Status of the Cherenkov Telescope Array

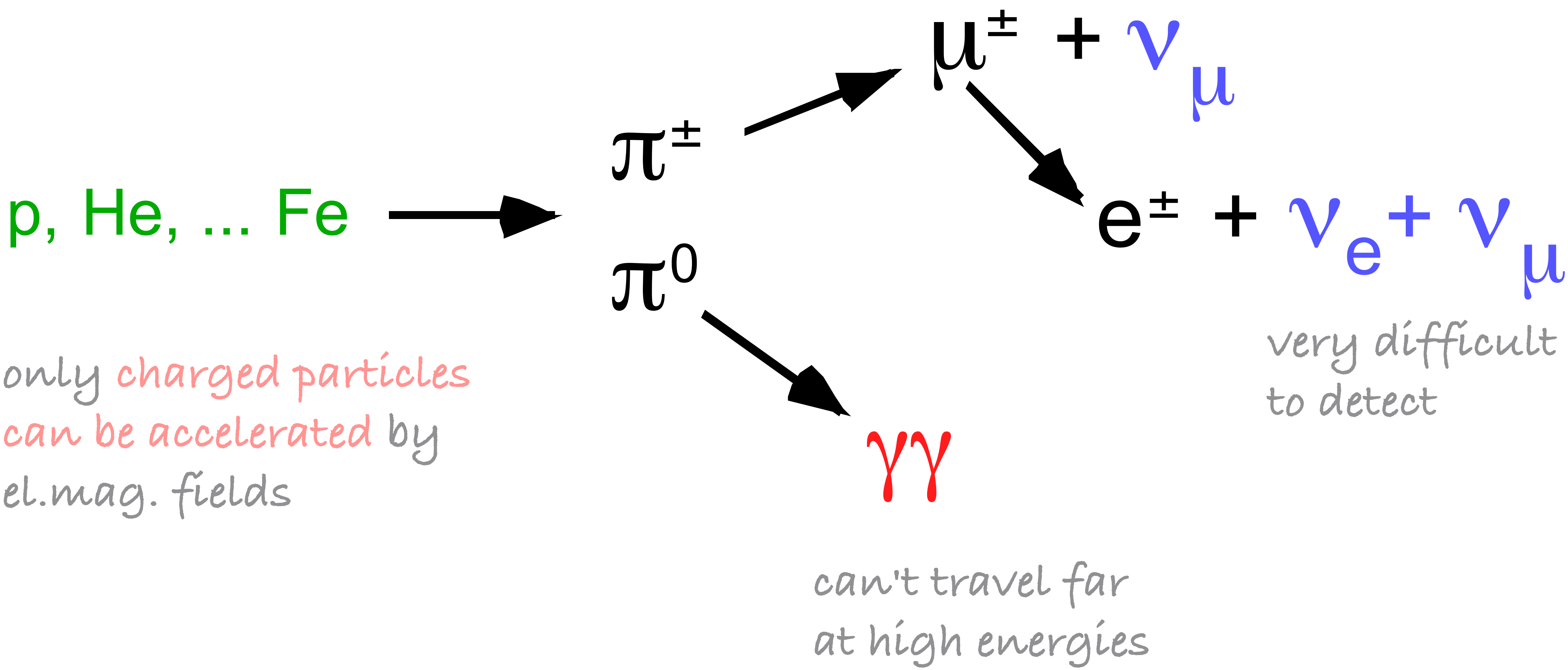
Johannes Knapp, U of Leeds, UK

Cosmic Ray Summer School

Nor Amberd, Armenia, June, 2012

If then Cosmic Rays exist, also γ and ν must exist at similar energies.

Cosmic Rays, Gamma Rays and Neutrinos are linked



γ and ν travel in straight lines, i.e. point back at source.

CRs are deflected in gal. and intergal. magnetic fields.

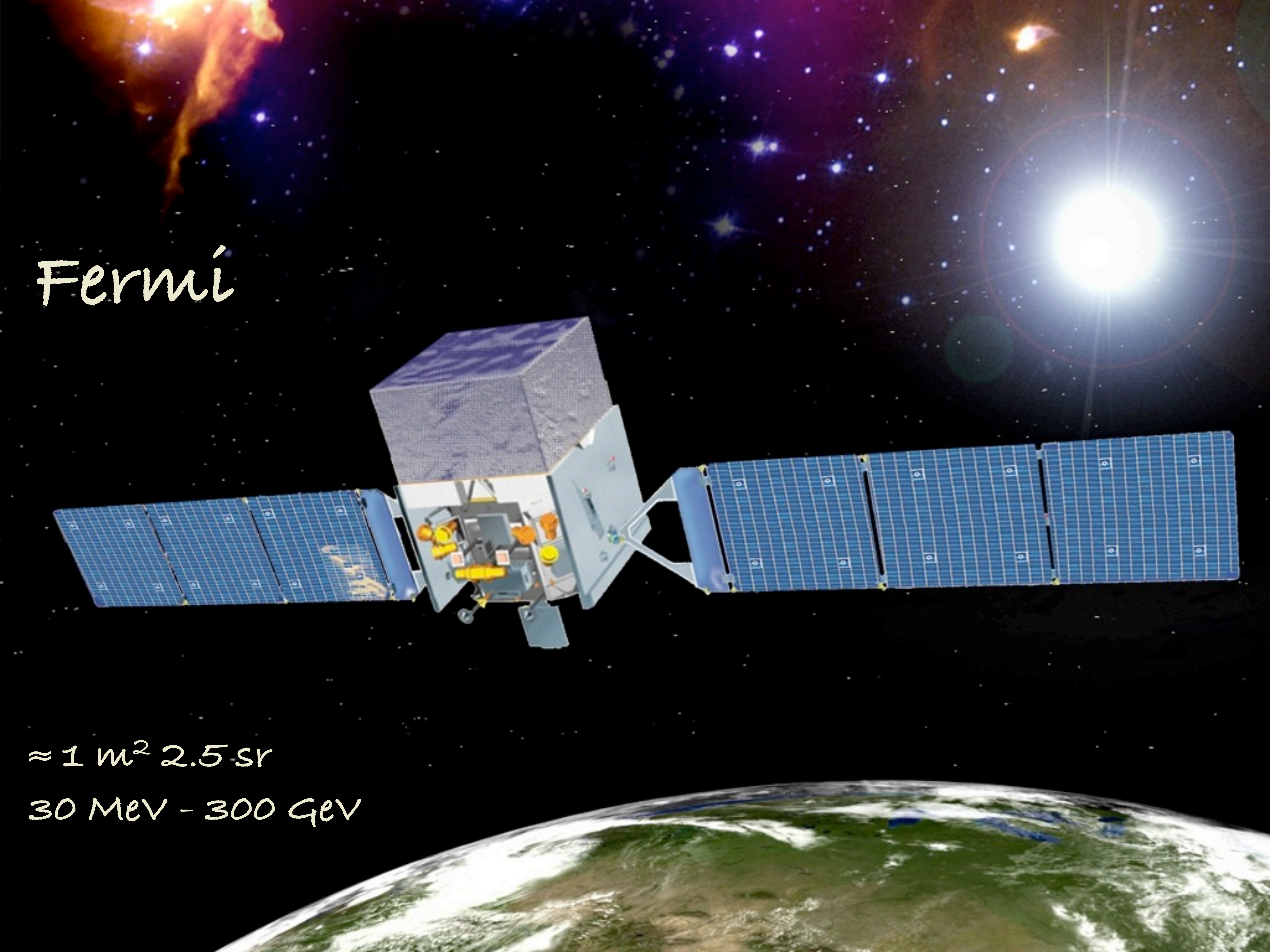
But:

Can γ and ν be detected above backgrounds ???

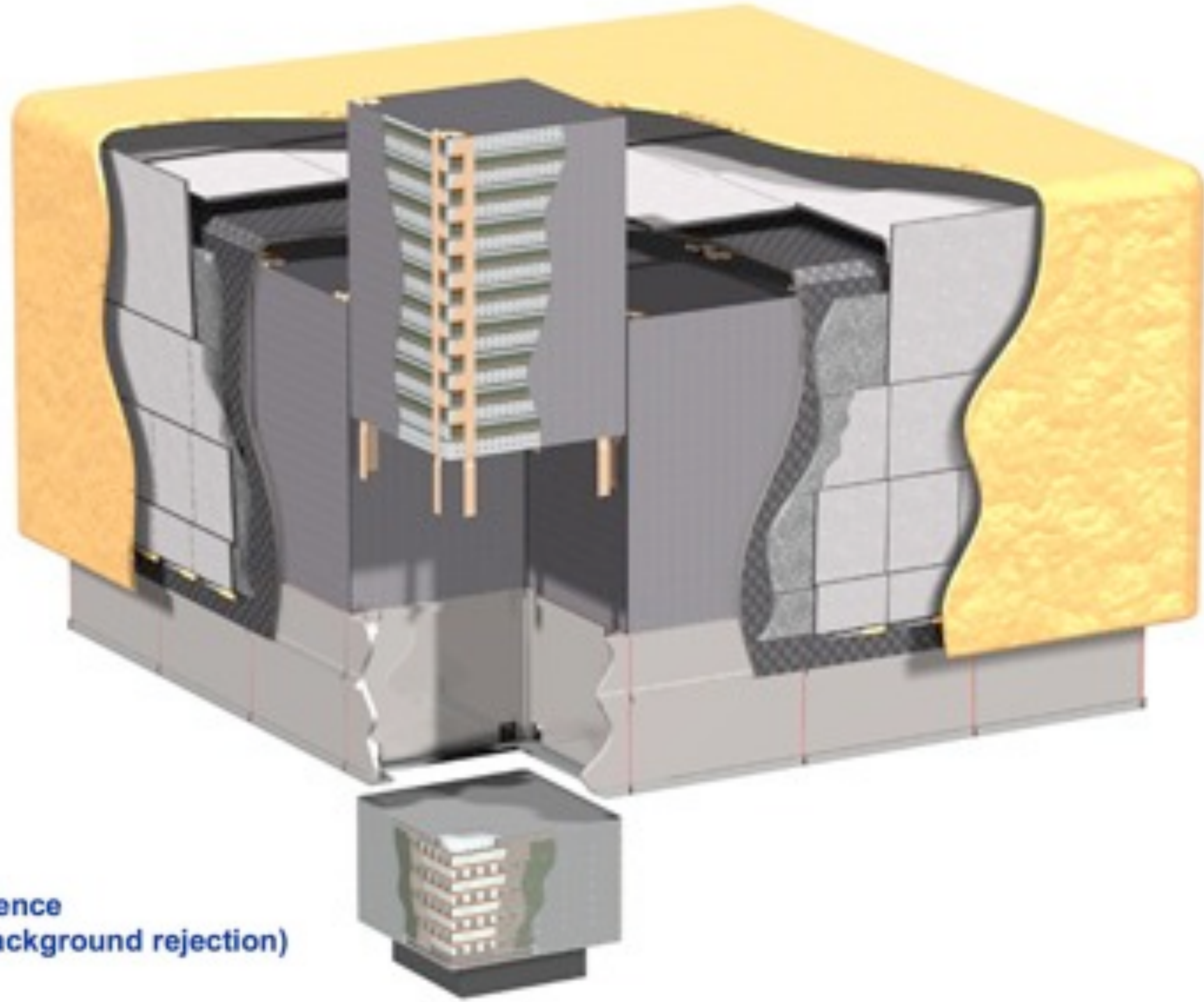
γ : 10^3-10^4 x more charged cosmic rays

ν : low interaction cross section

atmospheric neutrinos from atmosphere


Fermi
≈ 1 m² 2.5 sr
30 MeV - 300 GeV

Fermi - LAT

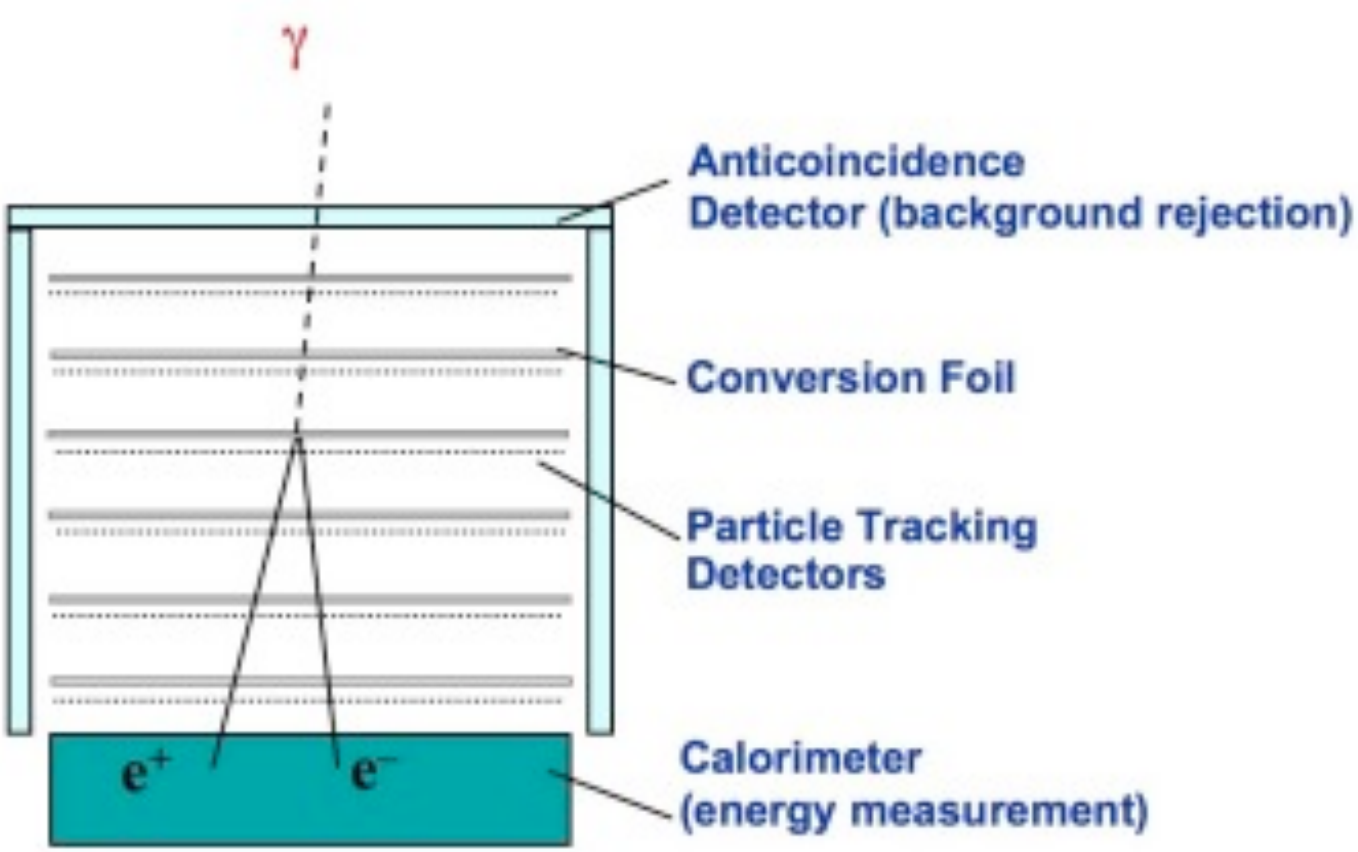


pair-conversion telescope with:

precision trackers
  18 layers tungsten converters
  and x, y silicon strip detectors.

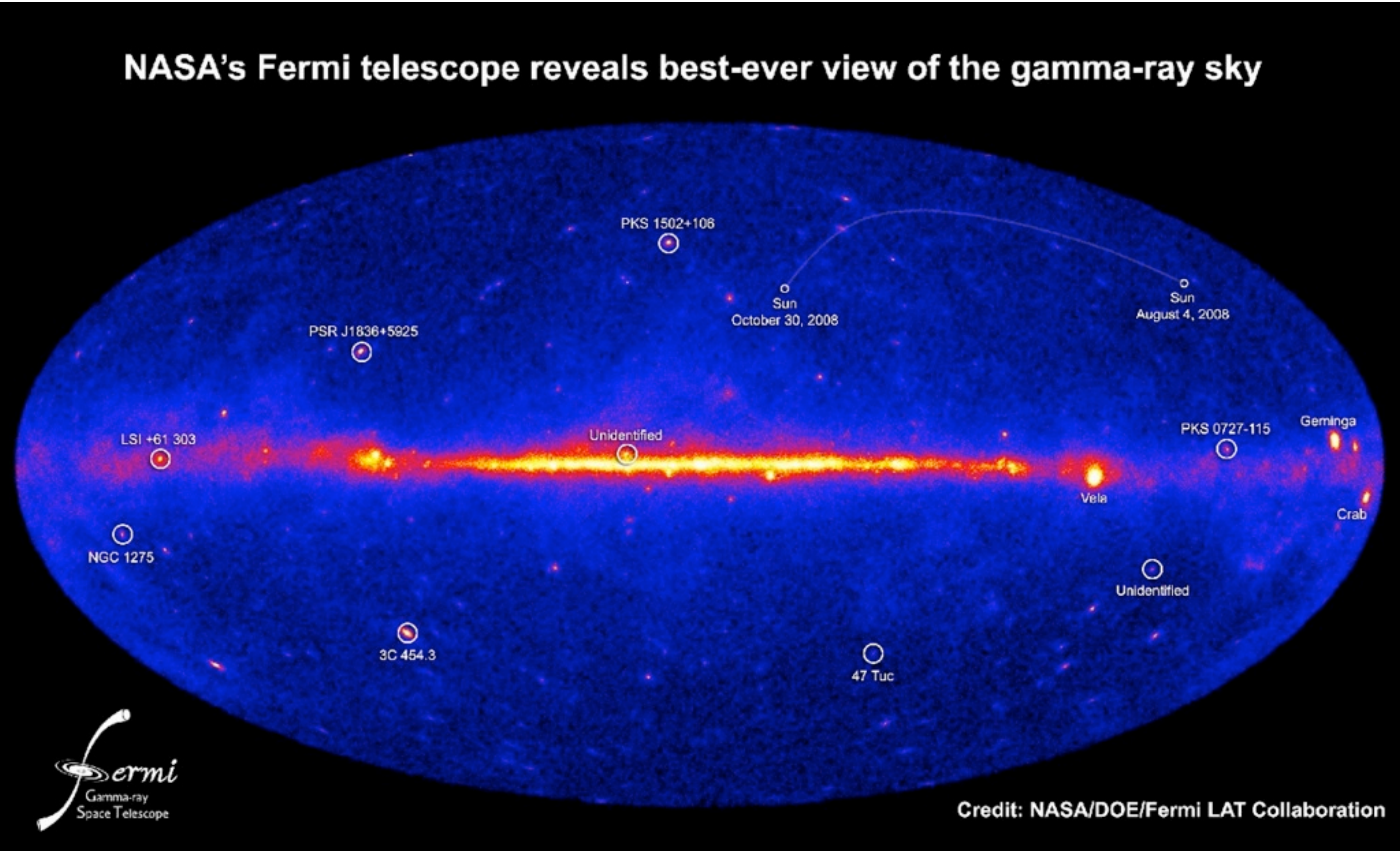
calorimeter
  96 CsI(Tl) crystals in an
  8 layer hodoscope (depth: 8.6 X_0)

