High Energy Gamma Astronomy from space and from ground in the past and the forthcoming decades

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Space, the method and EGRET (third) catalogue:

……. the “serependitous” blazars

ACT's : Whipple-10m, HEGRA, CAT, Cangaroo ....

The Crab nebula

The main two blazars :

Markarian 501 and Markarian 421

R&D towards lower energy ACT:

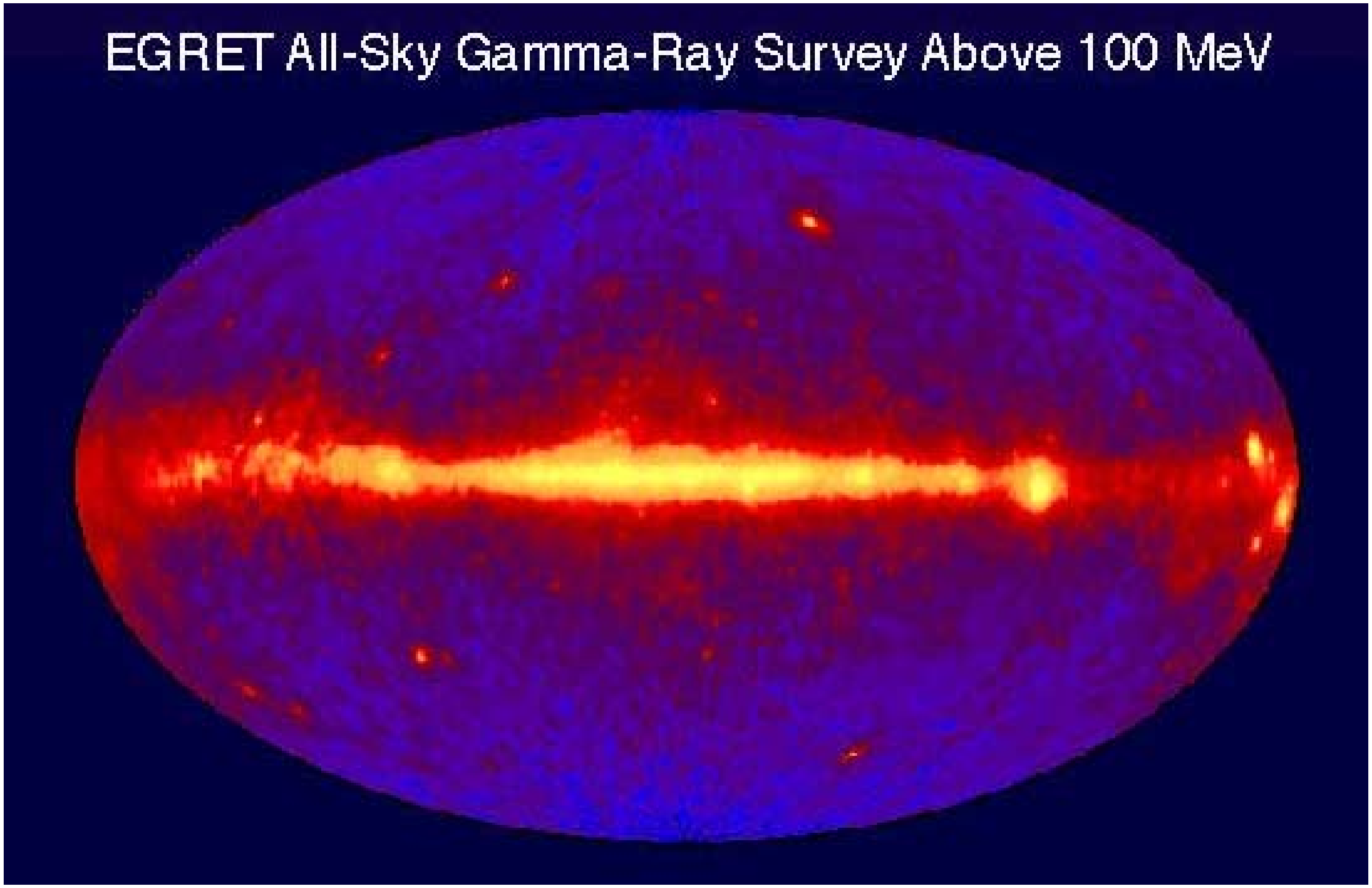
CELESTE, STACEE, SOLAR-II

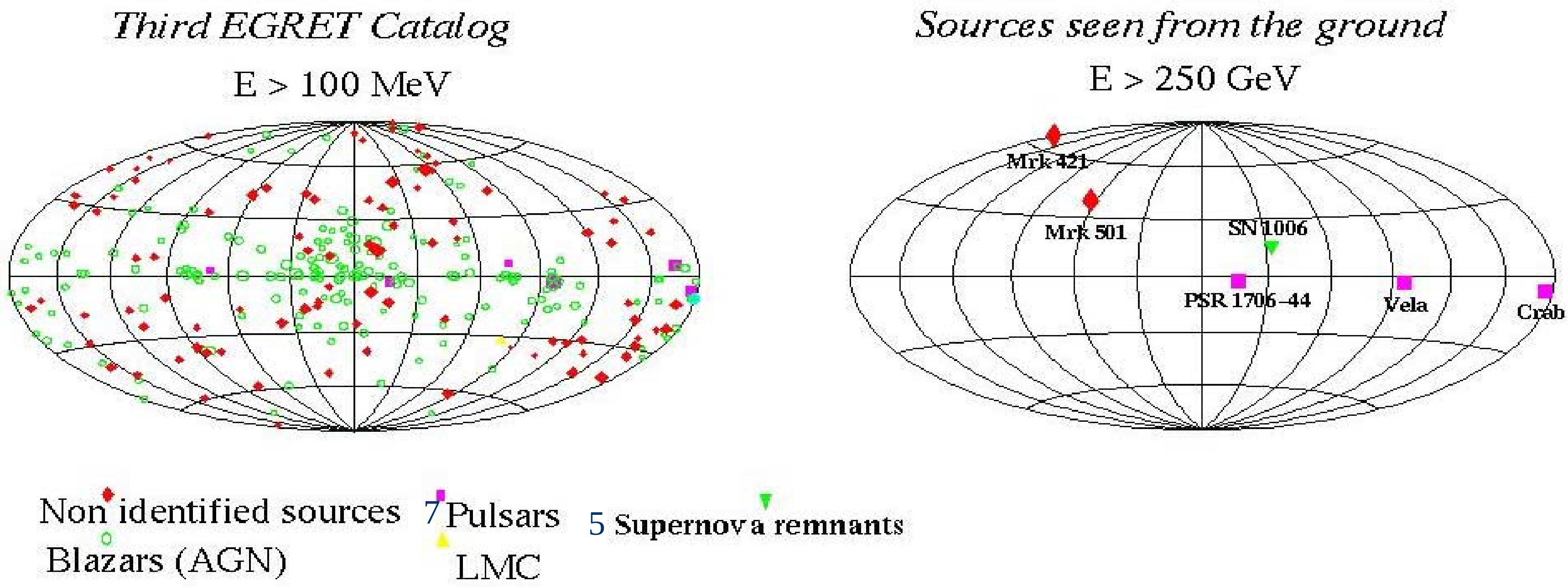
MAGIC.

The large collaboration projects:

