Very High Energy Gamma-ray:

the MAGIC telescopes and the CTA project

- Astroparticle Physics
- Very High Energy Gamma-ray
- The MAGIC telescopes
- The future: CTA

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27-01-2014, IMFP, Benasque

Astroparticle Physics

Astroparticle physics

Astroparticle physics, the same as particle astrophysics, is a branch of particle physics that studies elementary particles of astronomical origin and their relation to astrophysics and cosmology. It is a relatively new field of research emerging at the intersection of:

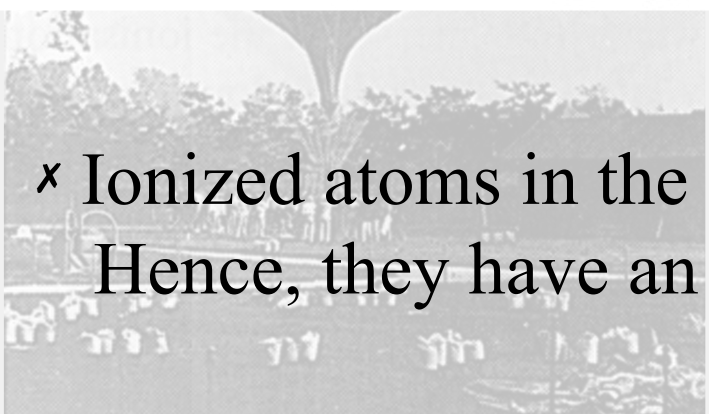
- **Particle physics**
- **Astrophysics**
- **Cosmology**

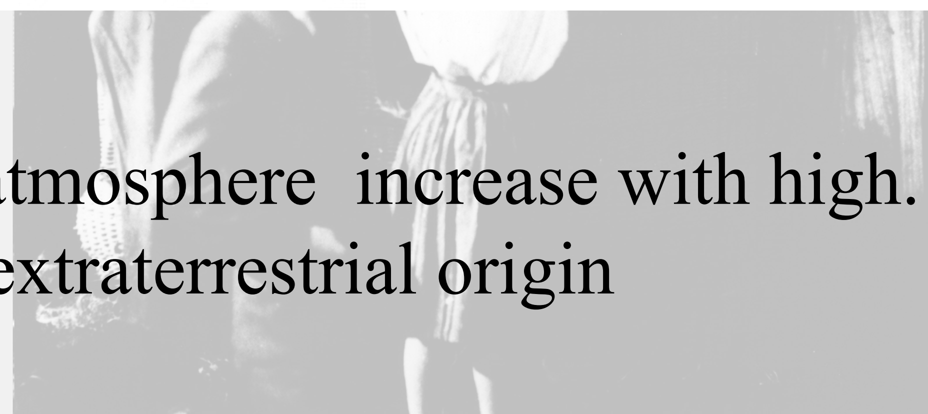
Cosmic Rays

Victor Hess: Discovery of cosmic rays

Tabelle der Mittelwerte.

Mittlere Höhe über dem Erdboden m	Beobachtete Strahlung in Ionen pro ccm und sec.			
	Apparat 1	Apparat 2	Apparat 3	
	Q_1	Q_2	Q_3 (reduziert)	Q_3 (nicht reduziert)
0	16,3 (18)	11,8 (20)	19,6 (9)	19,7 (9)
bis 200	15,4 (13)	11,1 (12)	19,1 (8)	18,5 (8)
200—500	15,5 (6)	10,4 (6)	18,8 (5)	17,7 (5)
500—1000	15,6 (3)	10,3 (4)	20,8 (2)	18,5 (2)
1000—2000	15,9 (7)	12,1 (8)	22,2 (4)	18,7 (4)
2000—3000	17,3 (1)	13,3 (1)	31,2 (1)	22,5 (1)
3000—4000	19,8 (1)	16,5 (1)	35,2 (1)	21,8 (1)
4000—5200	34,4 (2)	27,2 (2)	—	—



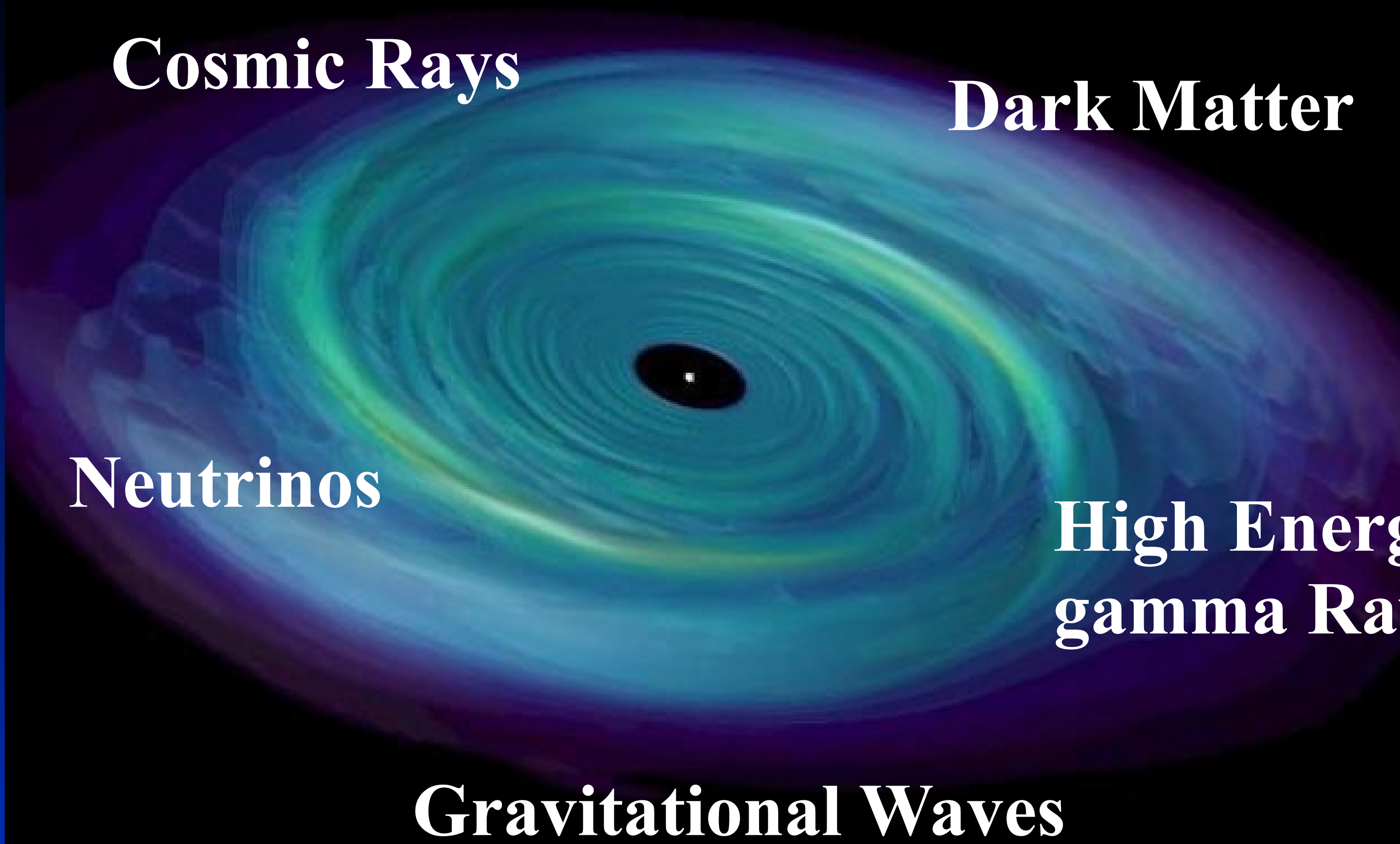


- Ionized atoms in the atmosphere increase with high. Hence, they have an extraterrestrial origin

Questions to be answered:

- What is the universe made of?
- What is dark matter?
- Do protons have a finite life time?
- What are the properties of neutrinos? What is their role in cosmic evolution?
- What do neutrinos tell us about the interior of the Sun and the Earth, and about Supernova explosions?
- What is the origin of cosmic rays? What is the view of the sky at extreme energies?
- Can we detect gravitational waves? What will they tell us about violent cosmic processes and about the nature of gravity?

The fifth Pillars of Astroparticle Physics



The messengers in Astroparticle Physics

The particles bringing the information are different

- ✗ Protons or heavier nuclei
- ✗ Electrons and positrons
- ✗ Neutrinos
- ✗ Photons
- ✗ Gravitational waves
- ✗ Dark Matter

Complementary informations

The messengers in Astroparticle Physics

The particles bringing the information are different

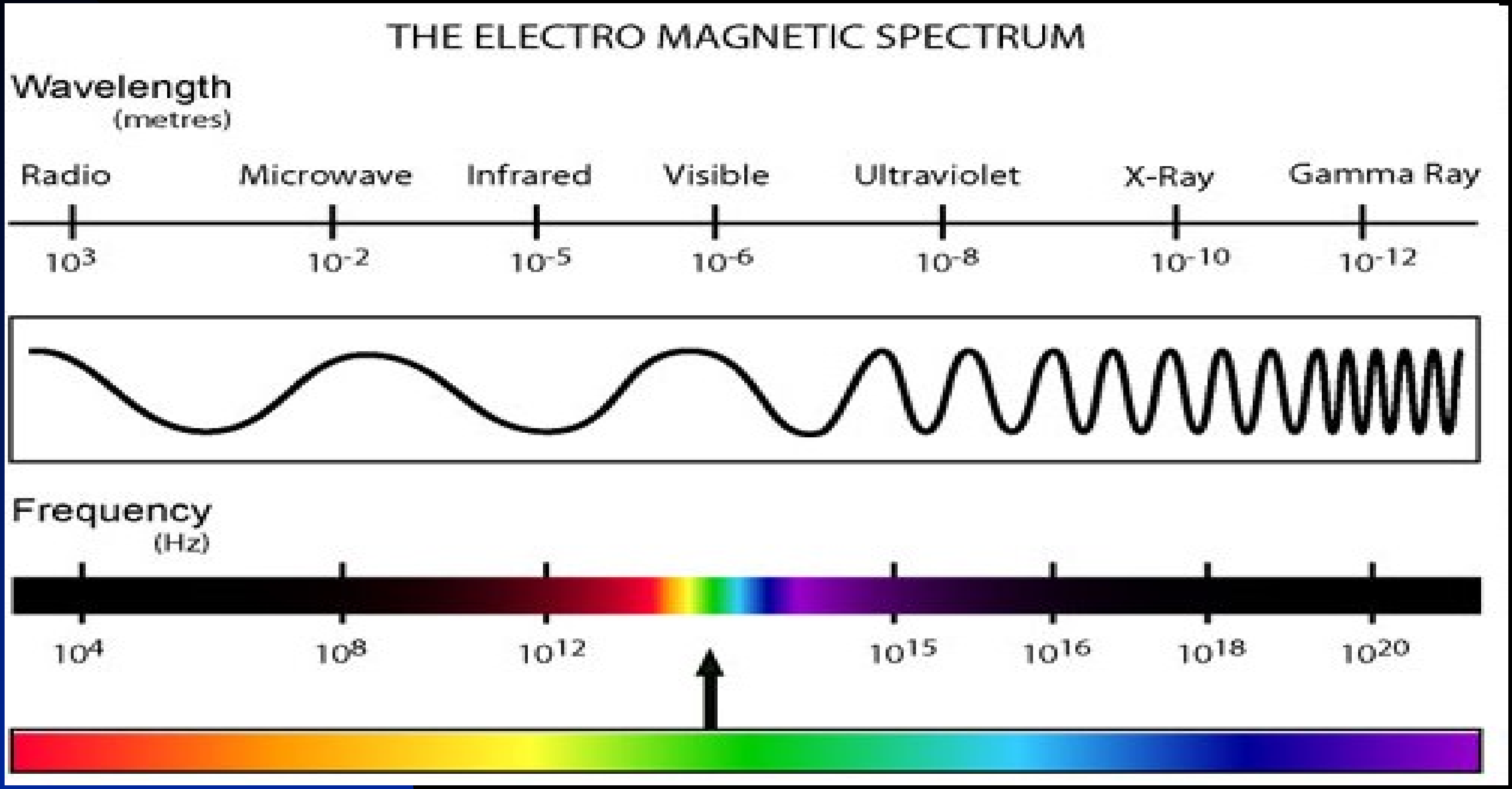
	Absorption	Deviation	Detection
✗ Protons or heavier nuclei	~	KO	OK
✗ Electrons and positrons	~	KO	OK
✗ Neutrinos	OK	OK	KO
✗ Photons	~	OK	OK
✗ Gravitational waves	OK	OK	KO
✗ Dark Matter	?	?	?

Complementary informations

Very High Energy Gamma-rays

Astrophysics with High Energy gamma-rays

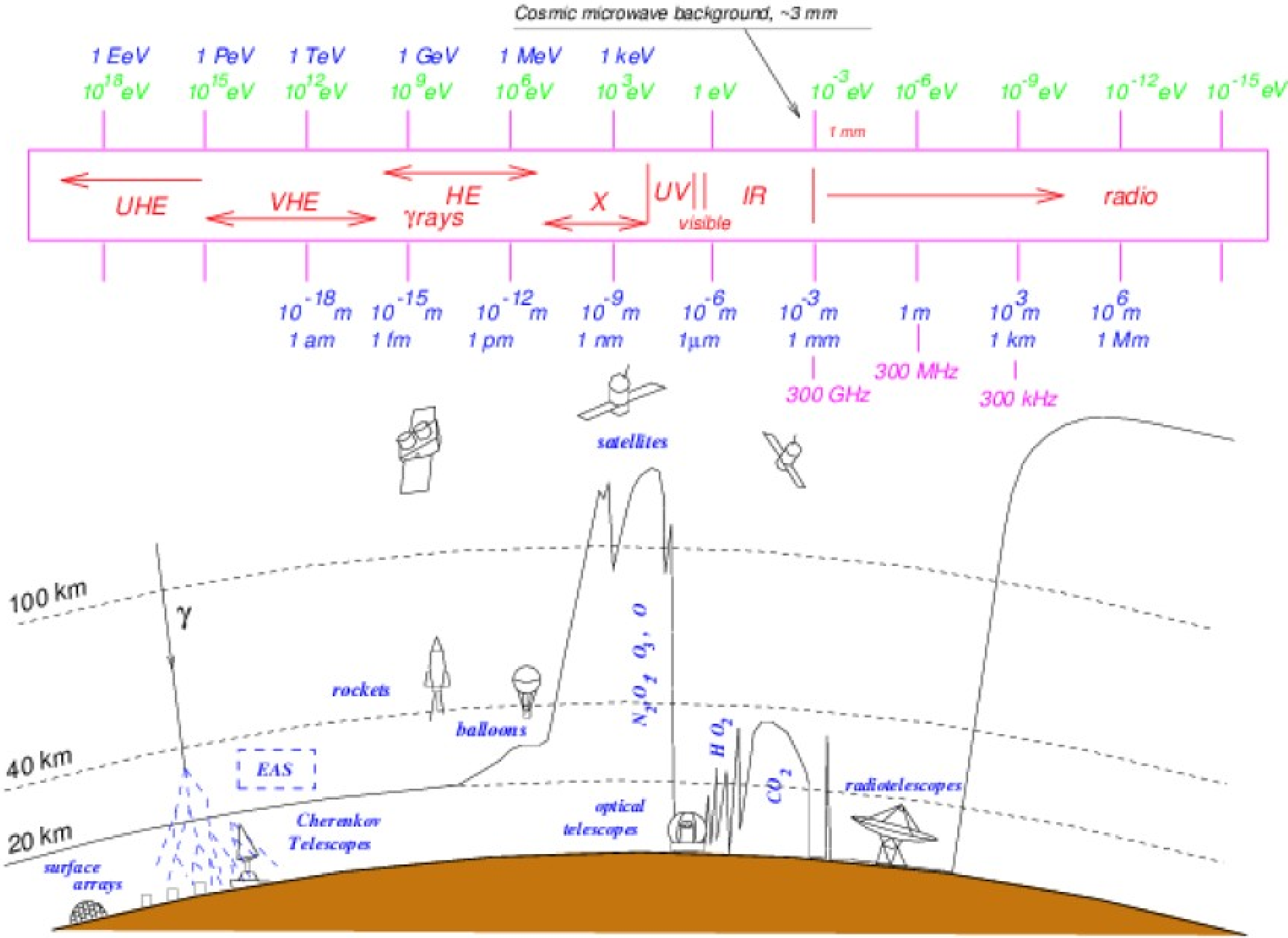
We get information from many different wavelength



Thermic radiation (black body) produces low energy photons

High Energy photons are generated in other processes: VIOLENT UNIVERS

Cherenkov Telescopes

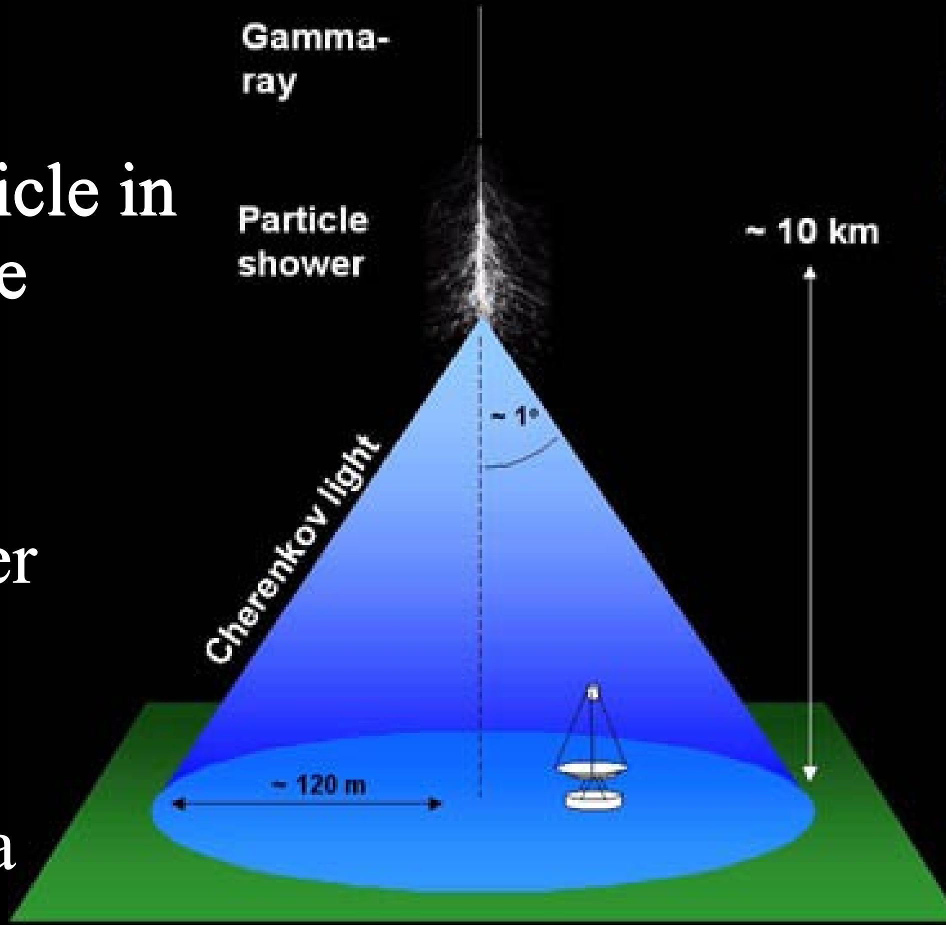


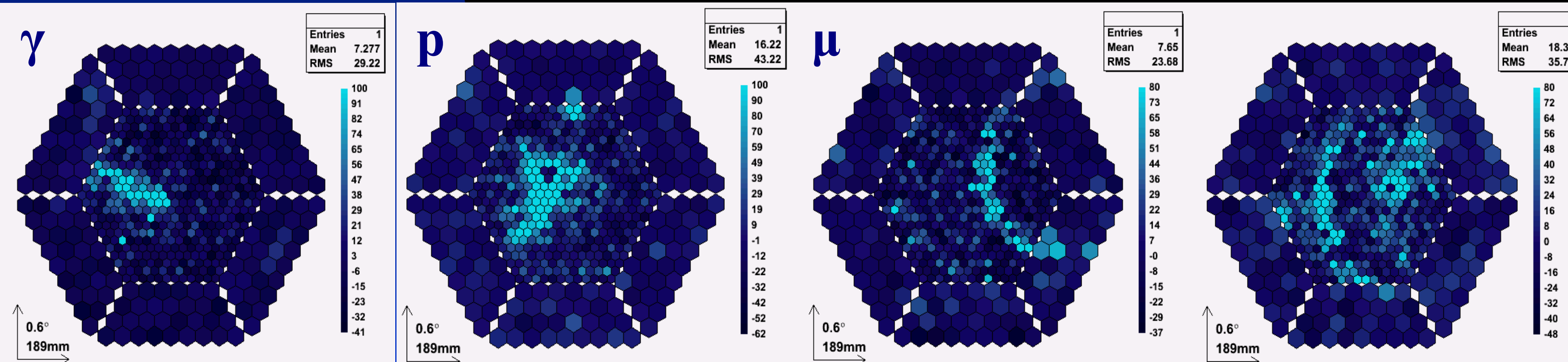
Cherenkov Telescopes

Gamma-rays interact with particle in the atmosphere and produce the "Extended Air Showers"

