Astroparticle physics with VHE gamma rays

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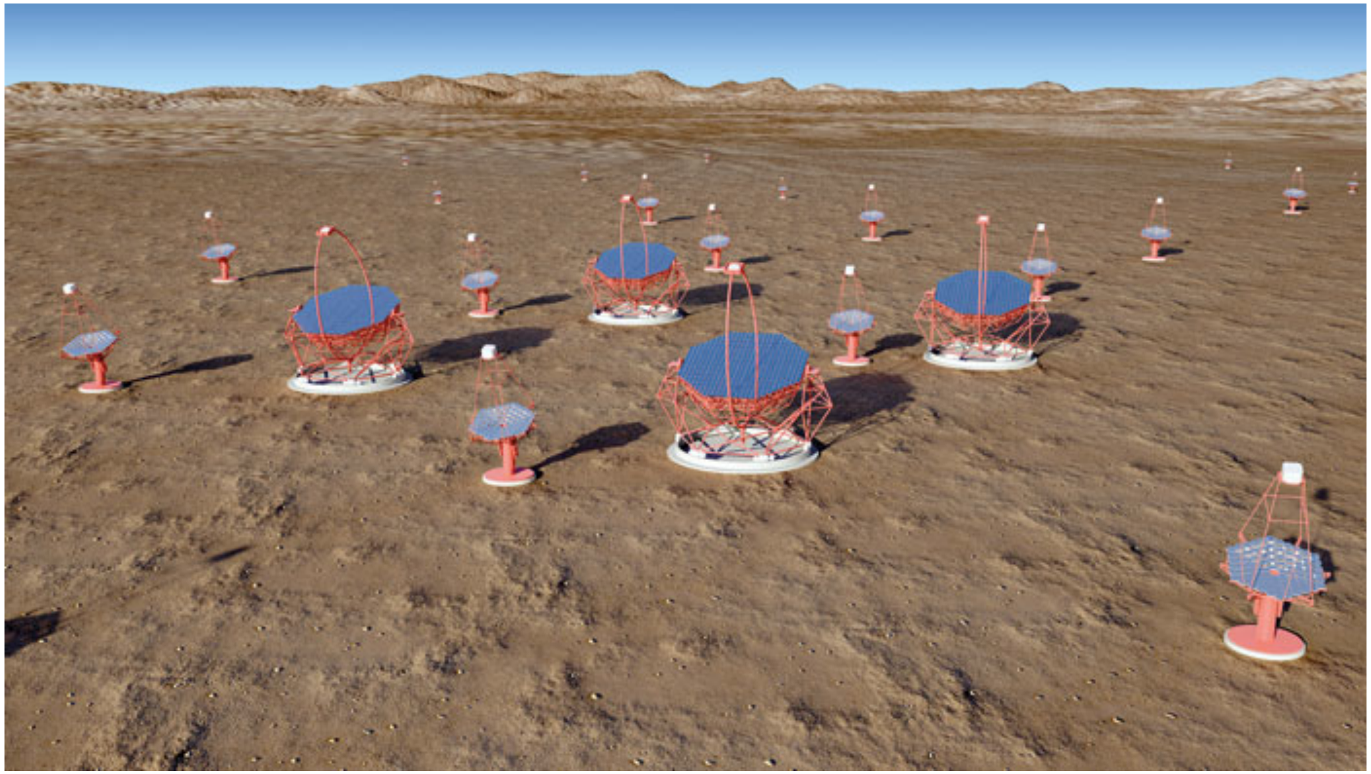
- VHE gamma rays: introduction; detection techniques
- Physics: answers and questions from present detectors
- The need for a new large project: the Cherenkov Telescope Array CTA

Belgirate, July 2014



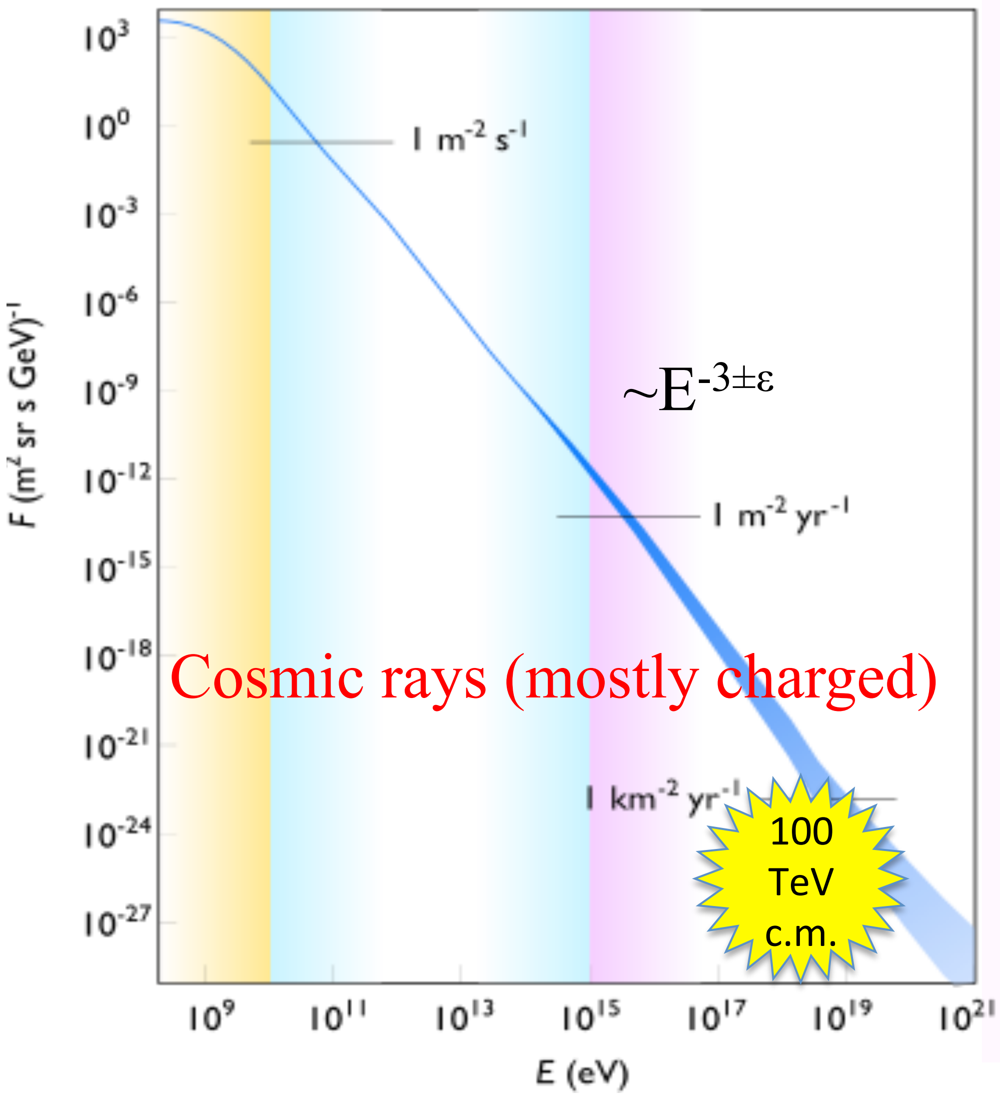
1953: the Cosmic Ray conference in Bagneres de Bigorre

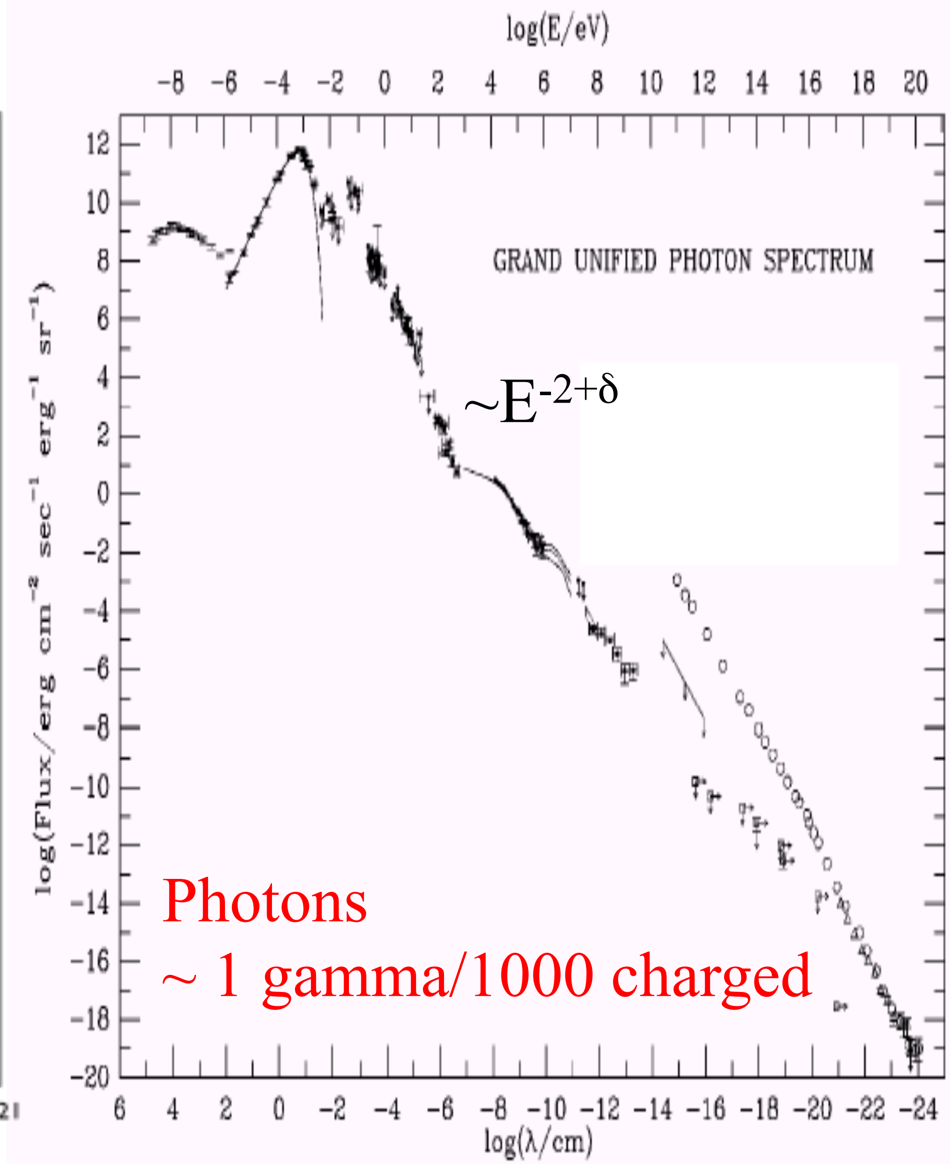
From the conclusions
(Leprince-Ringuet):

"What is the future of cosmic rays? Should we continue to struggle for a few new results or would it be better to turn to the machines?

One can no doubt say that that the future of cosmic radiation in the domain of nuclear physics depends on the machines […]. But probably this point of view should be tempered by the fact that we have the uniqueness of some phenomena for which the energies are much larger."

Very-High Energy gamma rays



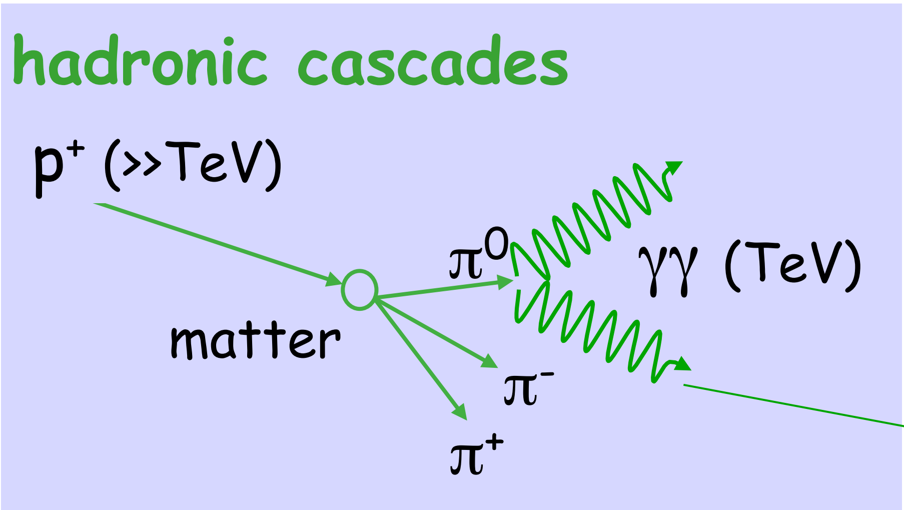


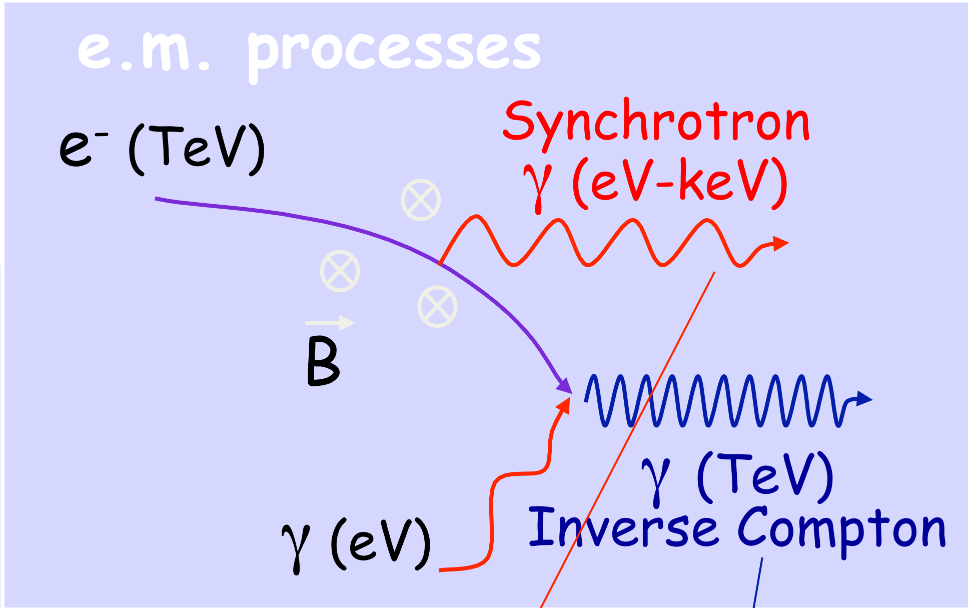
How are VHE (above 30 GeV) gamma rays produced?

- Radiation from accelerated charged particles
  - Interaction with photon fields & clouds
  - Hadronic and leptonic mechanisms at work
    - Hadronic: photons are signatures of hadrons at energies ~10x

- But also (unobserved up to now)
  - Top-down mechanisms
  - New particles? Dark matter?

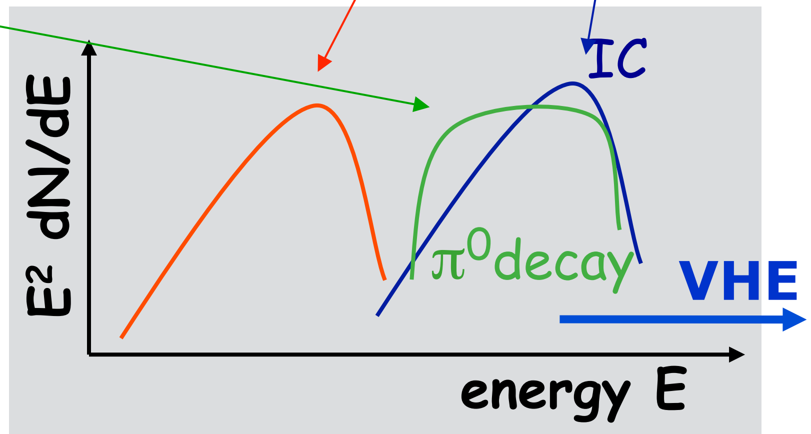
Cosmic γ rays: different production mechanisms expected to be at work





In the VHE region,
$dN/dE \sim E^{-\Gamma}$ (Γ: spectral index)

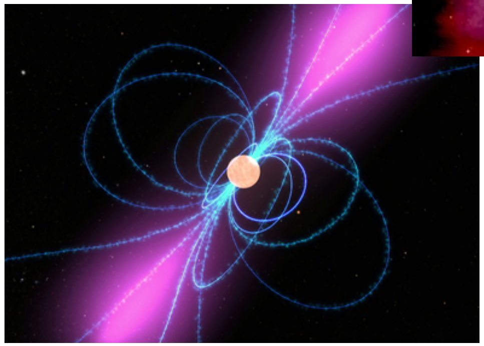
To distinguish between had/leptonic origin study Spectral Energy Distribution (SED):
(differential flux) · E^2



Where are these extreme environments?

In our galaxy

Mostly stellar endproducts:
SNRs, Pulsars

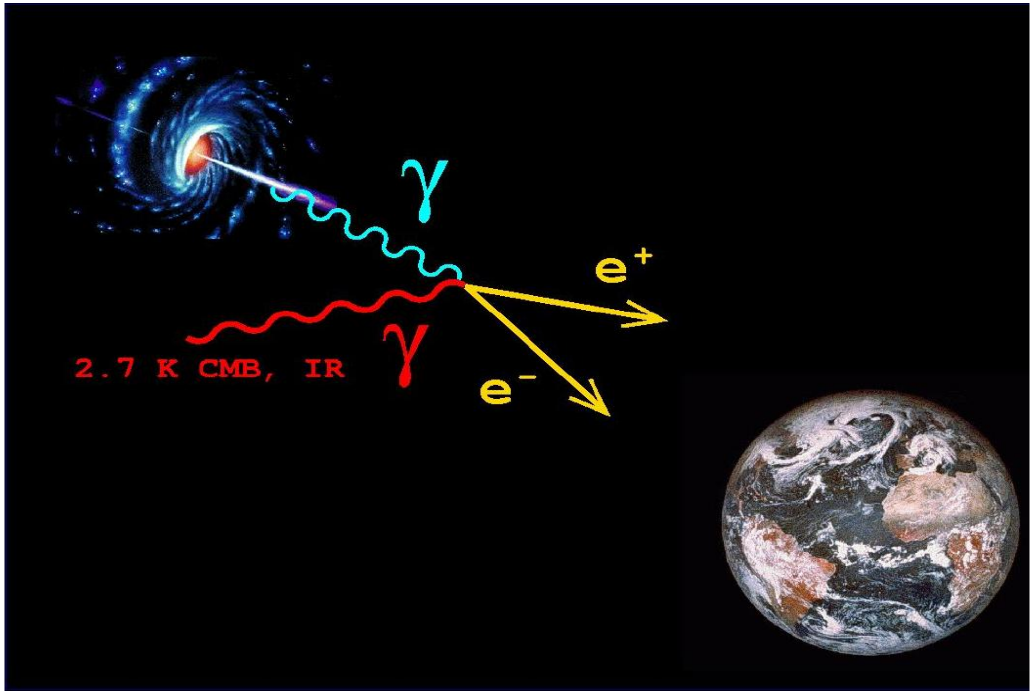


In other galaxies

Active Galactic Nuclei

Gamma-Ray Bursts

How do gamma rays reach us?

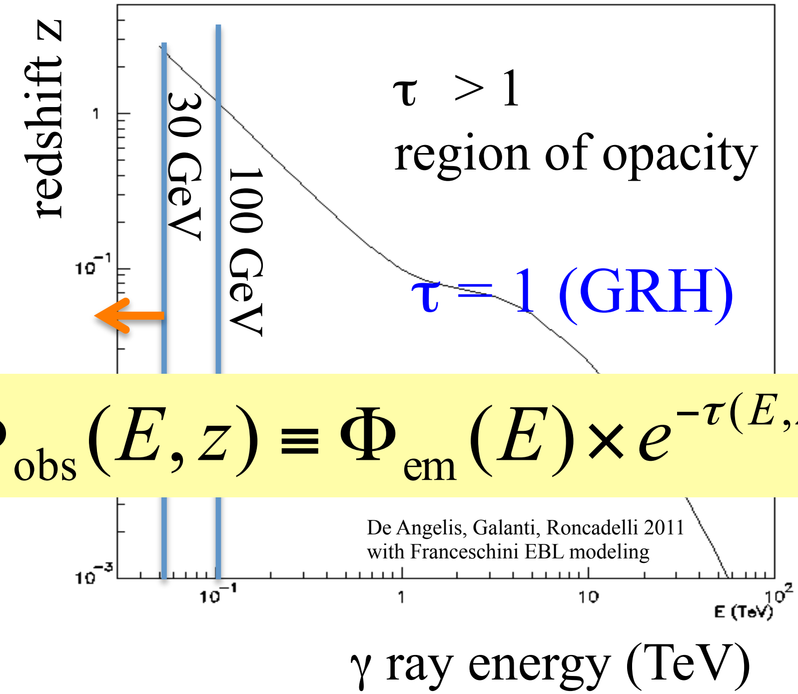


$$\gamma_{VHE}\gamma_{bck} \rightarrow e^+e^-$$

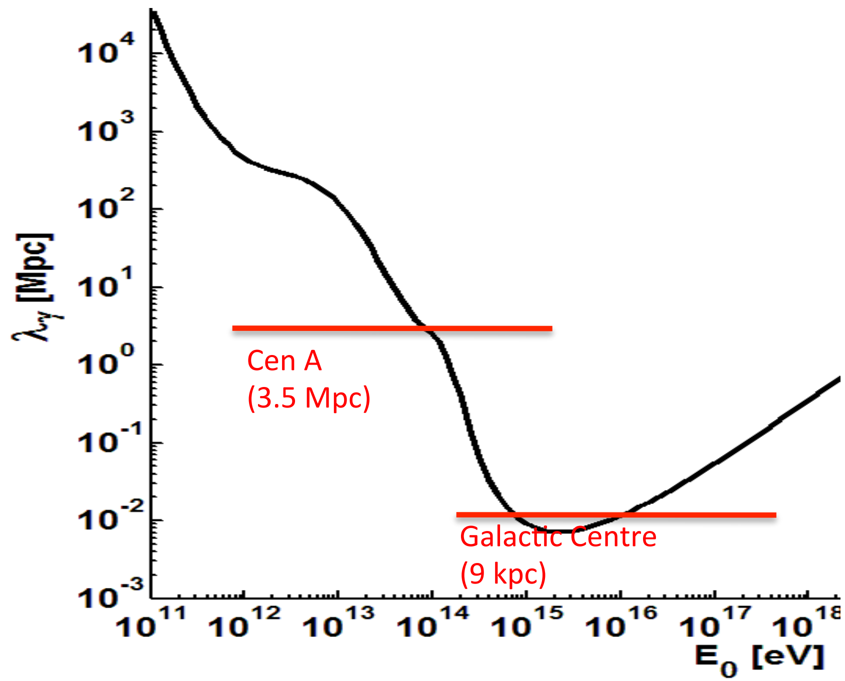
$$\sigma(\beta) \sim 1.25 \cdot 10^{-25}(1-\beta^2) \cdot \left[2\beta(\beta^2-2) + (3-\beta^4)\ln\left(\frac{1+\beta}{1-\beta}\right)\right] \mathrm{cm}^2$$

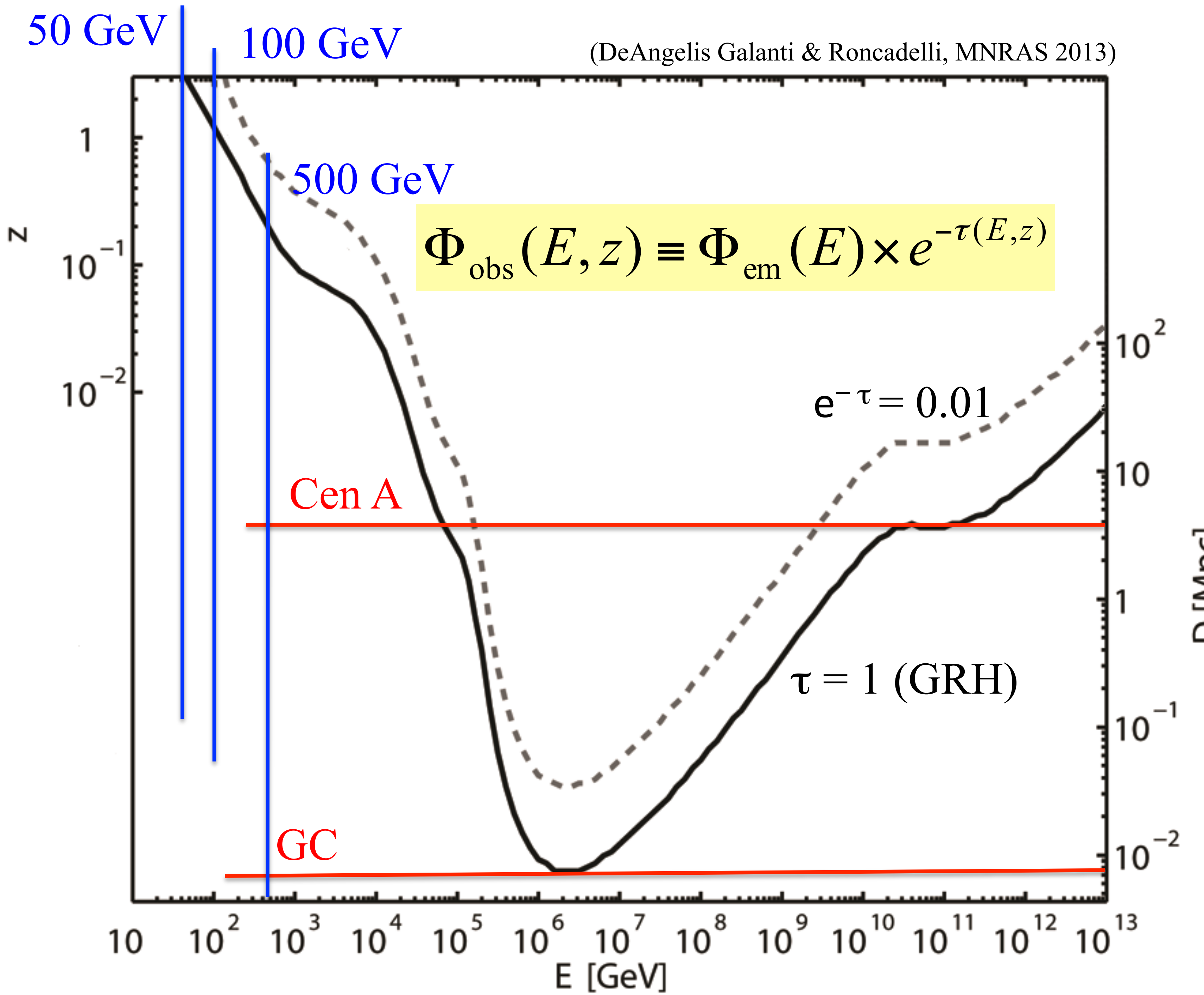
Max for: $\epsilon \simeq \frac{2m_e^2c^4}{E} \simeq \left(\frac{500\ \mathrm{GeV}}{E}\right)\mathrm{eV}$

7



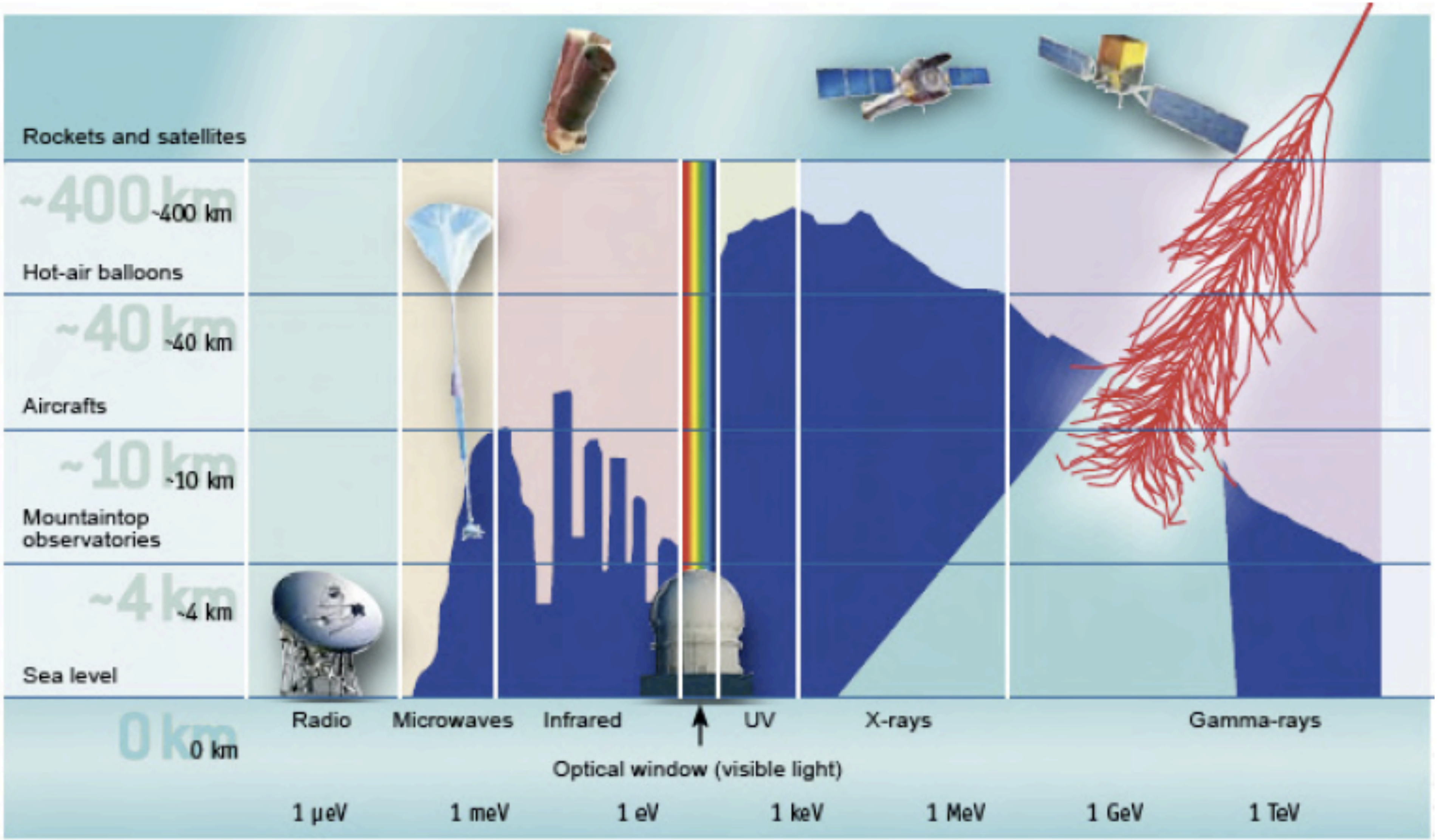
$$\Phi_{obs}(E,z) \equiv \Phi_{em}(E) \times e^{-\tau(E,z)}$$





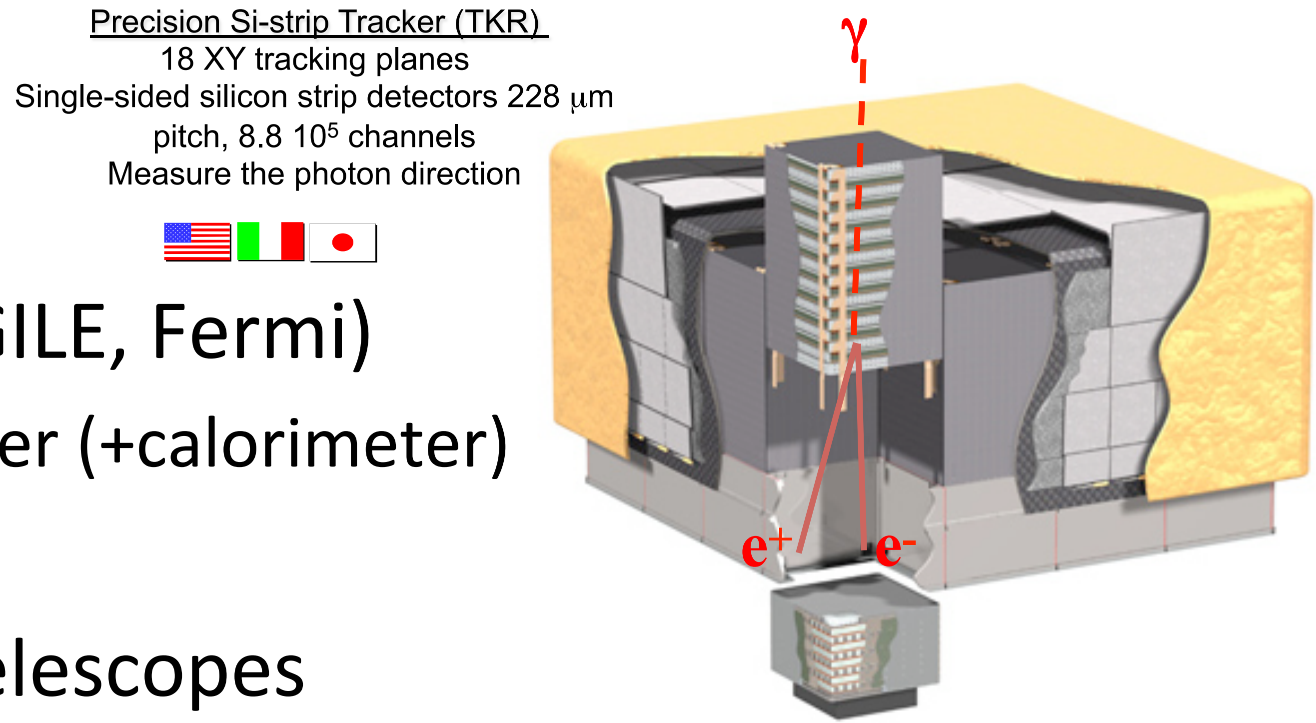
50 GeV
100 GeV
500 GeV
(DeAngelis Galanti & Roncadelli, MNRAS 2013)
$\Phi_{obs}(E,z) \equiv \Phi_{em}(E) \times e^{-\tau(E,z)}$
$e^{-\tau} = 0.01$
Cen A
$\tau = 1$ (GRH)
GC
z
1
10^{-1}
10^{-2}
D [Mpc]
10^{2}
10
1
10^{-1}
10^{-2}
10 10^{2} 10^{3} 10^{4} 10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12} 10^{13}
E [GeV]

Gamma rays interact with the atmosphere

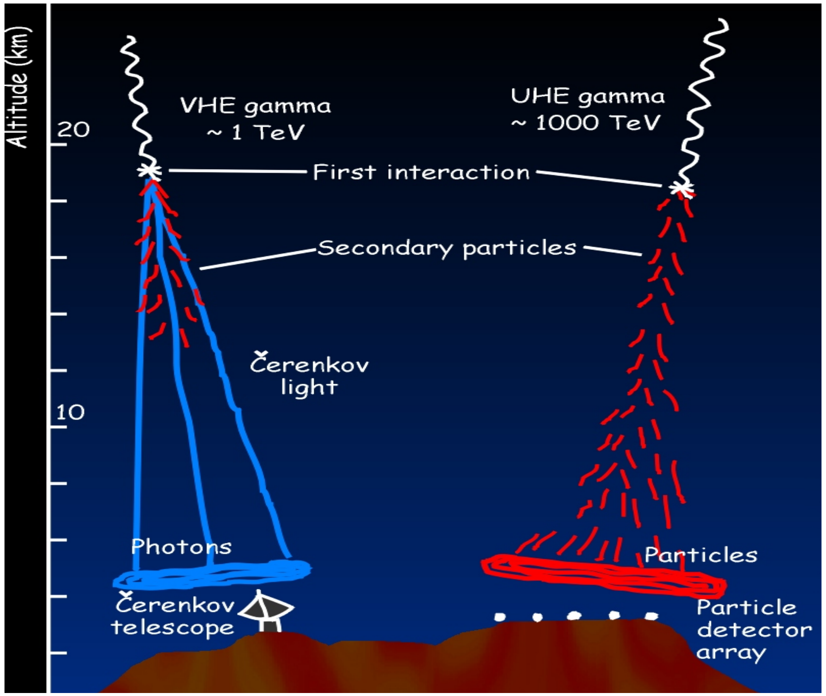


=> GeV (HE) detection requires satellites; TeV (VHE) can be done at ground

Detectors

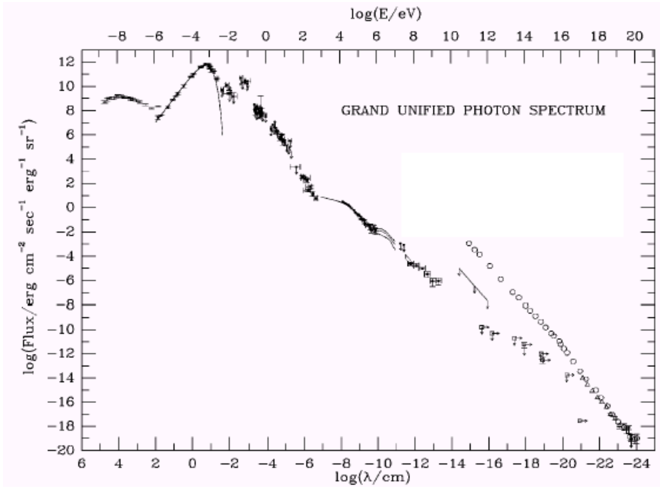


- Satellites (AGILE, Fermi)
  - Silicon tracker (+calorimeter)
- Cherenkov telescopes (HESS, MAGIC, VERITAS)
- Extensive Air Shower det. (ARGO): RPC, scintillators

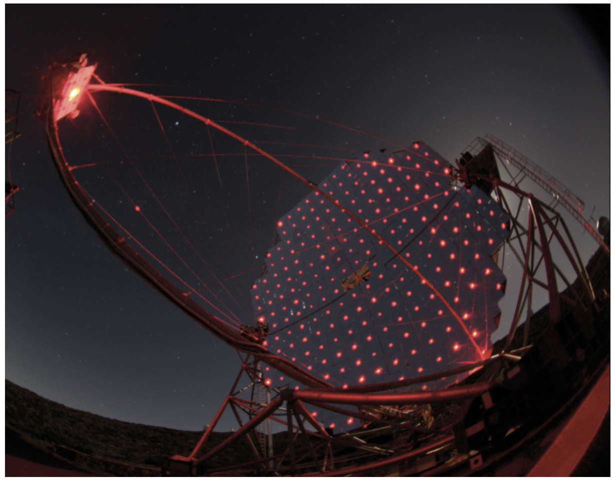


HEP detectors!

