Gamma astronomy with HESS/CTA

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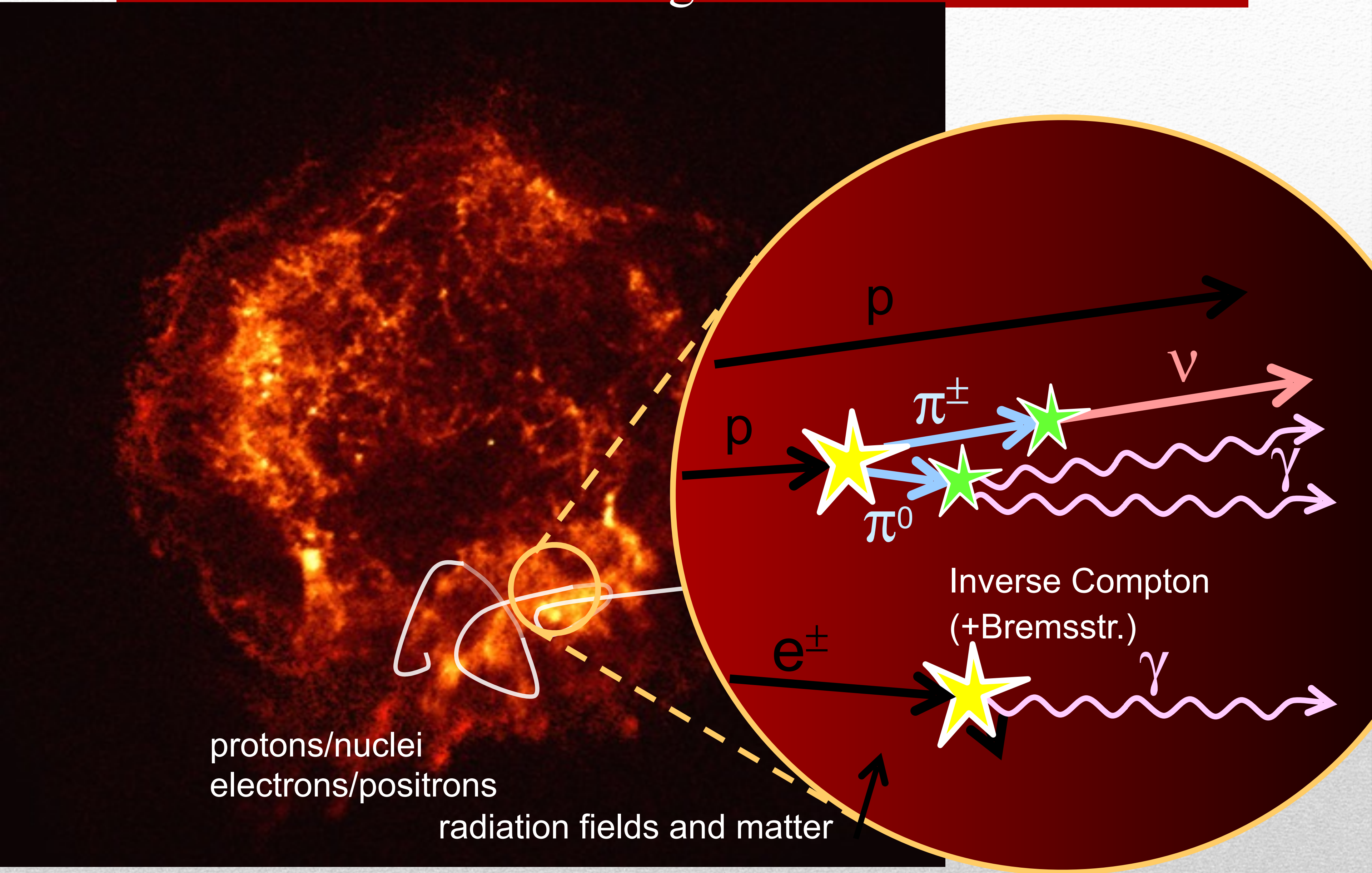
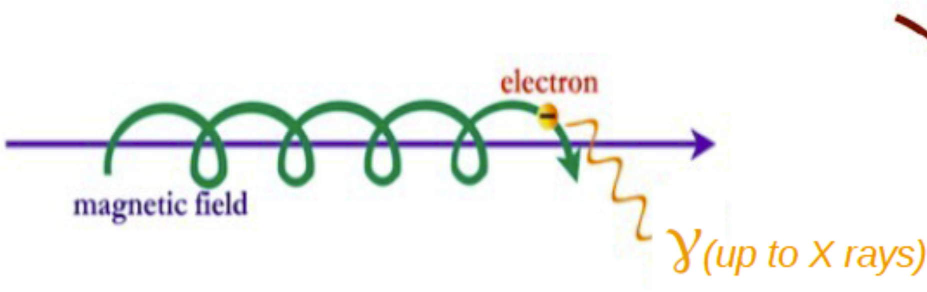
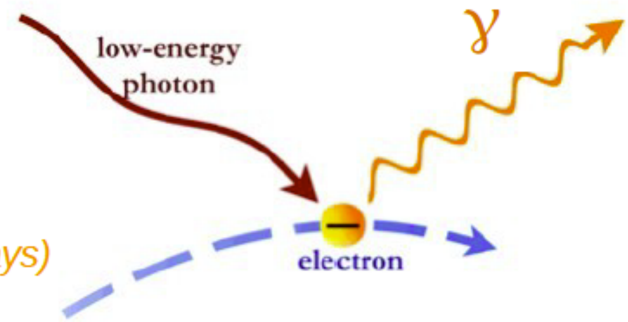
Connection CR-gamma-neutrino



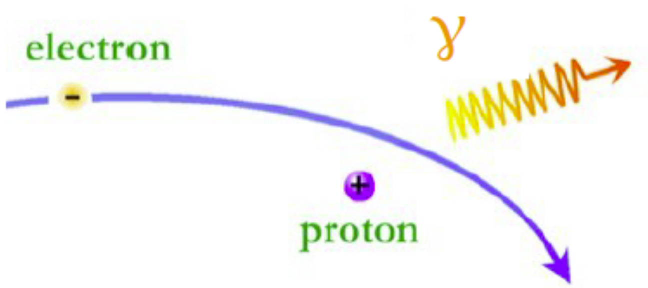
(Non-thermal) mechanisms of gamma-ray production



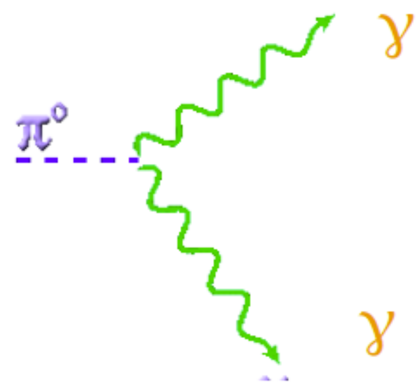
(1) Synchrotron (electromagnetic)



(2) Inverse Compton (electromagnetic)



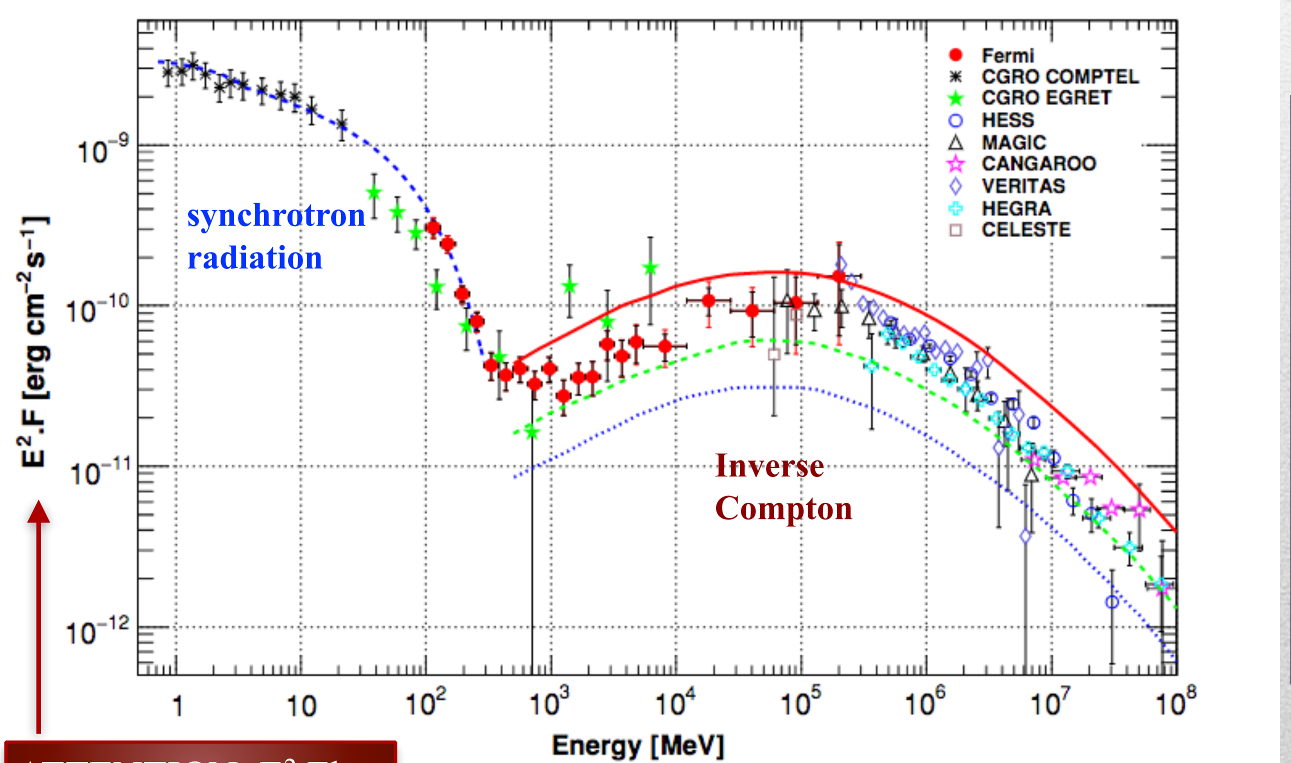
(3) Bremsstrahlung (electromagnetic)



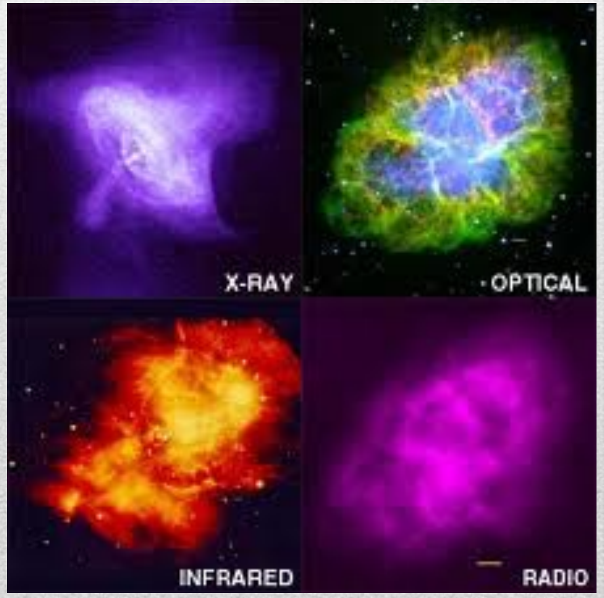
(4) Pion decay (hadronic)

Gamma sources: The Crab nebula: a reference

It is the remnant of a supernova observed in 1054, that was visible during the day for 6 weeks.
A fast rotating neutron star (PULSAR) is what remains of this supernova explosion : diameter of 20 km and rotation period of 30 tours/s.
The x-rays images show the acceleration regions (synchrotron radiation)
Particles are the reaccelerated in the shockwaves with the surrounding gas, producing TeV gamma rays (Inverse Compton mechanism)

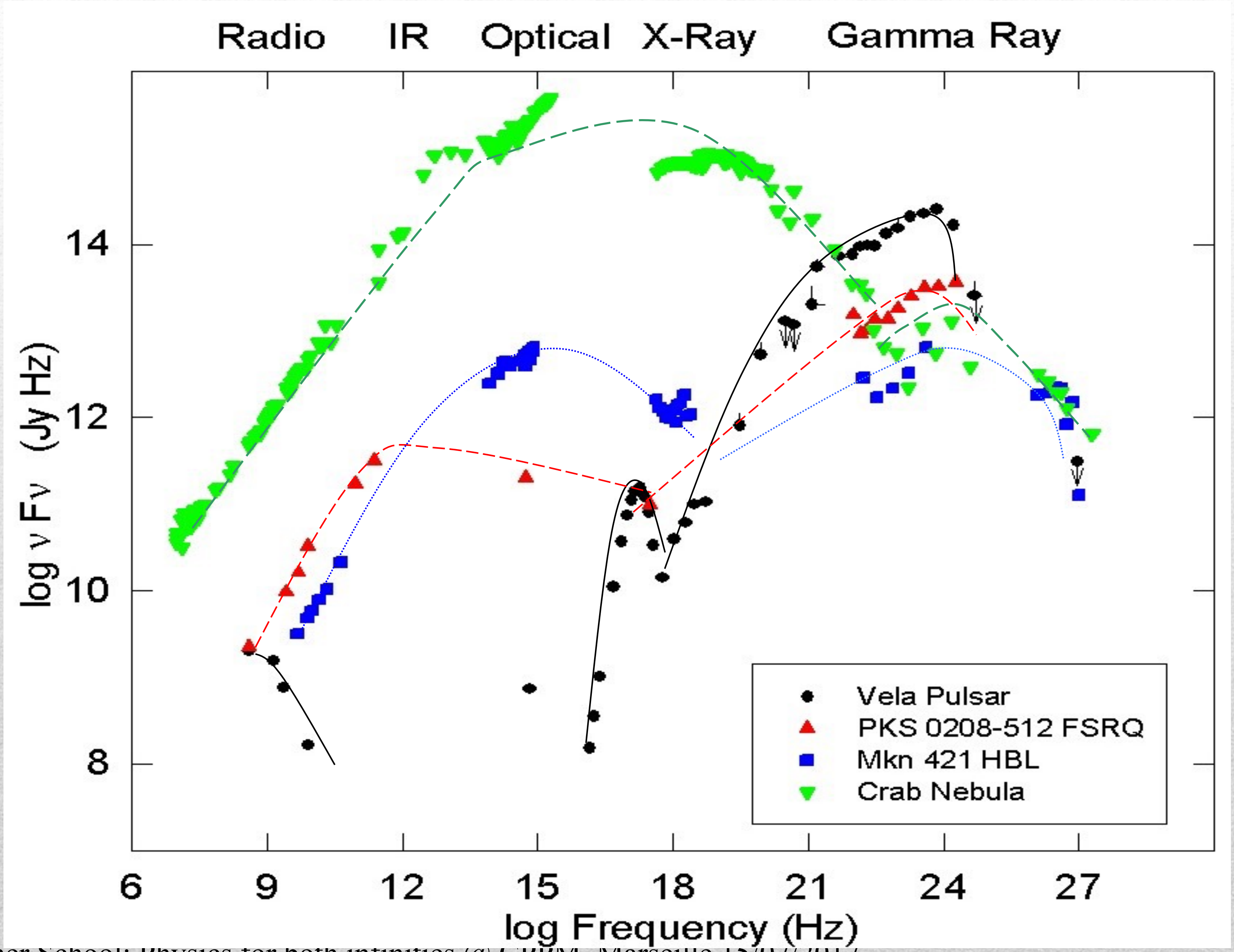


ATTENTION: E^2 Flux



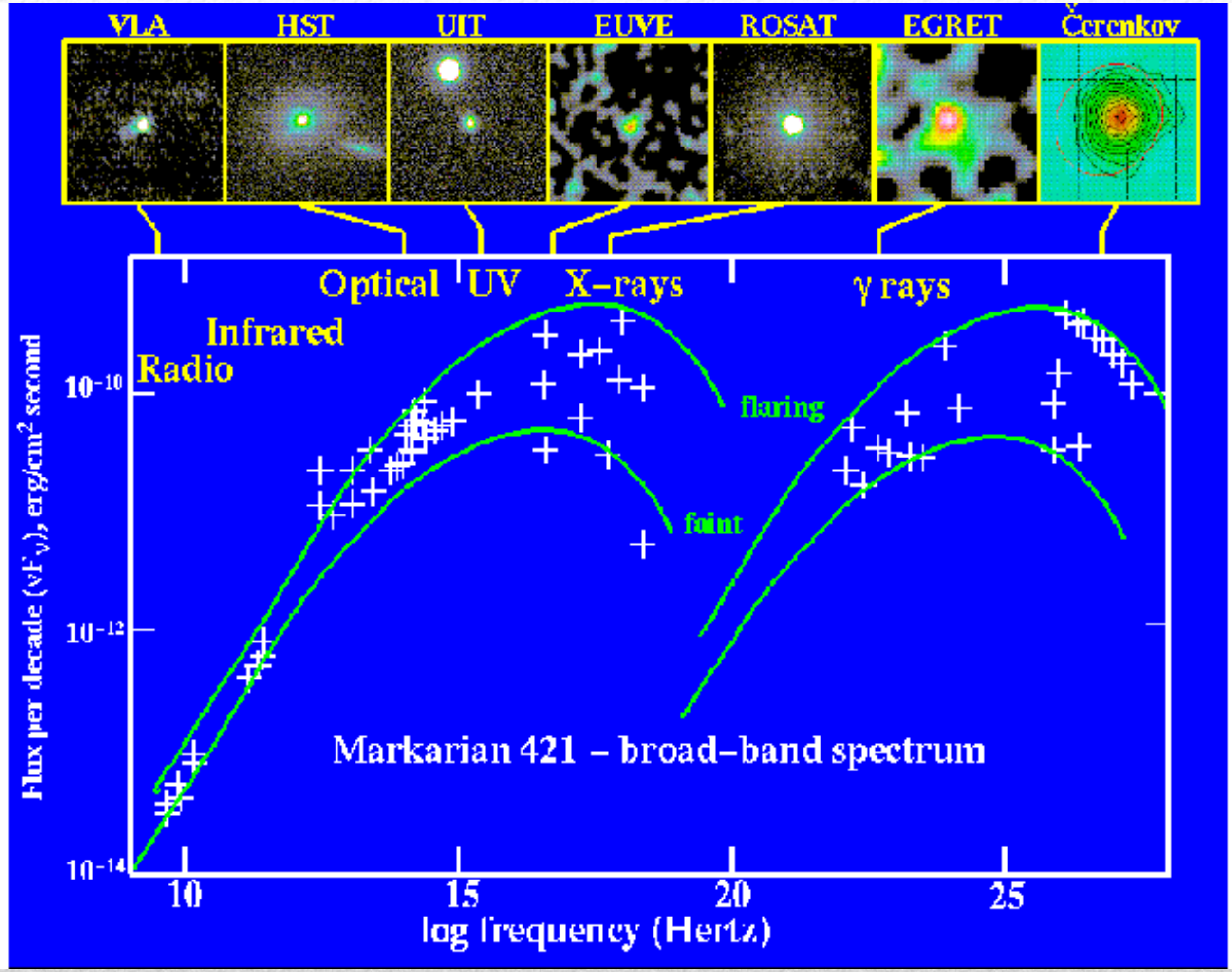
Multiwavelength observation

Gamma sources emit also in other wavelength

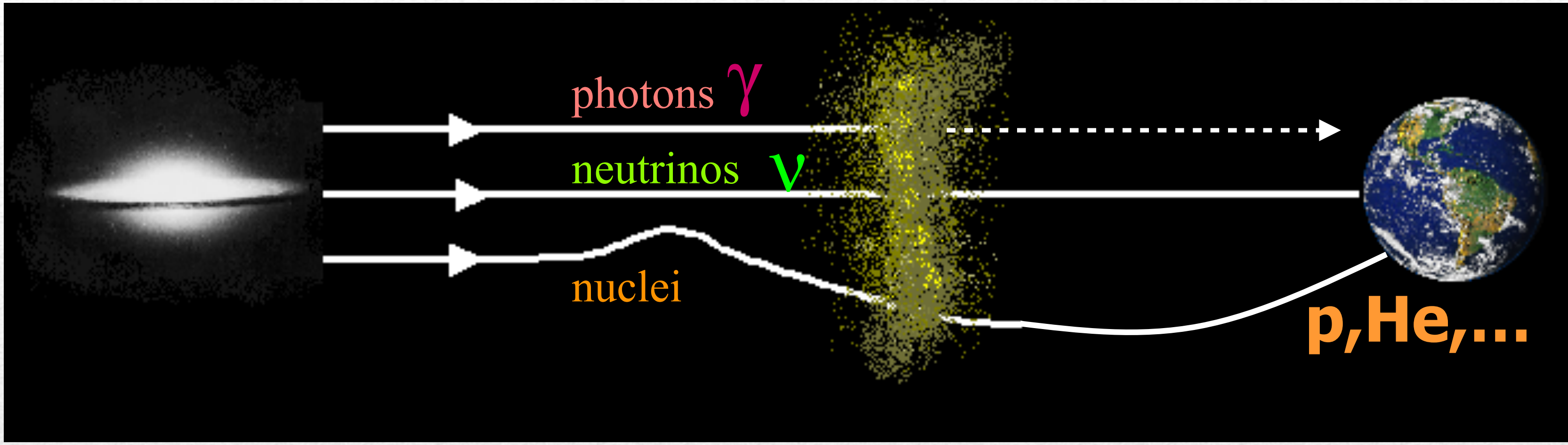


Multiwavelength observation

Mkn421(AGN) in different wavelengths



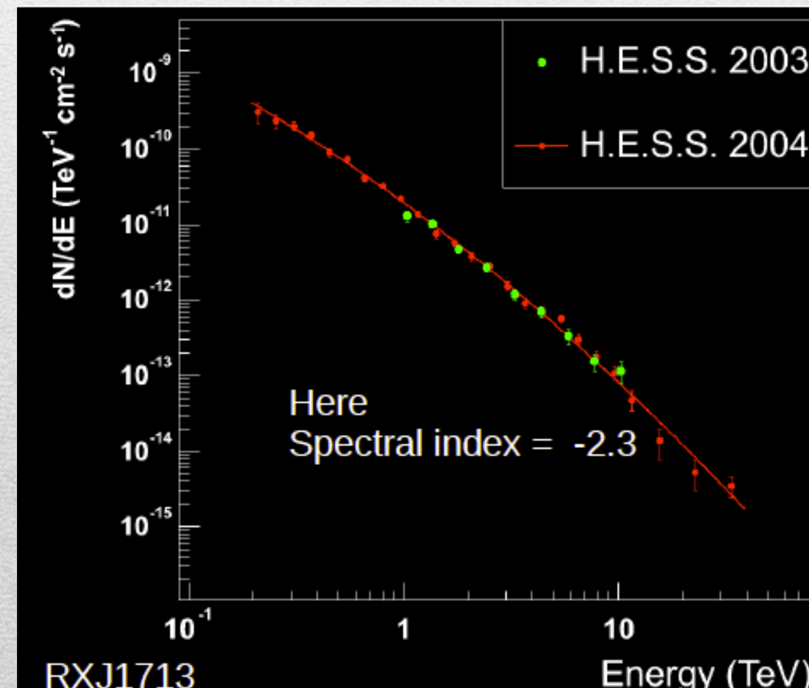
Which are the messengers?



