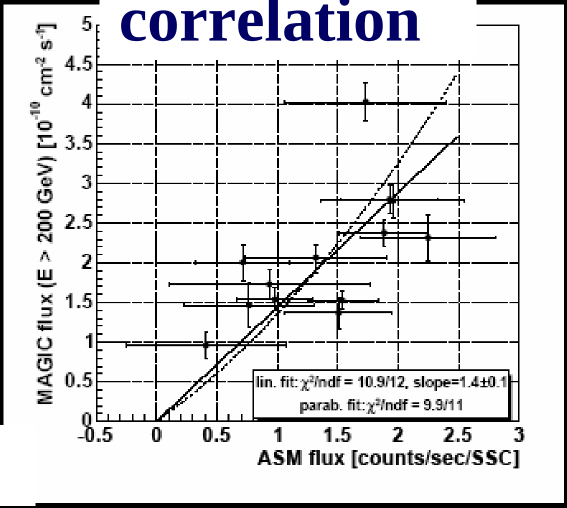
spectrum



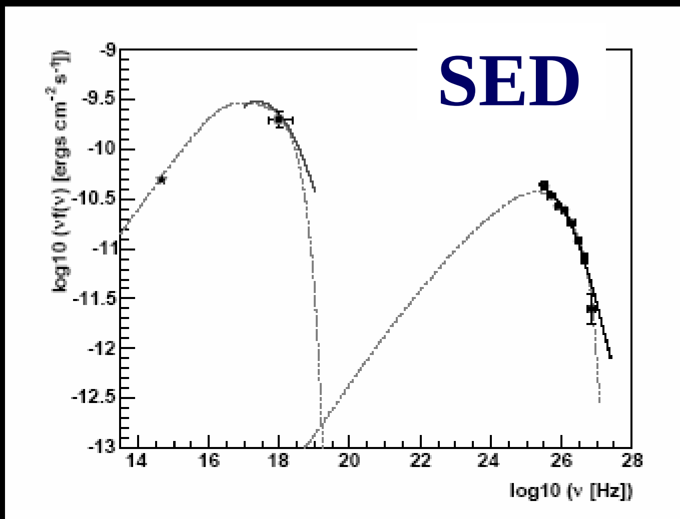
lightcurve



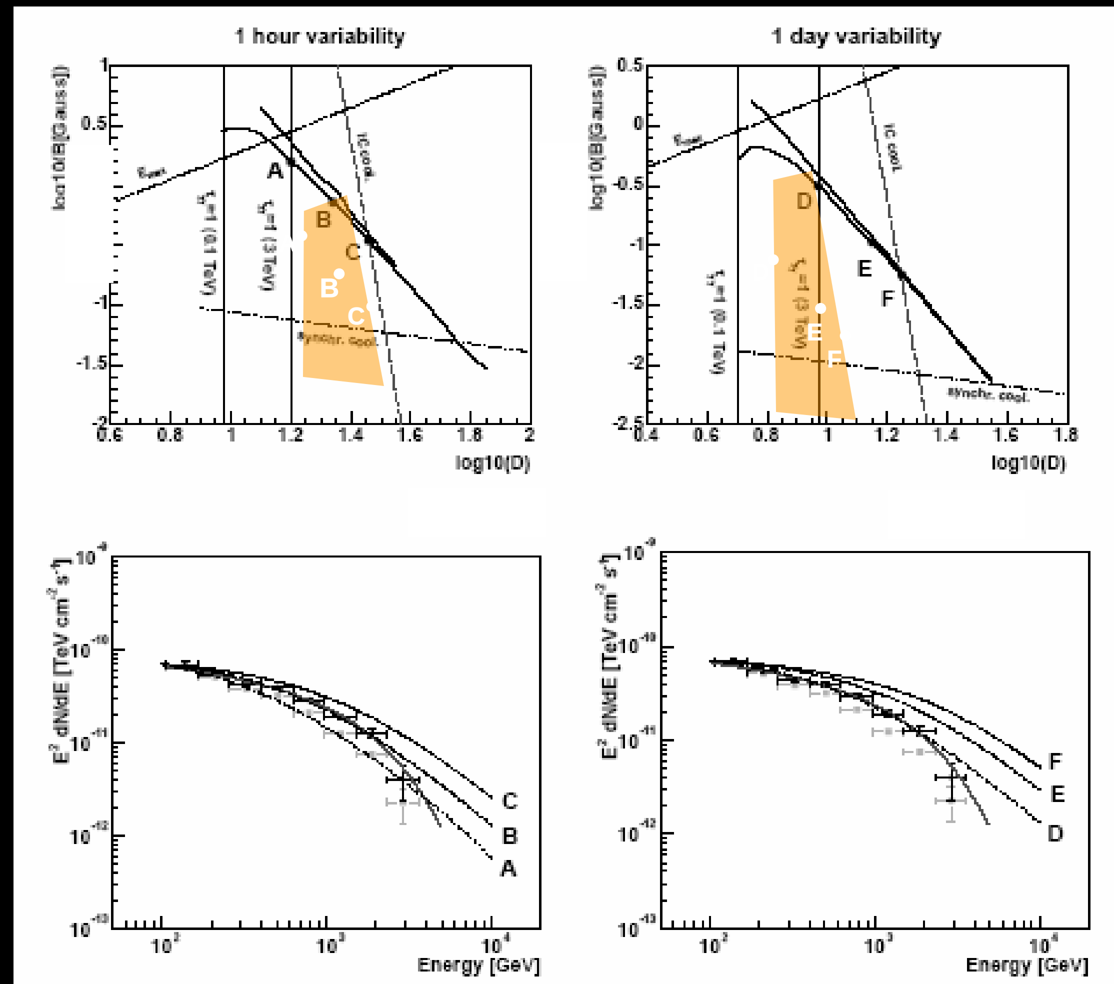
TeV-X-ray-correlation



Mkn 421 (z=0.030)