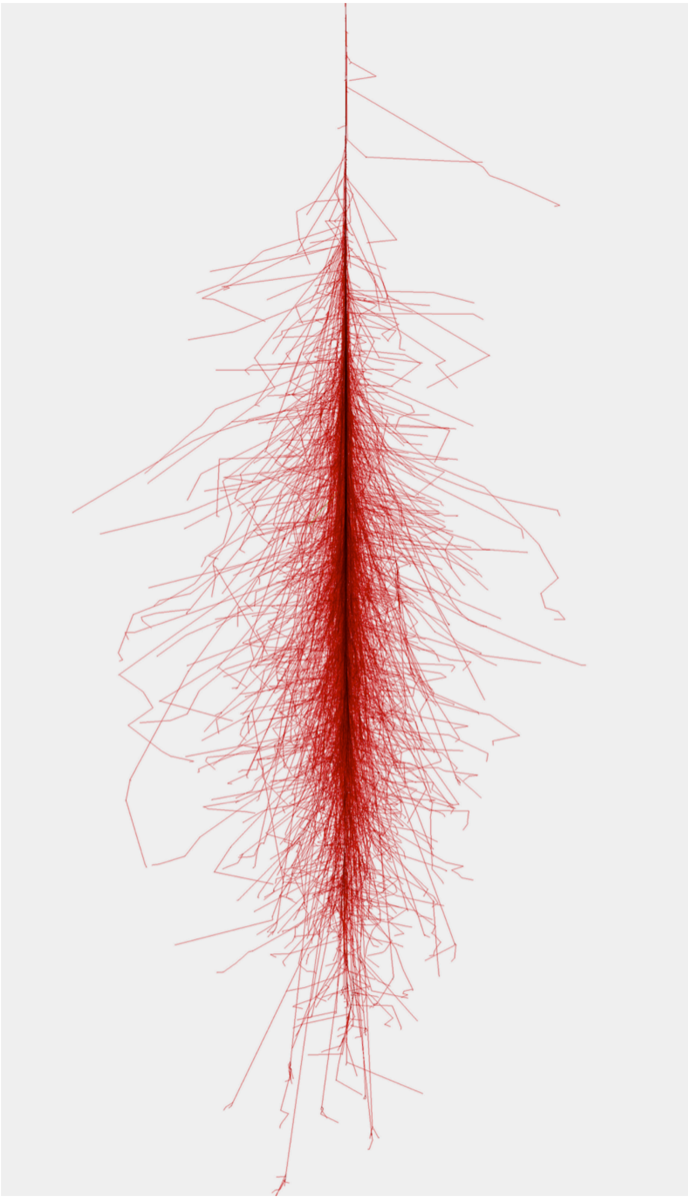
Why detection at ground?

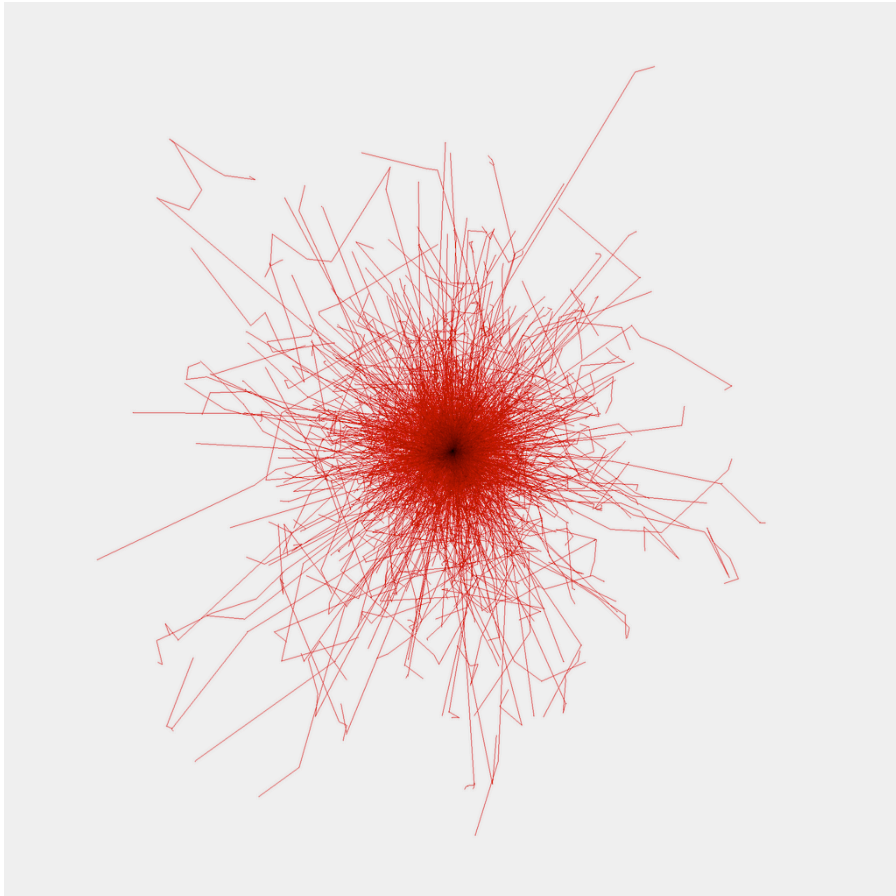


- High energies
  - Only way to build sensitive >TeV instruments
  - Maximum flux < 1 photon/h/m^2 above 200 GeV
- High statistics /short timescales
  - Large collection areas O(km^2)
- Precision (Cherenkov telescopes)
  - Superior angular resolution
- Limitations?
  - IACTs
    - Smaller duty cycle
    - Smaller field of view
  - EAS ground particle detectors
    - Modest resolution and background rejection power
  - Complementary approaches

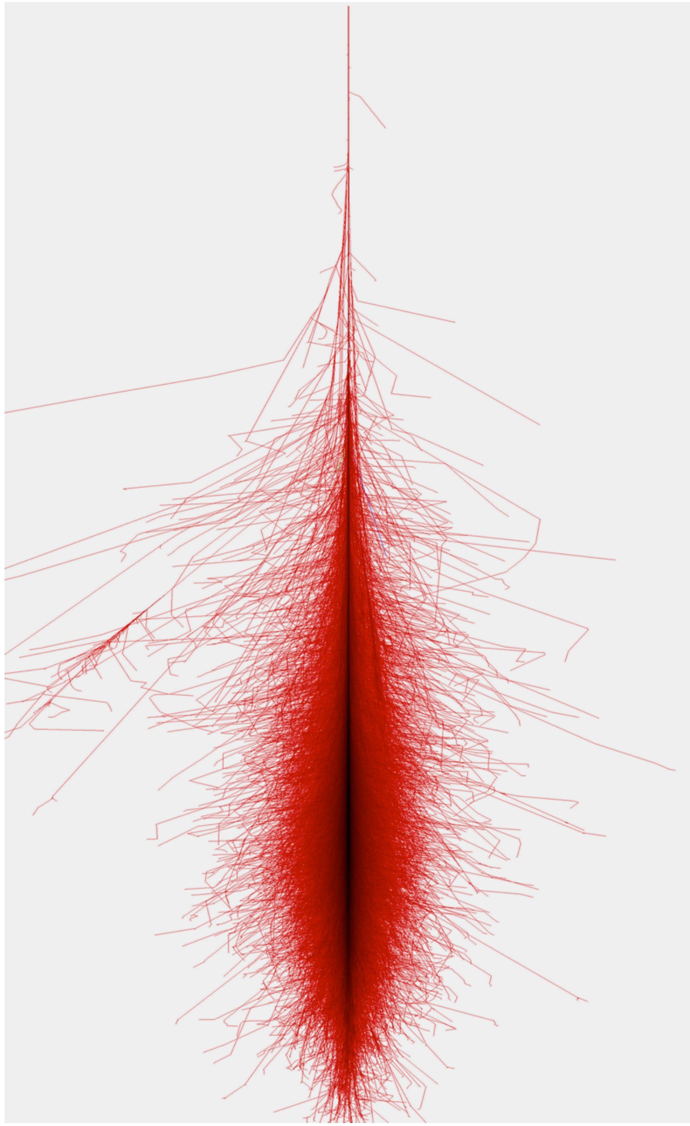


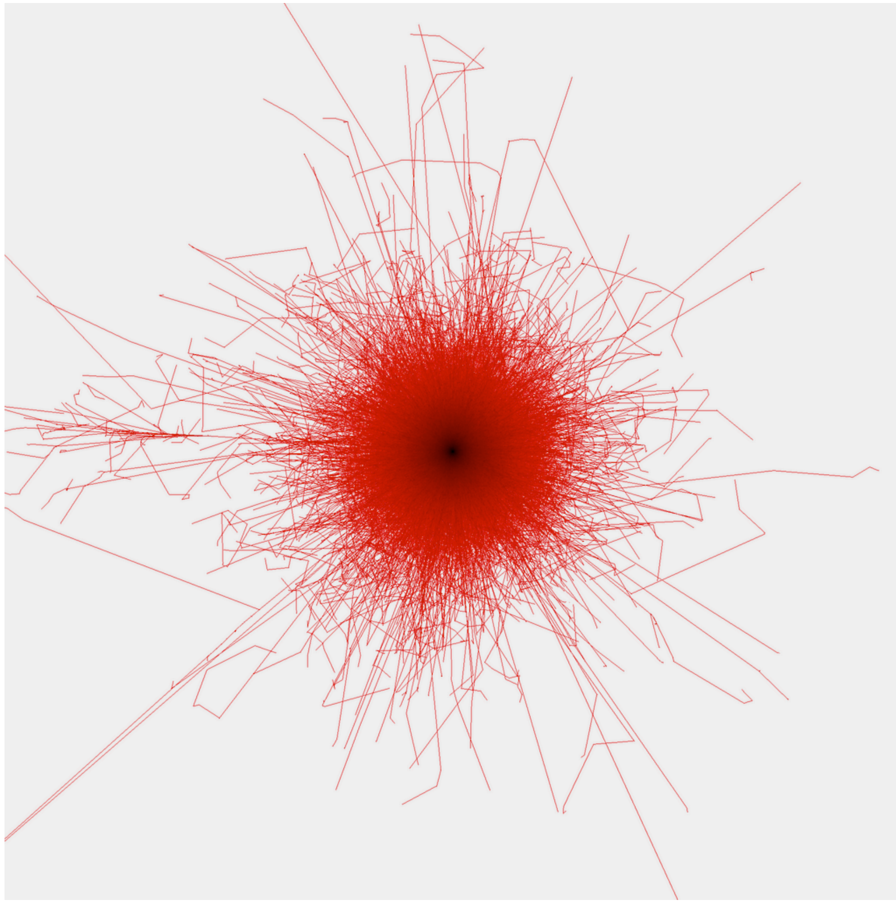
Simulated gamma
in the atmosphere:
50 GeV



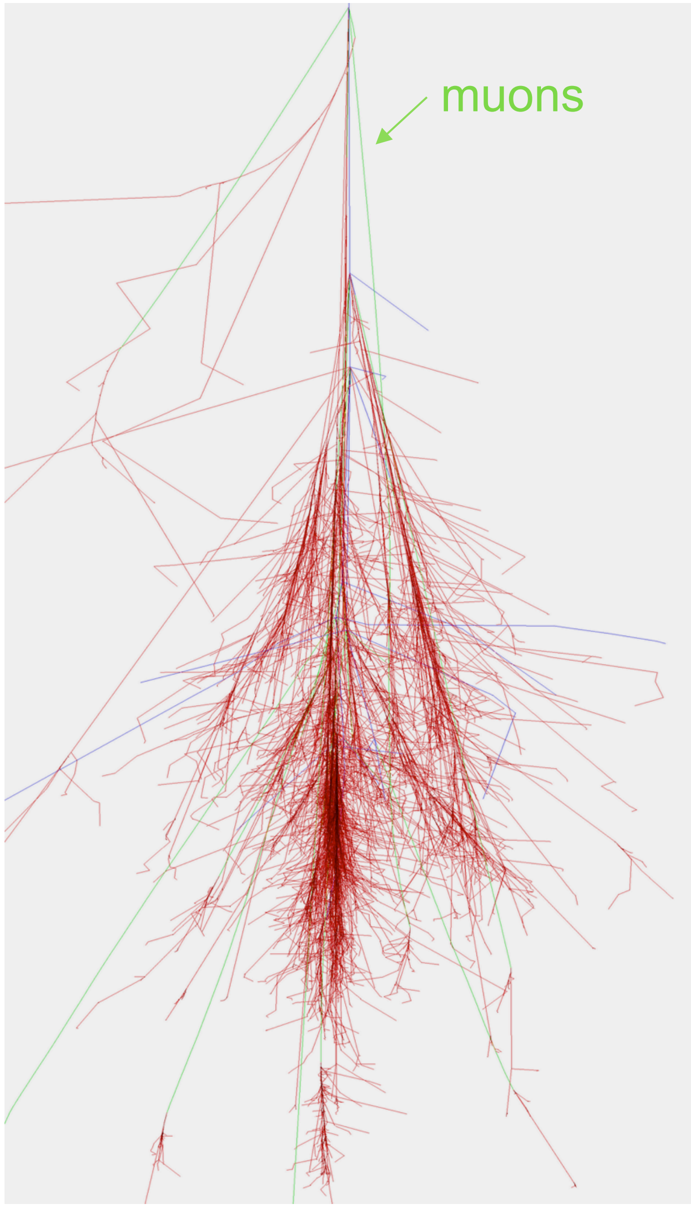


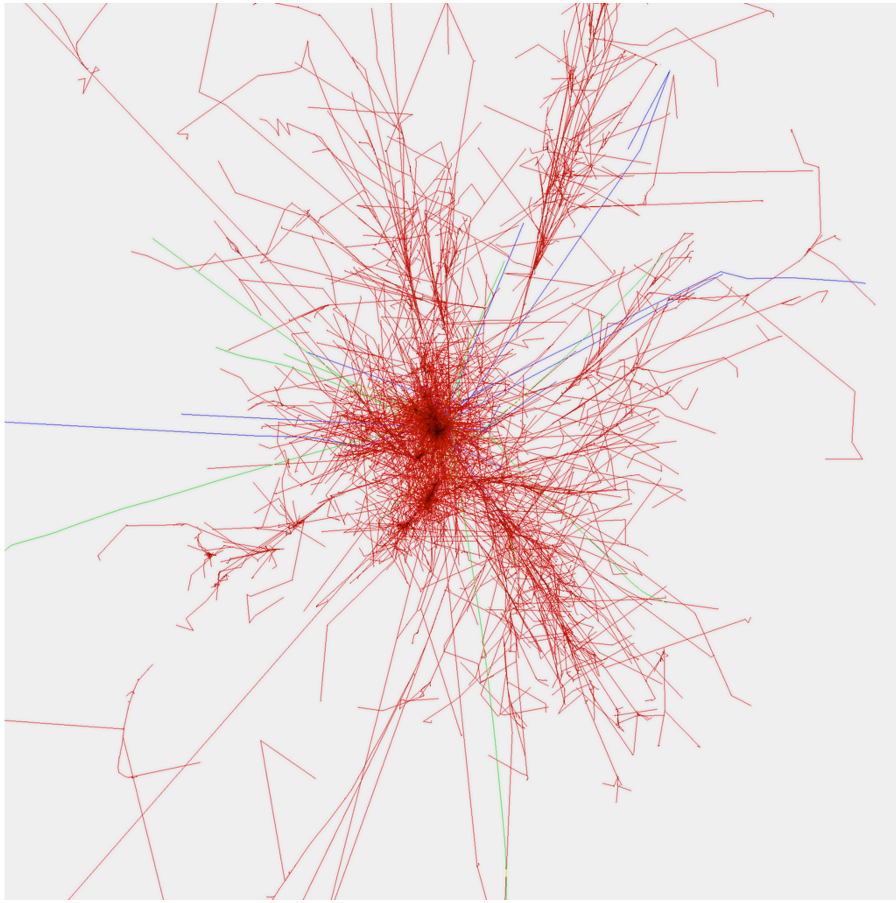
Simulated gamma
1 TeV

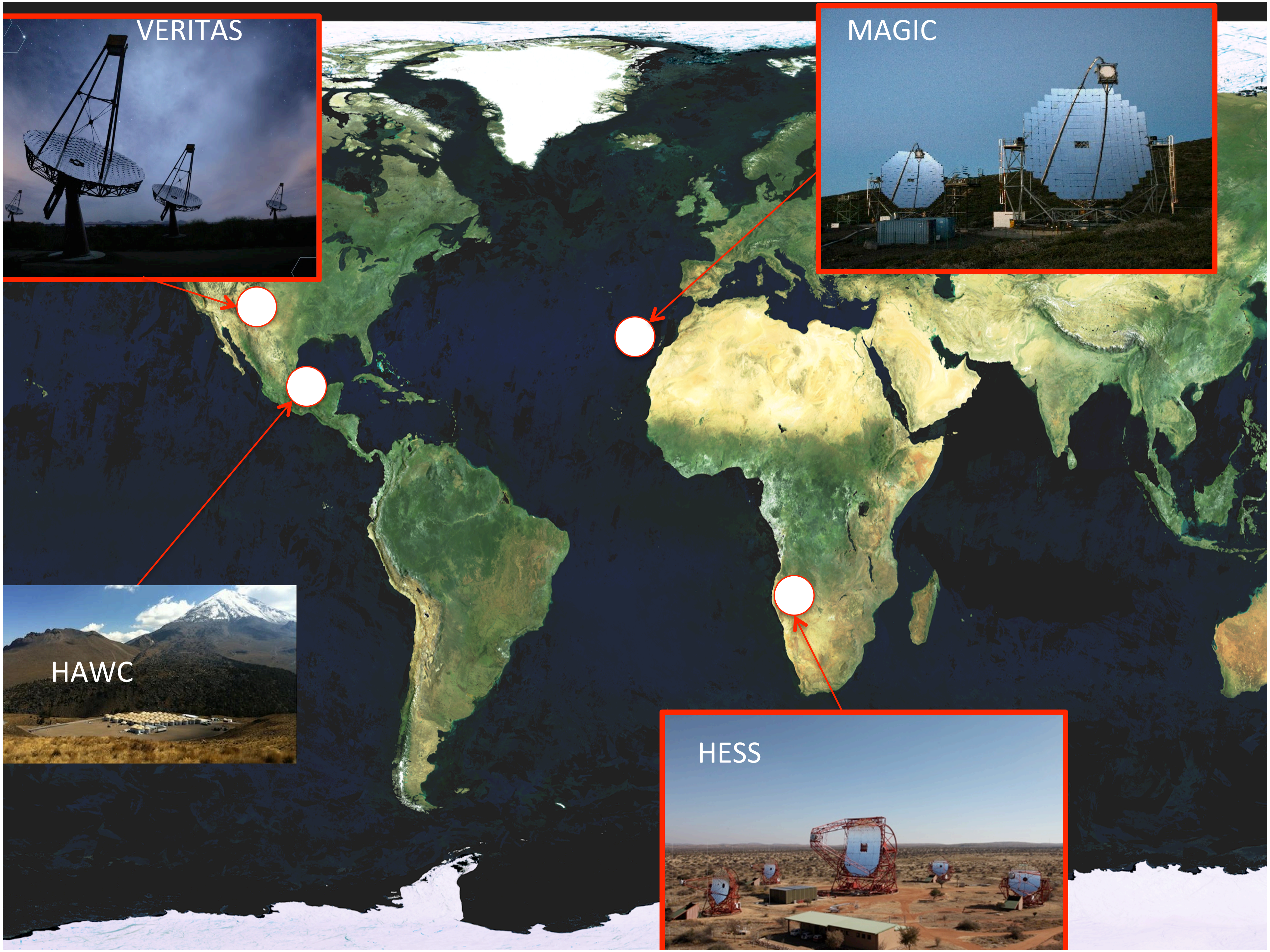




Simulated proton
100 GeV (the ennemy)

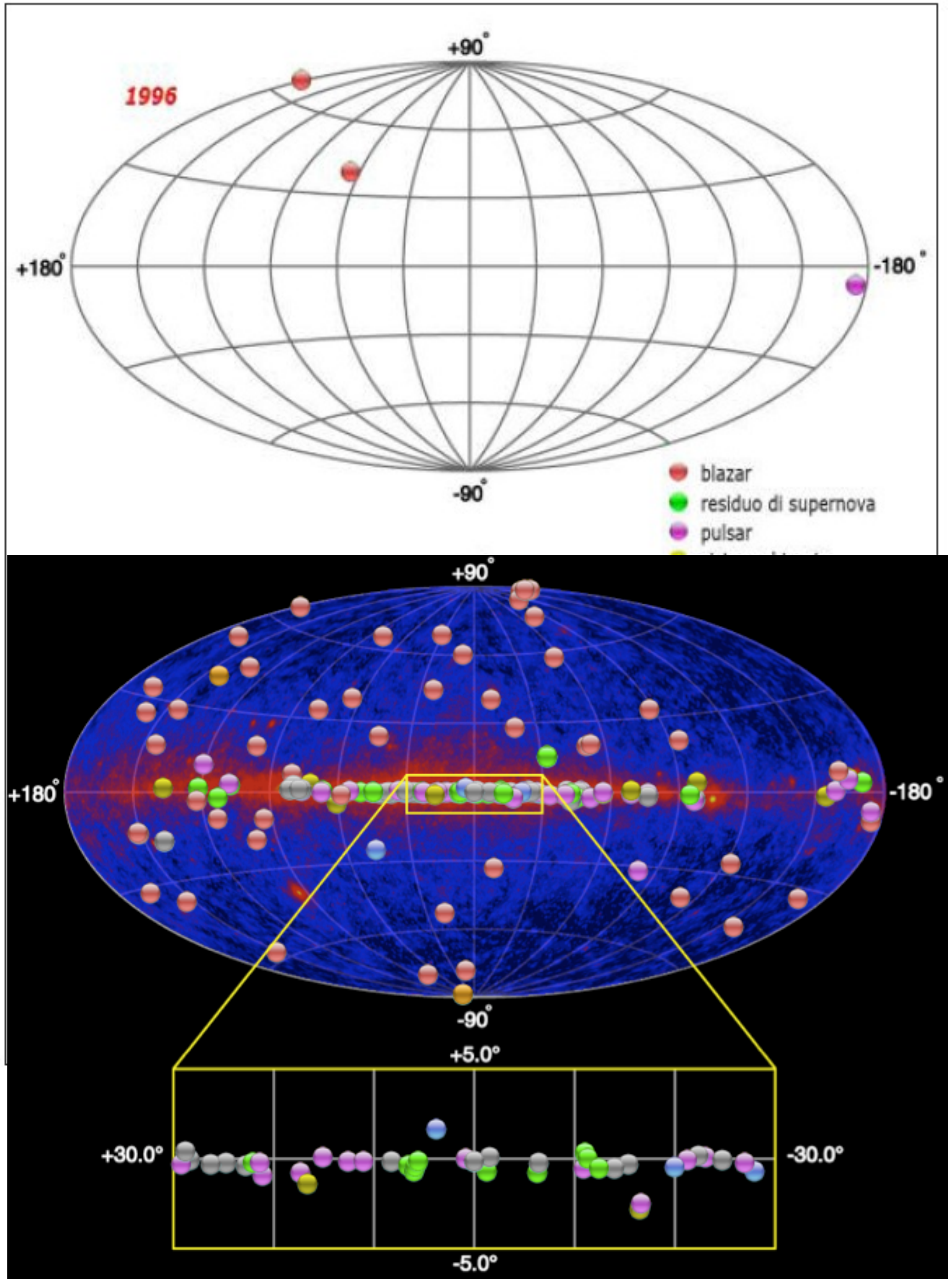





VERITAS
MAGIC
HAWC
HESS

Highlight in γ-ray astrophysics (mostly HESS, MAGIC, VERITAS)

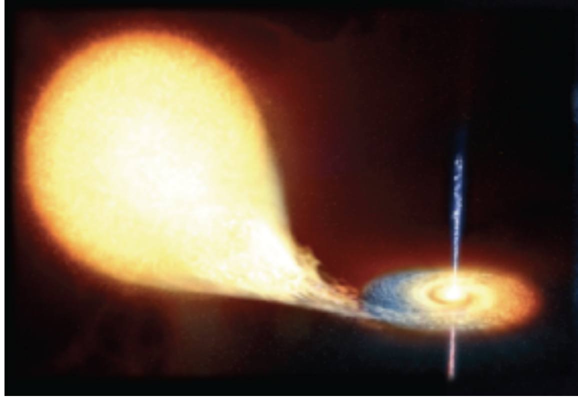
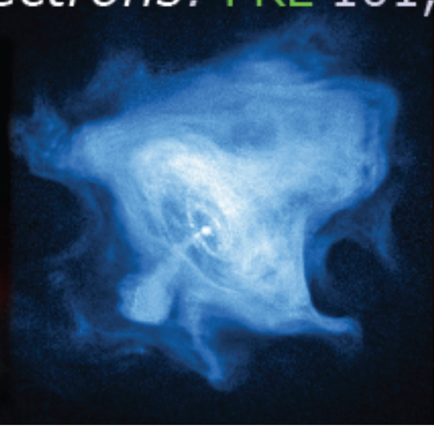
- Thanks mostly to Cherenkov telescopes, imaging of VHE (> 30 GeV) galactic sources and discovery of many new galactic and extragalactic sources: ~ 200 (and >200 papers) in the last 9 years
  - And also a better knowledge of the diffuse gammas and electrons
- A comparable success in HE (the Fermi realm); a 10x increase in the number of sources
- A new tool for cosmic-ray physics and fundamental physics

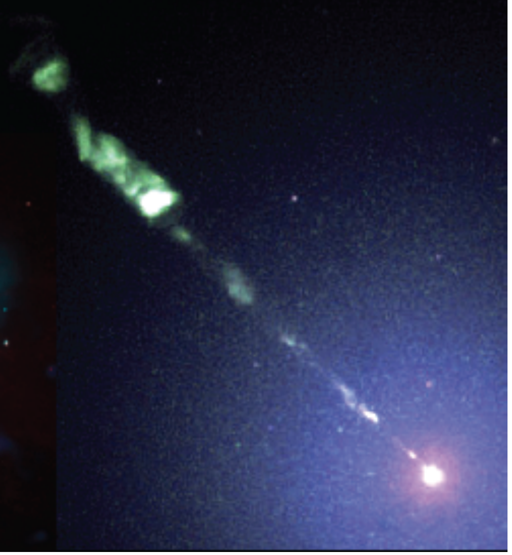


TeV Impact

Highlights from **HESS, MAGIC, VERITAS & MILAGRO**

- *Microquasars:* Science 309, 746 (2005), Science 312, 1771 (2006)
- *Pulsars:* Science 322, 1221 (2008), Science 334, 69 (2011)
- *Supernova Remnants:* Nature 432, 75 (2004)
- *The Galactic Centre:* Nature 439, 695 (2006)
- *Surveys:* Science 307, 1839 (2005), PRL 95, 251103 (2005)
- *Starbursts:* Nature 462, 770 (2009), Science 326,1080 (2009)
- *AGN:* Science 314,1424 (2006), Science 325, 444 (2009)
- *EBL:* Nature 440, 1018 (2006), Science 320, 752 (2008)
- *Dark Matter:* PRL 96, 221102 (2006), PRL 106, 161301 (2011)
- *Lorentz Invariance:* PRL 101, 170402 (2008)
- *Cosmic Ray Electrons:* PRL 101, 261104 (2009)

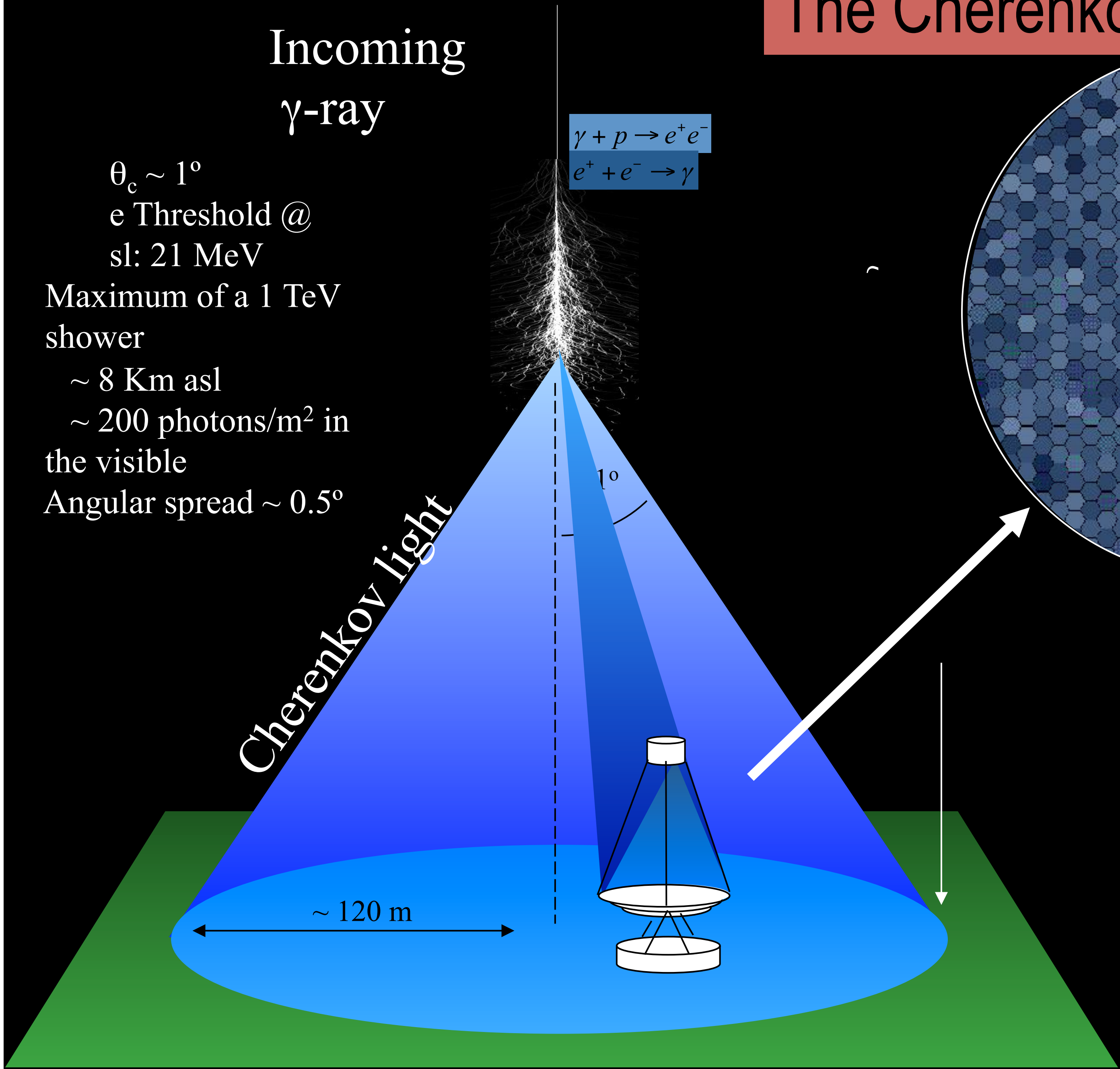





The Cherenkov technique

Incoming
γ-ray

$\theta_c \sim 1^o$
e Threshold @
sl: 21 MeV
Maximum of a 1 TeV shower
~ 8 Km asl
~ 200 photons/m^2 in the visible
Angular spread ~ 0.5º