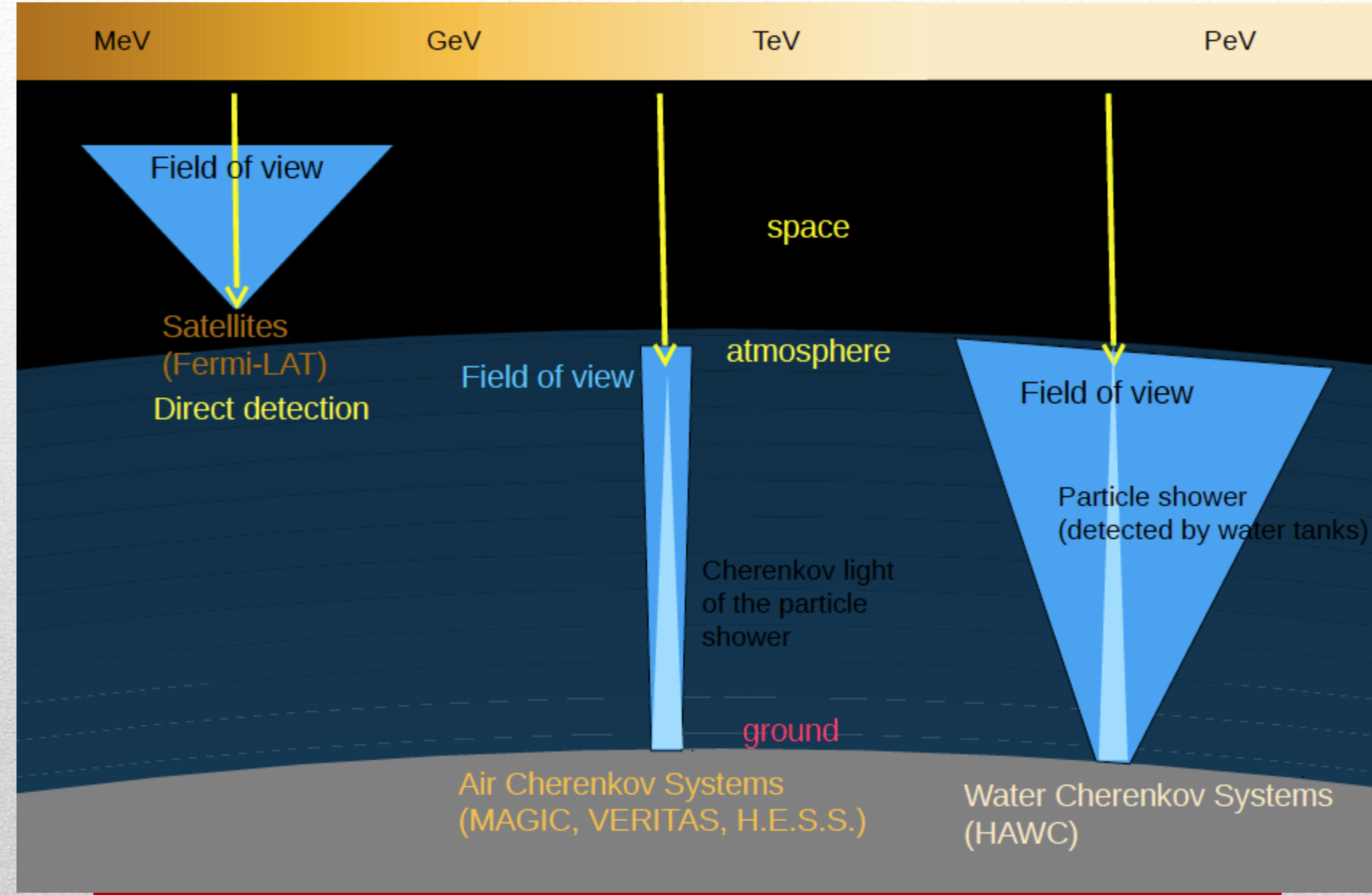
99 % nuclei
- 89% protons
- 10% helium
- 1% heavier nuclei (Fe, …)

1 % electrons

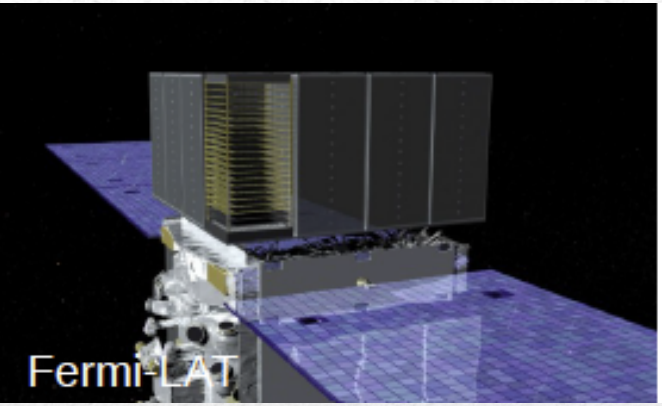
0.1 % photons

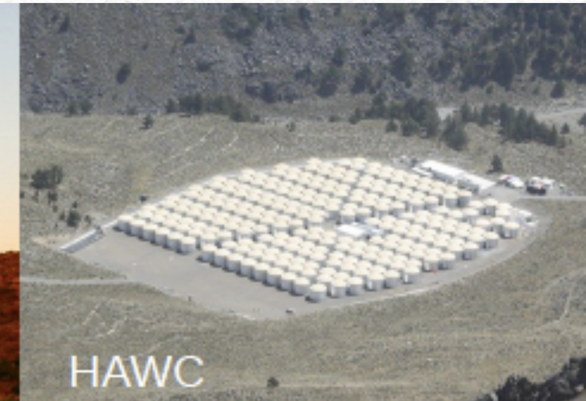


Experimental techniques

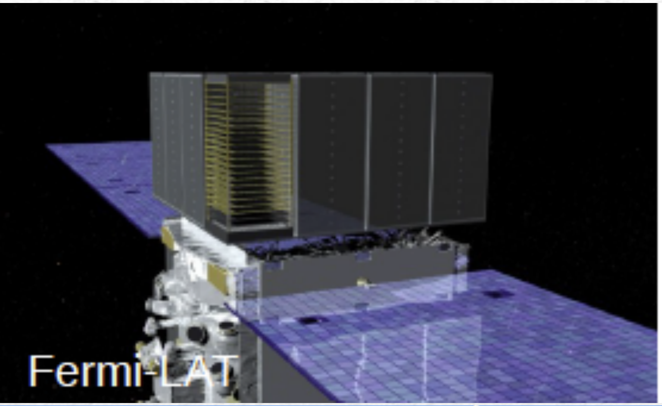


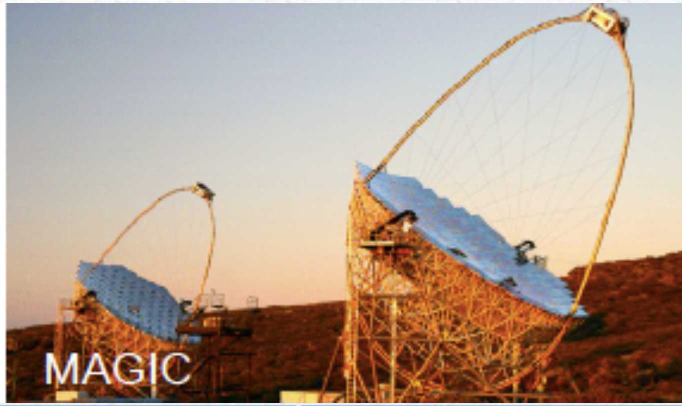
MeV GeV TeV PeV

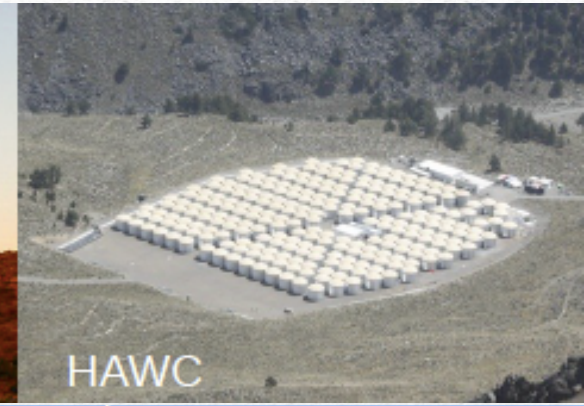




MeV GeV TeV PeV



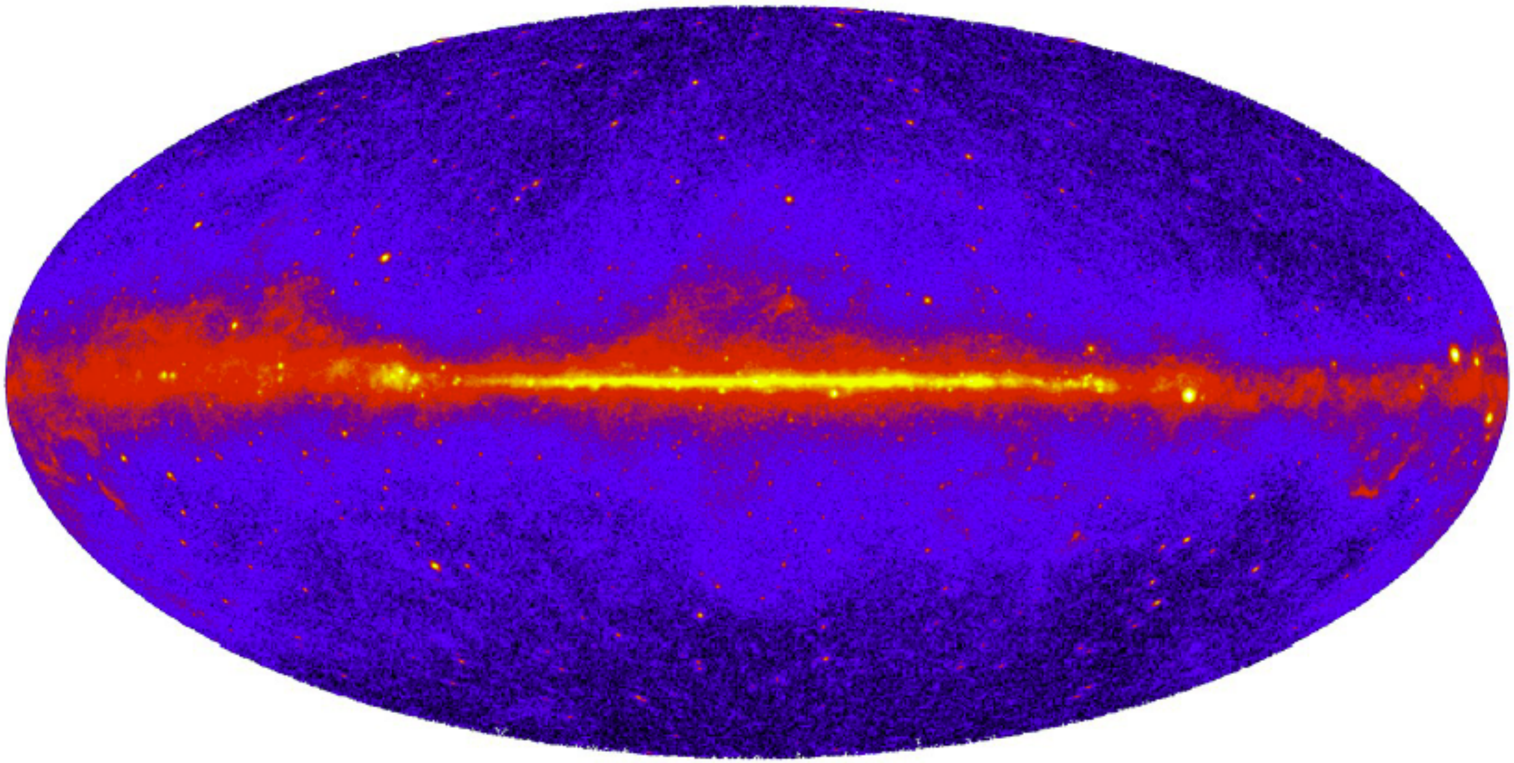




	Fermi LAT	**IACTs**	**HAWC**
Effective area	1 m^2	10^5 m^2	10^5 m^2
Field of view	**20% of the sky**	$3^o - 5^o$	**15% of the sky**
Energy res.	10%	**10%**	100% – 20%
Angular res.	$6^o - 0.3^o$	**0.1^o**	$1^o - 0.2^o$
Duty cycle	**Full year**	1400 h/year	**Full year**

The sources...

Gamma-ray Sky at GeV Energies

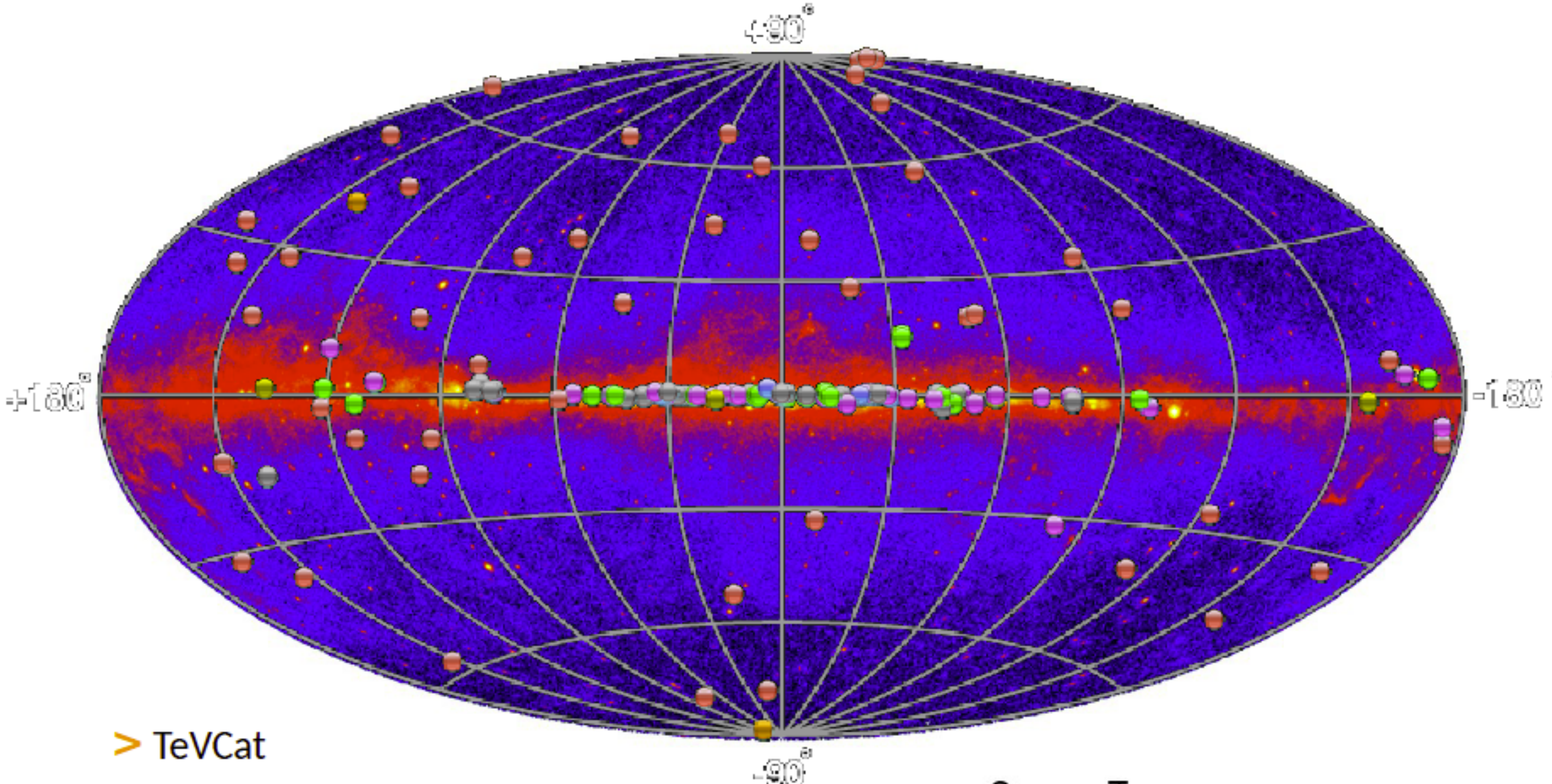


> Fermi 2FGL catalog

- 1800 sources; significant fraction Extragalactic; many Galactic sources confused with diffuse Emission

The sources...