4x4 modules covered by
anti-coincidence shield



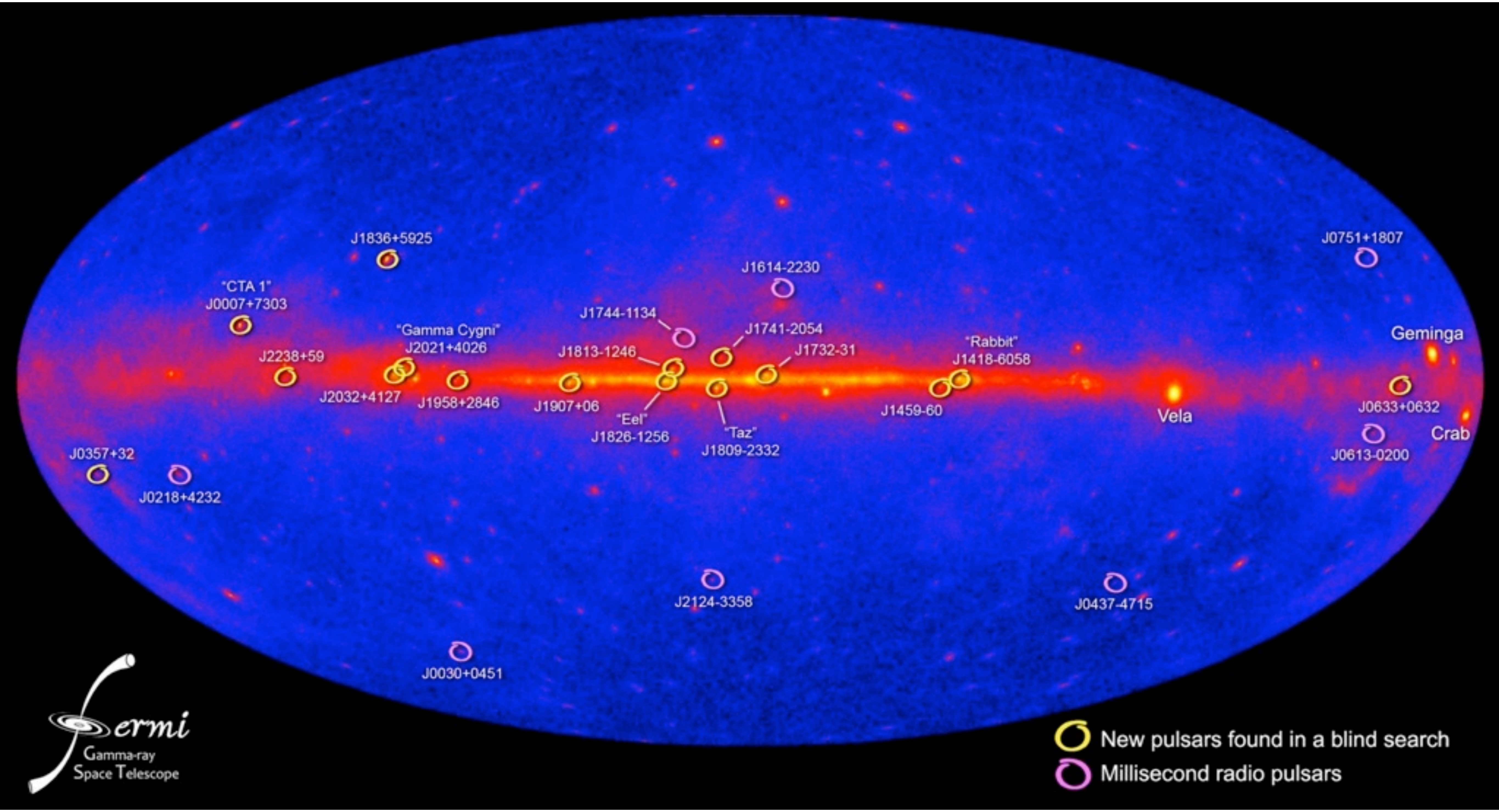
≈ 1 m² 2.5 sr

near-perfect rejection of
charged primaries



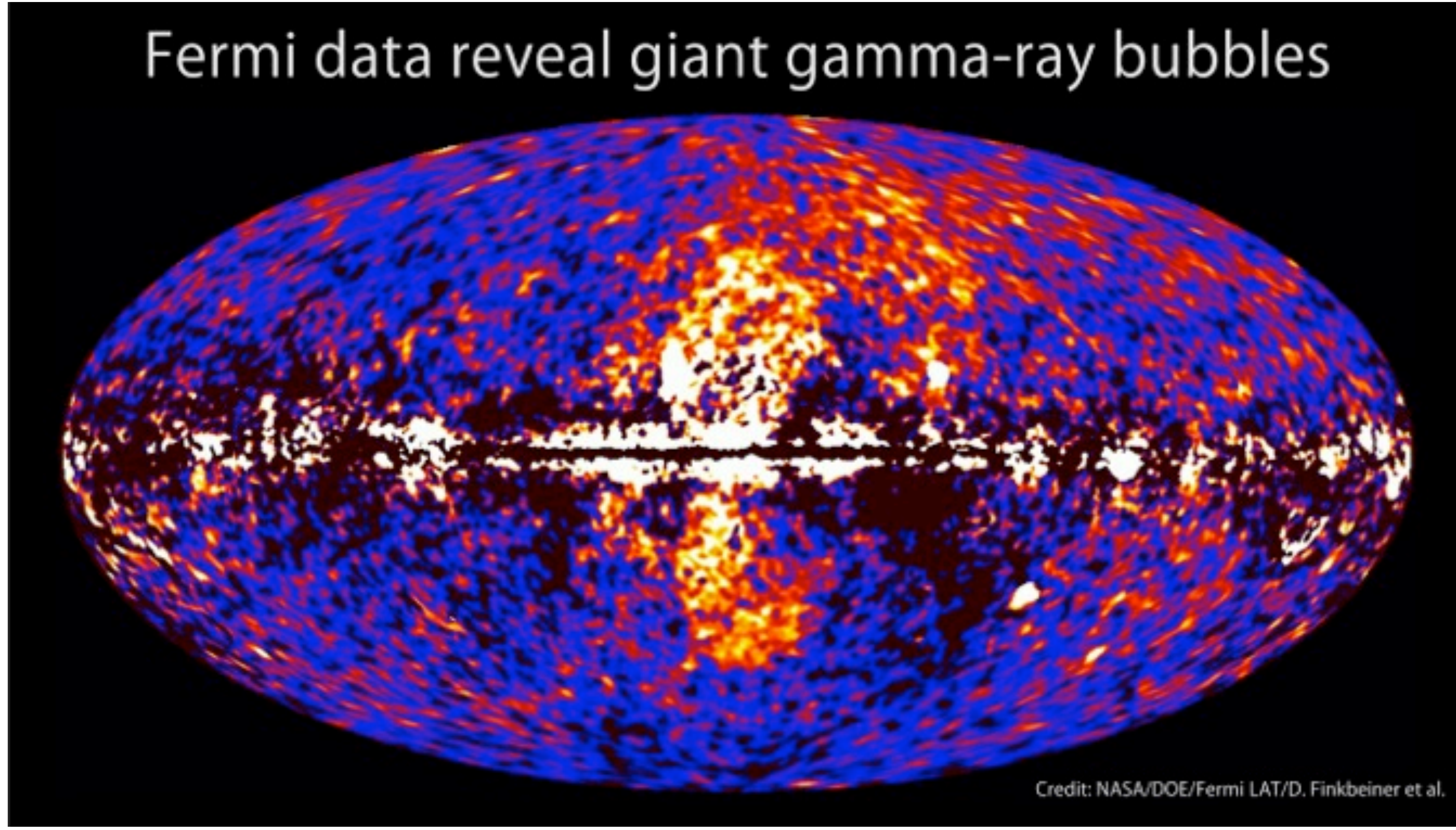
point sources, extended sources and diffuse emission

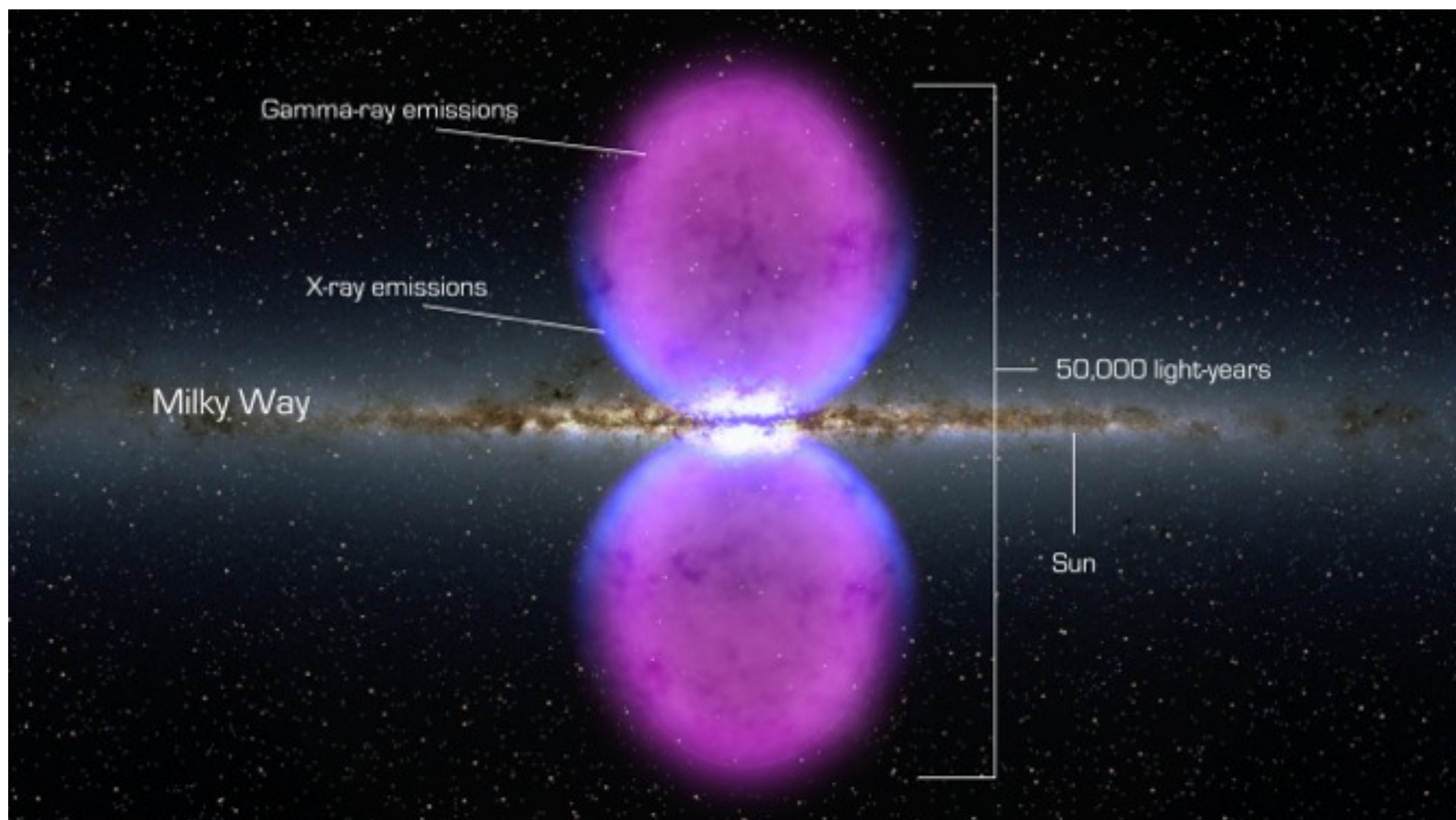
… many old and new gamma ray pulsars



The Fermi Bubble

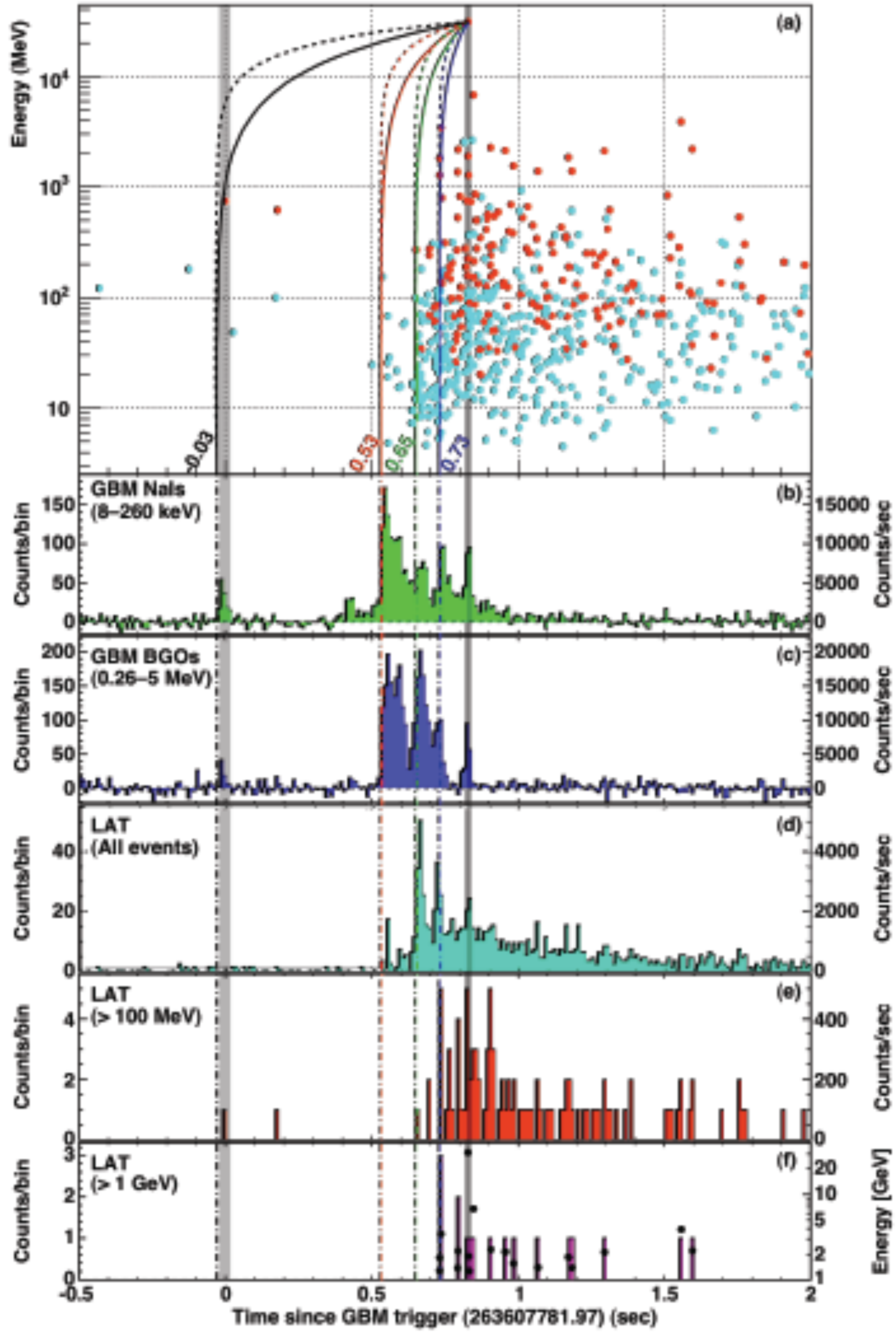
... a remnant of
recent activity
of our galaxy



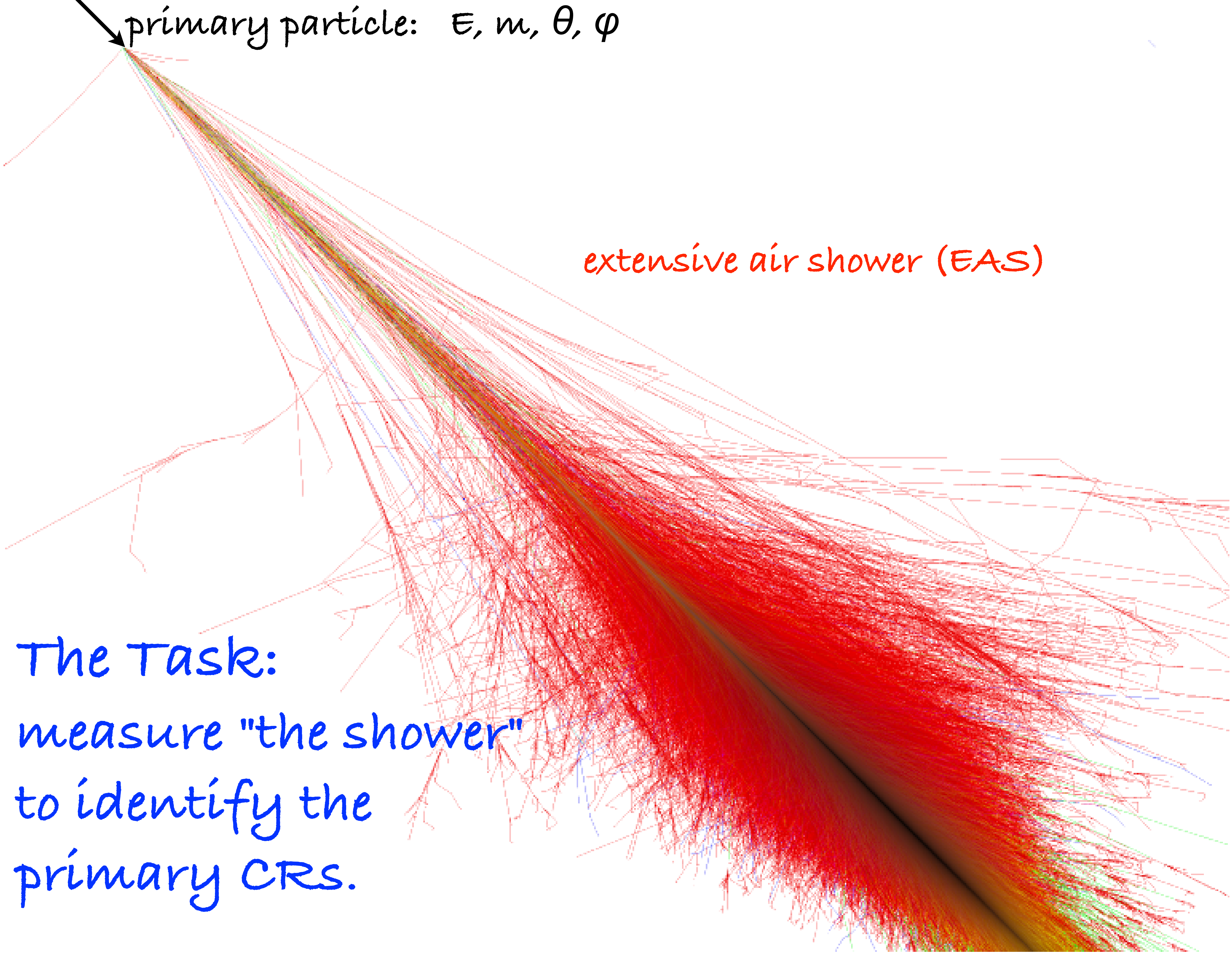


Fermi:

LIV test: GRB

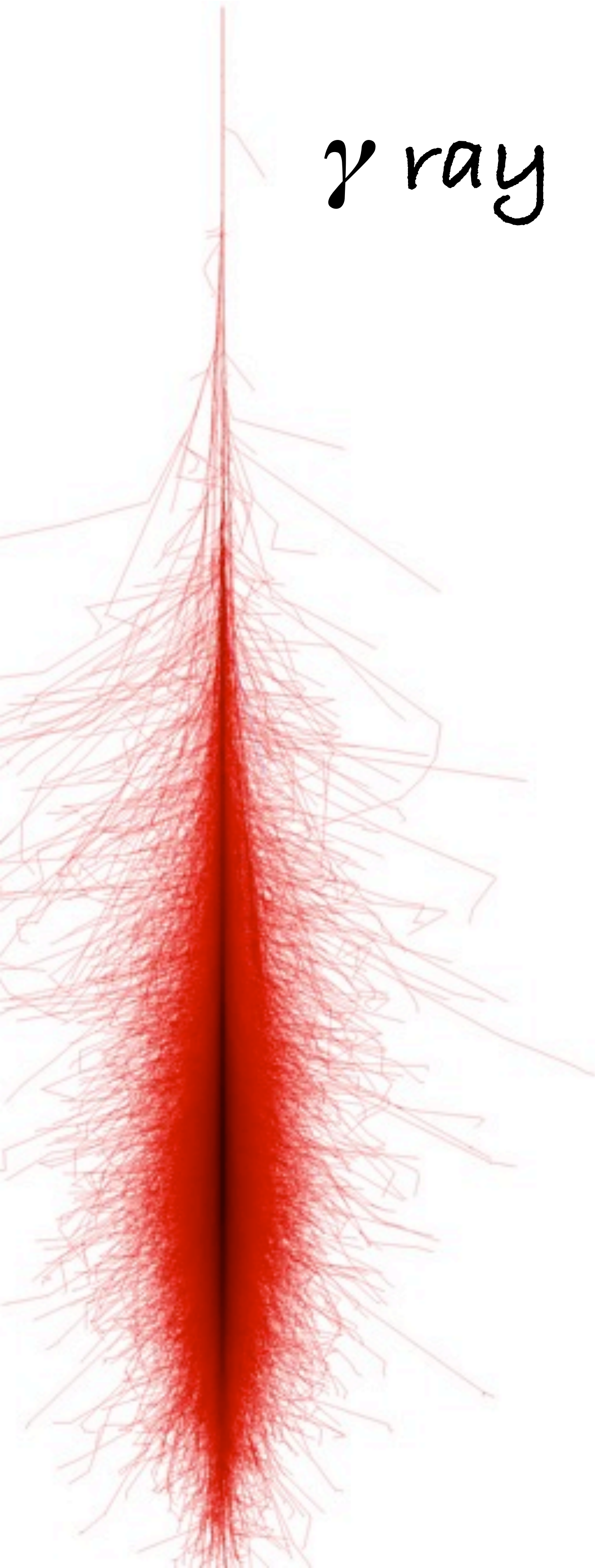


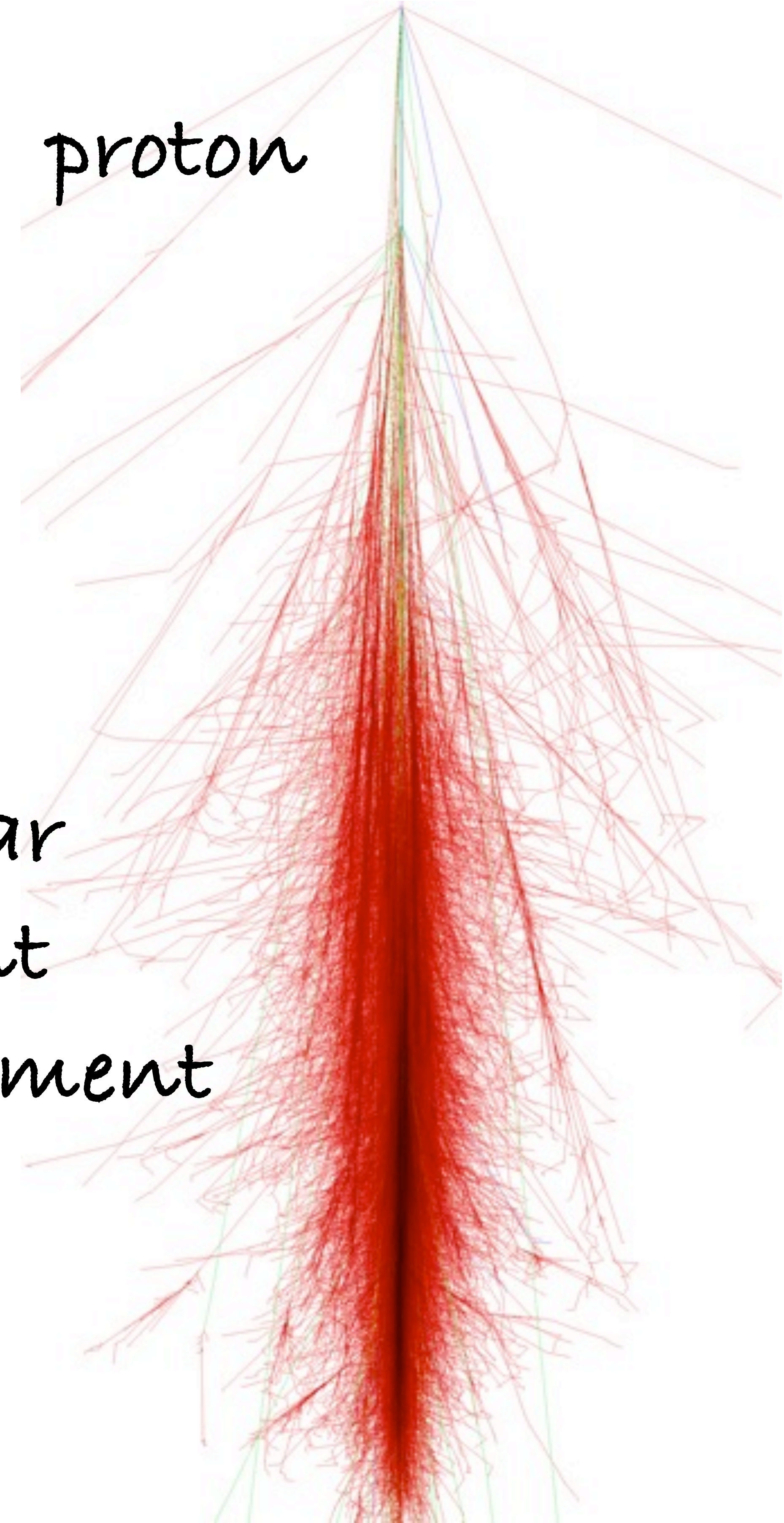
... plus many more exciting results. 100s of papers...