From the ground: VERITAS and HESS

From space: GLAST

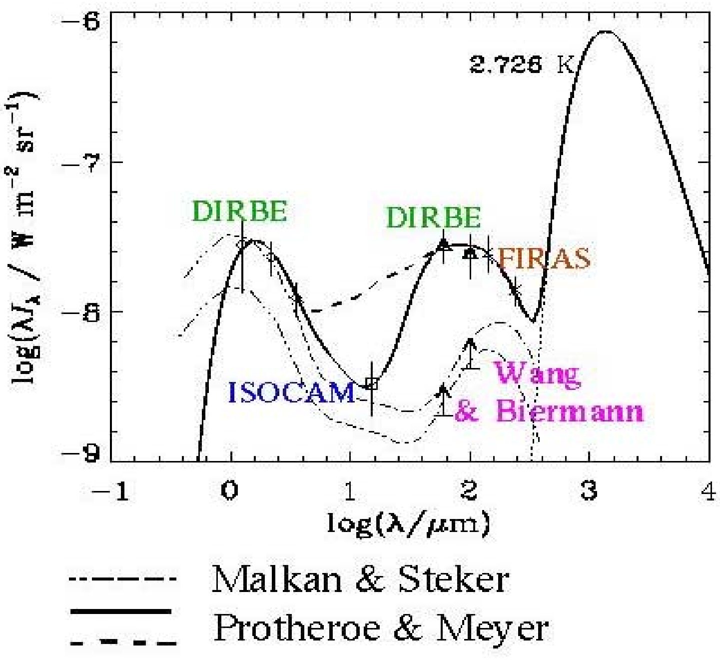

EGRET All-Sky Gamma-Ray Survey Above 100 MeV



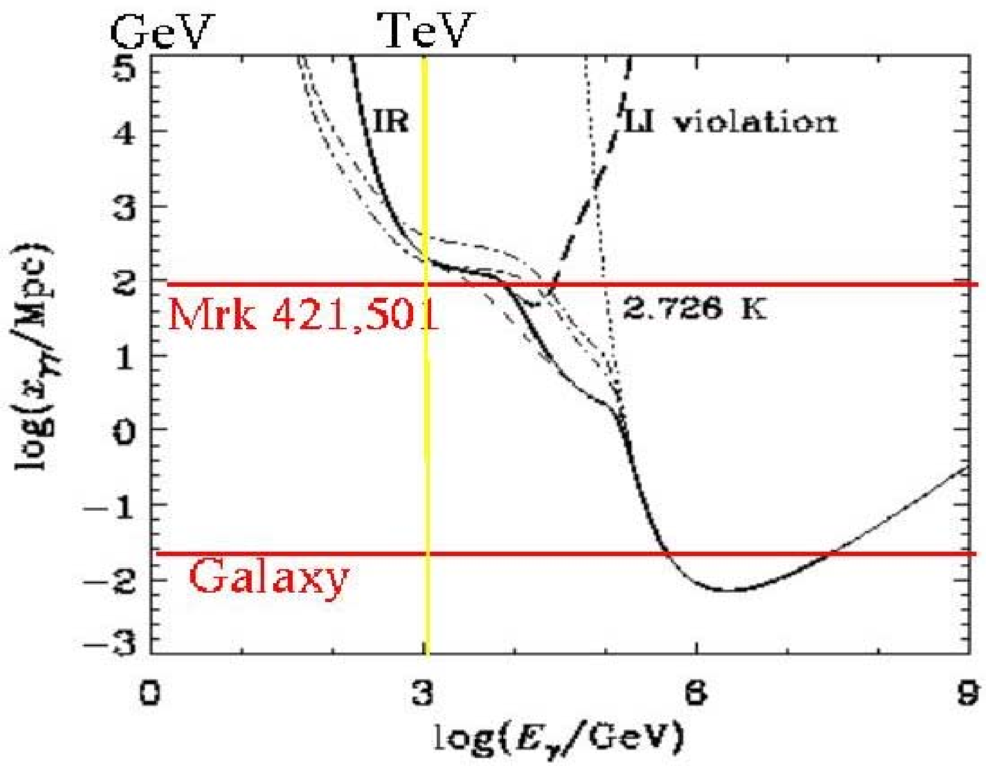
After COS-B, the great success of EGRET has been the rather unexpected discovery that ≈ 100 blazars are brilliant in the GeV energy range
with no turn-over at maximum energies

During about the same decade
the TeV observations broke through,
with no pre-notice.
The a posteriori suprise is the scarcity of sources

- the intermediate region, from 30 to 300 GeV, remains unexplored
- the (few) TeV blazars are weak EGRET sources
- the absorption ($\gamma\gamma \rightarrow e^+e^-$) obscures the far Universe for TeV γ's



Infrared background

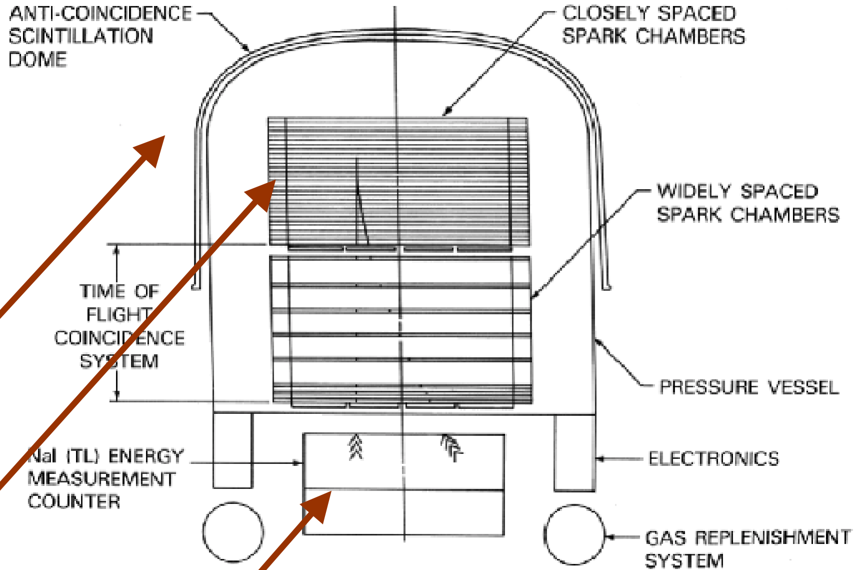


γ mean free path

$$\gamma_1\ \gamma_2 \rightarrow e^+e^-$$

$$\mathbf{E_1E_2 \geq m_e^2 \approx 0.3\ 10^{12}\ eV^2}$$

EGRET concept
(same for GLAST)



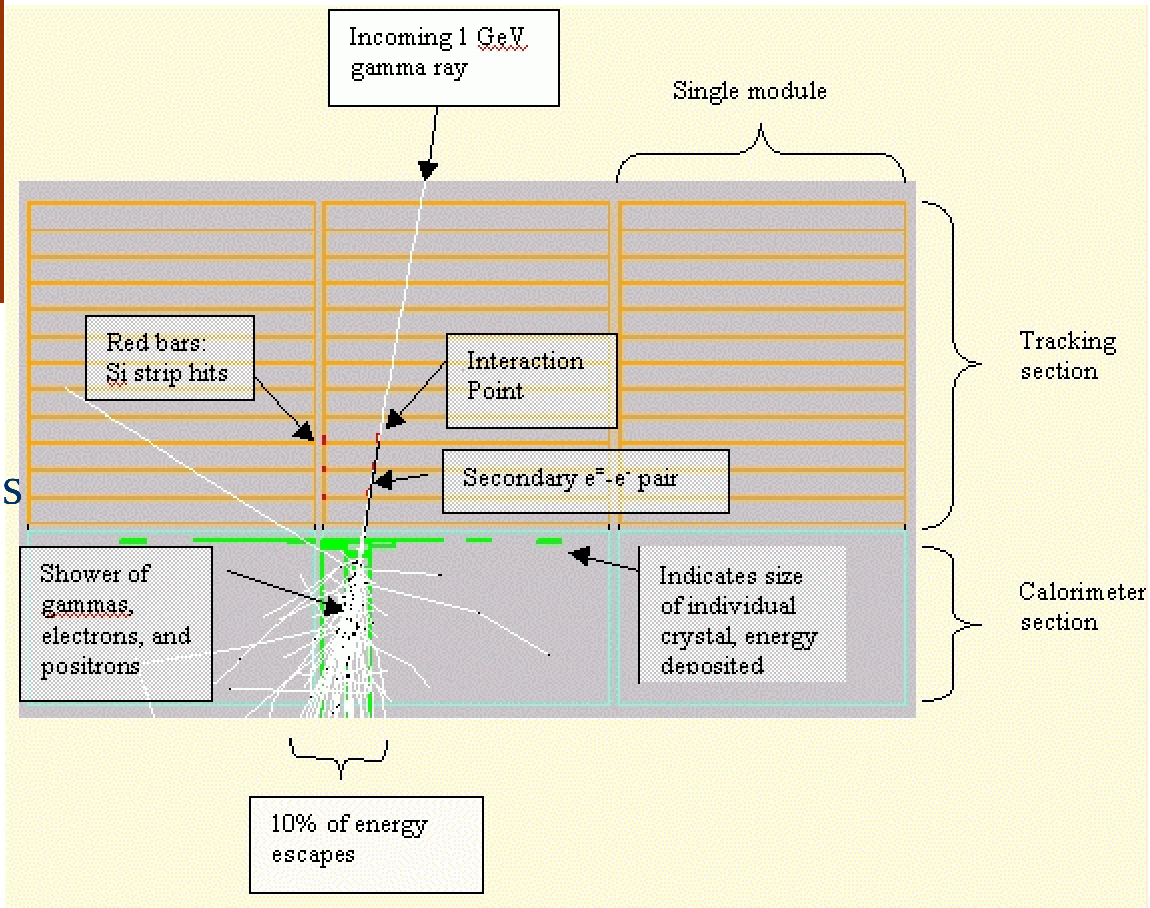
- Pair conversion

  $\gamma \rightarrow e^+e^-$ in the **tracker**

- Energy measurement
  by degradation in a calorimeter

- Veto against CR by a scintillator shield

Realistic Monte-Carlo simulation of the materialisation of a GeV γ ray in a structure like that of GLAST (or EGRET)



The tracker is a sandwich of

- trays of position measuring devices
- layers of converter thin enough, ≈ **0.03 RL**, to limit e-scattering

(radiation length ≡ RL)

The calorimeter depth does not exceed ≈ **10 RL**, which corresponds to ≈ **1 ton per m²**.
This is a major limitation for the detection from space..