Gamma-ray Sky at TeV Energies



> TeVCat
- ~50 extragalactic sources; ~100 Galactic sources

Some Numbers

1937: Discovery of Cherenkov effect

1950: Cherenkov light in the atmosphere observed but the effect was not exploited for astronomical observations

1989: Observation of Crab nebula and of some AGNs using a ground telescope that images the Cherenkov light: WHIPPLE (Arizona 1T 10m)

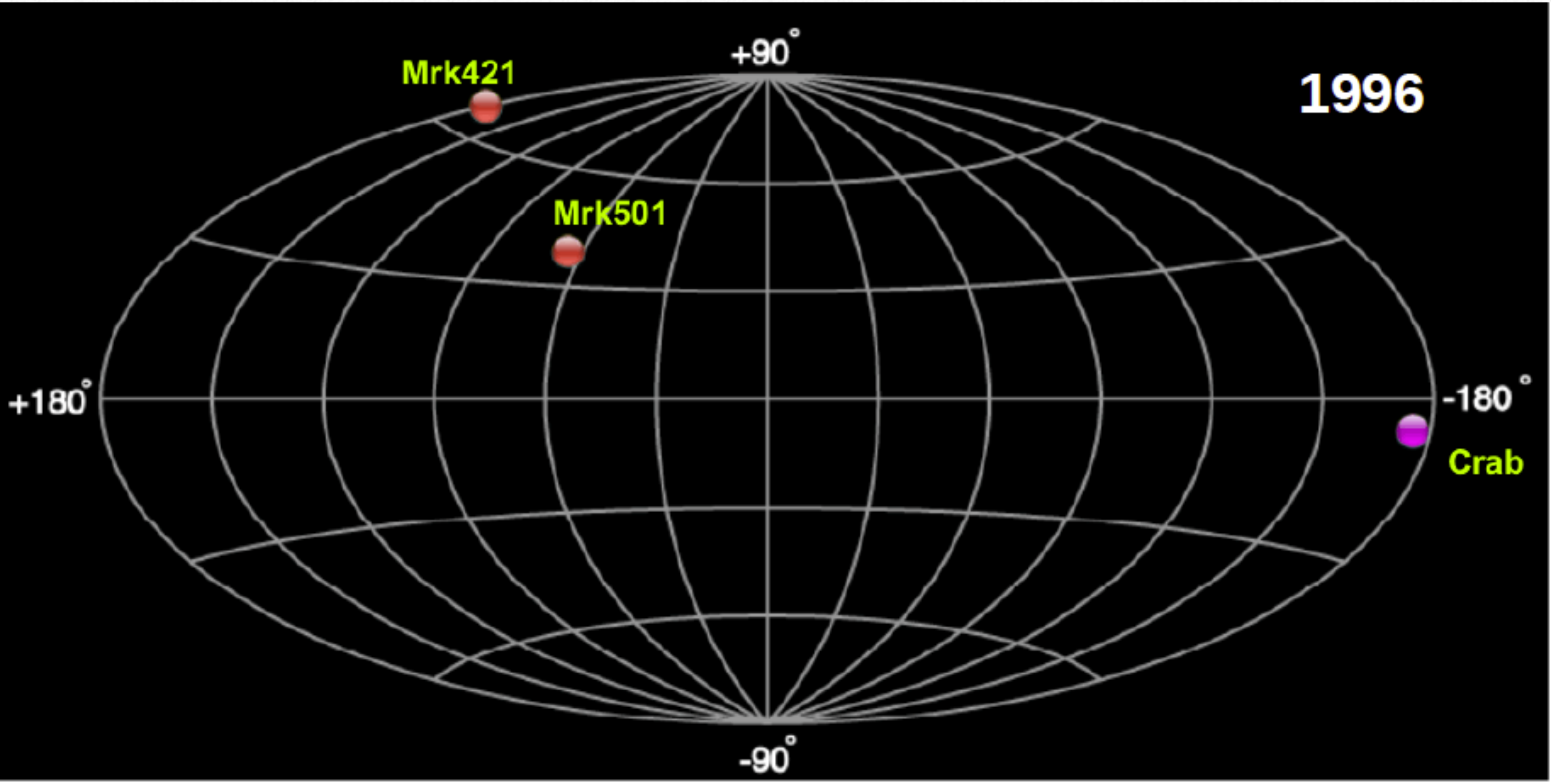
2003: beginning of HESS (4 telescopes, 12 m): detection passes from few sources to ~30 in 2 years

Now: MAGIC (2T, 17 m), HESS (4T), VERITAS (4T): ~100 sources detected

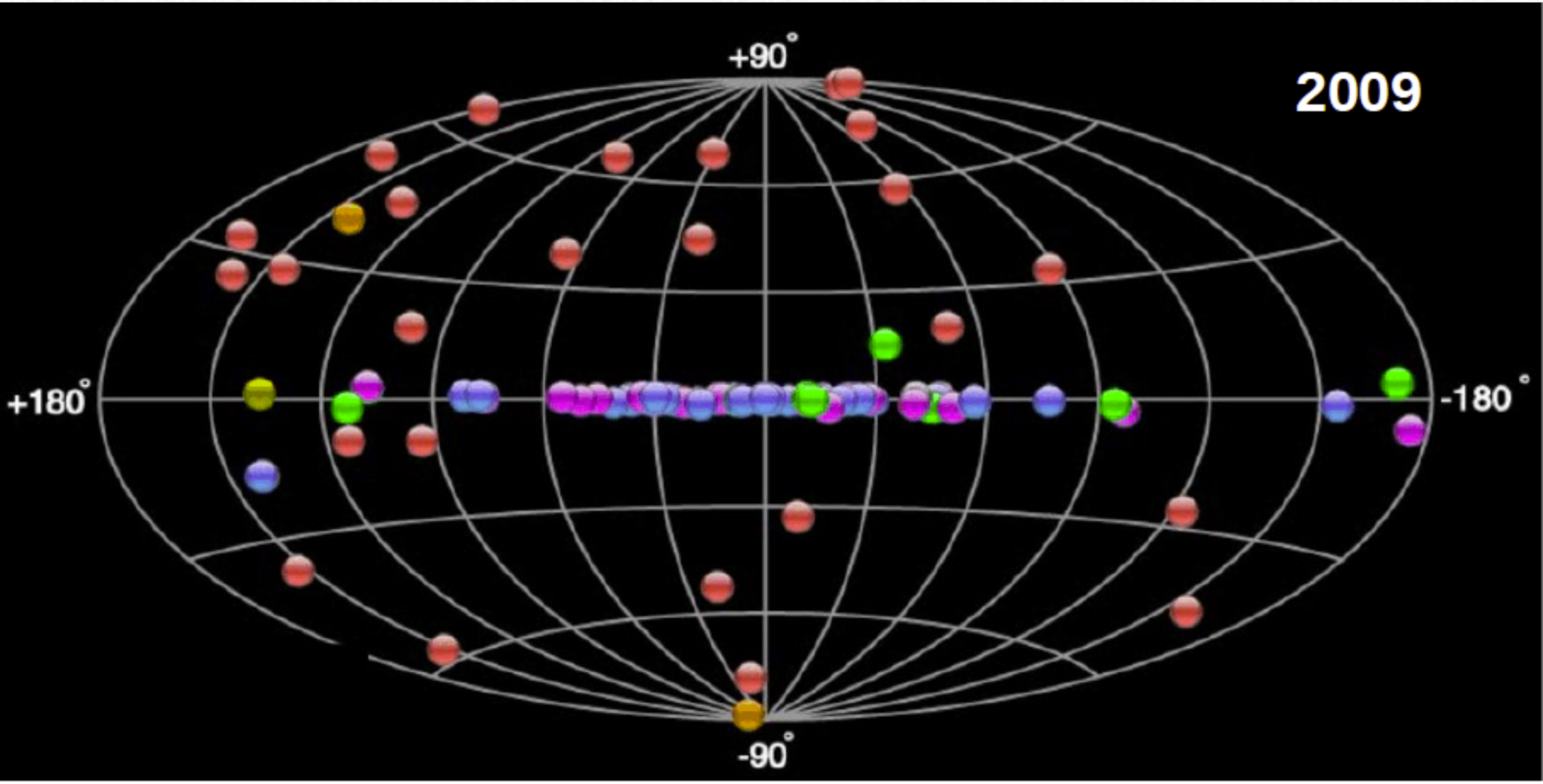
Future: CTA (Cherenkov telescope array) : 1000 sources