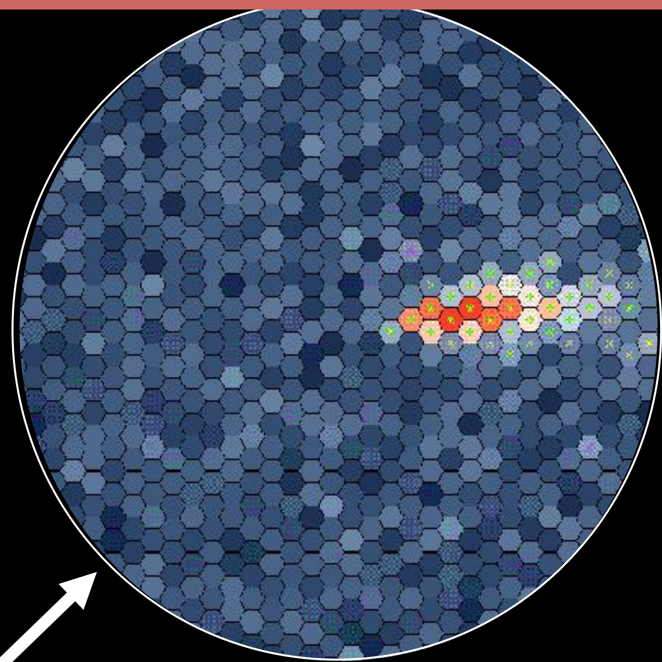


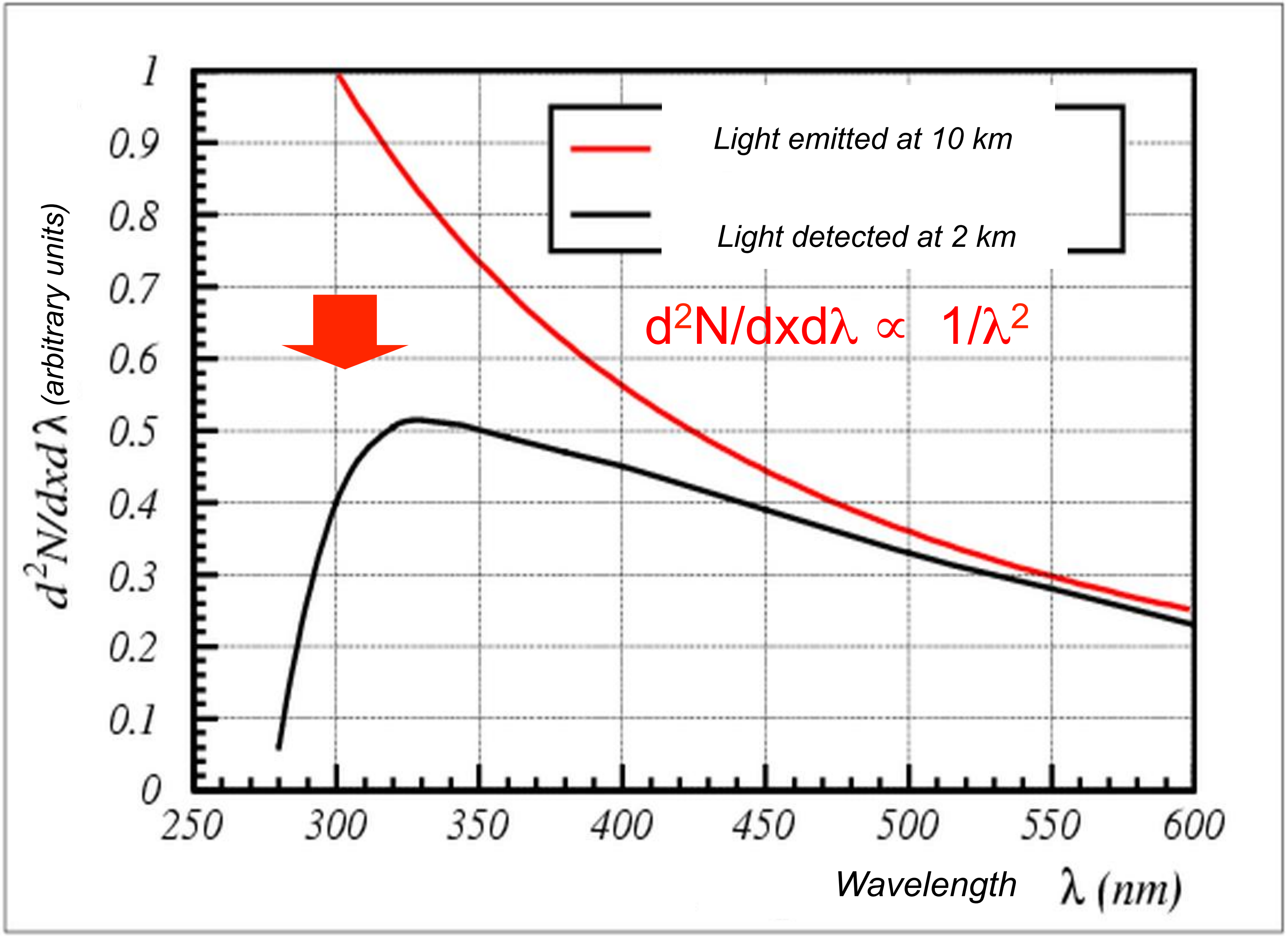
Image intensity
➔ Shower energy

Image orientation
➔ Shower direction

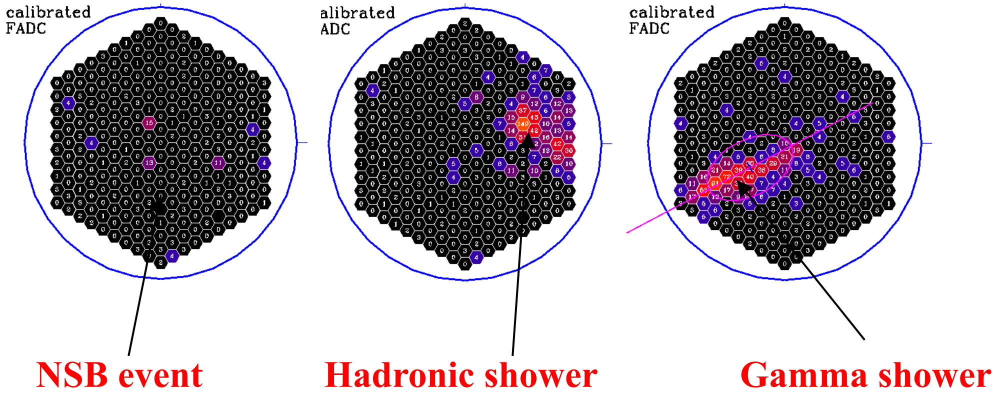
Image shape
➔ Primary particle

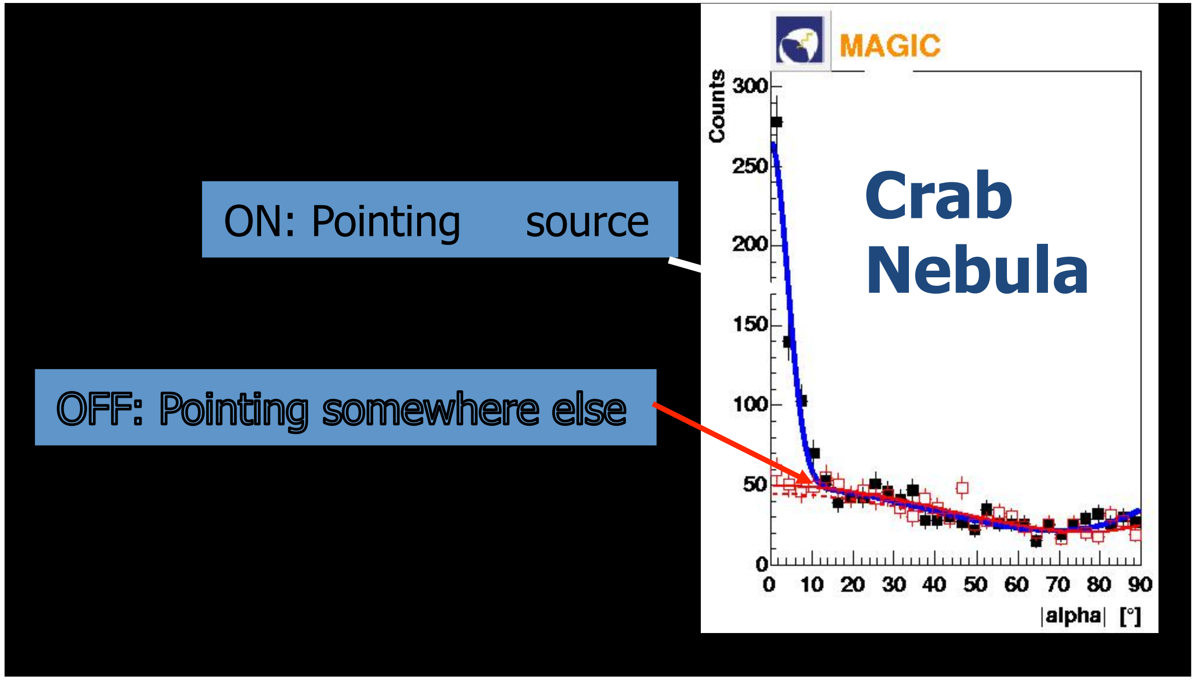
Signal duration: ~ 3ns

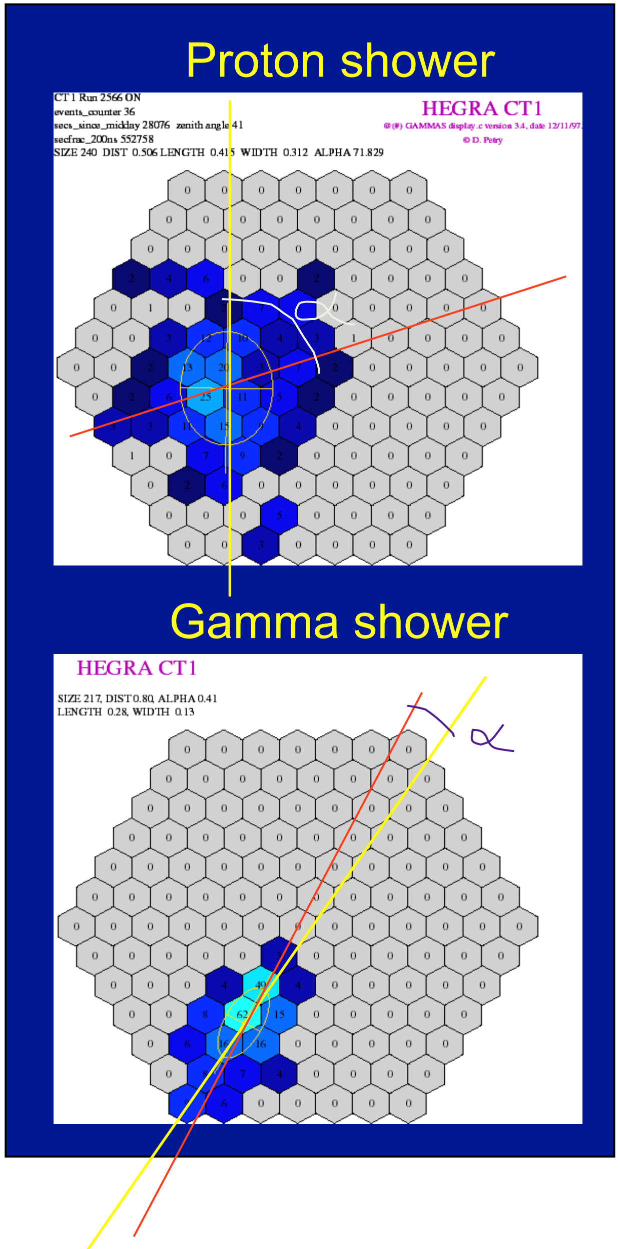
Wavelength spectrum of atmospheric Cherenkov light

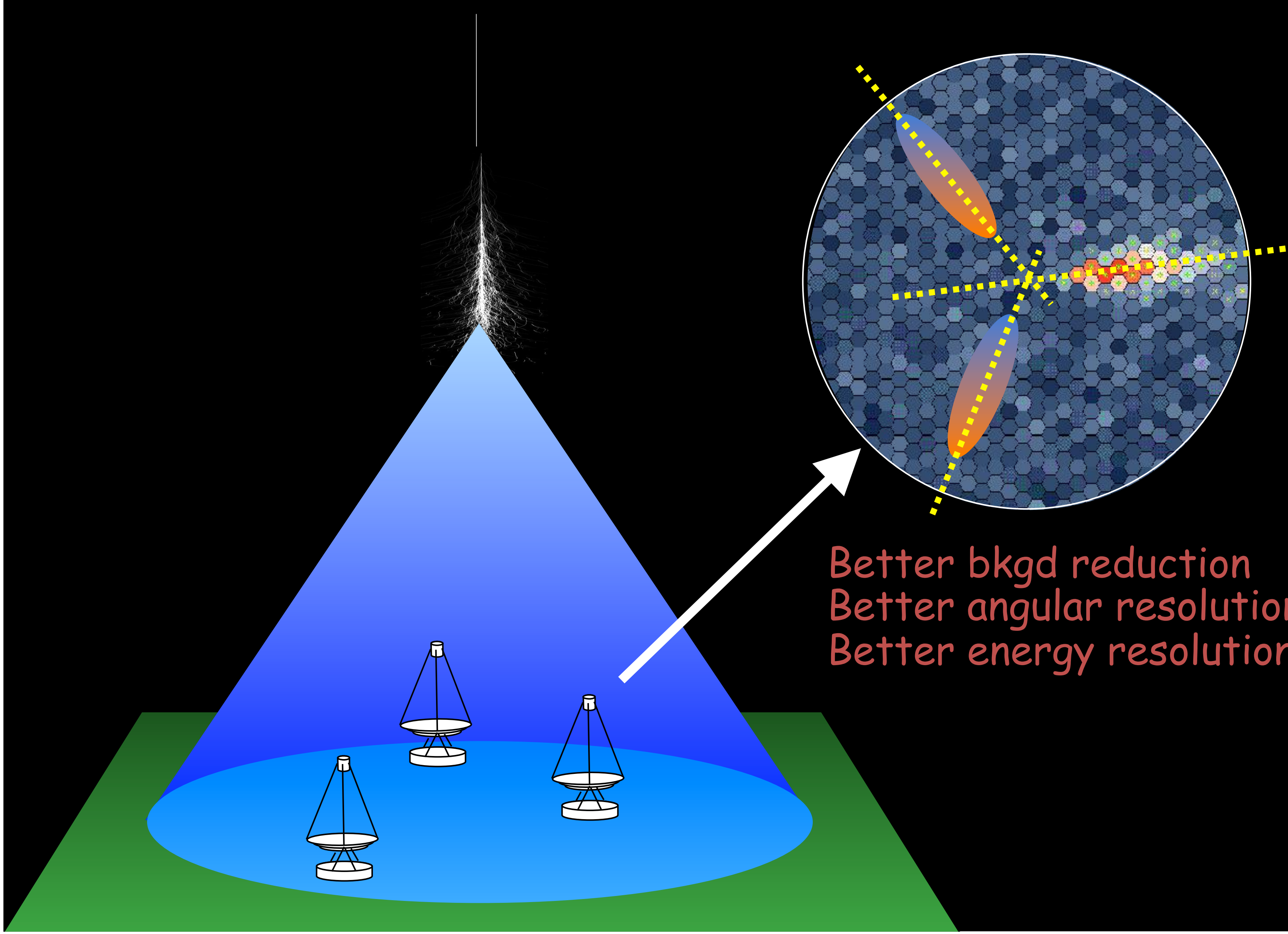


γ/h Separation









Better bkgd reduction
Better angular resolution
Better energy resolution

Instr.	Tels. #	Tel. A (m^2)	FoV (°)	Tot A (m^2)	Thresh. (TeV)	PSF (°)	Sens. (%Crab)
H.E.S.S.	4	107	5	428	0.1	0.06	0.7
MAGIC	2	236	3.5	472	0.05(0.03)	0.06	0.8
VERITAS	4	106	4	424	0.1	0.07	0.7

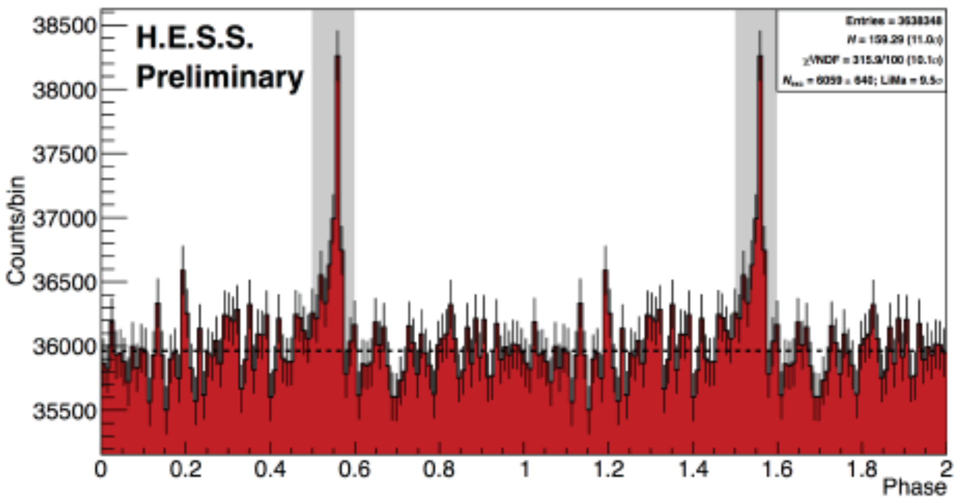

HESS
HESS-1: 4×12m tels
HESS-2: +28m tel.
Completed mid-2012

Why large telescopes?

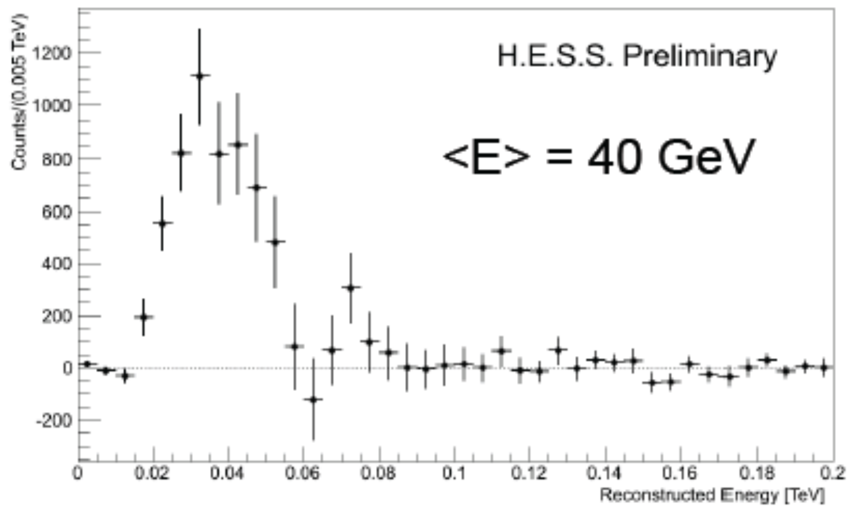
- The threshold is

$$E_{threshold} \propto \sqrt{\frac{\phi \Omega \tau}{\epsilon A}}$$

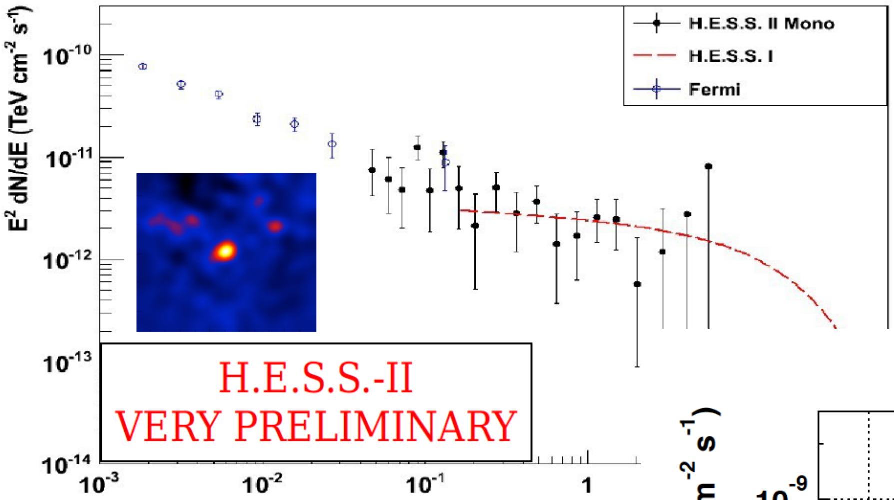
The Vela pulsar seen with CT5

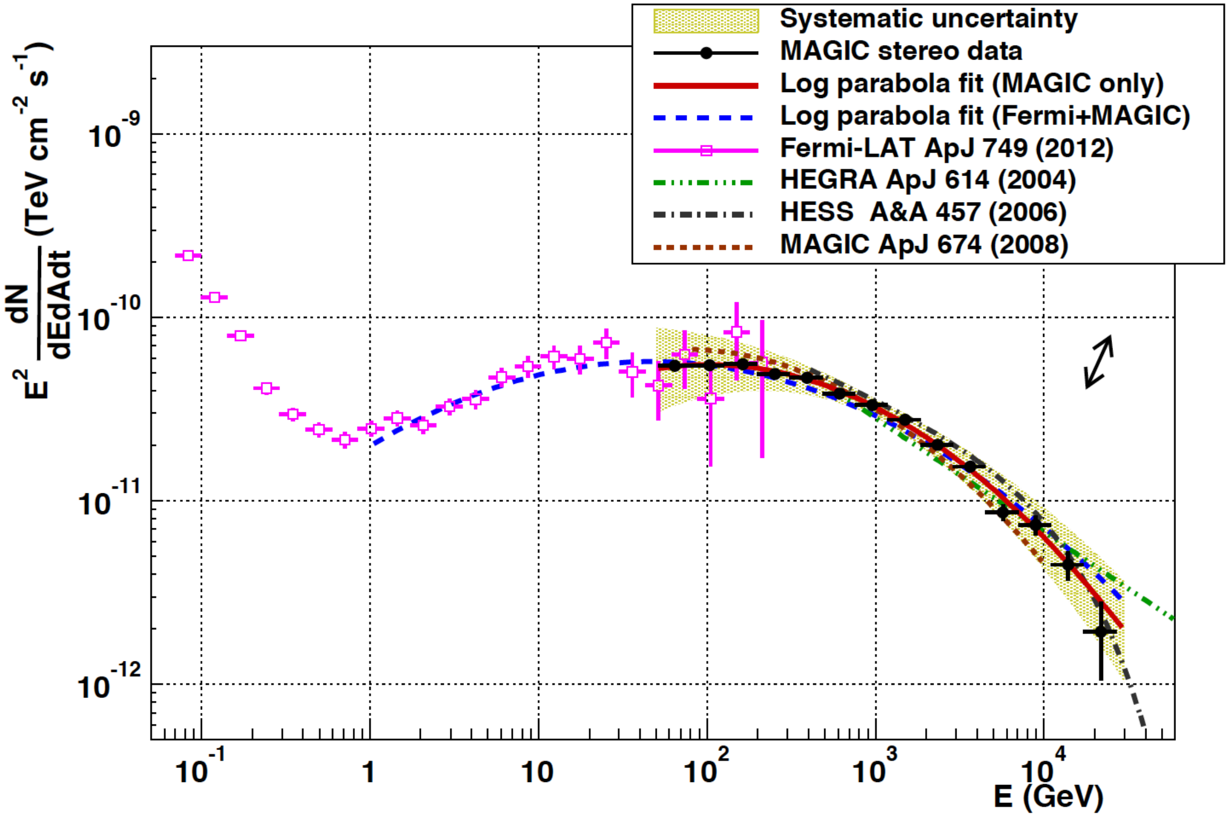


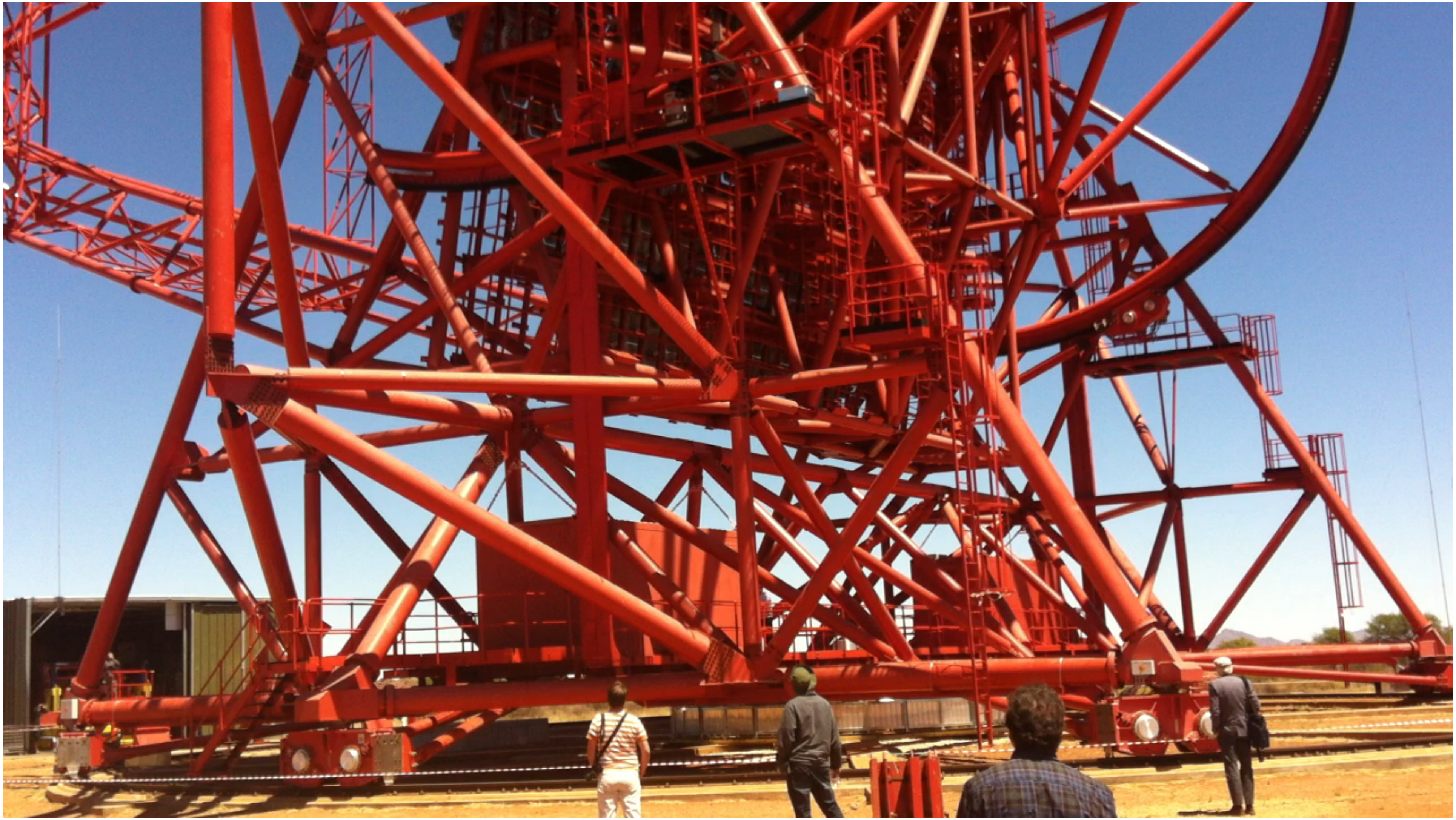
Energy distribution



Crab Nebula from HESS2 and MAGIC





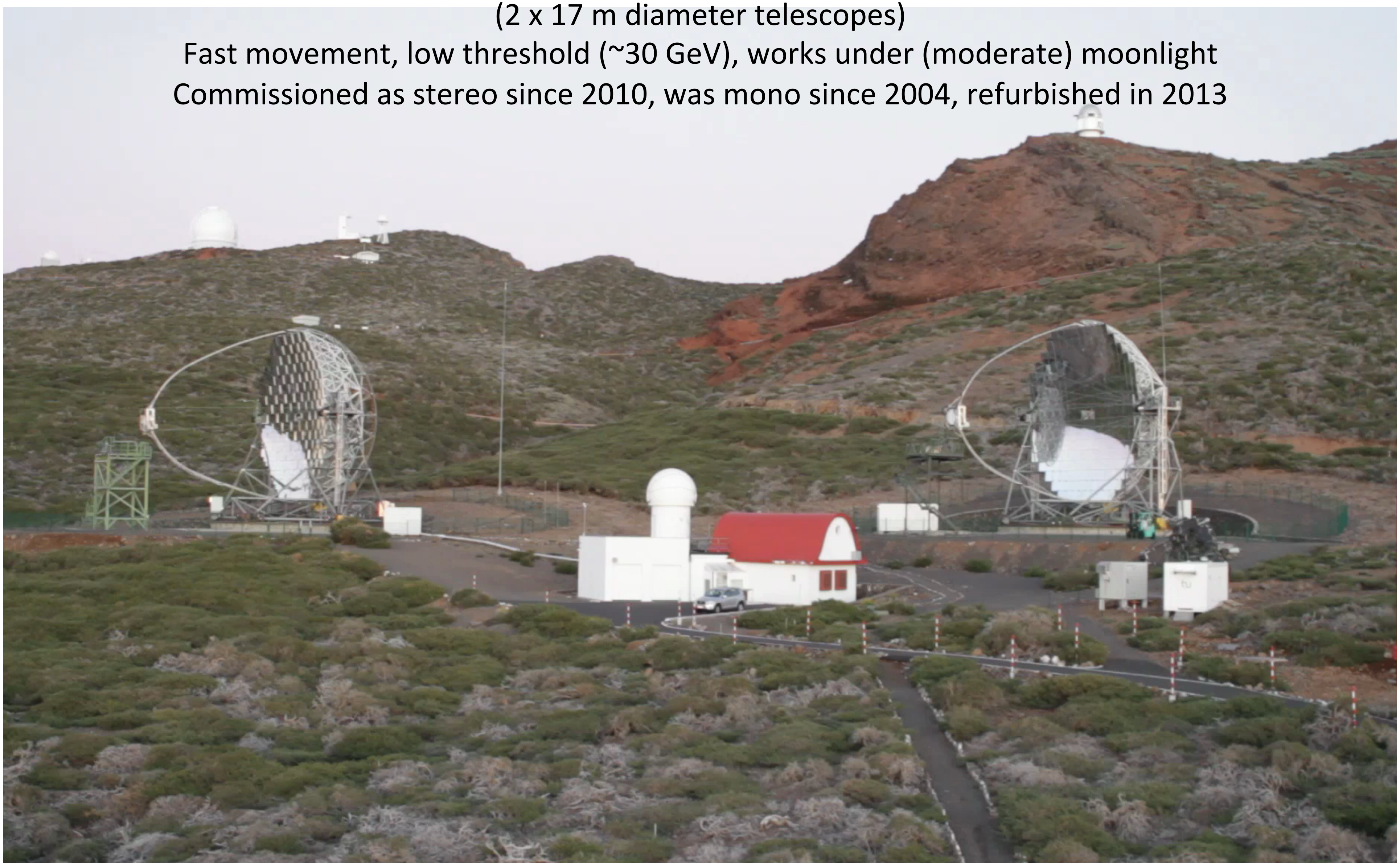


MAGIC at La Palma

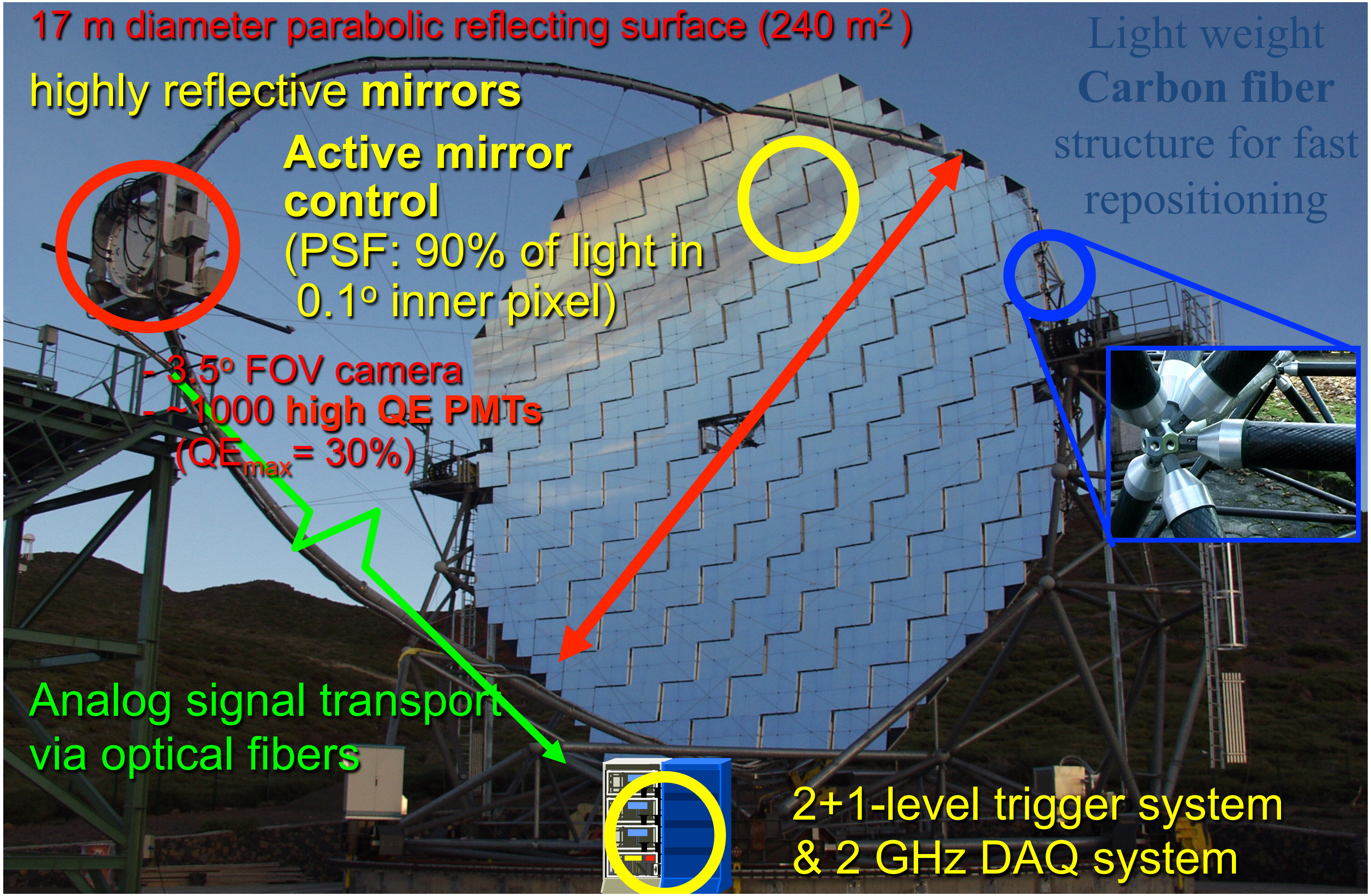
(2 x 17 m diameter telescopes)