Secondary particles travel faster than light → Cherenkov light

Light is collected in the camera

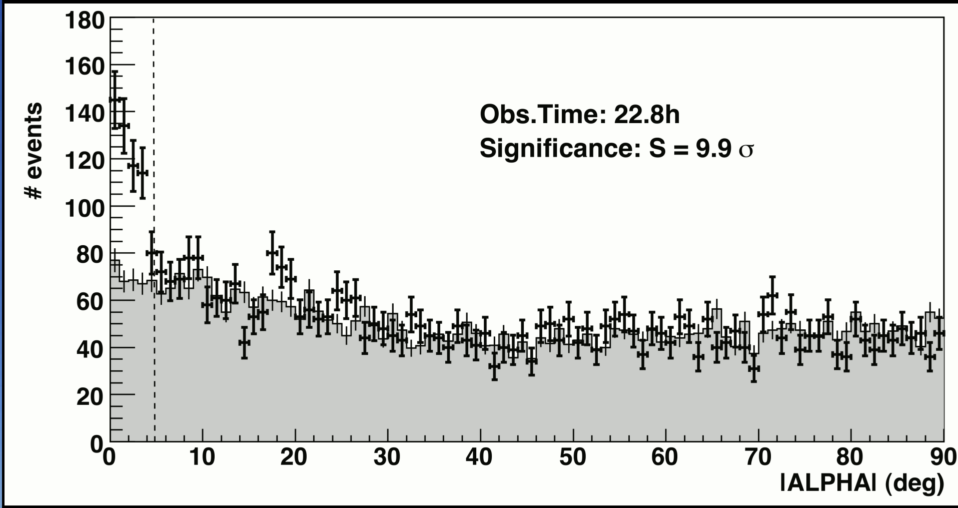




Cherenkov Telescopes

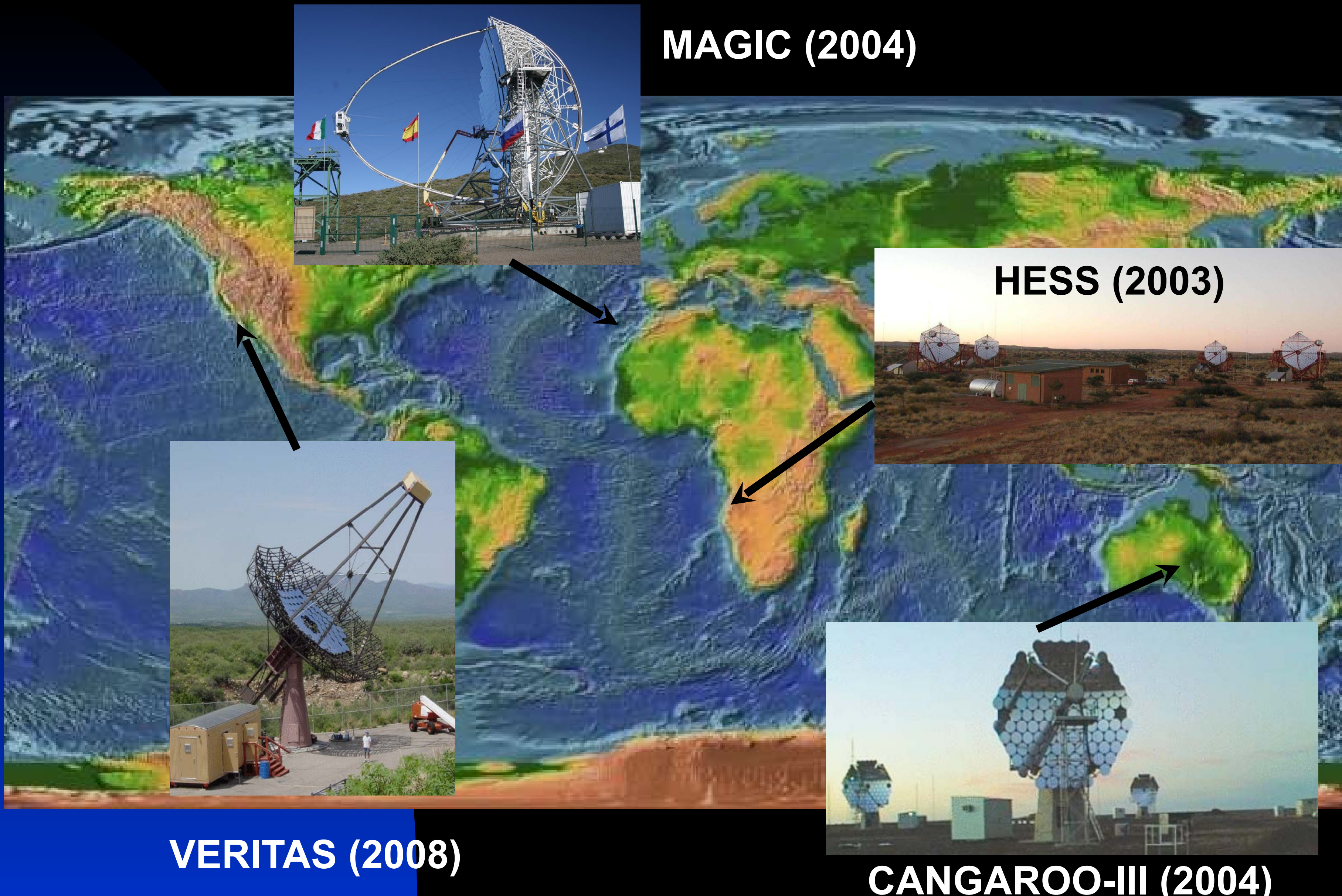
"Imaging Atmospheric Cherenkov Technique"

Whipple telescope (USA) was pioneer on using this technique very successfully between 1969 and 1989



Comparison between ON and OFF observations allows to see Very High Energy gamma-rays

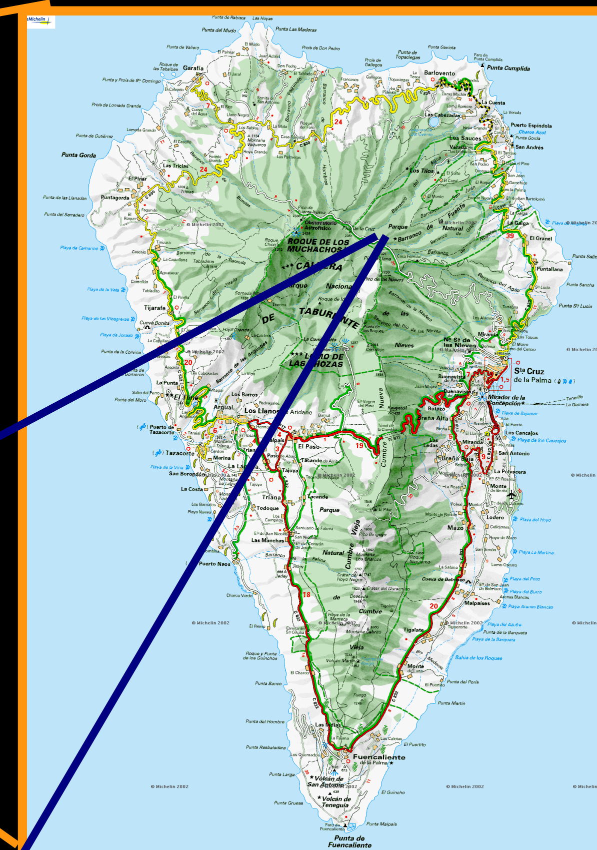
Cherenkov Telescopes



The MAGIC telescopes

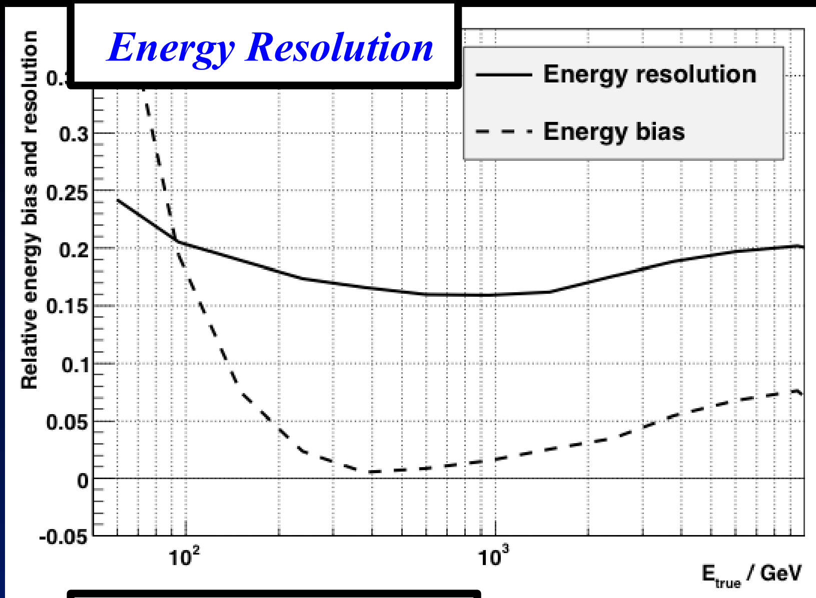
The MAGIC Telescopes

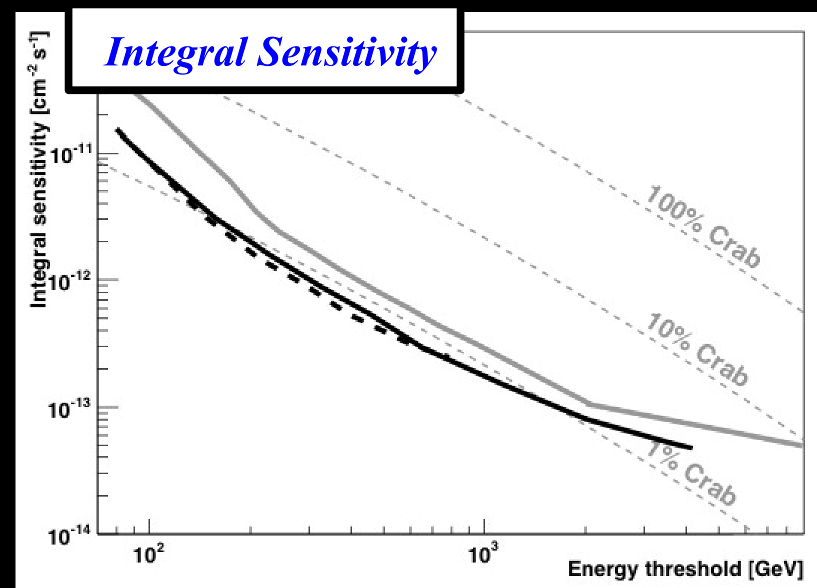
MAGIC is an Imaging Atmospheric Cherenkov Telescope system consisting of two 17m diameter telescopes, located on Canary island La Palma

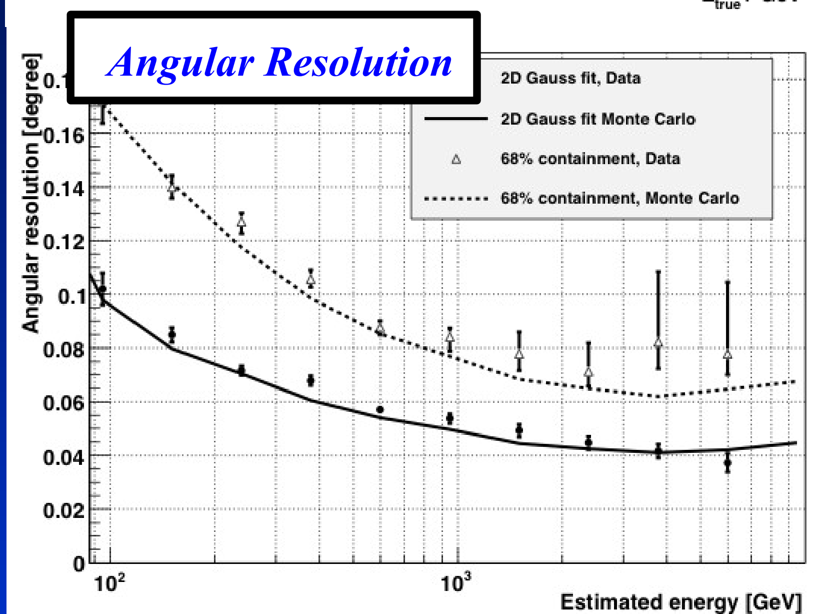


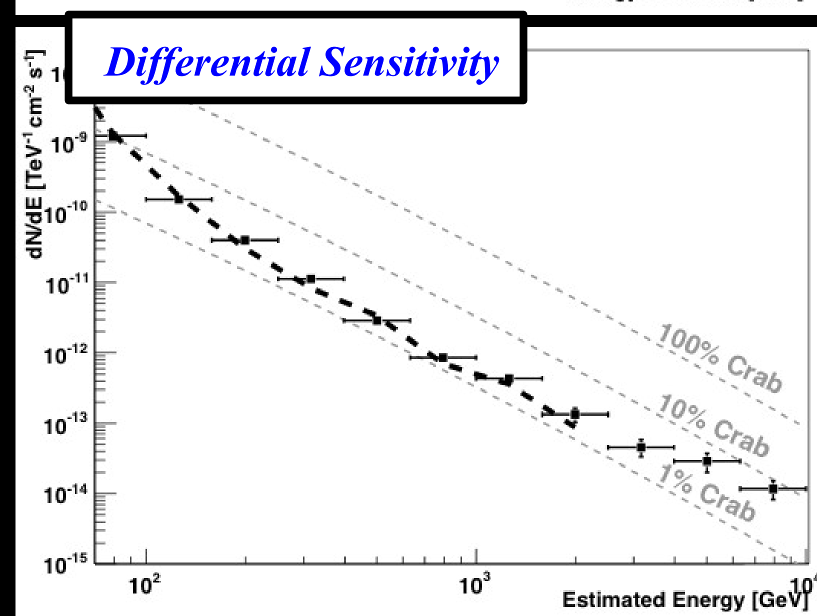
The MAGIC Telescopes

Aleksic et al. (MAGIC) APh 35, 2012

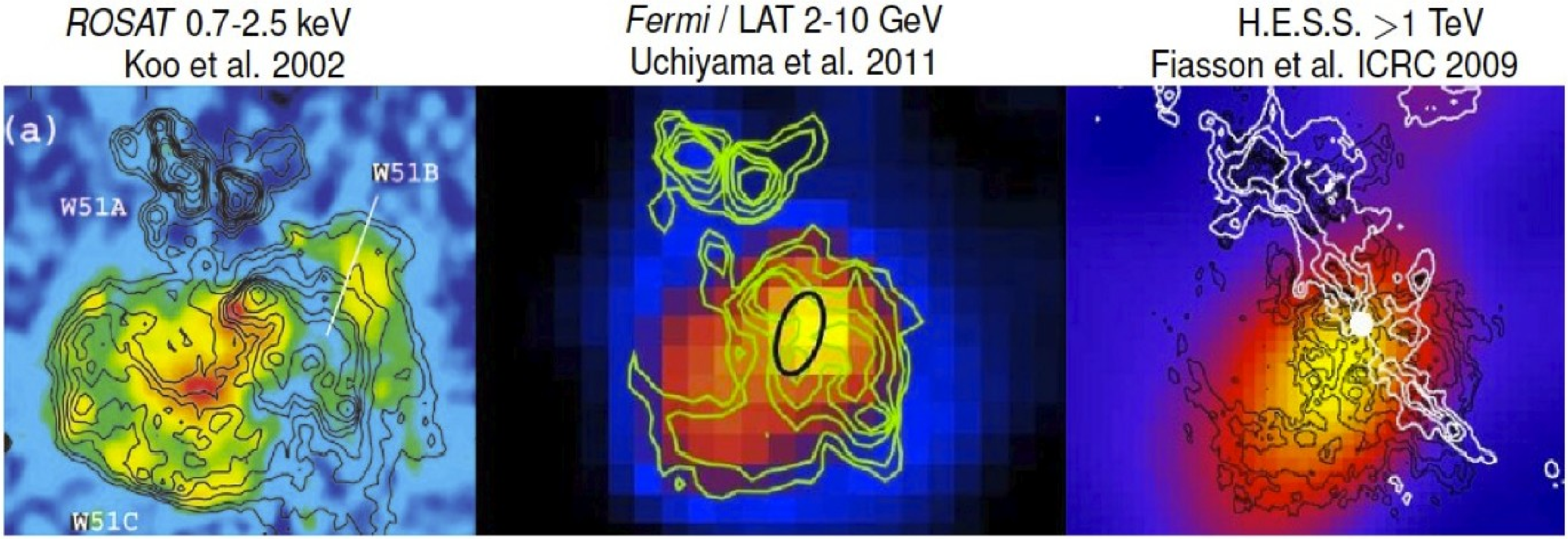








Supernova Remnants (SNR), the source of cosmic rays?



The W51 Complex

W51A & **W51B** are star forming regions,

W51C is a medium-age (~30kyr) SNR at d ~5.5 Kpc

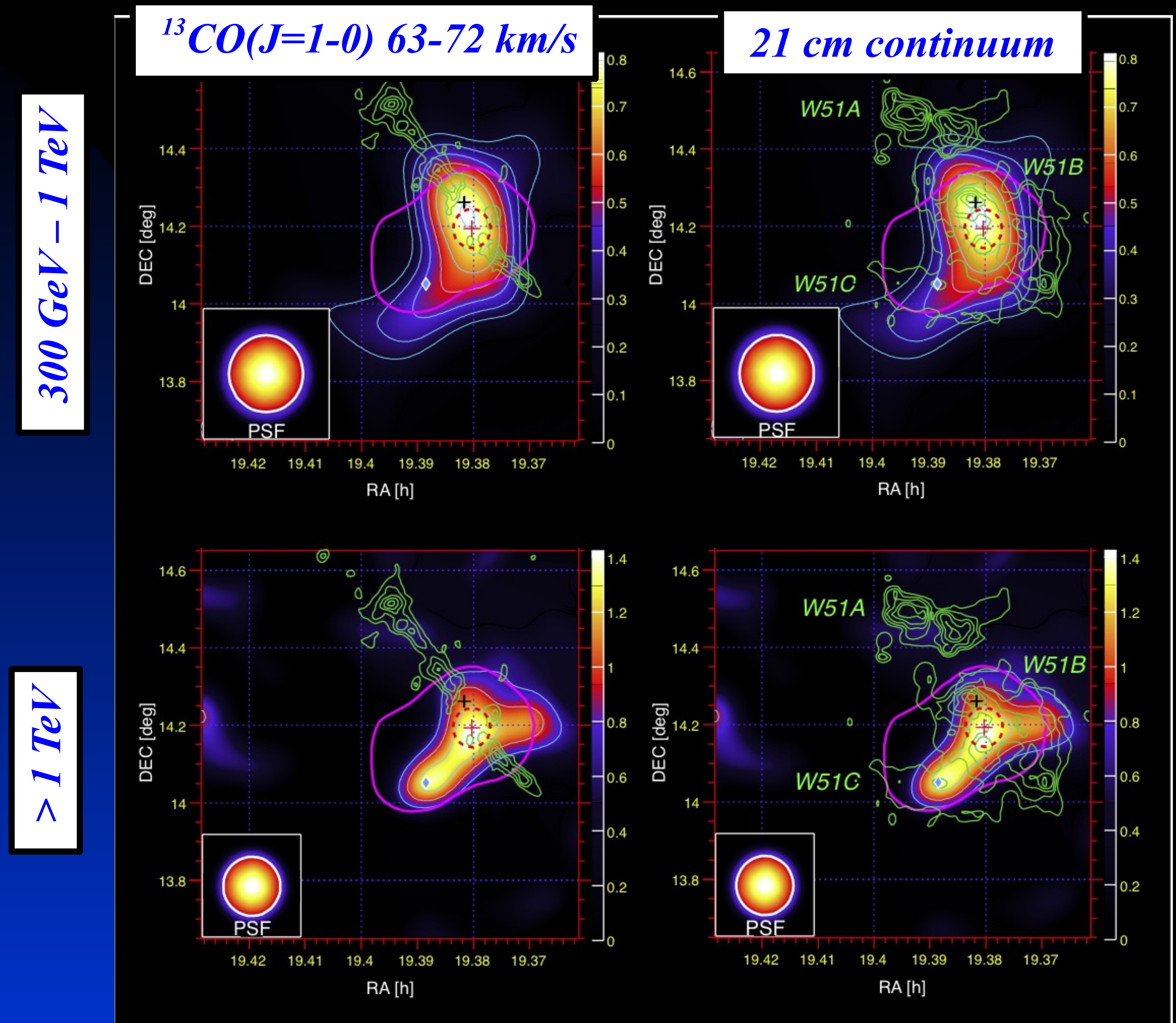
Possible PWN **CXO J192318.5+1403035** maybe associated with **W51C**

The SNR interacts with **W51B**

High Cosmic Ray ionization, ~100xISM value (*Ceccarelli et al. 2011 ApJ 740*)

Supernova Remnants (SNR), the source of cosmic rays?