Cherenkov Telescopes

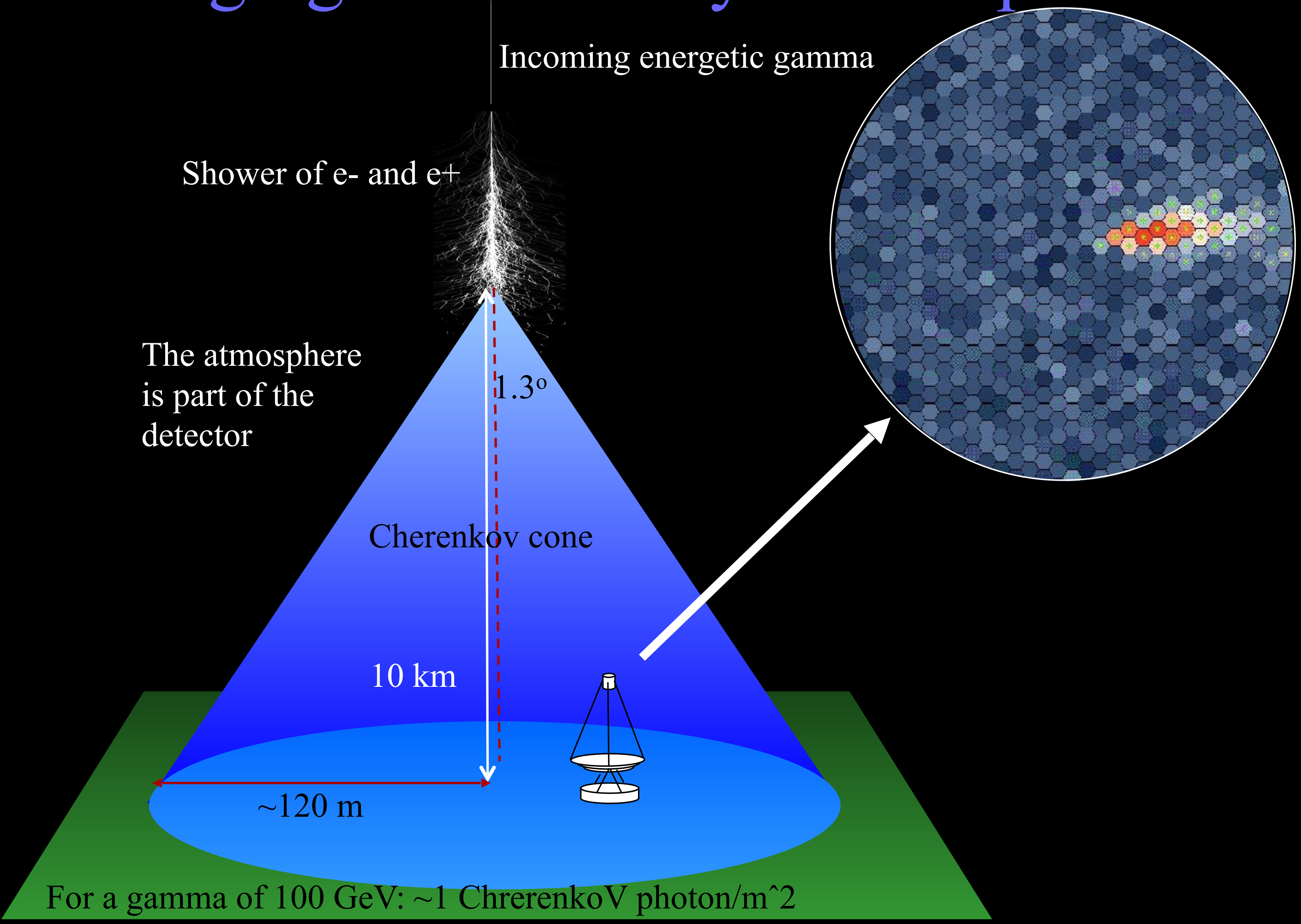
TeV source discovery history



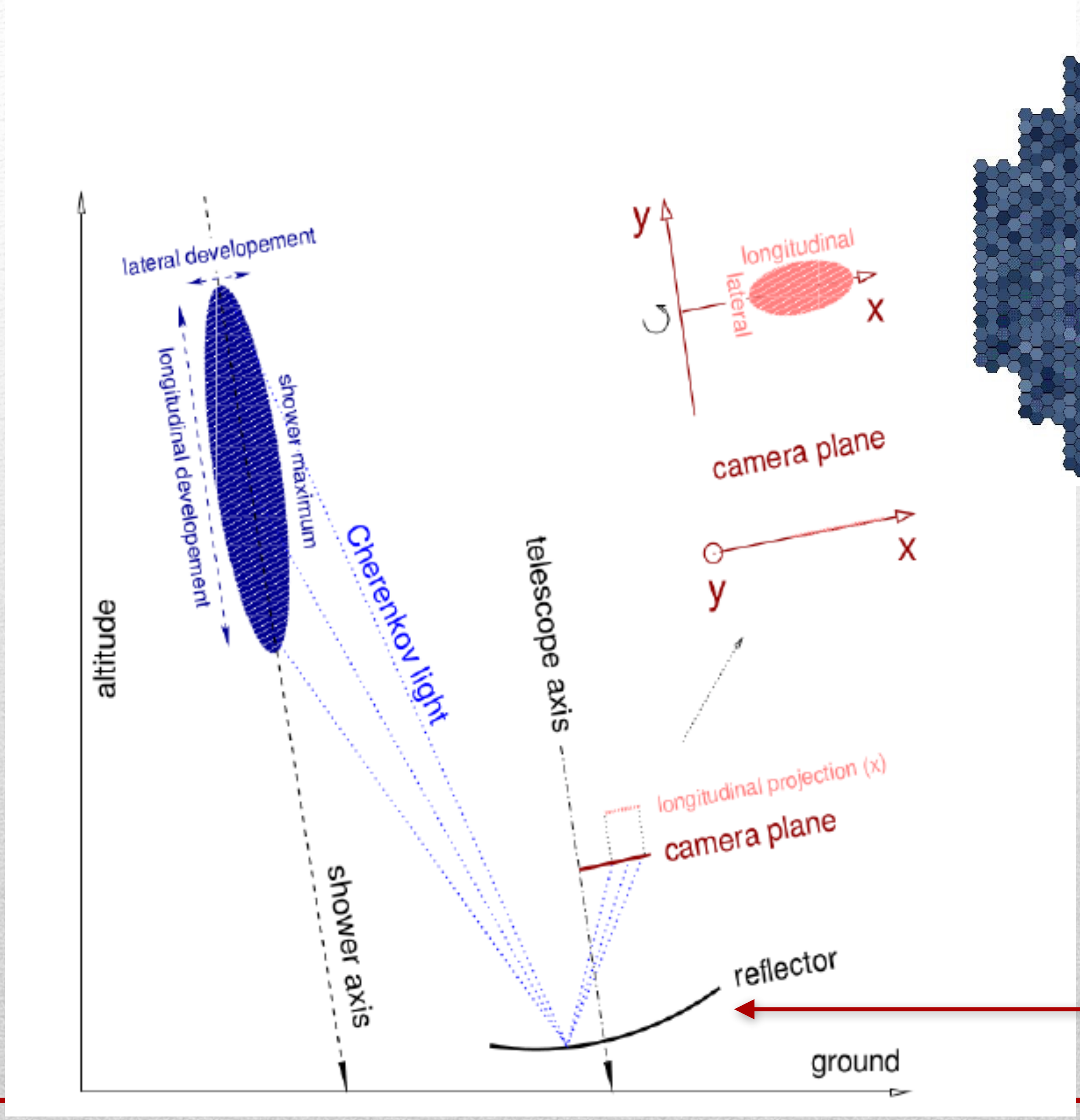
TeV source discovery history

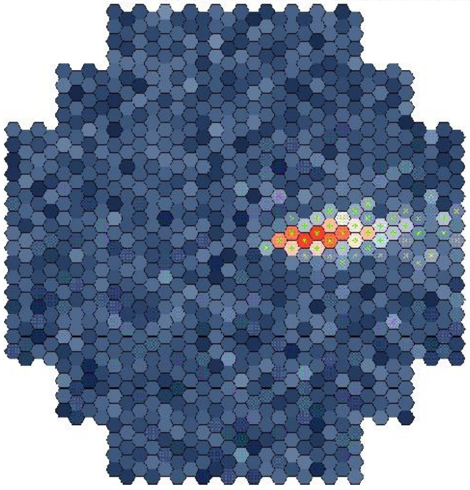


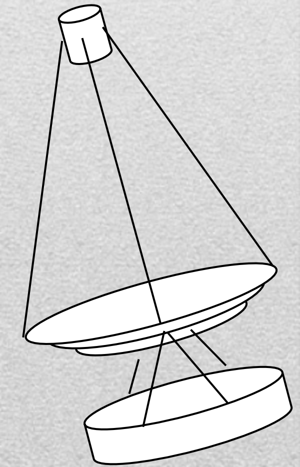
Imaging Gamma Ray Telescopes



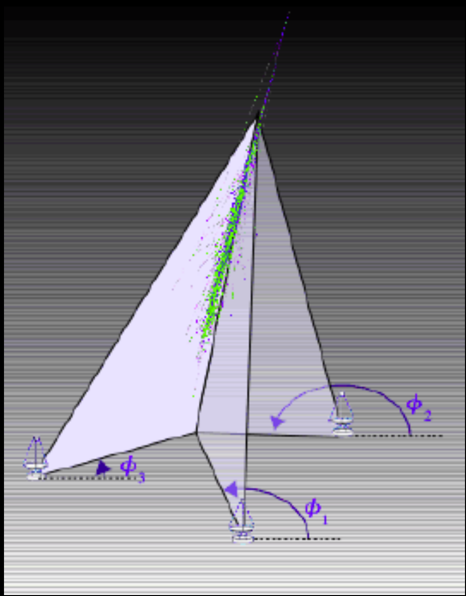
Optical principle

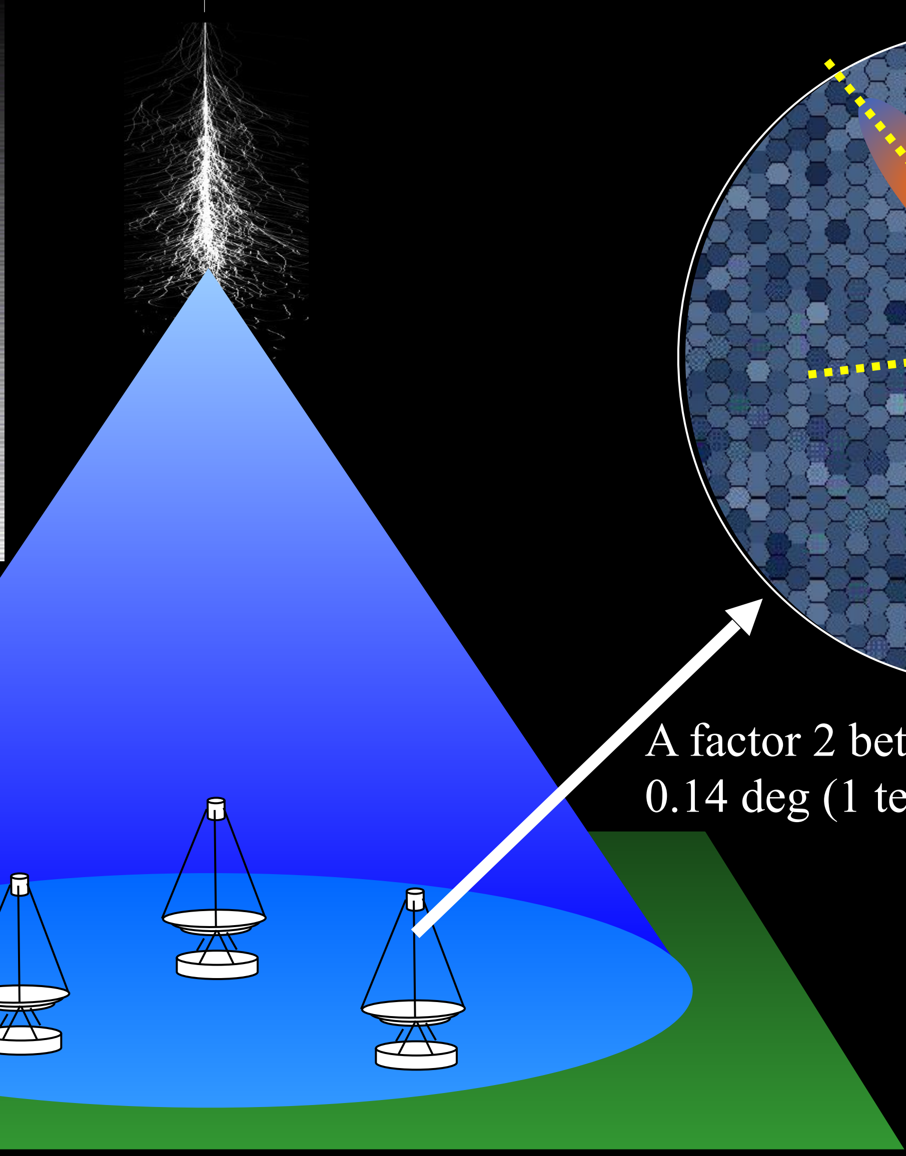


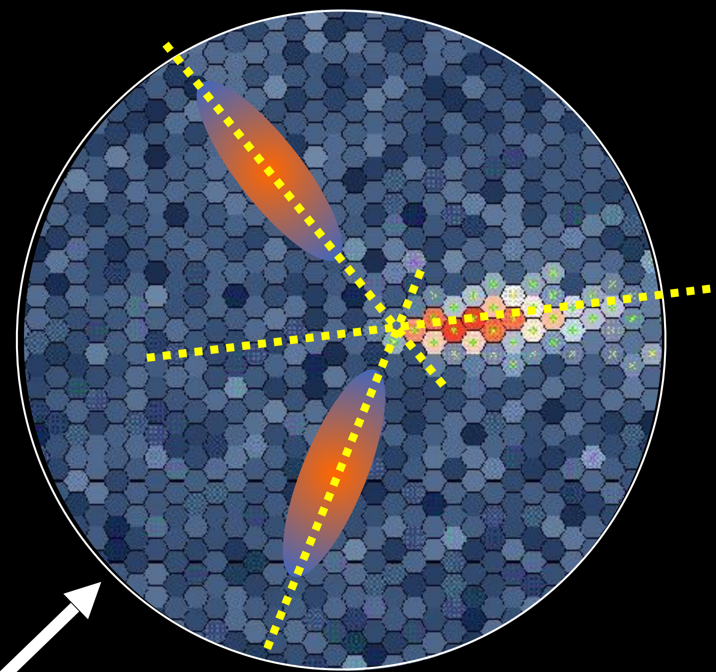




More telescopes: stereoscopy

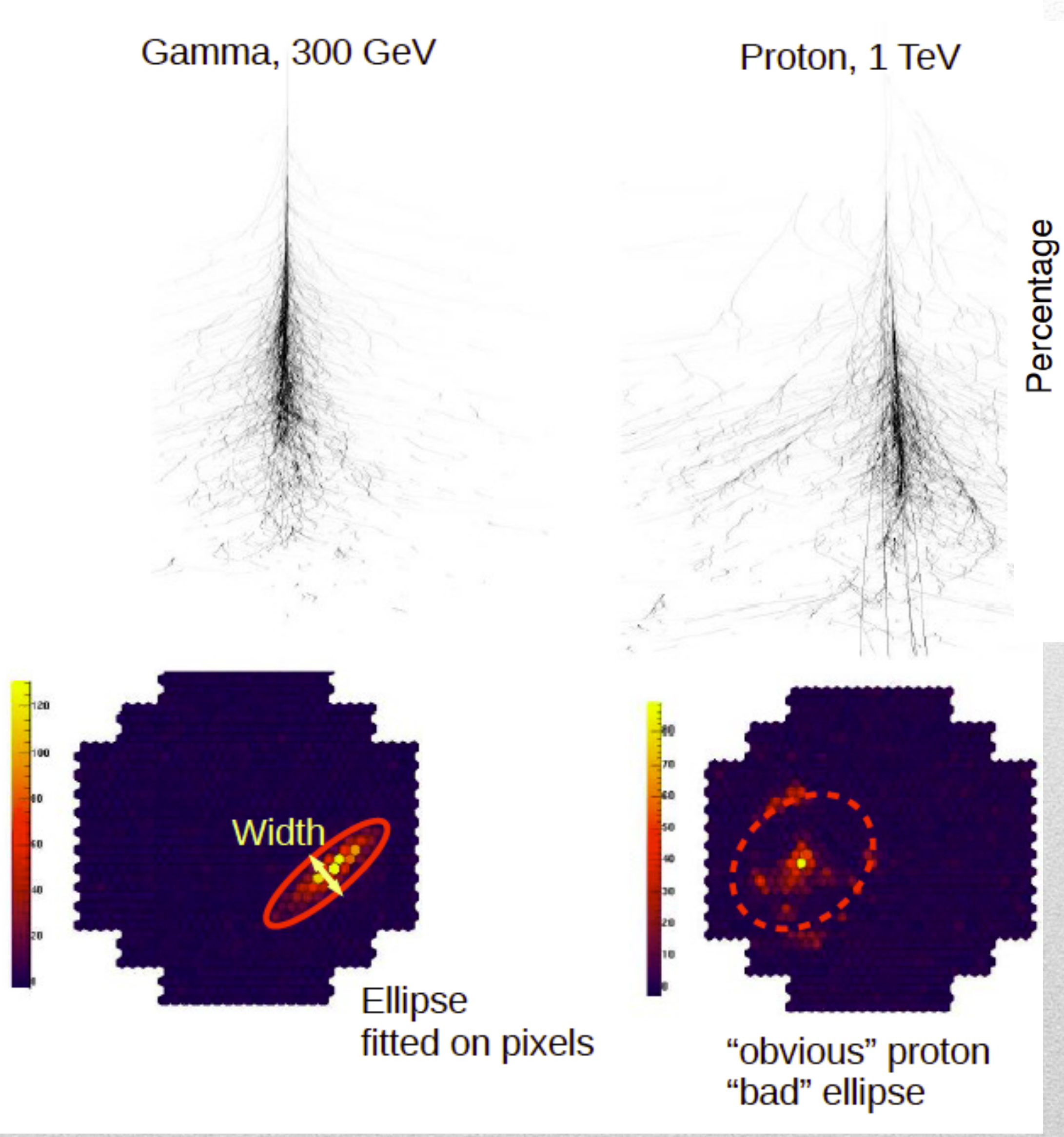


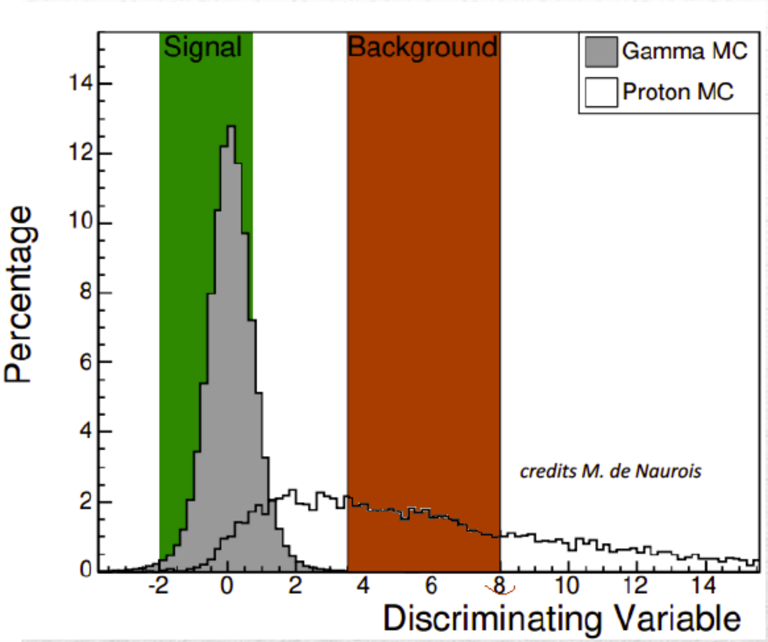




A factor 2 better angular resolution
0.14 deg (1 telescope)-> 0.06 deg (stereo)

Proton/Gamma separation



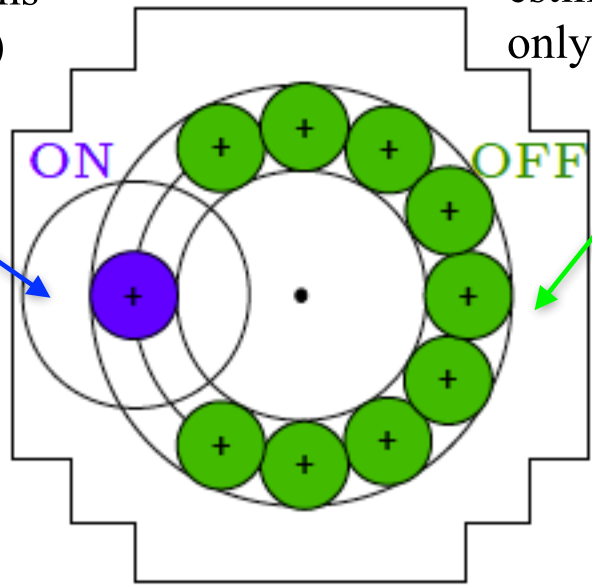


for example parameters connected to the width of the fitted ellipse

ON/OFF technique

Source position in the sky (contains gamma rays+ proton background)

Equivalent focal plane sections to estimate proton background (contains only proton background)



Gamma signal comes from the source

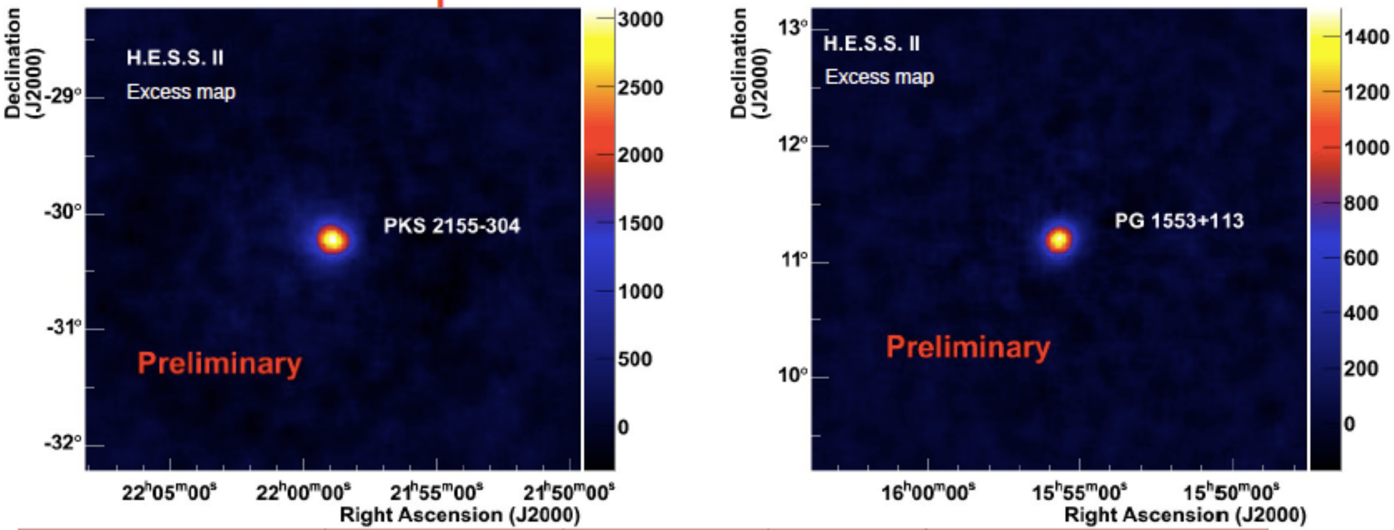
Proton background is isotropic

Excess = **ON** - **OFF** (normalized to ON) =gamma rays

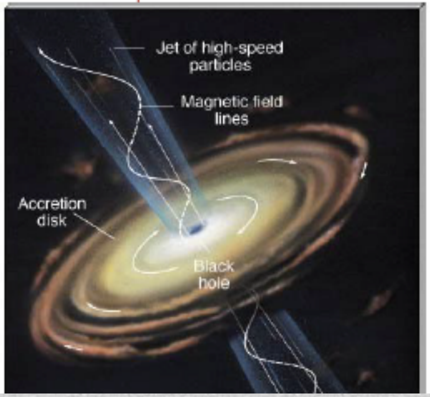
OFF regions must not fall in regions of sky emitting gamma rays (nearby sources):
We define "excluded" regions in order to avoid the problem

Example of source detected by IACT

Excess maps for Active Galactic Nuclei



	Live time	Excess	Sign.	Rate
PKS 2155-304	35.7 h	3669 γ	29 σ	1.71 ± 0.06 γ/mn
PG 1553+113	15.4 h	2358 γ	25 σ	2.55 ± 0.11 γ/mn



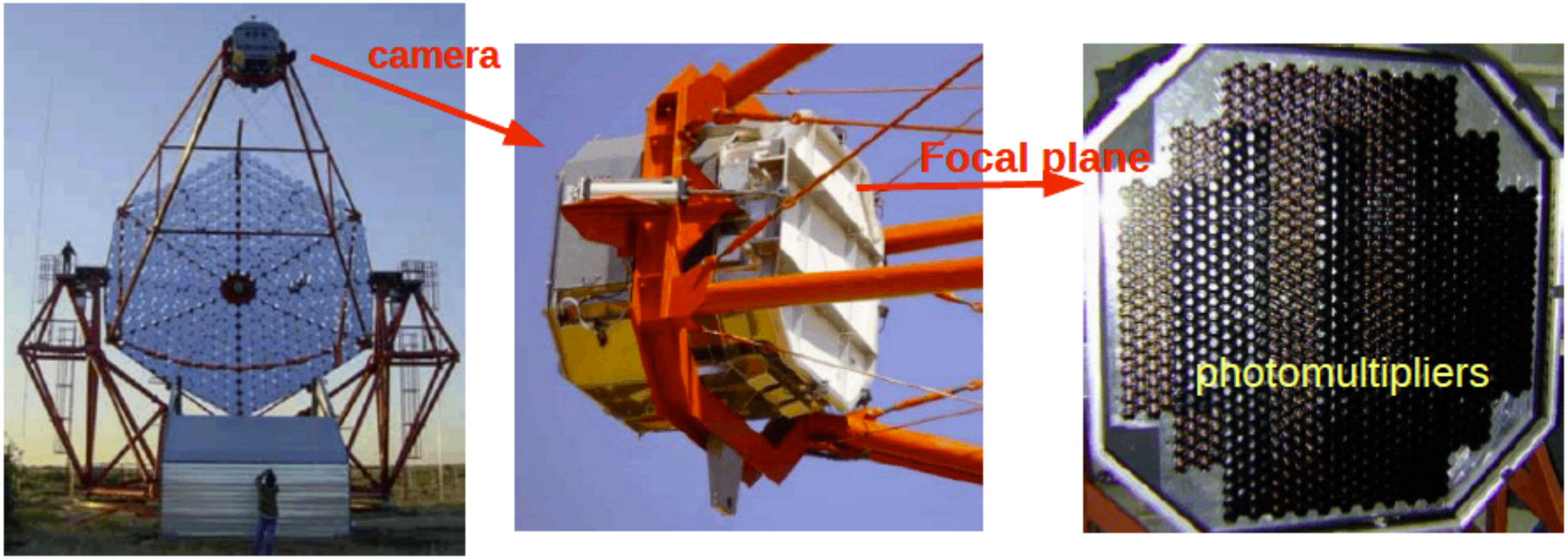
HESS

located in Namibia (1800 m a.s.l.)

- 12 m diameter telescopes : 107 m^2 each
- Observations on moonless nights, ~1000h/year
- Field of view of 5° in diameter
- Stereoscopic reconstruction

- Angular resolution < 0.1°/γ
- Energy threshold (zenith) ~ 200 GeV
- Energy resolution ~ 15%

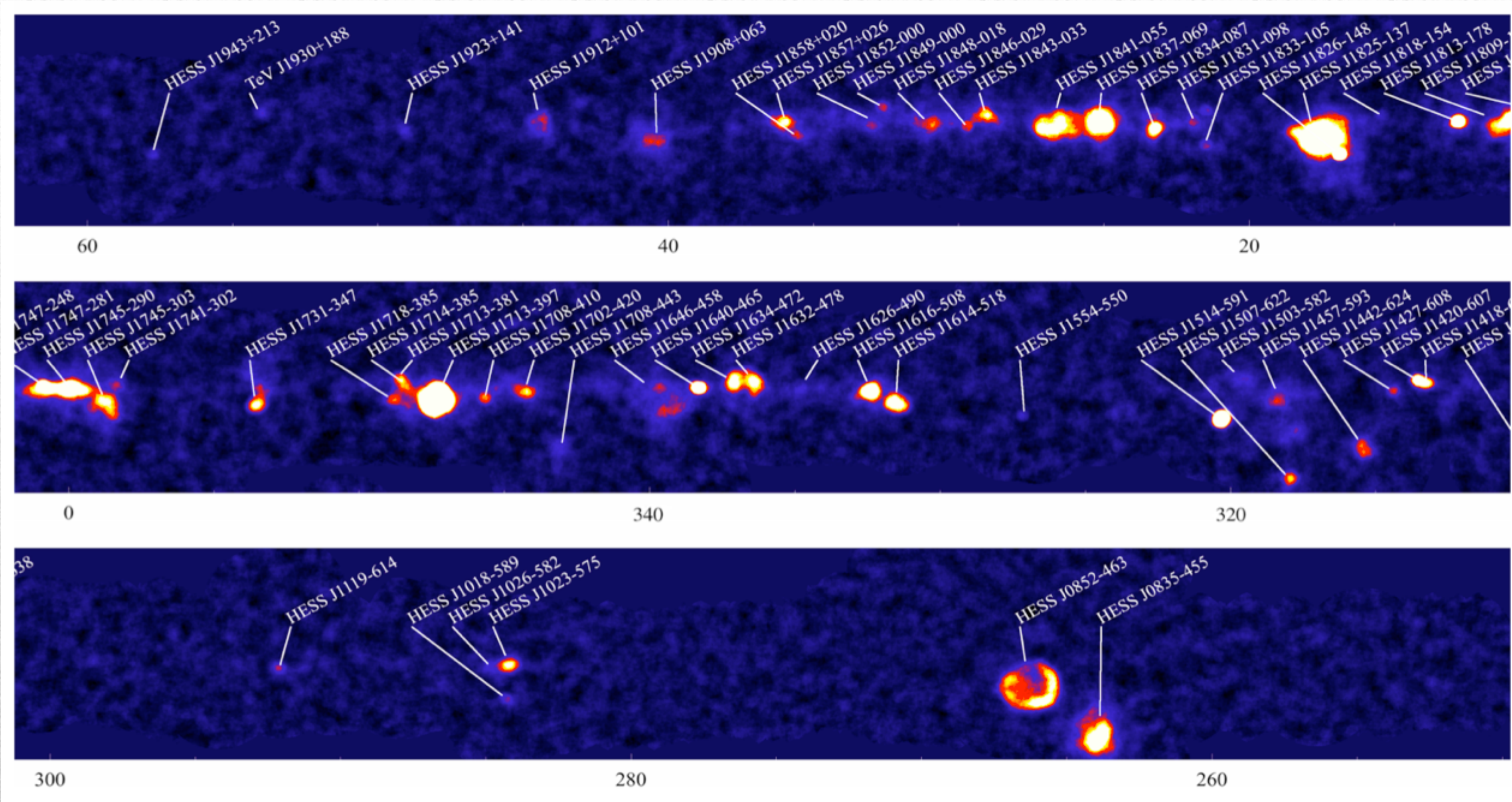
HESS



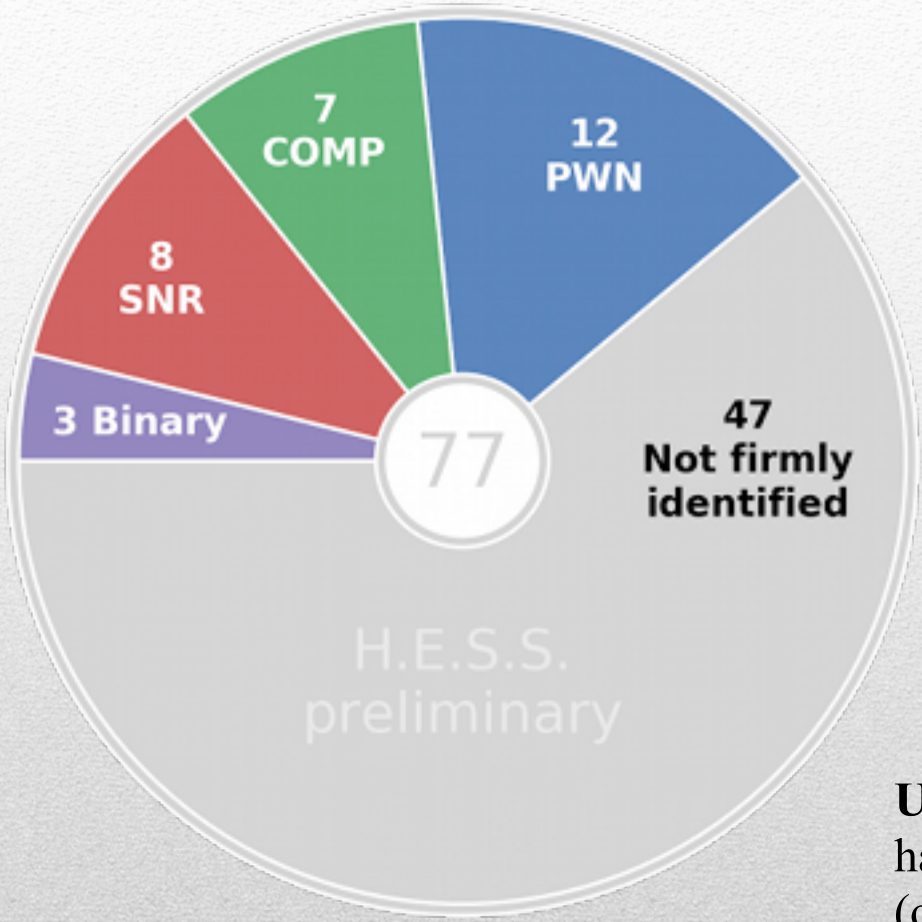
HESS II : inauguration Oct. 2012

5th telescope
26 m diameter
2048 PMTs
Low energy threshold 20 GeV

HESS Galactic Plane Survey



HESS Galactic Plane survey



PWN: Pulsar Wind Nebulae

SNR: SuperNova Remnants

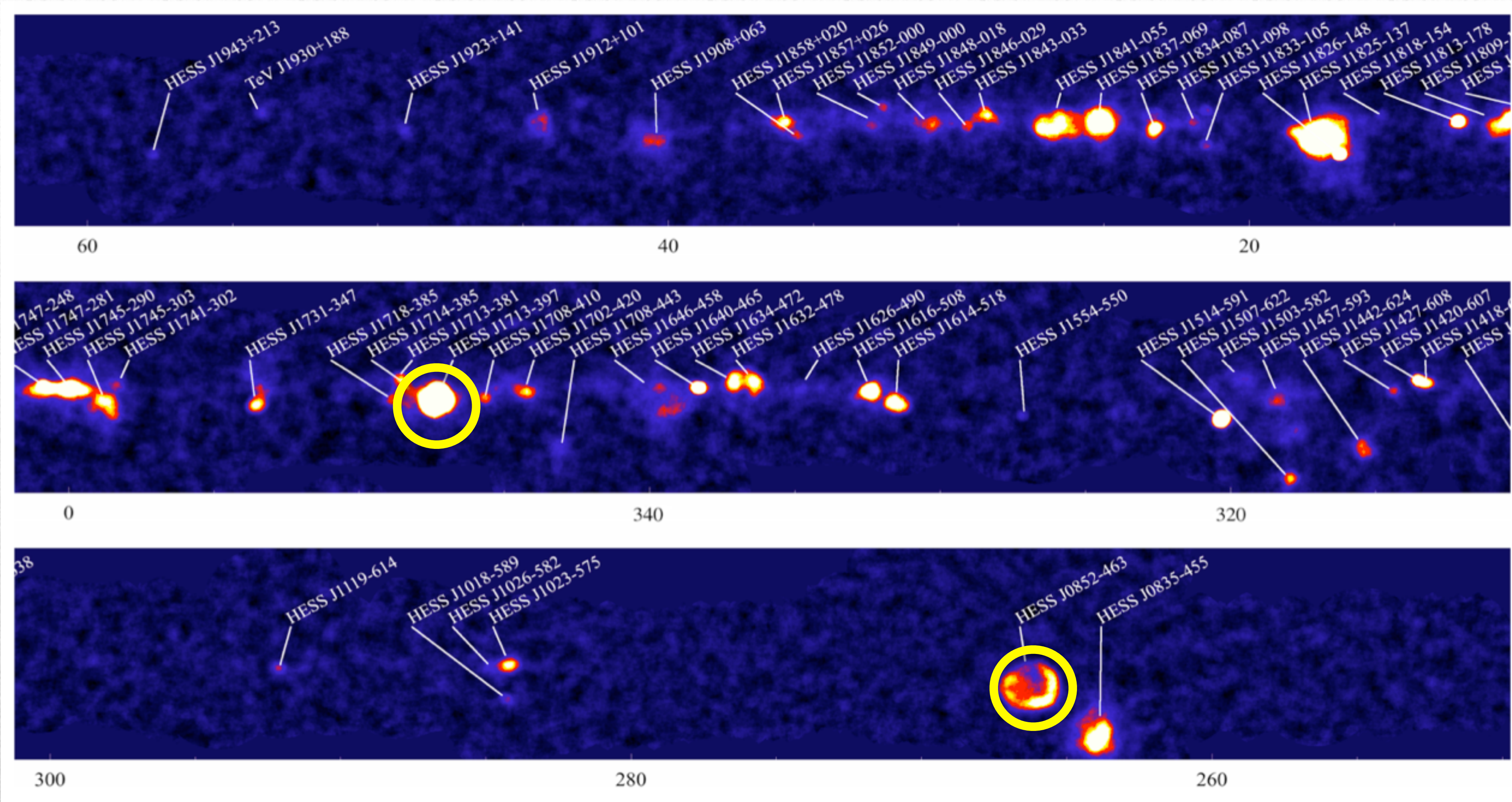
COMP: Composite Systems

47 sources are unidentified.