Fast movement, low threshold (~30 GeV), works under (moderate) moonlight

Commissioned as stereo since 2010, was mono since 2004, refurbished in 2013



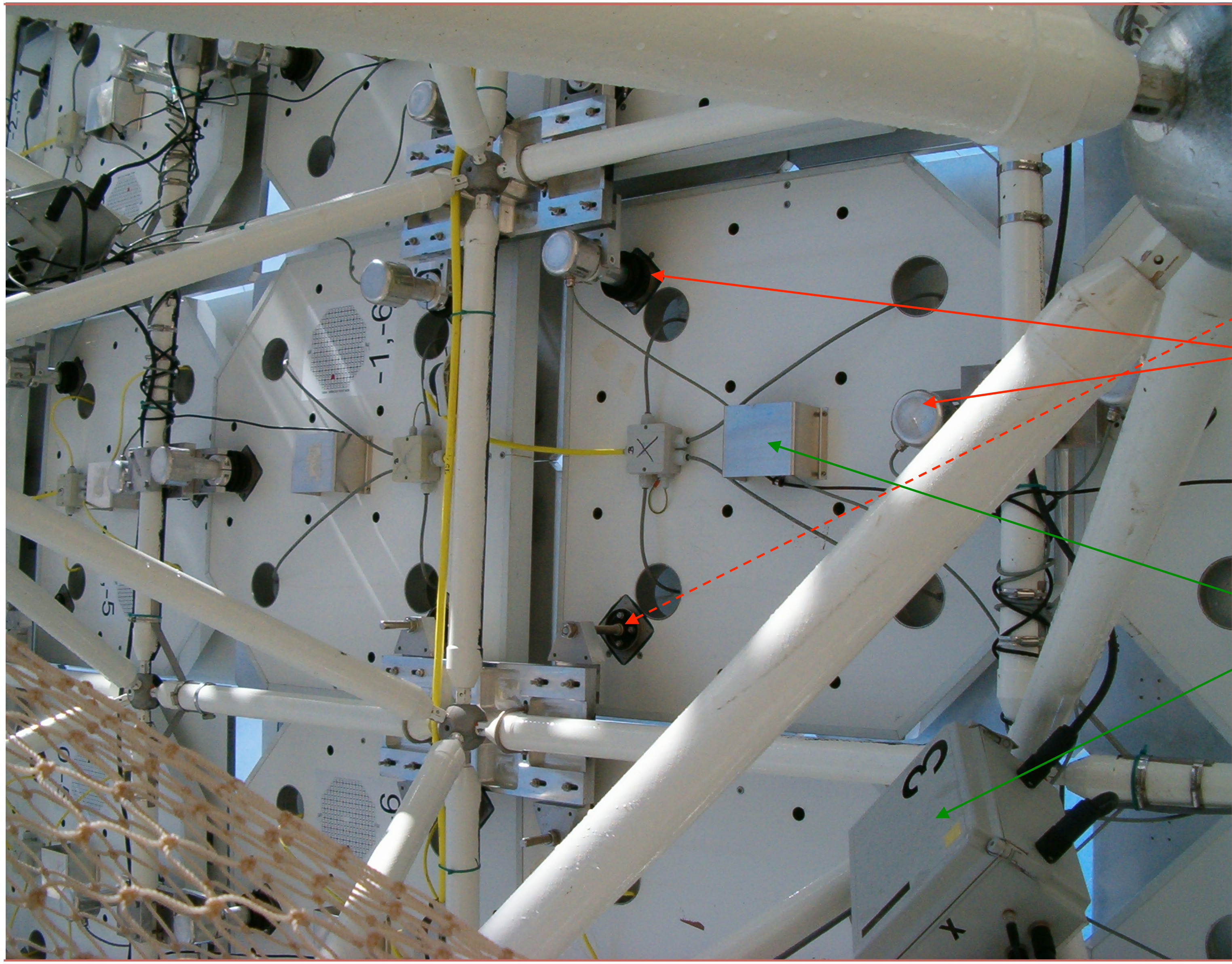
Key technological elements for MAGIC



Main technological novelties of MAGIC

- Active mirror control
- Light weight (60 tons), fast repositioning to catch transients (GRBs etc.)
- PMTs with low gain, to enhance duty cycle
- 2 GB sampling
- Smart triggers for low energy
- Daily monitoring of mirror performance thanks to a CCD camera
- …

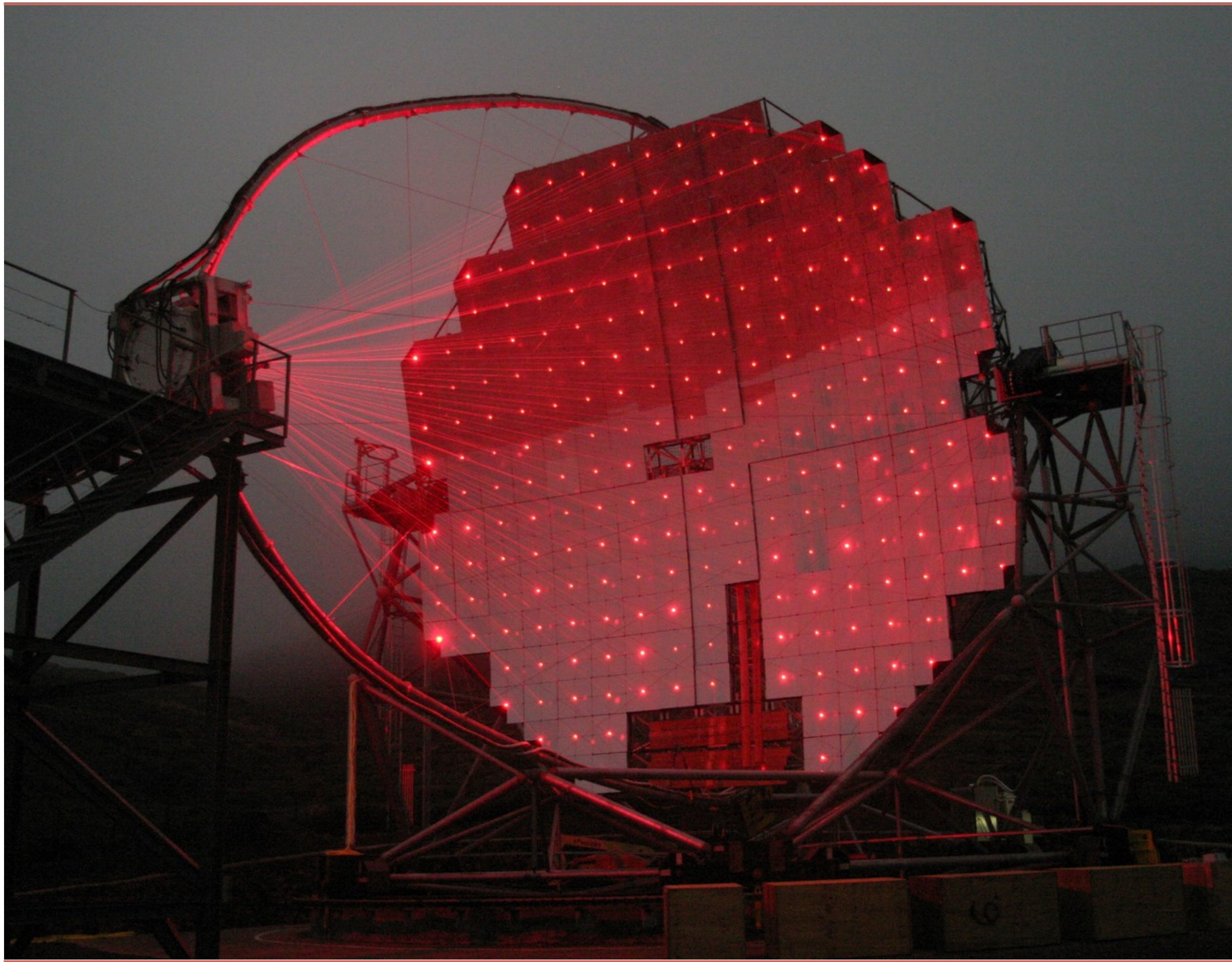
Active Mirror Control



Each segment attached to the support frame at 3 points :
1x fixed and
2x actuators

Other AMC components:
1 laser/segment
1 electr.box for 4 segments
1 CCD-camera (not shown)

The MAGIC AMC System



All AMC Lasers switched on during foggy night

(nice propaganda picture; does never look like that during operation …)

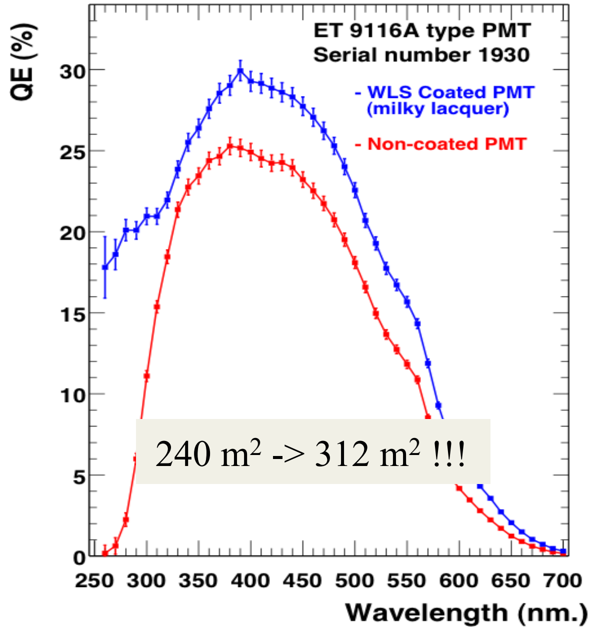
Enhanced QE PMTs Camera

6 stage PMTs (low gain)

- ET 9116A (1”) : 0.1°

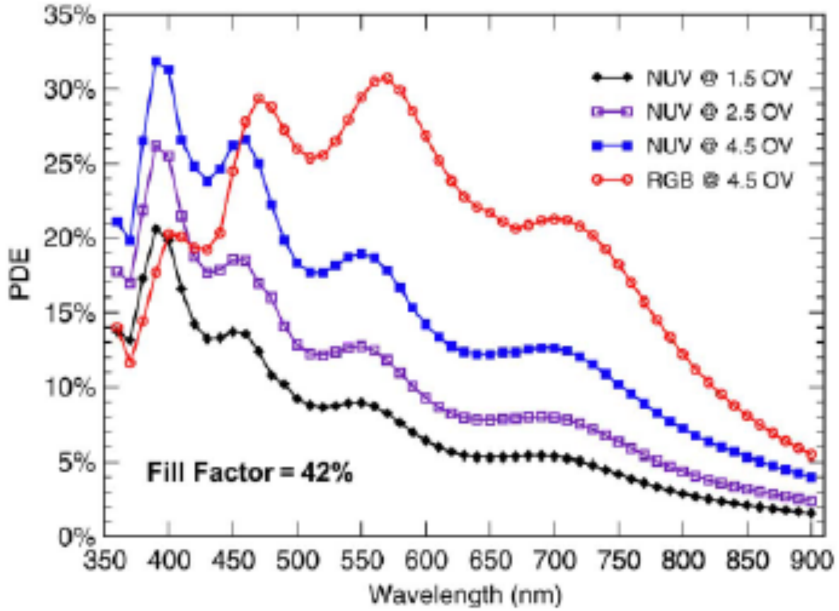
Quantum Efficiency increased up to 30 % with diffuse scattering coating

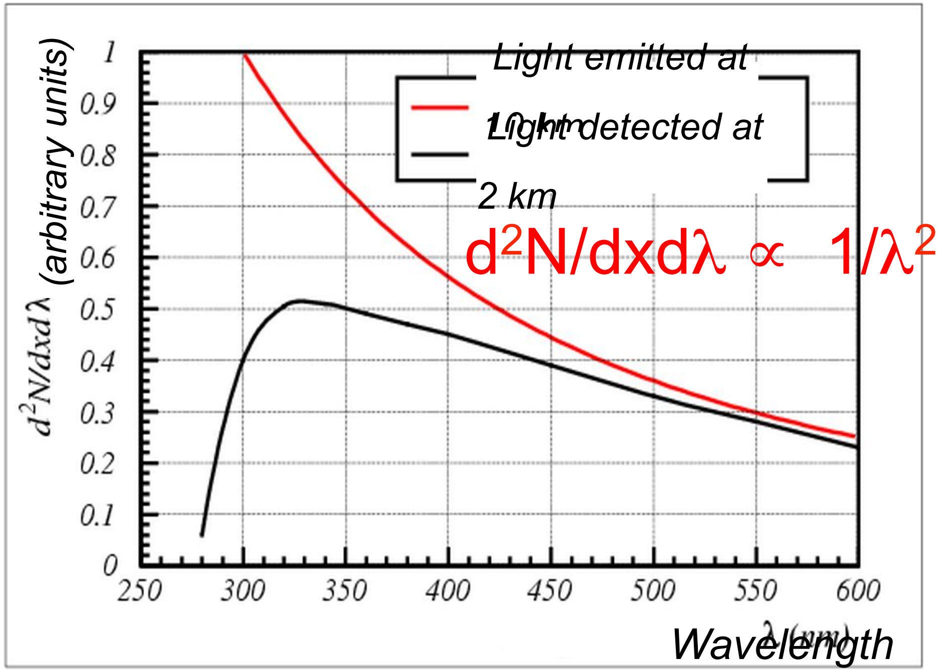
extended UV sensitivity using wavelength shifter coating



- Future is SiPM
- Technology already competitive
    - Wait some ~ 5 years to let prices to become comparable with PMT

(C. Piemonte et al., FBK)



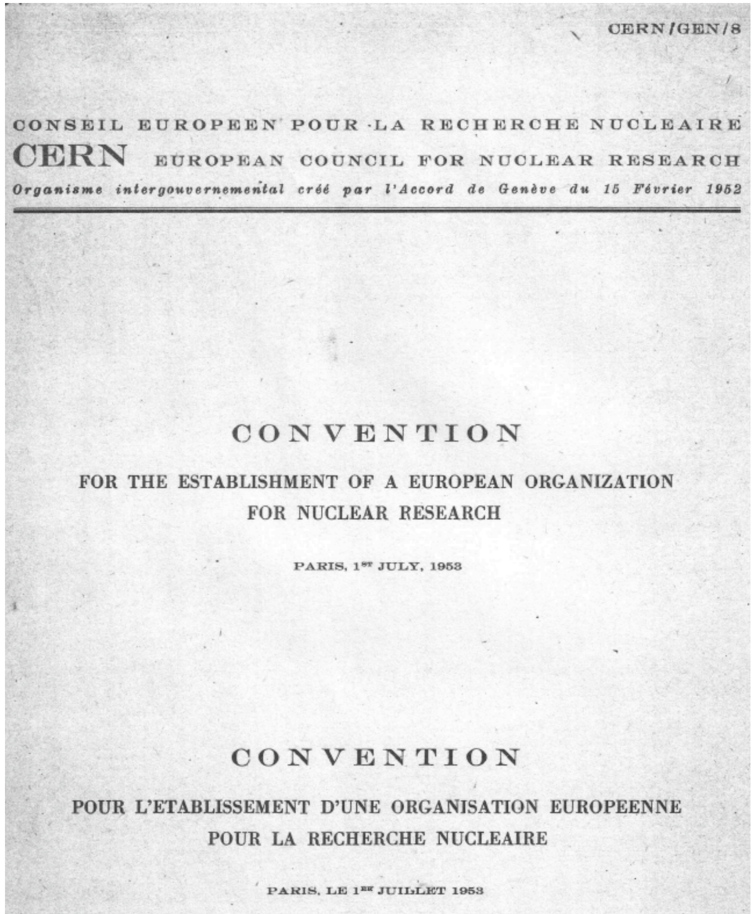


Main physics results and perspectives

- Cosmic Rays
  SNR established as sources of
  CR up to (almost) the knee

- Photon propagation
  Transparency of the Universe;
  Energy of the vacuum;
  Tests of Lorentz Invariance;
  Cosmology

- Search for “WIMP” Dark Matter



CERN/GEN/8

CONSEIL EUROPEEN POUR LA RECHERCHE NUCLEAIRE

CERN EUROPEAN COUNCIL FOR NUCLEAR RESEARCH

Organisme intergouvernemental créé par l'Accord de Genève du 15 Février 1952

CONVENTION

FOR THE ESTABLISHMENT OF A EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

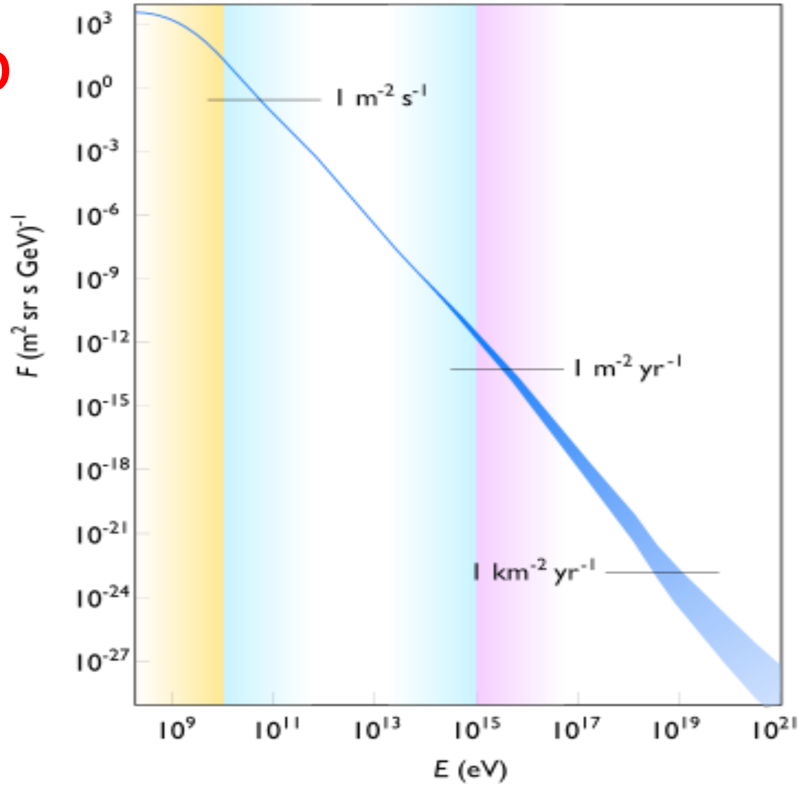
PARIS, 1ST JULY, 1953

CONVENTION

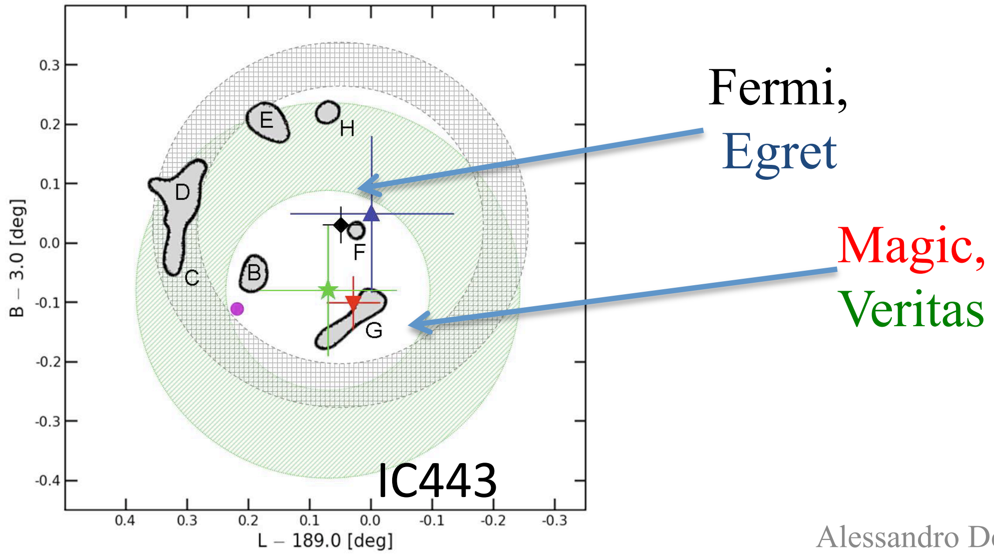
POUR L'ETABLISSEMENT D'UNE ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE

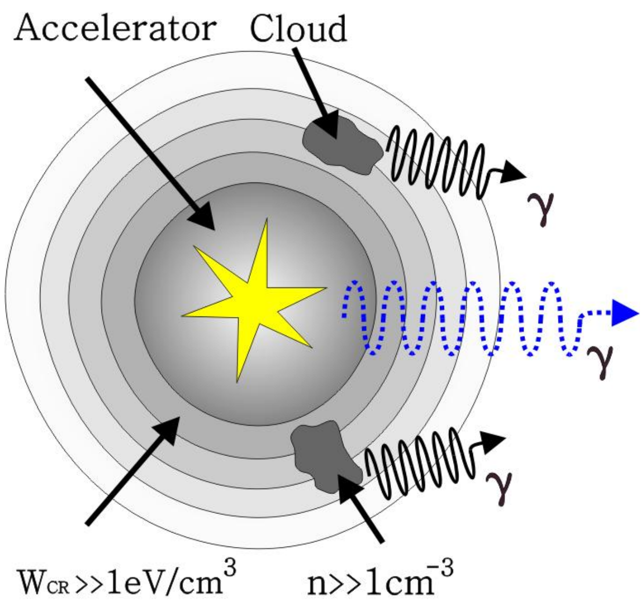
PARIS, LE 1ER JUILLET 1953

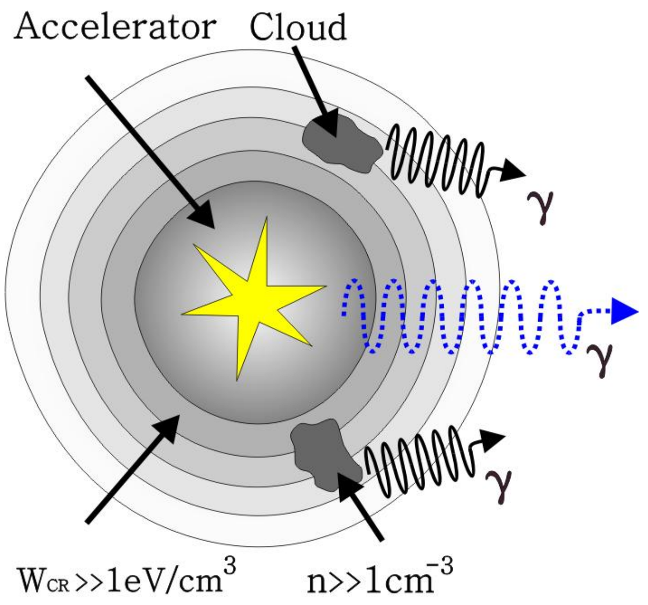
Proof of the origin of CR up to almost the knee

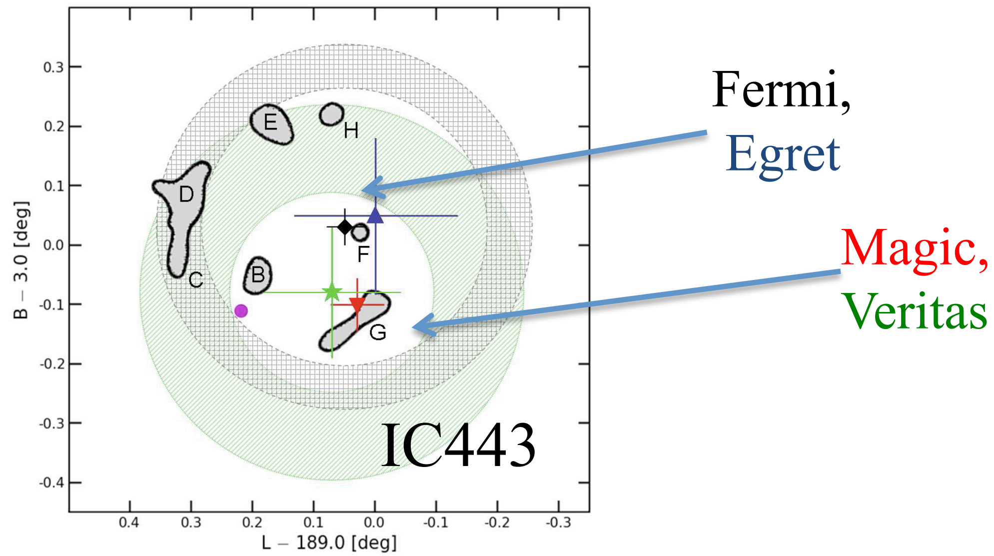


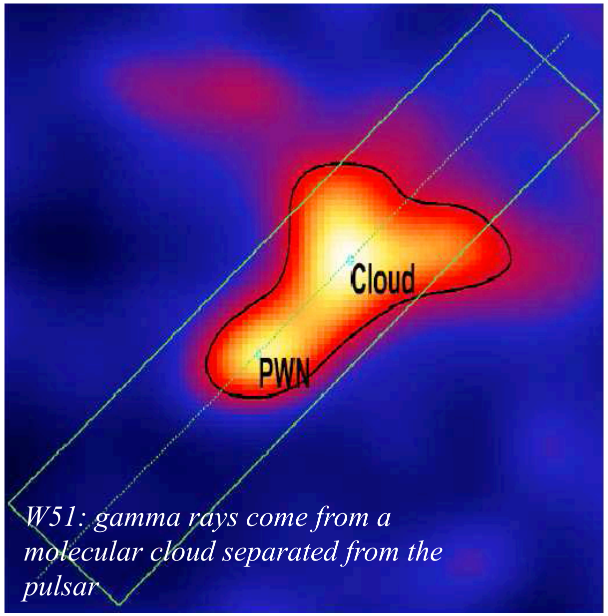
- Evidence that SNR are sources of CR up to ~1000 TeV (almost the knee) came from morphology studies of RX J1713-3946 (H.E.S.S. 2004) with photons
- Striking evidence from the morphology of SNR IC443 (MAGIC + Fermi/Agile 2010)

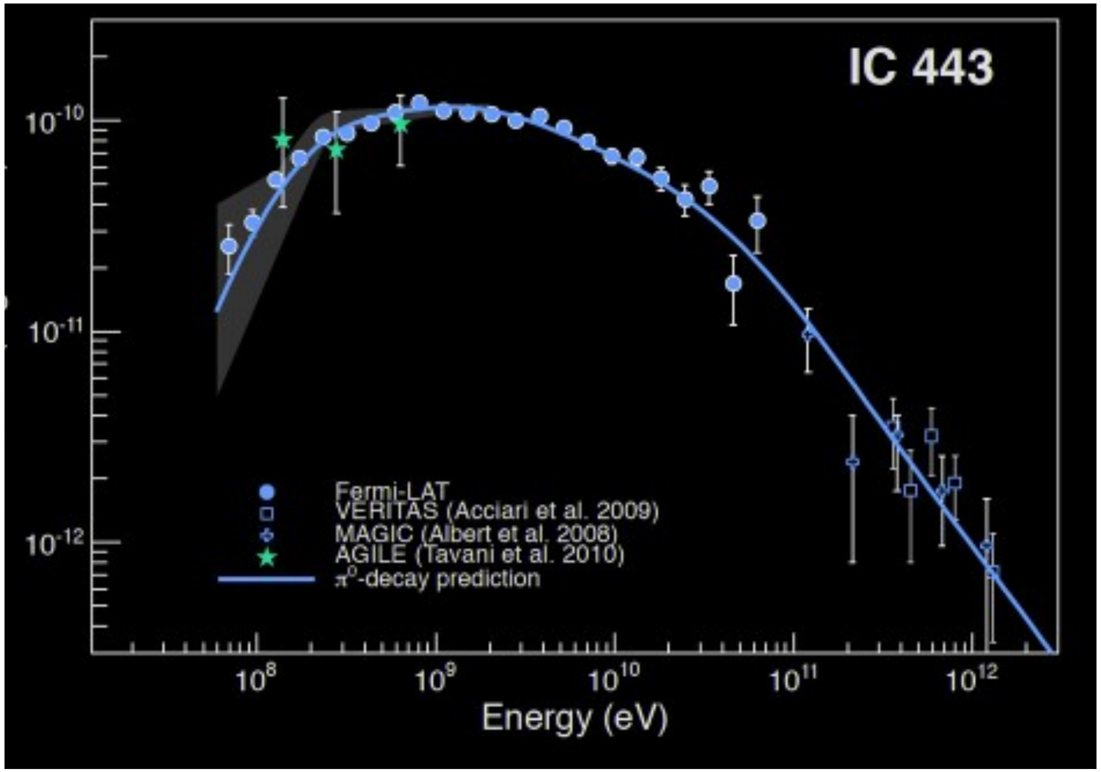




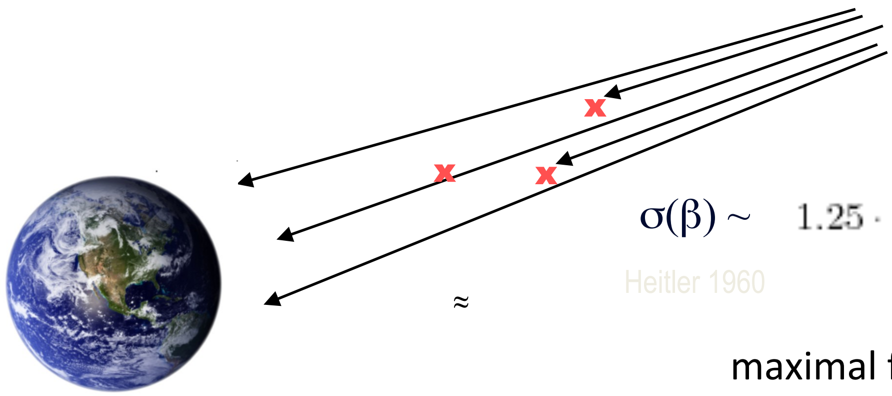

Accelerator
Cloud
γ
γ
γ
W_CR >>1eV/cm^3
n>>1cm^-3

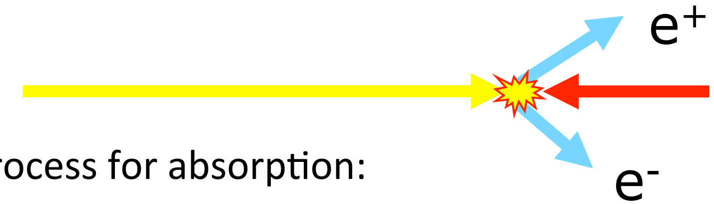

Fermi,
Egret
Magic,
Veritas
IC443
B – 3.0 [deg]
L – 189.0 [deg]
C
D
E
H
F
B
G


Cloud
PWN
W51: gamma rays come from a molecular cloud separated from the pulsar


IC 443
Fermi-LAT
VERITAS (Acciari et al. 2009)
MAGIC (Albert et al. 2008)
AGILE (Tavani et al. 2010)
π^0-decay prediction
Energy (eV)

Propagation of γ-rays





dominant process for absorption:

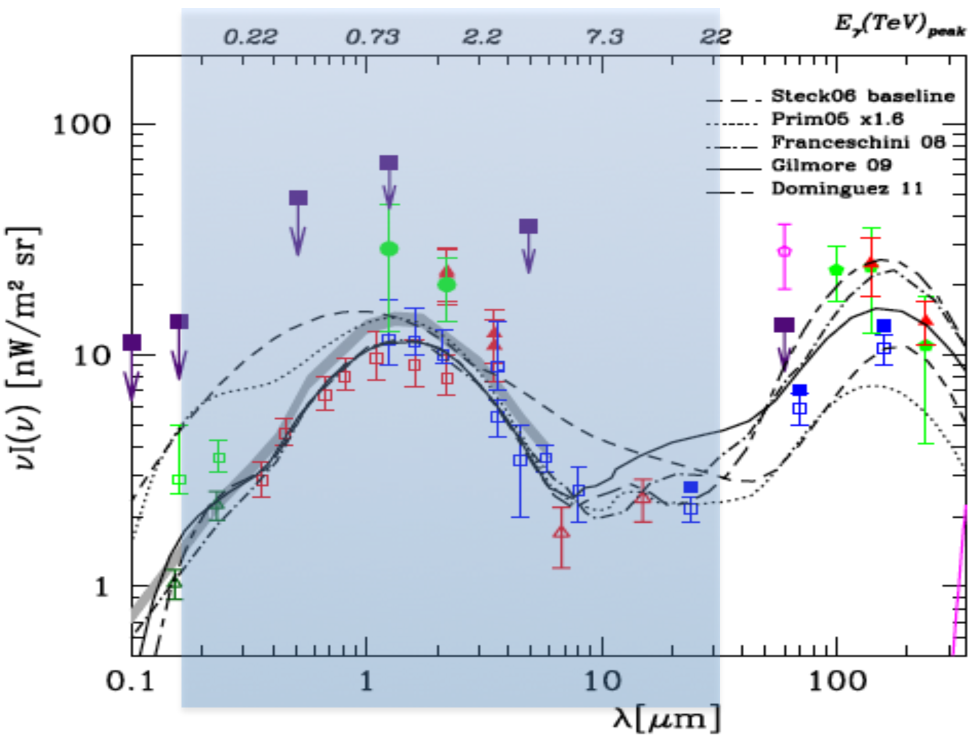
$$\gamma_{VHE}\gamma_{bck} \rightarrow e^+e^-$$

$$\sigma(\beta) \sim 1.25 \cdot 10^{-25}(1-\beta^2) \cdot \left[2\beta(\beta^2-2) + (3-\beta^4)\ln\left(\frac{1+\beta}{1-\beta}\right)\right] \mathrm{cm}^2$$