SSC constraints

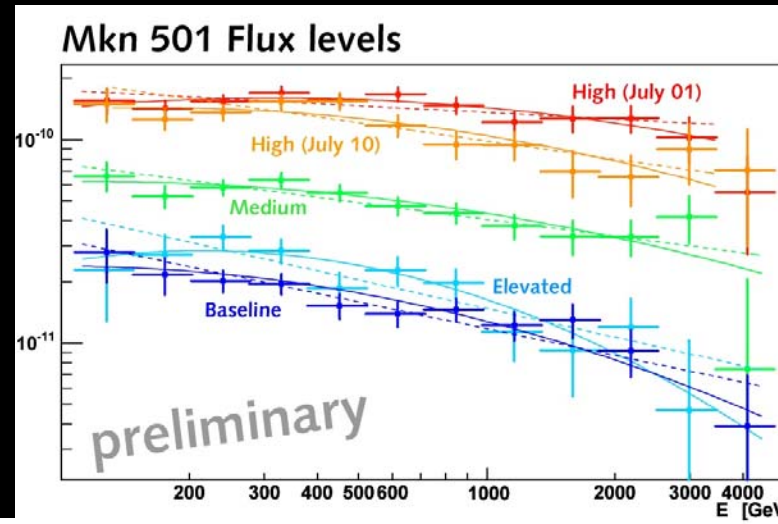


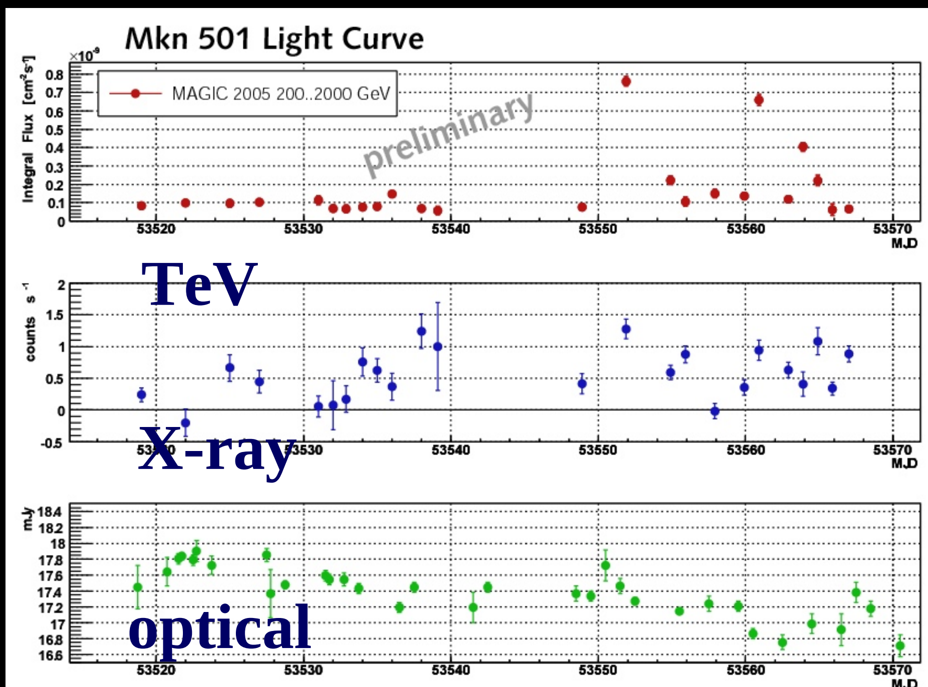
- In case of 1-day variability scale, the model provides similar parameters as from the 1994 flare: D=9, B=0.3G

astro-ph/0603478

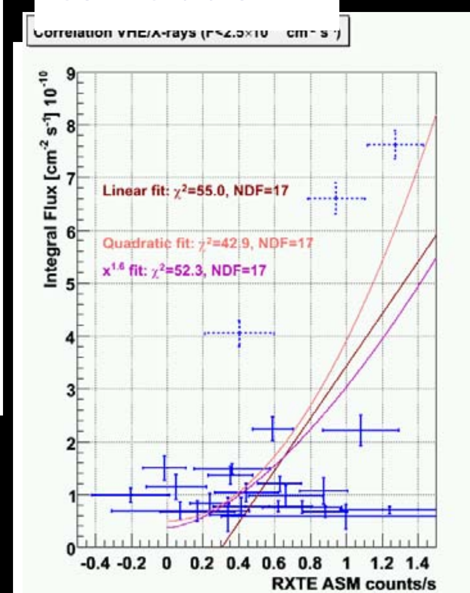
Mkn 501 (z=0.034)

- June – July 2005
- 23.1 h, over 85 σ, over 14000 excess events
- Analysis threshold: 150 GeV

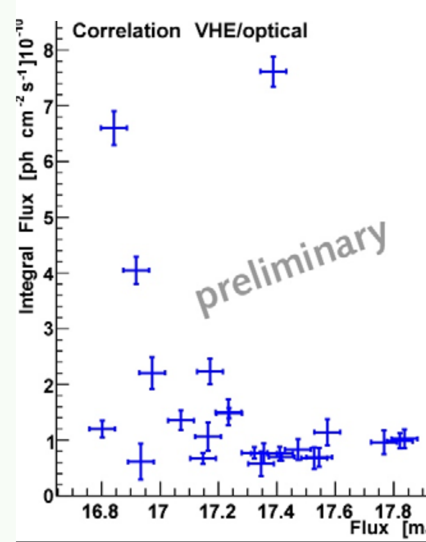




TeV/X-ray-correlation

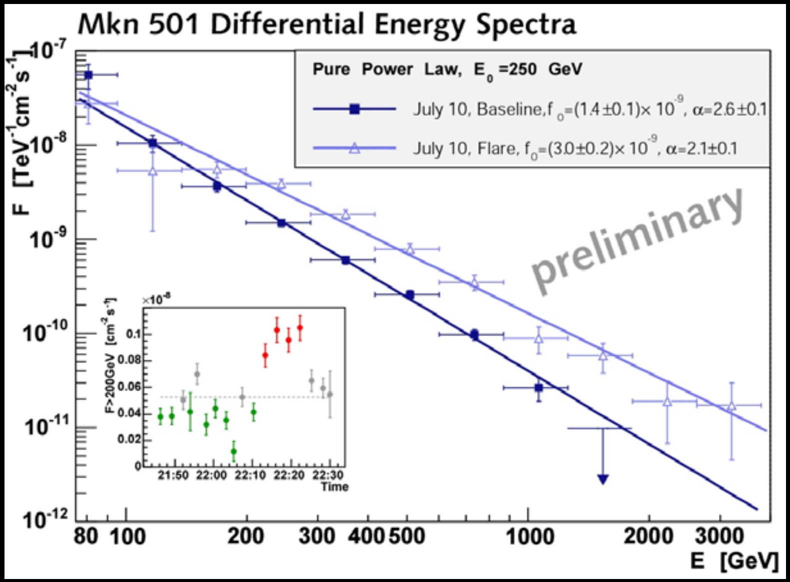


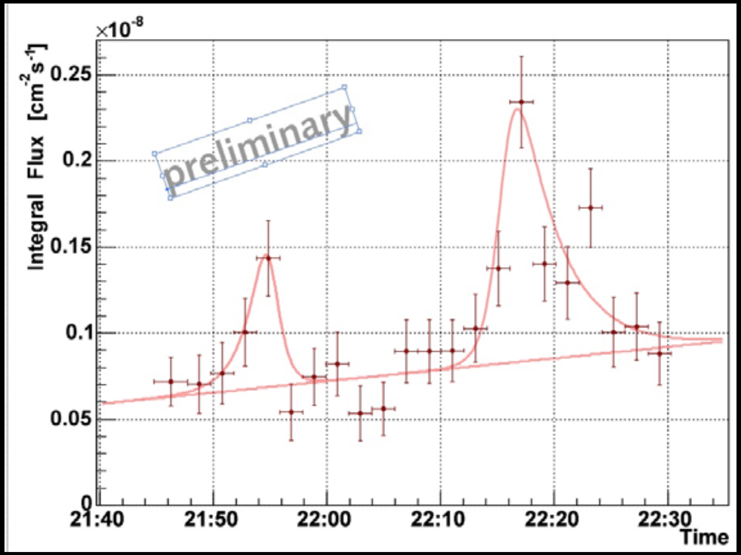
TeV-optical-correlation

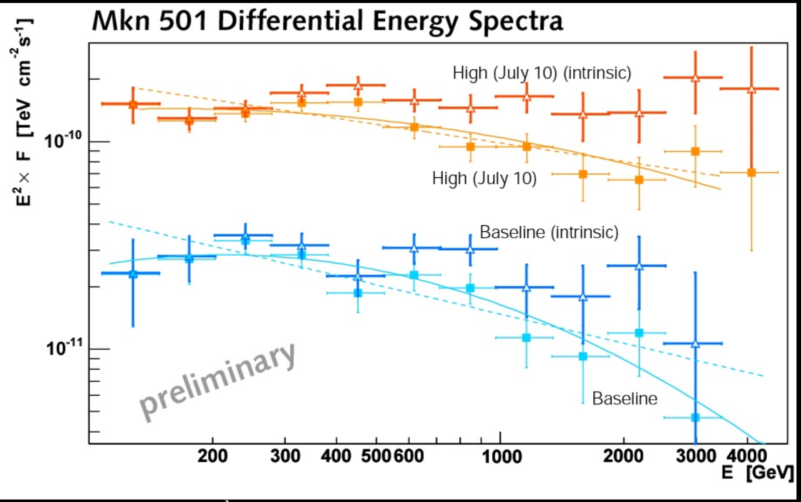


Mkn 501 (z=0.034)

- Flare on 9 July 2005
- Doubling time less than 5 min.
- Spectrum shape changes within minutes
- IC peak detected?