The Task:
measure "the shower"
to identify the
primary CRs.

10^{12} eV γ ray vs hadronic showers



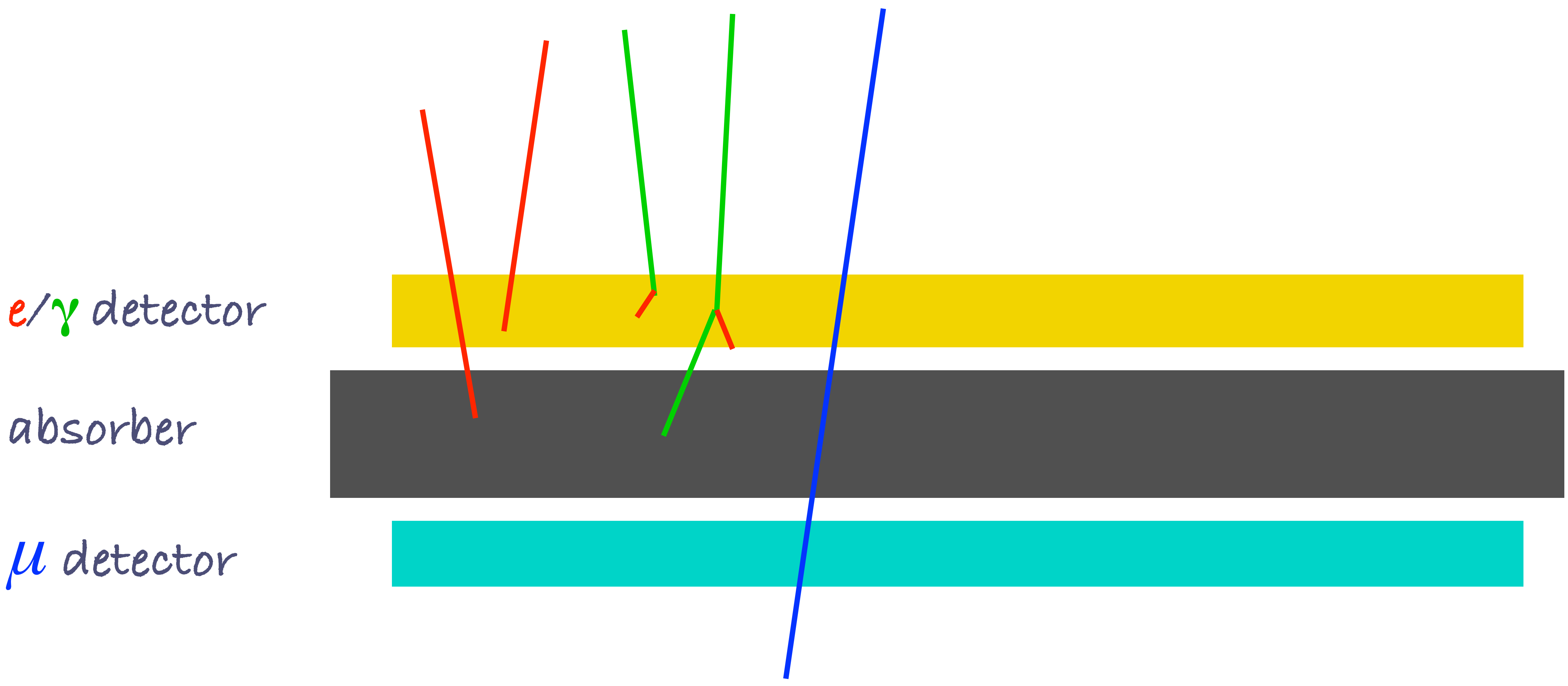


more irregular
muon content
long. development

Different detectors for different purposes ...

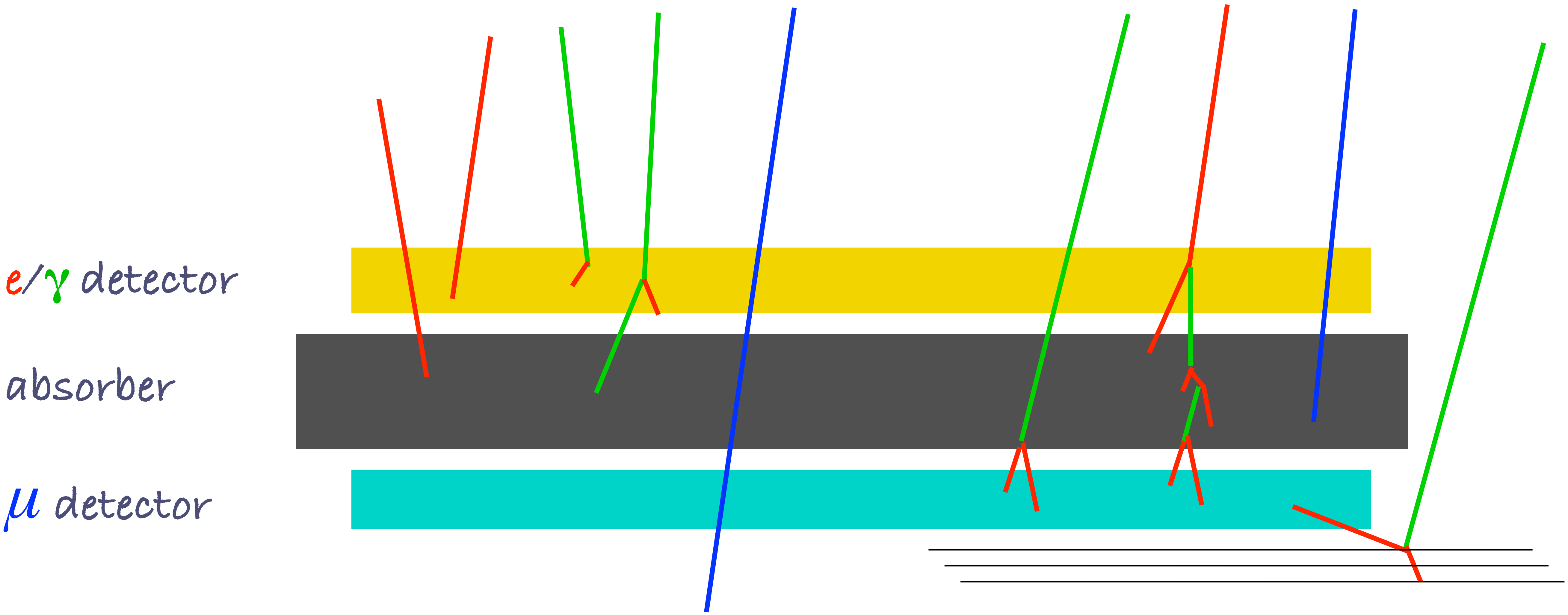
EAS Observables:		Suitable Detectors:
Number, distribution, fluctuation of electrons arrival times	....	arrays of scintillators, water Cherenkov detectors or gas chambers
Number, distribution, angle, energy, fluctuation of μ	....	buried detectors, tracking chambers
Number, distribution and energy of hadrons	....	deep hadronic calorimeters
Number and distribution, angular distribution of Cherenkov photons	....	wide angle and imaging Cherenkov detectors
angular distribution of fluorescence photons	....	fluorescence telescopes
Depth of shower maximum	....	Cherenkov or fluorescence detectors

Identifying secondaries is not so easy ....



detector response is crucial

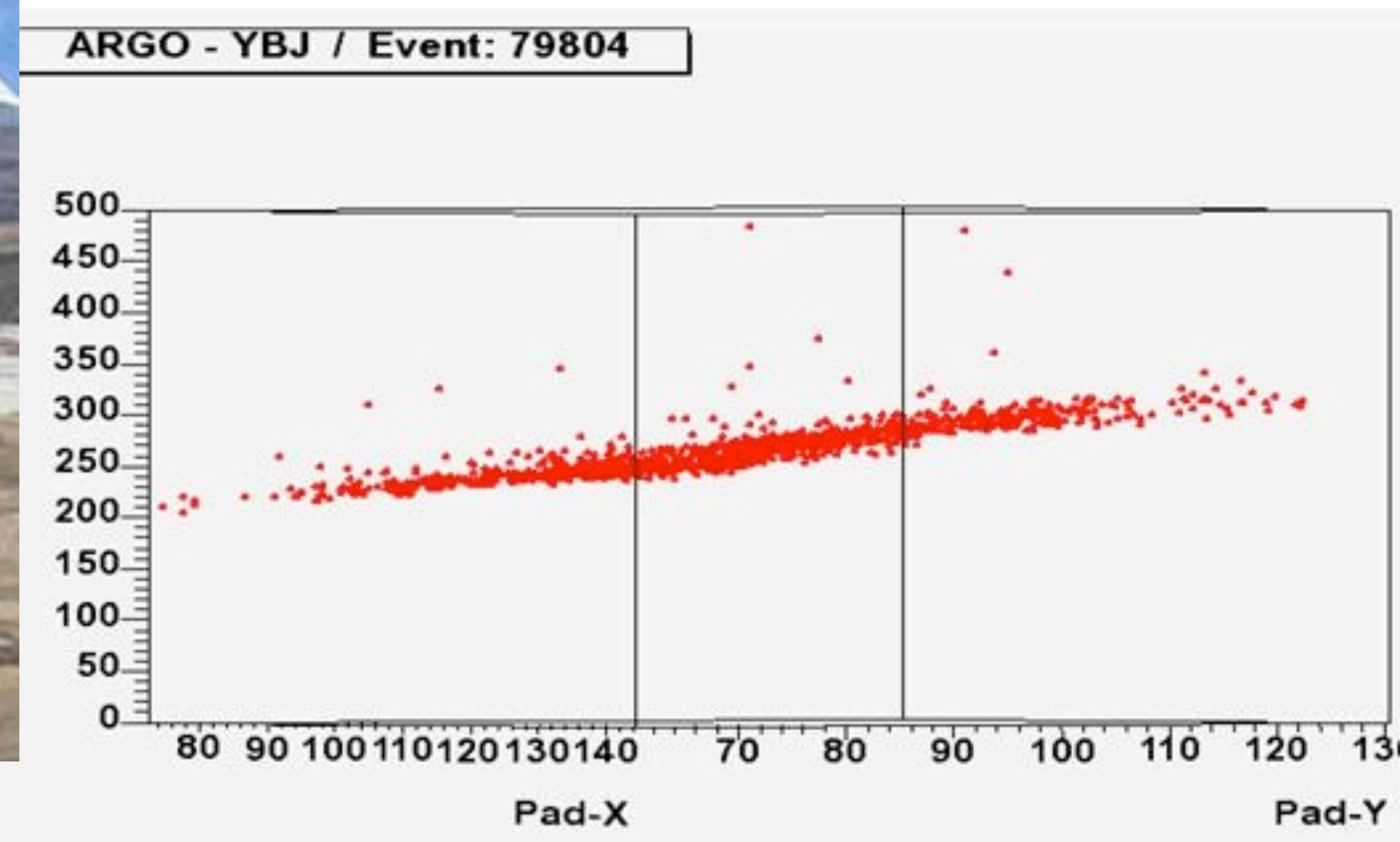
Identifying secondaries is not so easy ....



detector response is crucial

Gamma ray sources can be detected if they emit so many photons that the number of particles from this direction stands out of the background.

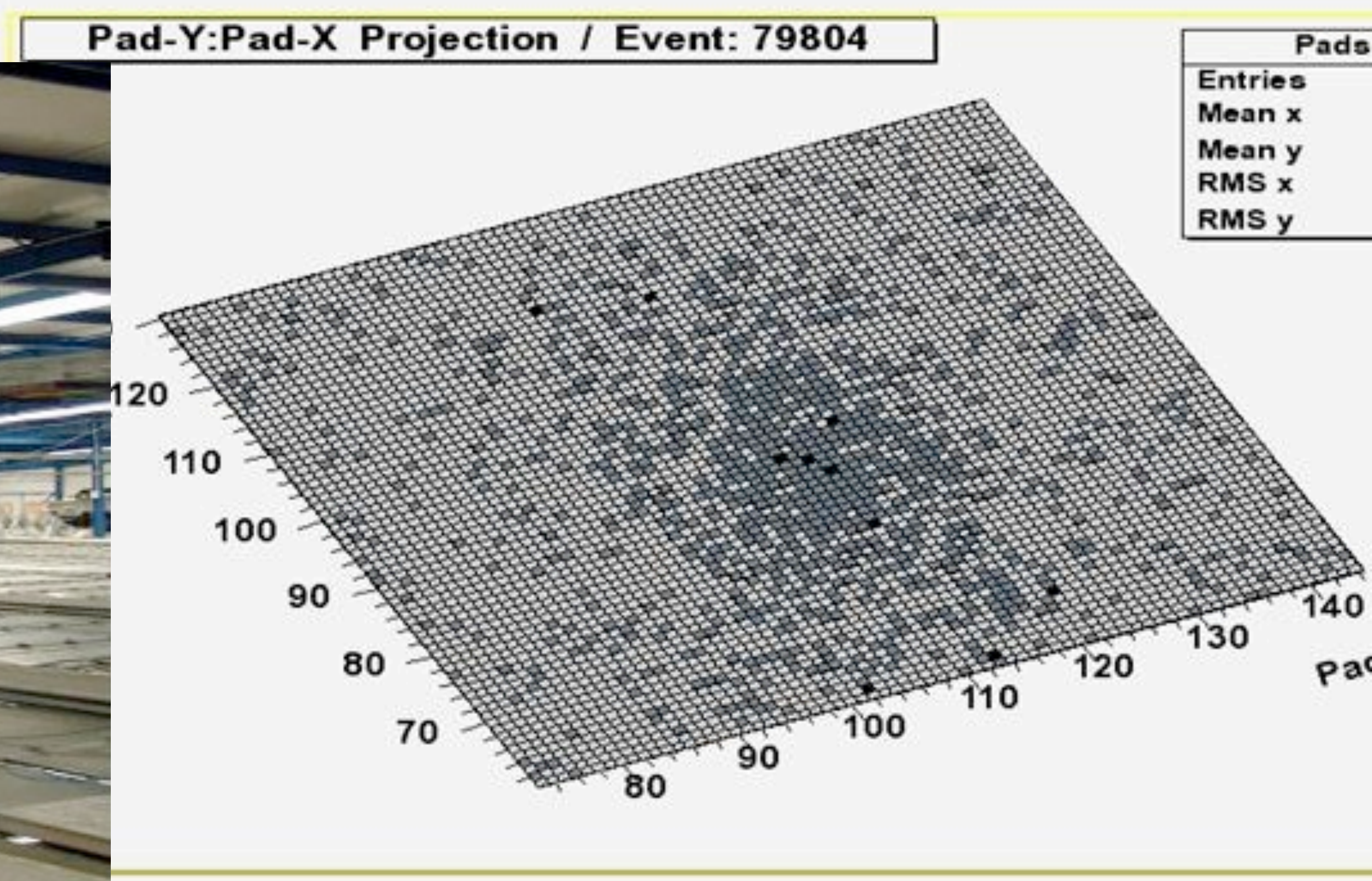
4200 m.a.s.l.



Argo

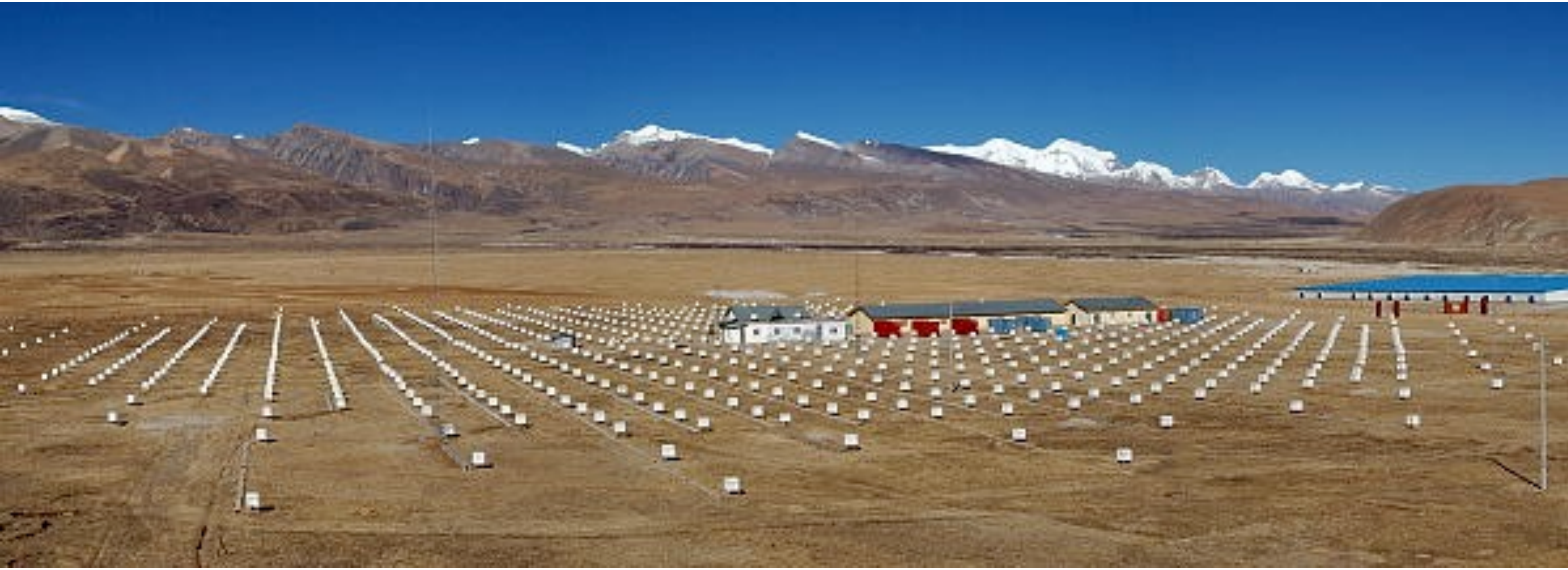
gamma sources

RPCs full coverage



Tibet AS Gamma

4200 m.a.s.l.



