GeV-TeV γ-ray Astrophysics

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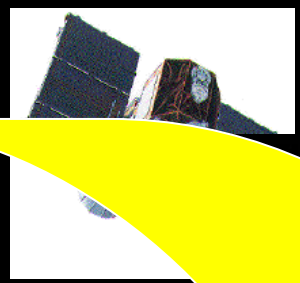
Scheme of the talk

- Very High Energy domain.
- New physics results.
- Latest experimental developments.
- Conclusions


The Very High Energy
γ-ray Domain

XX century: the new astronomies

Optical
(~1 eV)



UV
(5 eV-1 keV)

Infrared
(10^{-2} eV)

X-rays
(1 keV-500 keV)

Radio
(10^{-6} eV)

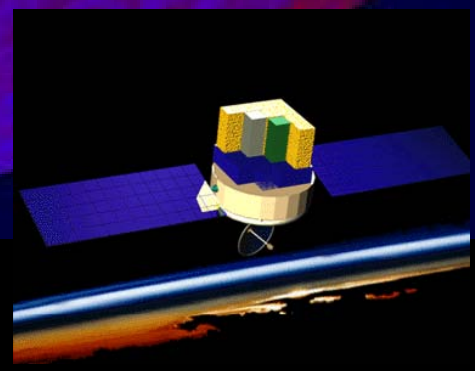
γ-rays (keV-1 GeV)

This way to VHE...

EGRET
Around 350 sources (250 unidentified)

High energy γ-rays (GeV = 10^9 eV)

The future at 1 GeV: GLAST

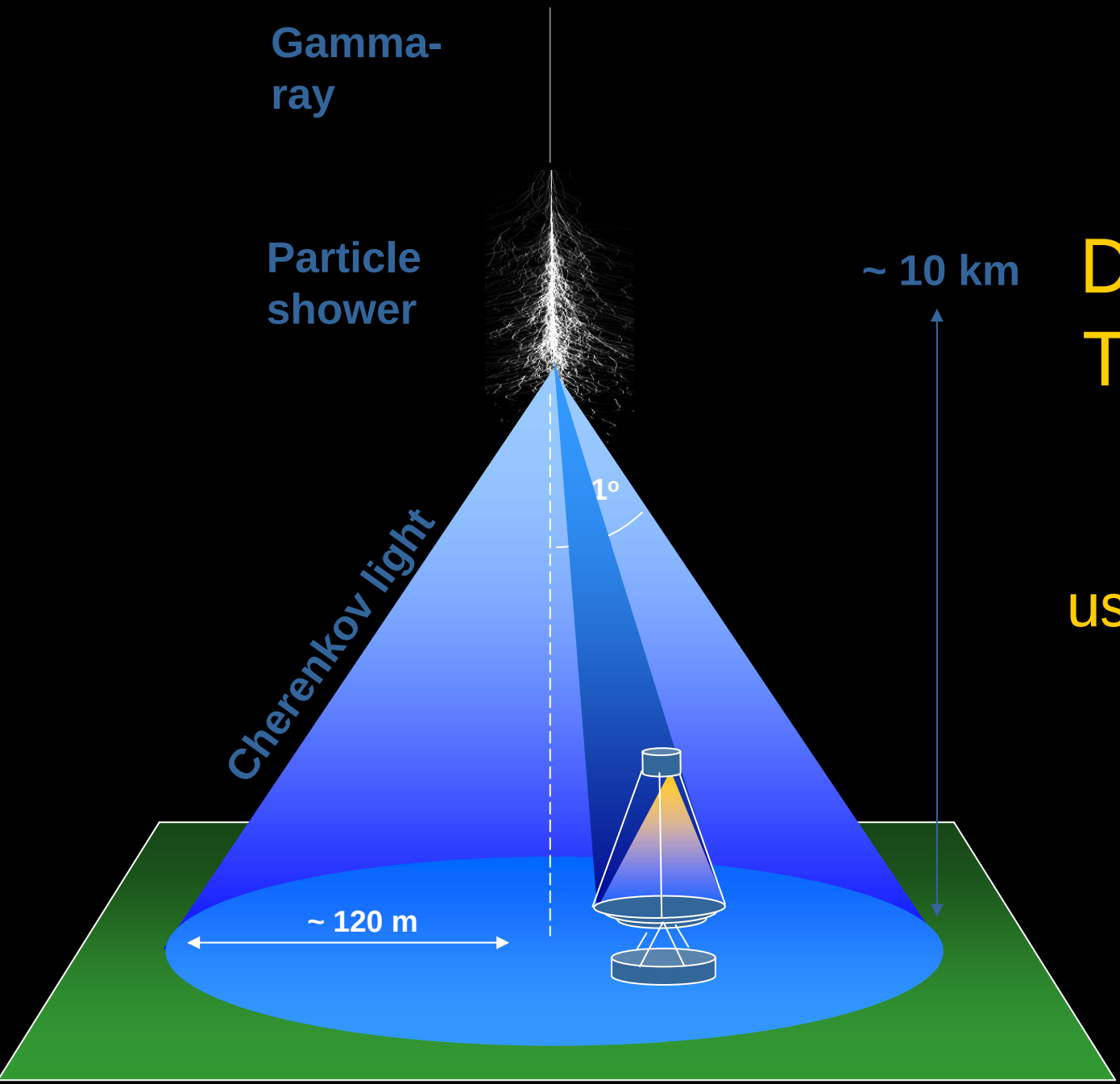


VHE γ-rays
(TeV = 10^{12} eV)

TeV Gamma rays
from the Crab Nebula
Whipple Cherenkov Telescope
1989

Even if TeV instruments have much better sensitivities than EGRET, they've only detected this handful of sources... and these sources are not related with the EGRET sources!

Need for a new generation of instruments...



Detection of TeV gamma rays

using Cherenkov telescopes

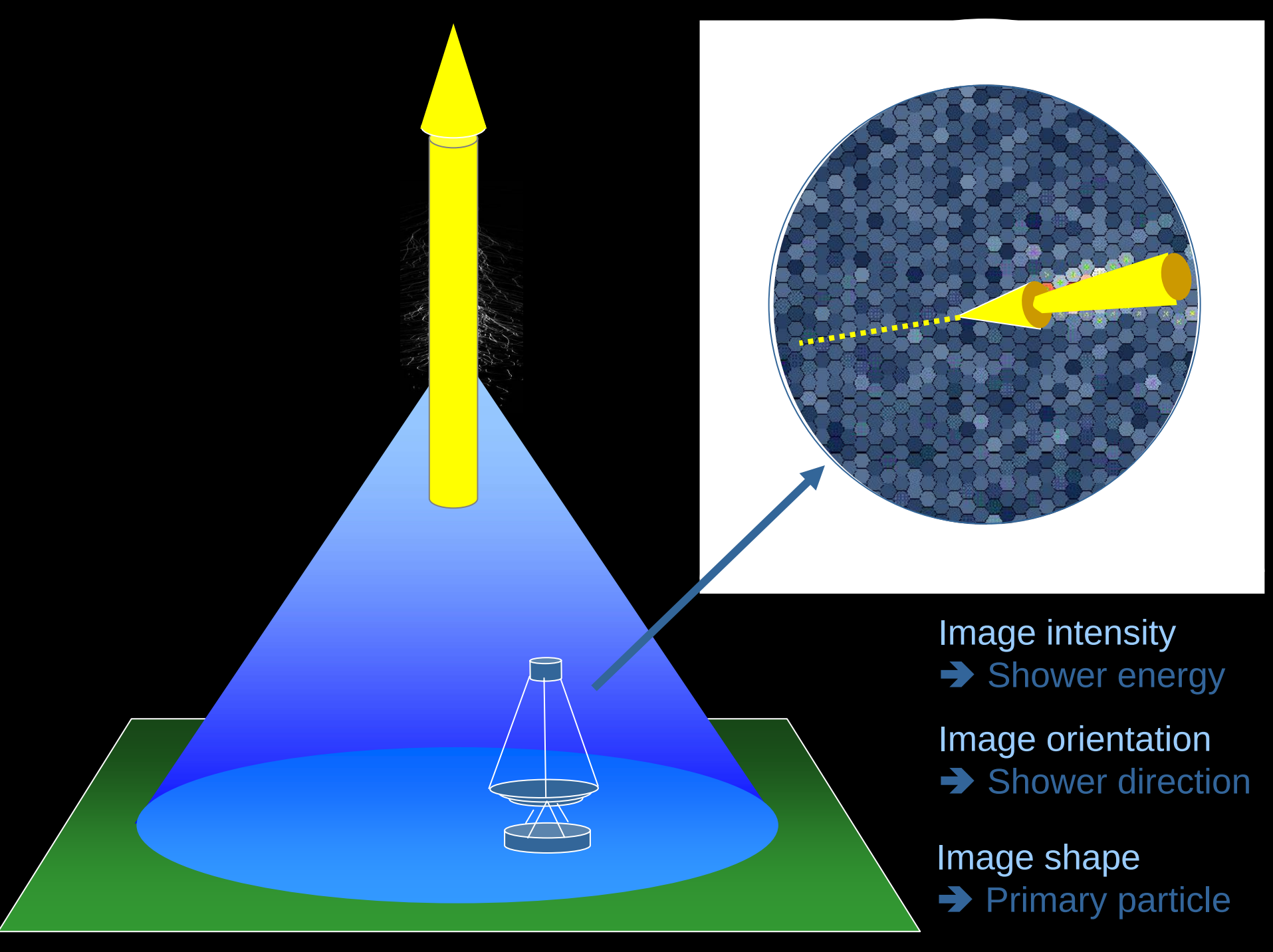
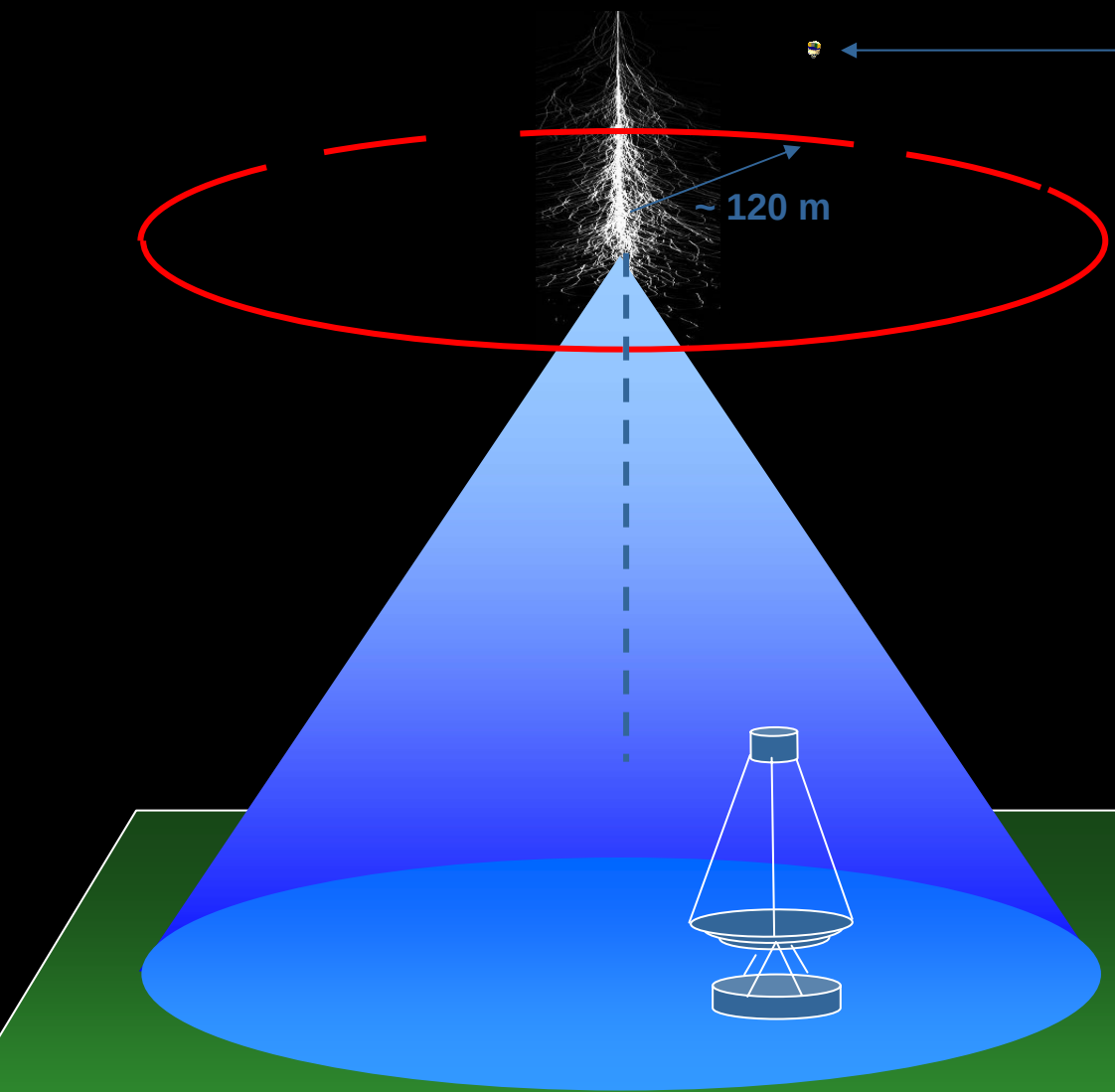


Image intensity
➔ Shower energy

Image orientation
➔ Shower direction

Image shape
➔ Primary particle

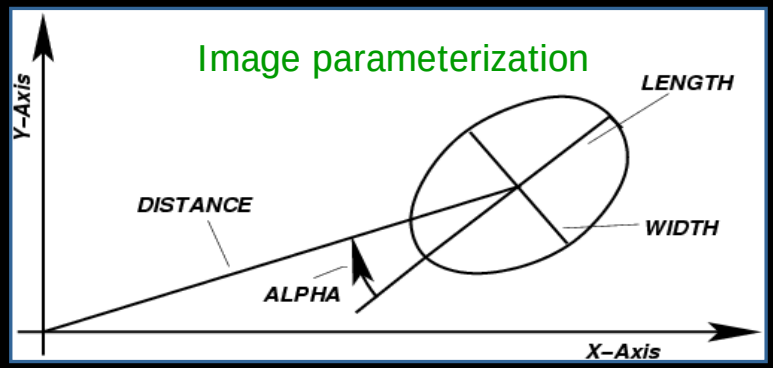
Detection area



~ 10^5 m^2

important since high energy gamma rays are quite rare (1 / m^2 year)

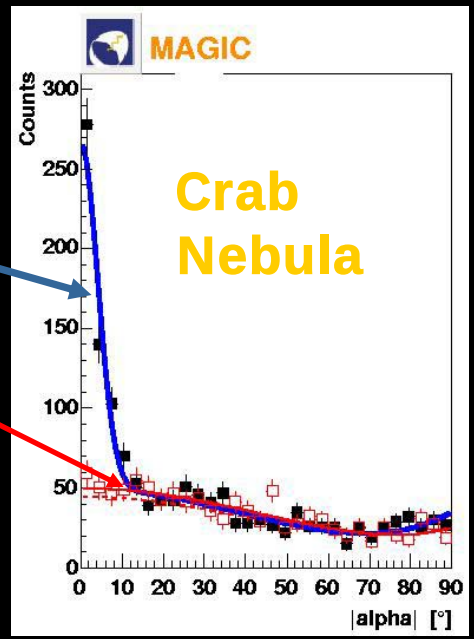
Getting rid of CR background I



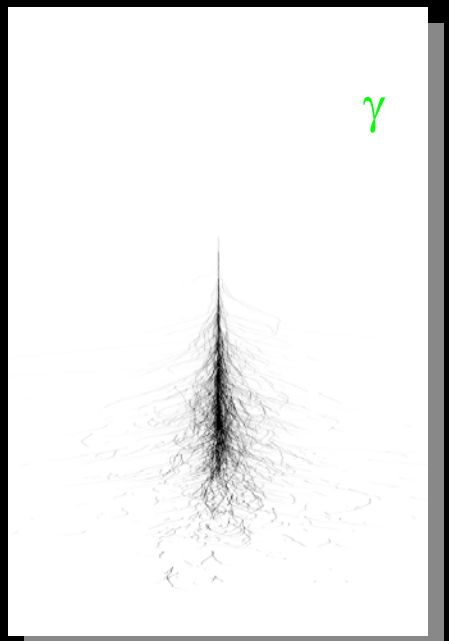
(1) **Orientation:** γ-rays point to the source: excess at small **alpha**