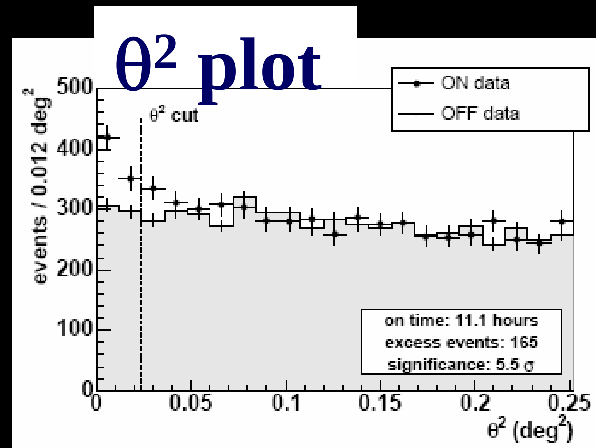


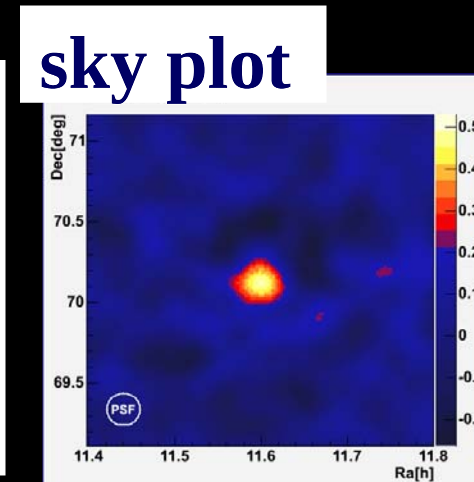


P.Majumdar, 24th August, IIA, India

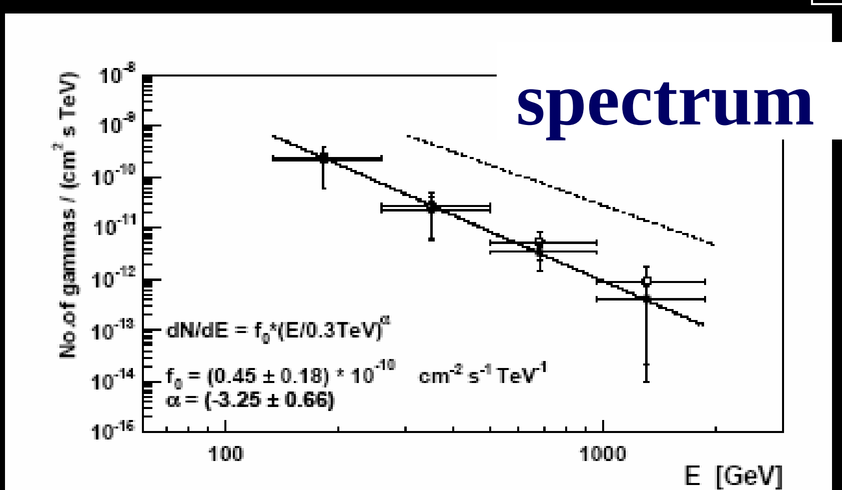
Mkn 180 (z=0.045)

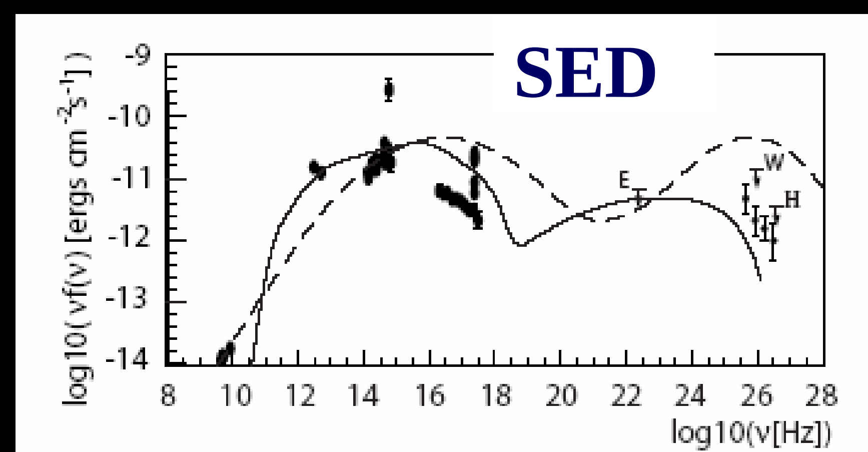
- Whipple: $F_{(>300GeV)}$<10.5% C.U.
- HEGRA: $F_{(>1.5TeV)}$<12% C.U.
- MAGIC: **DISCOVERY!**
- April 2006, 11.1 h
- Triggered by optical flare
- 5.5 σ, $F_{(>200GeV)}$ = 11%C.U., steep index: -3.3 ± 0.7