The known classified sources are based on firm identifications with multi-wavelength counterparts

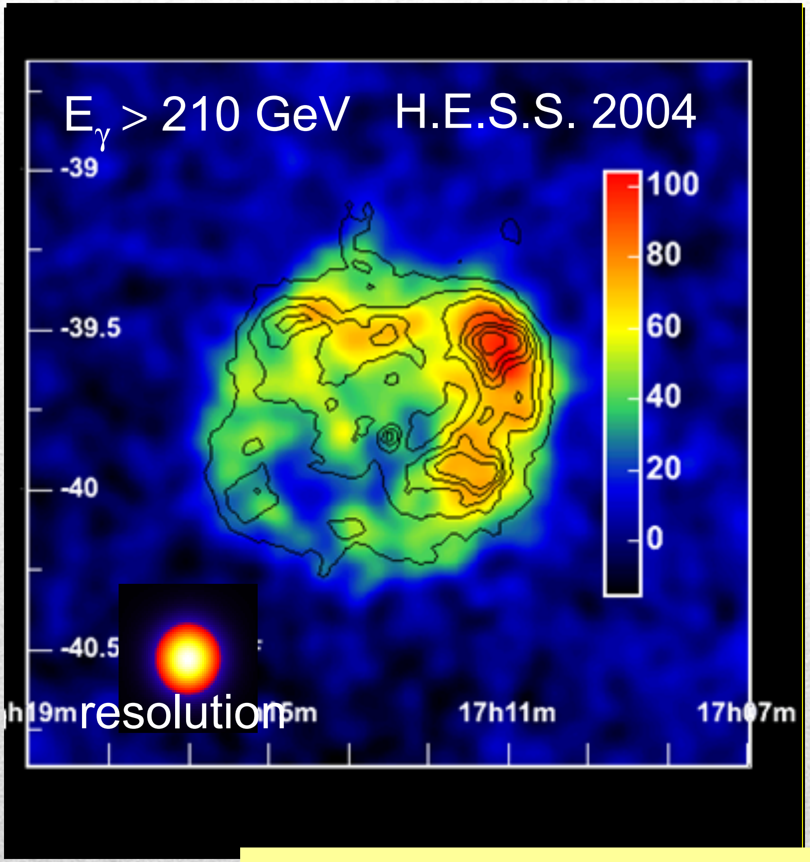
Unidentified sources means that they have multiple possible counterparts (only for some no promising counterpart could be found)

HESS Galactic Plane Survey

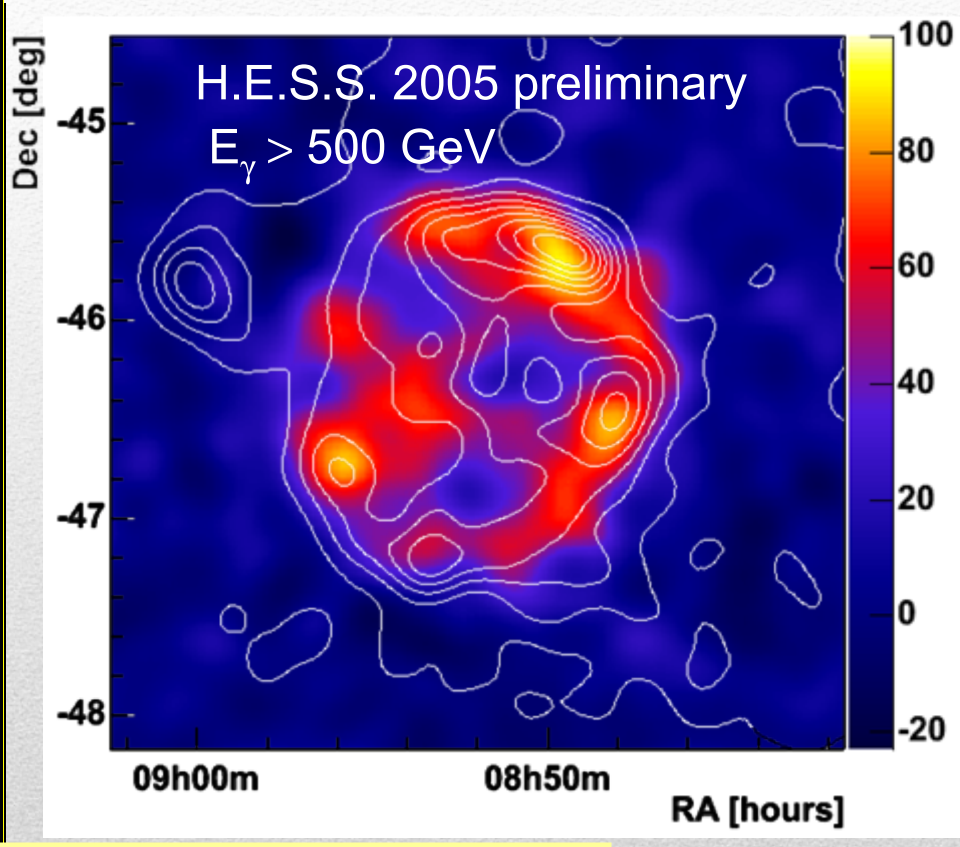


Supernova Remnants: Cosmic rays accelerators?

RX J1713.7–3946



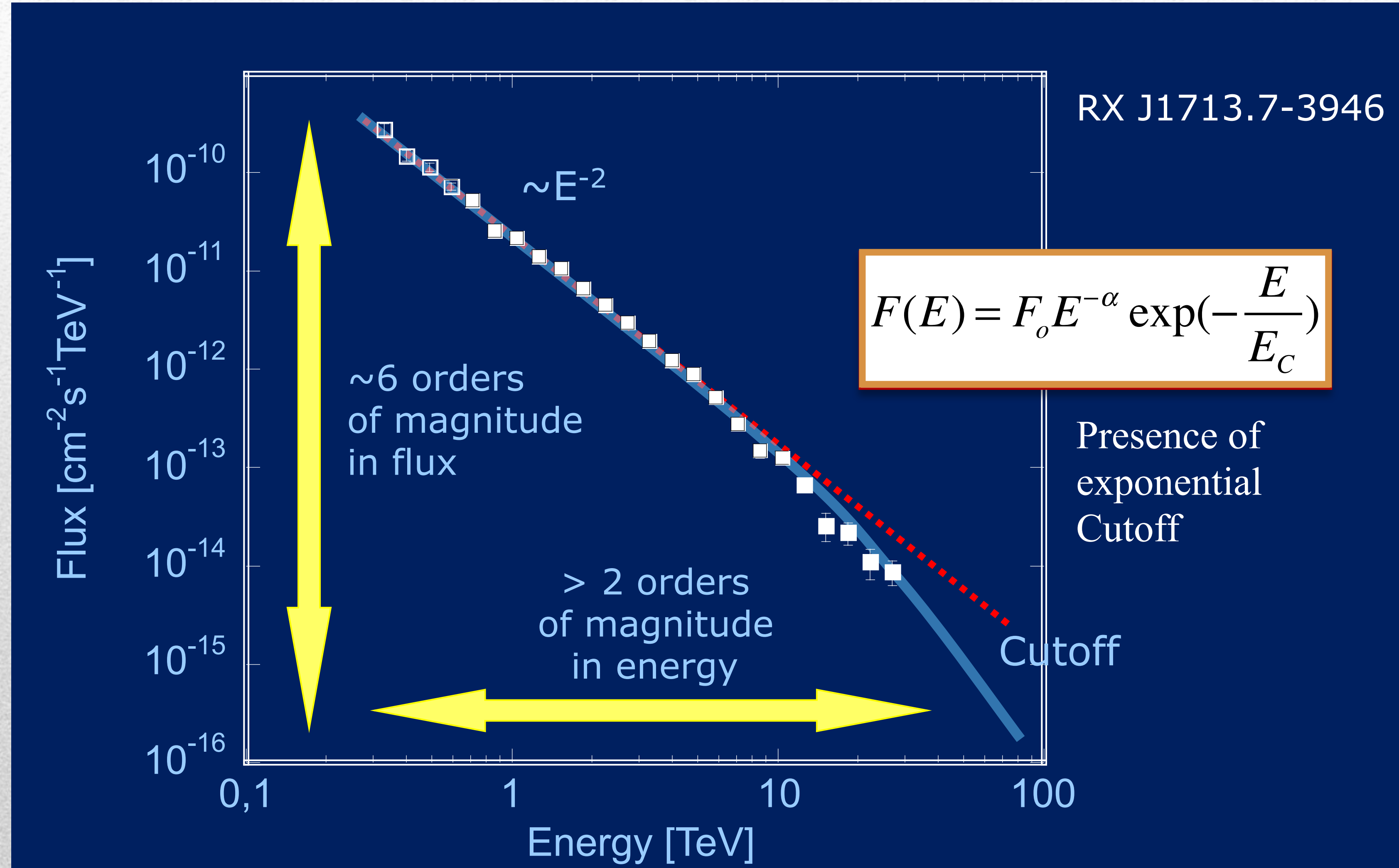
RX J0852.0–4622



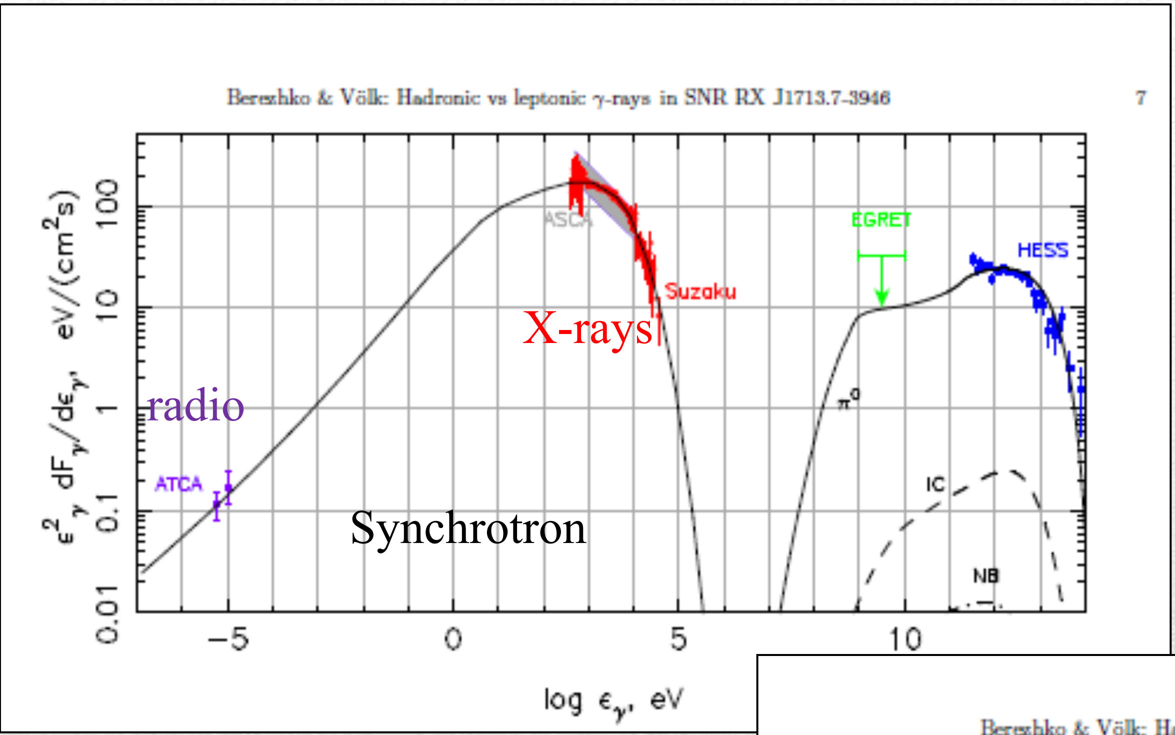
Strong Correlation with X-ray Intensities

- Is the origin of those Gammas hadronic or Leptonic?

Energy spectrum of RX J1713.7-3946



Electron or Hadron Accelerator?

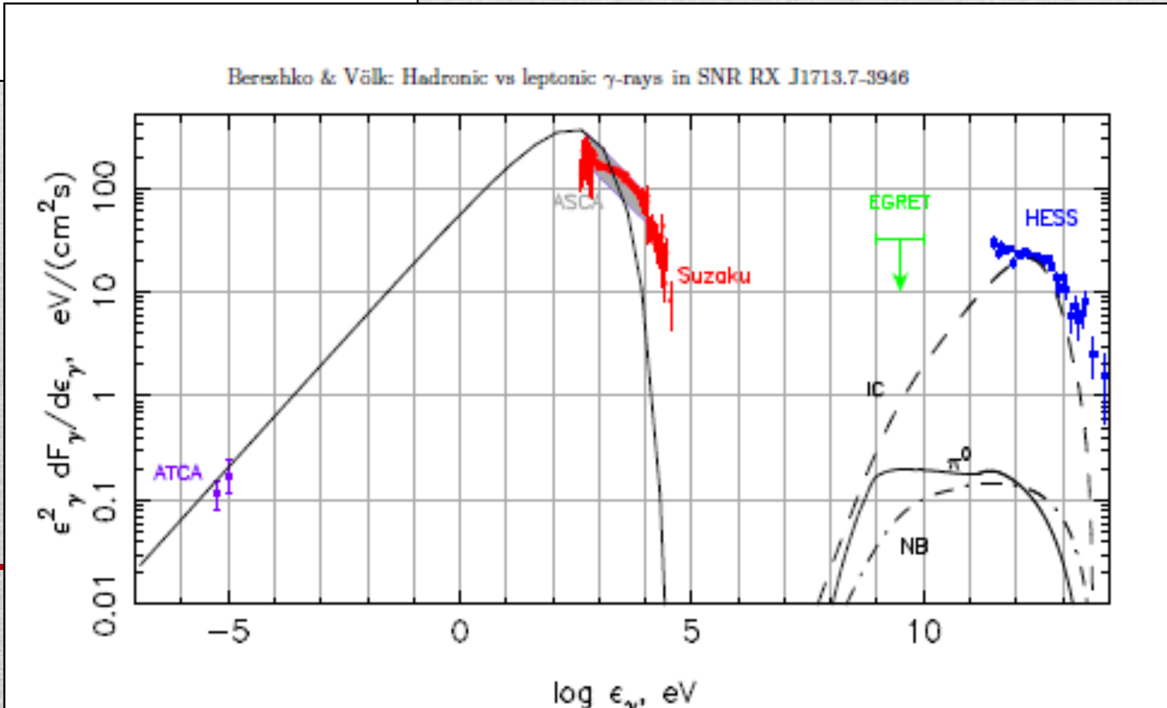


An example of model for RX J1713.7-3946

Hadronic model

Leptonic Model disfavoured

Leptonic model

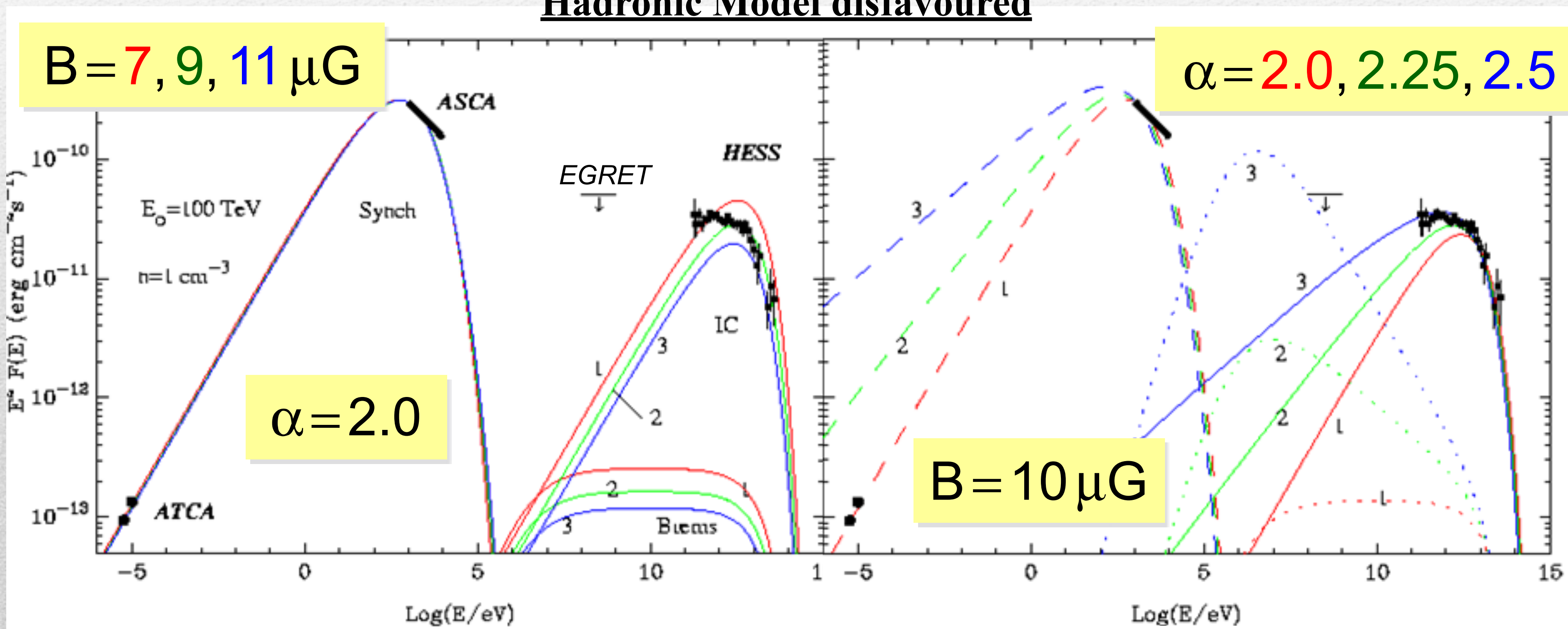


Electron or Hadron Accelerator?

An other model for RX J1713.7-3946 : Aharonian

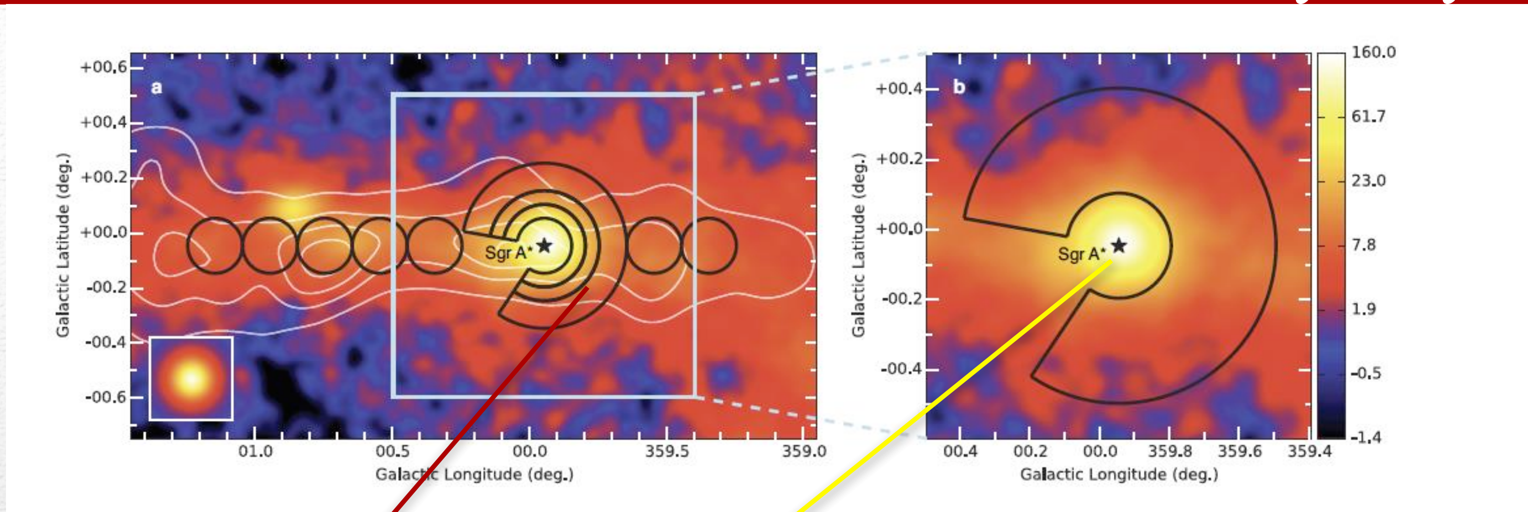
- Continuous electron injection over 1000 years
- Injection spectrum: power law $E_e^{-\alpha}$ with cutoff

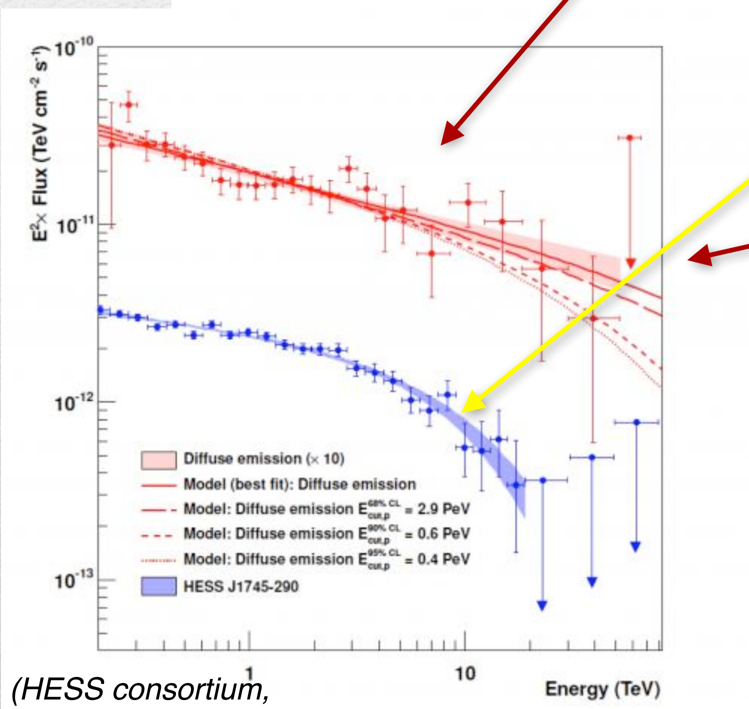
Hadronic Model disfavoured



Need more data at high energy and refined morphology studies → Better sensitivity and angular resolution

A Cosmic PeVatron at the center of the Milky Way ?