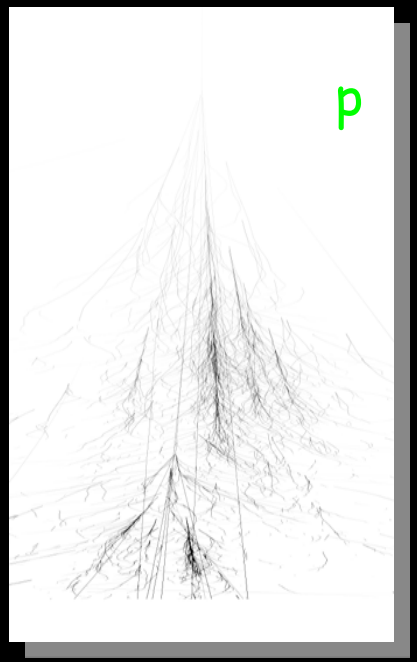
ON: Pointing to source

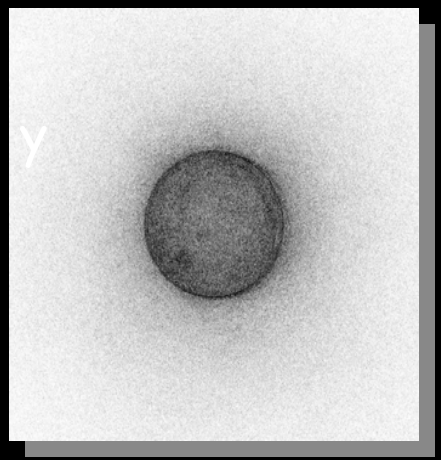
OFF: Pointing somewhere else

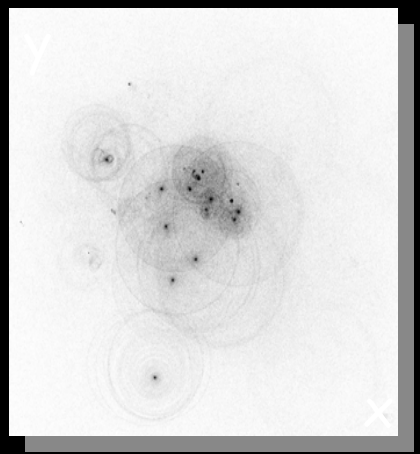


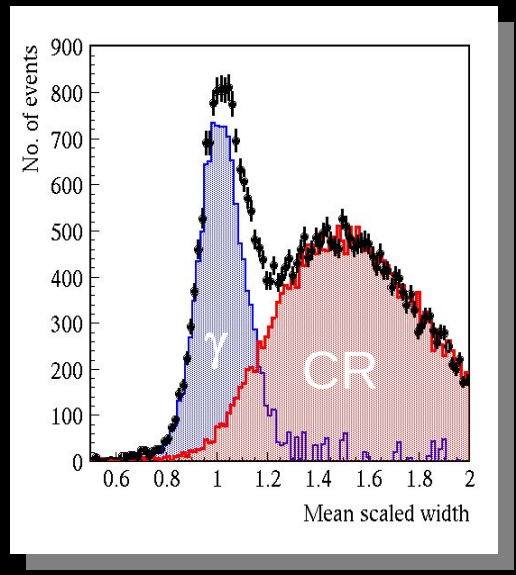
Getting rid of CR background II





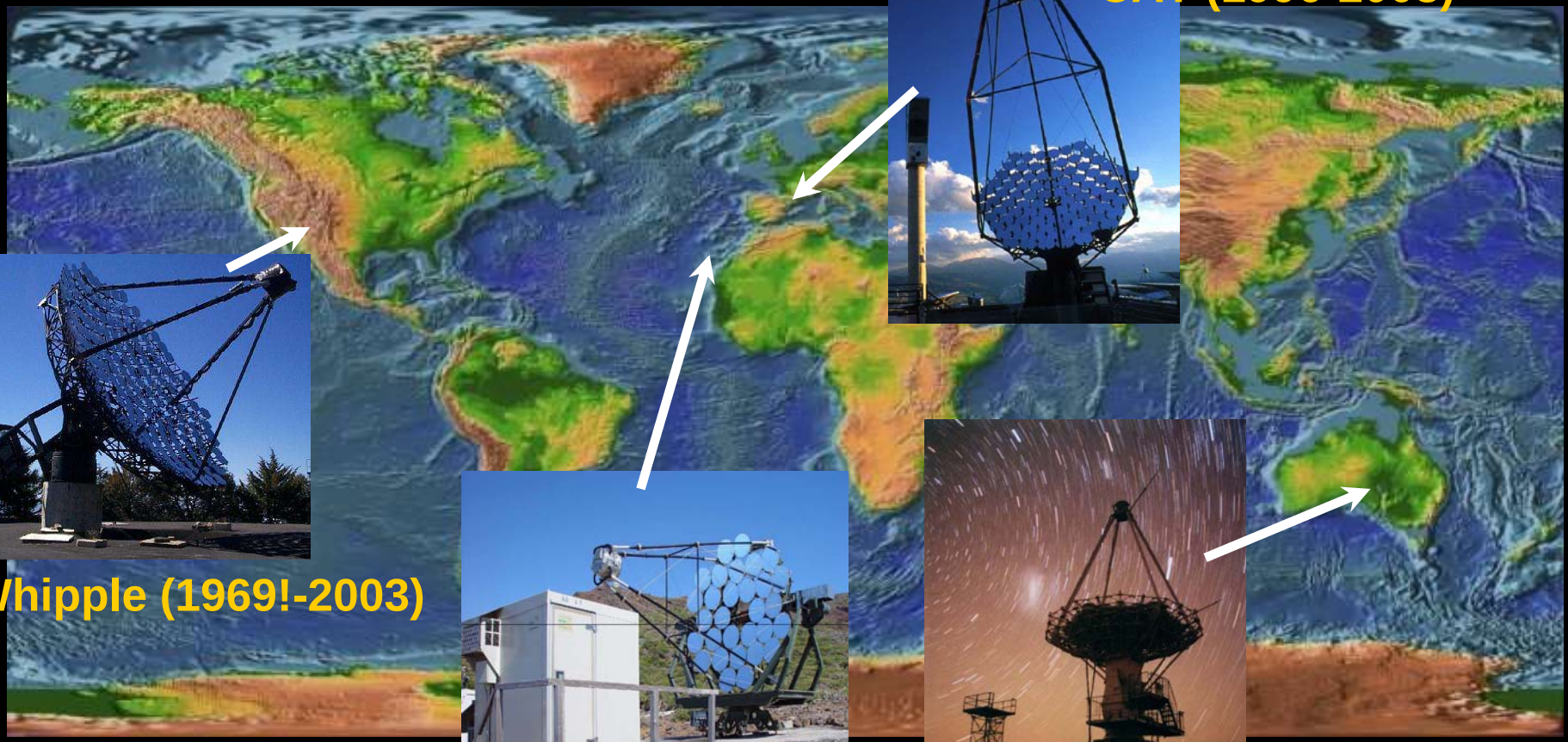




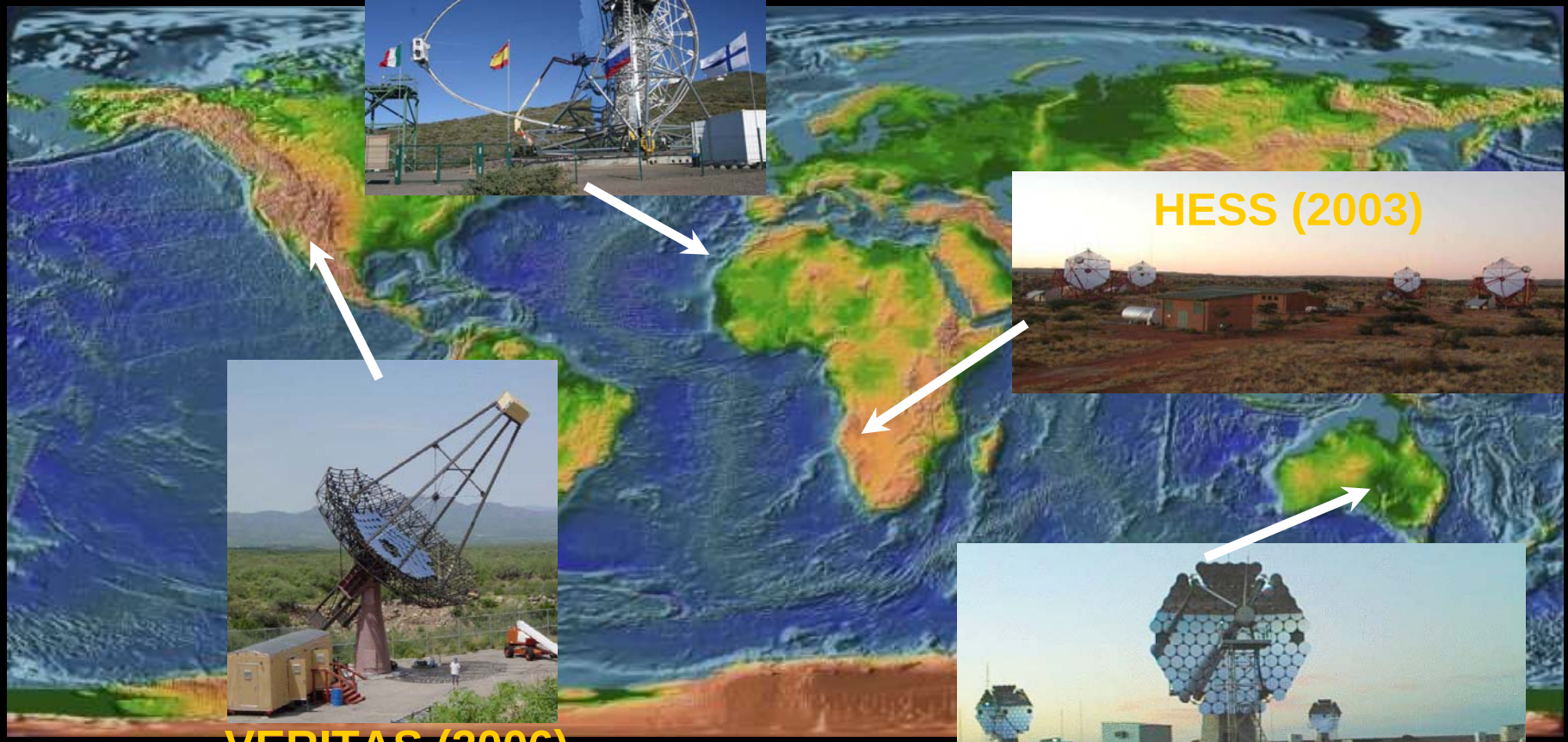


(2) **Shape:** γ –rays are narrower than cosmic rays.

First generation telescopes



Second generation telescopes



The H.E.S.S. telescopes

Stereoscopic system of 4 telescopes

107 m^2 mirror area each

960 PMT cameras, field of view 5^o

Inauguration: Sept 2004, taking data since 2003.

Germany, France, UK, Ireland, Namibia

Khomas Highland, Namibia

The MAGIC Telescope

The Major Atmospheric Gamma Imaging Cherenkov Telescope was built & is operated by a collaboration of around 100 Physicists in:

IFAE, UAB Barcelona, UCM Madrid, MPI München, U. Würzburg, U. Berlin, U. Dortmund, INFN/U. Padua, U. Siena, U. Udine, ETH Zürich, U. Lodz, Tuorla Observatory (Finland), UC Davis (USA), U. Potchefstroom (South Africa), Yerevan Phys. Institute., U. Ehime (Japan)

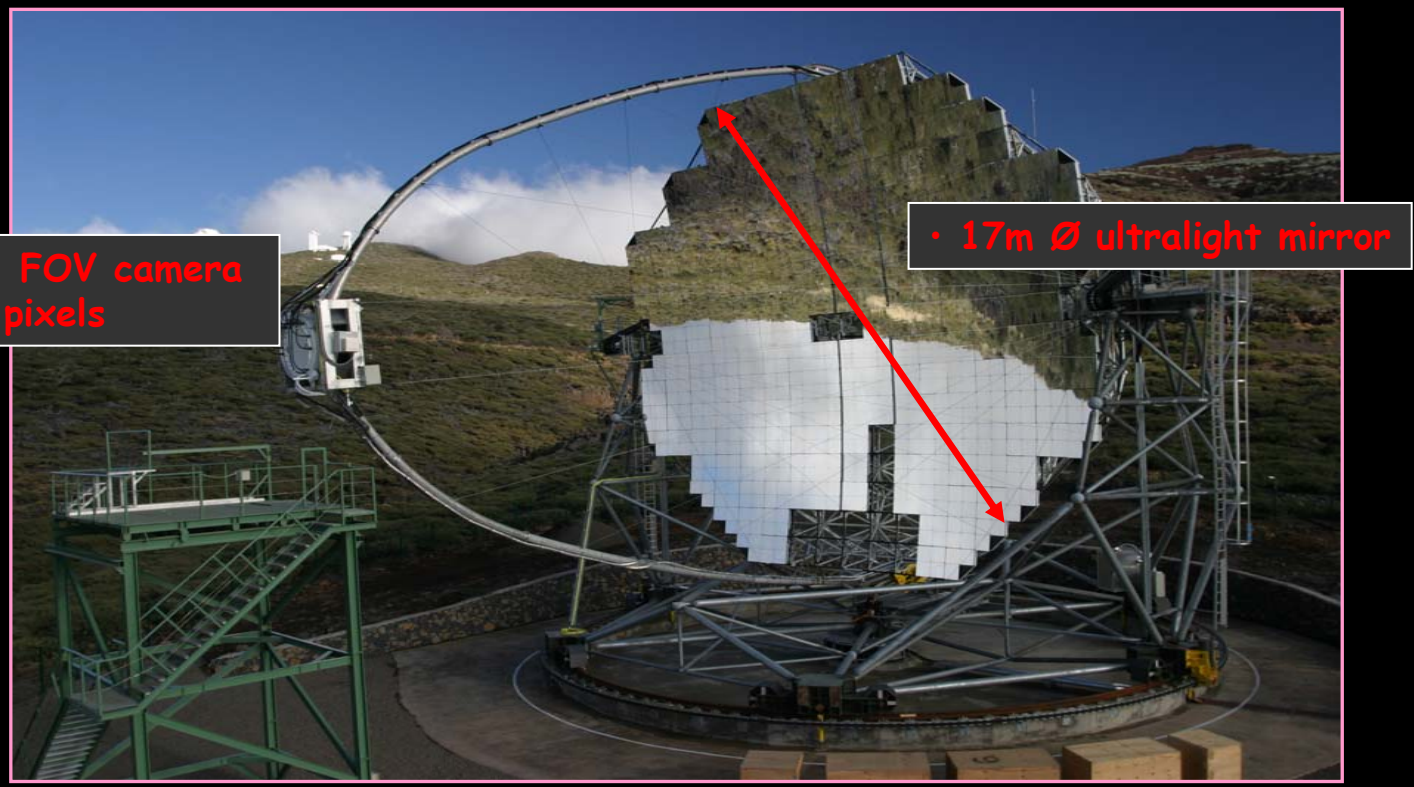
Location: La Palma, Canary Islands

End of commissioning: right now!

January 2005

MAGIC: the concept

A much larger mirror + all possible innovations to increase the sensitivity:
a "HiTech Giant"



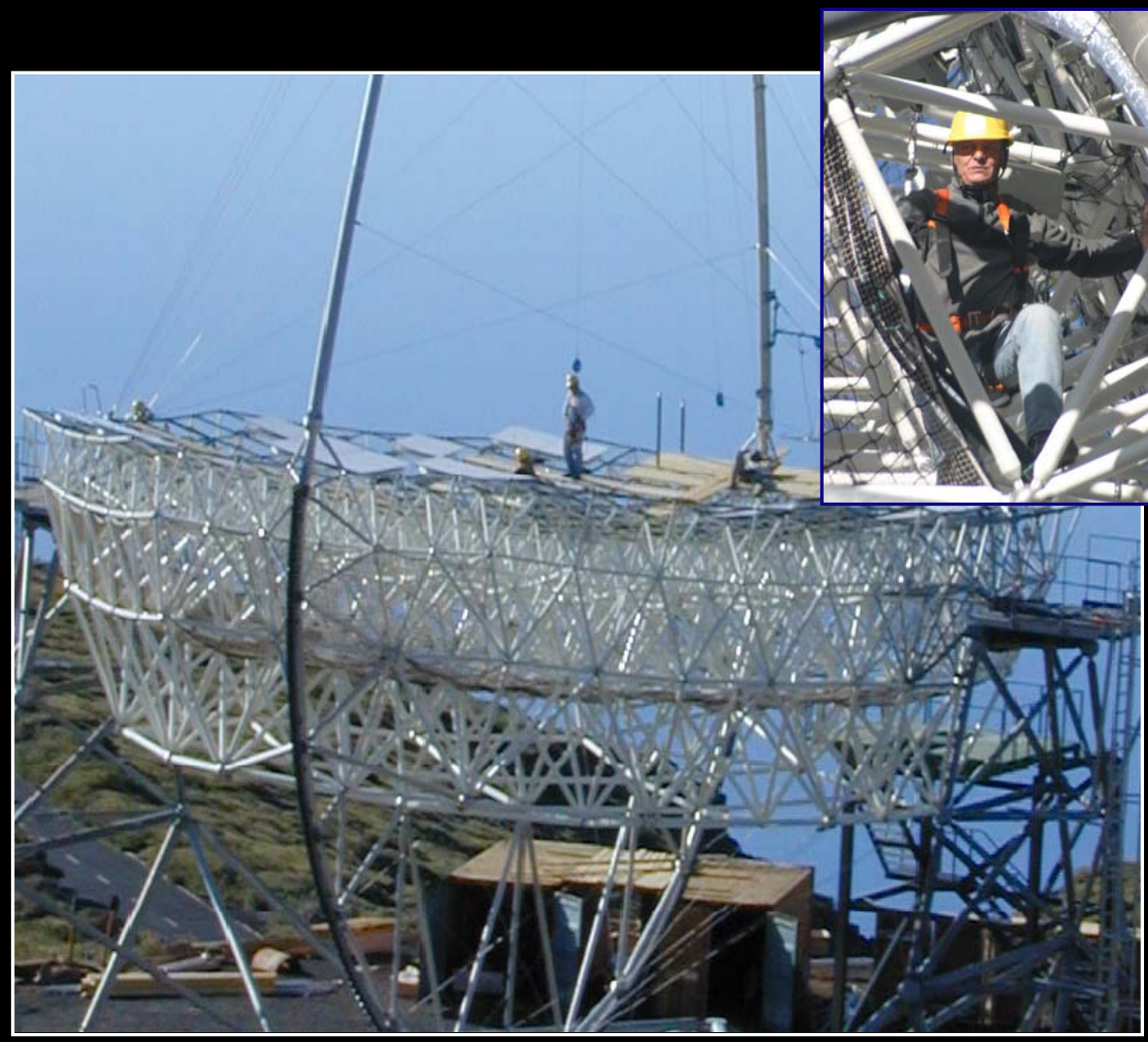
MAGIC: The Frame

• The largest telescope mirror ever built by Human Being: 240 m² surface.