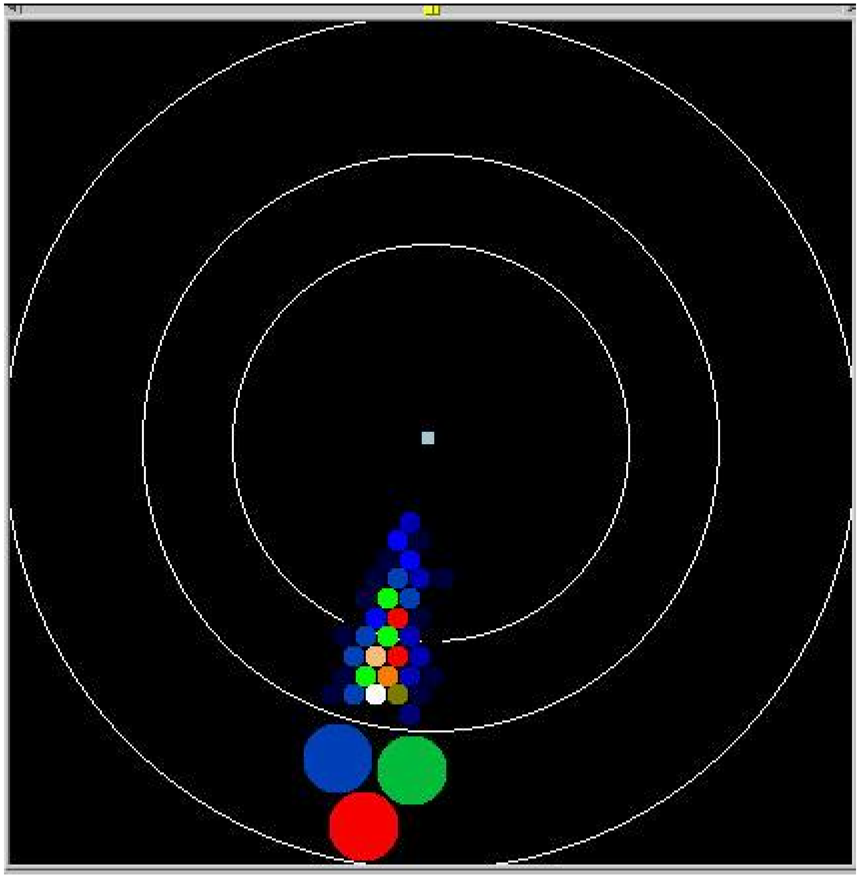
Imaging

Whipple-10m
since 1969
≈100 PMT's by 1990

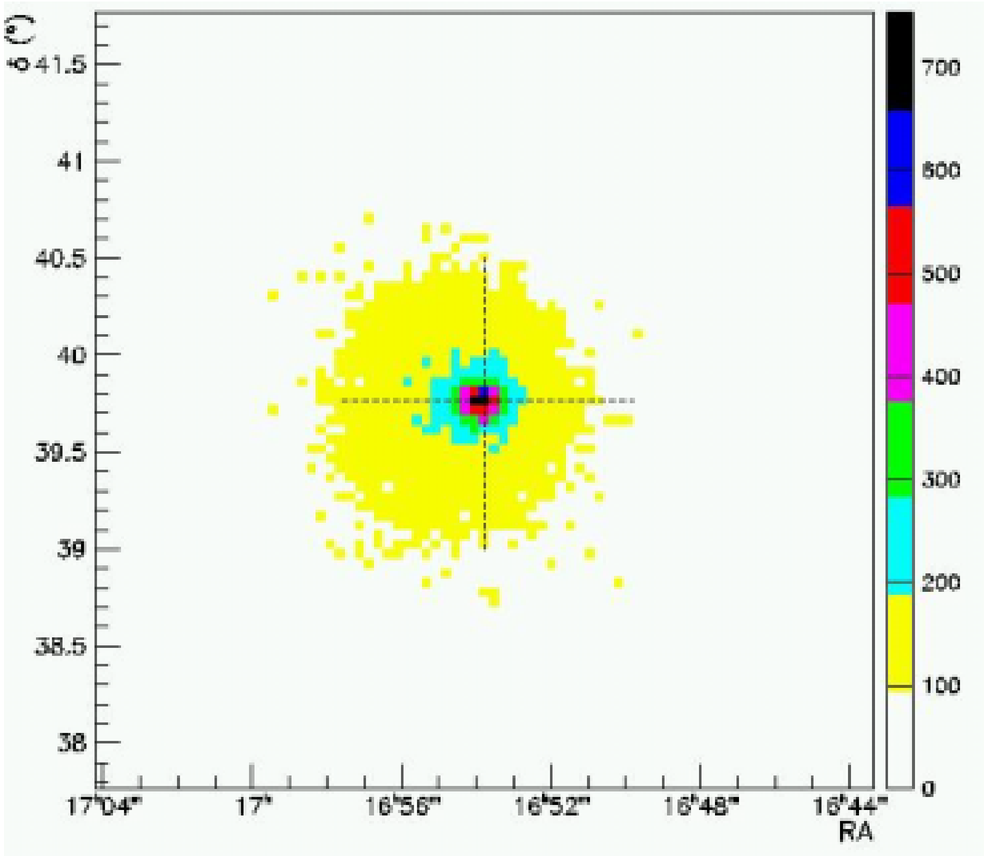
HEGRA
since 1994
5 telescopes / stereoscopy
La-Palma Canaries

CANGAROO
since 1994
Australia

CAT
Thémis (French Pyrénées)
- **first light summer 1996,**
- **fine camera : 600 pixels**



One γ event (at rather high energy)



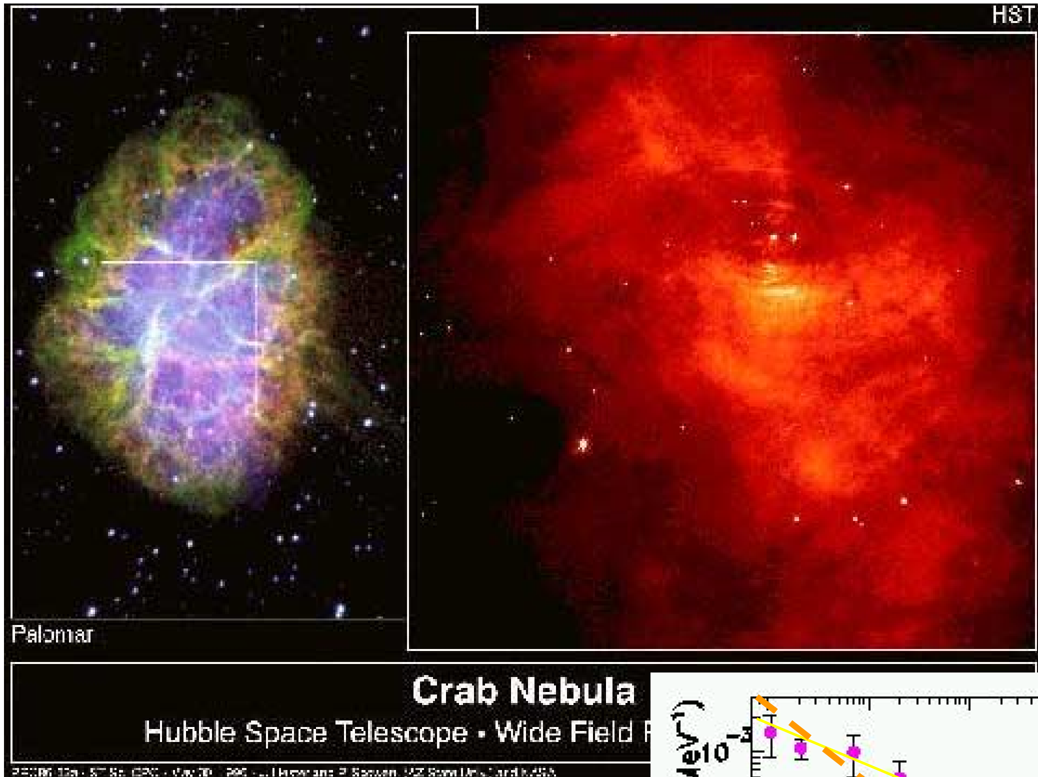
Mrk 501 one night flare (April 16 1997)

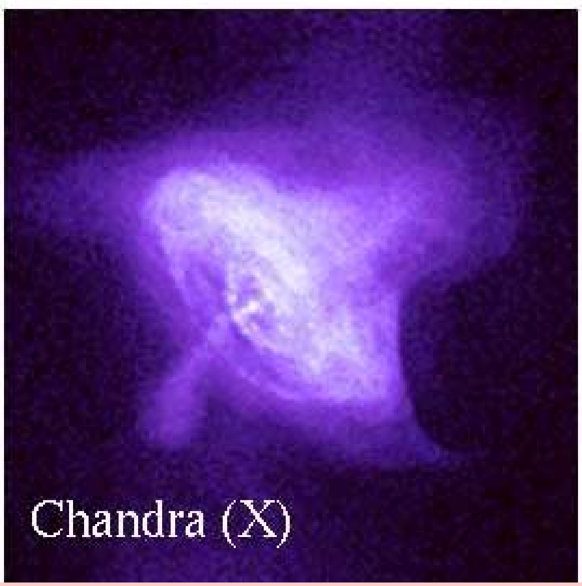
With a high resolution camera (such as CAT),

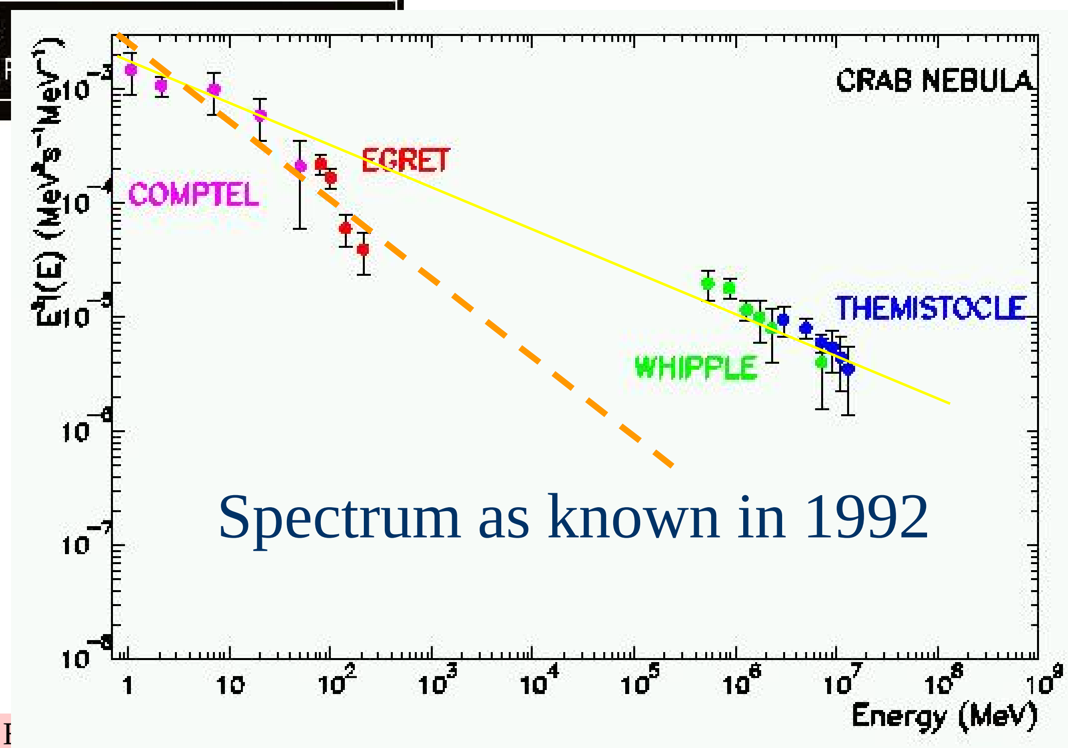
the angular origin of each individual event