Aleksic et al. (MAGIC) A&A 541, 2012



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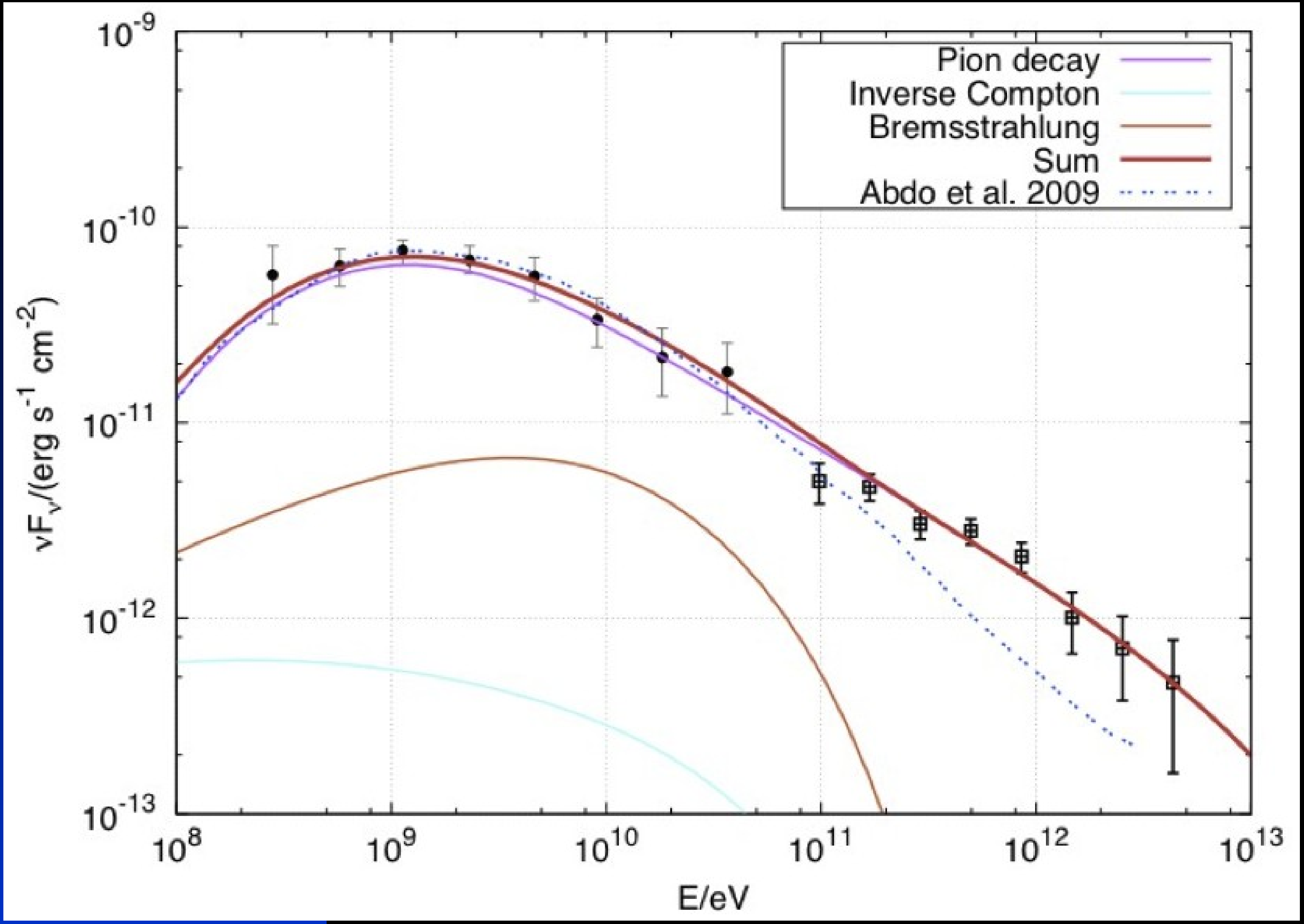
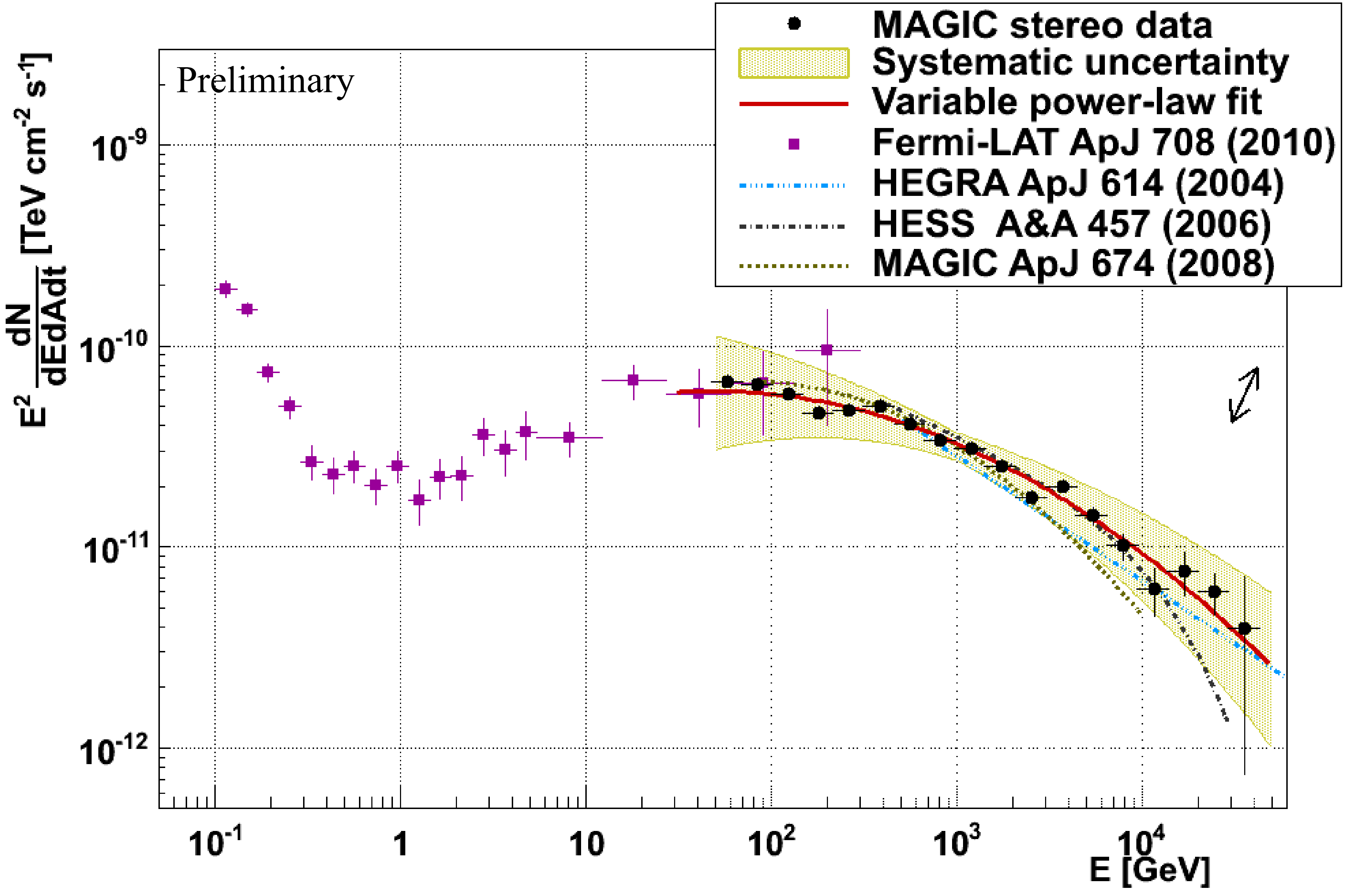


Crab Nebula: SNR and Pulsar Wind Nebula (PWN)



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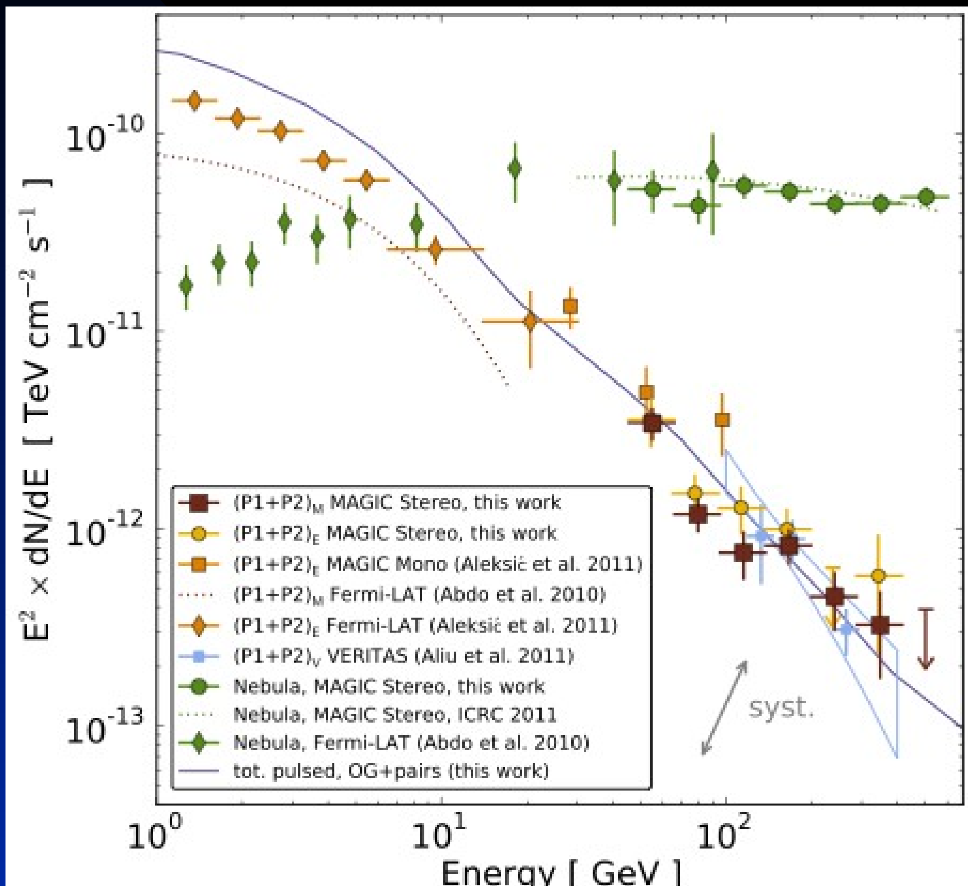
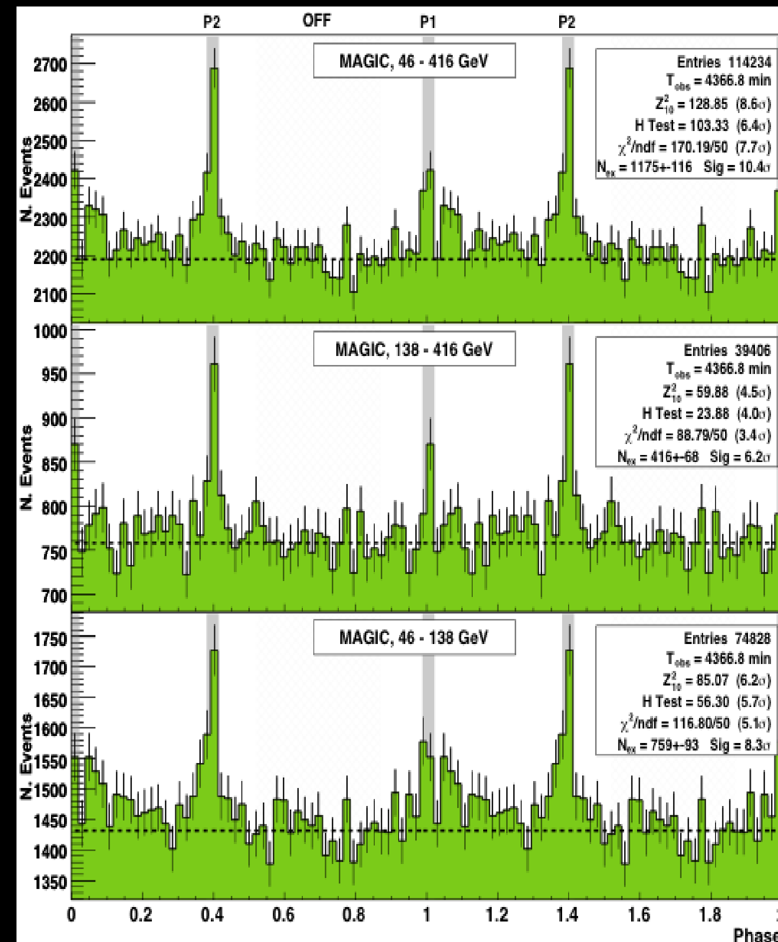




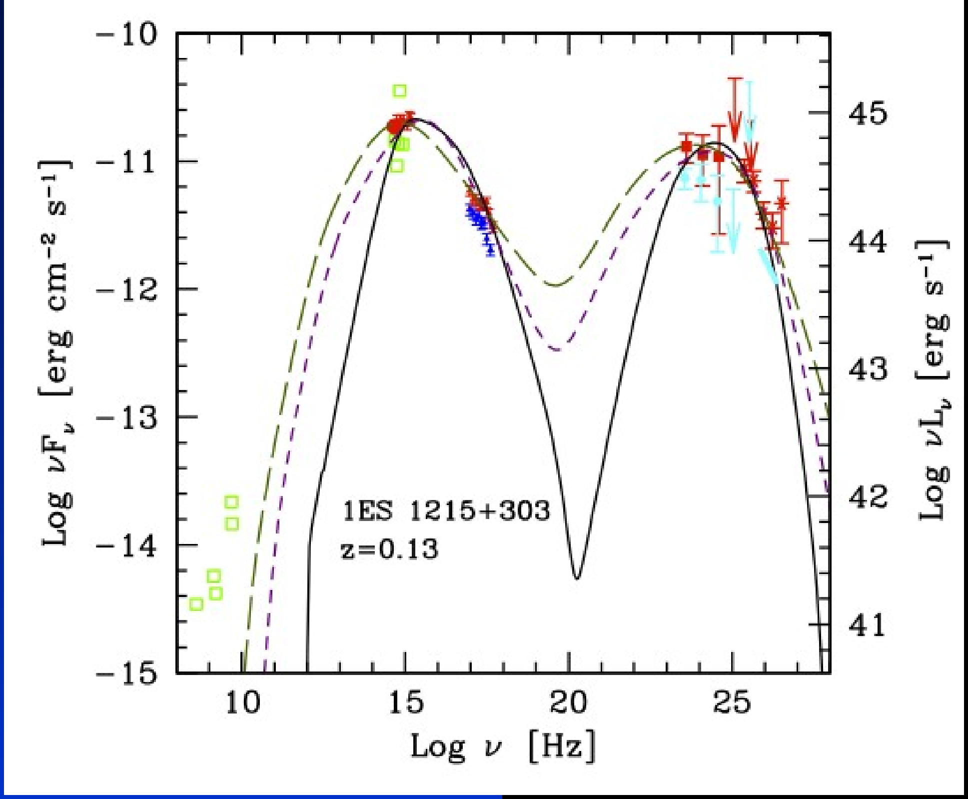
Simple models start to fail: 1ES 1215 + 303

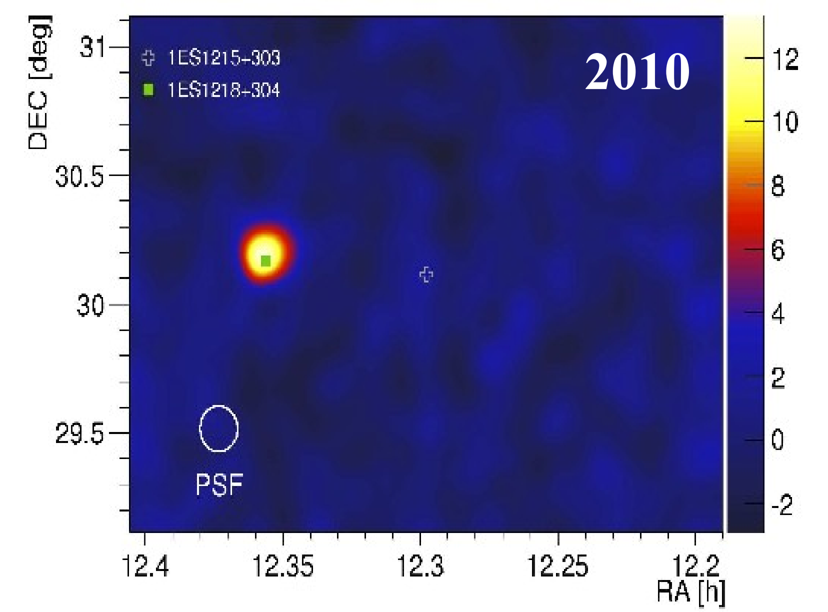
Aleksic et al. (MAGIC) A&A 544, 2012

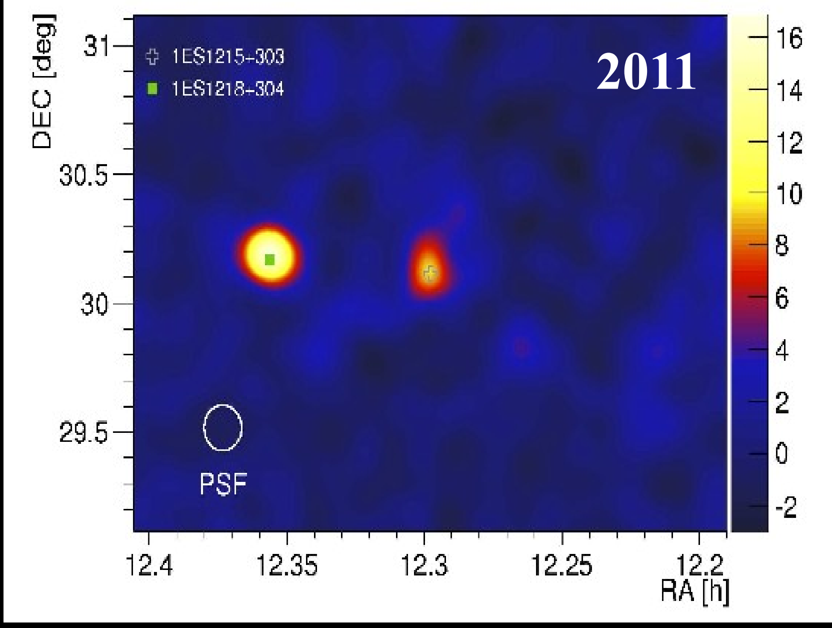
First detection – 2011 January/February

2010 observations lower flux

- Simultaneous MWL → High state also in optic and X-Ray
- Simple 1 zone SSC model → extreme values (doppler factor/e⁻ energy distributions)





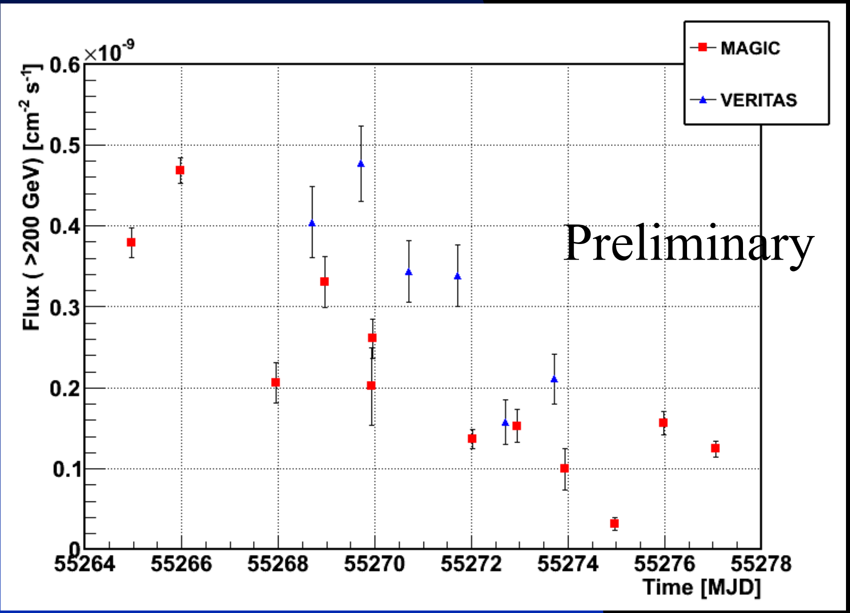


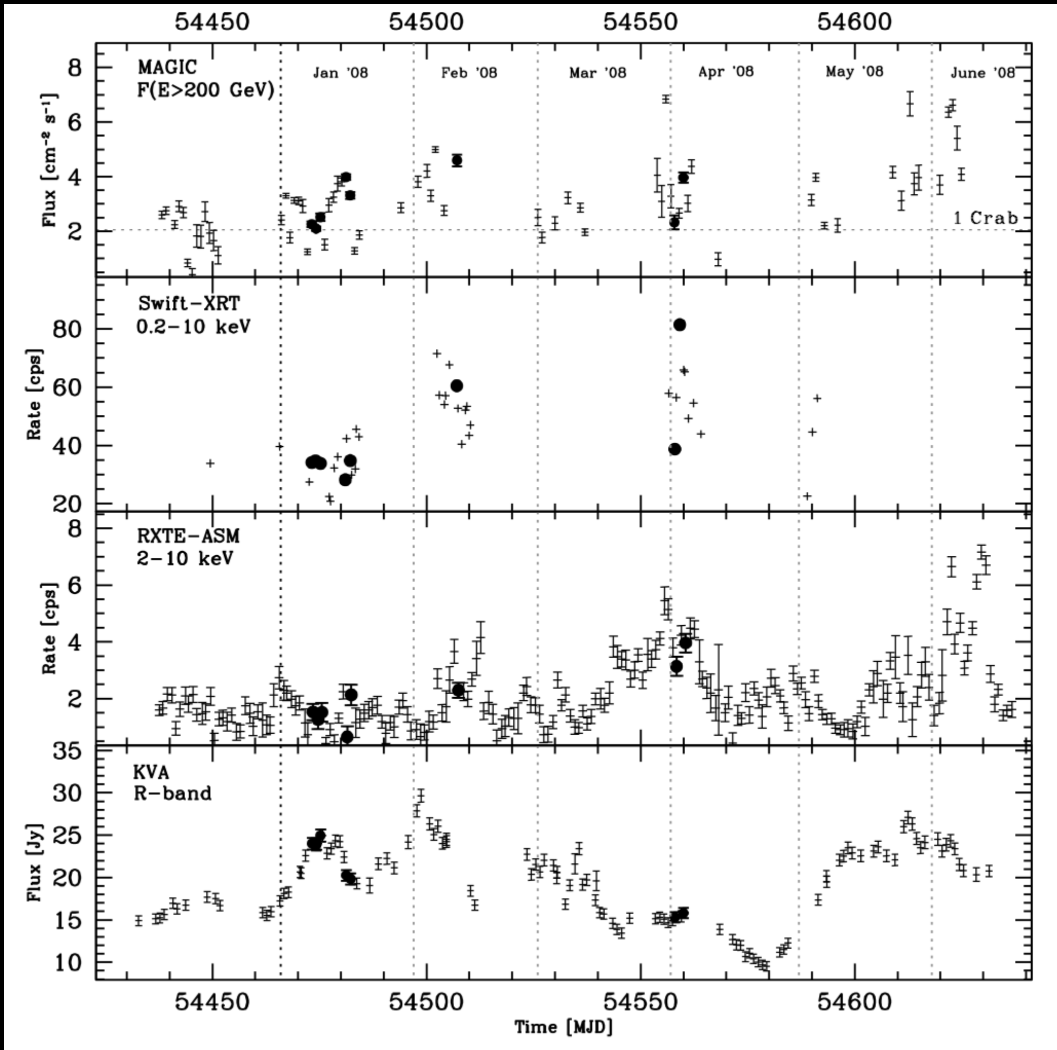
Multi-year and Multi-Wavelength monitoring: Mrk 401

Several flaring episodes:
- 2008 published
- 2010 analysis ongoing
- 2013 → highest level in VHE