(HESS consortium, Abramowski et al, Nature, 2016)

Power law sprectrum without break or cut-off up to several tens of TeV *from* ***diffuse emission*** *in the central 10 pc of the Milky Way*

→ signature of a hadronic PeVatron (Sgr A?) emetting up to 10^{15} eV*

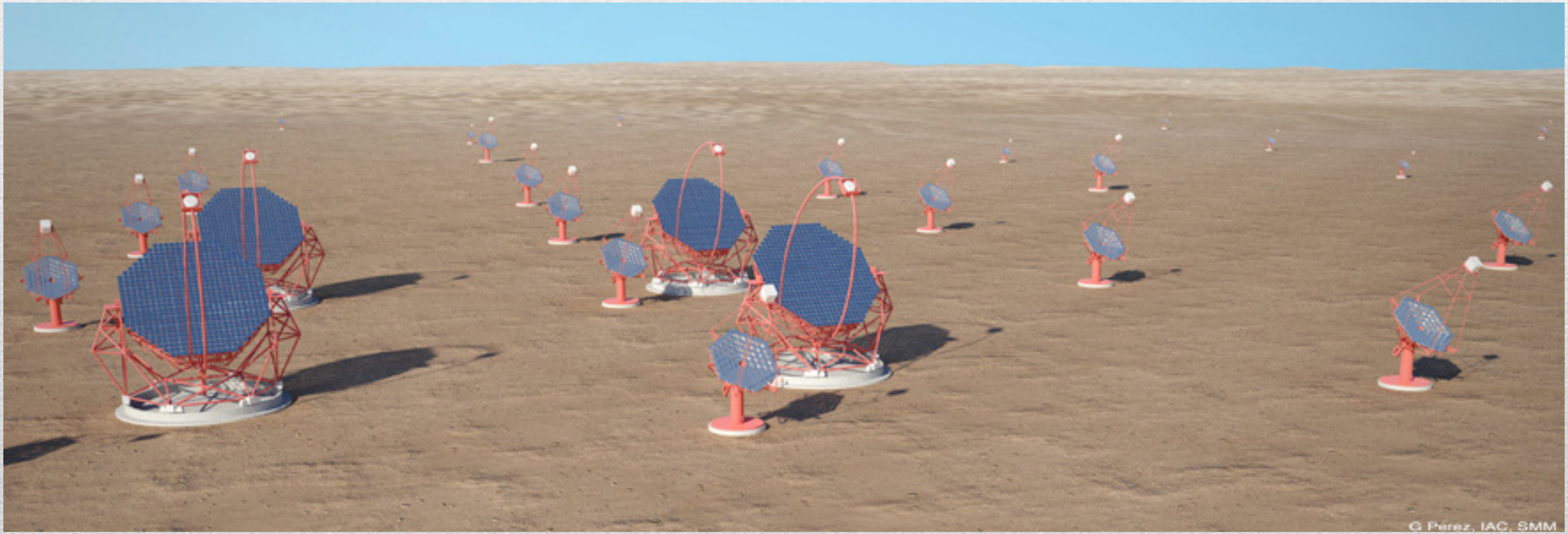
Detection of Gamma Rays at >100 TeV is a signature for CR sources!!

Detection of astrophysical neutrinos is smoking gun for CR source!!

CTA: Cherenkov Telescope Array

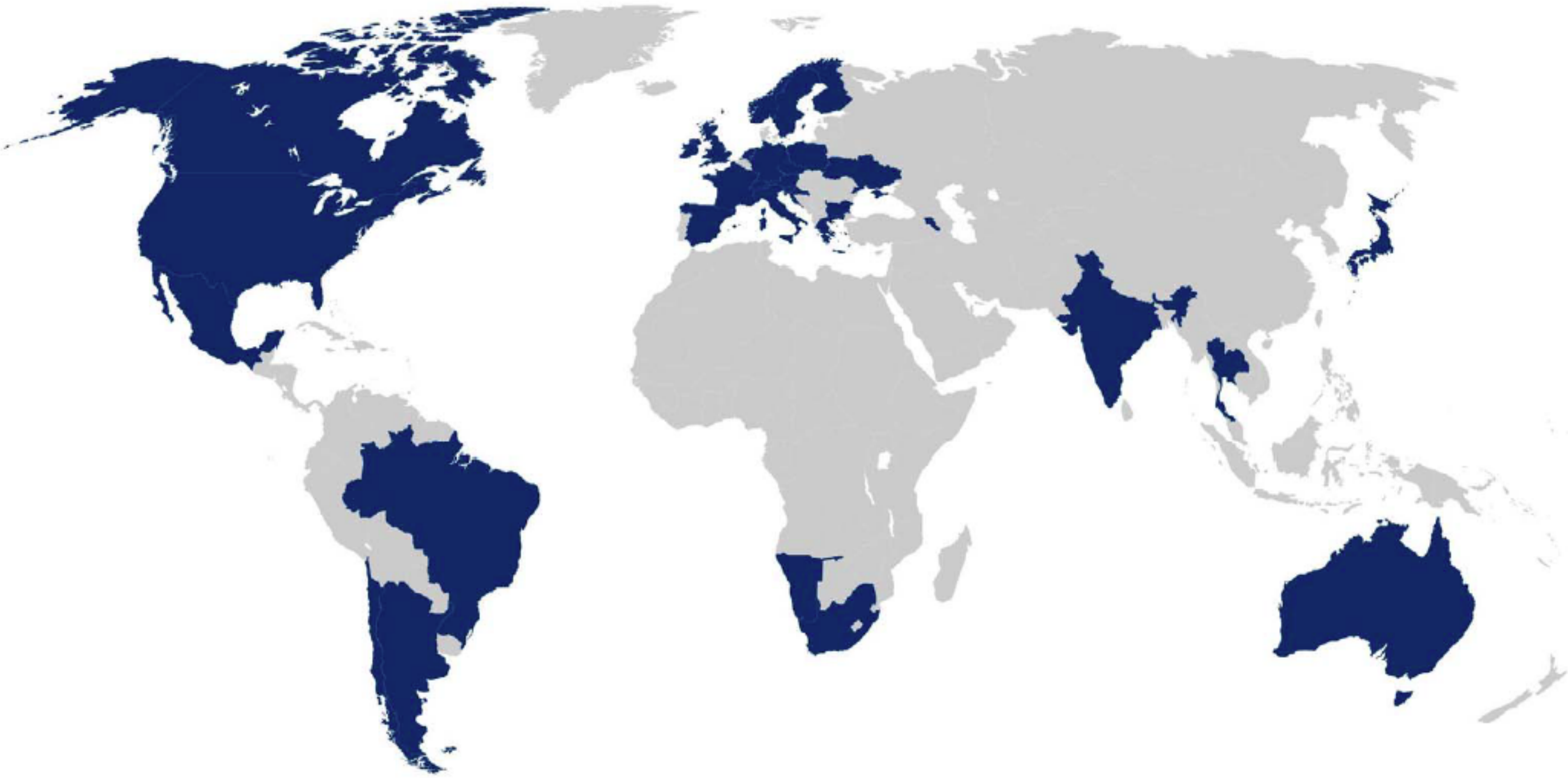
- Factor 10 higher sensitivity than existing instruments
- Angular Resolution <0.1 deg above most of the E range
- Large field of view (8-10 deg)
- Energy coverage: 20 GeV- 300 TeV
- Rapid Slew (20s) to catch flares
- 2 sites : North and South Hemisphere

cta cherenkov telescope array



CTA Consortium

The Consortium originated CTA and will contribute to the construction of the arrays



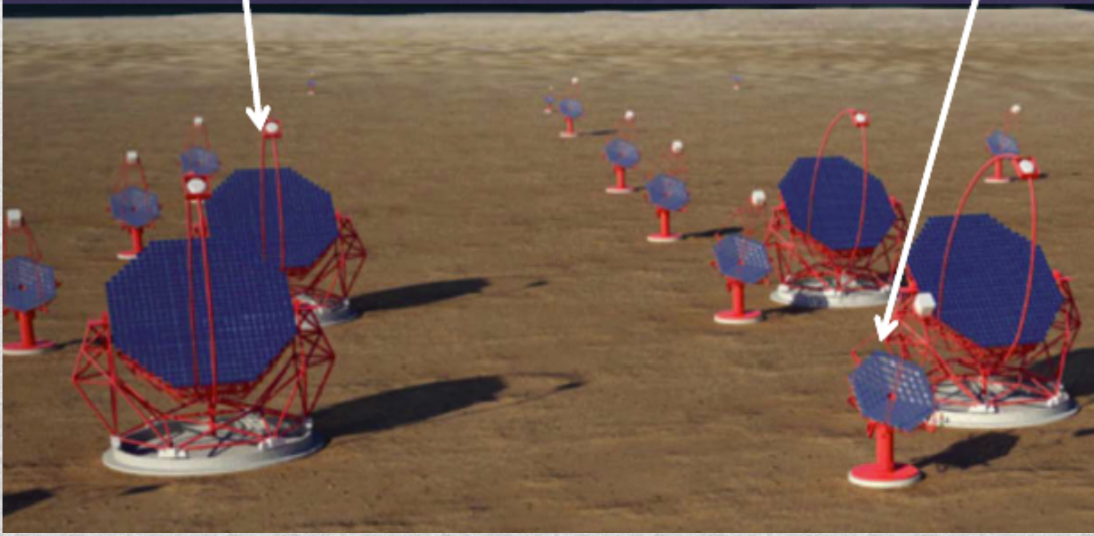
32 countries, ~1402 scientists, ~208 institutes, ~480 FTE

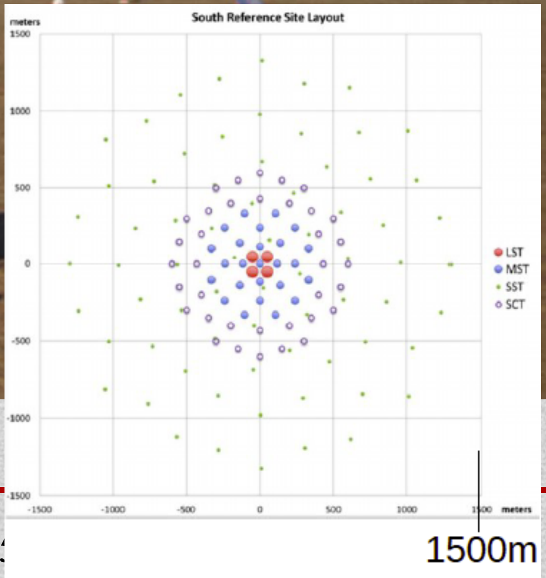
CTA South

Low energies
Energy threshold 20-30 GeV
23 m diameter
4 telescopes
(LST's)

Medium energies
100 GeV – 10 TeV
9.7 to 12 m diameter
25 telescopes
(MST's/SCTs)

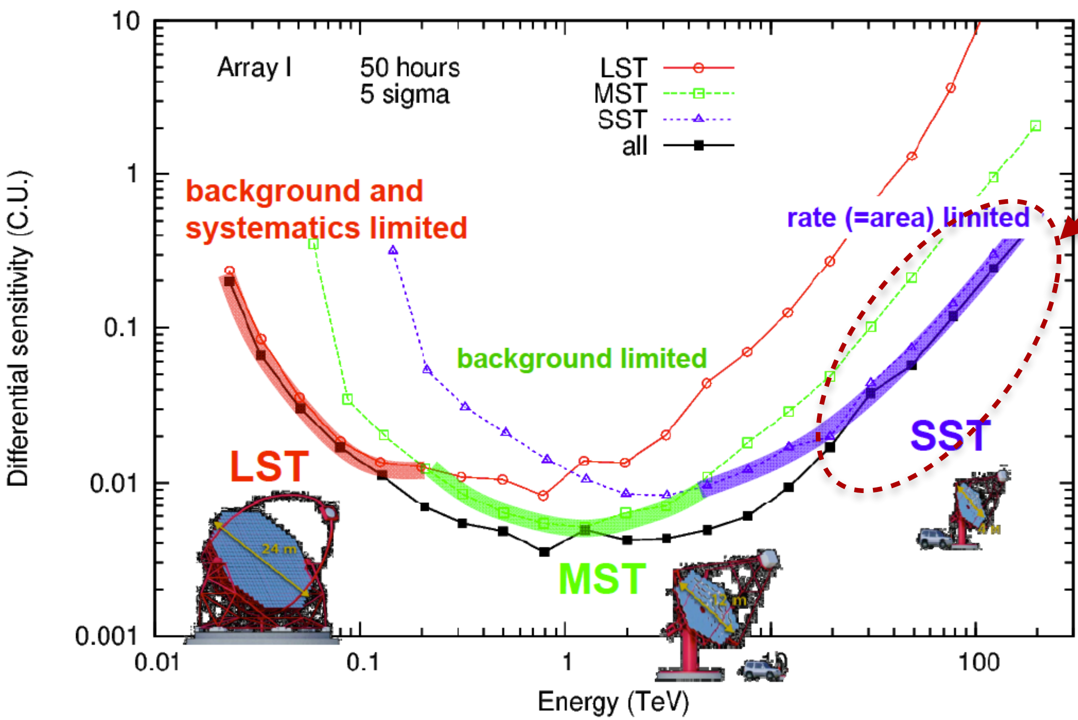
High energies
Up to > 300 TeV
10 km^2 eff. area @ 10 TeV
4m diameter
70 telescopes
(SST's)





CTA Sensitivity

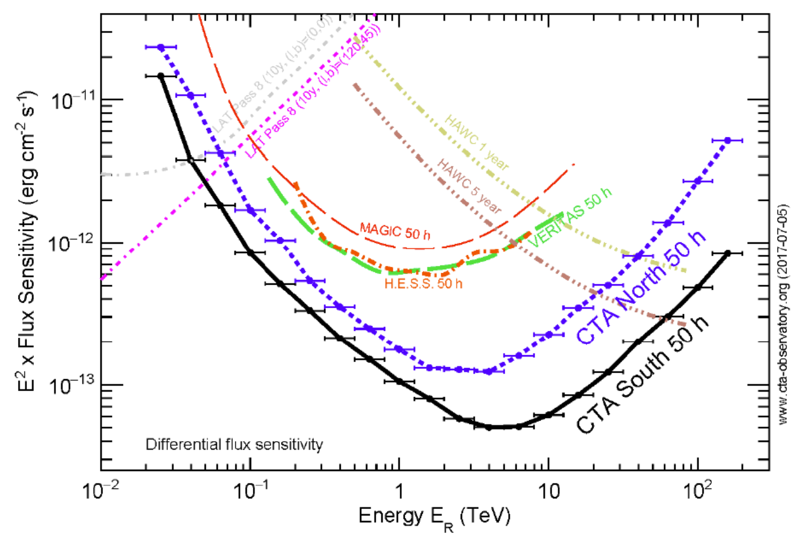
Sensitivity: Minimum flux that can be detected



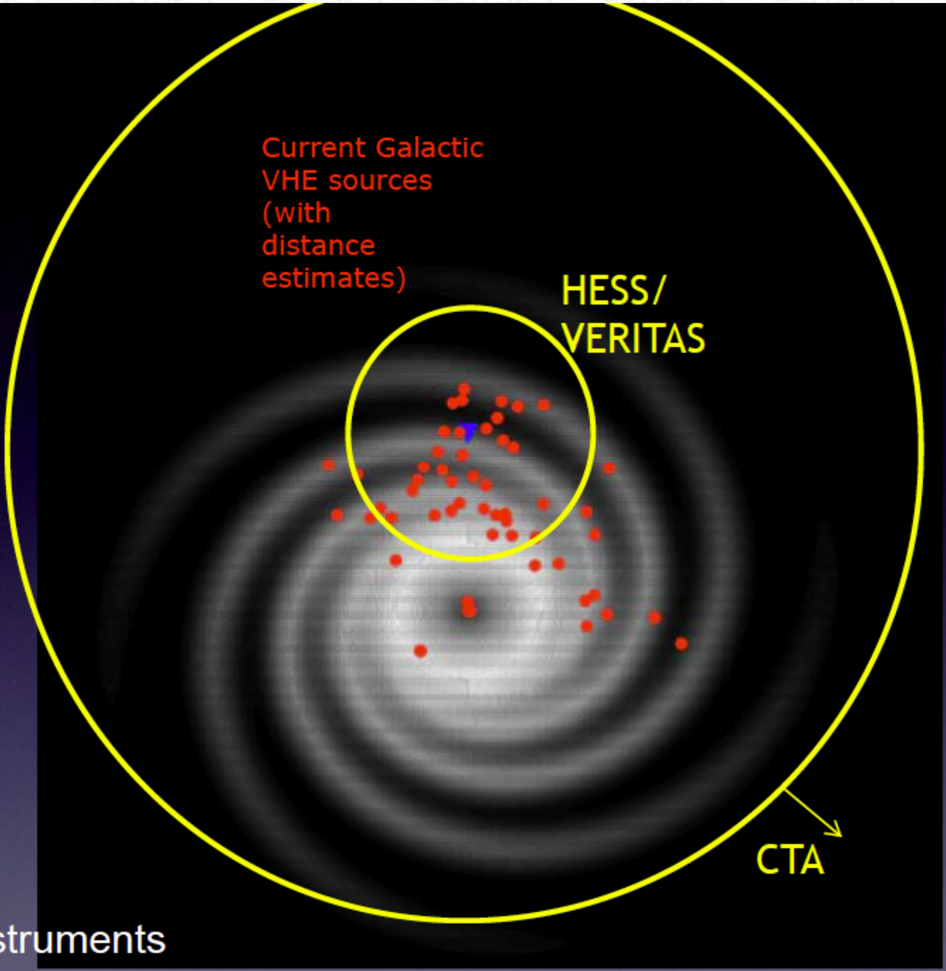
Opening with the SSTs a new electromagnetic window at extreme energies, above 5 TeV up to 300 TeV