is computed from its image profile

The unpulsed emission from the Crab nebula

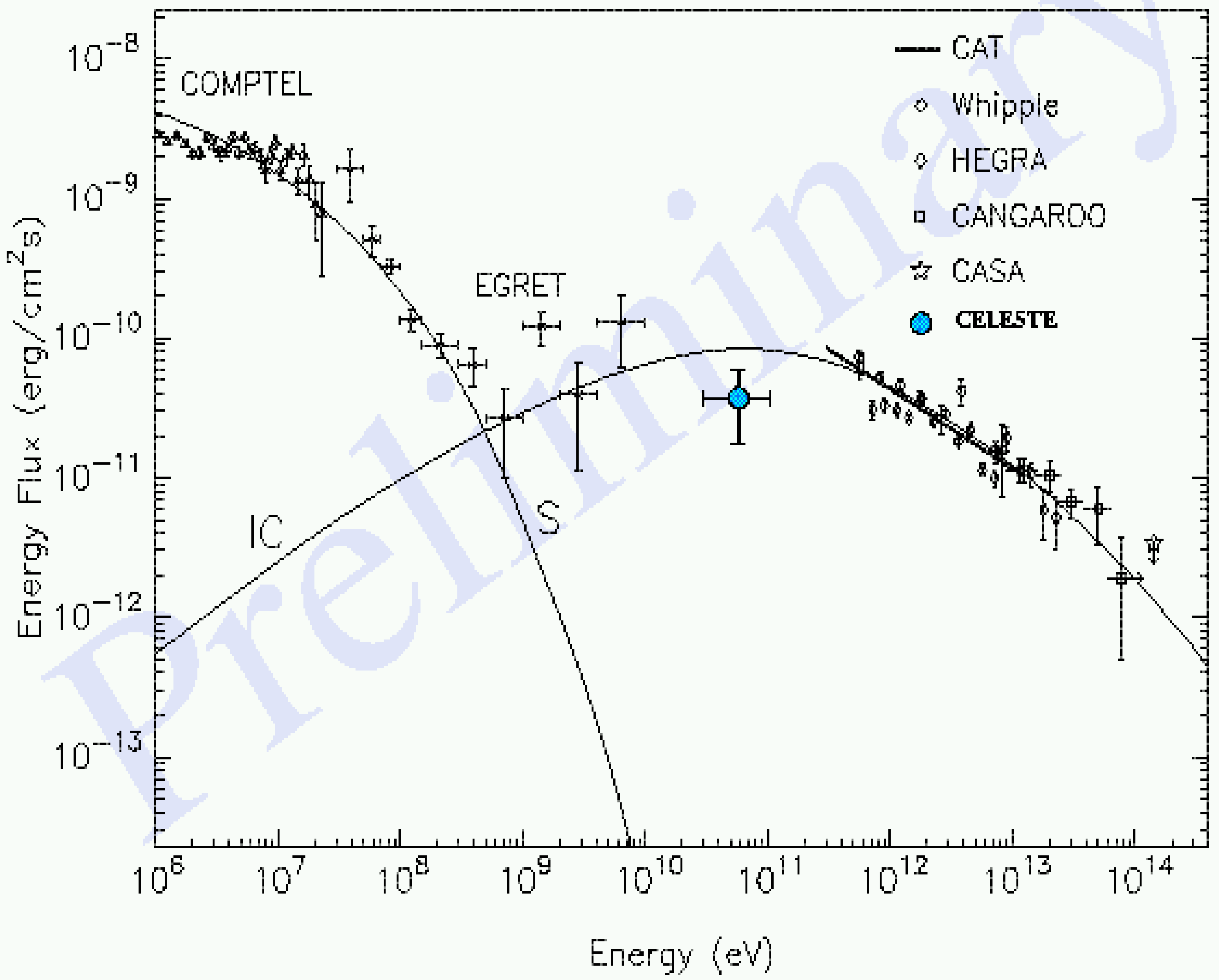


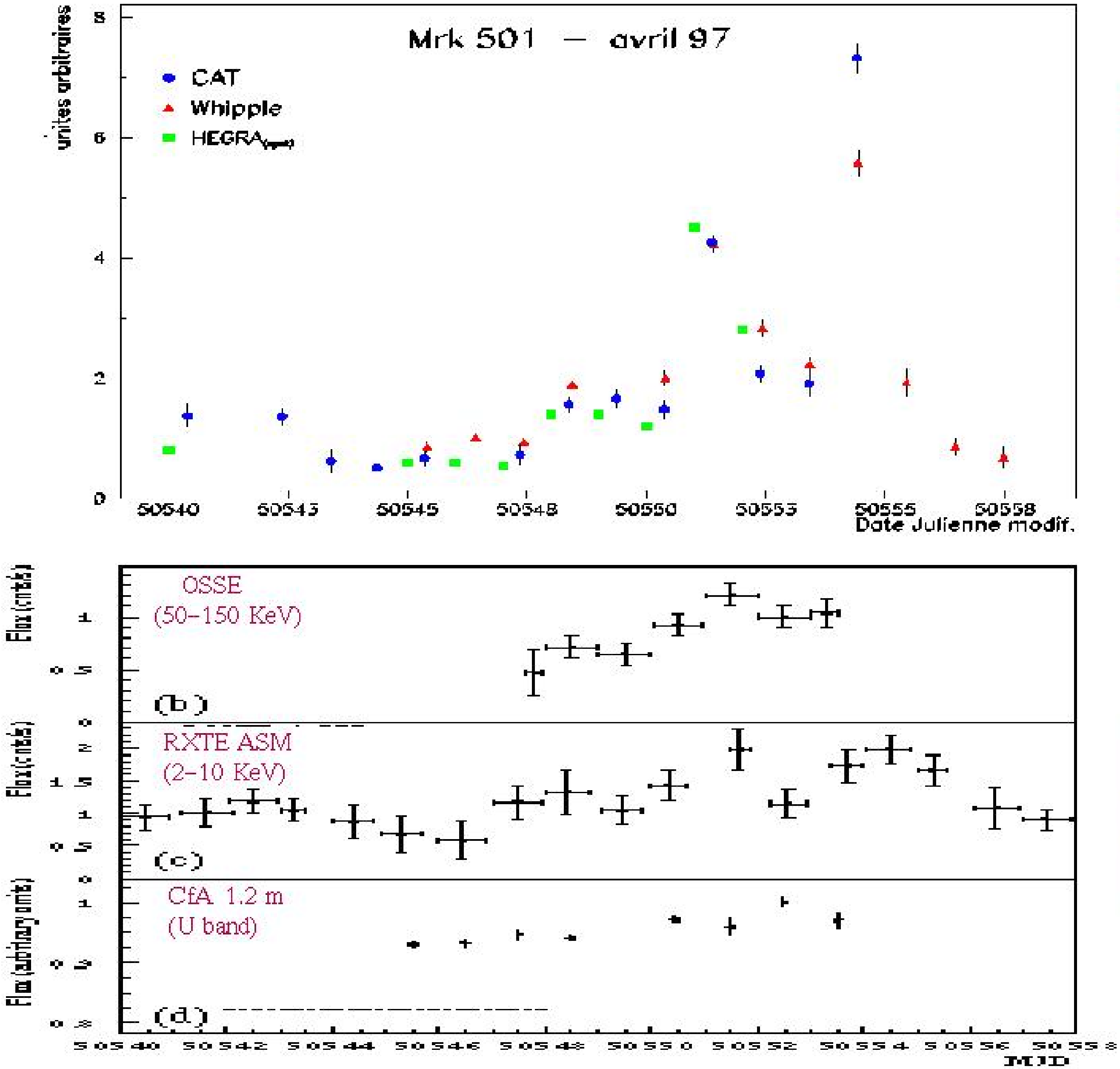




Winter 1999-2000

Preliminary evaluation from CELESTE data of the Crab Nebula around 60 GeV





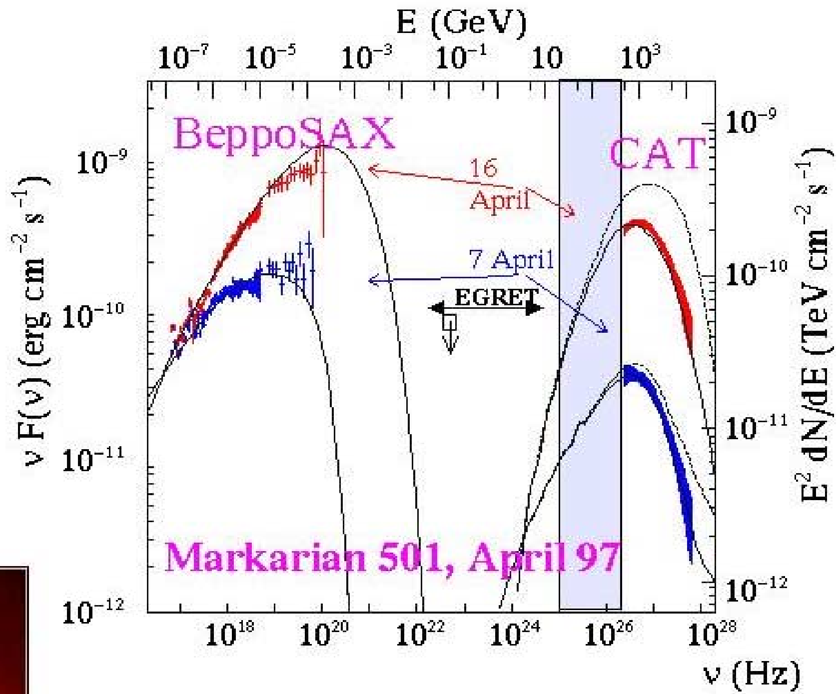
Mrk 501
flares of April 1997
showing variability
on a day scale