MAGIC, ATel#4976

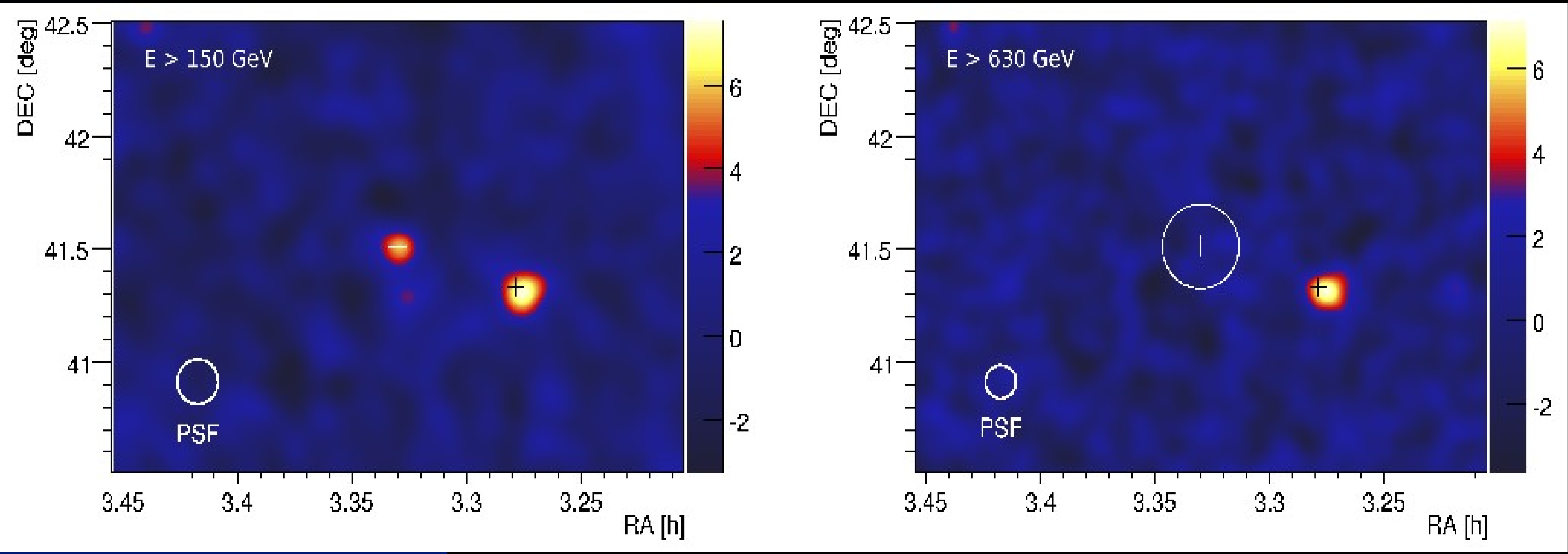
- Also low state (steady) emission





Aleksic et al. (MAGIC) A&A 542, 2012

Clusters of Galaxies: Perseus the brightest in X-ray



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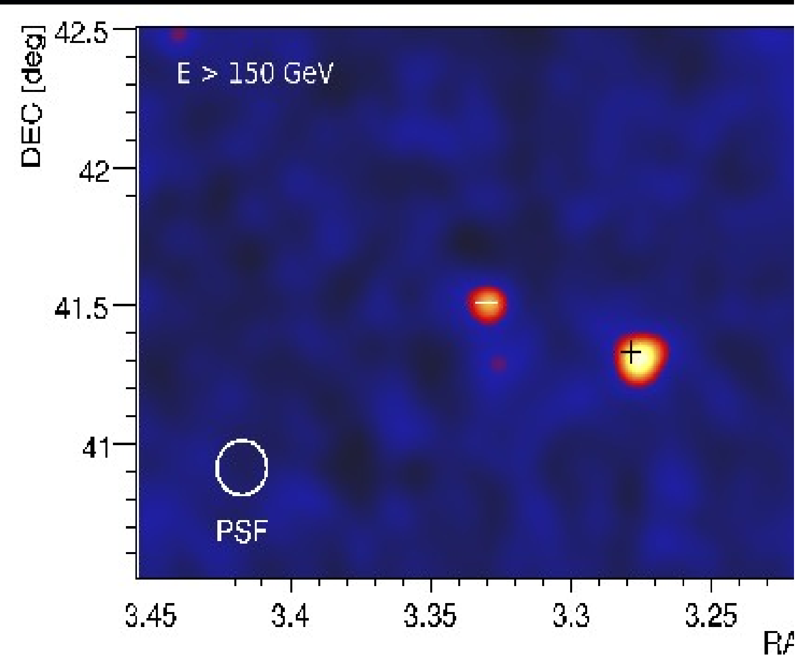
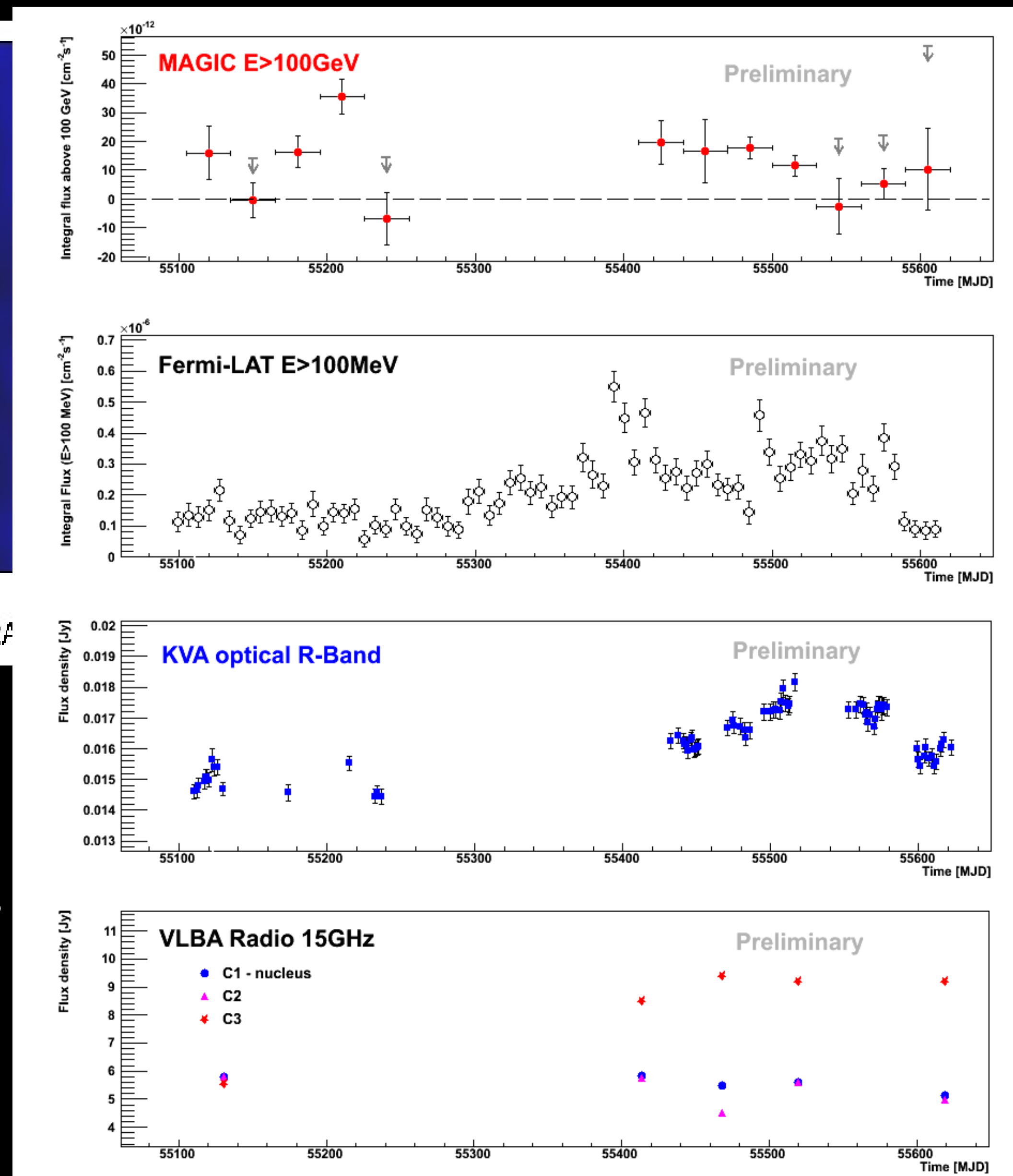




NGC1275

Dominant central galaxy of Perseus
Spectrum with MAGIC
$\Gamma = 4.1 \pm 0.7$
MAGIC light curve, with MWL

Aleksic et al. (MAGIC) A&A 539, 2012

Clusters of Galaxies: Perseus the brightest in X-ray

IC 310

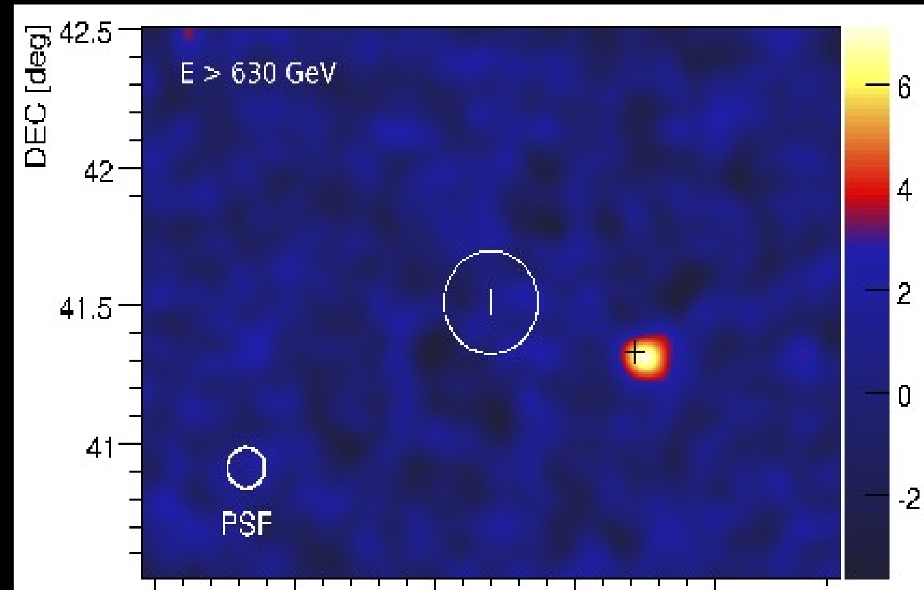
Originally classified as “head – tail”, MAGIC data suggest a blazar

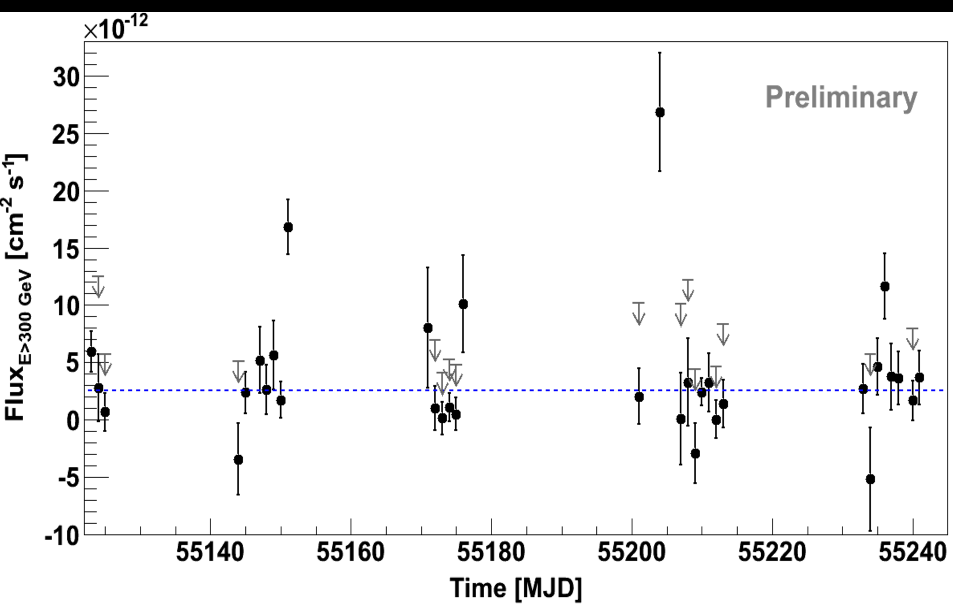
VHE spectrum very hard

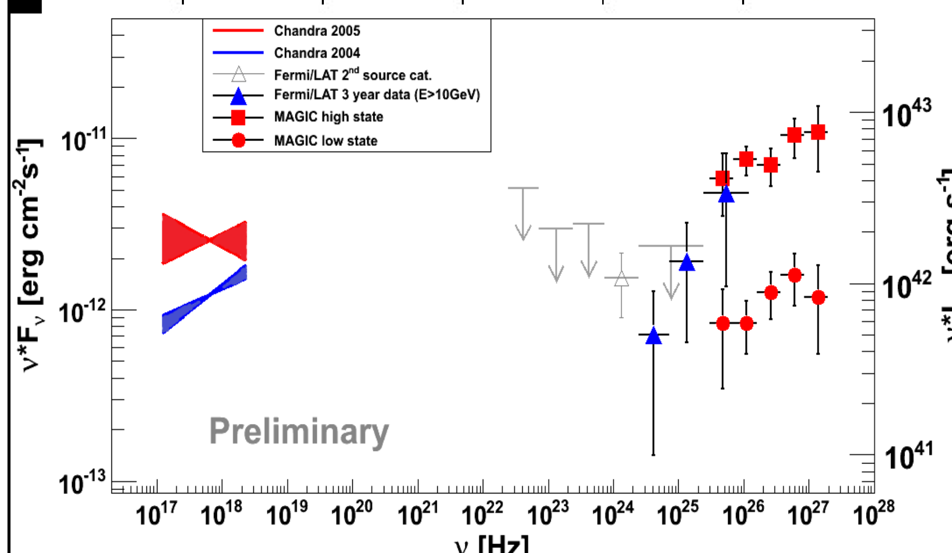
$$\Gamma = 1.8 \pm 0.1$$

Day scale variability, new flare in Nov'12

MAGIC, ATel#4976







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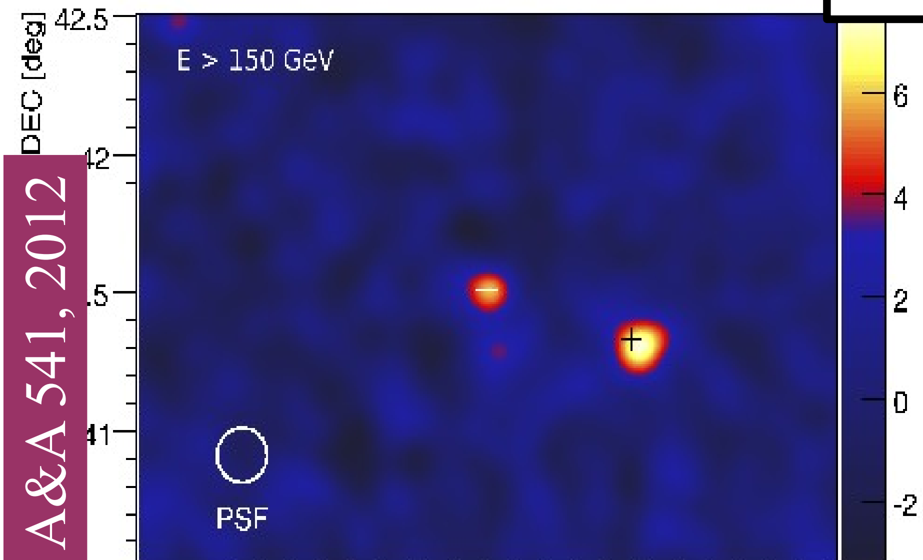
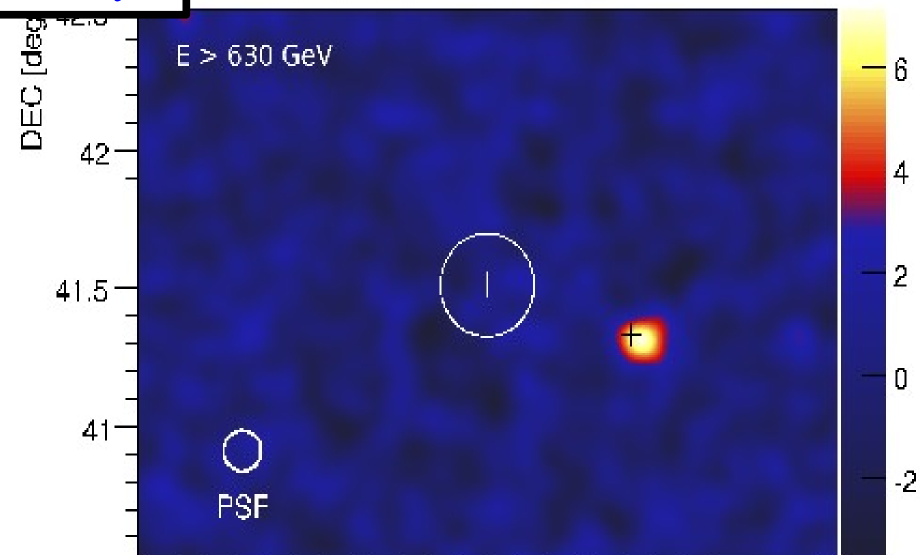
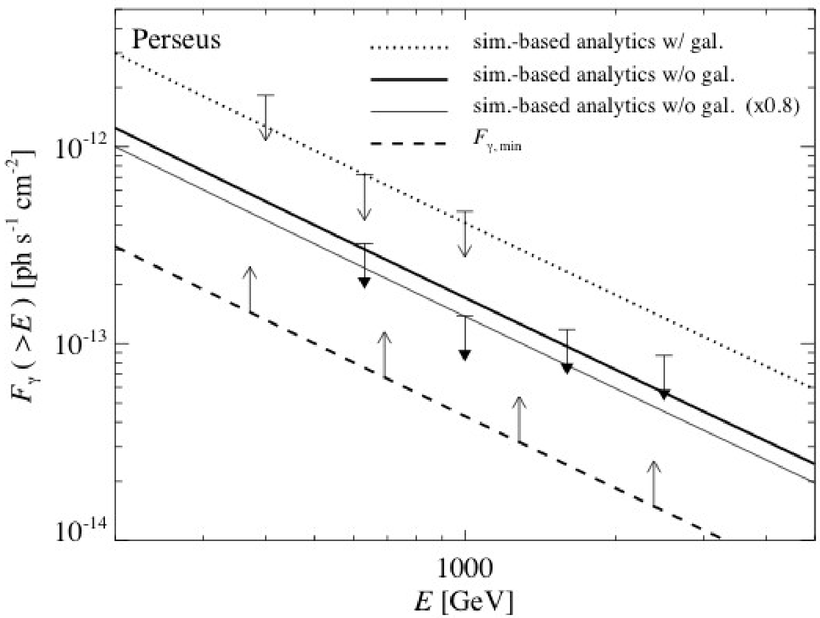
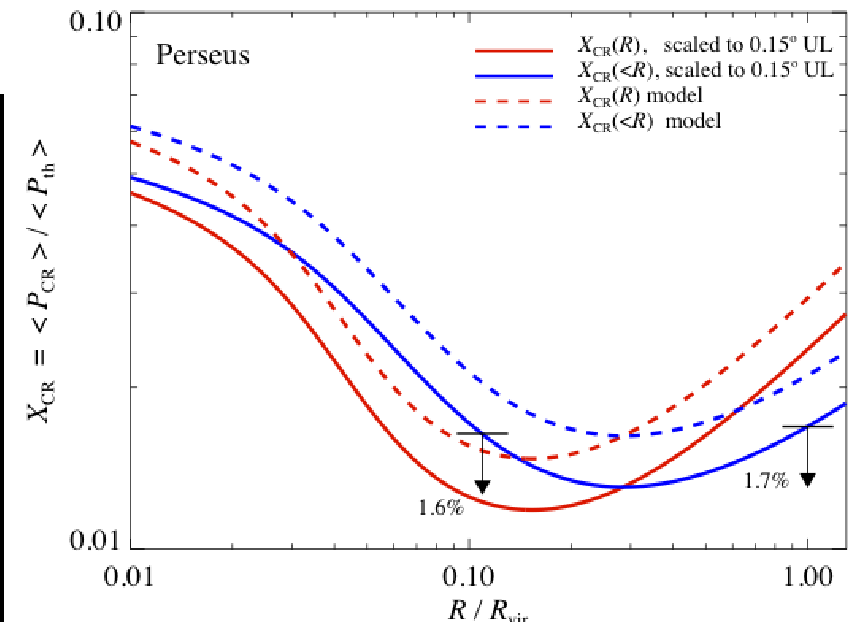
Cosmic Rays

