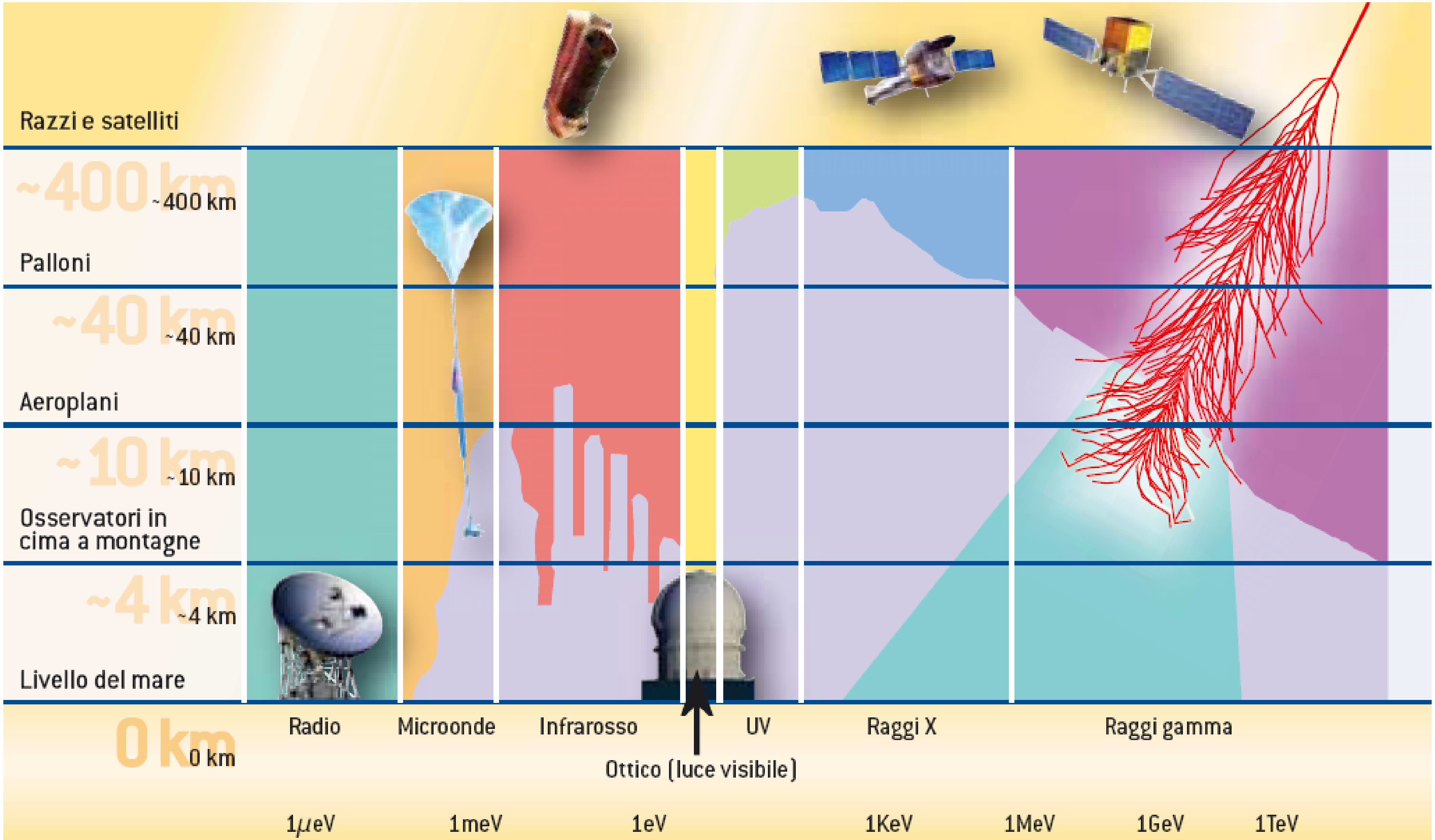
Astrofisica Nucleare e Subnucleare

TeV Astrophysics

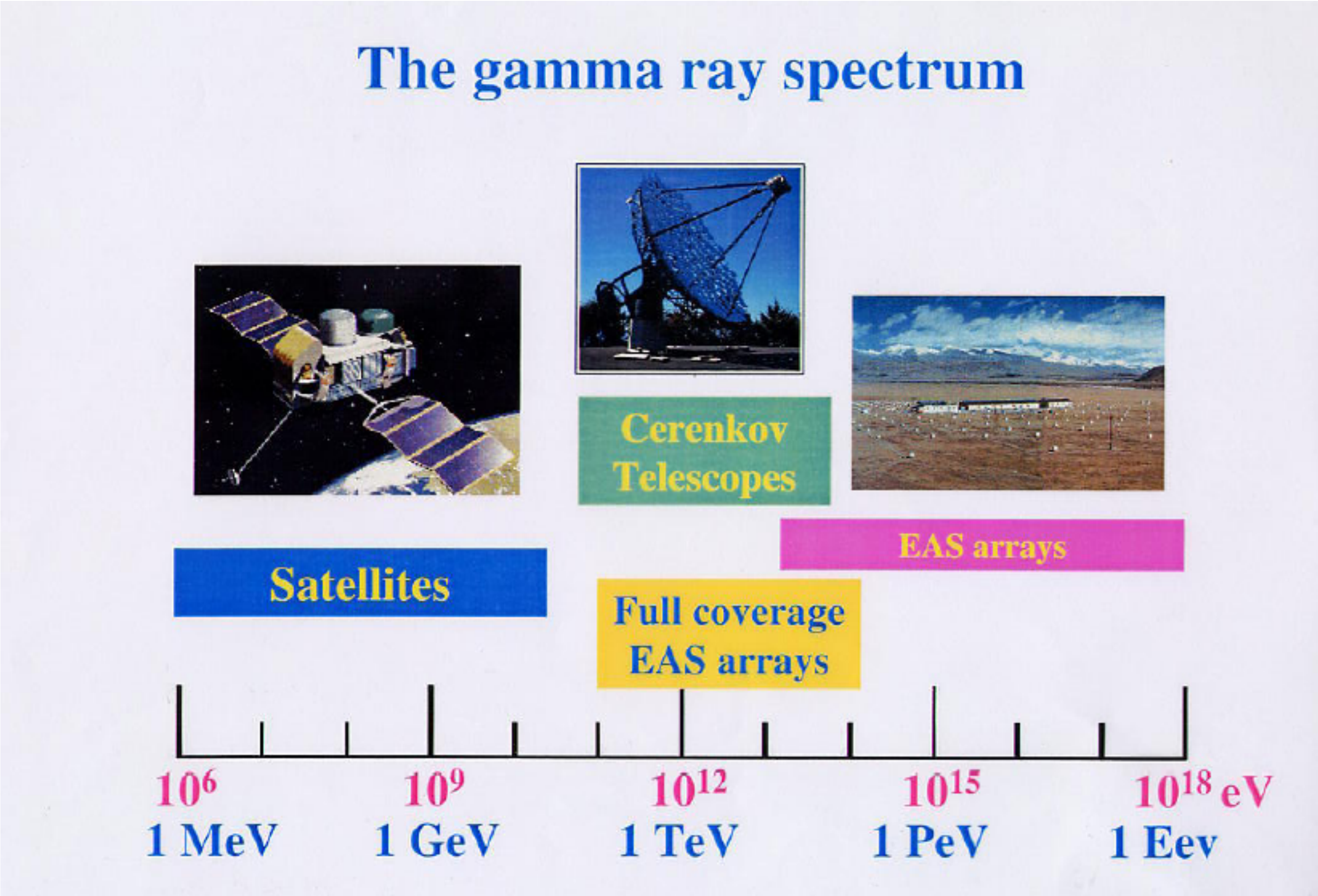
Exercise #5

- Find the information about the 3 major currently operating IACT telescopes
- Find information on the "HESS" source of the month
- Visit the web site of CTA

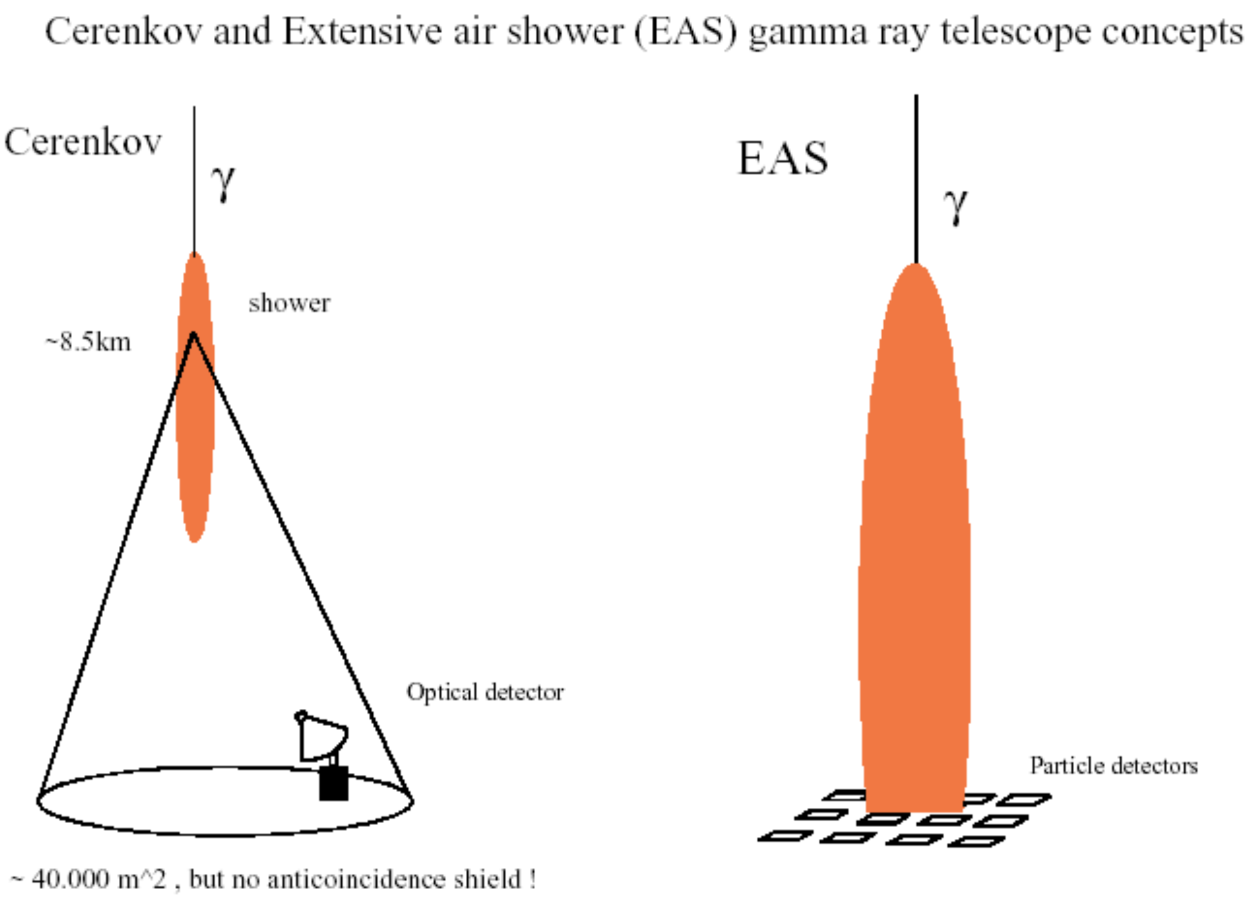
The opacity of the atmosphere



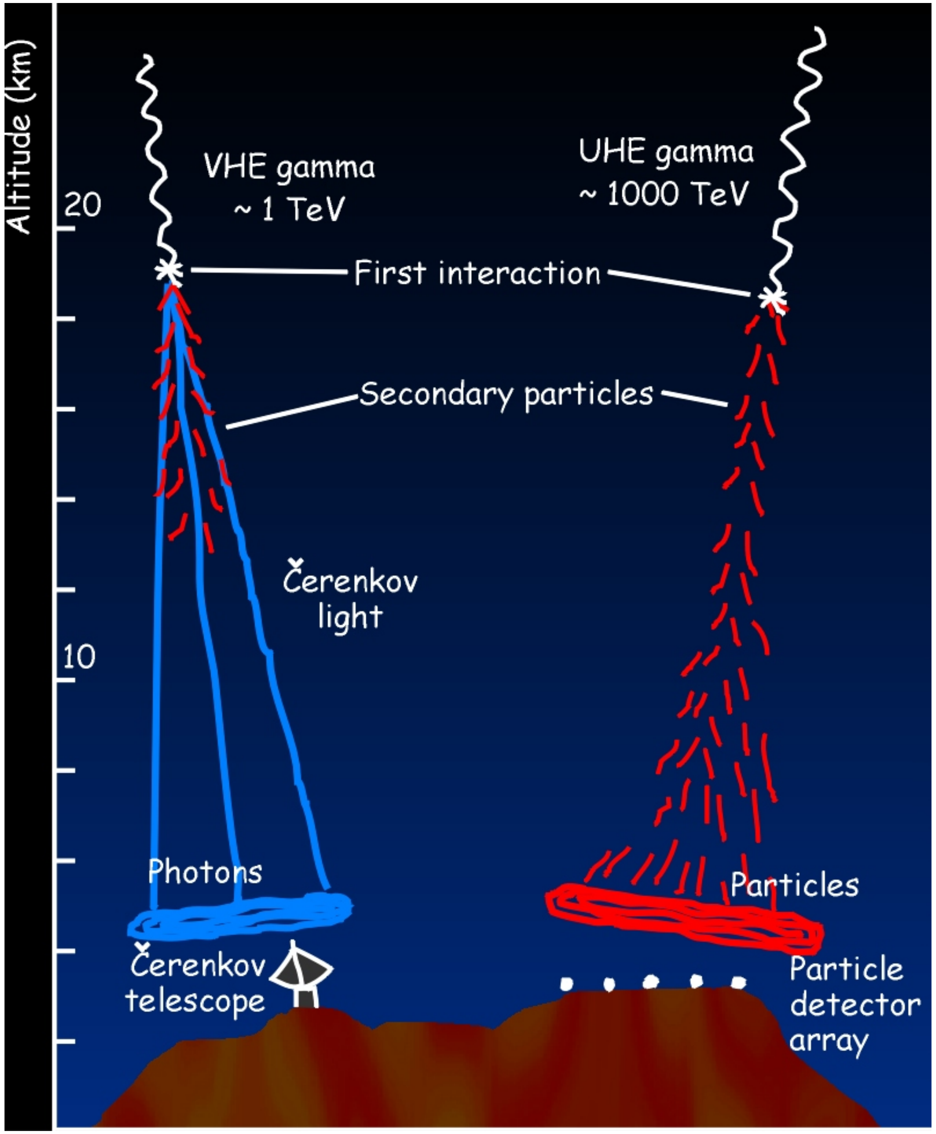
TeV detectors



TeV detectors



IACT & EAS experiments



- Cherenkov experiments consist of almost-optical telescopes devoted to detect Cherenkov light.
- EAS (Extensive Air Shower) experiments are huge arrays or carpets of particle detectors.
- Cherenkov experiments have lower energy thresholds, but also a lower duty-cycle as well as a smaller field of view.

Complementary Capabilities

Parameter	Ground-based		Space-based
	ACT	EAS	Pair
angular resolution	good	fair	good
duty cycle	low	high	high
area	large	large	small
field of view	small	large	large & can repoint
energy resolution	good	fair	good w/ smaller systematic uncertainties

The next generation of ground-based and space-based facilities are well matched!

EM Air Showers

Air shower development

- Pair production $I = I_0 \, e^{-x/\lambda}$

  λ = mean free path

- Bremsstrahlung $E = E_0 \, e^{-x/\chi_0}$

  χ_0 = radiation length

In the ultra-relativistic limit $\lambda \sim \chi_0 = 36.5 \text{ g/cm}^2$ in air

$R = \chi_0 \ln 2 \quad \Rightarrow$ After a distance nR :

$N_{e,\gamma} = 2^n \qquad E_{e,\gamma} \sim E_{pr} / 2^n$

EM Air Showers

The process continues until the electrons energy is $E > E_c$

E_c = critical energy = 83 MeV in air

Number of particles at the shower maximum:

$$N_{max} = 2^n = E_{pr} / E_c$$

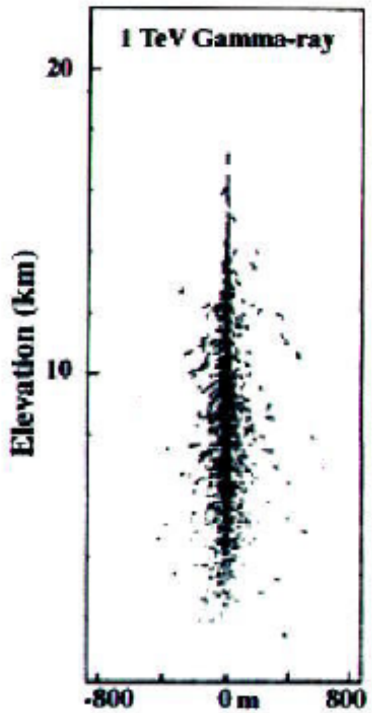
Depth of the maximum:

$$n_{max} = \ln (E_{pr} / E_c) / \ln 2$$

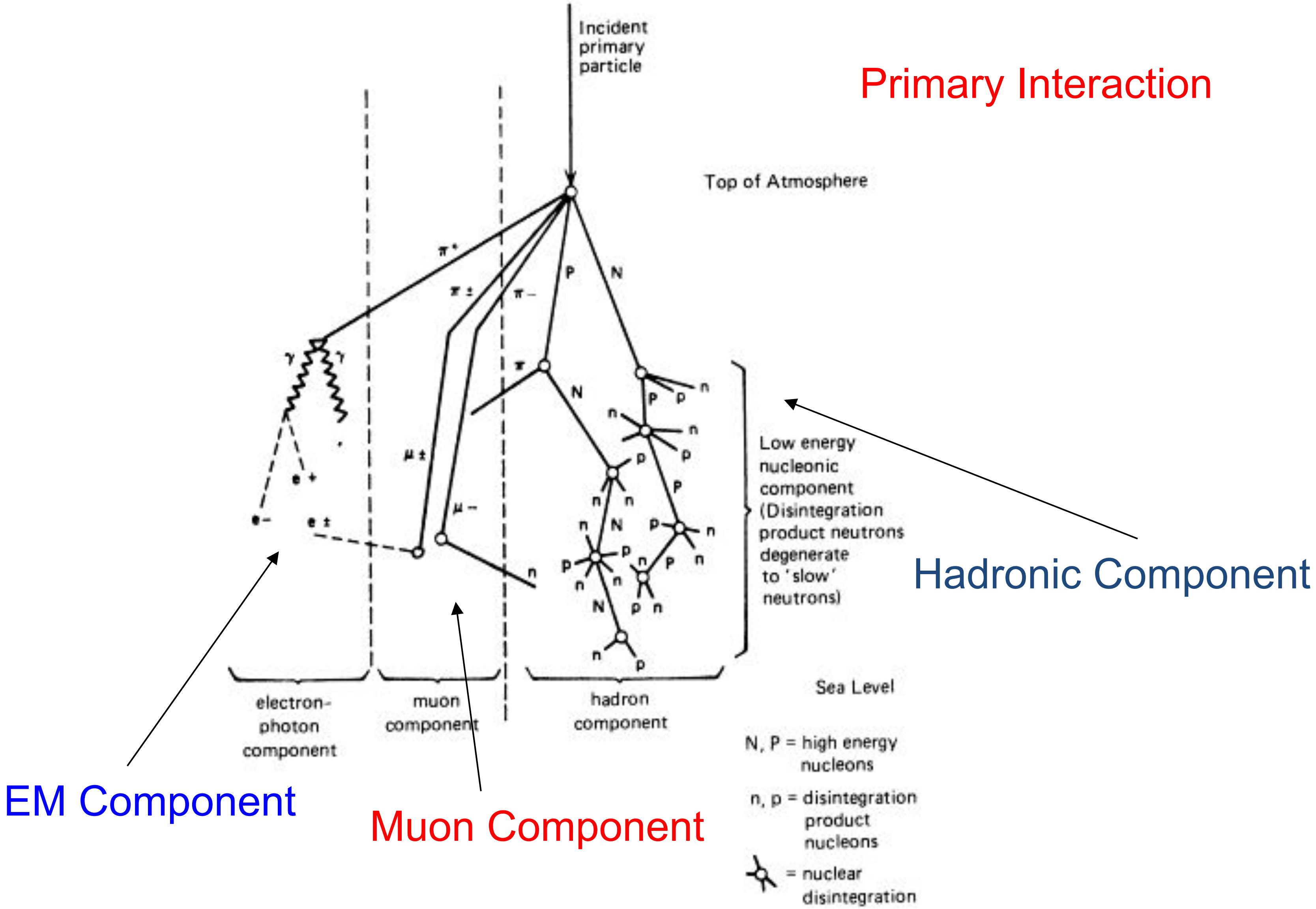
$$\Rightarrow X_{max} = n R = n \chi_0 \ln 2 = \chi_0 \ln (E_{pr} / E_c)$$

Example: $E_{pr} = 1$ TeV

$$\Rightarrow X_{max} = 340 \text{ g / cm}^2 \sim 8 \text{ Km}$$



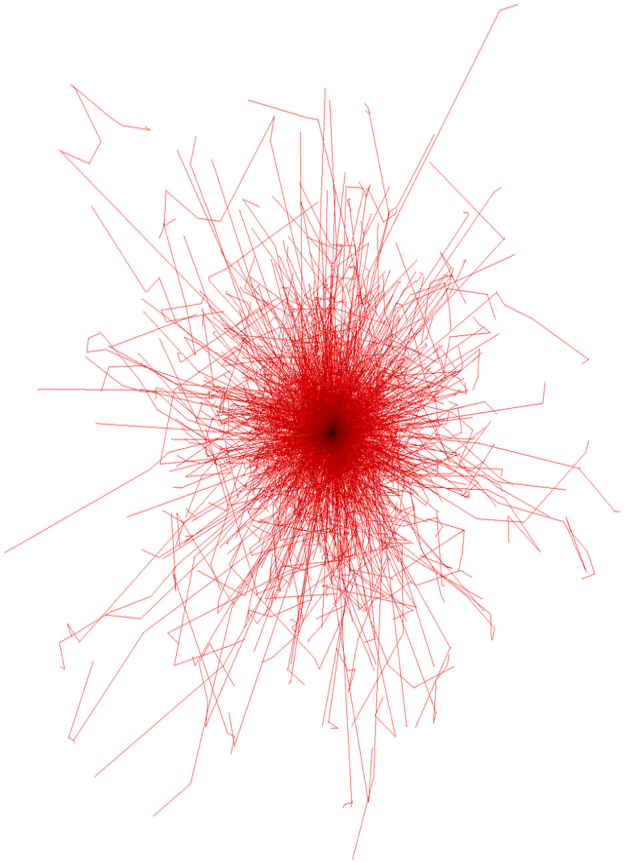
CR interactions

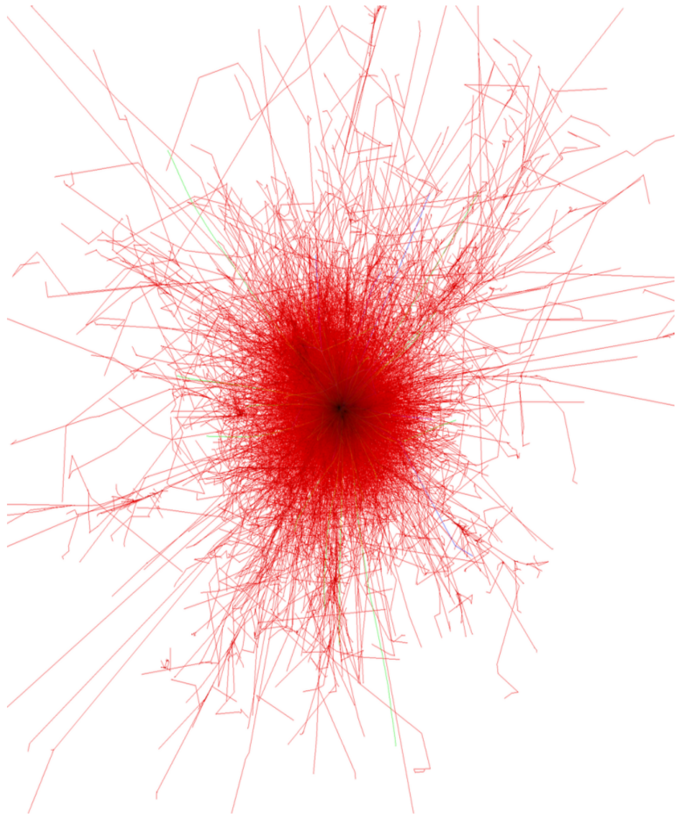


The importance of MC

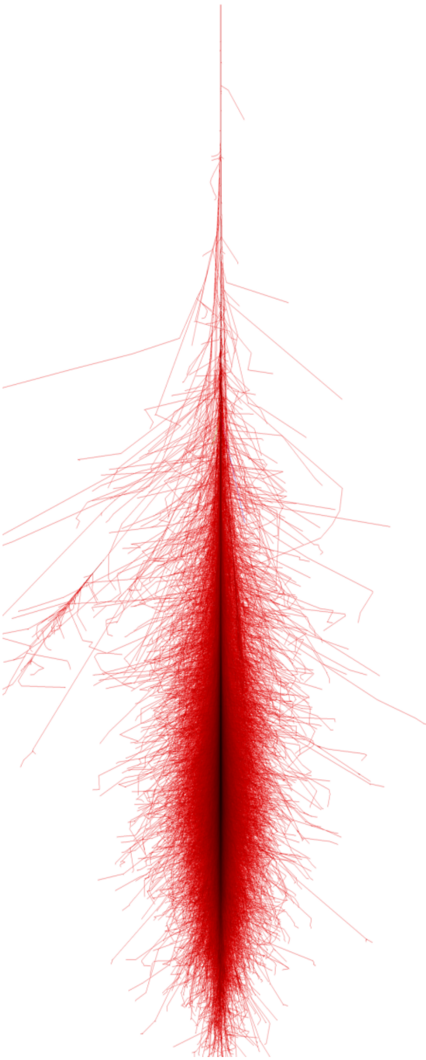
- CORSIKA (COsmic Ray SImulations for KAscade) is a program for detailed simulation of extensive air showers initiated by high energy cosmic ray particles. Protons, light nuclei up to iron, photons, and many other particles may be treated as primaries.
- The particles are tracked through the atmosphere until they undergo reactions with the air nuclei or - in the case of instable secondaries - decay.
- The hadronic interactions at high energies may be described by six reaction models alternatively: The VENUS, QGSJET, and DPMJET models are based on the Gribov-Regge theory, while SIBYLL is a minijet model. HDPM is inspired by findings of the Dual Parton Model and tries to reproduce relevant kinematical distributions being measured at colliders. The neXus model extends far above a simple combination of QGSJET and VENUS routines.
- Hadronic interactions at lower energies are described either by the GHEISHA interaction routines, by a link to FLUKA, or by the UrQMD model.
- In particle decays all decay branches down to the 1 % level are taken into account.
- For electromagnetic interactions a taylor made version of the shower program EGS4 or the analytical NKG formulas may be used.
- Options for the generation of Cherenkov radiation and neutrinos exist.
- CORSIKA may be used up to and beyond the highest energies of 100 EeV.
- http://www-ik.fzk.de/corsika/

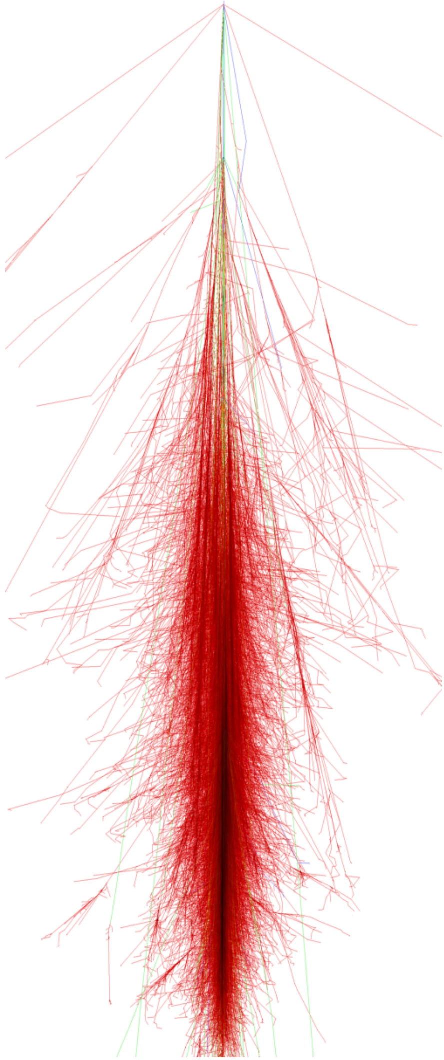
Shower Images



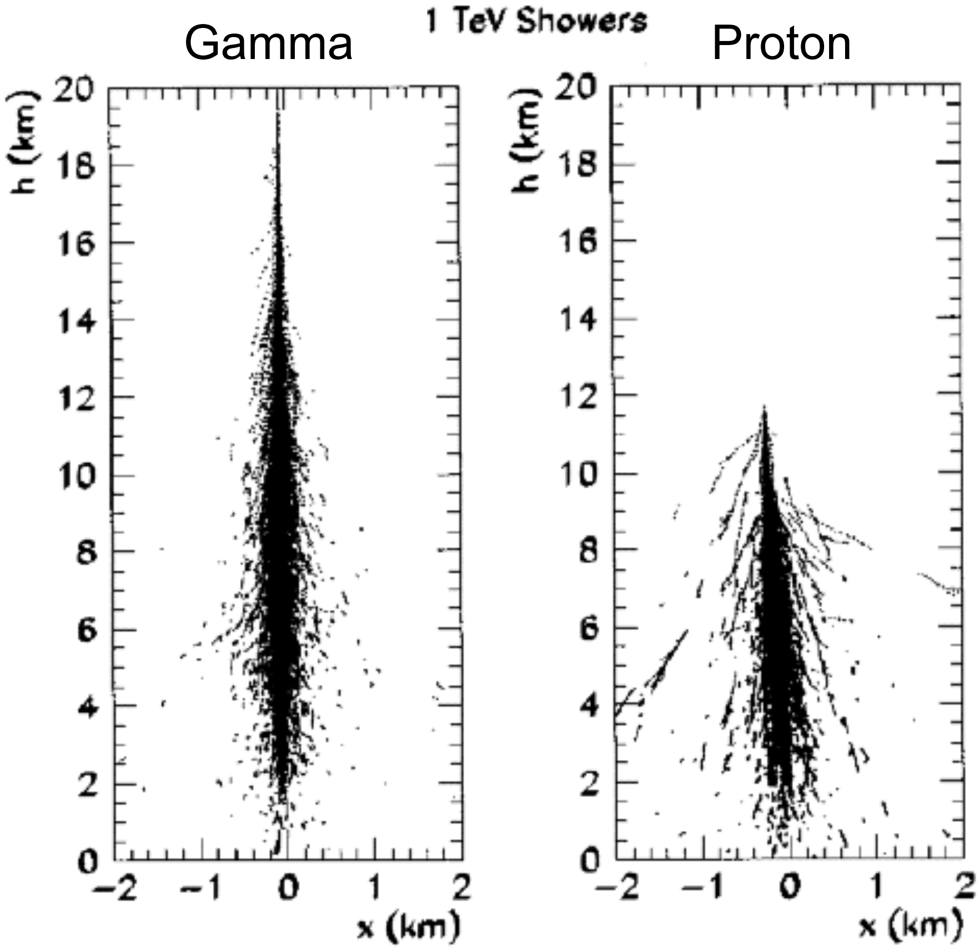


Shower Images



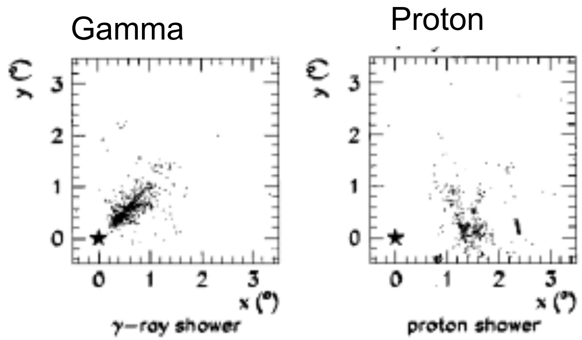


Development of vertical 1-TeV proton and γ-ray shower

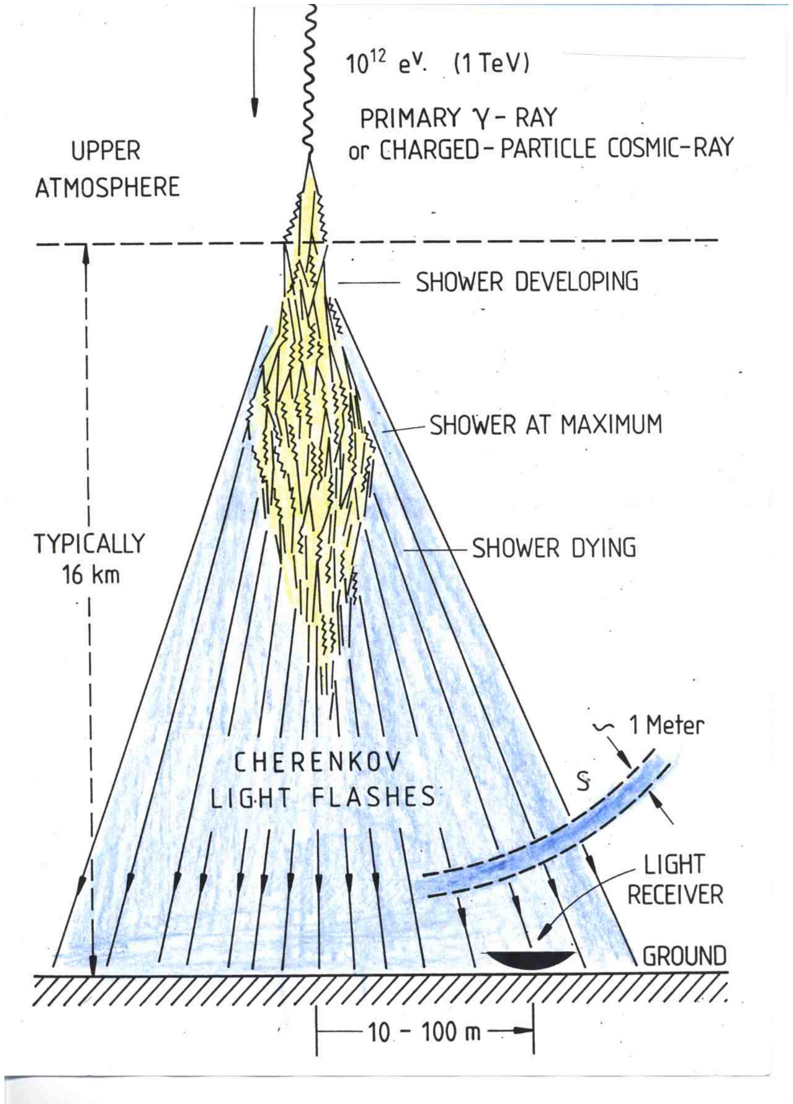


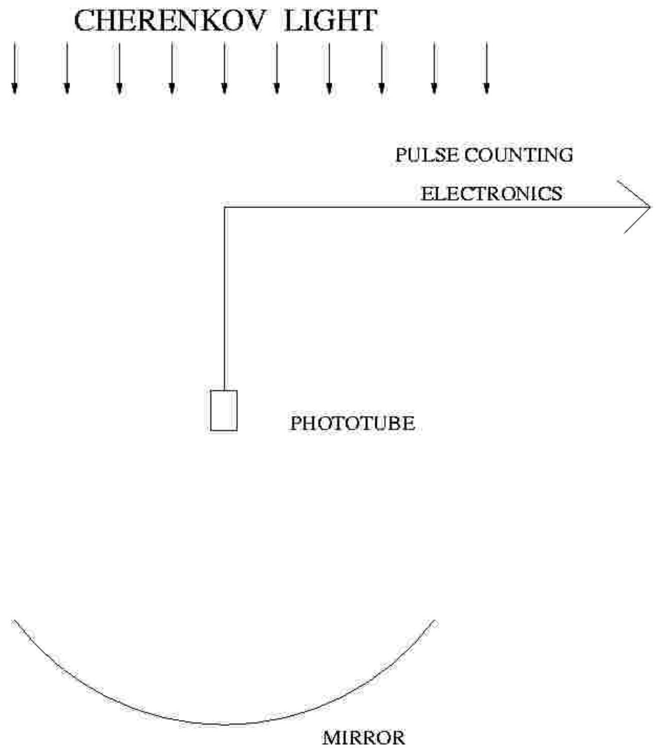
Positions in the atmosphere of all shower electrons above the Cerenkov threshold

Resulting Cerenkov images in the focal plane of a 10-m reflecting mirror .



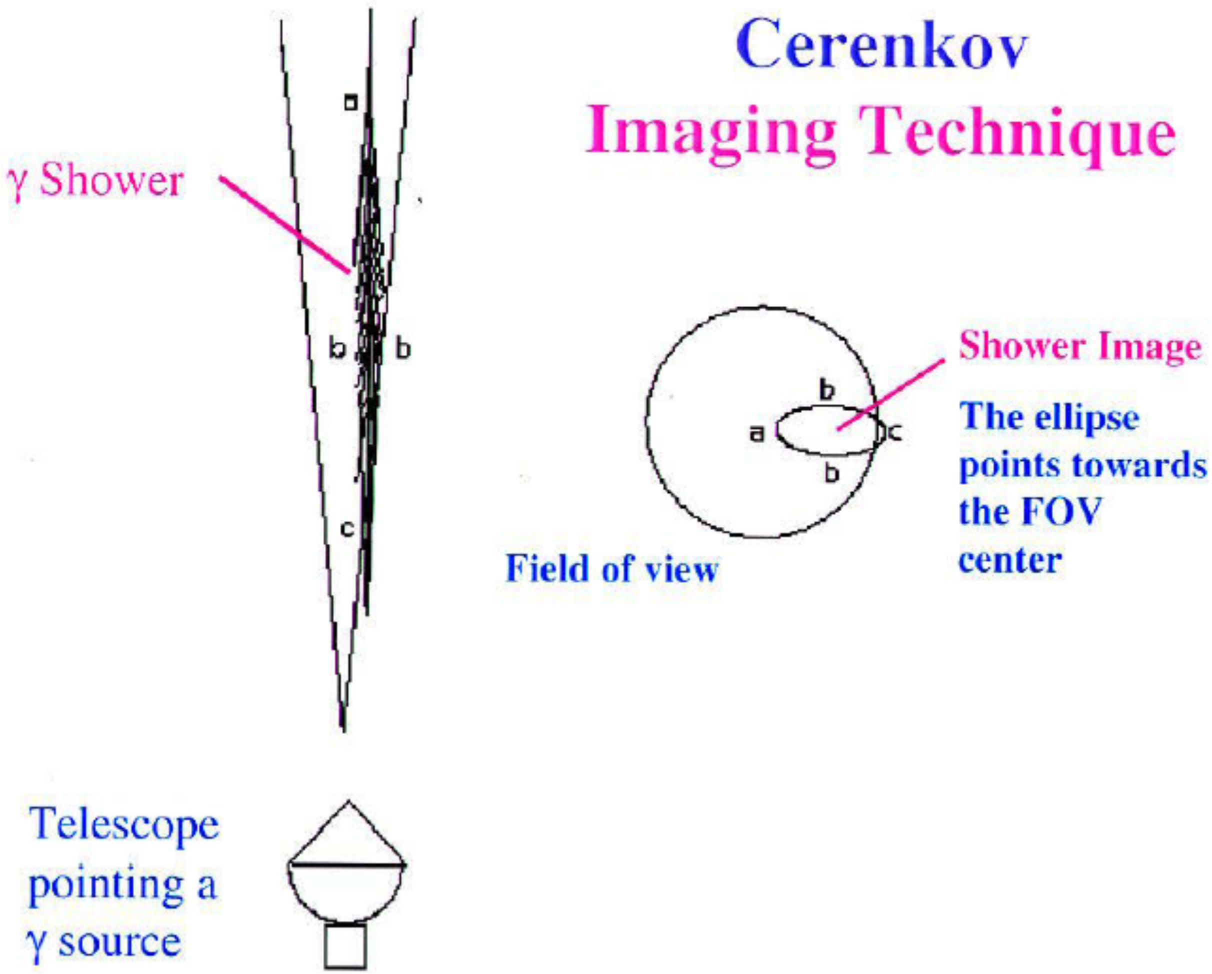
TeV detectors



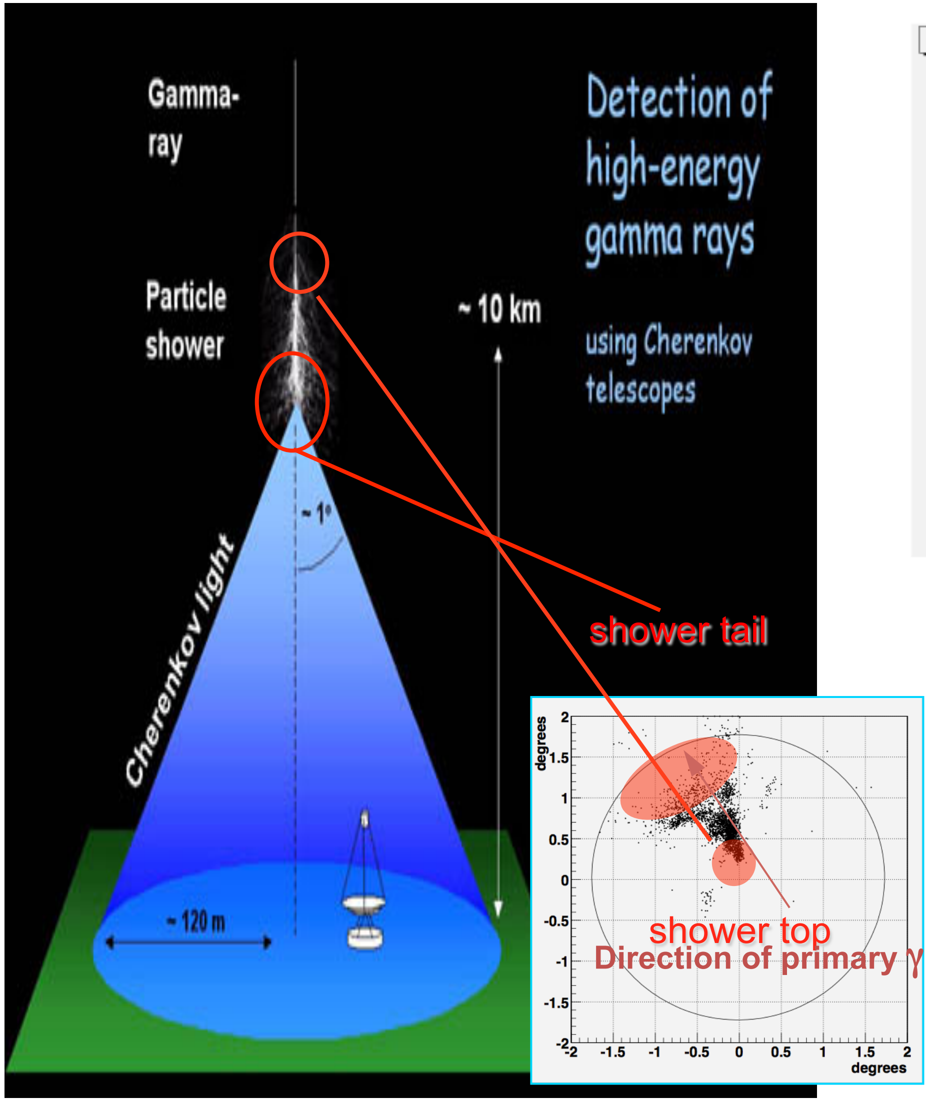


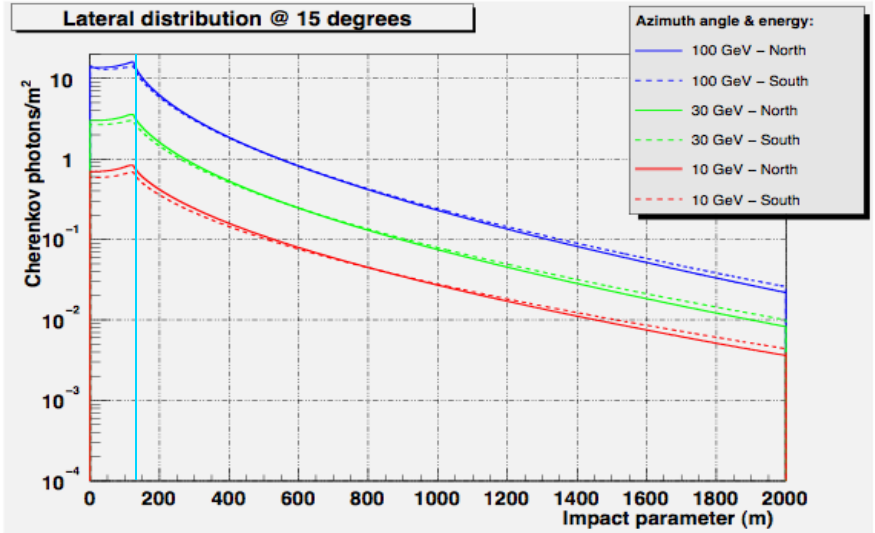
Direction ~ → arc-min
Energy Resolution ~ →10%
Background ~ →0

TeV detectors



Imaging Atmospheric Cherenkov Telescopes

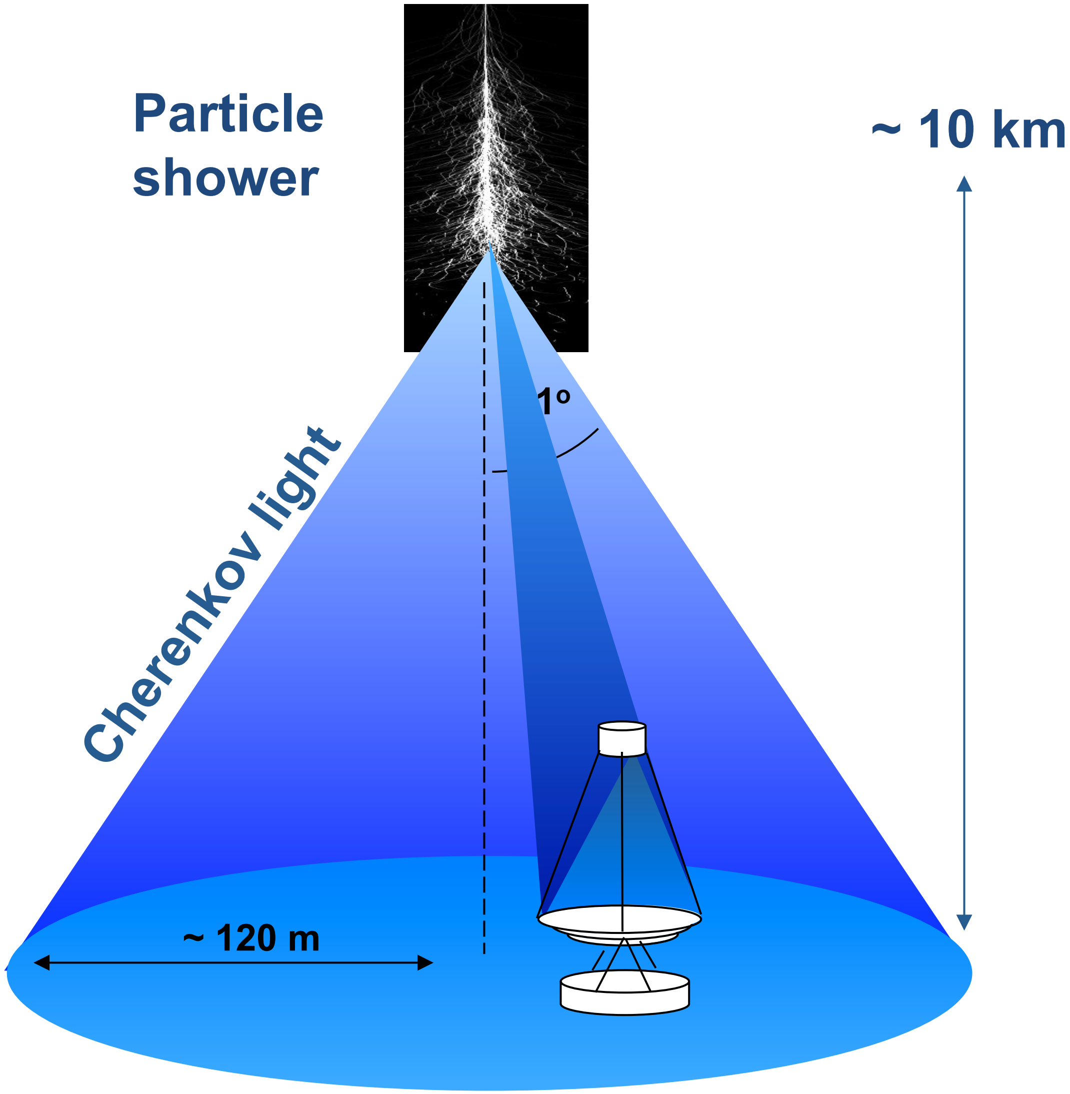




The principle:

A telescope placed inside the (huge) Cherenkov light pool can obtain an image of the development of the shower above the bkg fluctuations

Observation tecnique



Detection of TeV gamma rays

using Cherenkov telescopes

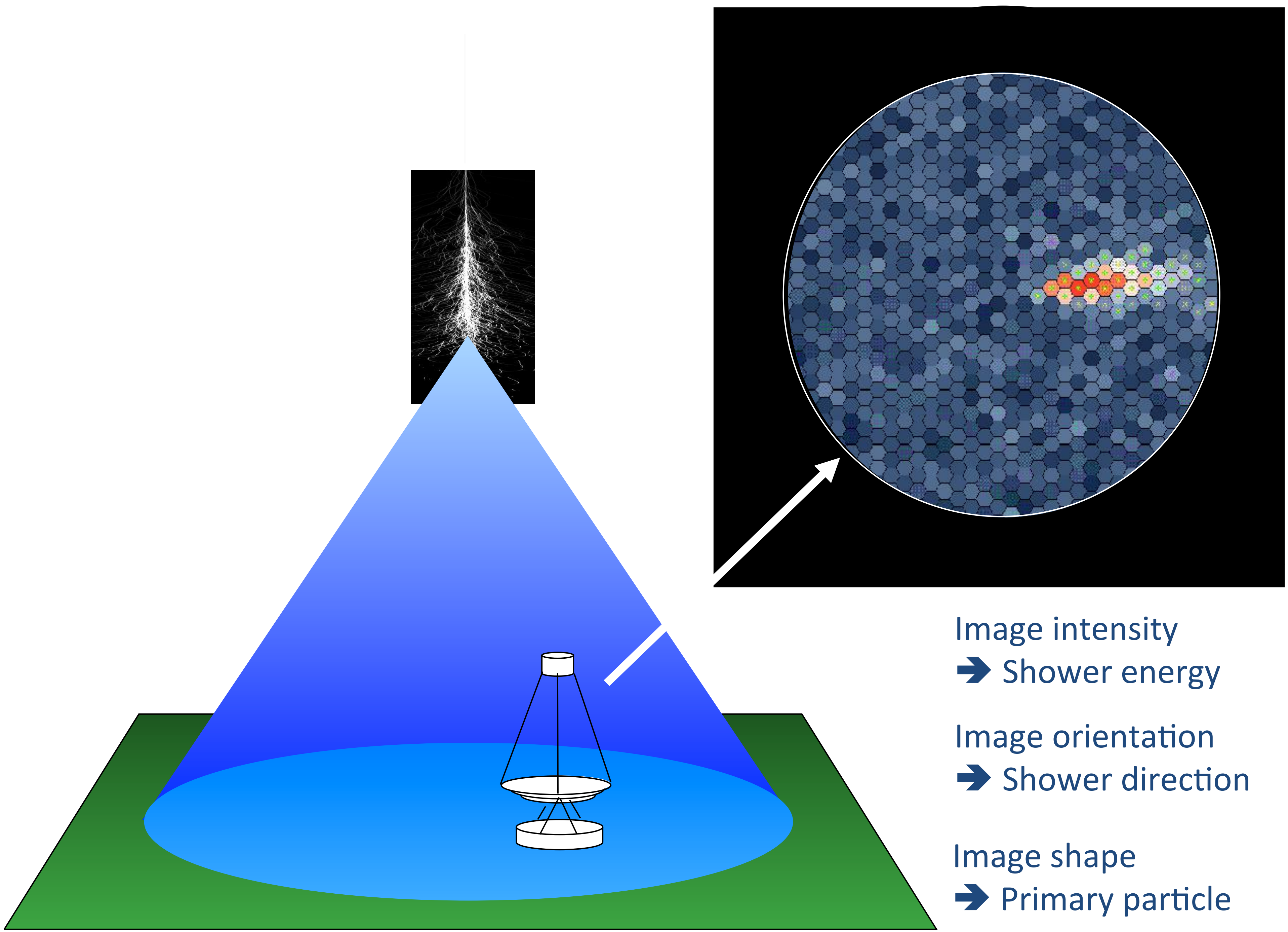
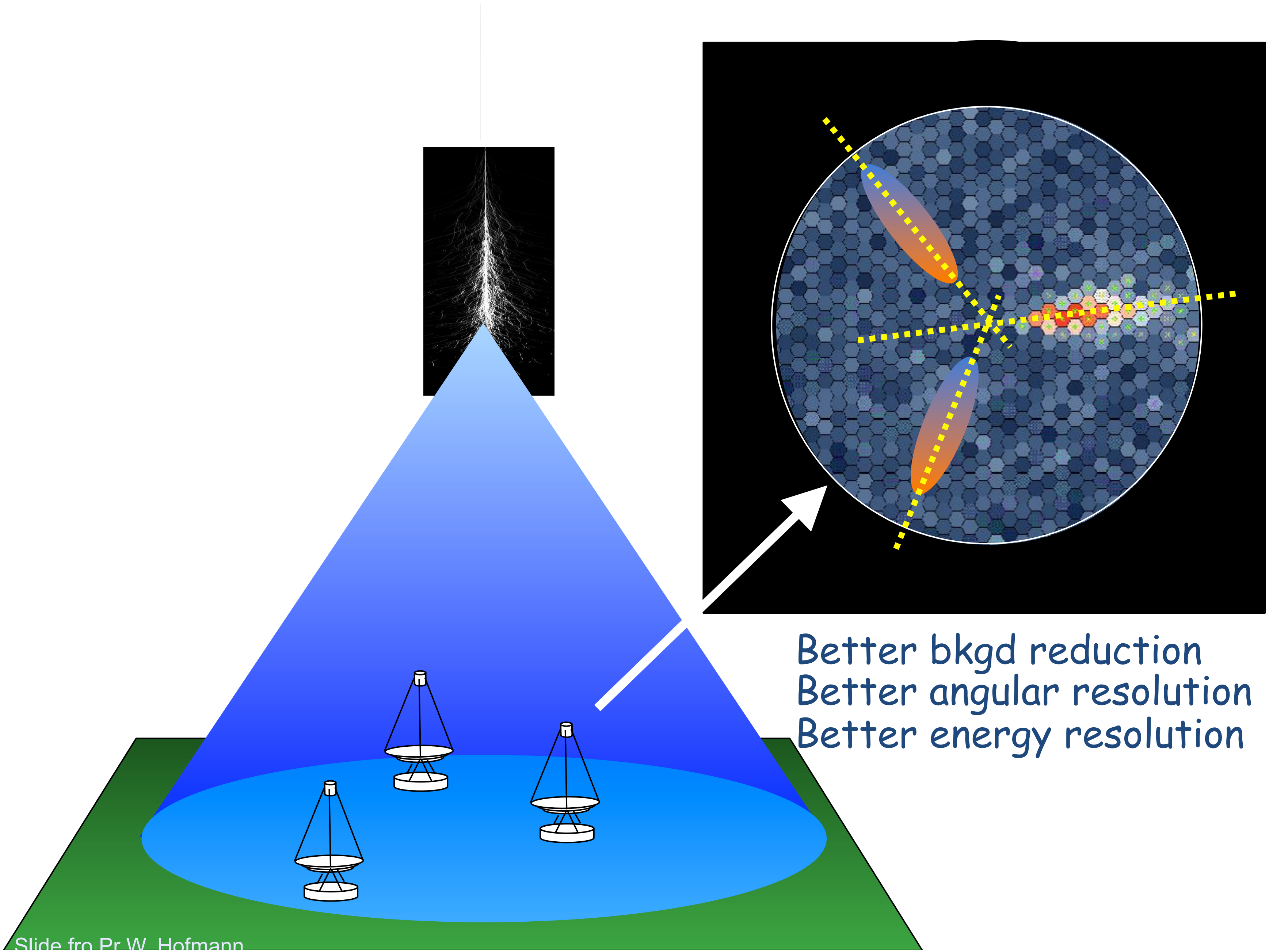
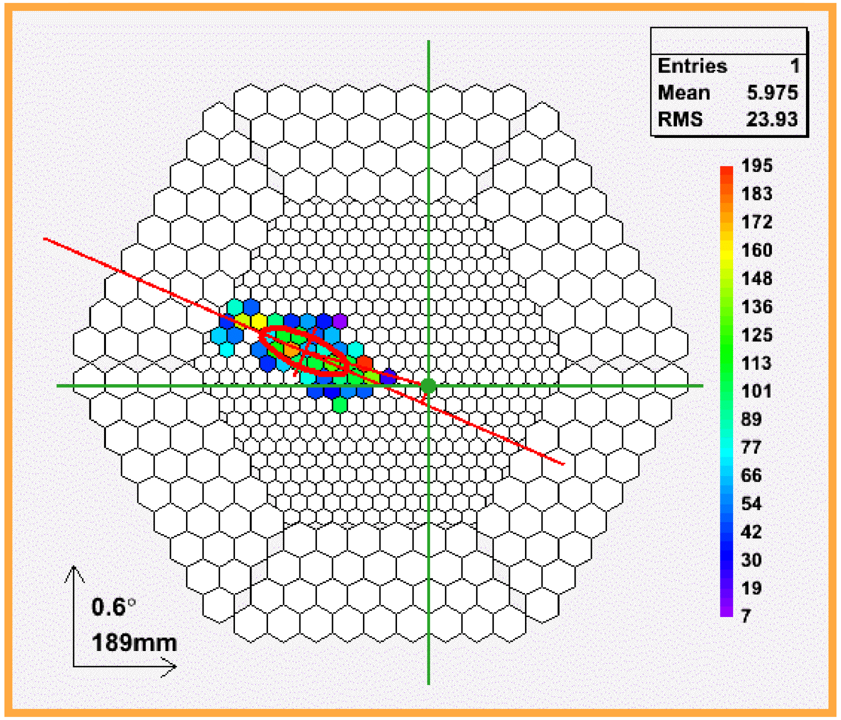


Image intensity
➔ Shower energy
Image orientation
➔ Shower direction
Image shape
➔ Primary particle

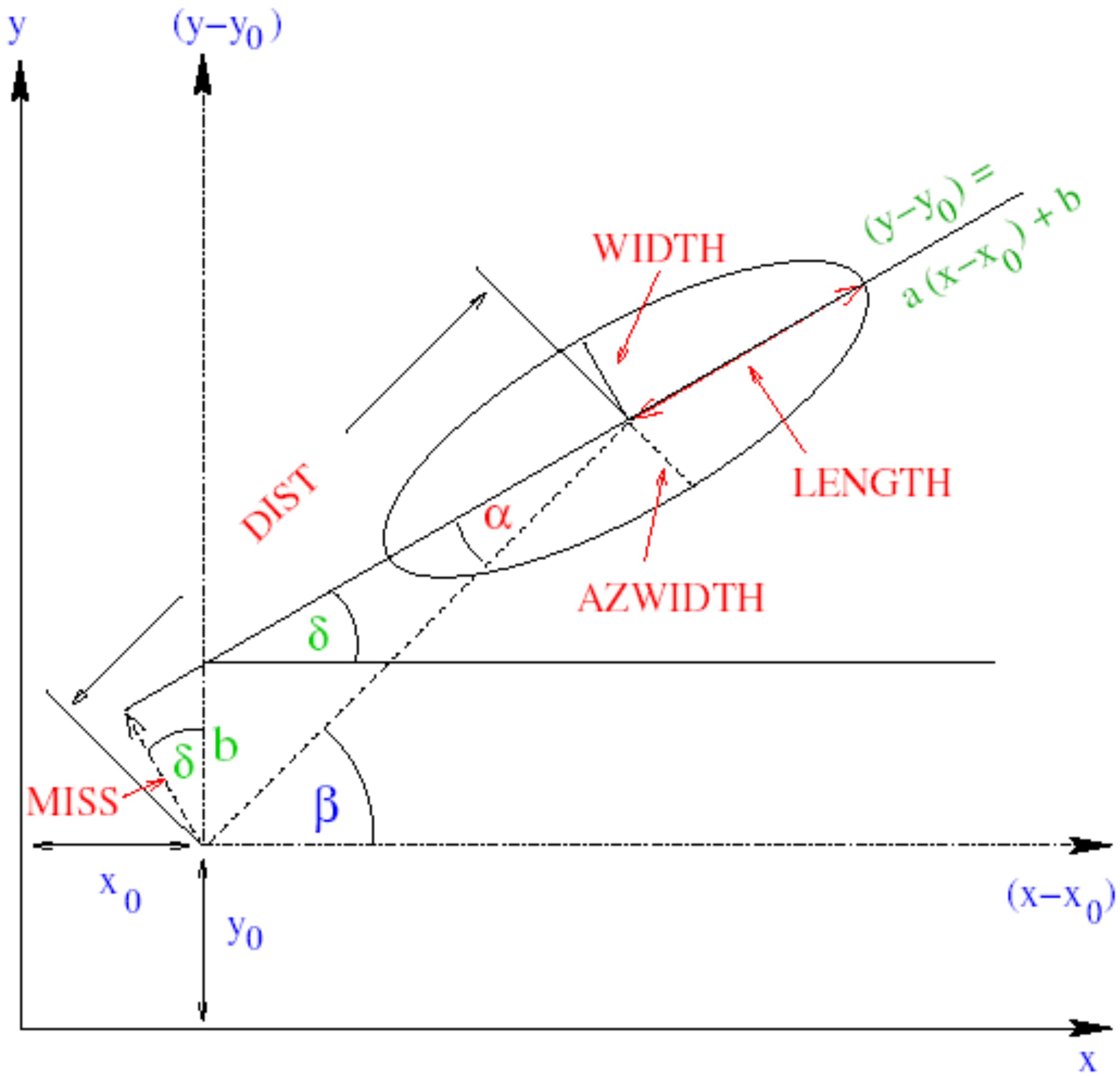

Better bkgd reduction
Better angular resolution
Better energy resolution
Slide fro Pr W. Hofmann

IACT image reconstruction

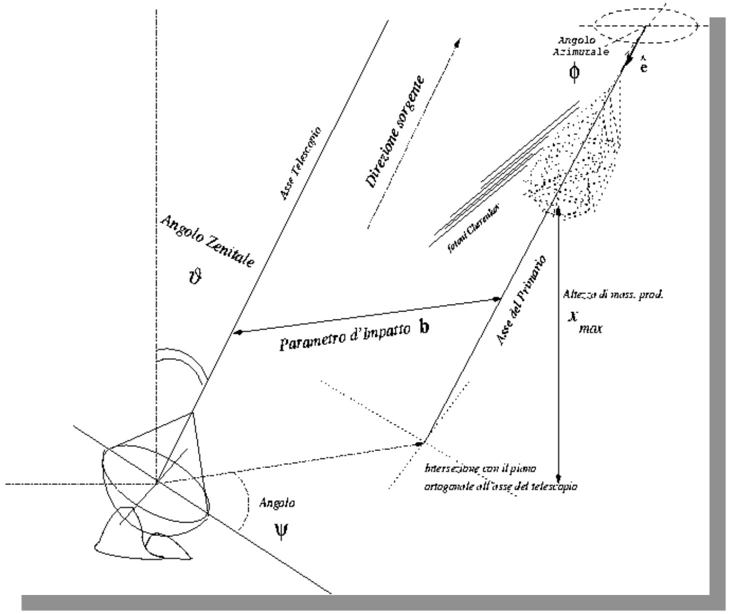
- Primary γ parameters reconstruction by particle shower image analysis
- Different primary particles give different image shapes
- Possible γ-hadron separation
- Reconstructed parameters of primary γ: energy, direction, arrival time
- Signal estimation
- Spectrum calculation
- Lightcurve



Hillas parameters

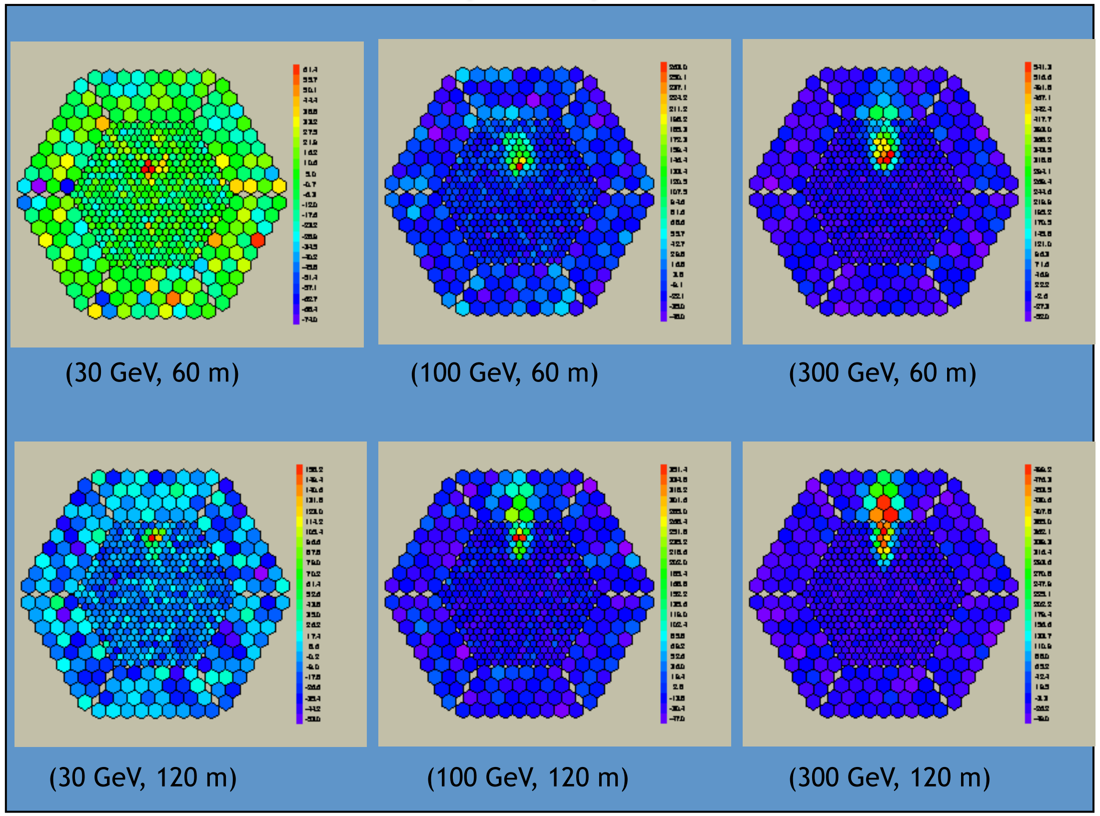


Imaging Atmospheric Cherenkov Telescopes

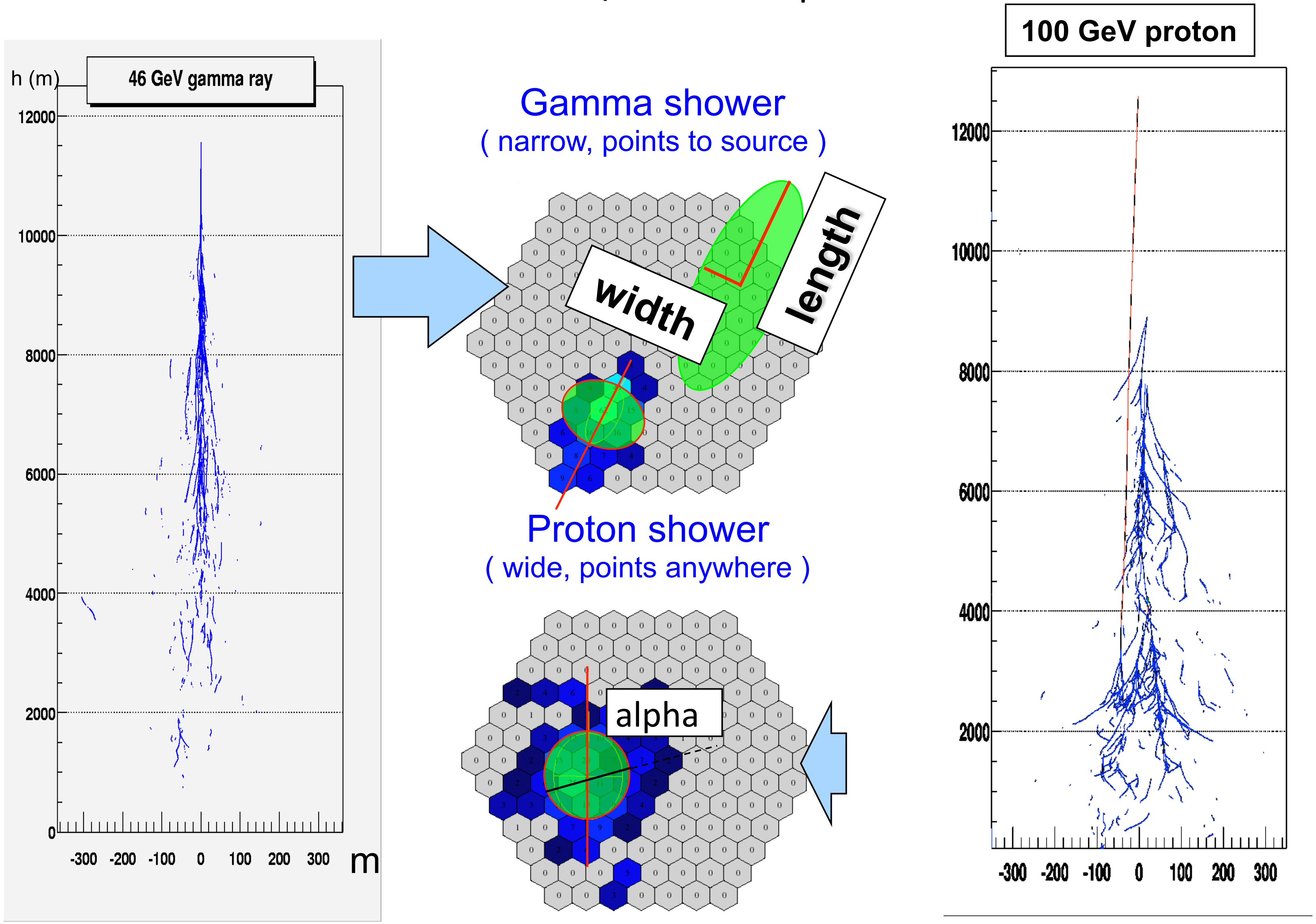


Geometric relations between a shower and the Cherenkov Telescope optics

Typical γ shower images simulated with different energy and different impact parameter

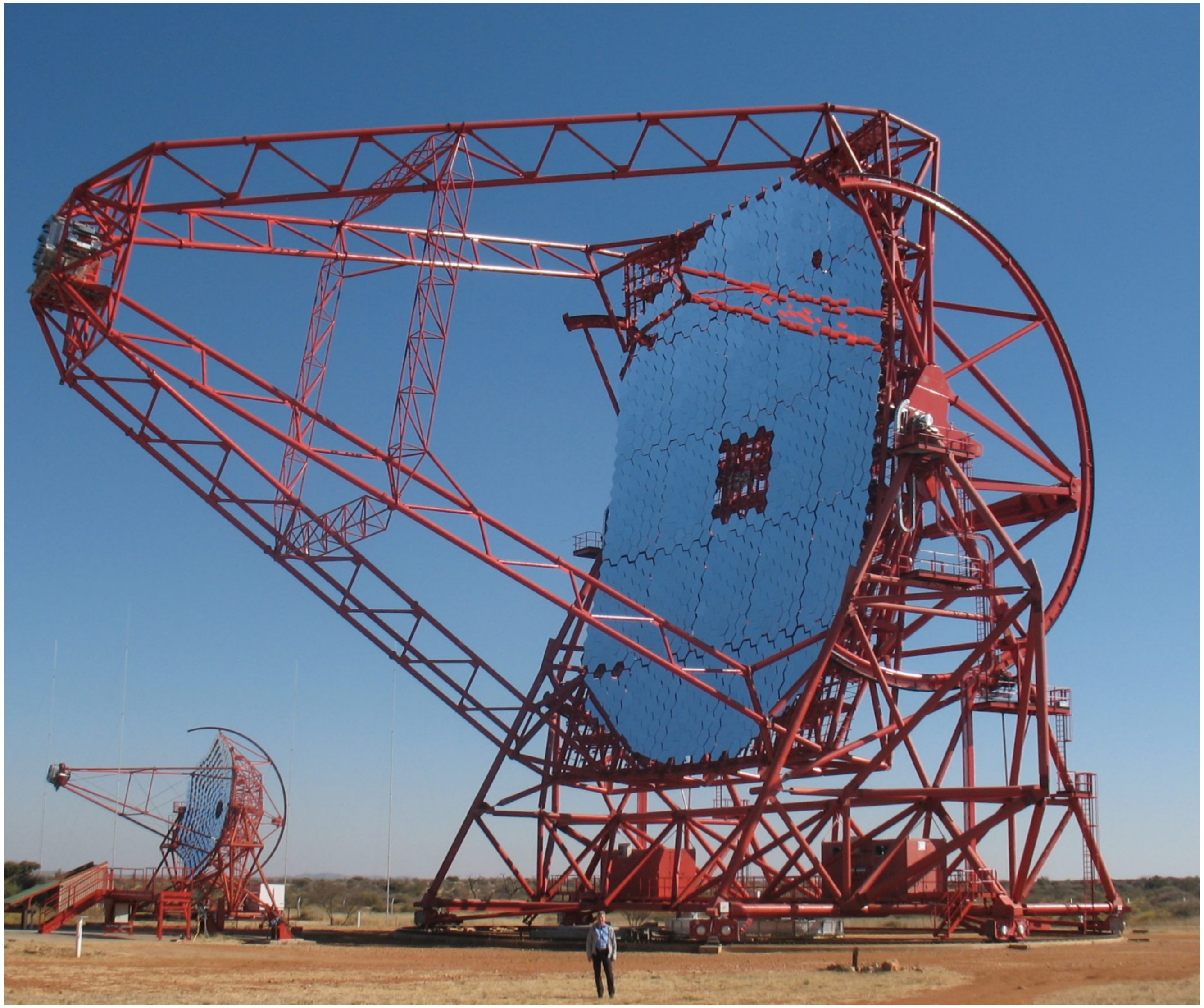


Gamma / hadron separation



HESS

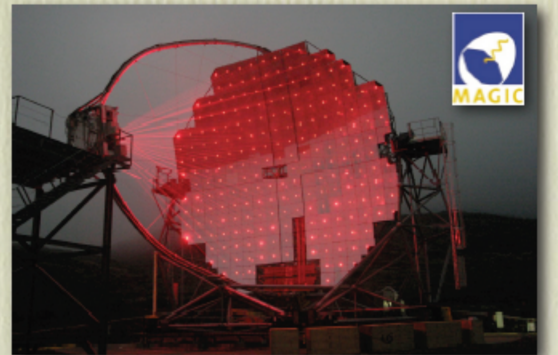
HESS-II



The MAGIC Telescope

Major Atmospheric Gamma Imaging Cherenkov telescope

Located at the Roque de los Muchachos on La Palma, Canary Islands (Spain) at ~2200 m *asl*



Largest imaging Cherenkov telescope for γ-ray astronomy

Designed for:

- Low energy threshold $E_{th} \approx 50$ GeV
- Fast repositioning in < 30 s

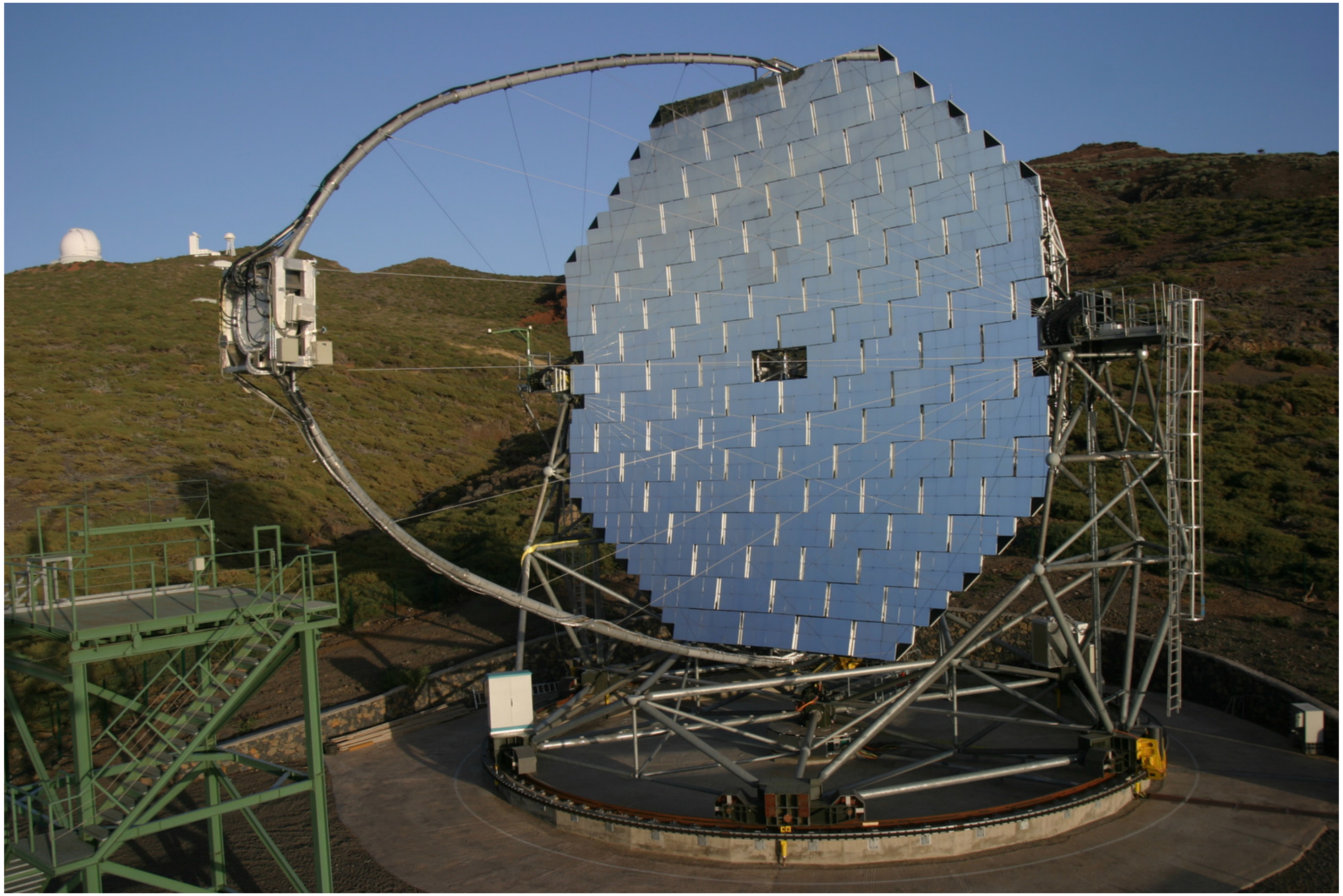
Construction 2001-2003

Inauguration 10/10/2003

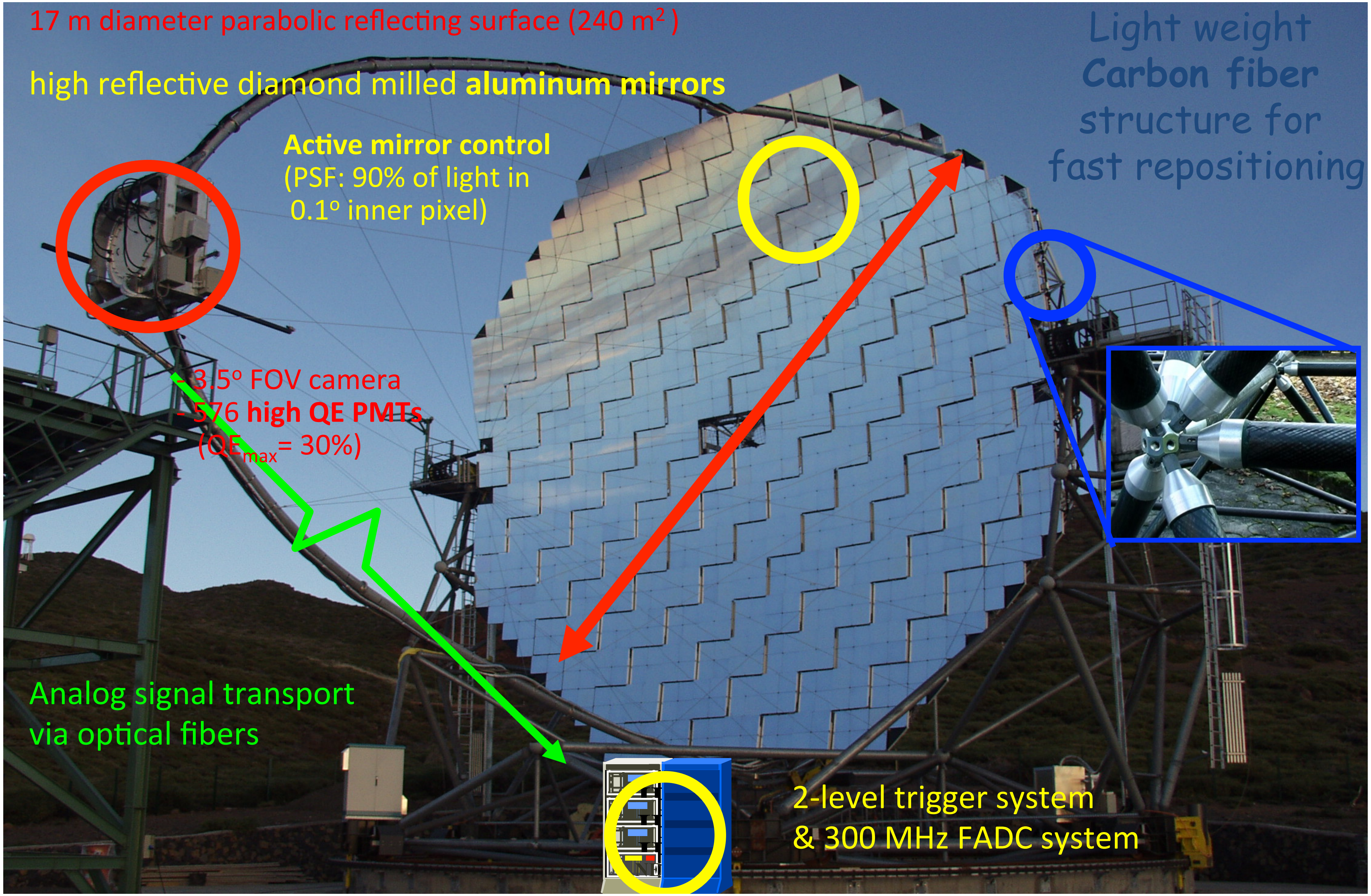
Commissioning 2004

Cycle I 2005-2006

MAGIC

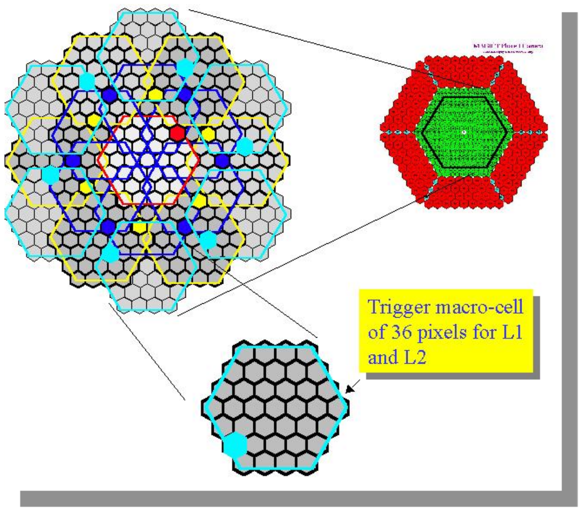


Key technological elements for MAGIC



The trigger architecture

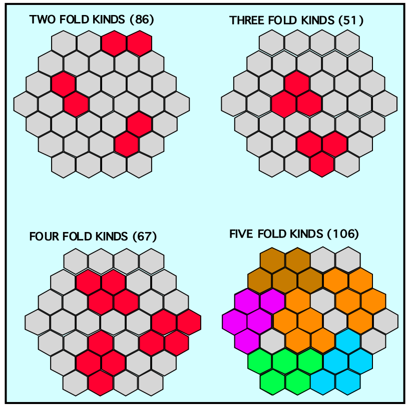
The trigger is split into two stages: level 1 (L1) and level 2 (L2). The L1 is a fast coincidence device (2-5 ns) with simple patterns (n-next-neighbor logic) while L2 is slower (50-150 ns) but can do a more sophisticated patter recognition.