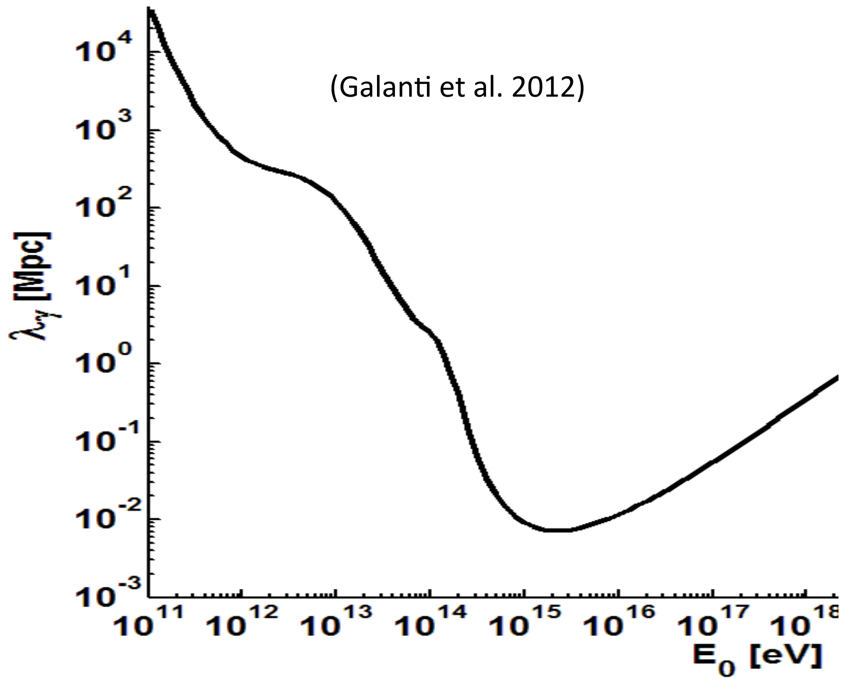
Heitler 1960

maximal for: $\epsilon \simeq \frac{2m_e^2c^4}{E} \simeq \left(\frac{500\ \mathrm{GeV}}{E}\right) \mathrm{eV}$

- For gamma rays, relevant background component is optical/infrared (EBL)
- different models for EBL: minimum density given by cosmology/star formation



2011)



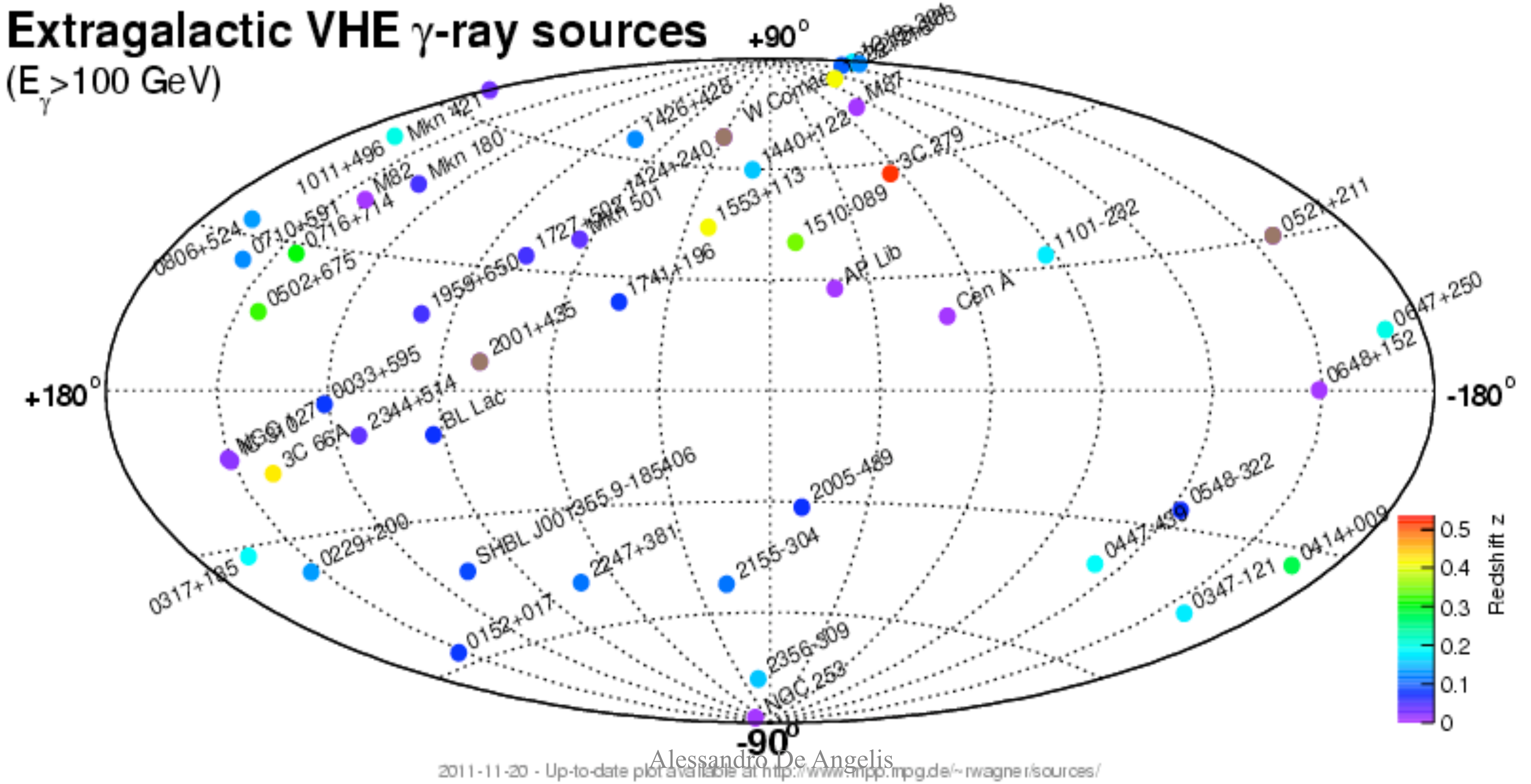
(Galanti et al. 2012)

Extragalactic Sources

~50 Sources

…

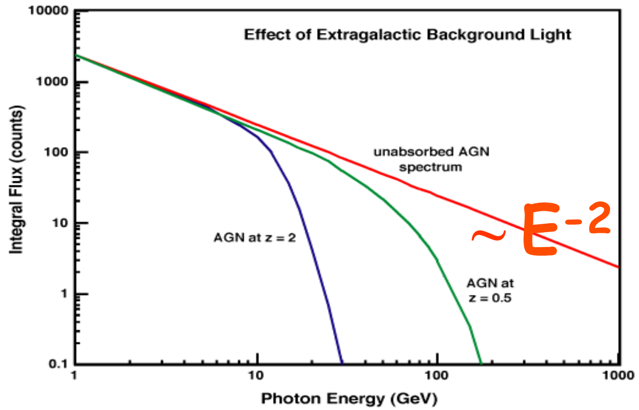
1ES 1011+496	**z=0.21**	**MAGIC 2007**
1ES 0414+009	z=0.29	HESS/Fermi 2009
S5 0716+71	**z=0.31±0.08**	**MAGIC 2009**
1ES 0502+675	z=0.34	VERITAS 2009
PKS 1510-089	z=0.36	HESS 2010
4C +21.43	**z=0.43**	**MAGIC 2010**
3C 66A	**z=0.44**	**VERITAS 2009**
3C 279	**z=0.54**	**MAGIC 2008**

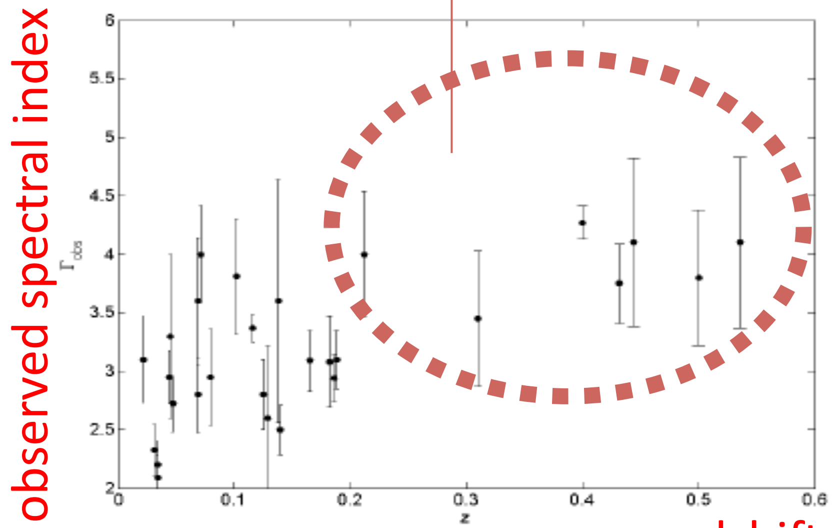


Are our AGN observations consistent with theory?

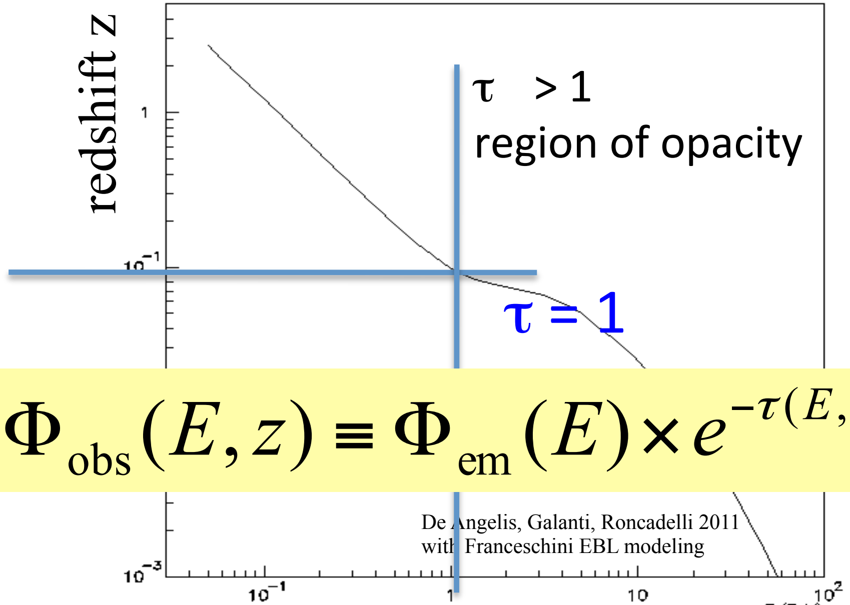
Selection bias?
New physics ?

Measured spectra affected by attenuation in the EBL:

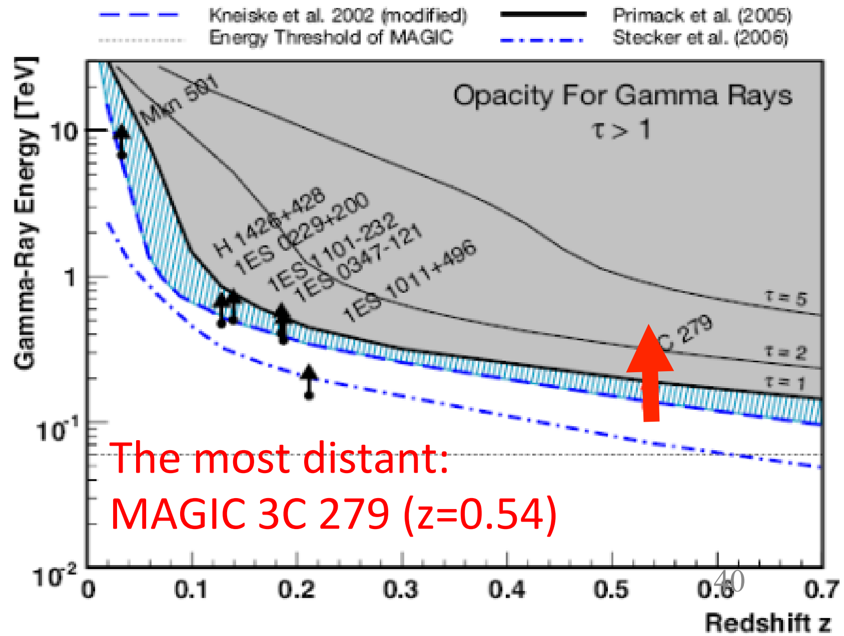




(DA, Galanti, Roncadelli; PRD 2011)

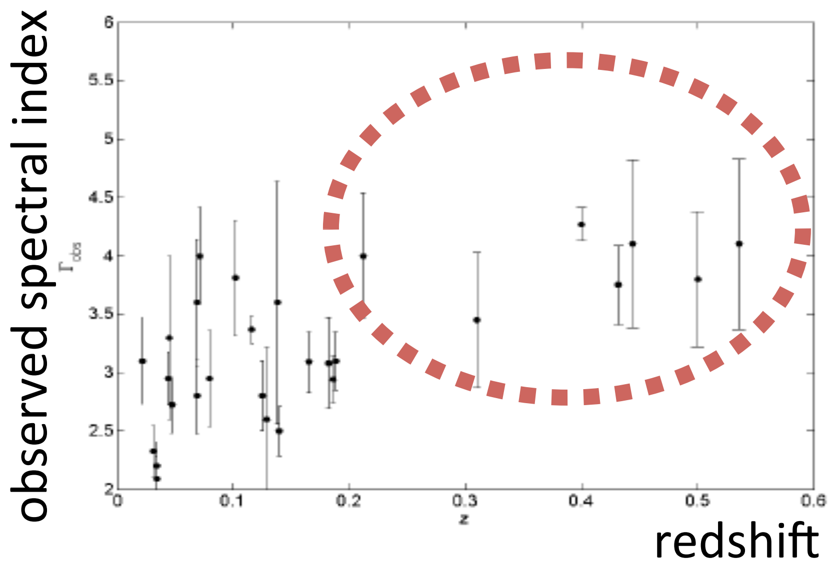


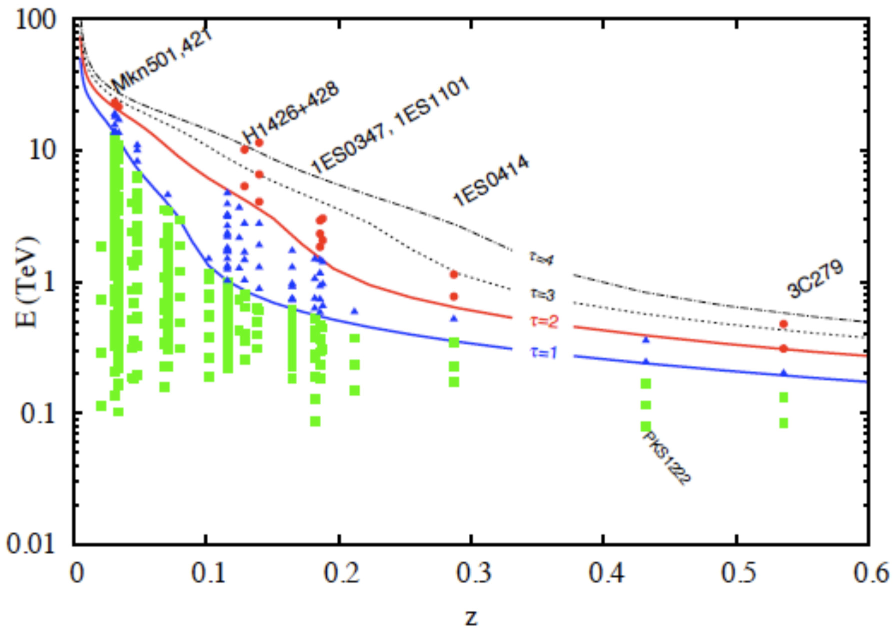
$$\Phi_{obs}(E,z) \equiv \Phi_{em}(E) \times e^{-\tau(E,z)}$$



The most distant:
MAGIC 3C 279 (z=0.54)

If there is a problem





Explanations from the standard ones

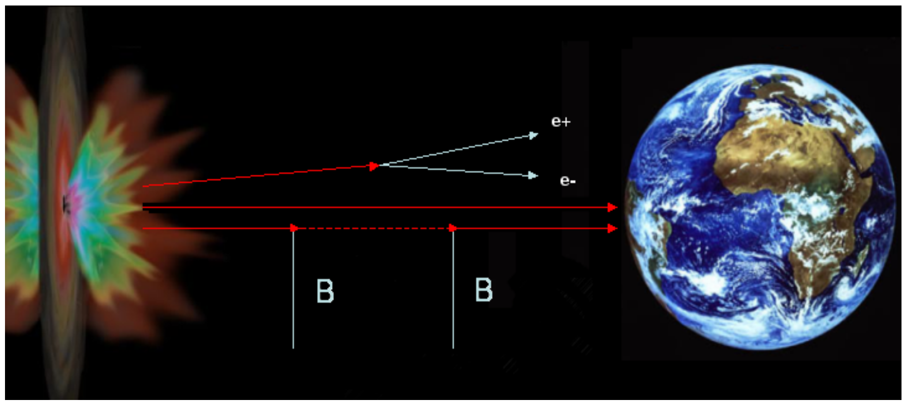
- very hard emission mechanisms with intrinsic slope < 1.5 (Stecker 2008)
- Very low EBL, plus observational bias, plus a couple of "wrong" outliers

to almost standard

- γ-ray fluxes enhanced by relatively nearby production by interactions of primary cosmic rays or ν from the same source

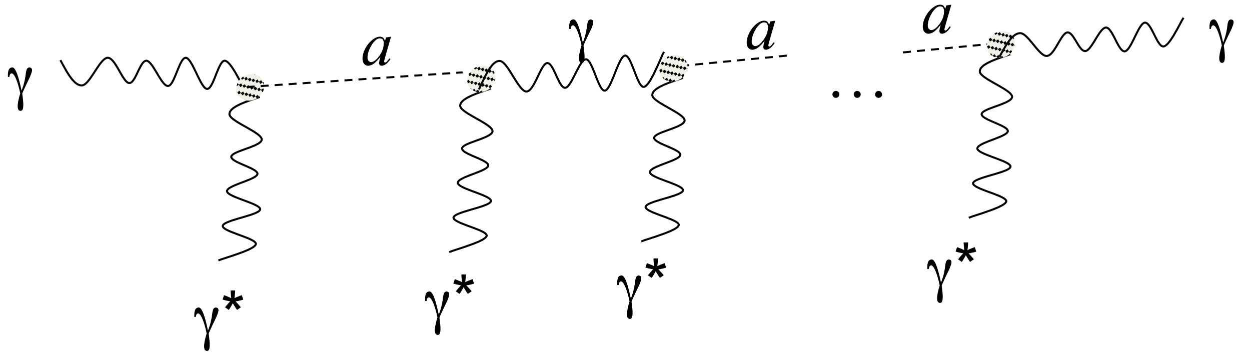
to possible evidence for new physics

- Oscillation to a light "axion"? (DA, Roncadelli & MAnsutti [DARMA], PRD2007, PLB2008)
- Axion emission (Simet+, PRD2008)
- A combination of the above (Sanchez Conde et al. PRD 2009)



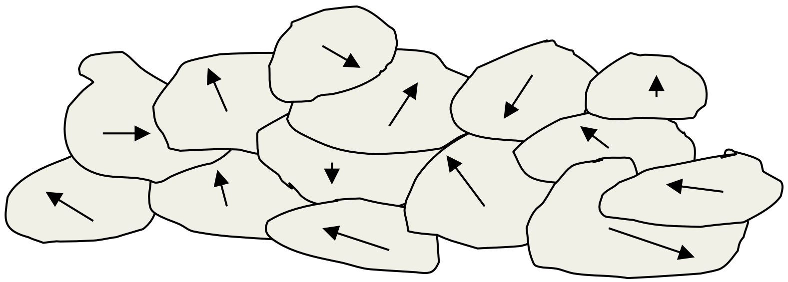
The photon-axion mixing mechanism

$$L_{a\gamma\gamma} = g_{a\gamma}\left(\vec{E}\cdot\vec{B}\right)a$$



Propagation: Raffelt-Stodolsky 1987; Csaki-Kaloper-Terning 2002; DA Roncadelli MAnsutti 2007; Simet Hooper Serpico 2008

- Magnetic field 1 nG < B < 1aG (AGN halos). Cells of ~ 1 Mpc



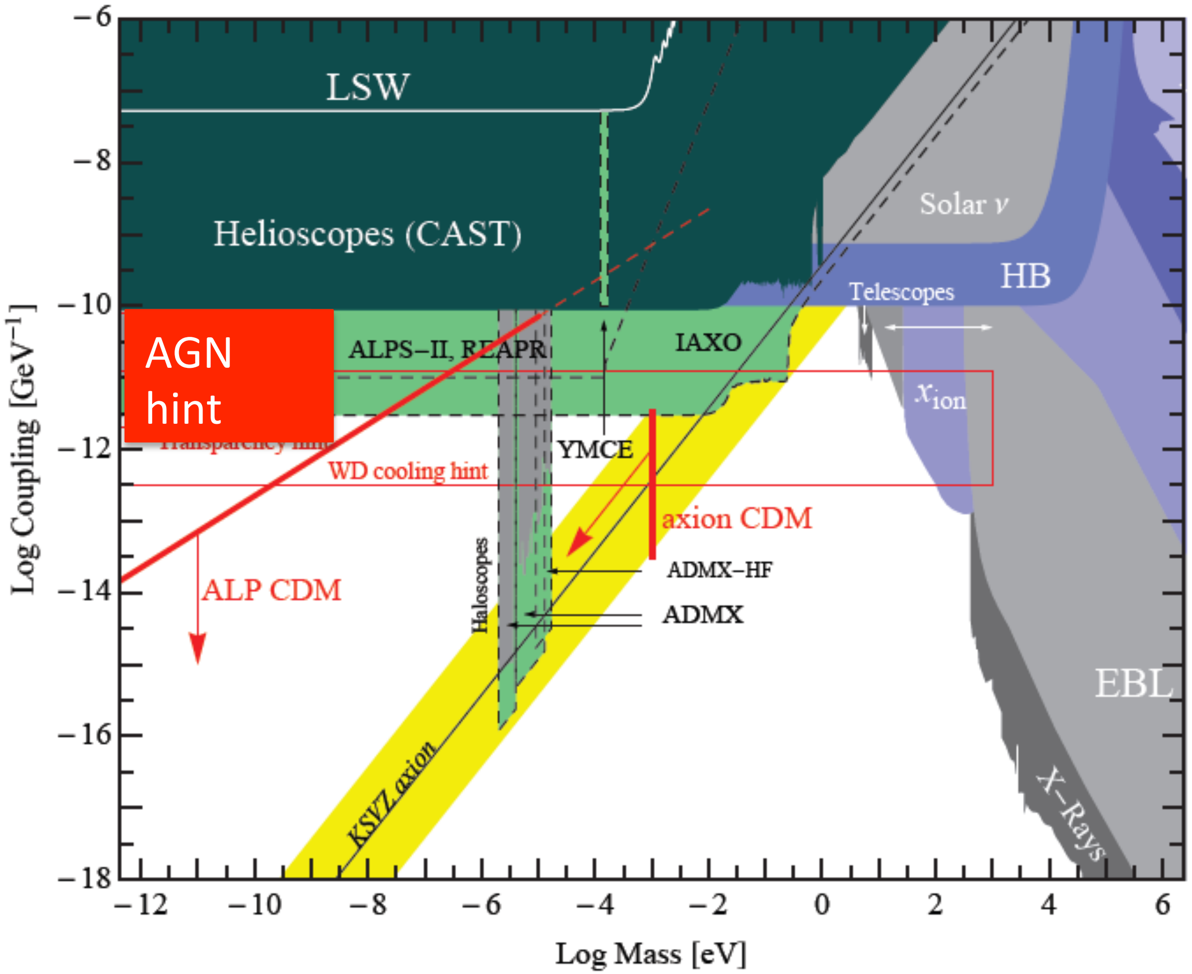
$$P_{\gamma\to a} \approx NP_1$$

$$P_1 \approx \frac{g_{a\gamma}^2 B_T^2 s^2}{4} \approx 2\times 10^{-3}\left(\frac{B_T}{1\text{nG}}\frac{s}{1\text{Mpc}}\frac{g_{a\gamma}}{10^{-10}\,\text{GeV}^{-1}}\right)^2$$

- m_a < 0.02 eV (direct searches)
- g < 10^{-10}GeV^{-1} from the non observation of γ-rays from the SN1987A, and direct searches

Axions

Parameter space for axions or axion-like particles

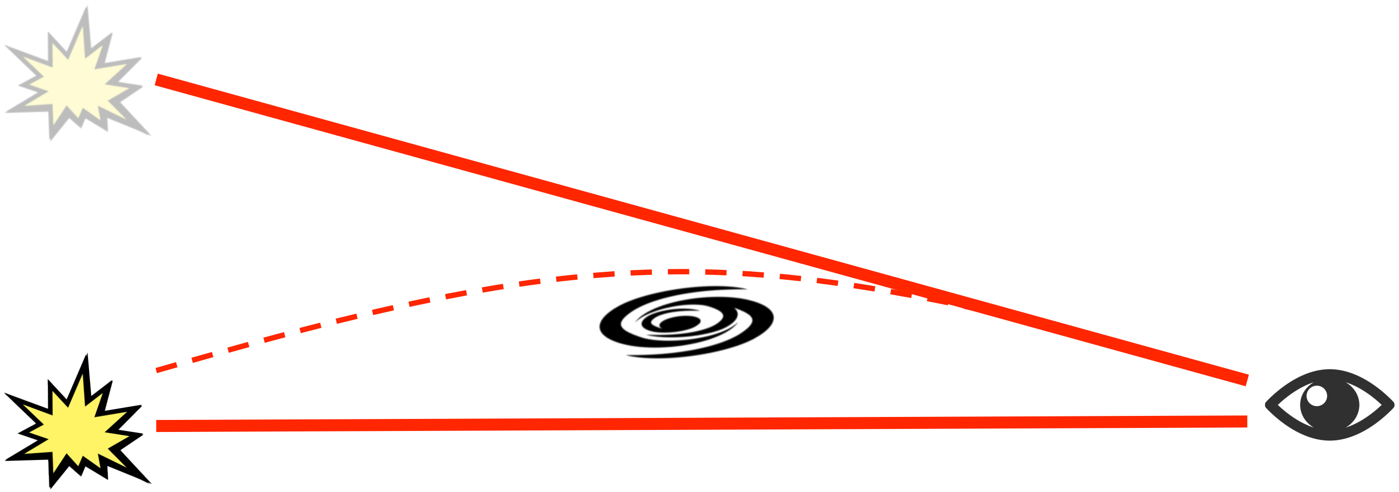


- **Experimentally excluded**
- **Astronomy constraints**
- **Cosmology constraints**
- **Sensitivity of planned experiments**

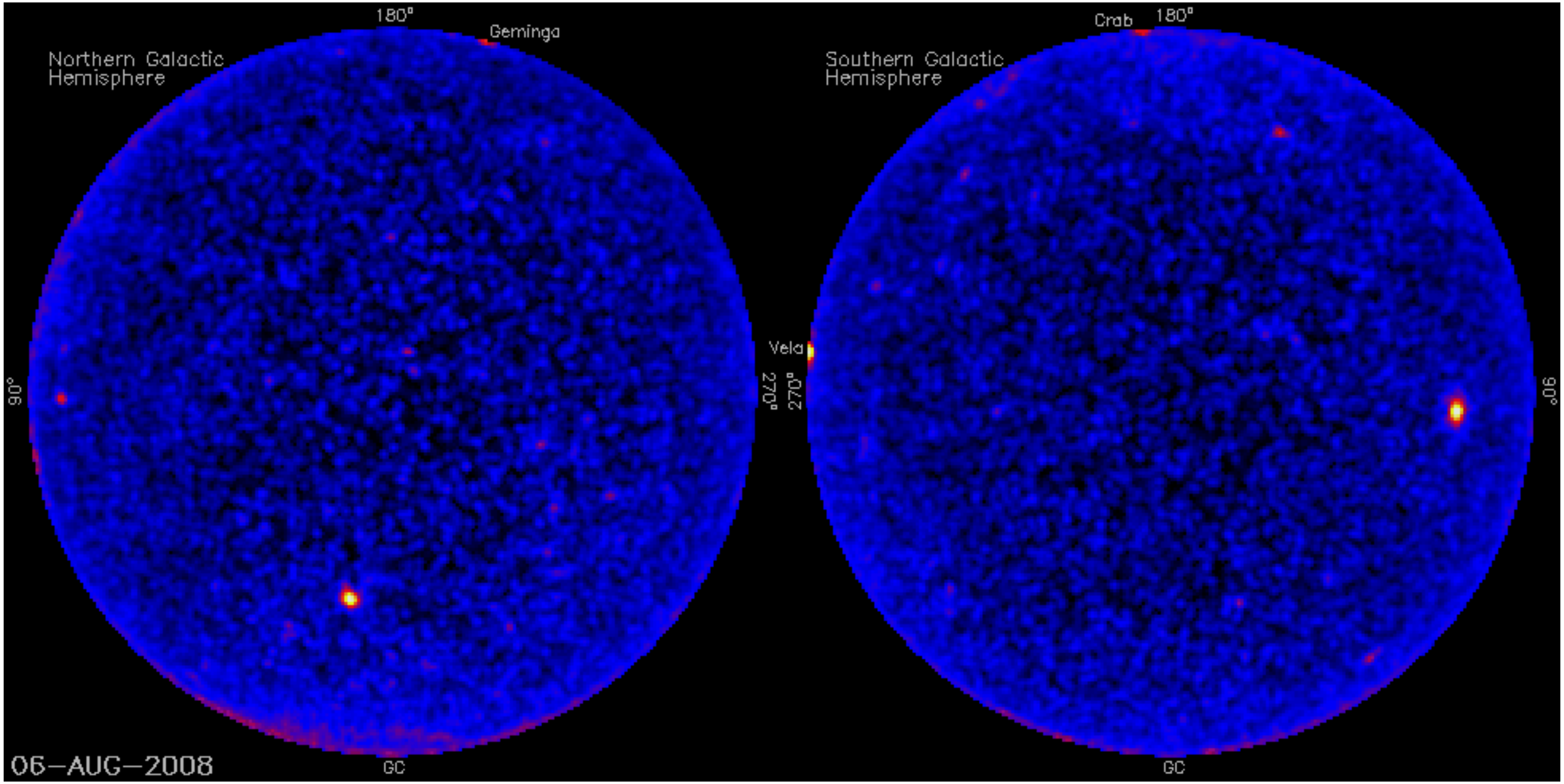
Breaking news! A blazar at z=0.944 detected 2 days ago…

- S3 0218 +357 detected by MAGIC at 200 GeV
  - Directly samples the EBL in the 100-200 nm region
- Alert by Fermi at lower energies…

… 11 days before!



Variability (down to the ~10s scale)



A heuristic approach: modified dispersion relations (perturbation of the Hamiltonian)

- We expect the Planck mass to be the scale of the effect

$$E_P = \sqrt{hc/G} \cong 1.2 \times 10^{19}\,\text{GeV}$$

$$H^2 = m^2 + p^2 \rightarrow H^2 = m^2 + p^2\left(1 + \xi\frac{E}{E_P} + \ldots\right)$$

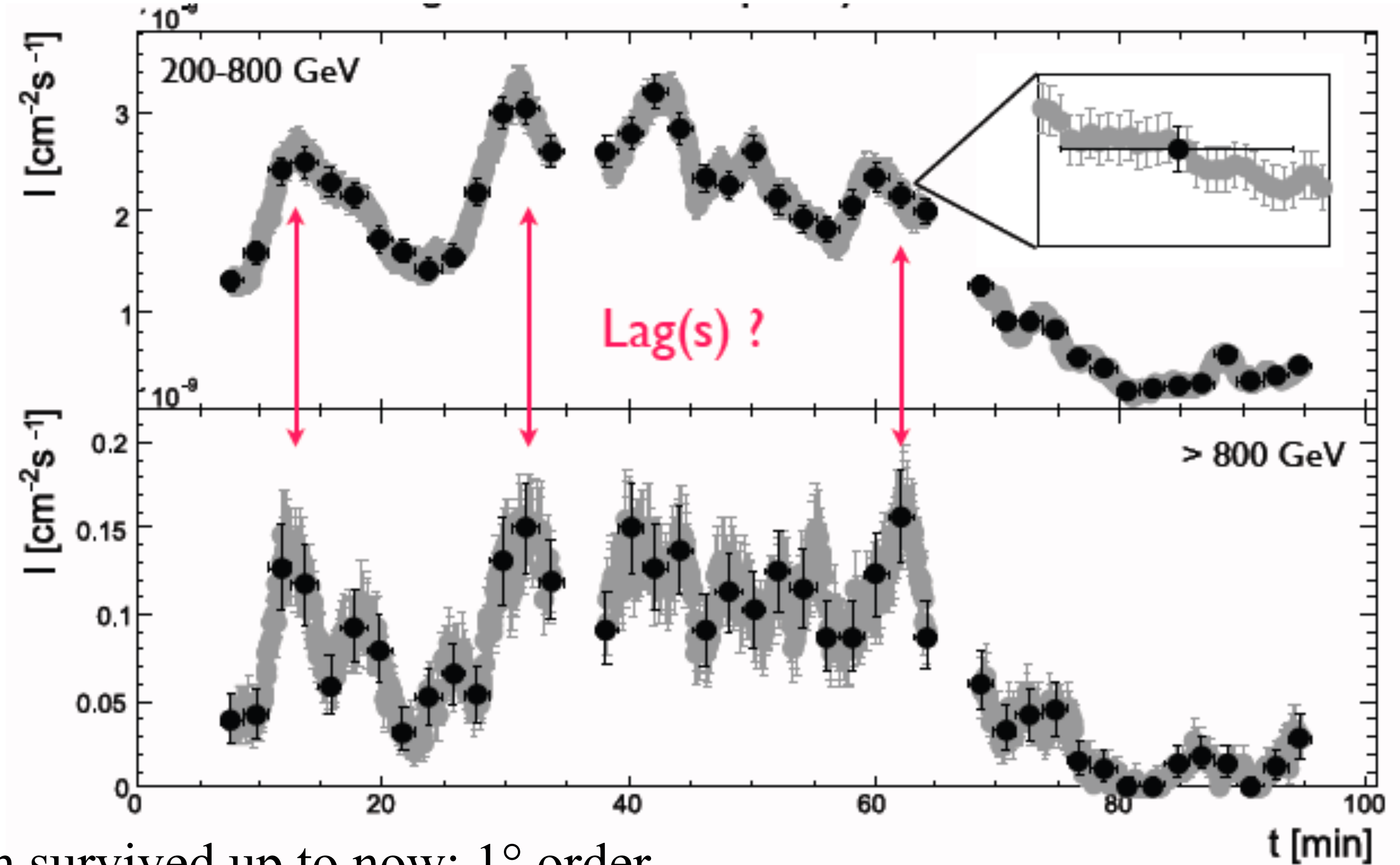
$$H \xrightarrow[p>>]{} p\left(1 + \frac{m^2}{2p^2} + \xi\frac{p}{2E_P} + \ldots\right)$$

$$v = \frac{\partial H}{\partial p} \cong 1 - \frac{m^2}{2p^2} + \xi\frac{p}{E_P} \Rightarrow v_\gamma \cong 1 + \xi\frac{E}{E_P}$$

=> effect of dispersion relations at cosmological distances can be important at energies well below Planck scale:

$$\Delta t_\gamma \cong T\Delta E\frac{\xi}{E_P}$$

Tests of Lorentz violation: the name of the game



No claim survived up to now; 1° order effects unlikely

HESS, PKS 2155

2^{nd} order? Cherenkov rules!