Aleksic et al. (MAGIC) A&A 541, 2012









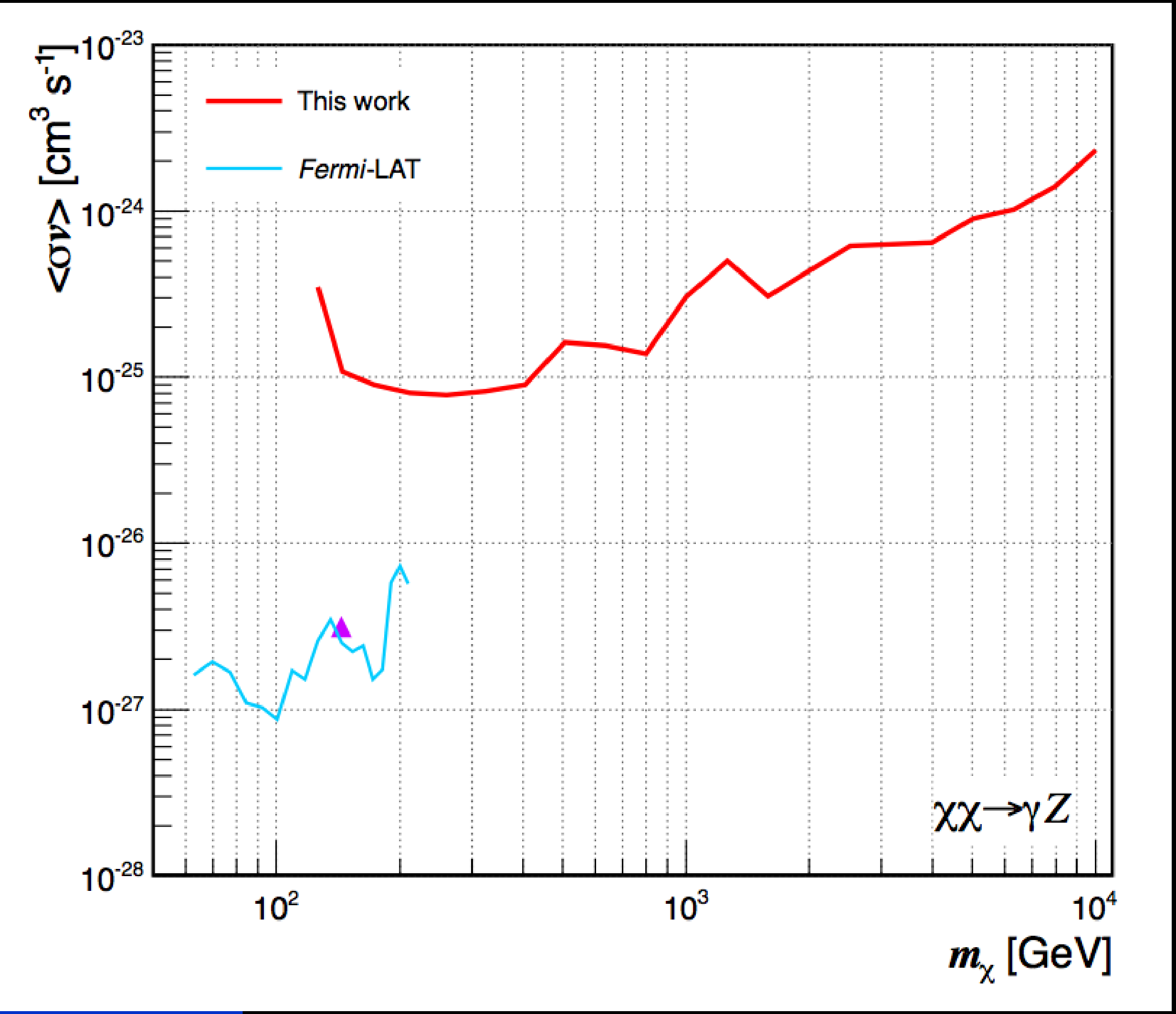
Dark Matter searches: The satellite galaxy Segue

No signal

→ For some cases most constraining limits (general or from SpheD)

→ Still … many models alive (more than killed)

Aleksic et al. (MAGIC) AstroPh 1312.1535



The future: CTA

A world wide collaboration

cherenkov telescope array

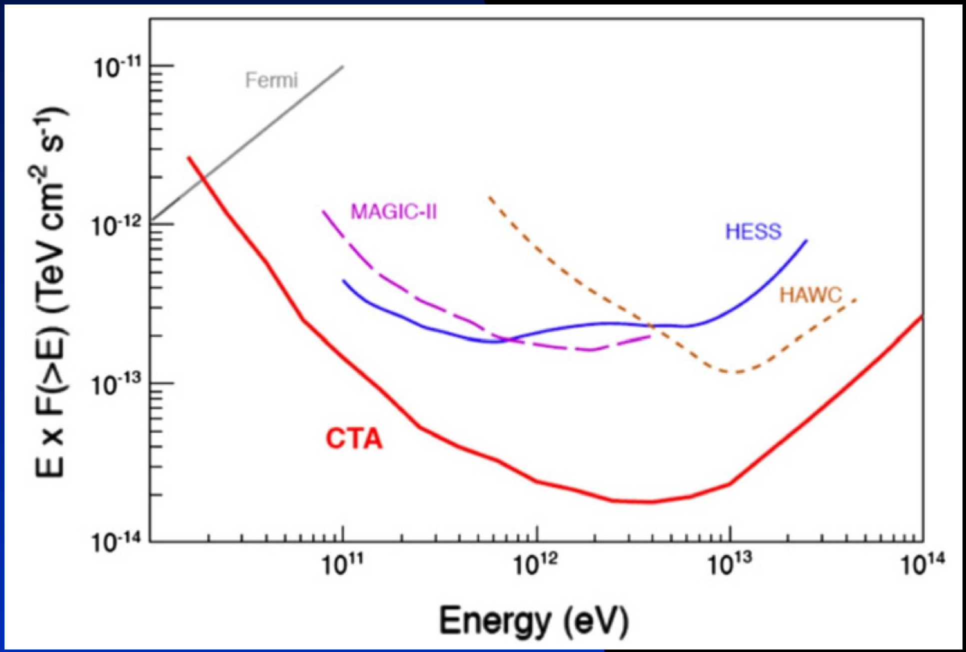
Currently:

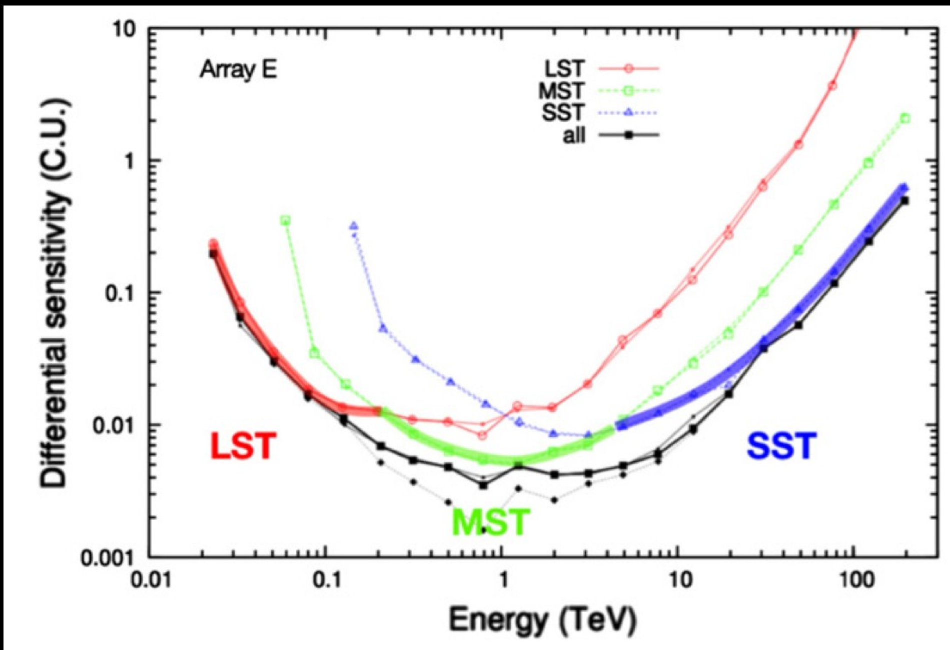
28 countries, 80 institutions 1138 members

Expected Performance for CTA

Design done aiming at:

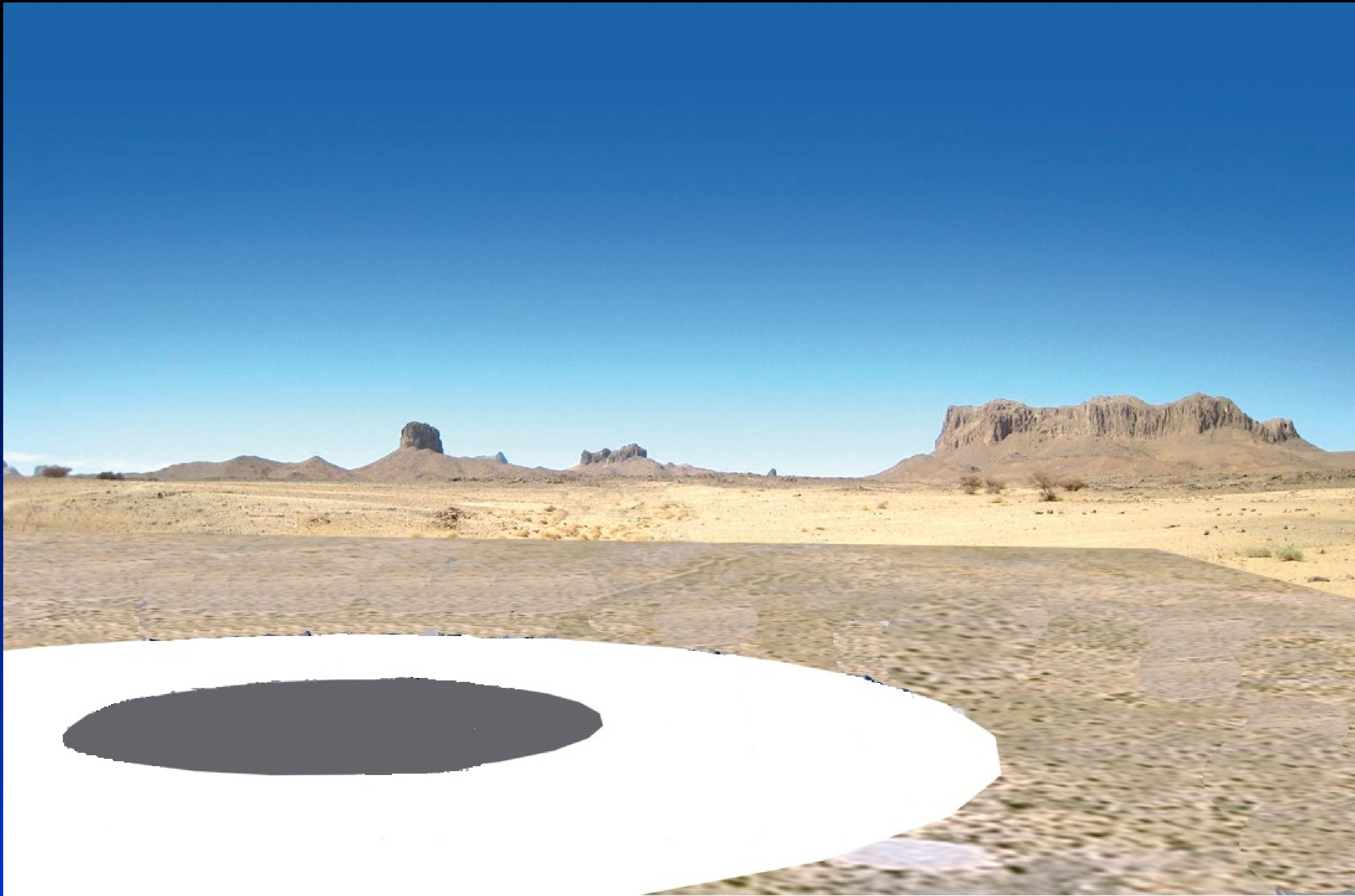
- Full sky coverage: 2 sites, one in each hemisphere
- Sensitivity improved by factor ~10
- Large energy range: < 30 GeV to > 100 TeV
- Improved energy and angular resolution and accuracy





Astroparticle Physics 43 (2013)

The Cherenkov Telescope Array concept



The Cherenkov Telescope Array concept

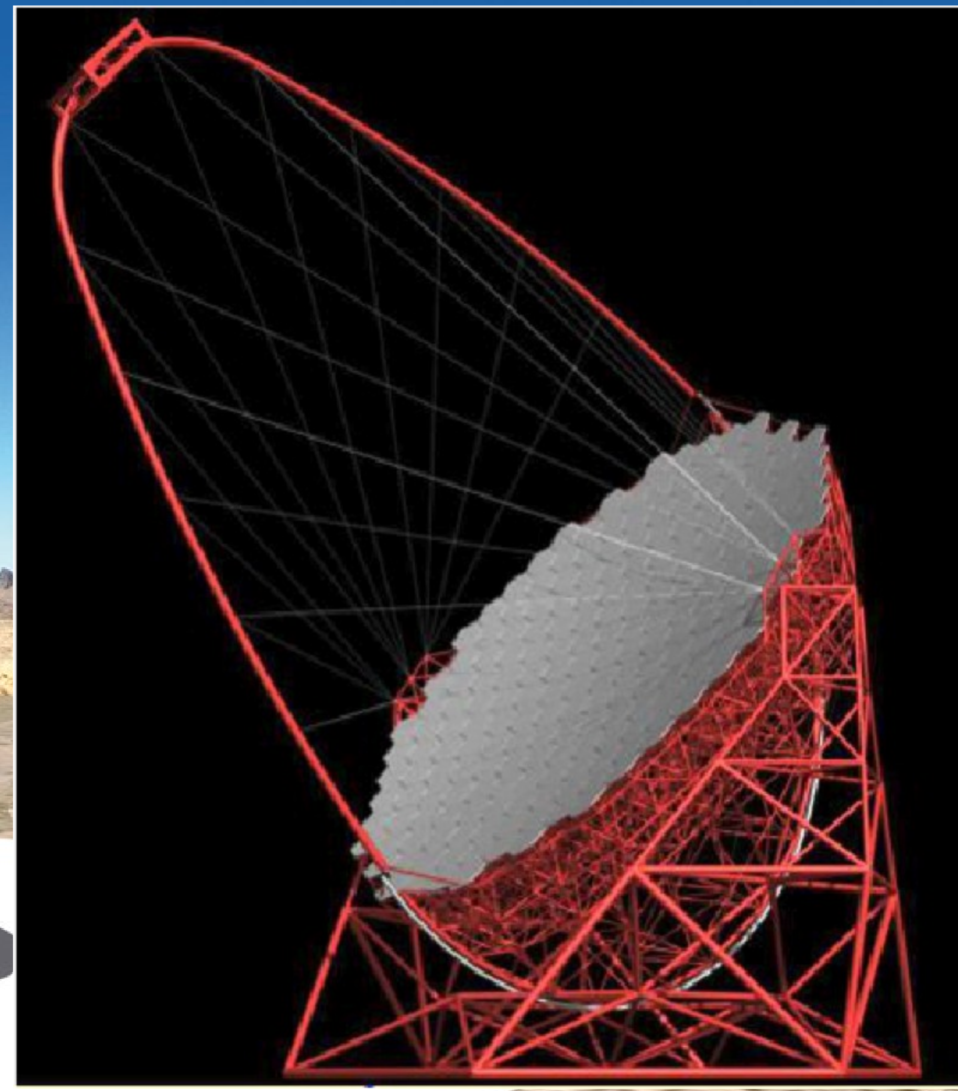
Low energy

Few 23 m telescopes

4.5° FoV

~2000 pixels

~ 0.1°



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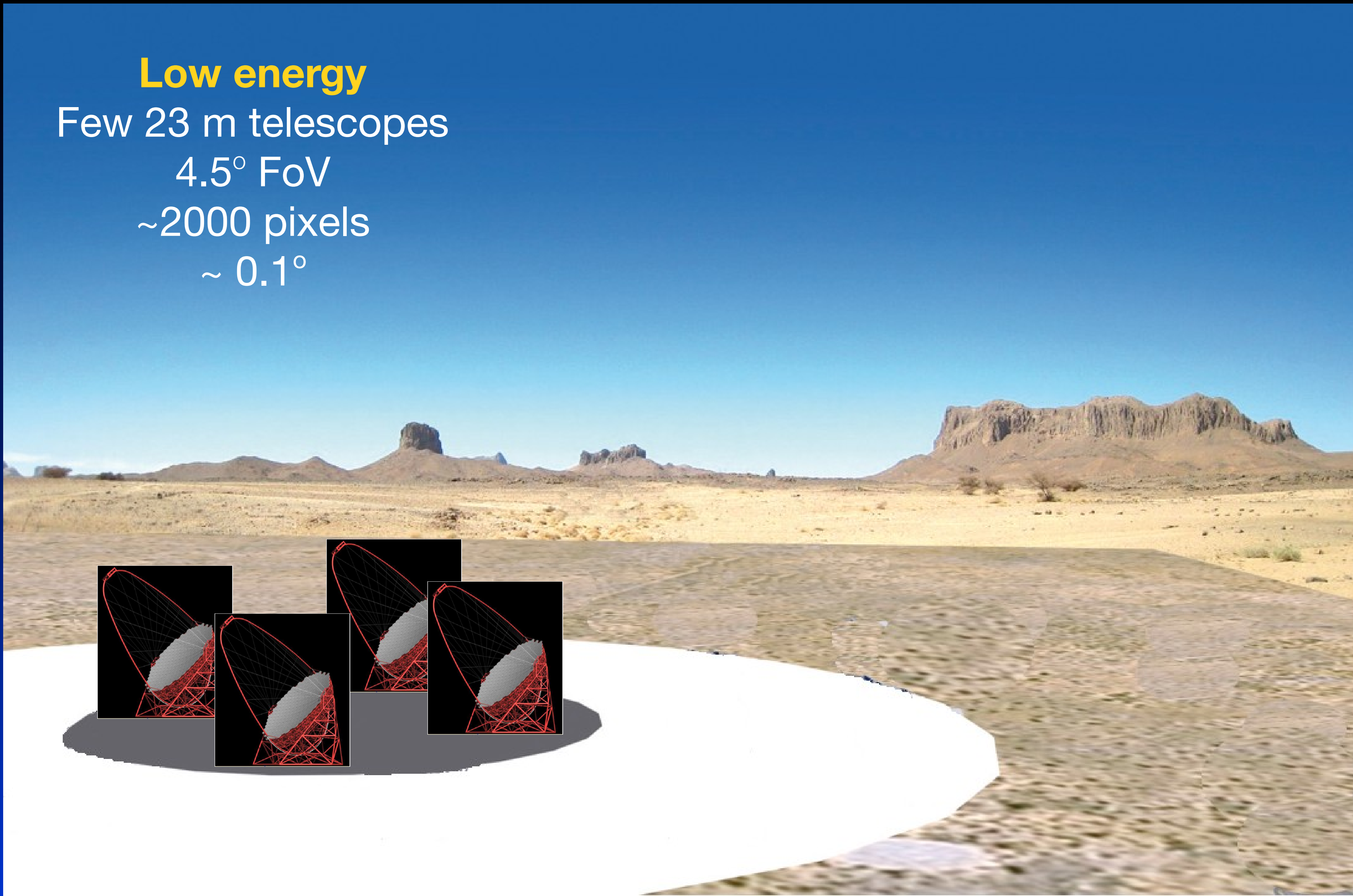

The Cherenkov Telescope Array concept

Medium energy

About twenty 12 m telescopes

~8° FoV

~2000 pixels

~ 0.2°

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Medium energy

About twenty 12 m telescopes

~8° FoV

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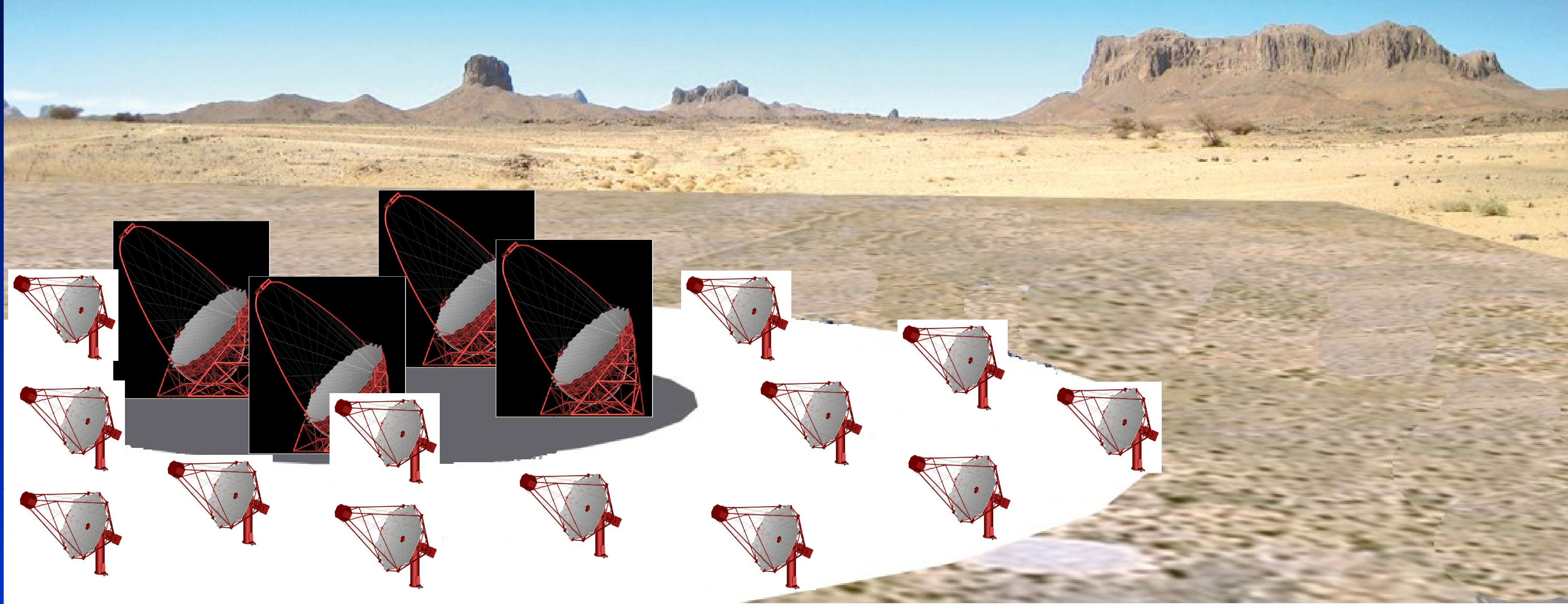