Discriminators
L0

Choose the **number of photoelectrons** per pixel you want to use in the trigger

Level 1
L1



Make a **tight time coincidence** on simple pattern of compact images and **enable L2**

Level 2
L2

Make an **advanced pattern recognition** to use topological constraint:

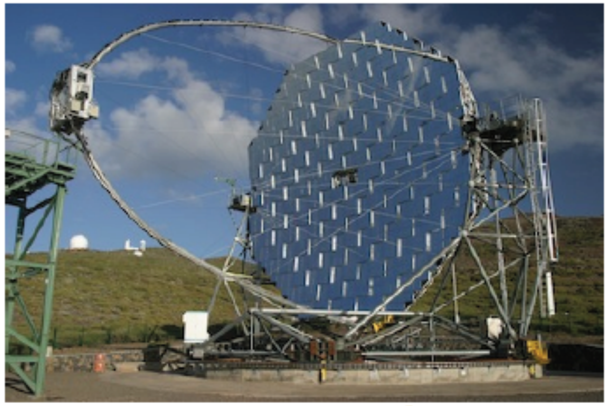
•pixel counting in a given region of the detector
•mask hot spots like bright stars
•rough center of gravity of the image…etc…..

To FADC

MAGIC telescopes

MAGIC – II

+ The telescope(s)



Design

- Solar power-plant design
- 17-m diameter
- F/D=1
- ~500kg camera
- Signal digitization off-telescope
- 64 tons total moving weight
- Fast-movement (GRBs): 20 sec ptp

Performance

- Energy threshold ~50 GeV (~ 25 GeV with a special trigger)
- FOV 3.5deg
- Energy Resolution ~16% (E>300 GeV)
- Angular Resolution ~0.07deg (E>300 GeV)
- Sensitivity (5 σ in 50 hours) ~0.8% Crab Nebula flux (> 250 GeV)

Colin, ICRC 2009

Several "firsts"

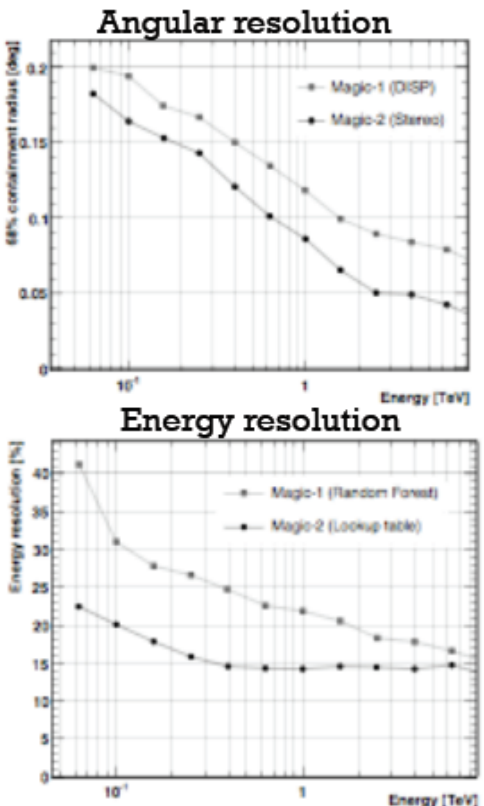
- Worldwide largest mirror dish.
- Lightweight CFRP tubes for structure
- Diamond milled light weight all-aluminum sandwich mirrors
- Active mirror control
- Low gain hemispherical PMTs with diffuse lacquer coating
- Transmission over 160 m by optical
- 2 GHz FADCs

MD, ICAPTT 2008

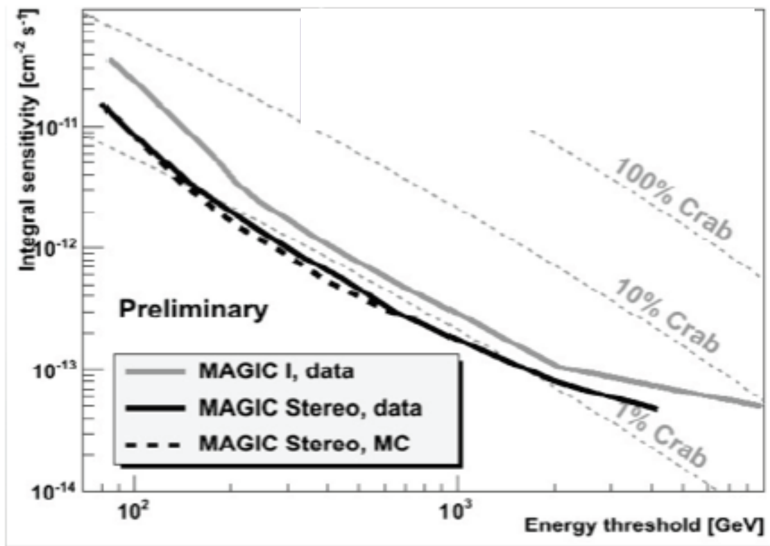
MAGIC – II

+ Improvements

- Extended sources and morphology now possible
- **Sensitivity improved of 100%** over most of the energy range
- Better performance specially at low energy (<100 GeV)



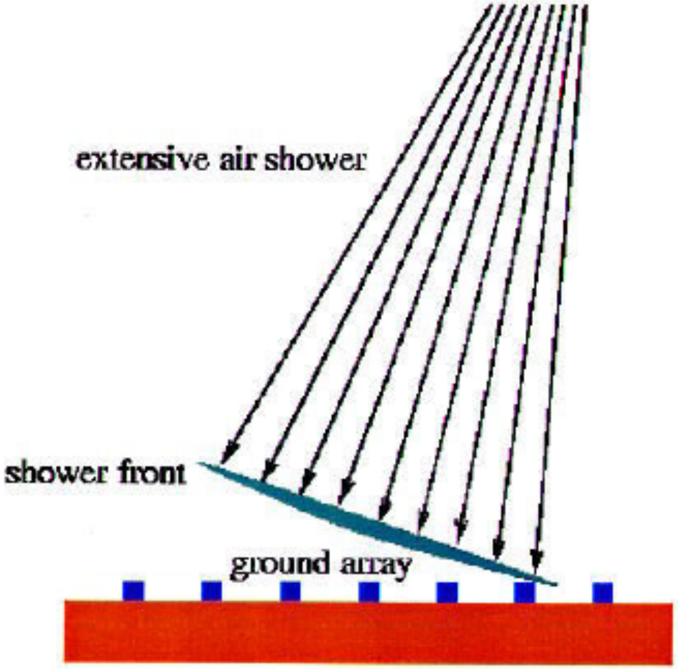
Colin+2009



VERITAS

TeV detectors

Air Shower Arrays



Reconstruction of the γ direction with the particles arrival times

Large field of view: ~ π sr

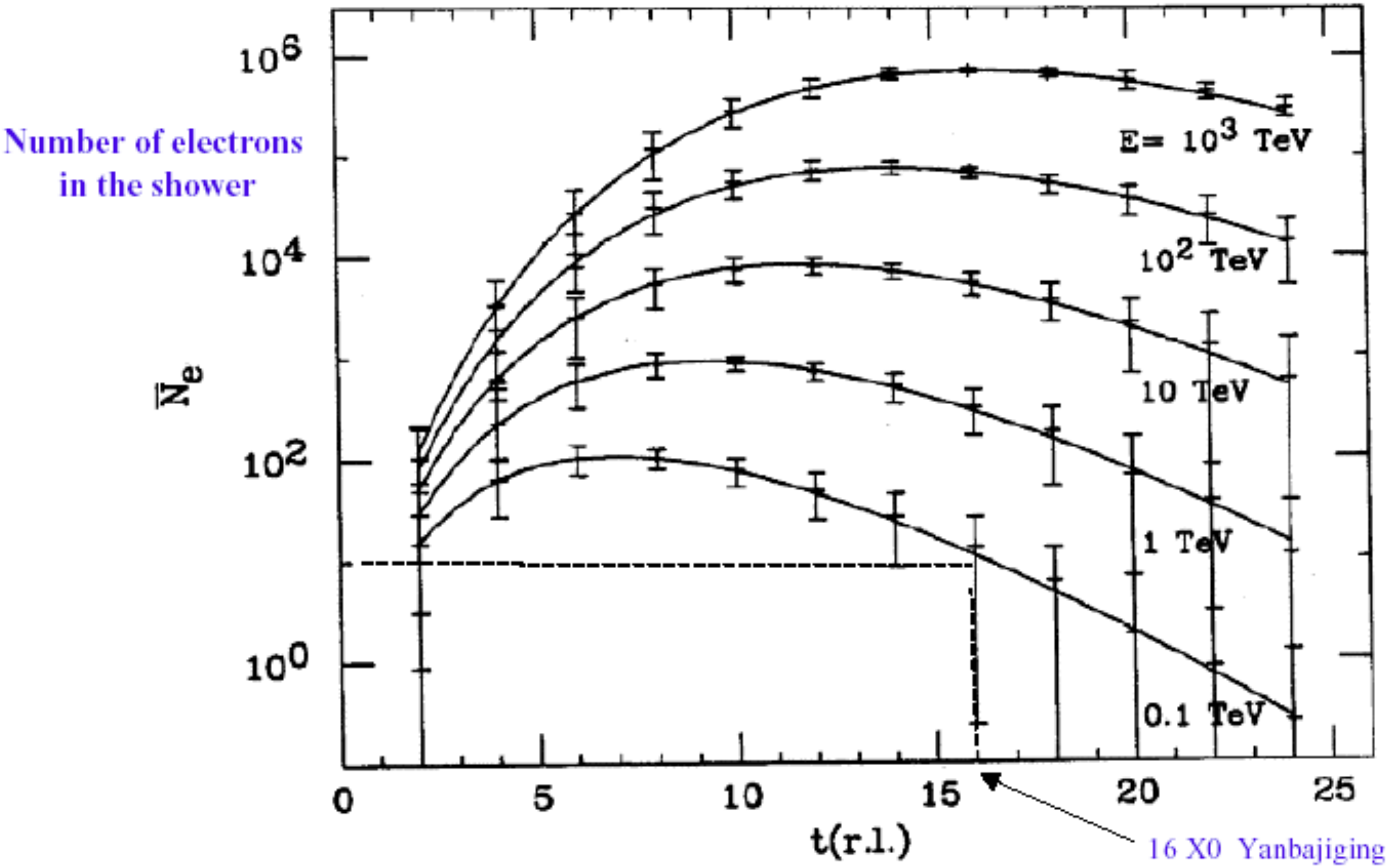
Duty cycle ~ 100%

Gamma-hadrons discrimination:

μ-poor showers

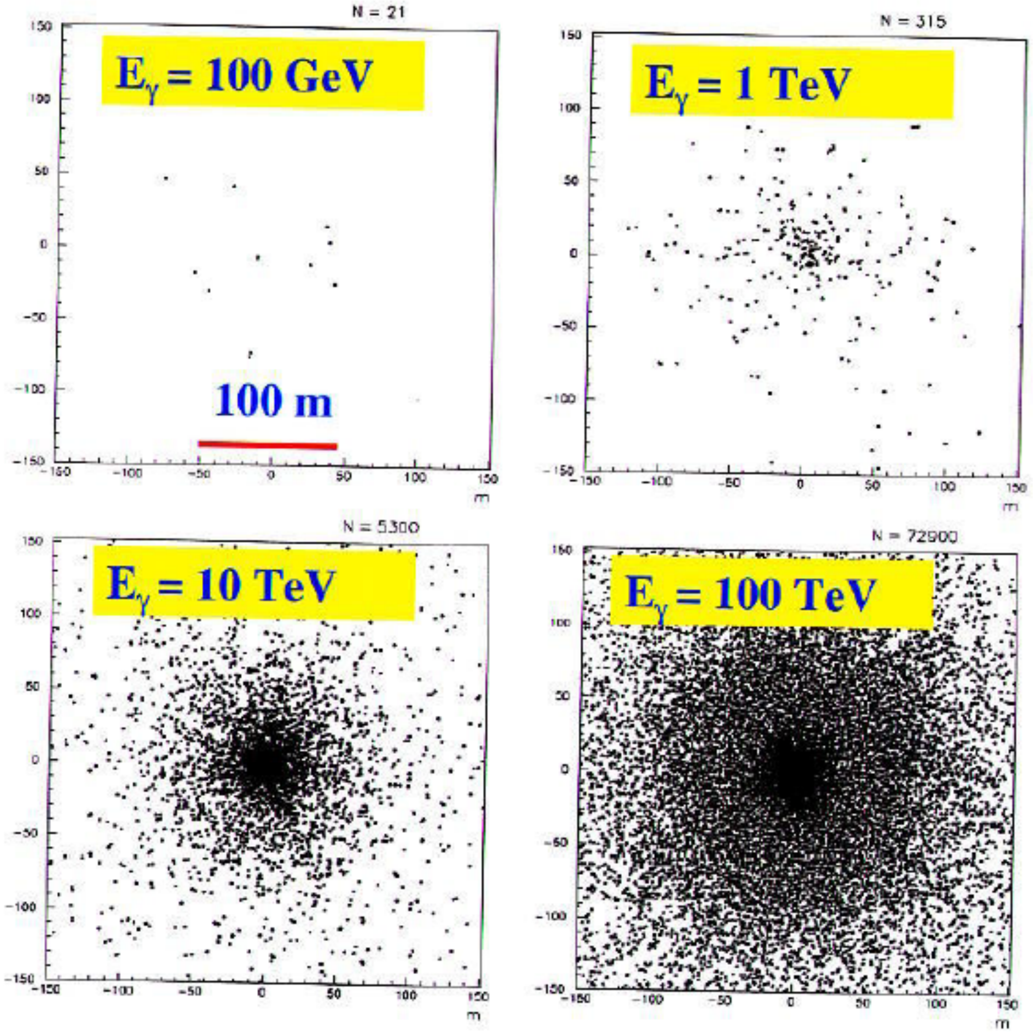
TeV detectors

Longitudinal development of the electron component of photon initiated shower
(with electron threshold energy of 5 MeV and fluctuations superimposed)

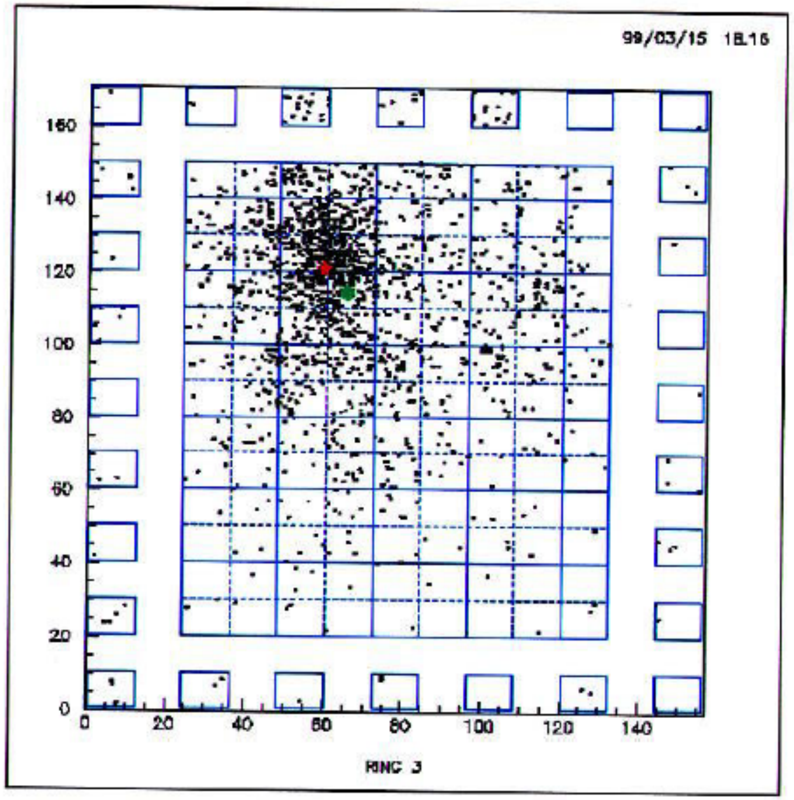


TeV detectors

EAS
at
4300 m



TeV detectors



Montecarlo simulation of a 10 TeV air shower

EAS technique

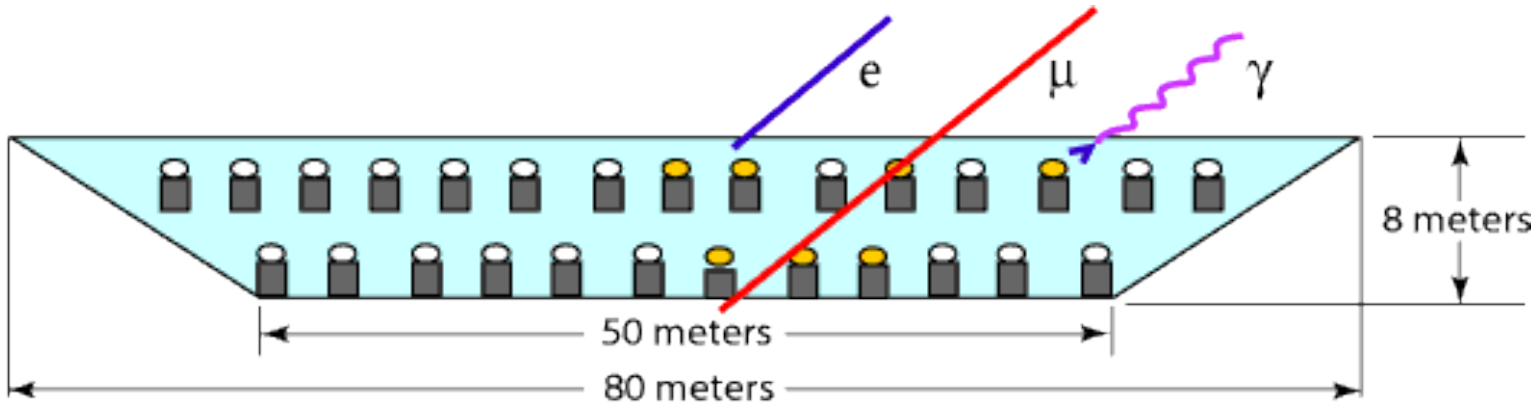
Charged particles produce Cherenkov photons in water

~1400 times more Cherenkov photons than in air per unit length track of charged particle

Cherenkov cone in water ~41° (in air: less than 1°)

Uniform sky view with an array of PMTs

Direction reconstruction through PMTs signal times



Wide Angle Telescopes

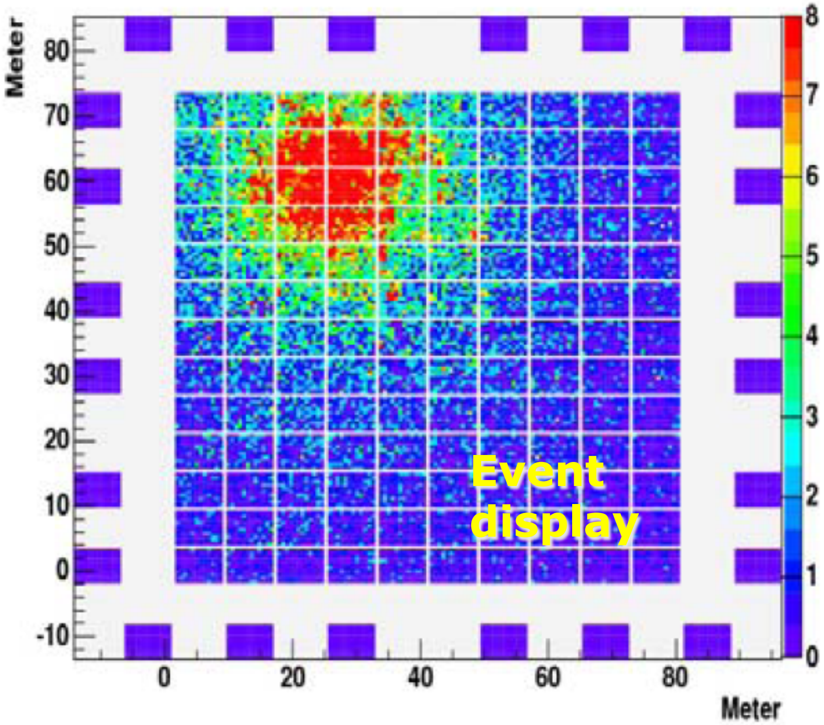
Tibet AS-γ– Air Shower Array
ARGO – Carpet array with RPC
MILAGRO – Water Cherenkov

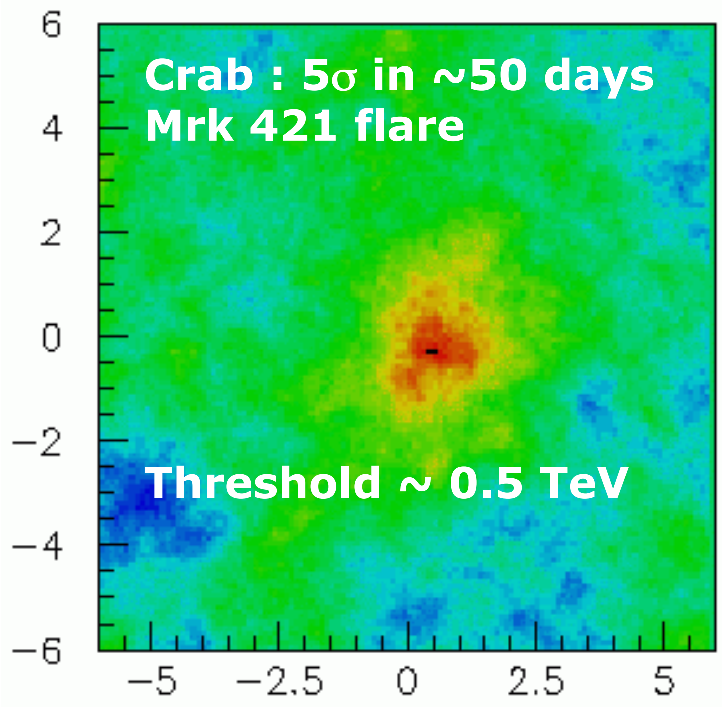
Advantage: Wide Angle 0.5π~1π
Non-bias observation

Cons: Moderate sensitivity
~5σ/yr$^{1/2}$ for Crab

ARGO-YBJ (RPC):

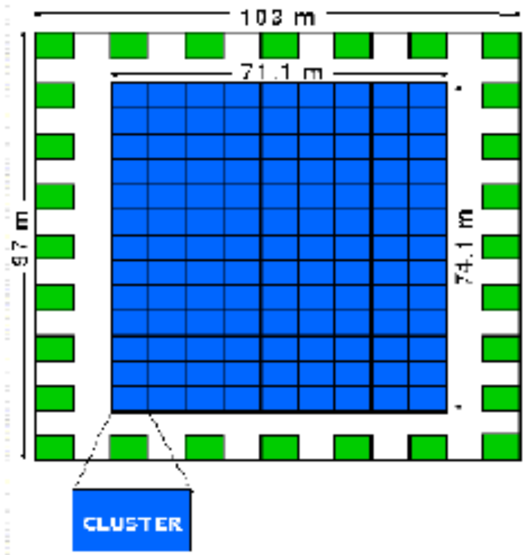

ARGO 实验厅


Event display
Meter
Meter
0
20
40
60
80
-10
0
10
20
30
40
50
60
70
80
0
1
2
3
4
5
6
7
8


Crab : 5σ in ~50 days
Mrk 421 flare
Threshold ~ 0.5 TeV
−5
−2.5
0
2.5
5
−6
−4
−2
0
2
4
6

ARGO

Area 5.200 m^2 (full coverage)
(10.000 m^2 with guard ring)
Field of view ~ 1 sr
E = 50 GeV - 50 TeV
Location: Tibet 4300m alt.



17400 Pads 56 by 60 cm^2 each of Resistive Plate Chamber (RPC).
Each pad subdivided in pick-up strips 6 cm wide for the space pattern inside the pad.
The CLUSTER is made of 12 RPCs Pads

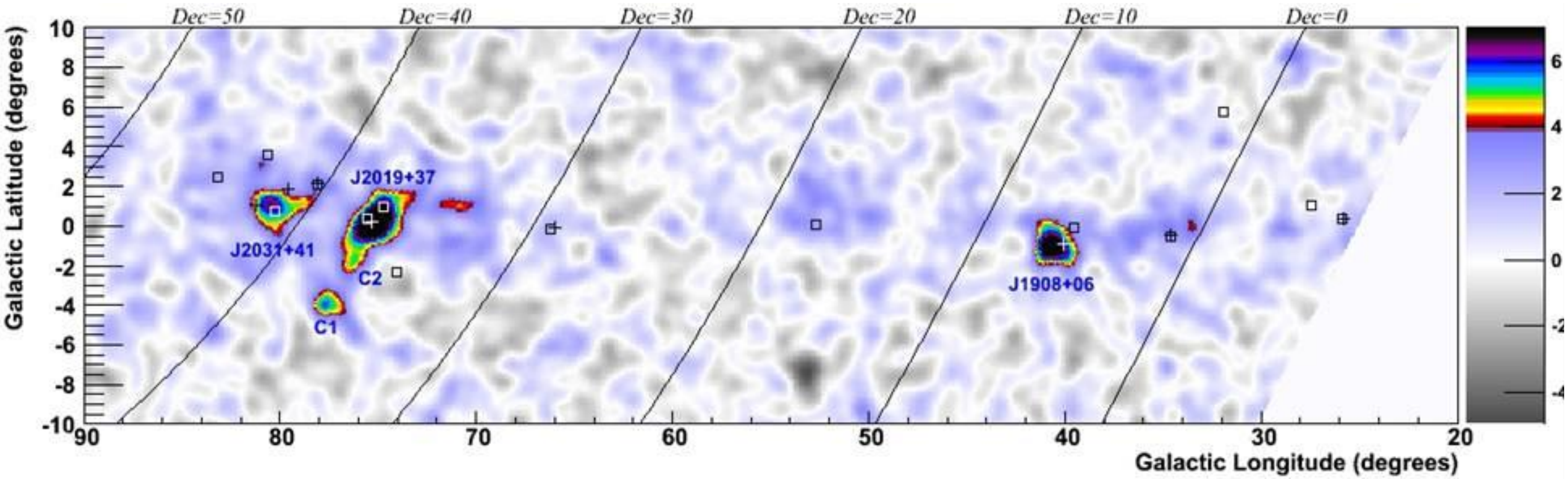
TIBET air shower array

Our air shower array consists of 697 scintillation counters which are placed at a lattice with 7.5 m spacing and 36 scintillation counters which are placed at a lattice with 15 m spacing. Each counter has a plate of plastic scintillator, 0.5 m^2 in area and 3 cm in thickness, equipped with a 2-inch-in-diameter photomultiplier tube (PMT). The time and charge information of each PMT hit by an air shower event is recorded to determine its direction and energy. The detection threshold energy is approximately 3 TeV, which is the lowest one achieved by an air shower array in the world.

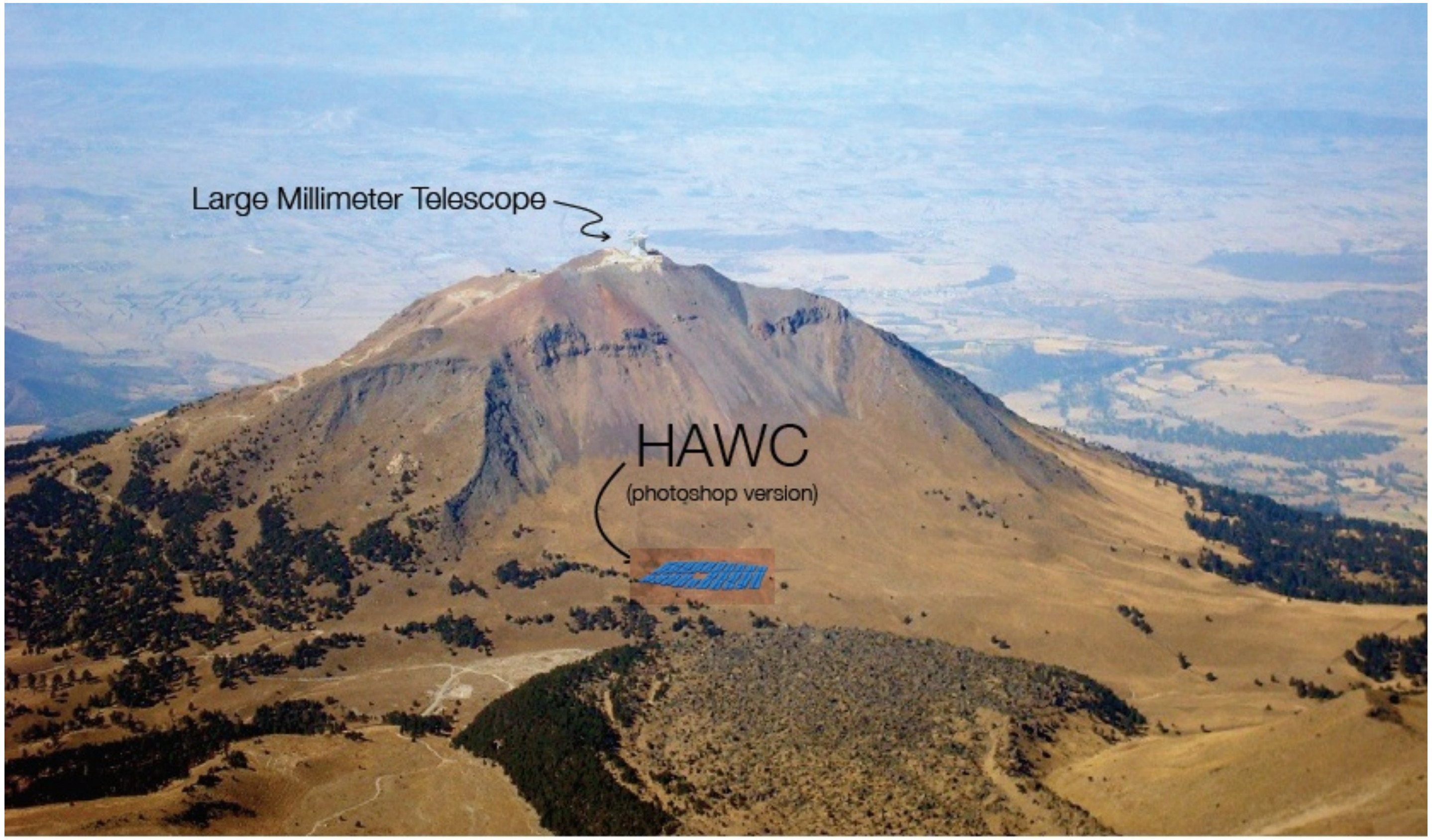
MILAGRO

Cherenkov in water, Arizona

Crab:
~5σ in 100 days
Median energy ~20 TeV



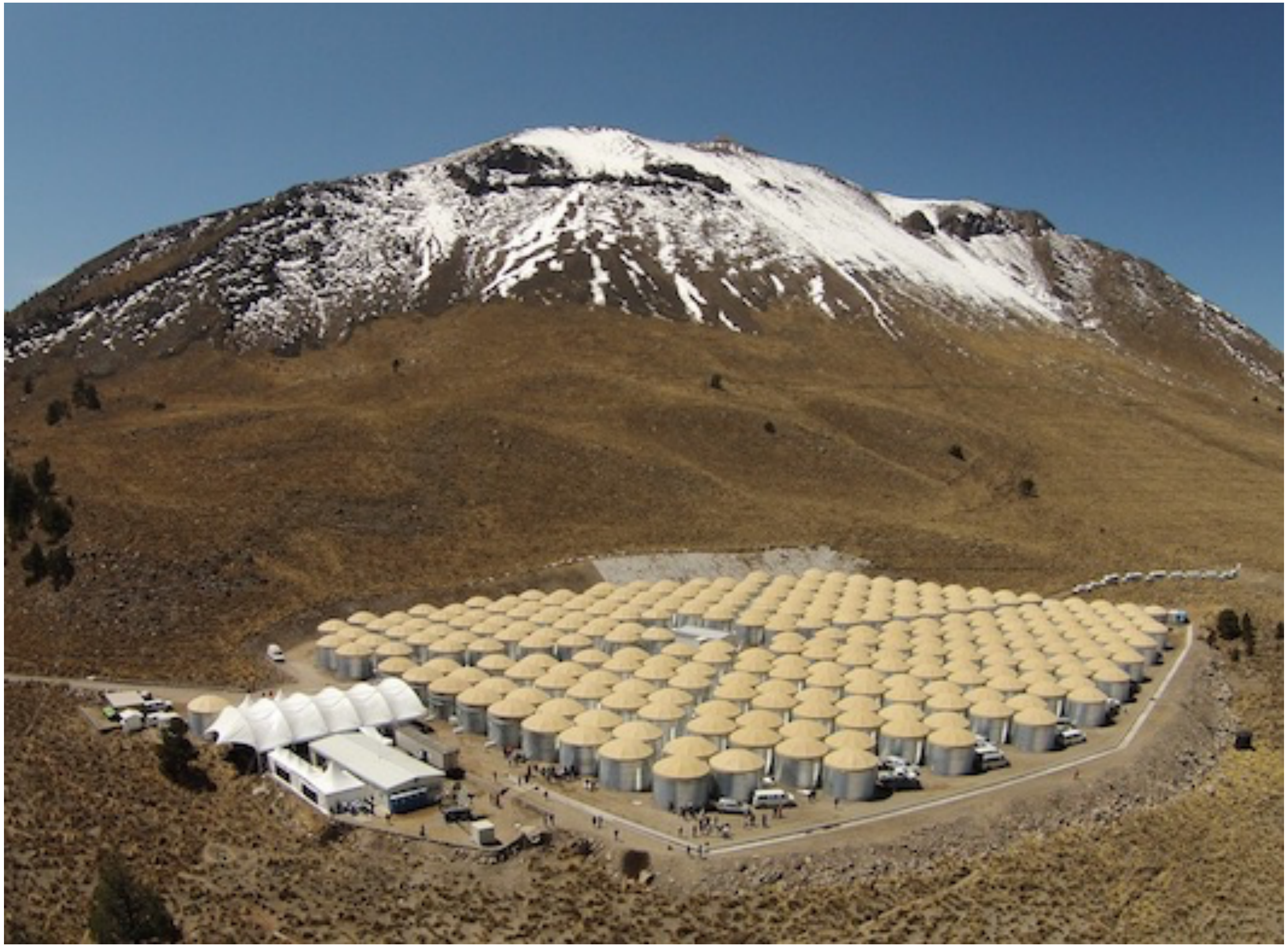
HAWC



HAWC

Pico de Orizaba, altitude 4100 m, latitude 18º 59' N
Two hours drive from Puebla, four from México City
Site of Large Millimeter Telescope (existing infrastructure)

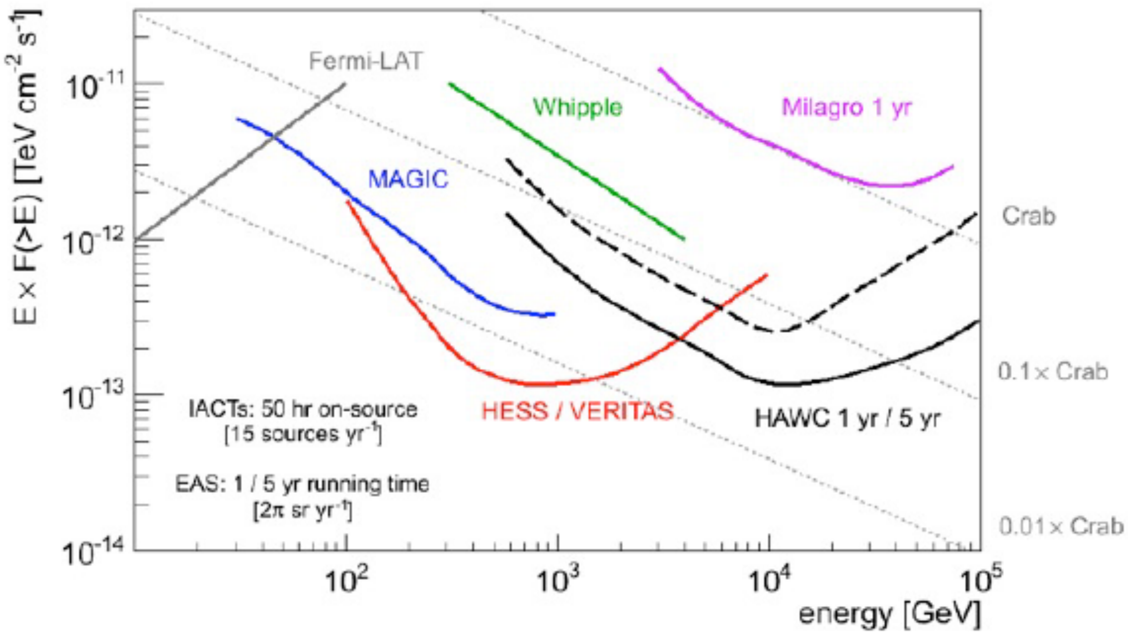
HAWC



HAWC

Sensitivity to Point Sources

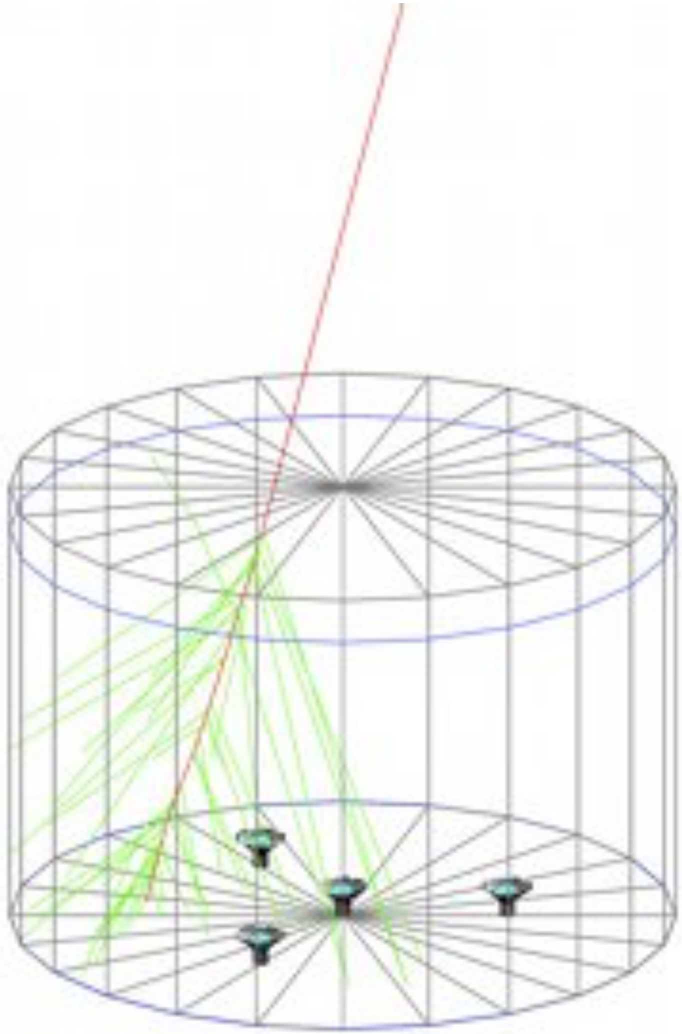
- Long integration times lead to excellent sensitivity at highest energies (> few TeV)



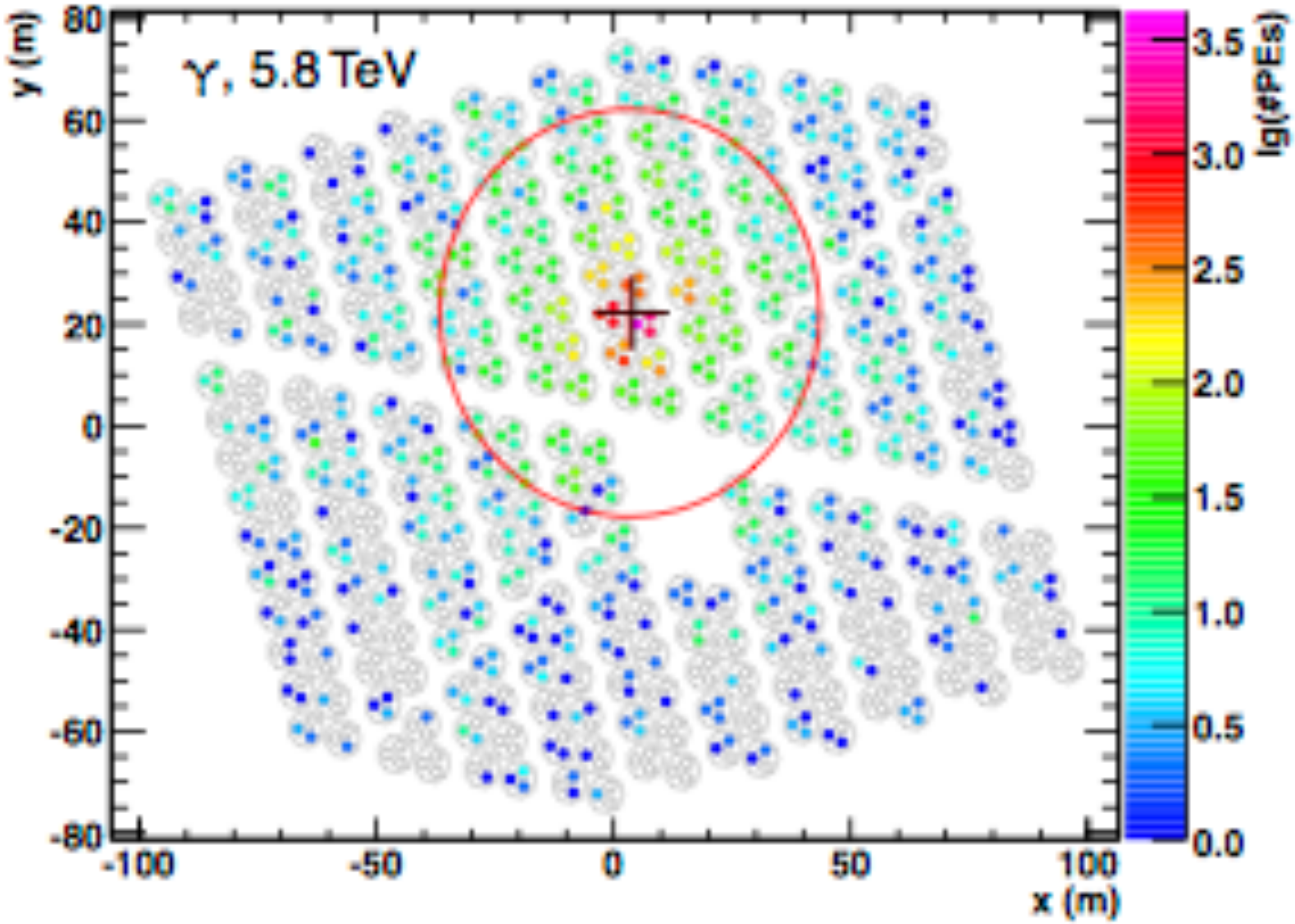
- 5σ sensitivity to:
  10 Crab in 3 min
  1 Crab in 5 hr
  0.1 Crab in ⅓ year

- Around 15x the sensitivity of Milagro

HAWC

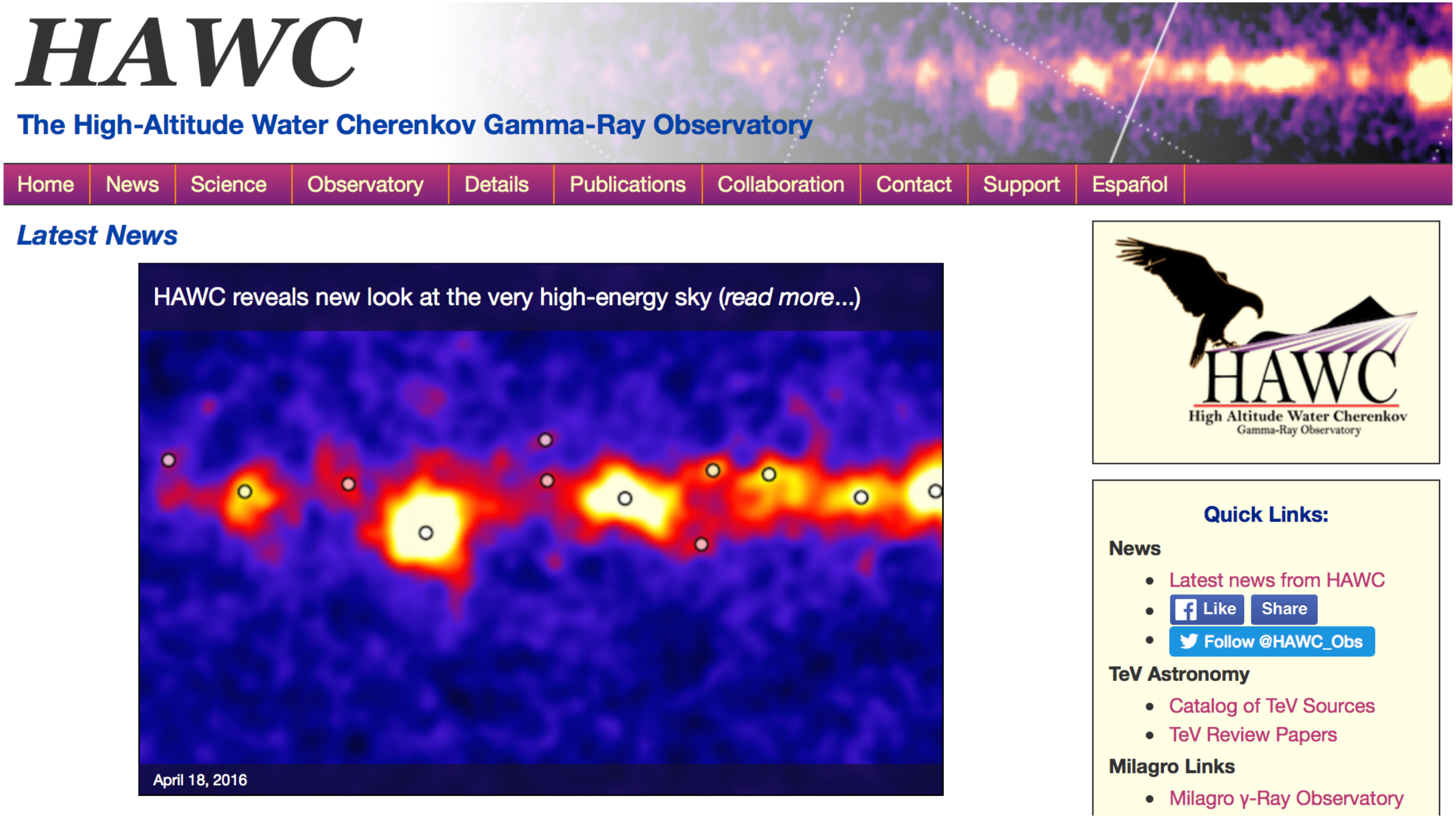


HAWC



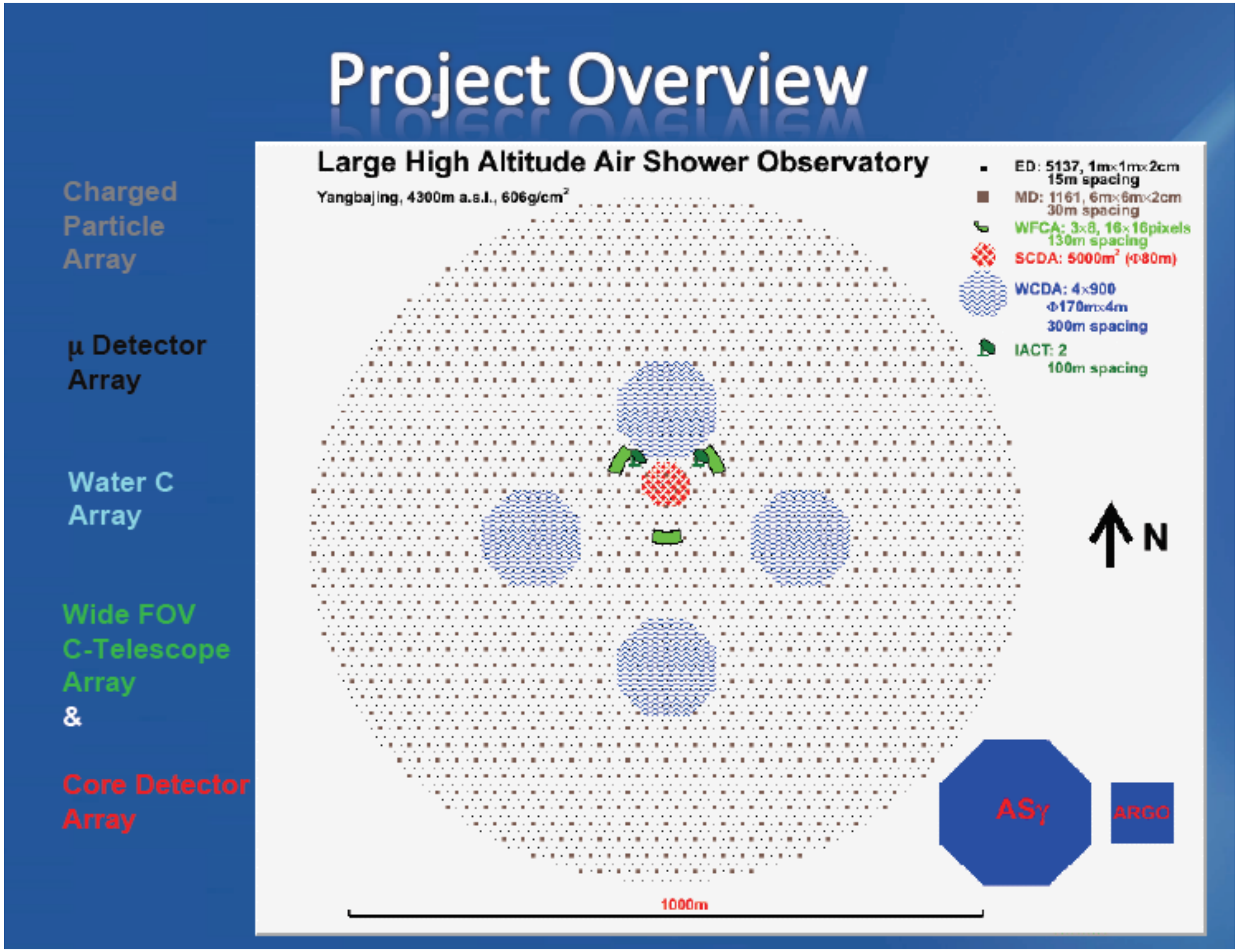
γ, 5.8 TeV
y (m)
80
60
40
20
0
-20
-40
-60
-80
-100
-50
0
50
100
x (m)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
lg(#PEs)

HAWC

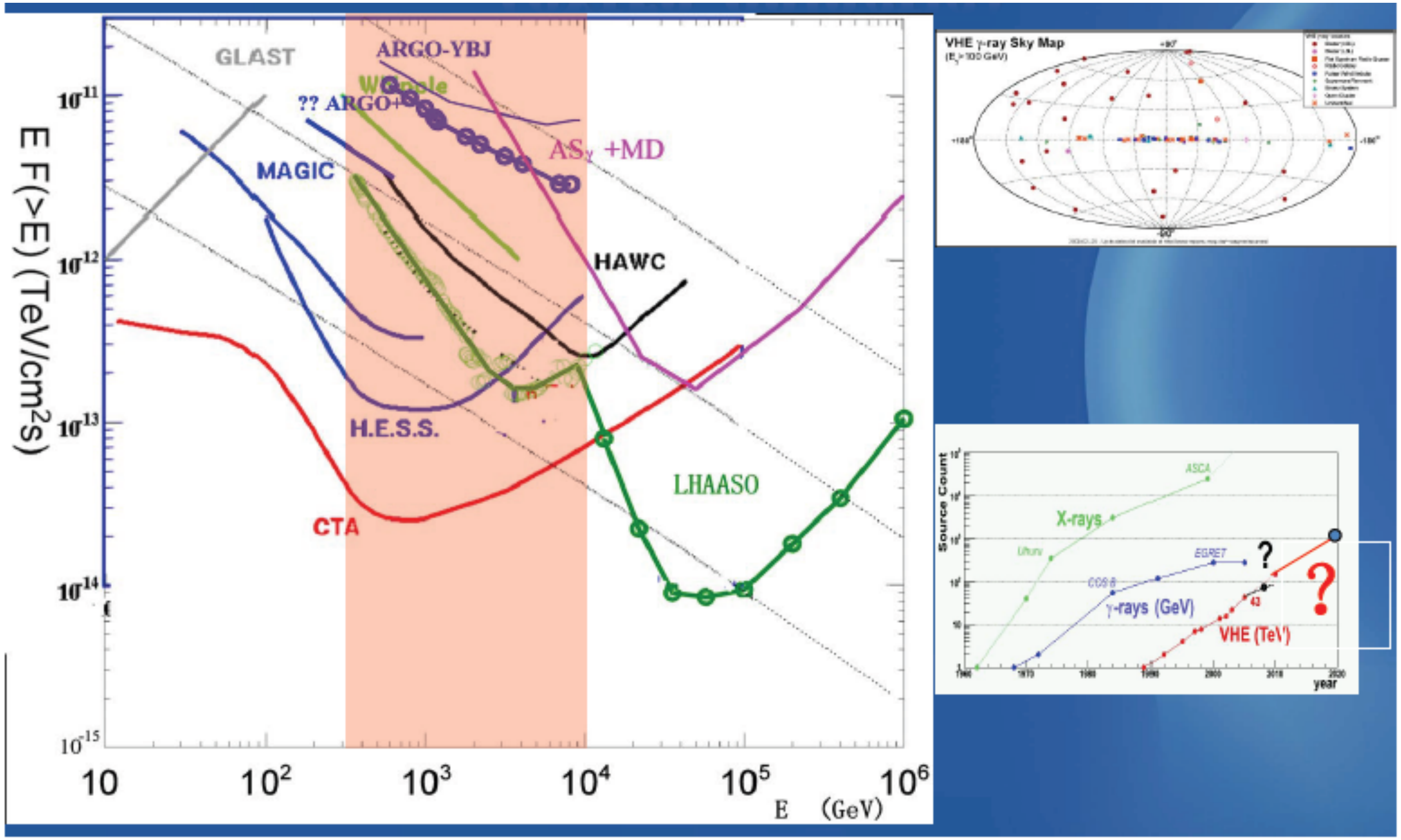


http://www.hawc-observatory.org

LHAASO


Project Overview
Charged Particle Array
μ Detector Array
Water C Array
Wide FOV C-Telescope Array
&
Core Detector Array
Large High Altitude Air Shower Observatory
Yangbajing, 4300m a.s.l., 606g/cm²
ED: 5137, 1m×1m×2cm
15m spacing
MD: 1161, 6m×6m×2cm
30m spacing
WFCA: 3x8, 16×16pixels
130m spacing
SCDA: 5000m² (Φ80m)
WCDA: 4×900
Φ170m×4m
300m spacing
IACT: 2
100m spacing
N
ASγ
ARGO
1000m

LHAASO


E F(>E) (TeV/cm^{2}s)
GLAST
ARGO-YBJ
?? ARGO+
Whipple
MAGIC
ASγ +MD
HAWC
H.E.S.S.
CTA
LHAASO
E (GeV)
10
10^2
10^3
10^4
10^5
10^6
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
VHE γ-ray Sky Map
Source Count
X-rays
ASCA
Uhuru
EGRET
COS B
γ-rays (GeV)
VHE (TeV)
?
year

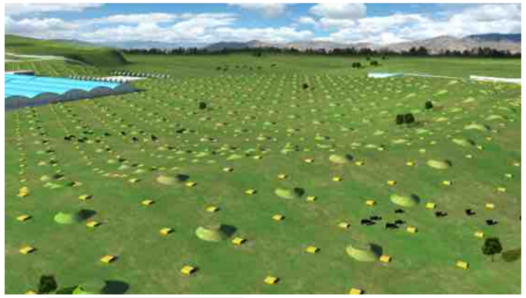
The LHAASO experiment

The Large High Altitude Air Shower Observatory (LHAASO) project is a new generation all-sky instrument to investigate the '*cosmic ray connection*' through a combined study of cosmic rays and gamma-rays in the wide energy range 10^{11} -- 10^{17} eV.

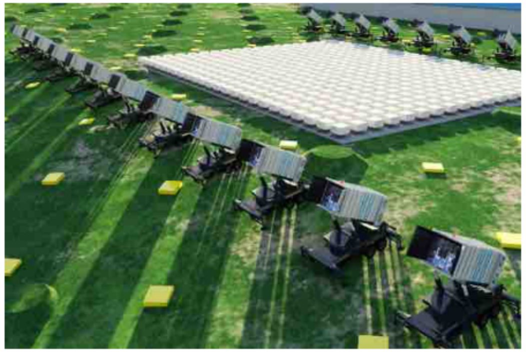
The first phase of LHAASO will consist of the following major components:

- 1 km^2 array (LHAASO-KM2A), including 5635 scintillator detectors, with 15 m spacing, for electromagnetic particle detection.
- An overlapping 1 km^2 array of 1221, 36 m^2 underground water Cherenkov tanks, with 30 m spacing, for muon detection (total sensitive area 40,000 m^2).
- A close-packed, surface water Cherenkov detector facility with a total area of 90,000 m^2 (LHAASO-WCDA), four times that of HAWC.
- 24 wide field-of-view air Cherenkov (and fluorescence) telescopes (LHAASO-WFCTA).
- 452 close-packed burst detectors, located near the centre of the array, for detection of high energy secondary particles in the shower core region (LHAASO-SCDA).

LHAASO main components



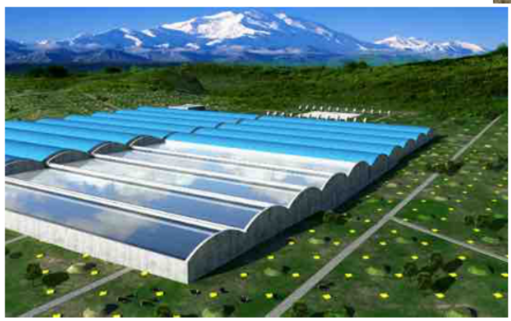
1 KM2A:
5635 EDs
1221 MDs



WFCTA:
24 telescopes
1024 pixels each

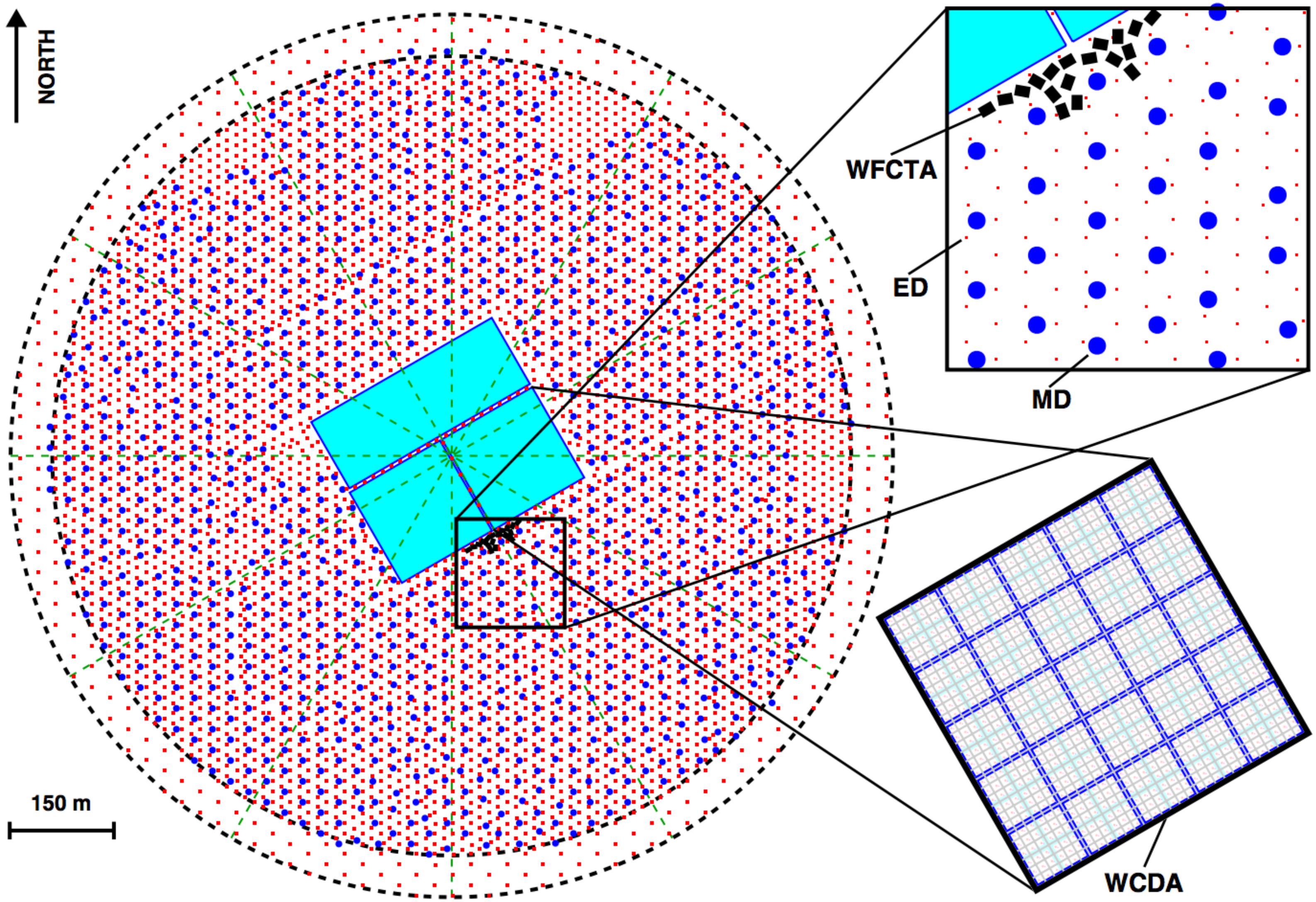
Coverage area: 1.3 km^2

WCDA:
3600 cells
90,000 m^2



SCDA:
452 detectors

LHAASO

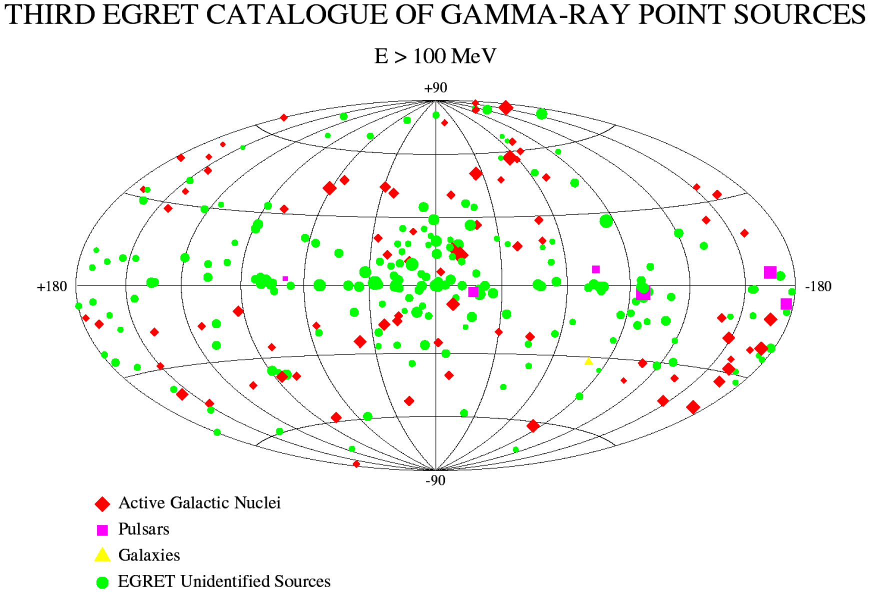


Astrofisica Nucleare e Subnucleare

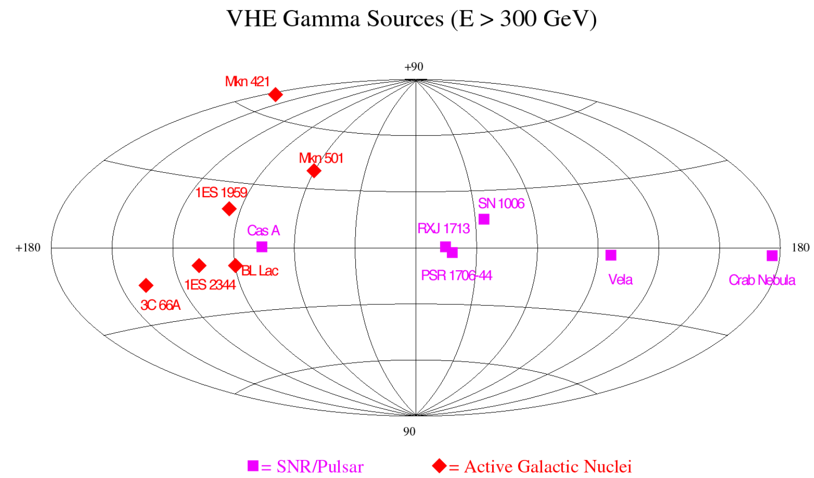
VHE Gamma Astrophysics

The unexplored spectrum gap

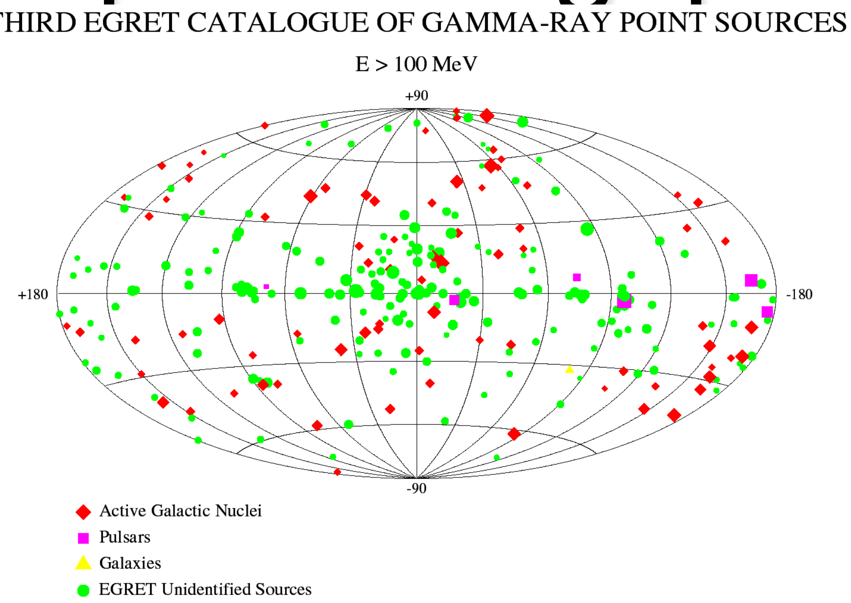
- Satellites give a nice crowded picture of energies up to 10 GeV.



- **Ground based experiments show very few sources with energies > ~300 GeV.**

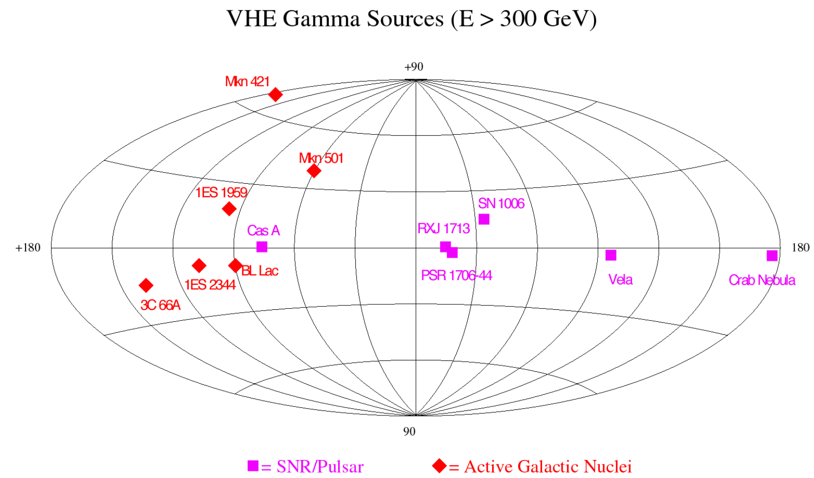


The unexplored spectrum gap



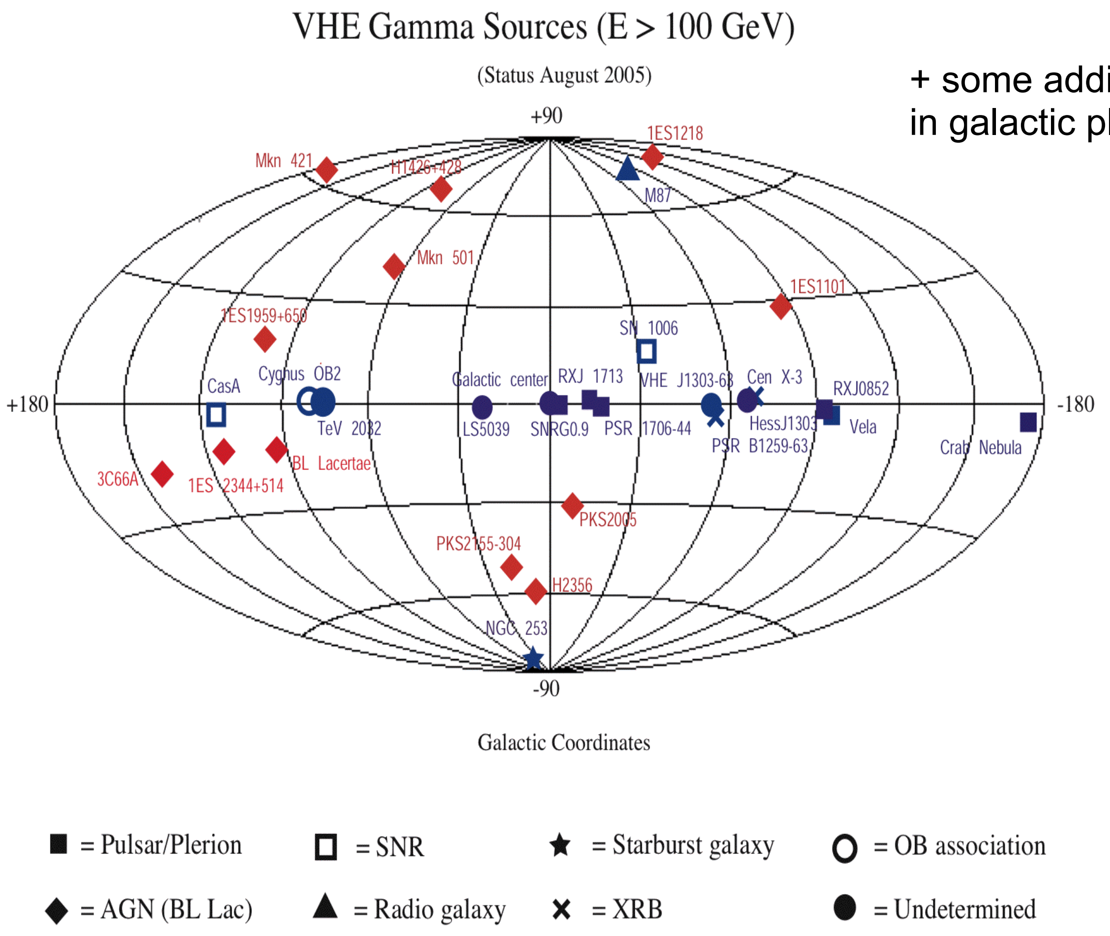
- Satellites give a nice crowded picture of energies up to 10 GeV.

