H.E.S.S. extragalactic gamma-ray sources

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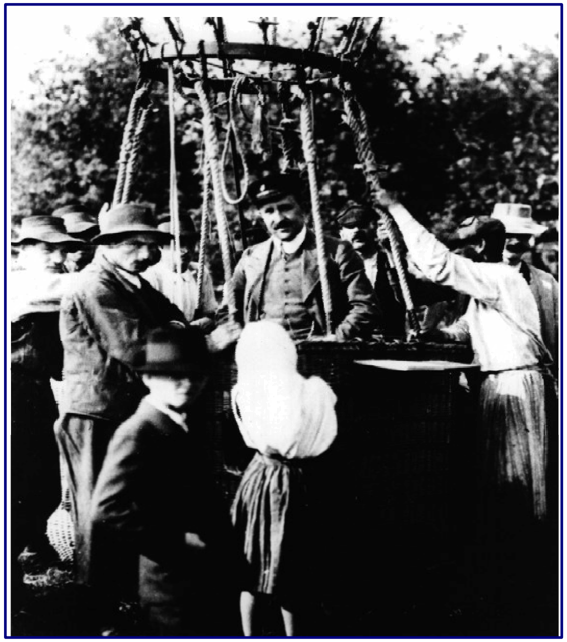
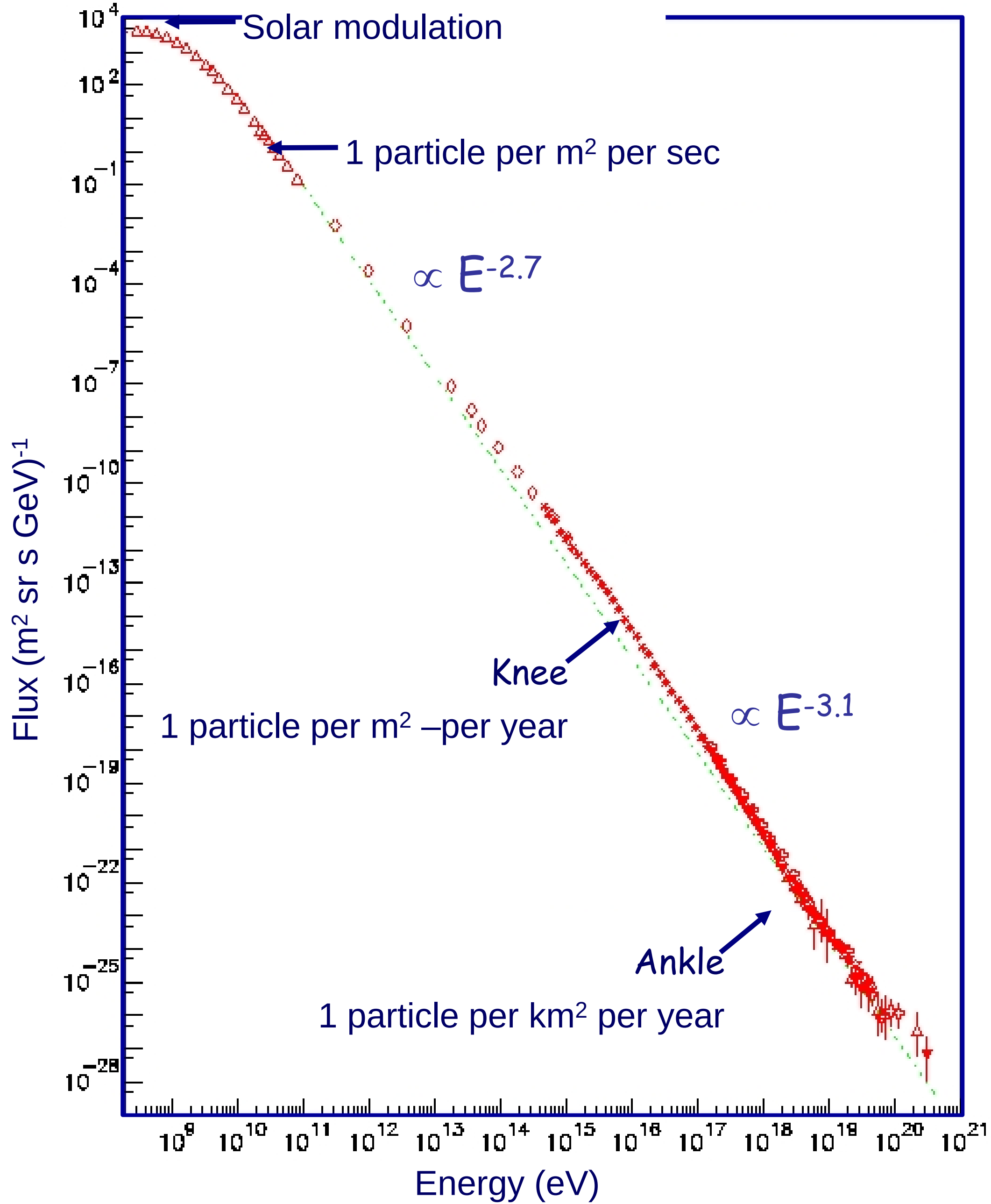
Outline

- Active Galactic Nuclei (AGN) candidate for Cosmic Rays studies
- γ-astronomy: Cherenkov telescopes (HESS)
- Detection of AGN in VHE band
- Monitoring of AGN in VHE band
- Multiwavelength observations of AGN
- Some conclusions on what we know about AGN and perspectives in this field

AGN: candidates for CR sources

The cosmic rays





- Discovered by HESS in 1912
- 30 orders of magnitude in energy, 10 in flux magnitude
- Origin still unknown: Holy grail of astrophysics

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Sources of cosmic rays

Charged cosmic rays :

- Galactic origin (CR Energy < 10^{15} eV)
- Propagation in turbolent magnetic field

→ Loss of information on the source

Gamma-rays:

- Sources of CR emitting γ
- Propagation in straight line

→ **INFORMATION ON THE SOURCE**

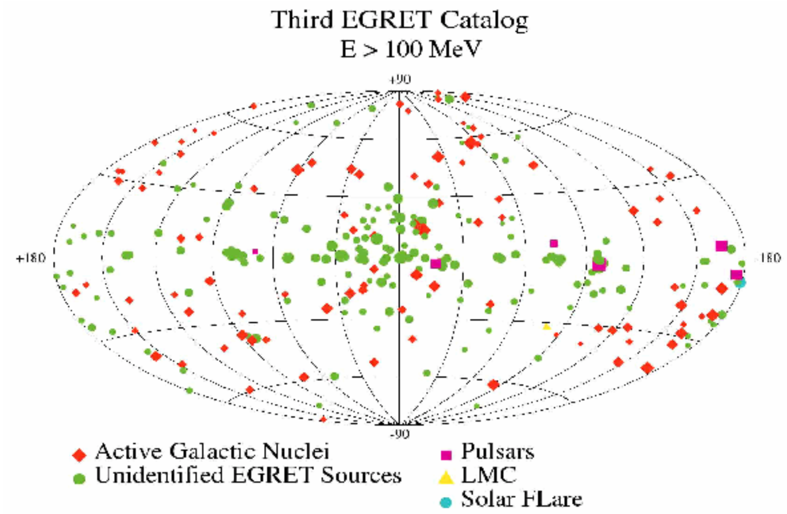
Non-thermal emission dominated by the conversion of gravitational energy into e.m energy

A POSSIBLE CANDIDATE (extragalactic sources):

ACTIVE GALACTIC NUCLEI

Active Galactic Nuclei

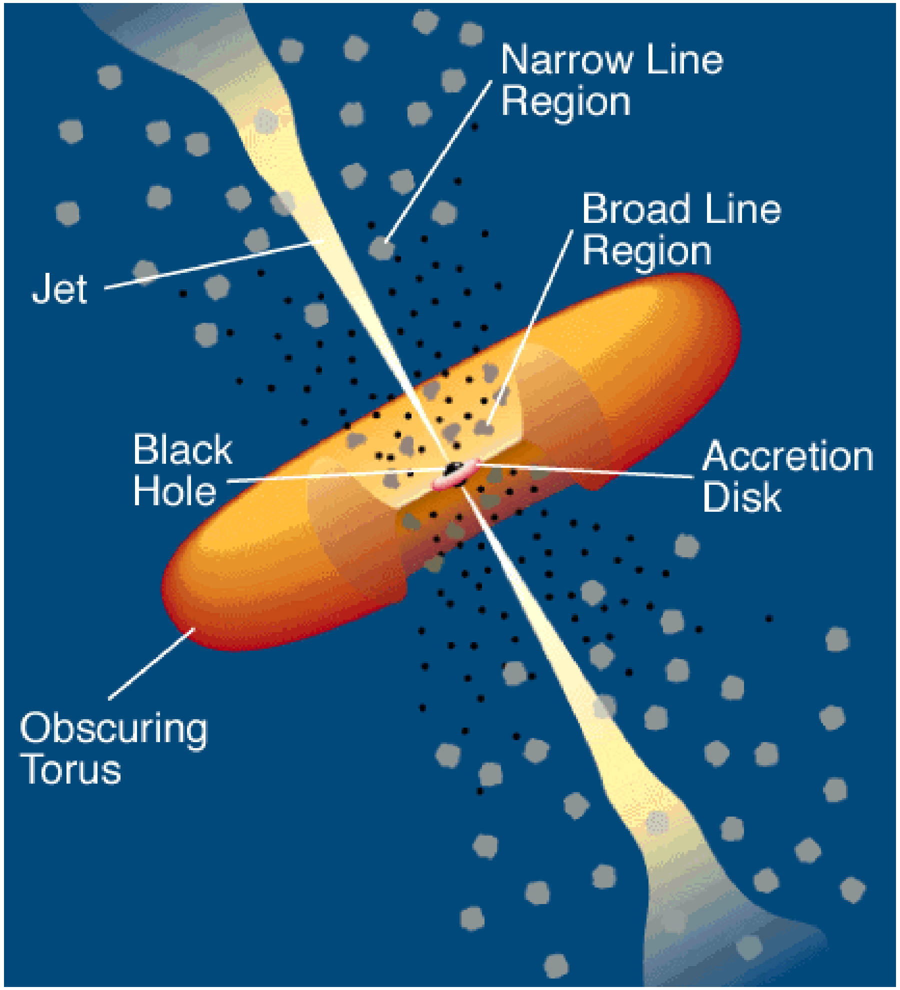
- ~10% of the galaxies are actives
- They possess an amazing source of energies at its nucleous
- High luminosities (10^{40}~10^{46} erg/s)
- Many sources, mostly classified according to observational criteria (at least so far)
- Unified AGN model (Begelman et al. 1984): 10% of the accreted mass is transformed into radiation
- Different models predict different γ spectra



- EGRET discovered > 60 extragalactic sources.
- All radio laud (~10% of AGN).
- All the extragalactic sources of EGRET belong to the "blazar" category

The Unified Model of AGNs Begelman et al. 1984

- Radio galaxies, quasars, QSOs, Seyferts, etc.. are the same type of object viewed from different angles.
- Centre of a galaxy is a black hole surrounded by an accretion disk, clouds of gas and a dusty torus.
- The energy output comes from accretion of material onto the black hole.



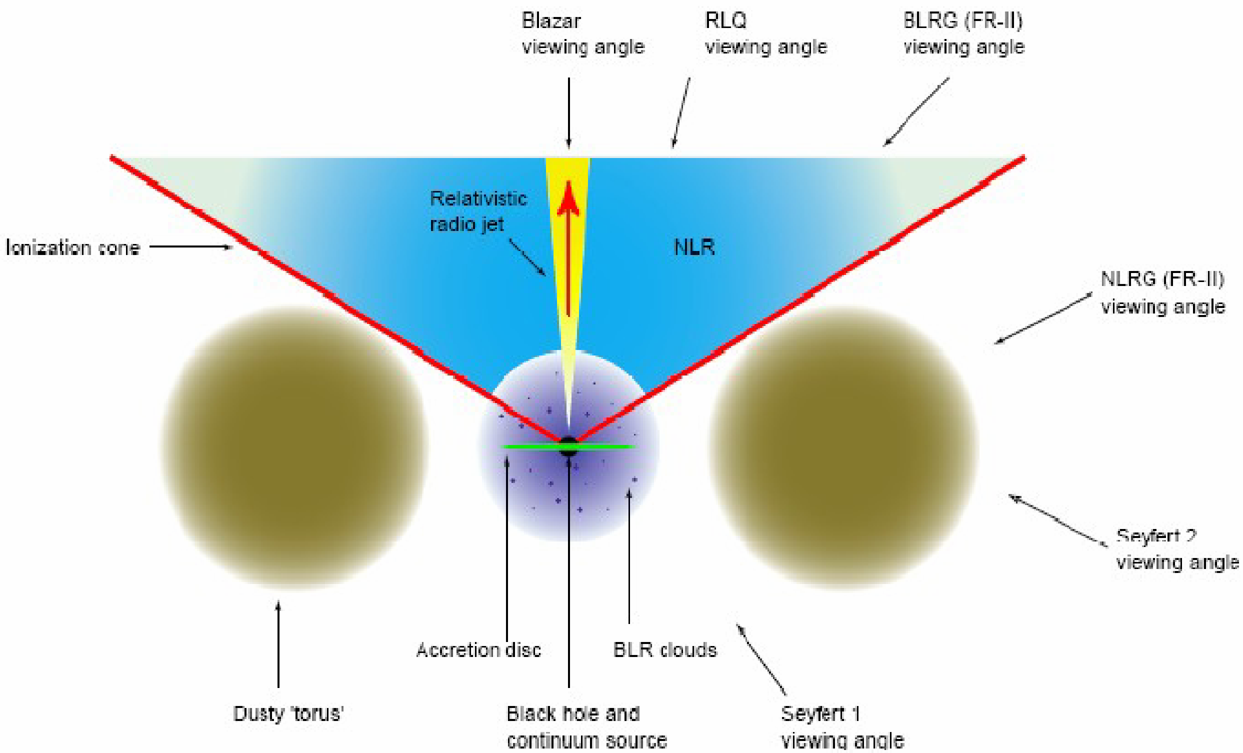
If conditions are right, the galaxy may also possess a magnetically-confined
jet which could be the source of radio emission.

AGN taxonomy

AGN are a very heterogeneous group

All AGN-type are the same but looked at from a different point of view

	Face-on	Edge-On
Radio-Quiet	Sy1	Sy2
	QSO	FIR Galaxy?
Radio-Loud	BL Lac	FR-I
	BLRG	NLRG
	Quasar	FR-II



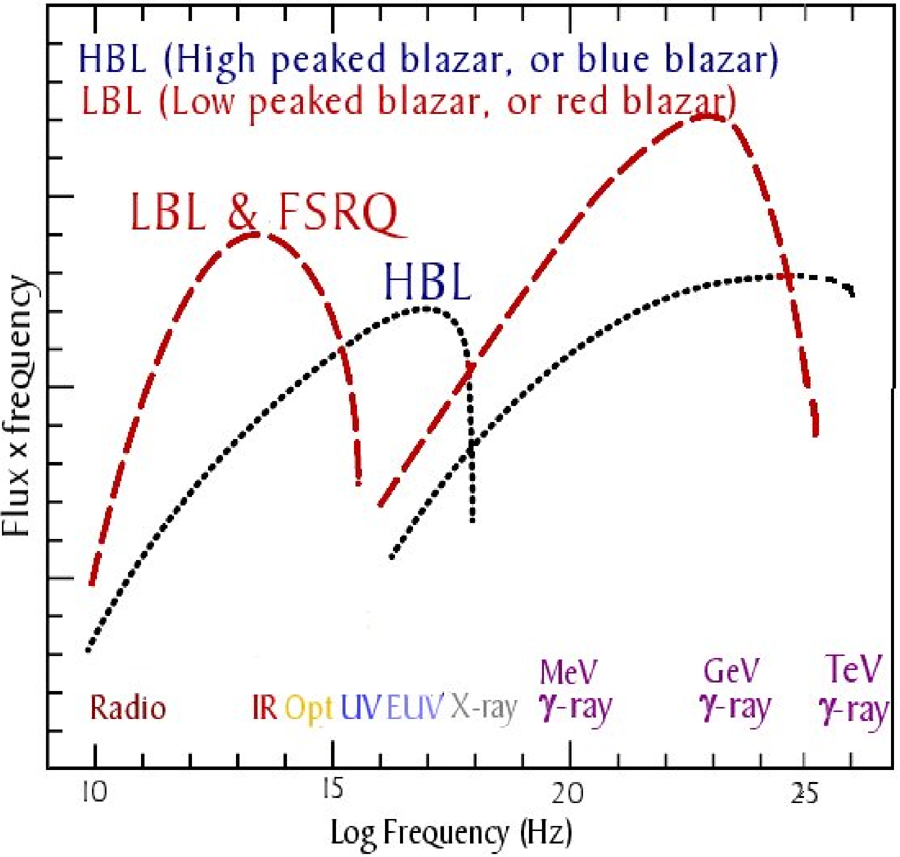
<u>Blazars:</u> special class of radio-loud AGN with their jets practically pointing towards the observer

Include: BL Lacertae and O.V.V.