Milagro

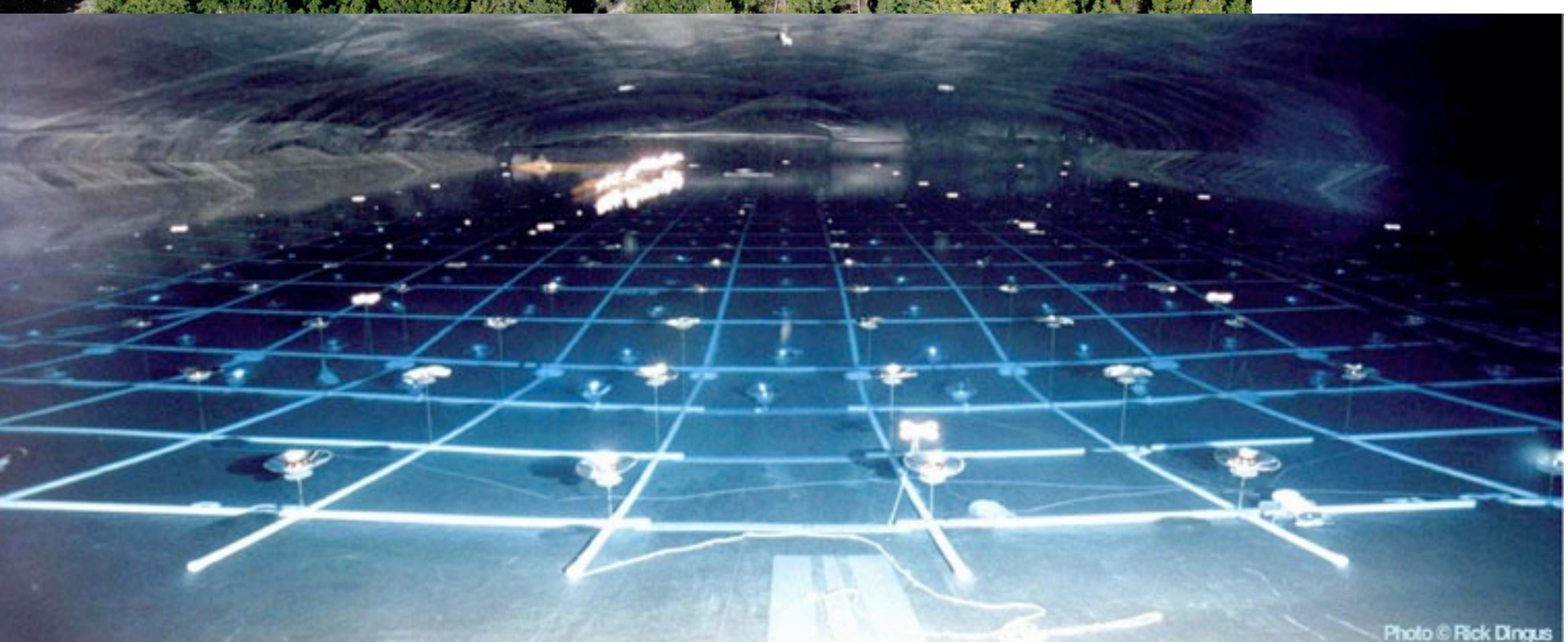
2650 m.a.s.l.

New Mexico

80 m x 60 m water pond
8 m deep.

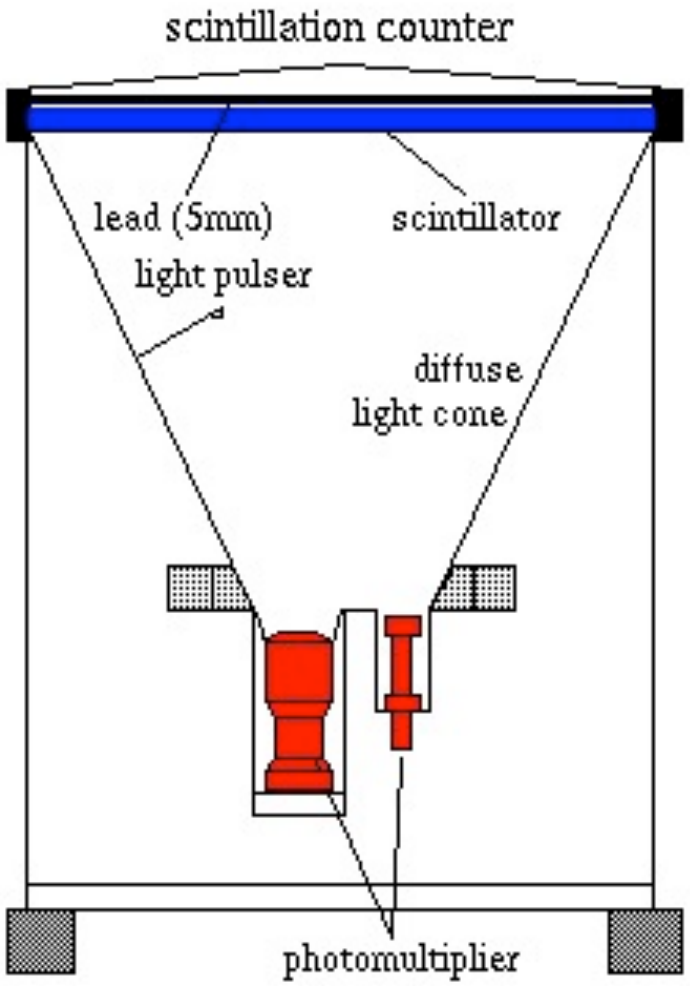
Detect shower particles via Cherenkov light in water

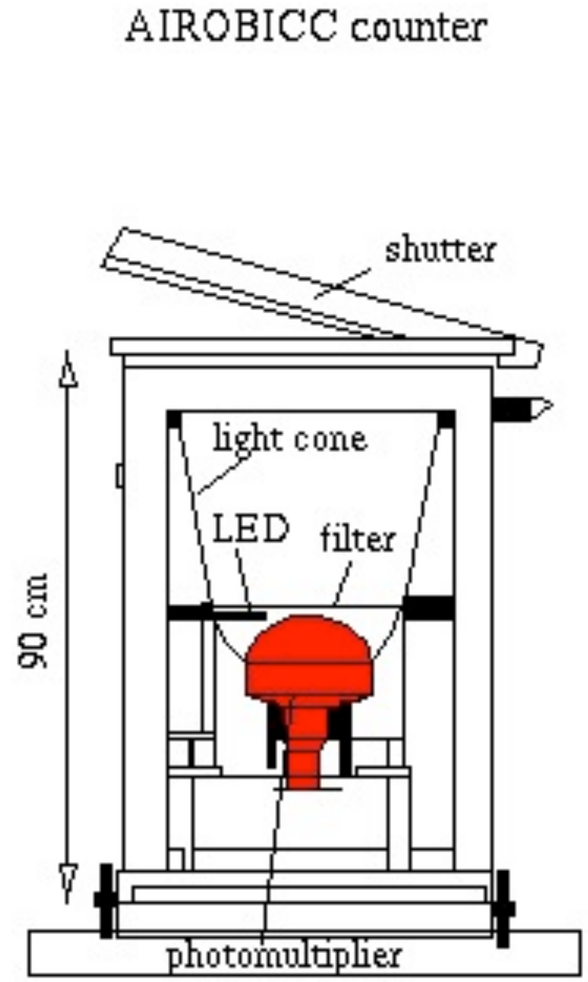
PMTs in 2 layers for el.mag. and muons.



look for excess:
gamma sources

2π sky view





Hegra, Airobicc
La Palma

scintillator array
Muon detectors
Cherenkov counter

poor γ- hadron separation

via muon content or particle pattern at ground

γ sources detected by excess counts from one direction

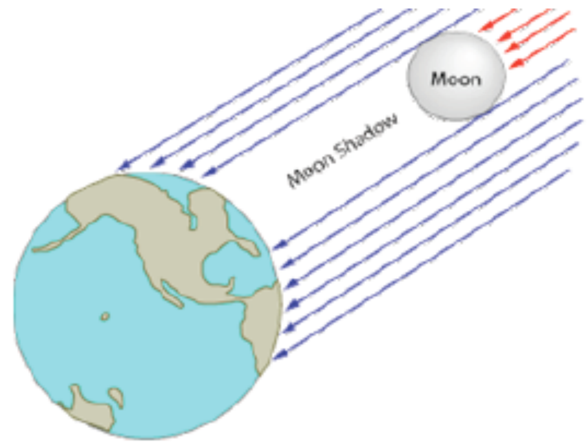
sources: Moon, Sun shadow

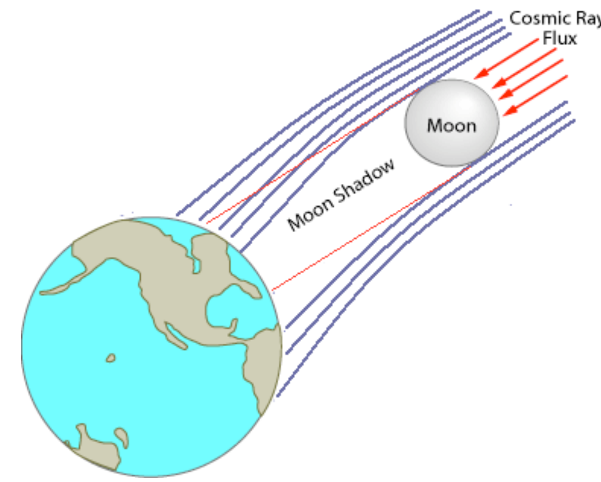
Crab nebula

few strong γ sources

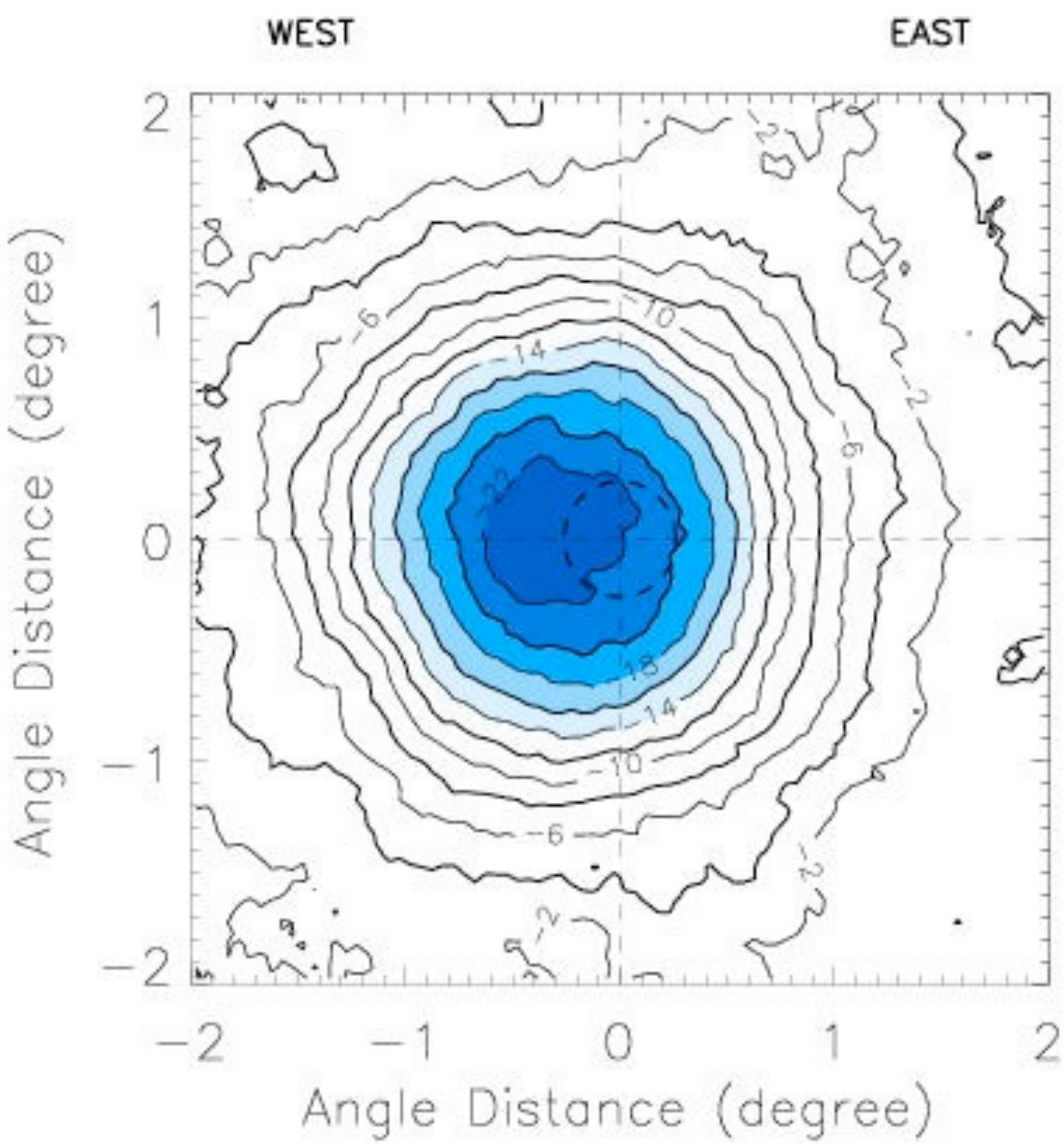
Moon Shadow … calibration of direction reconstruction