- **Ground based experiments show very few sources with energies > ~300 GeV.**



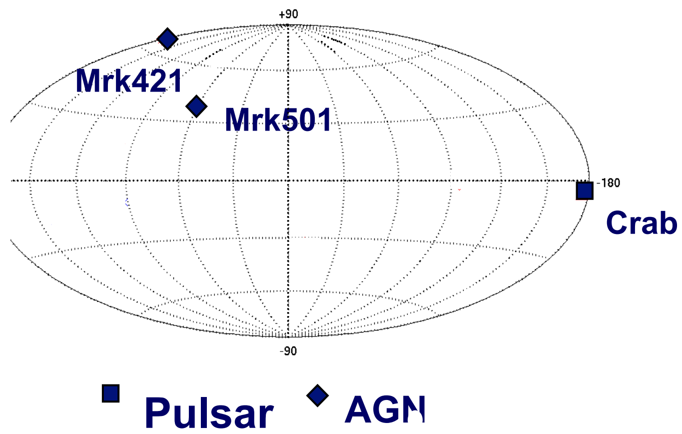
The VHE γ ray sky

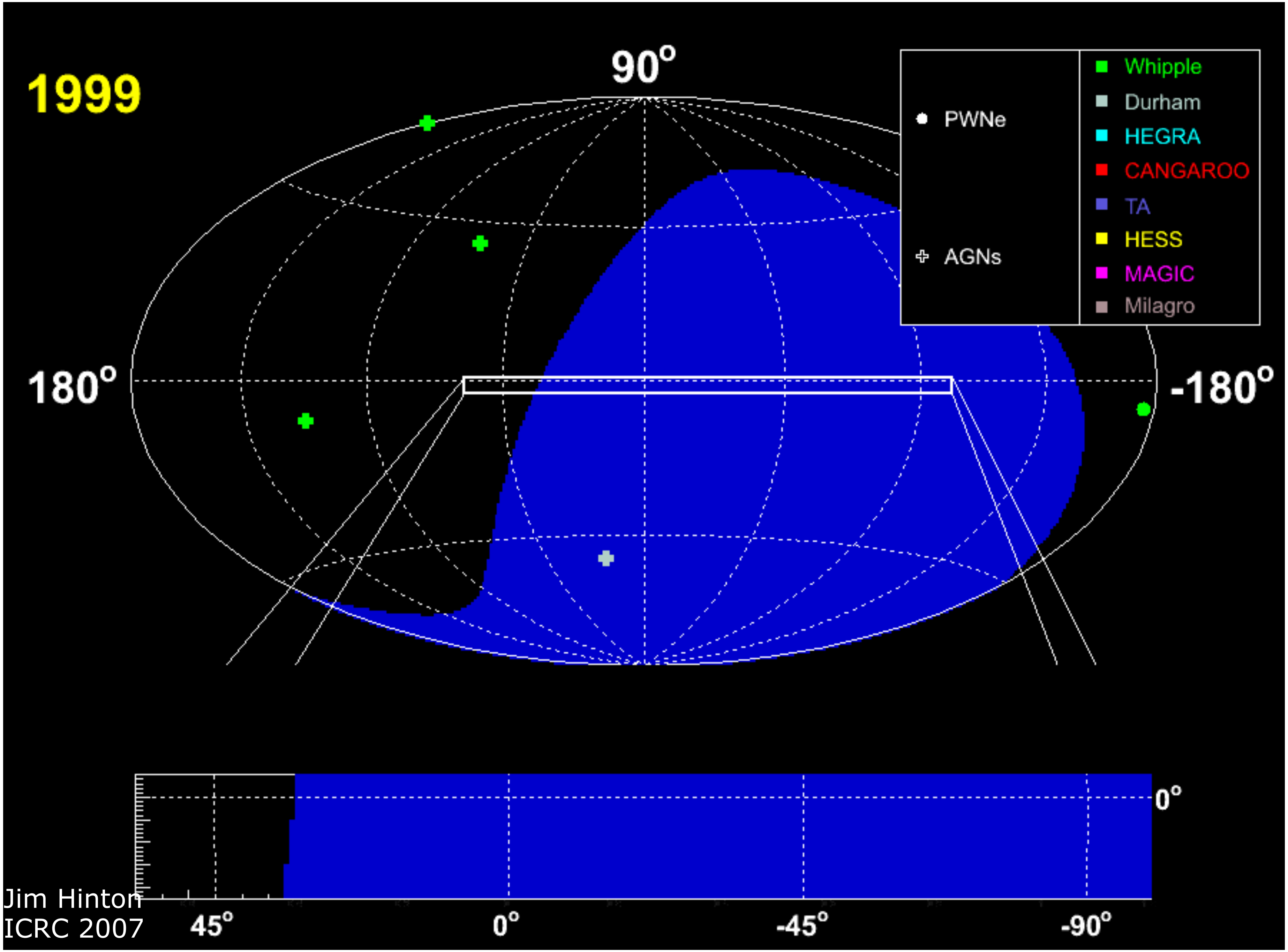
2005

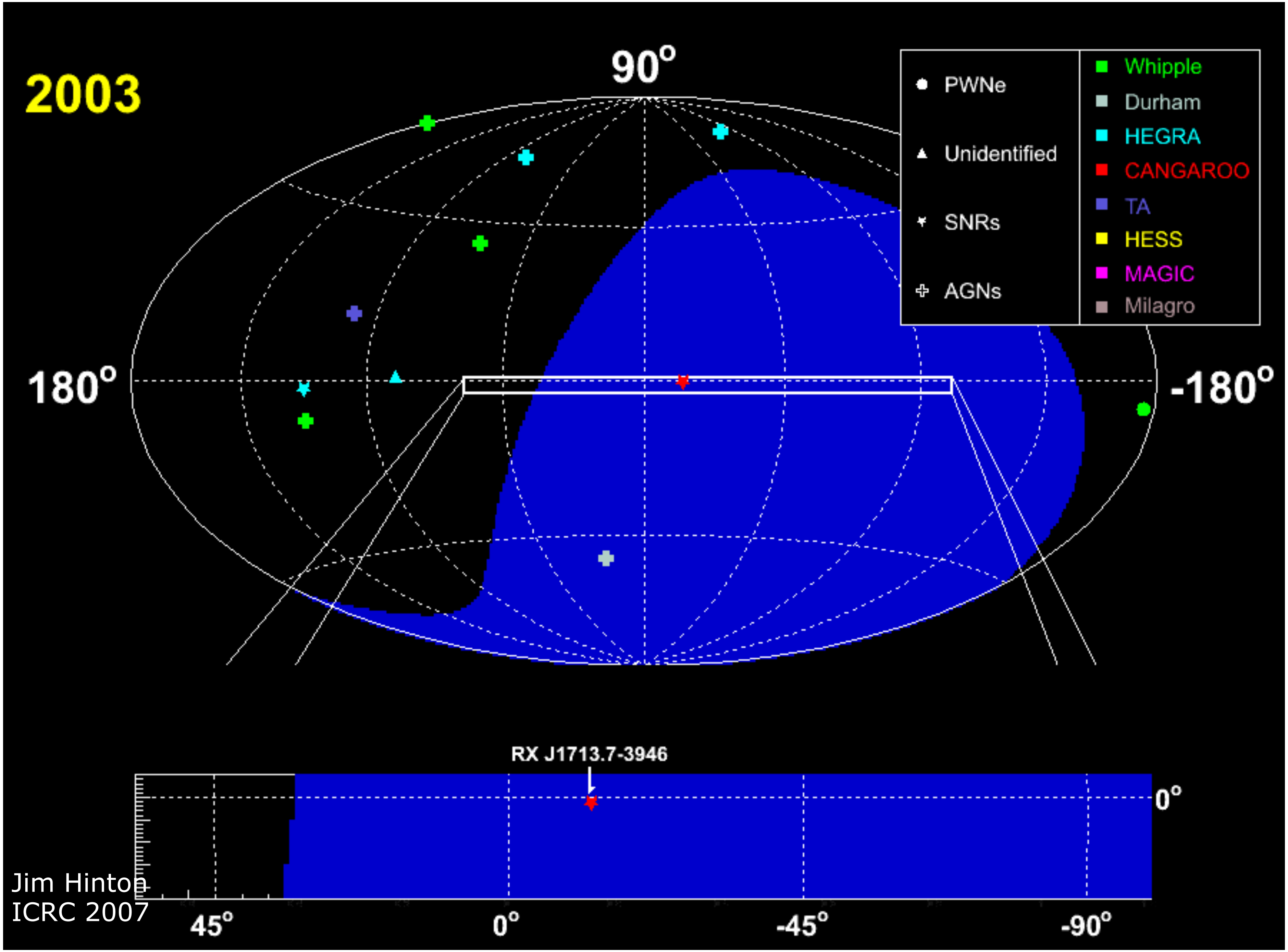


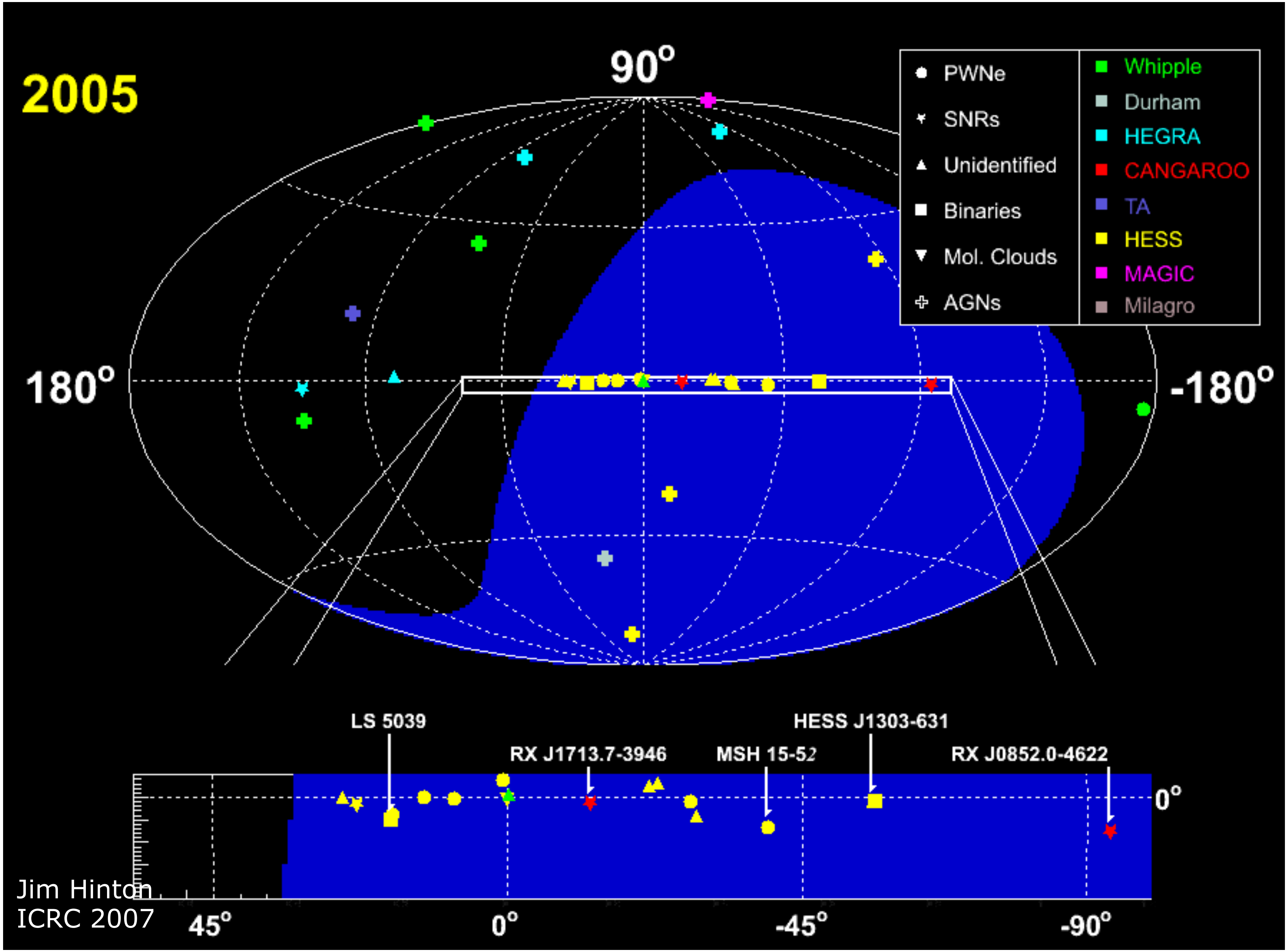
+ some additional sources in galactic plane.

1995

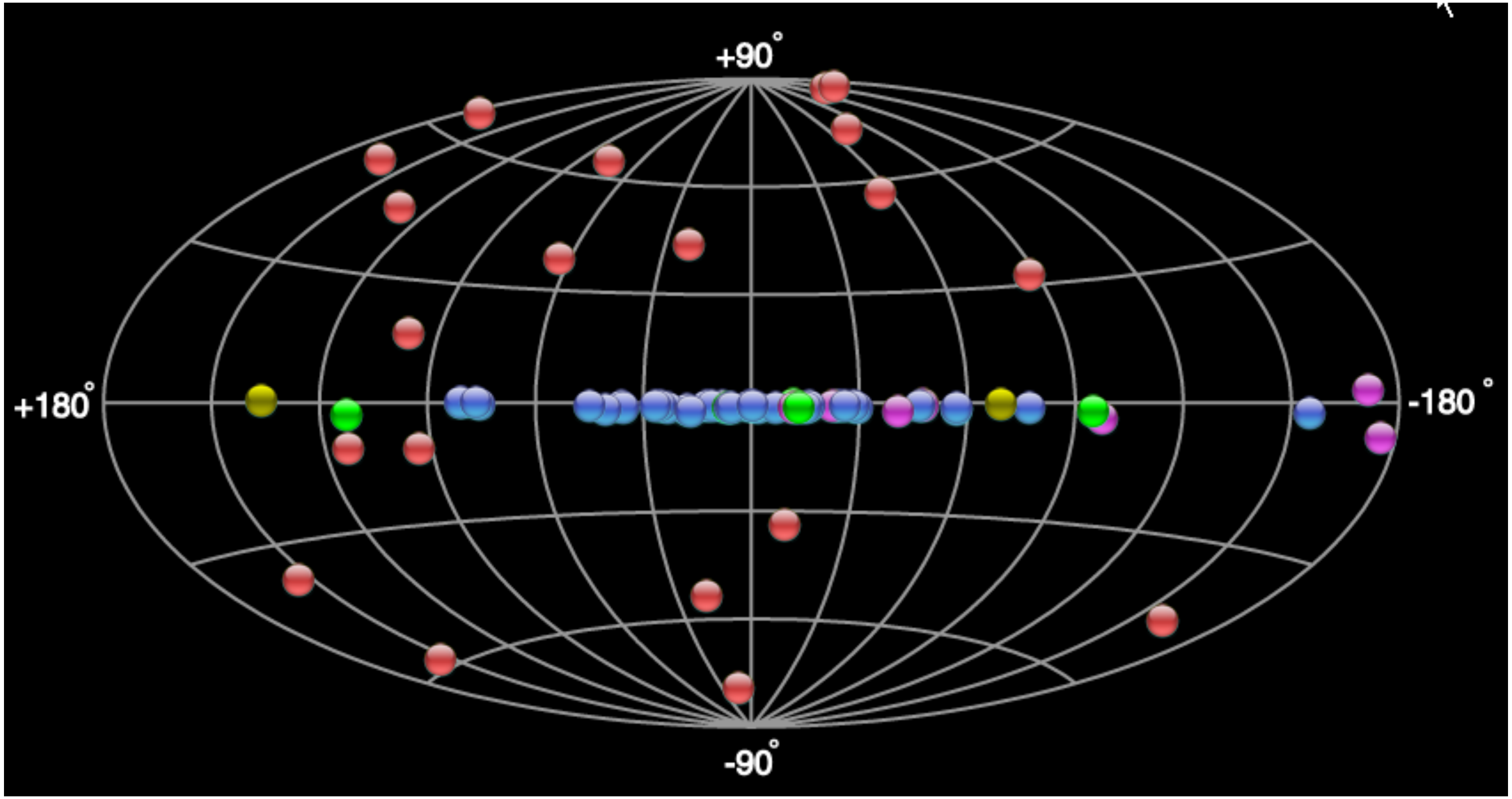



1999
90°
180°
-180°
PWNe
AGNs
Whipple
Durham
HEGRA
CANGAROO
TA
HESS
MAGIC
Milagro
0°
45°
0°
-45°
-90°
Jim Hinton
ICRC 2007


2003
90°
180°
-180°
PWNe
Unidentified
SNRs
AGNs
Whipple
Durham
HEGRA
CANGAROO
TA
HESS
MAGIC
Milagro
RX J1713.7-3946
0°
45°
0°
-45°
-90°
Jim Hinton
ICRC 2007

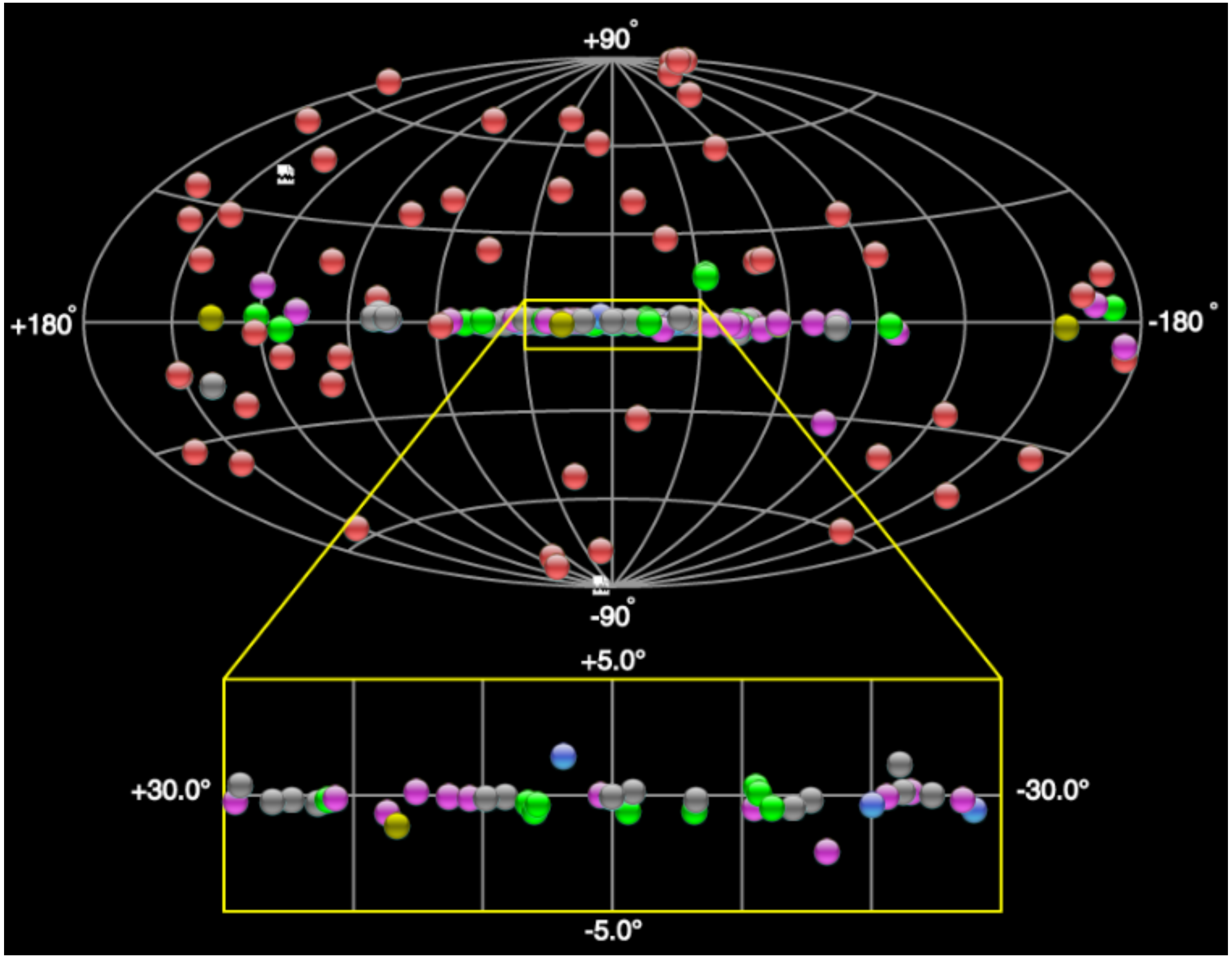

2005
90°
180°
-180°
PWNe
SNRs
Unidentified
Binaries
Mol. Clouds
AGNs
Whipple
Durham
HEGRA
CANGAROO
TA
HESS
MAGIC
Milagro
LS 5039
RX J1713.7-3946
MSH 15-52
HESS J1303-631
RX J0852.0-4622
0°
45°
0°
-45°
-90°
Jim Hinton
ICRC 2007

TeV Source Catalog

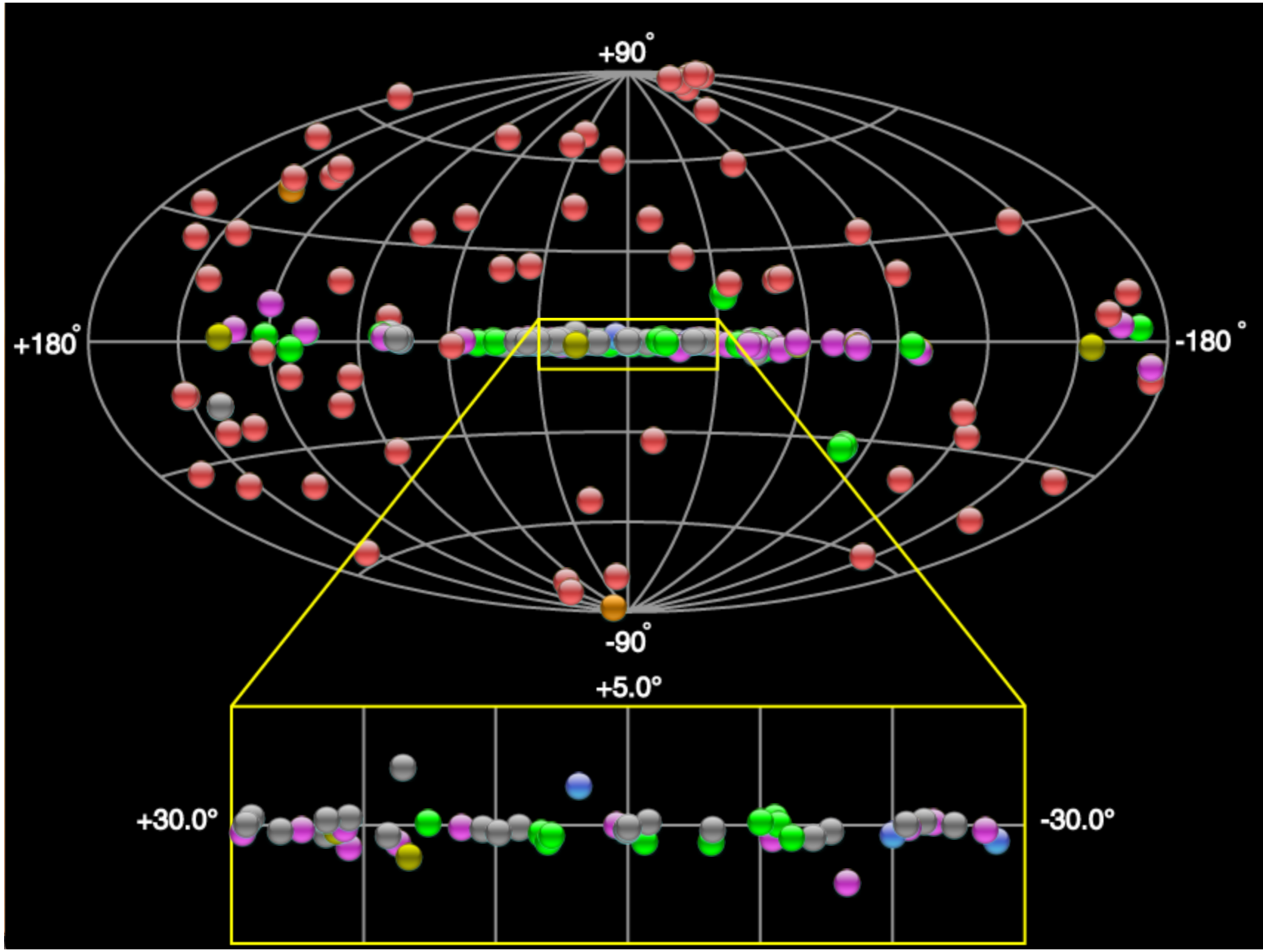


http://tevcat.uchicago.edu/

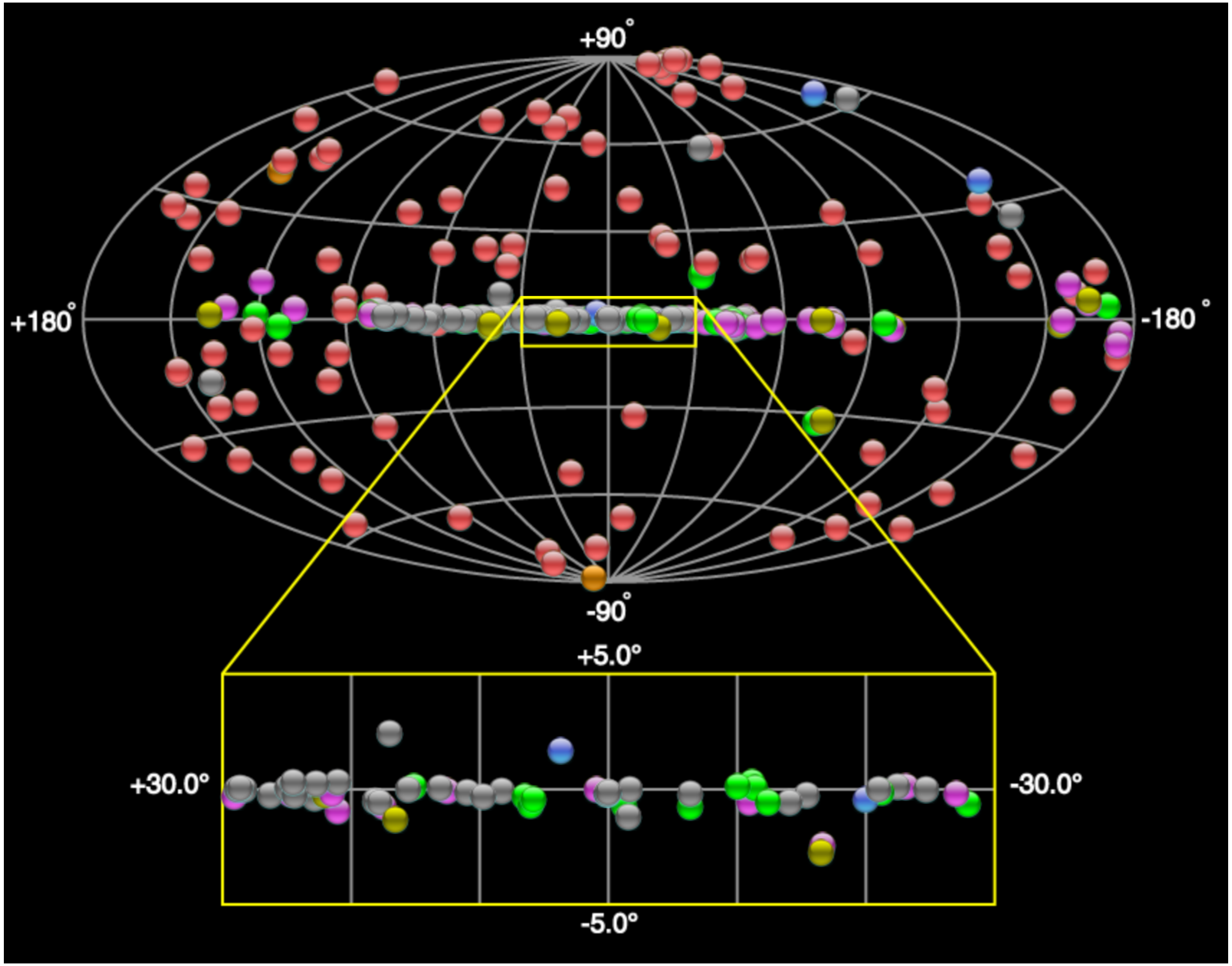
The TeV Catalog 2012



The TeV Catalog 2016

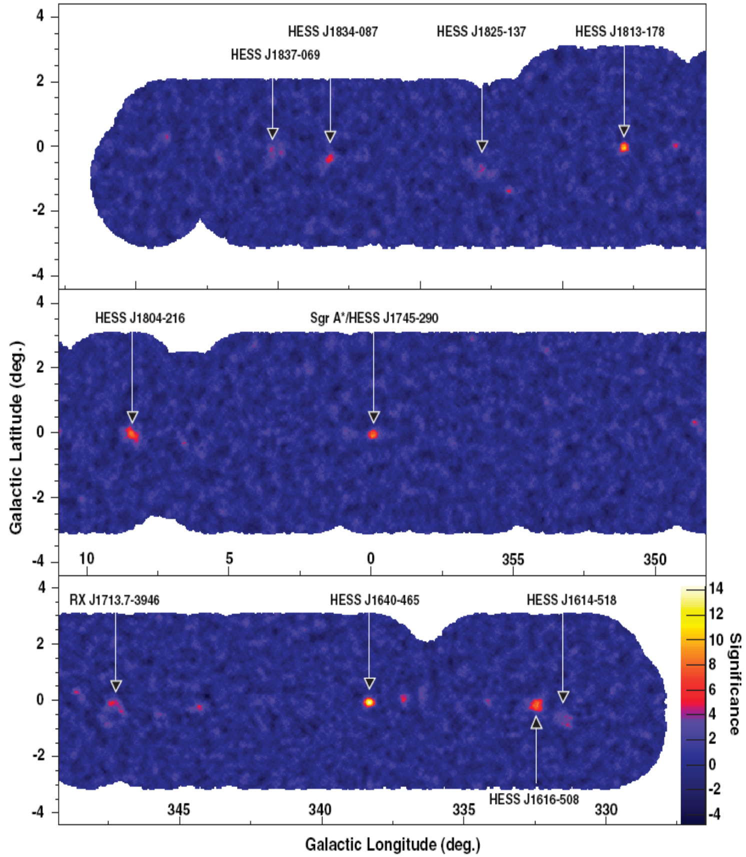


The TeV Catalog 2021

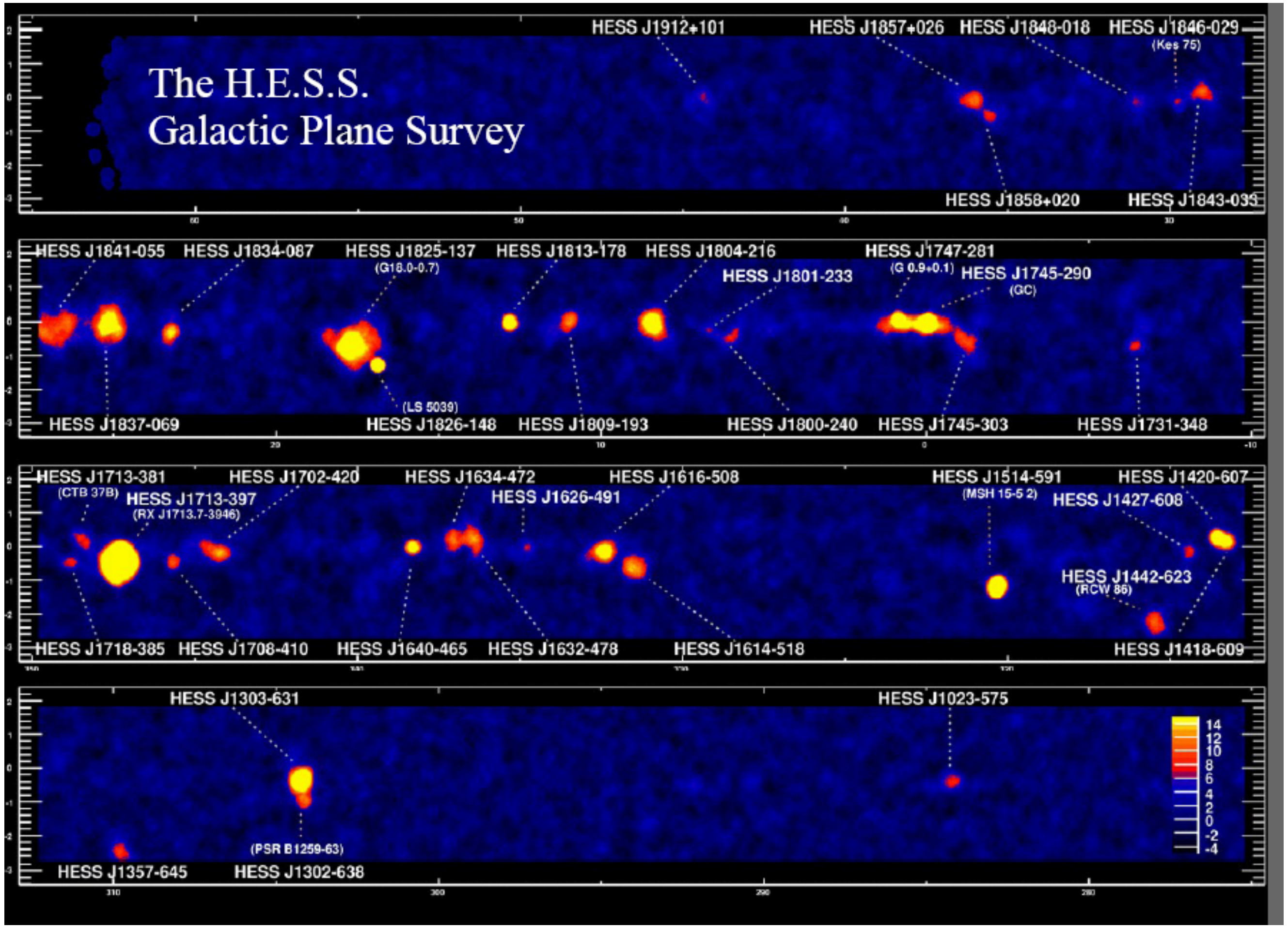


TeV Sky Survey

- HESS Galactic plane survey sees many new TeV sources (Aharonian et al. 2005)
  - This might possibly inform a detailed model of the distribution of CR sources, although the distribution is so confined to the plane that the sources (probably plerions and SNR) are at least several kpc distant

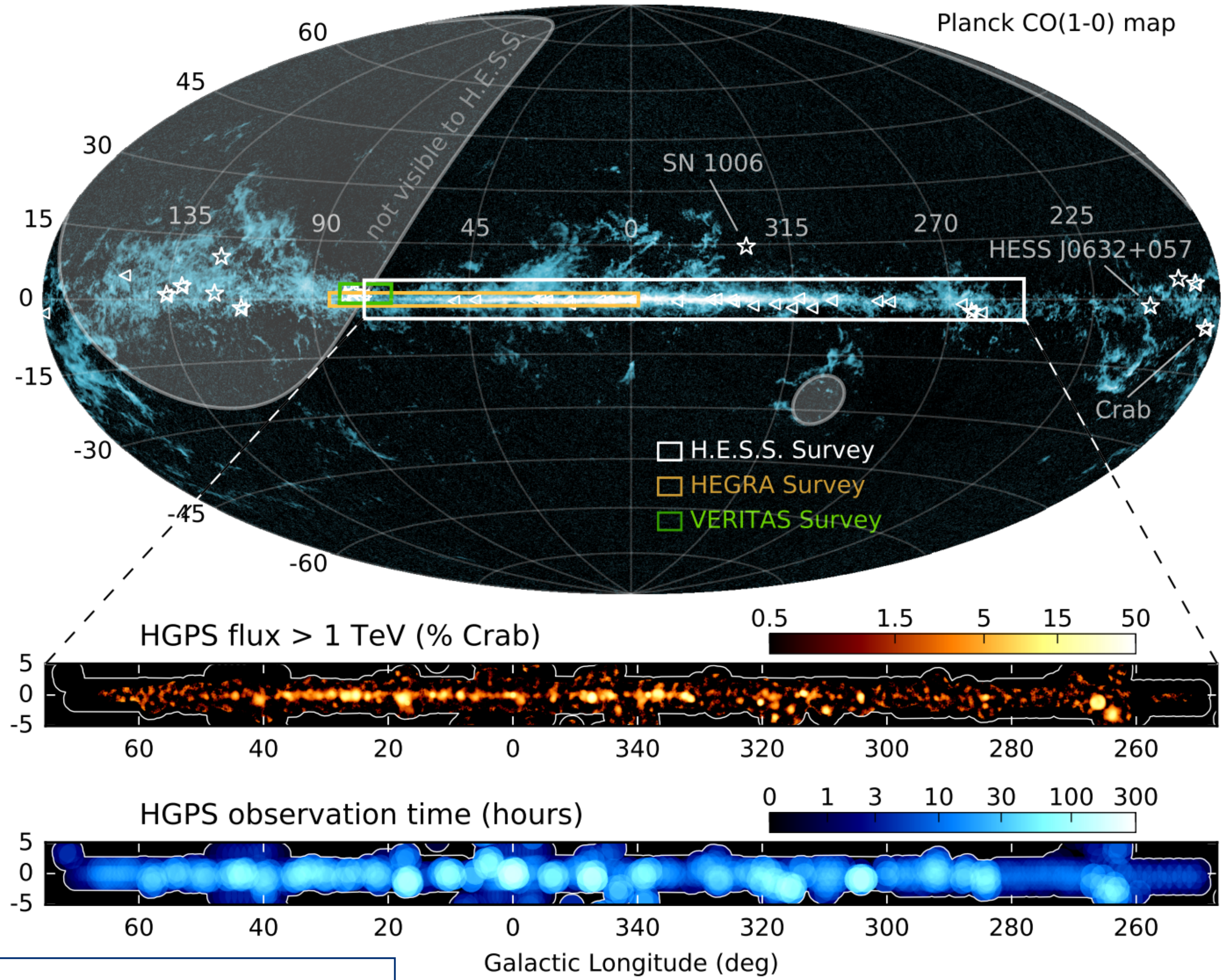


The Galactic Plane survey



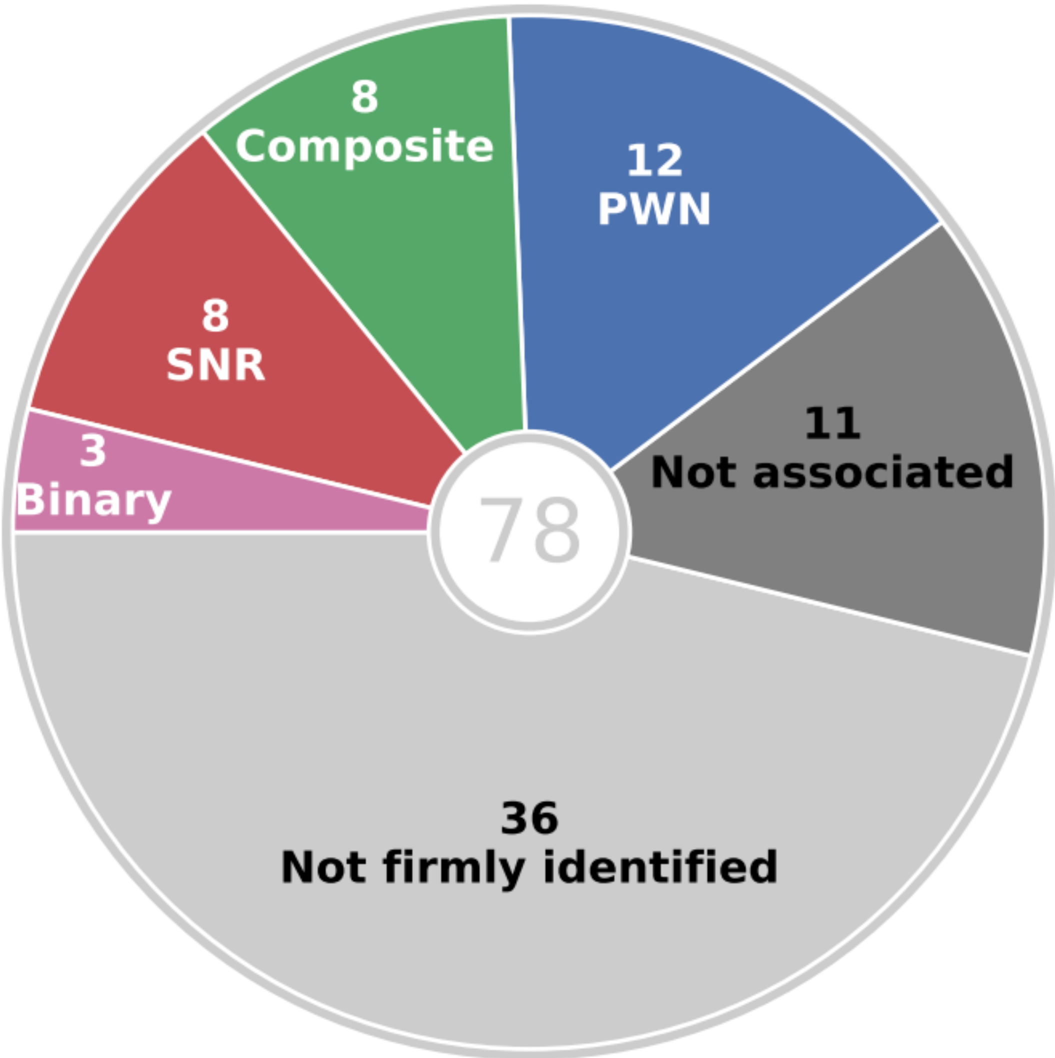
Aharonian et al. 2006

The Galactic Plane survey



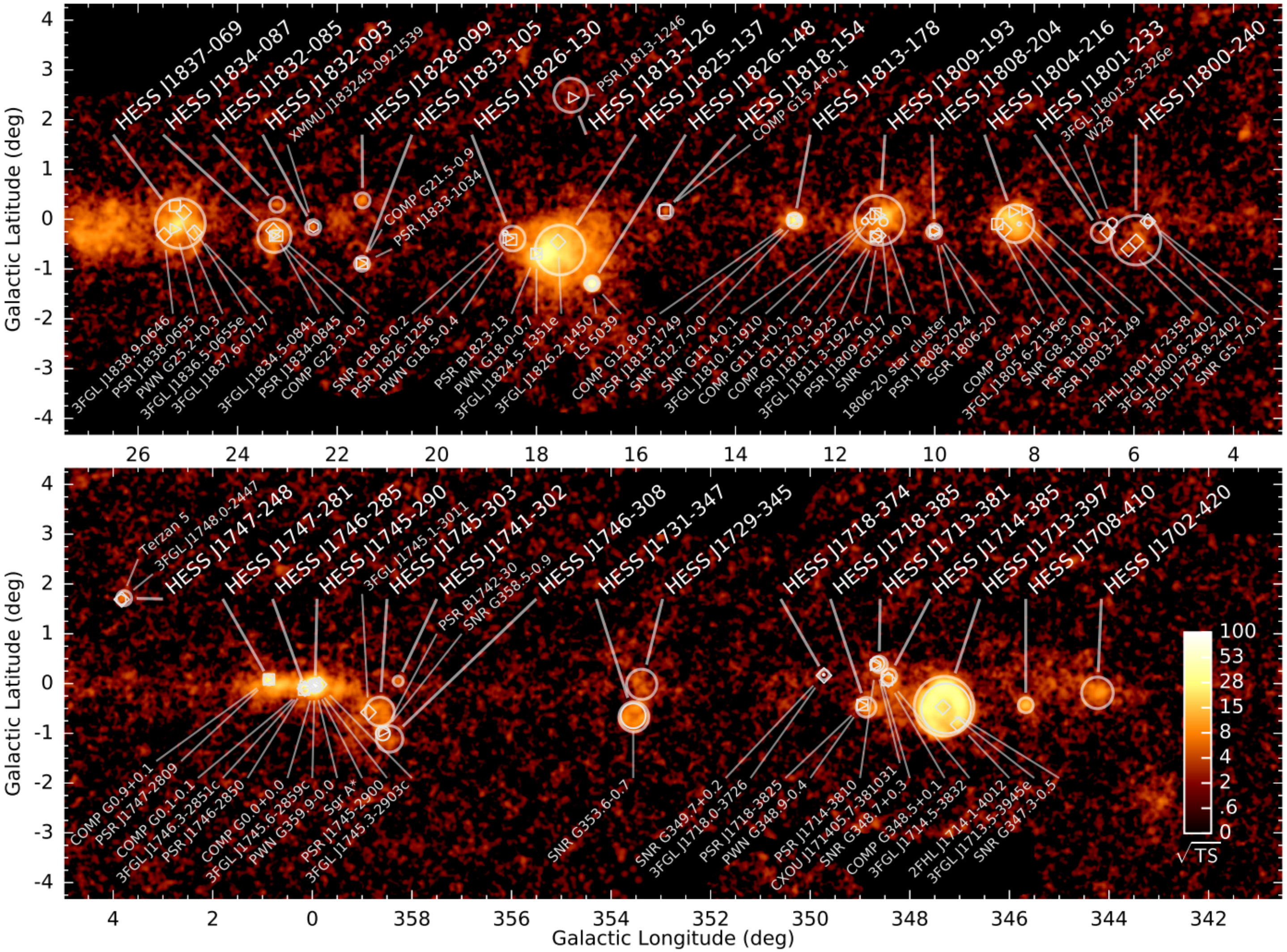
Aharonian et al. 2018

The Galactic Plane survey



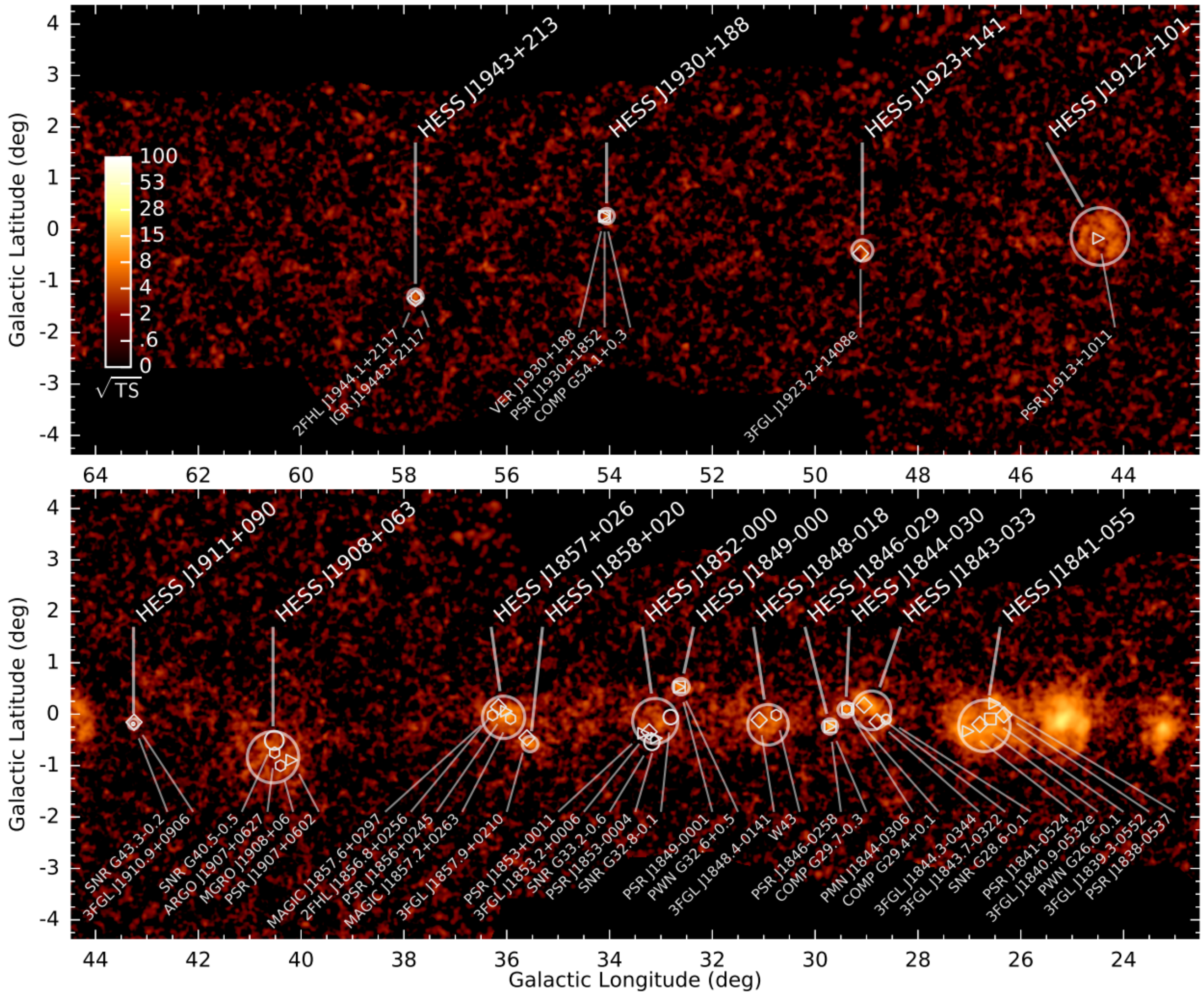
Aharonian et al. 2018

The Galactic Plane survey



Aharonian et al. 2018

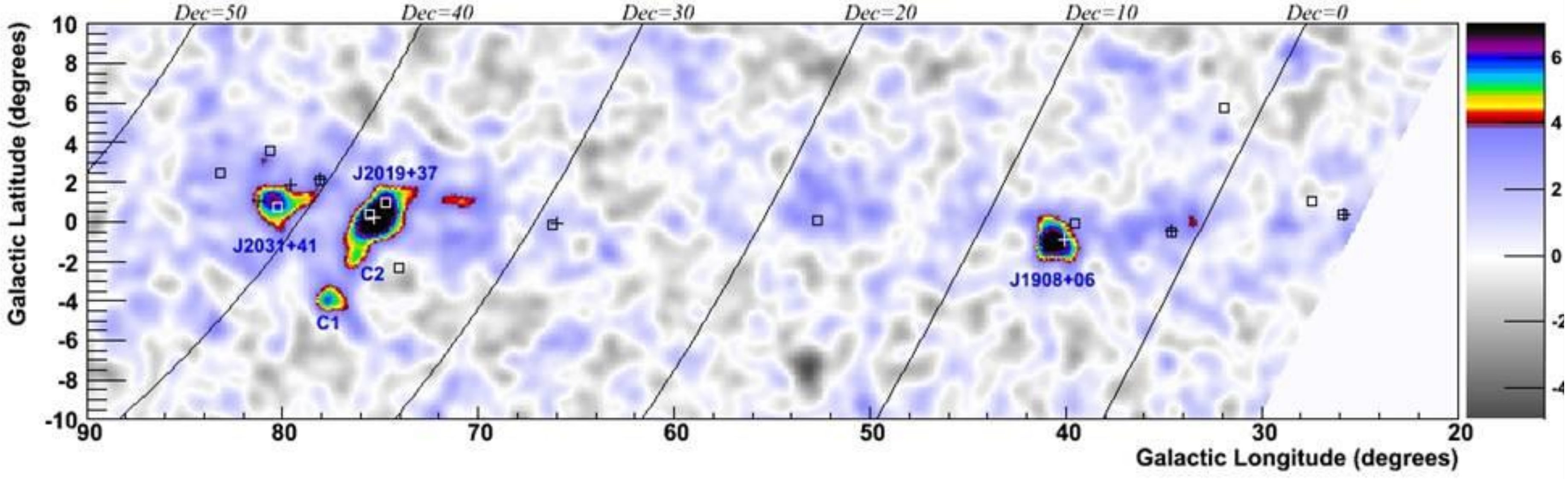
The Galactic Plane survey



Aharonian et al. 2018

MILAGRO Sky Survey

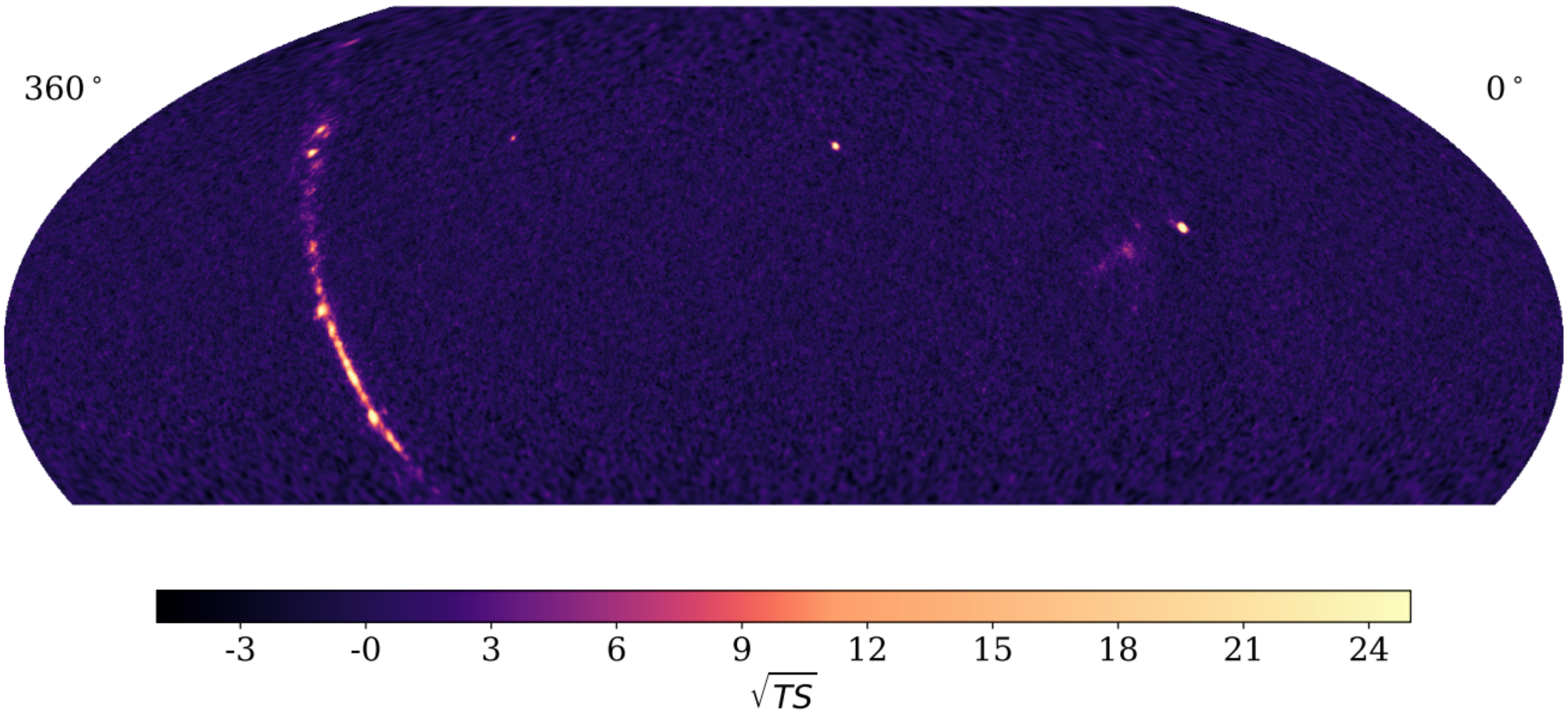
- Milagro reports detecting the diffuse emission of the Milky Way at >1 TeV energies (Abdo et al 2008)



Abdo et al. 2008

HAWC Sky Survey

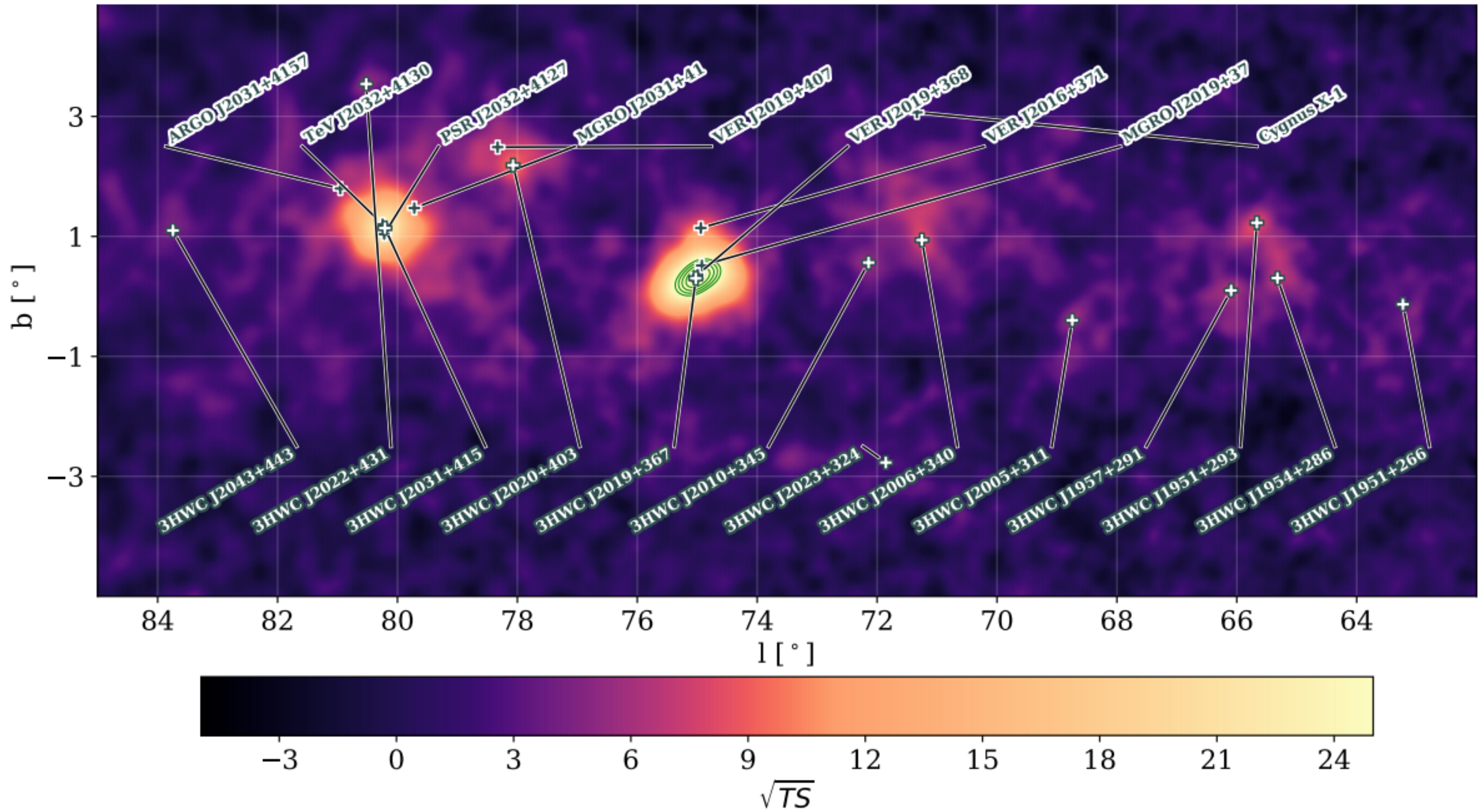
- HAWC 3rd catalog of Gamma Ray sources



Albert et al. 2021

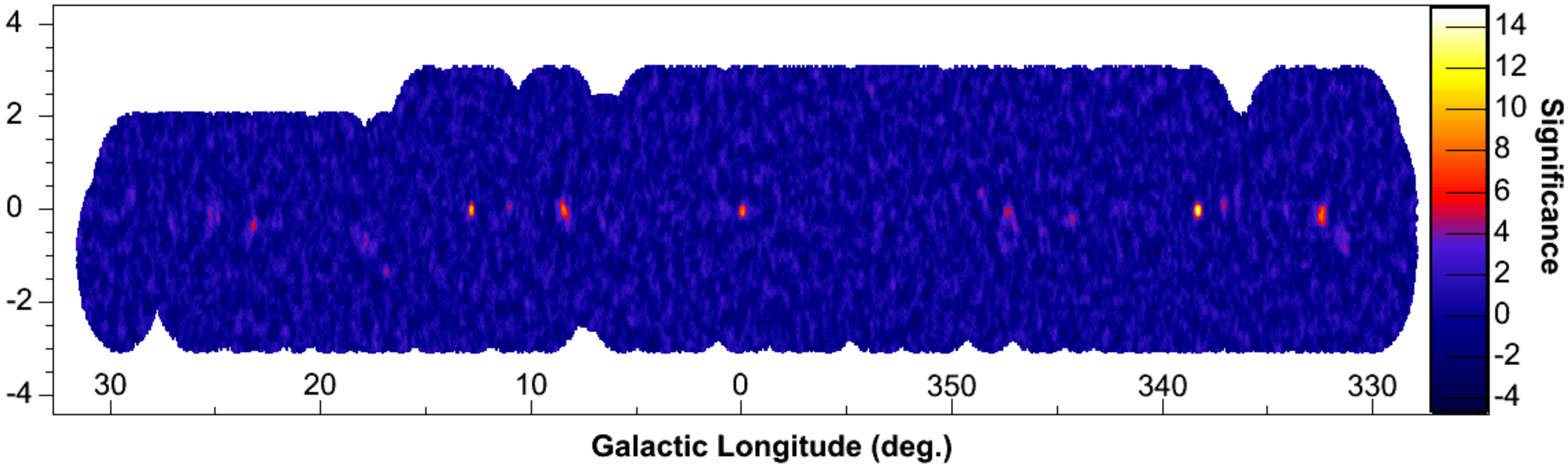
HAWC Sky Survey

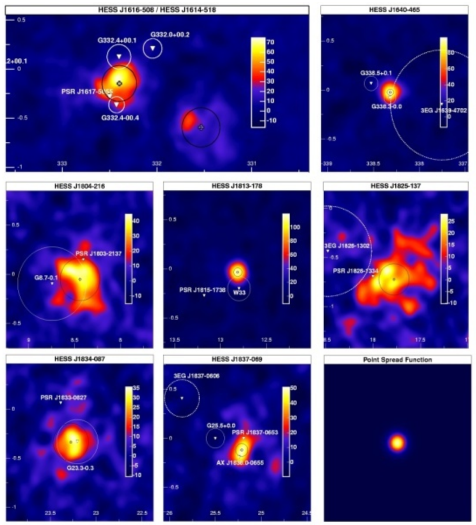
- HAWC 3rd catalog of Gamma Ray sources



Albert et al. 2021

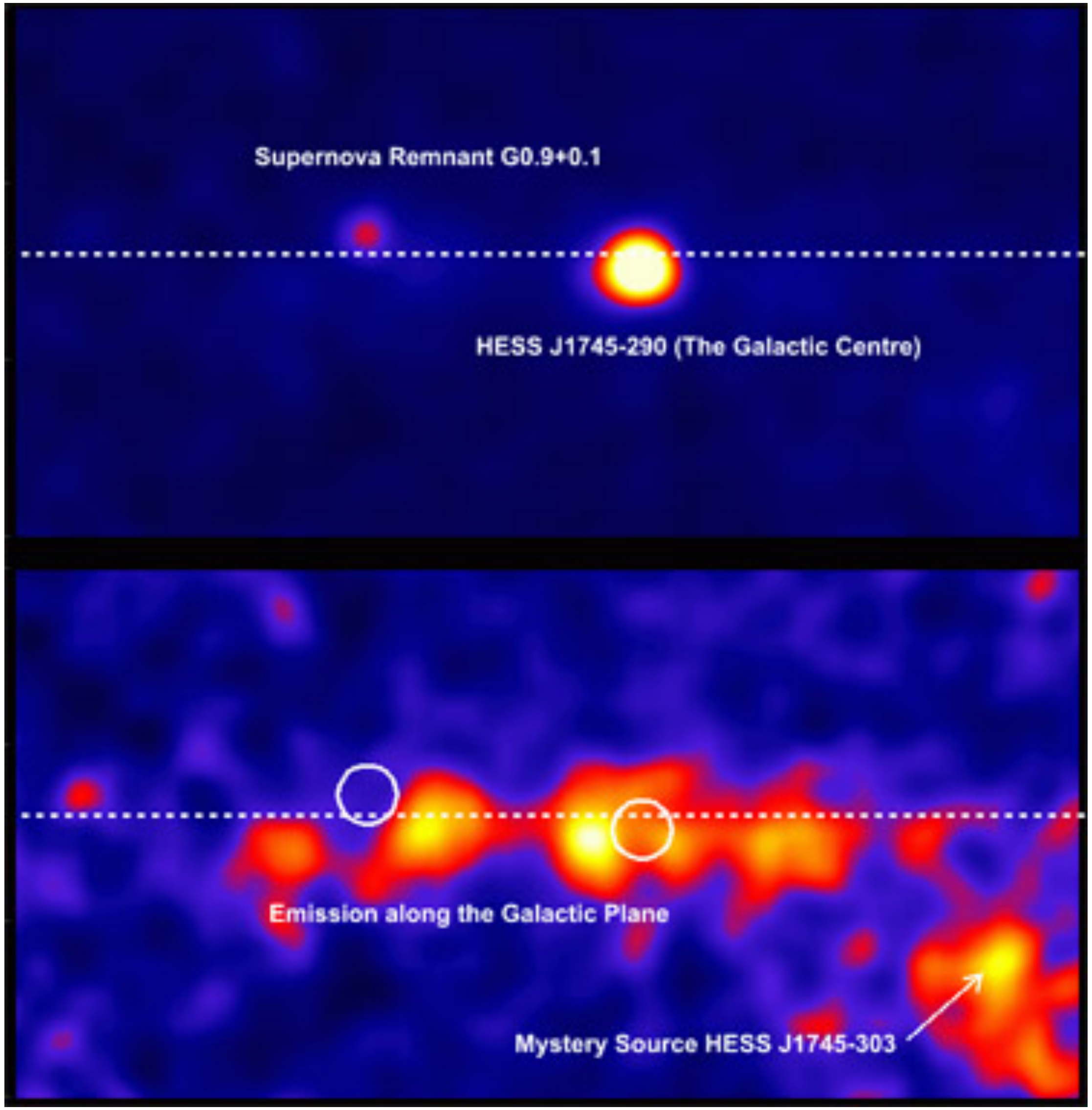
HESS “new” sources



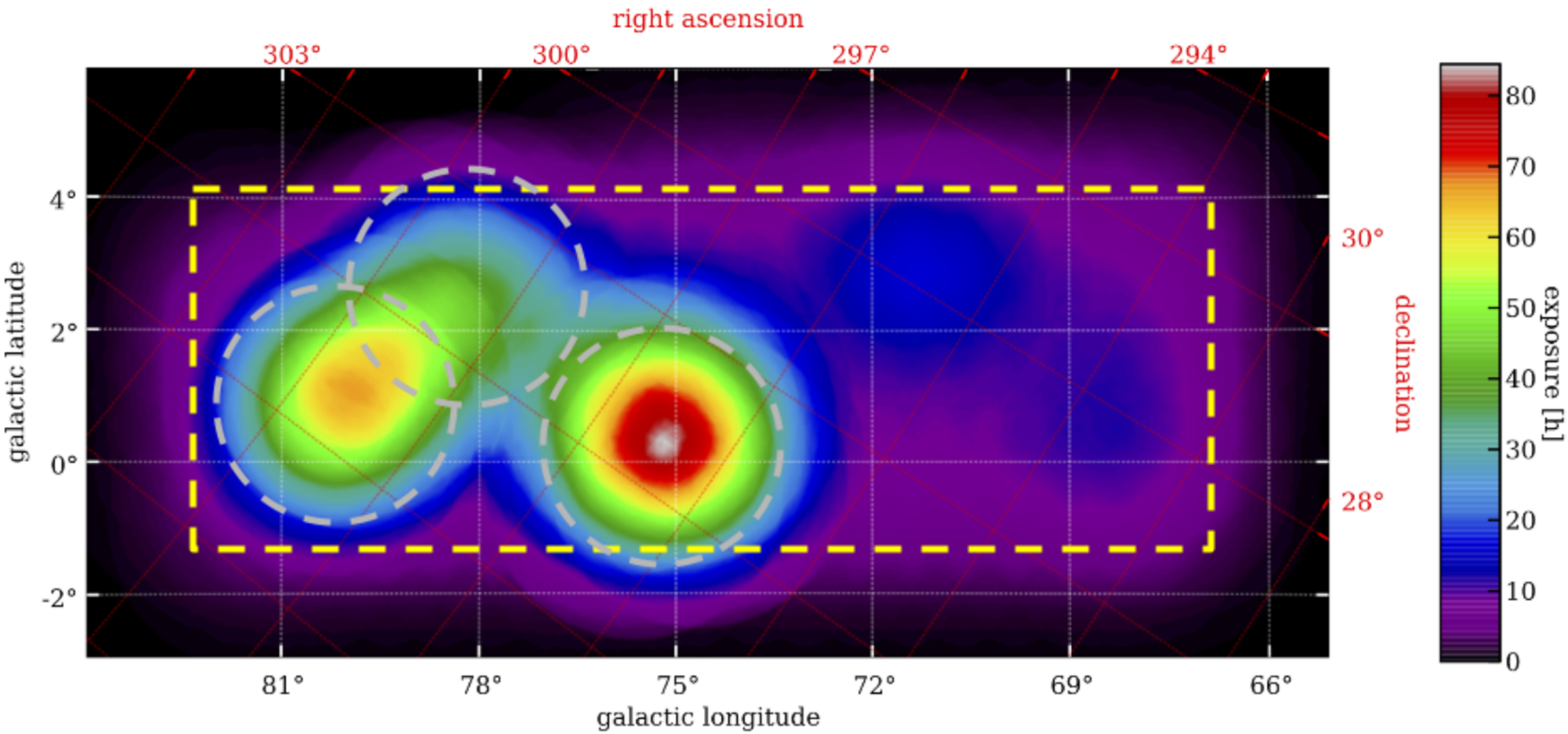


Close-up view of the new sources, discovered in the Galactic plane scan. Shown as white circles are close-by supernova remnants , that are known to be sources of very high energy gamma-rays (with the radius of the circle representing the size of the supernova remnant). Also shown in white are close-by pulsars, another class of sources of very high energy gamma-rays.

HESS Diffuse Gamma-Ray

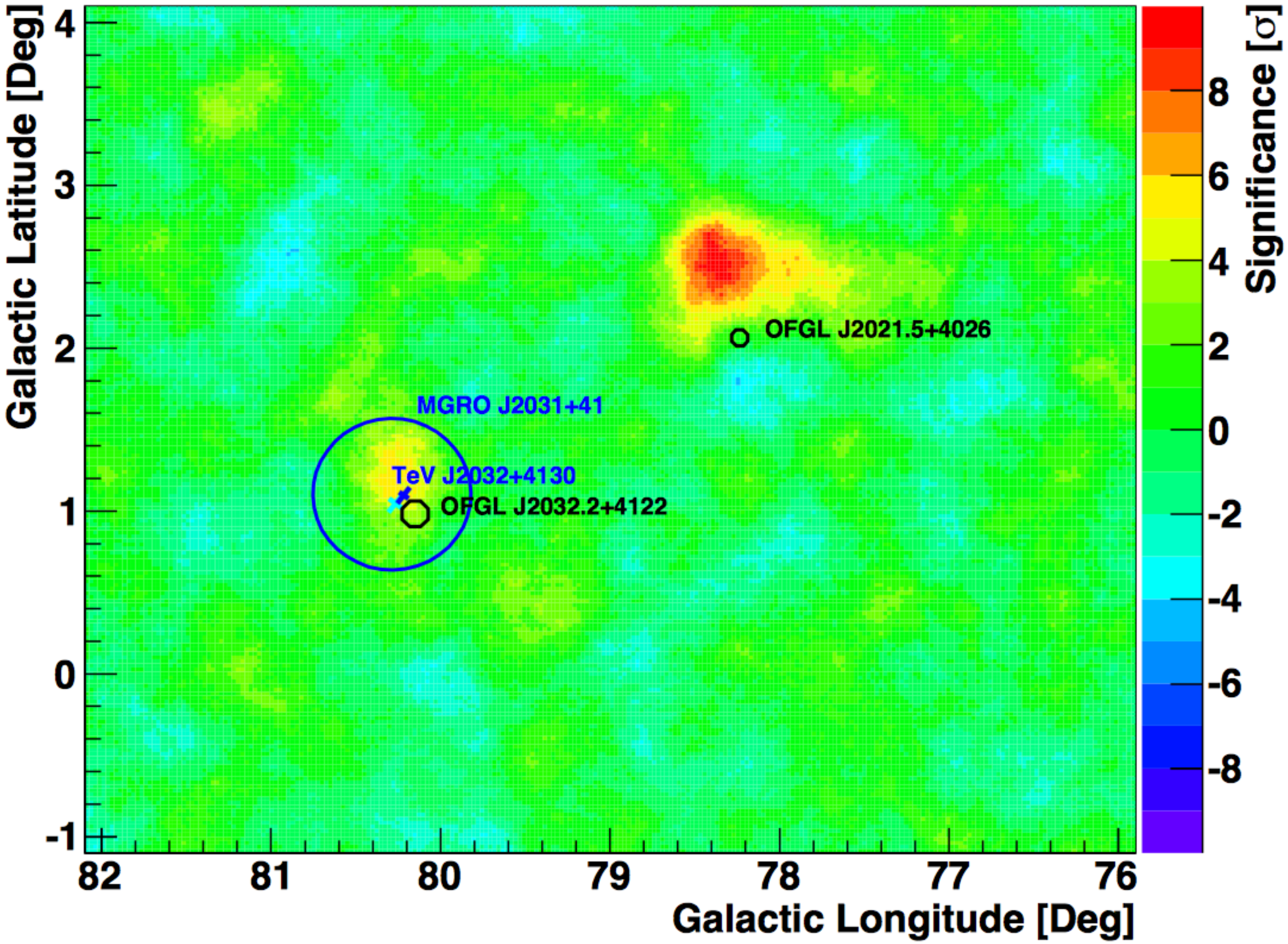


VERITAS Cygnus Survey



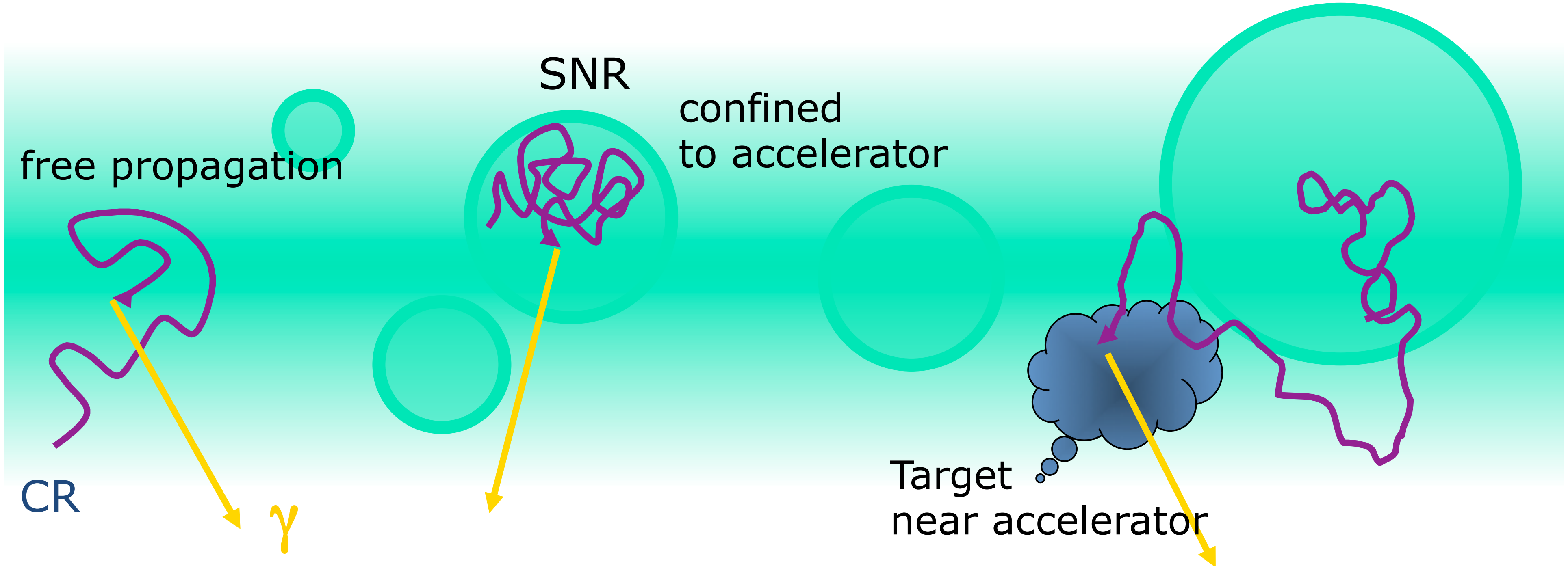
http://arxiv.org/abs/1508.06684

VERITAS Cygnus Survey



http://arxiv.org/abs/0912.4492

CR origin and propagation

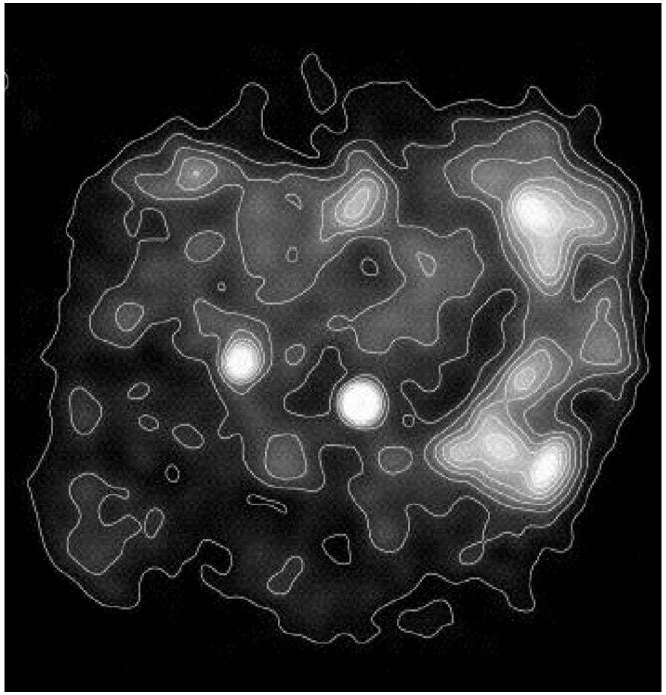


VHE gamma rays from secondary interactions:
p: π^o production and decay
e: Inverse Compton scattering and Bremsstrahlung
Trace beam density x target density

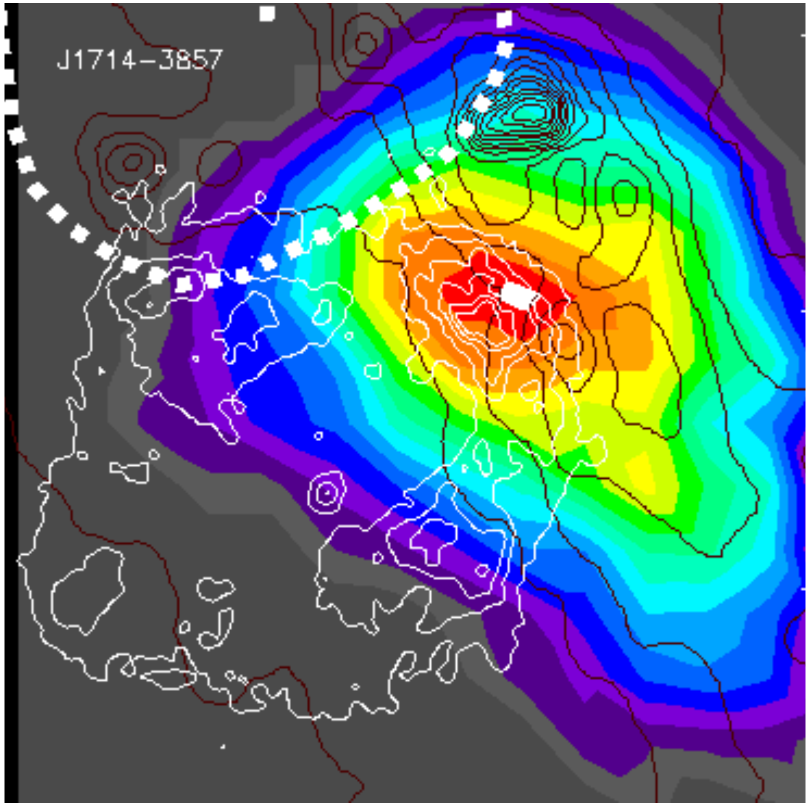
Astrofisica Nucleare e Subnucleare

VHE Galactic Sources

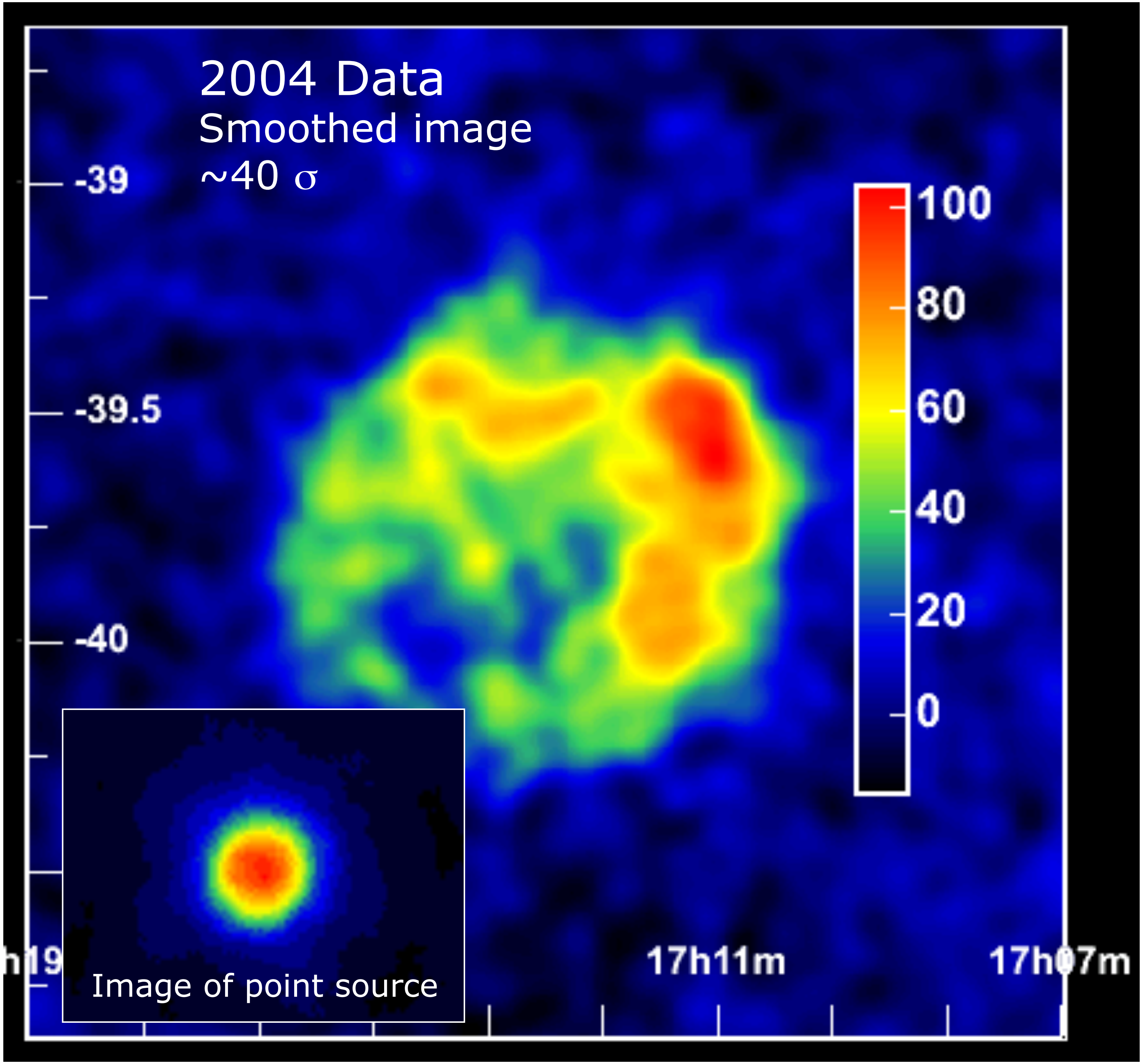
The supernova remnant G347.3-0.5 (RX J1713.7-3946)

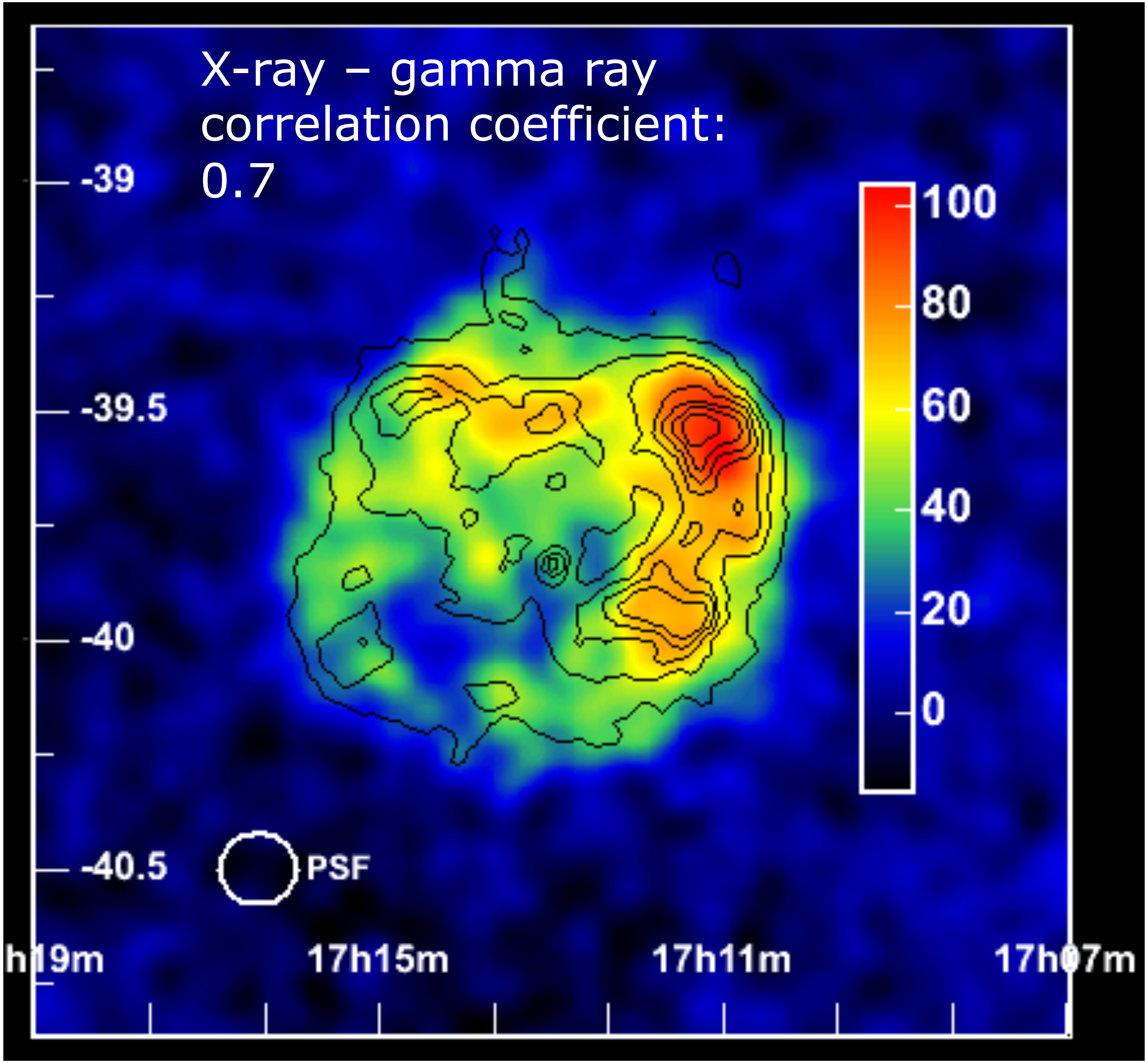


ROSAT
(keV)