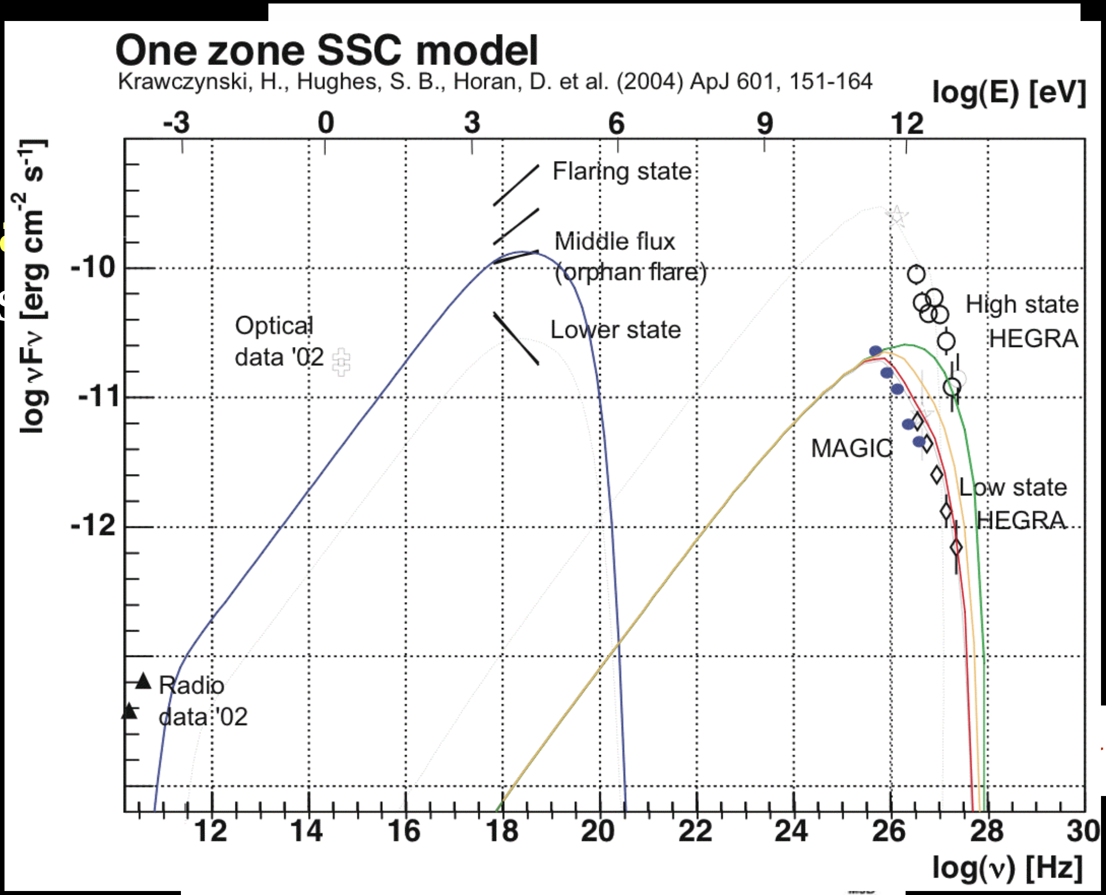
Accepted in ApJL

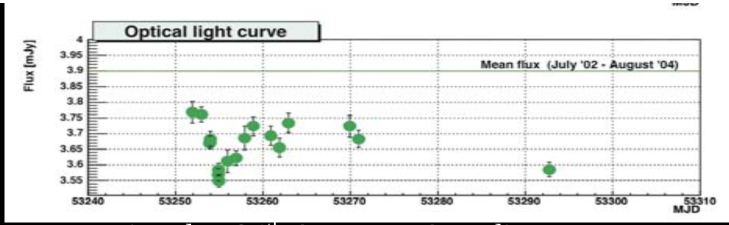




1ES1959+650 (z=0.047)

- Blazar famous for the orphan flare in 2002
- MAGIC: Significant signa in only 6h of effective obs ApJ, 639 (2006), 761
- Light curve: flaring or quiescent state?
- Current multiwavelength data not enough to distinguish between hardronic and leptonic models
- More data in pipeline

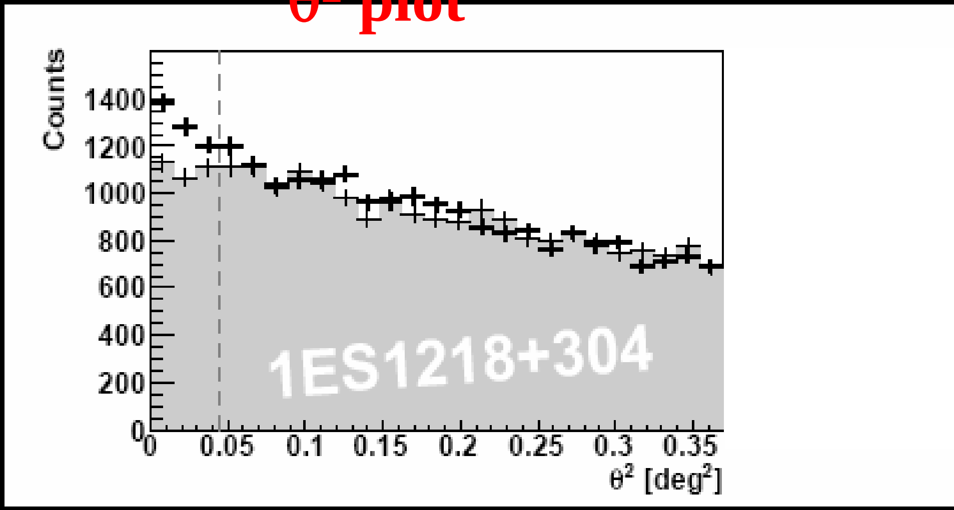




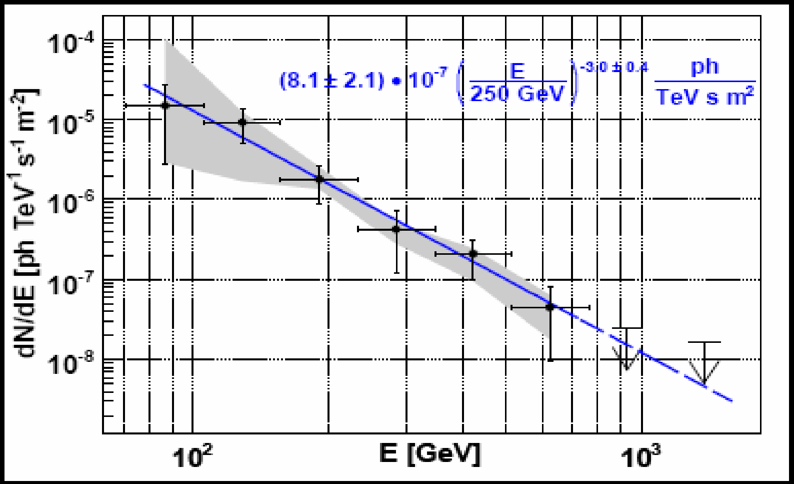
1ES1218+304 (z=0.182)

- Whipple: $F_{(>350GeV)}$<8% C.U.
- HEGRA: $F_{(>750GeV)}$<12% C.U.
- MAGIC: **DISCOVERY!**
- Jan 2005, 8.2 h
- 6.4 σ, $F_{(>120GeV)}$ = 13% C.U., index: -3.0 ± 0.4