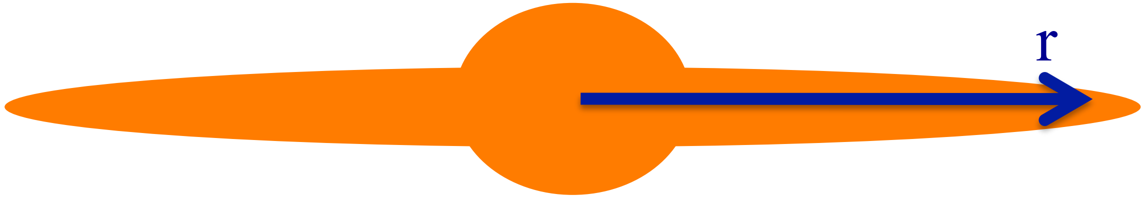
$$(\Delta t)_{obs} \cong \frac{3}{2}\left(\frac{\Delta E}{E_{s2}}\right)^2 H_0^{-1}\int_0^z dz' \frac{(1+z')^2}{\sqrt{\Omega_M (1+z')^3 + \Omega_\Lambda}}$$

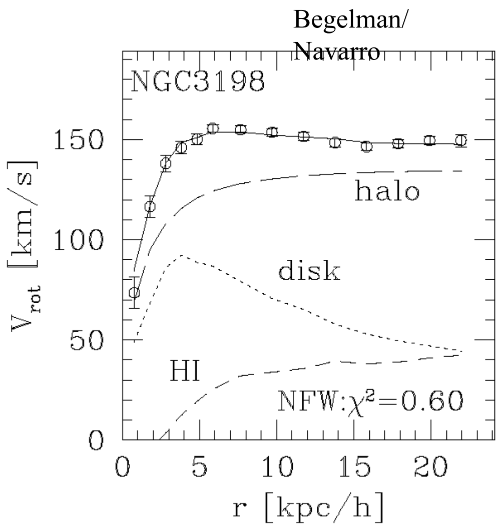
$E_{s2} > 6\ 10^{10}$ GeV ($\sim 10^{-9}\ M_P$) (HESS, MAGIC)

A no-loss situation:
if propagation is standard, cosmology with AGN

The Dark Matter Problem

Measure rotation curves for galaxies:



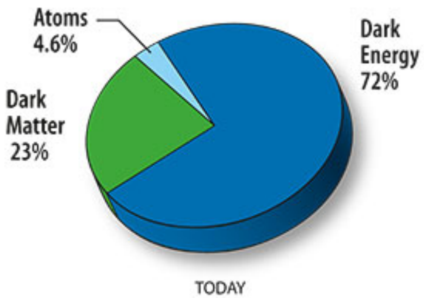


For large r, we expect:

$$G\frac{M}{r^2} = \frac{v^2(r)}{r} \quad \Longrightarrow \quad v(r) \sim \frac{1}{\sqrt{r}}$$

we see: flat or rising rotation curves

Hypothesized solution: the visible galaxy is embedded in a much larger halo of Dark Matter (neutral; weakly interacting; mix of particles and antiparticles - in SUSY Majorana)



Famous Bullet Cluster

(B. Atwood)

Which signatures for gamma detectors?

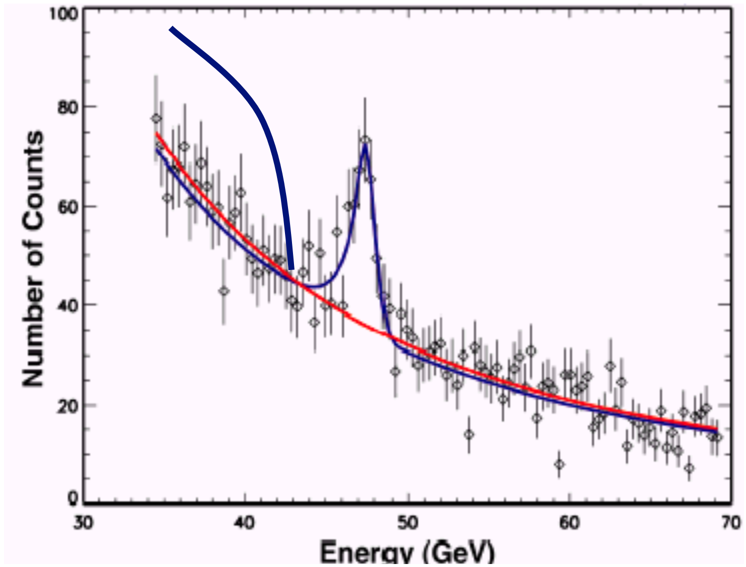
- Self-annihilating WIMPs, if Majorana (as the neutralino in SUSY), can produce:
  - Photon lines (γγ, γZ)
  - Photon excess at E < m from hadronization
- Excess of antimatter (annihilation/decay)
- Excess of electrons, if unstable

$$\Phi \propto \sigma \frac{\langle v \rangle}{m^2} \int_{los} \rho^2 \, dl$$

from particle physics

from astrophysics

Look to the closest point with M <<L



Many Places to Seek DM!

Galactic Center

Good statistics but source confusion/diffuse background

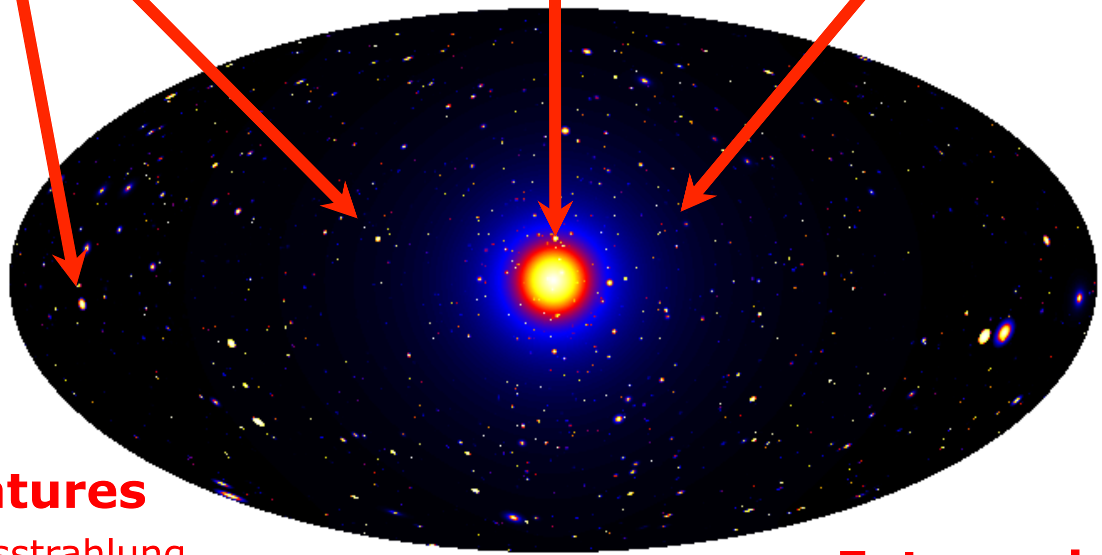
Satellites

Low background and good source id, but low statistics, astrophysical background

Milky Way Halo

Large statistics but diffuse background

All-sky map of simulated gamma ray signal from DM annihilation (Pieri et al 2006)



Spectral Features

Lines, endpoint Bremsstrahlung,...

No astrophysical uncertainties, good source Id, but low sensitivity because of expected small BR

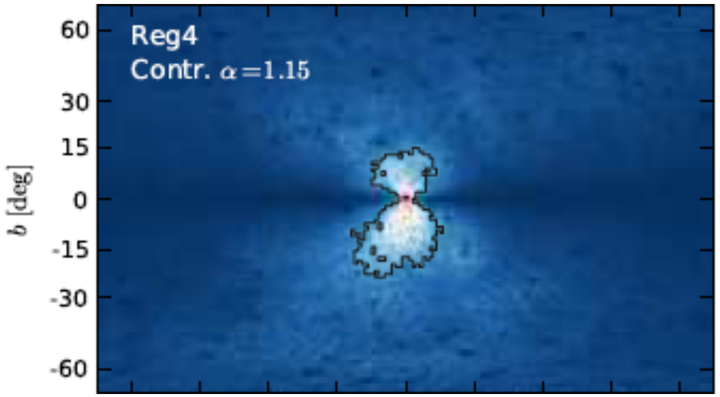
Extra-galactic

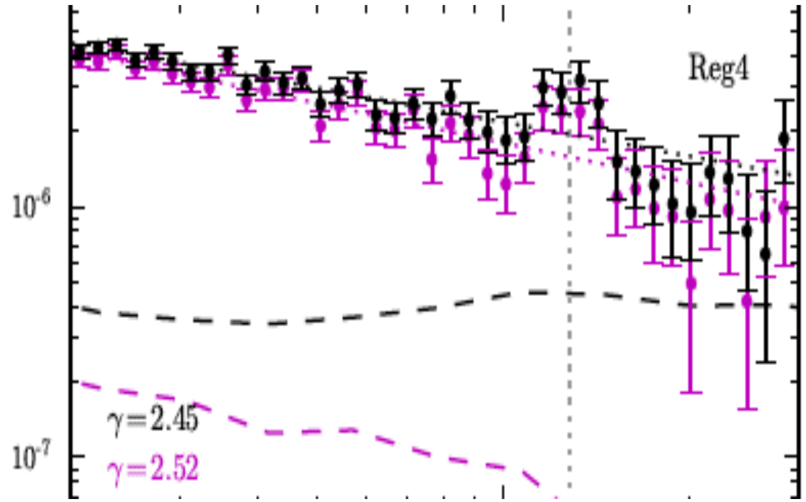
Large statistics, but astrophysics, galactic diffuse backgrounds

No signal from possibly expected sources

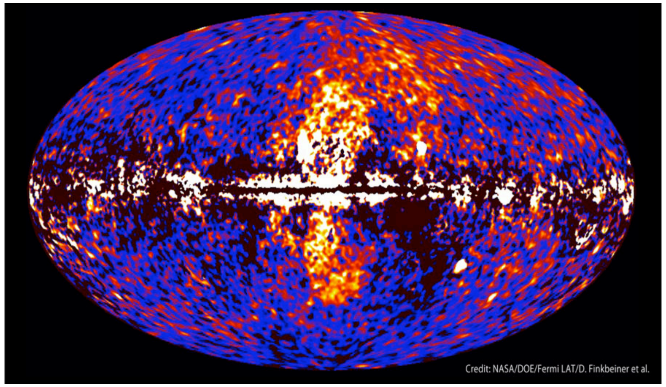
Data-driven line searches

- Very recently, one paper claims a positive signal (a ~4σ photon excess at ~130 GeV from Fermi data)
  - C. Weniger, arXiv:1204.2797





Selection of the region
b(i)ased on data
Large overlapping with
The Fermi "bubbles"
Prospects for present IACT: bad.
LHC? Future Cherenkov?

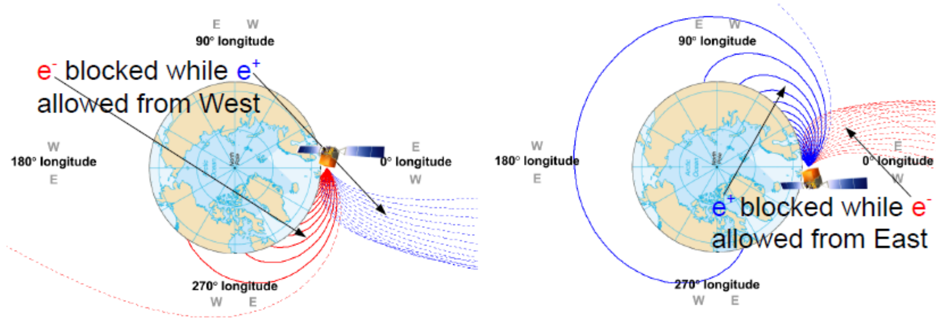


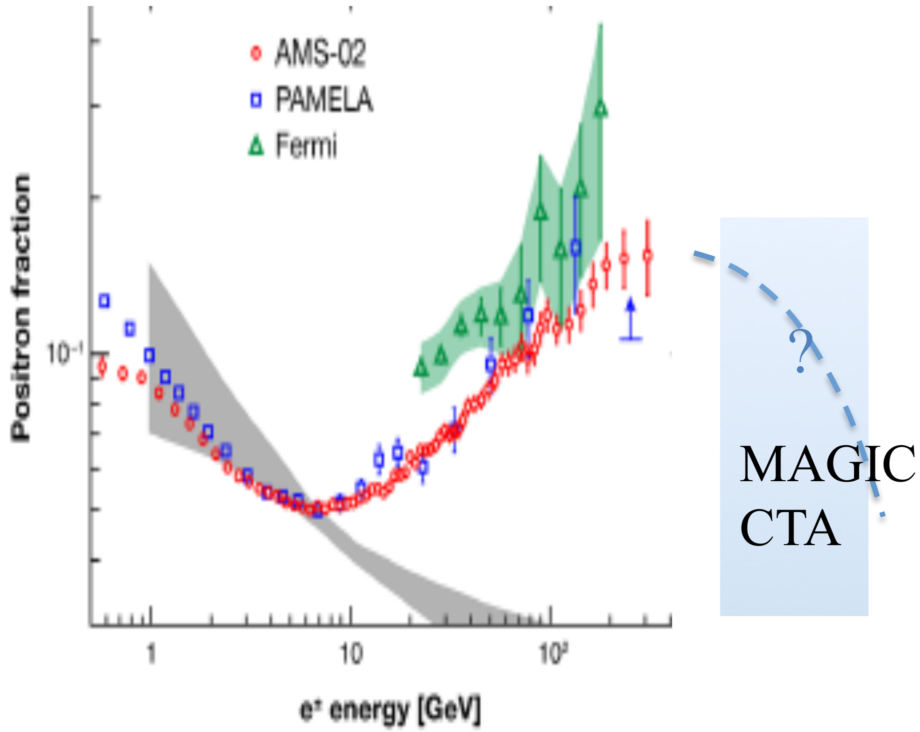
DM: interplay with accelerators

- LHC may find candidates but cannot prove that they are the observed Dark Matter, nor localize it
- *Direct searches (nuclear recoil) may recognize local halo WIMPs but cannot prove the nature and composition of Dark Matter in the sky*

- LHC reach limited to some 200-600 GeV; IACT sensitivity starts at some ~200 GeV (should improve)

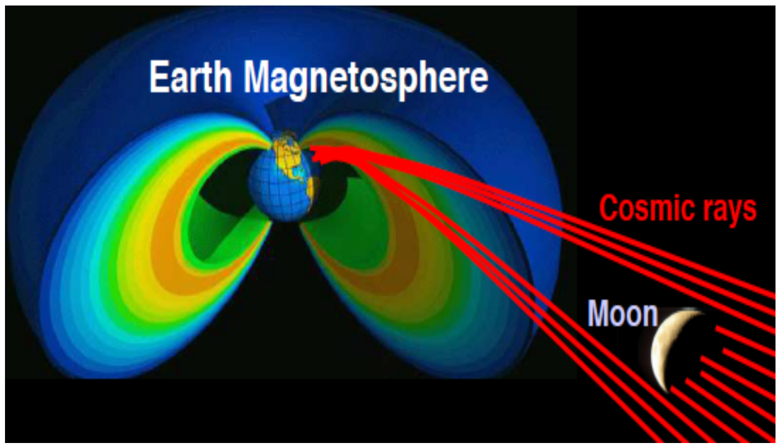
Antimatter: the PAMELA anomaly





probe e+/e- ratio at 300-700 GeV

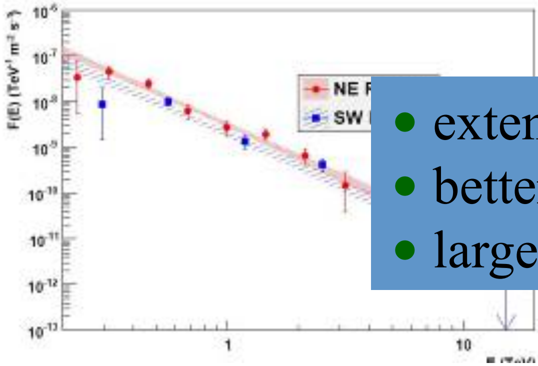
Moon shadow observation mode developed for the MAGIC telescopes [MAGIC ICRC 2011]

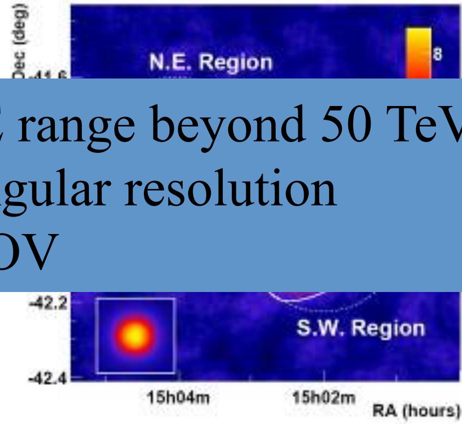


sensitivity (50h): 300-700GeV: ~4.4% Crab
measurement possible in few years

A wish list for the future

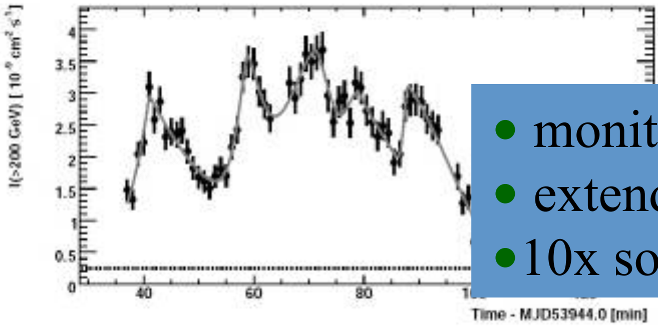
- Galactic sources & CR





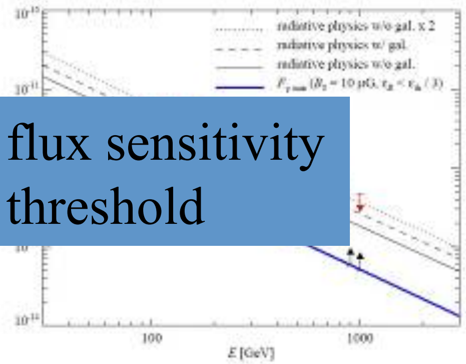
- extend E range beyond 50 TeV
- better angular resolution
- larger FOV

- AGN & gamma prop.



- monitor many objects simult.
- extend E range under 50 GeV
- 10x sources

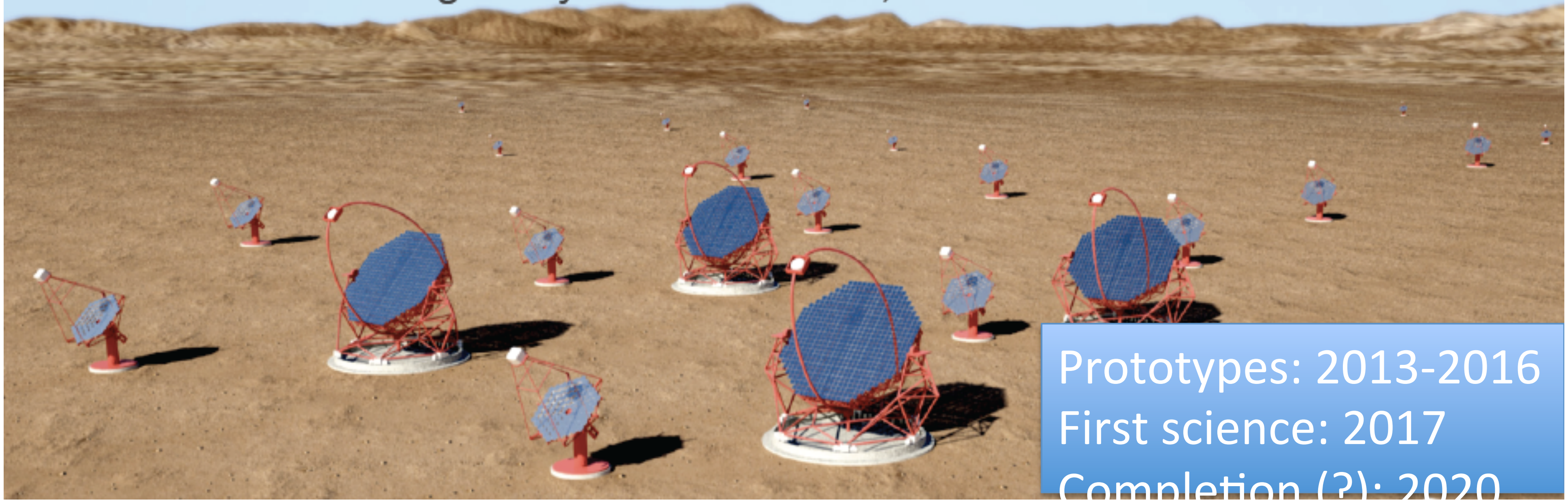
- New particles, new phenomena
  - dark matter and astroparticle physics



- better flux sensitivity
- lower threshold

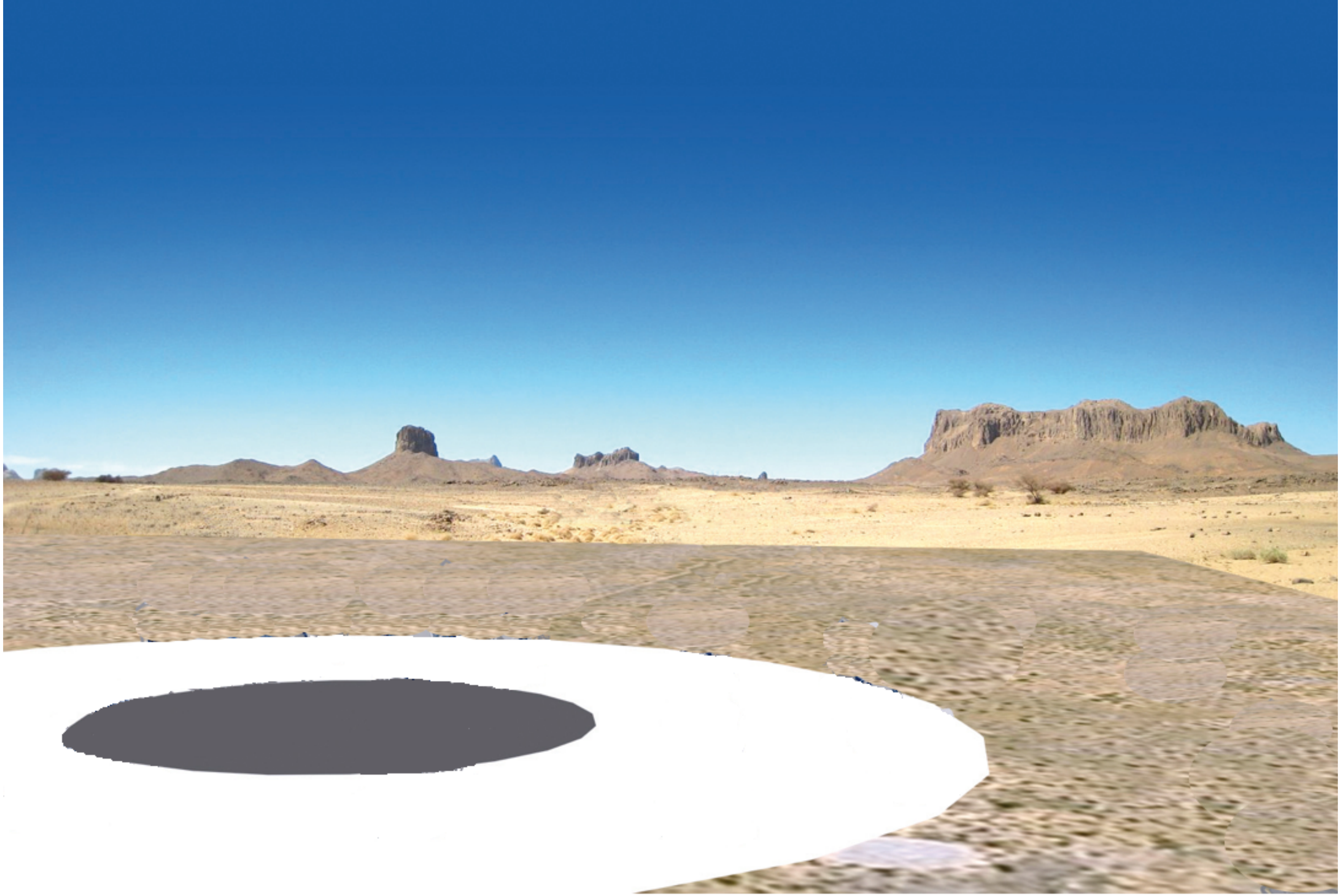
The Cherenkov Telescope Array

- A huge improvement in all aspects of performance
  - A factor ~10 in sensitivity, much wider energy coverage, much better resolution, field-of-view, full sky, …
- A user facility / proposal-driven observatory
  - With two sites with a total of >100 telescopes
- A 27 nation ~€200M project
  - Including everyone from HESS, MAGIC and VERITAS



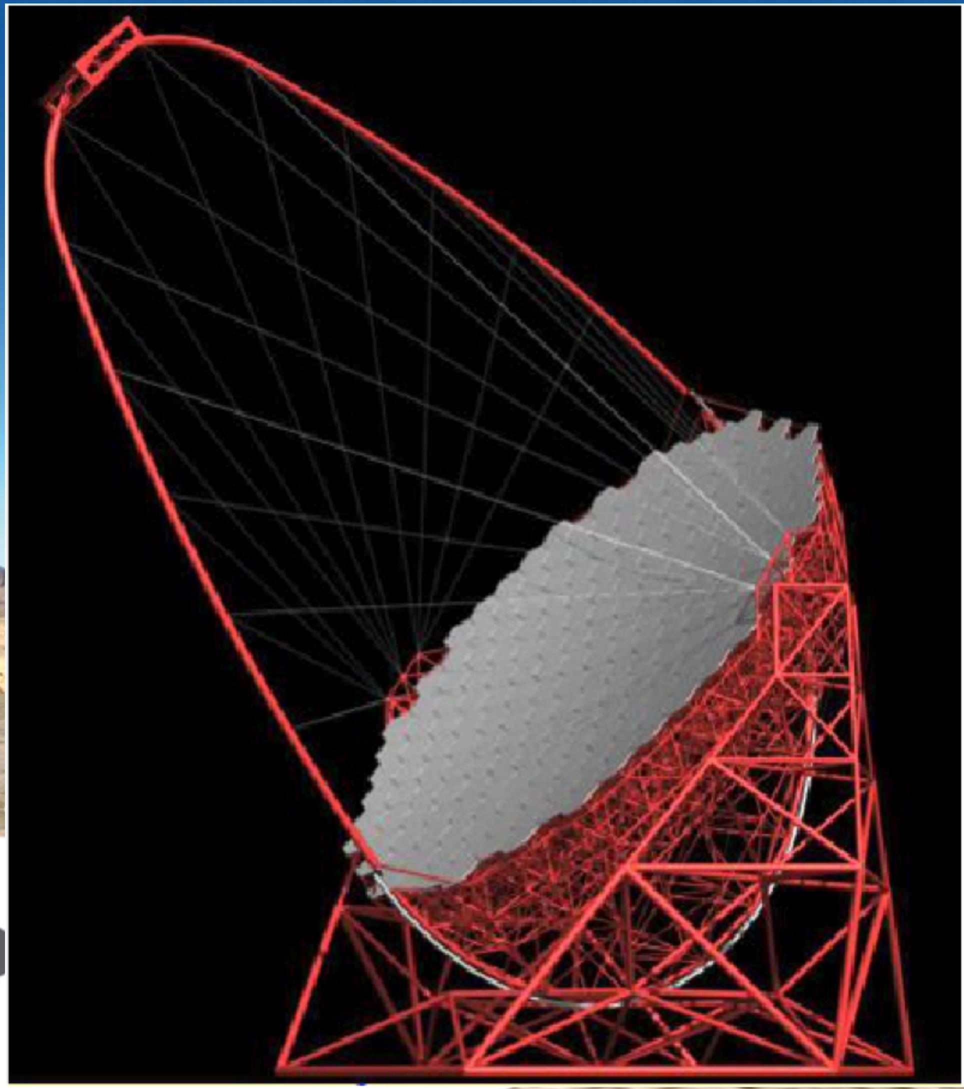
Prototypes: 2013-2016
First science: 2017
Completion (?): 2020

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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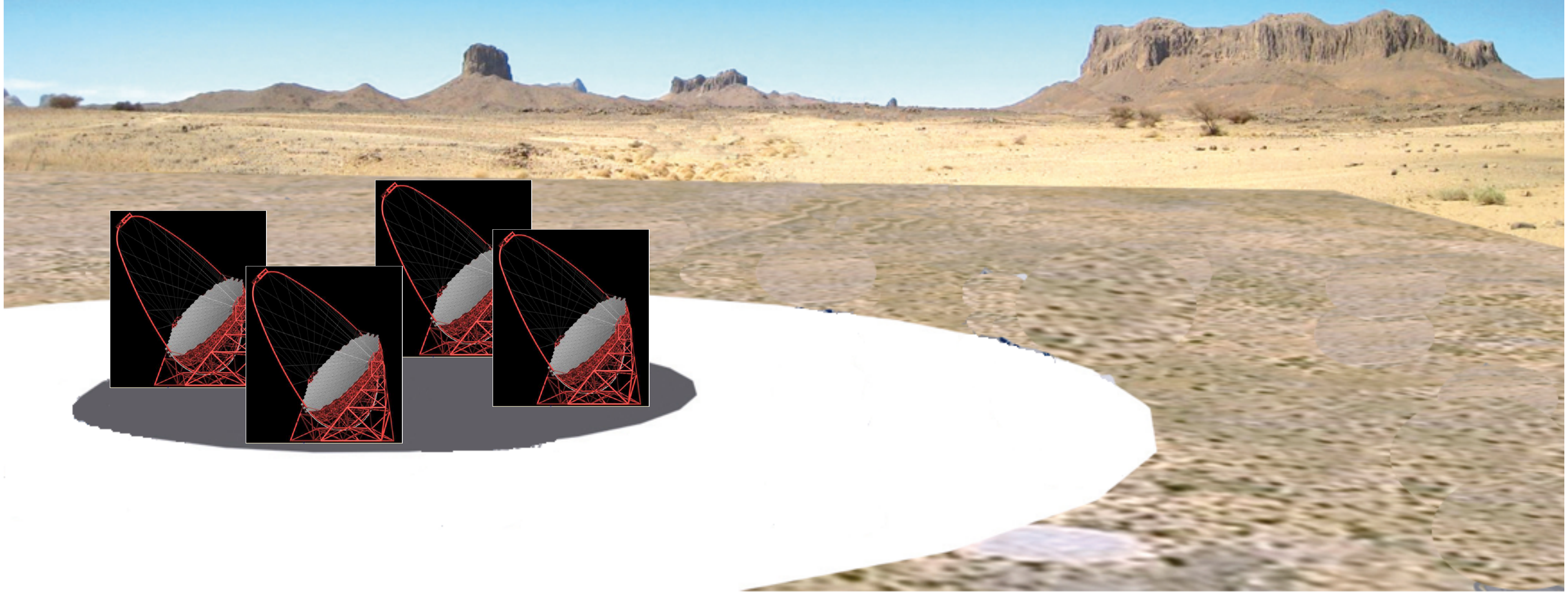