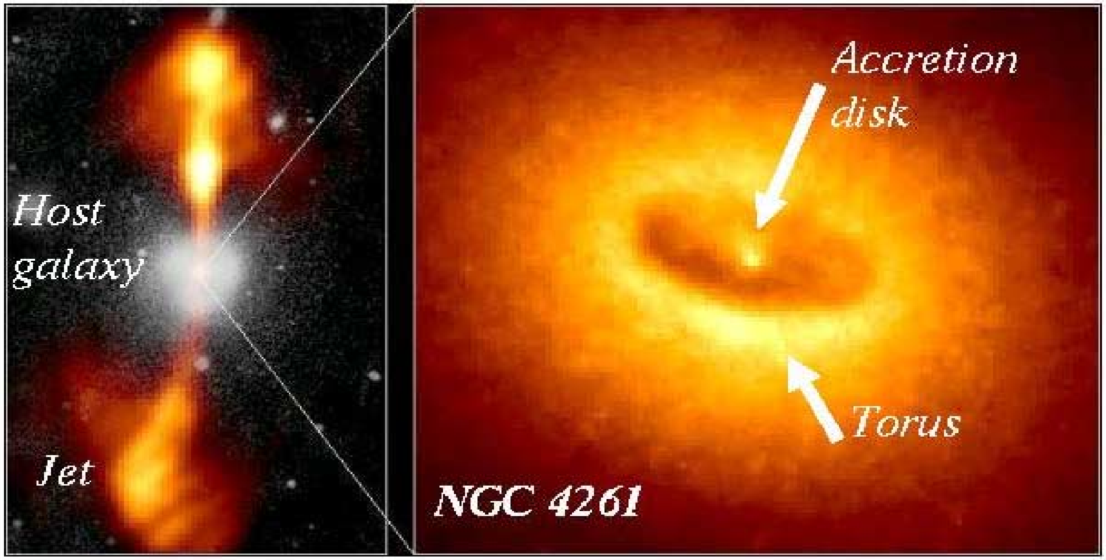
Even faster (<hr)
variations have
been evidenced by
the Whipple
on Mrk 421

Flux sensitivity
on the scale of
the hour is needed

- AGN / Blazar : Markarian 501
  - Supermassive Black Hole ($M > 10^6 M_\odot$)
  - With an acretion disk (1 pc)
  - Surrounded by a torus of dust (100 pc)
- Radio loud:

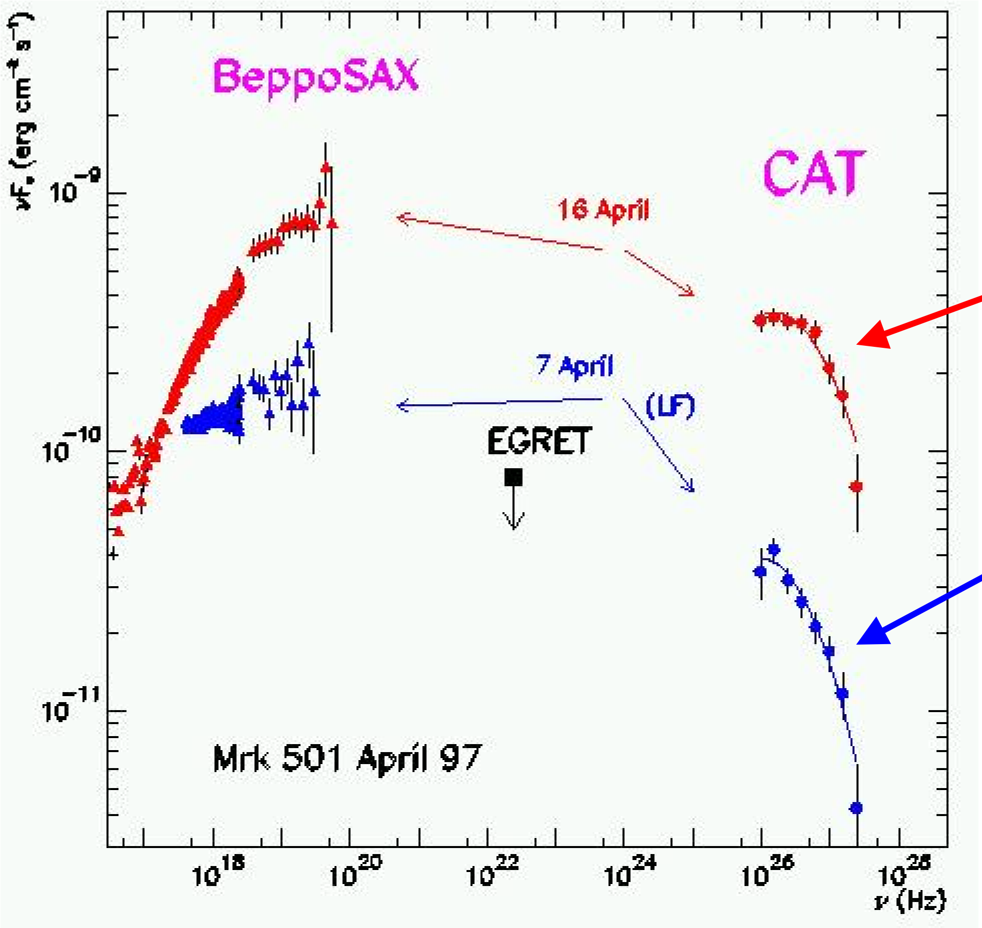
  Two jets (<100 kpc)

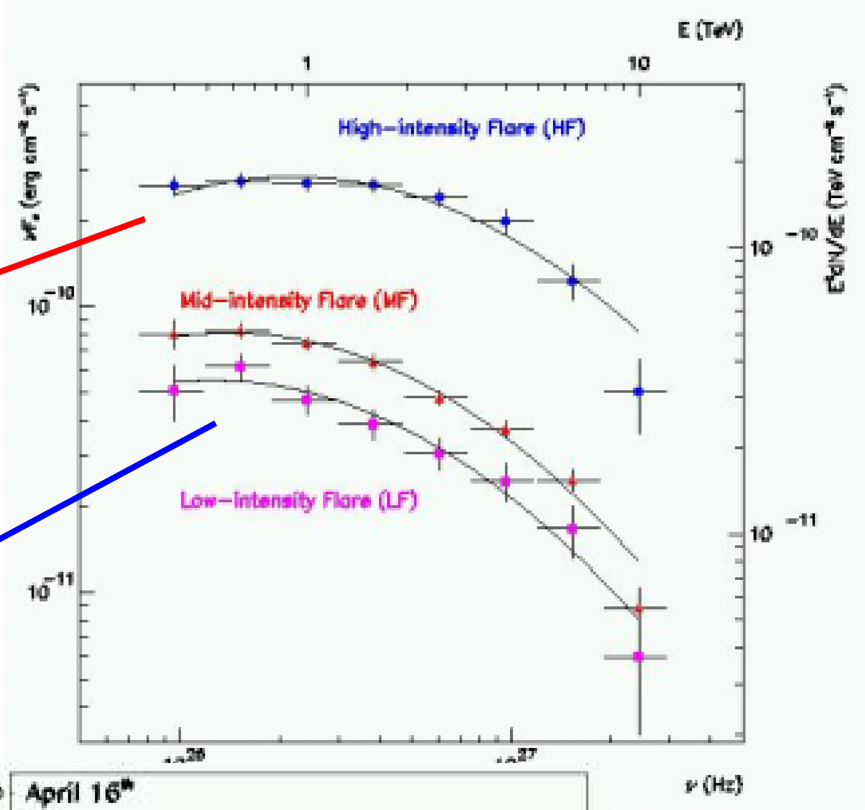


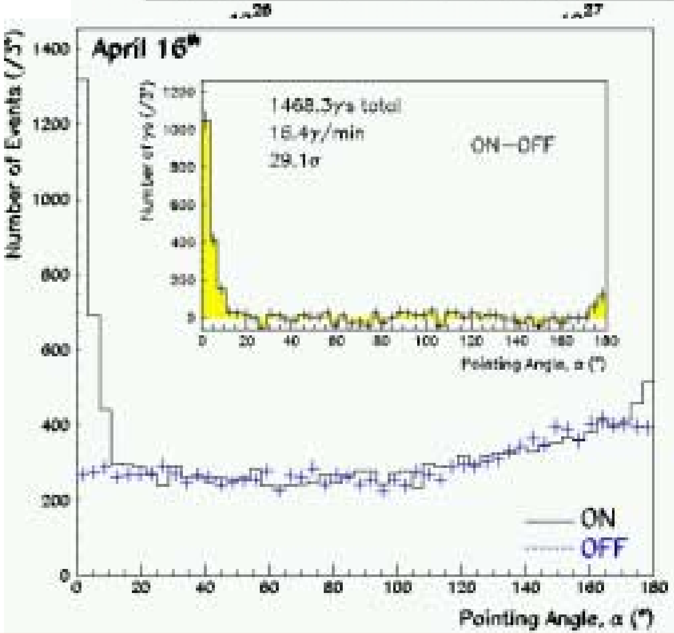


- *Blazars*
  - Near jet axis : $\theta \leq 1 / \gamma$

    -> High energy emission
  - Strong variability on time scale of a *day* or even less