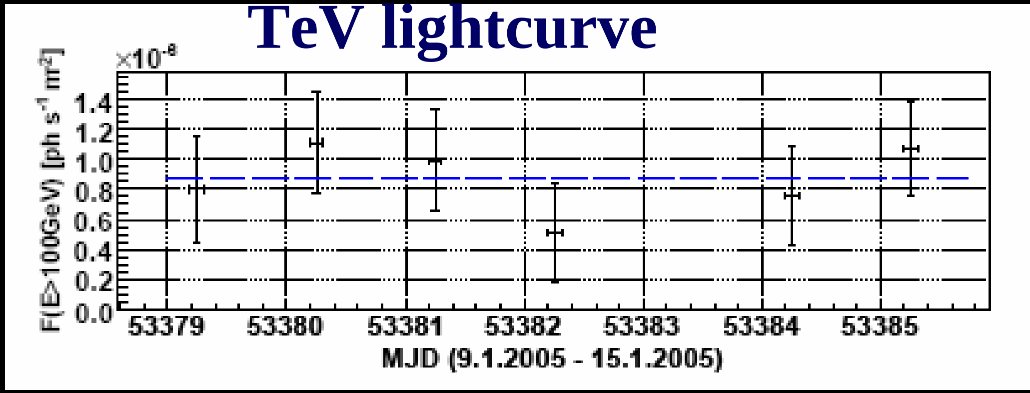
θ^2 plot



spectrum

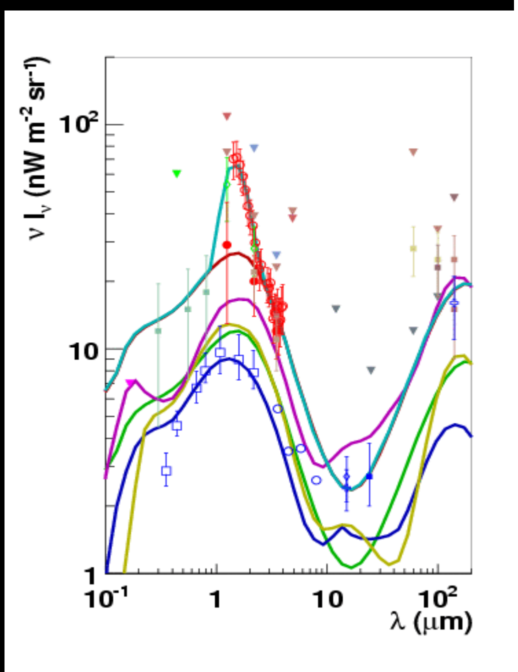


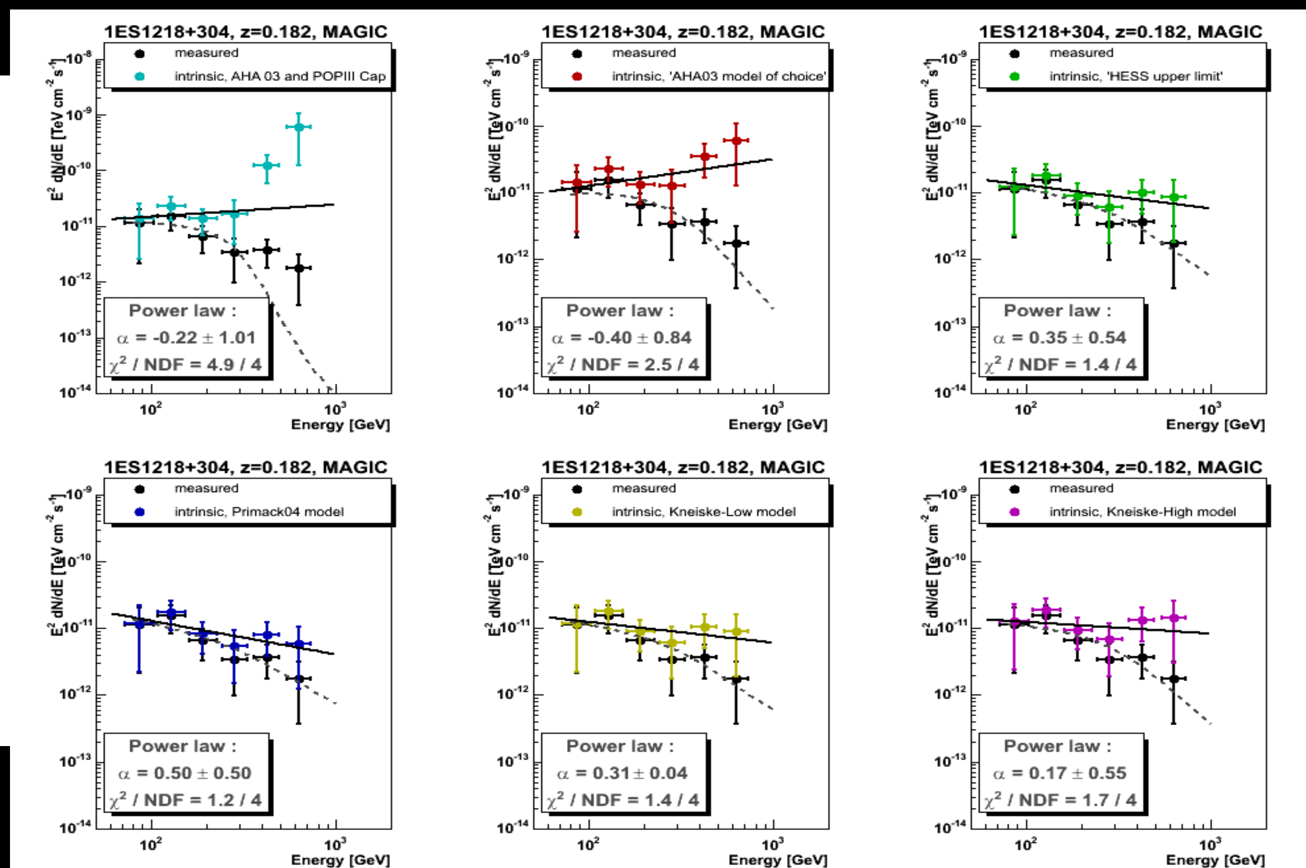
TeV lightcurve



1ES1218+304 (z=0.182)

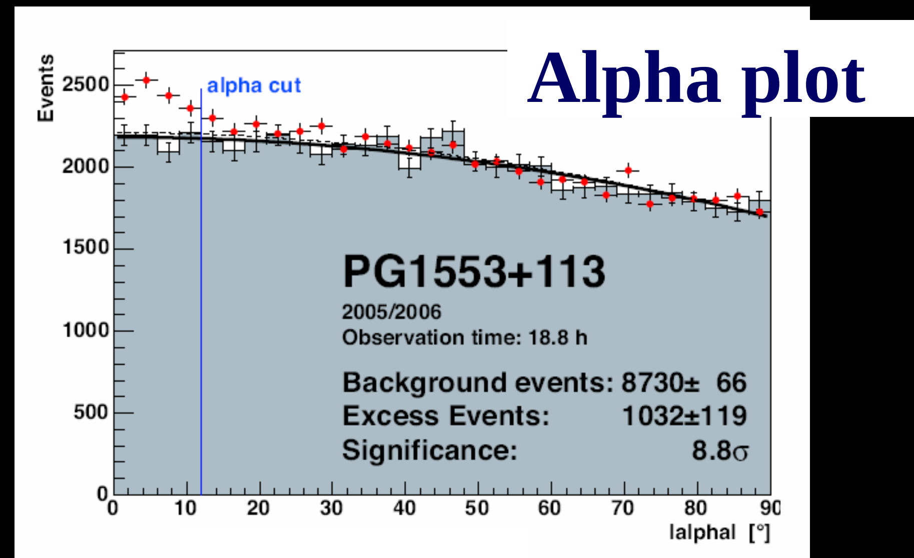
- Is it possible to derive EBL constraints from the 1ES1218 spectrum?
- Assuming 6 different EBL realizations, all reconstructed de-absorbed spectra do not contradict the rising slope dN/dE ~ $E^{-\Gamma}$, $\Gamma > 1.5$

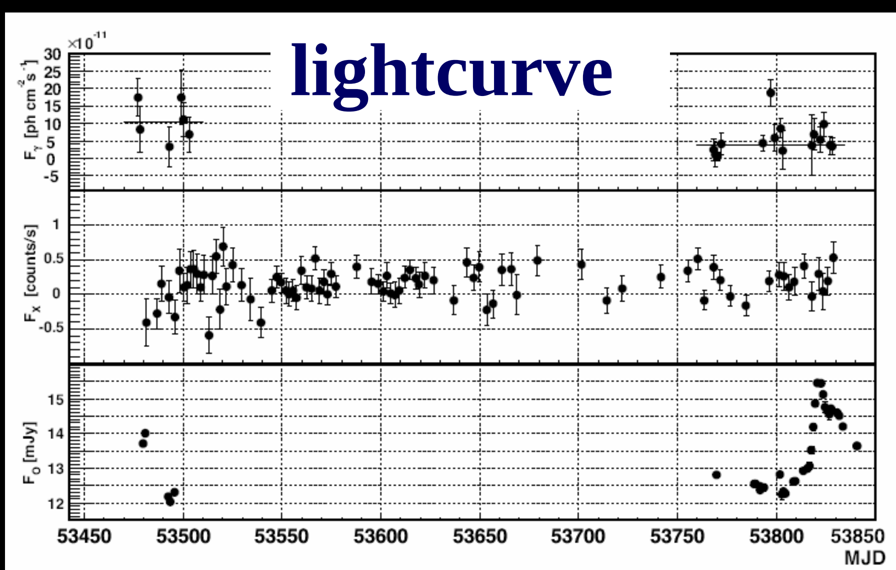


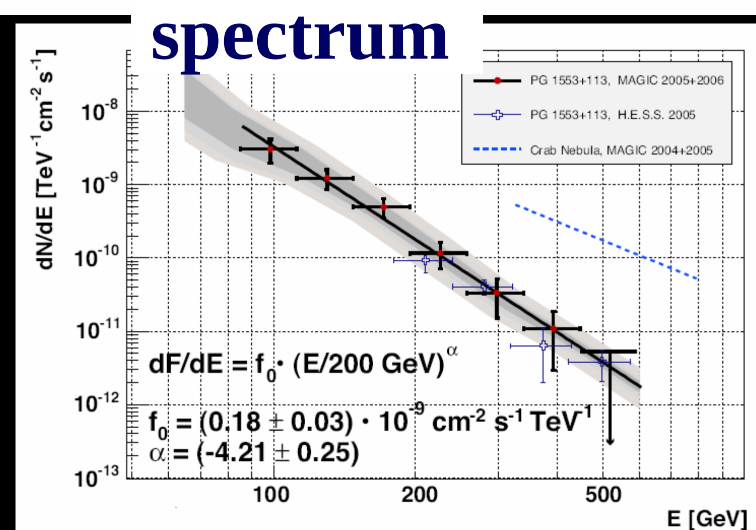


PG1553+113 (z>0.09)

- Observed 18.8h in 2005-06
- H.E.S.S.: 4.0σ evidence
  (A&A 448L (2006), 43)
- MAGIC: astro-ph/0606161
- 8.8σ, firm detection.