<u>Main properties</u>

- radio loudness;
- rapid variability (high $\Delta L/\Delta t$);
- high and variable polarization in Optic-radio band($P_{OPT} > 3\%$);

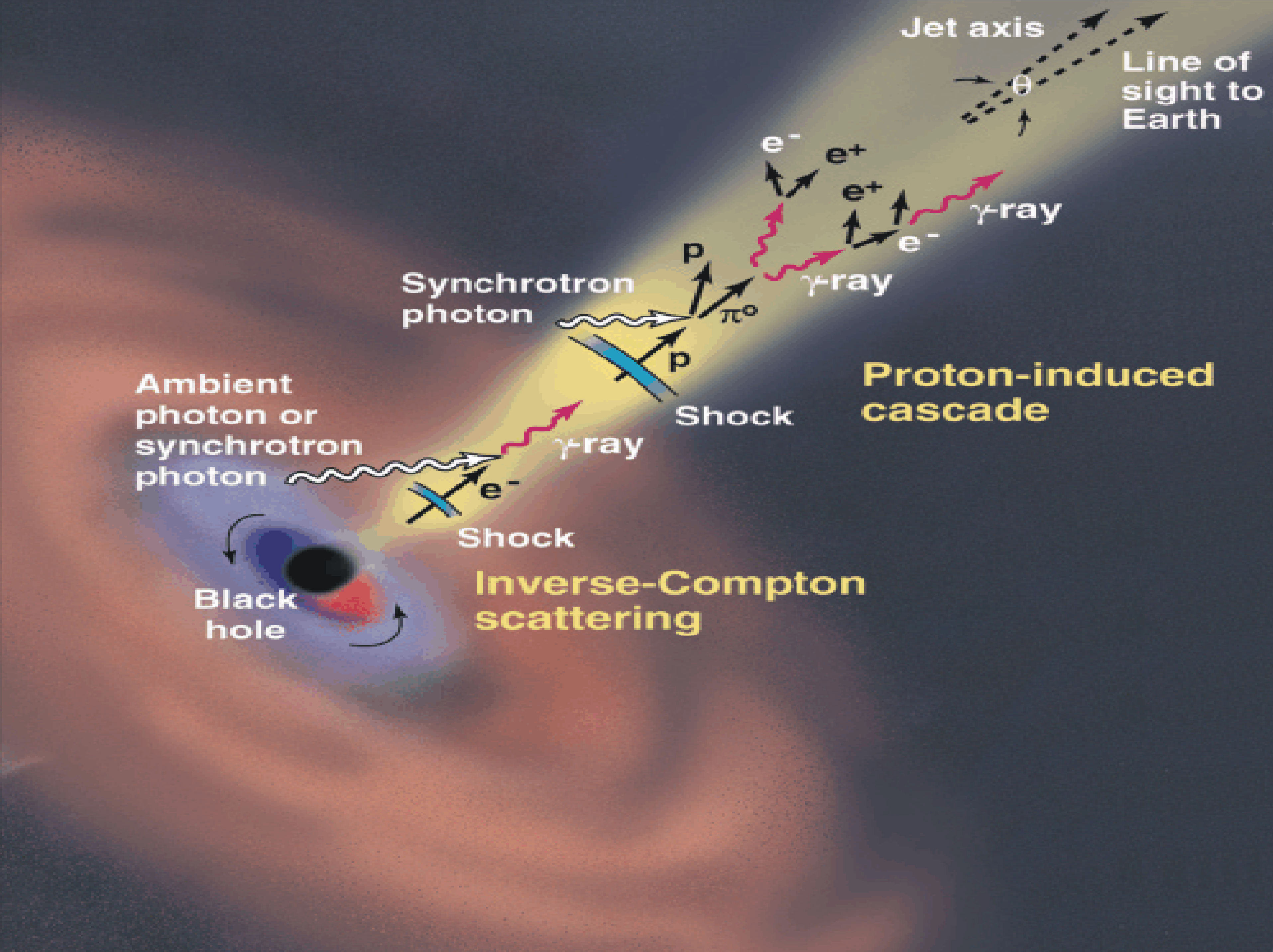
Spectral Energy Distribution of a blazar



Presence of two well defined components in blazars spectra
Low Energy peak -> synchrotron emission by relativistic electrons in the magnetic field
High Energy peak -> less well understood (inverse Compton of ambient photon)

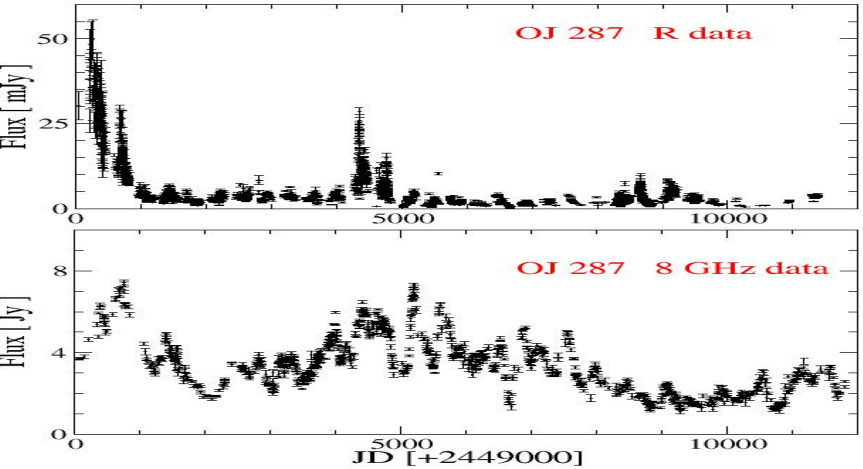
Leptonic scenario: Self-Synchro-Compton model (SSC) / External Radiation Compton

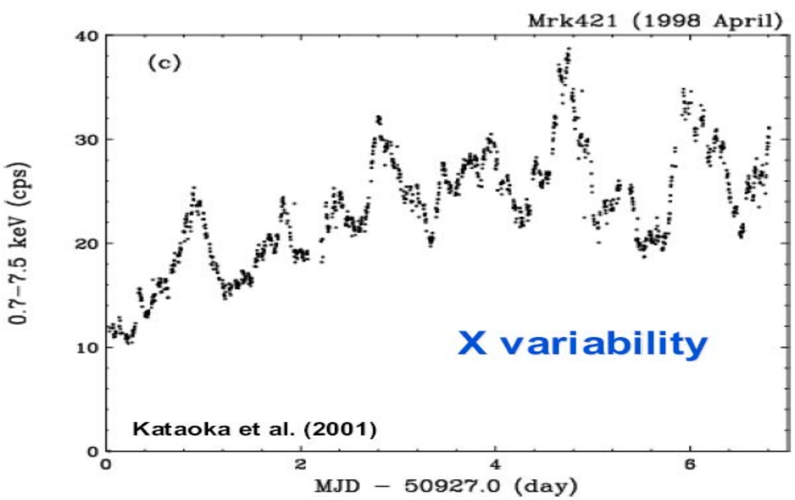
Hadronic scenario: protons are the primarly accelerated in the jet. Synchrotron radiation from $e^{\pm}$ produced in hadronic cascades



Jet axis
Line of sight to Earth
θ
e⁻
e+
e+
γ-ray
e⁻
p
Synchrotron photon
π⁰
γ-ray
p
Proton-induced cascade
Shock
Ambient photon or synchrotron photon
γ-ray
e⁻
Shock
Black hole
Inverse-Compton scattering

Time Variability





Main carachteristic of blazars:
rapid time variability with large amplitudes

Flares observed in many wavelengths

Insight on the acceleration mechanisms

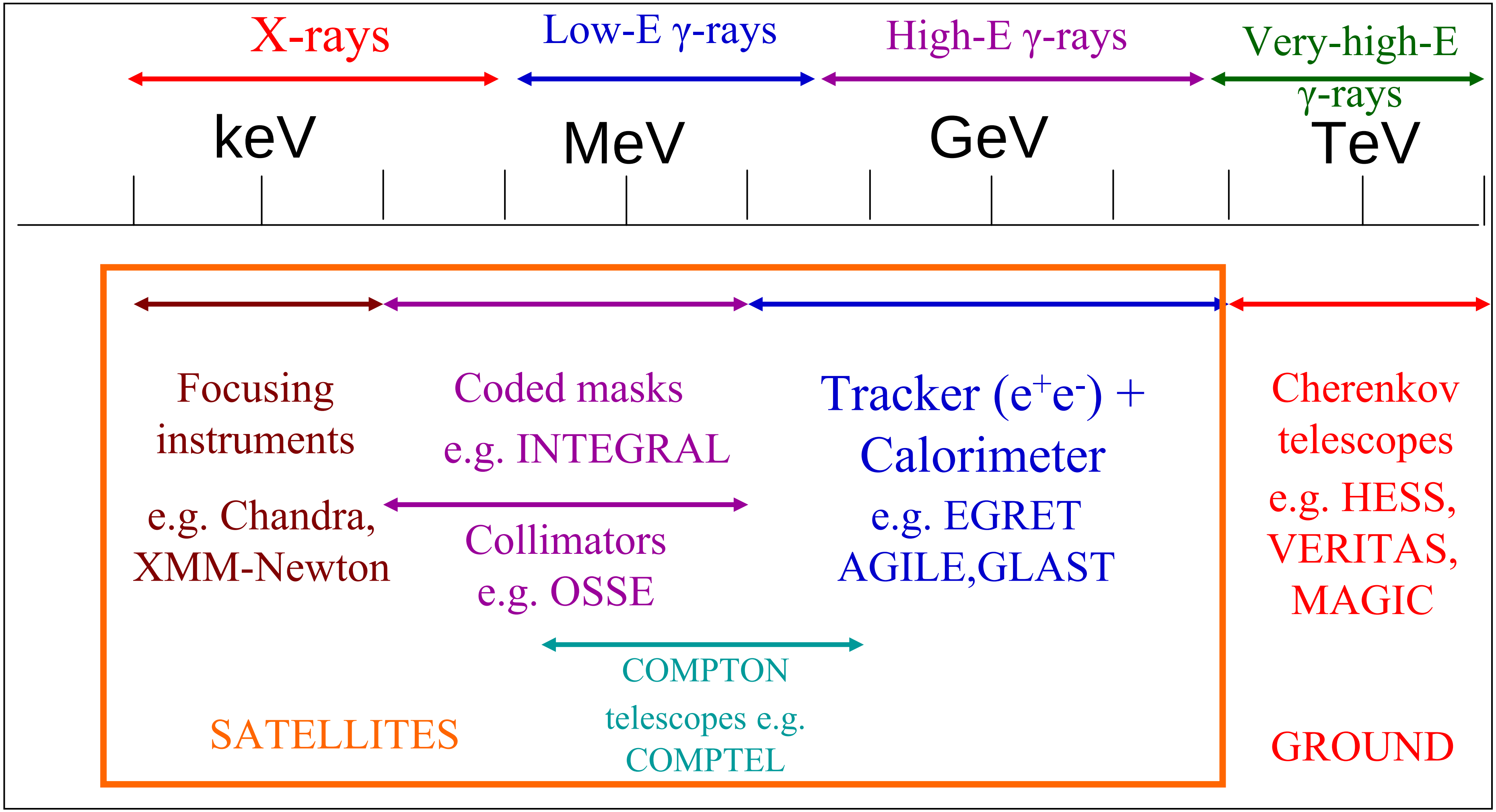
Open points

- What are we trying to learn on AGN?
- Jet formation and launching
- The accretion disk-jet relation
- Jet composition

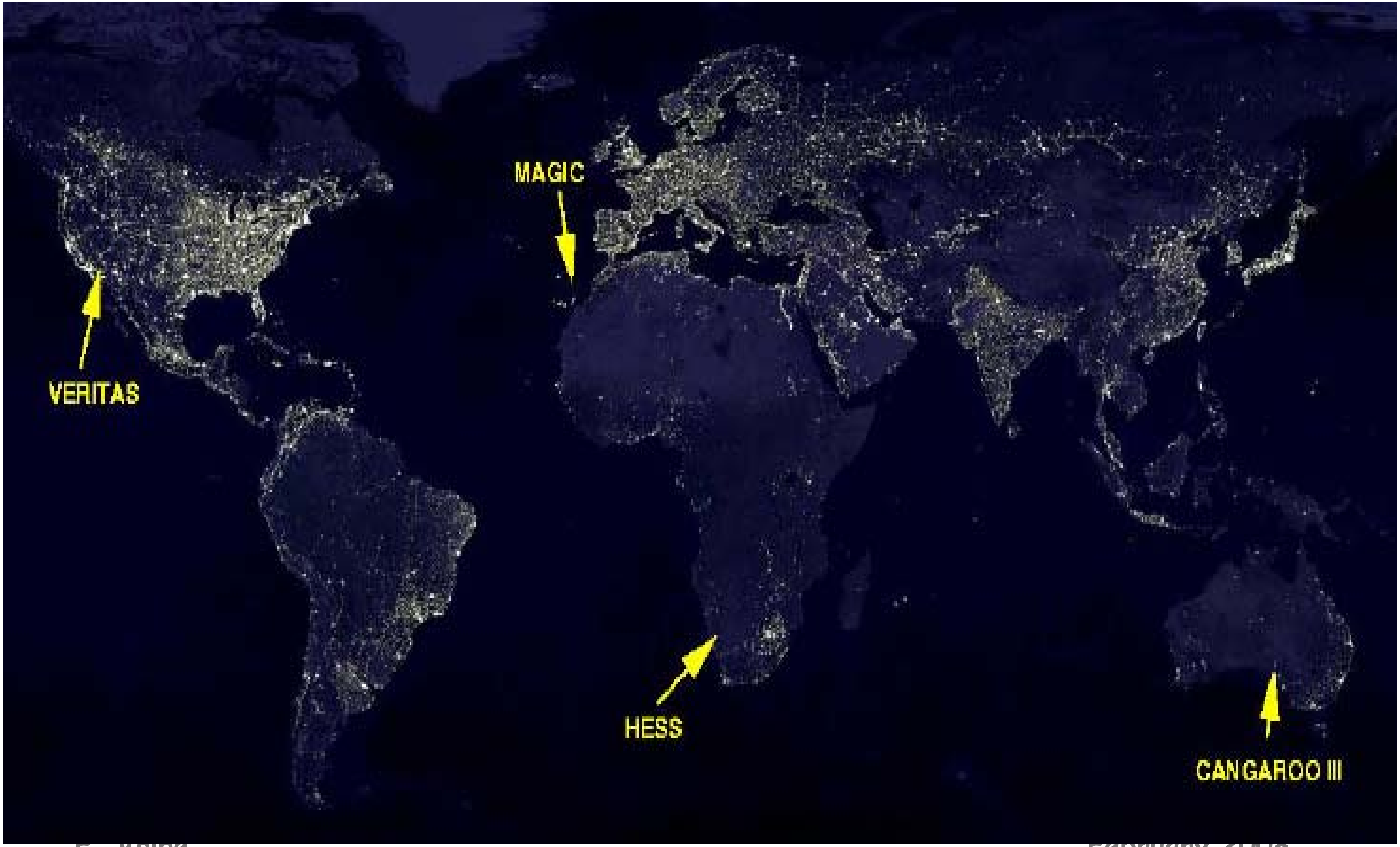
- What are we trying to learn from γ emission of AGN in VHE band?
- Acceleration mechanisms of cosmic rays
- Leptonic or hadronic scenario?
- γ_{VHE}-γ_{EBL} $\Rightarrow$ cosmological information on galaxies and star formation.
- Energy-dependent delays could probe quantum gravity.