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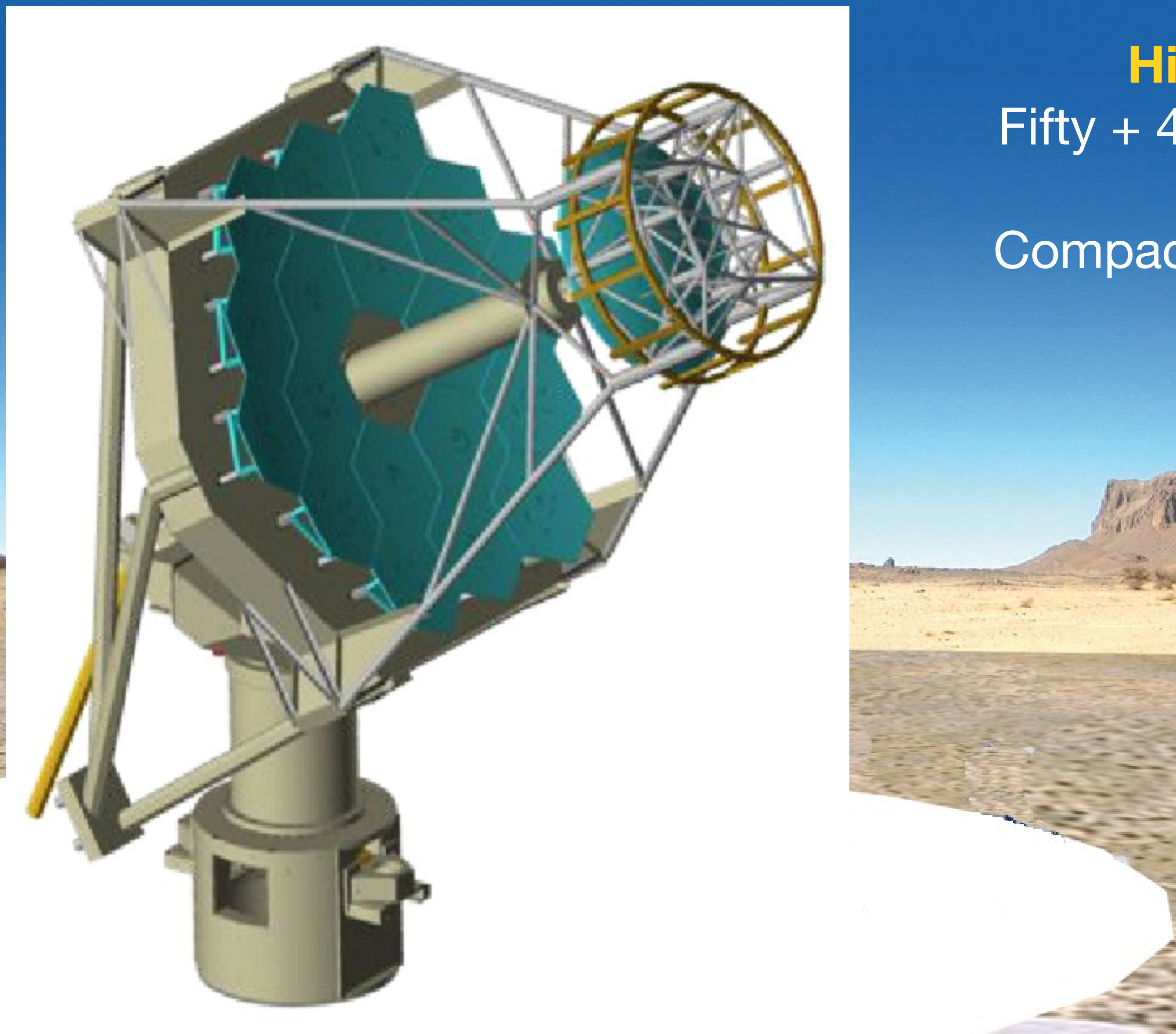


High energy

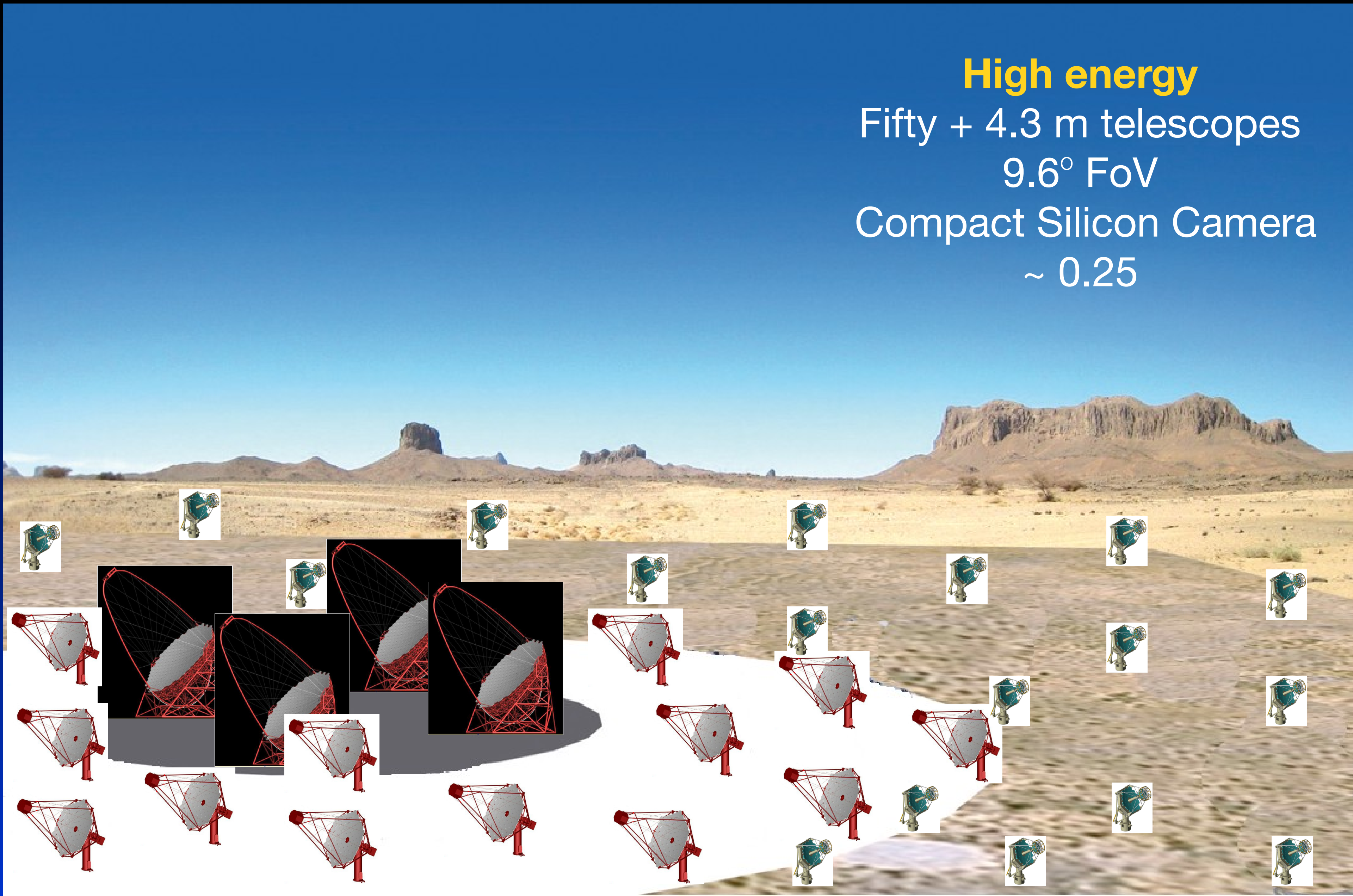
Fifty + 4.3 m telescopes

9.6° FoV

Compact Silicon Camera

~ 0.25

The Cherenkov Telescope Array concept



High energy

Fifty + 4.3 m telescopes

9.6° FoV

Compact Silicon Camera

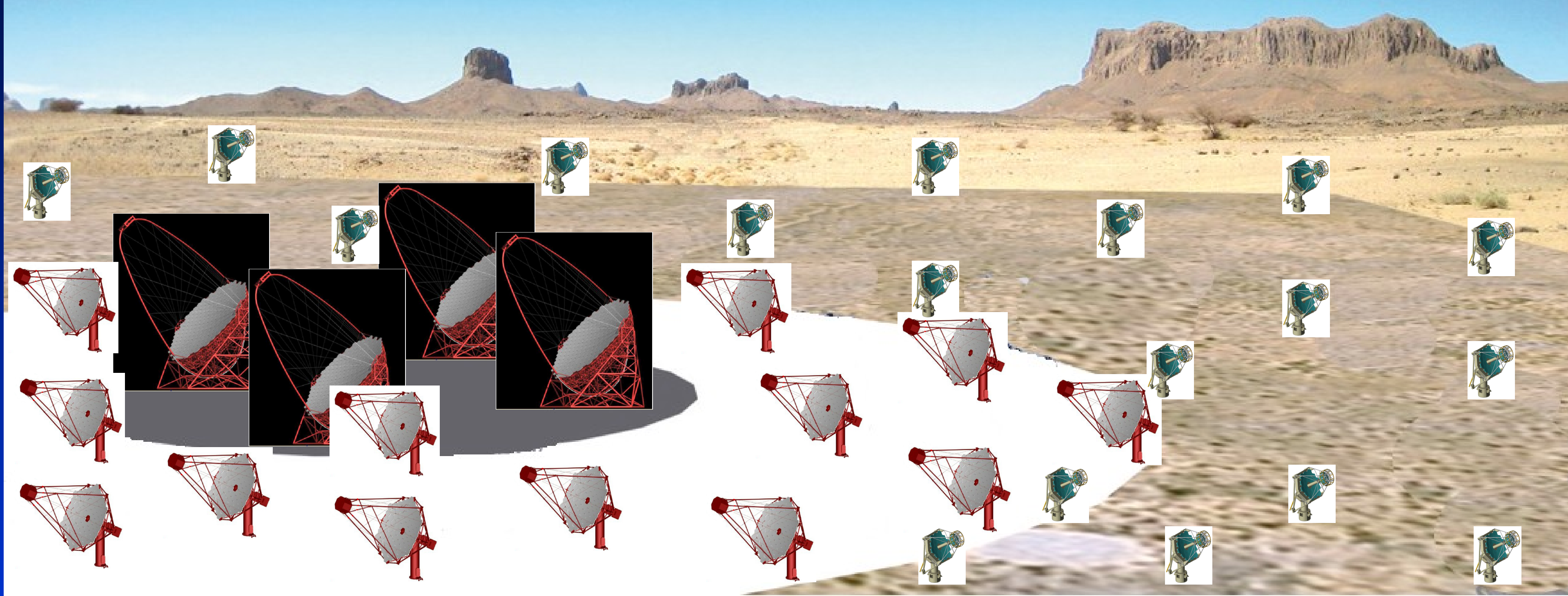
~ 0.25

The Cherenkov Telescope Array concept

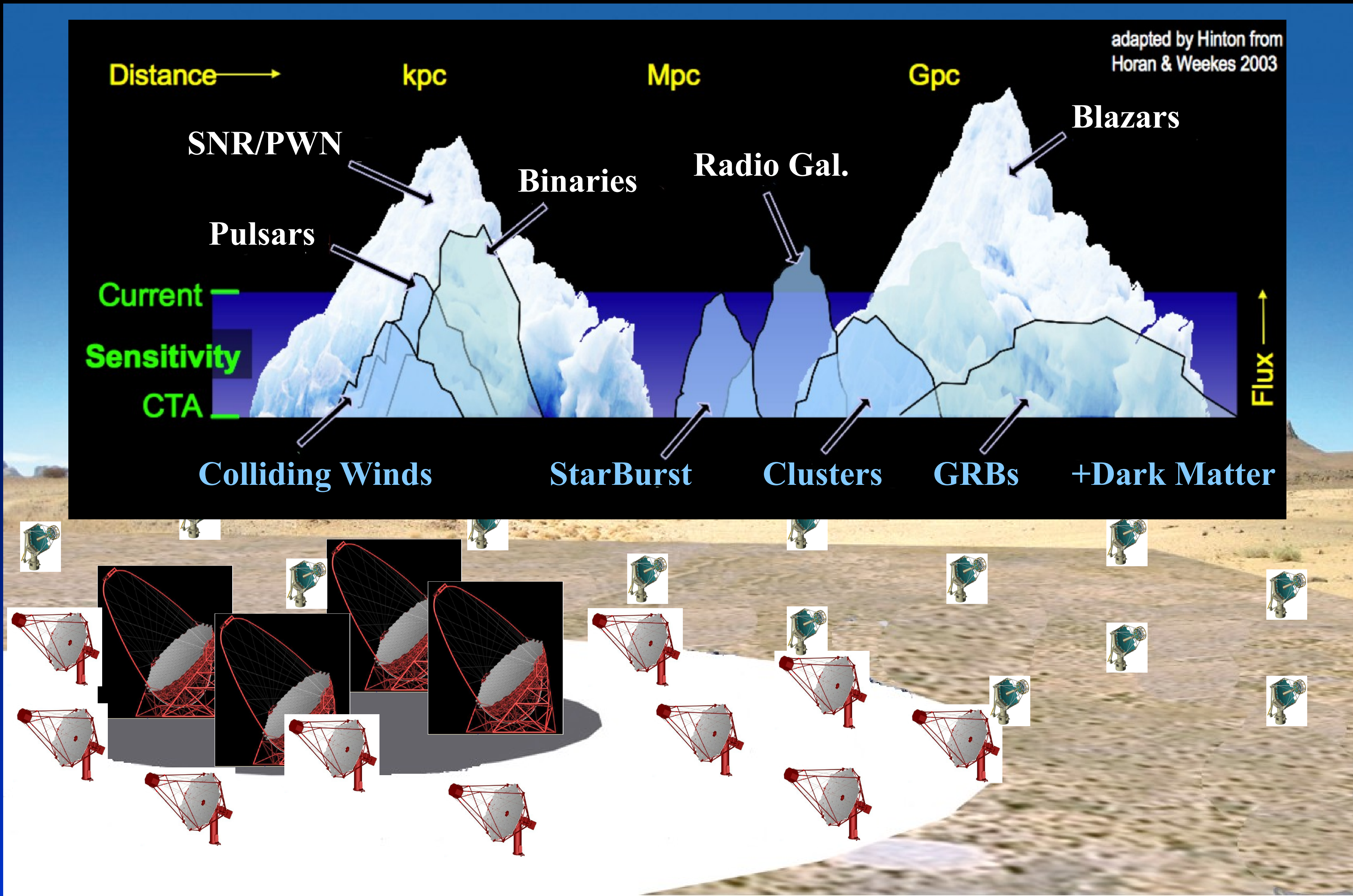
Low energy
~4 x 23 m CT
4.5° FoV
~2000 pixels
~ 0.1°

Medium energy
~20 x 12 m CT
~8° FoV
~2000 pixels
~ 0.2°

High energy
~50 x 4.3 m CT
9.6° FoV
Silicon Camera
~ 0.25



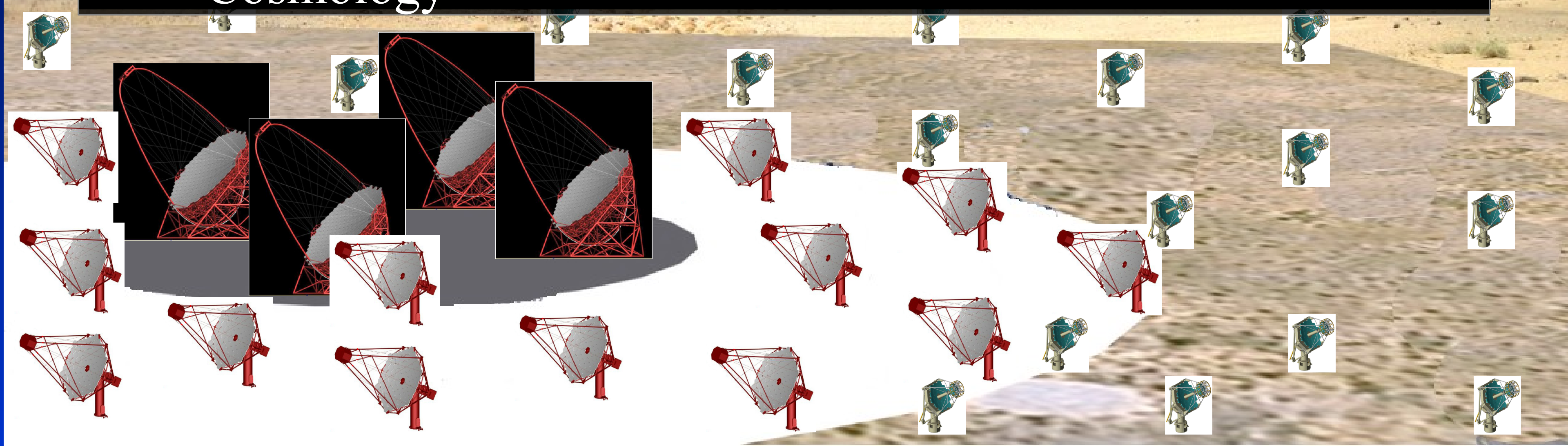
The Cherenkov Telescope Array concept



The Cherenkov Telescope Array concept

Data from CTA can also provide information on fundamental physics:

- Indirect Detection of Dark Matter
- Charged Particles Measurement
- Axion Like Particles
- Lorentz Invariance Violation
- Interaction of UHE Cosmic-Rays
- Extragalactic Background Light
- Cosmology

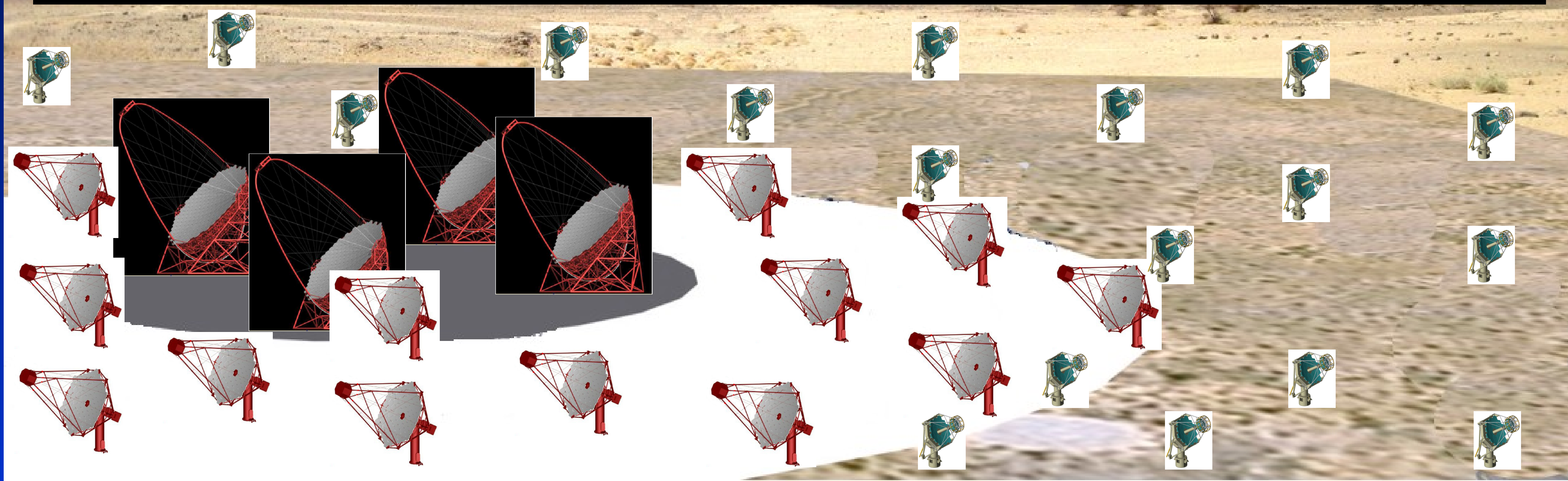


The Cherenkov Telescope Array concept

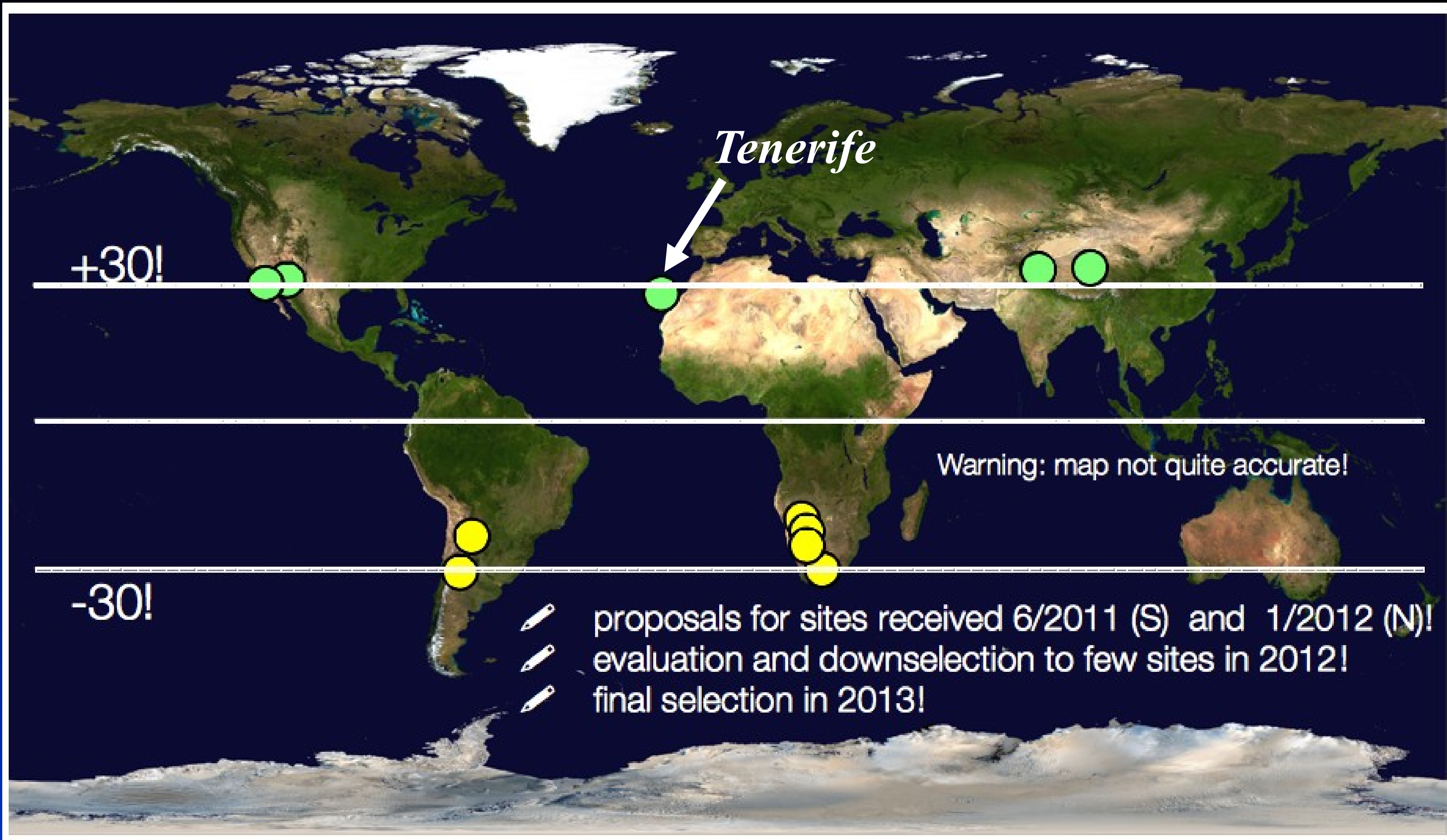
- Possibility to answer many questions still open both on Astro and Fundamental Physics.
- Some measurements will be complementary to other instruments
- But ... CTA is unique at least in:

Short time scale phenomena at VHE

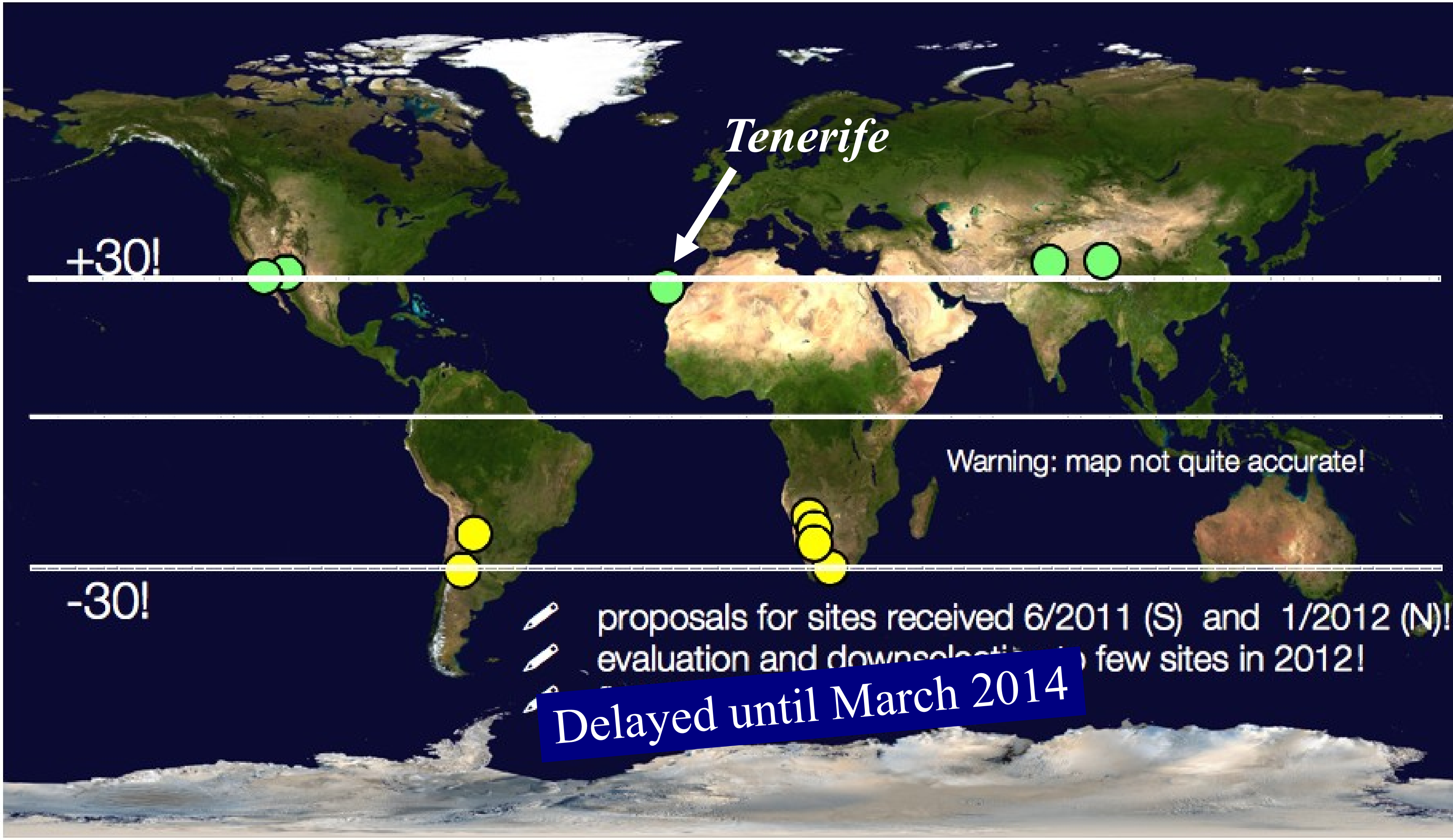
Sky survey at the highest energies



Spain in CTA


Tenerife
+30!
-30!
Warning: map not quite accurate!
proposals for sites received 6/2011 (S) and 1/2012 (N)!
evaluation and downselection to few sites in 2012!
final selection in 2013!

Spain in CTA


Tenerife
+30!
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proposals for sites received 6/2011 (S) and 1/2012 (N)!
evaluation and
few sites in 2012!
Delayed until March 2014

Summary

- Astroparticle Physics is very active field that is still growing

- Very High Energy Gamma-ray provides information
  - Astro Physics
  - Fundamental Physics (particles physics)
  - Cosmology

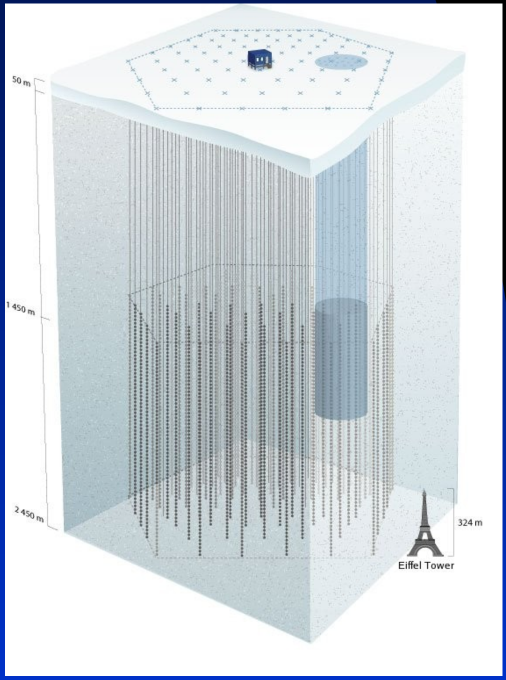
- The MAGIC telescopes have had a leading role in the field (with VERITAS and HESS) and will continue producing first class result until CTA becomes real

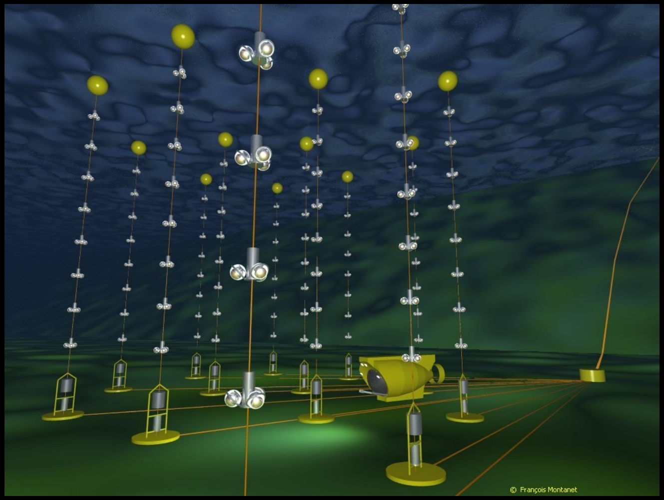
Backup

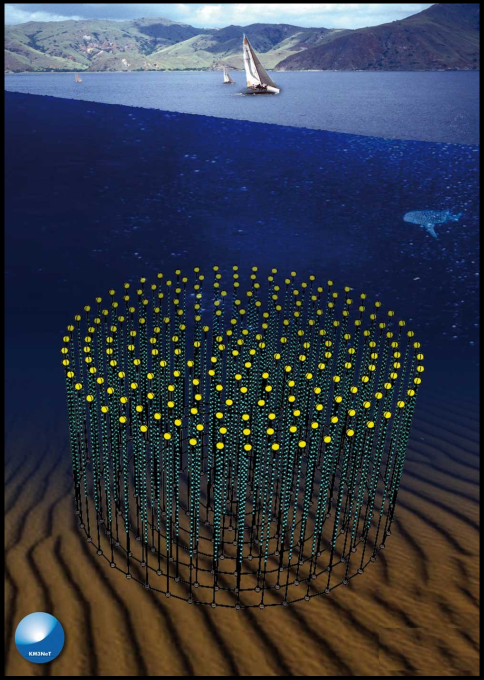
Neutrins

- Postulat d'existència (Wolfgang Pauli 1930)

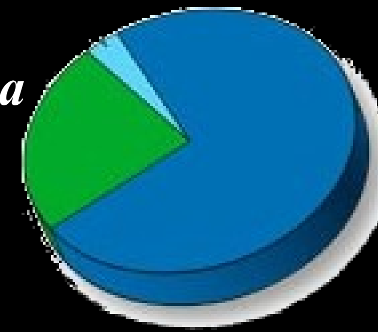
  Partícula molt lleugera necessària per mantenir lleis de conservació a la desintegració β.
- Primera confirmació experimental: 1956
- Neutrins extraterrestres: Sol i SN 1987A







Matèria fosca

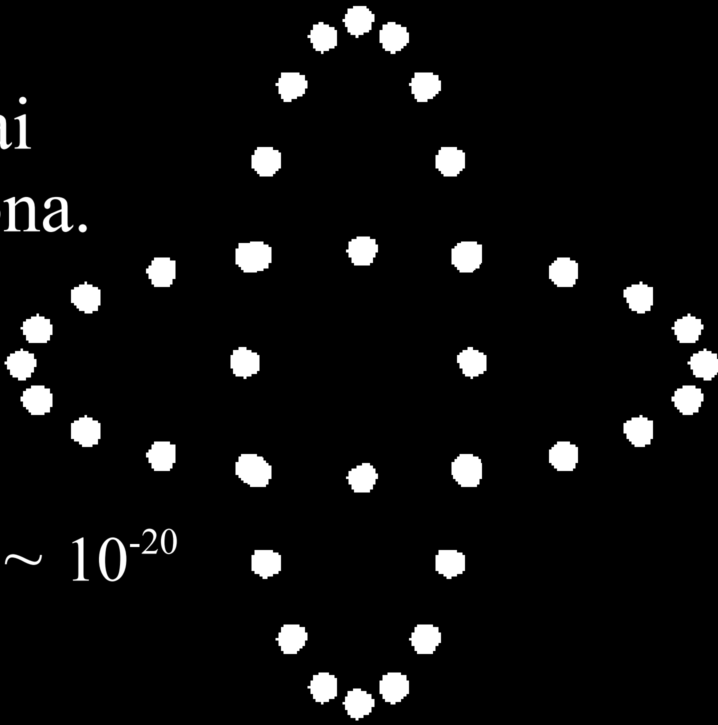


No emet ni reflecteix prou radiació electromagnètica per poder-se detectar directament.

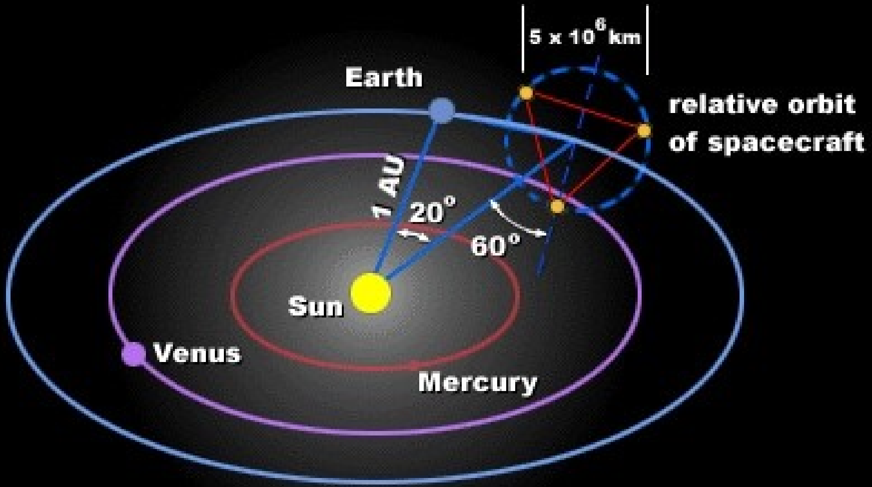
Composició desconeguda.

Ones gravitacionals

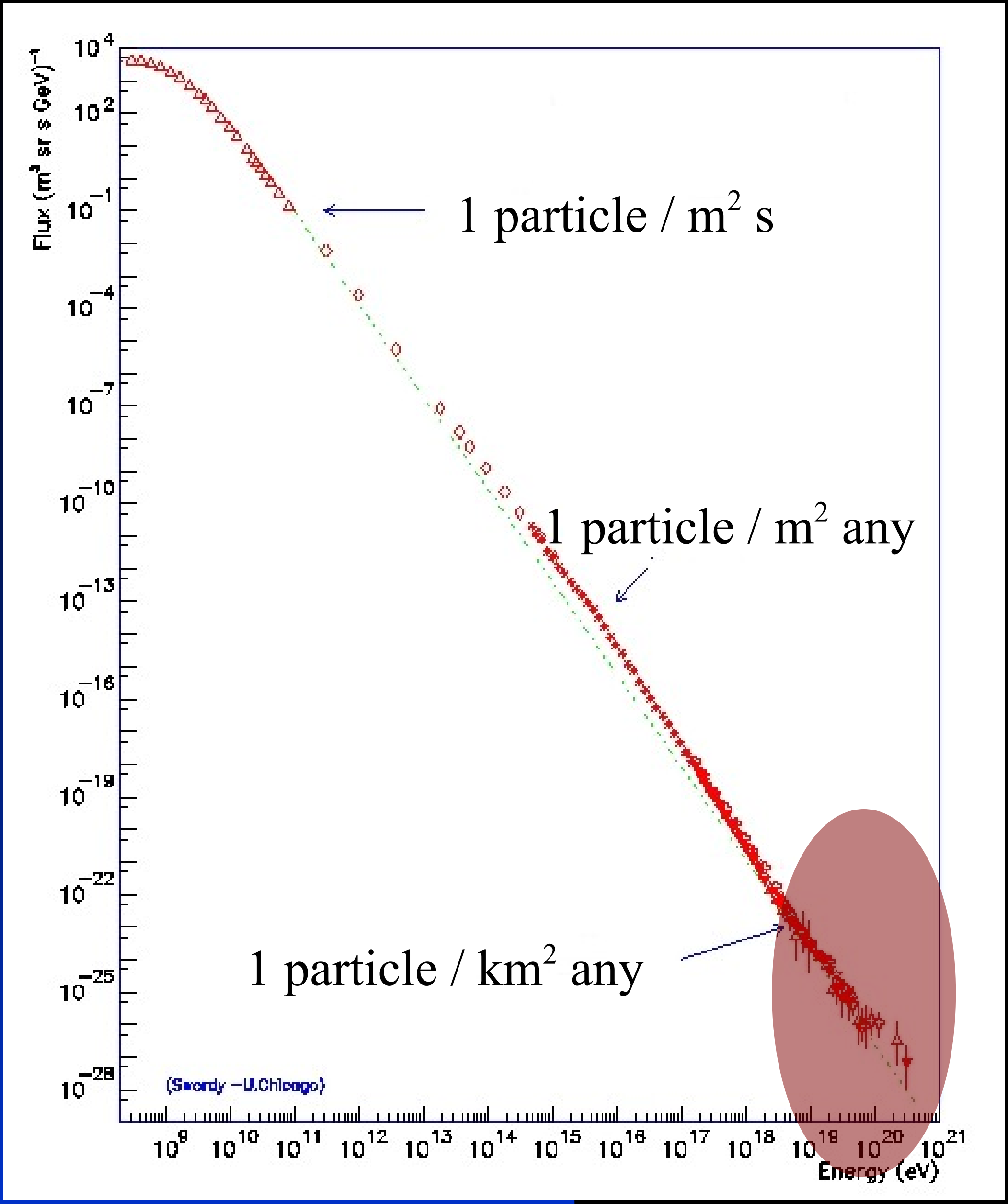
Fluctuacions de la curvatura de l'espai temps que es propaga en forma d'ona.



$dh/h \sim 10^{-20}$



Cosmic rays



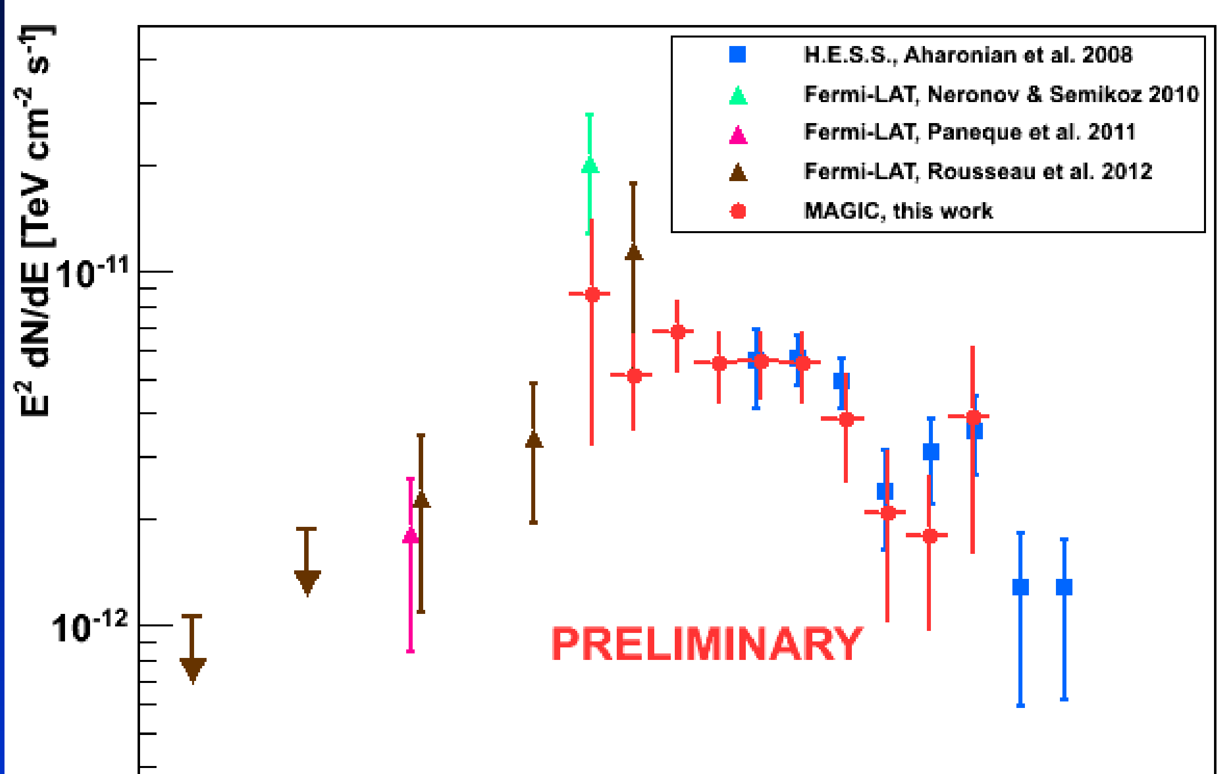
Flux (m² sr s GeV)⁻¹
1 particle / m² s
1 particle / m² any
1 particle / km² any
(Swordy – U.Chicago)
Energy (eV)

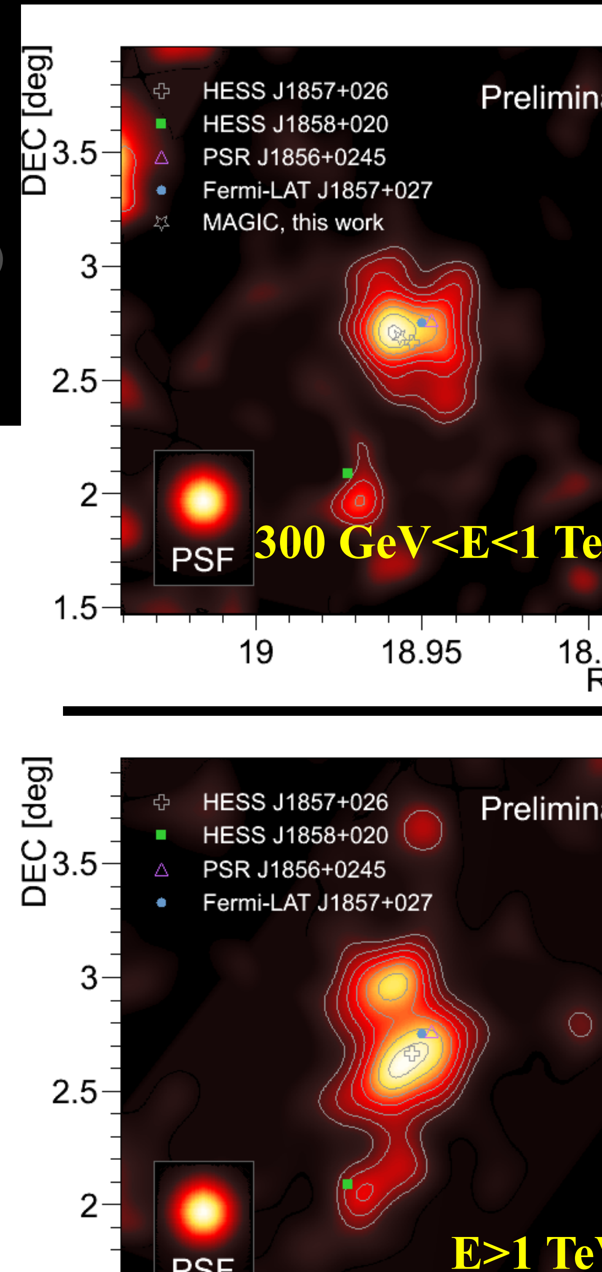
HESS 1857+026

Unidentified HESS source *(Aharonian et al. 2008 A&A 477)*
Young energetic pulsar PSR J1858+0245 later discovered *(Hessels et al. 2008 ApJ 662)*