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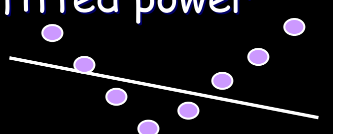
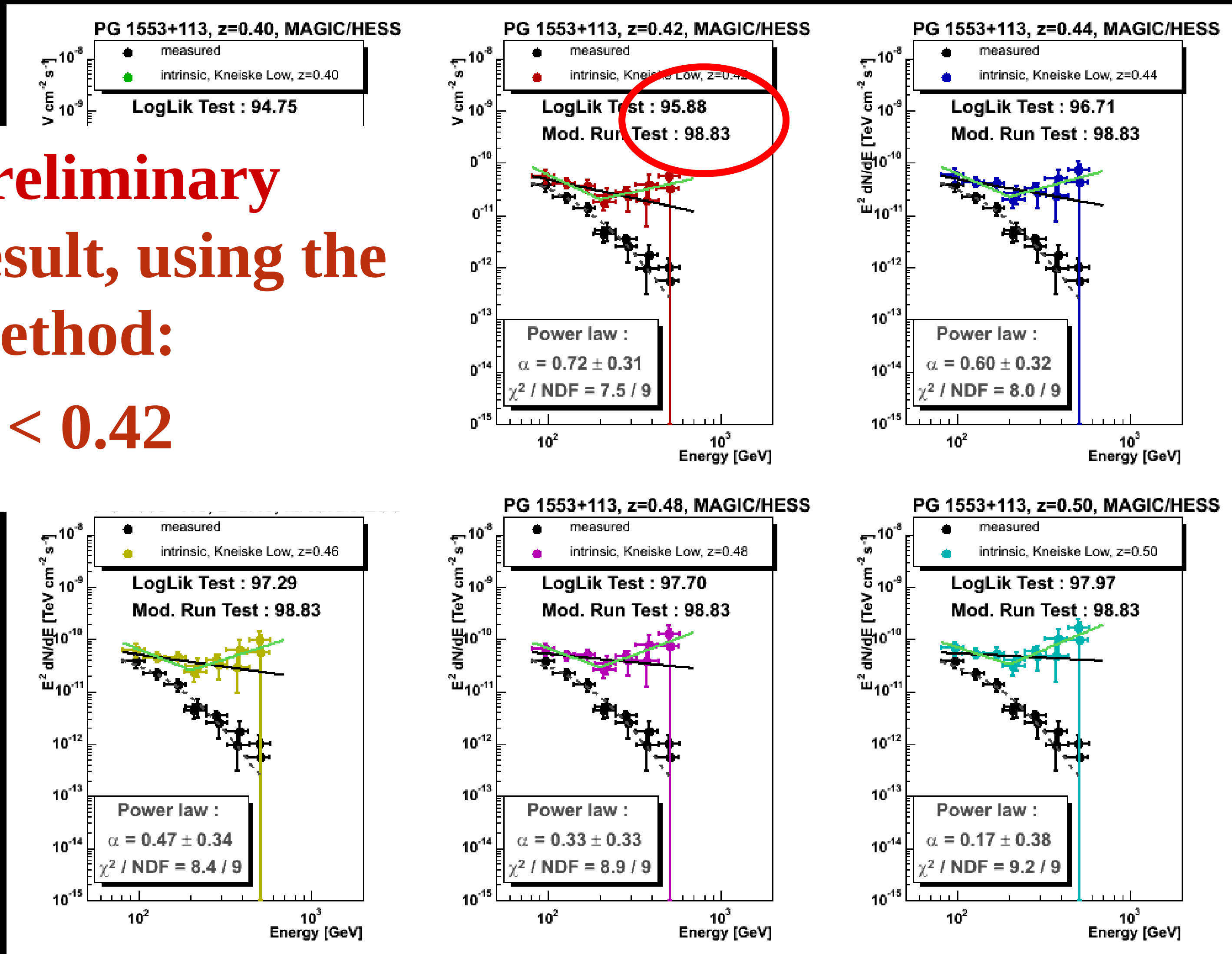
PG1553+113 (z>0.09)

- Put HESS/MAGIC Spectrum together
- Apply correction factor to accoun[t] for systematics
- Method 1: Loglikelihood tes[t] between power law and broken power law
- Method 2: modified run test; probability of the given distribution of points around the fitted power law





Preliminary result, using the method:

z < 0.42

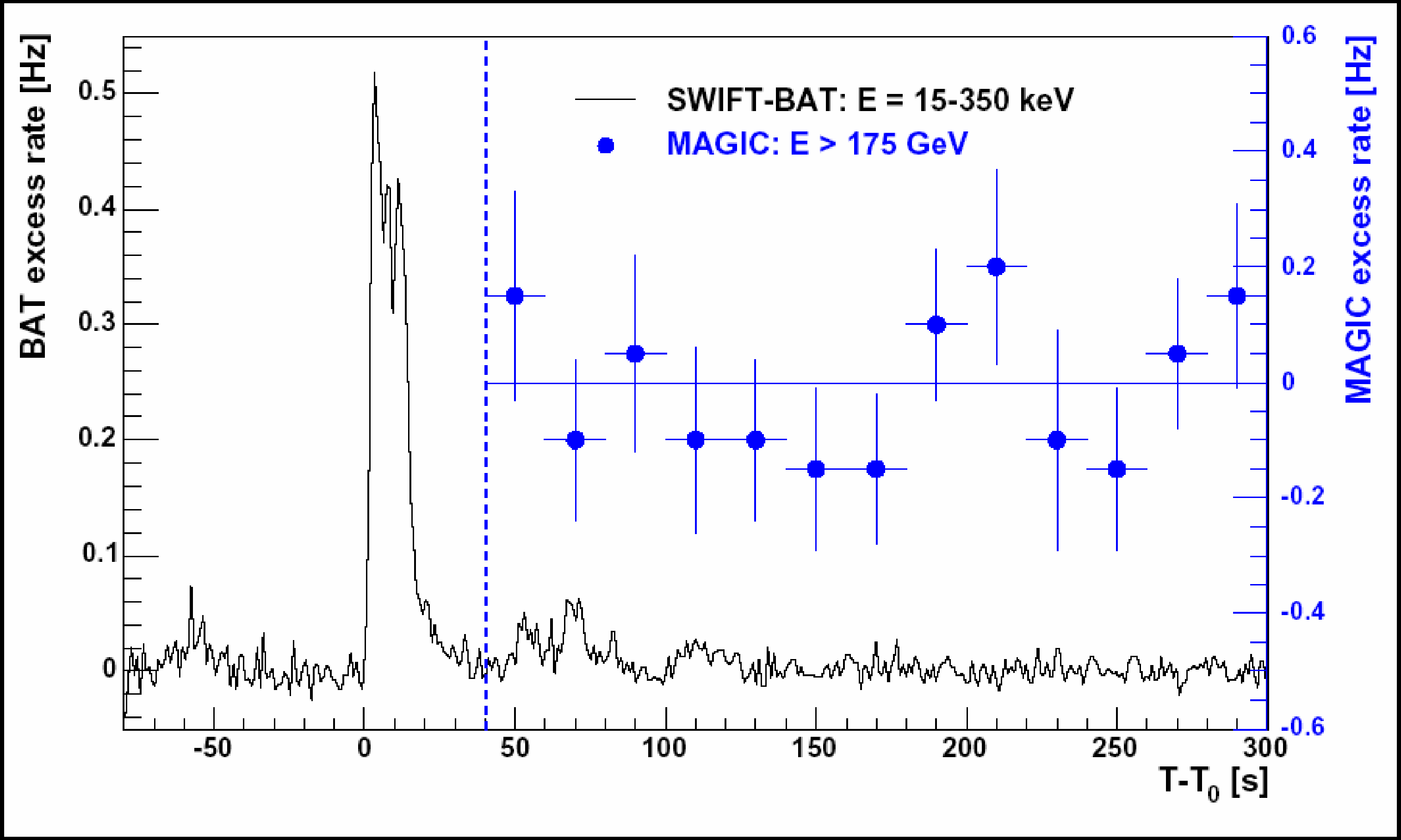
First year operation (Sep04-Sep05): Gamma-Ray Bursts