$E \approx TeV$

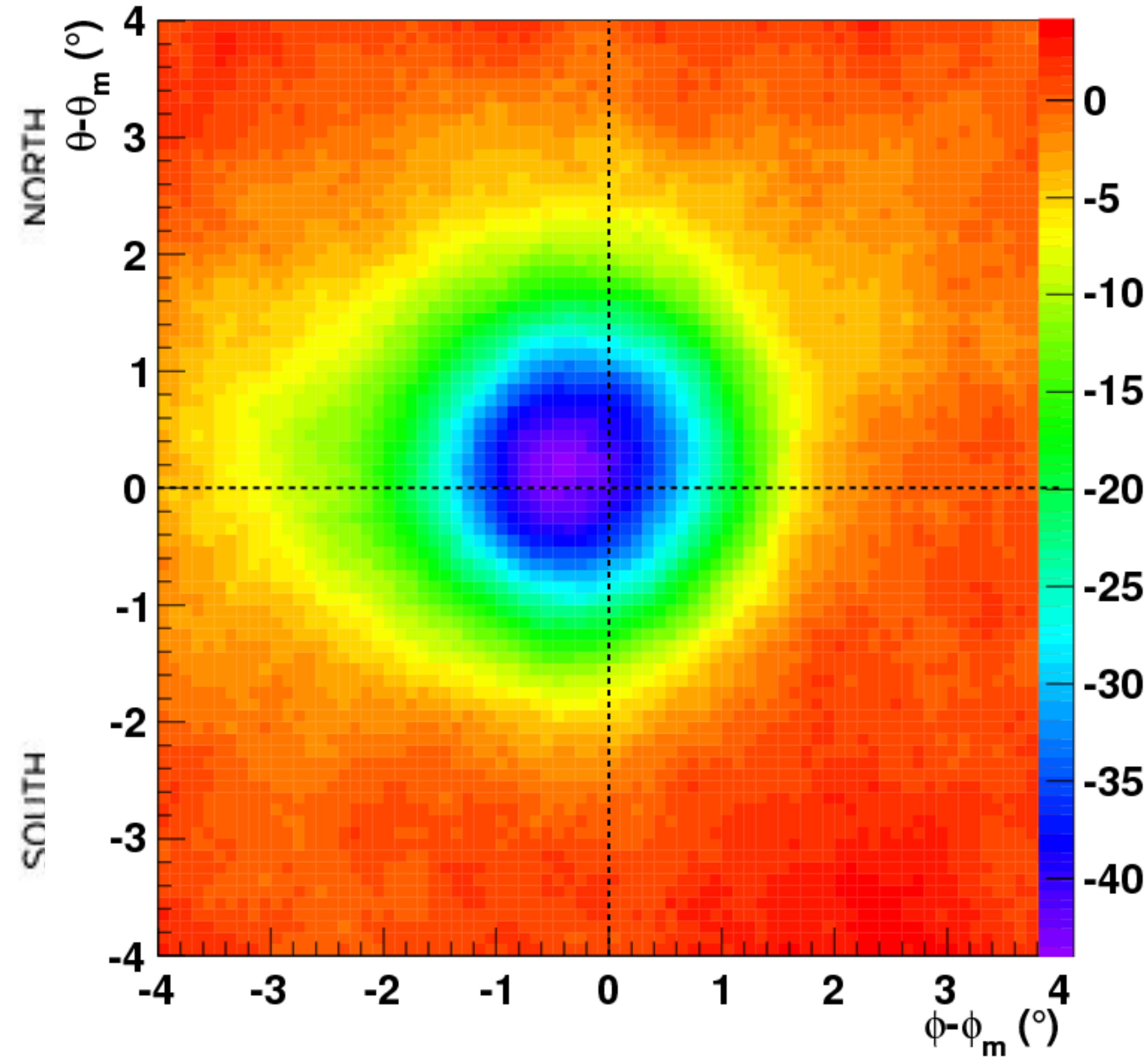




Tibet ASγ

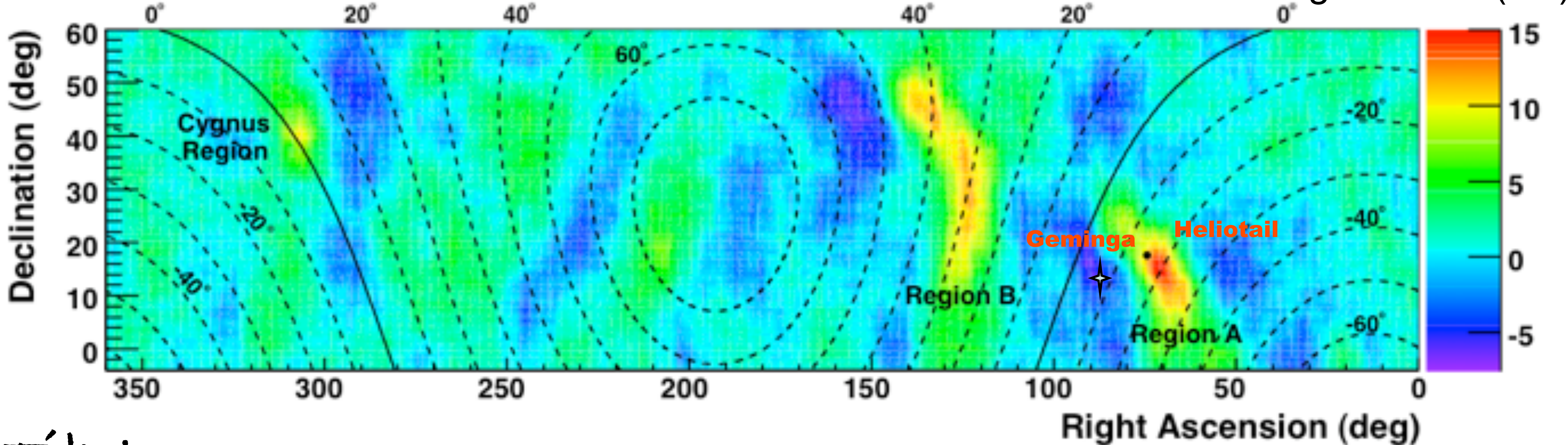


Argo

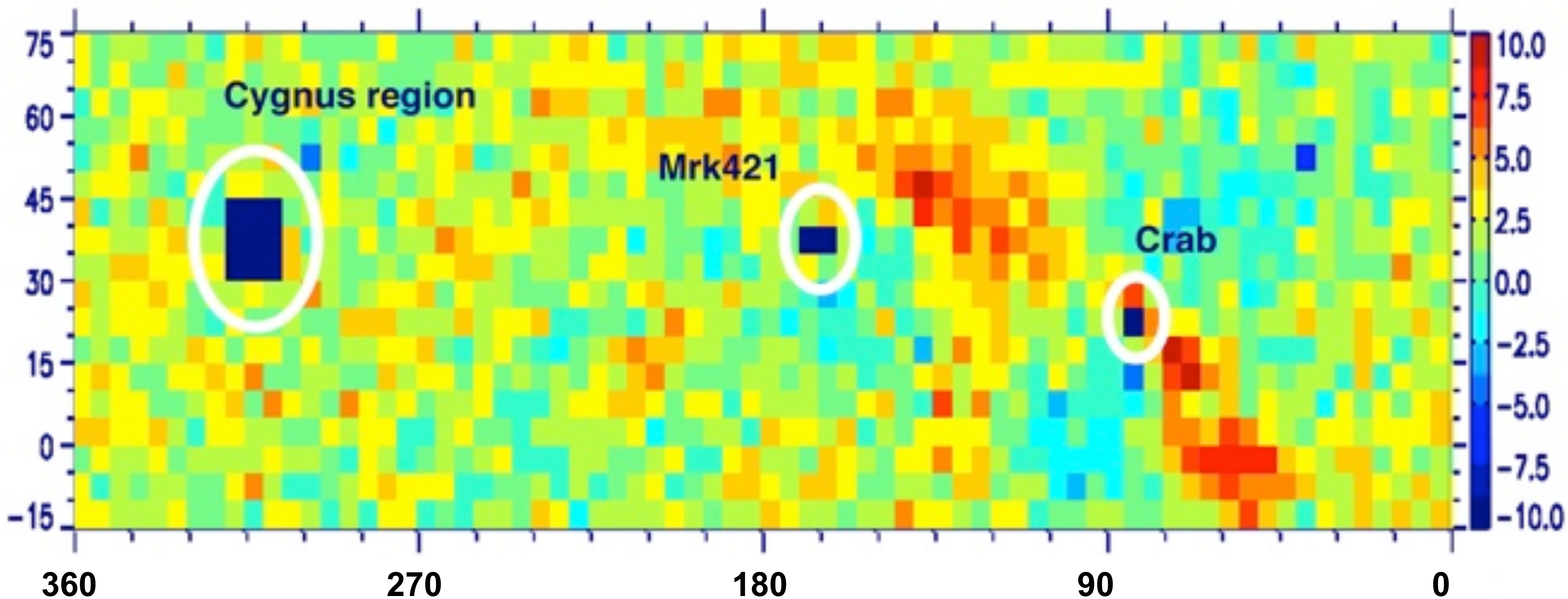


Milagro

15.0 σ and 12.7 σ   fractional excess: ≈ 5x10⁻⁴

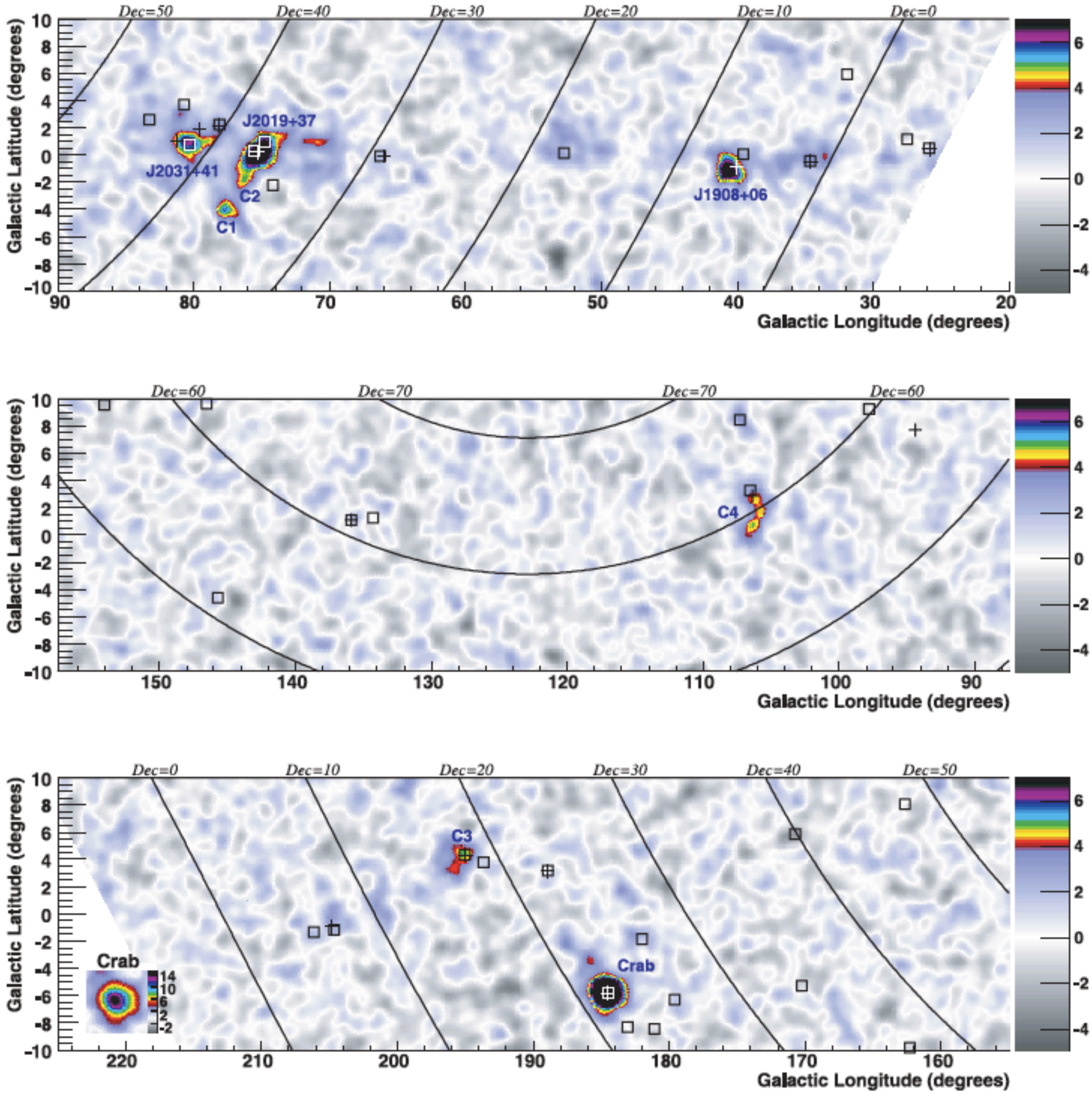


Tibet



MILAGRO
gal. plane

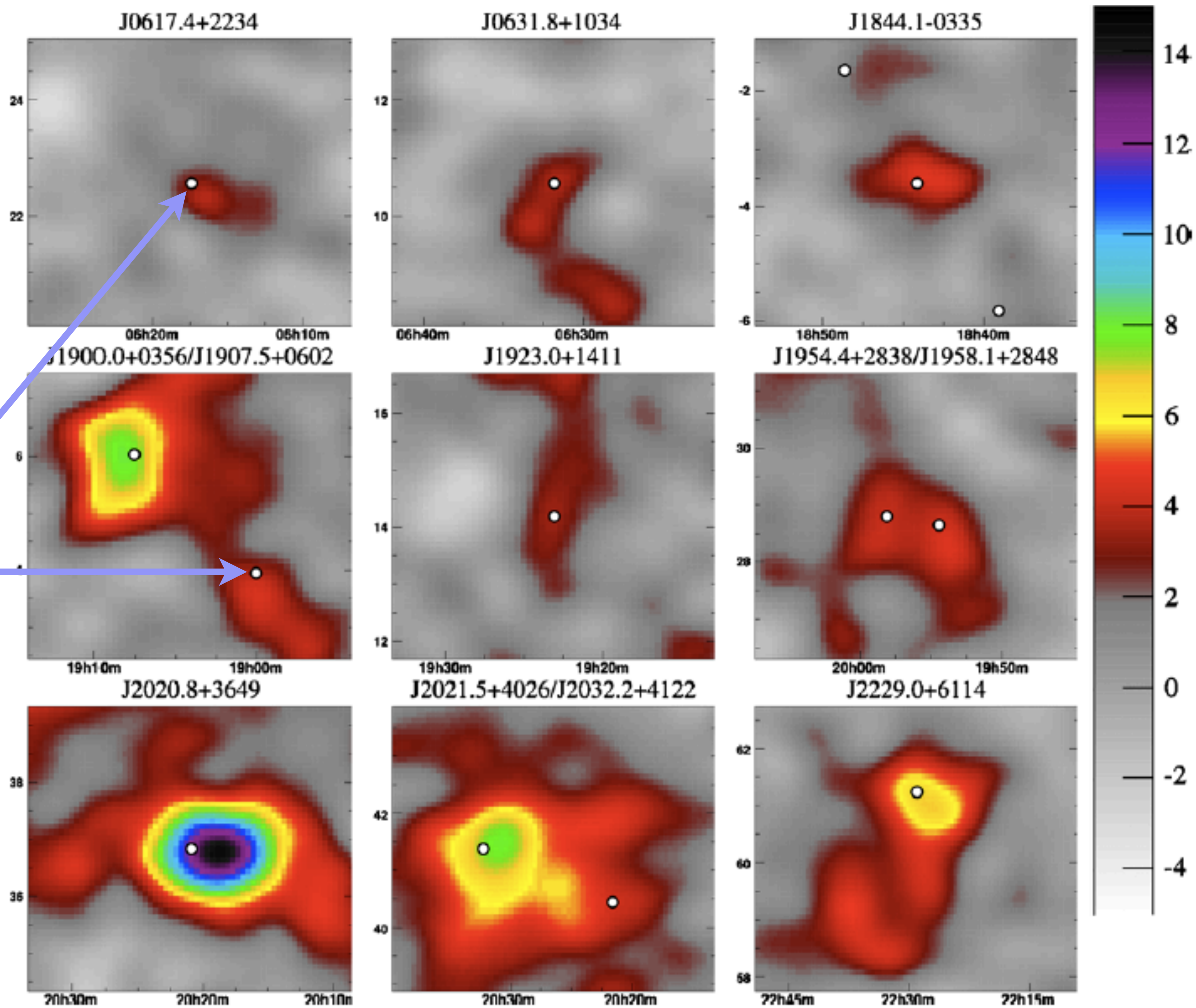
□ EGRET sources



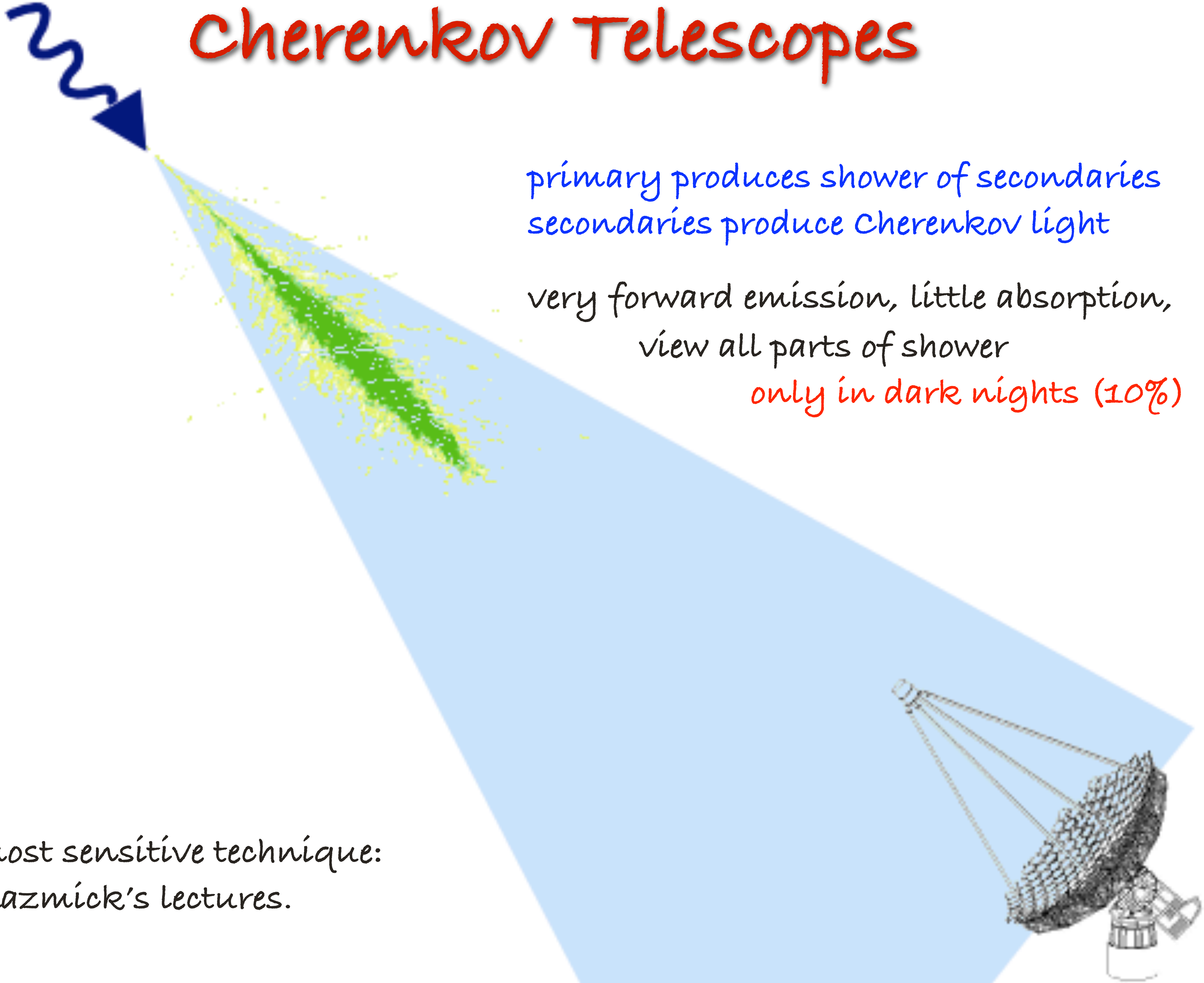
MILAGRO

(3 σ)

strong Fermi sources



Cherenkov Telescopes

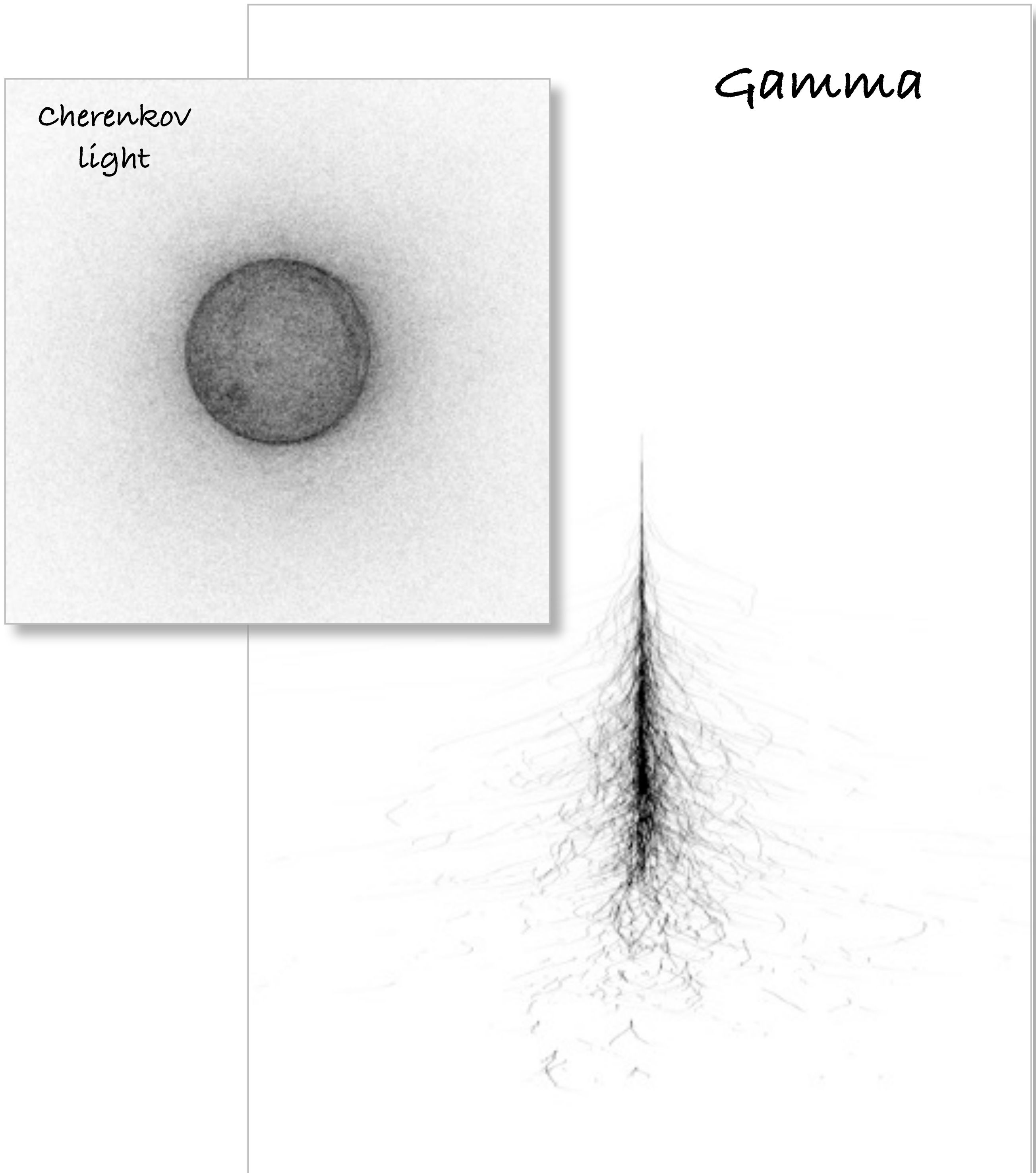


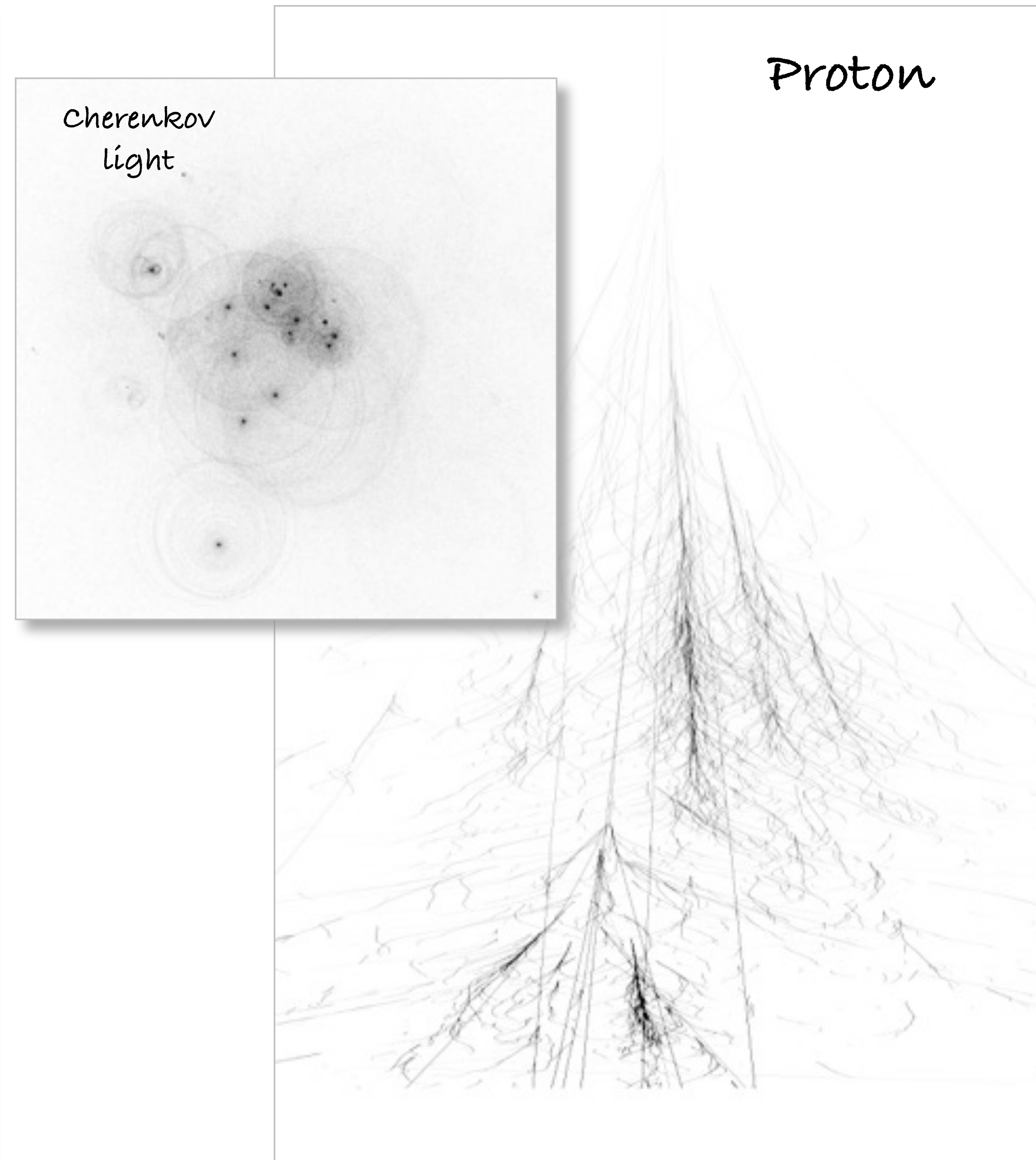
primary produces shower of secondaries
secondaries produce Cherenkov light

very forward emission, little absorption,
view all parts of shower
only in dark nights (10%)

the most sensitive technique:
see Razmick's lectures.