•Light weight carbon fiber structure

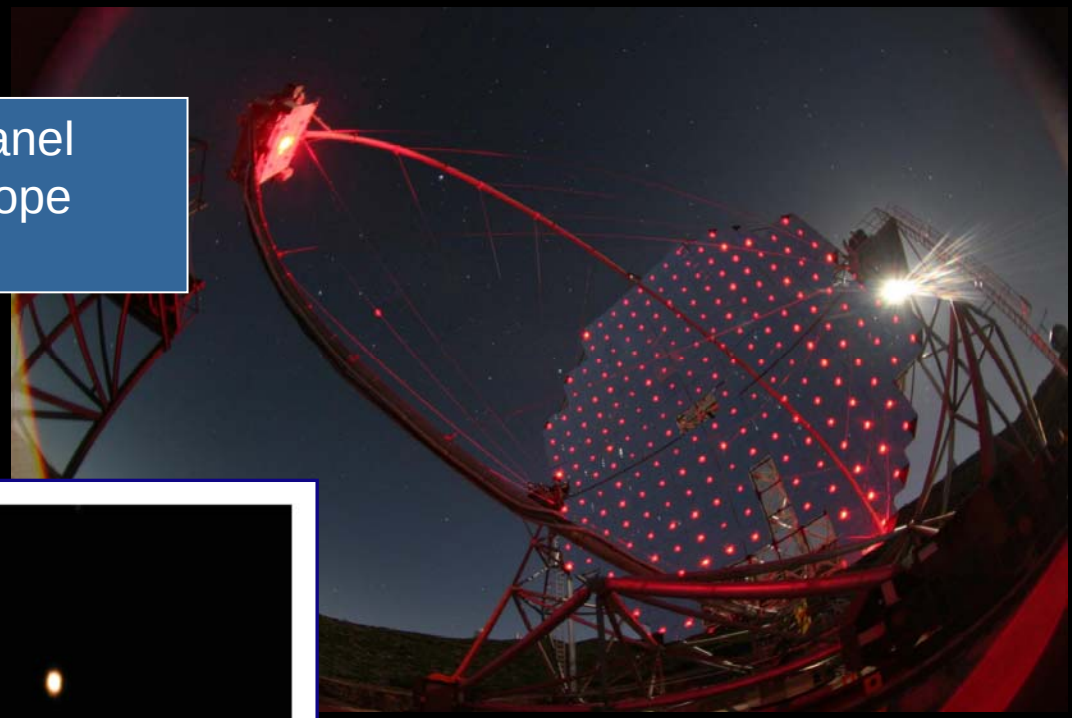
• Weight:
➔ Dish & Mirrors: 17 tons
➔Telescope: 65 tons

• Fast positioning over 180° in <30 sec
➔ Gamma Ray Bursts



MAGIC: Reflector & Active Mirror Control

Use lasers to recall panel positions when telescope deforms



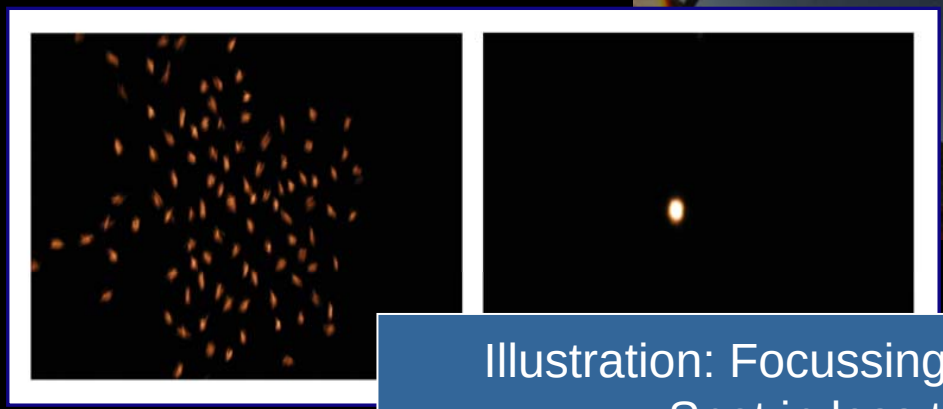
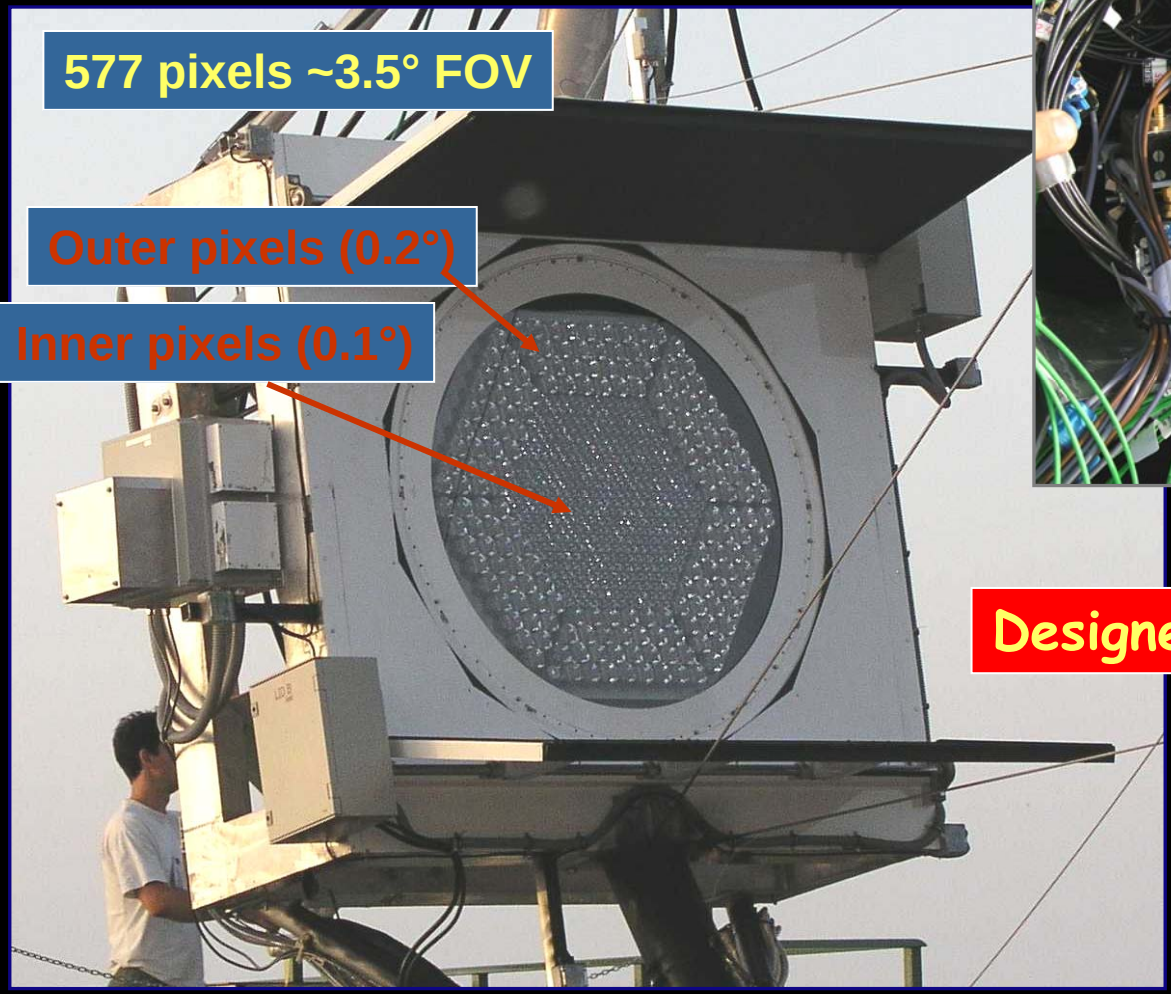
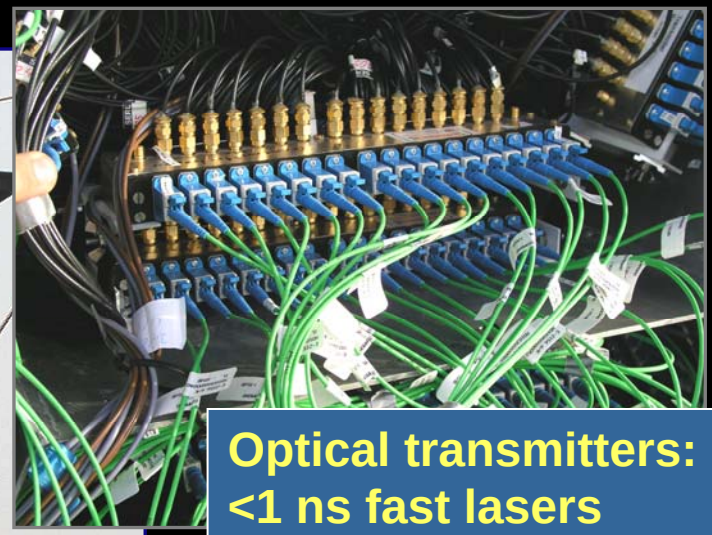


Illustration: Focussing all panels to Jupiter
Spot in less than 1 pixel

MAGIC: Camera & signal transmission





Optical transmitters:
<1 ns fast lasers

Designed & built at IFAE

MAGIC: Signal Processing

- Two Level Trigger:
  freely programmable
- 300 MHz, 8 Bit FADC:
  Can resolve time profile
- DAQ:
  Continuous 1 kHz evt rate
  ~1% deadtime
  ~ 2 Tbytes/month

Second generation telescopes: Performance summary

- Coming online in 2003-2006.
- Reflectors with >10 m diameter
  - Energy threshold down to 100 GeV
  - Down to <50 GeV for MAGIC
- Improved sensitivity:
  - Close to 1% Crab at 1 TeV
  - Around 10^{-11} photons cm^{-2} s^{-1} at 100 GeV
- First physics results this year...


First Physics Results

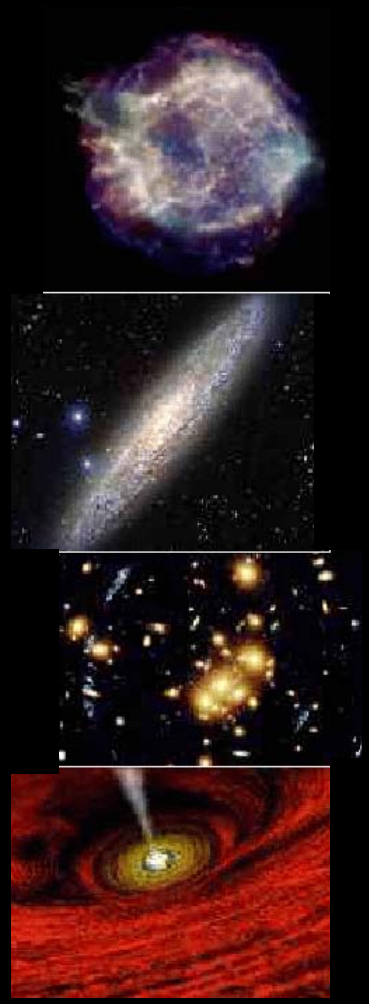
Physics in the VHE band

Astrophysics of compact objects
- AGNs
- Microquasars
- Pulsars and pulsar-wind nebulae
- Gamma-ray bursts

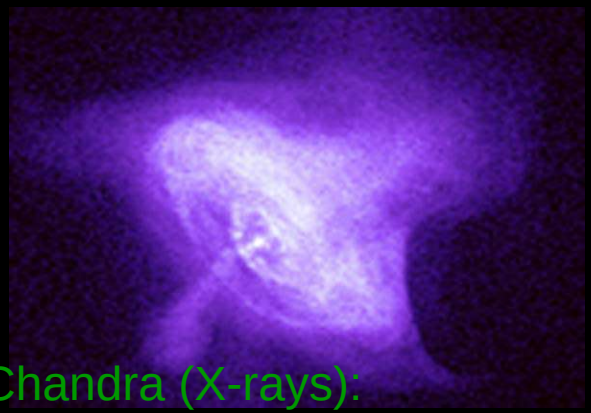
Cosmic ray origin and acceleration
- Supernova Remnants
- Starburst galaxies
- Unidentified galactic sources

Cosmology
- Diffuse extragalactic photon fields
- Clusters of galaxies

Fundamental physics
- Neutralino annihilation
- Lorentz invariance violation



Pulsar Wind Nebulae



Chandra (X-rays):
Crab Nebula

Pulsars generate a steady flux of HE particles.

Previous detections in VHE:

- Crab, our **standard candle**.
- 2 detections by CANGAROO.

Question:
how are these particles accelerated?

Whipple 1968

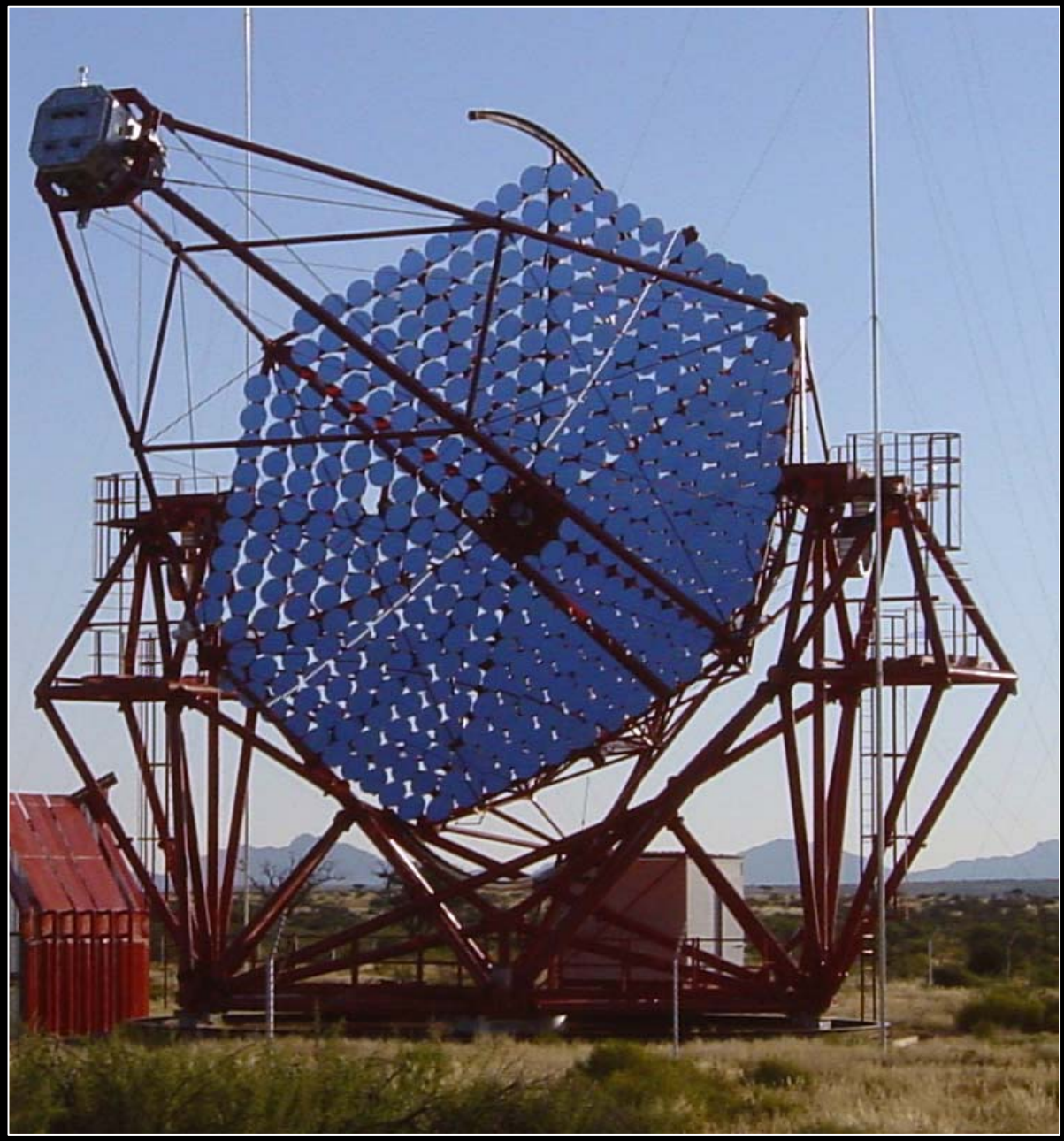
Detection of the Crab Nebula 1989:

50 h observation time for 5σ signal, **1 TeV** energy

HESS 2003

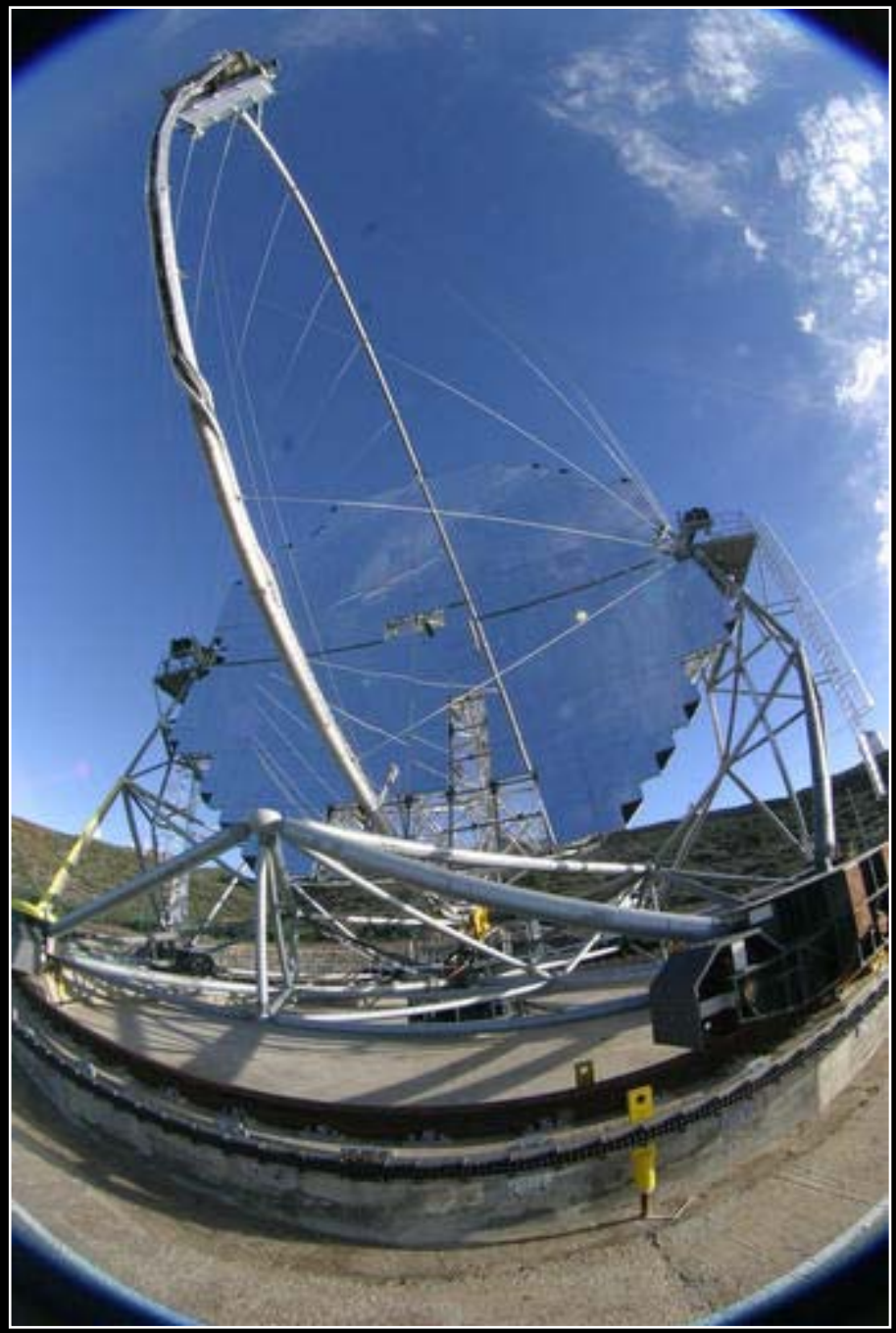
Detects Crab-like source at **100 GeV** in

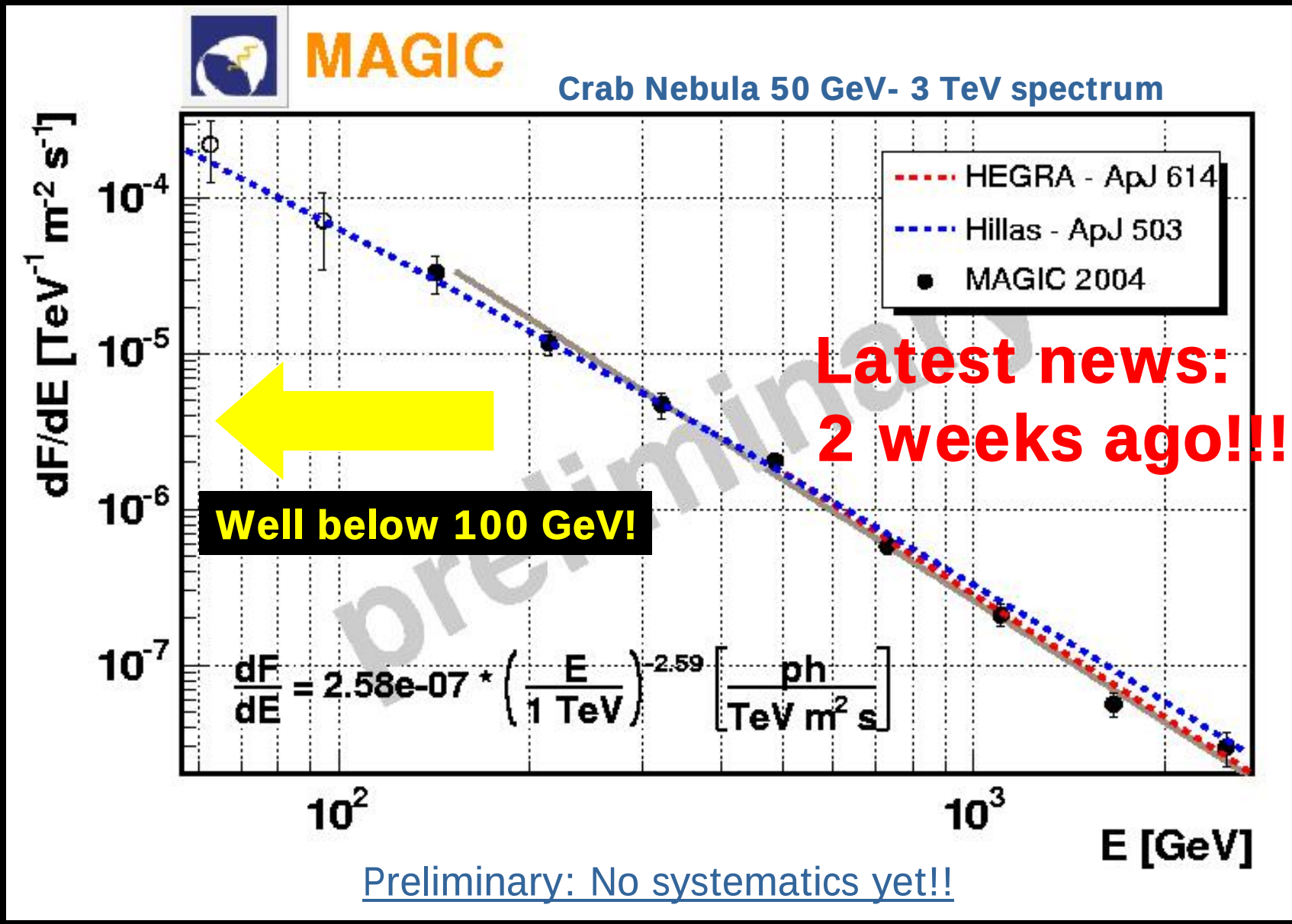
30 seconds



MAGIC 2004

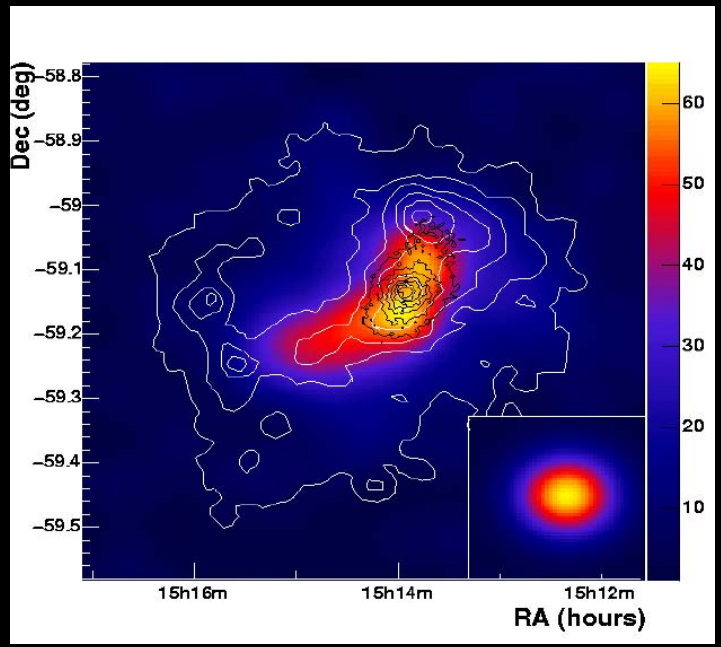
Energy threshold
Down to 50 GeV



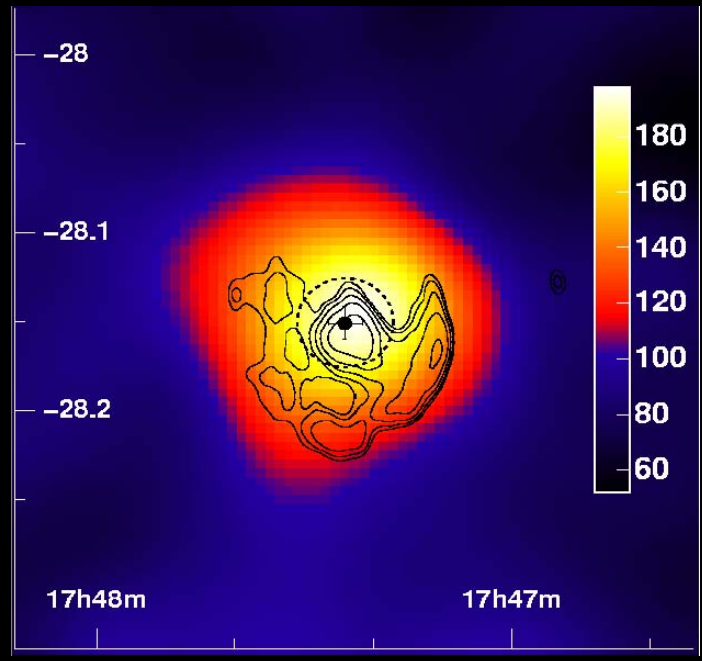


Preliminary: No systematics yet!!

More such objects

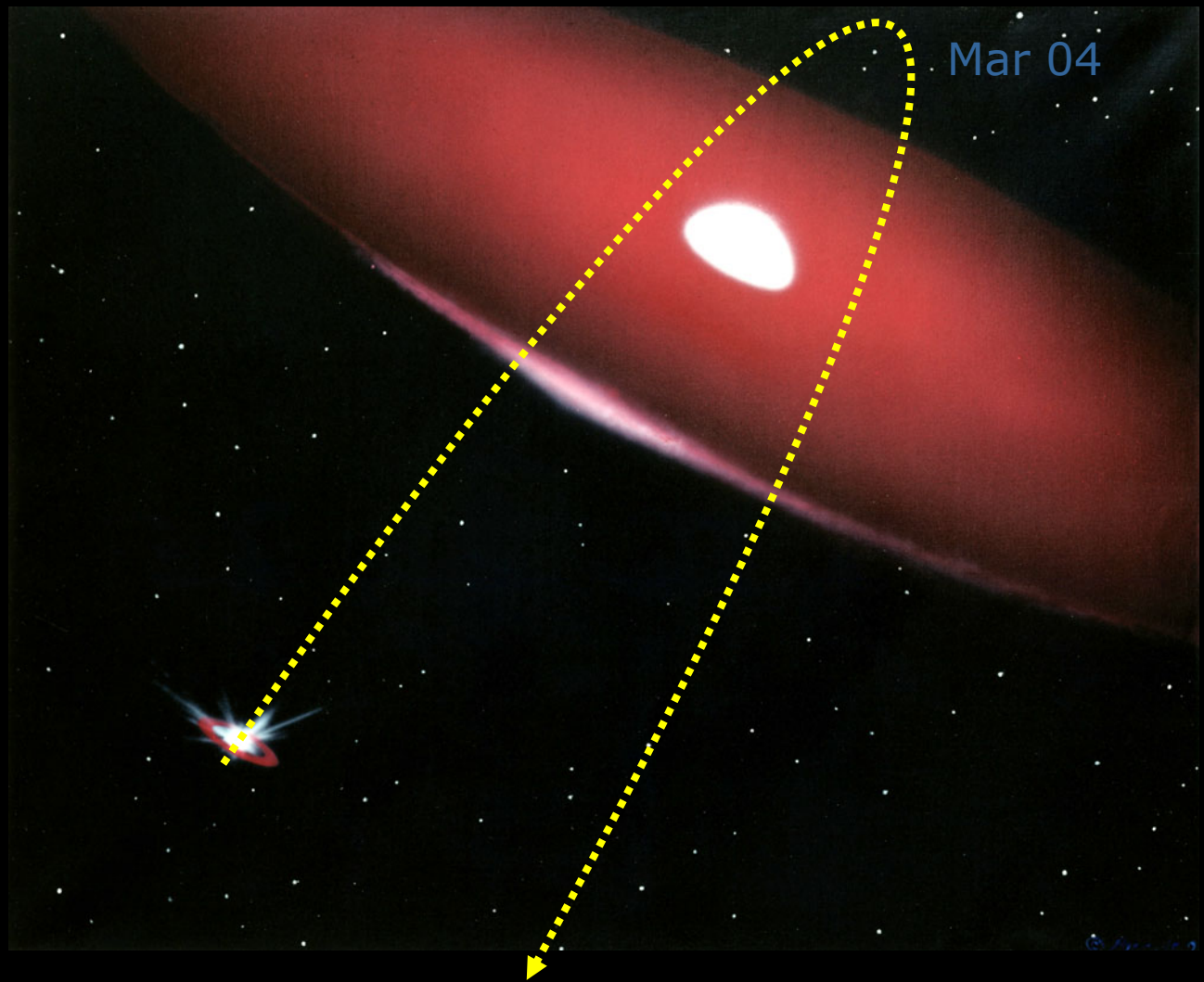


- MSH 15-52 detected by HESS
- Asymmetric excess: extended!
- Flux of 15% Crab

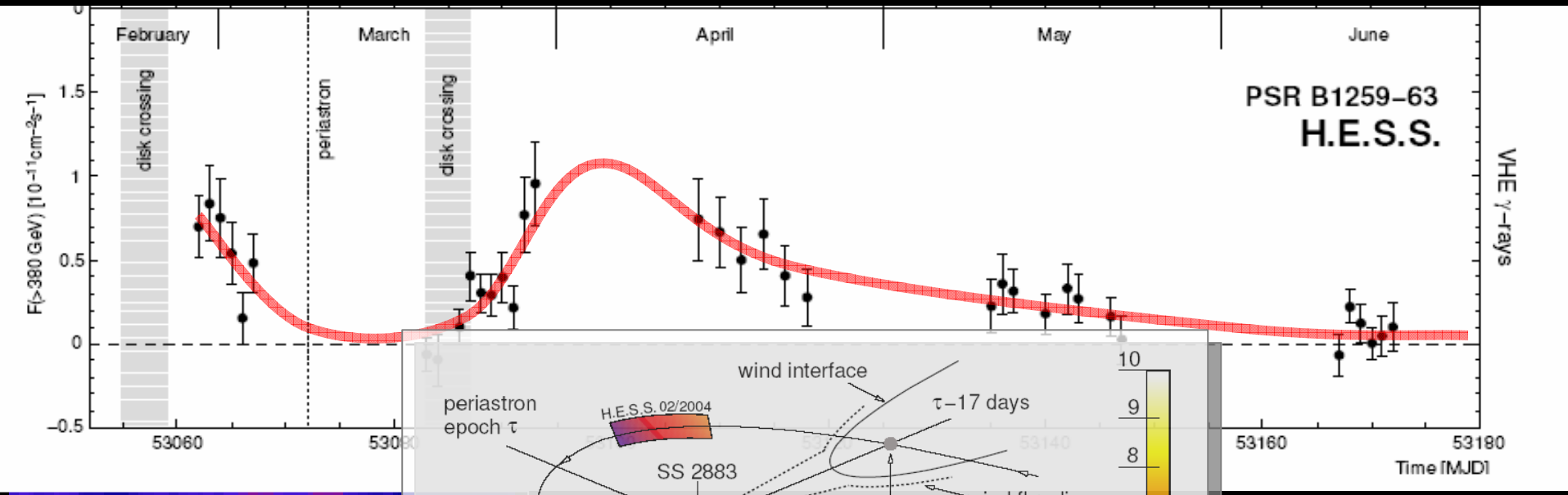


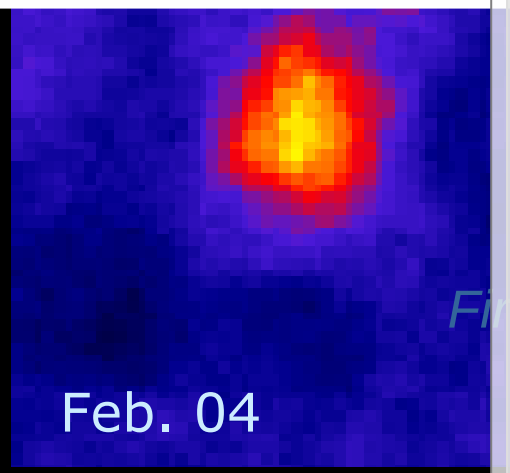
- G 0.9+0.1 detected by HESS near GC
- Point source
- Flux of 2% Crab.