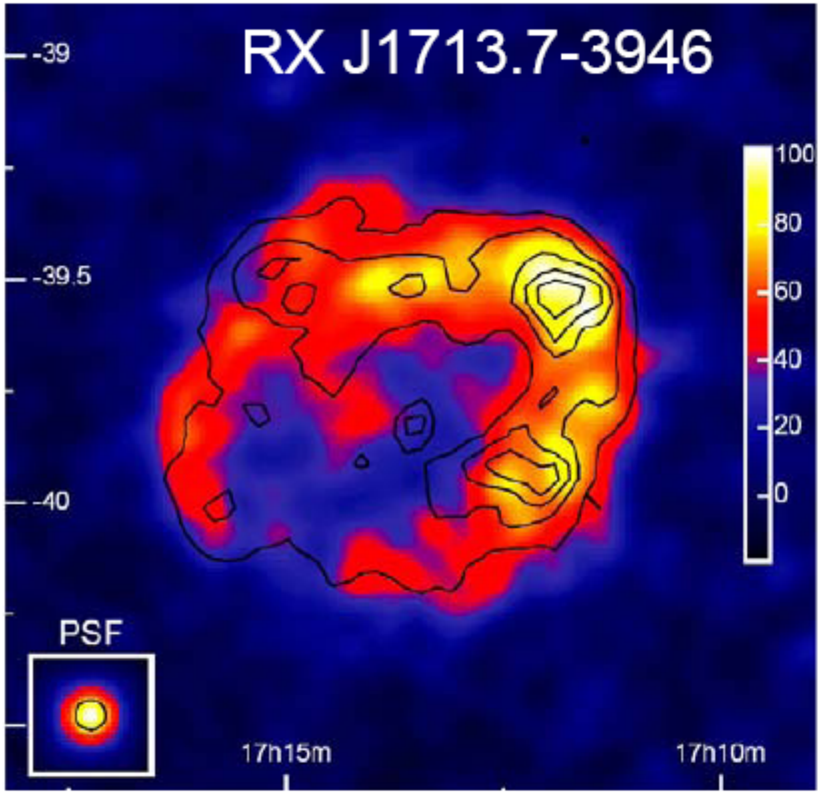


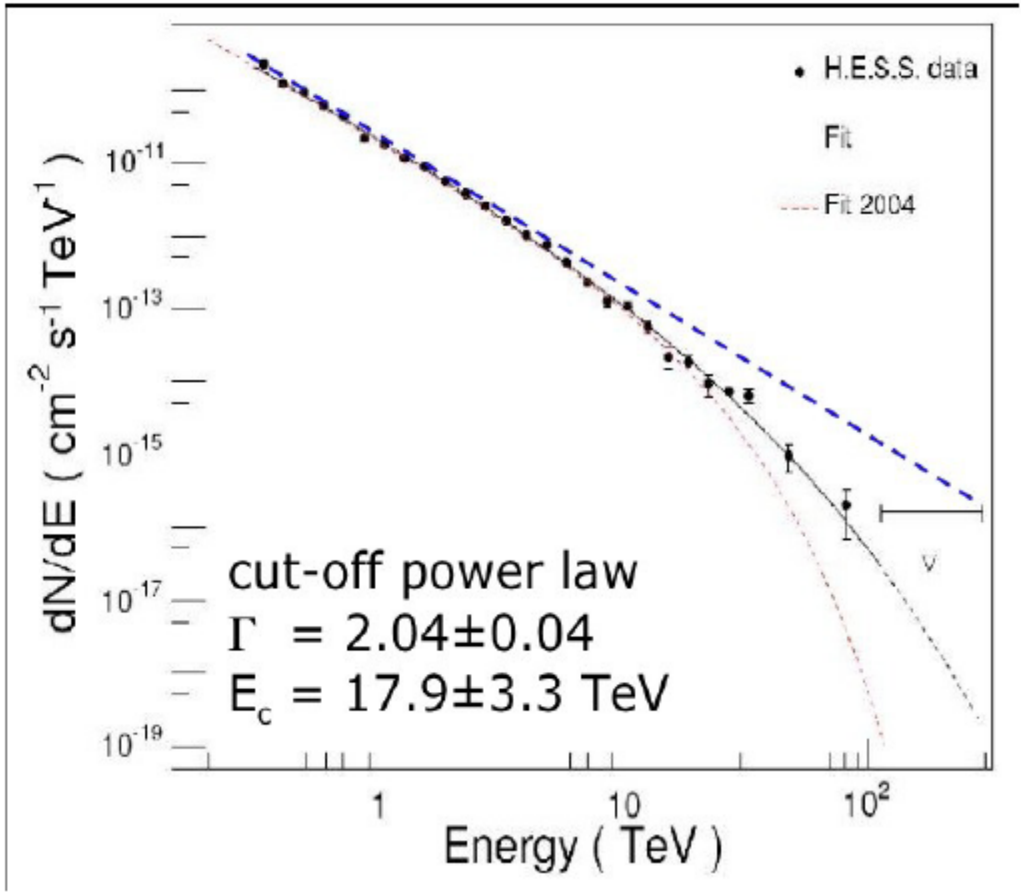
CANGAROO
(TeV)


2004 Data
Smoothed image
~40 σ
-39
-39.5
-40
100
80
60
40
20
0
h19
17h11m
17h07m
Image of point source


X-ray – gamma ray
correlation coefficient:
0.7
-39
-39.5
-40
-40.5
100
80
60
40
20
0
PSF
h19m
17h15m
17h11m
17h07m

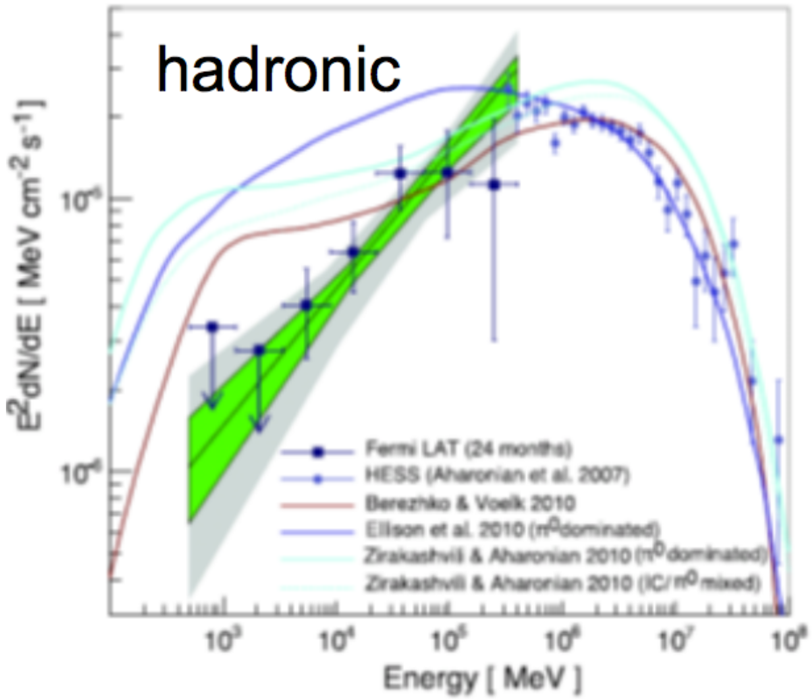
HESS – SNR in VHE gamma

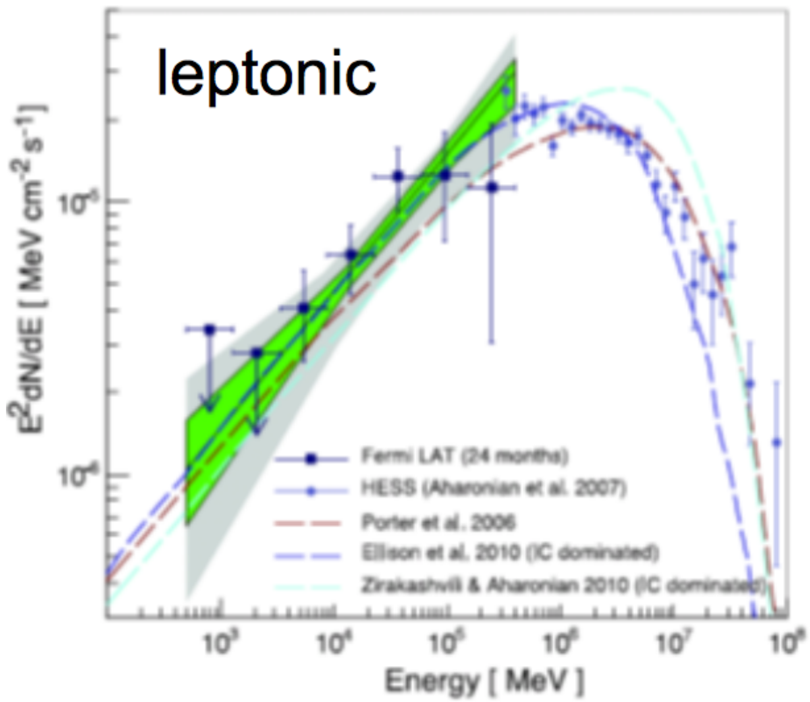




Aharonian et al. 2004

Fermi LAT results on RX J1713.7-3946 (Abdo et al. 2011)





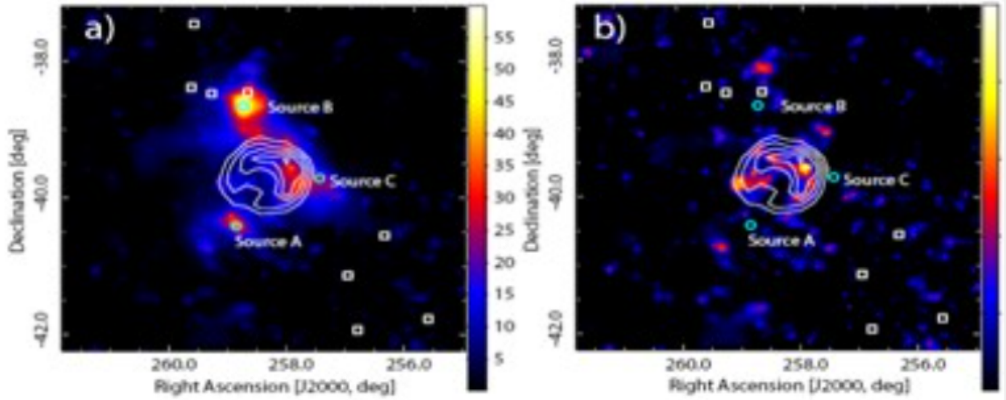
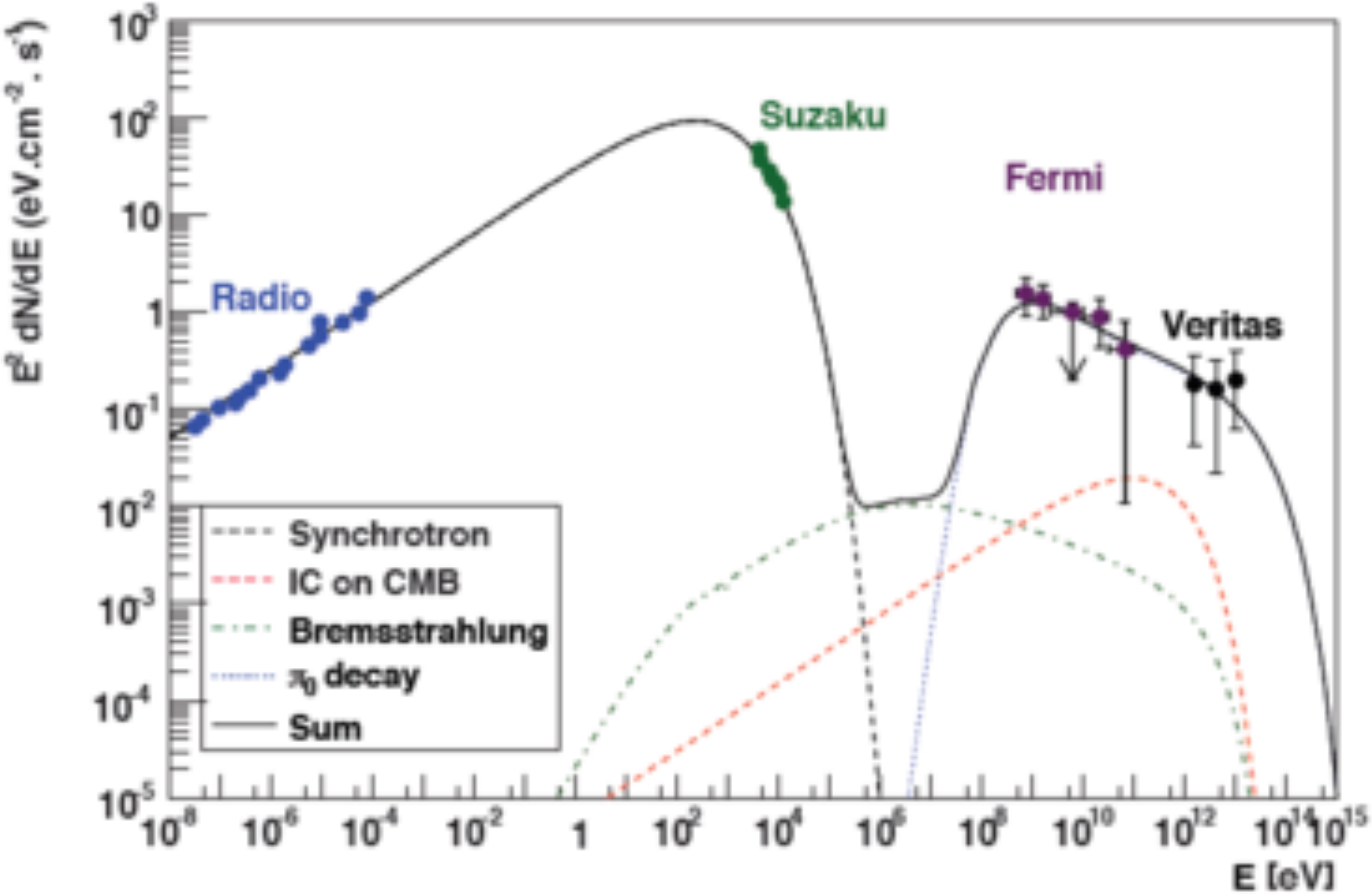


Fig. 1.— **Panel (a):** Map of the test statistic (TS) for a point source in the region around RX J1713.7−3946 obtained in a maximum likelihood fit accounting for the background diffuse emission and 1FGL catalog sources. Only events above 500 MeV have been used in this analysis. H.E.S.S. TeV emission contours are shown in white (Aharonian et al. 2007). Rectangles indicate the positions of 1FGL sources in our background model. Several TS peaks outside the SNR shell are visible. The 3 peaks marked by circles are added as additional sources to our background model (see text). **Panel (b):** Same map as panel (a), but with the 3 additional sources now considered in the background model.

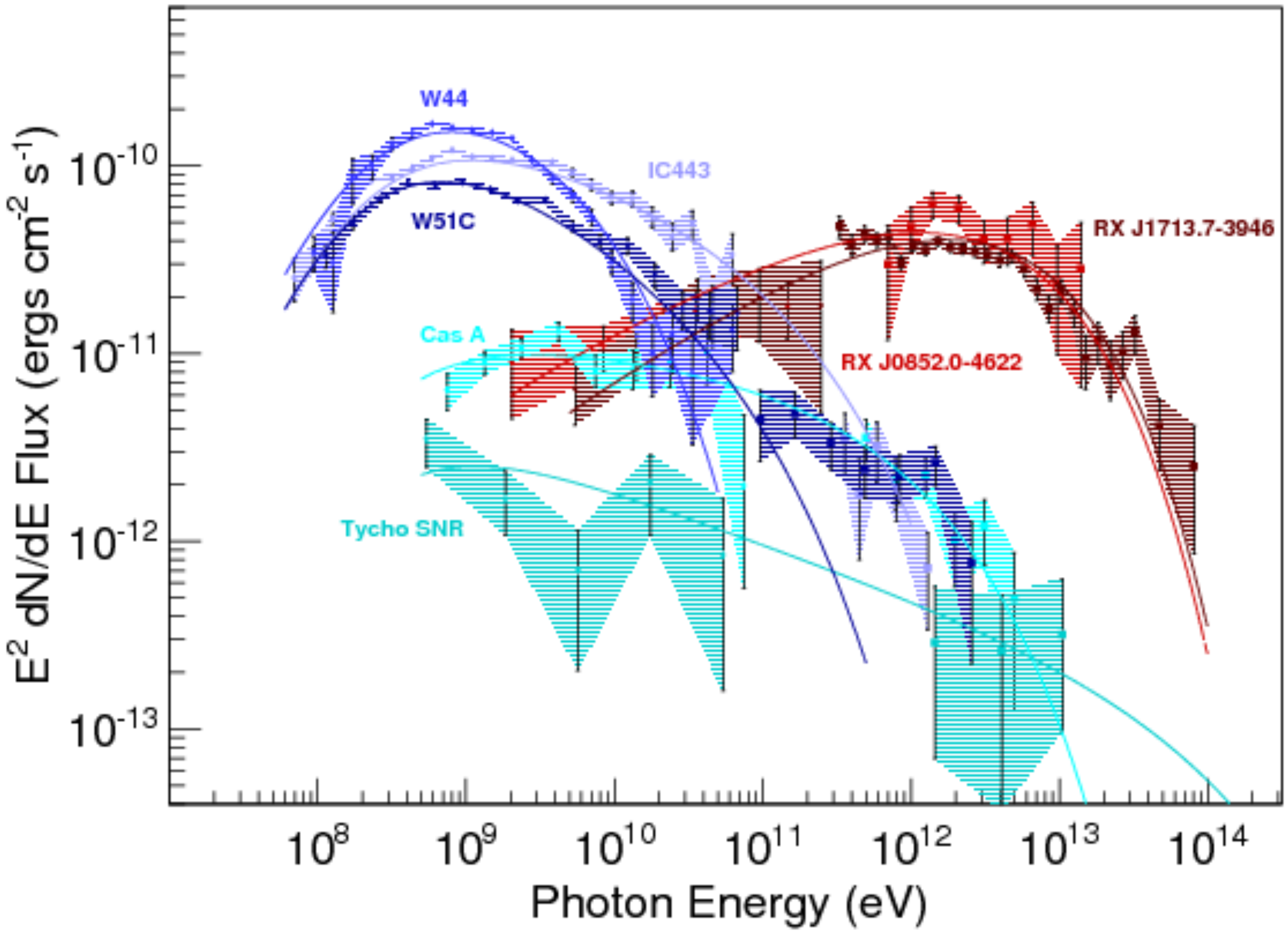
Although the leptonic model is preferable, the hadronic model is not excluded because of the possible energy dependent CR penetration in to the clouds. The main problem of the hadronic model is the absence of thermal X-rays.

… but Tycho ..



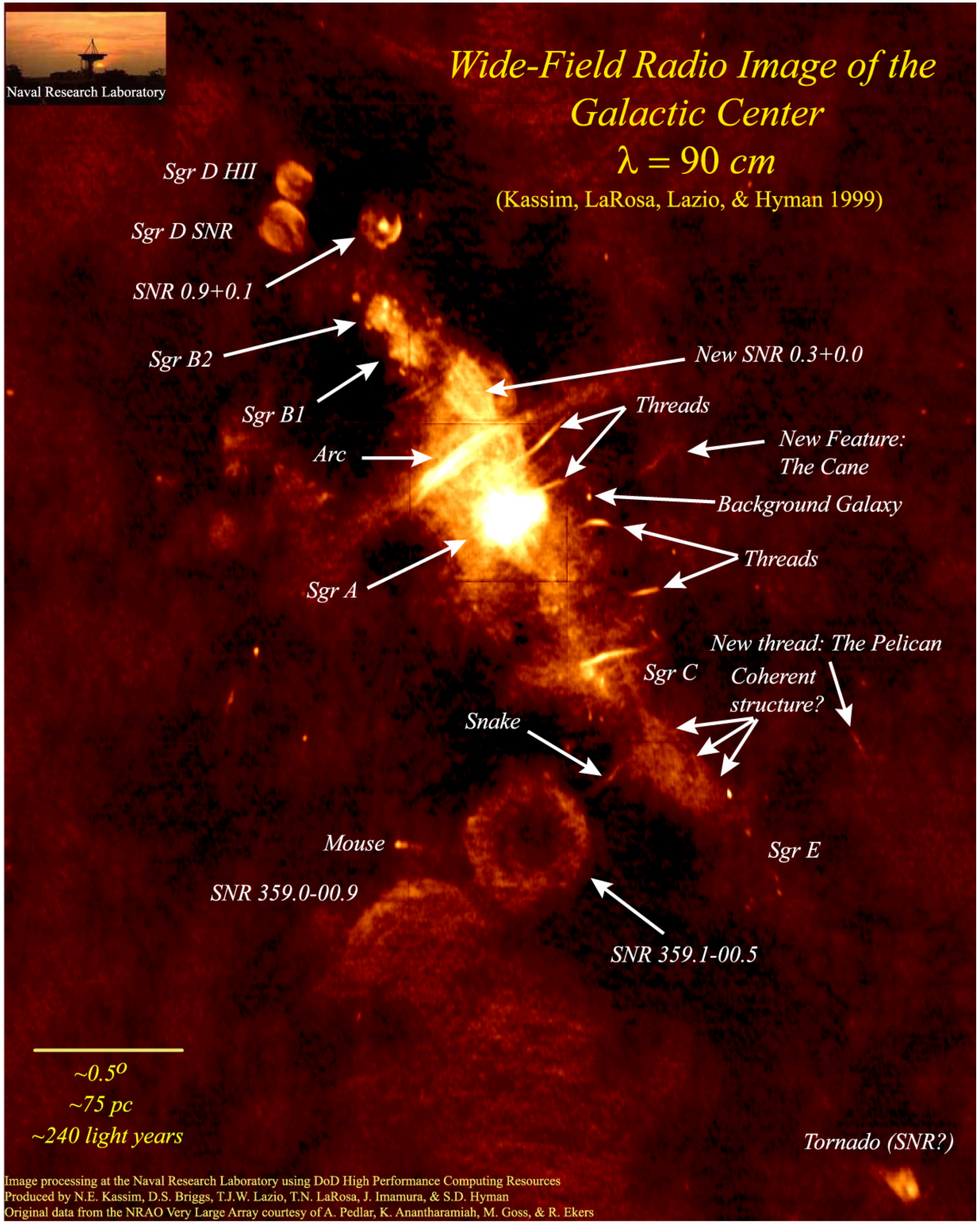
E^2 dN/dE (eV.cm^{-2} . s^{-1})
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Suzaku
Fermi
Radio
Veritas
Synchrotron
IC on CMB
Bremsstrahlung
π_0 decay
Sum
10^{-8}
10^{-6}
10^{-4}
10^{-2}
1
10^2
10^4
10^6
10^8
10^{10}
10^{12}
10^{14}
10^{15}
E [eV]

SNR age

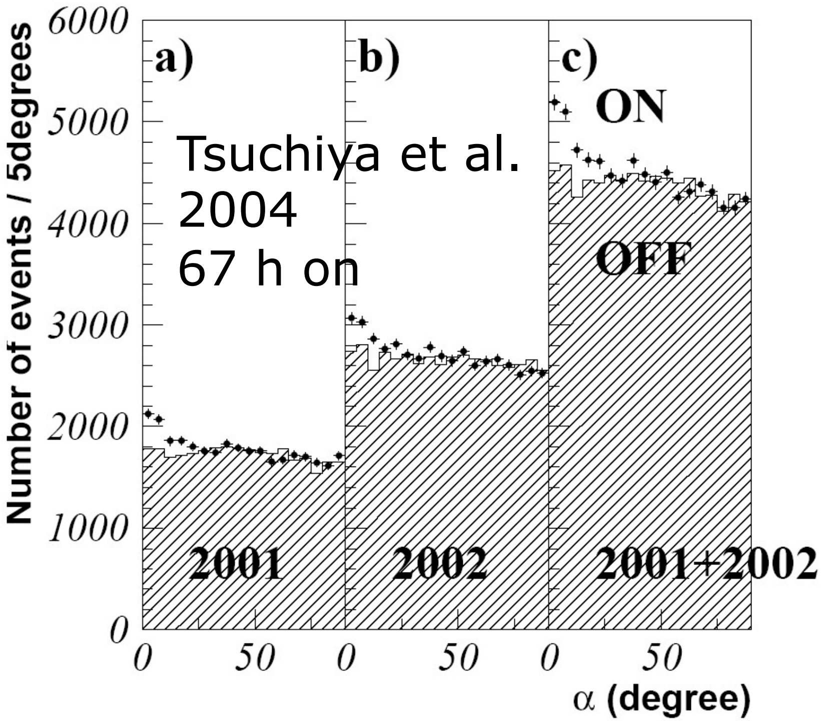


arXiv:1508.05190

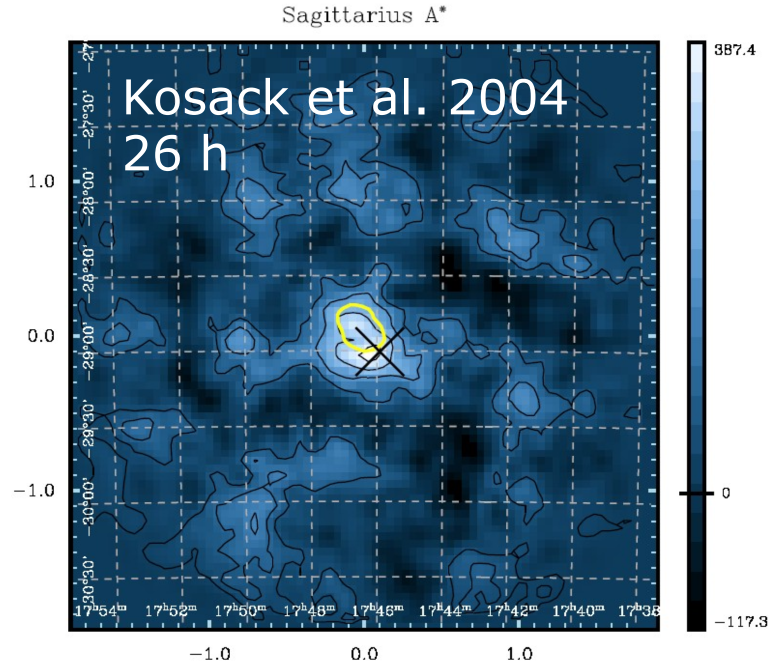
The Galactic center



TeV gamma rays from GC



CANGAROO
2001/2002
> 10 σ



Whipple
1995 – 2003
3.7 σ

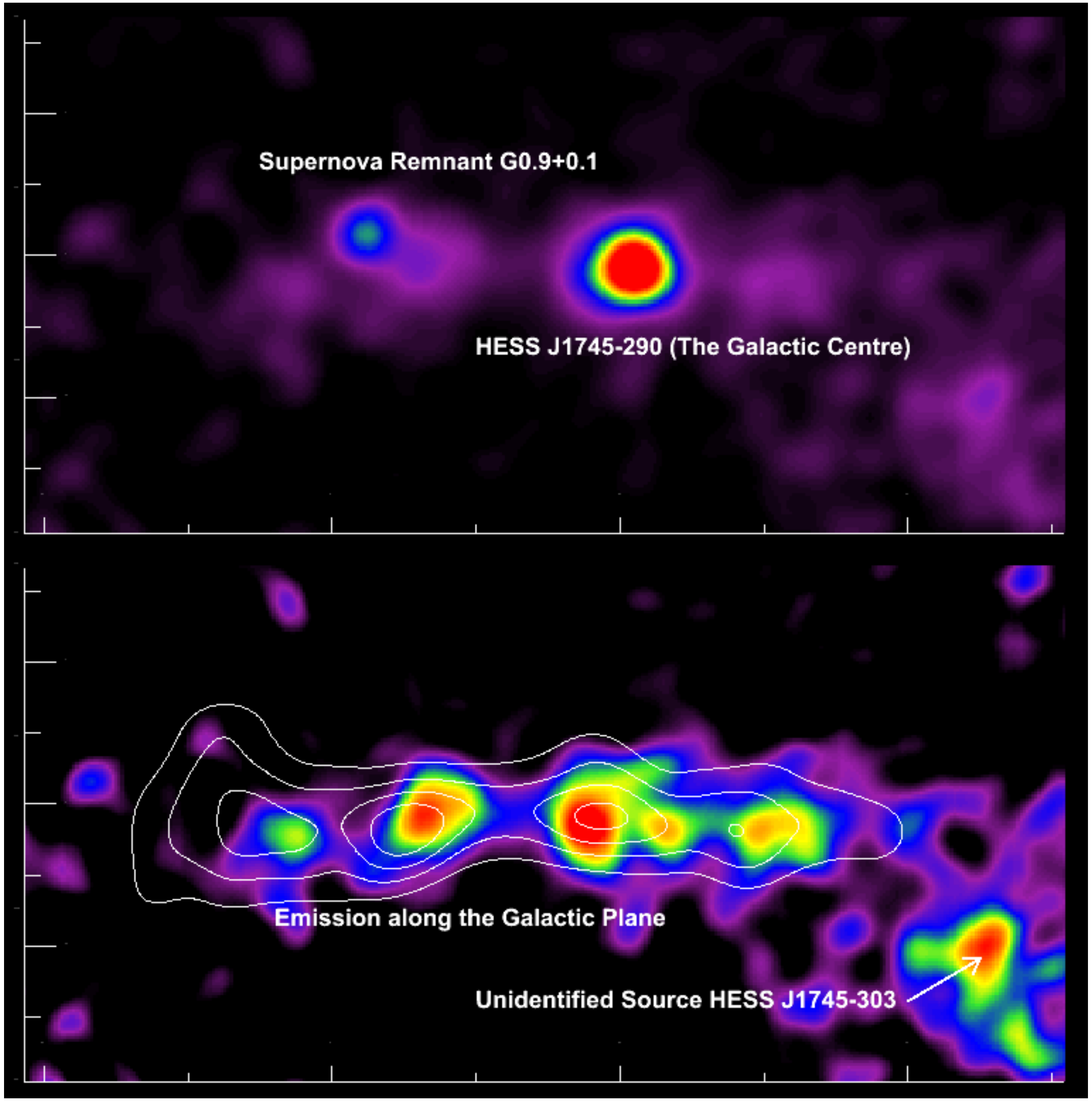
Point source (on 0.3° resolution scale)

Galactic Center

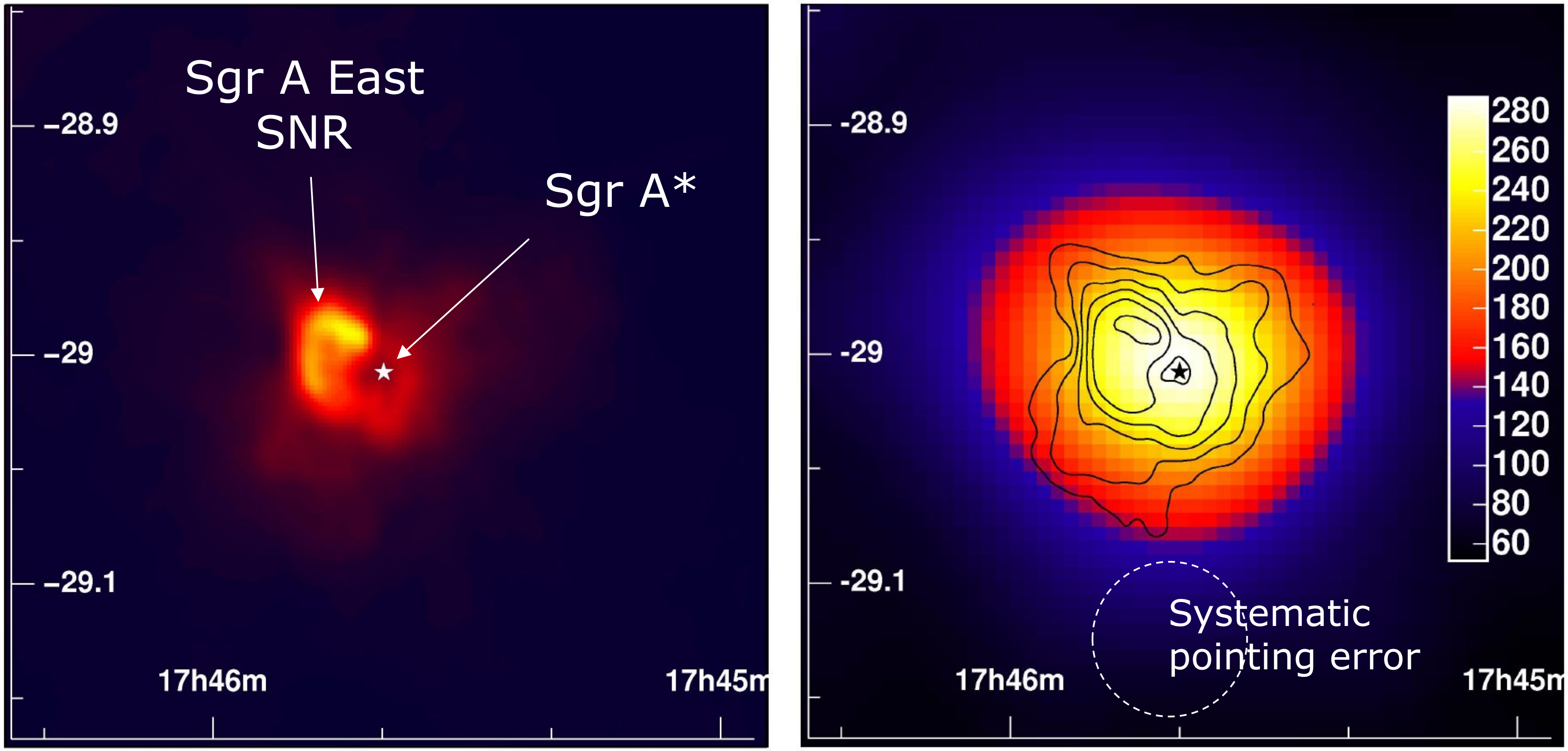
Sgr A

Diffuse emission

Nature, Feb. 9th 2006

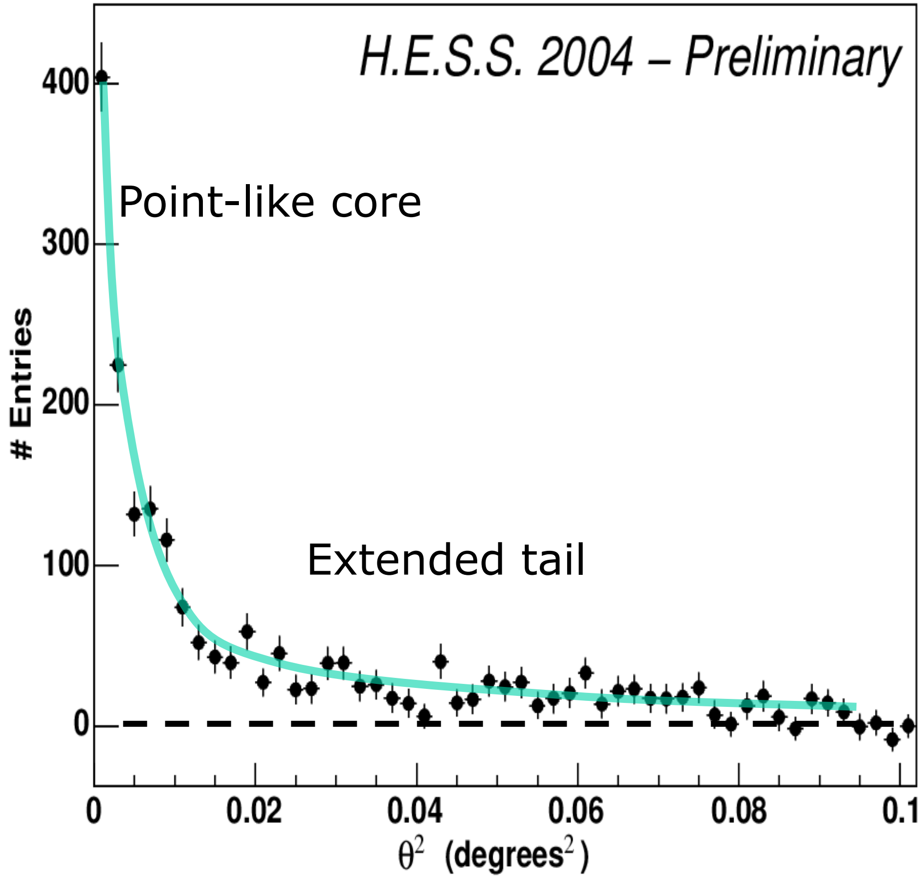


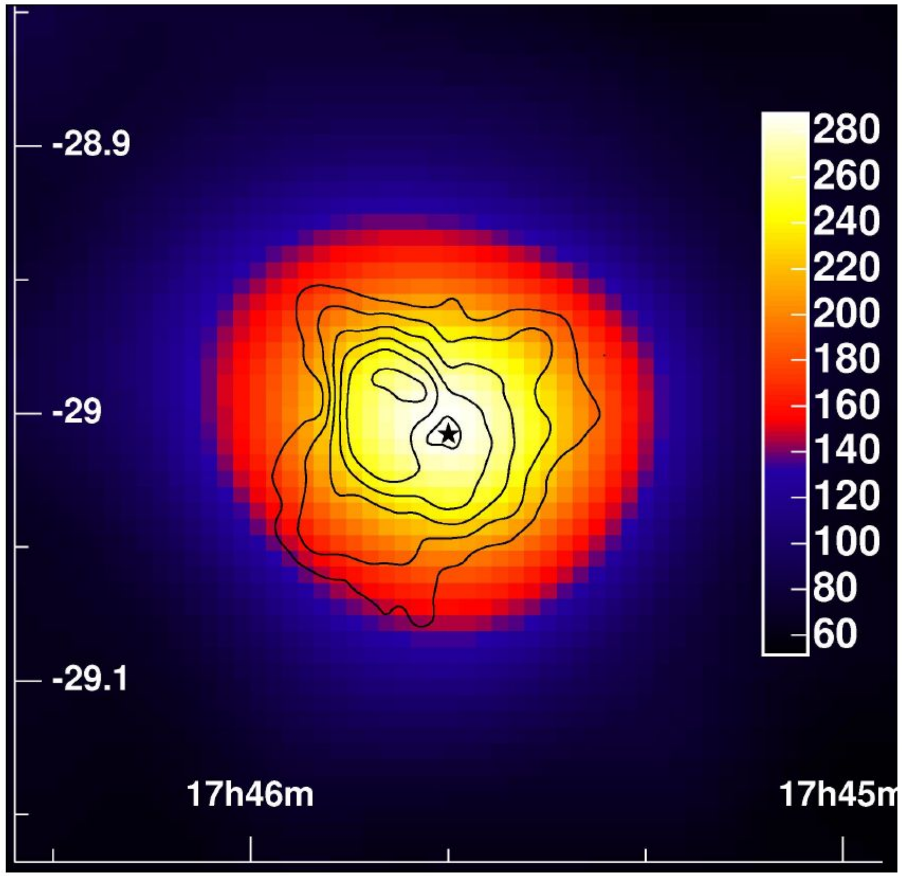
Sagittarius A



TeV H.E.S.S.

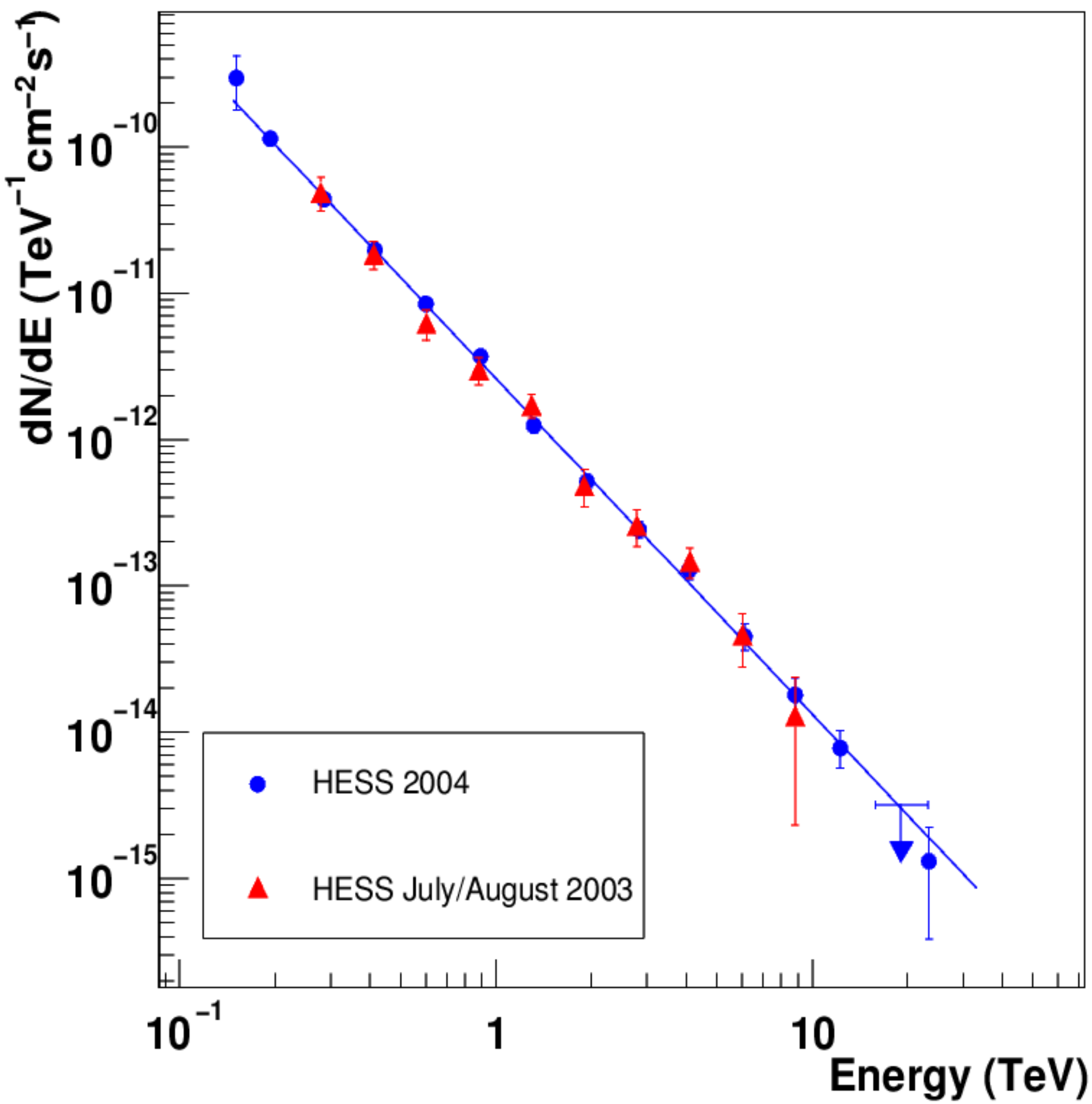
Sagittarius A





TeV H.E.S.S.

Gamma ray spectrum

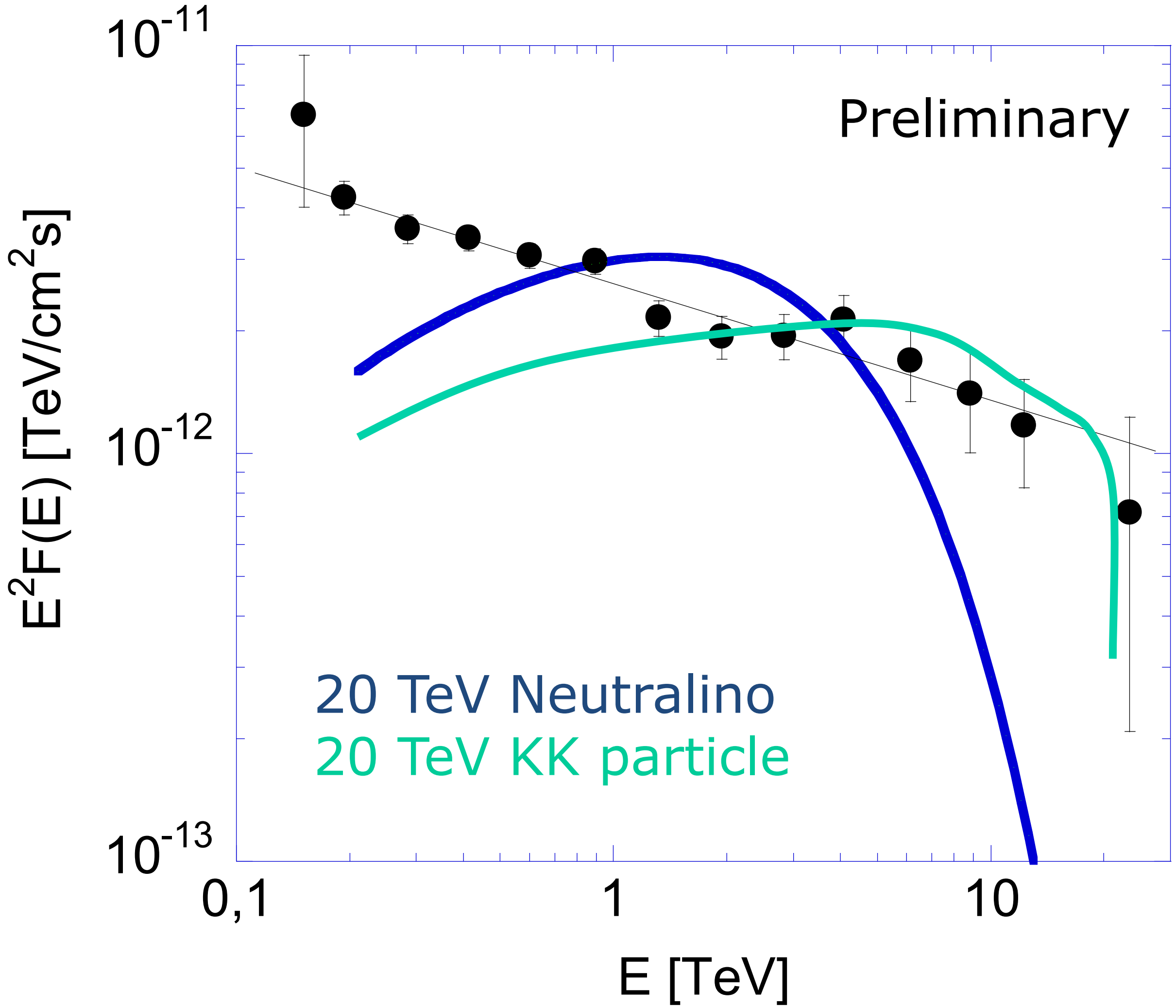


- Power law, index 2.3
- No significant variability
  - on year scale
  - on month scale
  - on day scale
  - on hour scale
  - on minute scale

Origin ?

- Sgr A East SNR as proton accelerator ?
- Decaying UHE neutrons ?
- Shocks in Sgr A* accretion flow or wind ?
- Curvature radiation of UHE protons near Sgr A*
- **Dark matter annihilation ?**
  - "Normal" SUSY neutralinos
  - Kaluza-Klein particles
  - SUSY messenger sector
- …

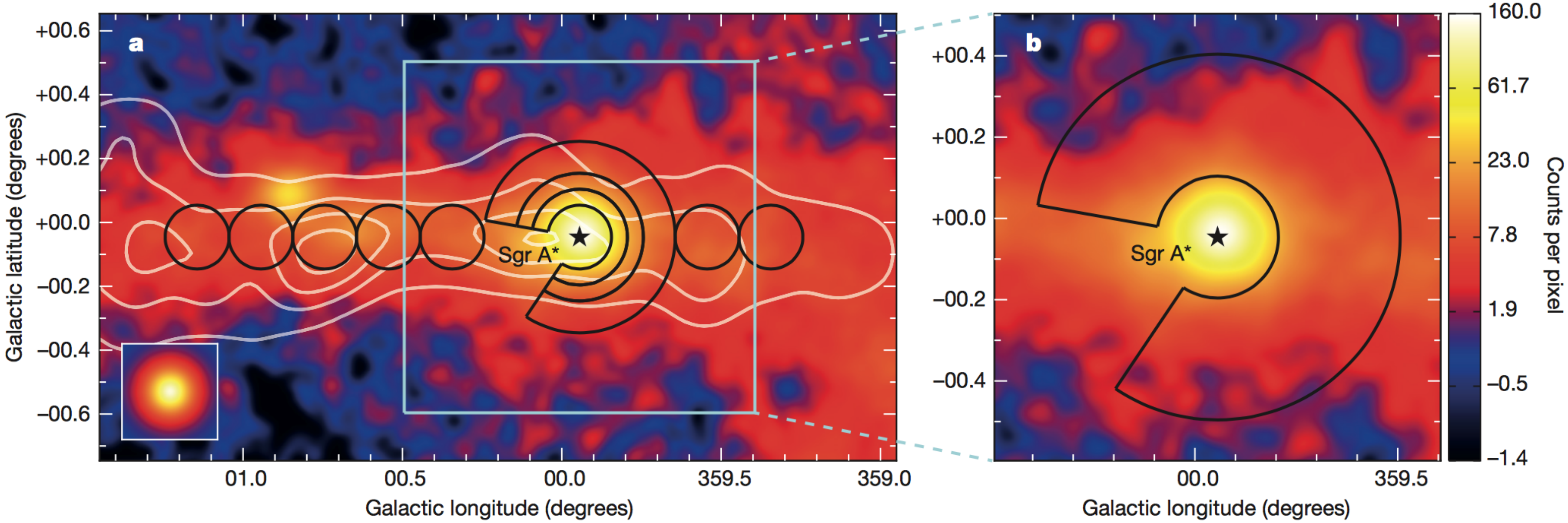
Dark matter annihilation ?



For pure DM origin

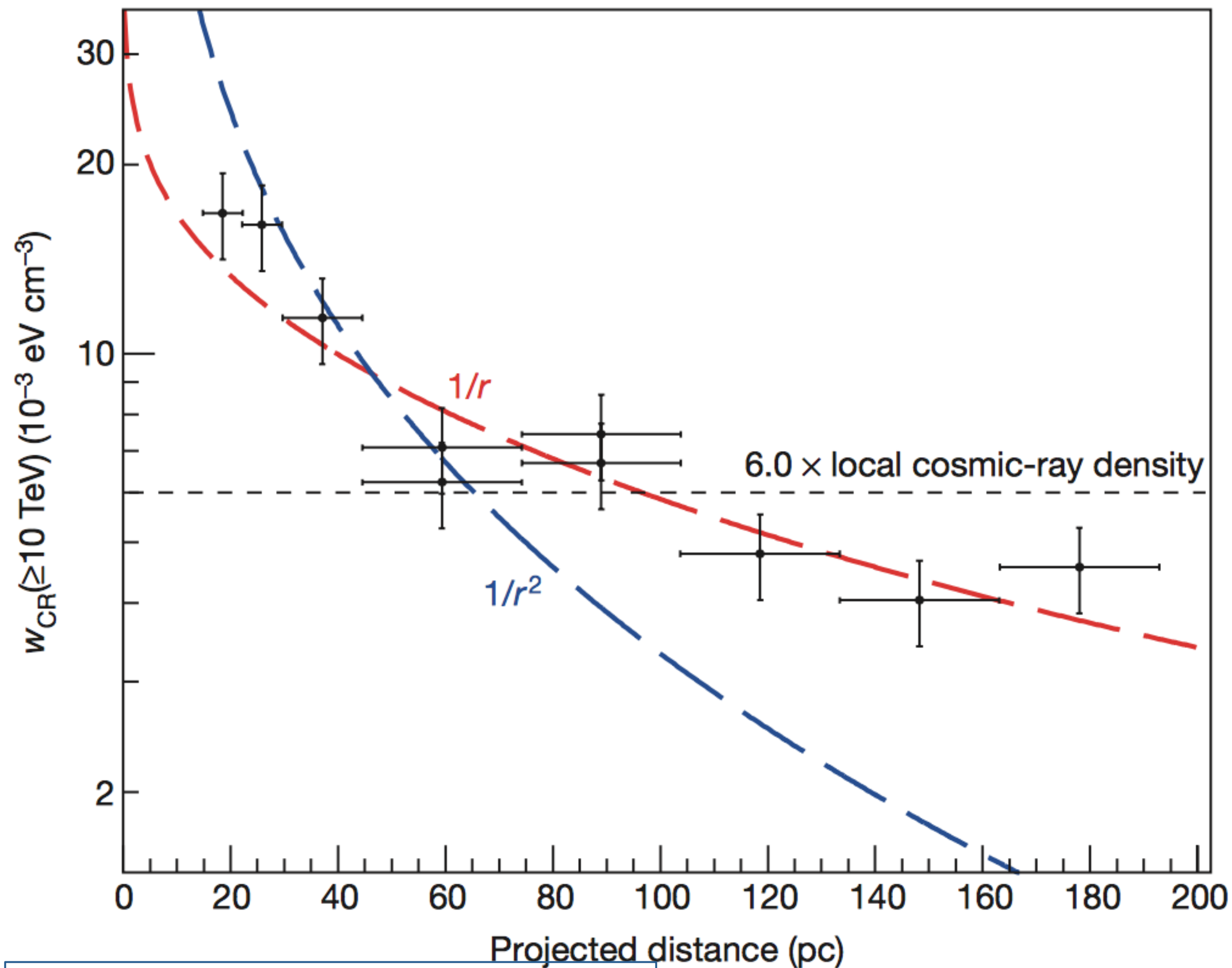
- rather large mass
- large x-section or density
- unusual spectrum or superposition of spectra

The “Pevatron”



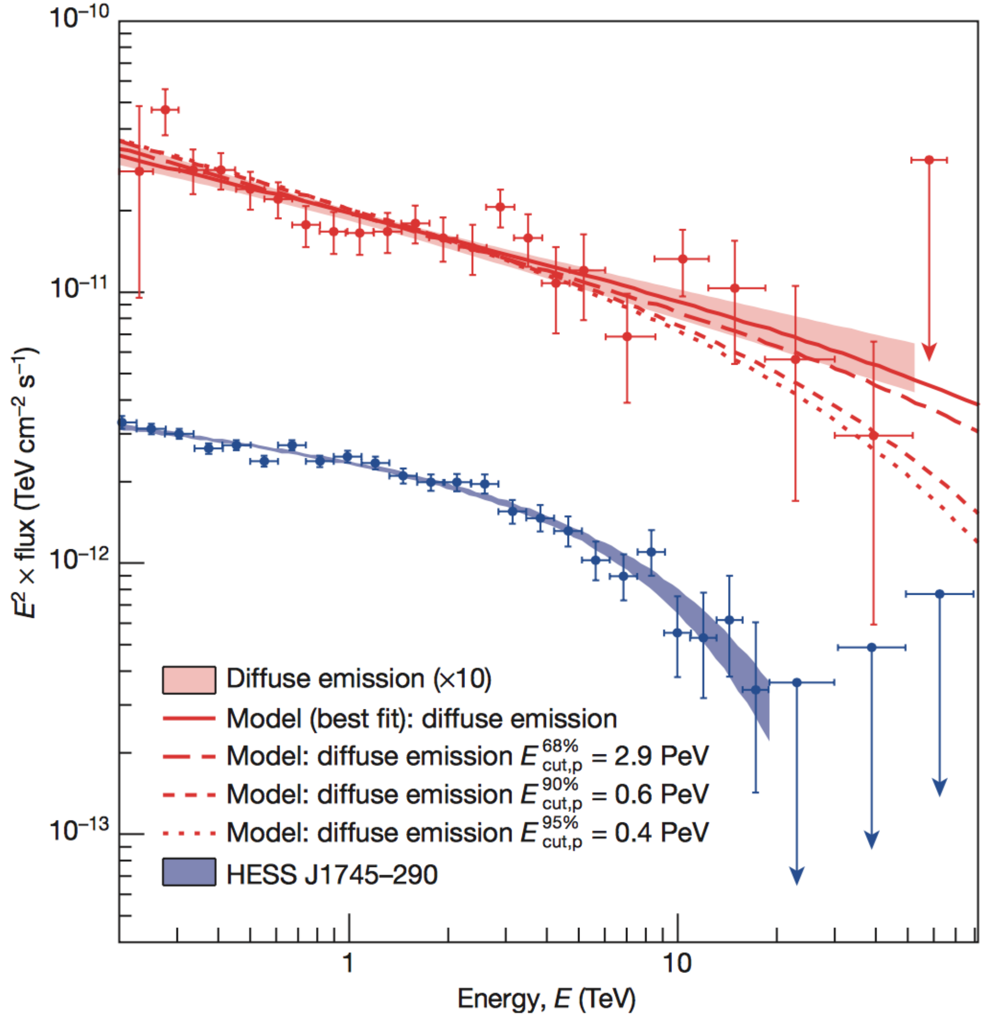
Abramovski et al. (2016)

The "Pevatron"



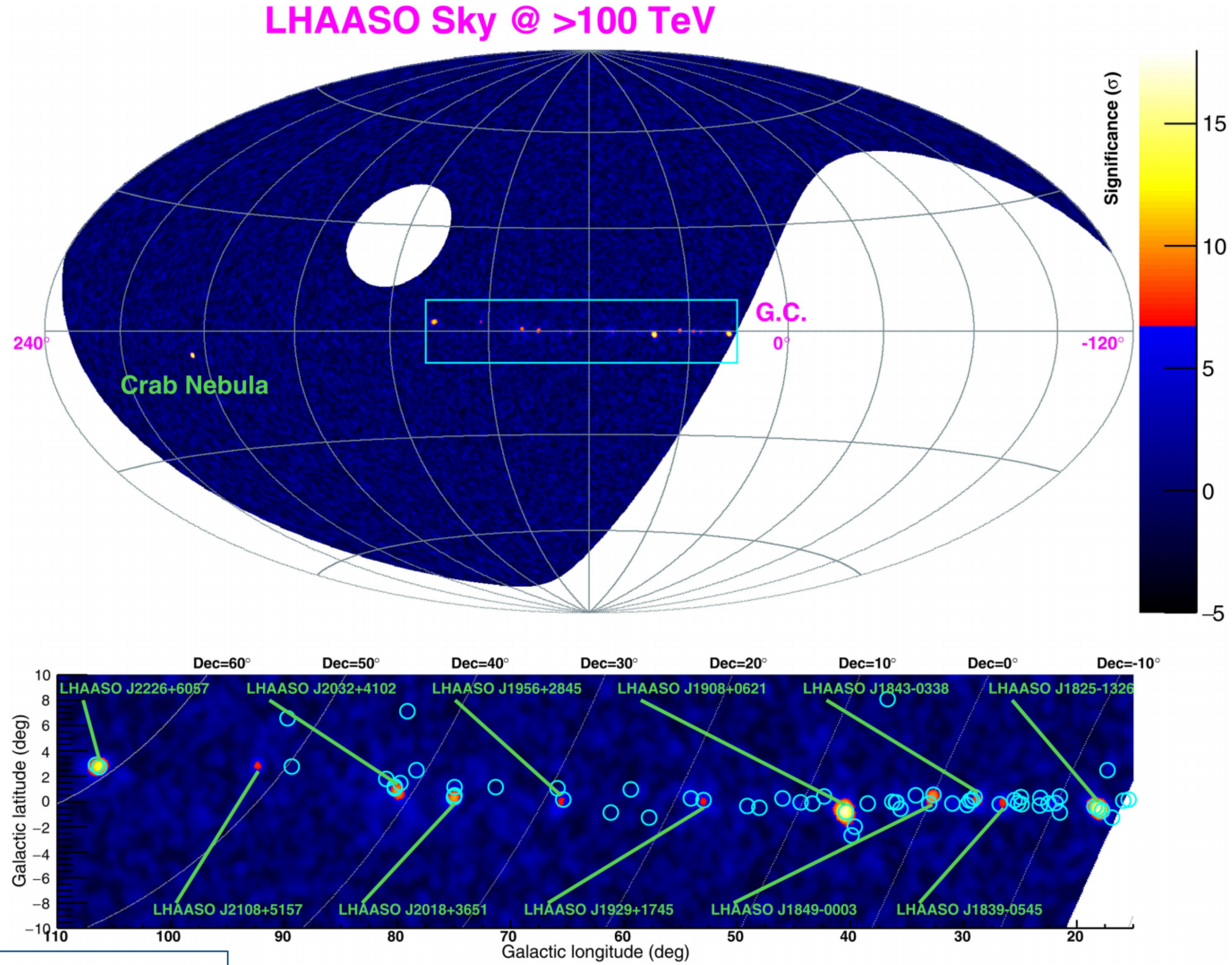
Abramovski et al. (2016)

The "Pevatron"



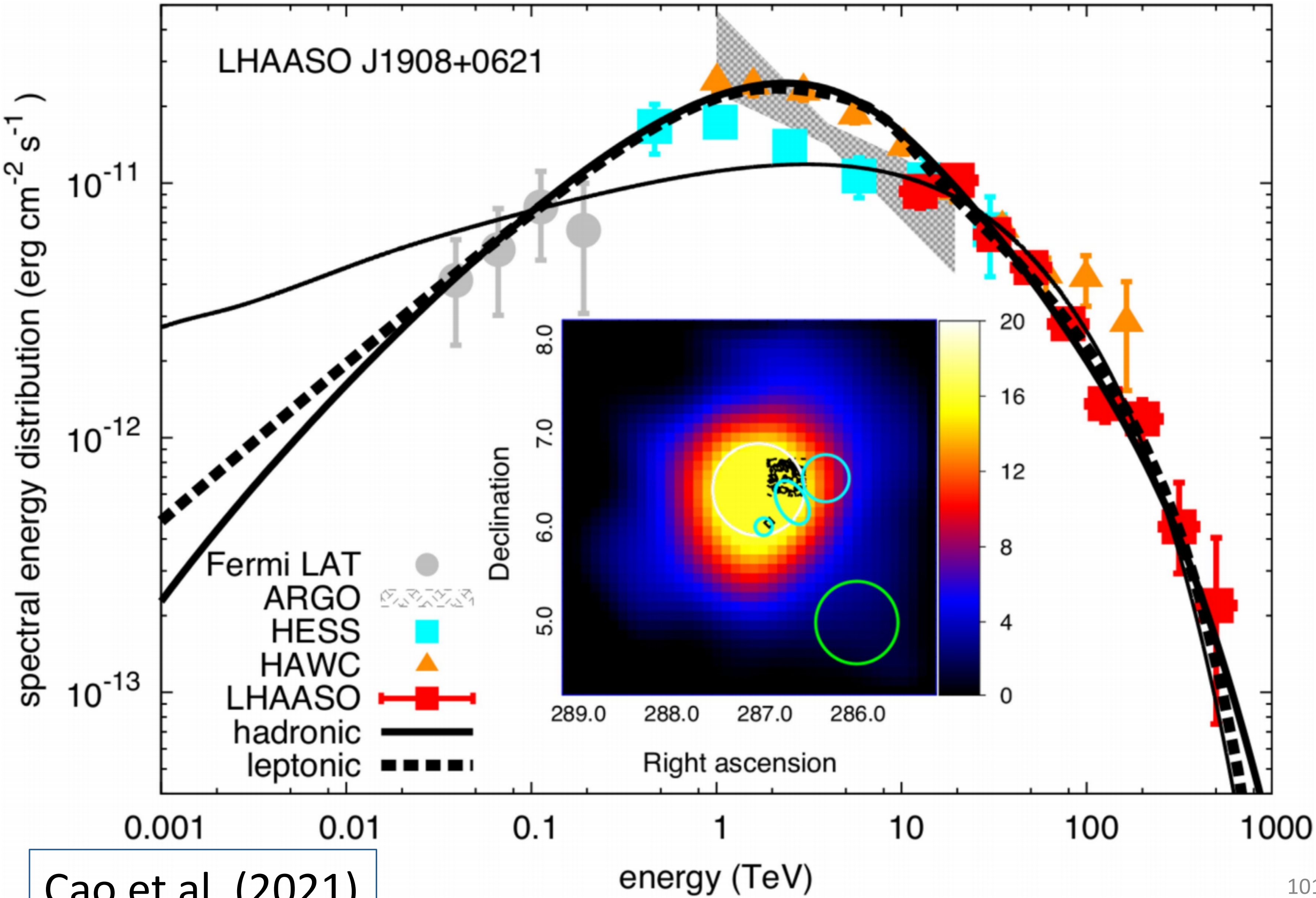
Abramovski et al. (2016)

LHAASO Pevatrons



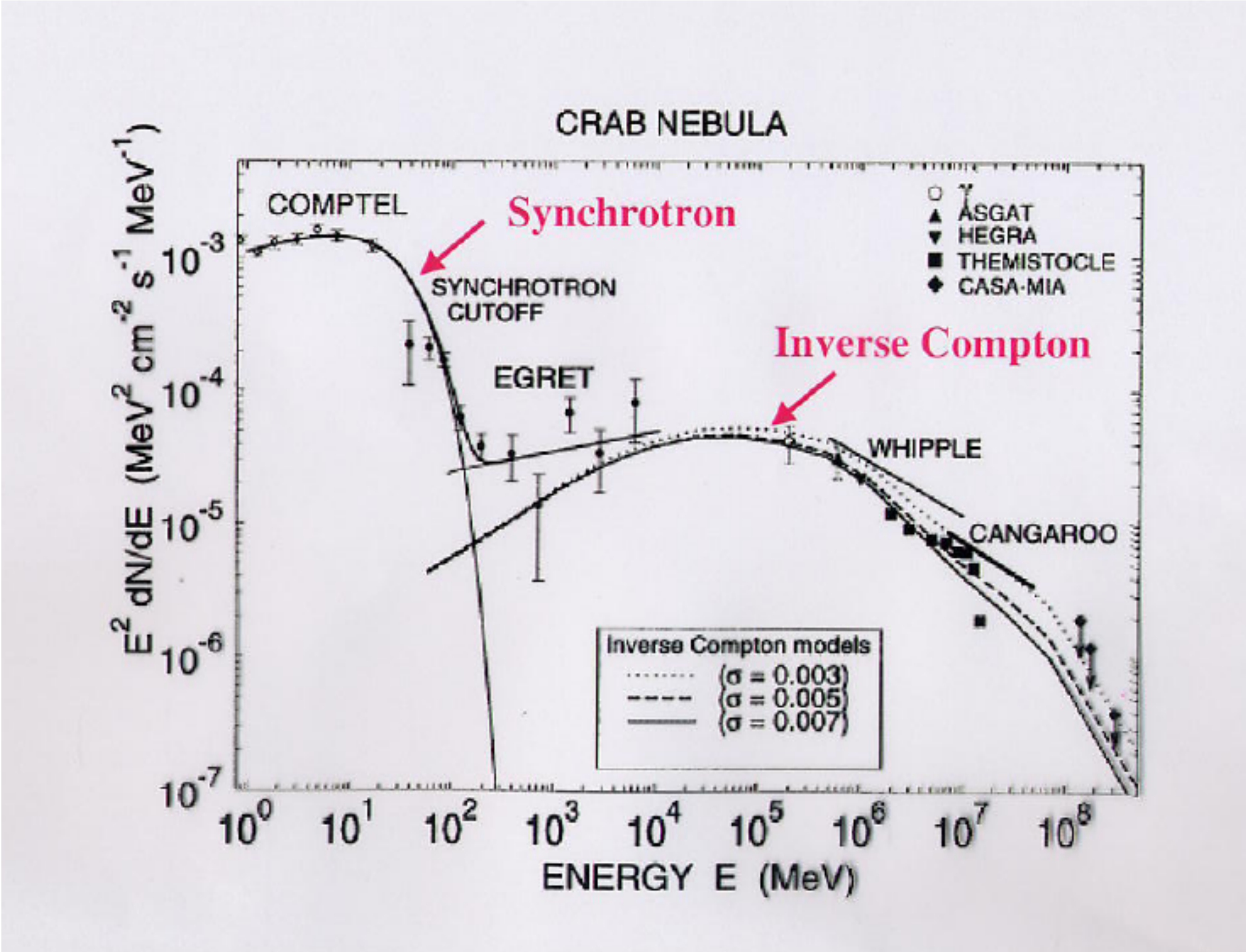
Cao et al. (2021)

LHAASO Pevatrons



Cao et al. (2021)

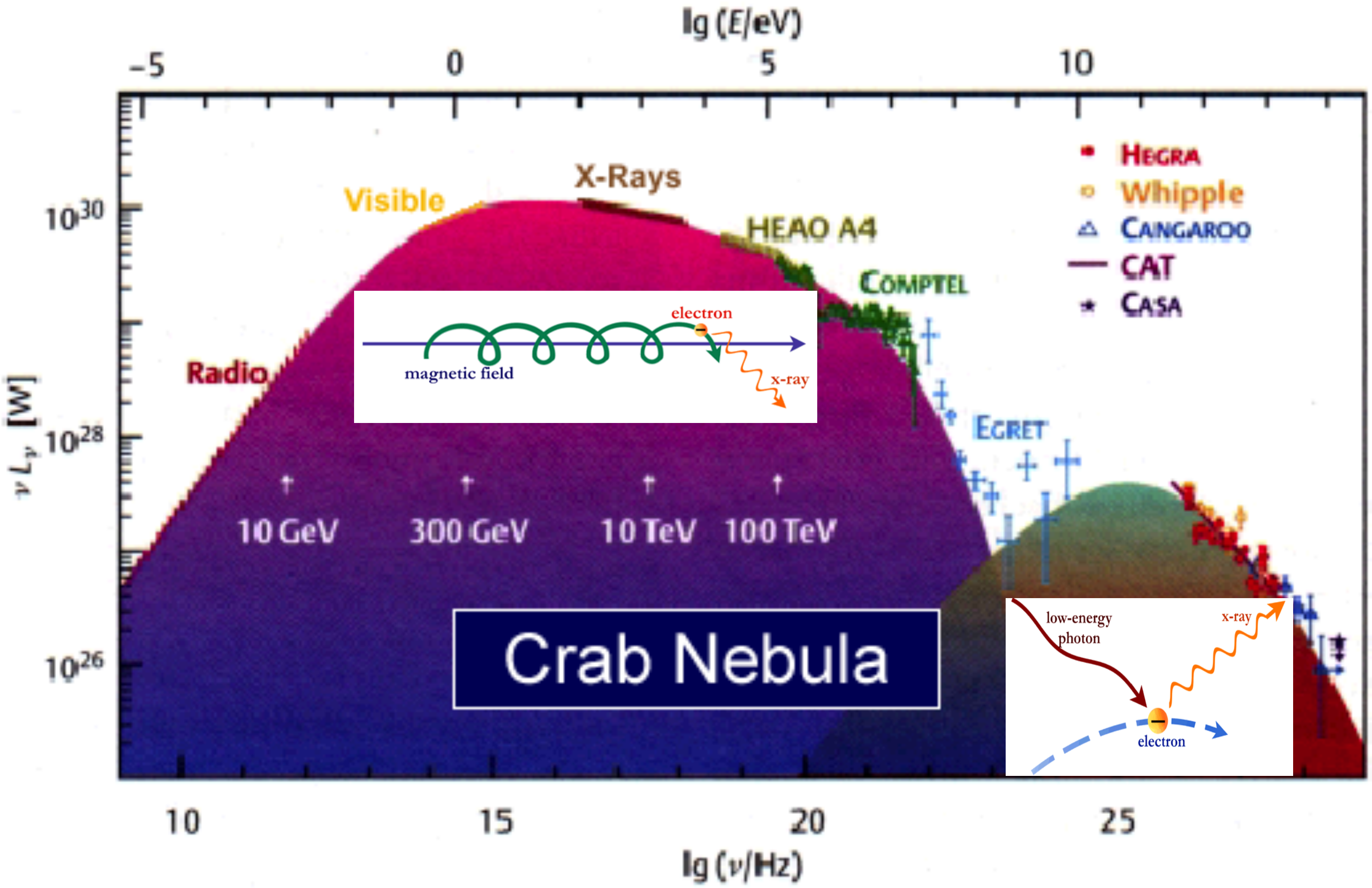
Crab Nebula



CRAB NEBULA
COMPTEL
Synchrotron
SYNCHROTRON
CUTOFF
EGRET
Inverse Compton
WHIPPLE
CANGAROO
ASGAT
HEGRA
THEMISTOCLE
CASA-MIA
Inverse Compton models
(σ = 0.003)
(σ = 0.005)
(σ = 0.007)
E² dN/dE (MeV² cm⁻² s⁻¹ MeV⁻¹)
ENERGY E (MeV)

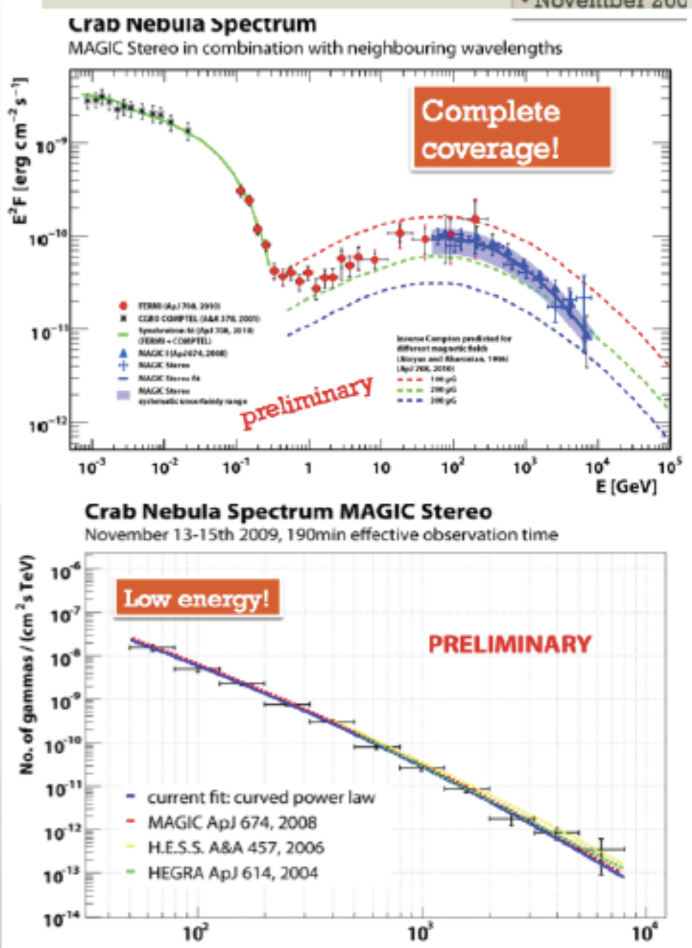
A (minimal) standard model: what do we expect?