#	GRB Event	Satellite	Onset [UTC]	Δt alert [sec]	Δt obs. [sec]	θ [deg]	z
1	GRB050408	HETE	16:22:50	14	3138	48	1.23
2	GRB050421	SWIFT	04:11:52	58	112	52	
3	GRB050502	SWIFT	02:14:18	18	990	33	3.79
4	GRB050505	SWIFT	23:22:21	540	793	50	4.27
5	GRB050509	SWIFT	01:46:29	16	115	57	
6	GRB050509	SWIFT	04:00:19	15	368	69	0.23
7	GRB050528	SWIFT	04:06:45	43	77	52	
8	GRB050713	SWIFT	04:20:02	13	40	49	
9	GRB050904	SWIFT	01:51:44	82	92	20	6.29

Drive system improvement

On 13 July 2005 MAGIC pointed to a GRB only 40 s after prompt emission

Light curve GRB050713, as observed with MAGIC



Published in ApJ Letters

No significant excess above 175 GeV

Extension of MAGIC => MAGIC II

- The MAGIC collaboration has started to build a second telescope

MAGIC II will
- increase the sensitivity of the observatory
- allow to further push for a lower energy threshold

Advantages of MAGIC II

- **Coincidence / Stereo mode**
  - better **sensitivity**
    - far and faint sources
    - time variability sources
  - better **angular resolution** (source location / identification)
  - **high purity** gamma selection (control of systemactics)

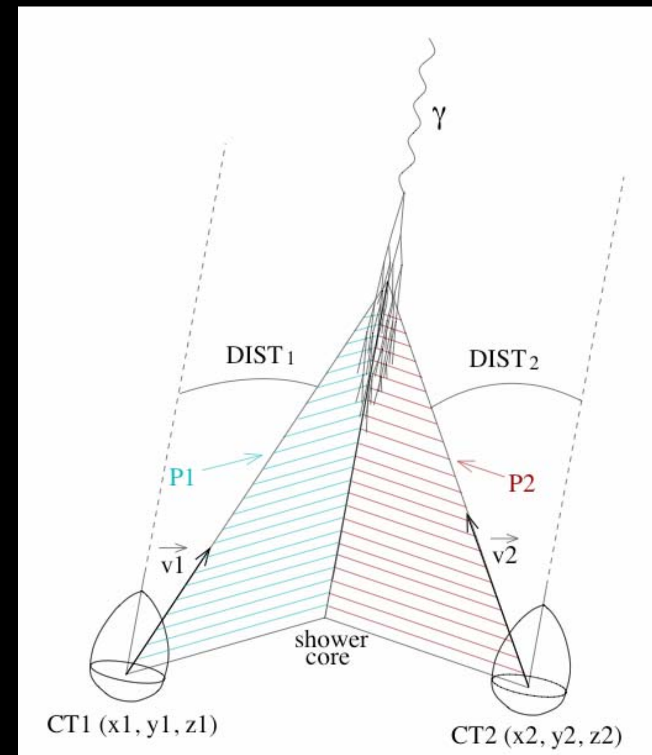
- **Parallel mode**
  - observe 2 objects simultaneously (e.g. search for flaring AGNs)

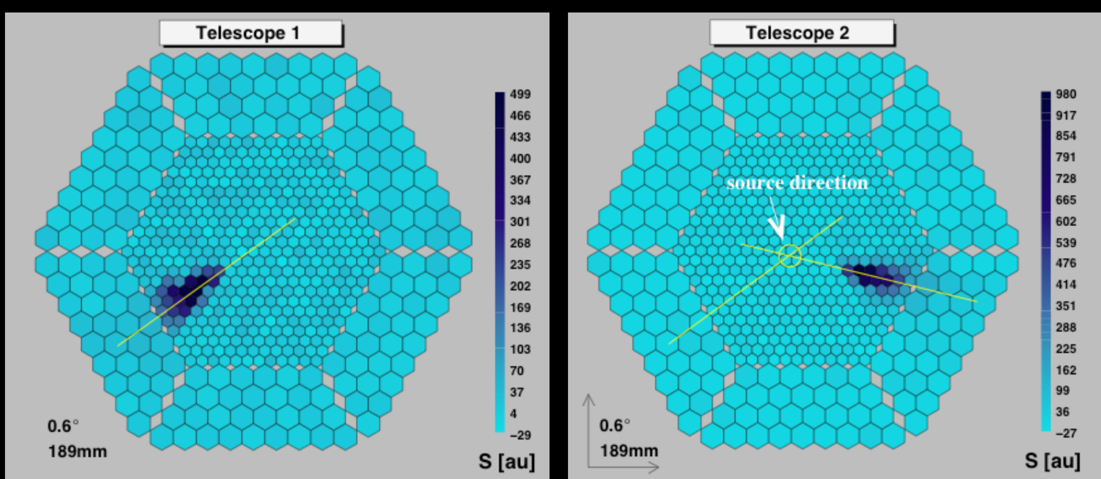
- **Testbench** for new technologies
  - higher Quantum Efficiency Camera
    => **lower energy threshold**
  - fast digitization
    2 GHz FADC => background reduction

MAGIC II Monte Carlo Studies

- **Stereo Analysis:**
  - observe shower simultaneously with 2 telescopes

  improve:
  - shower reconstruction (energy, arrival direction)
  - background rejection

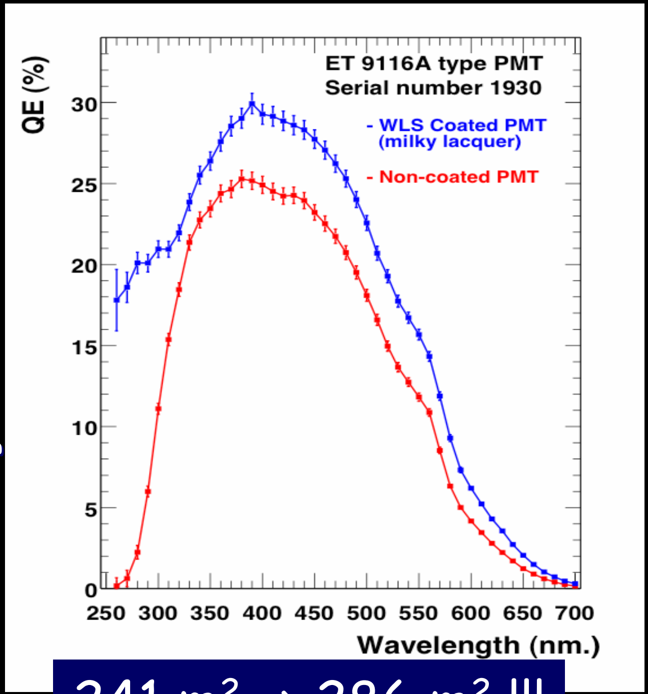




MAGIC II: "improved Clone"