Point-like source *(Rousseau et al 2012 A&A 544)*

Morphology and spectrum → Hint for PWN



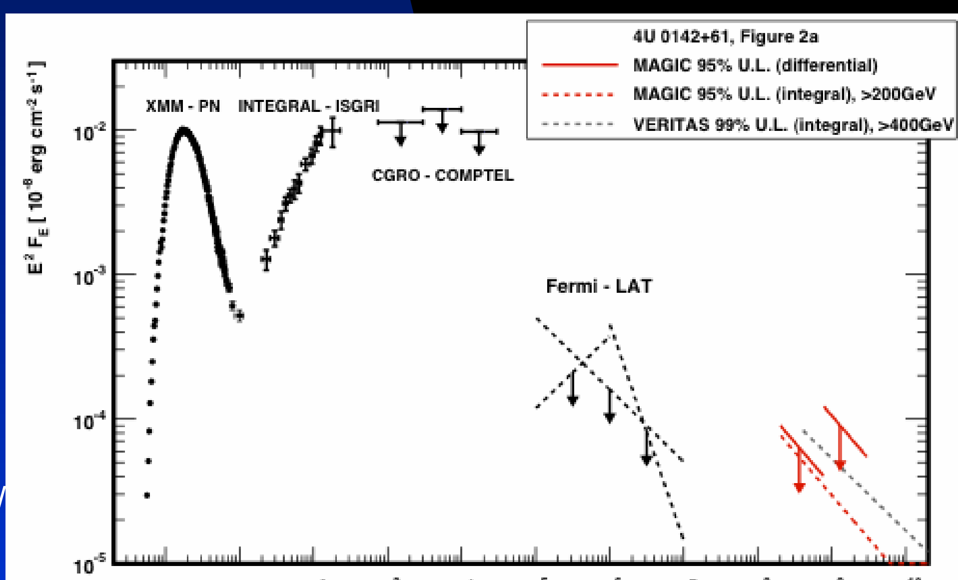


Upper limits on Magnetars

Aleksic et al. (MAGIC) A&A 541, 2012

4U 0142+61

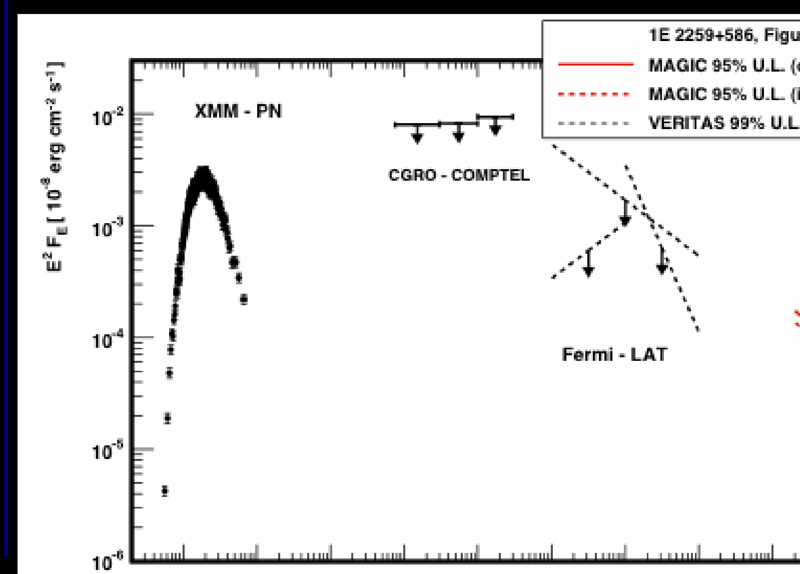
- $L_x \sim 10^{35}$ erg s^{-1} (among the brightest)
- B on surface: $1.3 \cdot 10^{14}$ G
- Distance: 3.5 ± 0.4 kpc
- MAGIC: 17h in 2008, mono data
- 95% upper limit at E > 200 GeV:
  ~ 0.5% C.U.



1E 2259+586

- $L_x \sim 0.3 \cdot 10^{35}$ erg s^{-1}
- B on surface: $0.59 \cdot 10^{14}$ G
- Distance: 4.0 ± 0.8 kpc
- MAGIC: 8h in 2010, stereo d
- 95% upper limit at E > 200 G
  ~ 0.

Similar UL with half of the tin

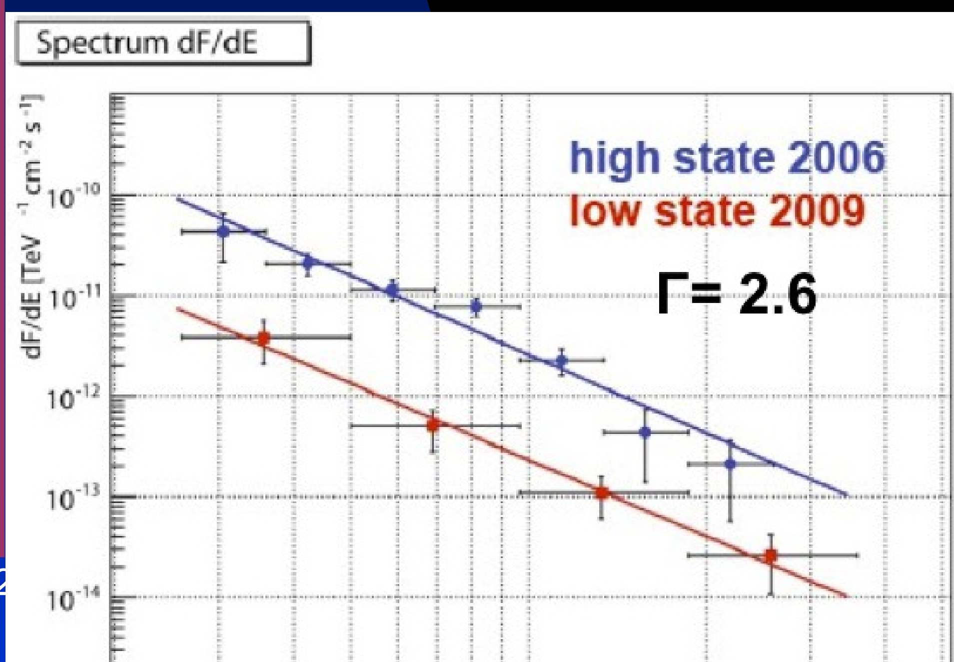


Binary Systems

LS I +61 303

Aleksic et al. (MAGIC) ApJ 746, 2012

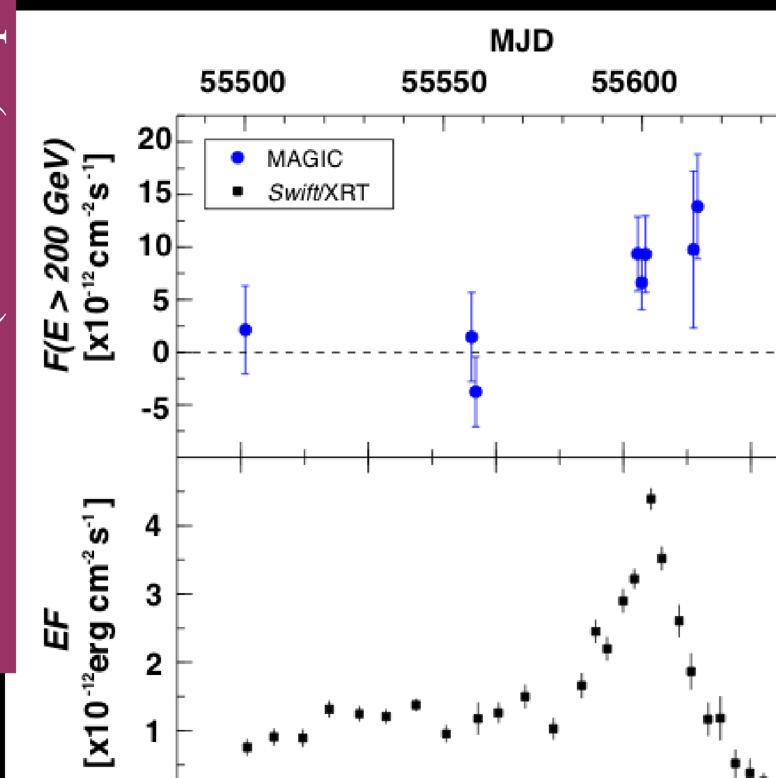
- Observed with MAGIC since 2005
- No spectral variability detected
- Low flux state detected in 2009
- Back to high state in 2011



HESS J0632+057

Aleksic et al. (MAGIC) ApJ 754, 2012

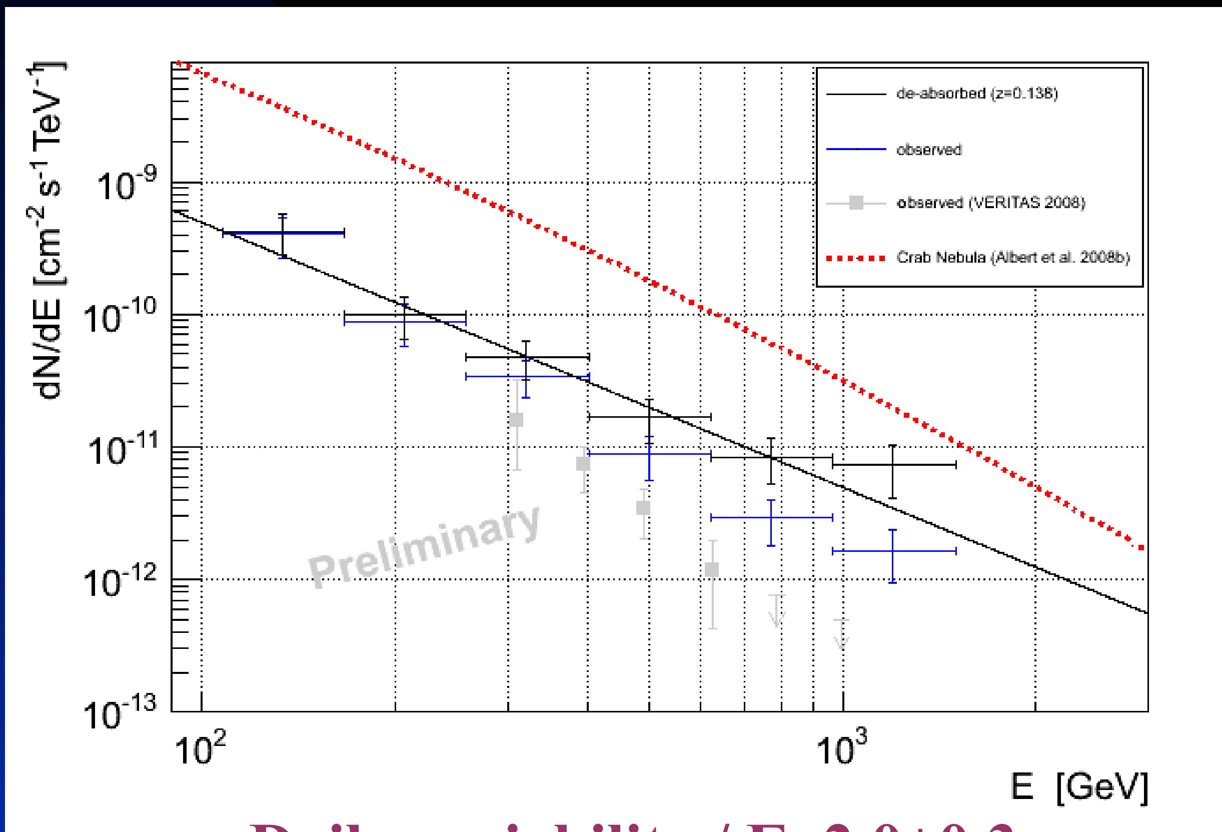
- Monitored with MAGIC since
- February 2011 → 6σ in 5.6 hou
  ~ 4 % C.U.



New MAGIC sources

1ES 0806+524

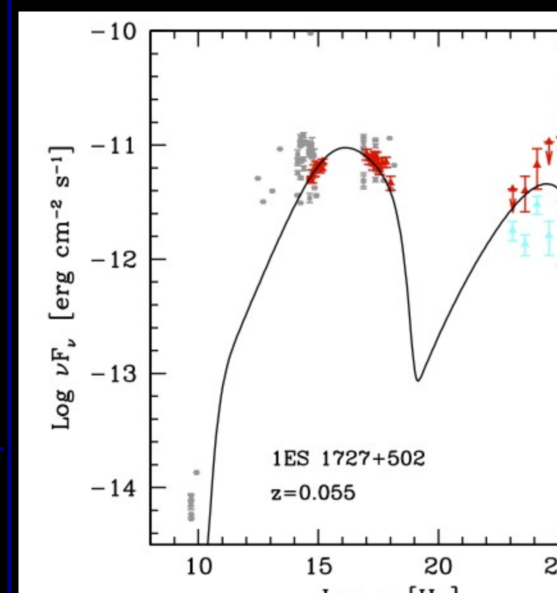
HBL discovered by VERITAS
Observation triggered high optic state (KVA)
16 hours in Feb'11



Daily variability / Γ=2.0±0.3

1ES 1727+502

HBL at z=0.055
13 hours 2011 → 5.5σ
No variability
$\Gamma = 3.2 \pm 0.4$



MS1221.8+2452

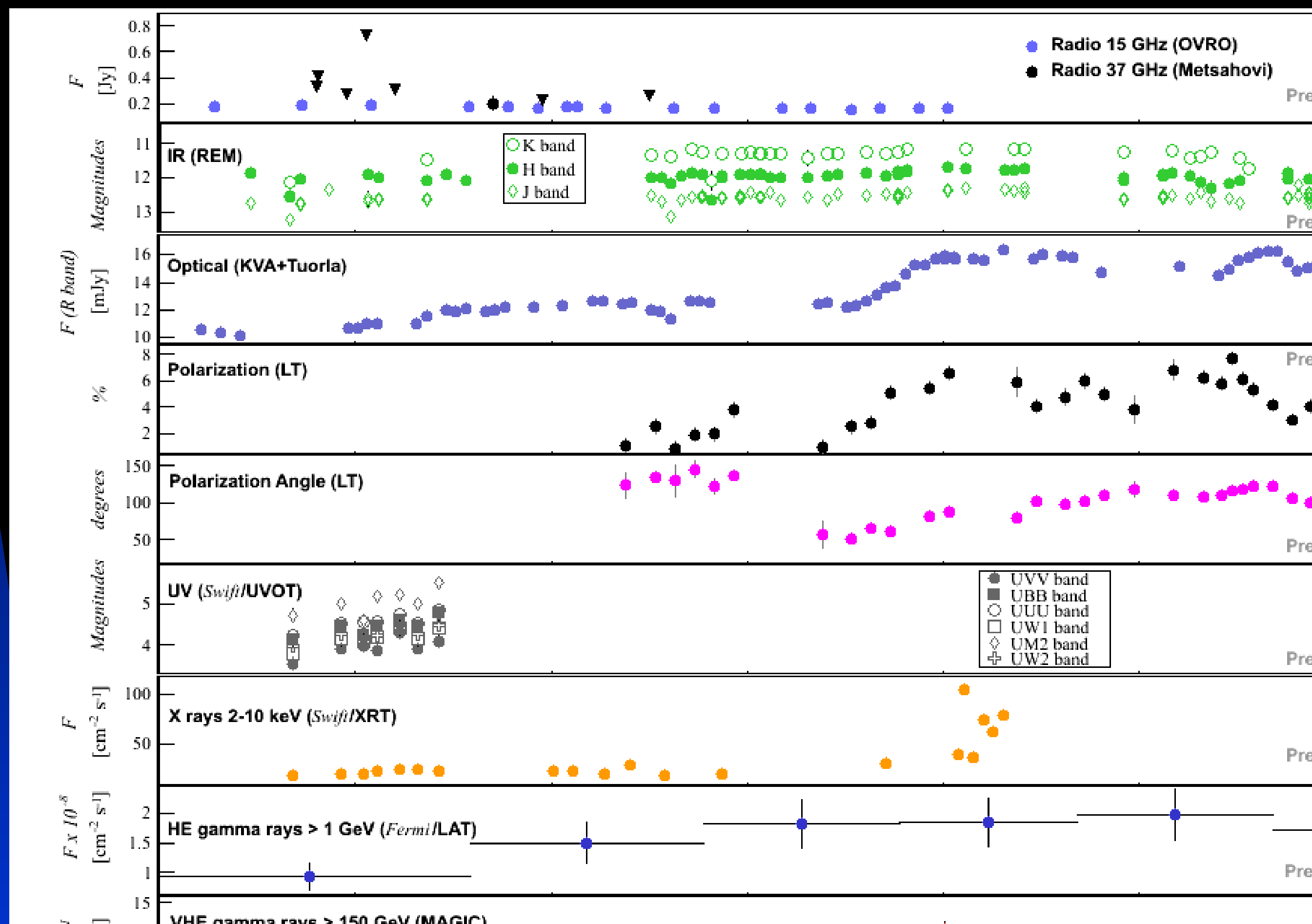
High Synchrotron peaked BL Lac
4 hours 1st of May

Flare of PG 1553 +113

year	Flux (E>150 GeV)[cm^{-2} s^{-1}]
2007	(1.40±0.38)*10^{-11} [2]
2008	(3.70±0.47)*10^{-11} [2]
2009	(1.63±0.45)*10^{-11} [2]
2012 (pre-flare)	(5.03±0.25)*10^{-11}
2012 (flare)	**(9.63±0.37)*10^{-11}**

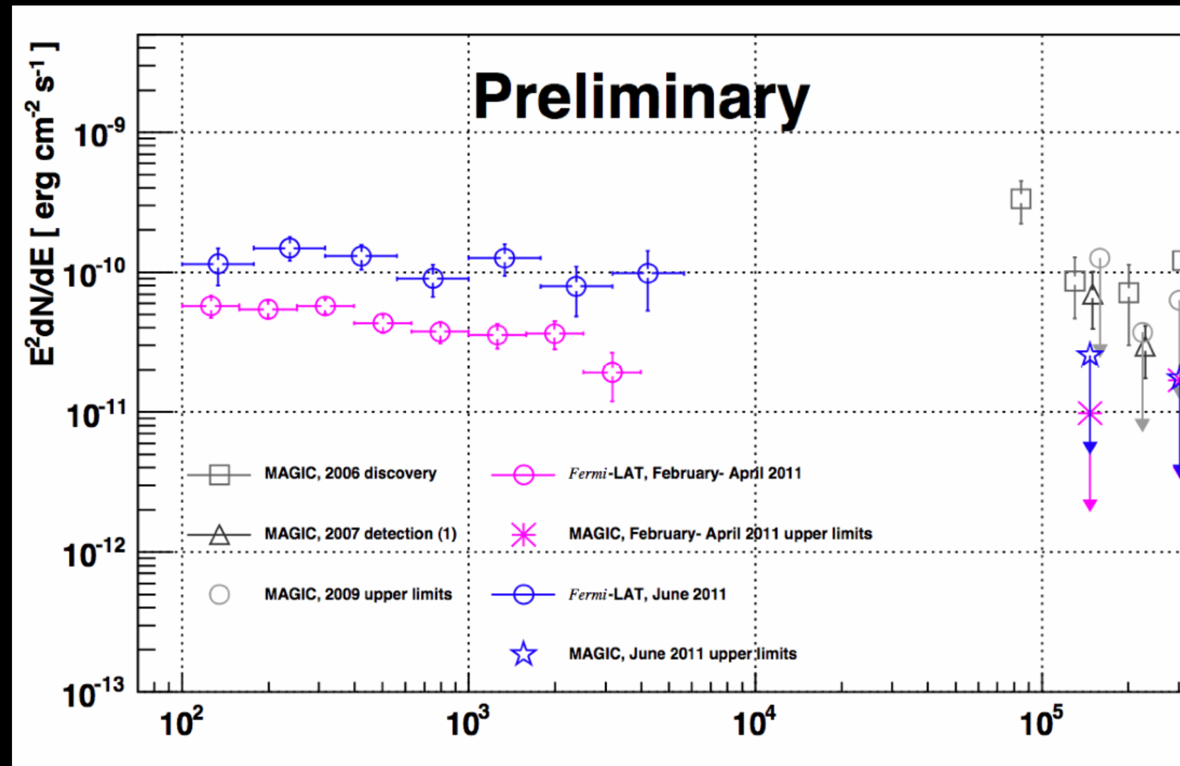
Preliminary

- BL Lac object with unknown redshift
  Estimated ~ 0.4
  (Prandini et al 2011, Danforth et al. 2010)
- First detected in 2005
  (HESS/MAGIC)
- February-May 2012:
  - About 50 σ in 17 hours
  - Strong flare ~1 C.U. at 100 GeV
  - Complete MWL picture



FSRQs

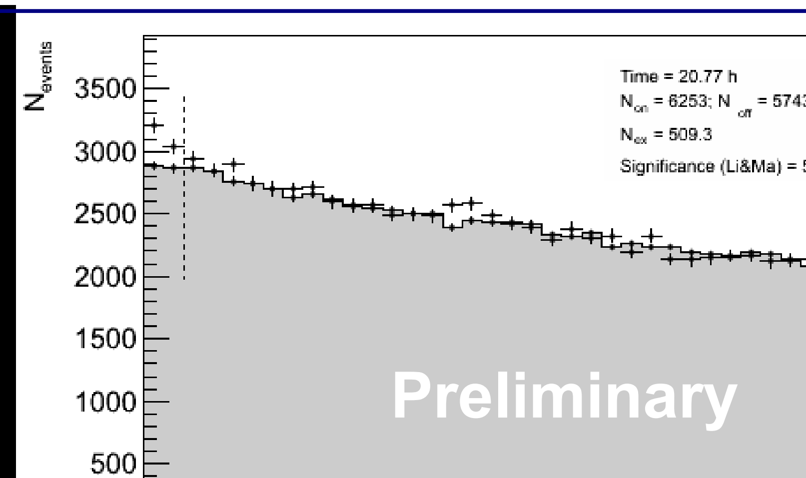
3c 279



- Discovered in VHE by MAGIC in 2006
- Seen again in 2007
- Monitoring and ToO in 2011

Upper limits below previous detections

PKS 1510 -089



- Discovered in VHE by HESS in 2009
- MAGIC observations (Feb-Apr'12) triggered by Fermi/LAT
- 21 hours → 5.7 σ

The end