Study @ TeV of these sources with ground-based instruments

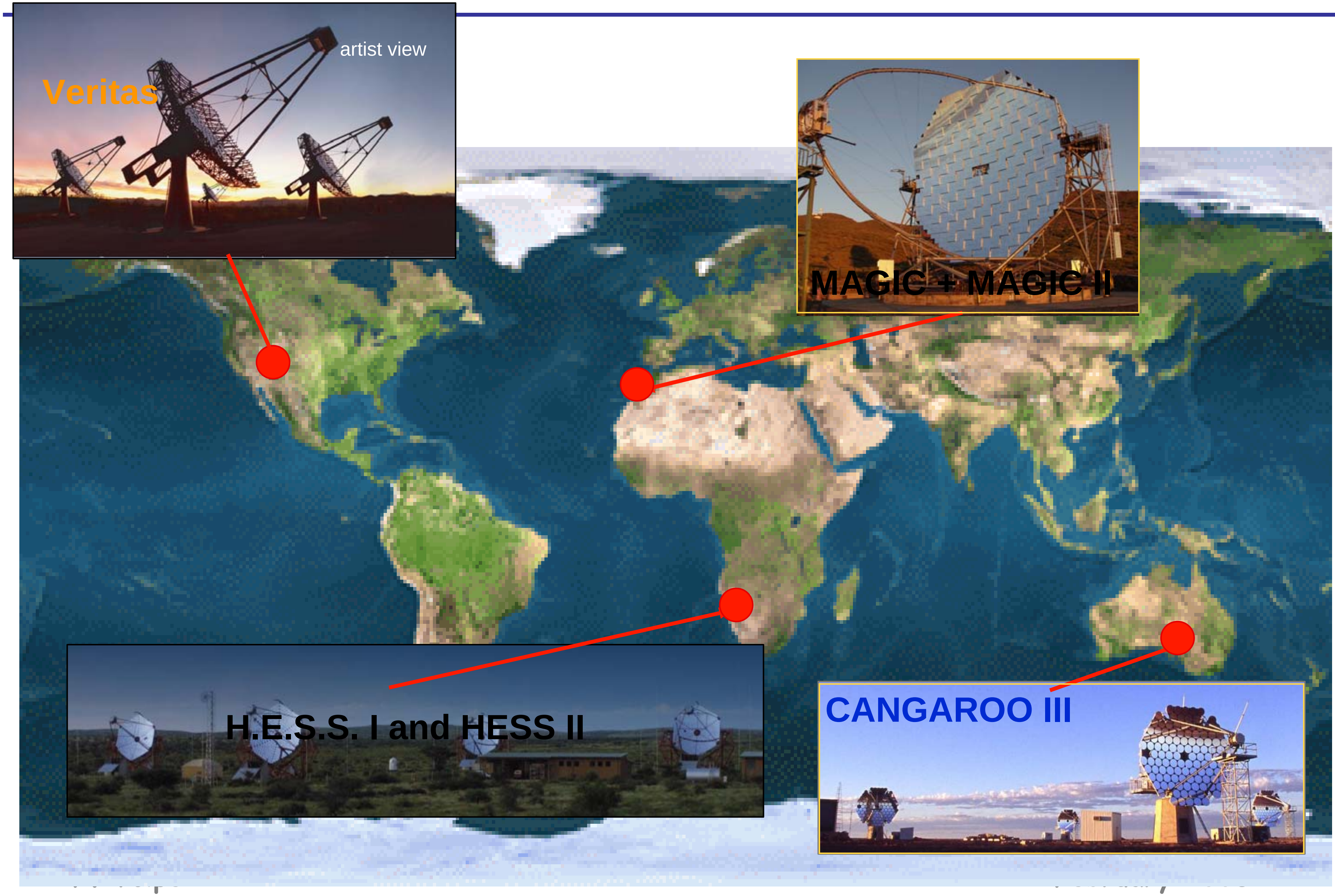
Instruments for HE photon detection



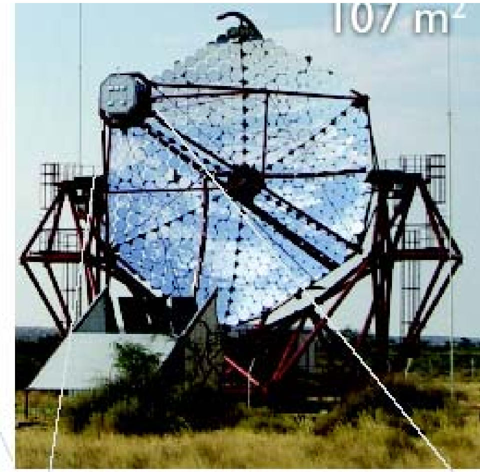
Cherenkov telescopes

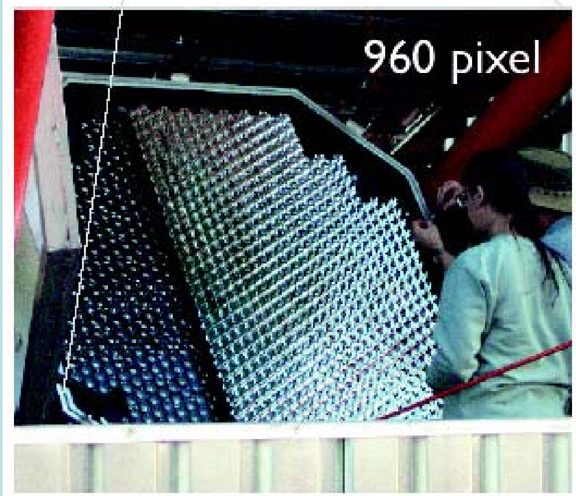


Major Atmospheric Cherenkov Telescopes



The H.E.S.S. array of Cherenkov Telescope





- 4 Cherenkov telescopes array located in Namibia
stereoscopic observation mode

- 107 m^2 mirror area per telescope

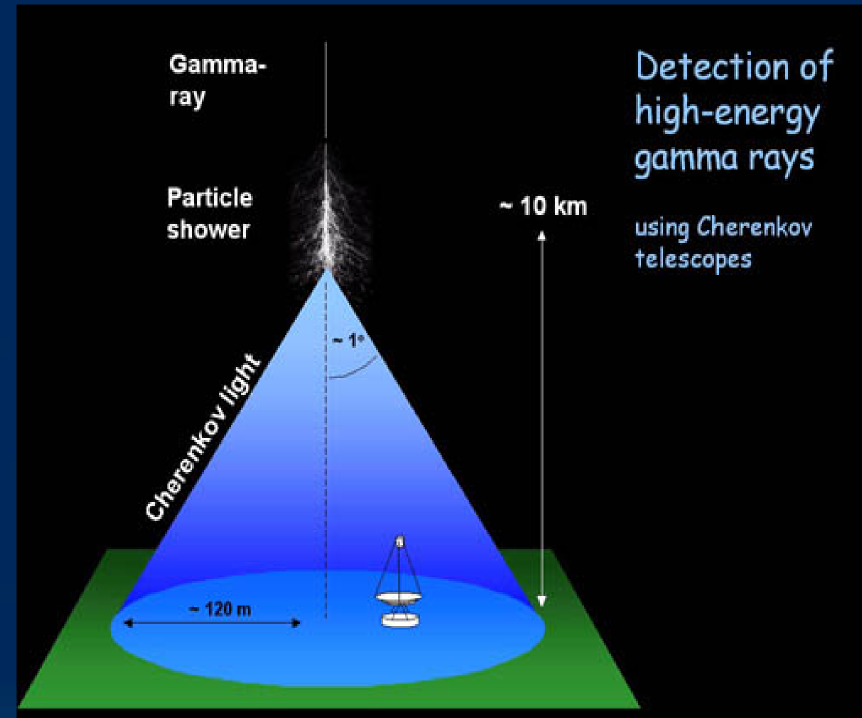
- Photomultiplier camera:
960 PMTs, ~5 deg field of view

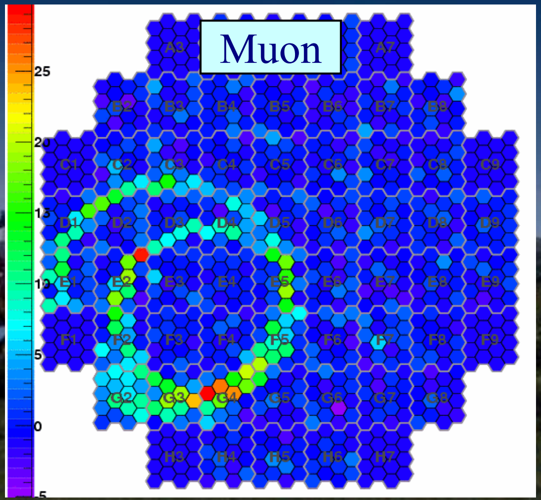
- Energy range: 100 GeV up to several 10 TeV
dE/E ~ 15%

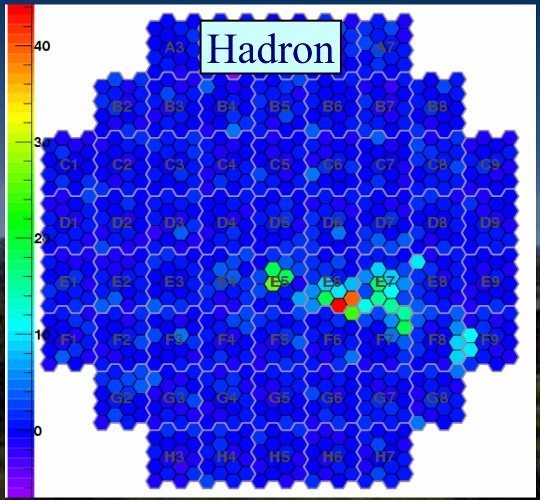
- Angular resolution: ~0.1 deg per event

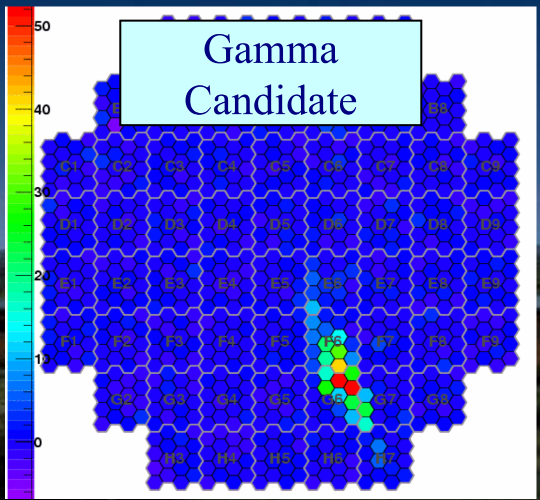
Cherenkov astronomy

- The e.m. showers develop in the atmosphere and emit Cherenkov radiation
- Image of a shower obtained in the camera at high definition
- Analysis of the morphology of the image
- Big handicap: high background level (hadrons)

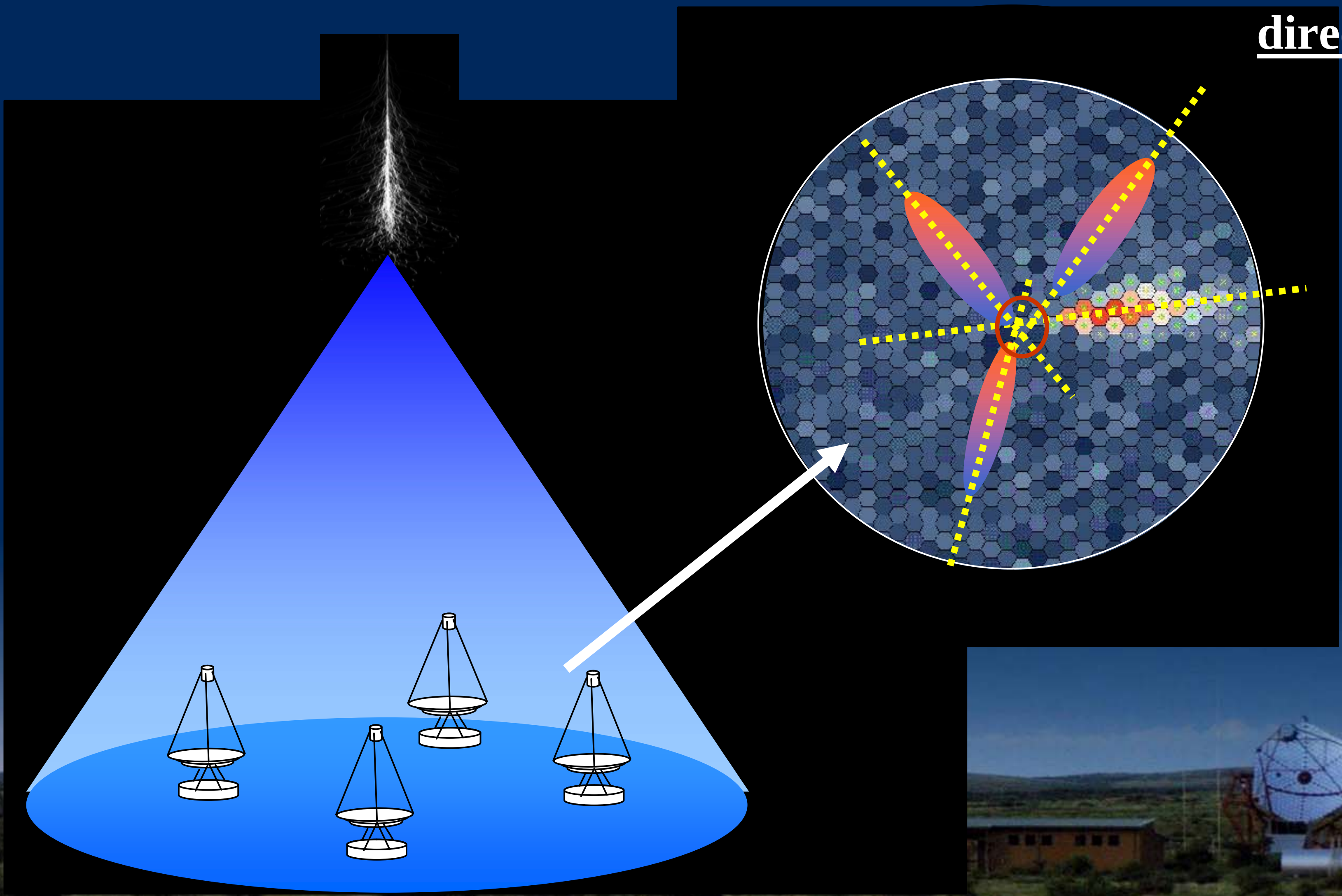


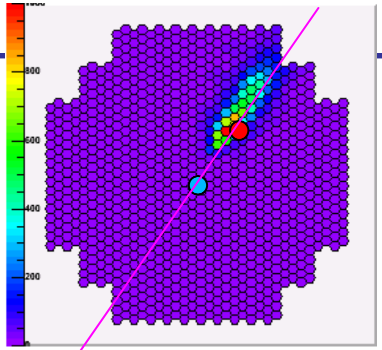


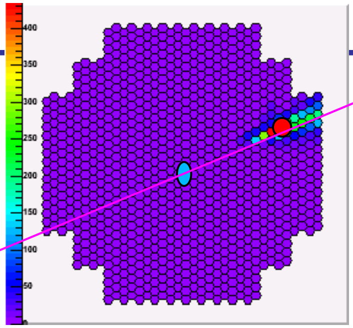




Stereoscopy







Position of the source

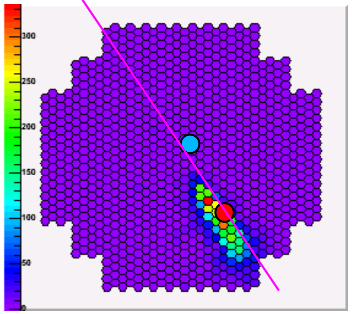
Stereoscopy permits to detect:

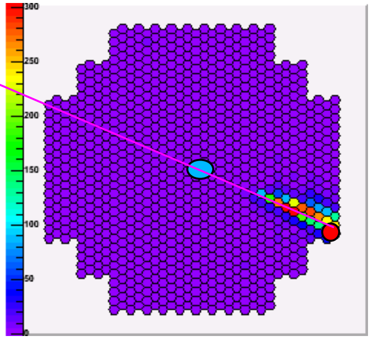
•Gamma direction in the FOV (extended sources)