Explains most of the observations, not necessarily the most interesting…



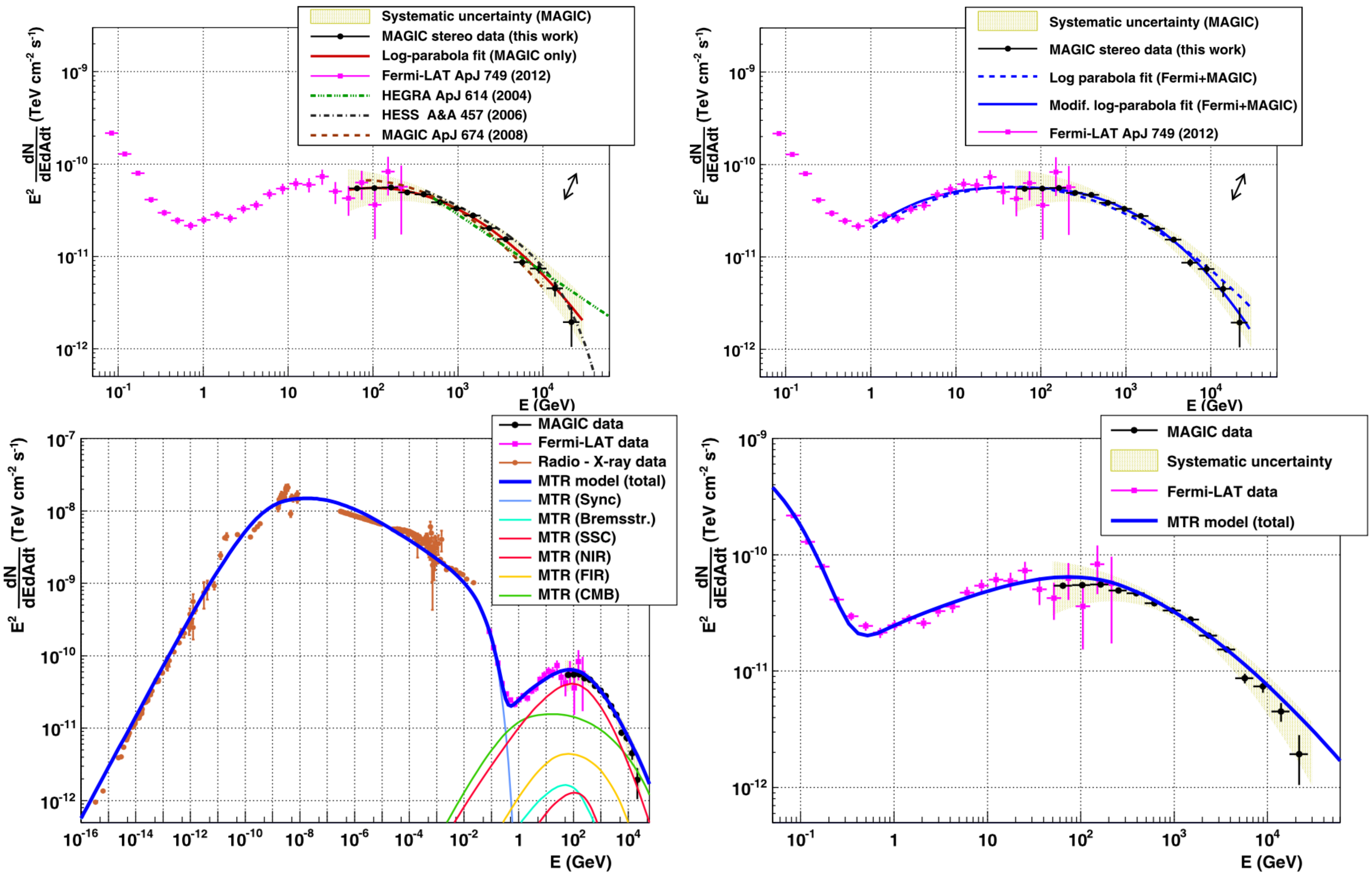
The Crab PWN

+ Crab Nebula HE-VHE coverage



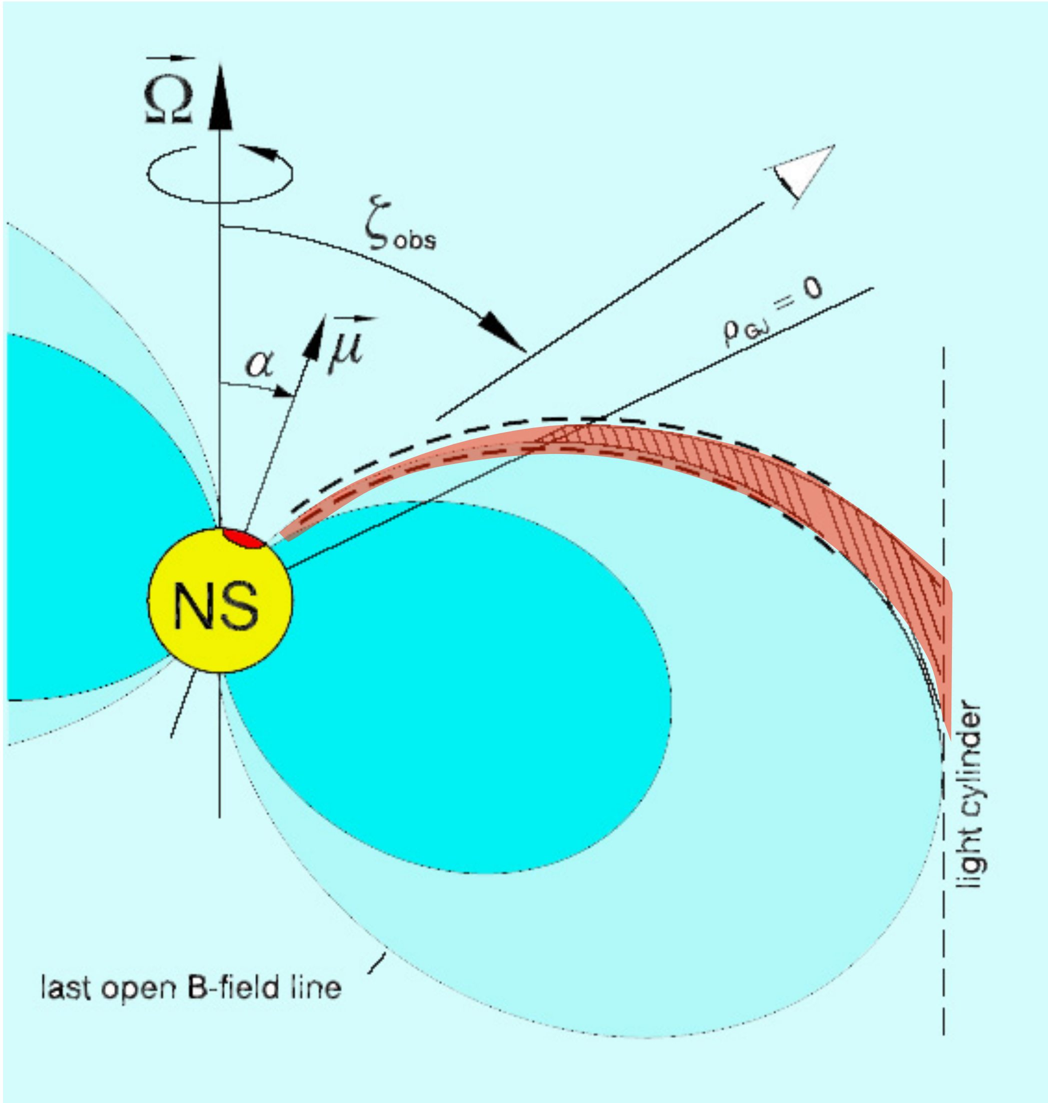
- 3.2 h of good data in Nov. 2010
- Complete overlap with Fermi
- Spectrum measured from 40-50 GeV to 30-40 TeV
- Test source for M-stereo
  - Technical Crab paper in prep.
  - Physics Crab paper in prep.
- Improved estimation of HE bump will be provided
- Regarding first HE flare (Agile, Fermi), MAGIC-stereo did not detect significant VHE flares (ATEL#2967, sep.2010)
- We monitor Fermi data for flares

The Crab Nebula



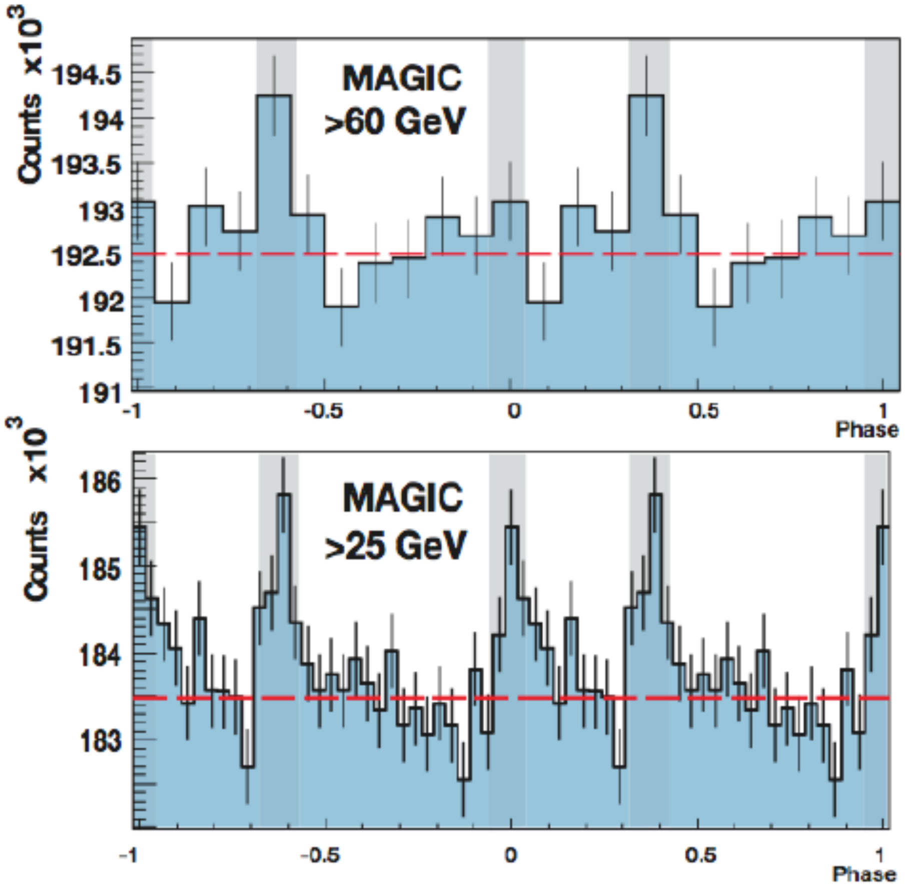
Aleksic et al. (2015)

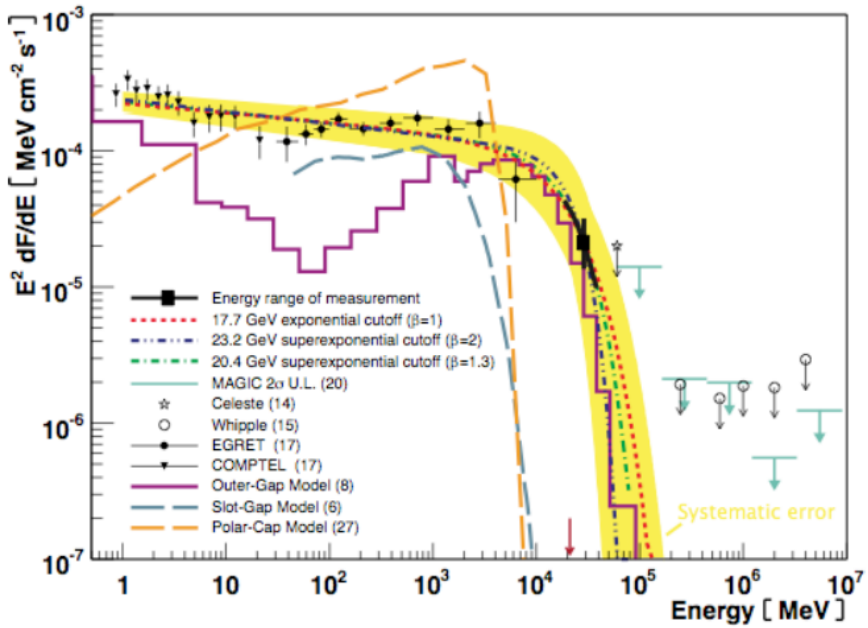
Pulsars: GR & Electrodynamics



from J. Dyks et al.

MAGIC – the Crab PSR

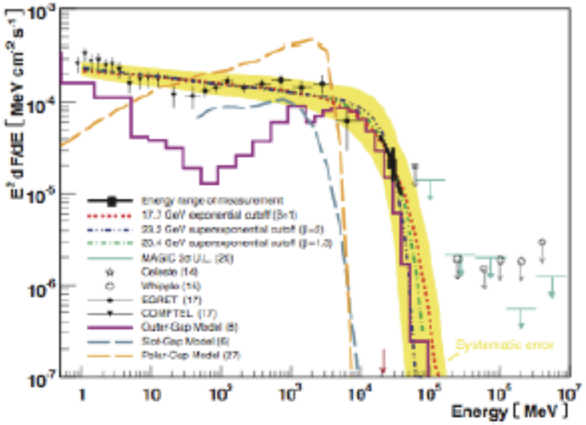




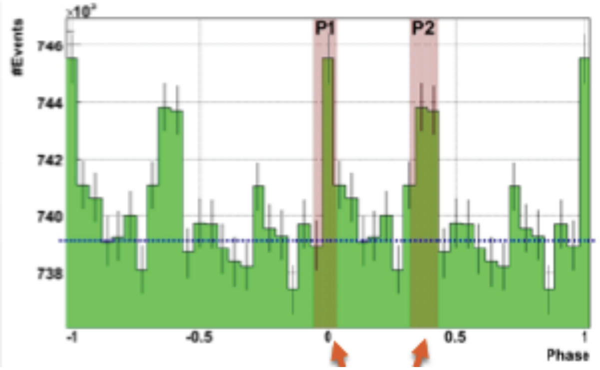
Albert et al. 2008

The Crab PSR

+ The Crab still beats.

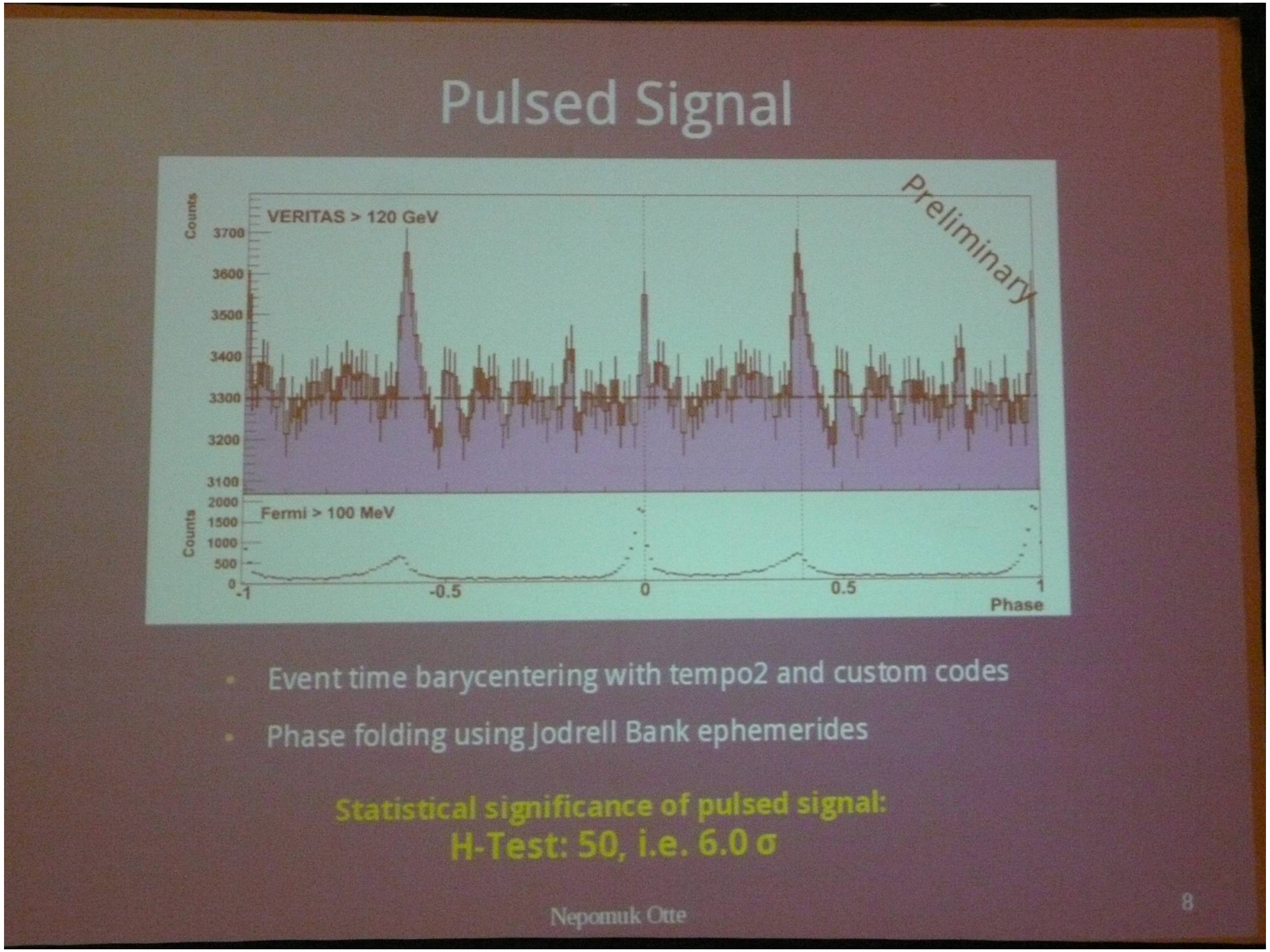


Crab Nebula pulsar phaseogram
(Oct 2007 – Jan 2009)

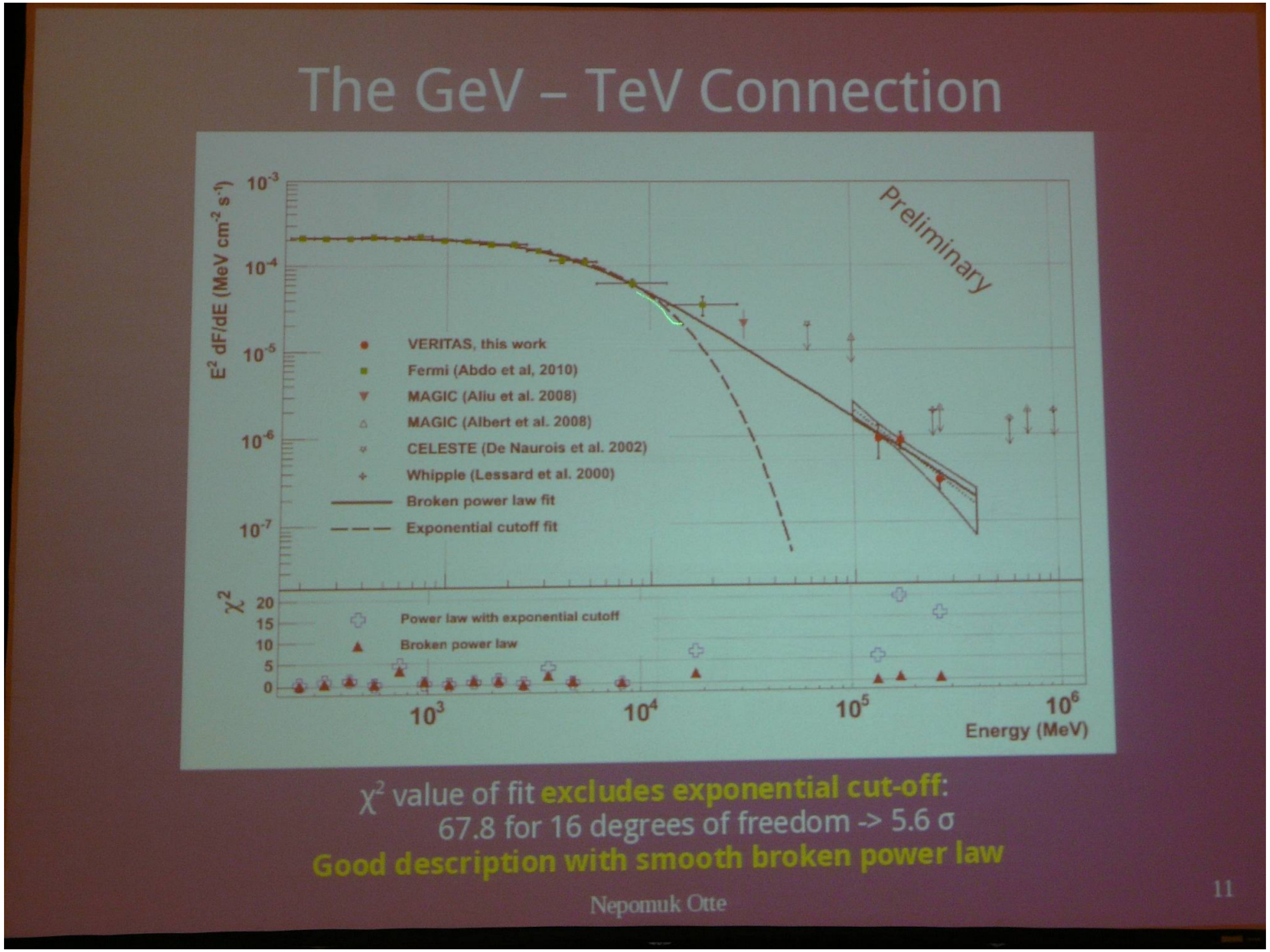


- To reach energy as low as 25 GeV special "sumtrigger" used
- In 2008, Crab pulsar detected at VHE (Science 322 (2008) 21)
- Again observed with M-stereo: publication in draft →see next ICRC
- Now used Fermi phaseogram rather than EGRET one
- Veritas showed here the detection above 100 GeV → see Ragan's talk

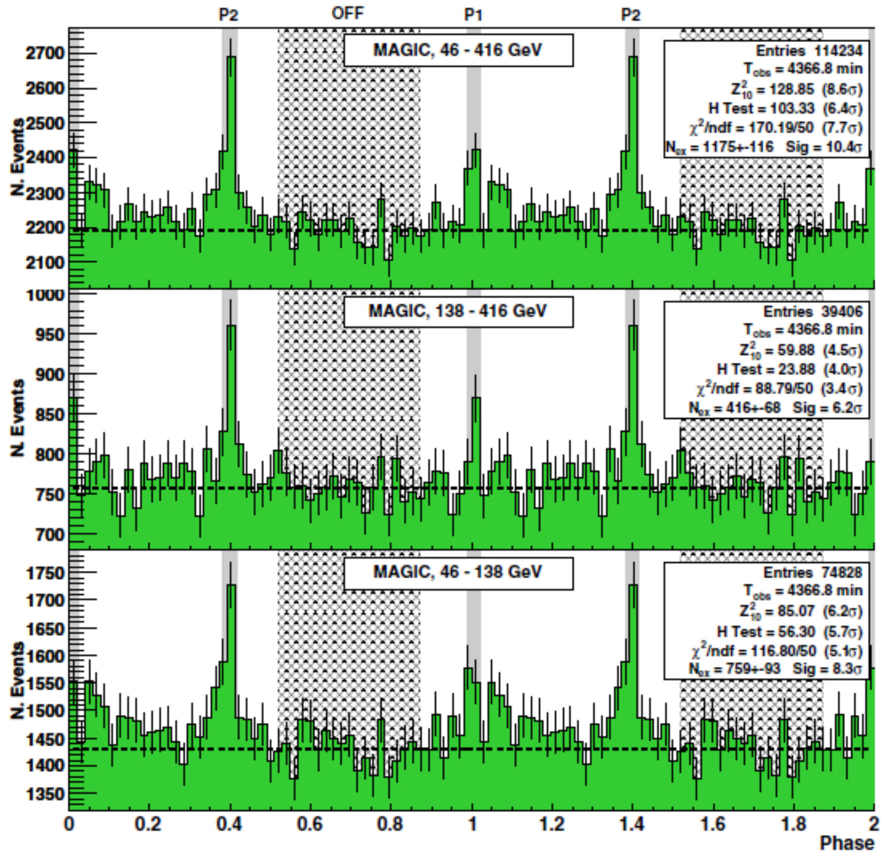
The Crab with VERITAS



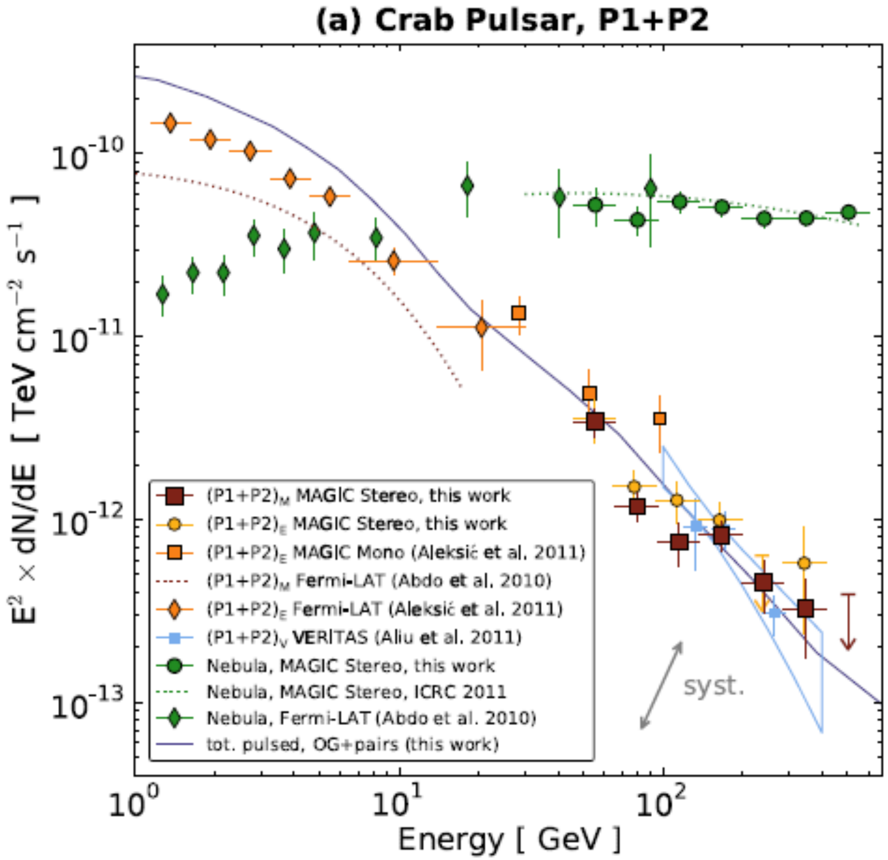
The Crab with VERITAS



Crab PSR

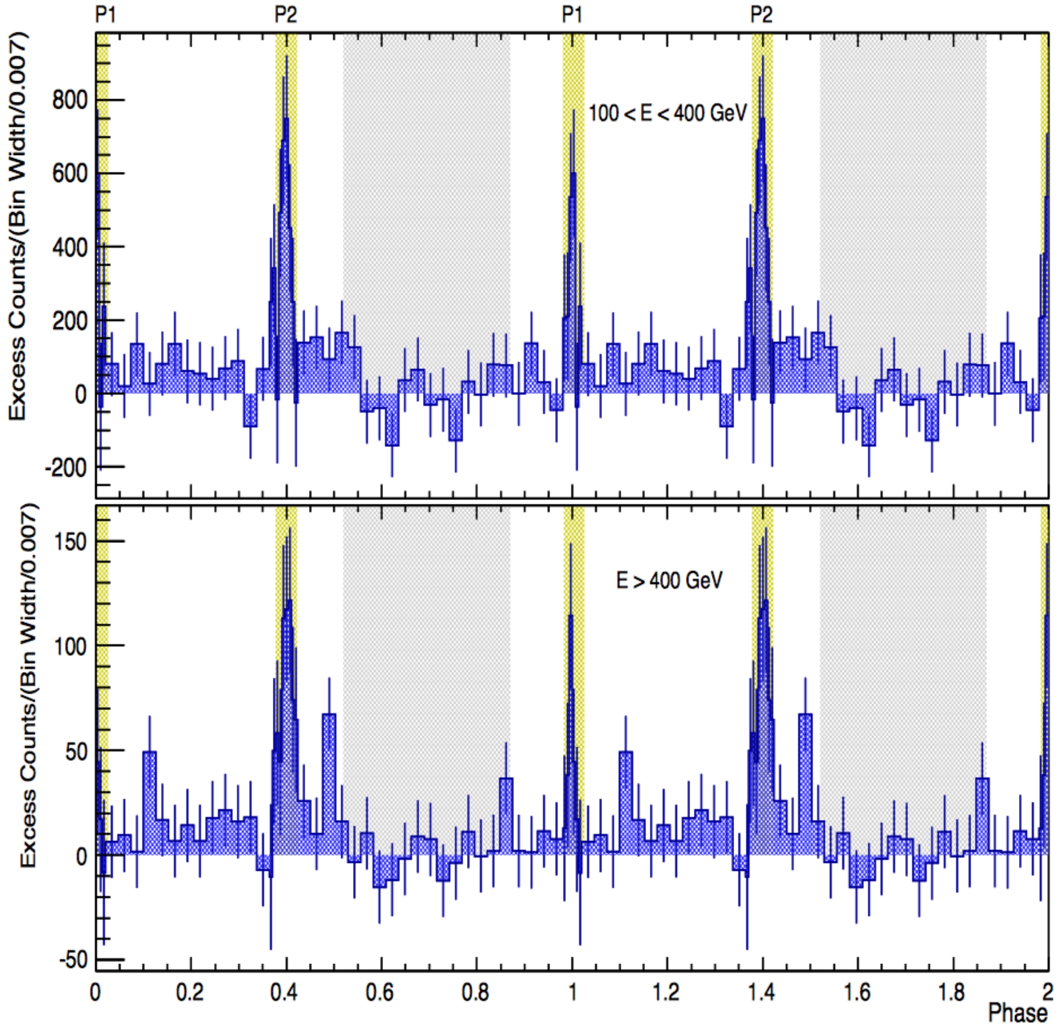


P2
OFF
P1
P2
MAGIC, 46 - 416 GeV
Entries 114234
MAGIC, 138 - 416 GeV
Entries 39406
MAGIC, 46 - 138 GeV
Entries 74828
N. Events
Phase



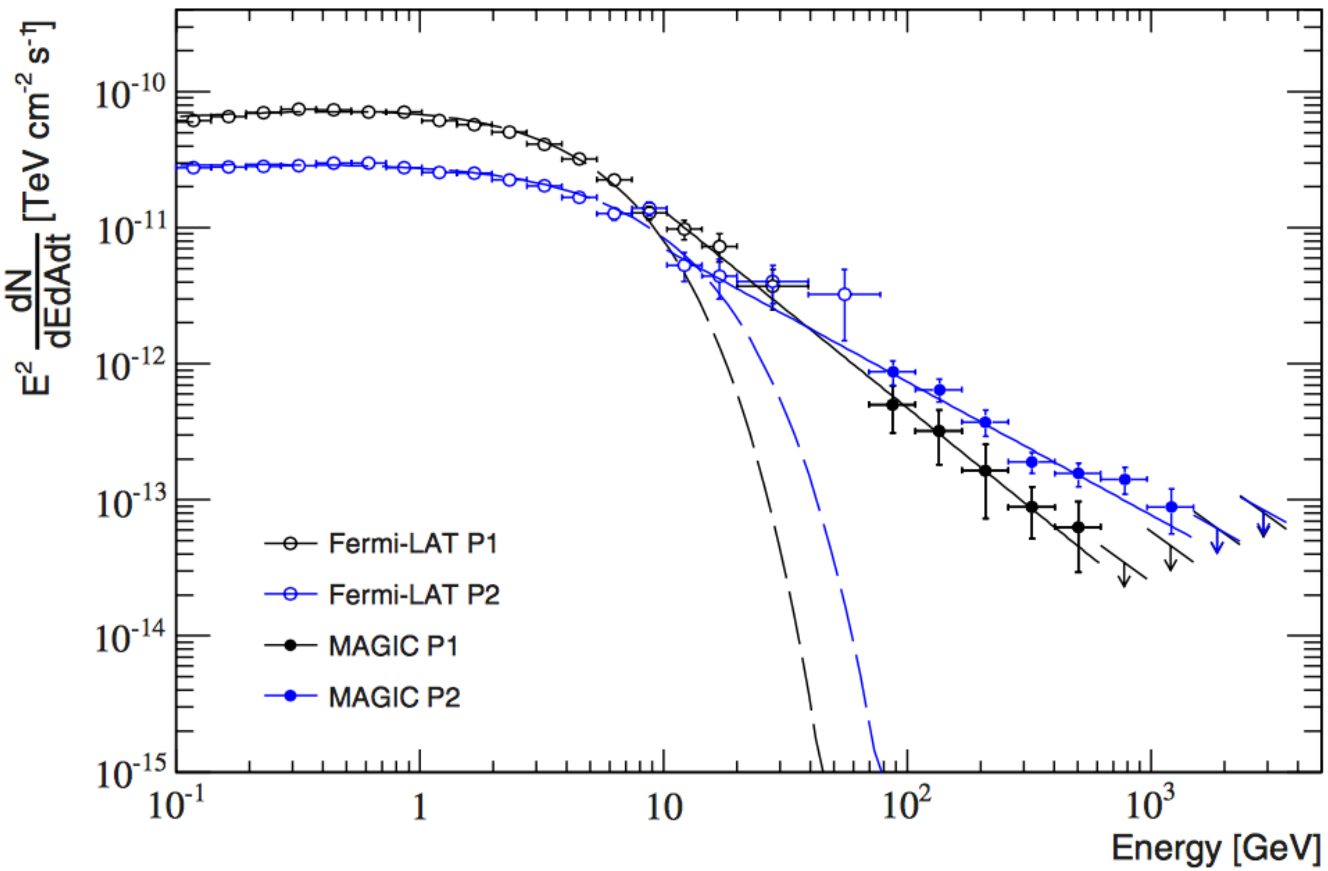
(a) Crab Pulsar, P1+P2
(P1+P2)M MAGIC Stereo, this work
(P1+P2)E MAGIC Stereo, this work
(P1+P2)E MAGIC Mono (Aleksić et al. 2011)
(P1+P2)M Fermi-LAT (Abdo et al. 2010)
(P1+P2)E Fermi-LAT (Aleksić et al. 2011)
(P1+P2)V VERITAS (Aliu et al. 2011)
Nebula, MAGIC Stereo, this work
Nebula, MAGIC Stereo, ICRC 2011
Nebula, Fermi-LAT (Abdo et al. 2010)
tot. pulsed, OG+pairs (this work)
syst.
Energy [GeV]

Crab PSR



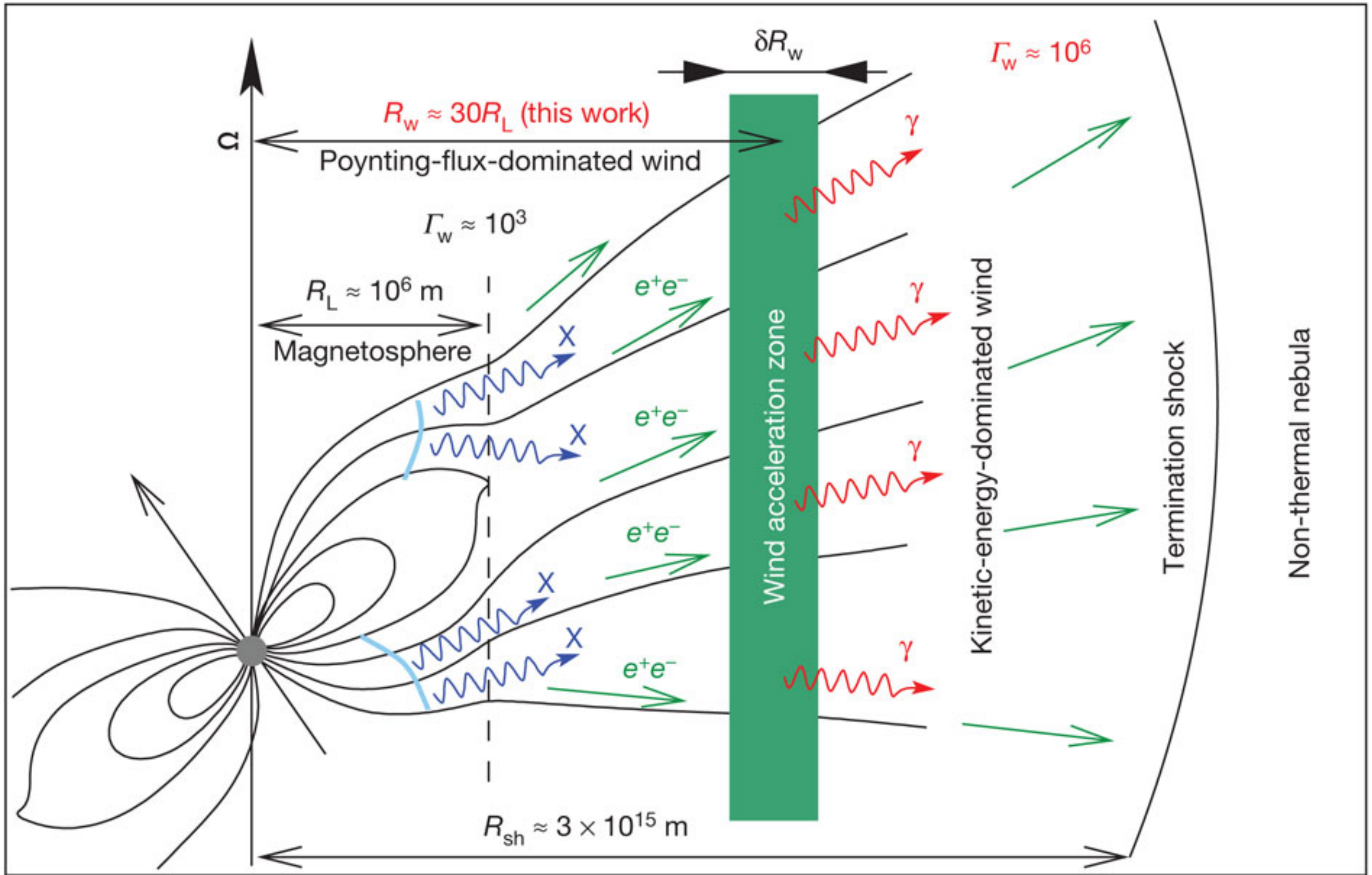
Ansoldi et al. (2016)

Crab PSR



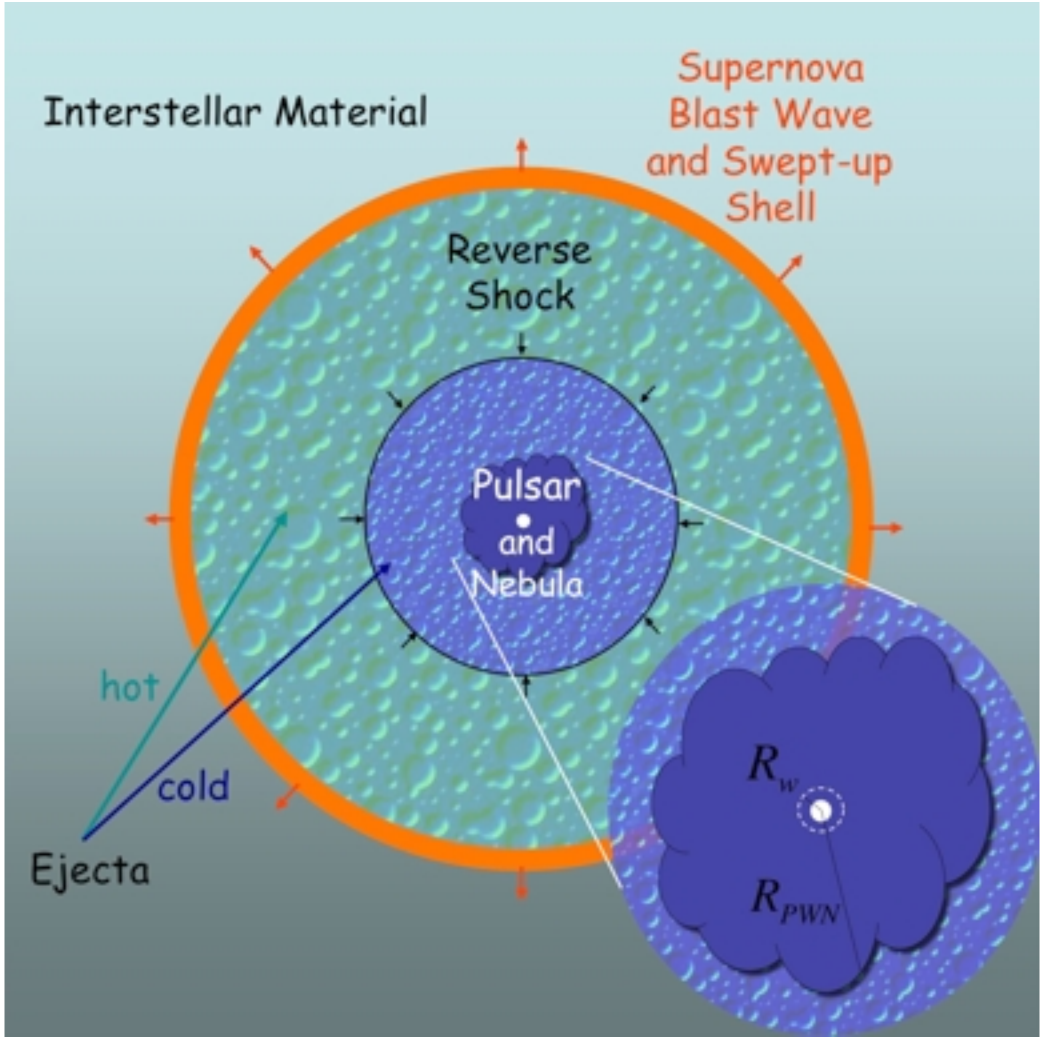
Ansoldi et al. (2016)

Crab PSR

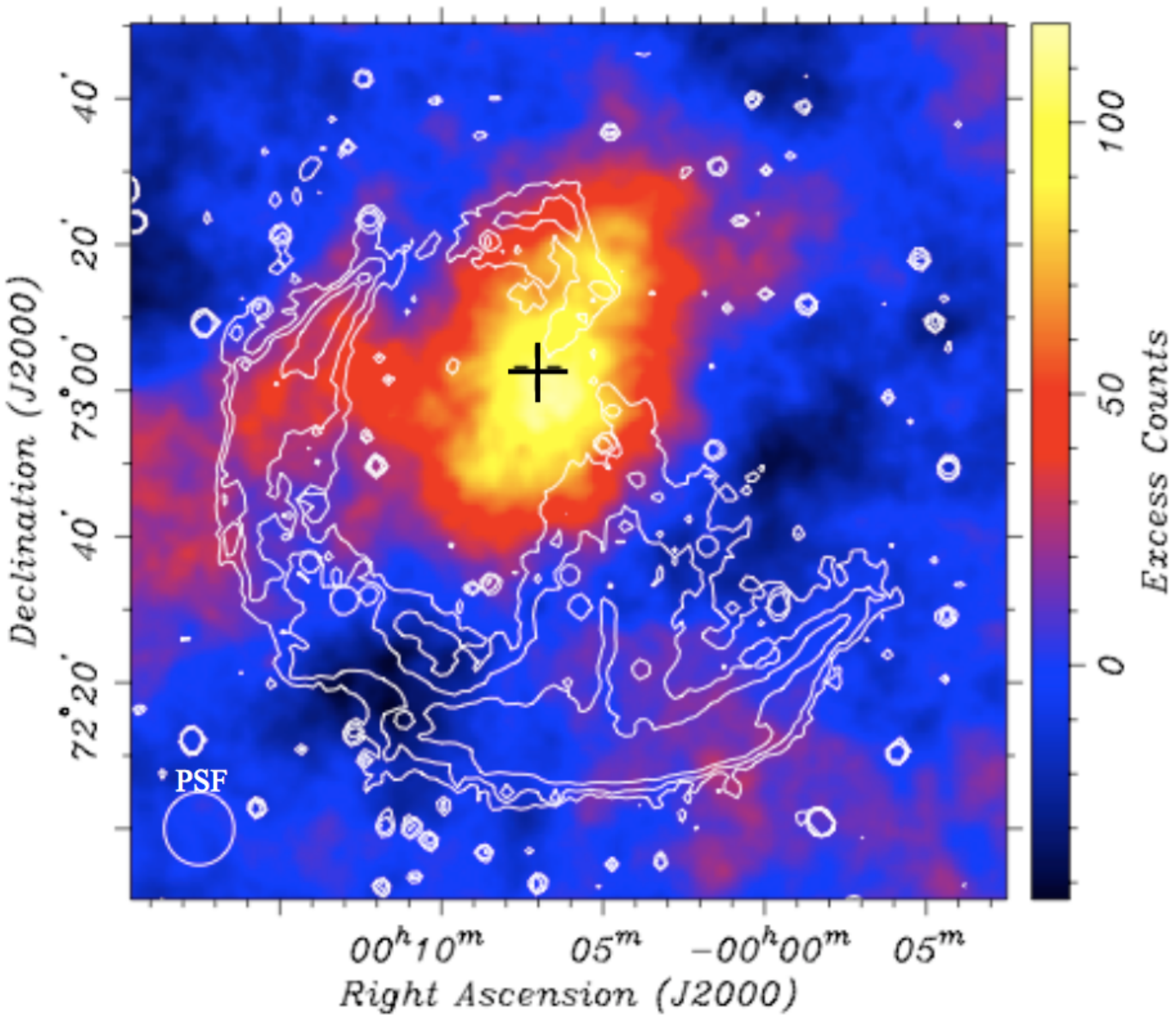


Aharonian et al. (2012)

Pulsar Wind Nebulae

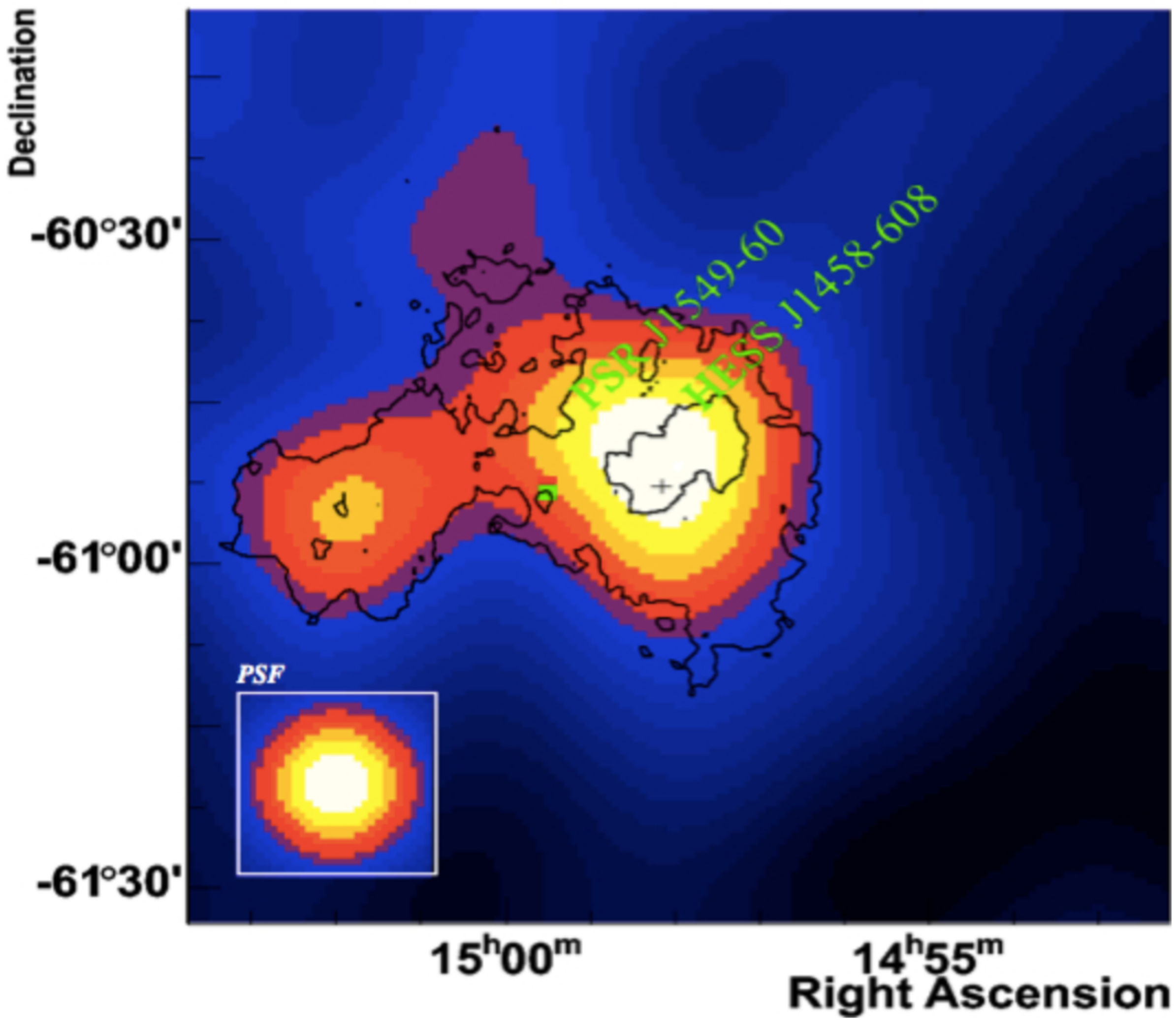


CTA1 PWN



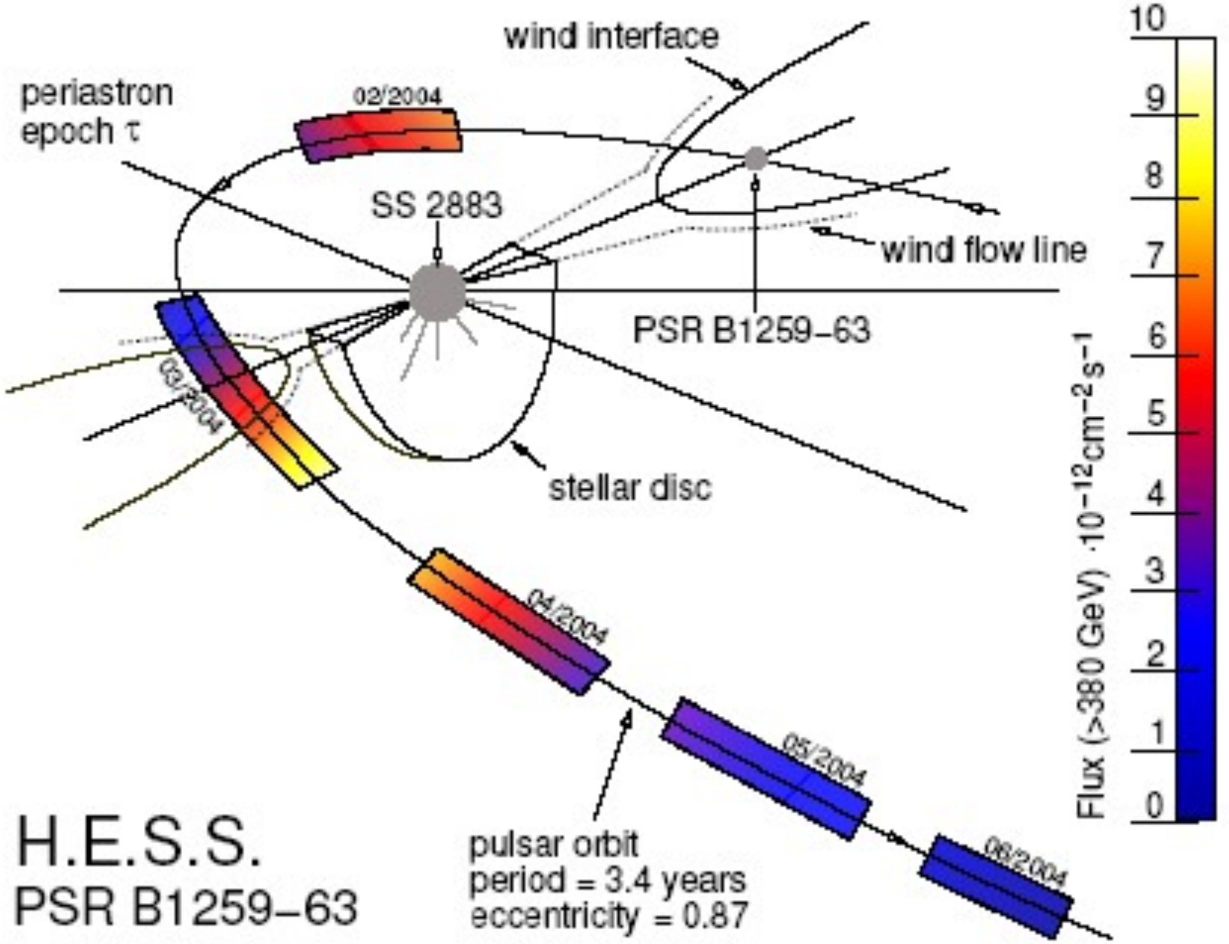
PSF
Declination (J2000)
Right Ascension (J2000)
Excess Counts

Pulsar Wind Nebulae

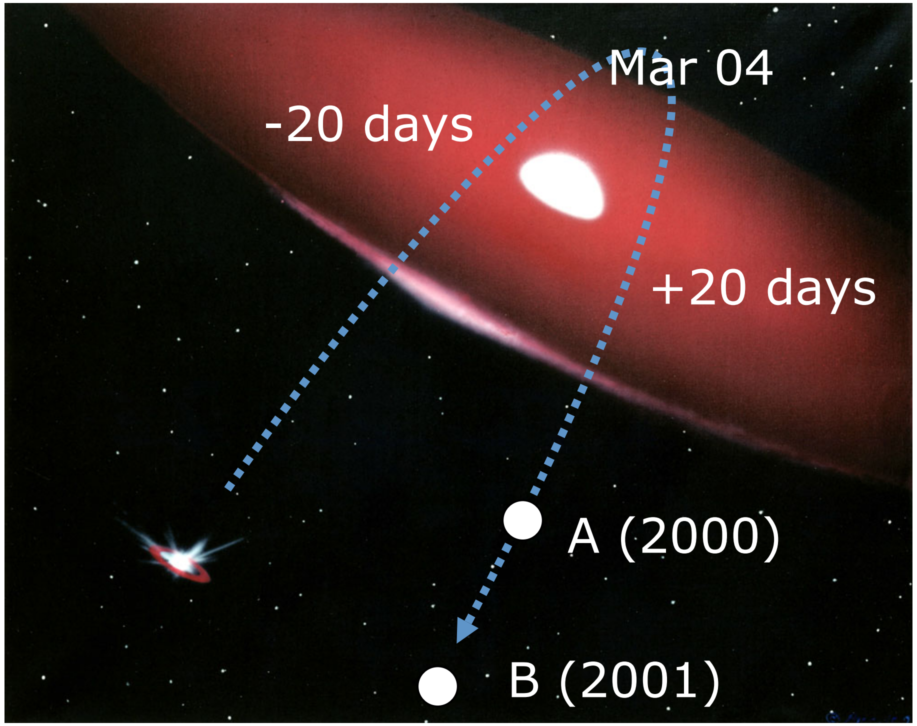


PSR B1259-63

- Binary system
- Strong stellar wind
- Shock at wind-pulsar interaction

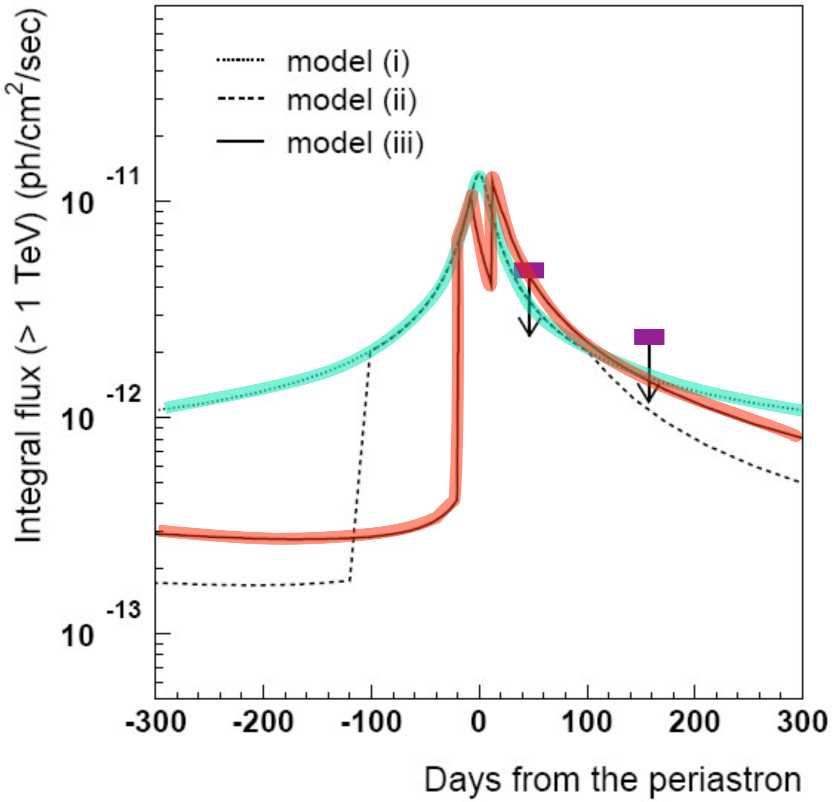


PSR B1259-63



Model: Ball & Kirk 2000

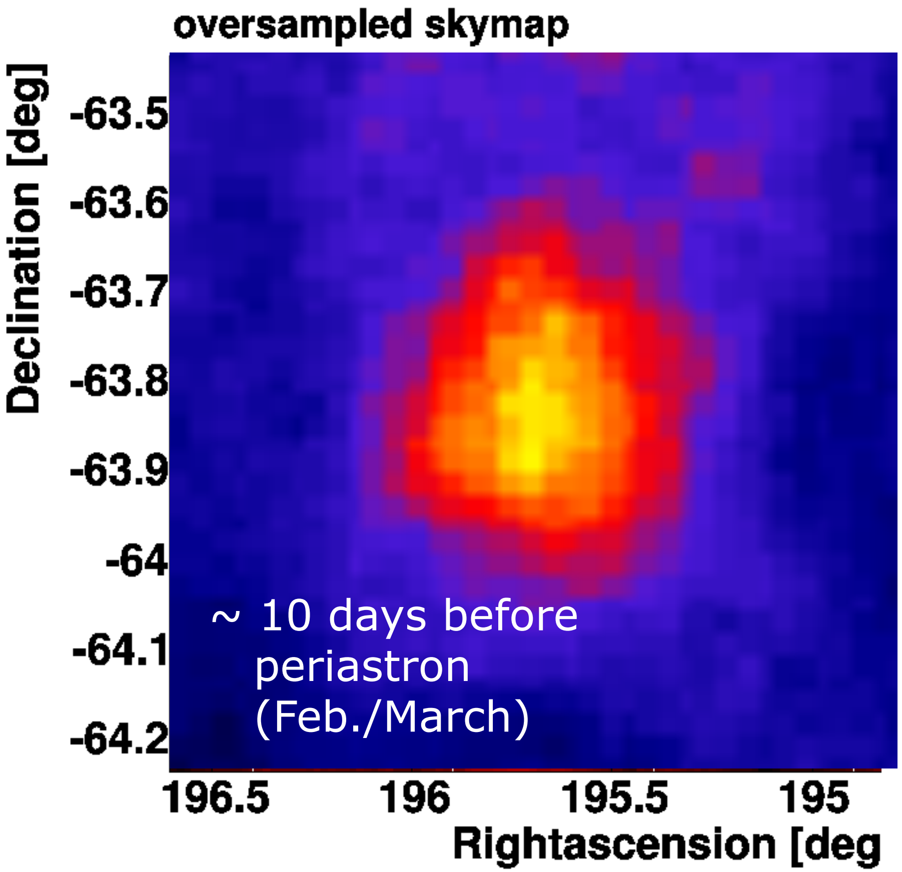
CANGAROO
Kawachi et al. 2004

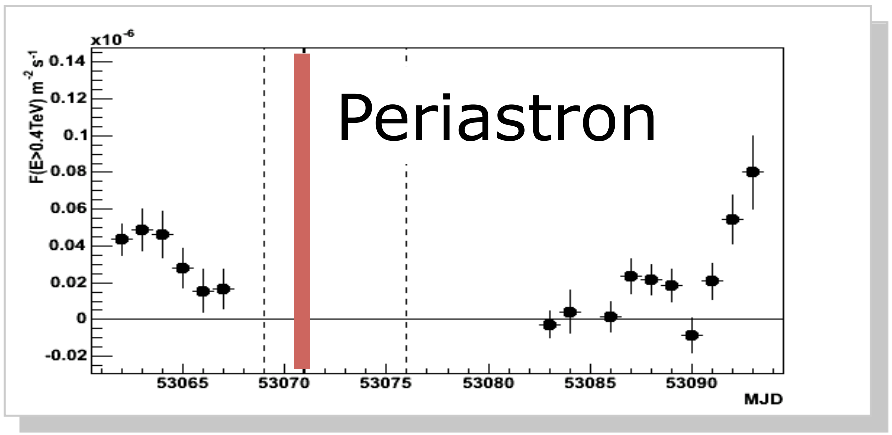


Complex structure depending on alignment of pulsar and stellar wind

PSR B1259-63

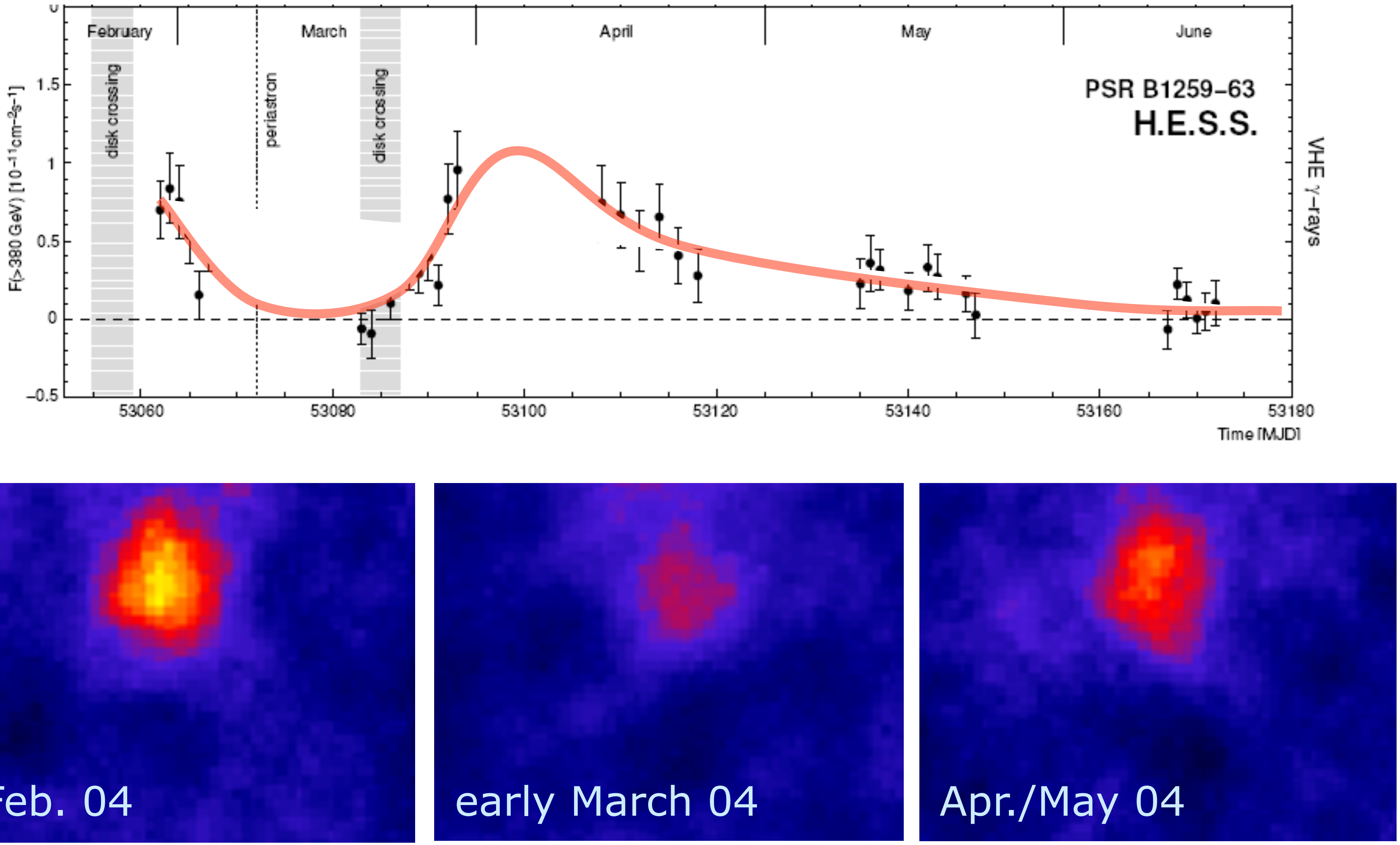
~ 9 σ pre-periastron
~ 6 σ post-periastron
Flux ~5% Crab
Index 2.8±0.3(stat)





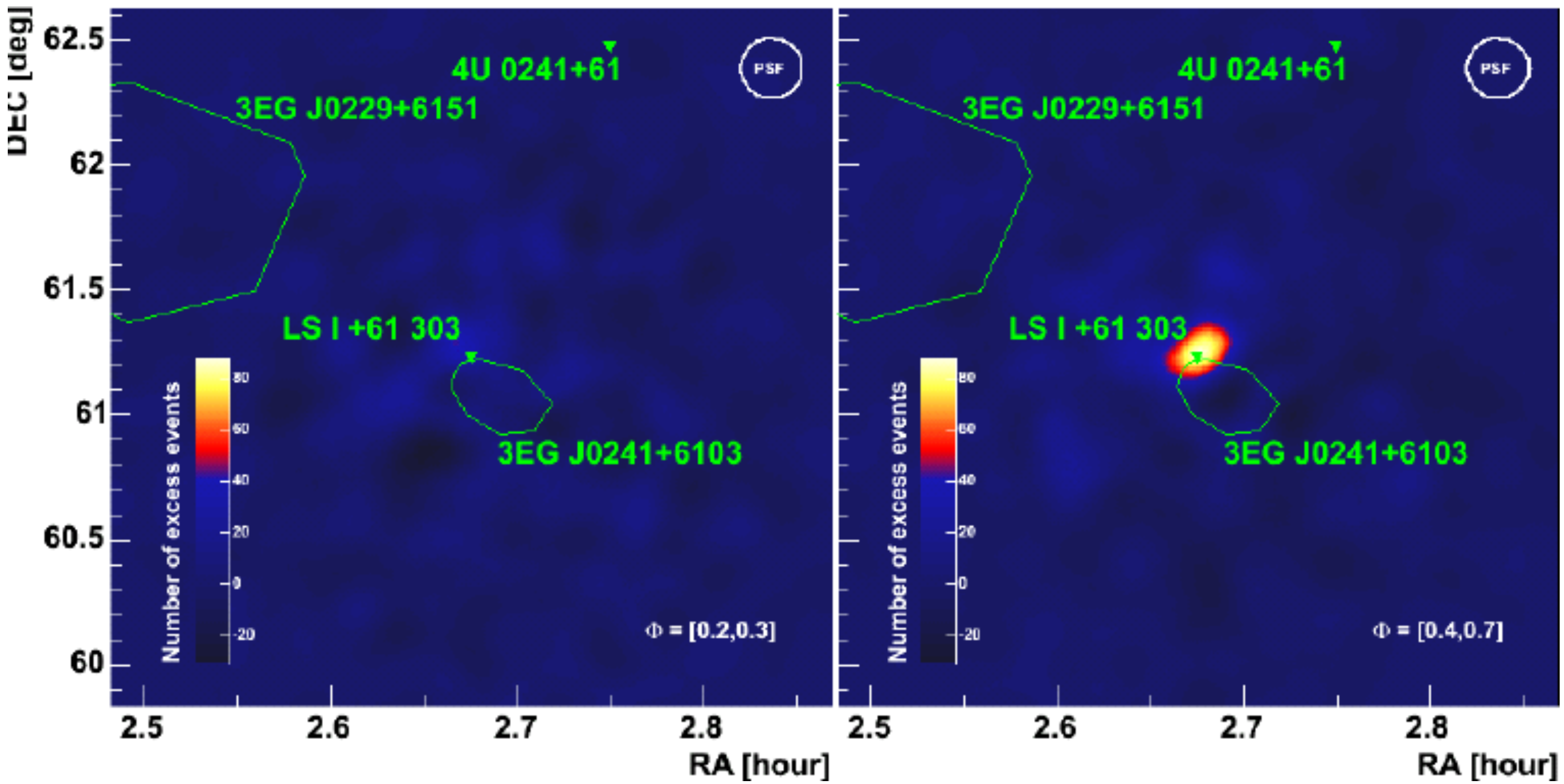
H.E.S.S.

The B1259-63 field of view

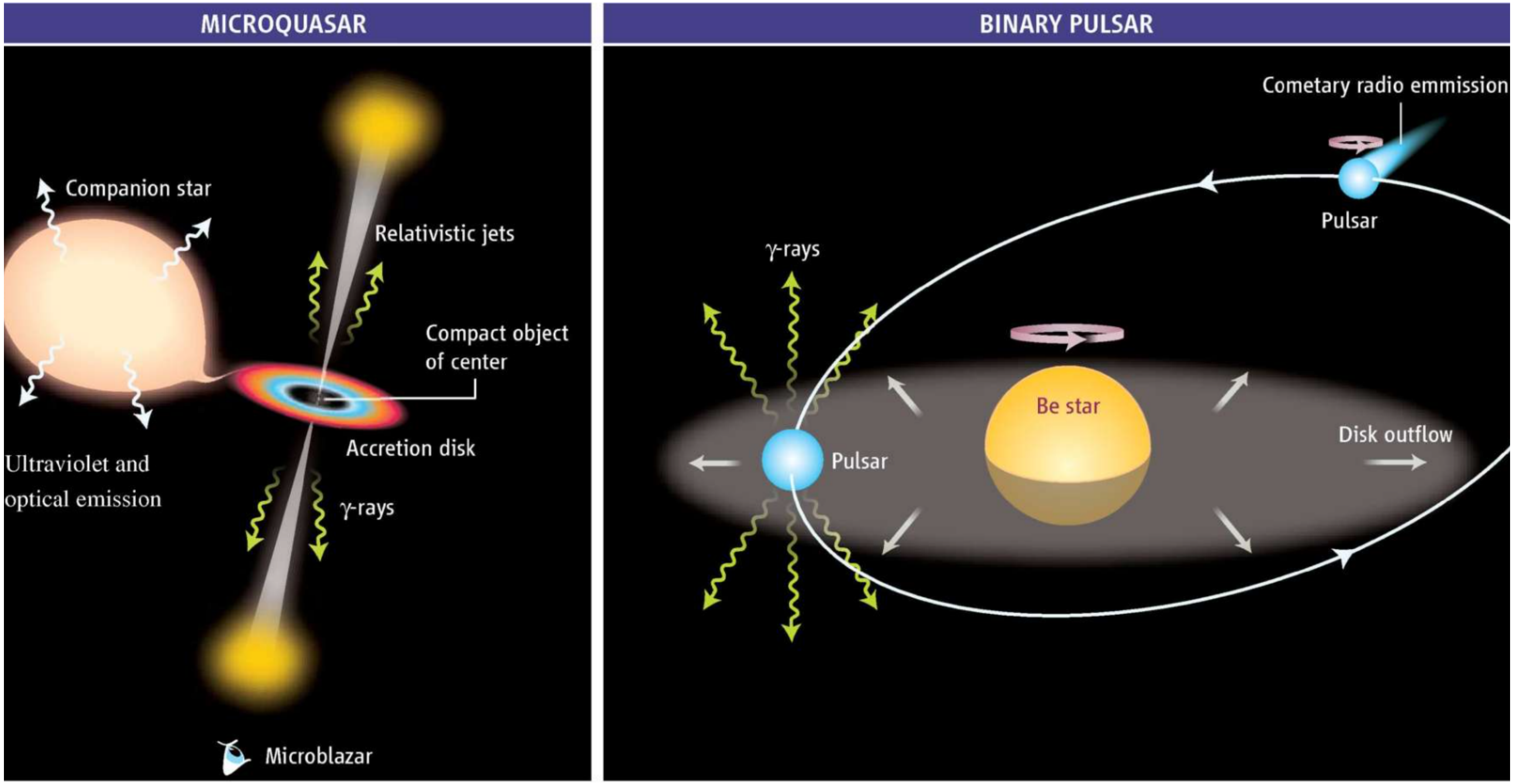


First variable galactic TeV source

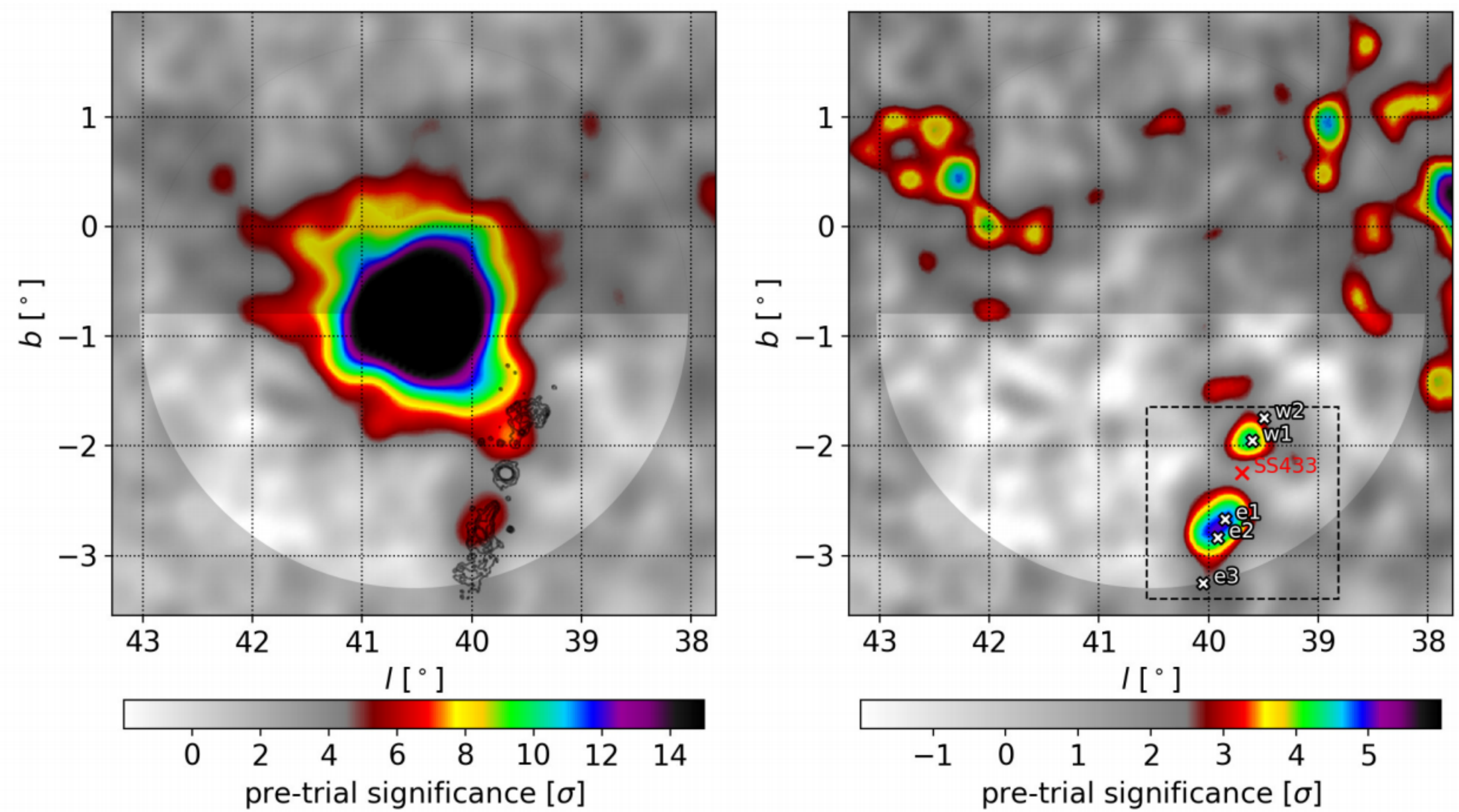
LSI 61+303 binary source



VHE Binary Sources

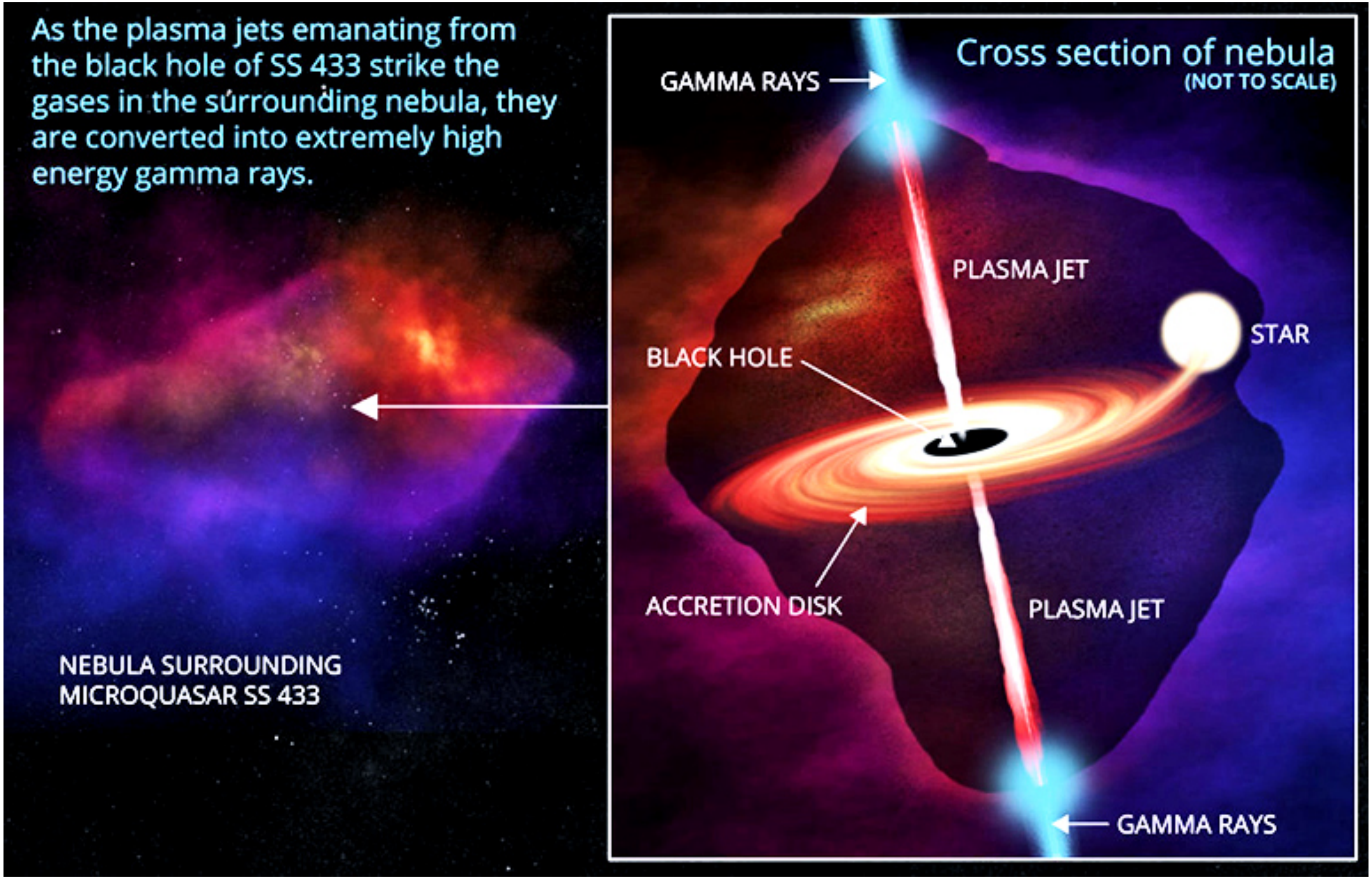


SS433 HAWC



b [°]
l [°]
pre-trial significance [σ]
pre-trial significance [σ]
w2
w1
SS433
e1
e2
e3

SS433 HAWC


As the plasma jets emanating from the black hole of SS 433 strike the gases in the surrounding nebula, they are converted into extremely high energy gamma rays.
Cross section of nebula
(NOT TO SCALE)
GAMMA RAYS
PLASMA JET
STAR
BLACK HOLE
ACCRETION DISK
PLASMA JET
GAMMA RAYS
NEBULA SURROUNDING
MICROQUASAR SS 433

Astrofisica Nucleare e Subnucleare

VHE Extra Galactic Sources

The unexplored spectrum gap

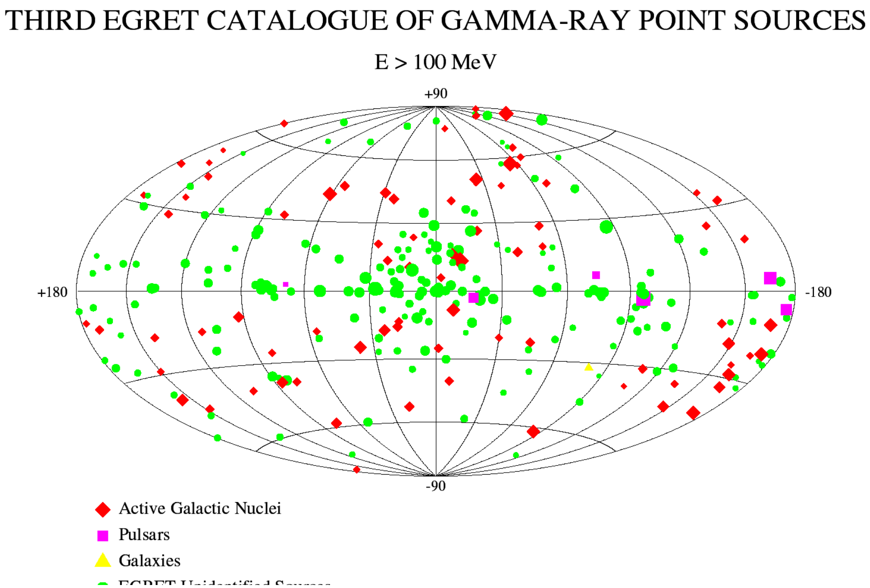
- γ-ray sources observed with EGRET satellite (E < 10 GeV)
- 271 sources (171 unidentified)

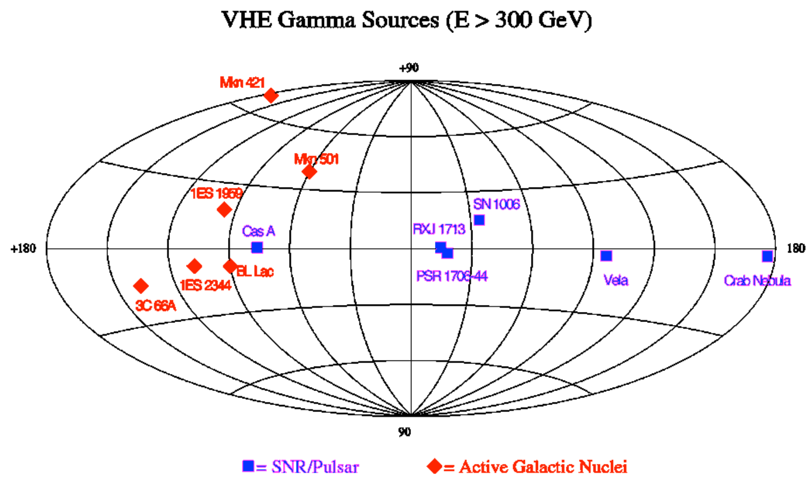
Satellite effective area < 1 m^2

- Old generation ground-based experiments observe few sources with E > 300 GeV.