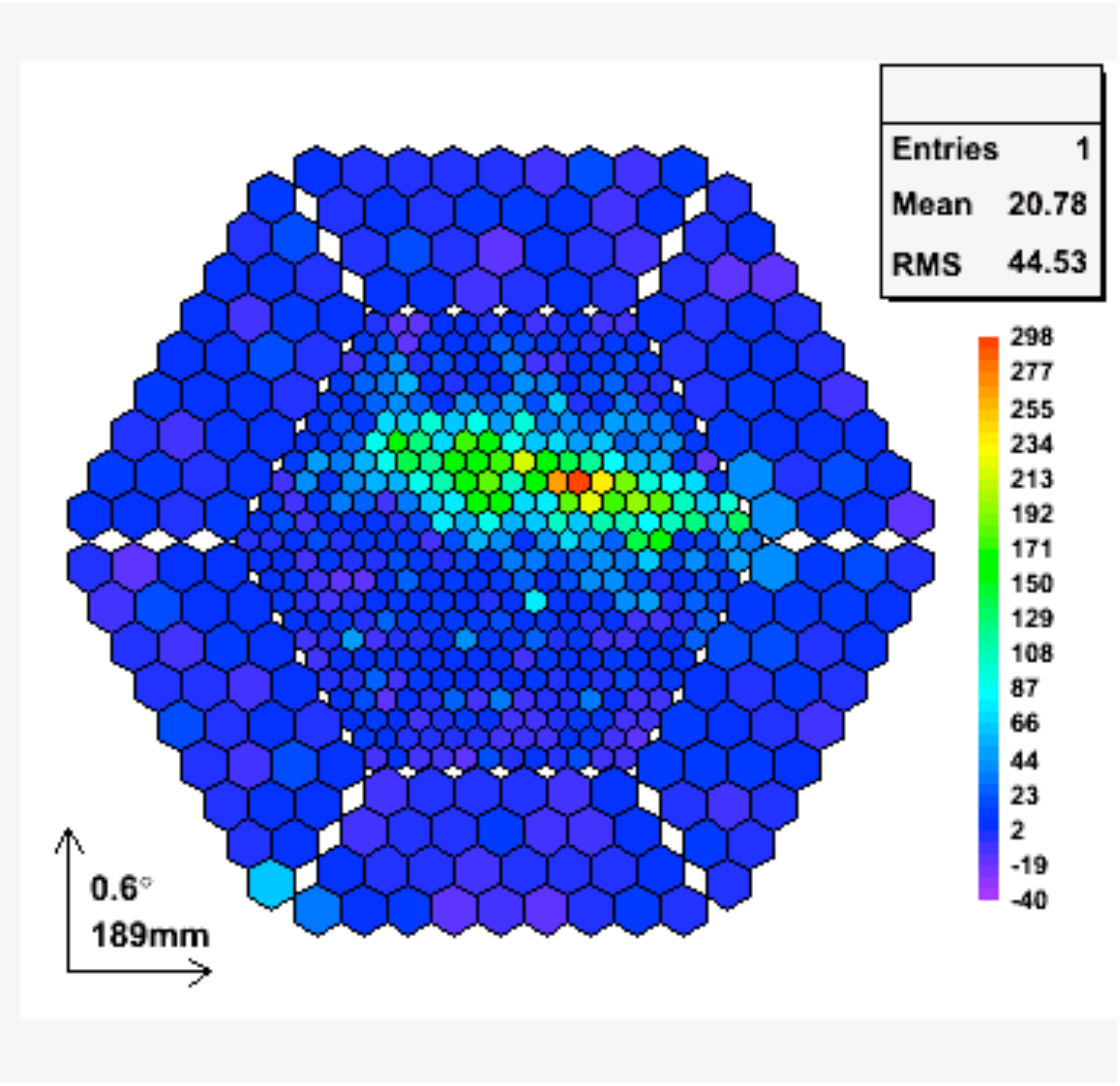
γ rays and Cosmic Ray background

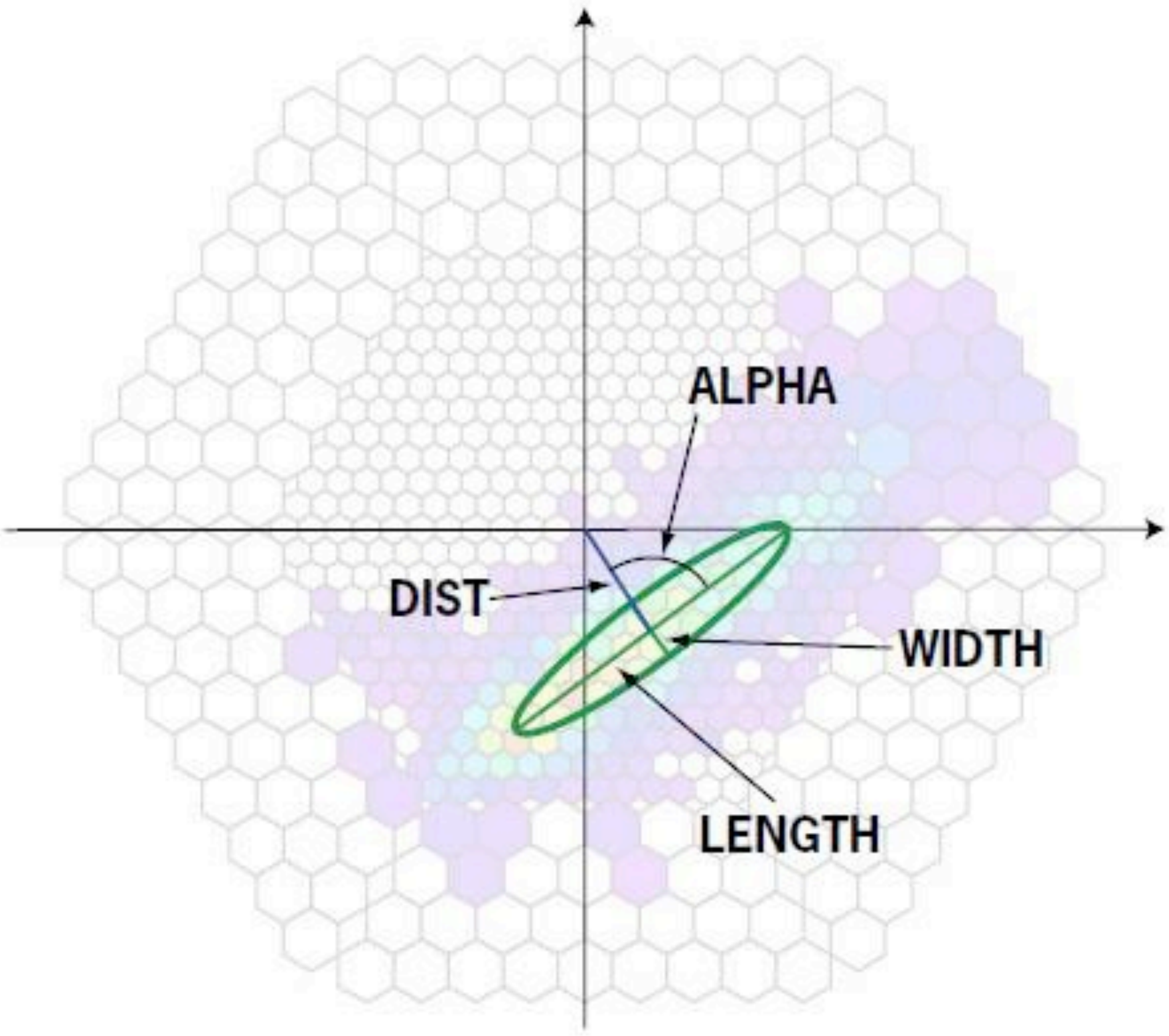




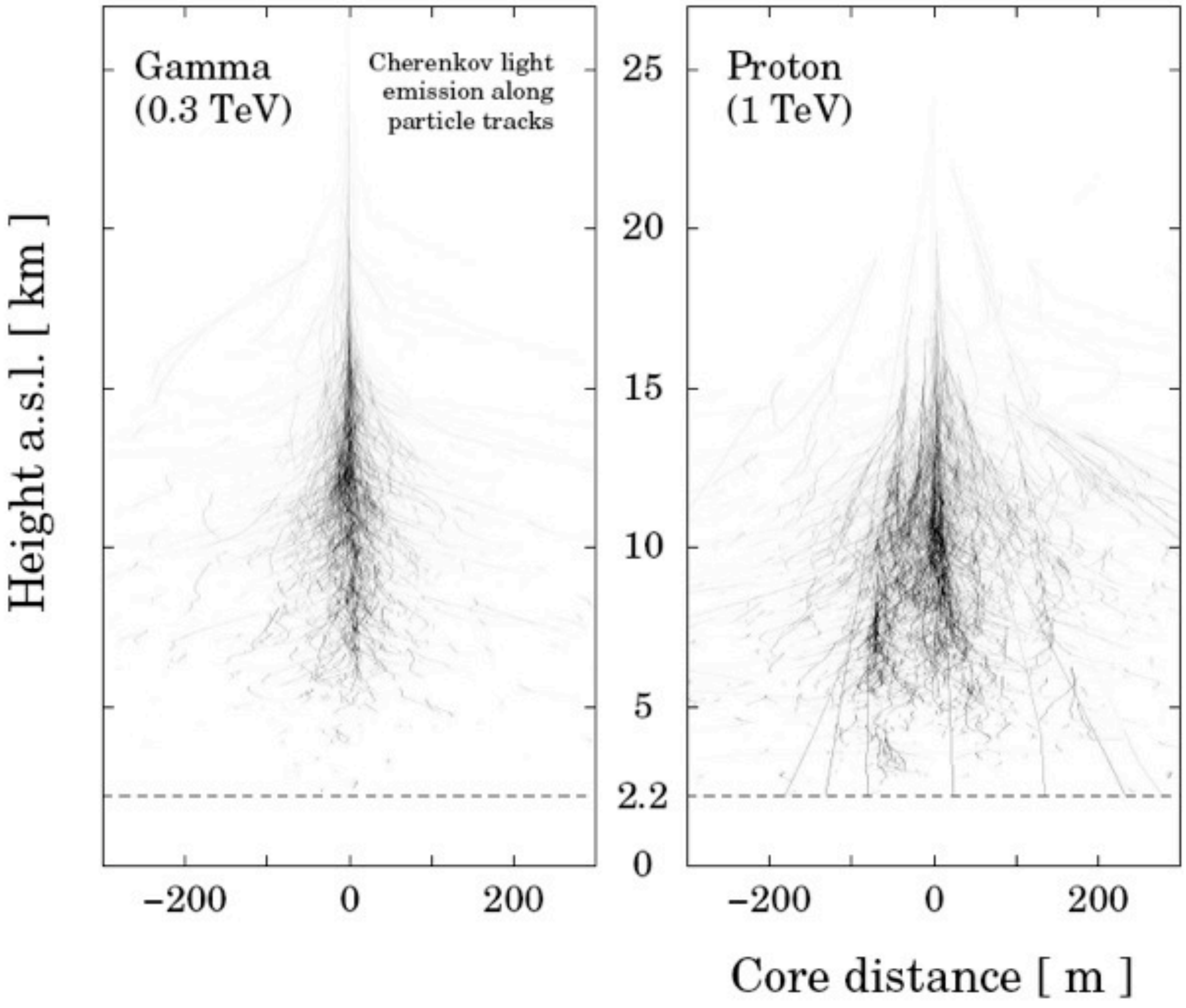
1 : $>10^4$

MAGIC Camera





Hillas image analysis



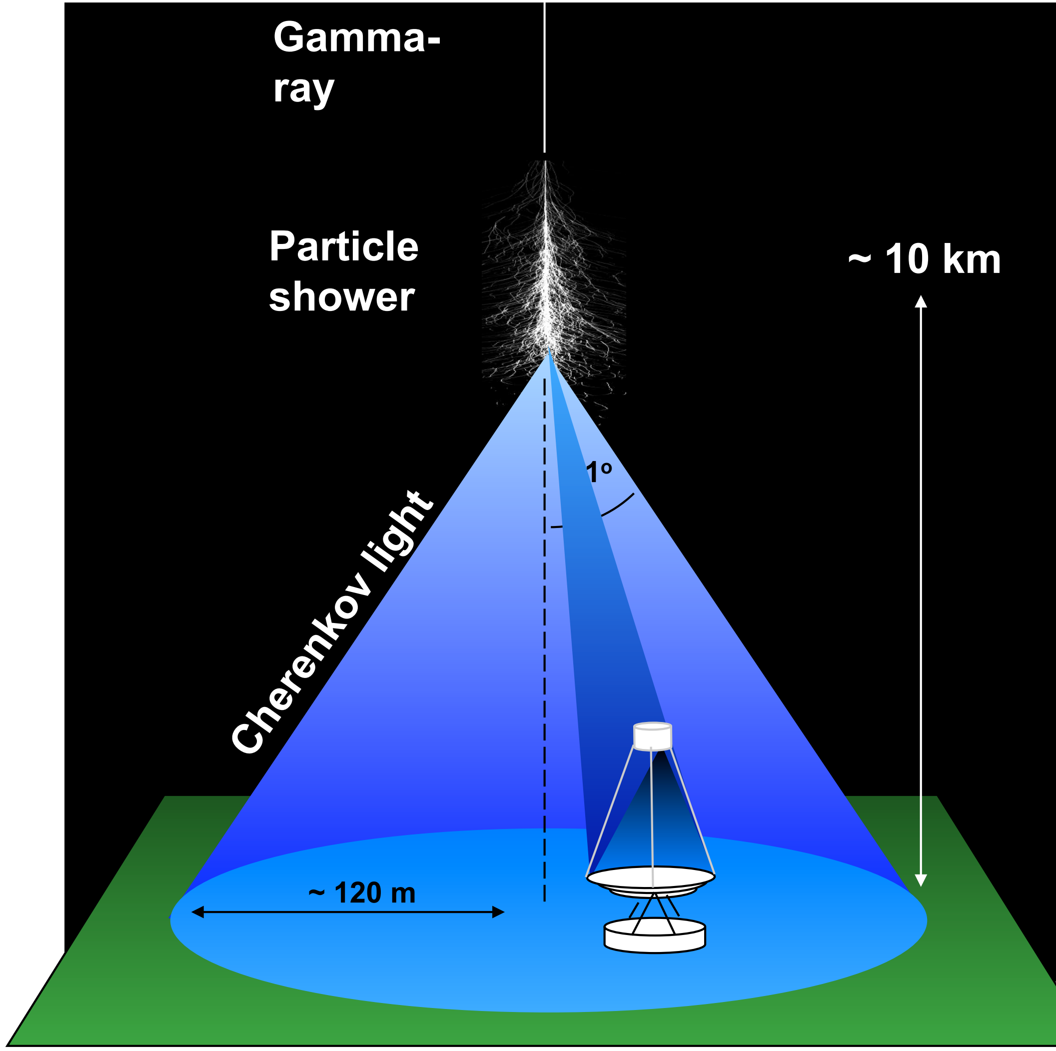
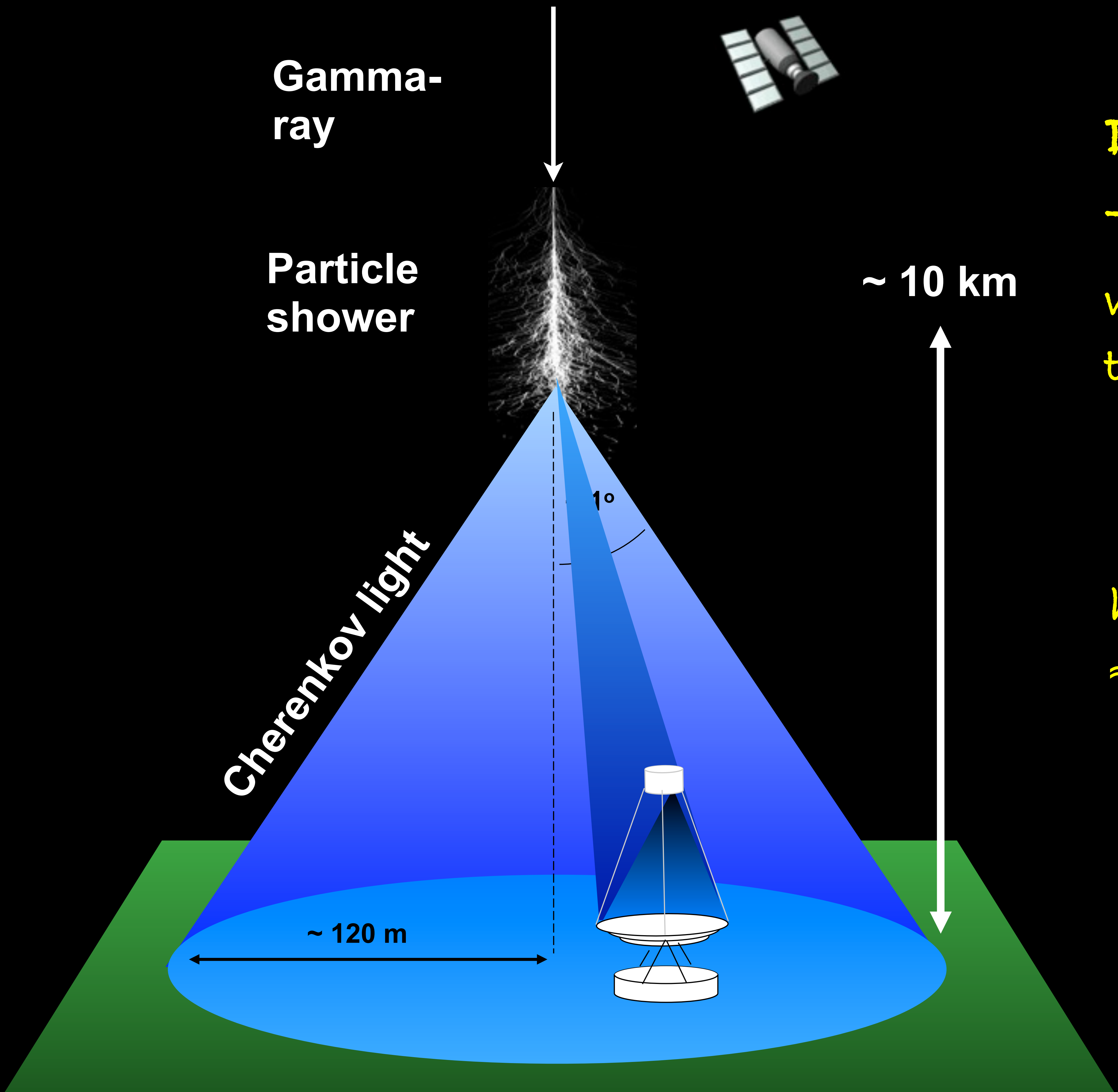


Image the shower,

distinguish protons and photons from the shape of their images.