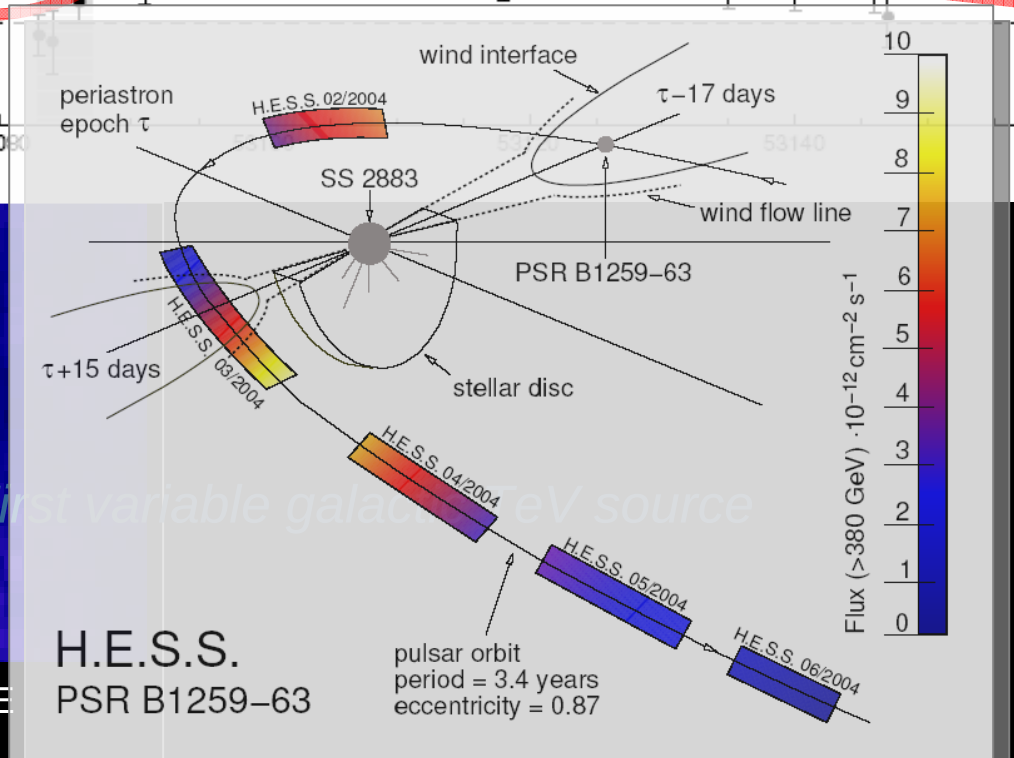
Pulsar B1259-63 by HESS



The B1259-63 field of view



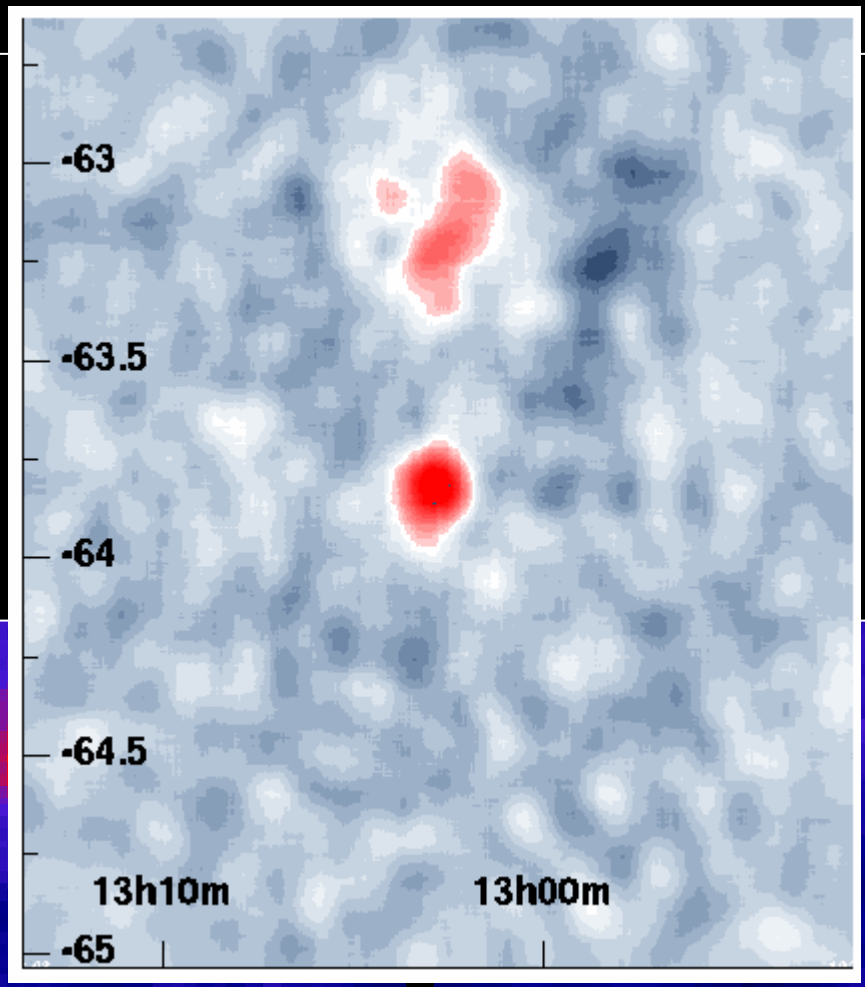




First variable galactic TeV source

J. Cortina, IFAE

The B1259-63 field of view



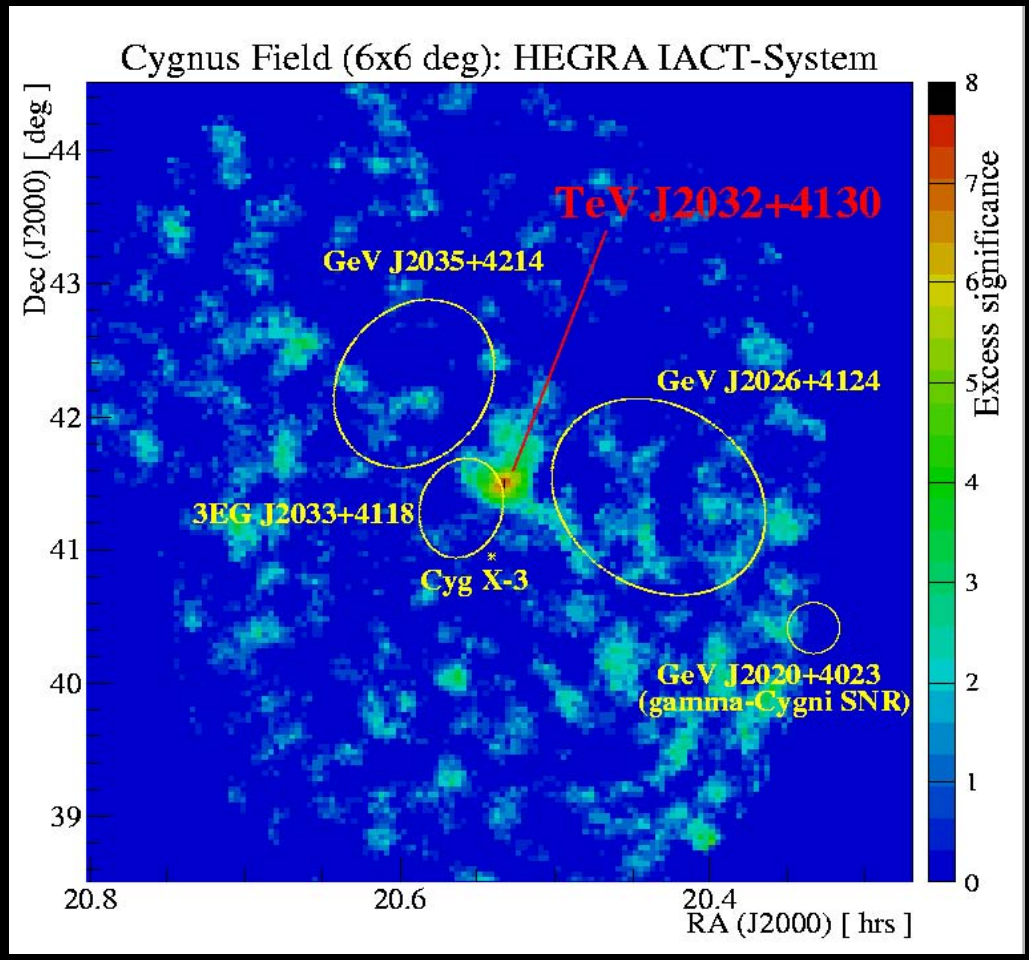
Source HESS J1303-631
- is extended
- has no radio or X-ray counterpart

Feb. 04

March 04

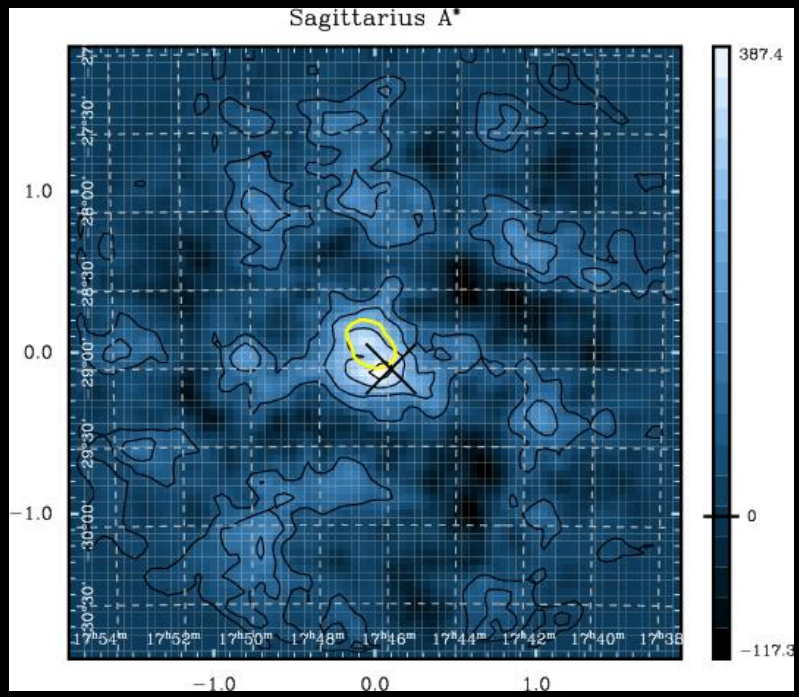
Apr./May 04

HEGRA TeV 2032+42: The First Unidentified TeV Source



- Discovered by **HEGRA**
- No counterpart at lower wavelengths!!
- 3% of Crab flux
- Deep observation by MAGIC under analysis....

The Galactic Center



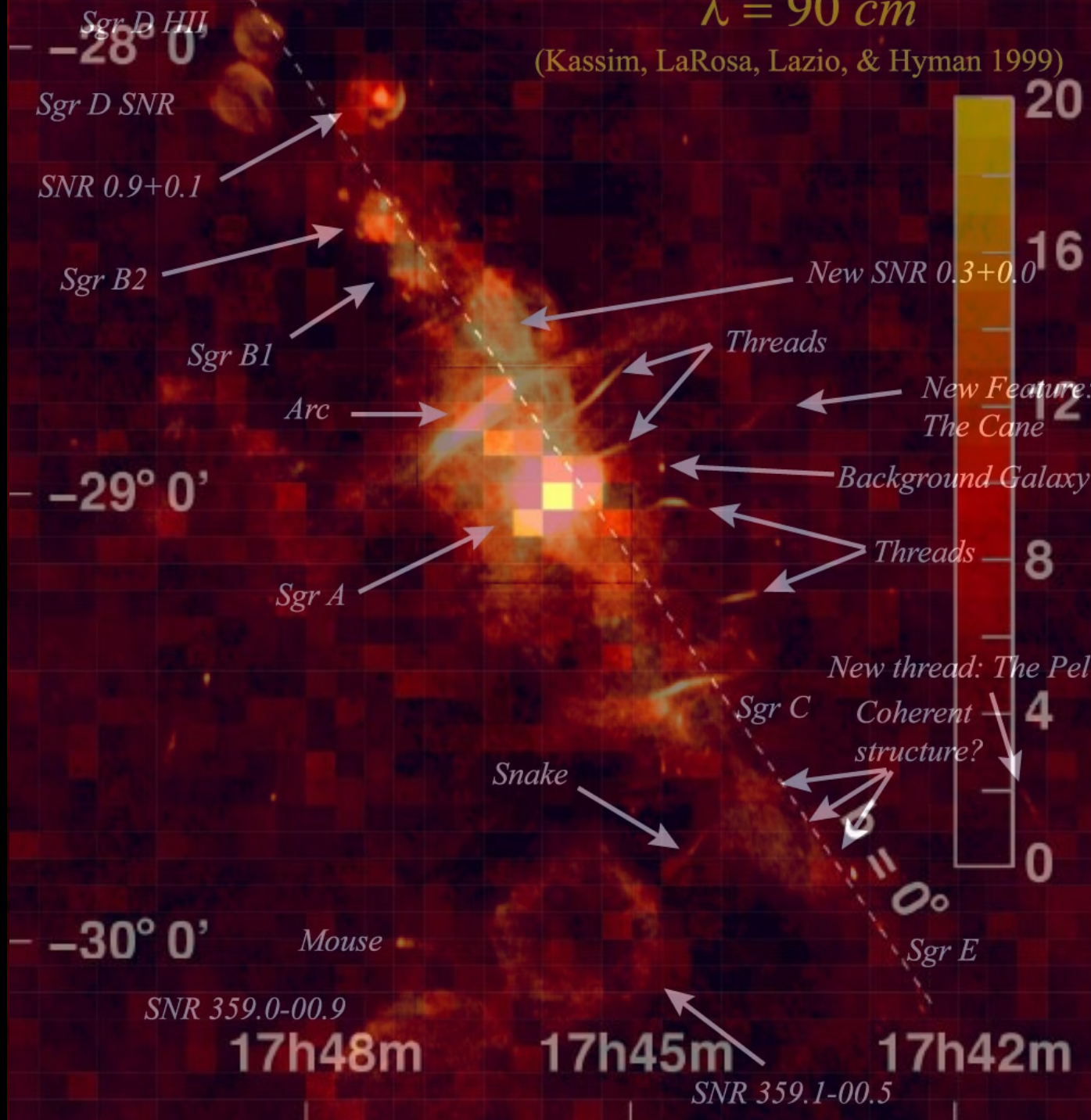
CANGAROO
Observations 1995-2003
E > 250 GeV
10% of Crab