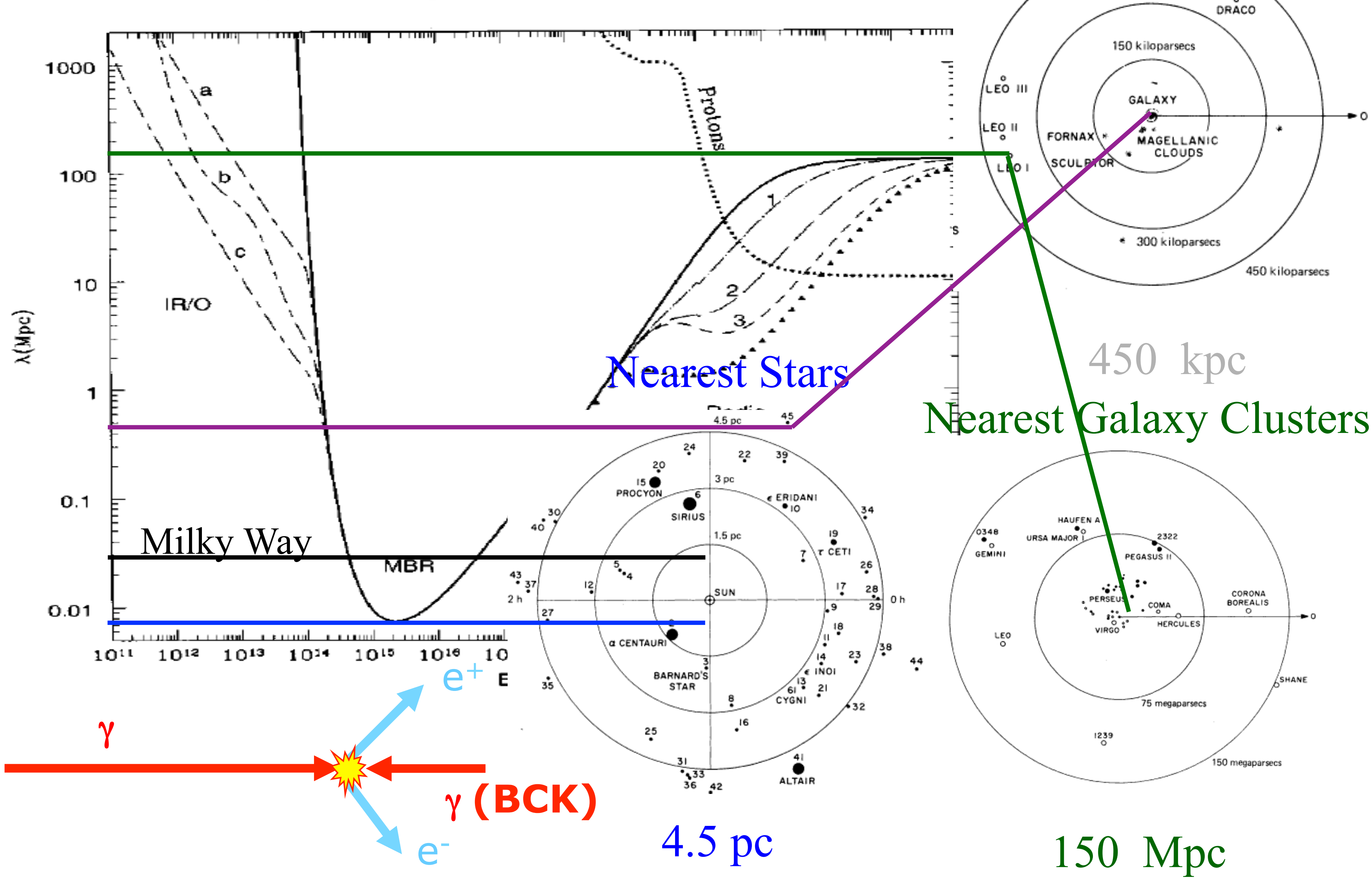
Effective area > 10^4 m^2

Strong cutoff in γ-spectrum for
30 Gev < E < 300 GeV
Explore energy gap with MAGIC

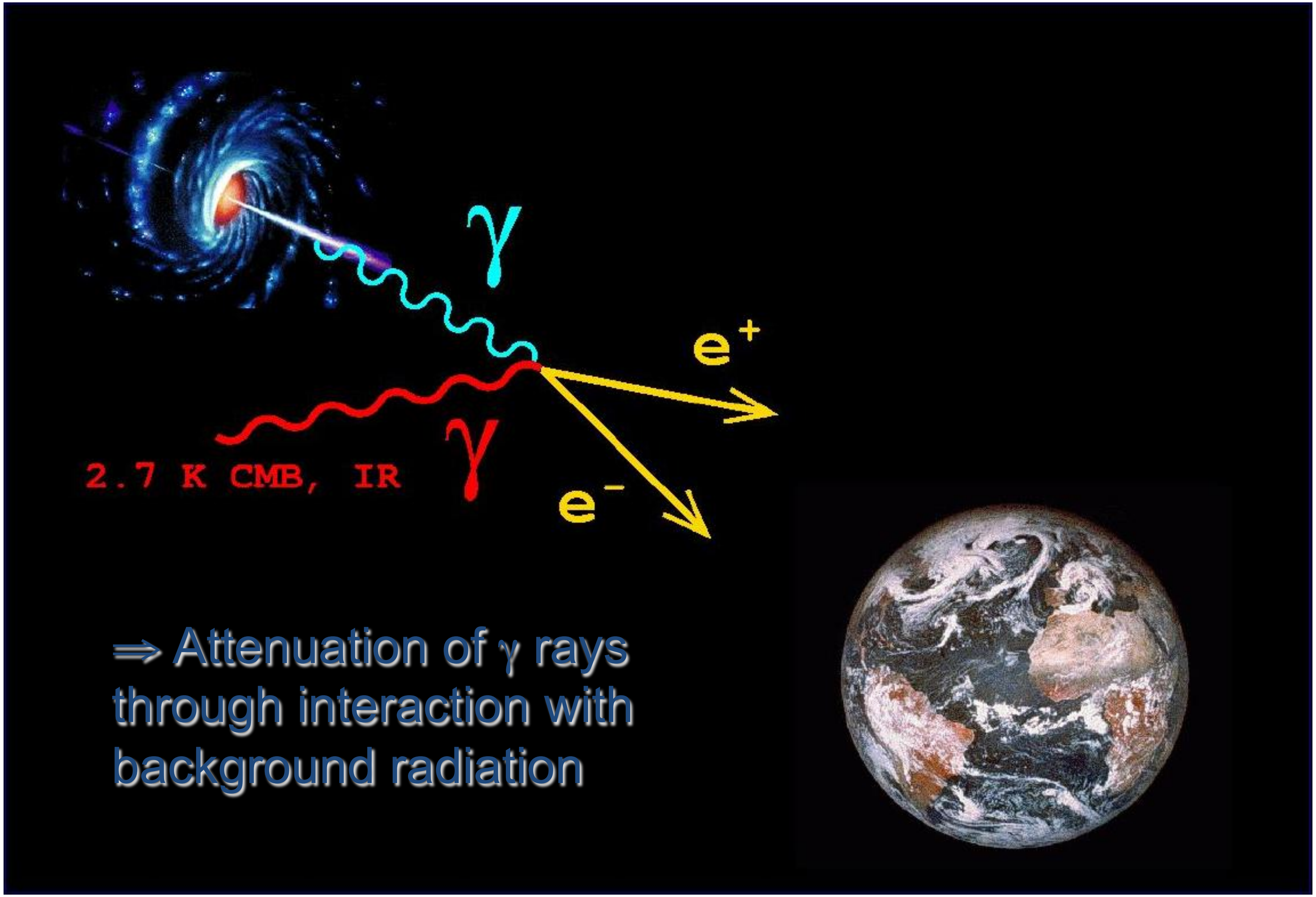




Large mean free path…
Transparency of the Universe



Photon Propagation Effects



Gamma Ray Horizon

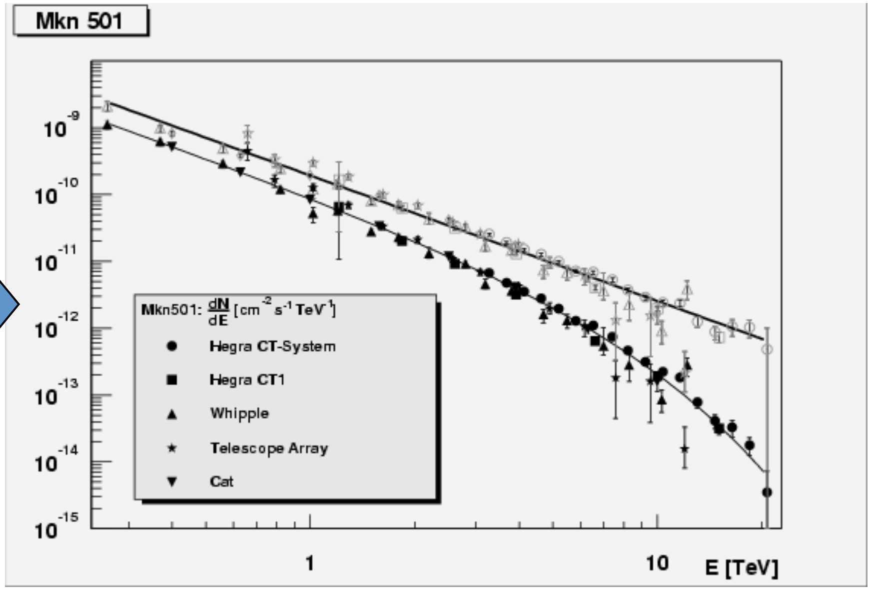
Any γ that crosses cosmological distances through the universe **interacts with the EBL**

$$\gamma_{HE}\,\gamma_{EBL} \rightarrow e^{+}\,e^{-}$$

$$E\varepsilon(1-\cos\theta) > 2\left(m_e c^2\right)^2$$

The absorption effect seen on a nearby blazar

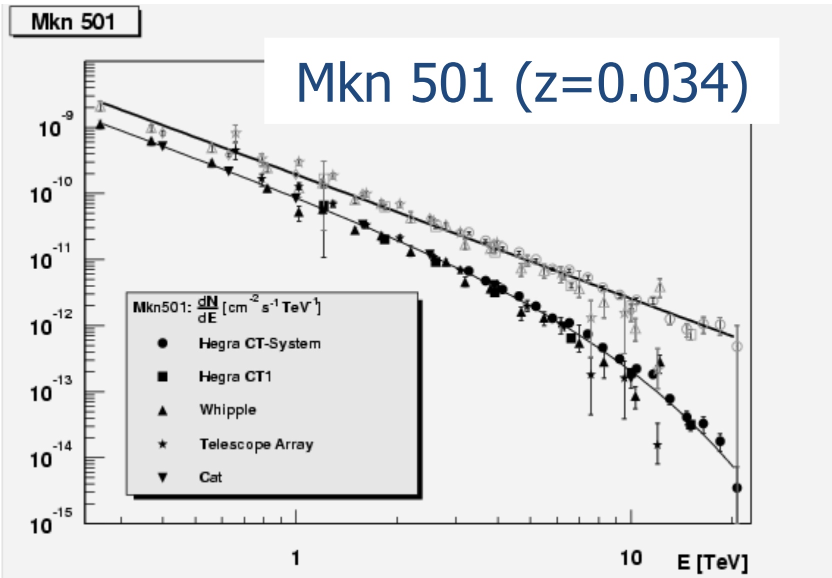
Mkn 501 (z=0.034)

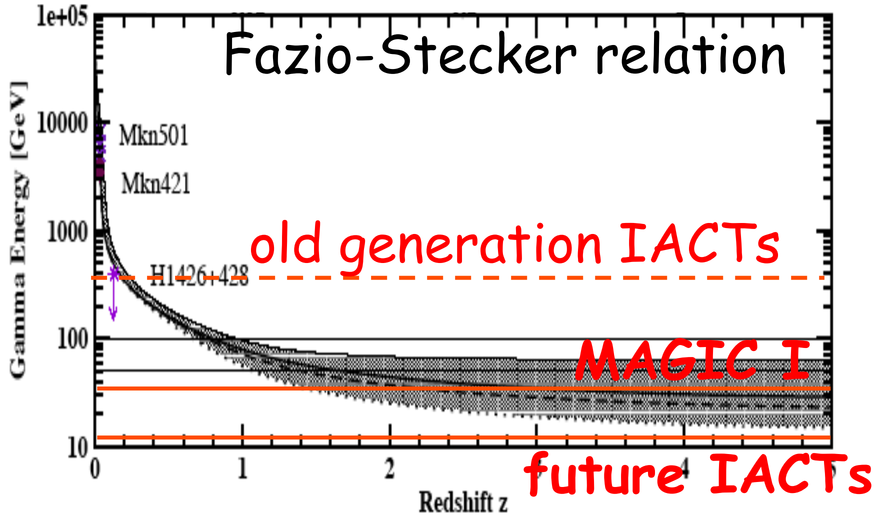


Gamma Ray Horizon

γ-rays traveling cosmological distances **interact** with **Extragalactic Background Light (EBL)**

$$\gamma_{HE}\,\gamma_{EBL} \rightarrow e^+\, e^-$$



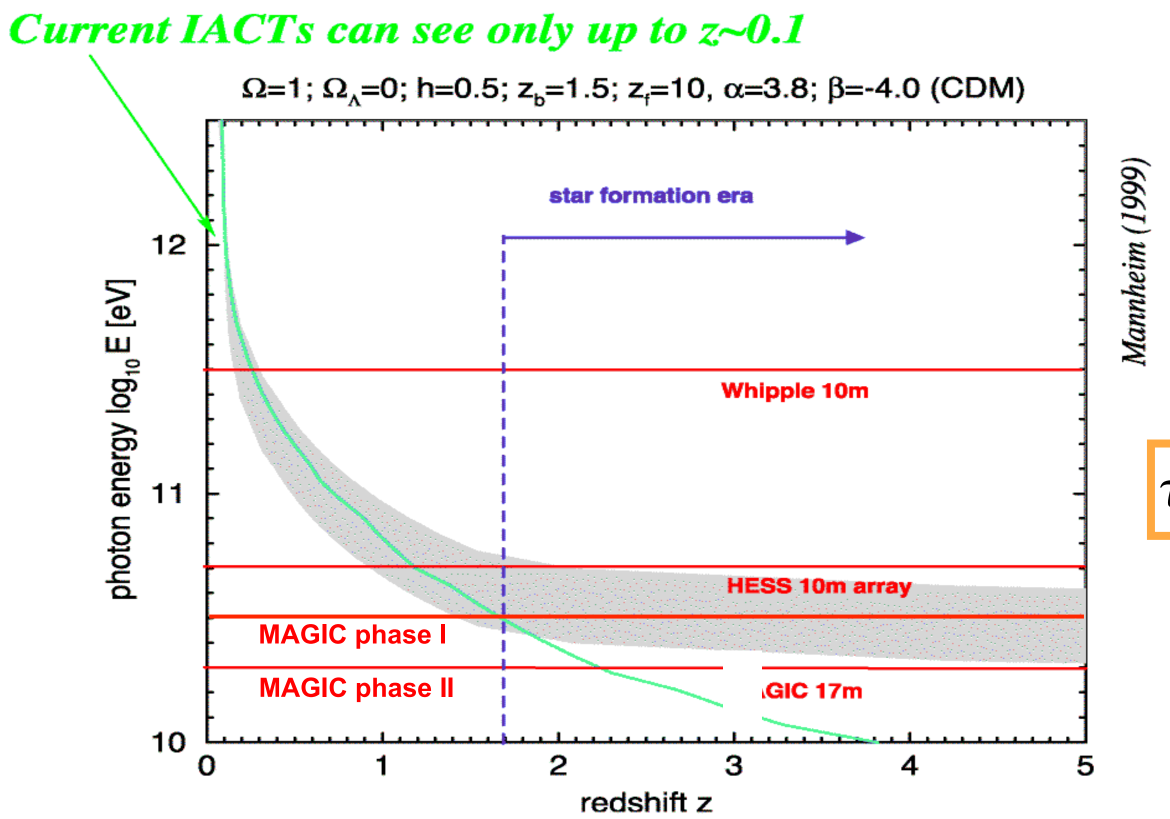


- lower energy threshold
  => observe more distant sources

- Absorption increases with energy of **γ-rays**
- Absorption leads to cutoff in AGN spectrum
- Measurement cutoff of several sources allows extraction of EBL

Gamma ray horizon (GRH)

Defined as the distance for which the optical depth for pair production process is $\tau = 1$ (i.e. a reduction 1/e of the flux of the extragalactic source).



$$\tau(E, z) = 1$$

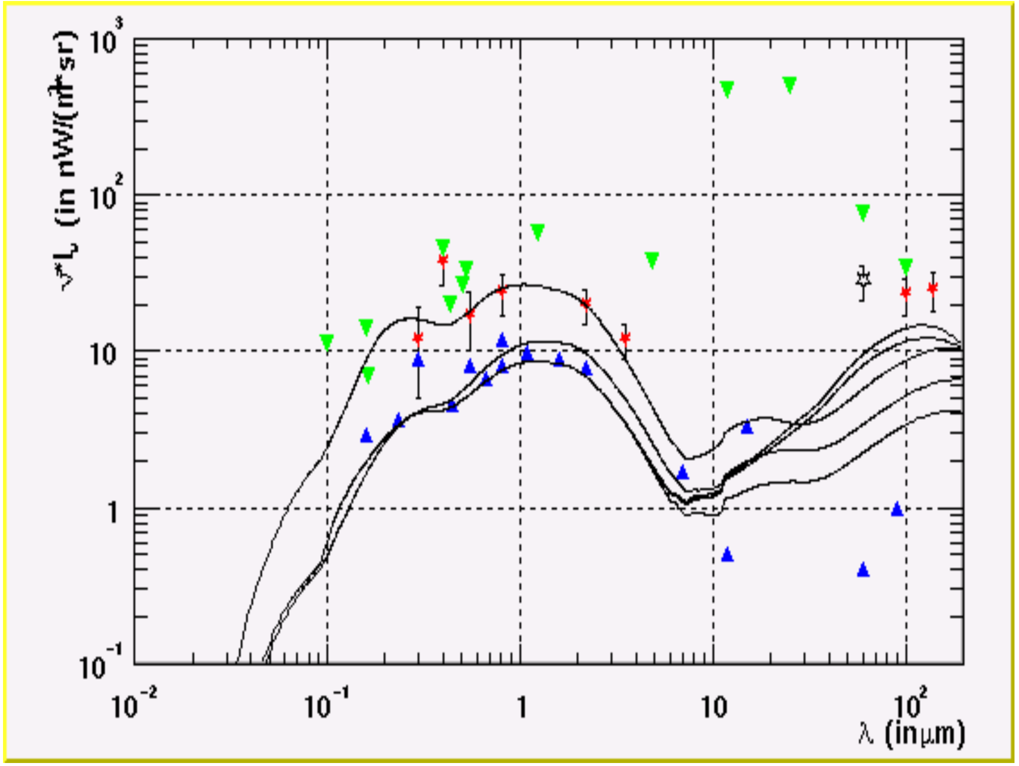
Extragalactic absorption

For the energy range of IACTs (10 GeV - 10 TeV), the interaction takes place with the **infrared** (0.01 eV - 3 eV , 100 μm - 1 μm).

Origin

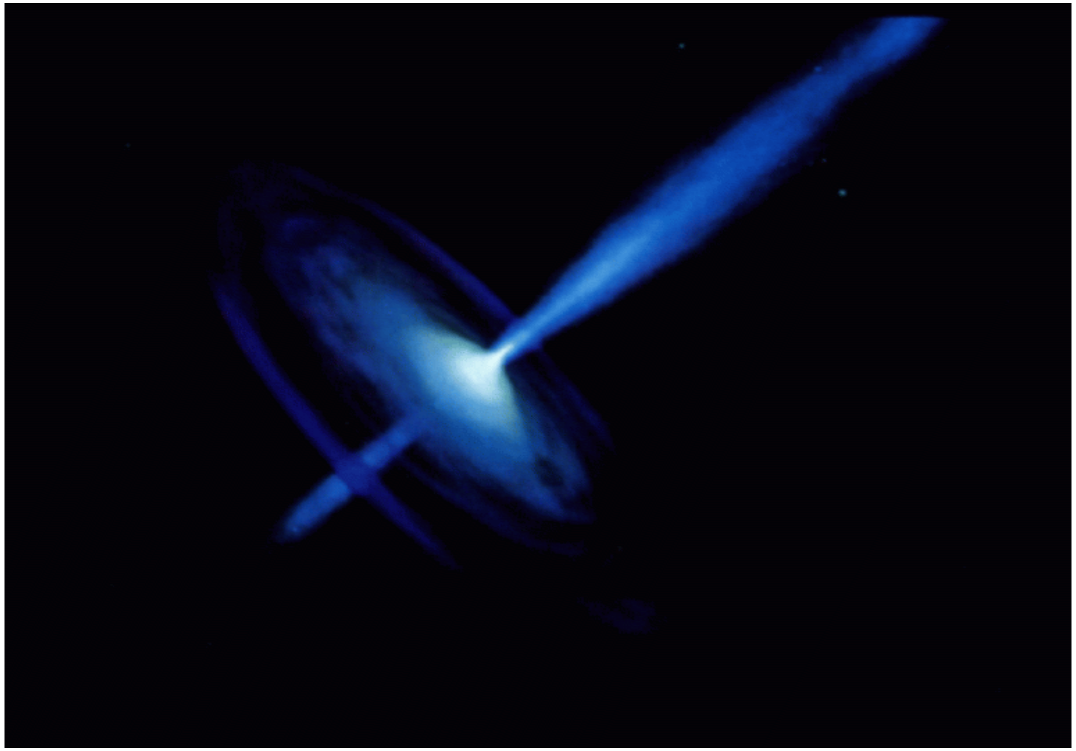
- Star formation
- Radiation of stars
- Absorption and reemission by ISM

By measuring the cutoffs in the spectra of AGNs within the, MAGIC can help in determining the IR background

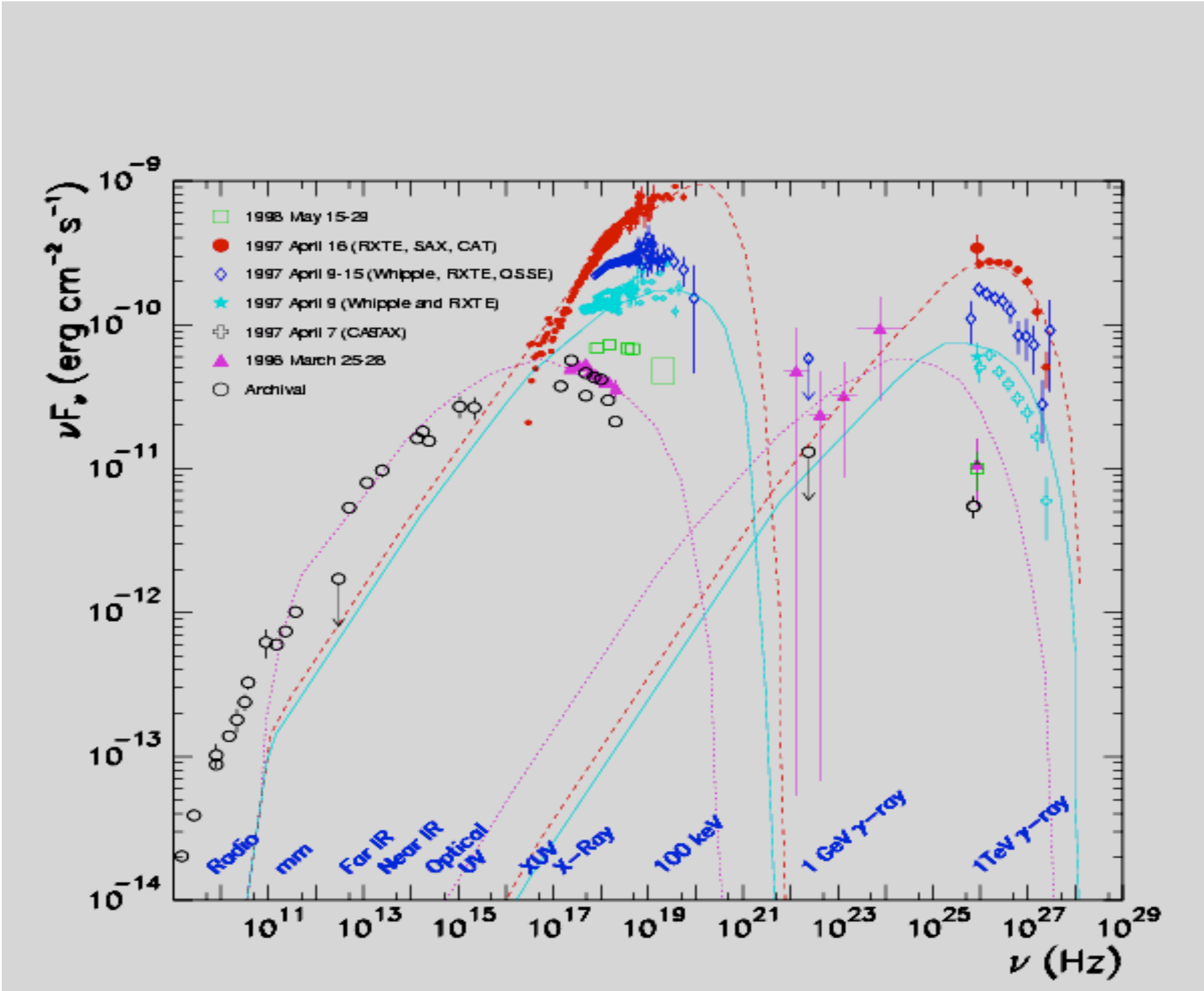


Extragalactic Sources

- Physics of AGN jets
- Cosmological extragalactic background light (EBL)



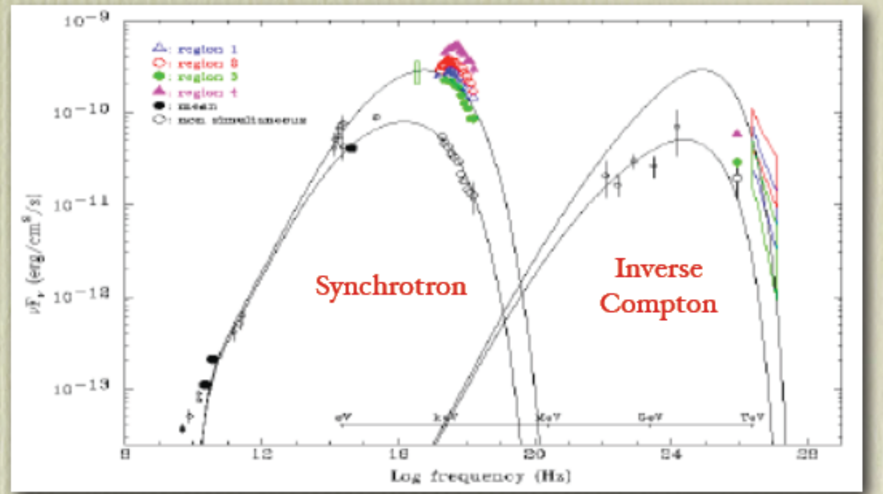
Active Galactic Nuclei



γ-ray Astronomy and Cosmic Rays

- Search for the sources of Cosmic Rays
- Investigate acceleration mechanisms
- γ-rays can be traced back to the origin

<u>Spectral Energy Distribution (SED)</u>
- characteristic two-peak structure
- competing leptonic and hadronic acceleration models.



Hadron acceleration

proton-proton interaction
p+ (TeV) + matter → π^{o}... → γ γ (GeV)

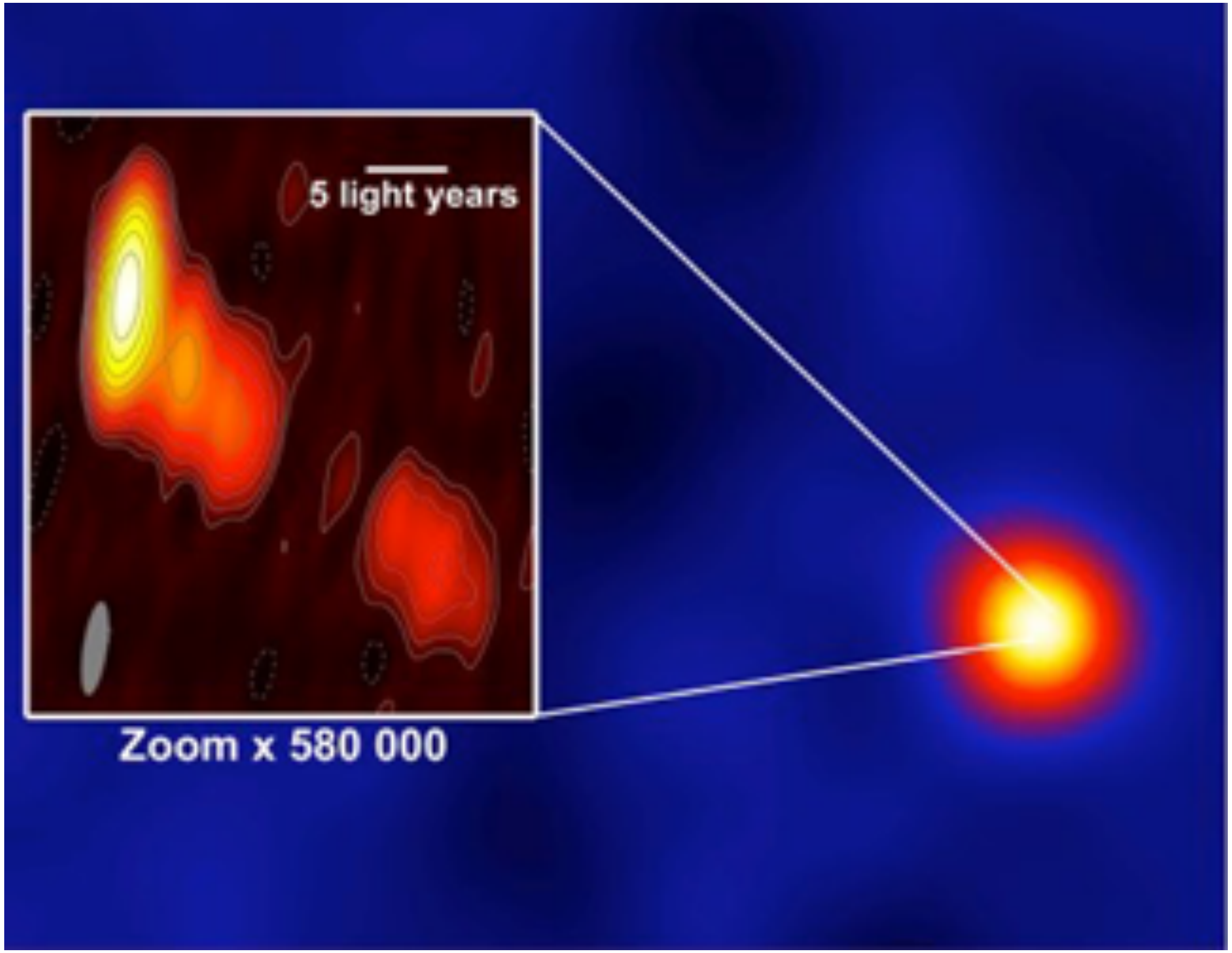
photo-hadron interaction
p+ (TeV) + γ (eV) → π^{o}... → γ γ (GeV)

Electron acceleration

Synchrotron Radiation
e^{-} + B → e^{-} + γ (eV-keV)

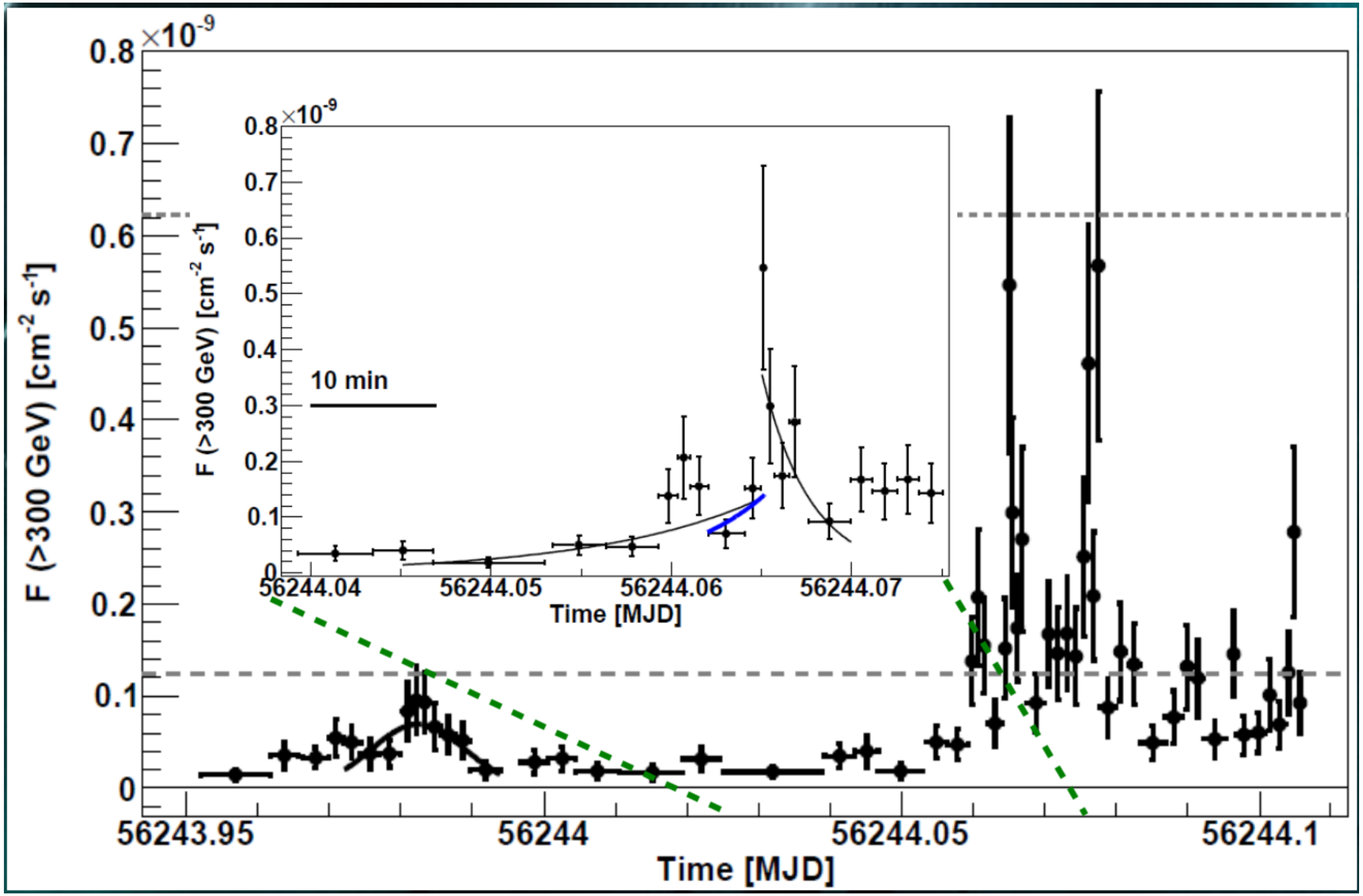
Inverse Compton Scattering
e^{-} (GeV) + γ (eV) → e^{-} + γ (GeV)

IC 310



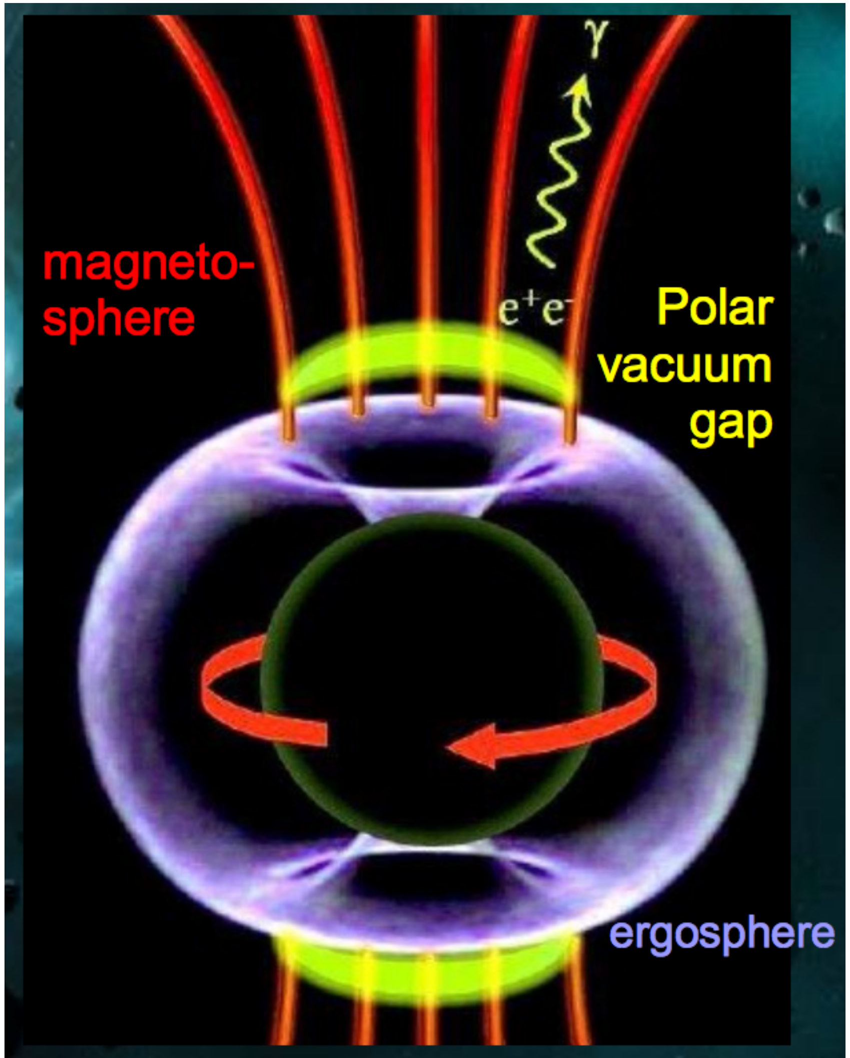
Aleksic et al 2015

IC310



Aleksic et al 2015

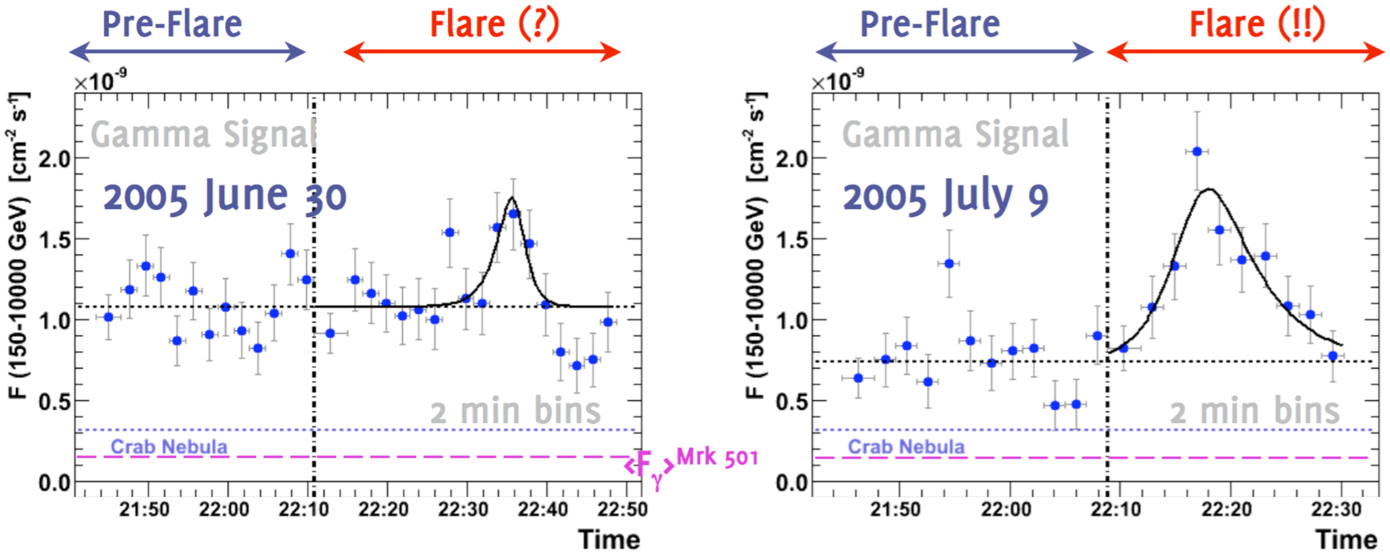
IC310



Aleksic et al 2015

Previous results

The Fastest Variability Observed So Far



Assumption: Flux variation (flare) on the top of a stable emission

b $(\frac{10^{-10}\ ph}{cm^2 \cdot s})$	c (s)	d (s)	χ^2/NDF^{d}	P [e] (%)
13.2±4.7	81±41	50±23	20.0/15	17.3[f]
20.3±3.3	95±24	185±40	4.2/7	75.8

a: pedestal (not fit)

b: amplitude of flux variation

t_0: ~ peak position (not fit)

c, *d*: flux-doubling times

Previous results

Results of the ECF Method

MAGIC Collab. + Ellis et al.
arXiv:0708.2889, PRL subm.

$$\tau_l = (0.030 \pm 0.012) \ \mathrm{s/GeV}$$

$$\tau_q = (3.71 \pm 2.57) \times 10^{-6} \ \mathrm{s/GeV^2}$$

$$M_{\mathrm{QG1}} = 1.398 \times 10^{16} (1 \ \mathrm{s}/\tau_l)$$

$$M_{\mathrm{QG2}} = 1.182 \times 10^{8} (1 \ \mathrm{s}/\tau_q)^{1/2}$$

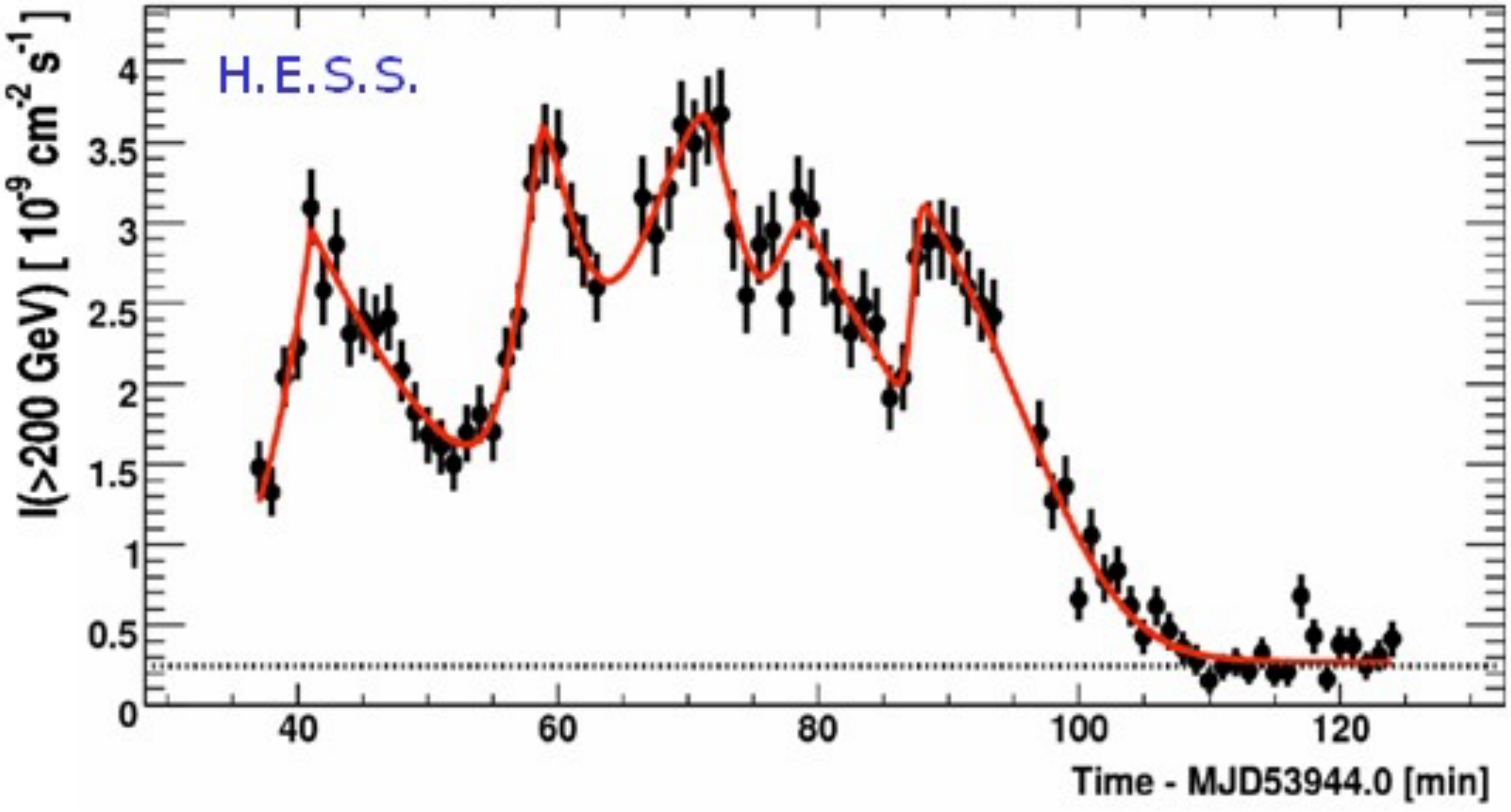
$$M_{\mathrm{QG1}} = (0.47^{+0.31}_{-0.13}) \times 10^{18} \ \mathrm{GeV}$$

$$M_{\mathrm{QG2}} = (0.61^{+0.49}_{-0.14}) \times 10^{11} \ \mathrm{GeV}$$

$$M_{\mathrm{QG1}} > 0.26 \times 10^{18} \ \mathrm{GeV}$$

$$M_{\mathrm{QG2}} > 0.27 \times 10^{11} \ \mathrm{GeV}$$

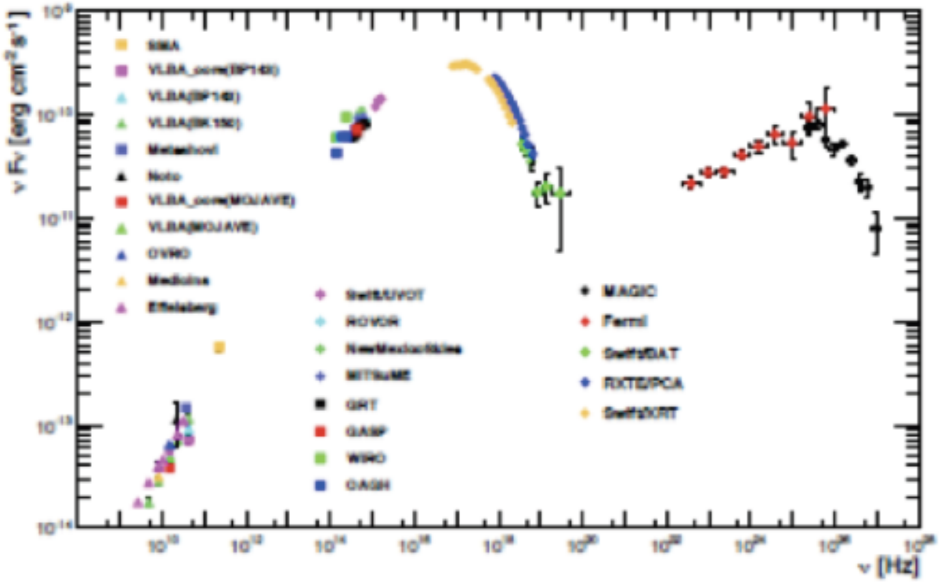
PKS 2155 -304



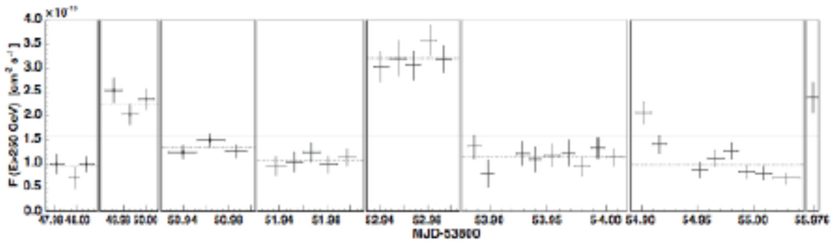
Aharonian et al 2007

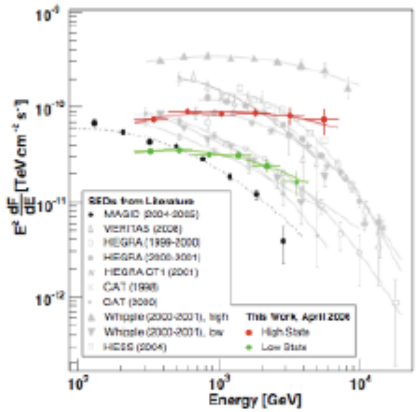
Contact with Fermi

+ Broadband radio-TeV Mrk421

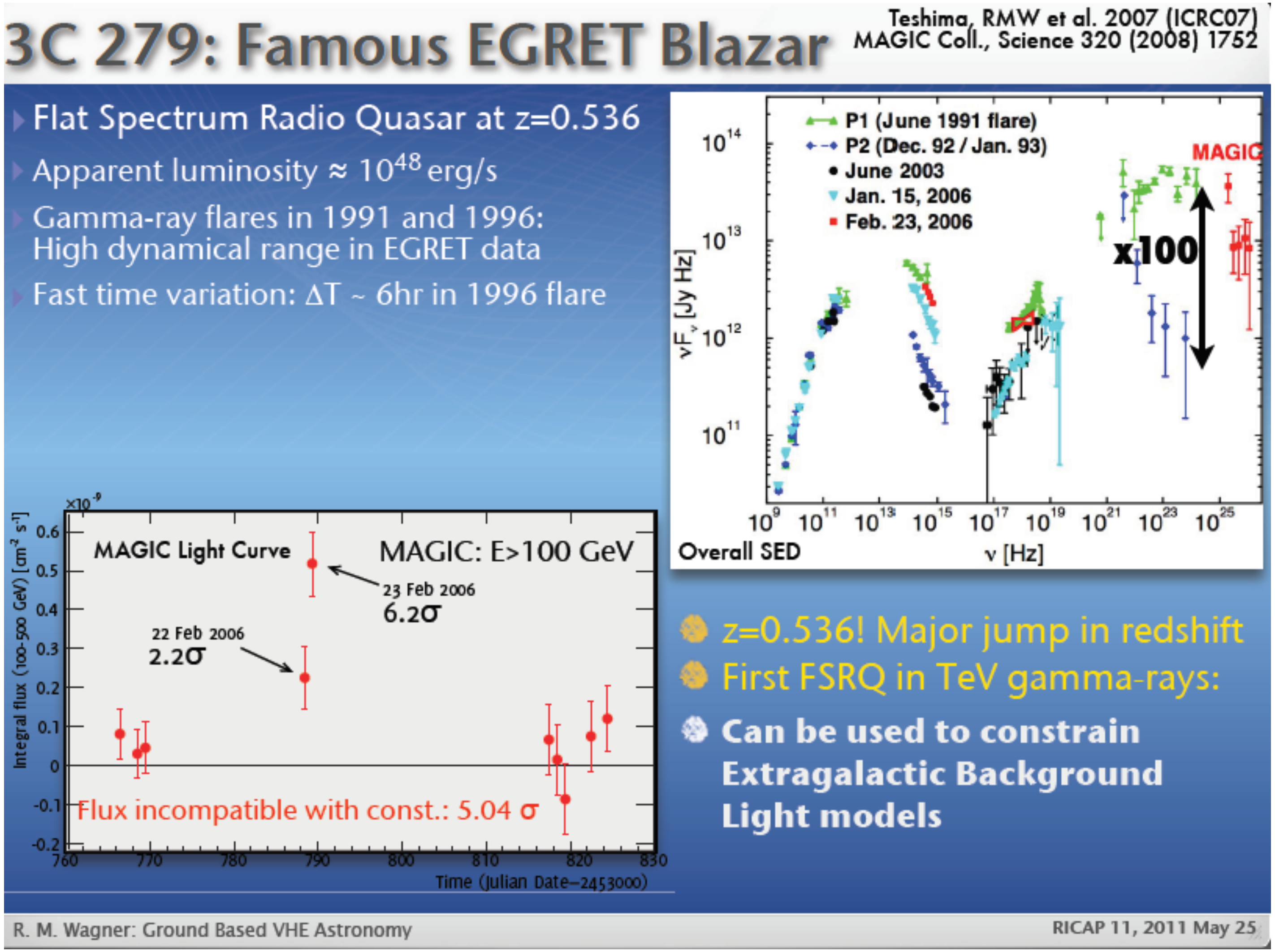


- 4.5 months campaign
- Most complete SED ever collected for Mrk421
- Total Fermi-MAGIC overlap over 5 decades in energy!
- HE-VHE connection!





3c279


3C 279: Famous EGRET Blazar
Teshima, RMW et al. 2007 (ICRC07)
MAGIC Coll., Science 320 (2008) 1752
Flat Spectrum Radio Quasar at z=0.536
Apparent luminosity ≈ 10^48 erg/s
Gamma-ray flares in 1991 and 1996:
High dynamical range in EGRET data
Fast time variation: ΔT ~ 6hr in 1996 flare
P1 (June 1991 flare)
P2 (Dec. 92 / Jan. 93)
June 2003
Jan. 15, 2006
Feb. 23, 2006
MAGIC
x100
νF_ν [Jy Hz]
Overall SED
ν [Hz]
MAGIC Light Curve
MAGIC: E>100 GeV
23 Feb 2006
6.2σ
22 Feb 2006
2.2σ
Flux incompatible with const.: 5.04 σ
Integral flux (100-500 GeV) [cm^-2 s^-1]
Time (Julian Date–2453000)
z=0.536! Major jump in redshift
First FSRQ in TeV gamma-rays:
Can be used to constrain
Extragalactic Background
Light models
R. M. Wagner: Ground Based VHE Astronomy
RICAP 11, 2011 May 25

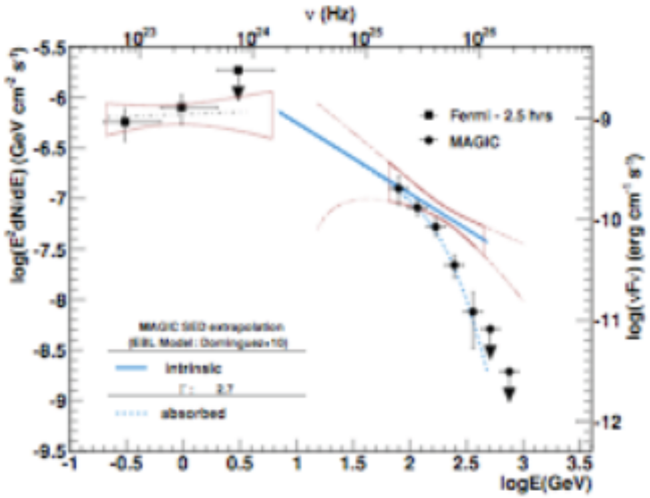
AGN

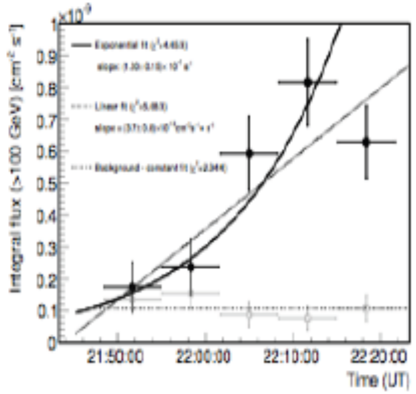
+ FSRQ PKS 1222+21 (4C21.35)

- Very good example of collaboration Fermi-IACTs (hard sources)
- Fermi Atel 2584 triggers MAGIC: 10.2 sigma detection in 0.5 h (1 Crab)
- 2nd farthest VHE source: $z=0.432$

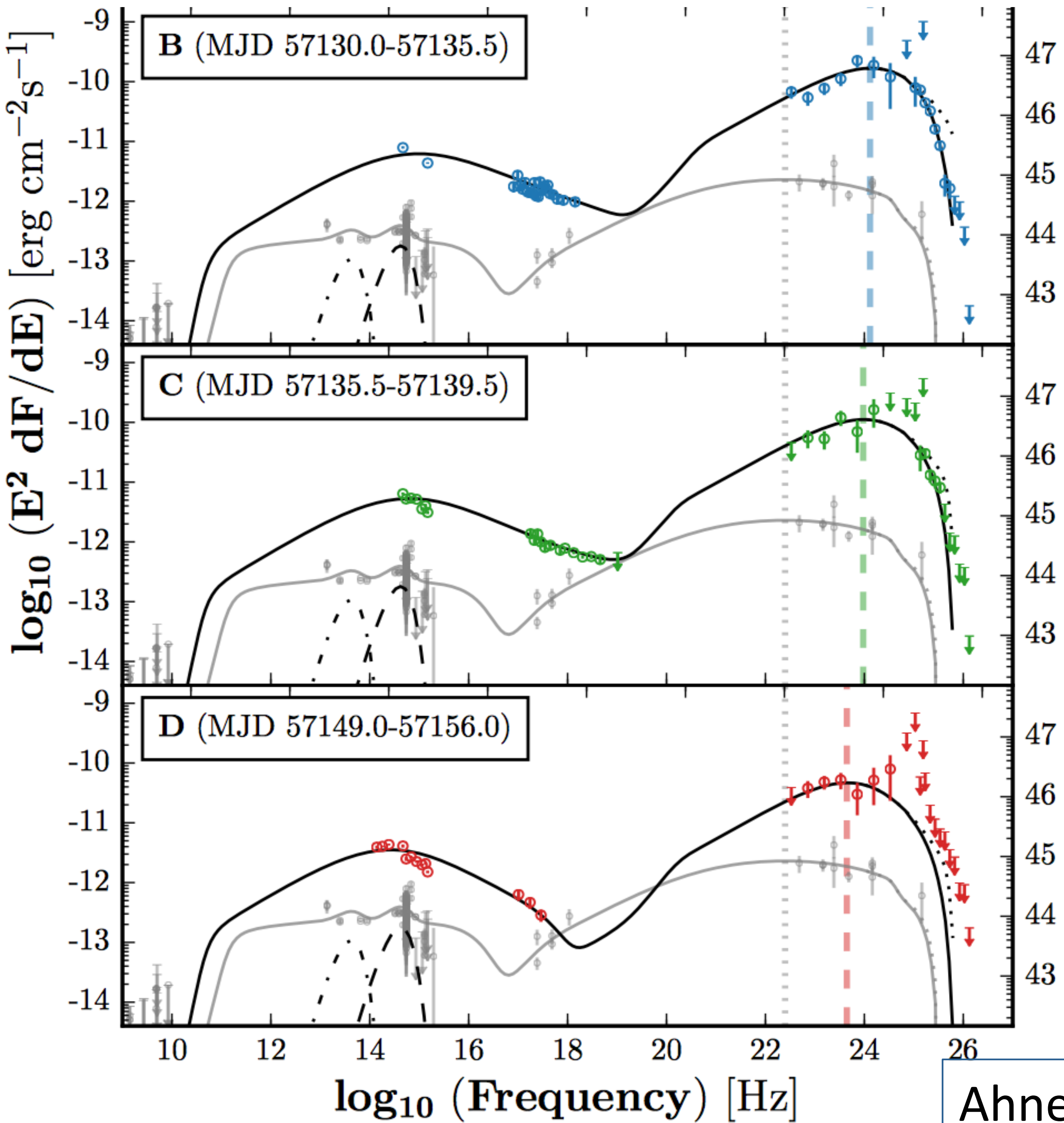
- MAGIC+Fermi: can fit to single power-law -2.7(0.3) between 3 and 400 GeV
- No-sign of any cutoff
- Most rapid variation ever observed at VHE: Flux doubling-time 8.6min!

- Single spectrum → emission due to unique component
- No GeV cutoff → emission outside the BLR region, in the relativistic jet?
- Flux rapid variability→compact emission
- CHALLENGE TO EMISSION MODELS!





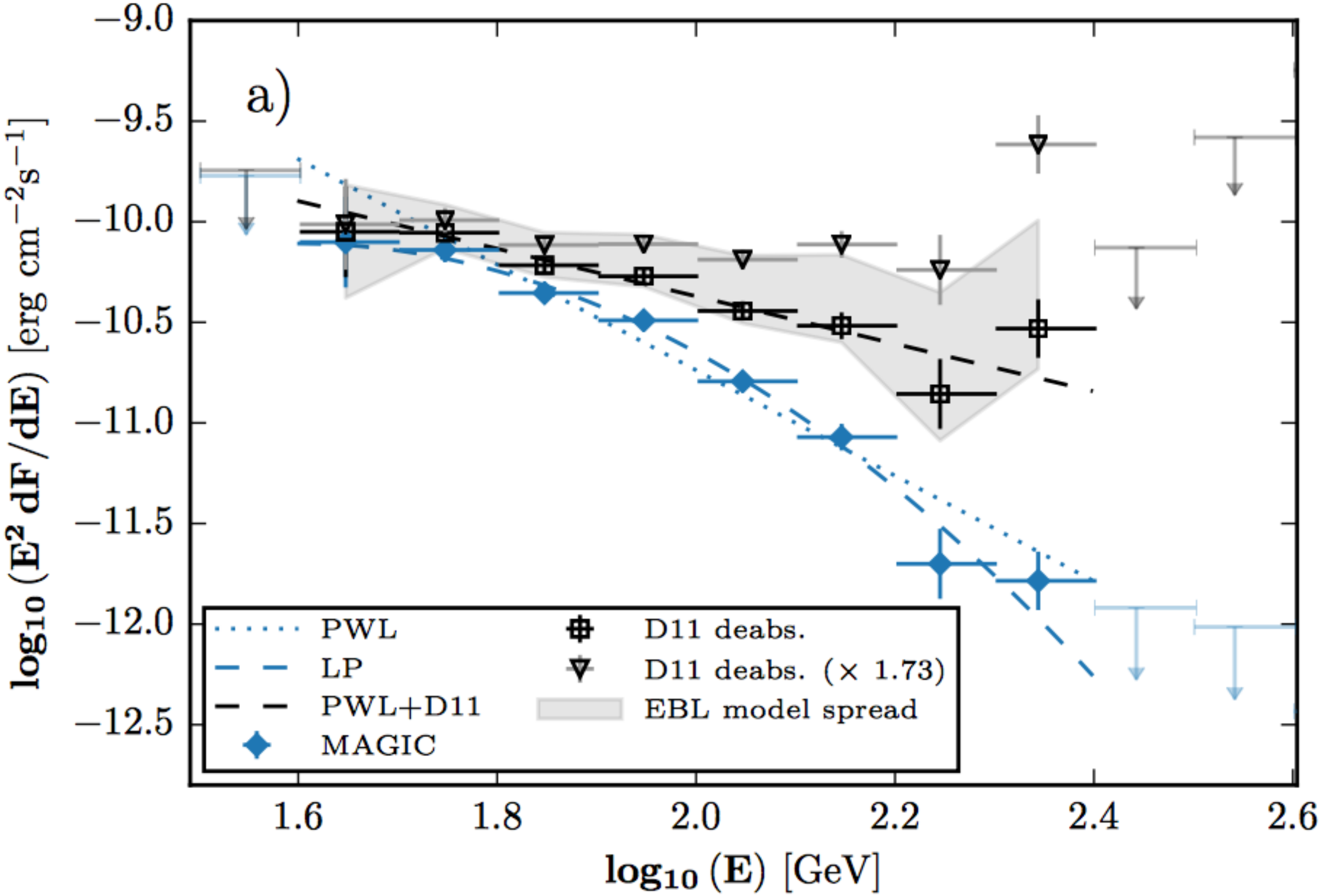
ApJL 730:L8 2011



PKS 1441+25
z=0.9397!

Ahnen et al 2016

PKS 1441+25
z=0.9397



Ahnen et al 2016

Lensed Blazar

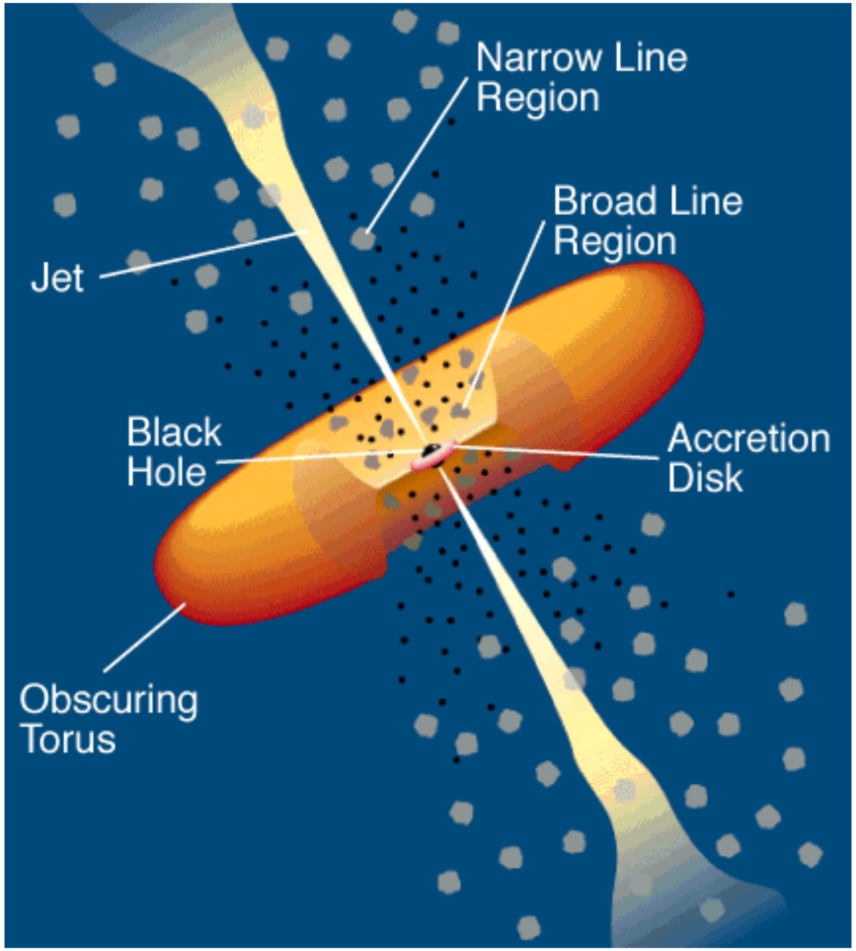
Discovery of Very High Energy Gamma-Ray Emission From Gravitationally Lensed Blazar S3 0218+357 With the MAGIC Telescopes

ATel #6349; ***Razmik Mirzoyan (Max-Planck-Institute for Physics) On Behalf of the MAGIC Collaboration***
on ***28 Jul 2014; 14:20 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

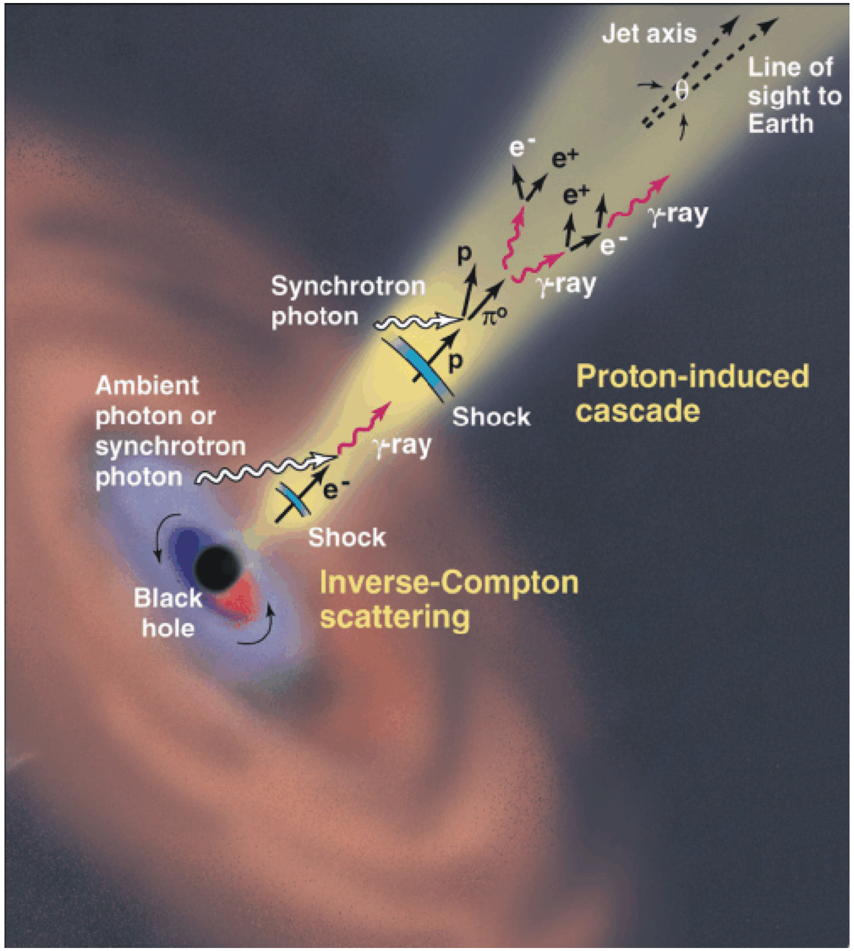
Subjects: Gamma Ray, >GeV, TeV, VHE, UHE, AGN, Blazar, Cosmic Rays, Microlensing Event

The MAGIC collaboration reports the discovery of very high energy (VHE; E>100 GeV) gamma-ray emission from S3 0218+357 (RA=02h21m05.5s, DEC=+35d56m14s, J2000.0). The object was observed with the MAGIC telescopes for a total of 3.5 hours from 2014/07/23 to 2014/07/26. The preliminary analysis of these data resulted in the detection of S3 0218+357 with a statistical significance of more than 5 standard deviations. From the preliminary analysis, we estimate the VHE flux of this detection to be about 15% of the flux from the Crab Nebula in the energy range 100-200 GeV. S3 0218+357 is a gravitationally lensed blazar located at the redshift of 0.944+/-0.002 (Cohen et al., 2003, ApJ, 583, 67). Fermi-LAT observations during the flaring state of S3 0218+357 in 2012 revealed a series of flares with their counterparts after 11.46+/-0.16 days delay, interpreted as due to the gravitational lensing effect (Cheung et al. 2014, ApJ, 782, L14). On 2014 July 13 and 14 Fermi-LAT detected another flaring episode (ATel #6316). Due to the full-moon time, the MAGIC telescopes were not operational and could not observe S3 0218+357 after the original alert. However, observations scheduled at the expected time of arrival of the gravitationally lensed component led to the first significant detection of a gravitationally lensed blazar and the most distant source detected at VHE with Cherenkov telescopes to date. MAGIC observations on S3 0218+357 will continue during the next days and multiwavelength observations are encouraged. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) and J. Sitarek (jsitarek@ifae.es). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Canary island of La Palma, Spain, and designed to perform gamma-ray astrophysics in the energy range from 50 GeV to greater than 50 TeV.

AGN model

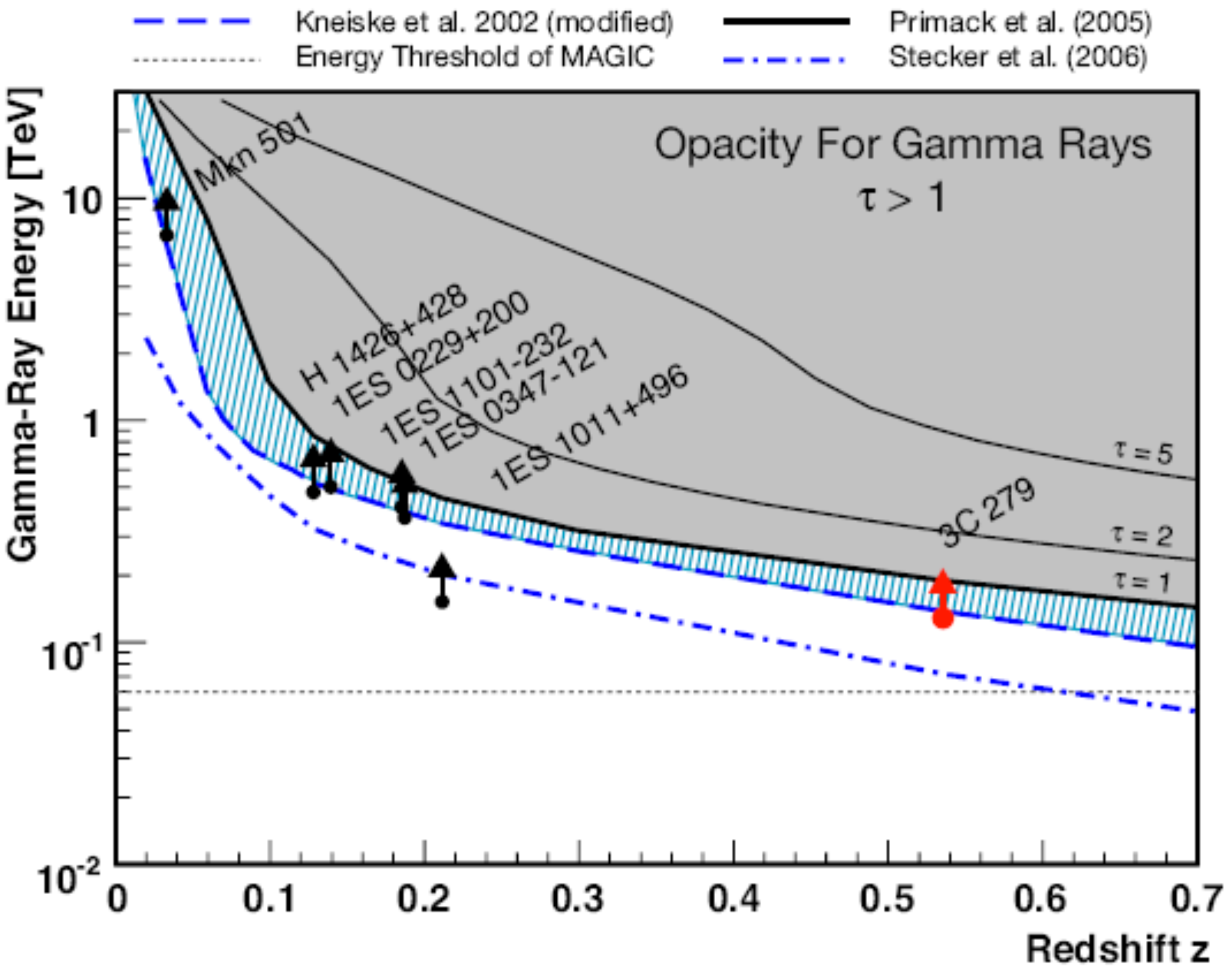


Narrow Line Region
Broad Line Region
Jet
Black Hole
Accretion Disk
Obscuring Torus



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

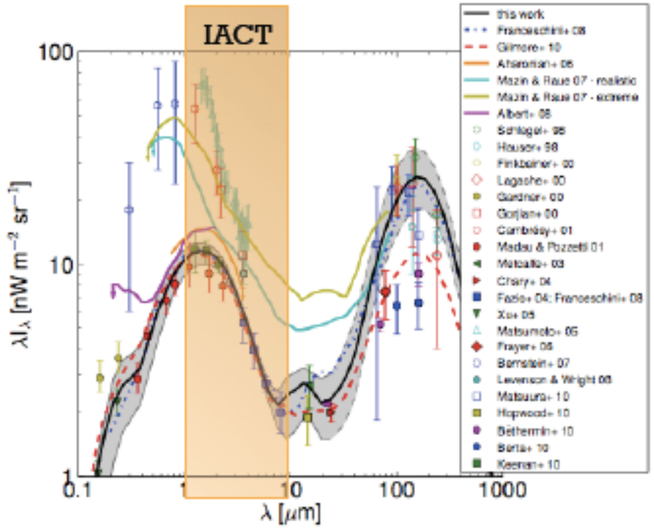
MAGIC – EBL measurements

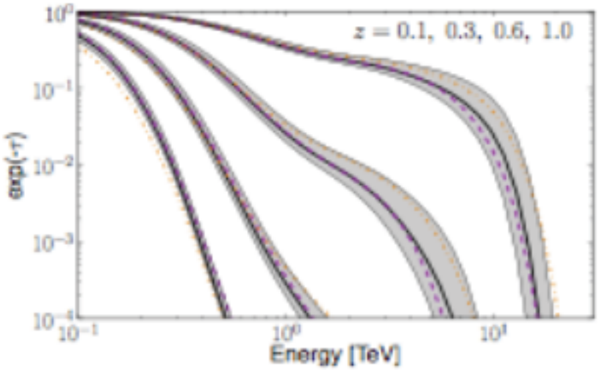


Albert et al. 2008

EBL measurements

+ Gamma-ray horizon





- VHE gamma-ray interacting with UV and far-IR photons, may pair produce:
  - Optical depth $\tau=\tau(E,z)$
- Distant AGNs are optimal targets (if distance is known):
  - 3C279 (z=0.536)
  - 3C66A (z=0.444?)
  - PG1553+113 (z=0.4)
  - S5 0716+714 (z=0.310?)
  - ...
- Absorption above 100 GeV makes observed spectrum:
  - Softer (steeper)
  - Difficult to observe
- IACT observation already constrained models to their minimum allowance (universe is more transparent)
- Distant AGNs are monitored by M-stereo (PG1553, 3C279)

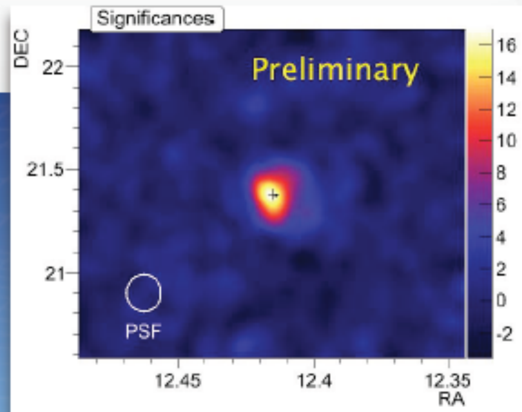
EBL measurements

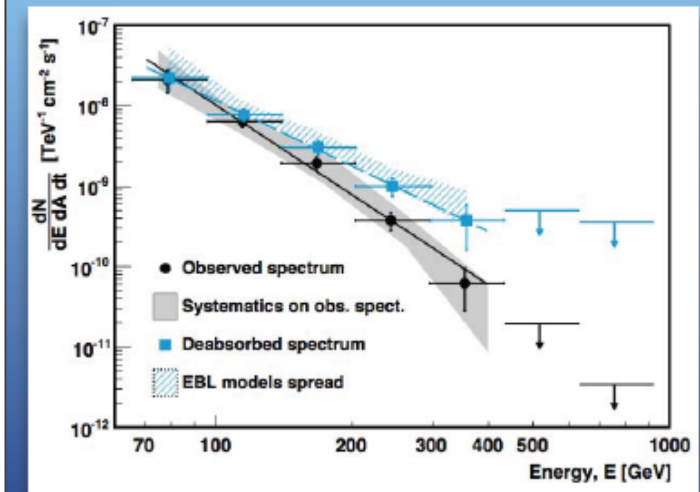
4C +21.35 aka PKS 1222+21

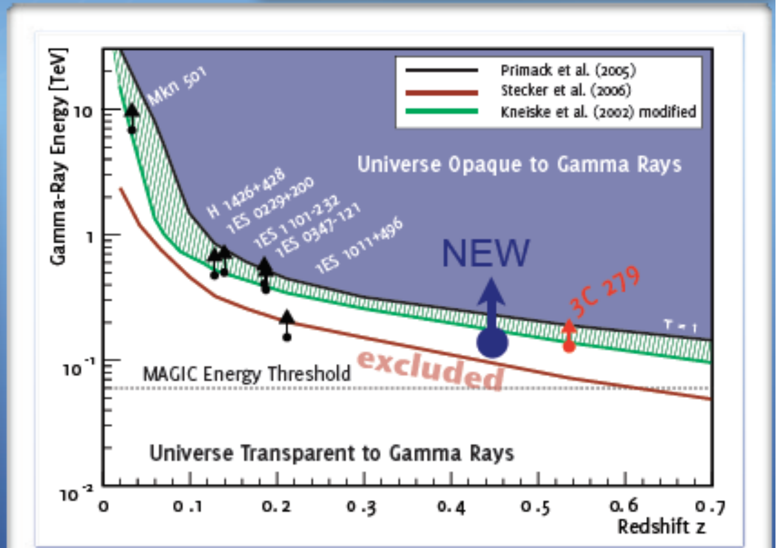
MAGIC Coll.,
A&A subm.

- 2010 June 17, flare state
- PKS 1222+21 (4C +21.35) is a high redshift (z=0.43) FSRQ

  (only 3C279, PKS1510-089 so far)
- Observations triggered by a high state reported by Fermi-LAT
- Can be used for EBL studies







Science 320 (2008) 1752

Photon – Axion Oscillation

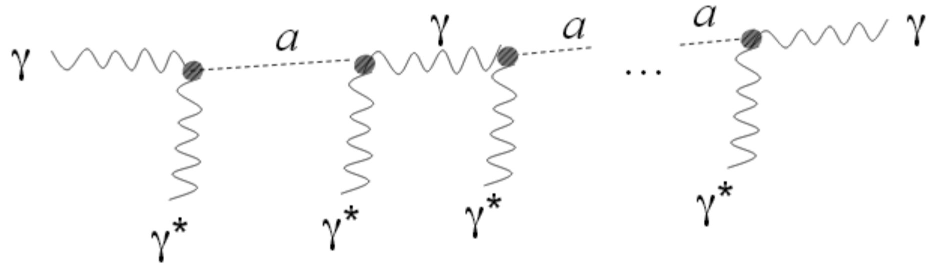
Axion Like Particle (ALP)

One intriguing possibility that have been recently proposed (DeAngelis-Mansutti-Roncadelli, 2007; DeAngelis-Mansutti-Persic-Roncadelli, 2008) is that conversion of γ's into axions into the random extragalactic magnetic fields give rise to a sort of cosmic *light-shining through wall* effect.

Axions have been introduced by Peccei & Quinn to solve the strong CP problem. Axion like particles with aγγ coupling are predicted in many extensions of the Standard Model. Pseudoscalar axions couple with the EM field through the effective Lagrangian

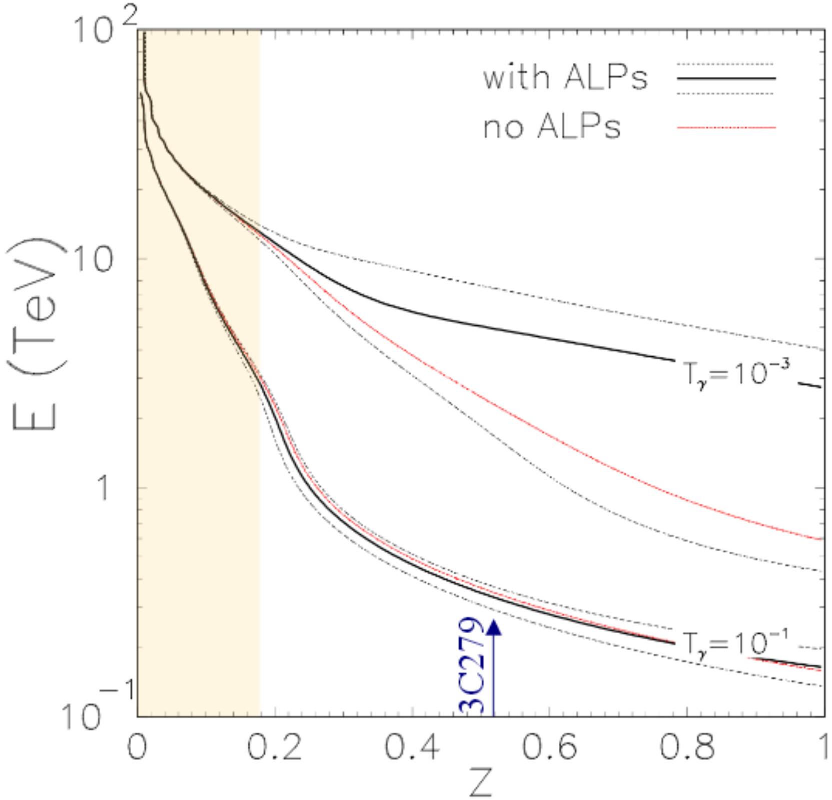
$$\mathcal{L}_{a\gamma} = -\frac{1}{4} g_{a\gamma} F_{\mu\nu} \tilde{F}^{\mu\nu} a$$

Photons propagating in an external magnetic field can undergo to photon-axion oscillations



Photon – Axion Oscillation

Realistic transfer function



For $z \leq 0.2$ the inclusion of the ALPs does not produce any significant change in the photon transfer function. Thus, it would be difficult to interpret in terms of ALP conversions the presumed transparency to gamma radiations for the sources at $z = 0.165$ and $z = 0.186$.