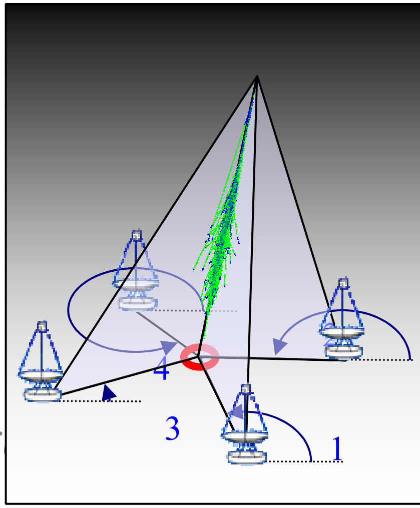
• energy measure

Centre of gravity of the image

Track on ground

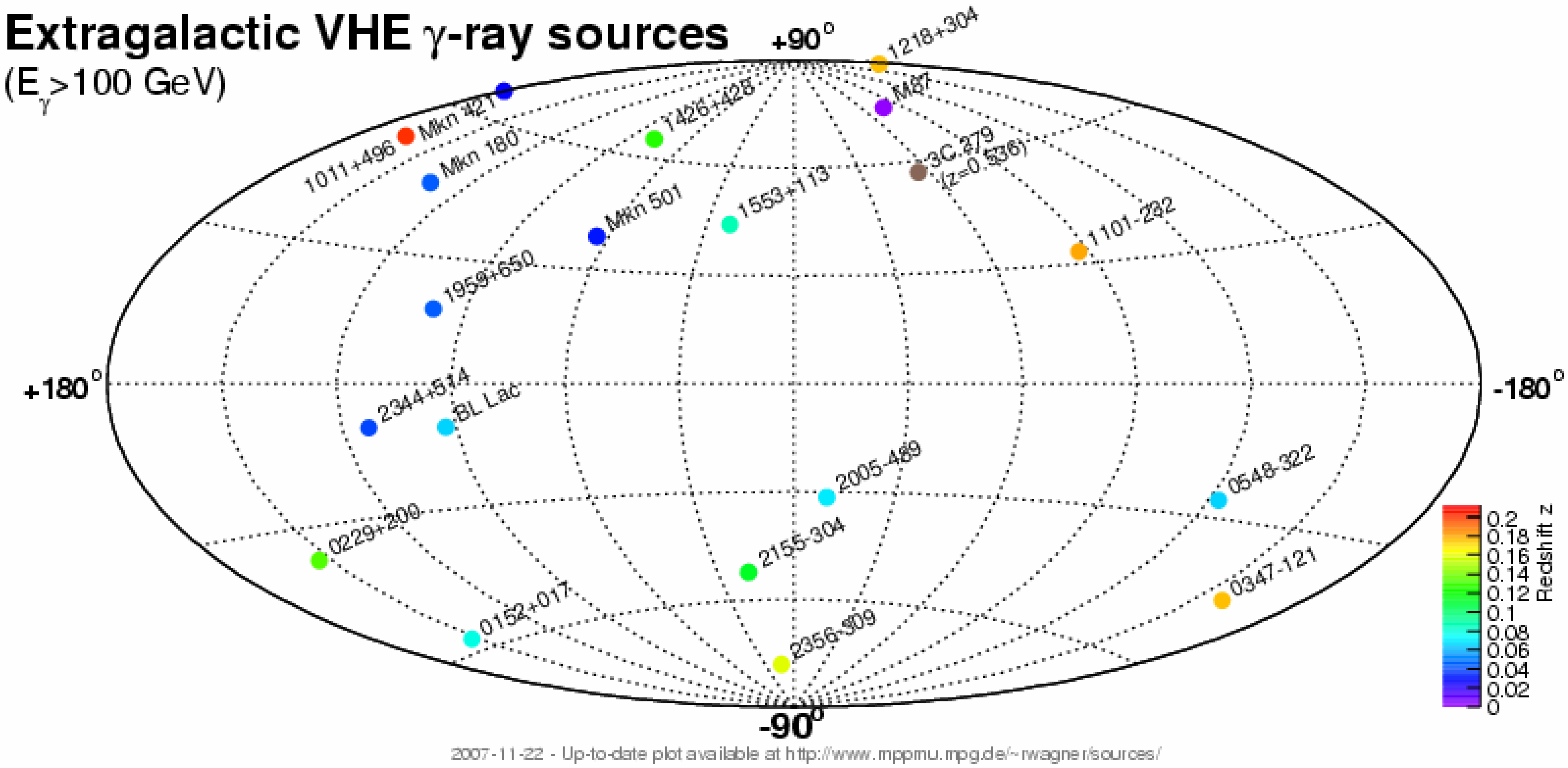






New blazars detection: increase the population

Skymap



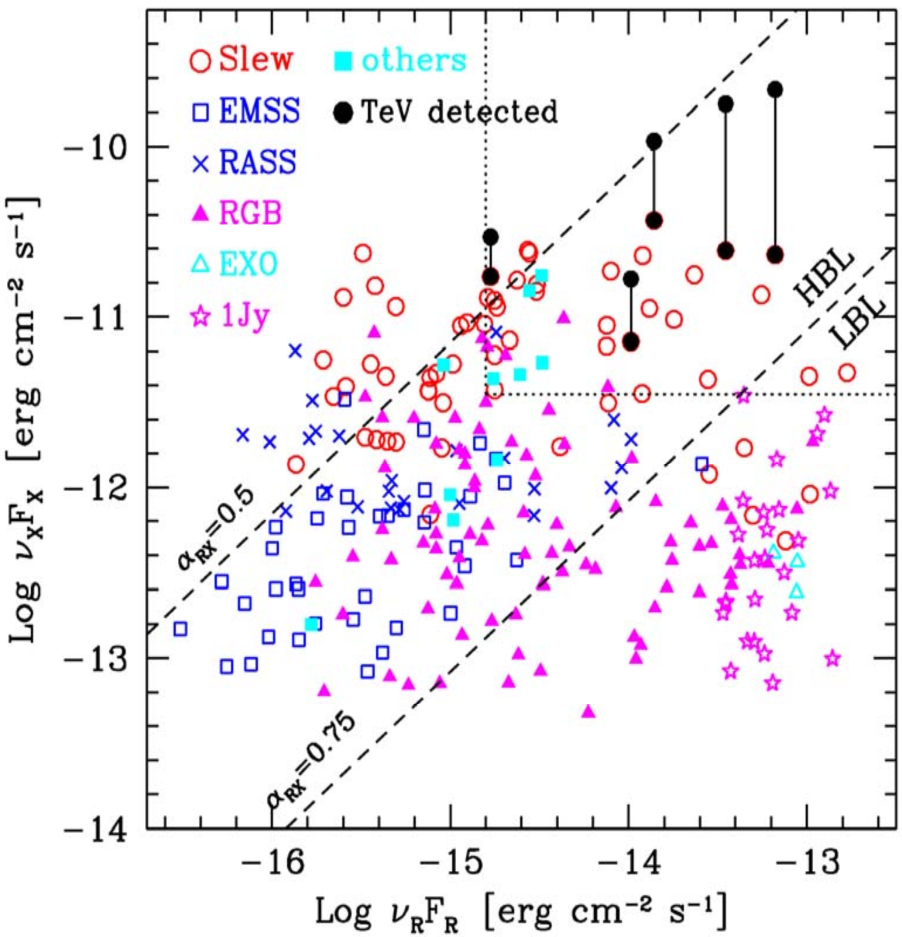
Detection at TeV is not a scan (EGRET)

VHE extragalactic sources

Name	RA	Dec	Type	Discovery	Date	Dist	
M87	12 30 49.4	12 23 28	FRI	HEGRA	june 2005	0,0044	
Markarian 421	11 04 27.3	+38 12 32	HBL	Whipple	aug 1992	0,031	
Markarian 501	16 53 52.2	+39 45 36	HBL	Whipple	jan 1996	0,034	
1ES 2344+514	23 47 04.8	+51 42 18	HBL	Whipple	july 1998	0,044	
Markarian 180	11 36 26.4	+70 09 27	HBL	MAGIC	sept 2006	0,045	
1ES 1959+650	19 59 59.9	+65 08 55	HBL	Tel. Array	aug 1999	0,048	
BL Lacertae	22 02 43.3	+42 16 40	LBL	MAGIC,Crimea(?)	apr. 2001	0,069	
PKS 0548-322	05 50 40.8	-32 16 18	HBL	H.E.S.S.	july 2007	0,069	ICRC 07
PKS 2005-489	20 09 29.3	-48 49 19	HBL	H.E.S.S.	june 2005	0,071	
RGB 0152+017	01 52 39.6	+01 47 17	HBL	H.E.S.S.	nov. 2007	0,080	Atel
PKS 2155-304	21 58 52.7	-30 13 18	HBL	Durham	june 1999	0,116	
H 1426+428	14 28 32.6	+42 40 21	HBL	Whipple	feb. 2002	0,129	
1ES 0229+20	02 32 48.4	+20 17 16	HBL	H.E.S.S.	dic. 2006	0,140	
H 2356-309	23 59 09	-30 37 22	HBL	H.E.S.S.	apr. 2006	0,165	
1ES 1218+304	12 21 21.9	+30 10 37	HBL	MAGIC	may 2006	0,182	
1ES 1101-232	11 03 38	-23 29 31	HBL	H.E.S.S.	apr. 2006	0,186	
1ES 0347-121	03 49 23.2	-11 59 27.0	HBL	H.E.S.S.	aug. 2007	0,188	
1ES 1011+496	10 15 04.1	+49 26 01	HBL	MAGIC	sept. 2007	0,212	
PG 1553+113	15 55 43.0	+11 11 24	HBL	H.E.S.S.	march 2006	0.35?	
3C 279	12 56 11.1	-5 47 2.2	FSRQ	MAGIC	july 2007	0,536	ICRC 07

AGN VHE γ-ray emitters : 17 + 3 (TBC) sources

HESS AGN campaign



HESS selection of extragalactic observation targets relies strongly on this plot of X-ray intensity versus radio intensity for the BL Lac objects (Costamante & Ghisellini, 2002)

- Objects having their jet pointing towards us.
- Virtually all active galaxies detected previously at TeV energies (full black points) belong to this class and are characterized by high X-ray and radio flux, indicative of the presence of high-energy electrons in the source.
- Scattering off ambient or synchrotron photons, these electrons produce TeV gamma rays.

HESS AGN campaign: recent discoveries

Two recent HESS discoveries

Higher red-shifts

•1ES 0347-121 (z=0.188)

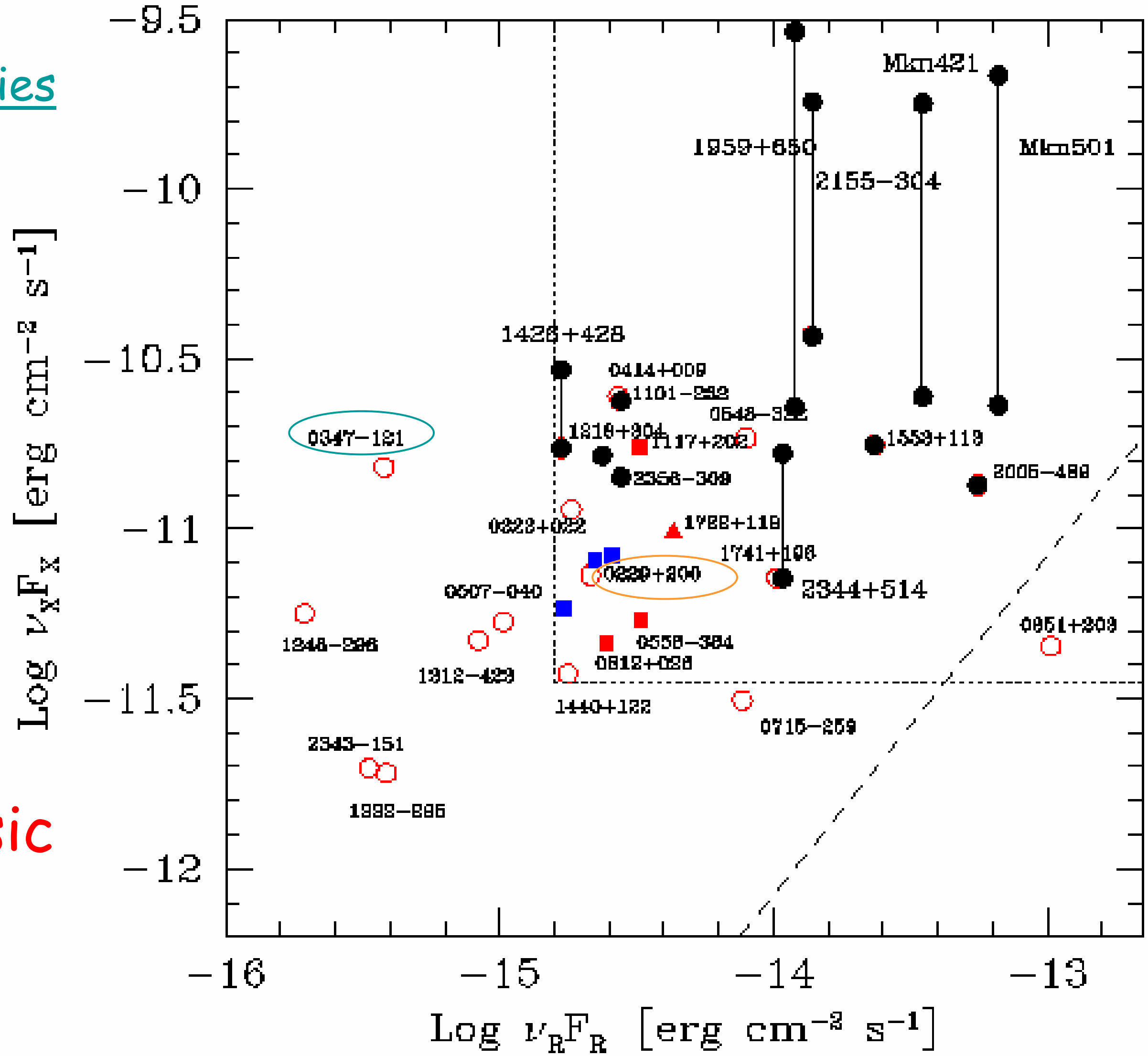
Aharonian et al. –

A&A 473 (2007) L25-L28

•1ES 0229+200 (z=0.14)

Aharonian et al. –

A&A, 475 (2007) L9-13



Disentangle intrinsic spectra from EBL features

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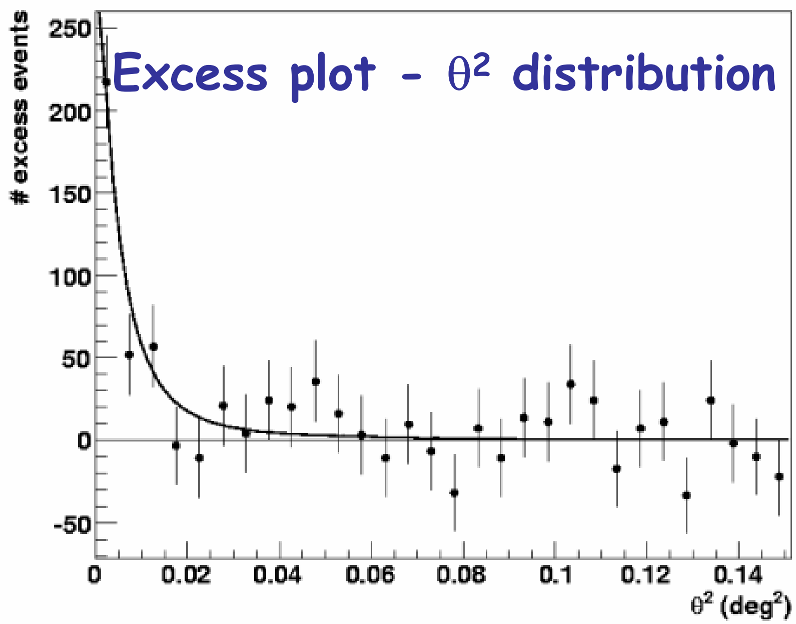
1ES 0347-121 (z=0.188)



25.1 h live time – data taken in 2006

mean zenith angle ~19^0

- 327 γ

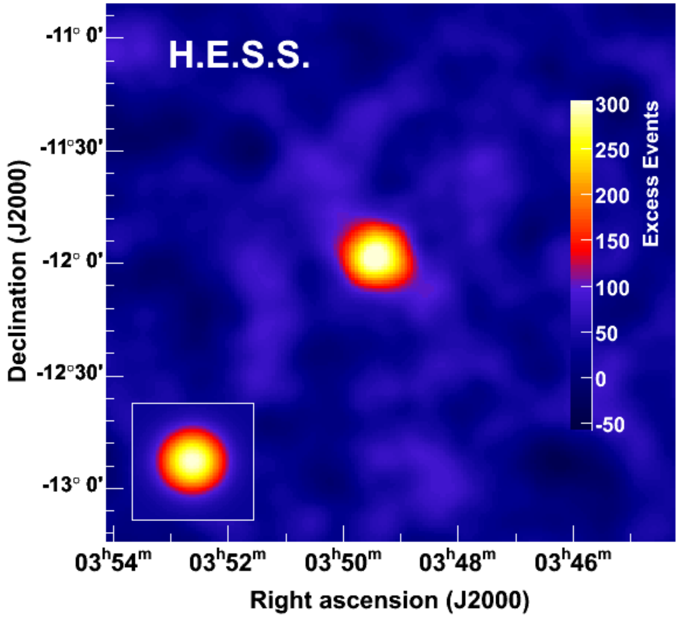
Significance 10.1 (Li&Ma)

Fit Position:

3h 49m 24.6s, -11d 58′49″

ΔRA=24″±23″, Δdec=38″±27″

Point-like source



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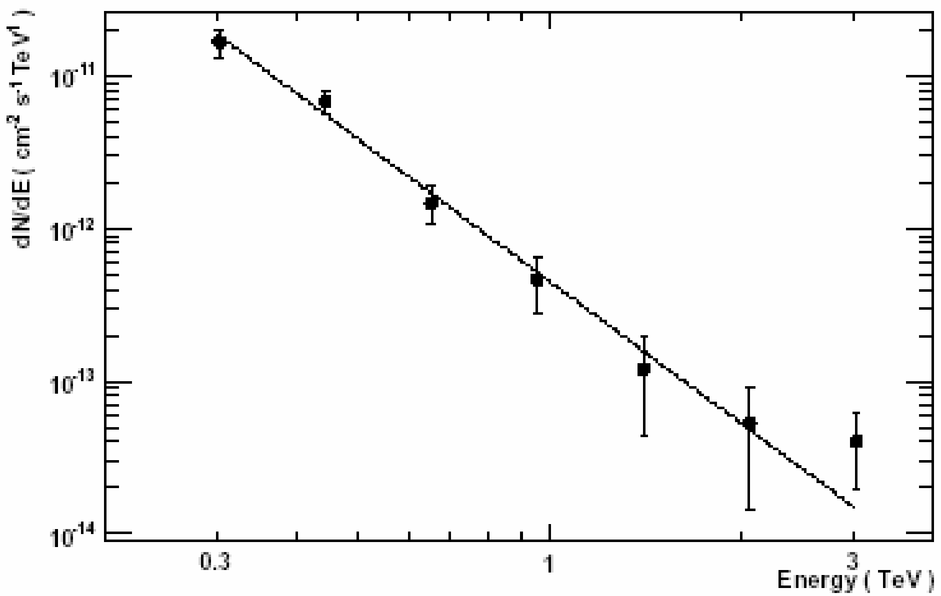
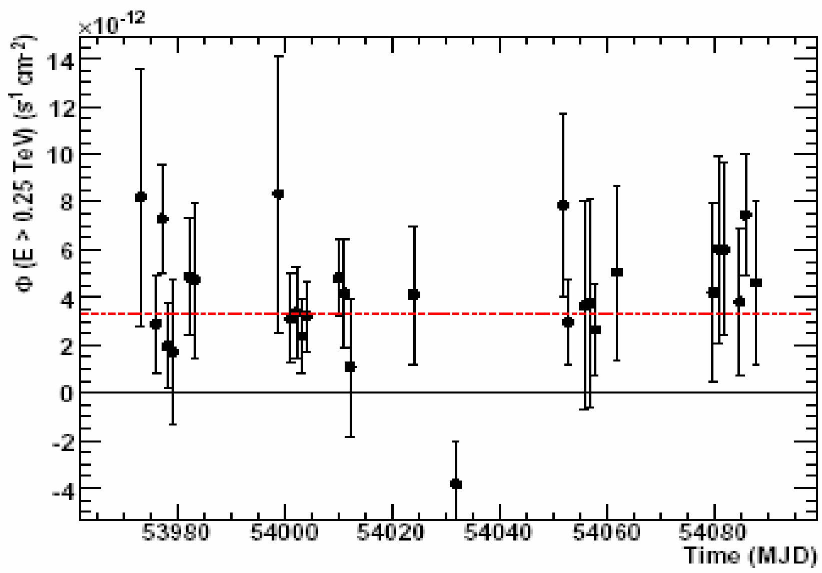
1ES 0347-121 spectrum & LC