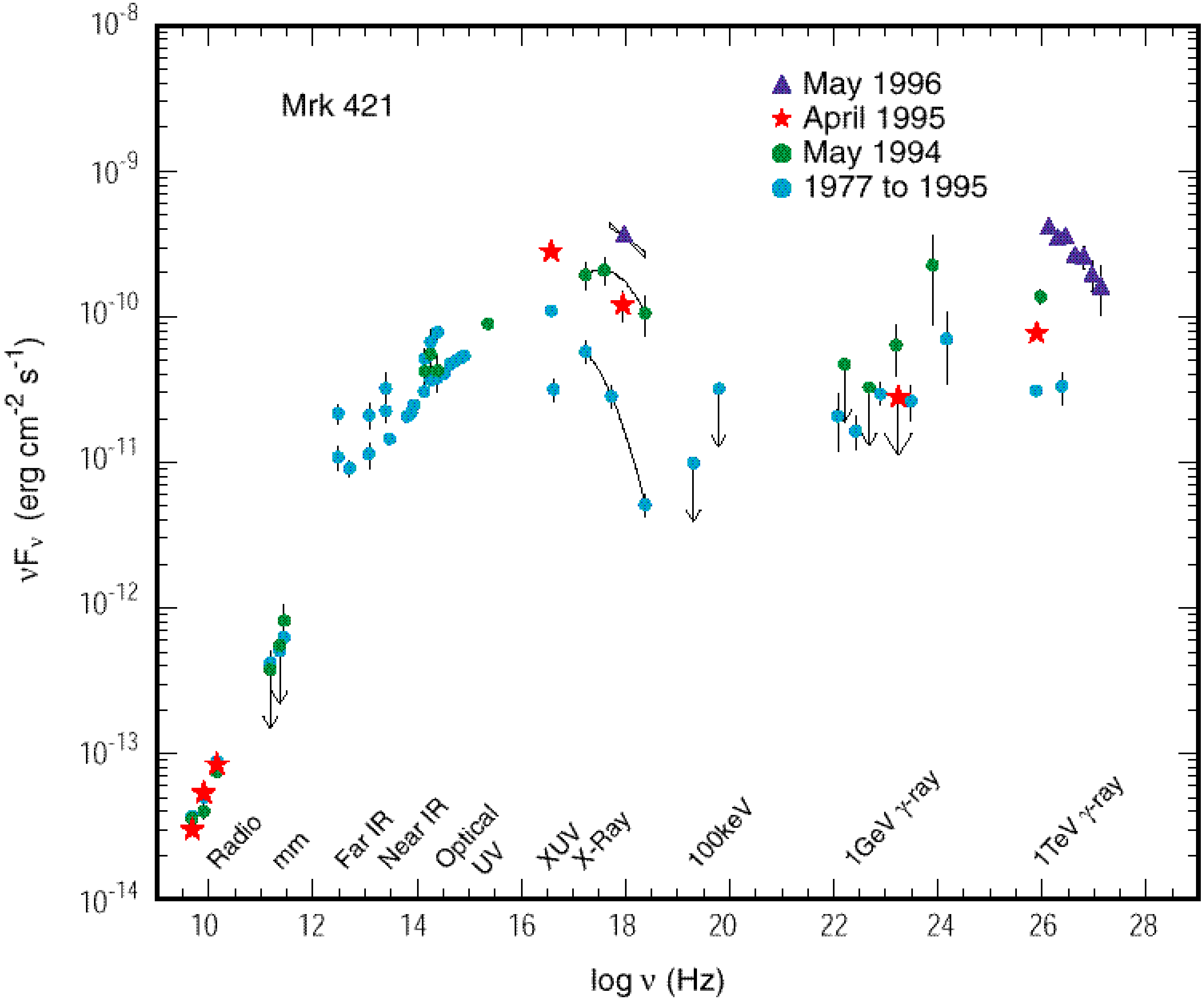






Markarian 501

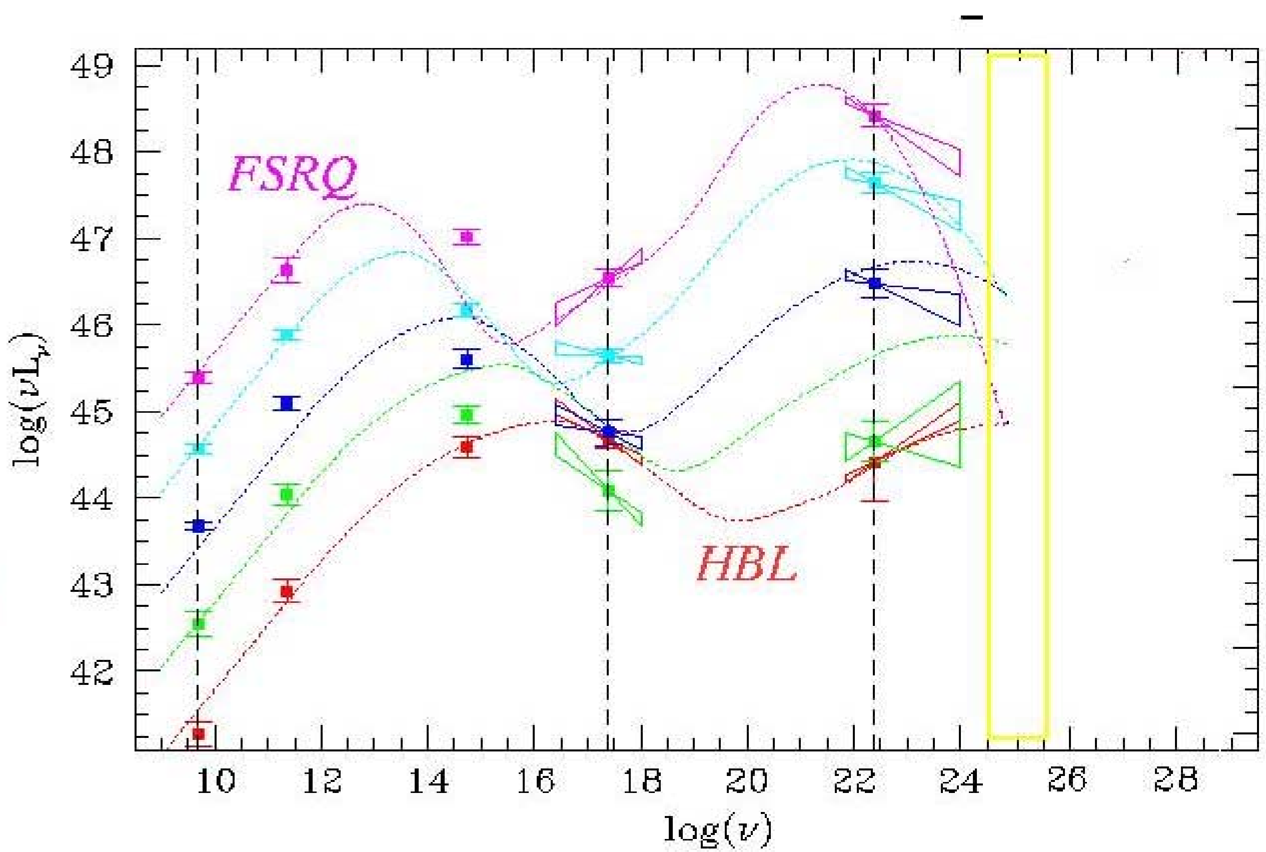
Flare of April 1997



Mrk 421
May 1996
April 1995
May 1994
1977 to 1995
νFν (erg cm-2 s-1)
log ν (Hz)
Radio
mm
Far IR
Near IR
Optical
UV
XUV
X-Ray
100keV
1GeV γ-ray
1TeV γ-ray

Unified spectral sequence of blazars

Ref. G. Ghisellini et al., MNRAS **301**, 451 (1998)



"complete" sample of 126 blazars, distributed in 5 sub–sets according to their intrinsic luminosity at 5 Ghz.

– Observed : anti correlation L / ν (related to damping by photon target ...)
– In support of a leptonic model : Synchrotron + (Self)–inverse–Compton. (SSC – model)

$$e^{\pm} + \gamma_{soft} \longrightarrow e^{\pm} + \gamma_{GeV-TeV}$$

Solar plants

SOLAR-I → -II *1992, 1999* @ Barstow, Cal. (Tumay Tümer)
STACEE *taking data* @ Sandia, Cal. (René Ong)
CELESTE *operational* @ Thémis, Fr. (Eric Paré → David Smith)

Use of existing large mirror collection areas

- **Solar plants have adequate optical & pointing precisions**
- **BUT, they do not fit with the "imaging" requirements**

Distributed sampling of times & amplitudes

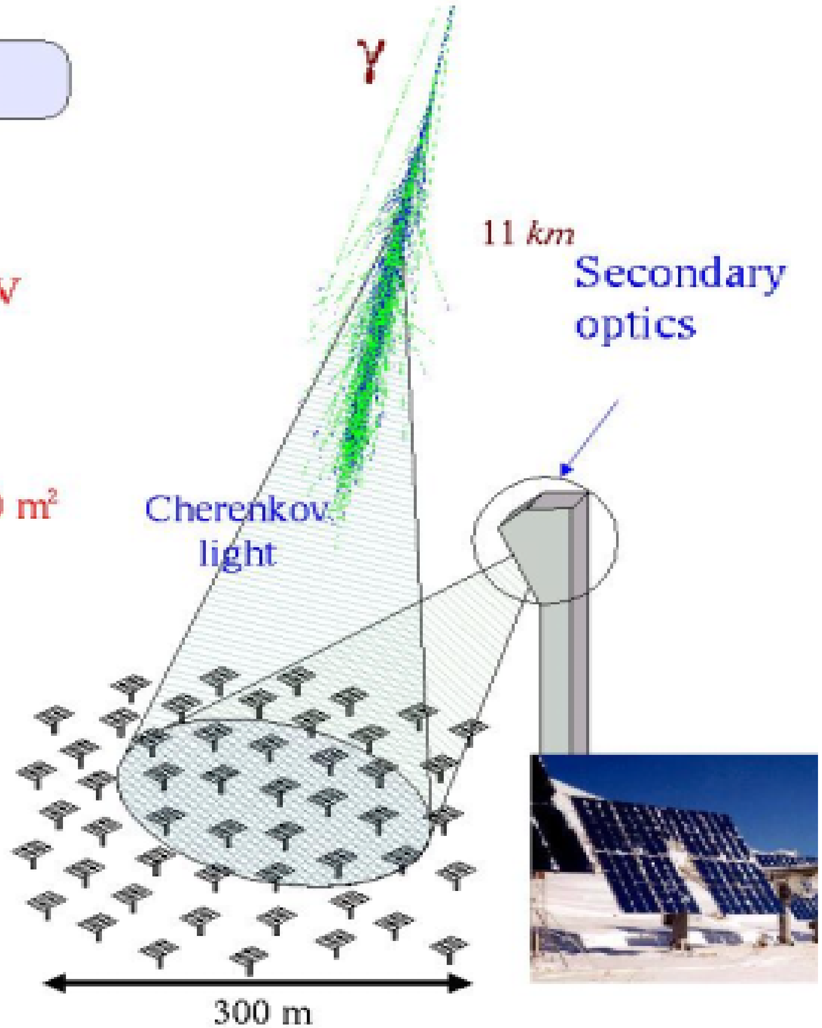
by adding a secondary optics to single out each helisotat