Conversely, ALP conversions could play a significant role for the source 3C279 at redshift $z = 0.54$

GRB repoint

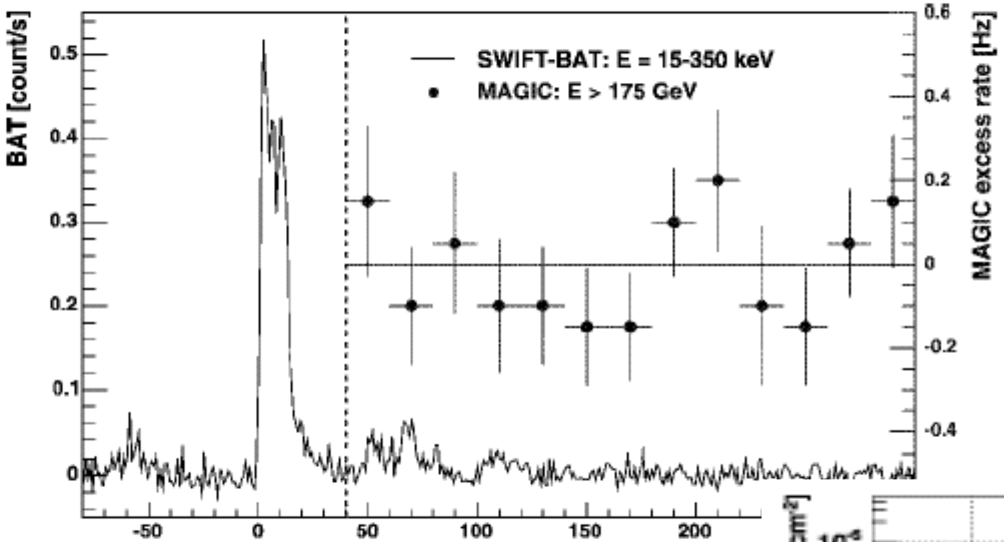
Current satellites giving alerts in short time: *FERMI, INTEGRAL, SWIFT*

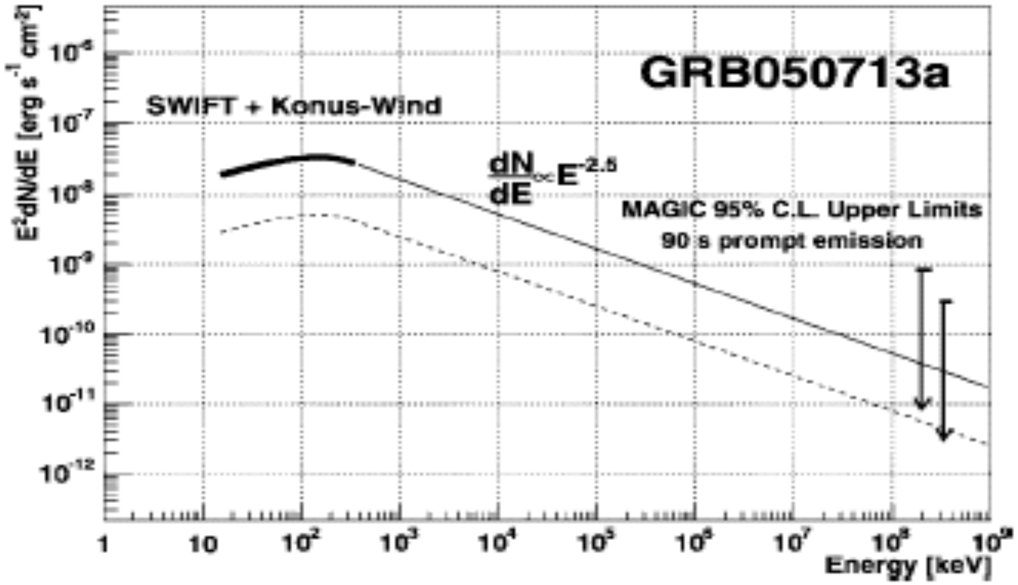
Delays of alerts from less than 10s to some minutes

Very fast repositioning capabilities are therefore requested:

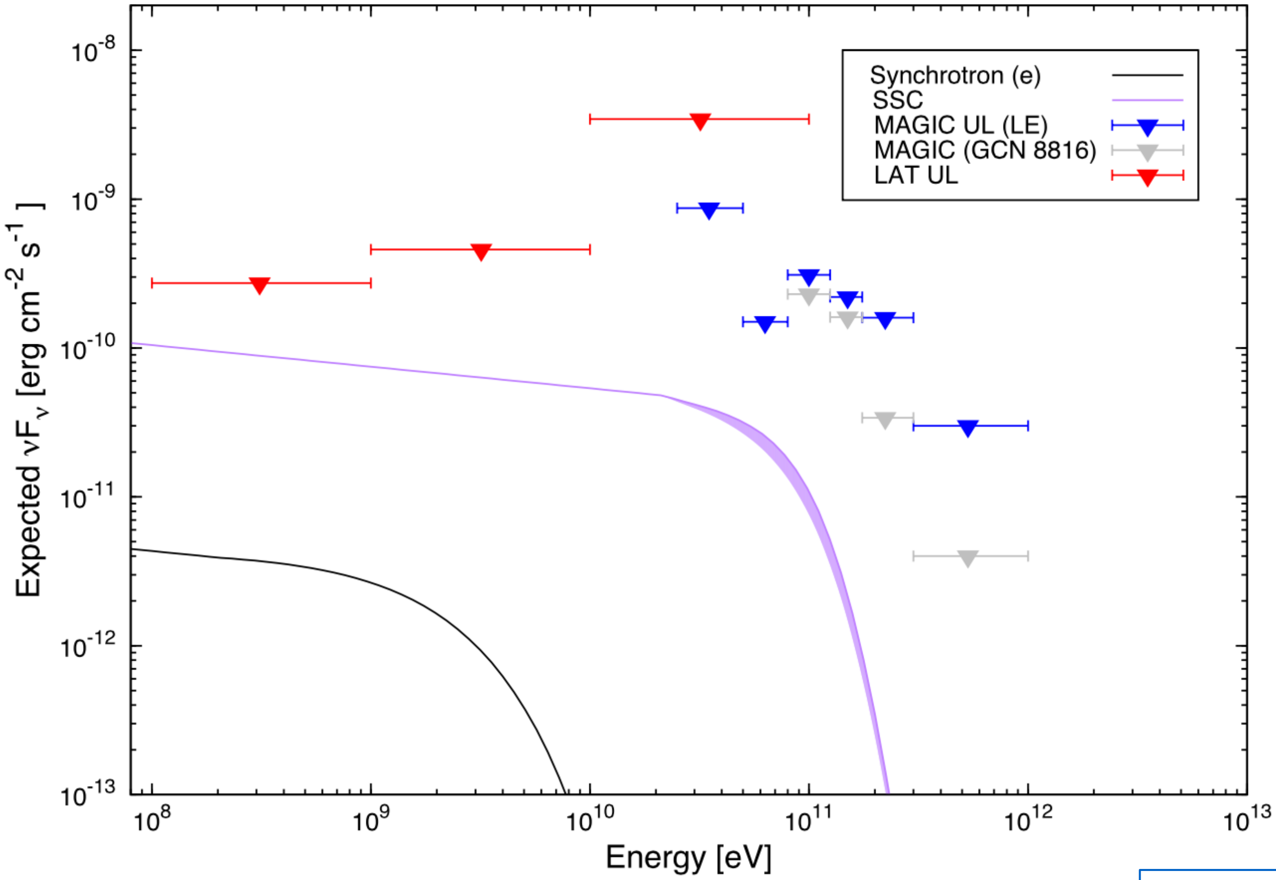
10 to 20 seconds!

GRBs


BAT [count/s]
MAGIC excess rate [Hz]
SWIFT-BAT: E = 15-350 keV
MAGIC: E > 175 GeV
0.5
0.4
0.3
0.2
0.1
0
0.6
0.4
0.2
0
-0.2
-0.4
-50
0
50
100
150
200


GRB050713a
SWIFT + Konus-Wind
$\frac{dN}{dE} \propto E^{-2.5}$
MAGIC 95% C.L. Upper Limits
90 s prompt emission
$E^2 dN/dE$ [erg s^{-1} cm^{-2}]
Energy [keV]

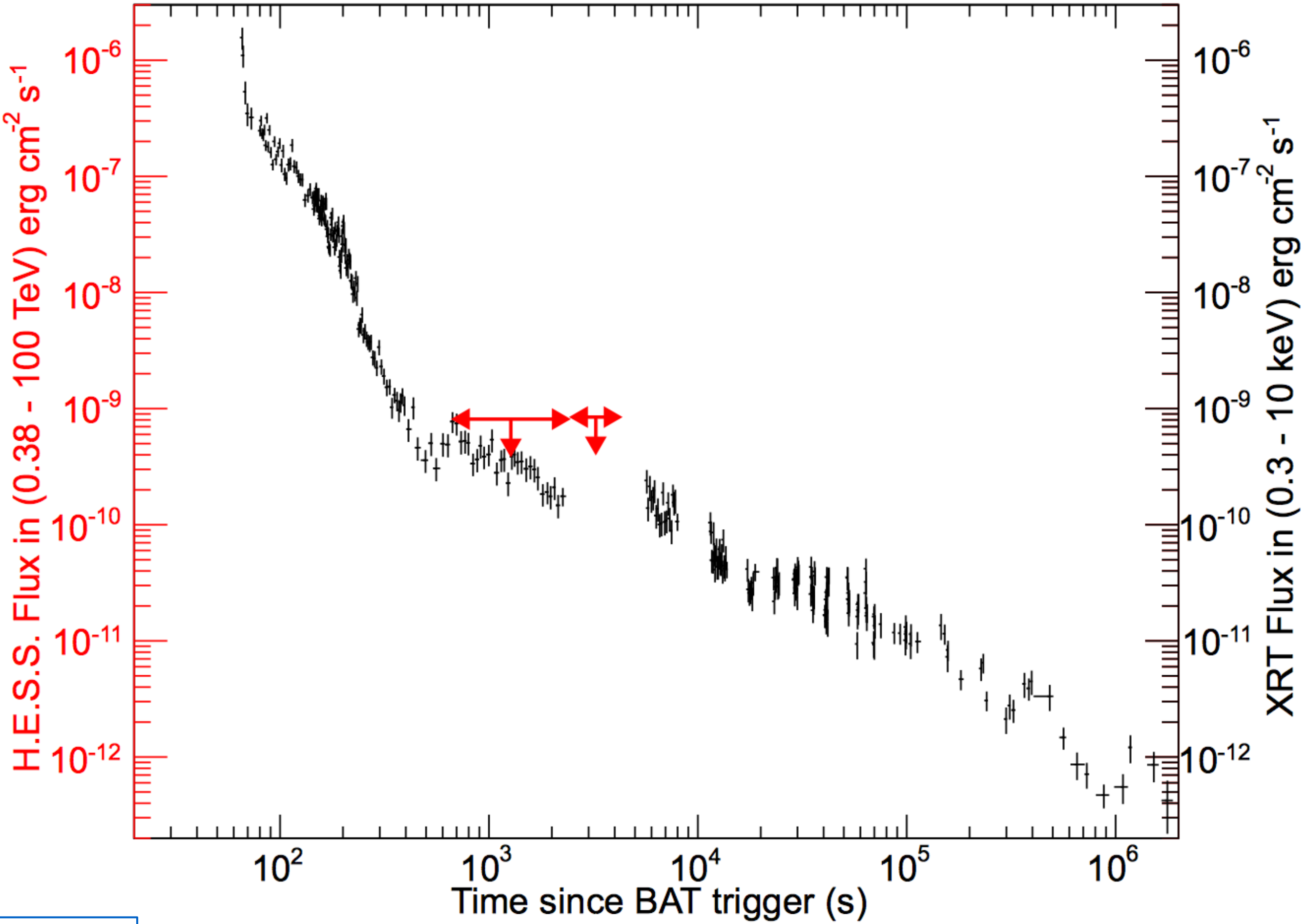
MAGIC– I upper limits



GRB 090102

J. Aleksic et al., 2014

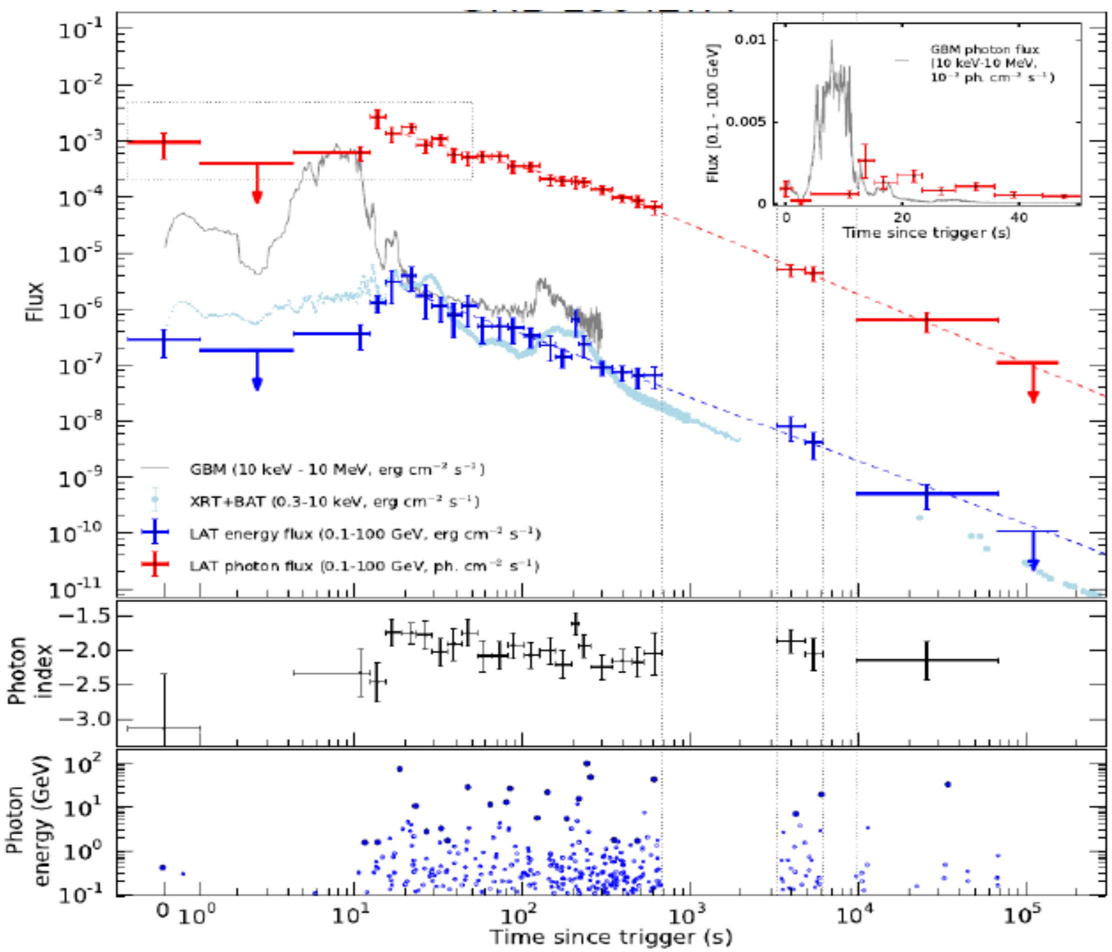
HESS - I upper limits



GRB 100621A

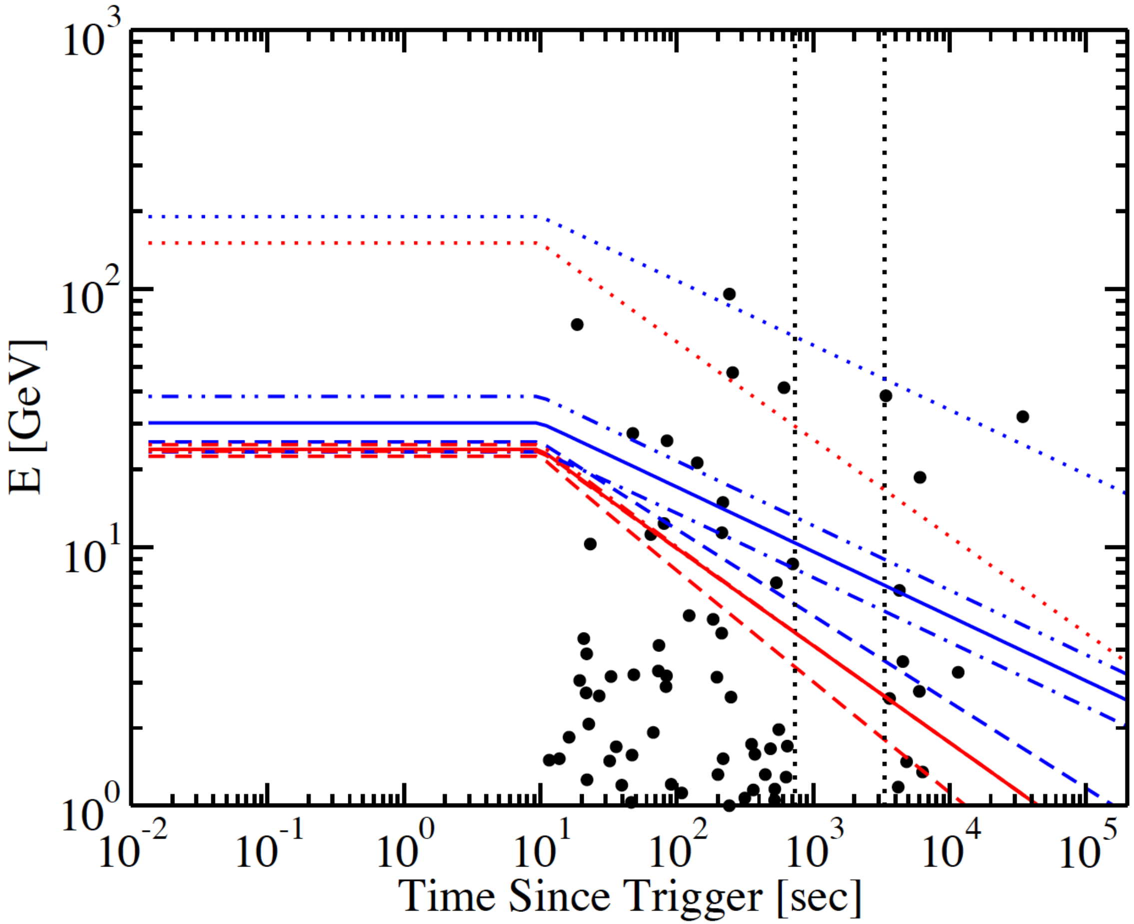
Abramowski et al. 2014

GRB 130427A



in today poster session
(Ackermann et al.,
Science, Vol. 343 no. 6166
pp. 42-47)

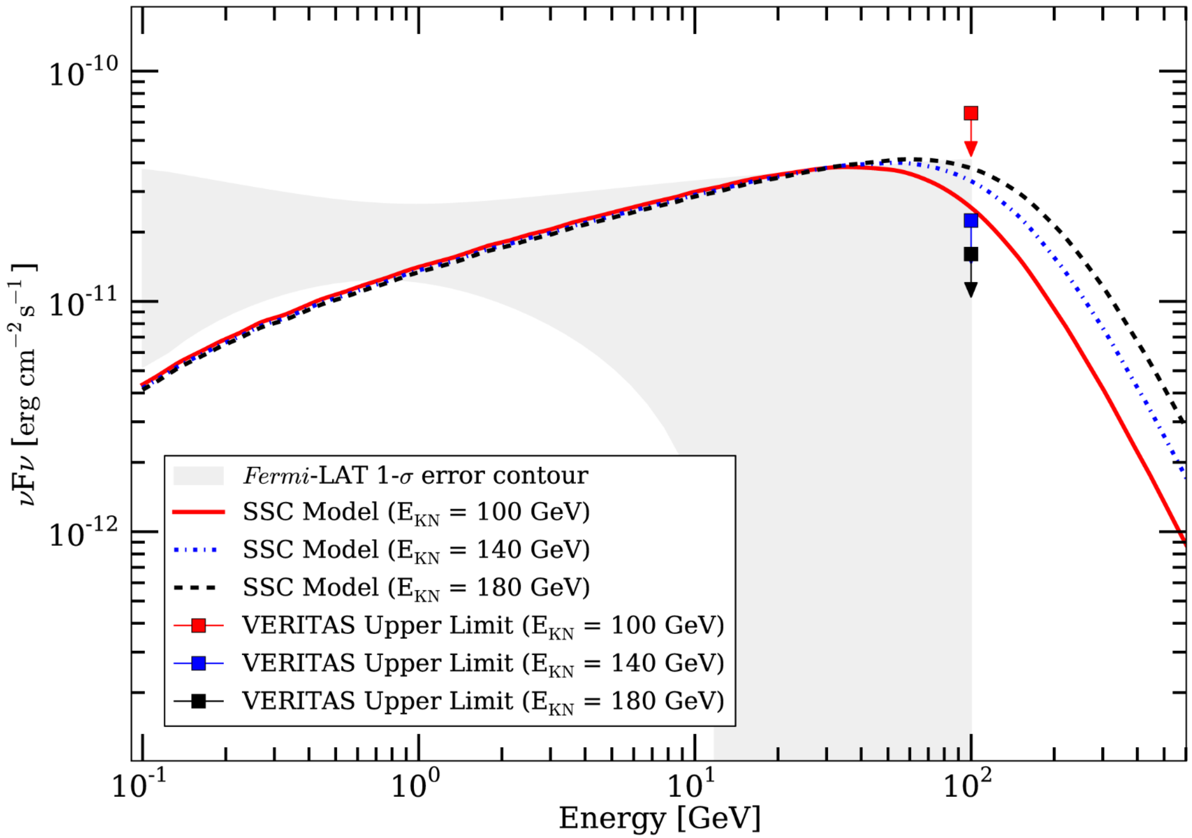
GRB VHE emission. Single photons matter



GRB 130427A

Ackermann et al. 2014

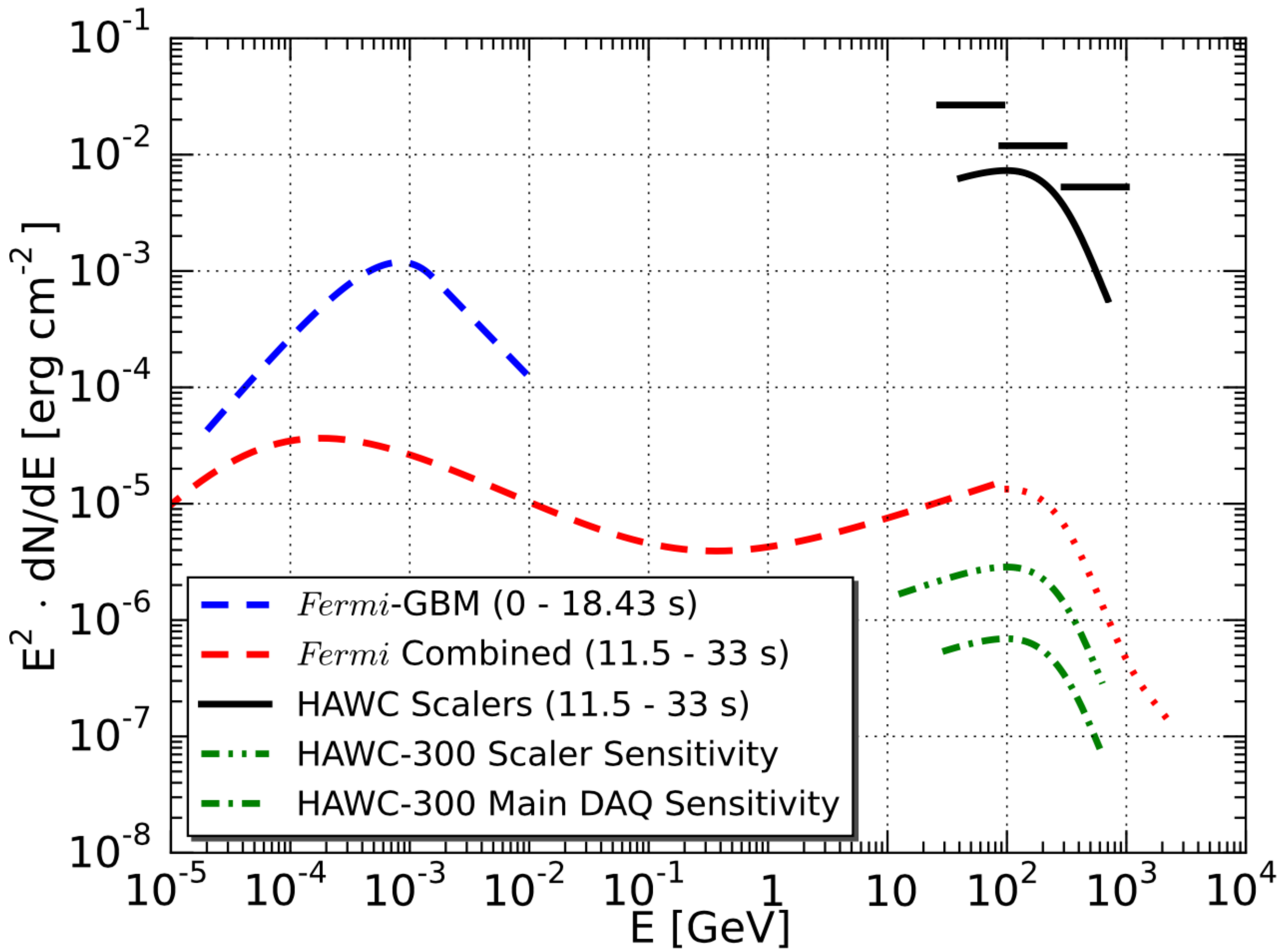
VERITAS upper limits



GRB 130427A

Aliu et al. 2014

HAWC upper limits



Abeysekara et al. 2015

GRB 130427A

MAGIC detection

First time detection of a GRB at sub-TeV energies; MAGIC detects the GRB 190114C

ATel #12390; ***Razmik Mirzoyan on behalf of the MAGIC Collaboration***
*on **15 Jan 2019; 01:03 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

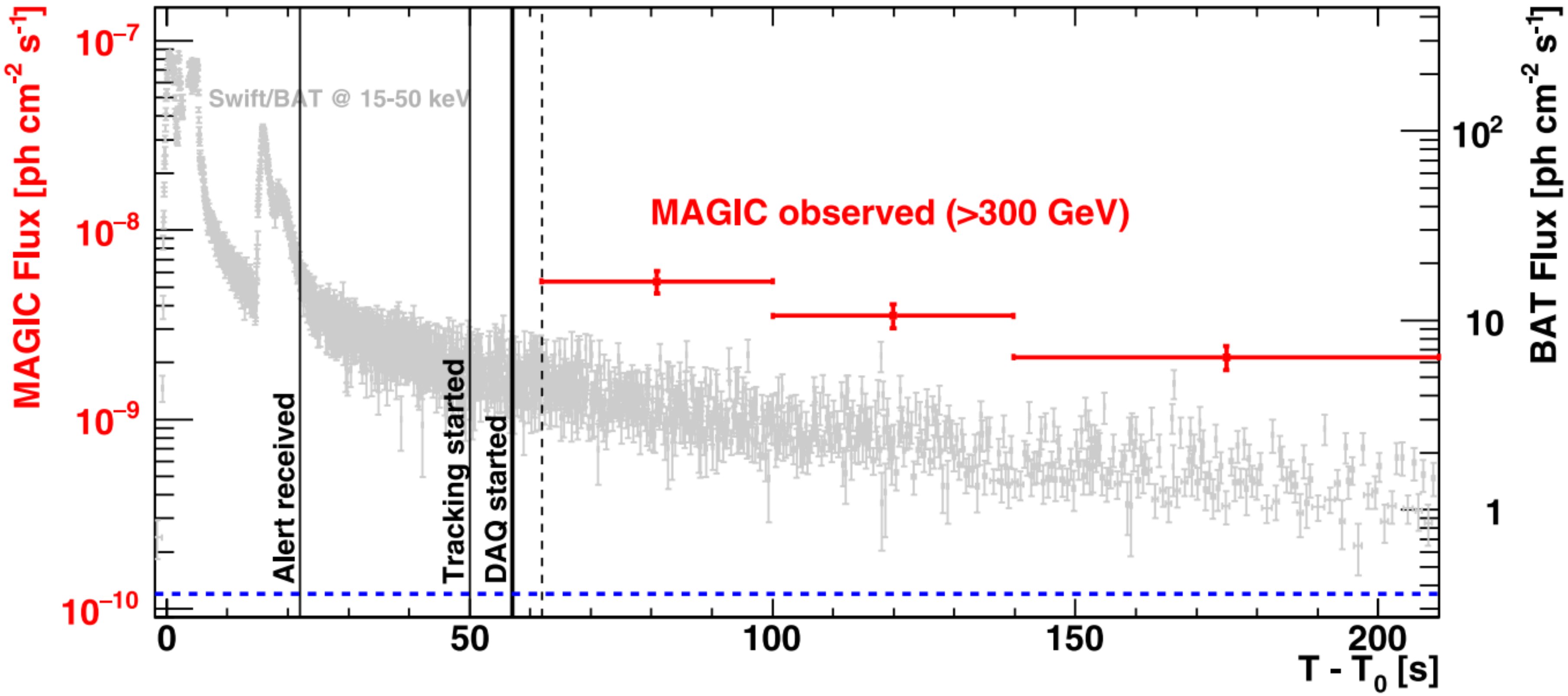
Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, Gamma-Ray Burst

Referred to by ATel #: 12395, 12475

Tweet

The MAGIC telescopes performed a rapid follow-up observation of GRB 190114C (Gropp et al., GCN 23688; Tyurina et al., GCN 23690, de Ugarte Postigo et al., GCN 23692, Lipunov et al. GCN 23693, Selsing et al. GCN 23695). This observation was triggered by the Swift-BAT alert; we started observing at about 50s after Swift T0: 20:57:03.19. The MAGIC real-time analysis shows a significance >20 sigma in the first 20 min of observations (starting at T0+50s) for energies >300GeV. The relatively high detection threshold is due to the large zenith angle of observations (>60 degrees) and the presence of partial Moon. Given the brightness of the event, MAGIC will continue the observation of GRB 190114C until it is observable tonight and also in the next days. We strongly encourage follow-up observations by other instruments. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) and K. Noda (nodak@icrr.u-tokyo.ac.jp). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatory Roque de los Muchachos on the Canary island La Palma, Spain, and designed to perform gamma-ray astronomy in the energy range from 50 GeV to greater than 50 TeV.

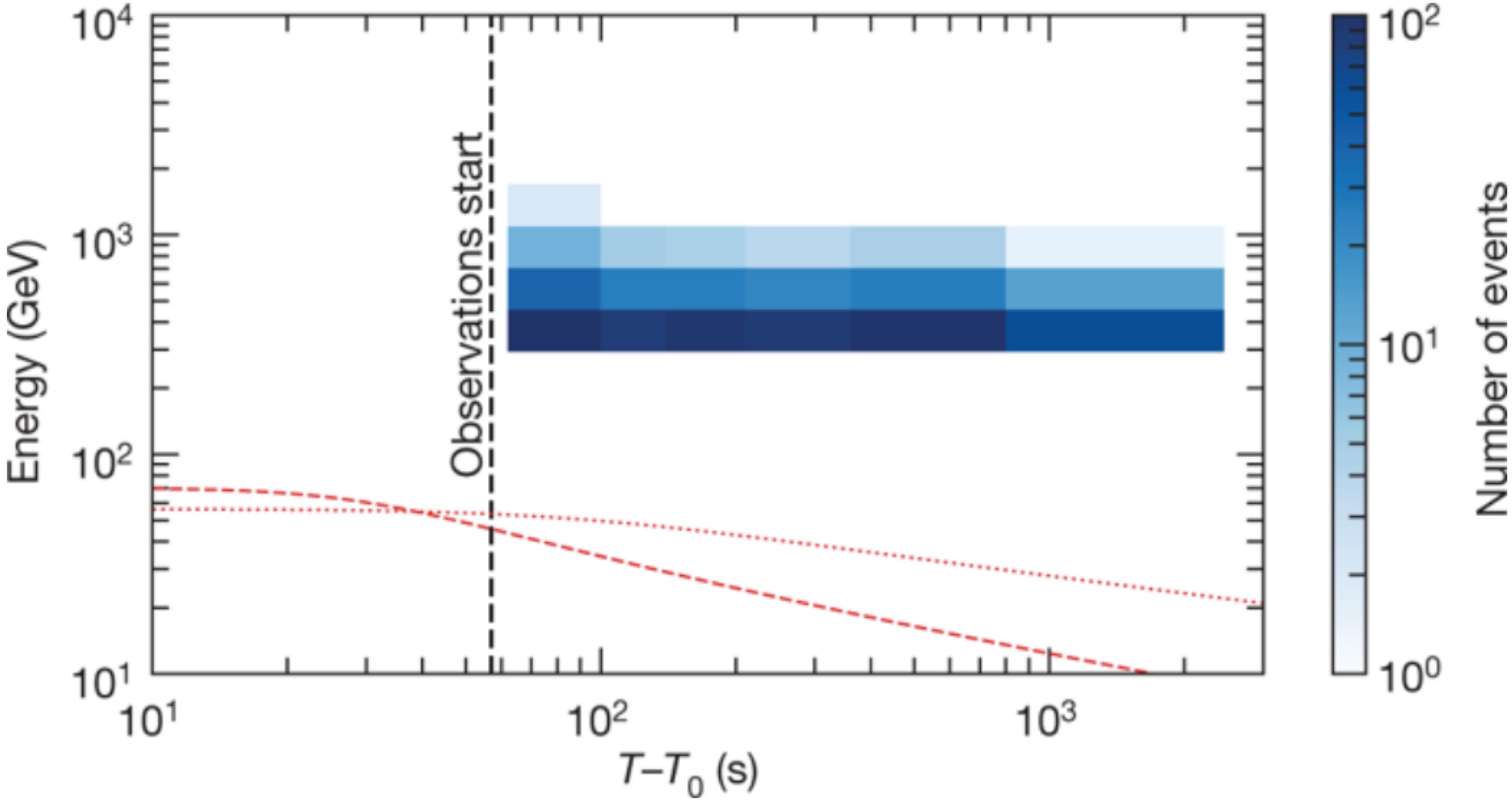
MAGIC detection



GRB 190114C

Acciari et al. 2019a

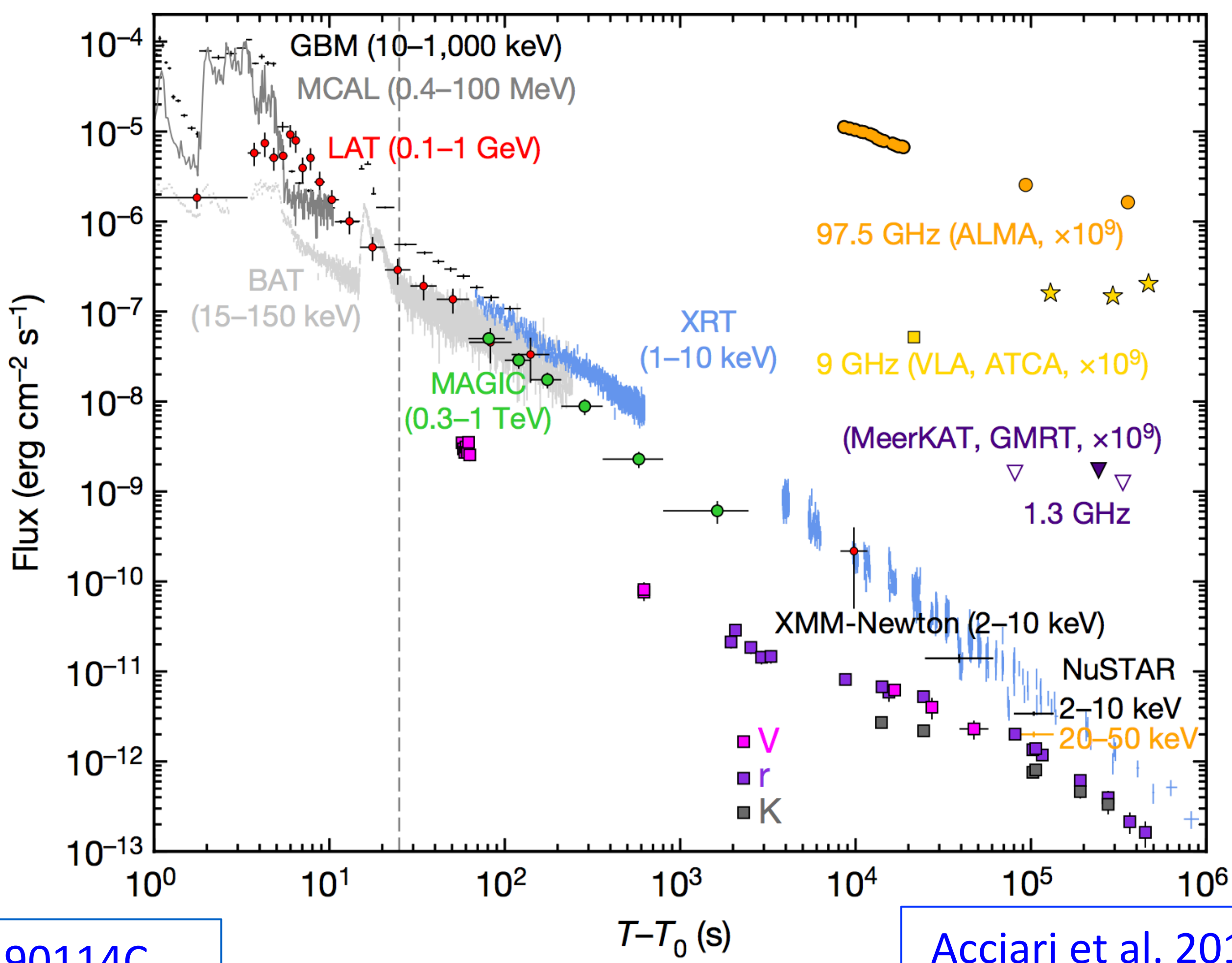
MAGIC detection



GRB 190114C

Acciari et al. 2019a

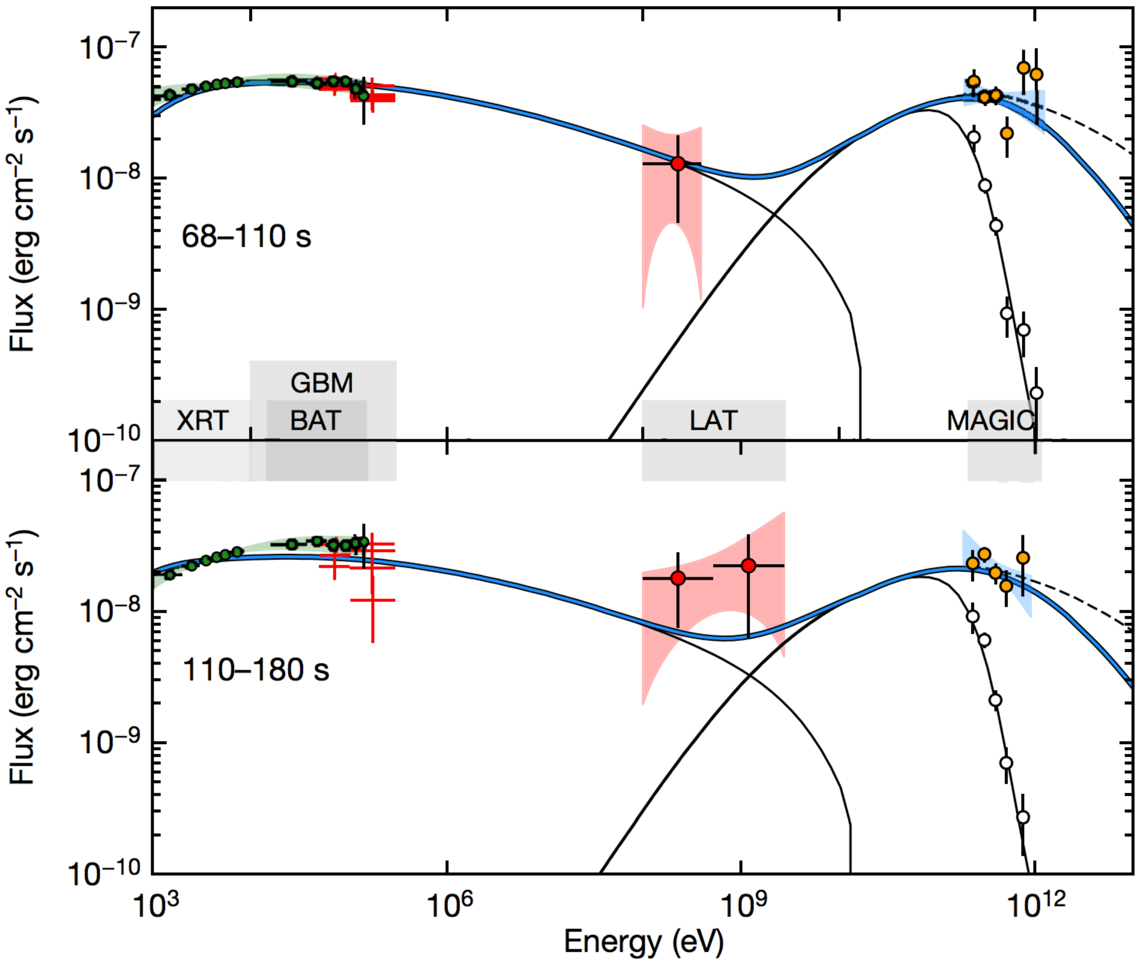
MAGIC detection



GRB 190114C

Acciari et al. 2019b

MAGIC detection



GRB 190114C

Acciari et al. 2019b

Astrofisica Nucleare e Subnucleare

Future detectors

2004	2005	2006	2007	2008	2009	2010

Roadmap to the Next Generation Cherenkov Gamma Ray Telescope


H.E.S.S.


H.E.S.S. II

Technology for Fully Robotic Telescope

Experimental Study of High Altitude effect

Design Study of Large Telescope

Site Survey

Characterization of Low Energy Showers

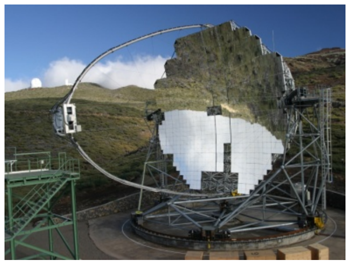
Design Study of Wide Angle Telescope

Advanced photon detector

Science Review

Final Conceptual Design under New collaboratio

Ultimate Ground-based Cherenkov Telescope System
Larger Dish,
High Altitude,
Advanced detector,
Wide Angle

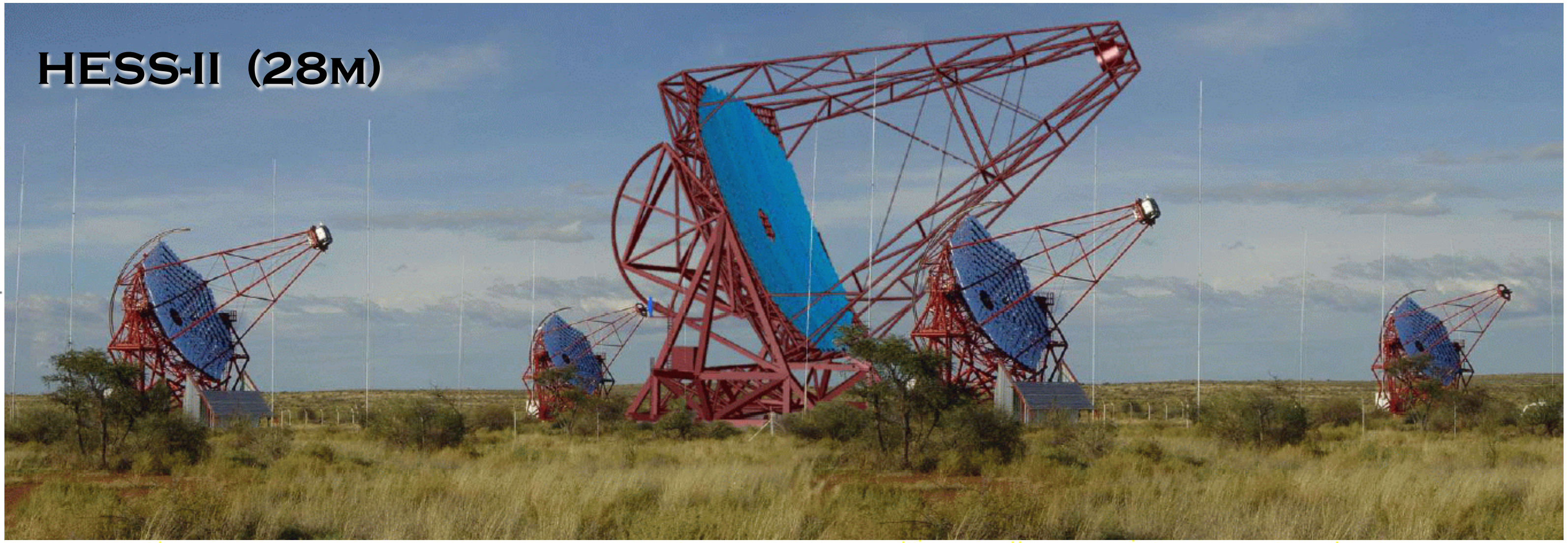

MAGIC


MAGIC II

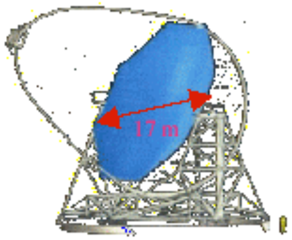
International collaboration CANGAROO, VERITAS, etc.

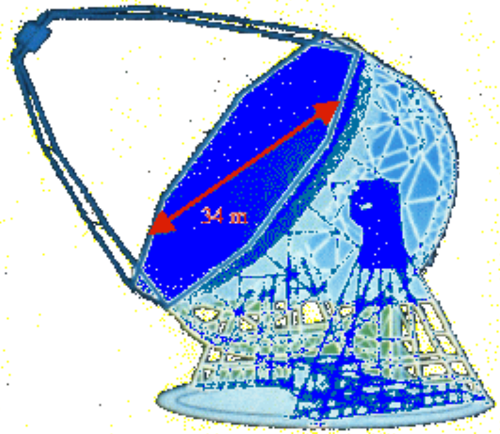
New Cherenkov telescopes

HUNT FOR LOWEST THRESHOLD: BIGGER IS BETTER !!!???



ECO-1000 ? (34M)

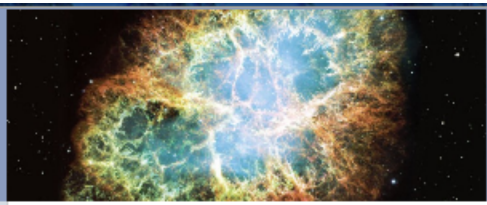




New Cherenkov telescopes

ISDC INTEGRAL Planck Gaia FACT ASTRO-H POLAR CTA
LOFT SAFARI JEM-EUSO ATHENA CAP HEAVENS

ISDC



FACT

FACT

- Welcome
- Facts about FACT
- Science Program
- Publications
- FACT Collaboration

Data

- Data Archive
- Data Analysis
- Science Products

Operations

- Planning
- Log Book

Internal Pages

FACT

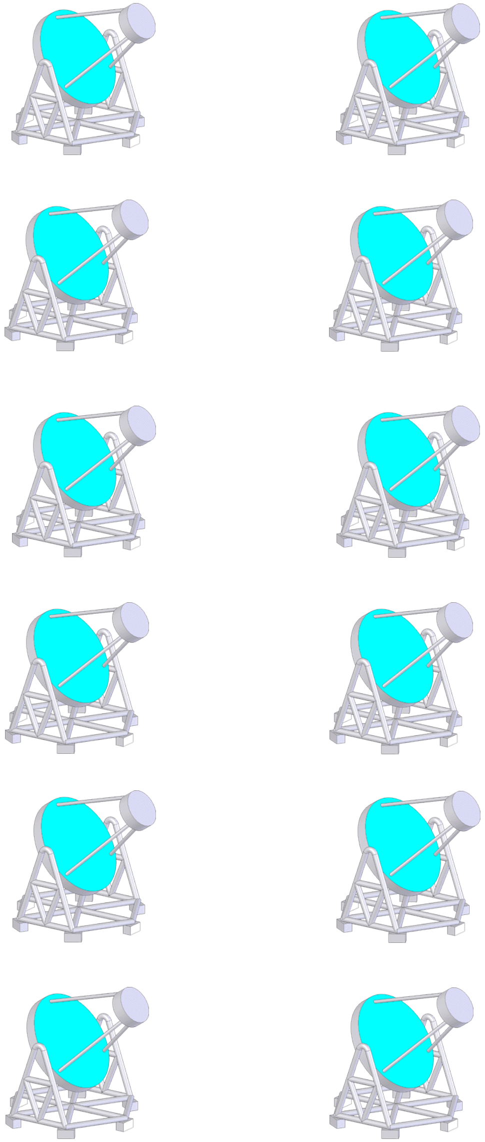
The First G-APD Cherenkov Telescope

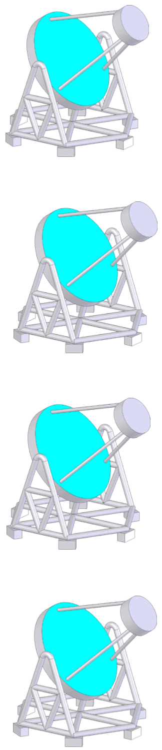
FACT
First G-APD Cherenkov Telescope

The **F**irst G-**A**PD **C**herenkov **T**elescope (FACT) is the first imaging atmospheric Cherenkov telescope using Geiger-mode avalanche photodiods (G-APDs) as photo sensors. The rather small, low-cost telescope will not only serve as a test bench for this technology in Cherenkov astronomy, but also monitor bright active galactic nuclei (AGN) in the TeV energy range.

http://isdc.unige.ch/fact/

Outlook: What next ?





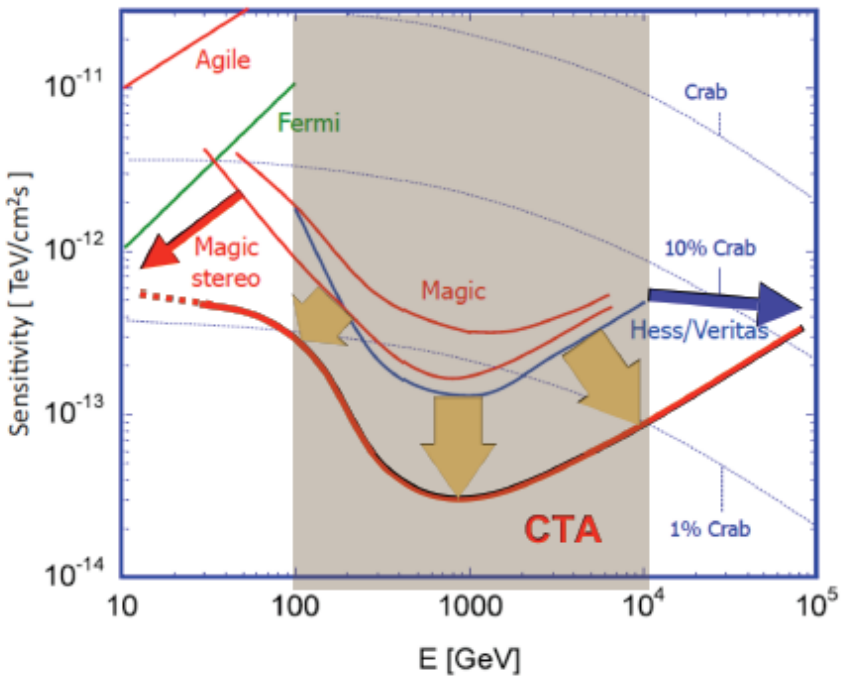
The Cherenkov Telescope Array (CTA)

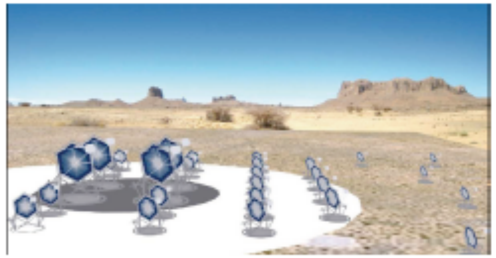
- aims to explore the sky in the 10 GeV to 100 TeV energy range
- builds on demonstrated technologies
- combines guaranteed science with significant discovery potential
- is a cornerstone towards a multi-messenger exploration of the nonthermal universe

CTA

cta
cherenkov telescope array

Improve sensitivity





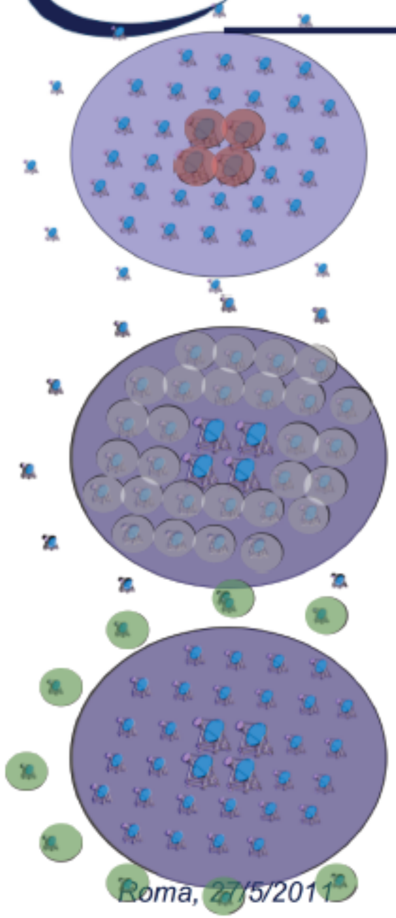
CTA will be about a factor of 10 more sensitive than any existing instrument in the 100 GeV-10 TeV energy band.

CTA will also extend the observed energy band reaching both the lower (10 GeV) and the higher (100 TeV) energies.

CTA

CTA concept

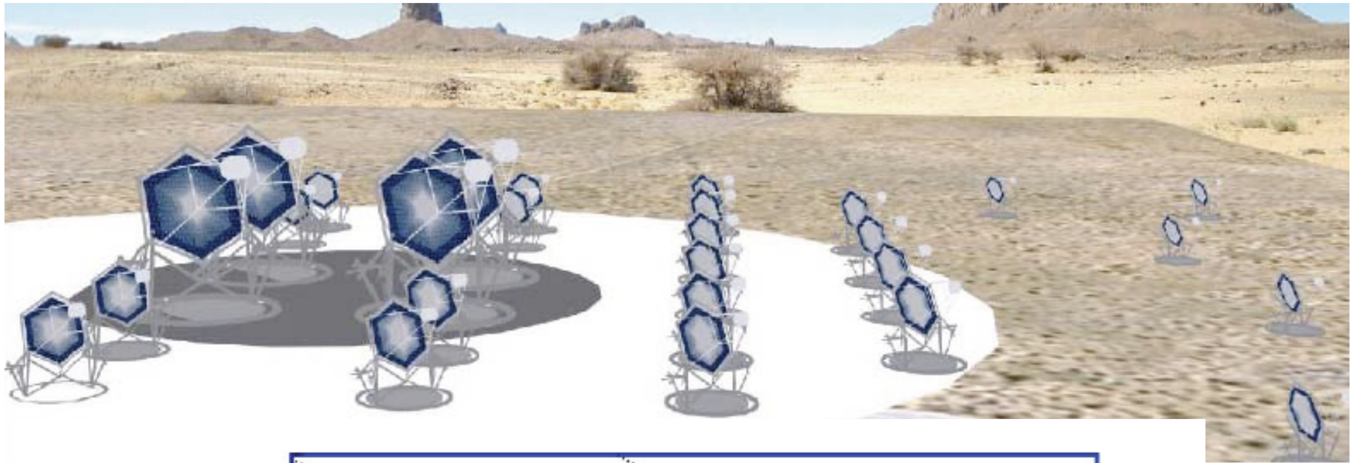
cta
cherenkov telescope array

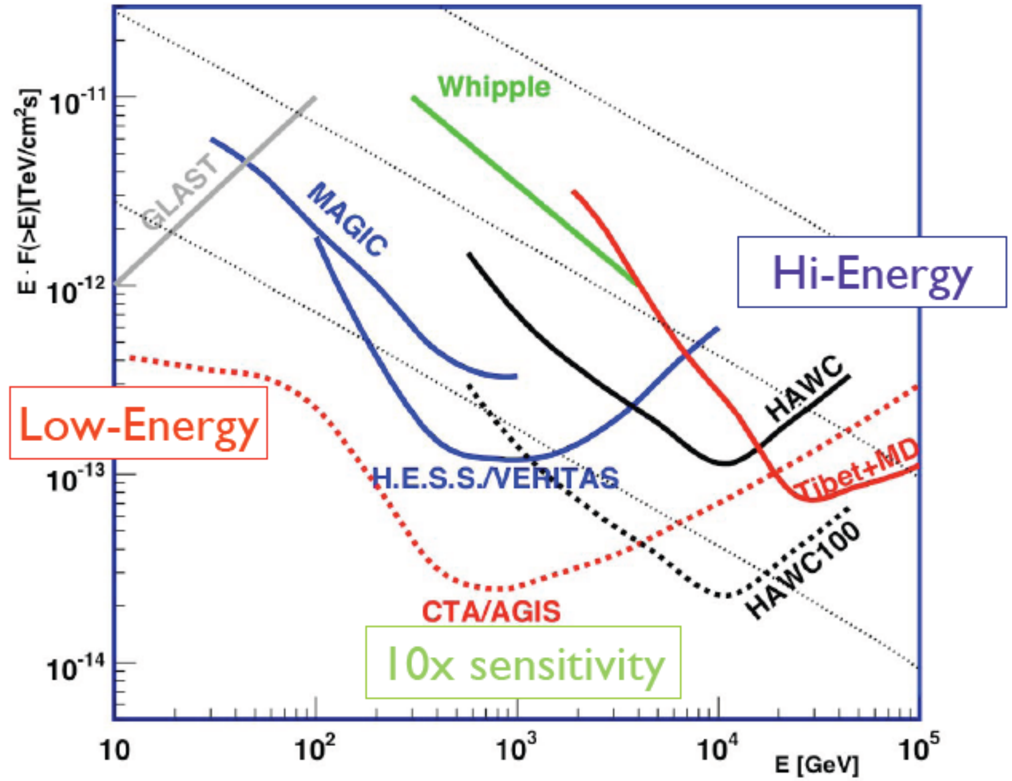


- Few Large Size Telescopes should catch the sub-100 GeV photons
  - Large reflective area
  - Parabolic profiles to maintain time-stamp
  - Contained FOV
- Several Medium Size Telescopes perform 100 GeV-50 TeV observation
- well-proven techniques (HESS, MAGIC)
- goal is to reduce costs and maintenance
- core of the array
- act as VETO for LSTs

- Several Small Size Telescopes perform ultra-50 TeV observation
- challenging design
- Large field-of-view (8°)
- New camera technology

CTA



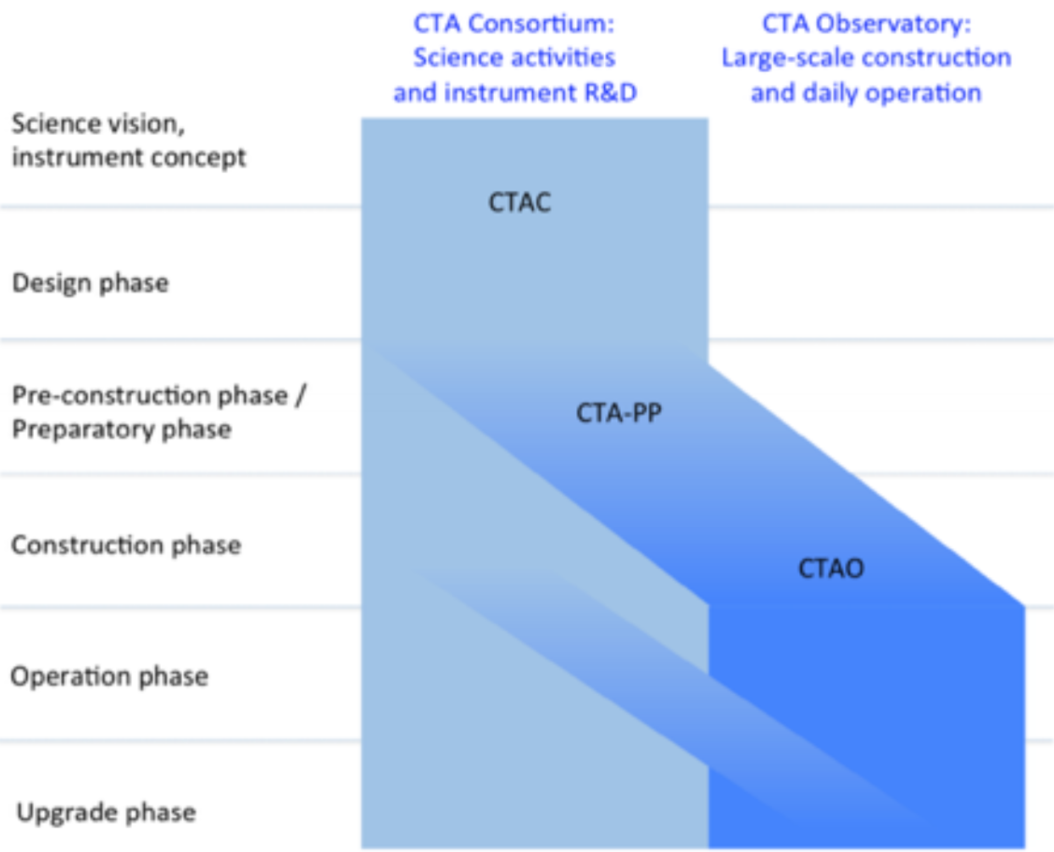


E · F(>E)[TeV/cm²s]
10^-11
10^-12
10^-13
10^-14
Whipple
GLAST
MAGIC
Hi-Energy
HAWC
Low-Energy
H.E.S.S./VERITAS
Tibet+MD
HAWC100
CTA/AGIS
10x sensitivity
10
10^2
10^3
10^4
10^5
E [GeV]

Toward the future!

A next generation Cherenkov Observatory

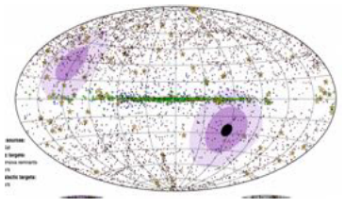
Status and observatory planning…

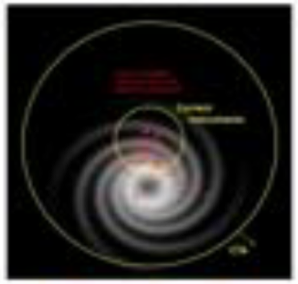


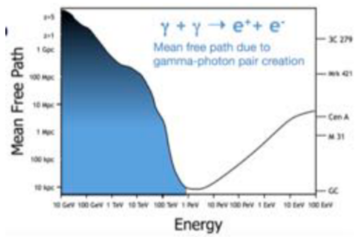
From:
Concept for CTA
construction and operation
WH 2011/12

- CTA as open observatory
- Regular AOs
- Proposals evaluated by TAC
- Observations carried out in queue mode
- Fully calibrated photon lists and analysis tools provided to observers
- Data open after proprietary period of 1 year

Design drivers

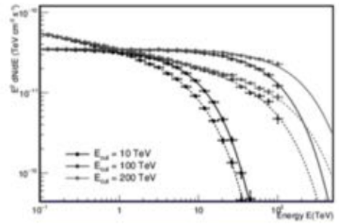






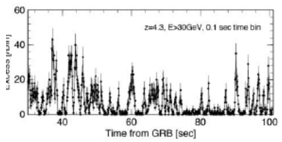
Full sky coverage

10 x sensitivity



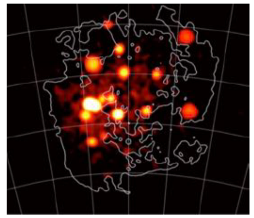
Energies down to 20 GeV

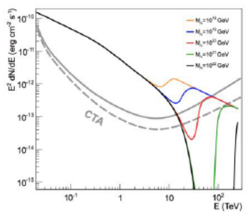
Energies up to 300 TeV



Rapid slewing 20 sec

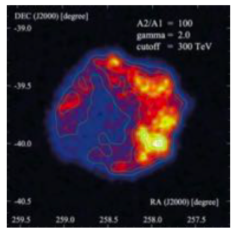
~ 10° FoV





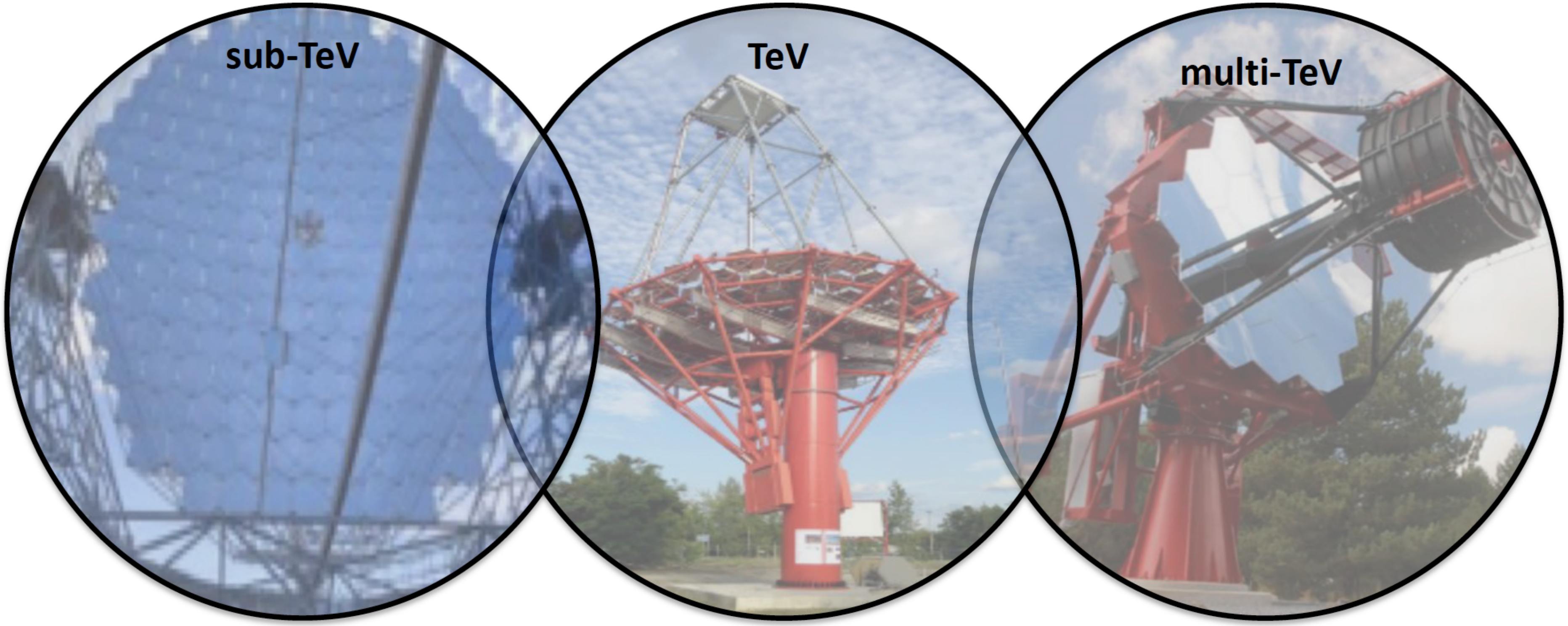
10% energy resolution

arcmin angular resolution



R.Zanin – TeVPa 2019

Science cases and design

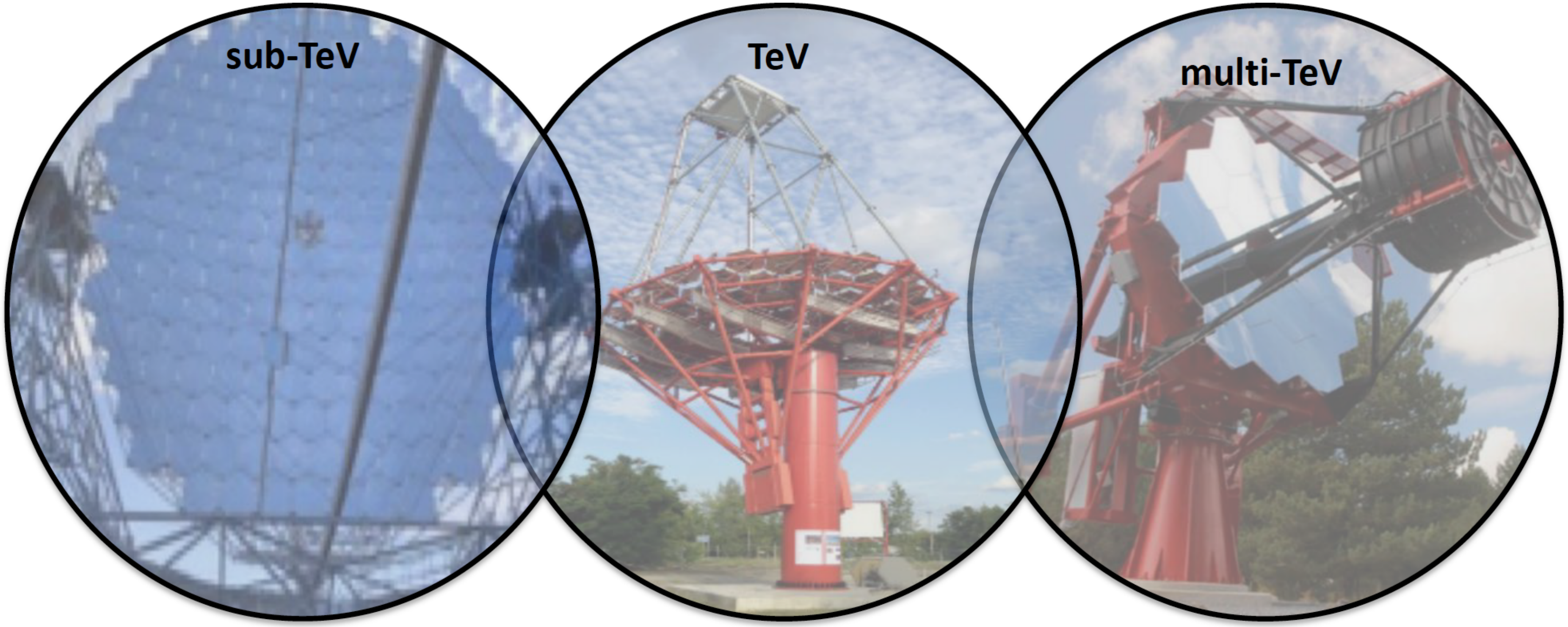


- Parabolic optical design
- 23 m mirror diameter
- PMT camera

- Davies-Cotton optical design
- 12 m mirror diameter
- PMT camera

- Schwarzschild-Couder optical design
- 4 m dual mirror
- SiPM T camera

Science cases and design



- Lowest energies (tens of GeV)
  → **cosmological sources**
- Deepest sensitivity for short timescale phenomena
  → **Time domain unexplored**

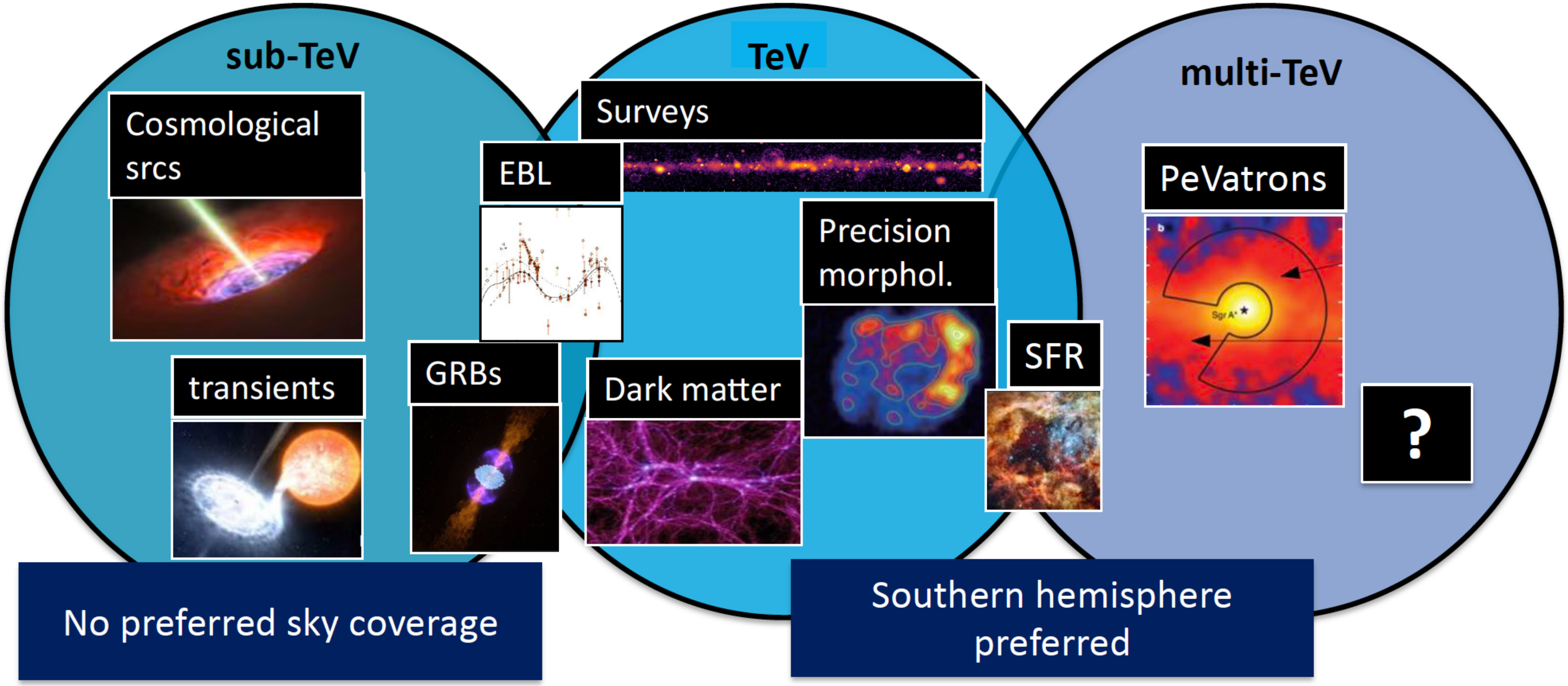
- deepest sensitivity ever
- arcmin angular resolution
- large FoV

- Surveys & precision studies

- Precision measurements in a still little explored energy range

- **100 TeV range unexplored**
- **precision studies**

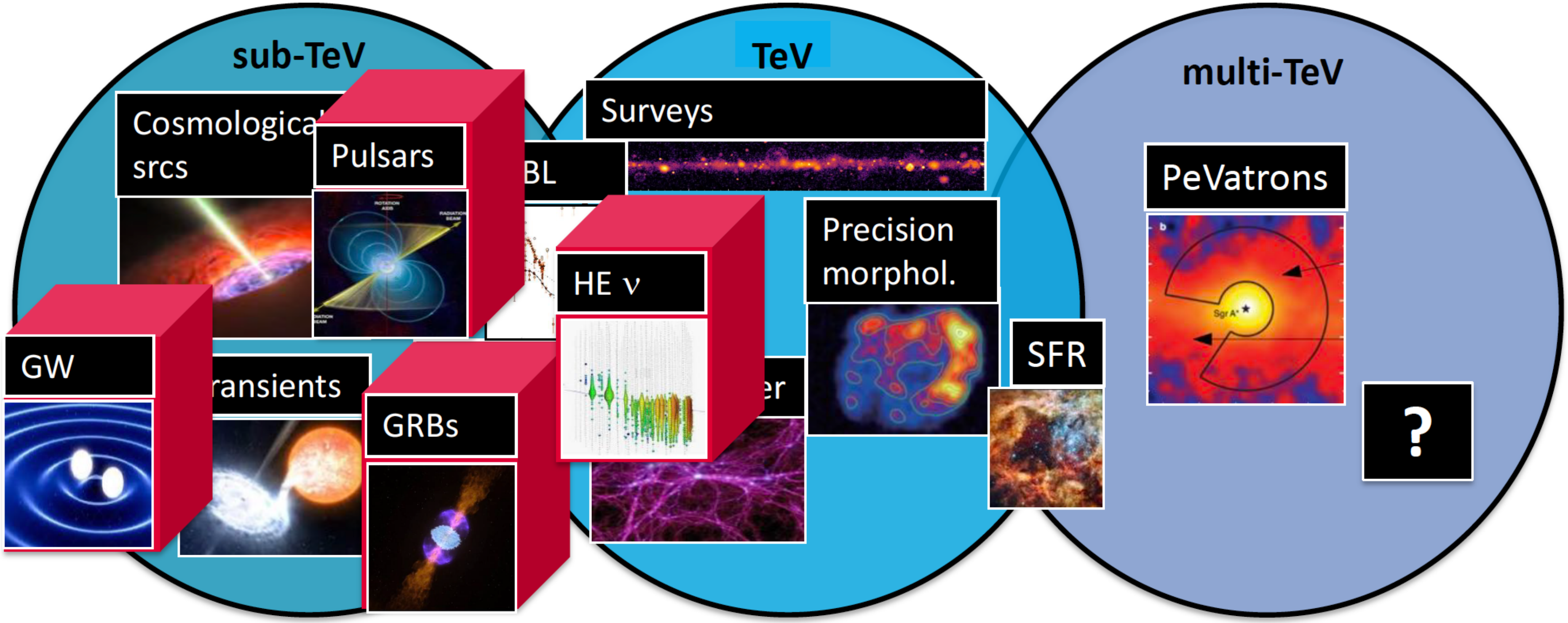
Science cases



- **Mainly CTA consortium involved in the definition of the science cases**

(Science with CTA, CTA Consortium 2019 - https://doi.org/10.1142/10986)

Science cases



- **Mainly CTA consortium involved in the definition of the science cases**

(Science with CTA, CTA Consortium 2019 - https://doi.org/10.1142/10986)