Hard Spectrum

$\Gamma = 3.1 \pm 0.2$

Most distant blazar with measured spectrum



$\Phi(E>250\ GeV) =$

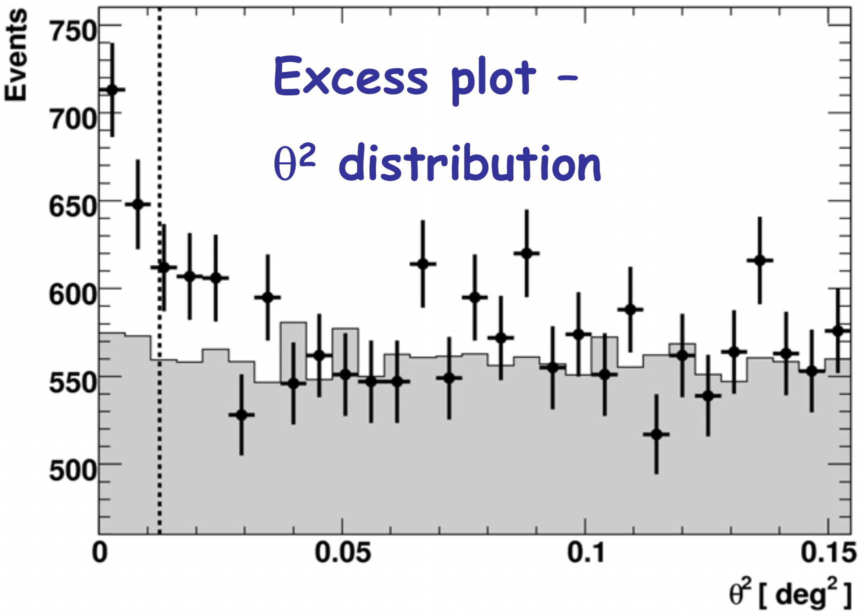
$(3.32 \pm 0.44_{stat}) \times 10^{-12}\ cm^{-2}\ s^{-1}$

~ 2% Crab

No significant variability

$(\chi^2/d.o.f.=3.04/28)$

1ES 0229+200 (z=0.1349)



Excess plot – θ^2 distribution

data taken in 2005-2006

mean zenith angle ~46^0

- 41.8h livetime :
- 261 γ

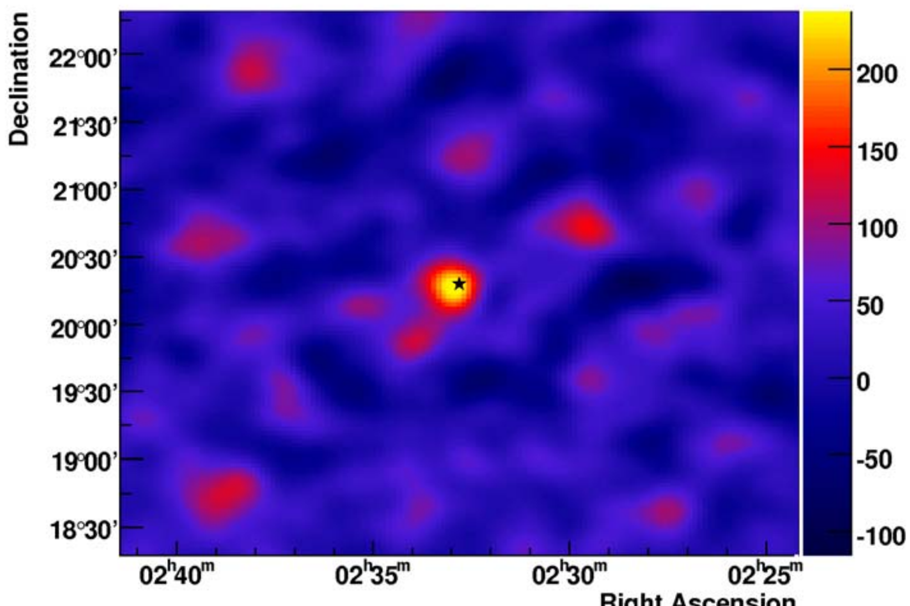
Significance 6.6 (Li&Ma)

Fit Position:

2h 32m 53.2s, 20d 16′21″

ΔRA=69″±46″, Δdec=-57″±44″

Point-like source



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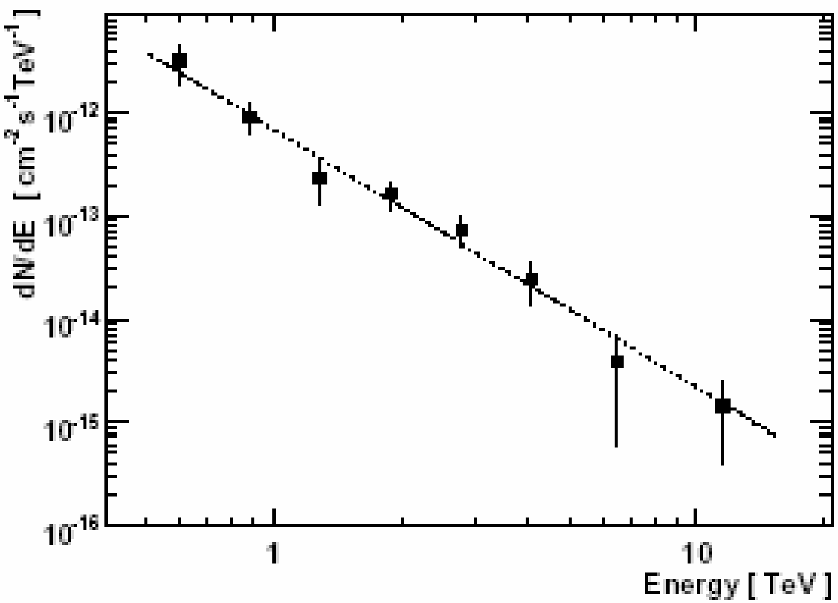
1ES 0229+200 spectrum



Hard Spectrum

$\Gamma = 2.5 \pm 0.19$

Φ (E>580 GeV) =

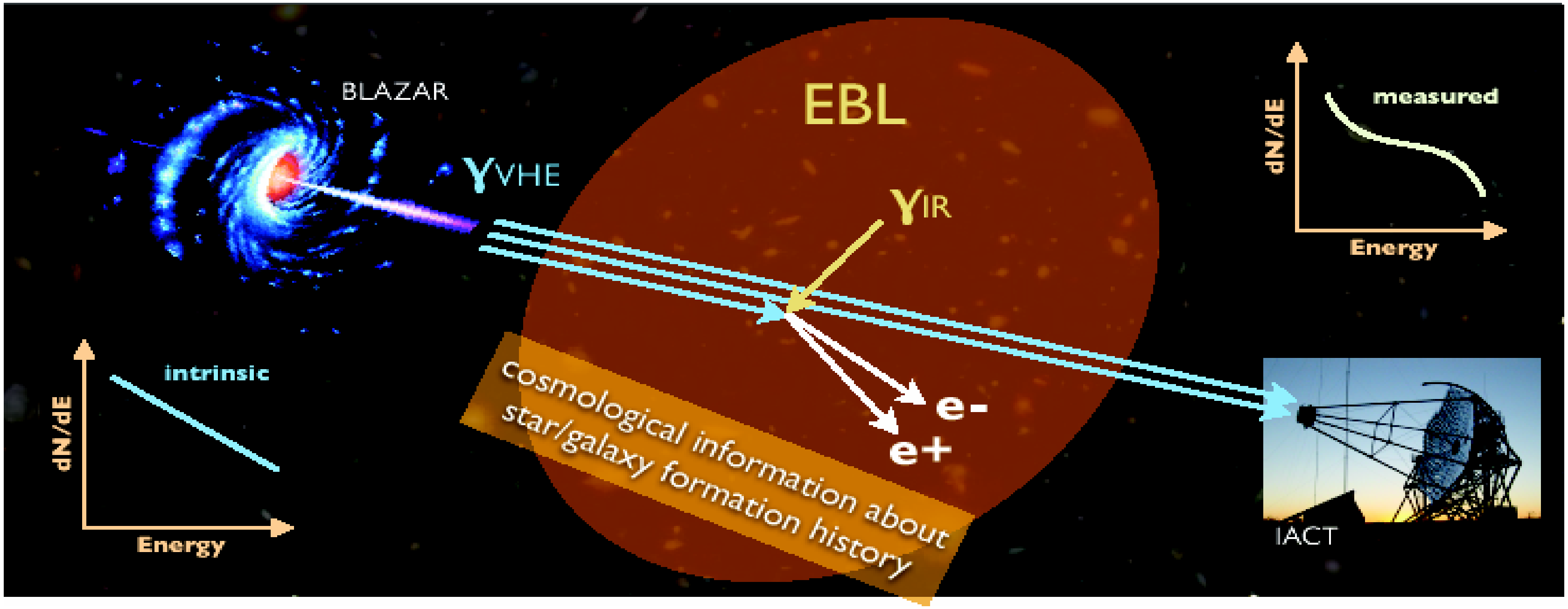
$(9.4 \pm 1.5_{stat}) \times 10^{-13}$ cm^{-2} s^{-1}

~ 1.8% Crab

Spectrum up to 10 TeV
⇒enable EBL constraints
in Mid-Infrared (2-20μm)

No significant variability

Extragalactic Background Light



- Emitted from galaxies at the time of their creation, re-emitted from dusts and red-shifted from the Universe expansion
- Obstacle for TeV γ-rays
- Direct measurements of the EBL in the UV to IR wavelength region are difficult (dominant foregrounds: solar system, Galaxy).

EBL limits from VHE spectra with assumptions about the intrinsic limit on Γ

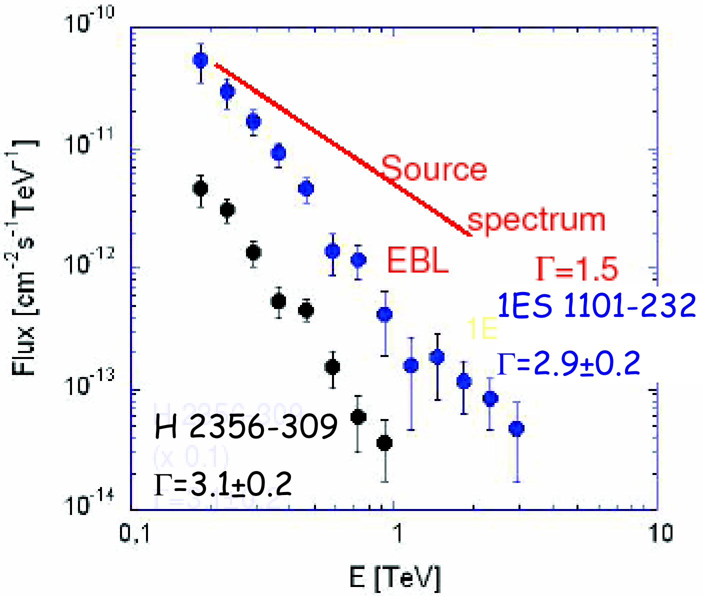
EBL constraints

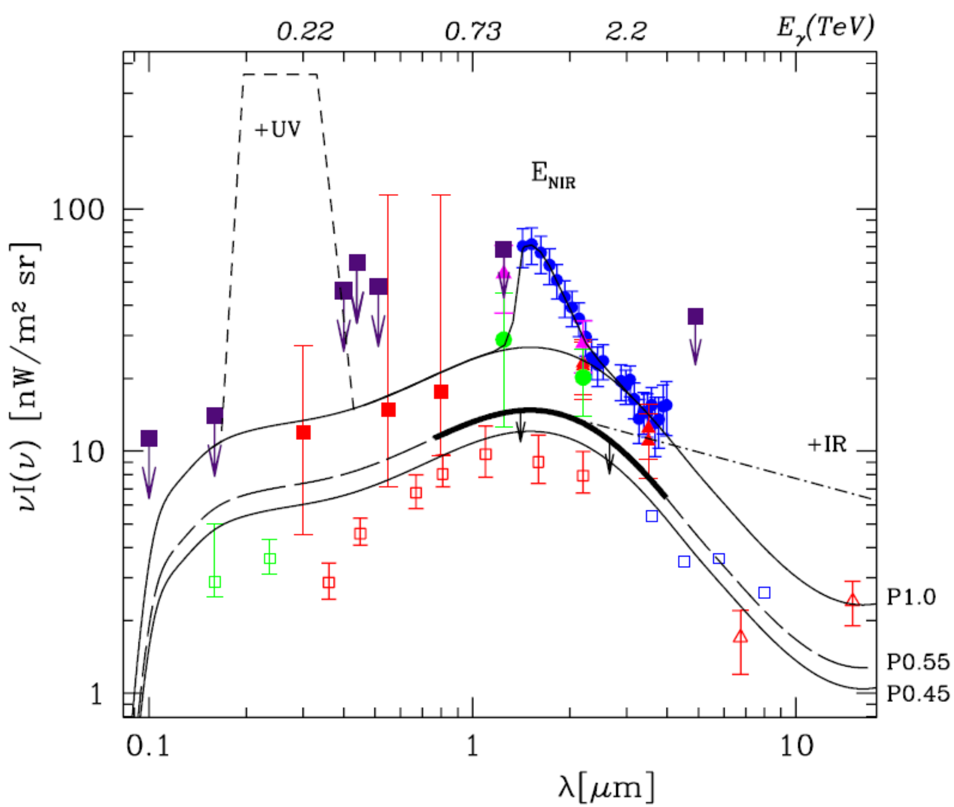
Aharonian et al., Nature 440 (2006) 1018

➢Deduce the intrinsic spectrum correcting the absorption with a spectrum-model for the background light: curves P1 , P0.55 , P0.45.

➢Demand a « reasonable » spectral index compatible with the Fermi mechanisms + Compton Inverse: corrected spectral index must be $\Gamma > 1.5$

1ES 0229+200 spectrum up to 10 TeV->explore Mid IR region





Monitoring of known blazars

PKS 2155-304 (z=0.116)

- High-frequency peaked BL-Lac object (HBL) – the first seen by HESS

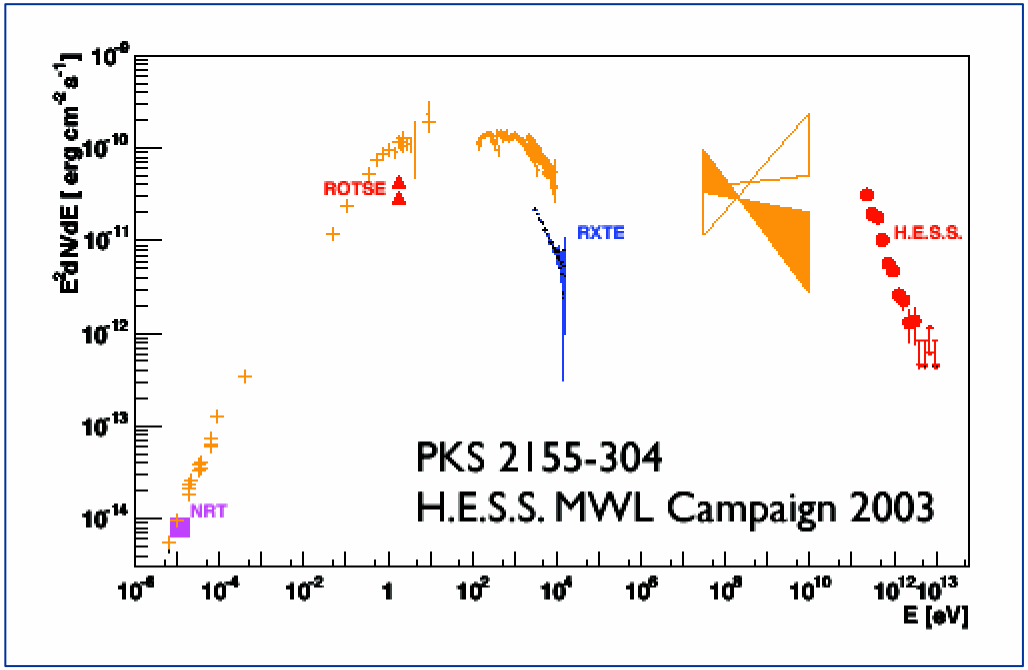
- Discovered in TeV in 1999 (Mark 6) / Confirmed by H.E.S.S.
Chadwick et al. (1999), Aharonian et al. , A&A, 430, 865 (2004)

- Extensive multi wavelength studies in 2003 and 2004
Simultaneous radio, optical ,x-ray & TeV observations
Aharonian et al. 2005, A&A, 442, 895 (2005),
Aharonian et al. in prep.