The Cherenkov Telescope Array concept

Medium energy

About twenty 12 m telescopes

~8° FoV

~2000 pixels

~ 0.2°

The Cherenkov Telescope Array concept

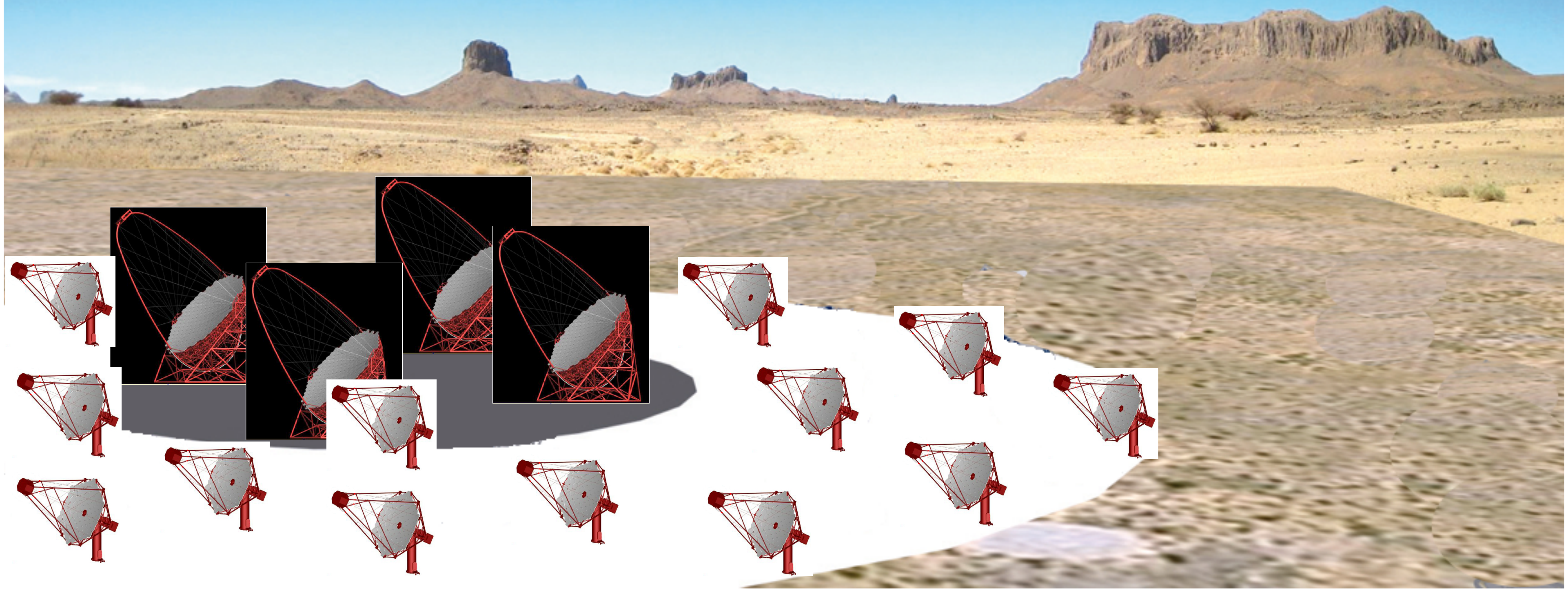
Medium energy

About twenty 12 m telescopes

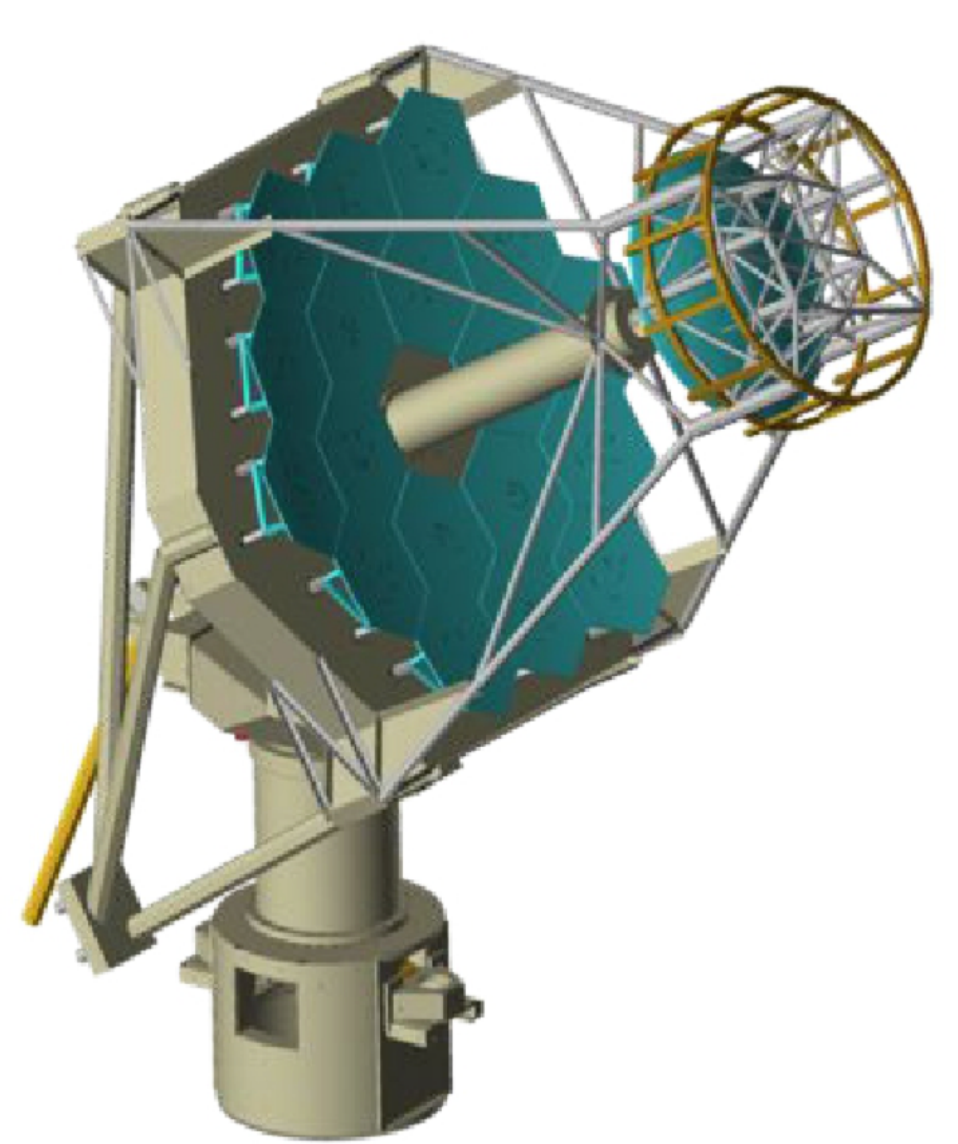
~8° FoV

~2000 pixels

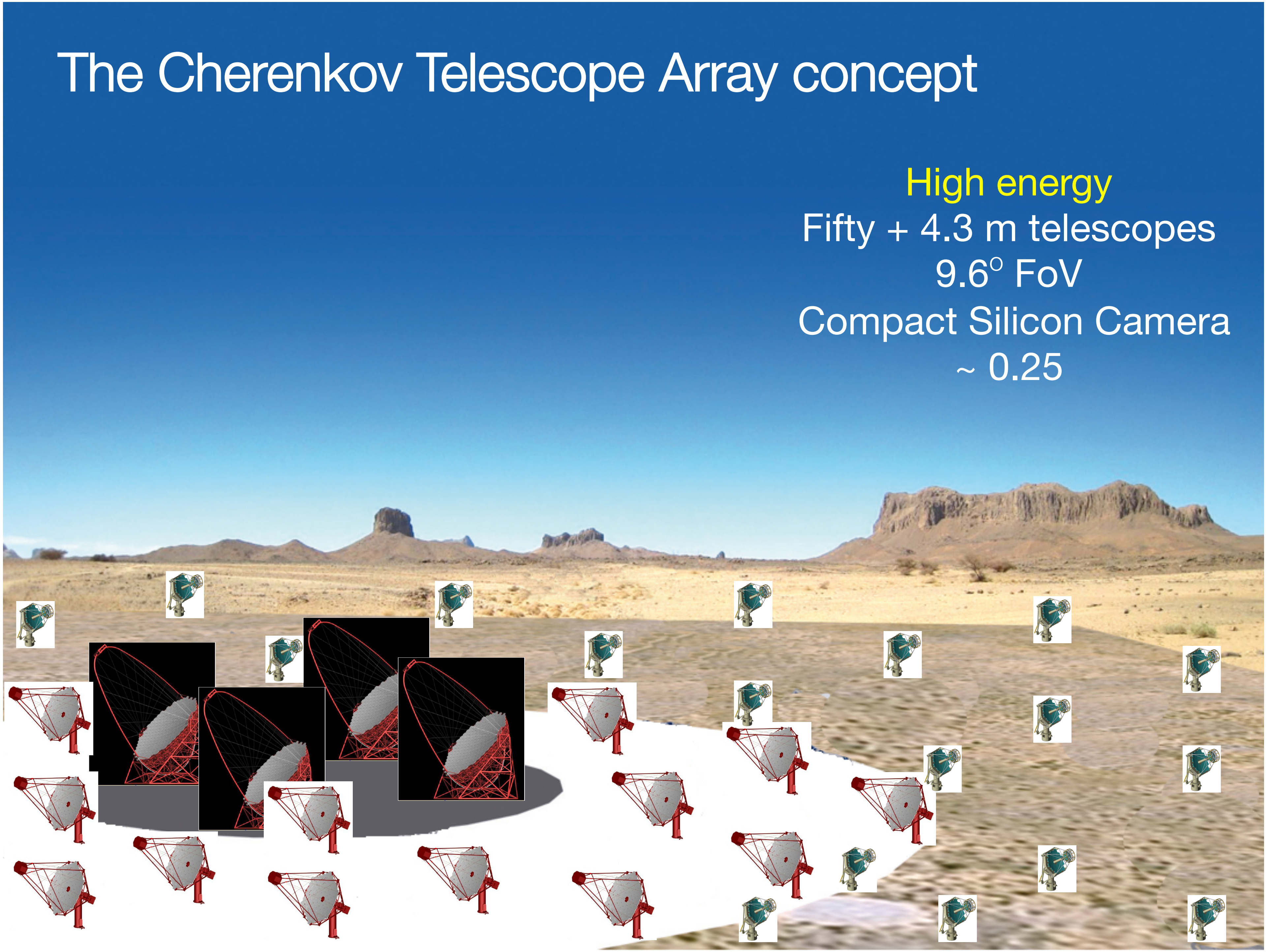
~ 0.2°



The Cherenkov Telescope Array concept



High energy
Fifty + 4.3 m telescopes
9.6^{o} FoV
Compact Silicon Camera
~ 0.25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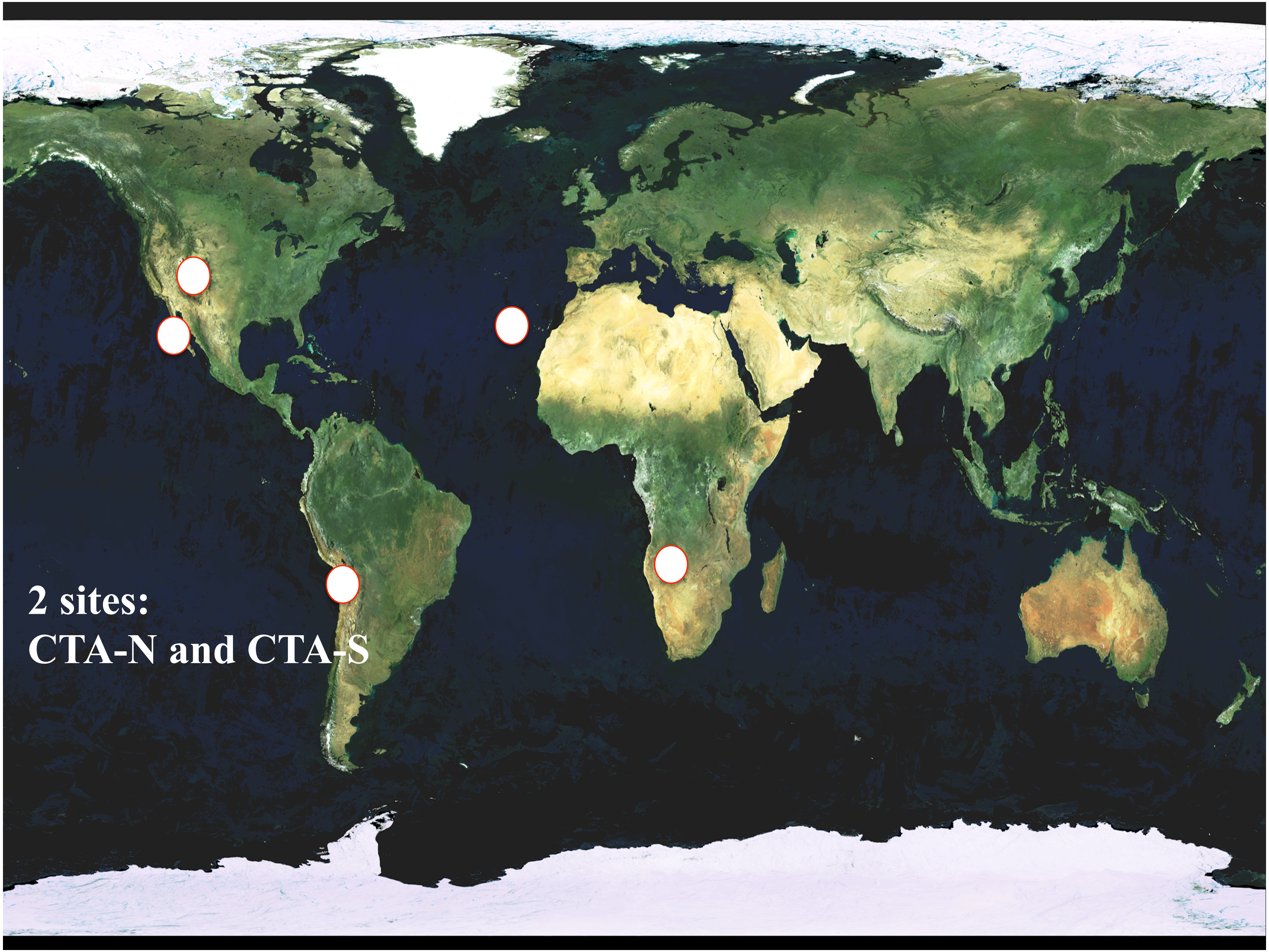
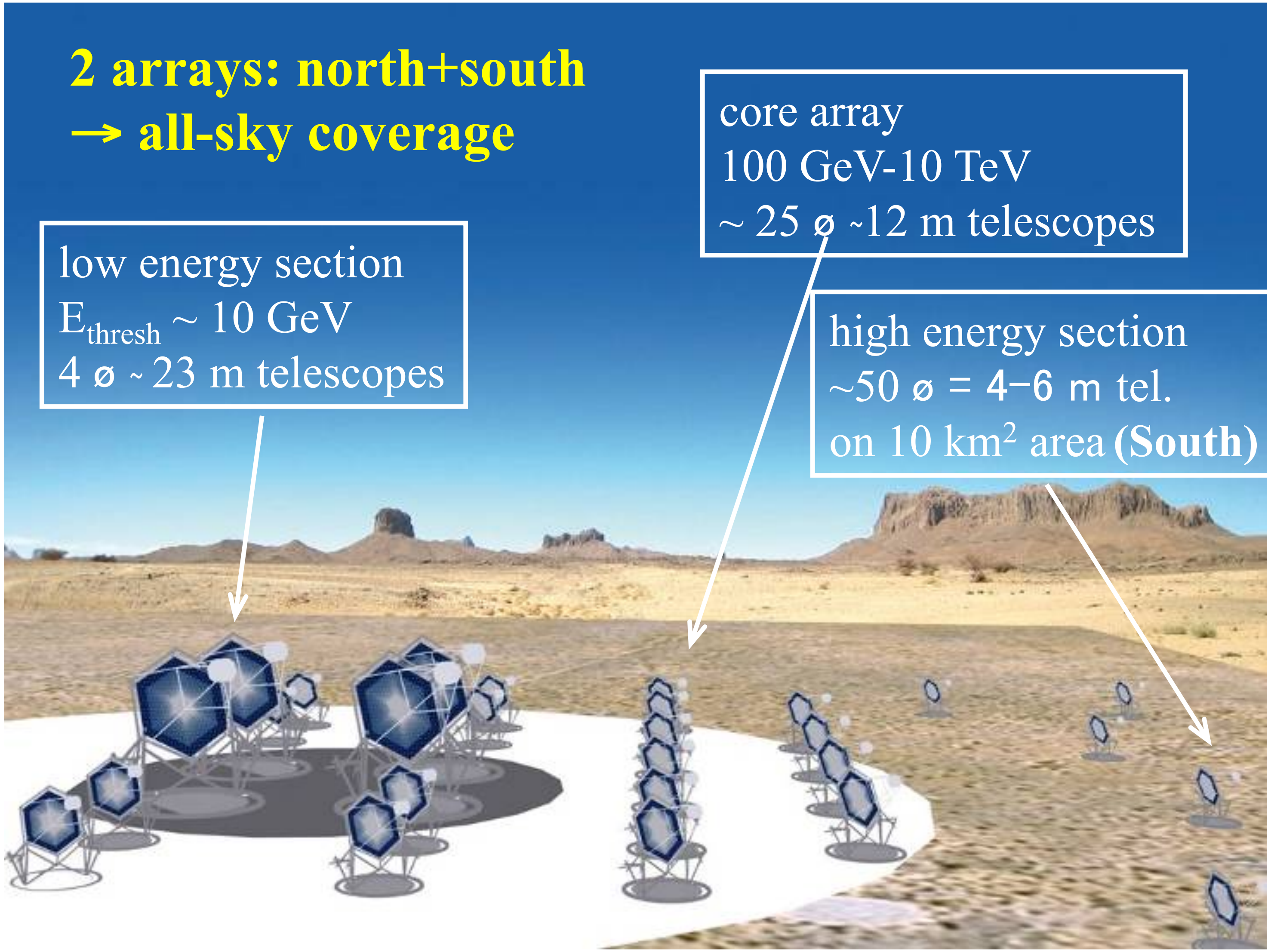
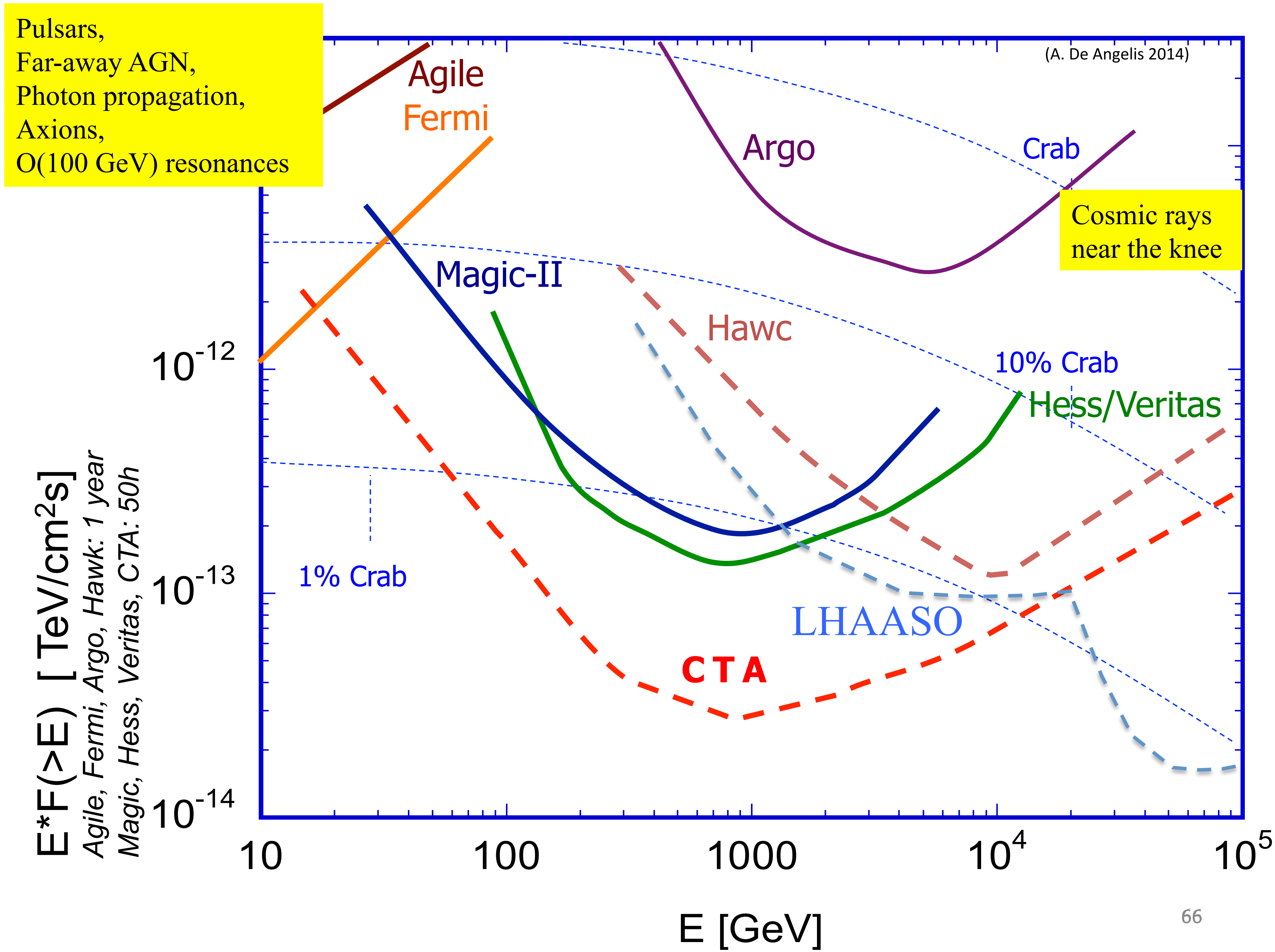
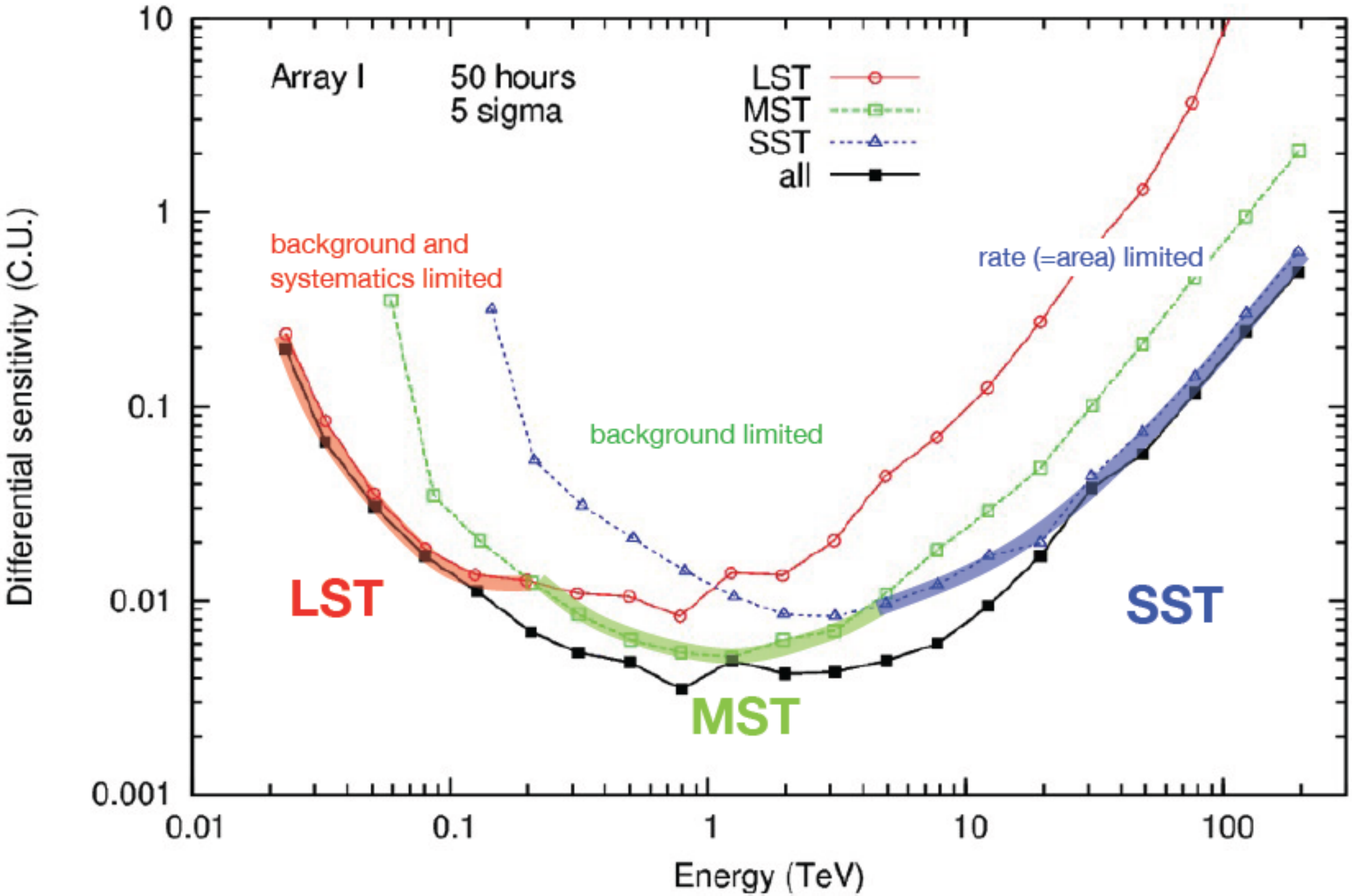

2 sites:
CTA-N and CTA-S

The CTA concept (a possible design)




Pulsars,
Far-away AGN,
Photon propagation,
Axions,
O(100 GeV) resonances
(A. De Angelis 2014)
Agile
Fermi
Argo
Crab
Cosmic rays near the knee
Magic-II
Hawc
10% Crab
Hess/Veritas
1% Crab
LHAASO
CTA
E*F(>E) [TeV/cm2s]
Agile, Fermi, Argo, Hawk: 1 year
Magic, Hess, Veritas, CTA: 50h
10-12
10-13
10-14
10
100
1000
104
105
E [GeV]

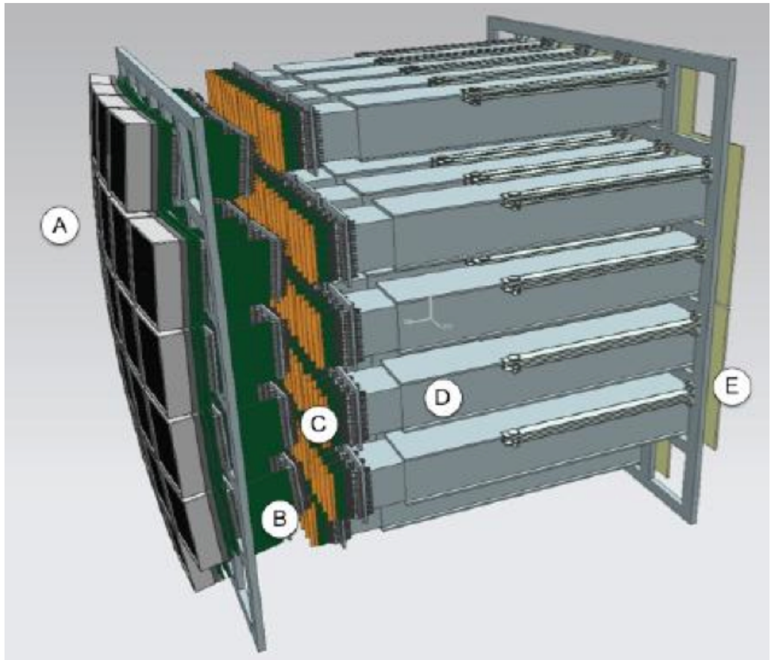
Large/Medium/Small Size Telescopes in CTA

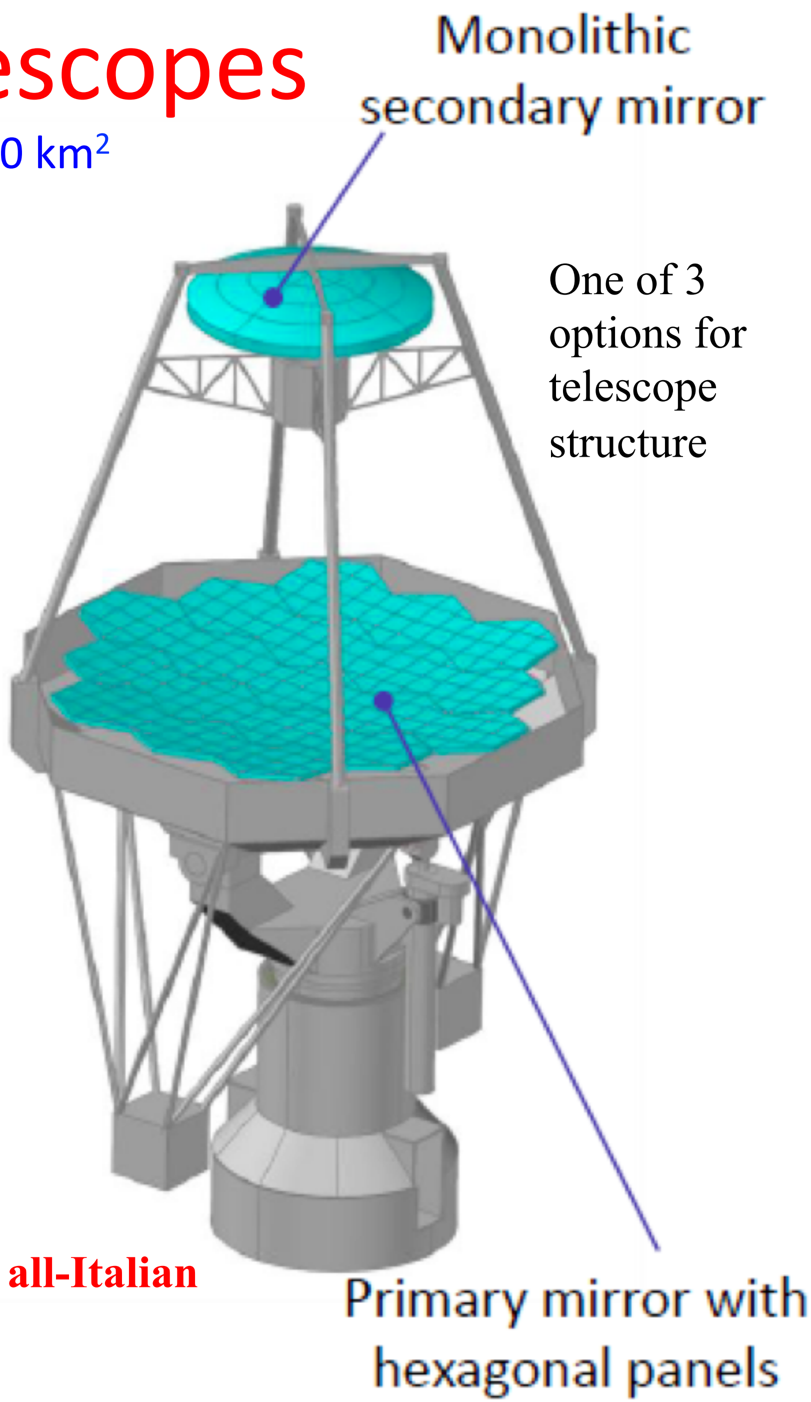


Dual-mirror 4-6 m Telescopes

cover the range above few TeV across 10 km^2

PMT camera option



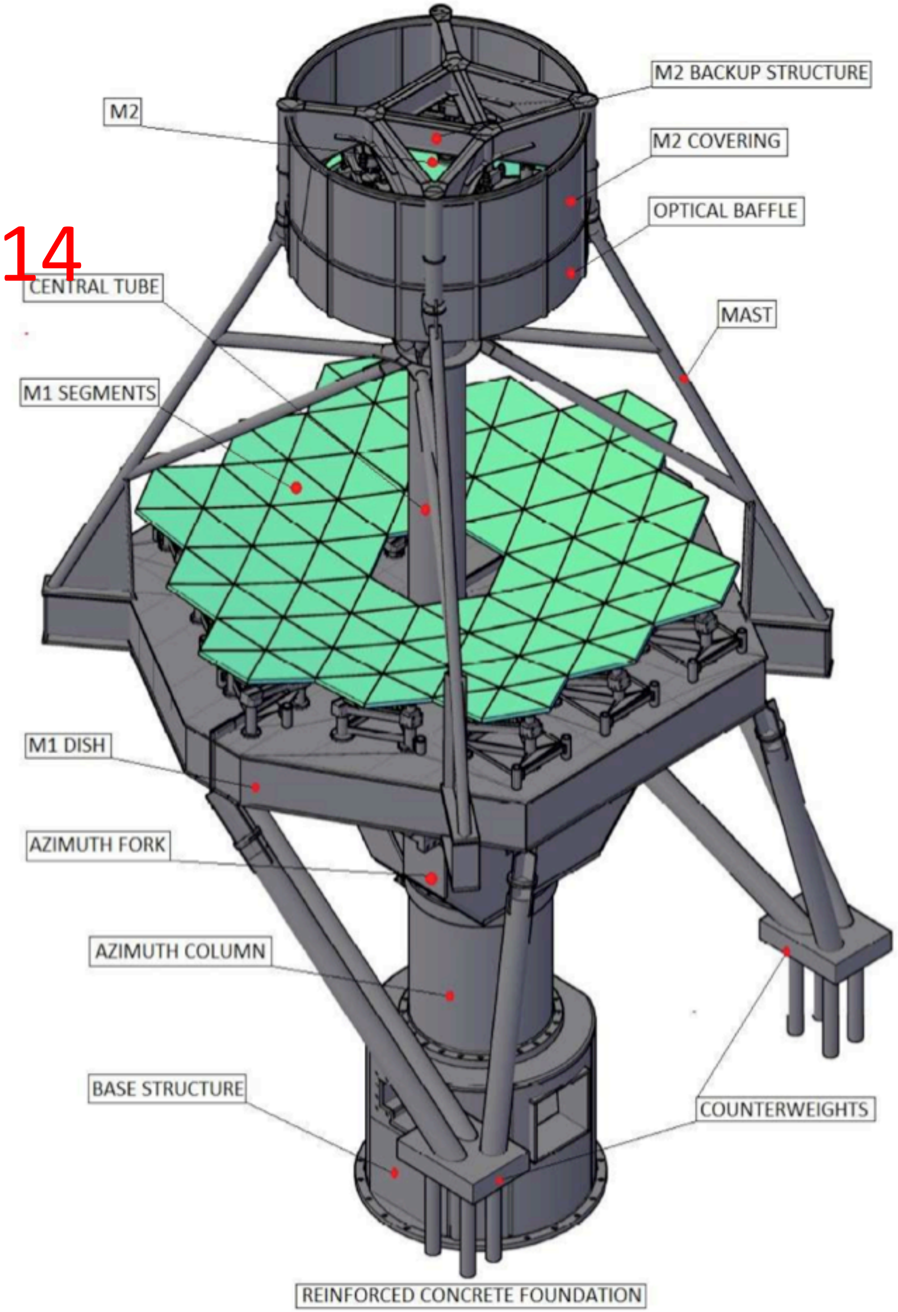


Under study:
dual-mirror optics with compact photo sensor arrays
Si-based sensors
➜ Not yet conclusive which solution is most cost-effective