- Clone overall design / telescope structure of MAGIC I
  => save time and money for redesign

- Employ improved technologies for key elements:
- High(er) Quantum Efficiency Camera
  (=> lower energy threshold)
  - HPDs (QE up to 50%)
  - long term: SiliconPMs
    (QE up to 60 - 80% possible)
- Fast 2Gsamples/sec digitization
  - multiplexer FADC (planned already for MAGIC I)
  - switch capacitors
    (fast & flexible solution ready end 2006)

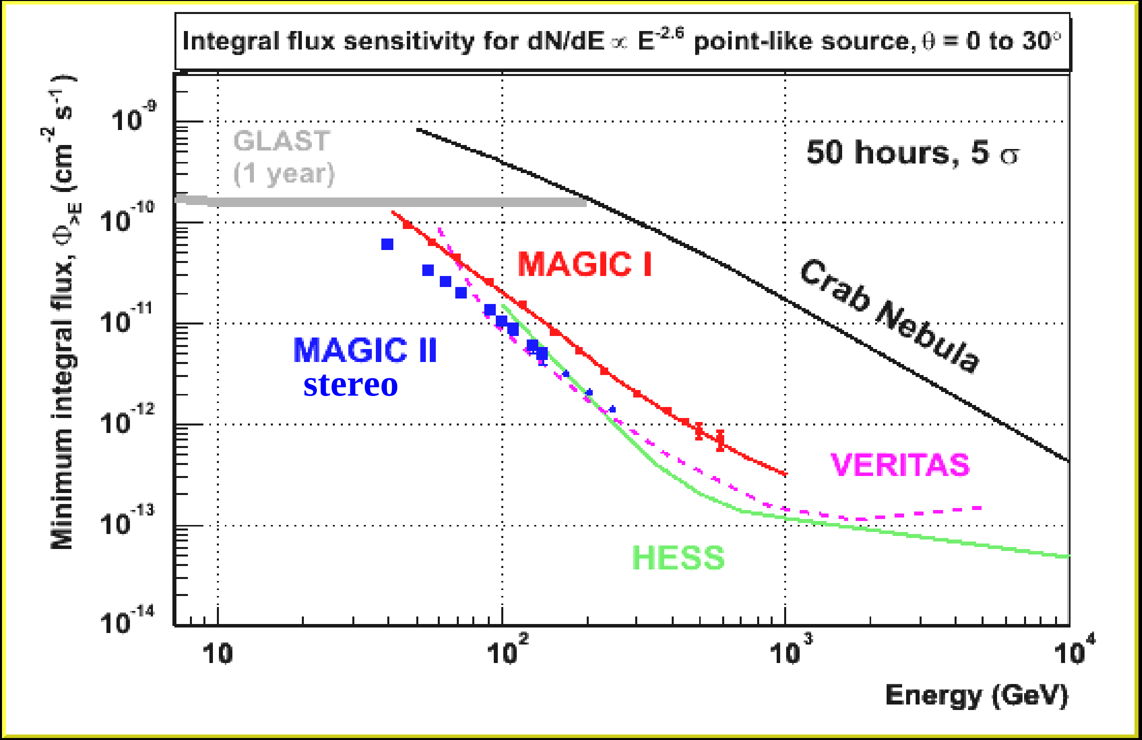


241 m^2 -> 286 m^2 !!!

MAGIC II: Sensitivity gain

using Stereo Analysis

- better **background rejection** down to low energies
- **increase sensitivity by factor 2**
  => reduce observation time by factor 4



Conclusions

- MAGIC is a successful pioneering telescope for low energy gamma ray astronomy producing quality results
- Succ
- Tele
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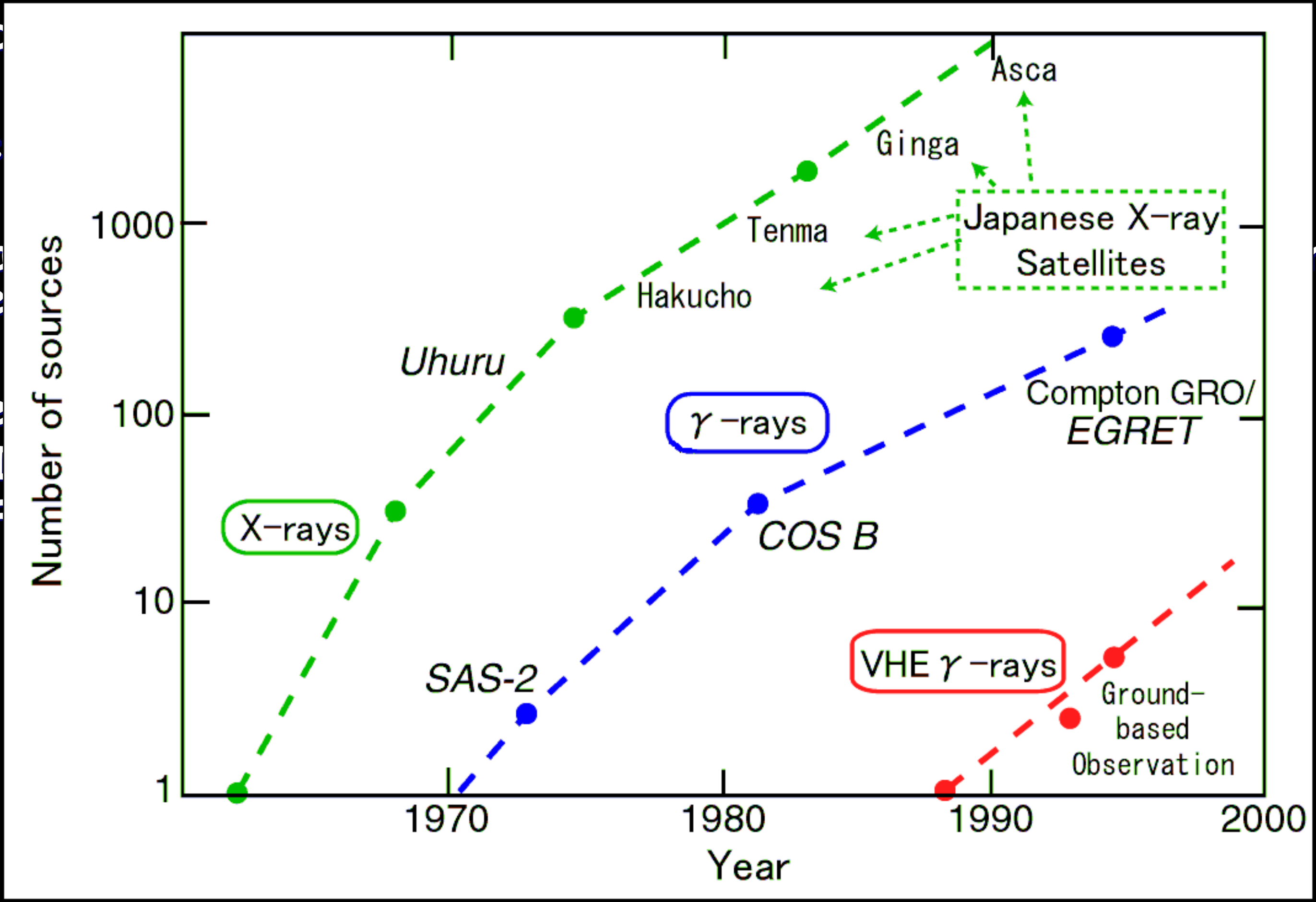

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