- Source always detected in TeV!
"quiescent state" (0.08-0.15 Crab)

- Significant nightly HESS detection systematic

LONG & RICH MWL HISTORY!!



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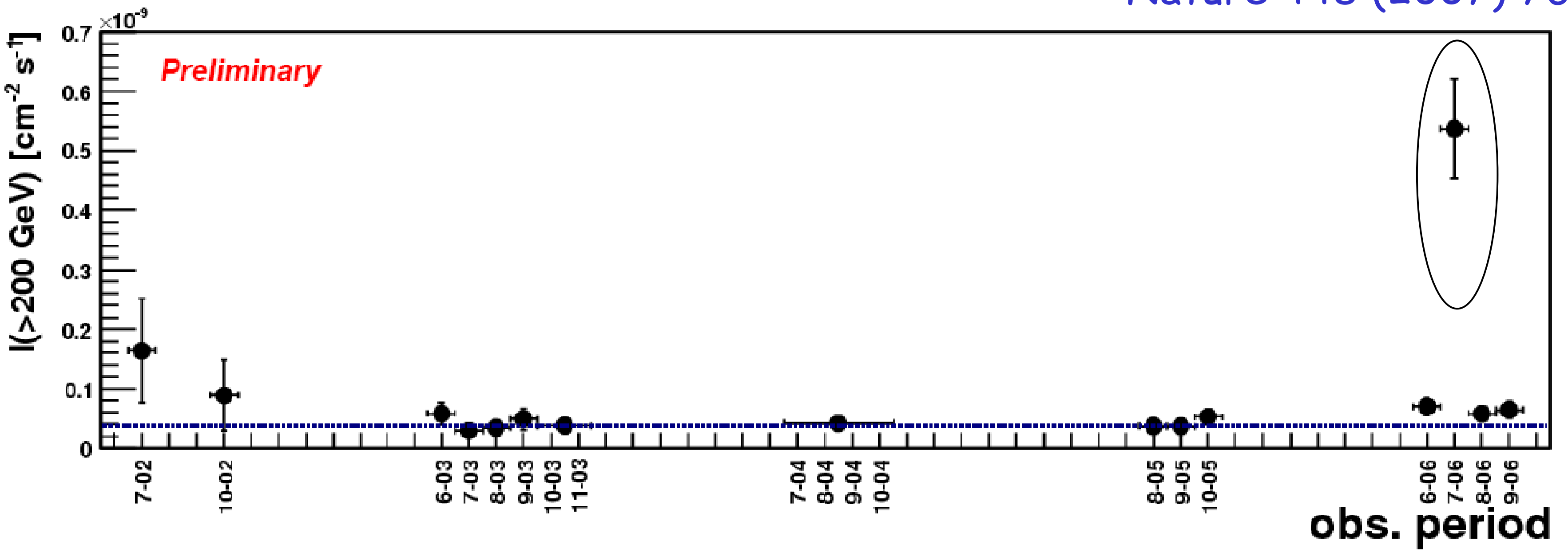
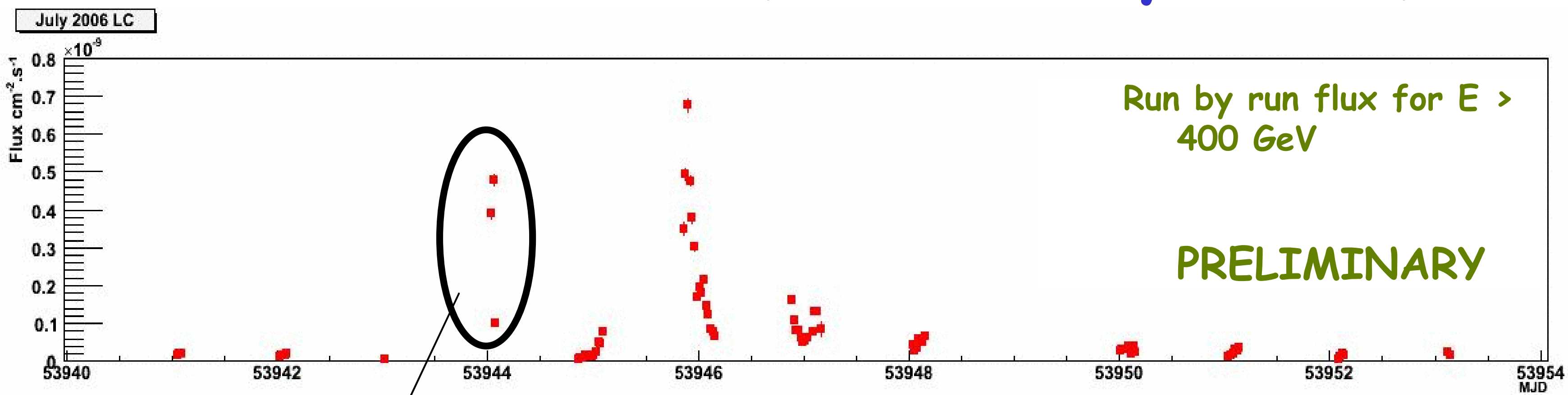
PKS 2155-304 (HESS campaign)

- Monitored by HESS from 2002 to 2007 (~240 h)
- Quiescent state at $\Phi_{E>200GeV} \sim (4 \pm 0.4) \times 10^{-11}\ cm^{-2}s^{-1}$

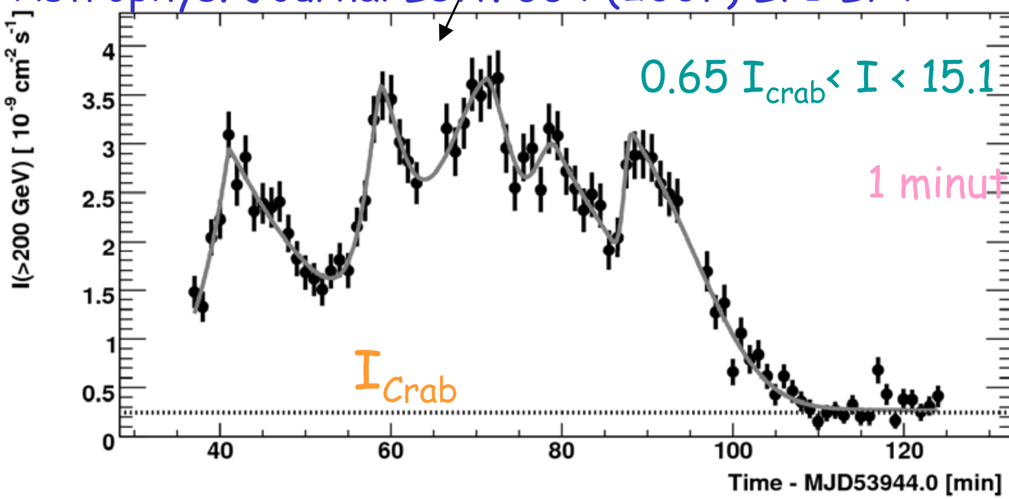
Serendipity in astronomy
T. Weeks
Nature 448 (2007) 760



PKS 2155-304 (HESS July 2006)



Astrophys. Journal Lett. 664 (2007) L71-L74



5 GRB-type peaks

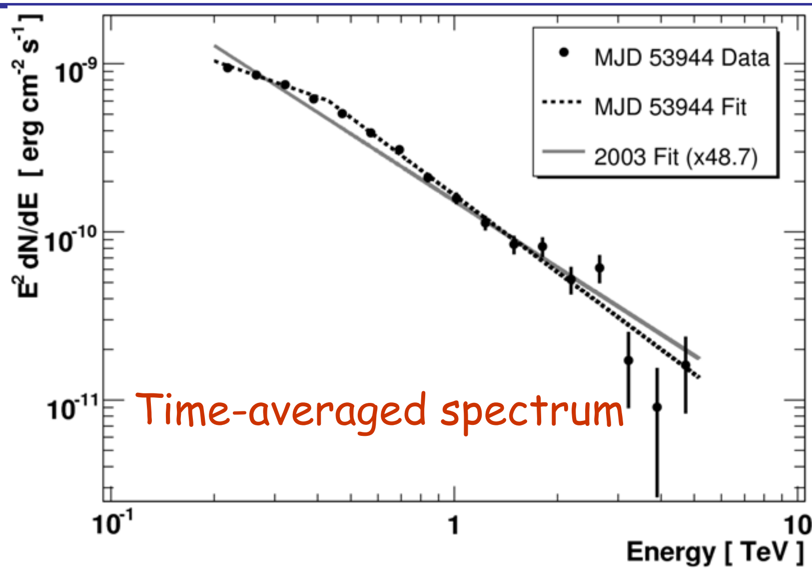
fastest rise time τ_r = 174 ± 28 s

July 28, 2006 (MJD 53944) exceptional VHE gamma-ray flare

3 runs → 1.32h live time

In the past VHE-flux variability on daily time scales. The most rapid flux variability measured is 25 min in X range

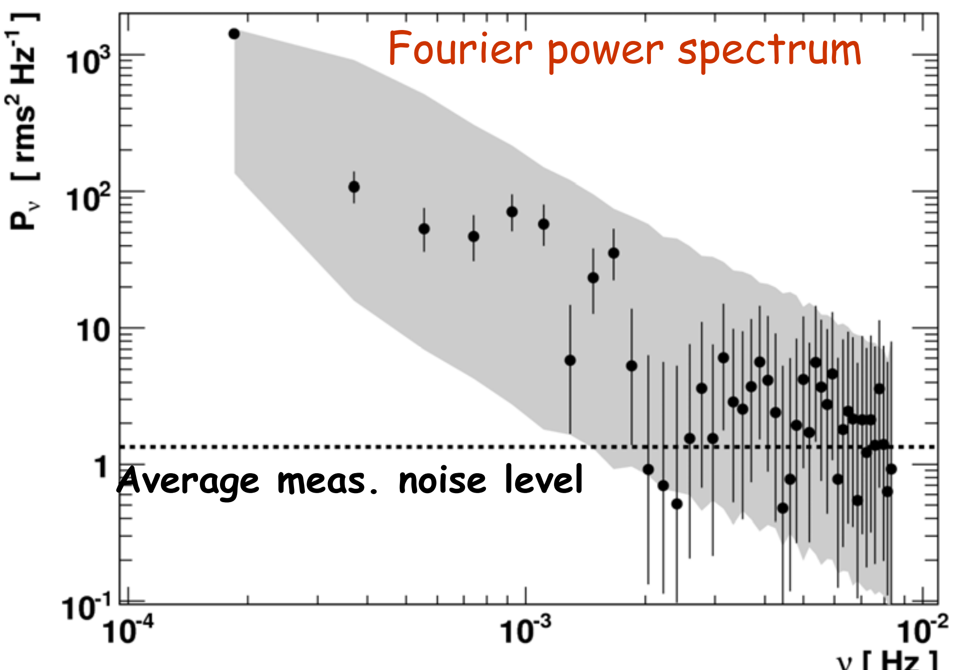
PKS 2155-304 Spectral Analysis



Steep spectrum probably due to EBL absorption

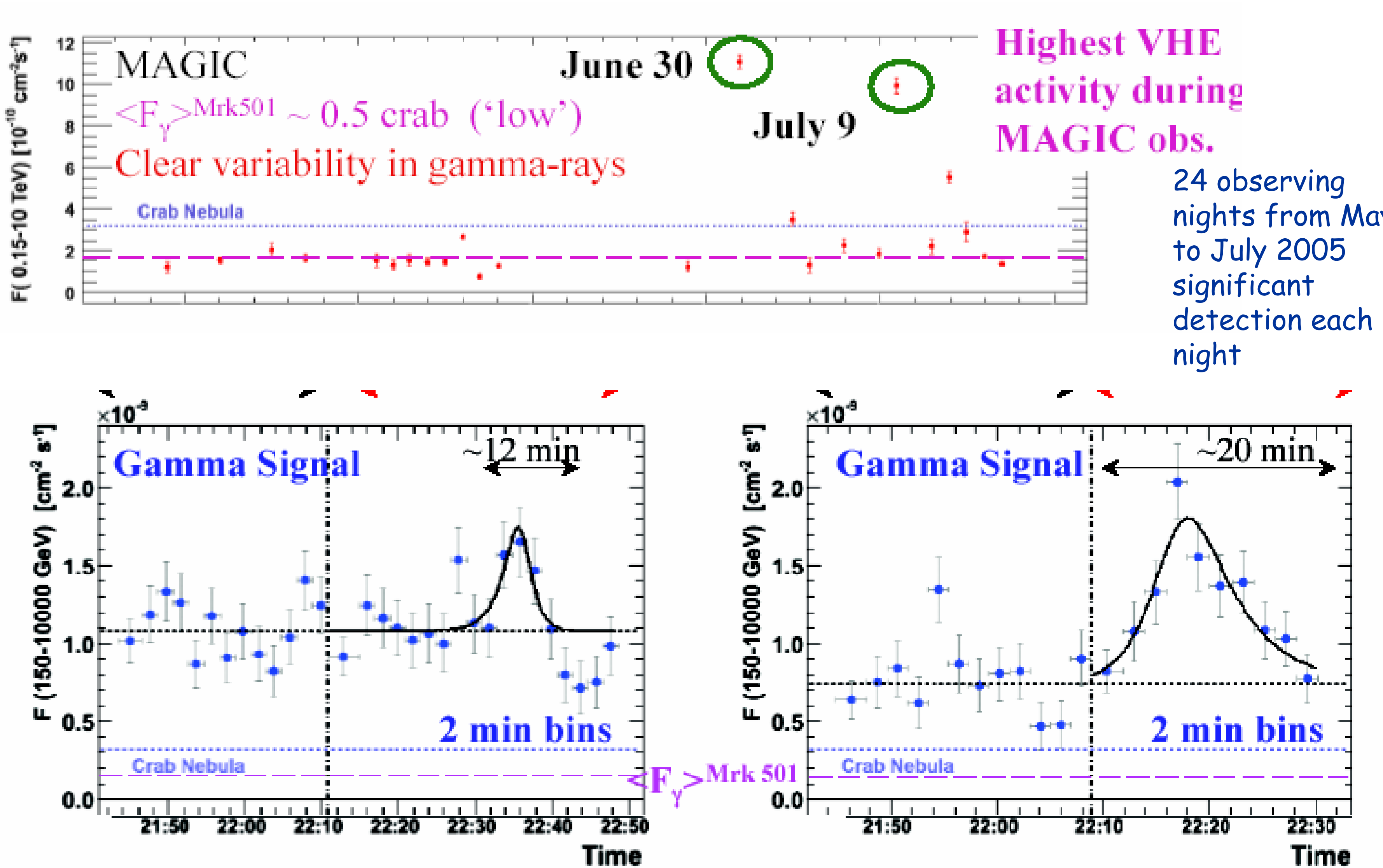
Despite 50 × higher flux, $\Delta\Gamma < 0.2$

NO EVIDENCE OF SPECTRAL VARIABILITY!



- Most of the power is at low frequencies
- Power significantly above the noise level up to 1.6×10^{-3} Hz (600s)
- Power spectrum compatible with a light curve generated by a stochastic process with a power-law Fourier spectrum of index -2.
- Power spectra similar in X-rays.