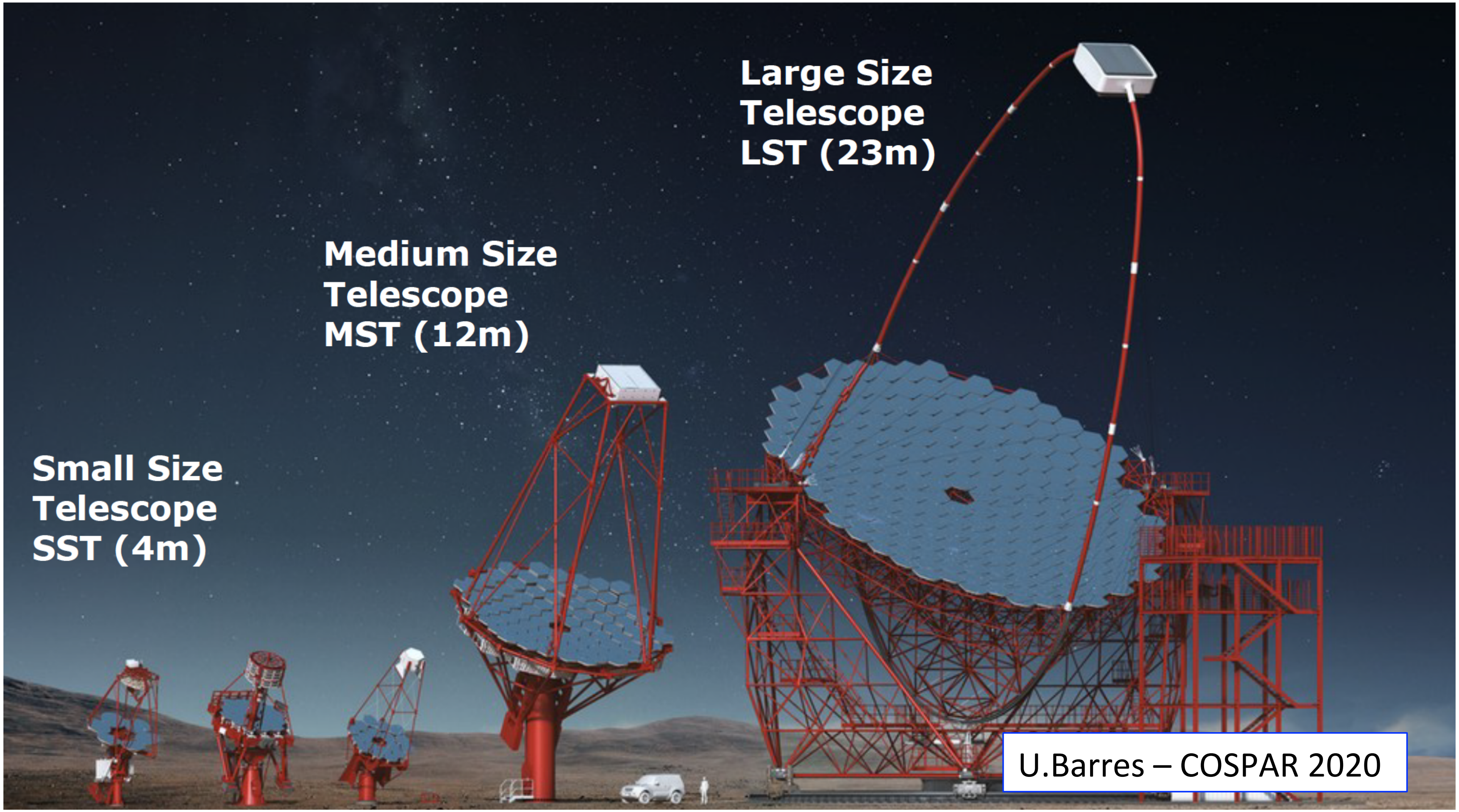
The CTA Sites

A Global Observatory…

U.Barres – COSPAR 2020

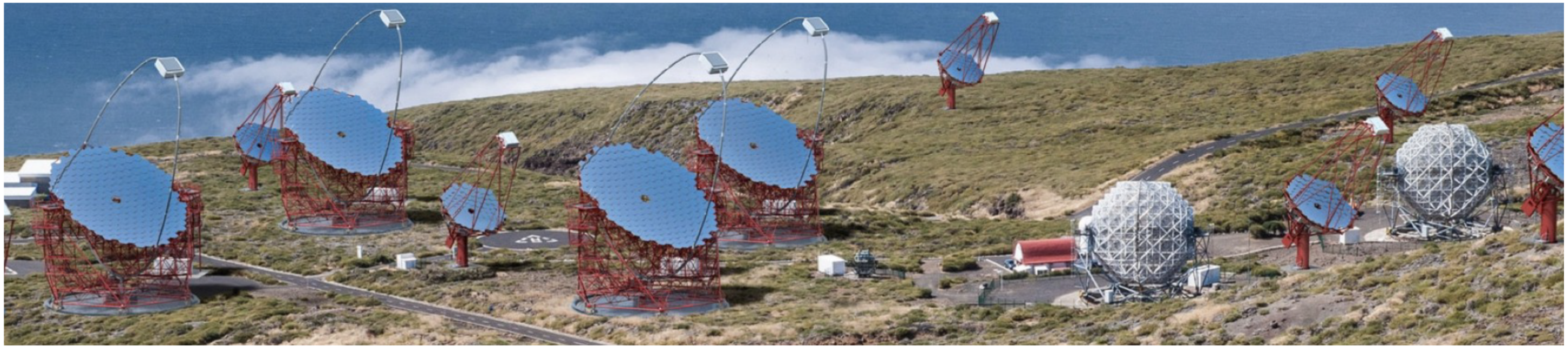
The CTA Telescopes

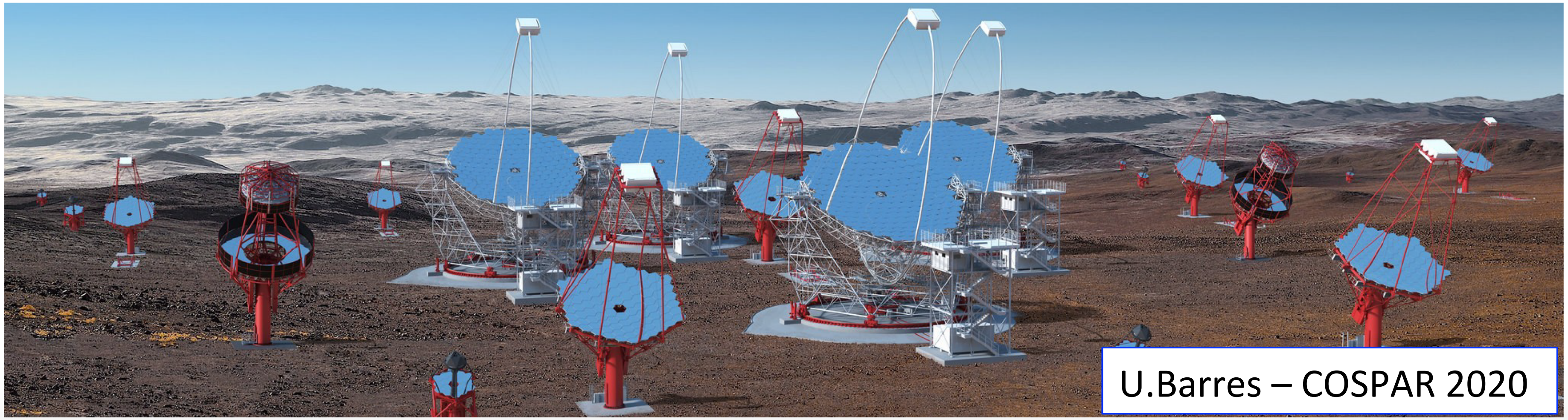
A Hybrid Observatory…



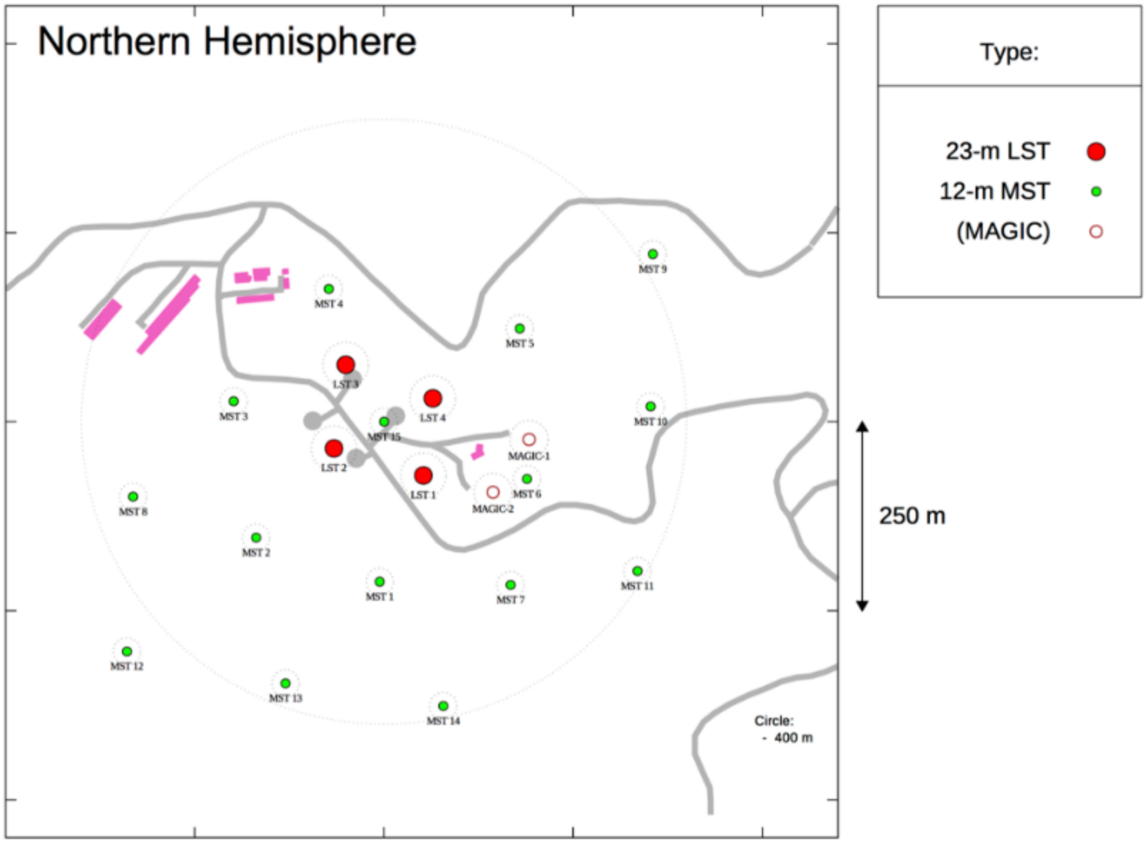
CTA North & CTA South

Phase 1		CTA Construction
Northern Array	Number of LSTs	4
	Number of MSTs	5
Southern Array	Number of LSTs	0
	Number of MSTs	15
	Number of SSTs	50
Total		74





CTA - North

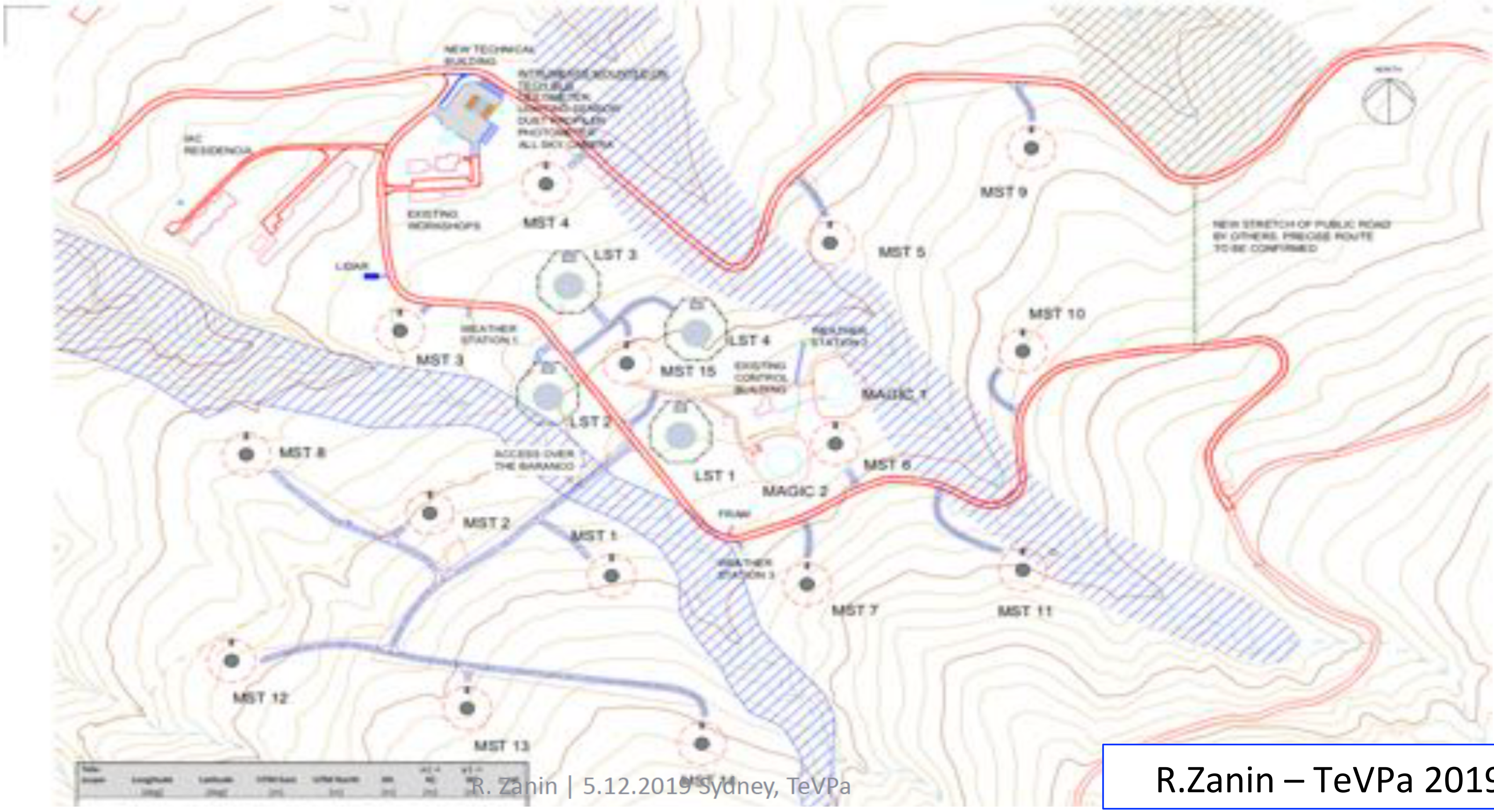


4 LS4 LSTs, 15 MSTs

https://www.cta-observatory.org/science/cta-performance/

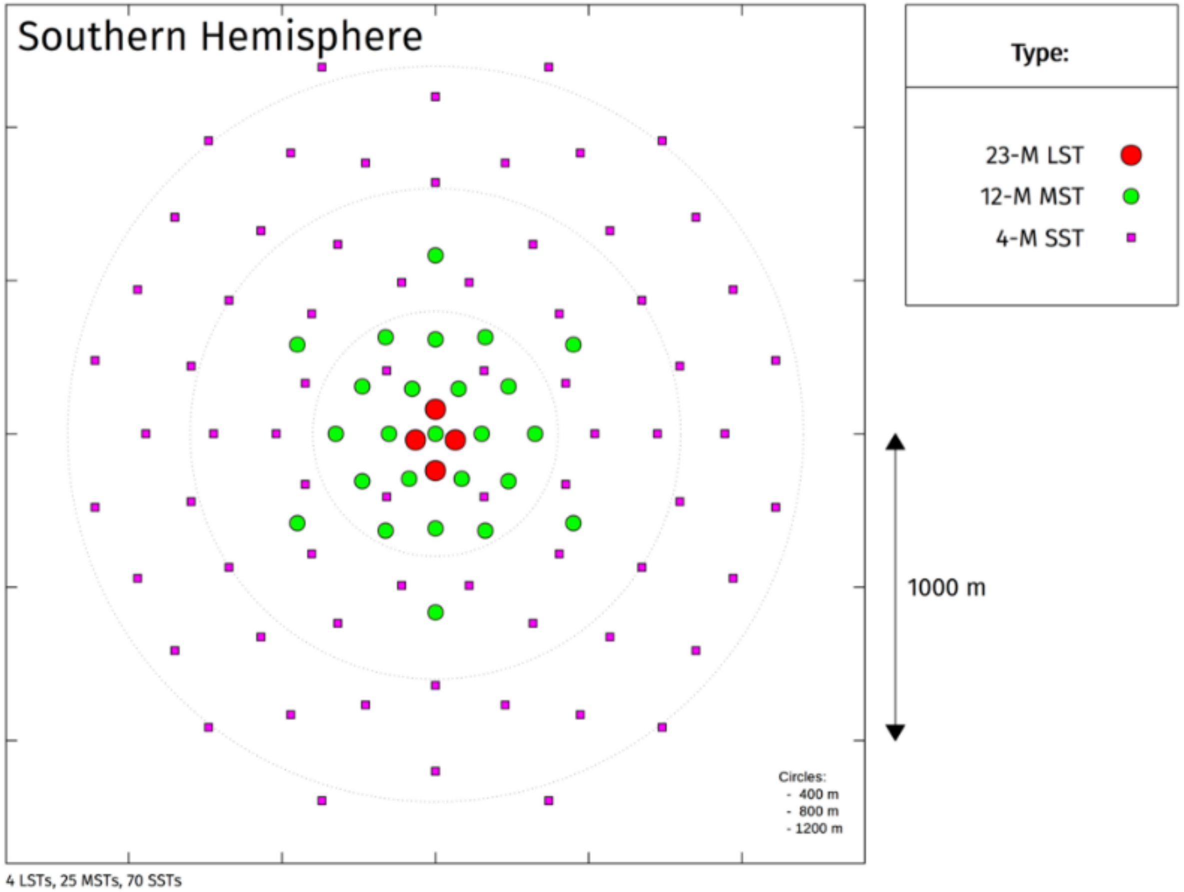
CTA-North site

- **4 LSTs + 15 MSTs (baseline configuration)**
  - **Focus on sub-TeV and TeV energy range**



R.Zanin – TeVPa 2019

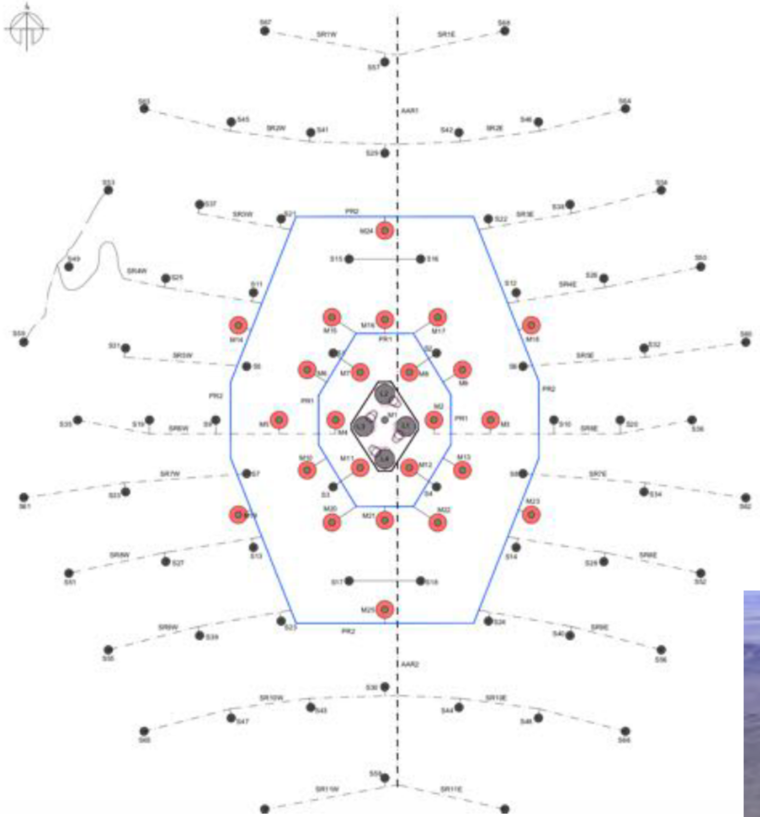
CTA – South



https://www.cta-observatory.org/science/cta-performance/

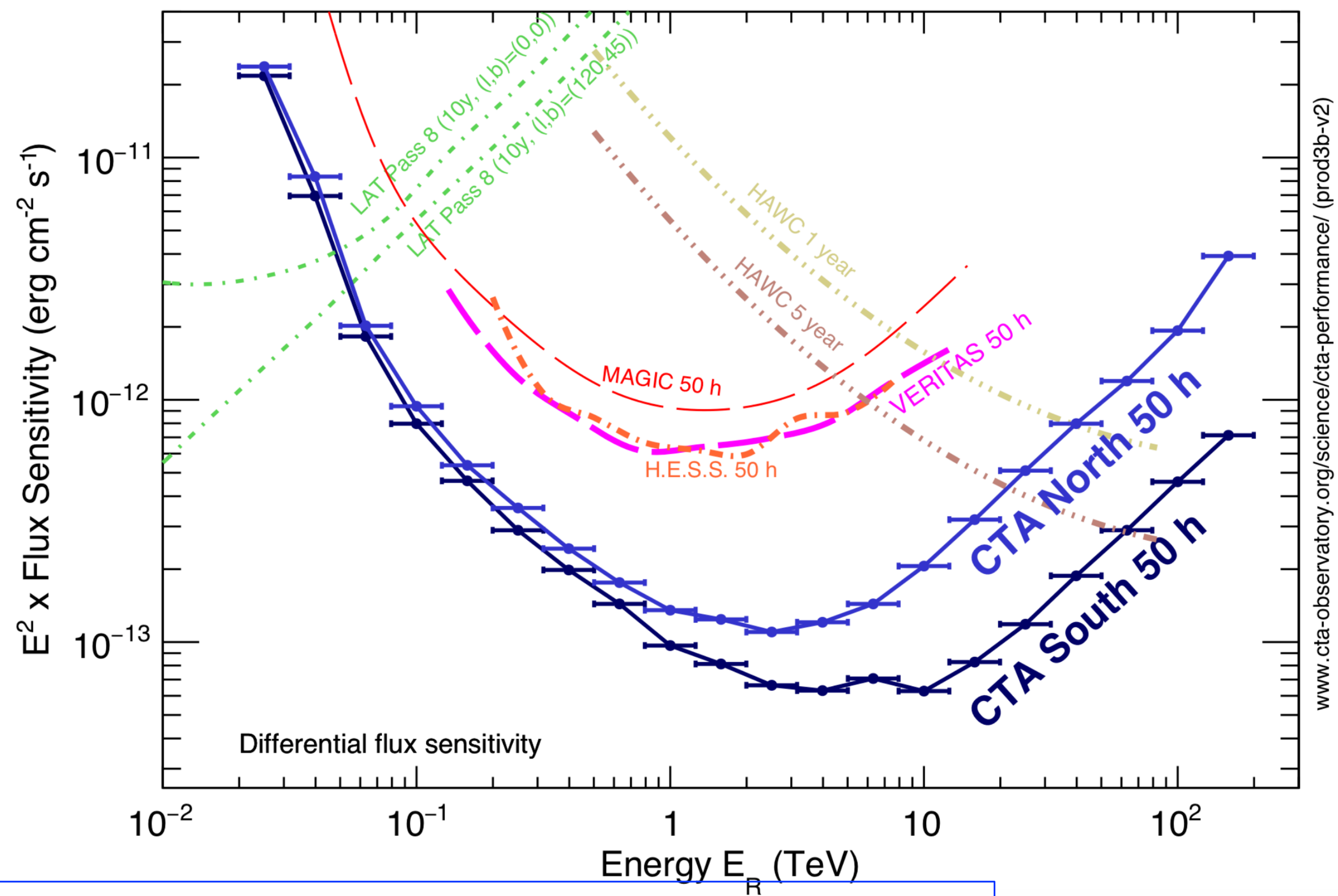
CTA-South site

- **4 LSTs + 25 MSTs + 70 SSTs (baseline-configuration)**



- **Site agreement signed in Dec 2018**
- **Aim to start with site infrastructure construction soon**

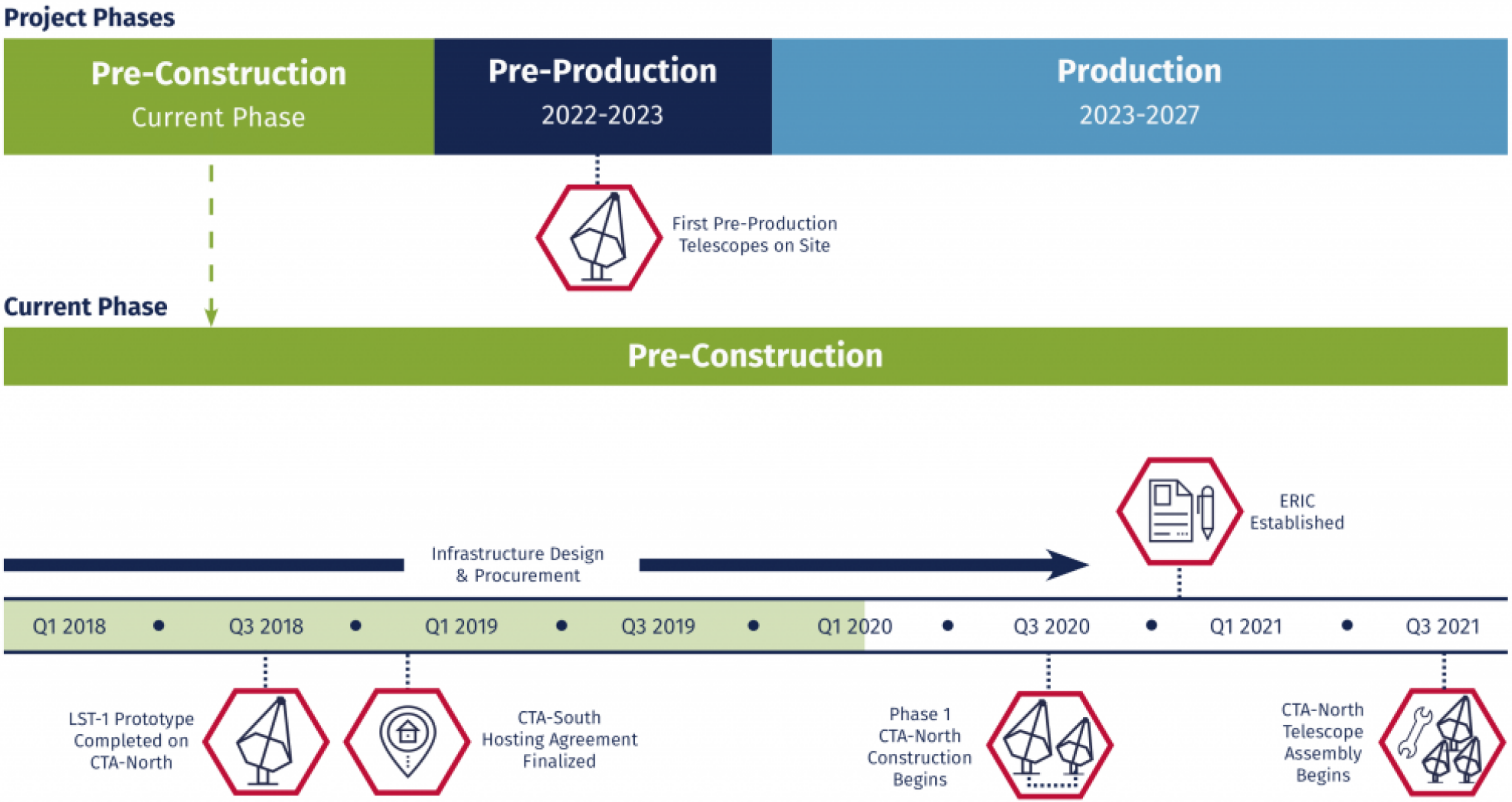
CTA performance



https://www.cta-observatory.org/science/cta-performance/

CTA Timeline

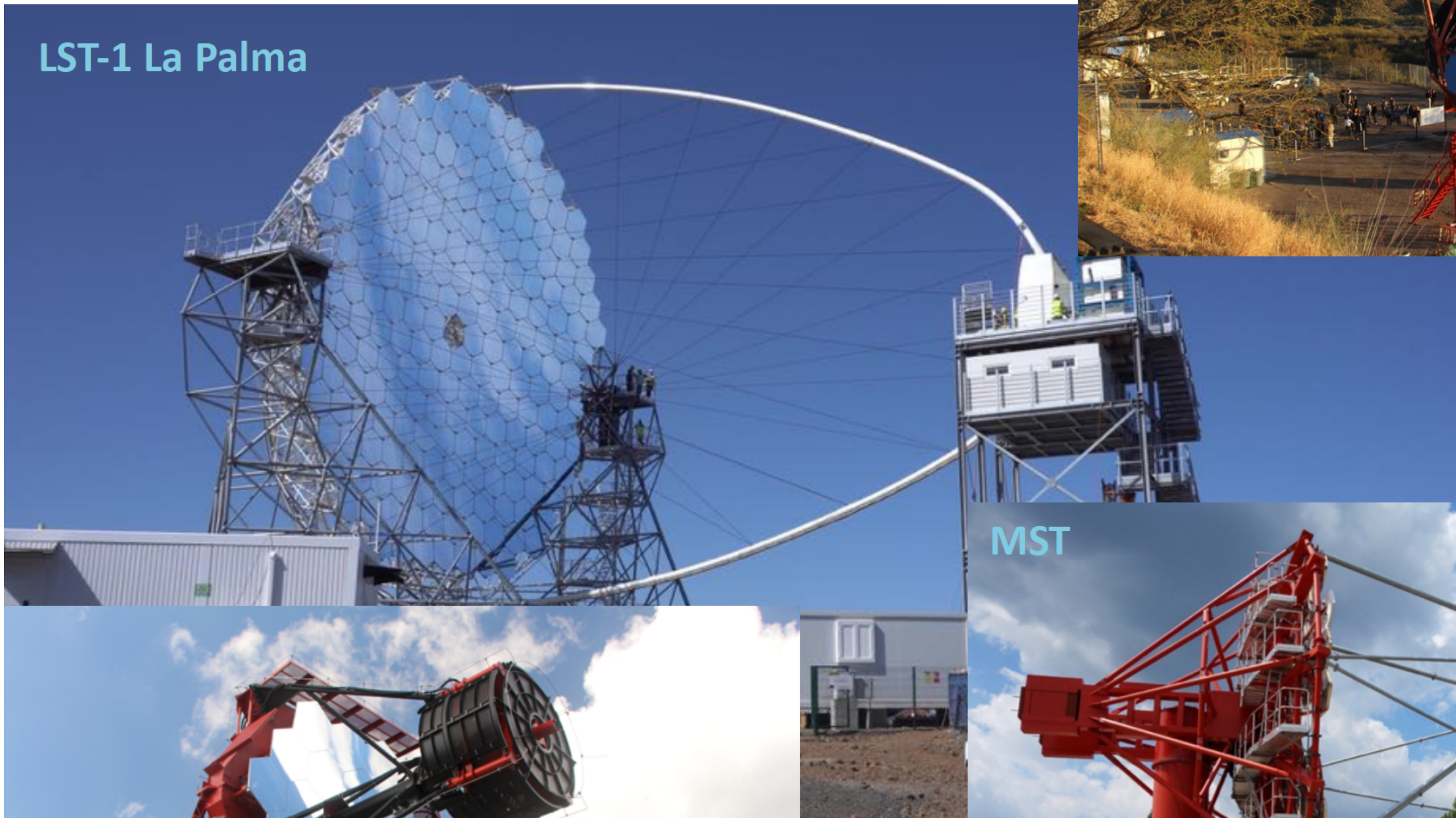
https://www.cta-observatory.org/project/status/



an updated timeline is in draft for 2021

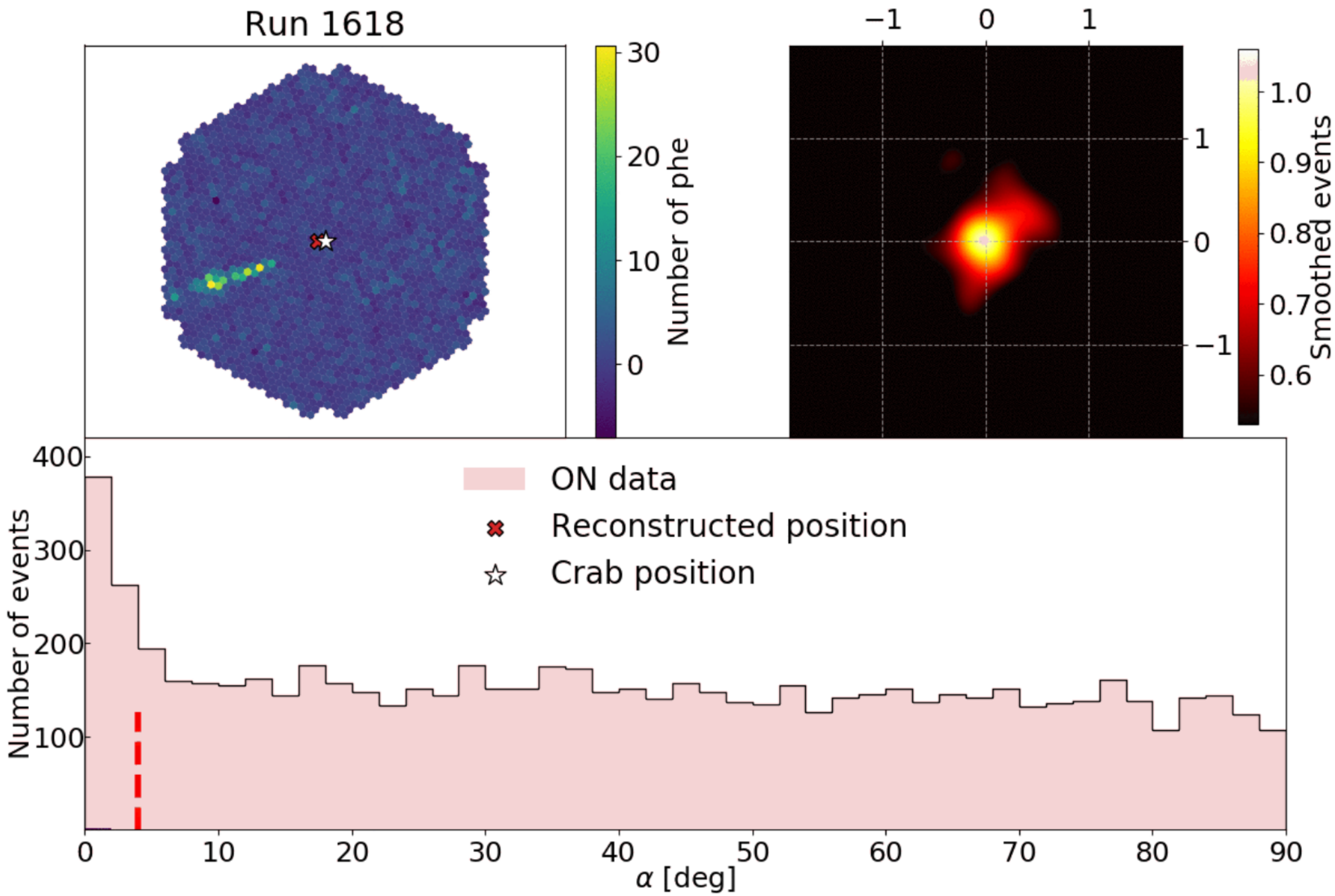
G. Rowell – COSPAR 2020

The CTA Telescopes



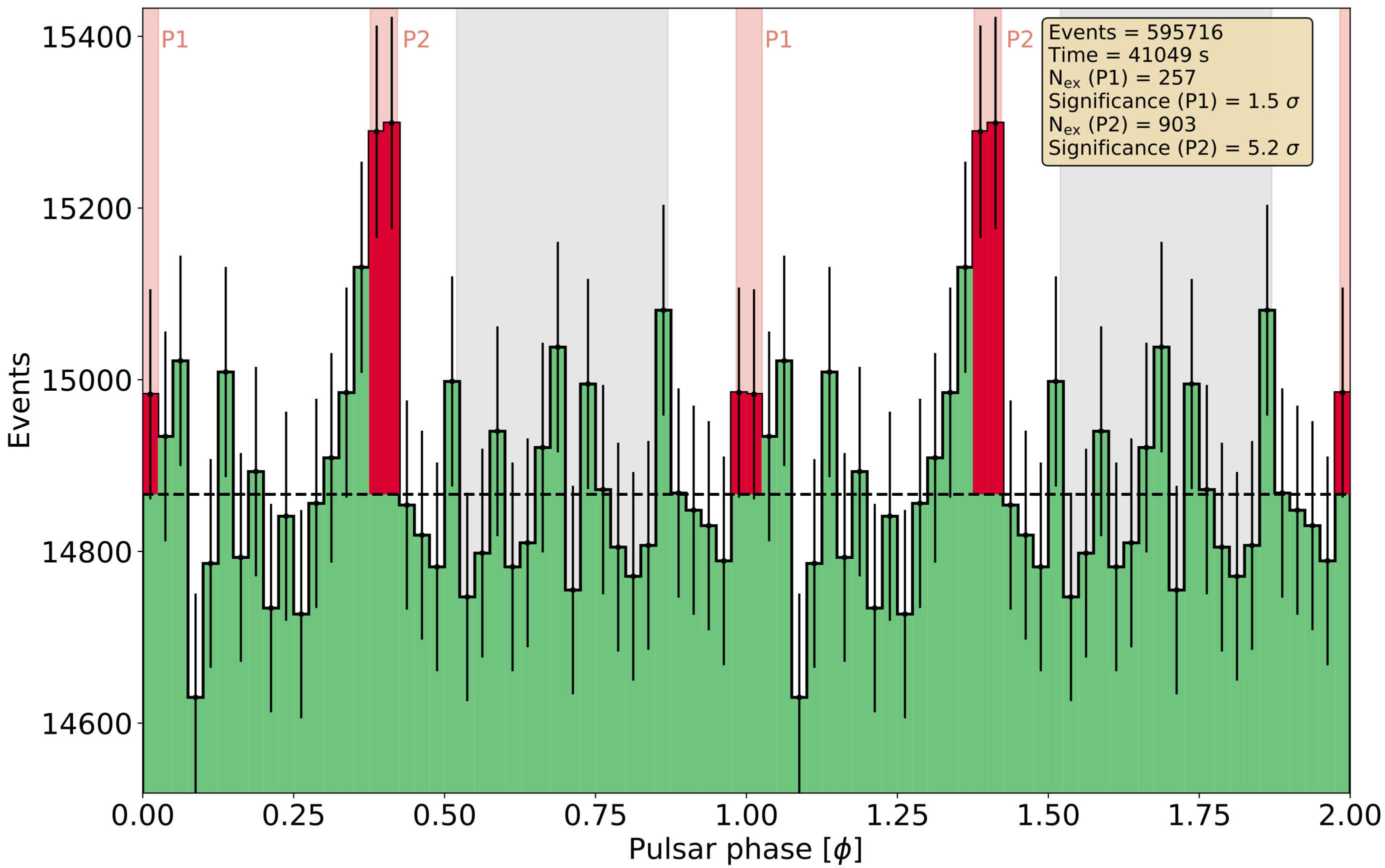
U.Barres – COSPAR 2020

CTA telescopes – first results



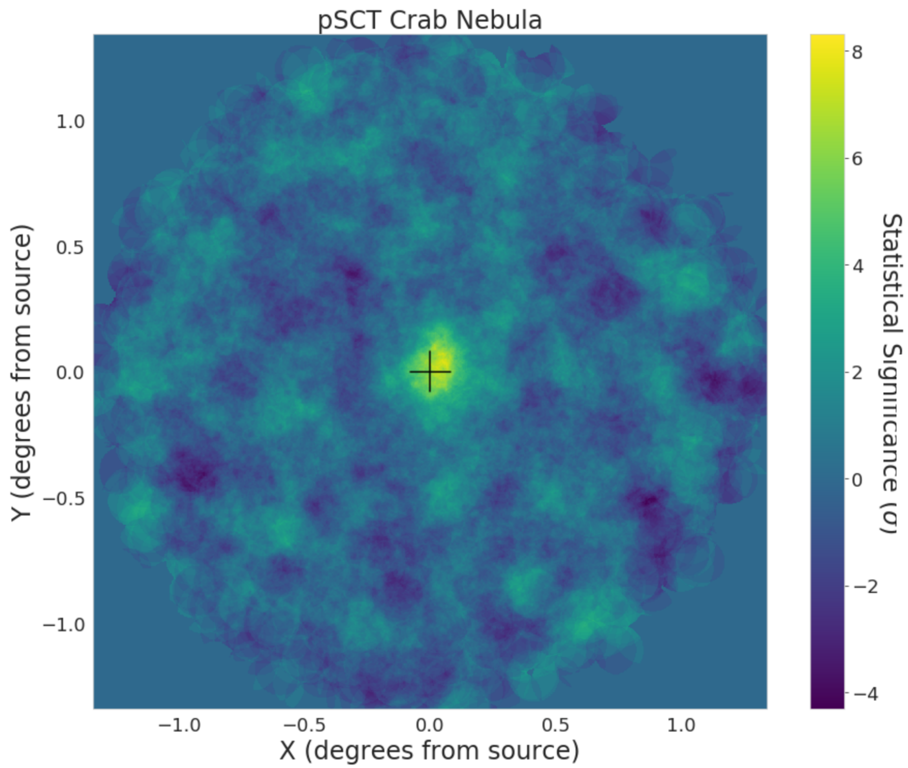
https://www.cta-observatory.org/lst1-detects-first-gamma-ray-signal/

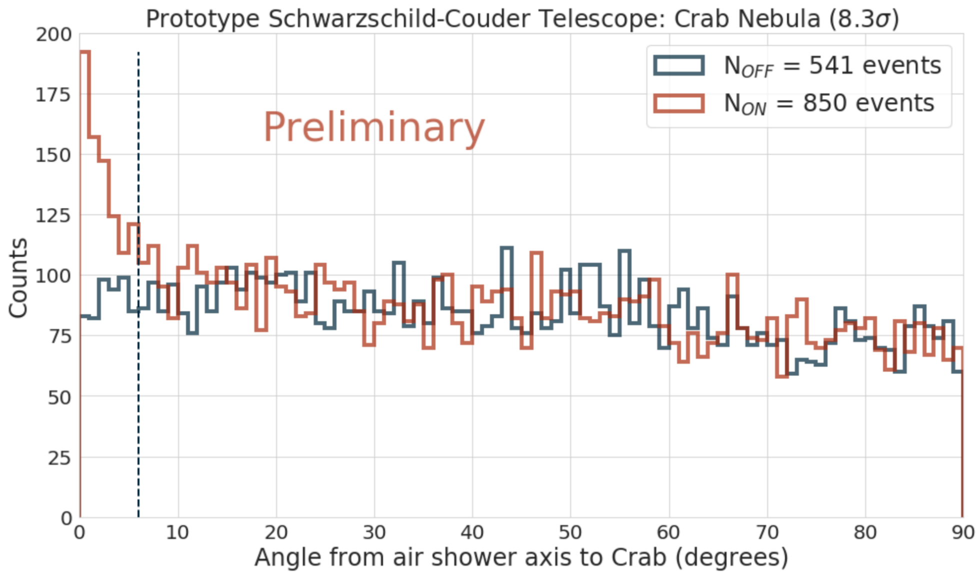
CTA telescopes – first results



https://www.cta-observatory.org/lst1-detects-vhe-emission-from-crab-pulsar/

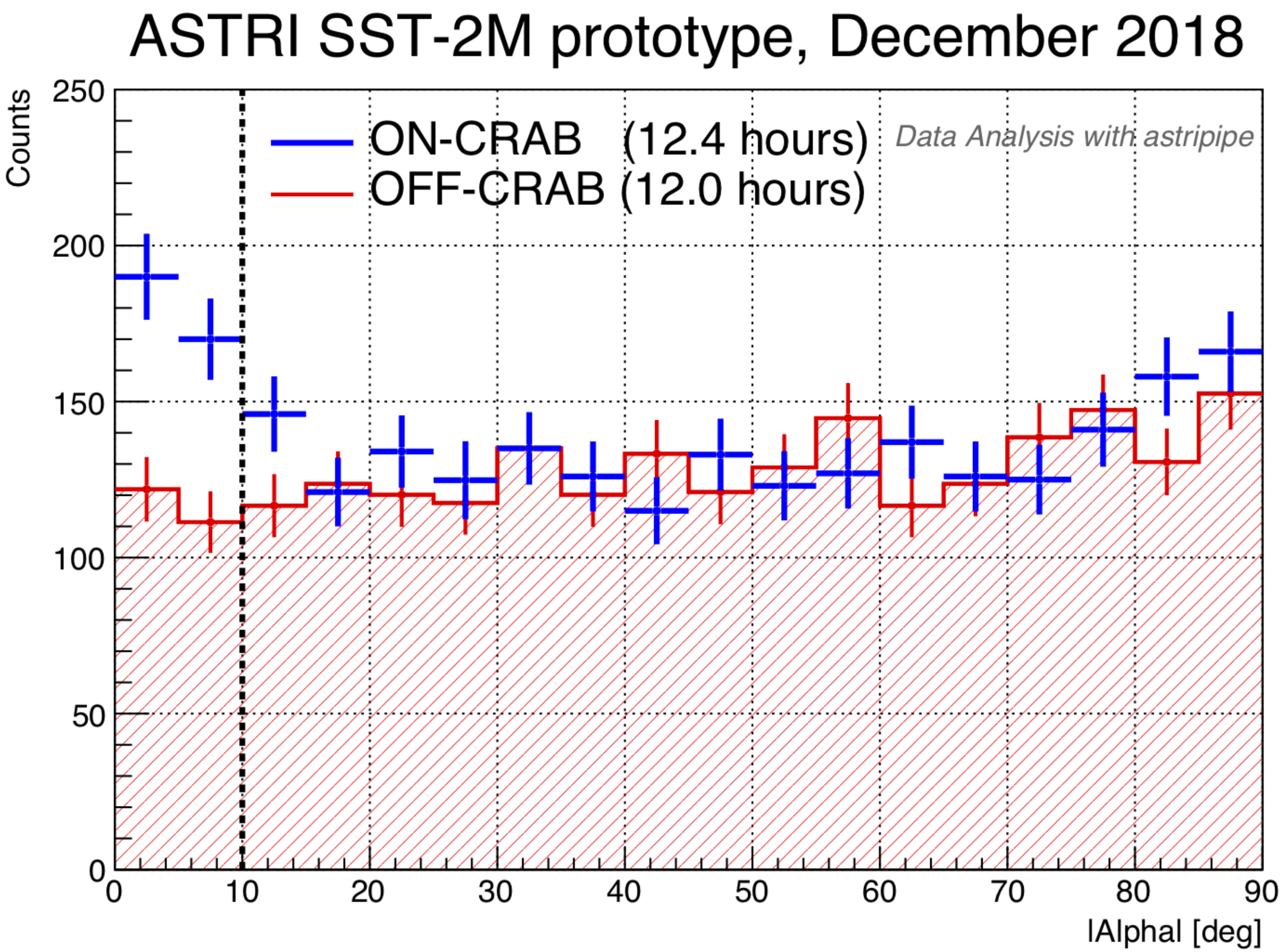
CTA telescopes – first results





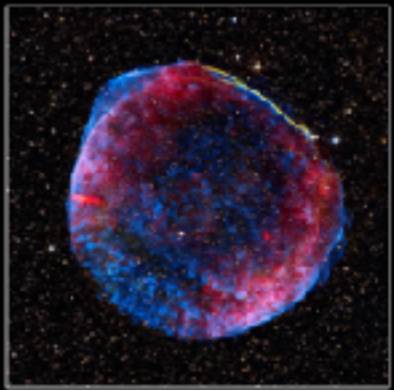
https://www.cta-observatory.org/sct-detects-

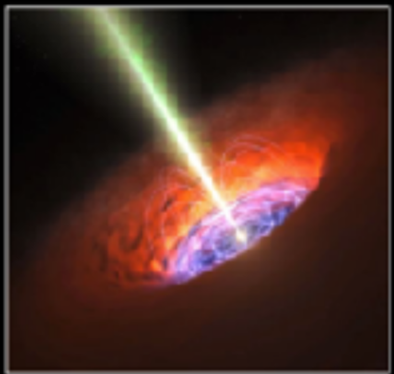
CTA telescopes – first results

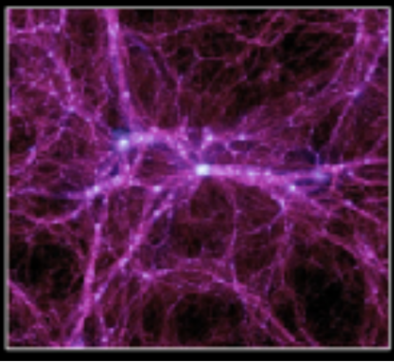


https://www.cta-observatory.org/astri-detects-crab-at-

Astrophysics with IACTs







- **COSMIC PARTICLE ACCELERATION**

What are the sites and mechanisms of particle acceleration in the cosmos?

- **EXTREME ASTROPHYSICAL ENVIRONMENTS**

The physics of neutron stars, black holes and their energetic environments, such as relativistic jets, winds and stellar explosions.

- **FUNDAMENTAL PHYSICS FRONTIERS**

Probing the nature of Dark Matter, the existence of axion-like particles, and Lorentz invariance violation

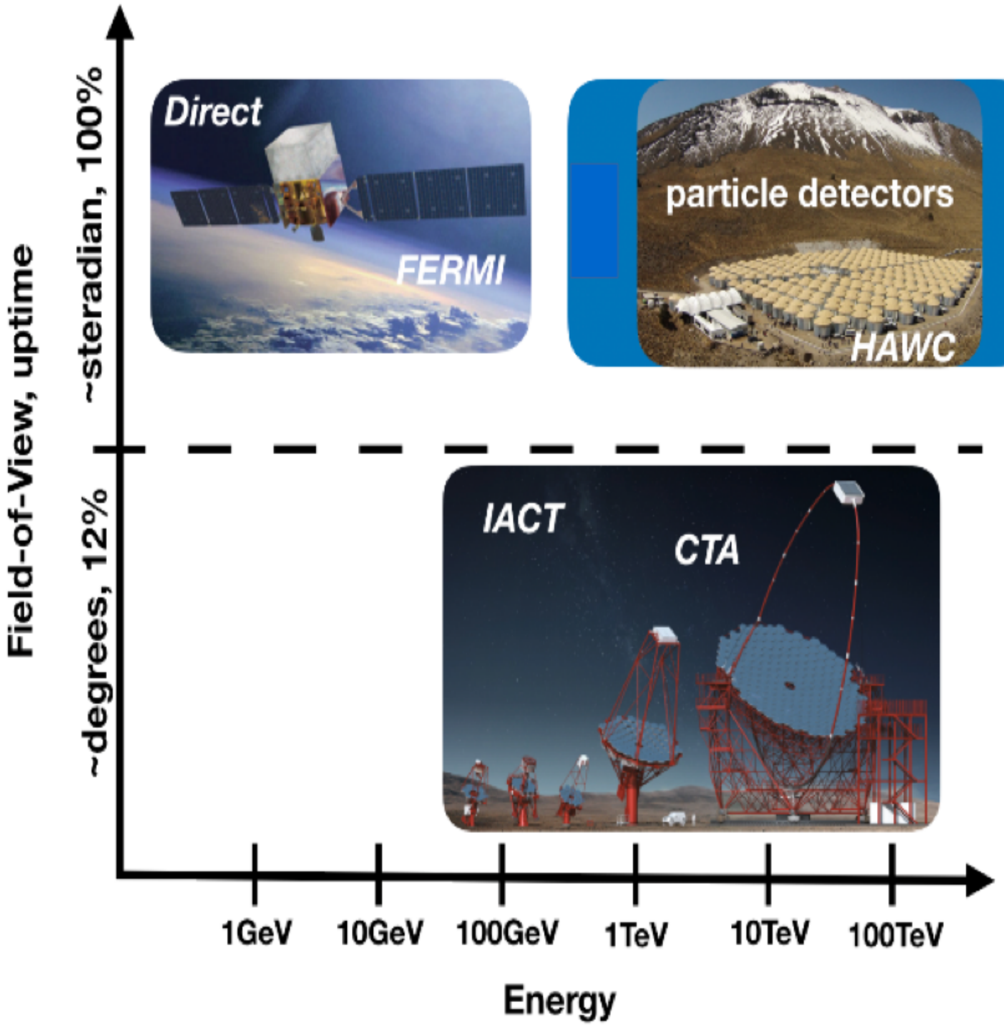
Science with CTA

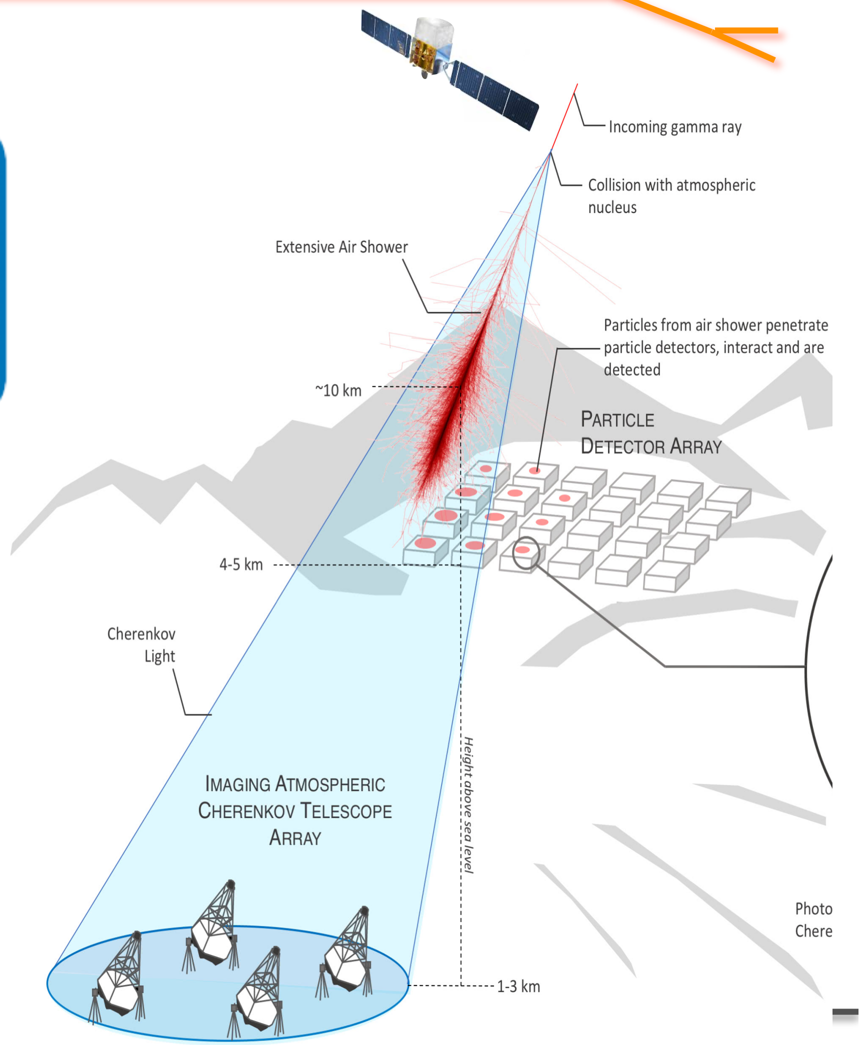
CTA will have important synergies with many of the new generation of major astronomical and astroparticle observatories. Multi-wavelength and multi-messenger approaches combining CTA data with those from other instruments will lead to a deeper understanding of the broad-band non-thermal properties of target sources, elucidating the nature, environment, and distance of gamma-ray emitters. Details of synergies in each waveband are presented.

https://arxiv.org/abs/1709.07997

SWGO
The Southern Wide-field Gamma-ray Observatory

Gamma-ray Astronomy





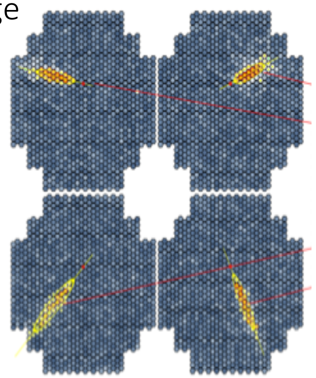
Shower image, 100 GeV γ-ray adapted from: F. Schmidt, J. Knapp, "CORSIKA Shower Images", 2005, https://www-zeuthen.desy.de/~jknapp/fs/showerimages.html

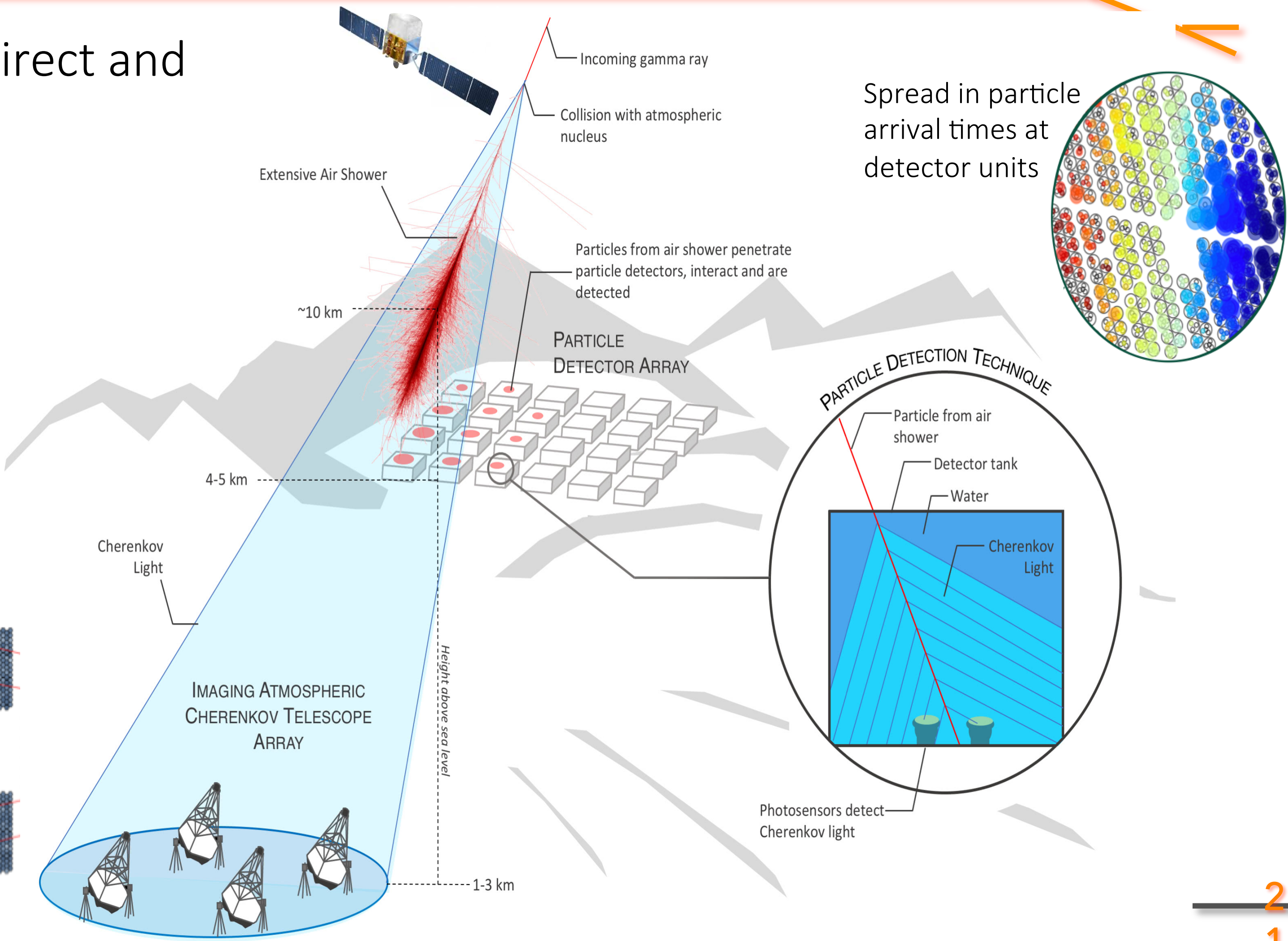
SWGO
The Southern Wide-field Gamma-ray Observatory

Gamma-ray Astronomy

Complementary direct and indirect detection techniques

Atmospheric Cherenkov light image

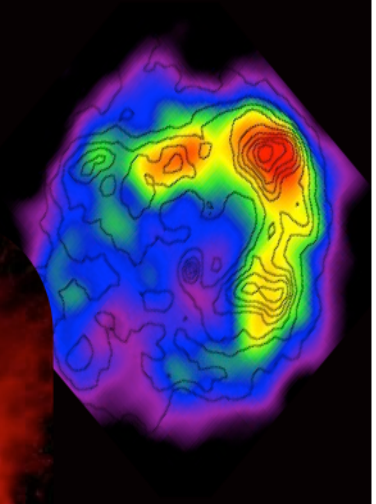
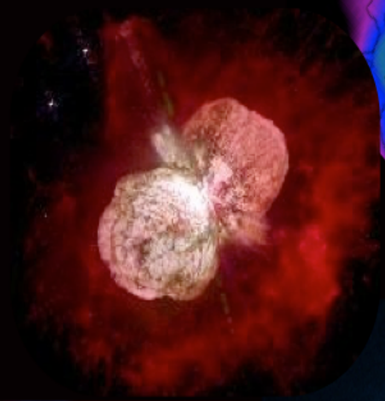
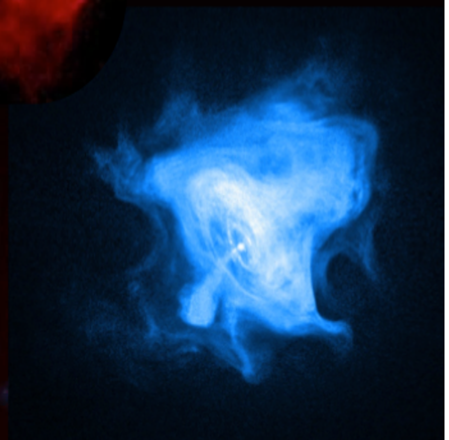




Shower image, 100 GeV γ-ray adapted from: F. Schmidt, J. Knapp, "CORSIKA Shower Images", 2005, https://www-zeuthen.desy.de/~jknapp/fs/showerimages.html

Not to scale

- Astonishing variety of TeV* emitters
  - Within the Milky Way
    - Supernova remnants
    - Bombarded molecular clouds
    - Stellar binaries - colliding wind & X-ray
    - Massive stellar clusters
    - Pulsars and pulsar wind nebulae
    - Supermassive black hole Sgr A*
  - Extragalactic
    - Starburst galaxies
    - MW satellites
    - Radio galaxies
    - Flat-spectrum radio quasars
    - 'BL Lac' objects
    - Gamma-ray bursts

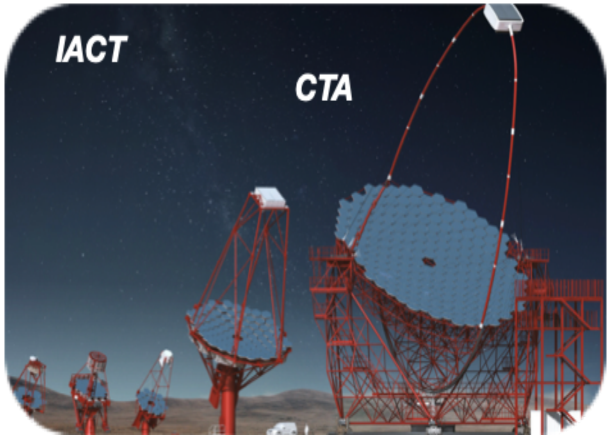




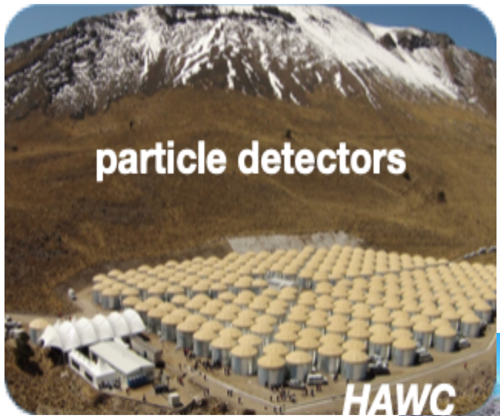

- Acceleration to TeV energies is common, gamma-rays are an effective probe
  - Strongly complementary to sync. measurements


*0.05-50 TeV

Observational Panorama

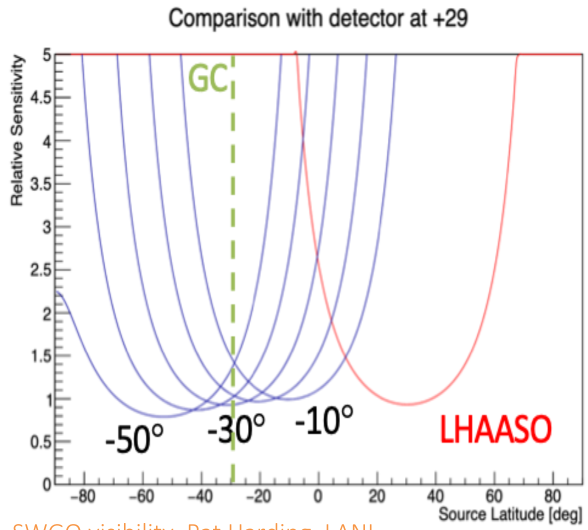
◎ Cherenkov Atmospheric Telescopes
- 20% duty-cycle
- Pointing (few degrees FoV)
- Energy threshold down to 10s GeV
- Good energy and angular resolution





◎ Particle Detector Arrays
- → 100% duty-cycle
- → Wide-field of View (~ steradian)
- → Energy range 100s GeV up to 100s TeV
- → Continual view and accurate background determination

Geographic distribut

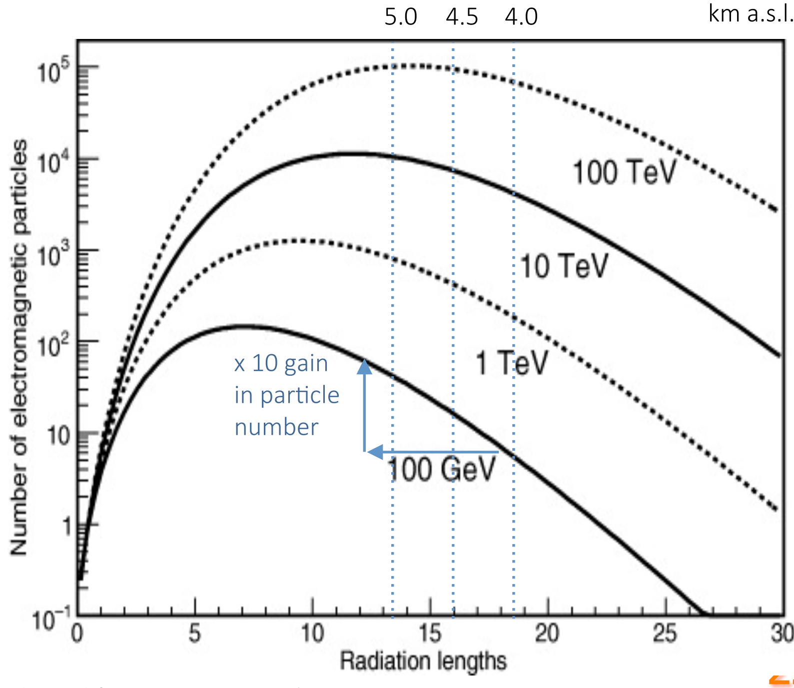


SWGO visibility, Pat Harding, LANL

SWGO
The Southern Wide-field Gamma-ray Observatory

The high-altitude frontier

The Andes provides a number of high-altitude plateaus and high-altitude lakes that constitute suitable sites for a particle array aiming to extend the low-energy frontier for Wide-Field Observatories.



Adapted from G. Sinnis, NJPh, 2009

The Southern Wide-field Gamma-ray Observatory

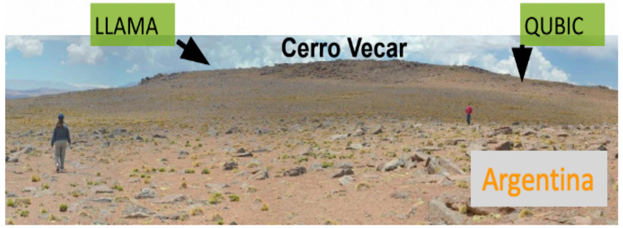
Candidate Sites

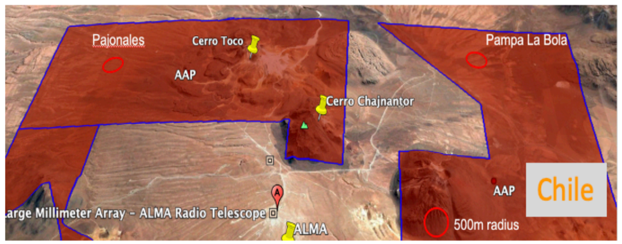
lat. 15 S

lat. 23 S

- Alto Tocomar (Argentina)
- Cerro Vecar (Argentina)
- Chacaltaya (Bolivia)
- AAP Pajonal (Chile)
- AAP Pampa La Bola (Chile)
- Lake Sibinacocha (Peru)
- Imata (Peru)
- Sumbay (Peru)
- Peru National Observatory
- Yanque (Peru)

The complete list of potential sites is still under investigation, aiming at an evaluation for site choice by 2021.



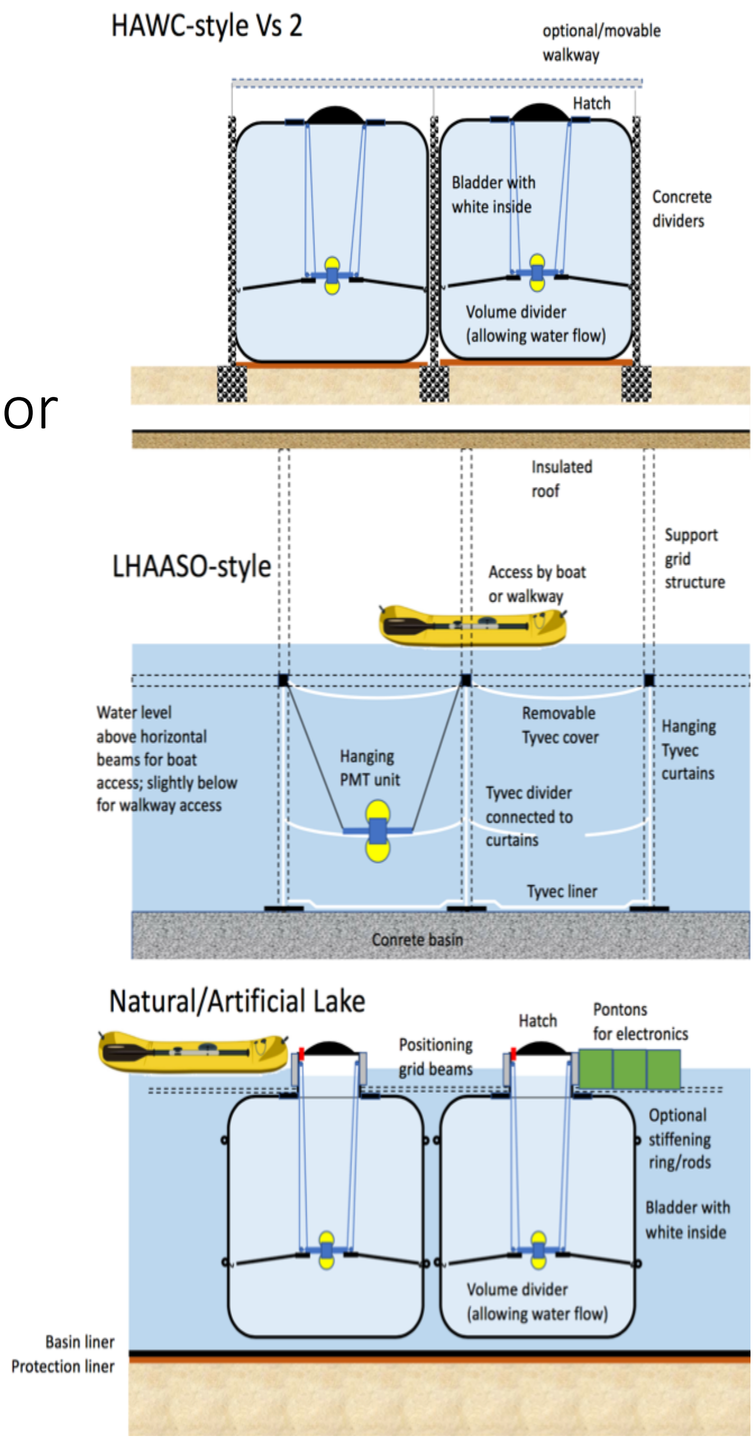


SWGO
The Southern Wide-field Gamma-ray Observatory

The SWGO Concept

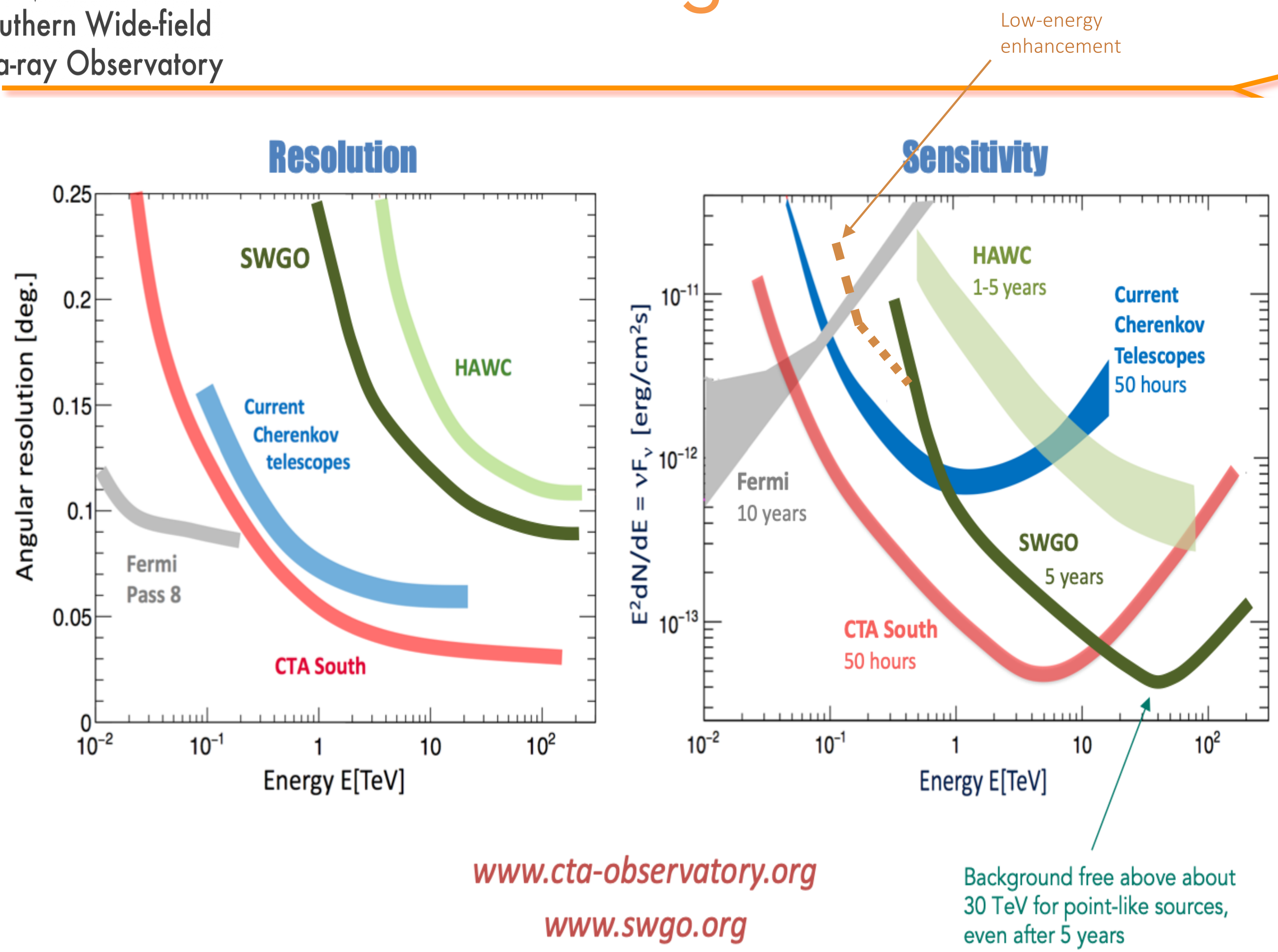
Multiple detector options to be investigated

Detector units



- Core unit is a water-Cherenkov Detector
  - Options being investigated based on tanks (HAWC-like), ponds (Milagro-like) and lake-base (test pool under construction at MPIK-Heidelberg)
- Simulations currently ongoing to constrain all aspects of the detectors
- Design strongly dependent on site choice
  - Water access, construction costs, infrastructure feasibility, compatibility with scientific driven main design goals…

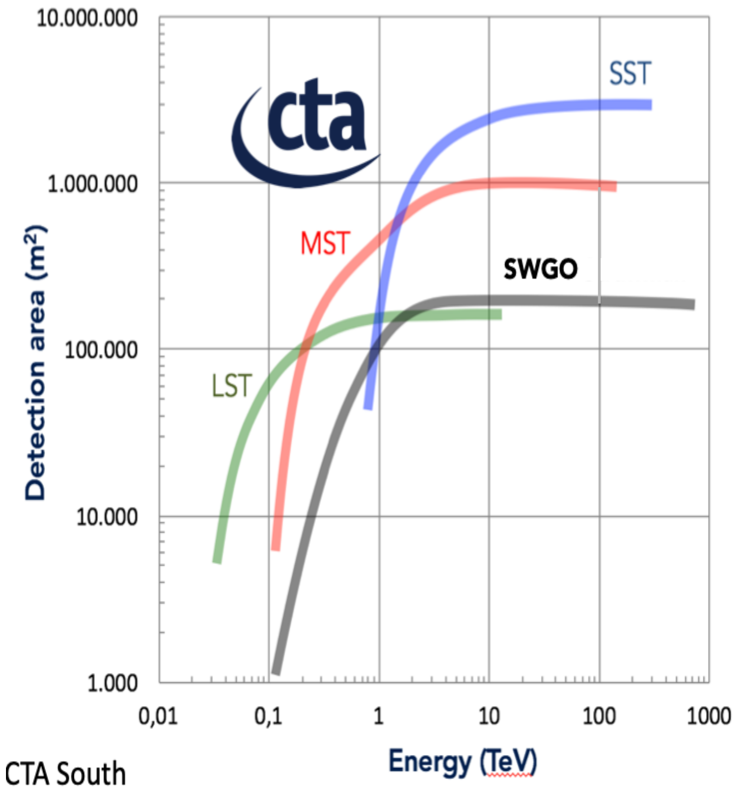
Performance goals



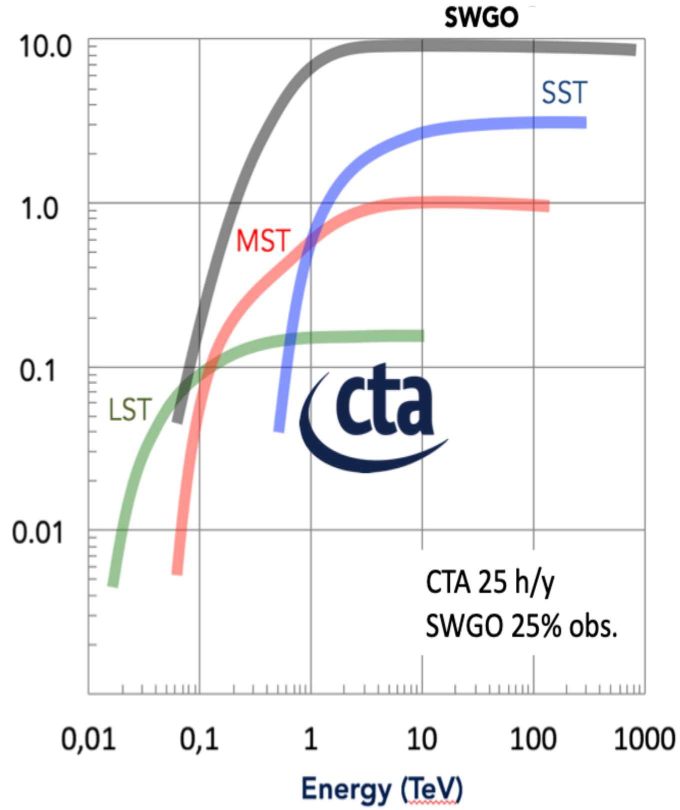
www.cta-observatory.org

www.swgo.org

Performance goals



Detection Area



Annual Exposure

Potentially more sensitive than CTA over several years integration time provided good background suppression is achieved.

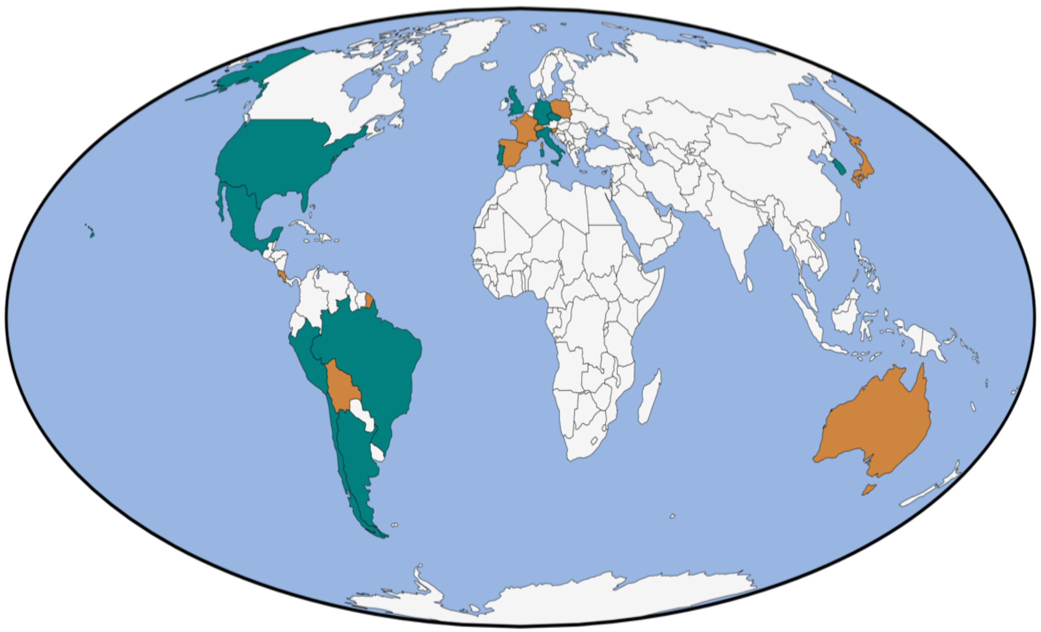
SWGO
The Southern Wide-field Gamma-ray Observatory

The Collaboration

- Southern Wide-Field Gamma-ray Observatory
  - + higher altitude (4400+ m asl) and larger area
  - + more efficient detector units + muon tagging capability
  - → improved sensitivity and lower E threshold

Established in July 2019
3 year R&D Programme

www.swgo.org



Institutes
Argentina*, Brazil, Chile, Czech Republic, Germany*, Italy, Mexico, Peru, Portugal, South Korea, United Kingdom, United States*

Member institutes signed the SoI.

Supporting scientists
Australia, Bolivia, Costa Rica, France, Japan, Poland, Slovenia, Spain, Switzerland

**also supporting scientists*

Any interested individual can become supporting scientist.