Confirmation:
Whipple
Observations 1995-2003
E > 4 TeV
40 % of Crab

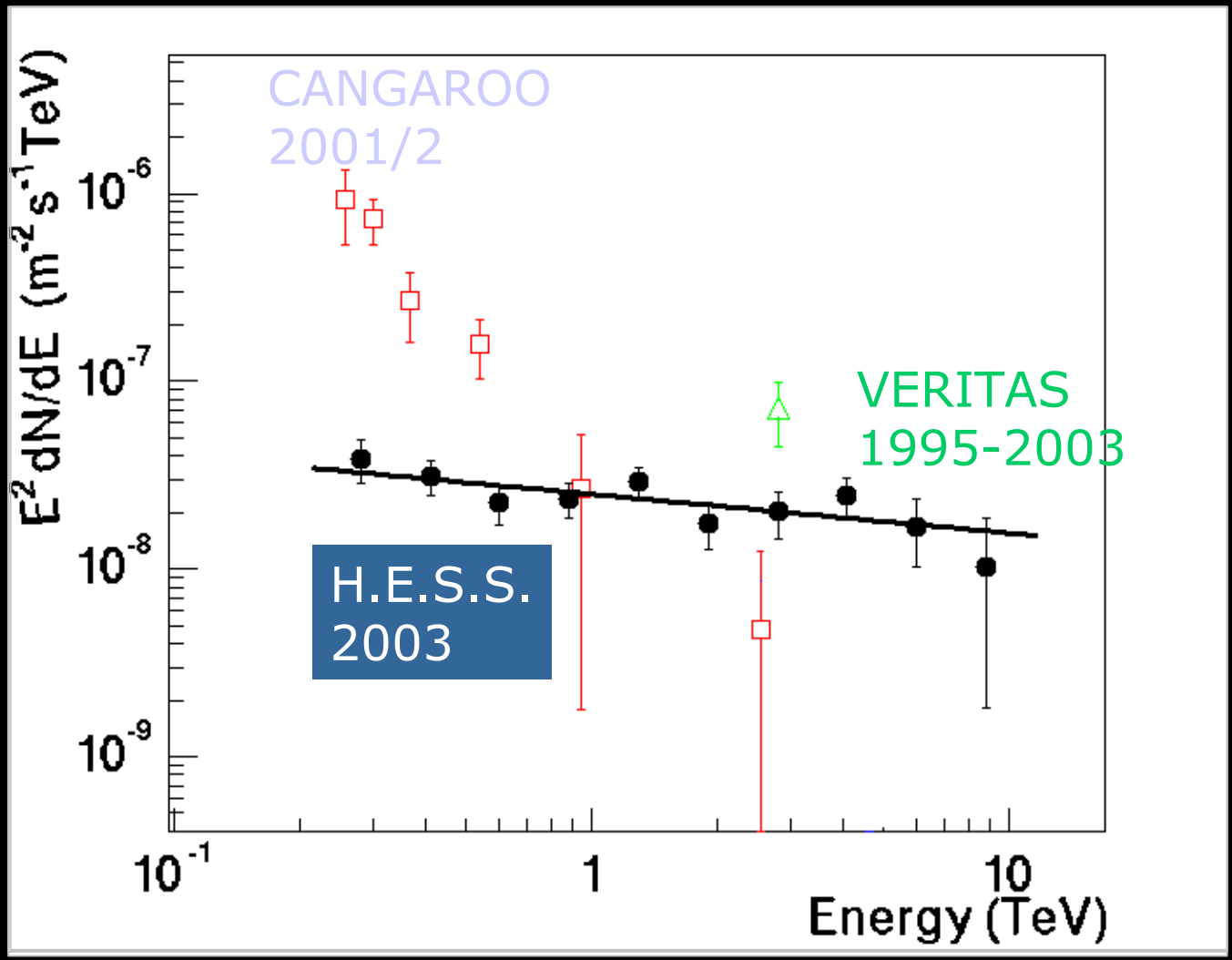
The Galactic Center

H.E.S.S. 2003 data

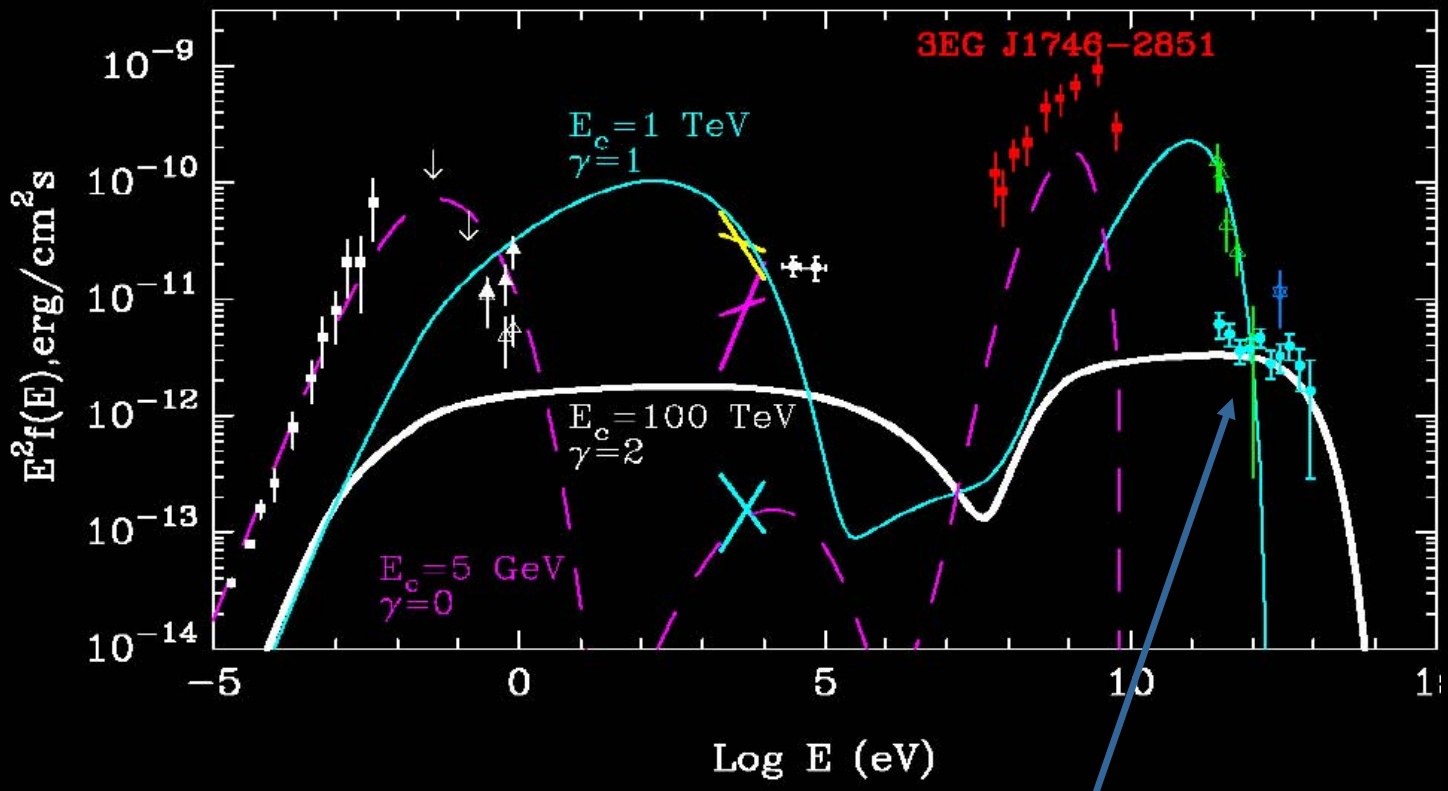
A&A 425, L13 (2004)



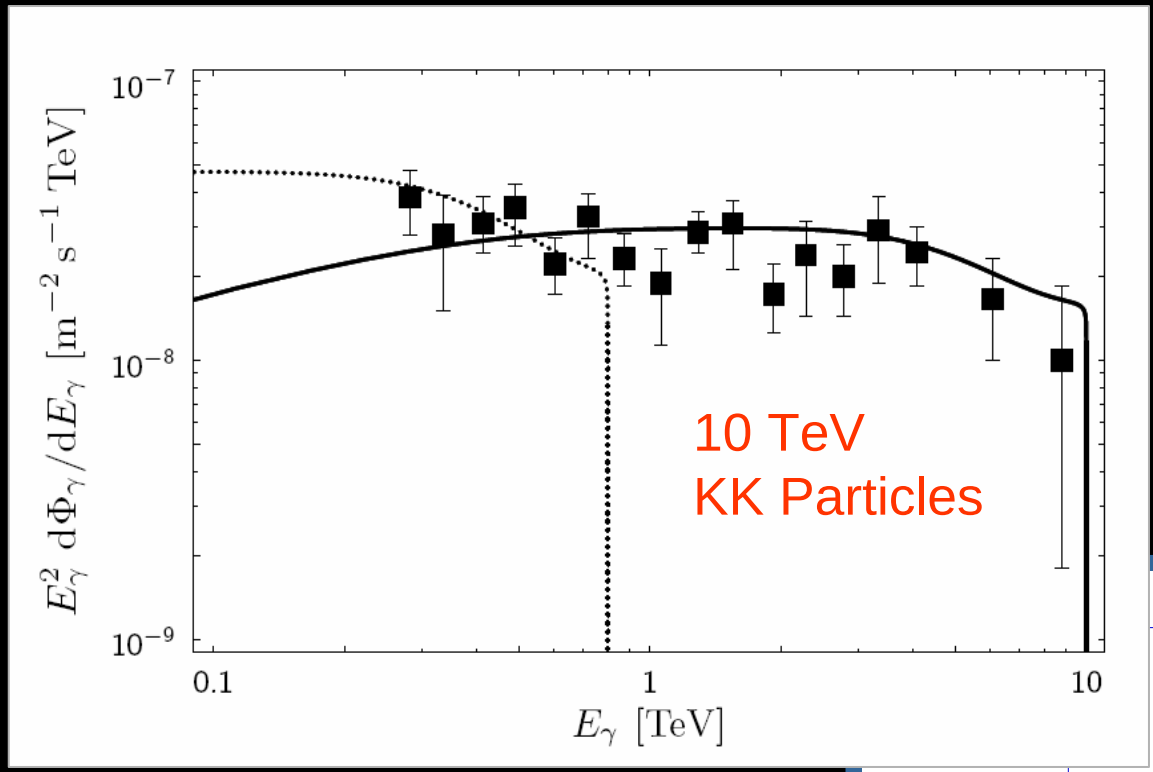
Galactic center spectra



“Ordinary” CR accelerator



Radiation of accelerated protons
A. Levinson PRL 85, 912 (2000); Aharonian et al.

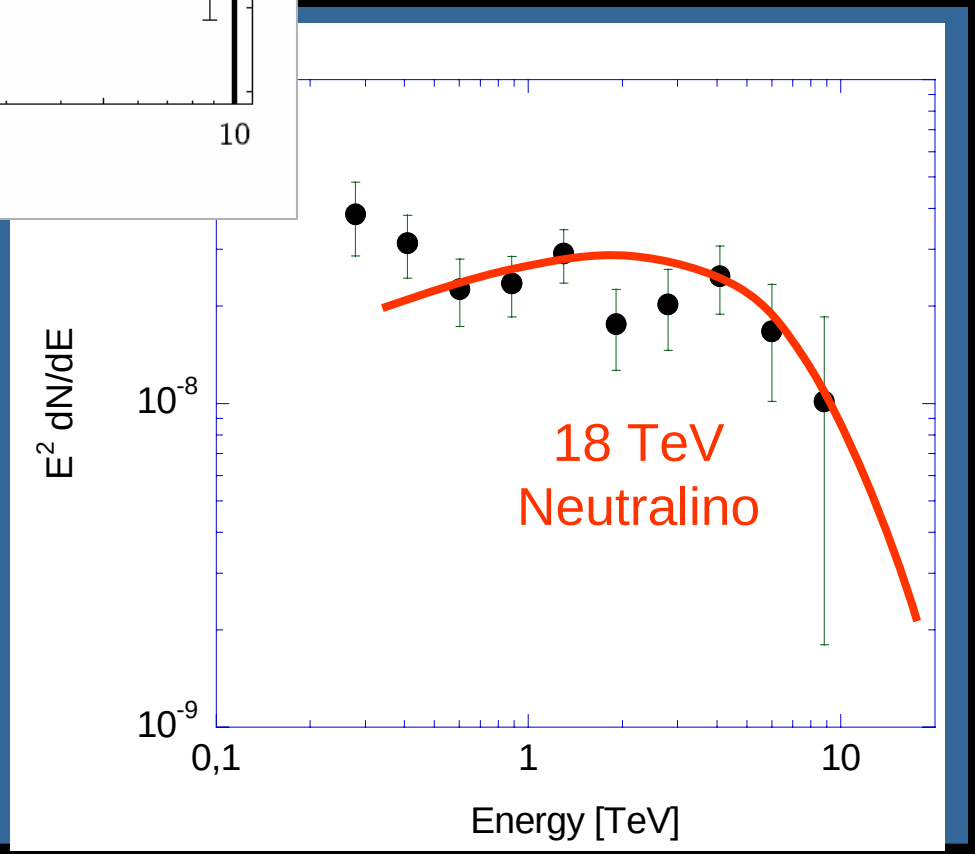


SUSY Dark Matter ?

D. Horns
astro-ph/0408192

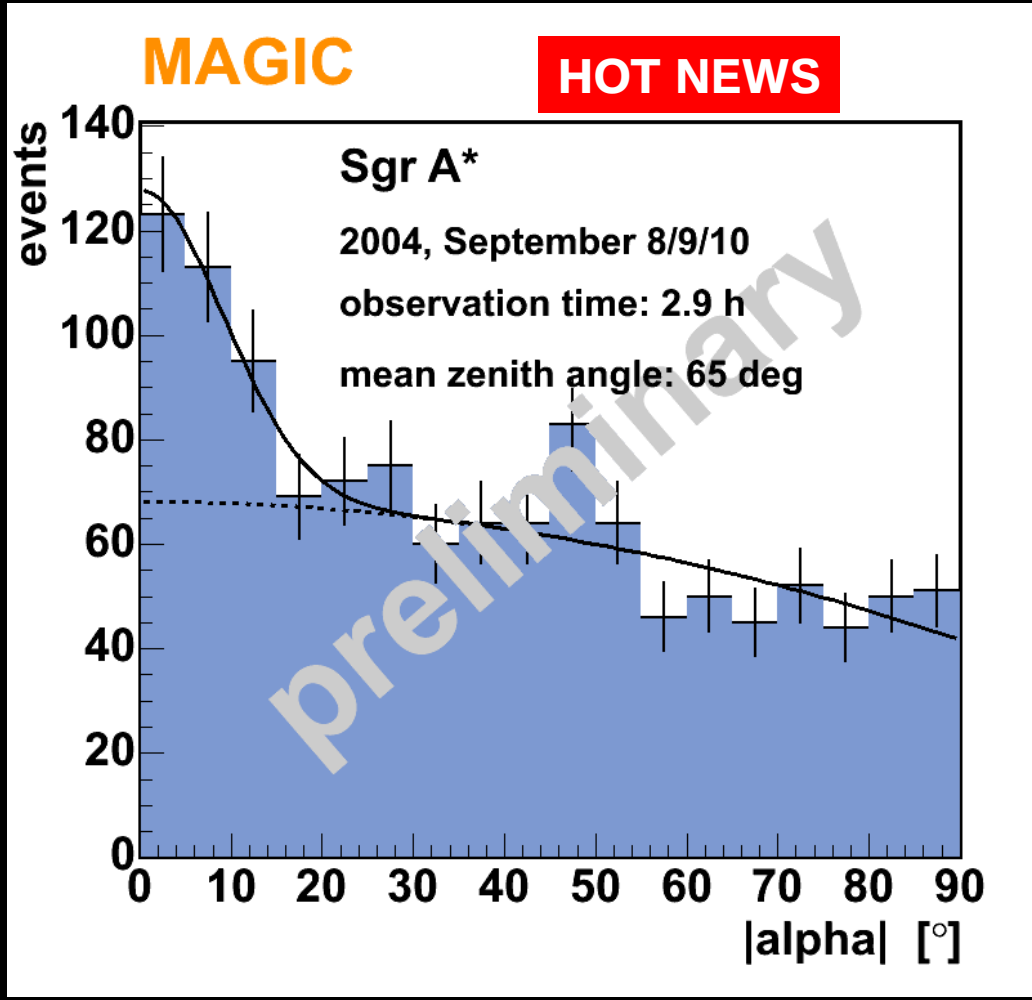
Kaluza-Klein Dark Matter?

L. Bergström et al.
astro-ph/0410359



Galactic center by MAGIC

- Southern hemisphere: extremely hard to observe with MAGIC.
- Hint of a detection after first analysis of 3h last summer.
- Help to establish spectrum above 10 TeV: rule out dark matter.



Supernova Remnants
The origin of cosmic rays

CRs believed to originate in SNRs:

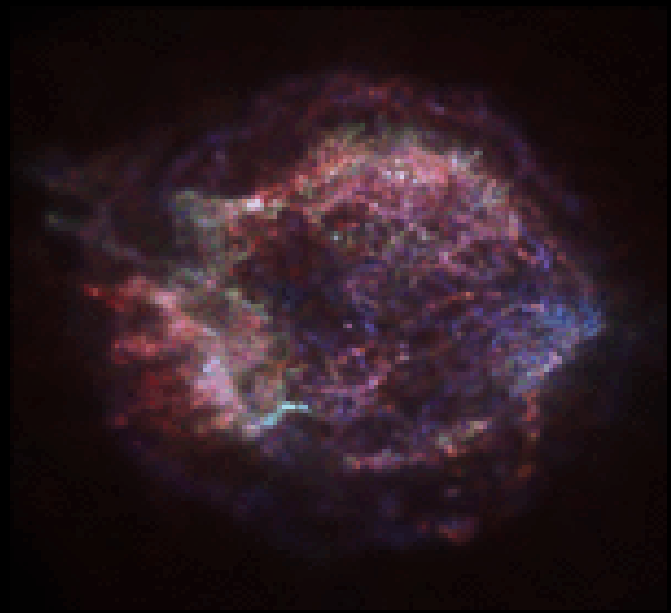
- Shock front expanding at 10000 km/s.
- Get deflected randomly on their way to Earth: not point back to source.
- Can tell where the sources are through their γ-ray (or ν) indirect emission:

  Synchrotron

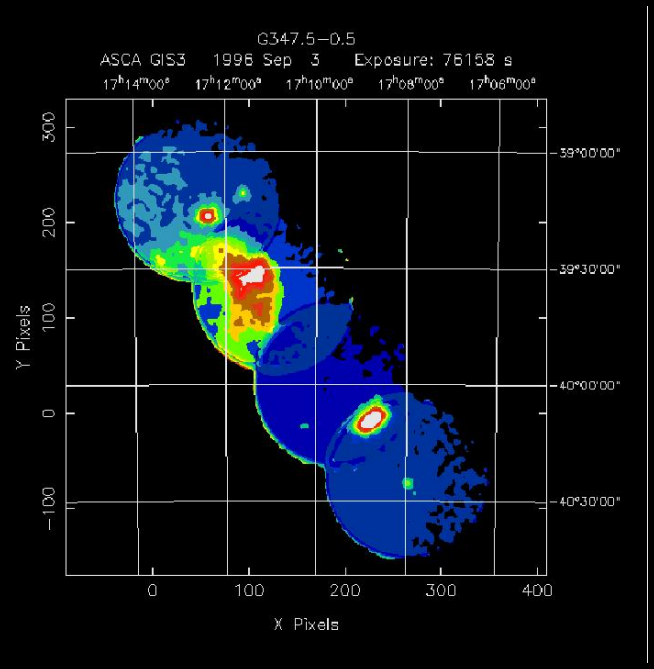
  Bremsstrahlung

  Inverse Compton

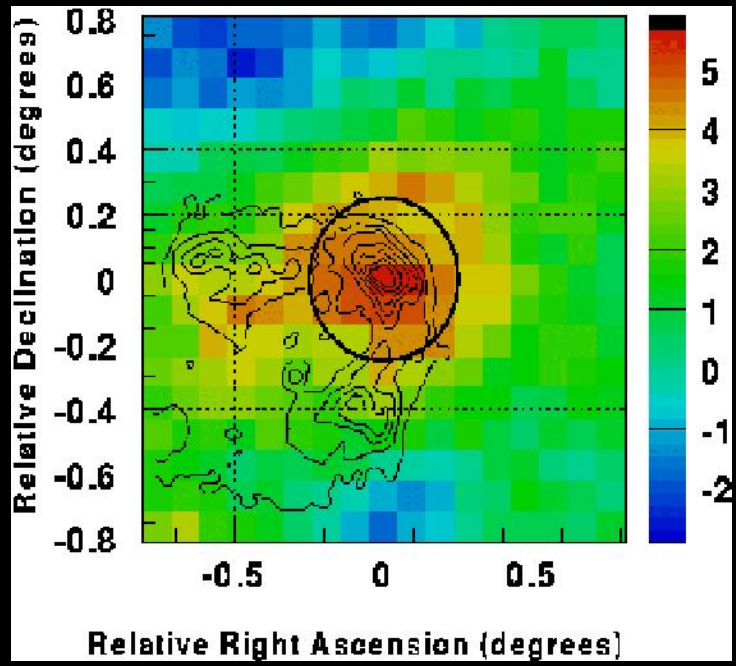
  π^0 Production



Example: RX J1713.7-3946

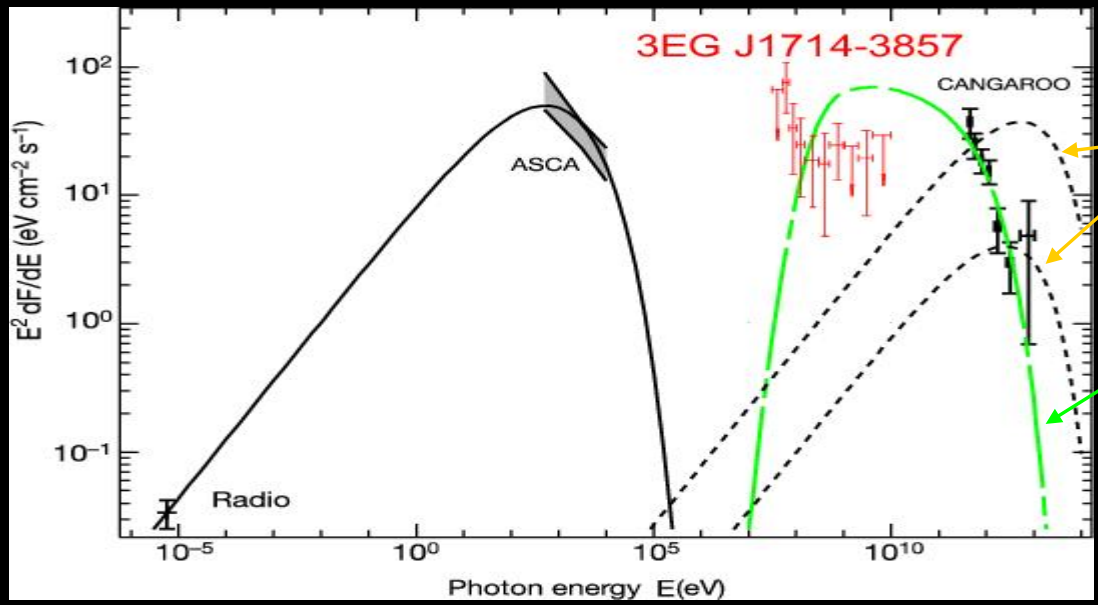


X-rays by ASCA:
Synchrotron of TeV electrons



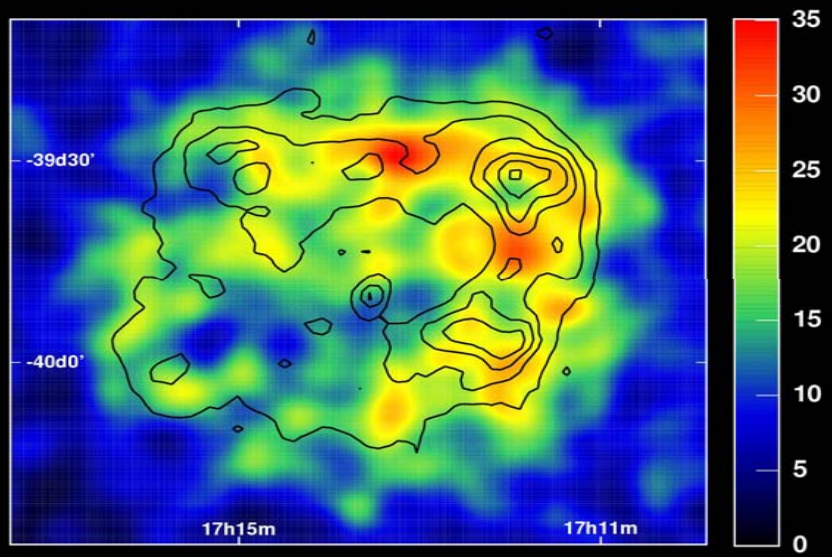
TeV by CANGAROO:
IC or π^0?

RX J1713.7-3946: CANGAROO



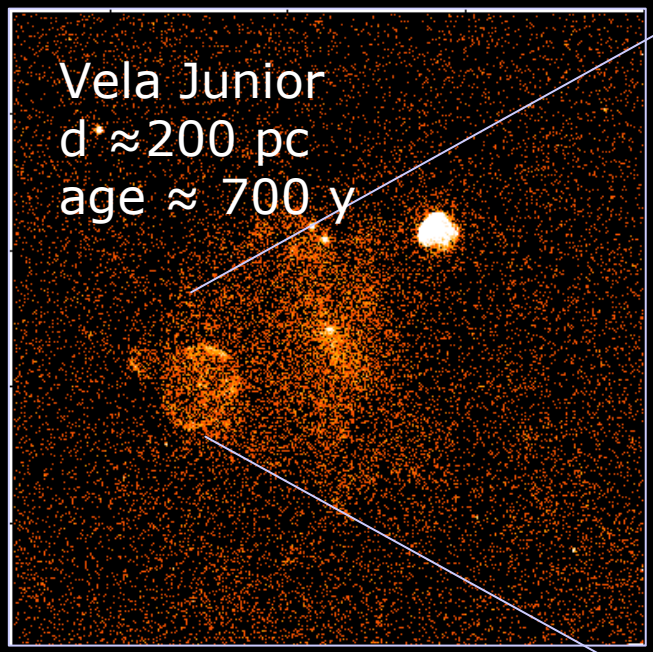
- CANGAROO (Nature '02): cannot be IC. π^0!!
- Reimer et al: violates EGRET limits.
- Conclusion: unclear whether it's hadronic or electronic

RX J1713.7-3946: HESS



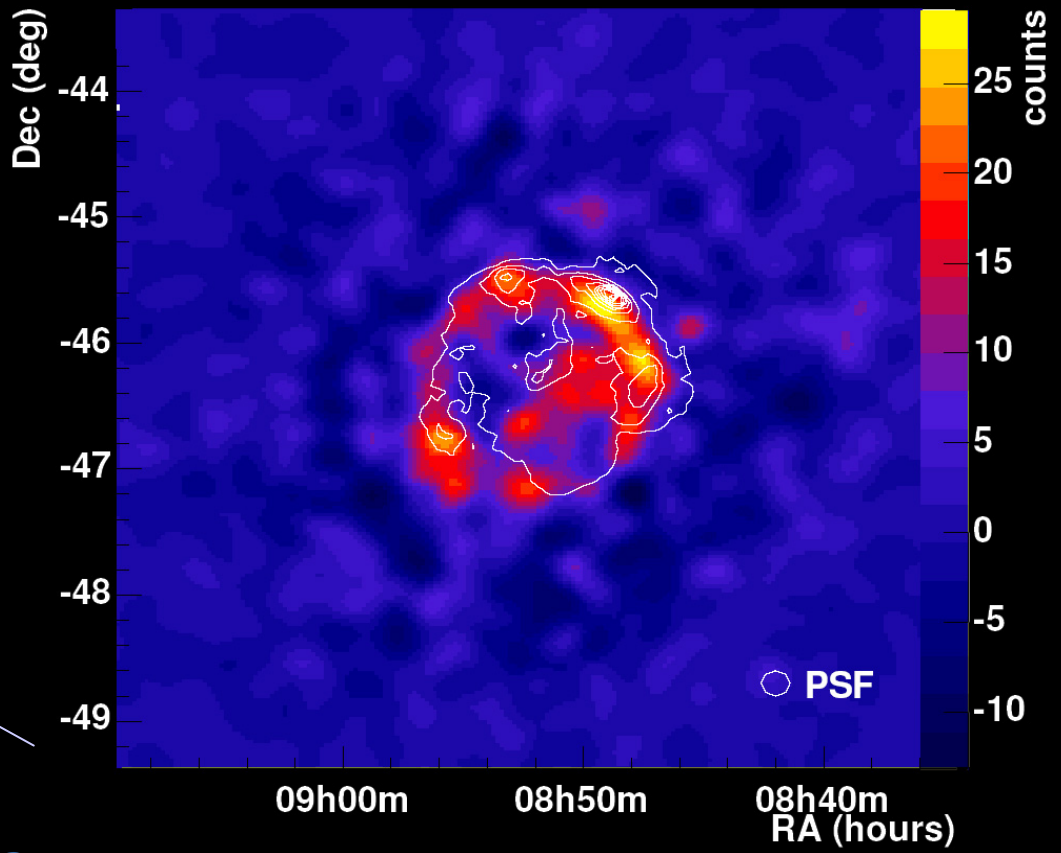
- HESS has confirmed the source (Nature ‘04).
- And additionally resolved a spatial structure that resembles the X-ray shell.

there are more such objects...



Vela (Rosat)

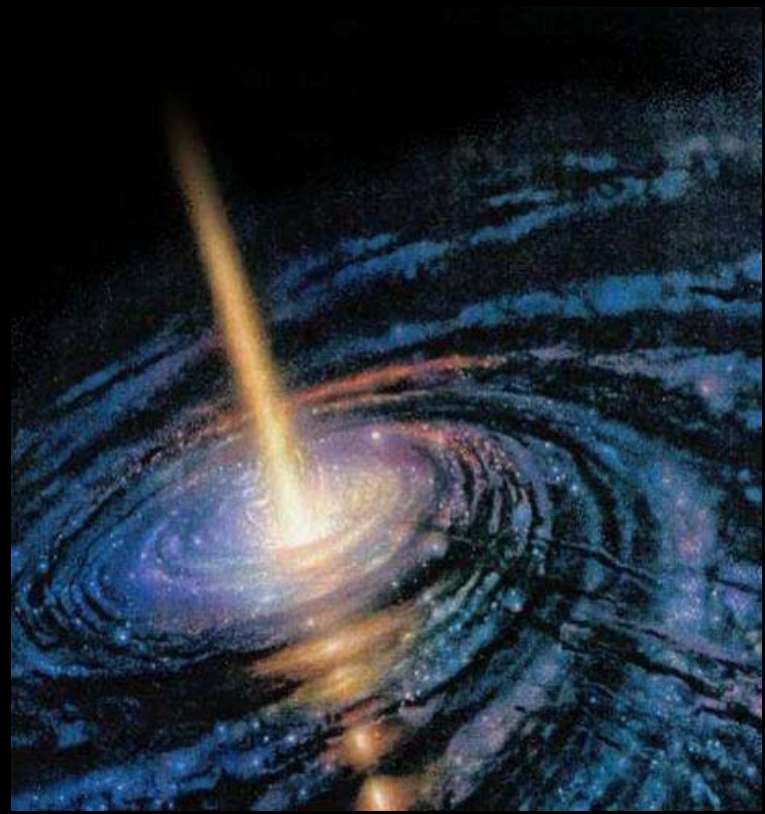
H.E.S.S. 2004 – 3.2 h obs. time



First detected by CANGAROO
Katagiri et al., astro-ph/0412623

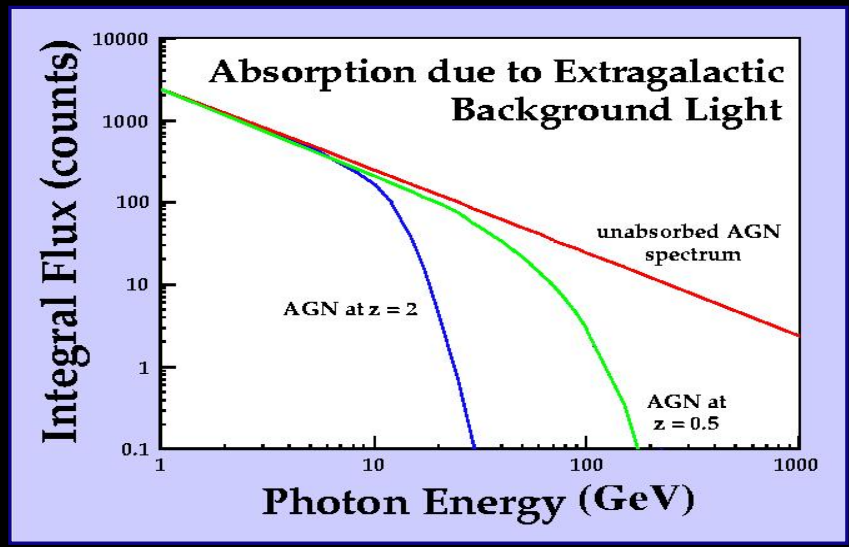
Extragalactic sources

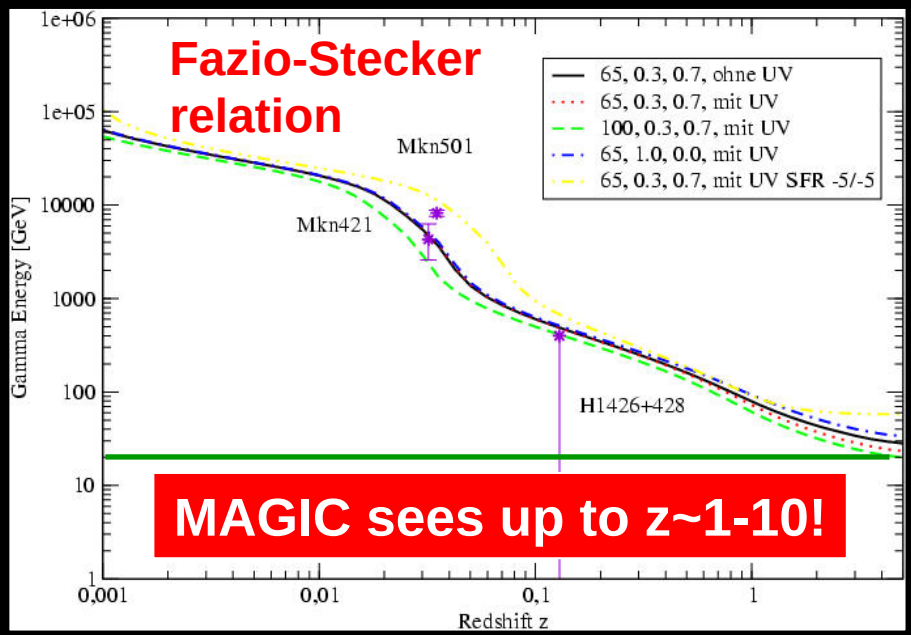
- Active Galactic Nuclei
  - BL Lacs: jets pointing to Earth.
  - Strong flux variability as fast as 20 minutes.
  - Correlation with X-rays... or not?
  - Hadronic vs leptonic models.