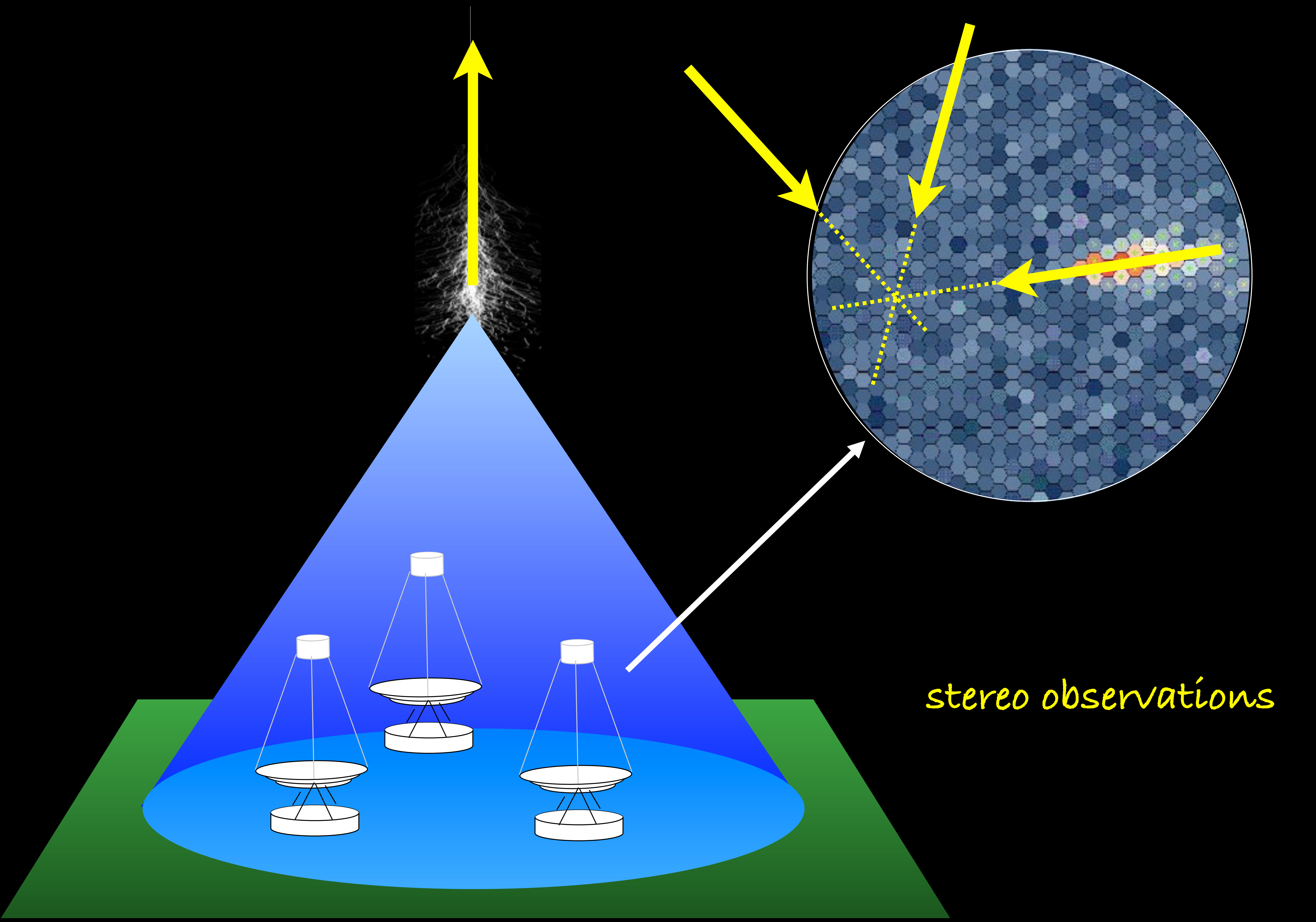
.... very successful technique

also possible to identify e^- and Fe



Detection of
TeV γ rays
with Cherenkov
telescopes

huge detection area
$\approx 10^5\ m^2$


stereo observations

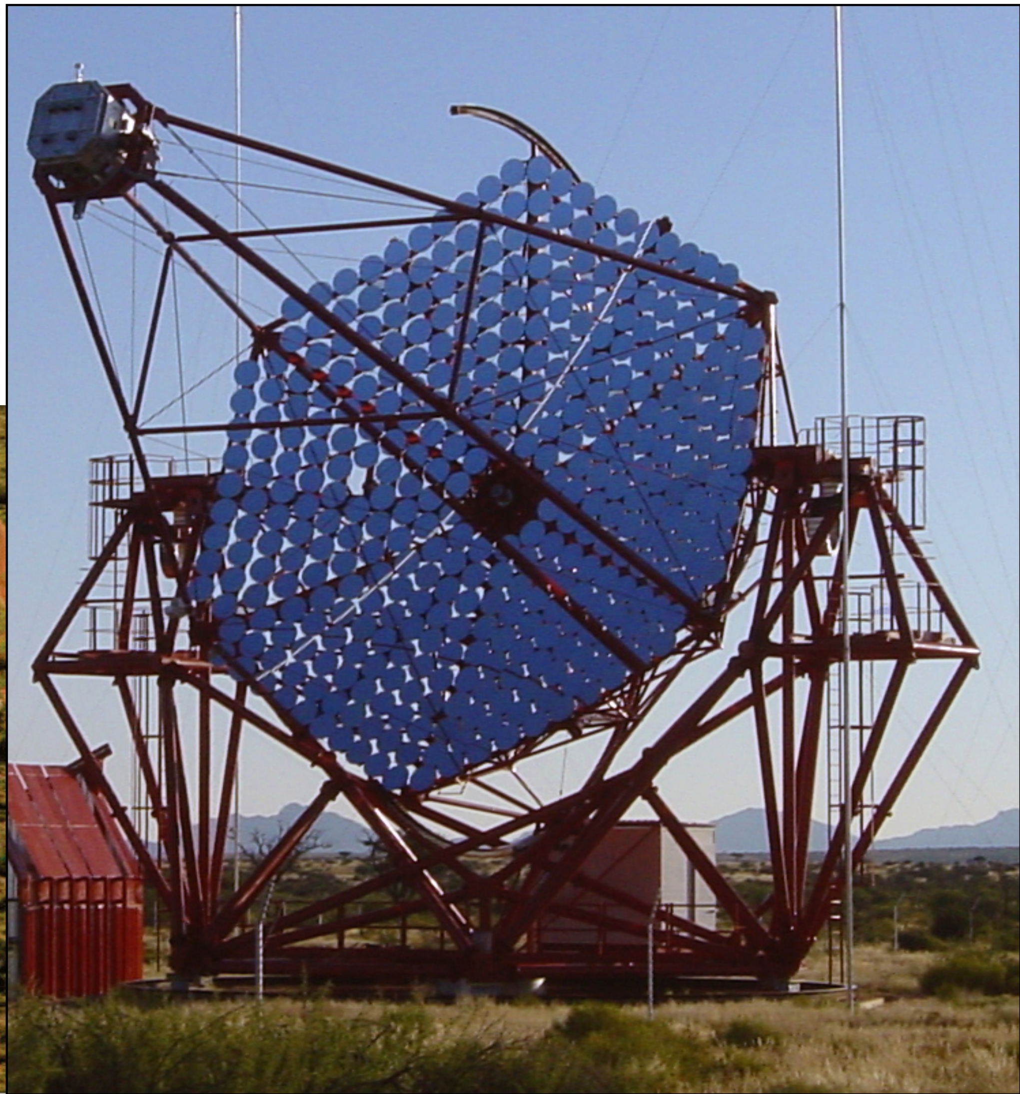
Air showers look like meteors

Imaging Cherenkov Telescopes

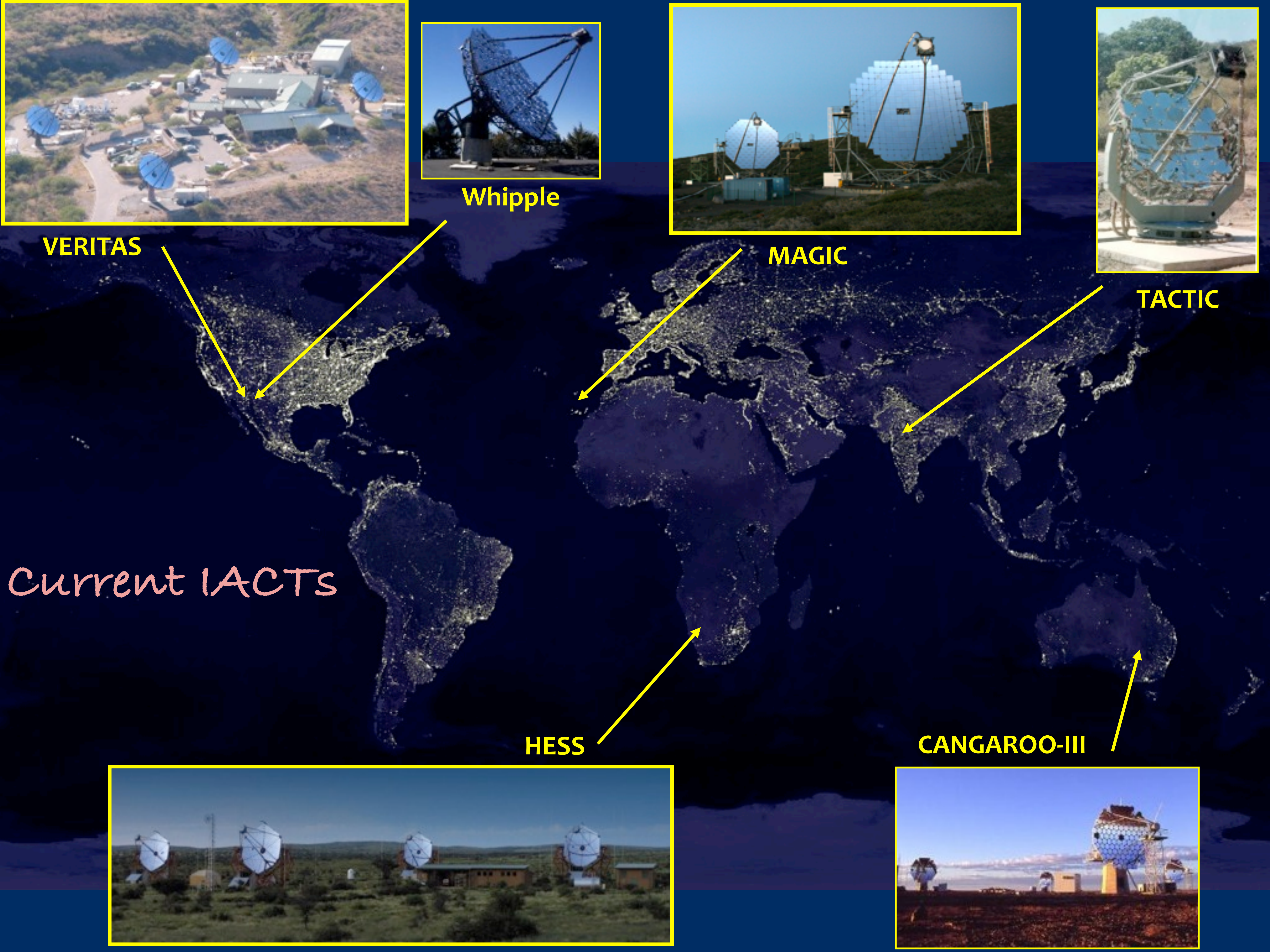
TeV gamma ray astronomy (100 GeV - 50 TeV)
requires good knowledge of atmospheric conditions

Imaging Atmospheric Cherenkov Telescopes:

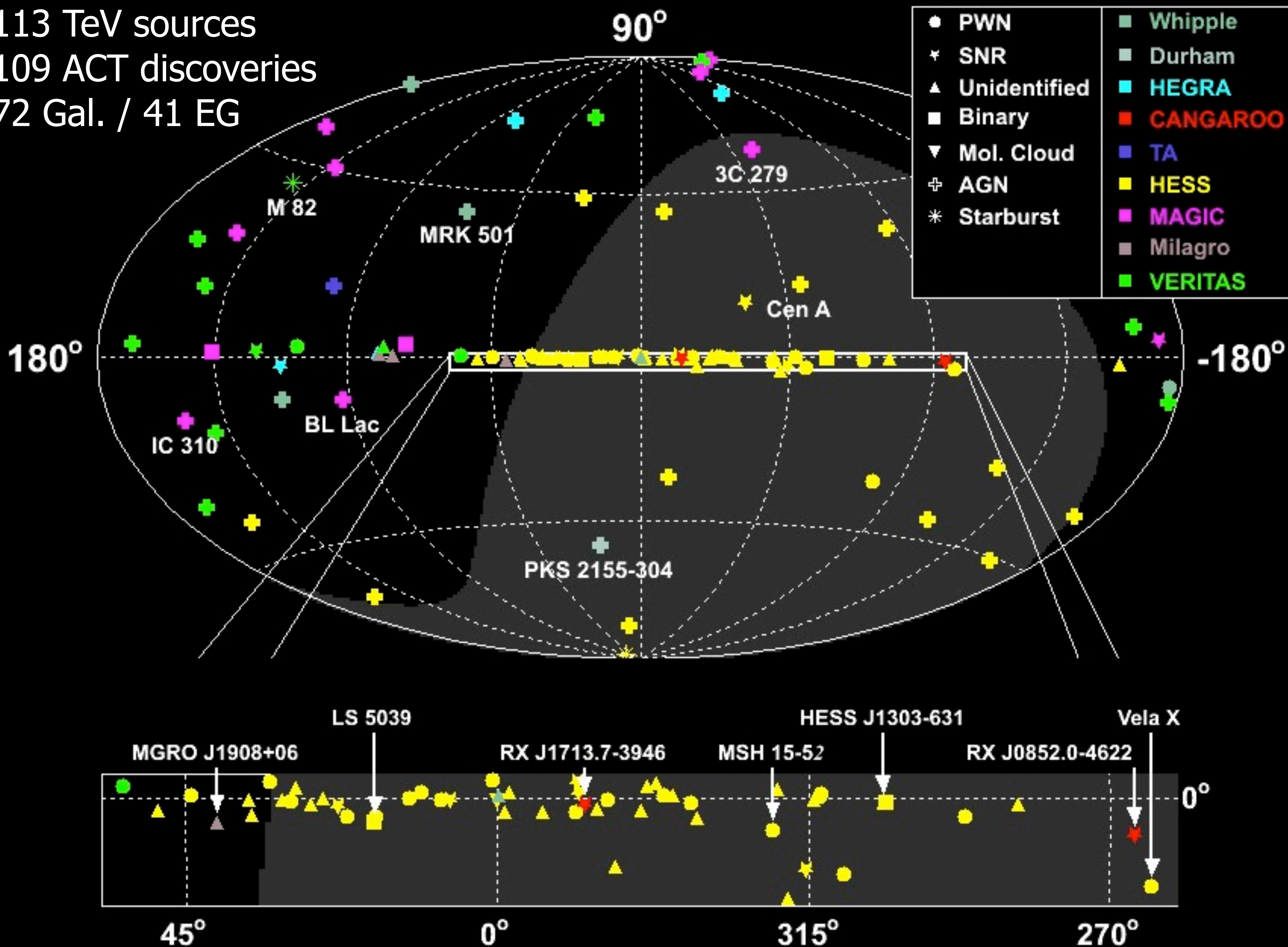
e.g. HESS, MAGIC, VERITAS,




HESS, Namibia
detects Crab
in 30 seconds
1% Crab in 25 h
4 x 12m telescopes
5° FOV, 0.16°
960 pixels


Whipple
VERITAS
MAGIC
TACTIC
Current IACTs
HESS
CANGAROO-III

2010:
113 TeV sources
109 ACT discoveries
72 Gal. / 41 EG



TeV Astronomy Highlights

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

Results from HESS, MAGIC and VERITAS
Descartes Prize for HESS

Scientific Objectives:

Cosmic energetic particles

Origin of the galactic cosmic rays

Also UHECR signatures

Role of ultra-relativistic particles in

in clusters of galaxies, AGN, Starbursts...

The physics of (relativistic) jets and shocks

Fundamental Physics

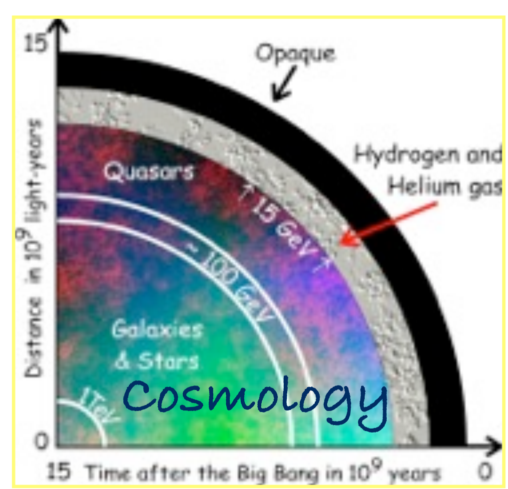
Dark Matter annihilation / decay

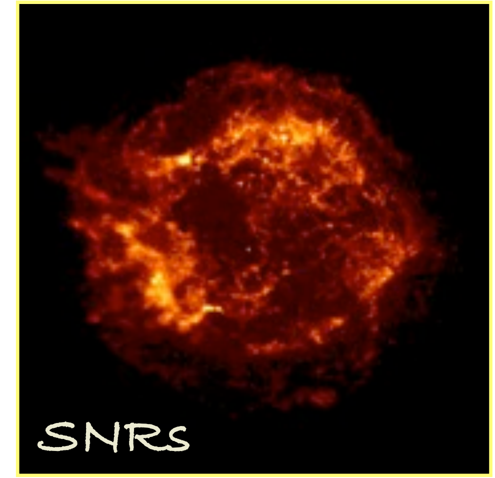
Lorentz Invariance violation

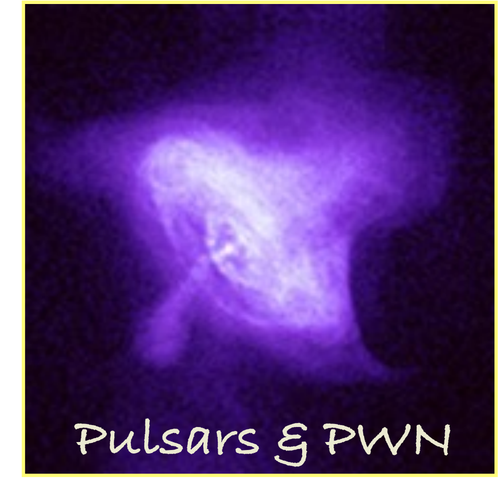
Cosmology

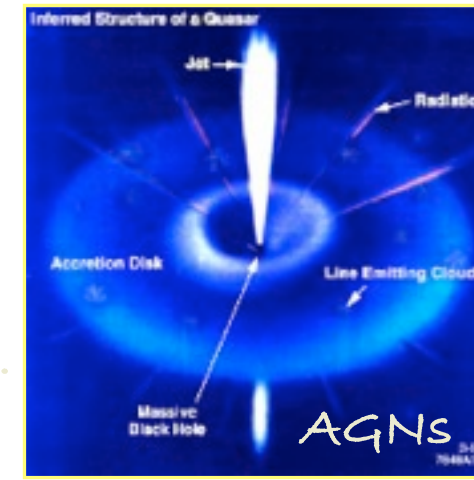
cosmic FIR-UV radiation,

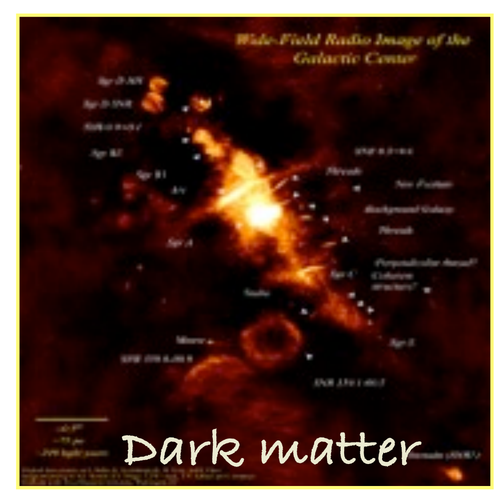
cosmic magnetism

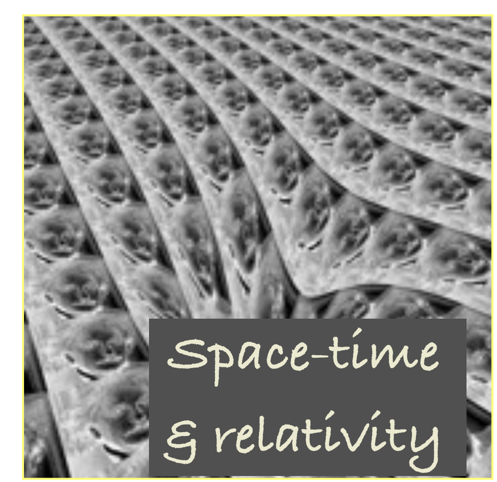












How to do even better with Ch. telescopes ?

A future Cherenkov observatory needs:

for E > TeV:

bigger collection area

(i.e. large array of telescopes, wider FOV)

more events

for E < TeV:

better background rejection

(i.e. large array of telescopes, wider FOV for multiple shower images)

better events

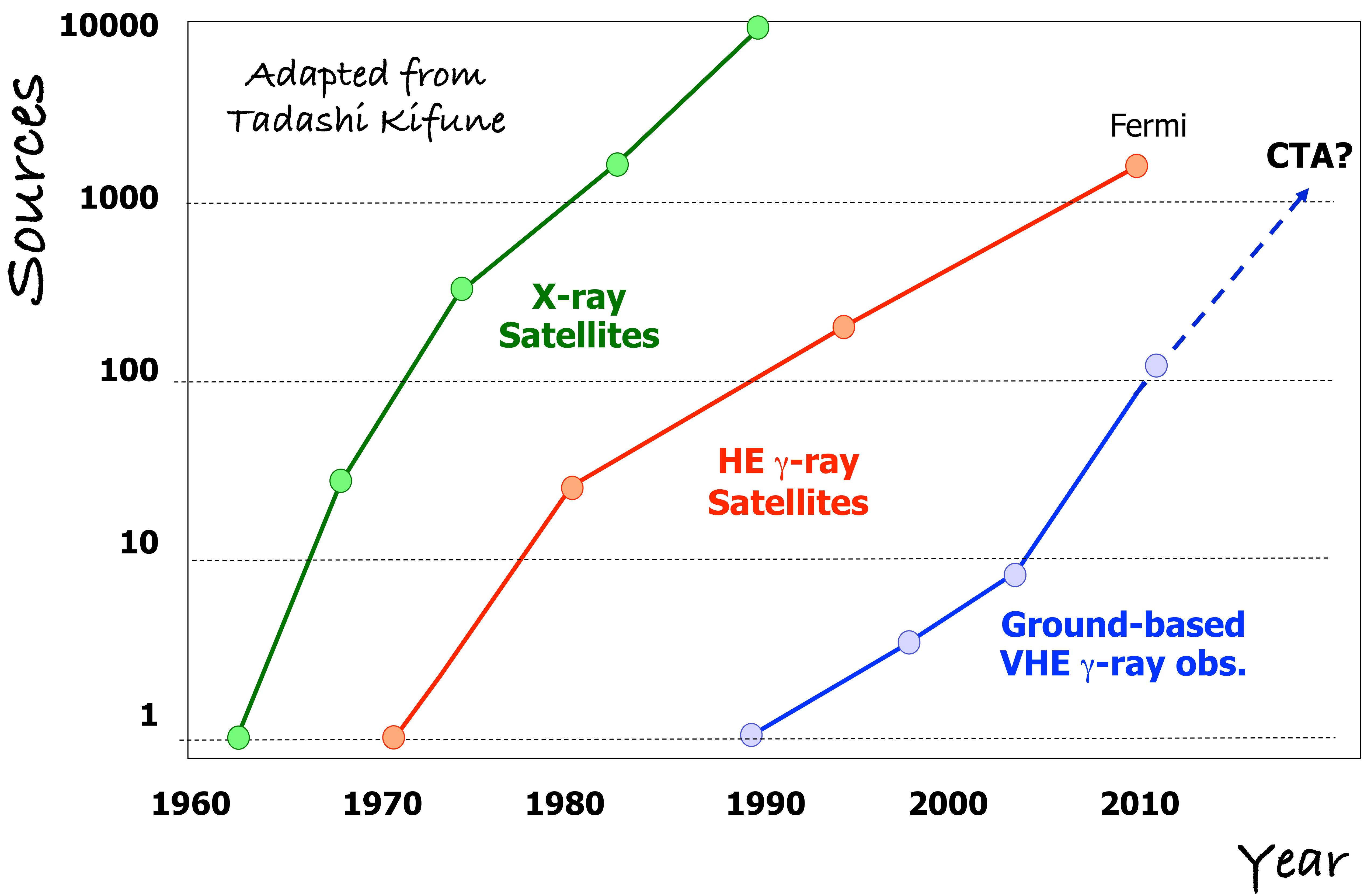
cta
cherenkov telescope array

... an advanced facility for ground-based gamma-ray astronomy

CTA is the global next generation project.