A guaranteed scientific return and high potential for breakthrough discoveries

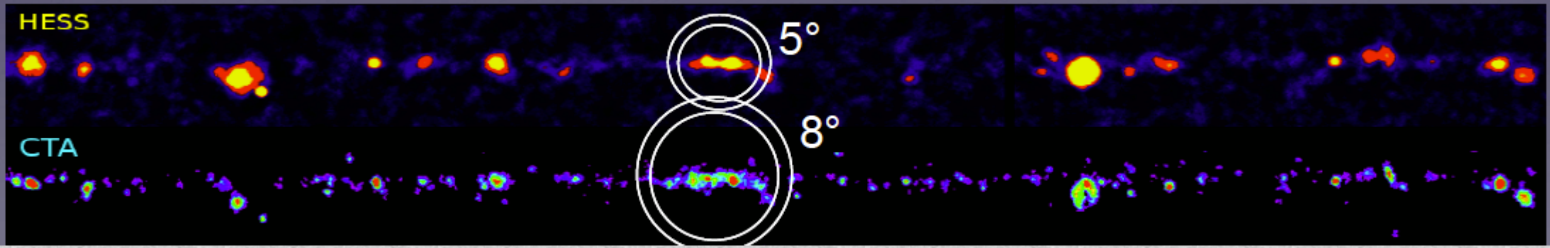
Comparison to other instruments



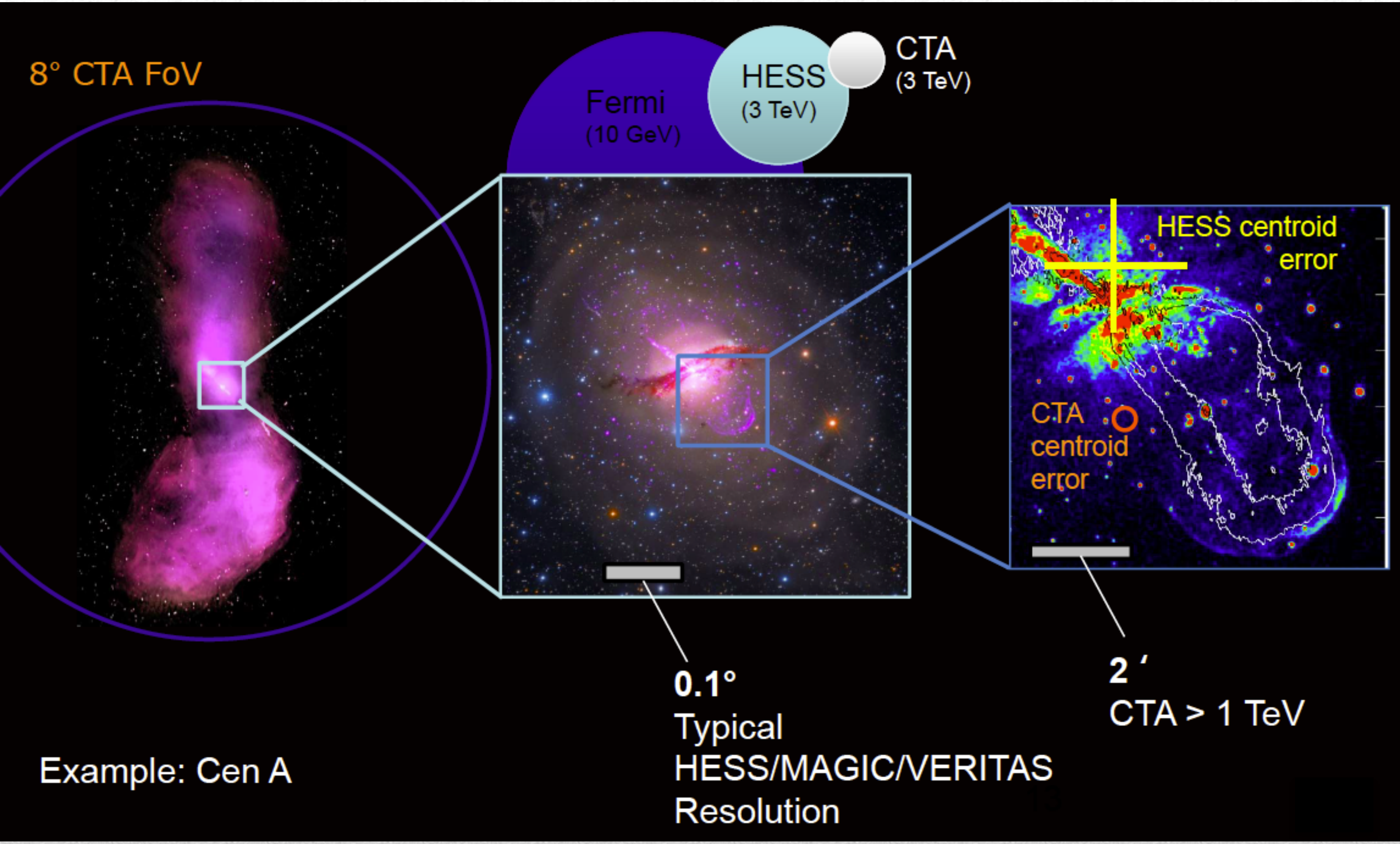
Galactic Discovery Reach



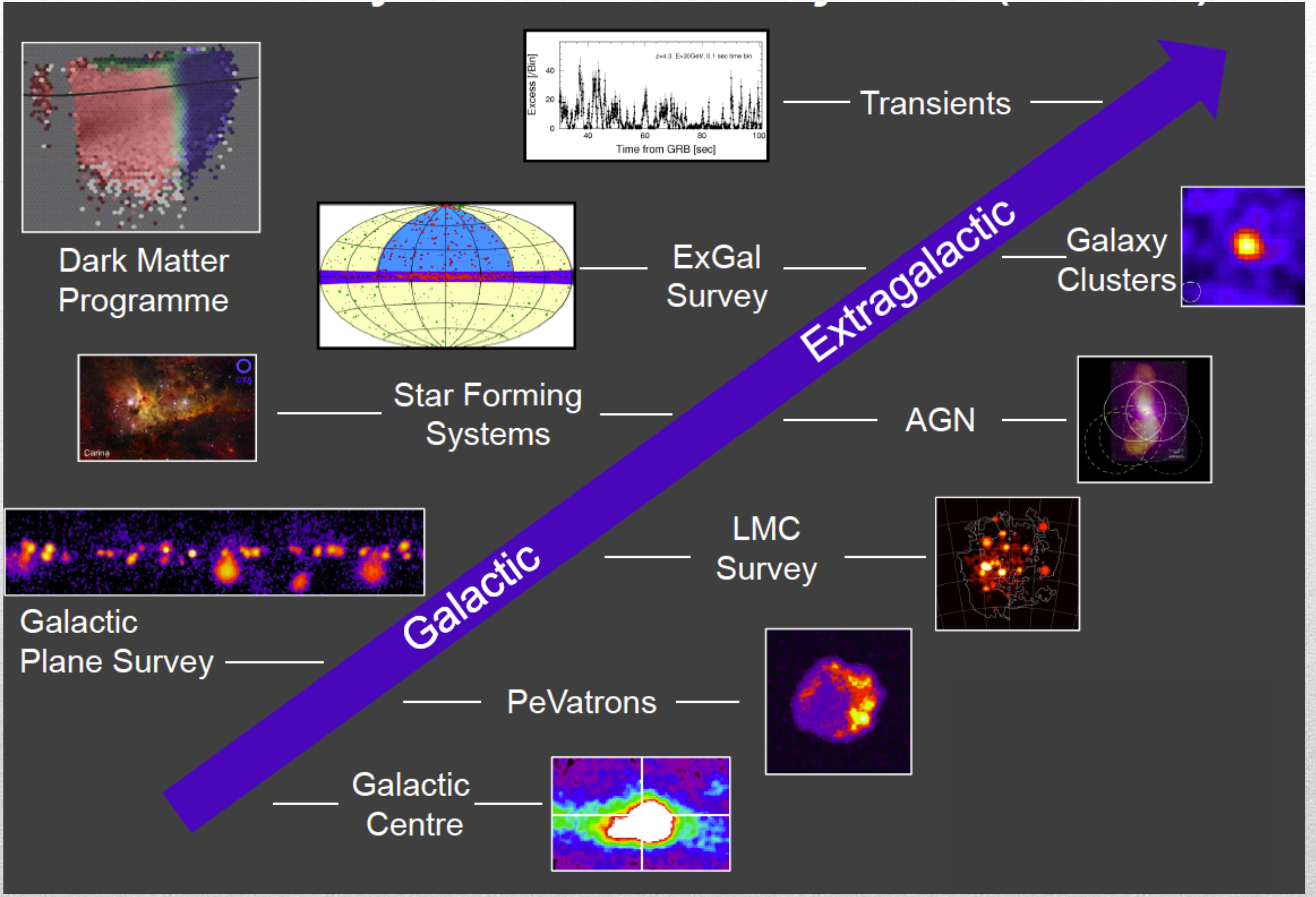
Survey speed:
x300 faster than current instruments



CTA Angular Resolution

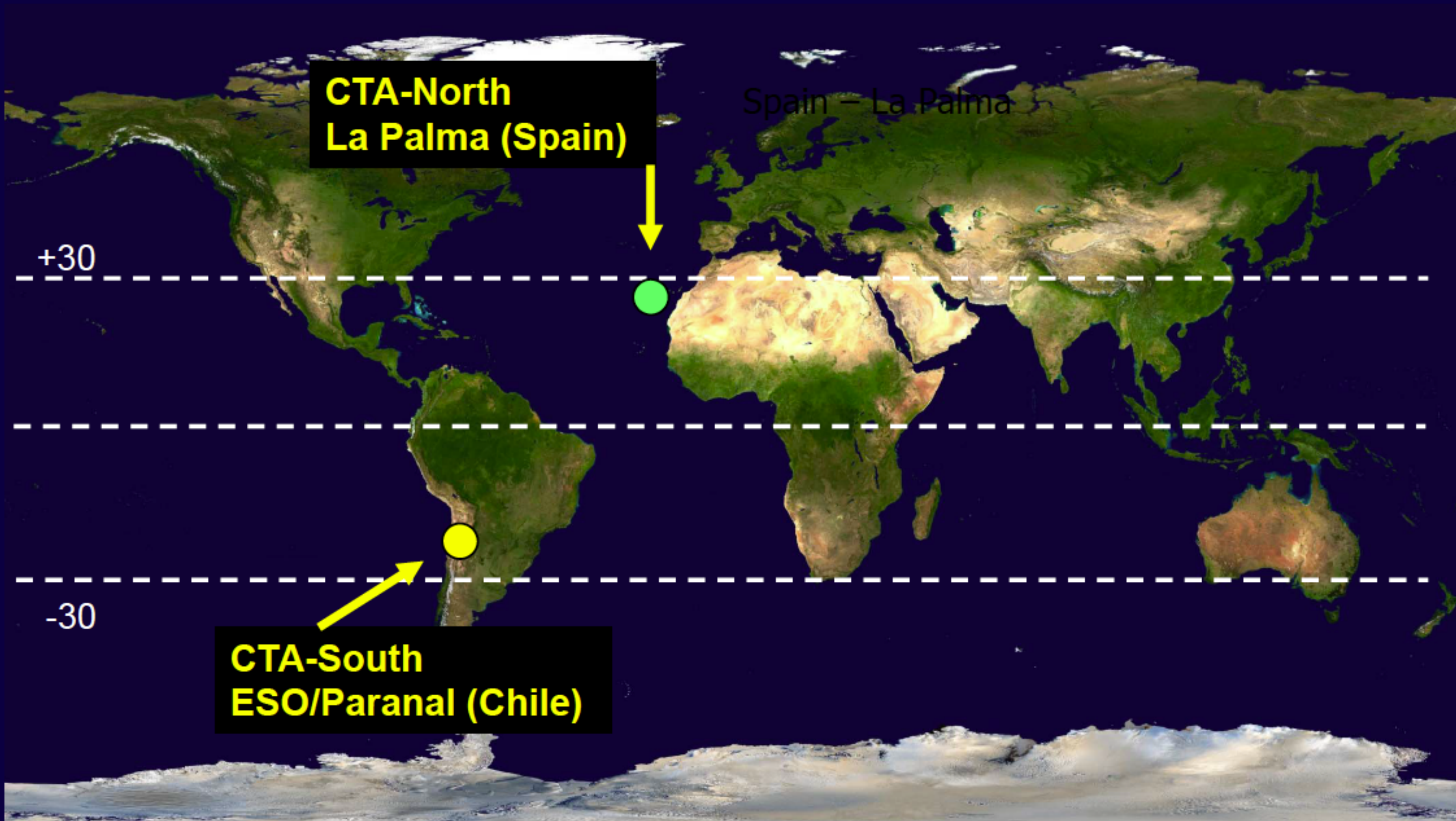


Key Science Projects

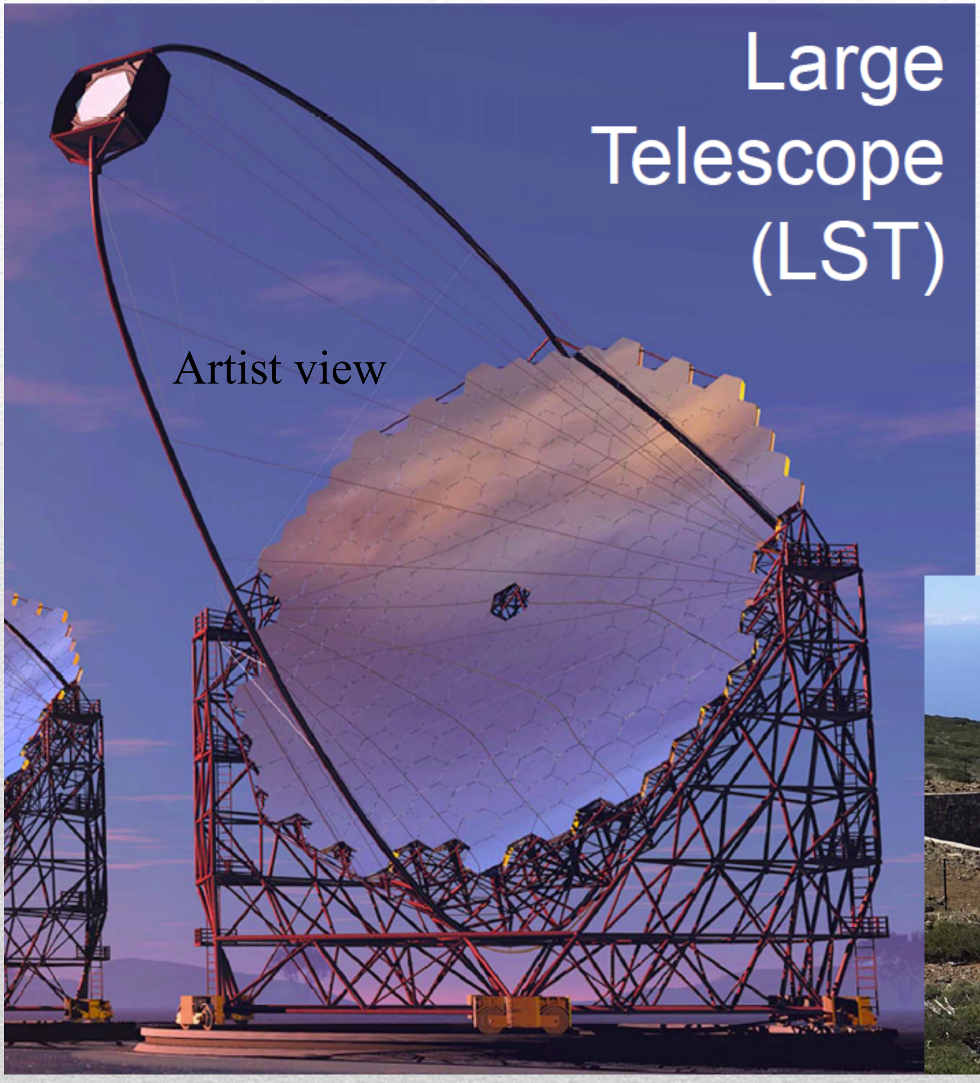


CTA Sites

cherenkov telescope array



3 Types of Telescopes: LST

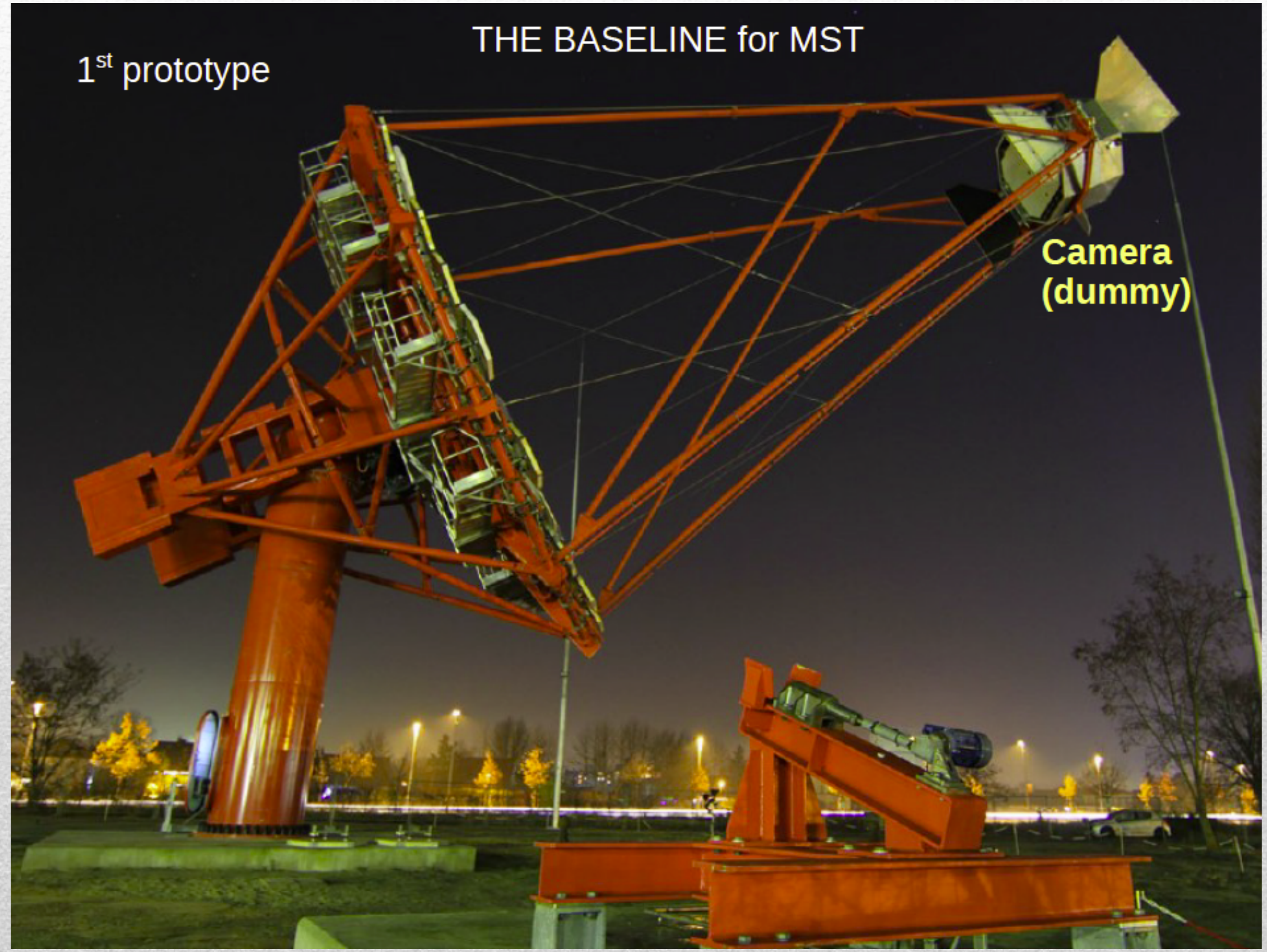


23 m diameter
390 m^2 dish area
28 m focal length
1.5 m mirror facets

4.5^o field of view
0.1^o PMT pixels
Camera ø over 2 m

3 Types of Telescopes: MST

MST: Medium Size Telescope



$100m^2$ mirror dish area
16 m focal length
1.2 m mirror facets

8^o field of view
~2000 x 0.18^o PMT pixels

3 Types of Telescopes: SST

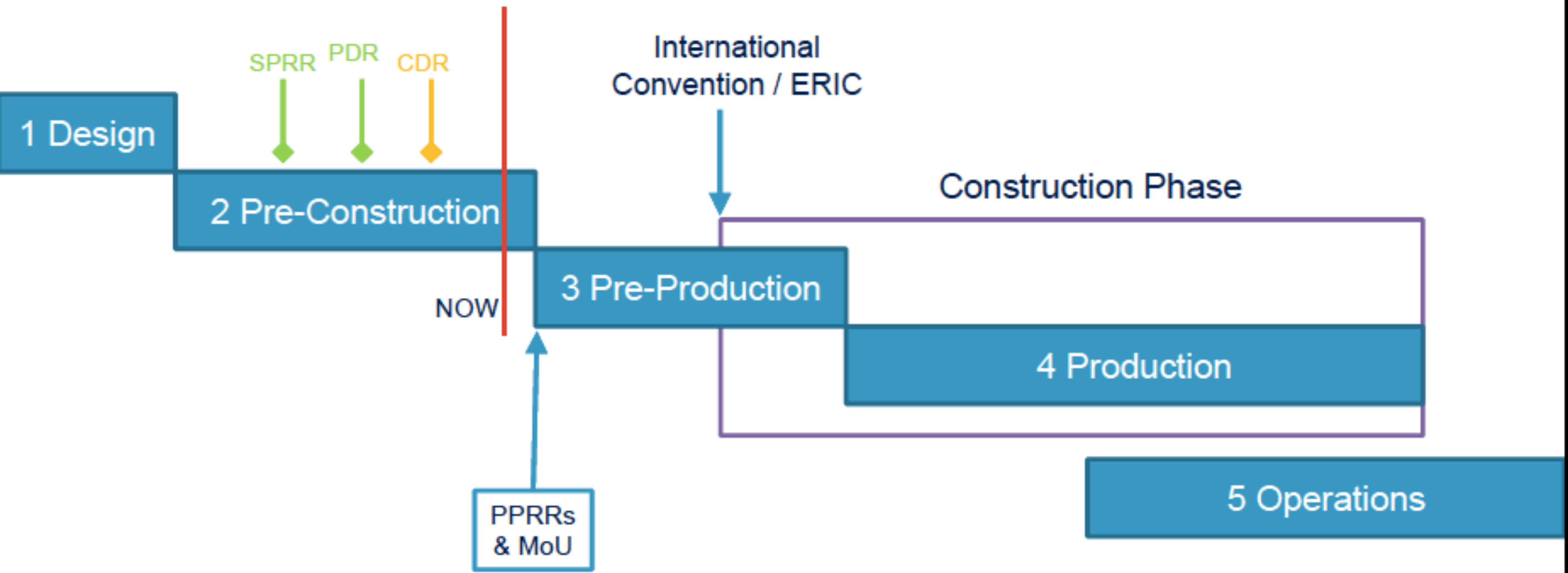
- 3 different prototype designs
- 2 designs use two-mirror approaches (Schwarzschild-Couder design)
- All use Si-PM photosensors
- 8-10 m^2 mirror area, FOV > 9^o

SST-1M
Krakow, Poland

SST-2M ASTRI
Mt. Etna, Italy

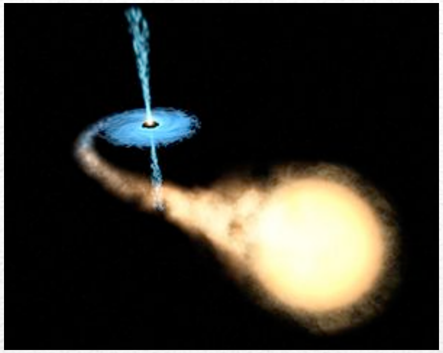
SST-2M GCT
Meudon, France

CTA Phases and Timeline



- 2016-7: Hosting agreements, site preparations start
- 2018: Start of construction
- Funding level at ~65% of required for *baseline implementation*
  → start with *threshold implementation*
  → additional funding & telescopes needed to complete baseline CTA
- Construction period of ~6 years
- Initial science with partial arrays possible before construction end

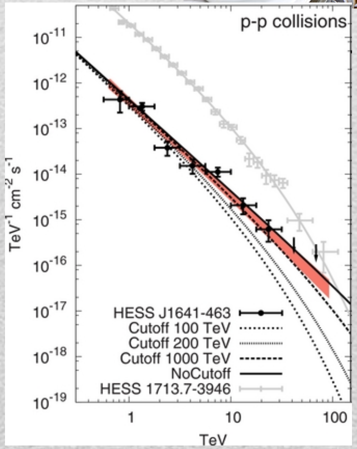
Activities at CPPM



- **HESS**: research of TeV gamma rays from μQuasars
  - observations following alerts
  - monitoring of X-rays and radio data to trigger HE observations with HESS

- **CTA**:
  - MC simulations and performance evaluation of GCT (one of the SST prototypes)

  - Acquisition system of the Camera for the MST (NectarCam)
  - Search for PeVatron candidates in the galactic plane survey



Conclusions

- **Thanks to many discoveries, VHE gamma-ray astronomy has become a major exiting field of research**
- **Outstanding science potential and the power of Atmospheric Cherenkov technique has brought to CTA**
- **CTA will open new windows on the Universe with a huge potential for new discoveries**
- **Construction will start very soon!**

VERY EXITING PERIOD TO JOIN!!