(Ref. Tumay Tümer 1992)

Solar plant as Gamma detector

- Few e^- per shower :
  $n_e \approx E\,(GeV)/2$ → 3 γ_e / héliostat @30 GeV
  → Large collection (40 x 50 = 2000 m^2)
- Night sky noise : 1 γ_e /héliostat/ns
  → must restore <1 ns synchronism on 20 000 m^2
- Muons are killed at trigger,
  but many CR's remain
  → use irregular light pool of hadrons

Use a Secondary optics
to single out each héliostat
Register times (0.3ns) and amplitudes
Fast trigger (2–3 ns)



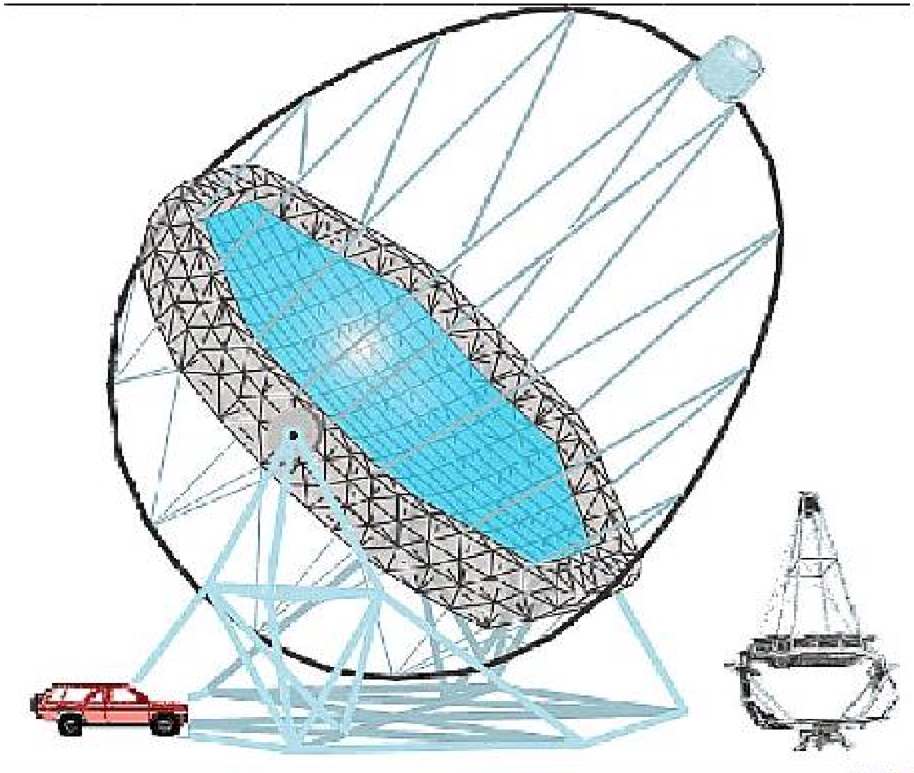
Strong signals are obtained on the Crab nebula and on Mrk-421 (partly with synchronous data from CAT & Celeste)

Site of Thémis
(France)

Pyrénées Orientales
In the far distance :
Pyrénées mountains in Spain;
in between :
the Cerdagne valley.

The site was built as a test for solar plant
It was turned to astrophysics since 1986 :

- 1986-1993 Themistocle & Asgat
- 1993-1996*(first light)* CAT
- 1994-1999*(first light)* CELESTE



MAGIC

The 17mΦ light collector will be of diamond milled aluminium mirrors;

Simple active optics will be developed to maintain the shape of the dish whilst tracking an object across the sky.

First camera will use PMT's with GaAsP photocathode which has a peak QE of >45% between 450 and 620 nm.

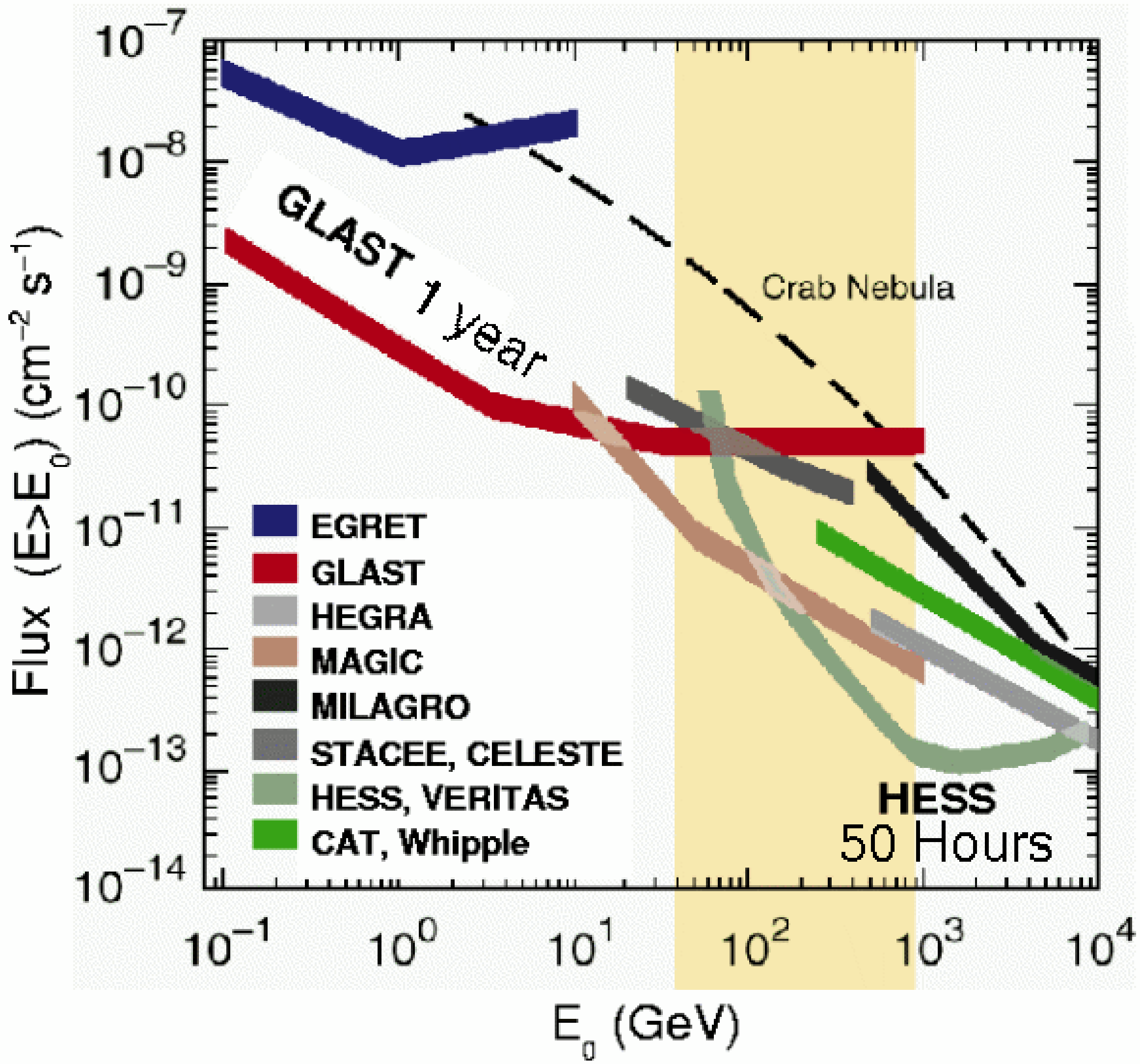
Ultimatly, "all silicon" camera based on the low noise Avalanche Photodiodes (APDs)

MAGIC is exploring the utmost capability of a single imaging device with the goal of a very low threshold (10 GeV)

It could also be deployed in arrays
Its technical achievements could radiate to the whole field

Sensitivity of Space & Ground γ detectors

for the past & forthcoming decades



Redundancy is important :

- **large angular acceptance in space → « completeness »**
- **large sensitive area of Cherenkov → fast variability**

IMAGING (existing)	*IMAGING (future)*	*SAMPLING & TIMING*	*CHARGE PARTICLE DETECTORS*
Whipple	Cangaroo-3	CELESTE	MILAGRO
HEGRA	VERITAS	STACEE	Tibet-array
CAT	HESS	(SOLAR-2)	ARGO
Narrabri/Durham	MAGIC		
Cangaroo-1			
Shalon			

The main multi–imaging telescopes

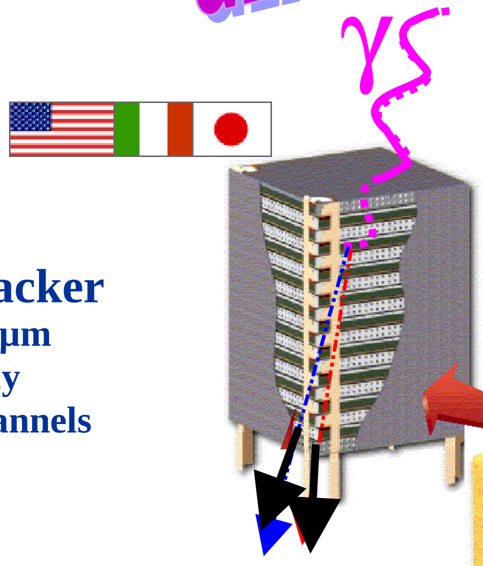
name	Nb of dishes	Diameter (/ Focal)	Pixels Nb	Pixels Size	Pixels FoV	Rate stereo mode	Location Altitude	Energy (GeV) Trigg / Spectr	Calendar
HESS	4 → 10–16	12m (/ 15m)	1000	0.16°	5.0°	≈ 1 kHz	23° S 16° E 1800 m	<50 / <100	2001 → 2003
VERITAS	7	10m (/ 12m)	500	0.16°	3.5°	≈ 1 kHz	32°N 111°W 1800 m	50 / 100	2002 → 2004
CANGAROO–III	4	<10m (/ 8m)	500	0.16°	3.0°	?	31° S 136°E 150 m	100 / 150	2000 → 2004

HESS

Photo-montage of the first four telescopes
on site in Namibia.