AGN: The γ-ray Horizon

- γ-rays interact with the IR-visible photon background by $\gamma\gamma \rightarrow e^+e^-$ ➔ γ-ray attenuation
- Cutoff in source spectrum





Knowledge of gamma ray horizon:

- Cosmic star formation history
- Limits on cosmic parameters

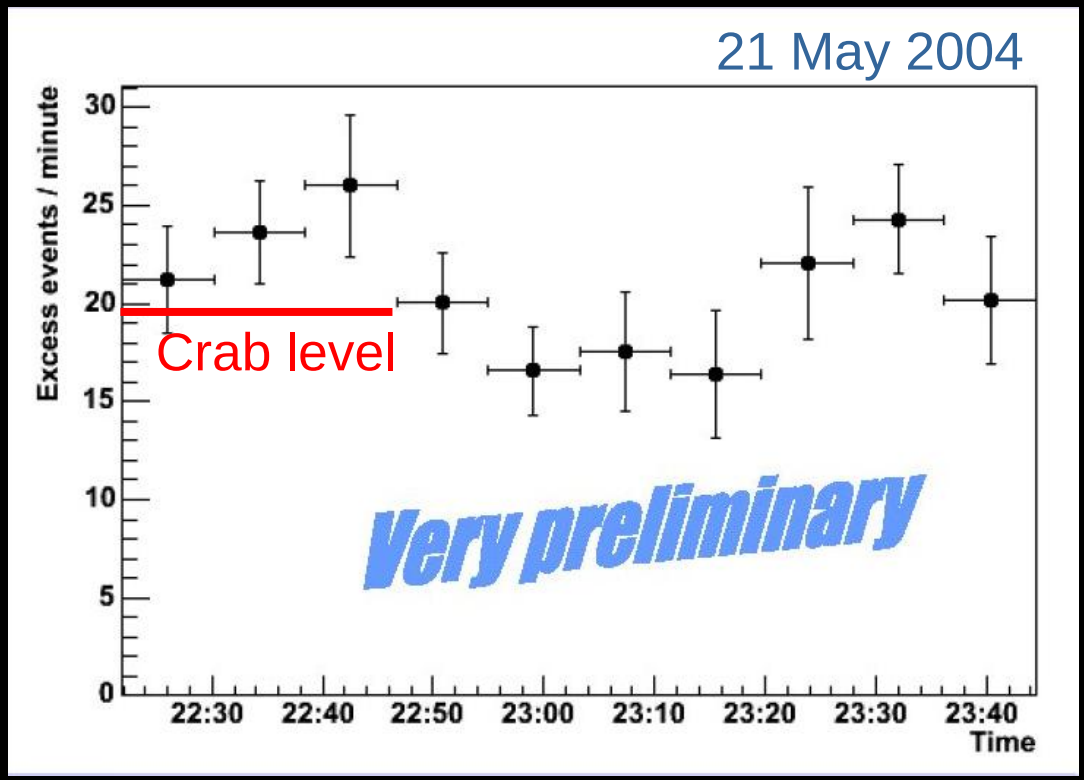
TeV Catalog of AGN

Source	Date/Group	Type	Redshift
Mrk 421	1992/Whipple	HBL	0.031
H1426+428	2002/Whipple	HBL	0.129
Mrk 501	1995/Whipple	HBL	0.033
1ES1959+650	1999/TA	HBL	0.048
PKS2155-304	1999/Durham	HBL	0.116
1ES2344+514	1997/Whipple	HBL	0.044

HBL = High frequency BL Lac
Spectra measured
Light-curves determined
Multi-wavelength Correlations

MAGIC: Mrk 421

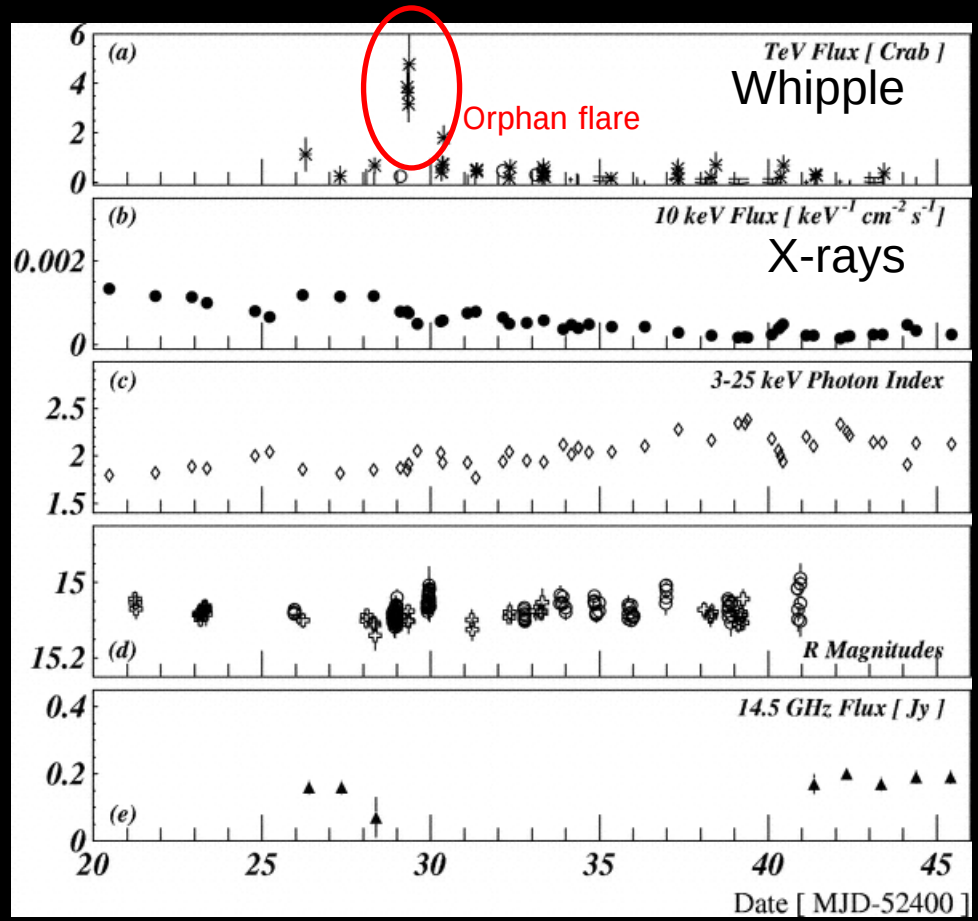
Mrk 421 flaring during 2004. Most of the data not analyzed yet.



- **Compare to rates 20 events / HOUR in first generation Telescopes**
- **Allows to sample faster time variations**

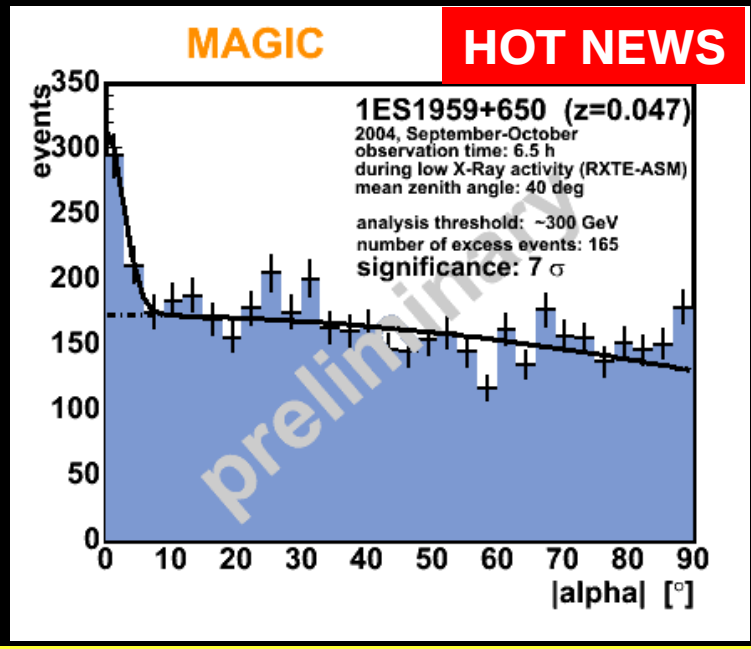
1ES 1959+650

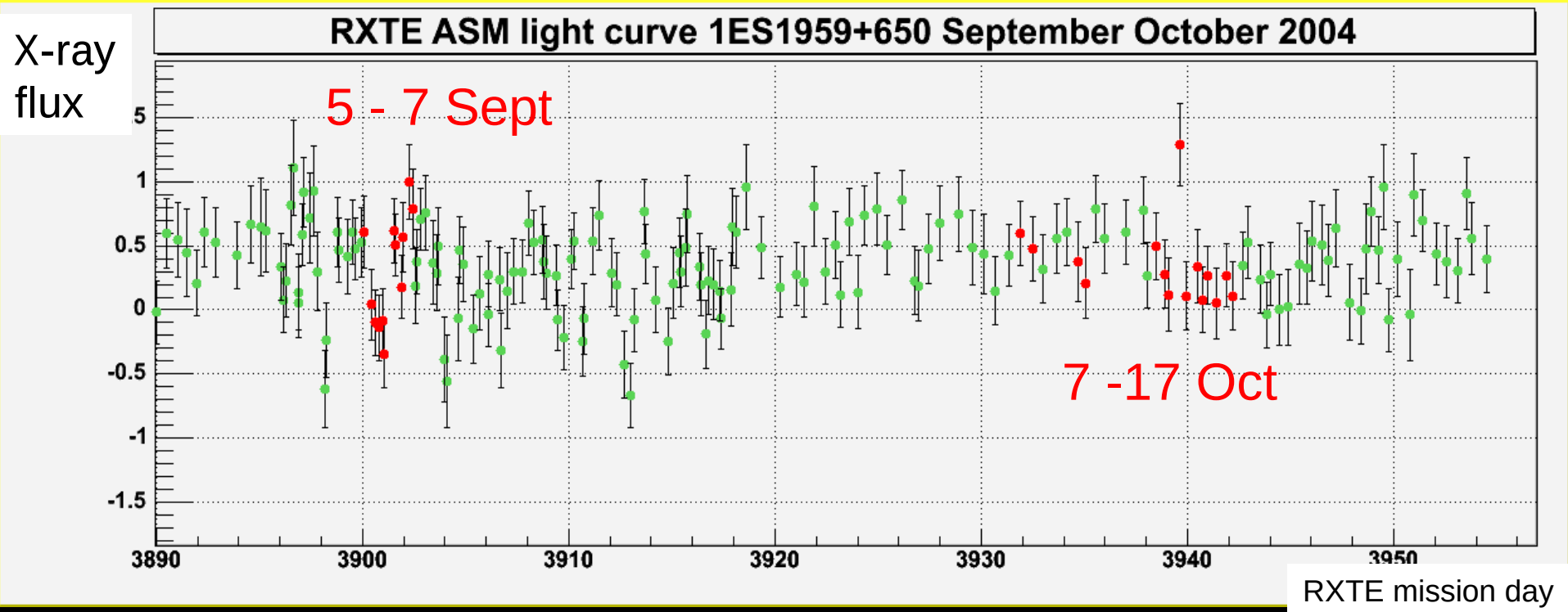
- Detected by Telescope Array, confirmed by Whipple and HEGRA.
- Observed “orphan flare”: Crab-level flare in TeV but not in X-rays.
- Could it be a “hadronic AGN”??
- Hint of a signal in AMANDA…?



MAGIC: 1ES 1959+650

Source detected while quiescent in X-rays and optical: 10% crab.



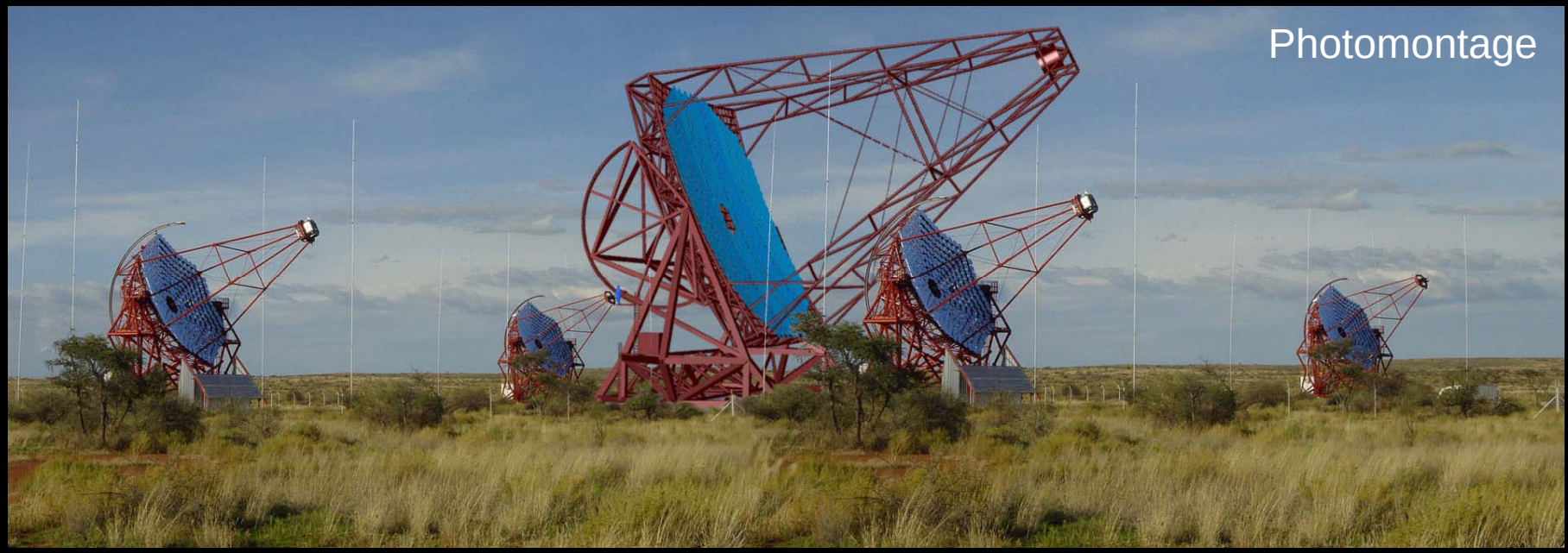


Complementary ν flux limited by CRs and extragalactic γ-rays

- CR and all hadronic sources (AGN, winds...) must produce ν's, so CR density can be used to limit ν fluxes expected in future detectors.
- Conversely ν's may constitute the only solid proof of hadronic origin of γ-rays.

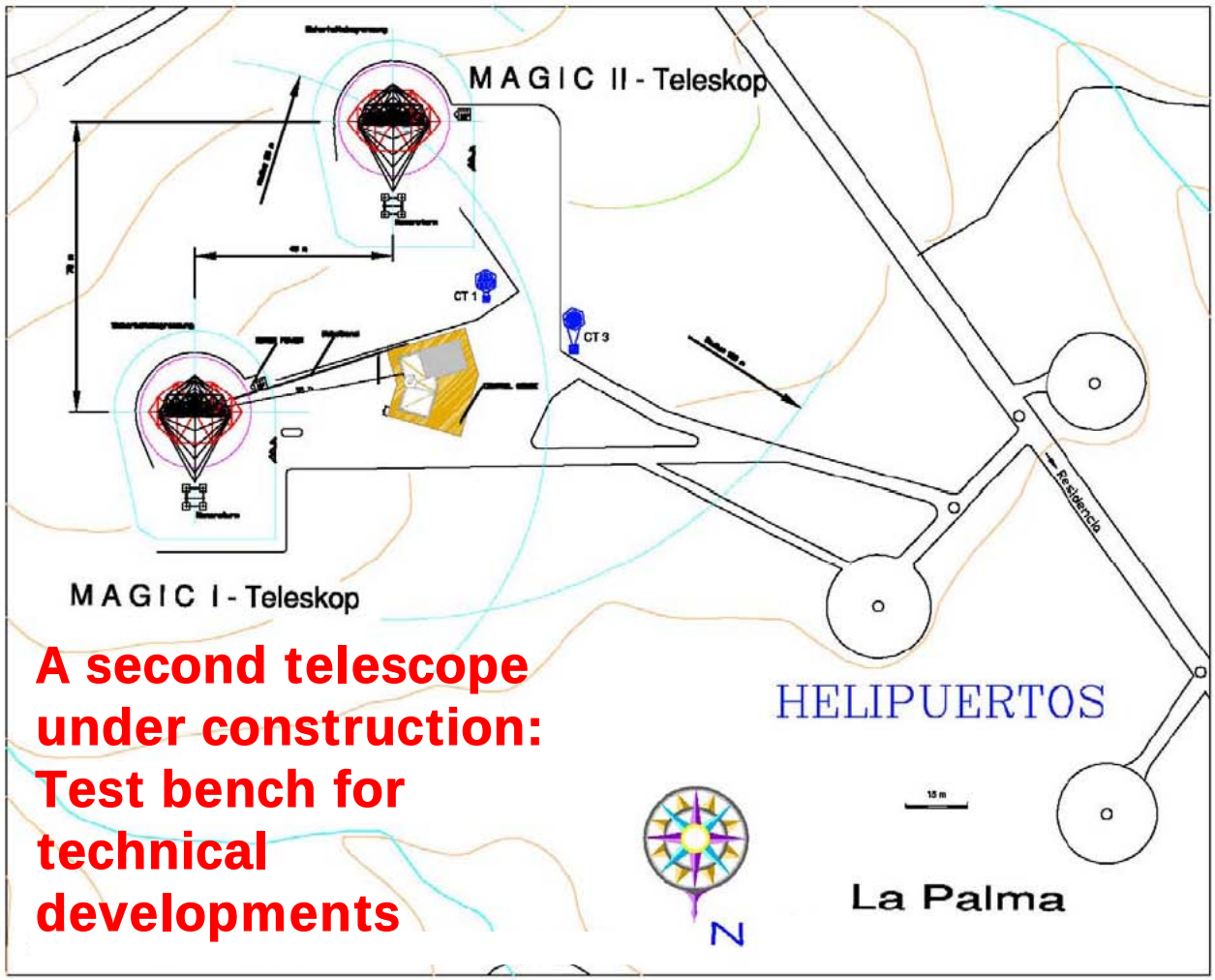
Latest instrumental developments

HESS-II



The HESS collaboration is starting the construction of a 30 m diameter mirror telescope at the HESS site.

MAGIC-II



A second telescope under construction: Test bench for technical developments

CONCLUSIONS

- The new generation of Cherenkov telescopes in the VHE γ-ray band from <50 GeV to >10 TeV is alive and kicking.
- HESS taking data regularly, MAGIC coming online, VERITAS and CANGAROO-III around the corner.
- The last generation just scratched the tip of the iceberg: The number of confirmed sources has already doubled!
- Stay tuned for hadronic accelerators, high redshift AGNs, GRB, indirect dark matter searches and unknown sources!