Thank you for your attention!!!

Questions?

Why do we want to detect Gammas?

- ***Understanding the origin and the role of relativistic Cosmic Particles:***
  - ***what are the sites of high energy particle acceleration in the Universe?***
  - ***What are the mechanisms for cosmic particle accelerations?***
- Probing extreme environments:
  - What physical processes are at work close to neutron stars and black holes?
  - What re the characteristics of relativistic jets , winds and explosions?
  - How intense are radiation fields and magnetic fields in cosmic voids and how do these evolve over cosmic time?
- Exploring Frontiers in Physics:
  - What is the nature of dark matter?
  - Are there quantum gravitational affects on photon propagation?
  - Do axion-like particle exists?

- At sea level $(n - 1) = \varepsilon \approx 3\ 10^{-4}$.
- Per $v \approx c$, $\cos\theta = 1/\beta n \approx 23$ mrad $\approx 1.3°$
- Threshold energy for Cherenkov effect : $\cos\theta = 1 = 1/\beta n$; $\beta > 1/n$

$$E = \gamma mc^2 = mc^2/(1-\beta^2)^{1/2} \ ; \ (1-\beta^2)^{1/2} = (1-1/n^2)^{1/2} = [(n^2-1)/n^2]^{1/2}$$

$$E = mc^2/\sqrt{(2\varepsilon)} \qquad 1/\sqrt{2\varepsilon} \approx 41$$

- The threshold is electrons $E \approx 21$ MeV

  muons $E \approx 4.4$ GeV
- The maximum Cherenkov production is at 10 km height
- The illuminated area is an ellipse or a circle of radius $r = h \cdot \theta = 10^4\ 23\ 10^{-3} = 230$ m

with a surface of $1.6\ 10^5\ m^2$.

- The number of photons produced in visible light (350-500 nm) by a gamma of 1 TeV is

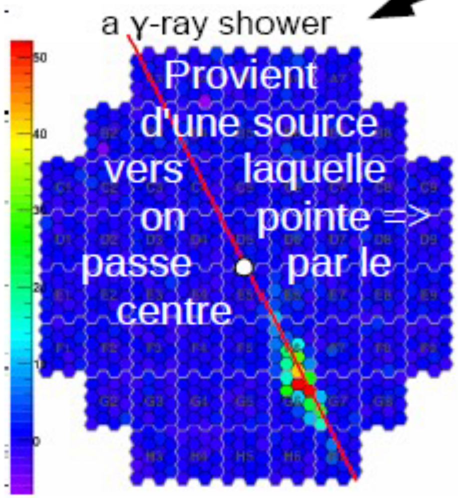
$$N\gamma \approx 8.2\ 10^3 \text{ fotoni}/\lambda$$

Equal to 30-50 photons/m2 in an area of 100 m from the shower axis

Caractéristique des images

Flash 5-8 ns

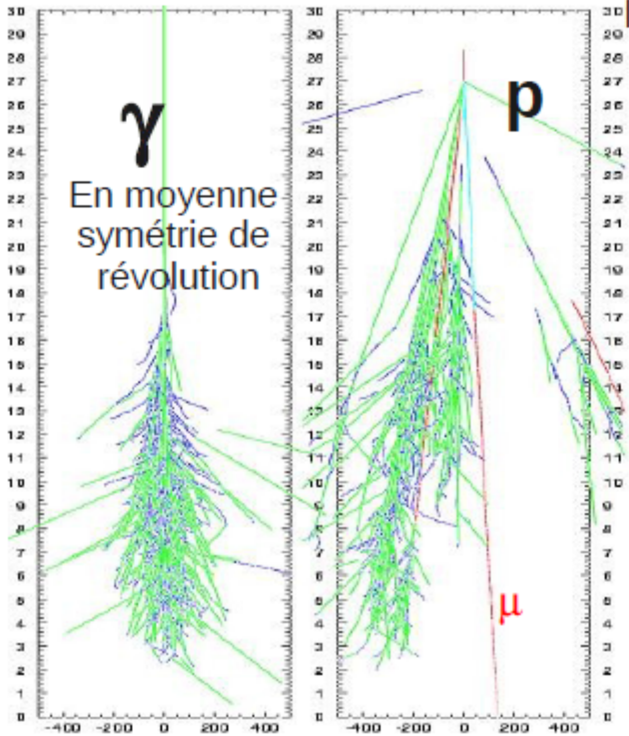
Pas de symétrie de révolution
Plus étendue latéralement



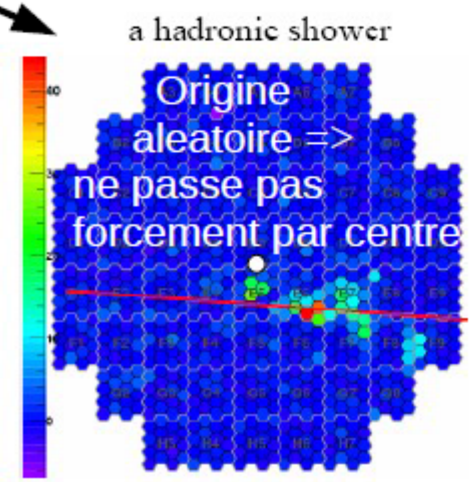
IMAGE

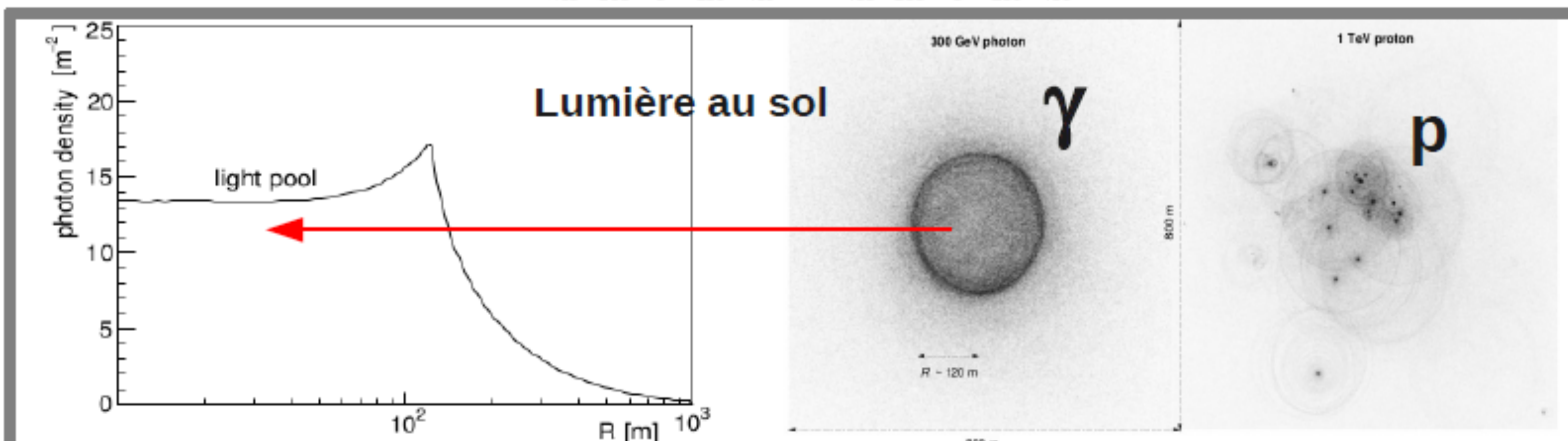
GERBE

GERBE



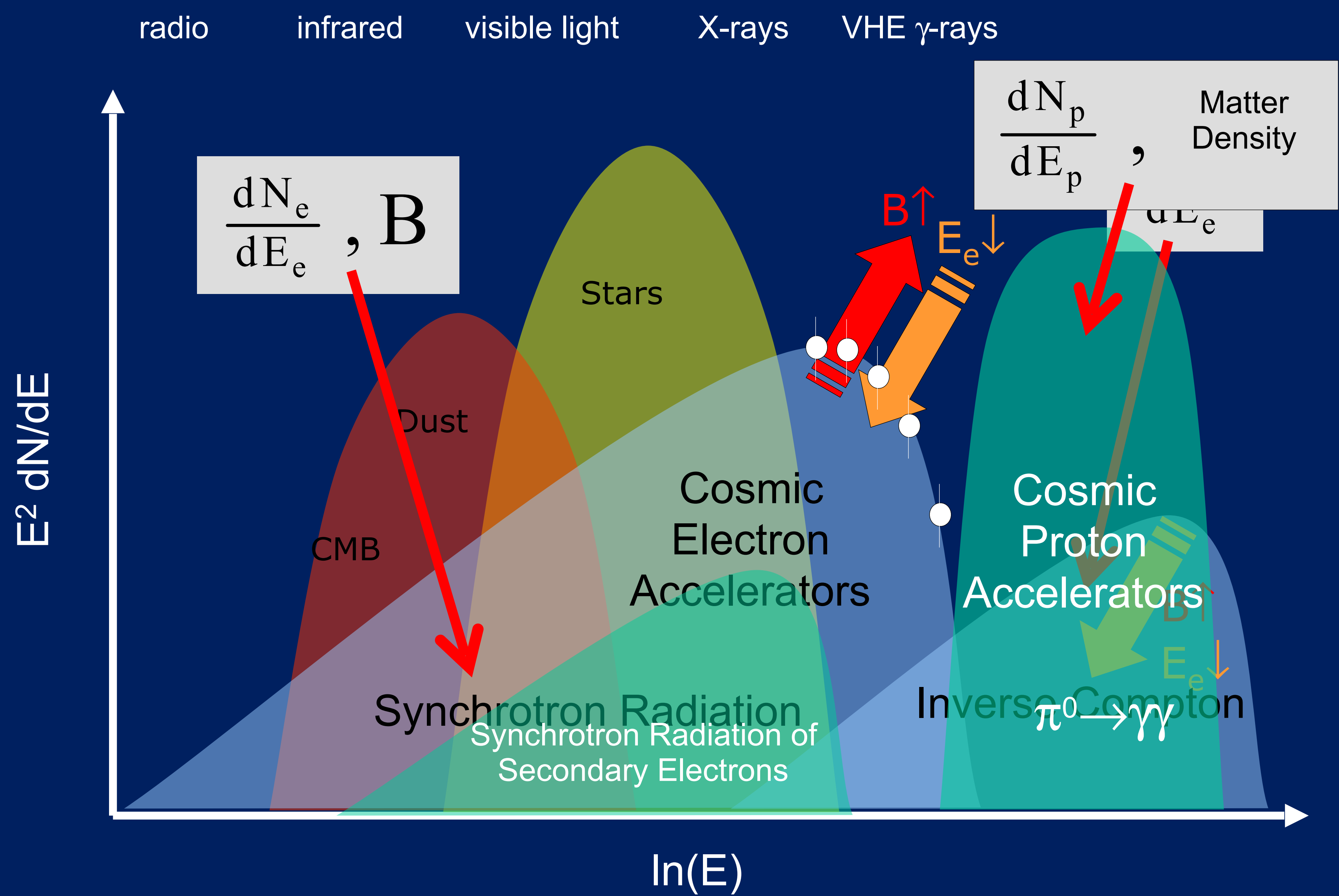
IMAGE



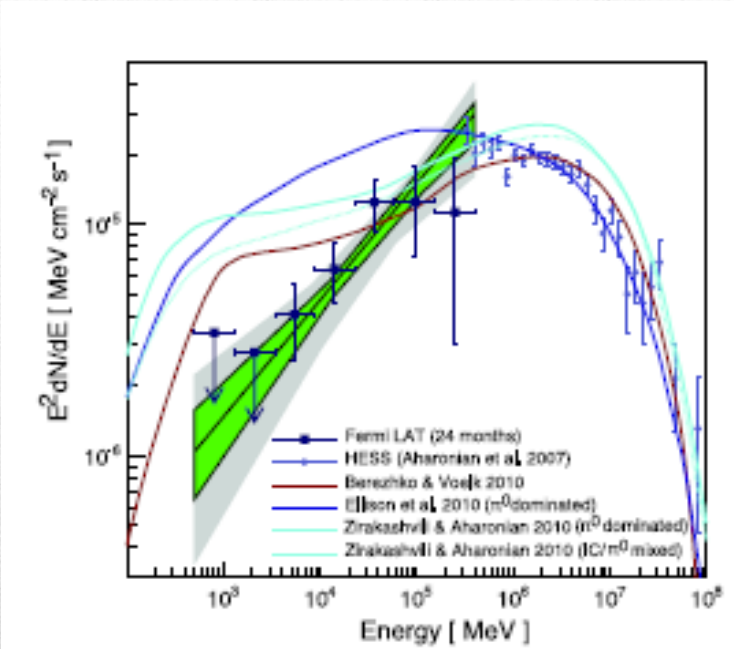


As

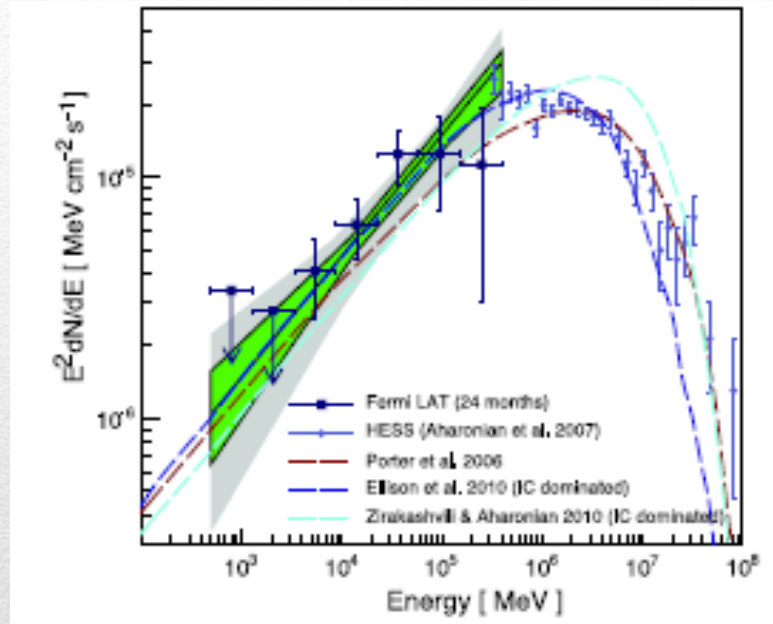
Electron or Hadron Accelerator?



Electron or Hadron Accelerator?



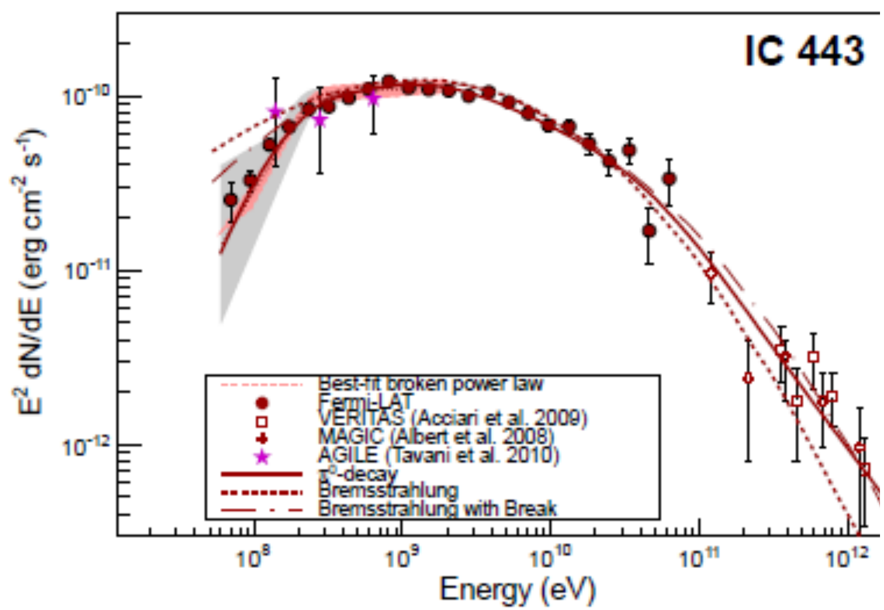
Comparison with hadronic models

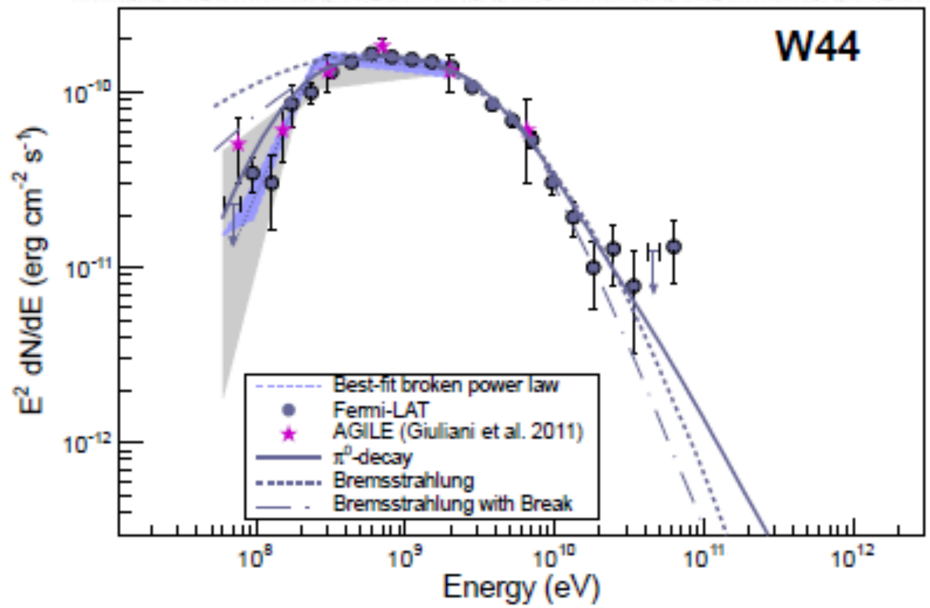


Comparison with leptonic models

Fermi measurements; 2011 **arXiv:1103.5727**

First evidence of hadronic origin of g-rays?





Pion decay signature from W 44 and IC 443

Figure 2: (A and B) Gamma-ray spectra of IC 443 (A) and W44 (B) as measured with the *Fermi*-LAT. Color-shaded areas bound by dashed lines denote the best-fit broadband smooth broken power law (60 MeV to 2 GeV), gray-shaded bands show systematic errors below 2 GeV due mainly to imperfect modeling of the galactic diffuse emission. At the high-energy end, TeV spectral data points for IC 443 from MAGIC (*29*) and VERITAS (*30*) are shown. Solid lines denote the best-fit pion-decay gamma-ray spectra, dashed lines denote the best-fit bremsstrahlung spectra, and dash-dotted lines denote the best-fit bremsstrahlung spectra when including an ad hoc low-energy break at 300 MeV c^{-1} in the electron spectrum. These fits were done to the *Fermi* LAT data alone (not taking the TeV data points into account). Magenta stars denote measurements from the AGILE satellite for these two SNRs, taken from (*31*) and (*19*), respectively.

Fermi measurement: Ackermann, M. et al., 2013, Science, 339 (6121), 807