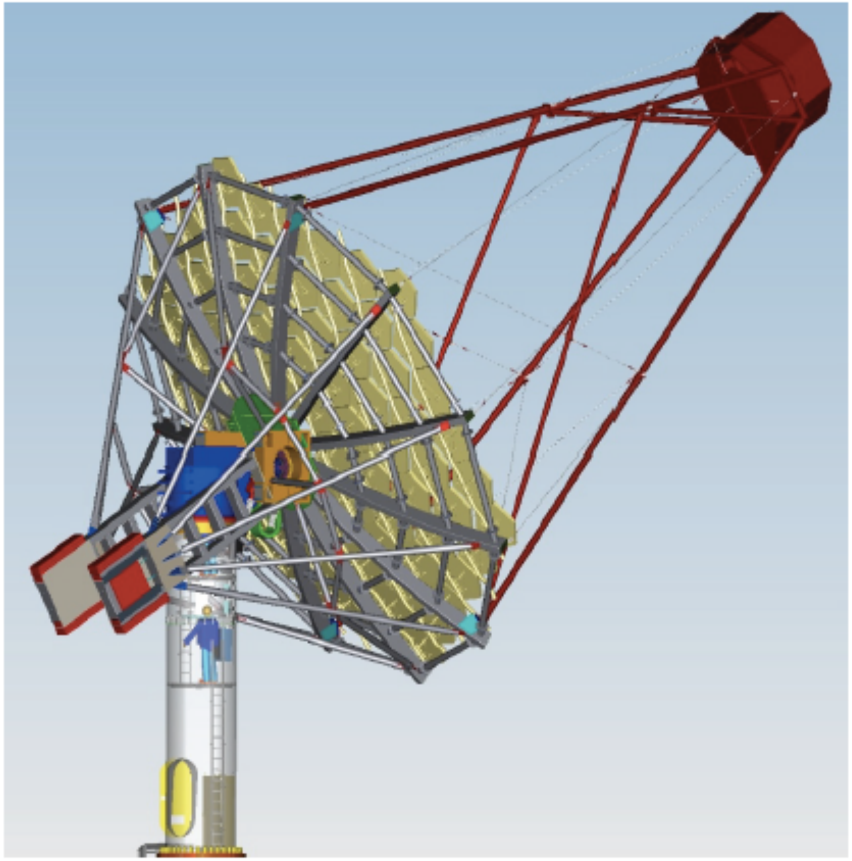
INAF prototype (ASTRI) ready soon, INFN working on all-Italian camera & electronics (TECHE)

A demonstrator: the ASTRI telescope (INAF) Mechanical prototype in 2014

- Camera diam. D_C = 36 cm, FoV = 9.6°
- Mechanics ready in September; prototype under Mount Etna
- Full prototype in 2015



The Medium size telescope

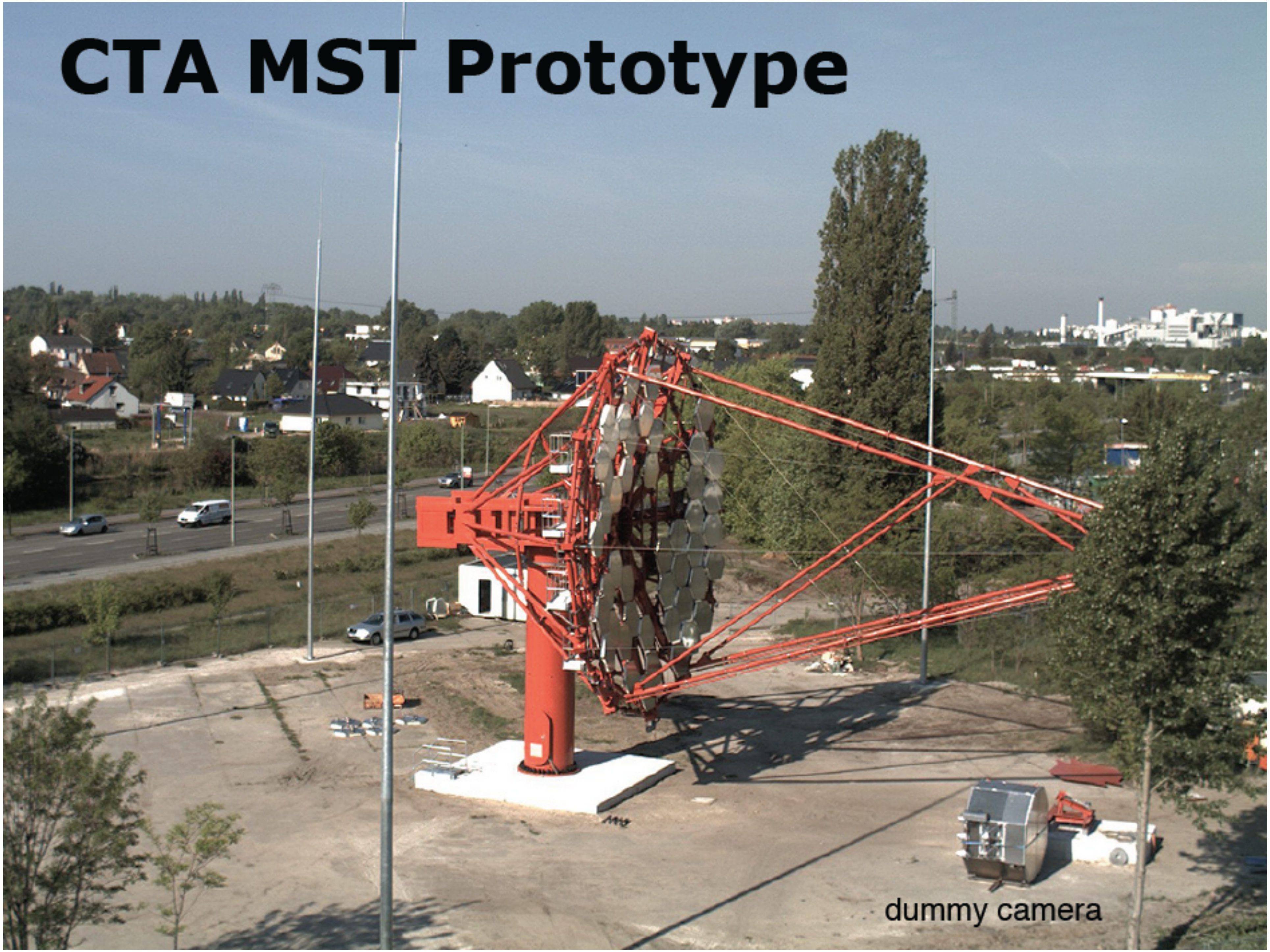


Hot numbers & parameters

- Diameter 12 m
- Focal length ~ 16.2 m.
- (Modified) Davies-Cotton optics.
- Camera support and dish in steel.
- Camera ~ 2 t.
- Central tower cheaper wrt rails
- Designed by ANL-DESY-CEA
- Prototype installed in Berlin by DESY

(camera is missing)

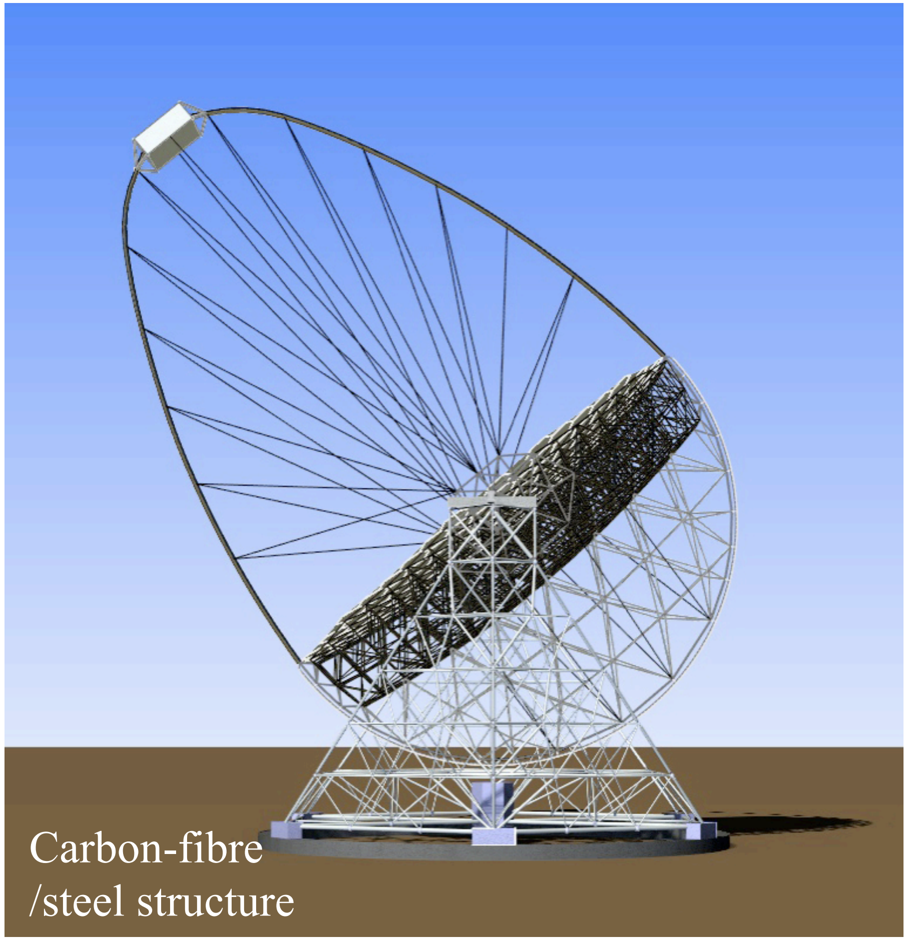
CTA MST Prototype



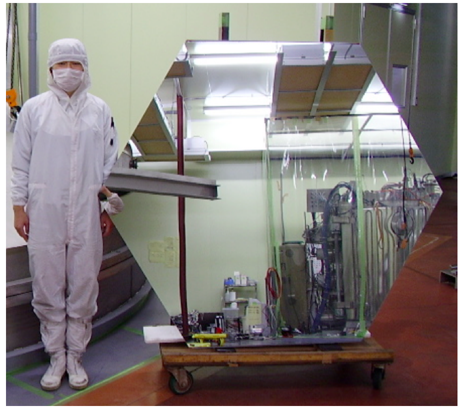
CTA: 23 m LST (precursor in 2016)

Japan/Germany/Spain/CNRS/INFN

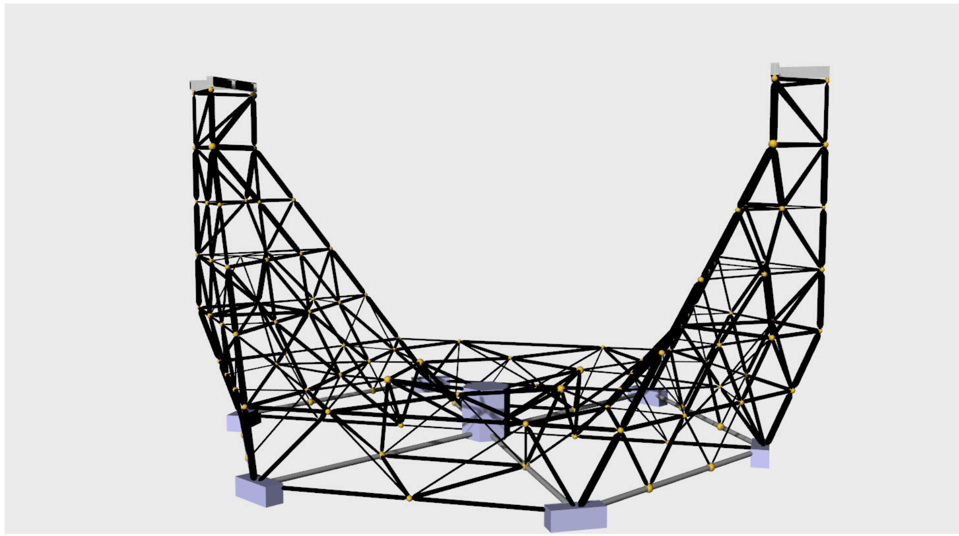
27.8 m focal length
4.5° field of view
0.1° pixels



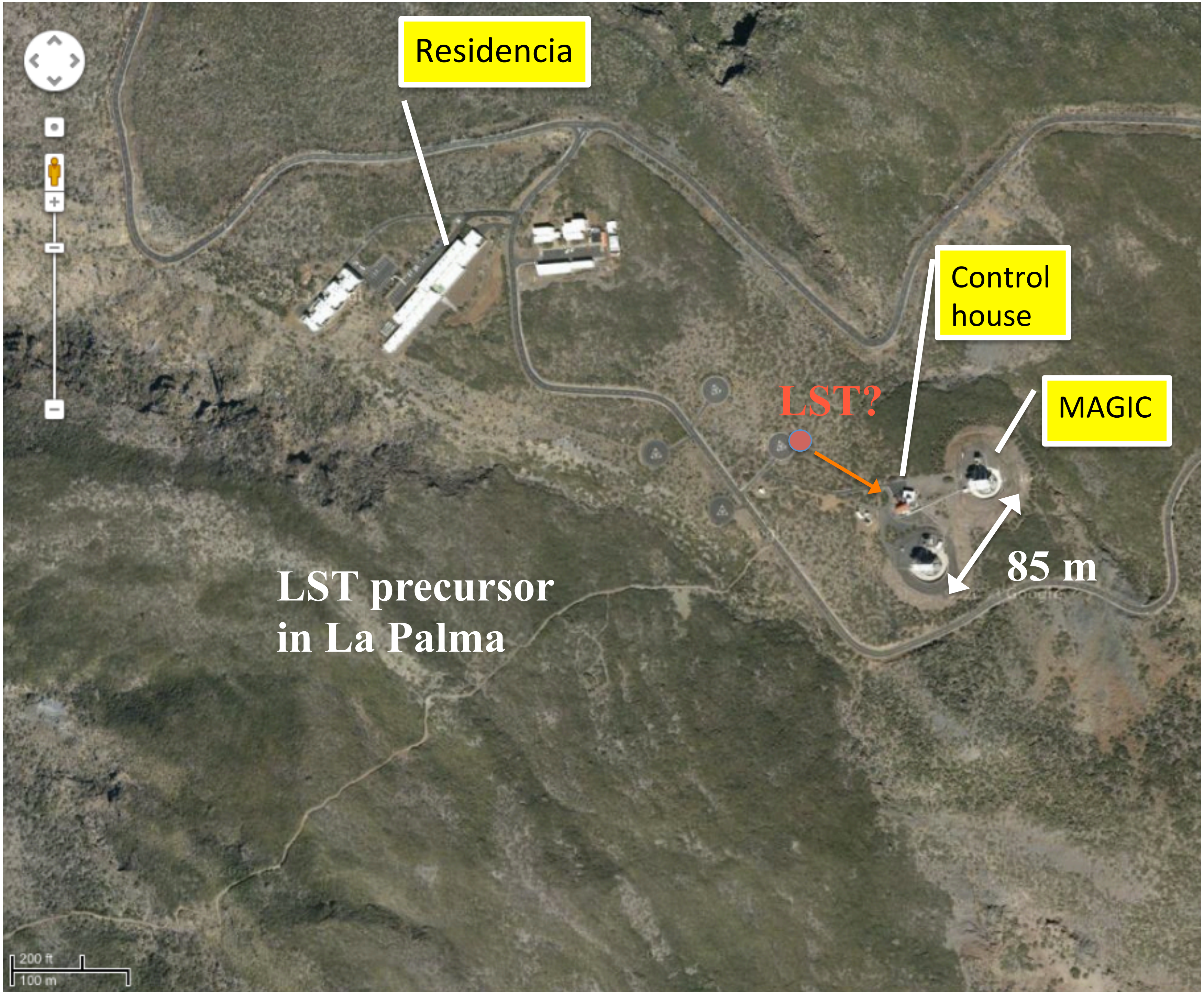
400 m^2 dish area
1.5 m sandwich
mirror facets

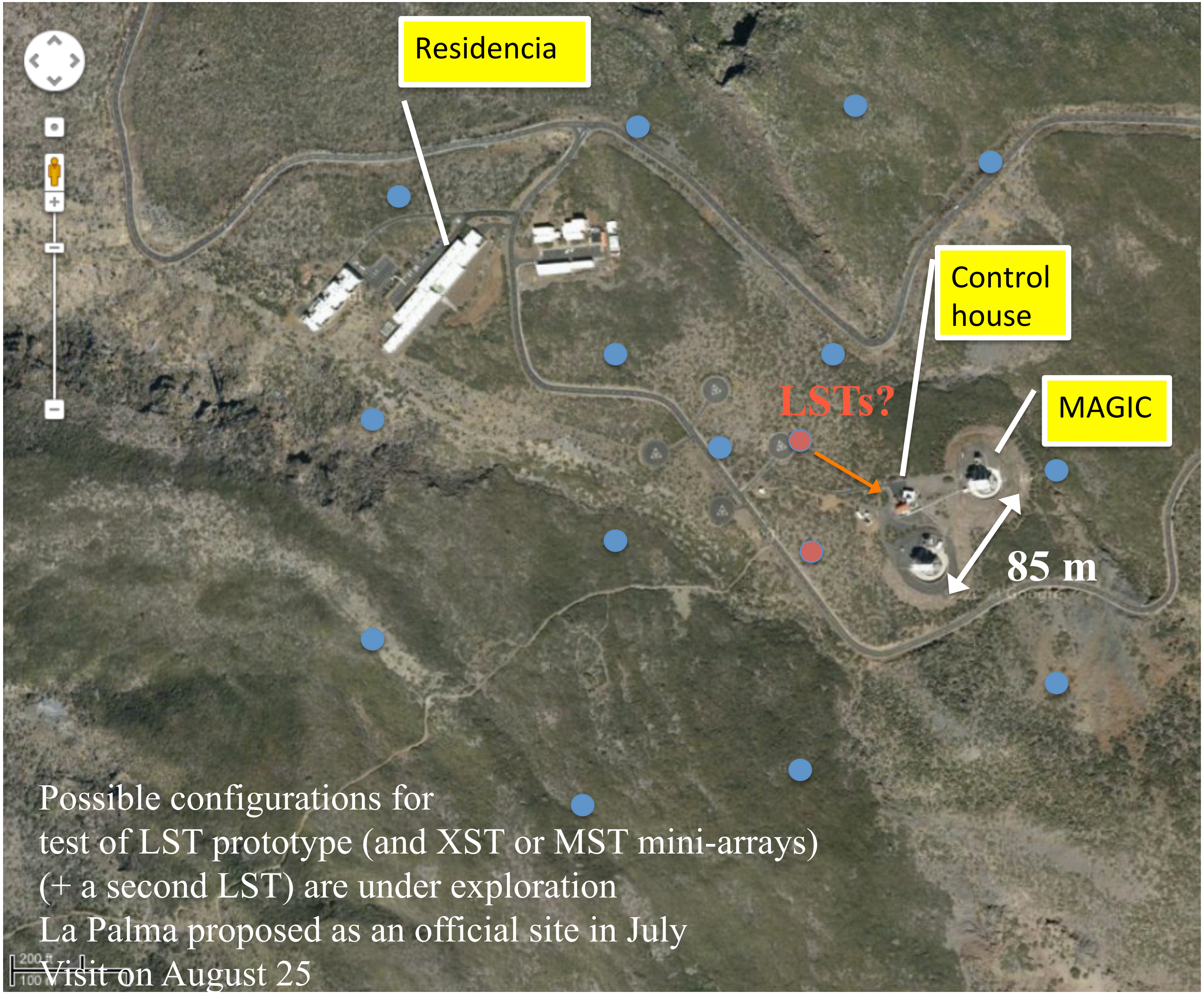


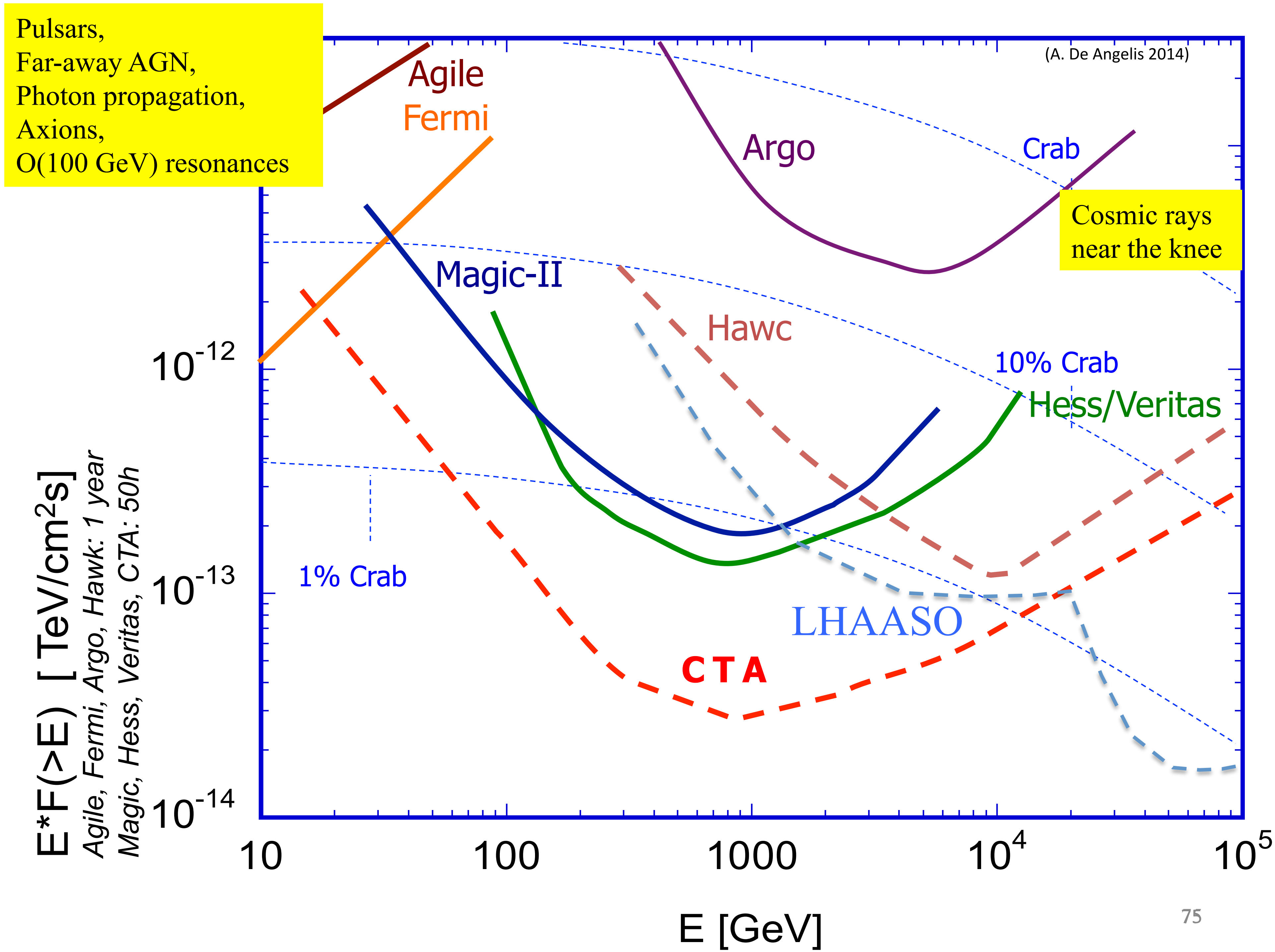
On (GRB) target
in < 20 s



INFN working on electronics, mechanics and a cluster for a possible SiPM camera & electronics


Residencia
Control house
MAGIC
LST?
85 m
LST precursor in La Palma
200 ft
100 m

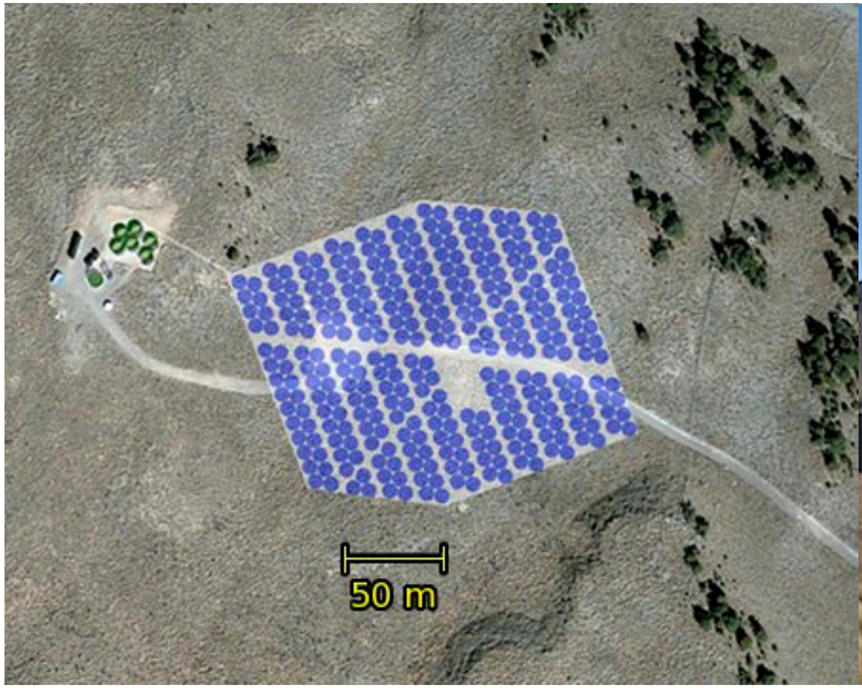

Residencia
Control house
MAGIC
LSTs?
85 m
Possible configurations for
test of LST prototype (and XST or MST mini-arrays)
(+ a second LST) are under exploration
La Palma proposed as an official site in July
Visit on August 25

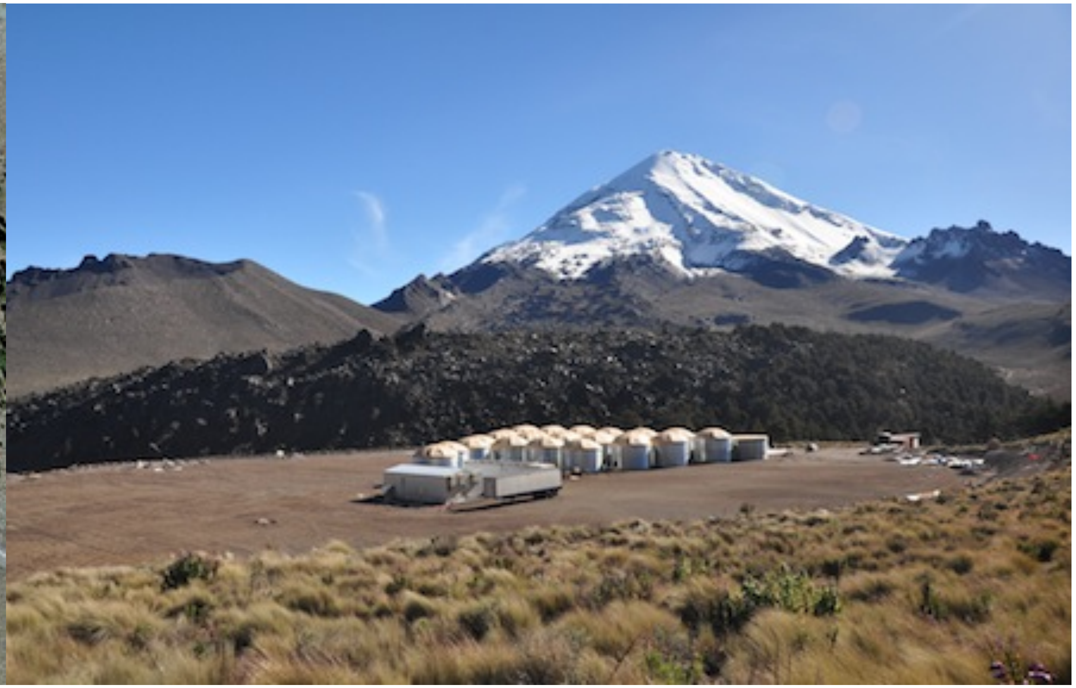


Pulsars,
Far-away AGN,
Photon propagation,
Axions,
O(100 GeV) resonances
(A. De Angelis 2014)
Agile
Fermi
Argo
Crab
Cosmic rays near the knee
Magic-II
Hawc
10% Crab
Hess/Veritas
1% Crab
LHAASO
CTA
10^{-12}
10^{-13}
10^{-14}
10
100
1000
10^4
10^5
E*F(>E) [TeV/cm^{2}s]
Agile, Fermi, Argo, Hawk: 1 year
Magic, Hess, Veritas, CTA: 50h
E [GeV]

HAWC

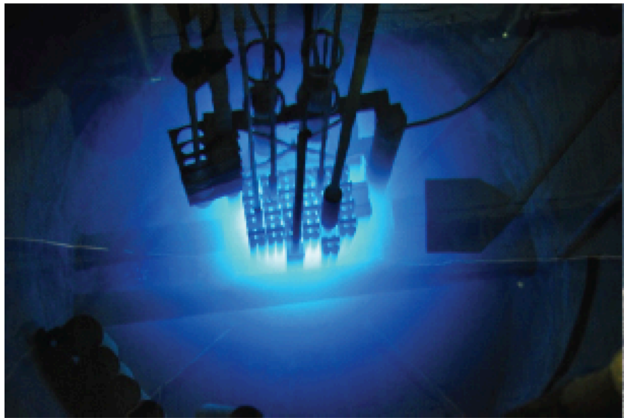
- EAS detectors have advantages on Cherenkov: duty cycle, serendipitous searches
- But the EAS up to now (Argo, Milagro, Tibet) were not sensitive enough
- The High-Altitude Water Cherenkov Observatory, or HAWC, is a facility designed to observe TeV gamma rays and cosmic rays with large FOV, with sensitivity better than 10% Crab in 1 year between 200 GeV and 100 TeV
- HAWC is under construction at 4100 m asl in Mexico

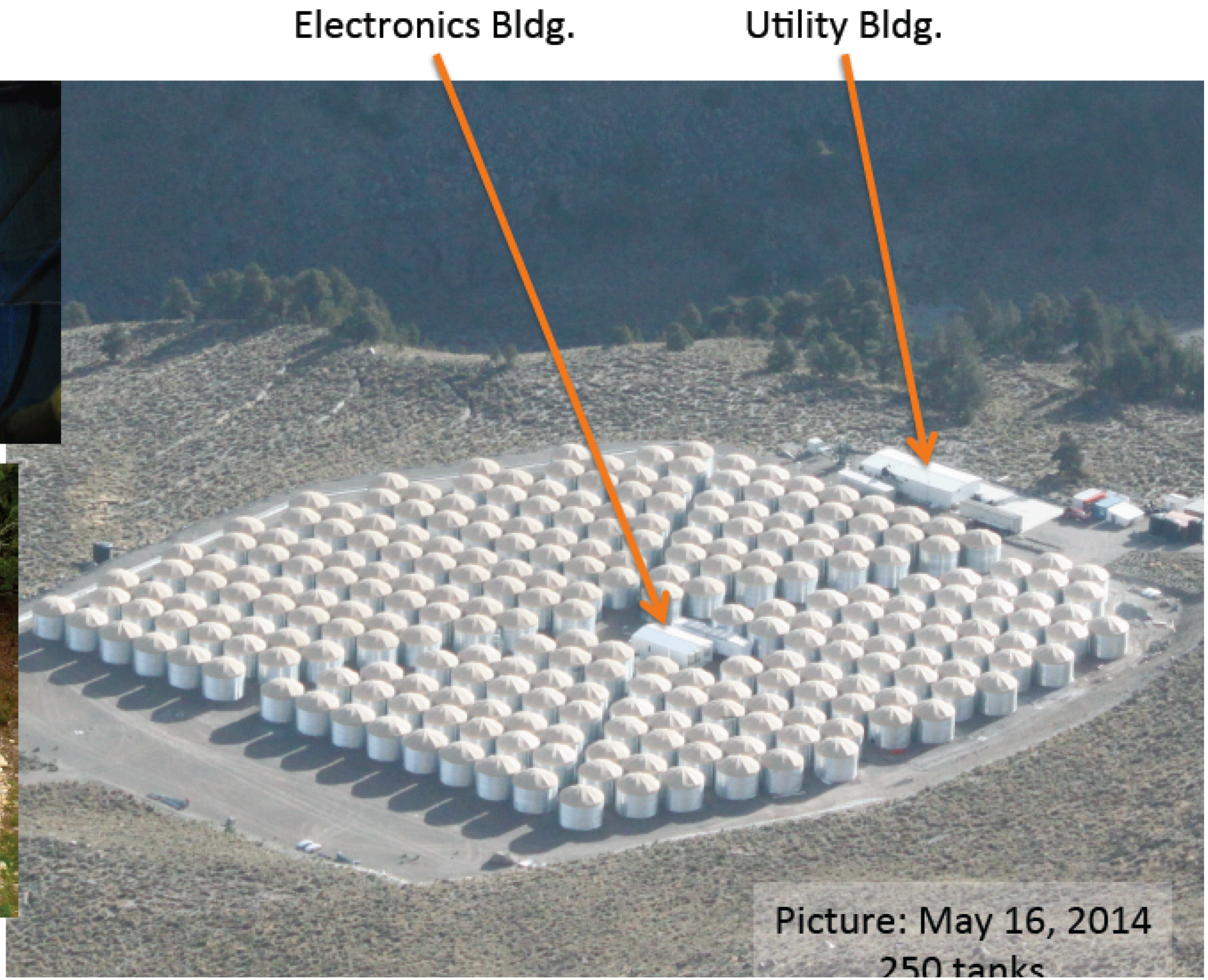




HAWC is almost complete…

HAWC 300 Water Tanks. 7.3 m (diam), 4.5 m deep. 20,000 m^2





Summary

- Clear interplay between VHE (γ) astrophysics and fundamental physics; this model of cooperation has worked well, and can work well in the future
- Cosmic Rays:
  - SNR as galactic sources established
- Still no detection of DM
- Many new things to discover, some in a clear scenario; few clouds (photon propagation?) might hide new physics
- Rich fundamental science (and astronomy/astrophysics) from gamma rays
  - HEA is exploring regions beyond the reach of accelerators
  - A "simple" extension of present detectors is in progress: CTA
- Technology and phenomenology are the key ingredients for this rich new science
  - A genuine astroparticle topic