Mkn 501(z=0.034) -MAGIC 2005 campaign

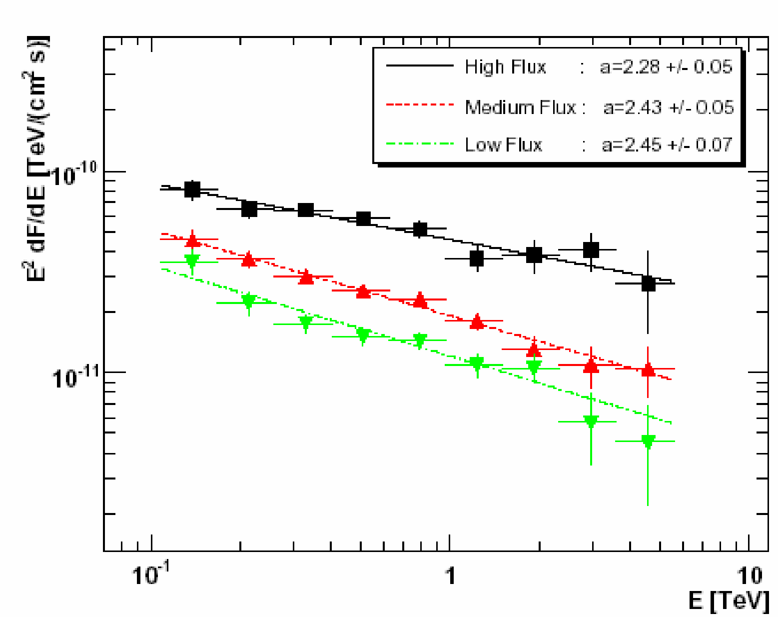


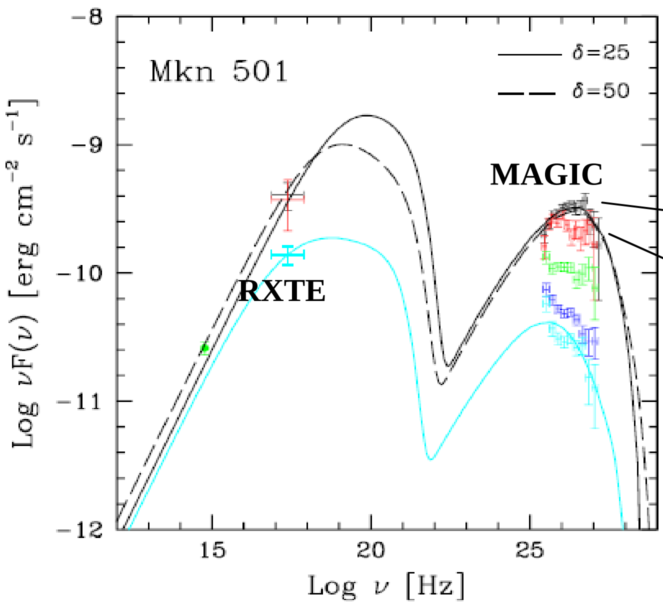
24 observing nights from May to July 2005 significant detection each night

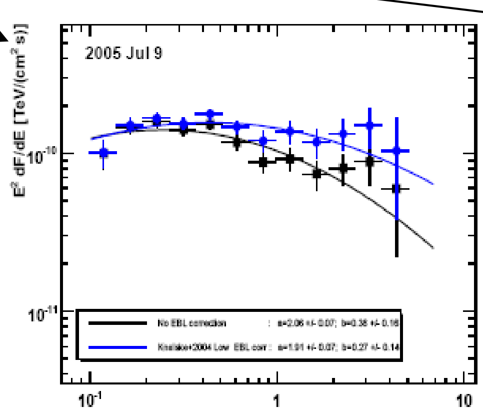
flux-doubling times down to 2 minutes

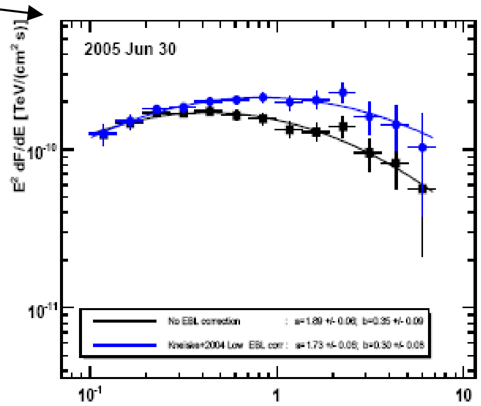
Mkn 501 (MAGIC)

- Clear hardening when flux increases
- 2 main flaring nights ⇒Peak evidence at ~ 0.25 and ~ 0.43 TeV
- Such variability seen by CAT during the 1997 flare









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What can we learn from these flares?

Assuming causality arguments the size of the emission region is

$$R \leq c\, t_{var}\, \delta/(1+z)$$

where $\delta = [\Gamma(1-\beta\cos\theta)]^{-1}$; Γ is Bulk Lorentz factor of the plasma in the jet; β=v/c; and θ is the angle to the line of sight.

PKS2155-305 for HESS (t_{var}=173±28 s) $\Rightarrow$ $R \leq 4.65\times10^{12} \times \delta$

Assuming the size of the emission region ~ R_S, the t_{var} limits the SMBH mass to ~1-2 $\times10^9 M_O$

$\Rightarrow$ $\delta > 100$ to accommodate this variability time scales.

Similar for Mkn 501 but less dramatic δ ~50

Models?

Strong impact on the astrophysical community!!!

High values of Doppler factor are not required if the γ-ray production zone is far from the black hole.

- Begelman et al.; arXiv:0709.0540v2

These variability shorter than inferred light-crossing times at the black hole horizon $\Rightarrow$ External Radiation Compton model favoured than SSC (lower Γ)

- Ghisellini & Tavecchio; arXiv:0801.2569v1

ERC favoured but better the Needle/Jet model (the variable flux originated in a small portion of the jet moving at Γ=50)

- Levinson; arXiv:0709.1549v1

Radiative deceleration of blobs on scales where the local dissipation occurs

Quantum Gravity Limits

Widely speculated that space-time is subject to quantum-gravitational (QG) effects (fluctuations at Planck time and distances scales) ⇒

- velocities of massless particles in vacuo deviate from c?
- Lorentz invariance violation?

$$\frac{V}{c} = 1 + \xi\left(\frac{E}{E_{QG}}\right) + \xi_2\left(\frac{E}{E_{QG}}\right)^2 + ...$$

which leads to time delay (at first order) to photons of different energies:

$$\Delta t \approx \xi \frac{E}{E_{QG}} \frac{L}{c}$$

To quantify this small effect one needs large energy differences and large distances ⇒ ex AGN or GRB

Quantum Gravity

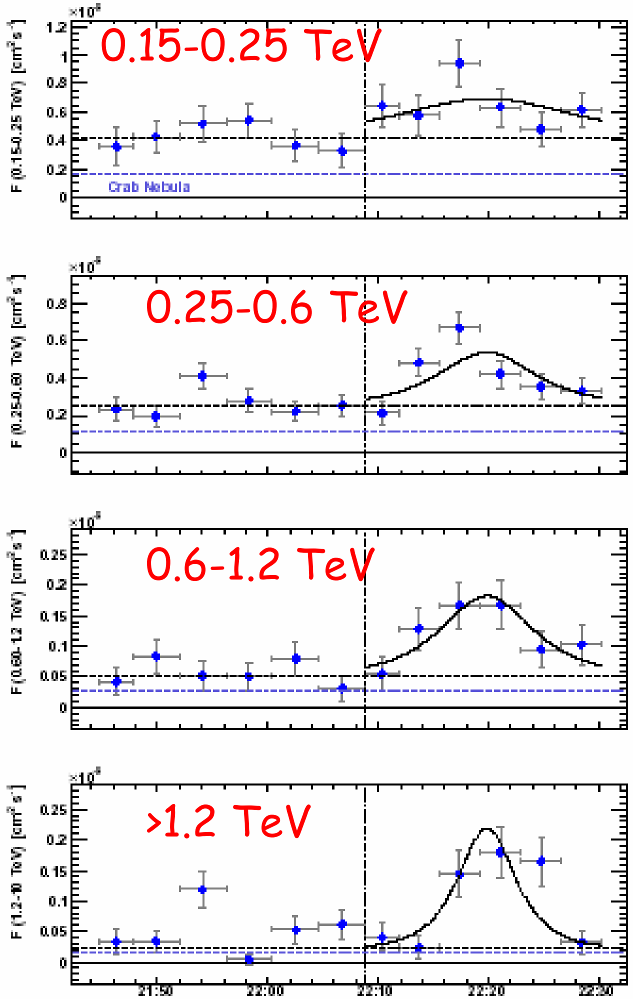
LCs for different energy ranges (4 min bins)

Probing Quantum Gravity using the timing of the photons of different energies from atrophysical sources. (ex. AGN)

If photons at diff. E are emitted simultaneously and
$\Delta T \sim 4$ min, $\Delta E \sim 1$ TeV
$\Rightarrow E_{scale} \sim 10^{17\div18}$ GeV

NOT CONFIRMED FOR MKN 501 from MAGIC !!!!

Soon appearing results by HESS on PKS2155-304



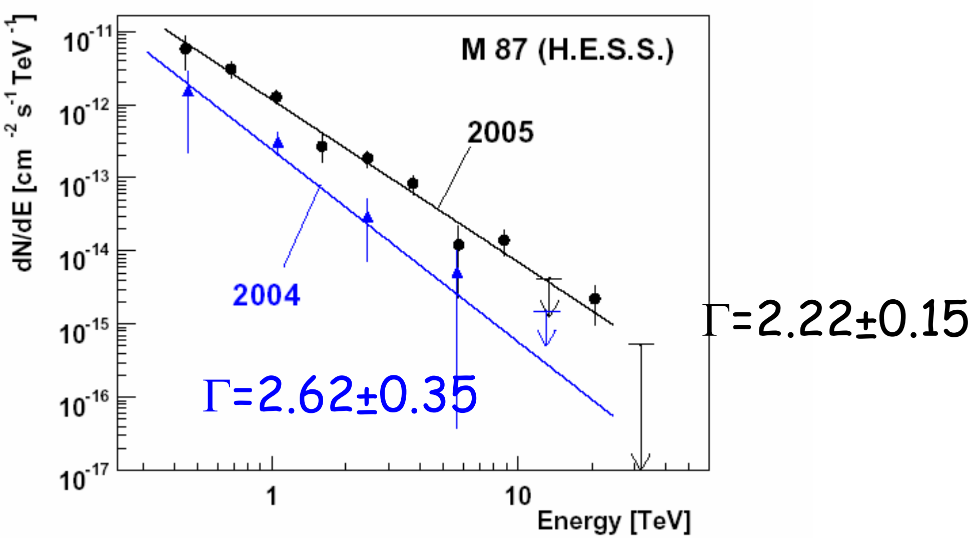
J.Albert et al., ApJ 669 (2007) 862

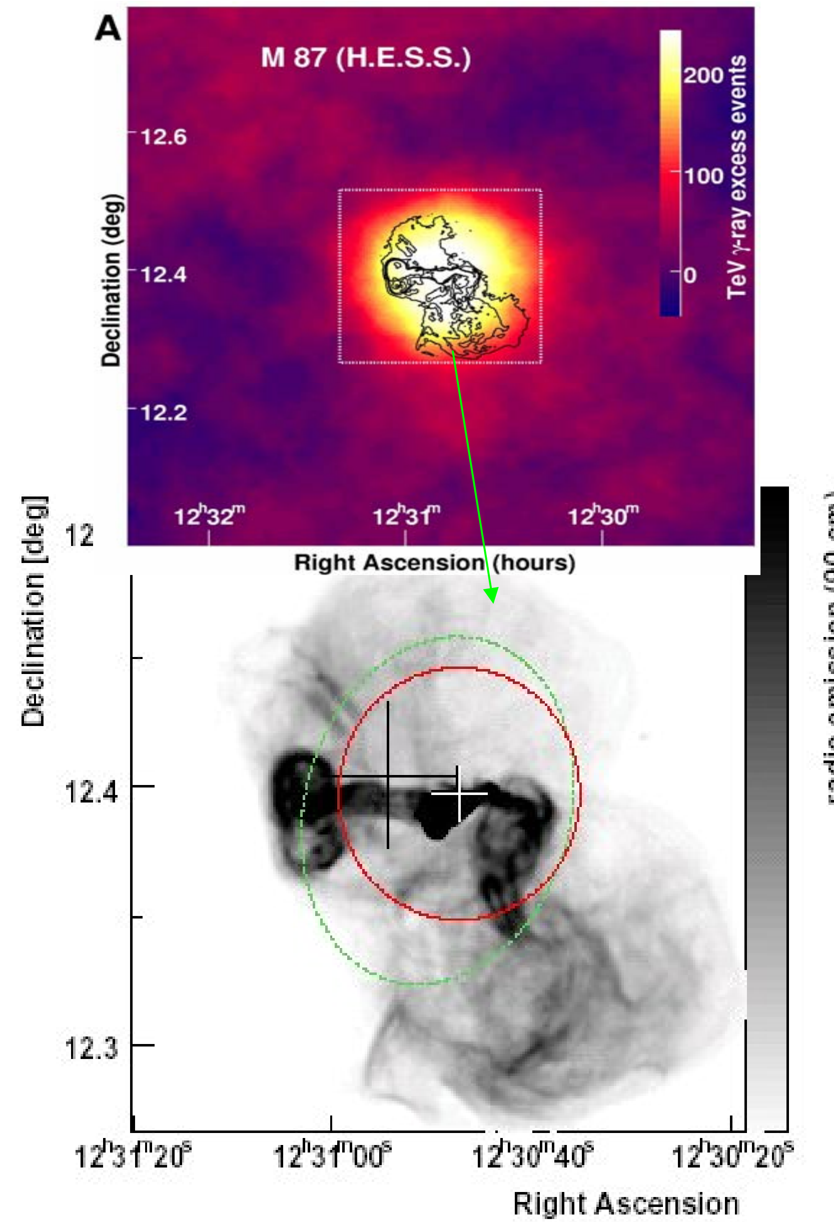
M87 (HESS)

Science 314 (2006) 1424

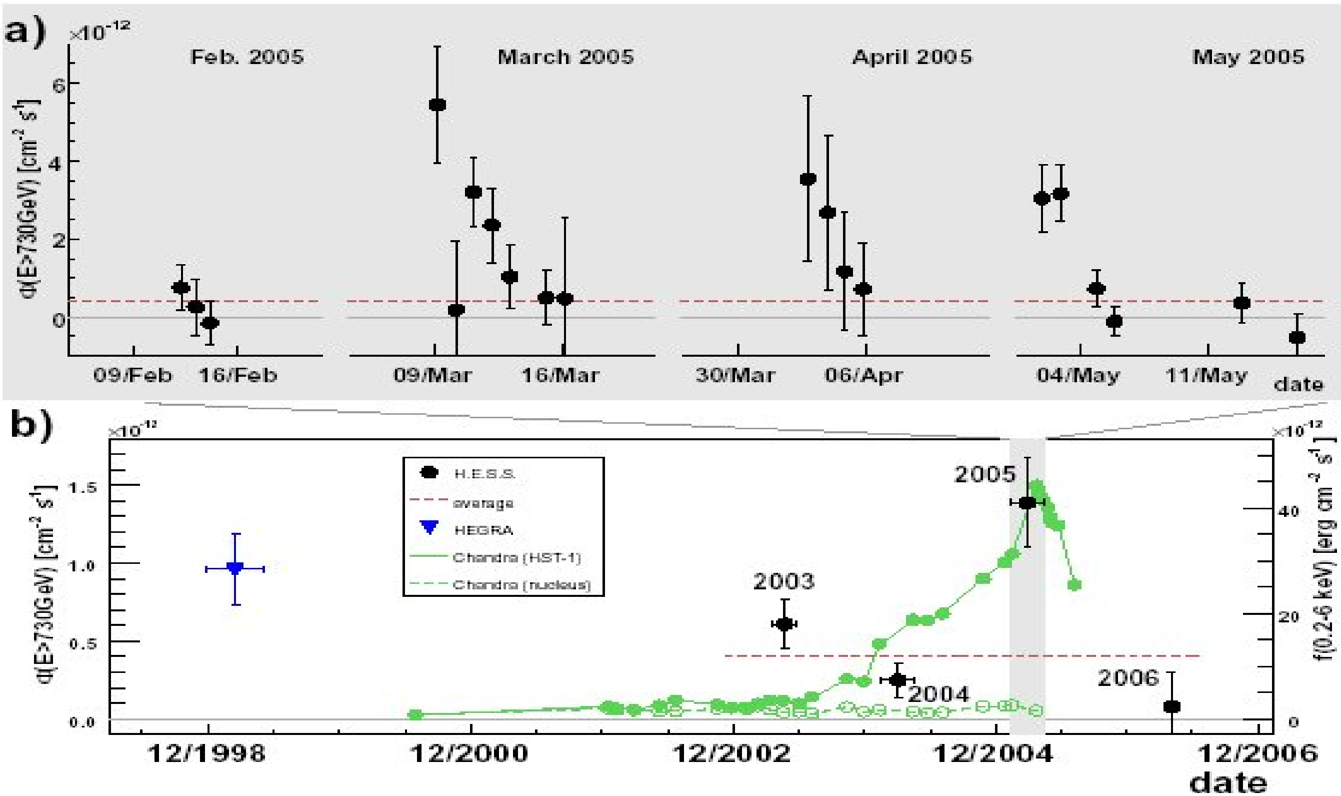
- Radiogalaxy of FRI type
  - First extragalactic γ-ray emitter not BL Lac
  - Jet angle ~ 30°
  - Close AGN : ~16 Mpc

- HEGRA : 4.7 σ in 77 hours (1998-1999)
- Whipple : UL in 2000-2003
- HESS : ~ 13 σ in 89 hours (2003-2006)





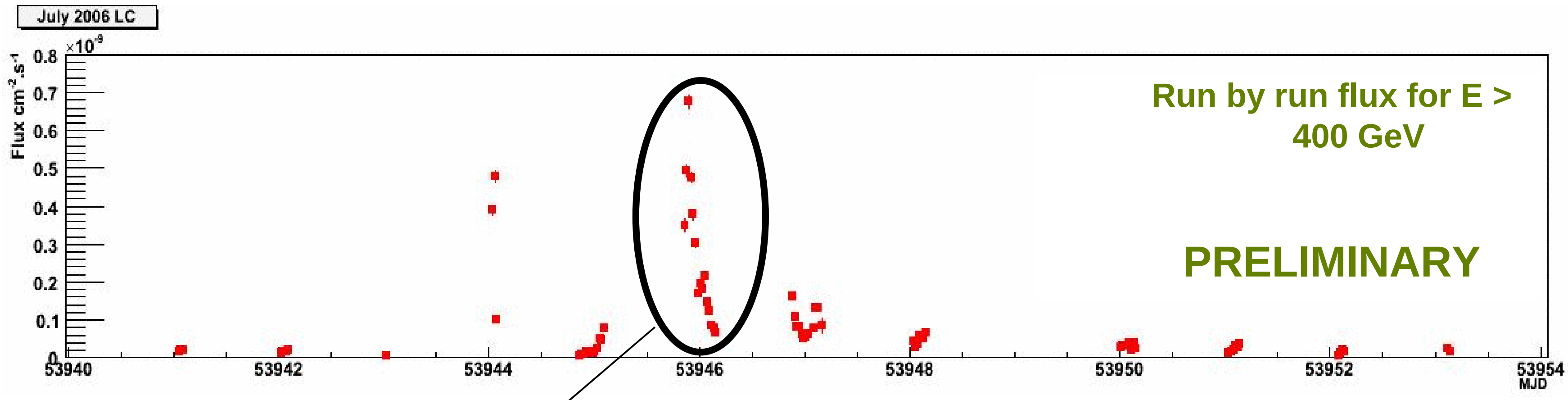
M87 (HESS)