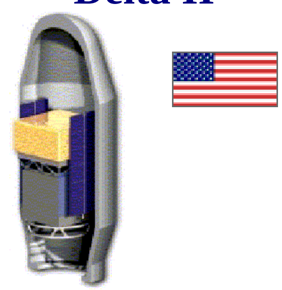
First light of the first telescope this year (2001)

GLAST *a Particle Physics detectors*



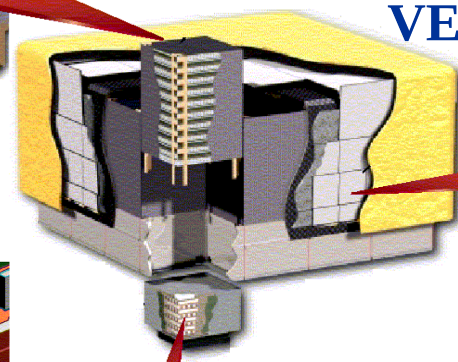
Si-Pb Tracker
pitch = 200 µm
18 layers x,y
1000000 channels

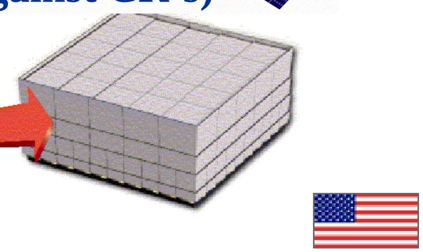
Delta II

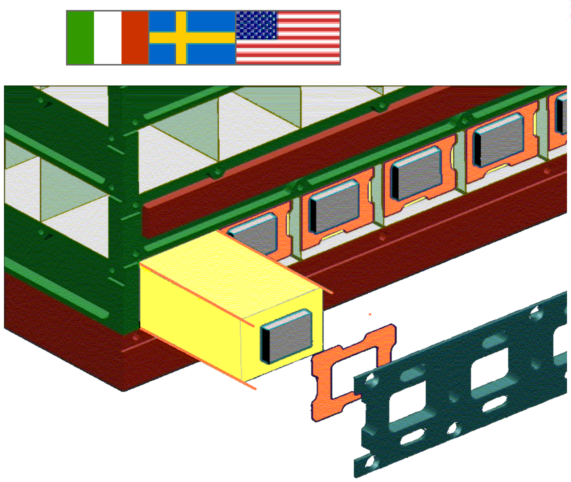


10 MeV - 1 TeV
2560 kg, **520 W**
1.73^2 x 1.06 m

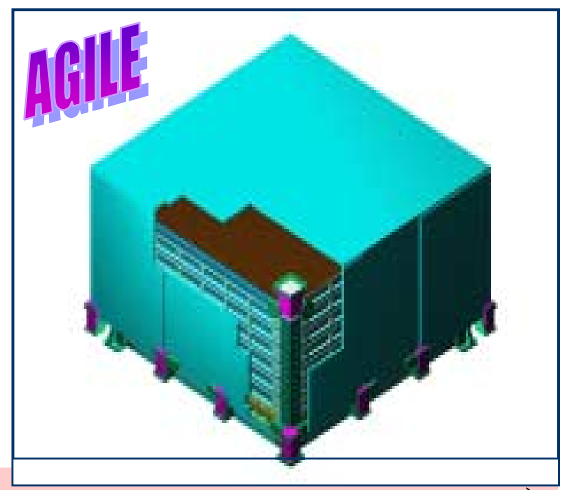
VETO (against CR's)



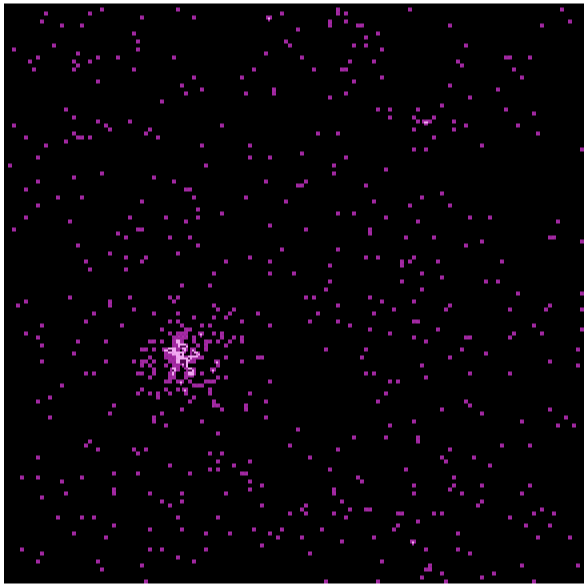


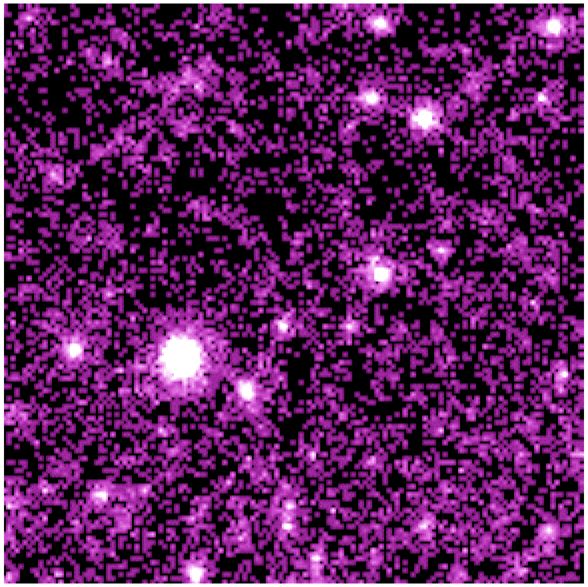


CsI Calorimeter
(energy measurement)
8.6 RL,
(x,y) segmented in 8 layers



	EGRET	GLAST (1 year)	
Energy	50 MeV -30 GeV	10 MeV- 1 TeV	
Area max.	1500 cm^2	12900 cm^2	x 8,6
Field of View	0,6 sr	2,4 sr	x4
Sensitivity	$>10^{-7}$ g $cm^{-2}s^{-1}$	$>1,6\ 10^{-9}$ g $cm^{-2}\ s^{-1}$	x50
Localisation	0,5 °	20 " - 7 '	x100 - 4



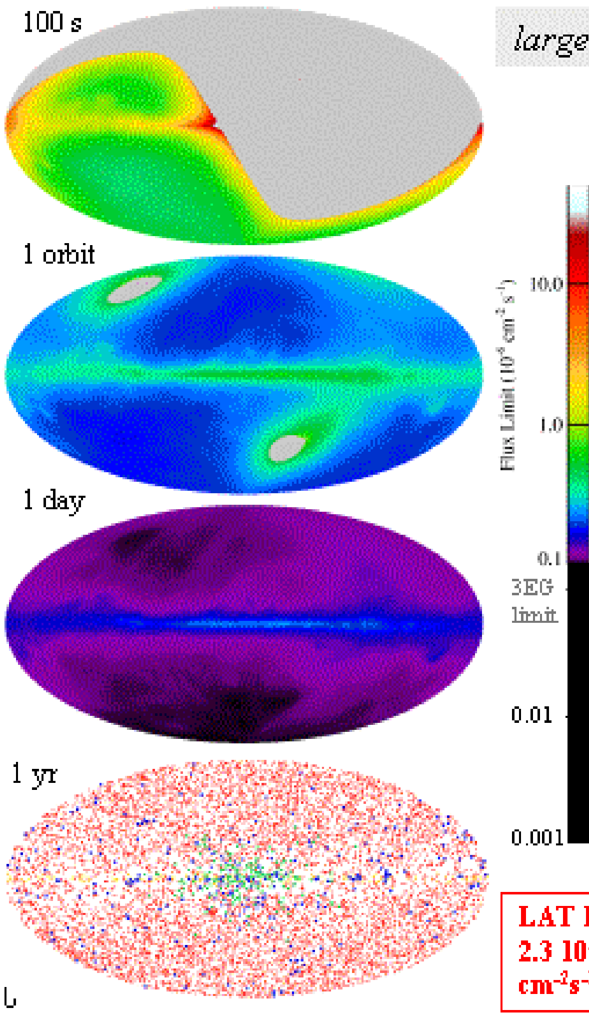


Virgo (E > 100 MeV)

To conclude

Space ⊕ Ground

Science Capabilities : sensitivity



LAT 1 yr
2.3 10^{-9}
cm^{-2}s^{-1}

large field-of-view

200 γ bursts per year

prompt emission sampled to ≈20 μs

AGN flares > 2 mn mostly from Ground

time profile +ΔE/E ⇒ physics of jets and acceleration

Space ⊕ Ground should conclude on

- Optical depth due to cosmic diffuse light
- SNR's / CR - origin

all 3EG sources should **be identified**

⇒ periodicity searches (pulsars & X-ray binaries)

⇒ pulsar beam & emission vs. luminosity, age, B

10^4 sources in 1-yr survey

⇒ AGN: logN-logS, duty cycle,

emission vs. type, redshift, aspect angle

⇒ extragalactic background light (γ + IR-opt)

⇒ new γ sources (μQSO, external galaxies, clusters)