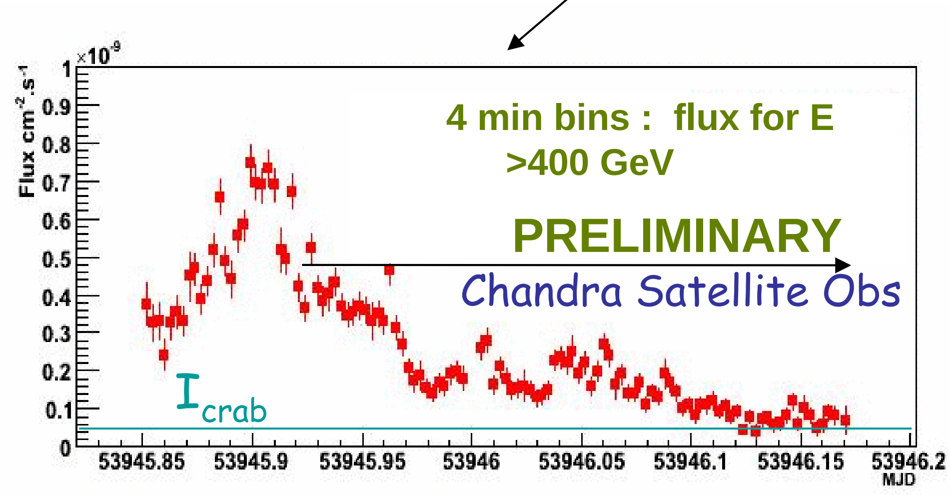


- Variability at 2 days scale
- ~10 times faster than in other wave-lengths
- imply a very compact emission region with a dimension (~10^{13}m) similar to the Schwarzschild radius of the central black hole

Multiwavelength observations of AGN

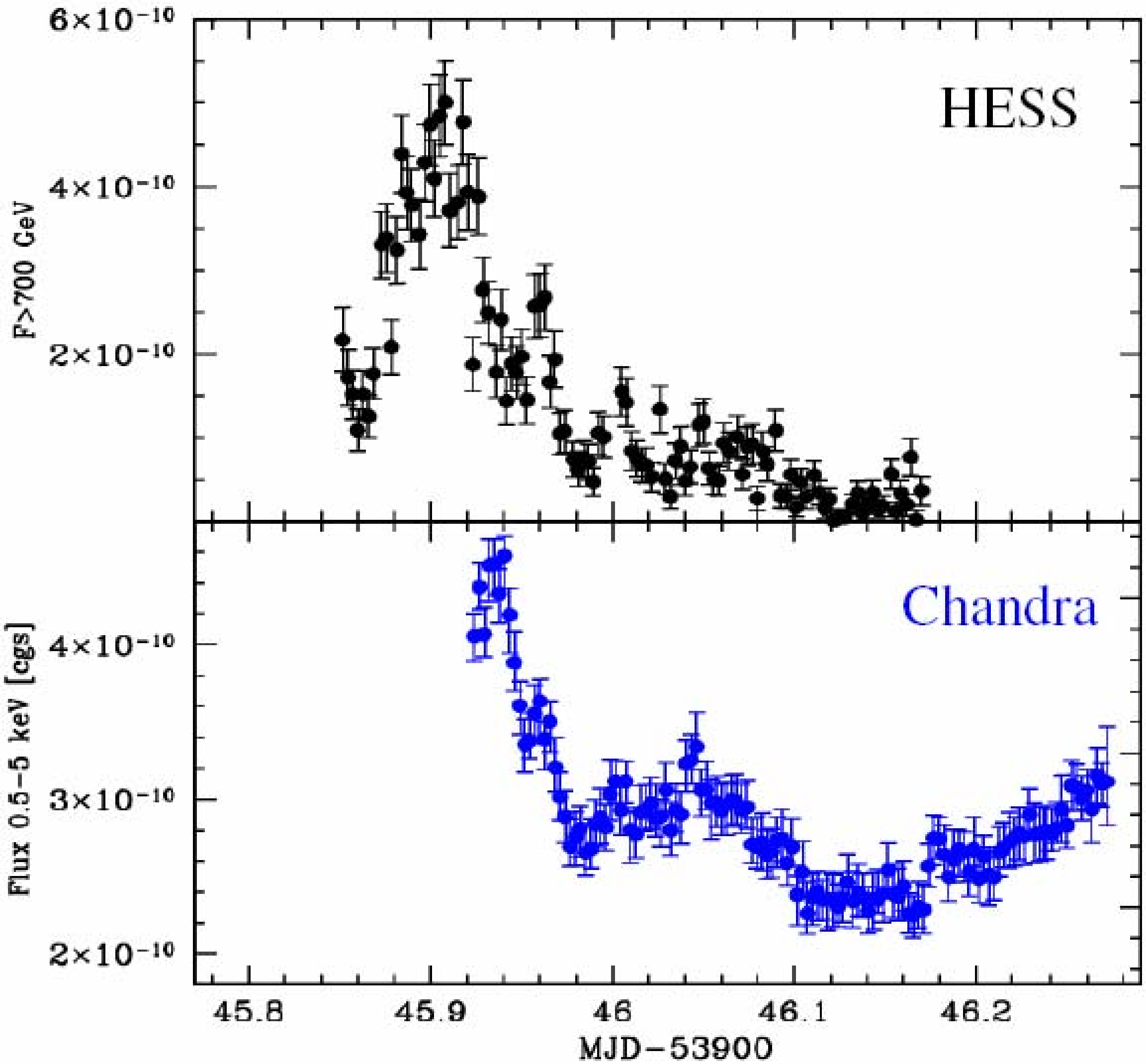
PKS 2155-304 (HESS second flare)





- All night covarage (~6.6h)
- Fast variability
- Chandra contemporaneous observation

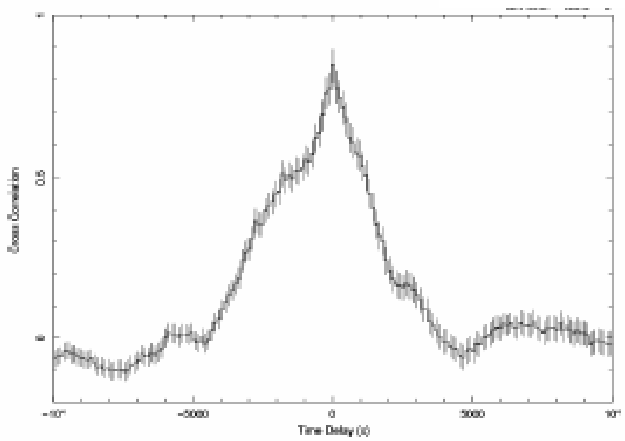
HESS & Chandra simultaneous observations



4 min. bins

PRELIMINARY!

Discrete Correlation Factor



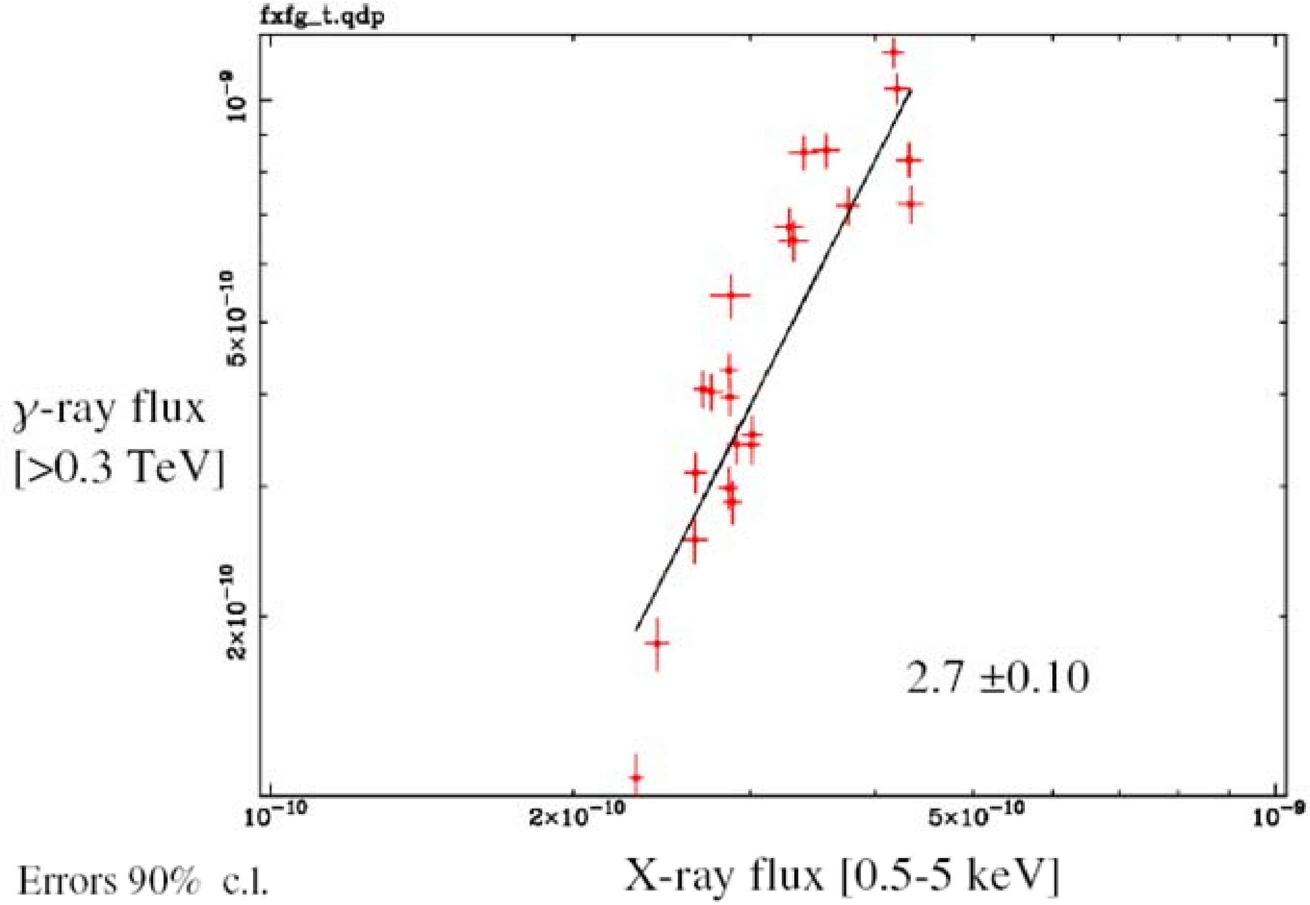
Strong correlation between X and TeV

2008

Correlations

PRELIMINARY!

Power law functional relation



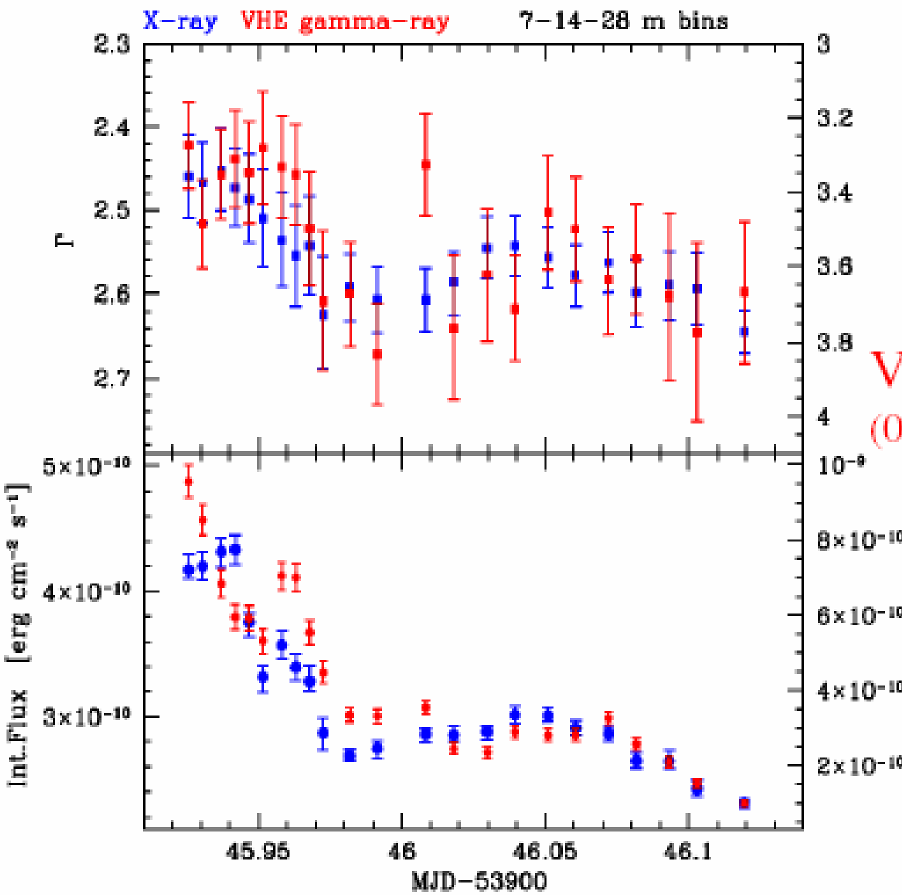
$$F_{\gamma} \propto F_{X}^{\alpha}$$

α = 2.7±0.1

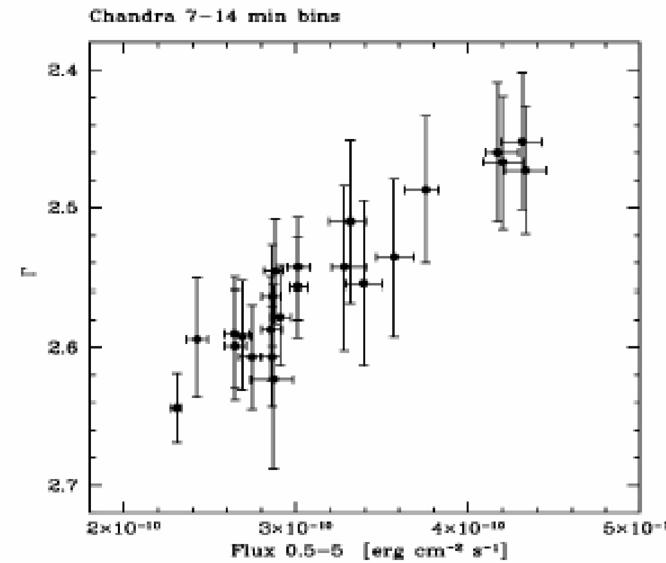
Spectral variations

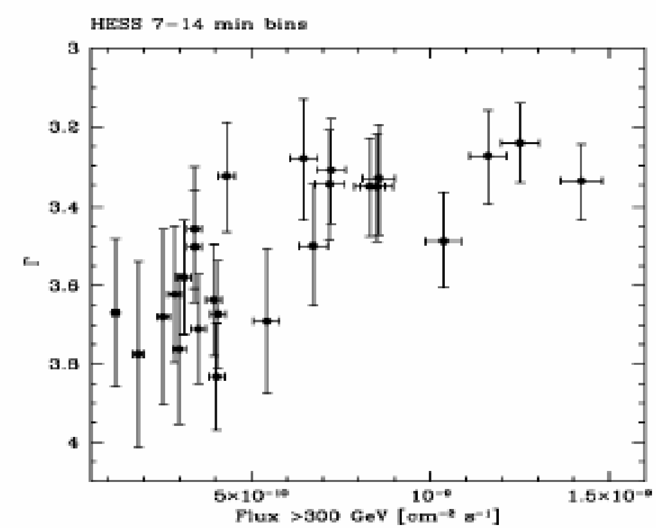
PRELIMINARY!

X



VHE
(0.3-3 TeV)





F. Volpe

Spectral hardening not seen two days before

Some considerations on correlations X-TeV

- X & γ-ray fluxes strongly correlate
- exponent~2.73 i.e. more than quadratically
- Large Compton dominance: Lc/Ls ~10
- Same population responsible of the emissions?
- How modeling this correlation?
- HESS paper appearing soon

Conclusions

ACT have

- increased the number of VHE emitting extragalactic objects
- deteted short timescale variability
- functional relation between X/γ rays still to be investigated (more MWL observations)

The future scenario:

- H.E.S.S.&MAGIC II increase the sensitivity and reduce the threshold
- GLAST launch: possibility to explore with continuity the spectrum of AGN, different population studies and triggering ACT
- Cherenkov Telescope Array (sensitivity to time scales ~20 sec)