A precise and sensitive probe of the extreme universe, with huge potential for extreme astronomy and fundamental physics with TeV photons

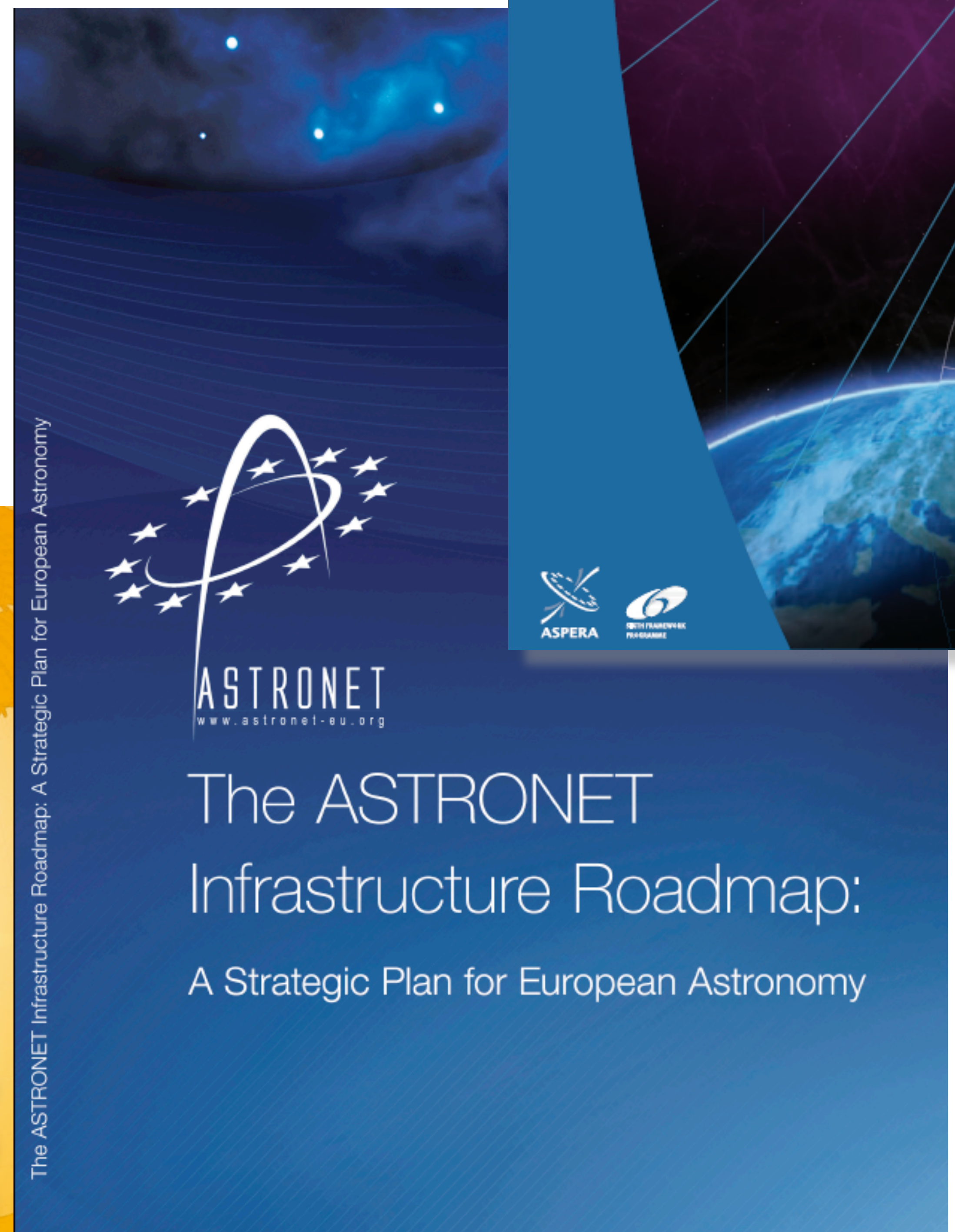
Source Numbers



Very Good reviews for CTA:

ASPERA:

ASTRONET:



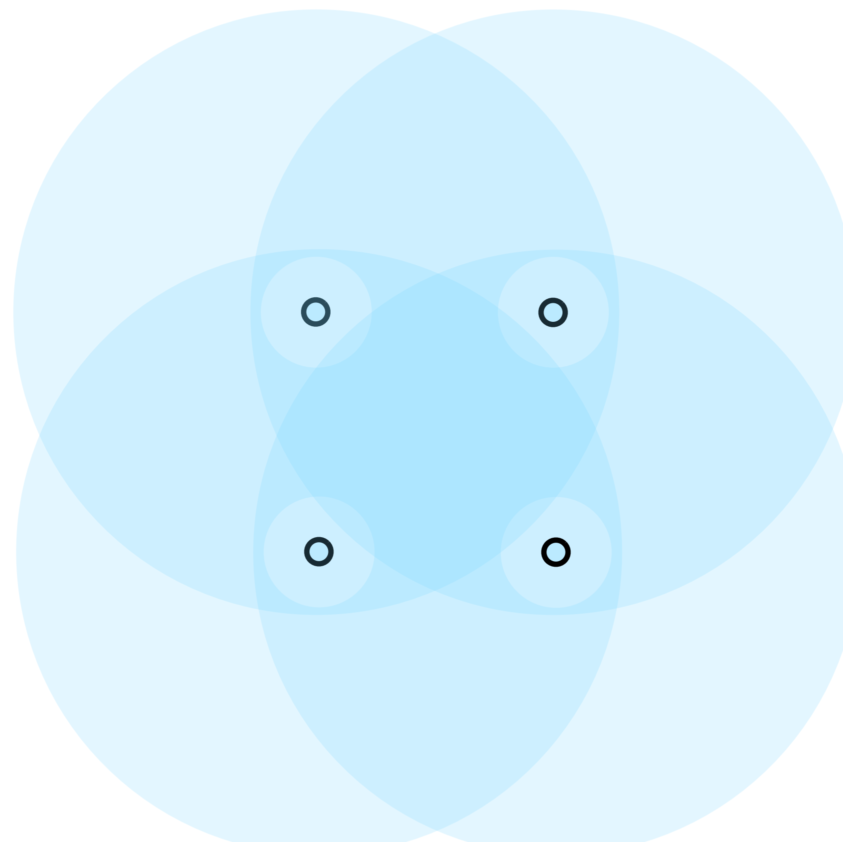
ESFRI:

Boosting sensitivity & resolution: Arrays of Cherenkov telescopes

Single telescope

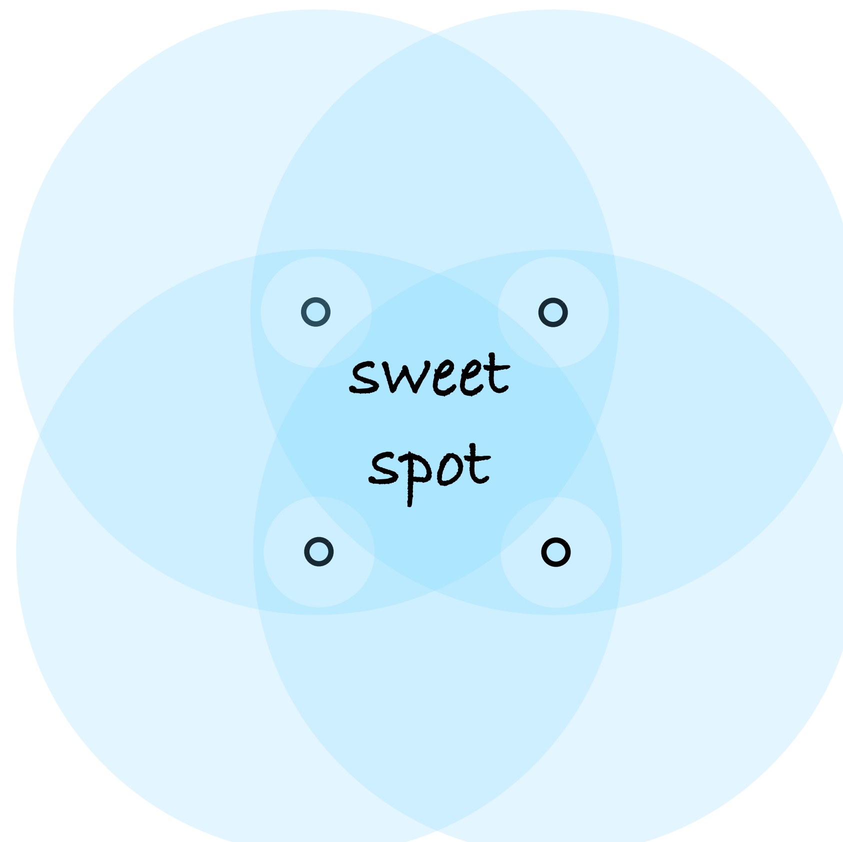
Boosting sensitivity & resolution: Arrays of Cherenkov telescopes

Single telescope

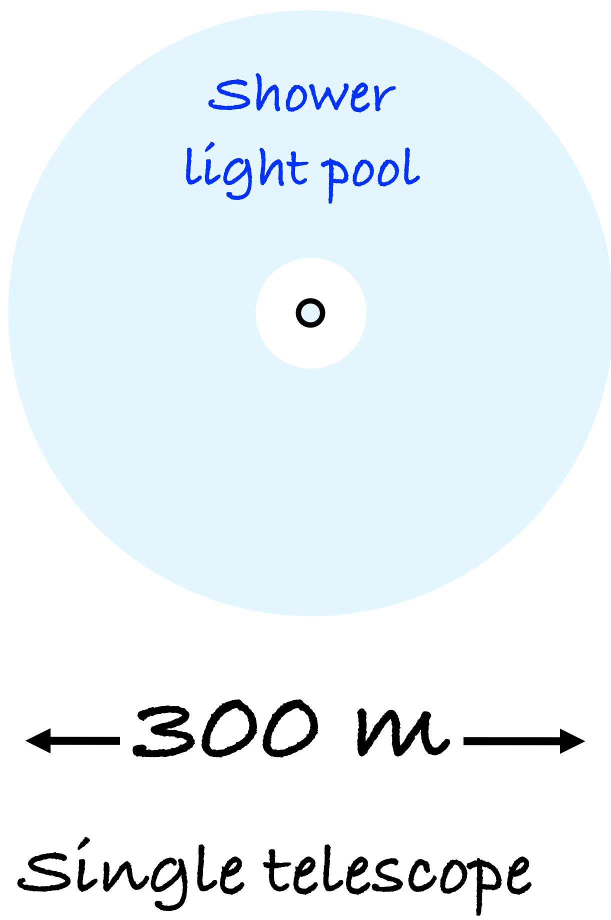


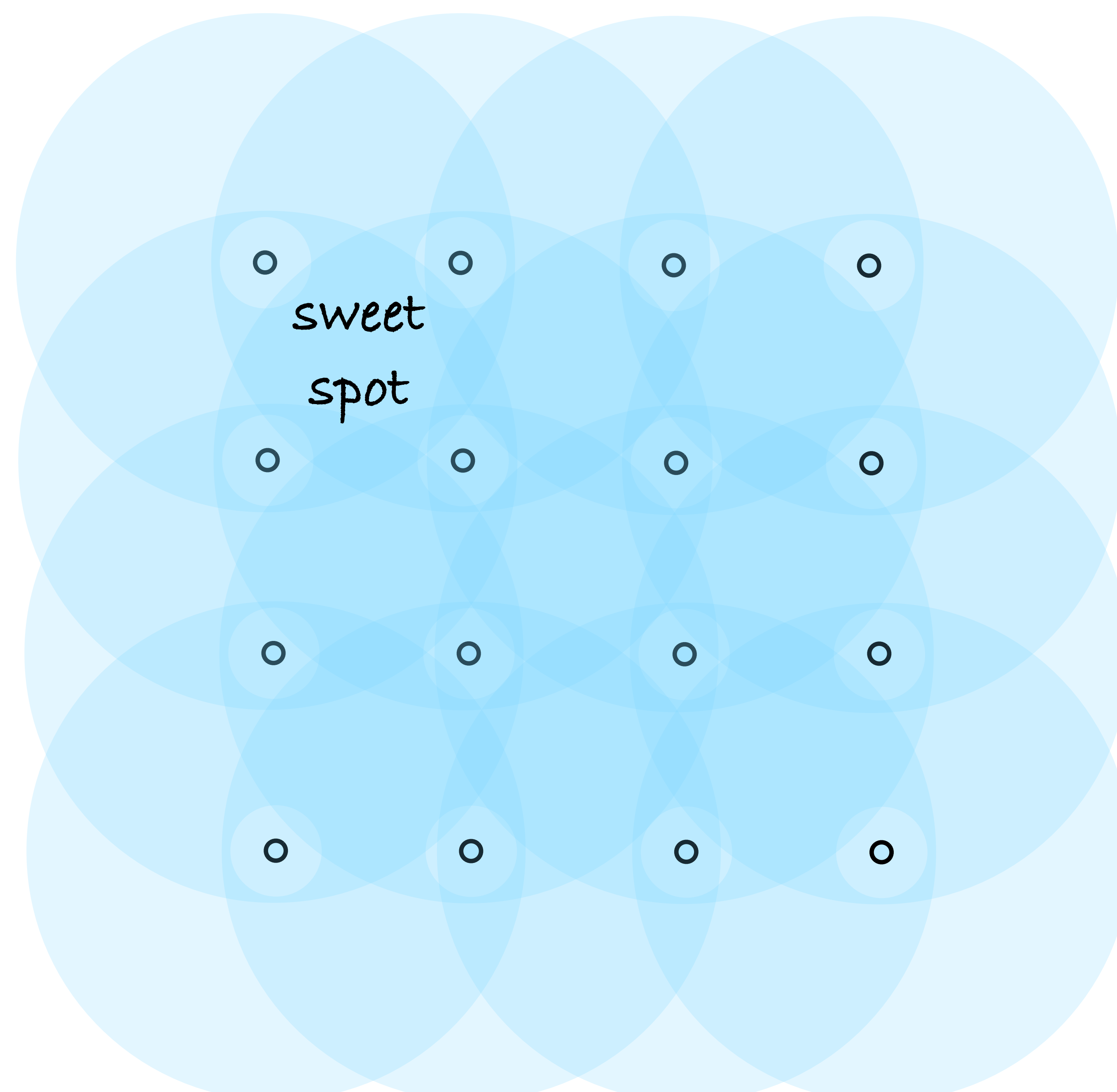
Boosting sensitivity & resolution: Arrays of Cherenkov telescopes

Single telescope

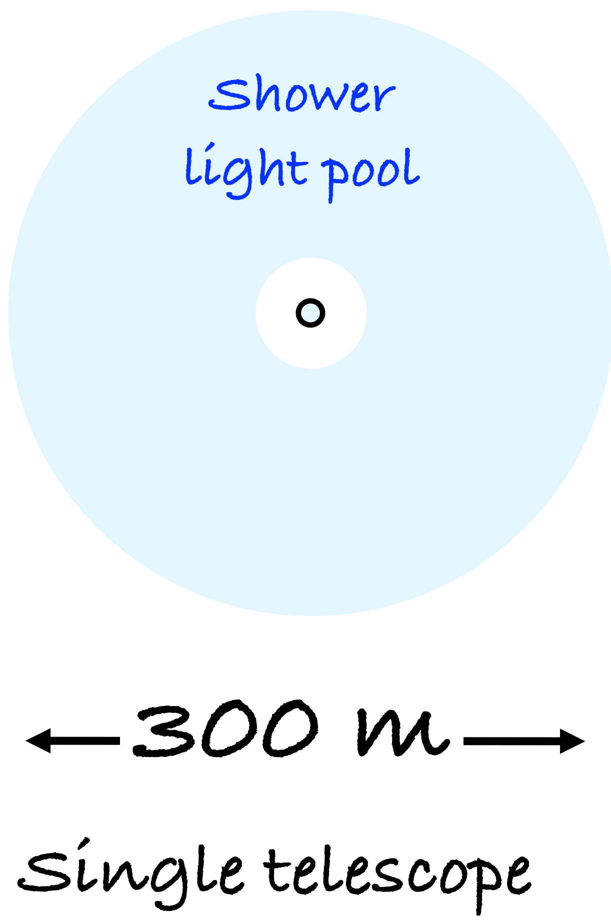


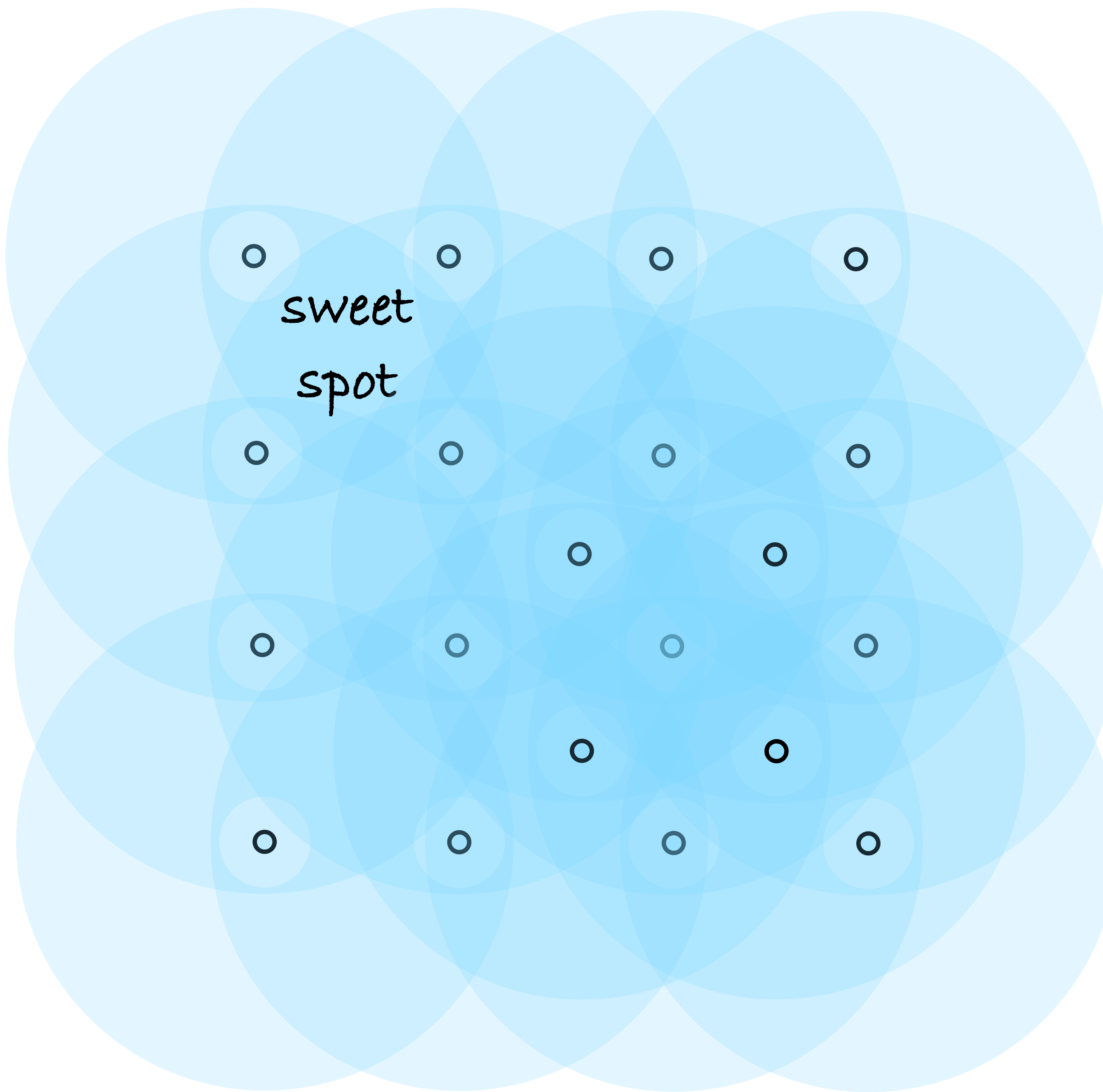
Boosting sensitivity & resolution: Arrays of Cherenkov telescopes

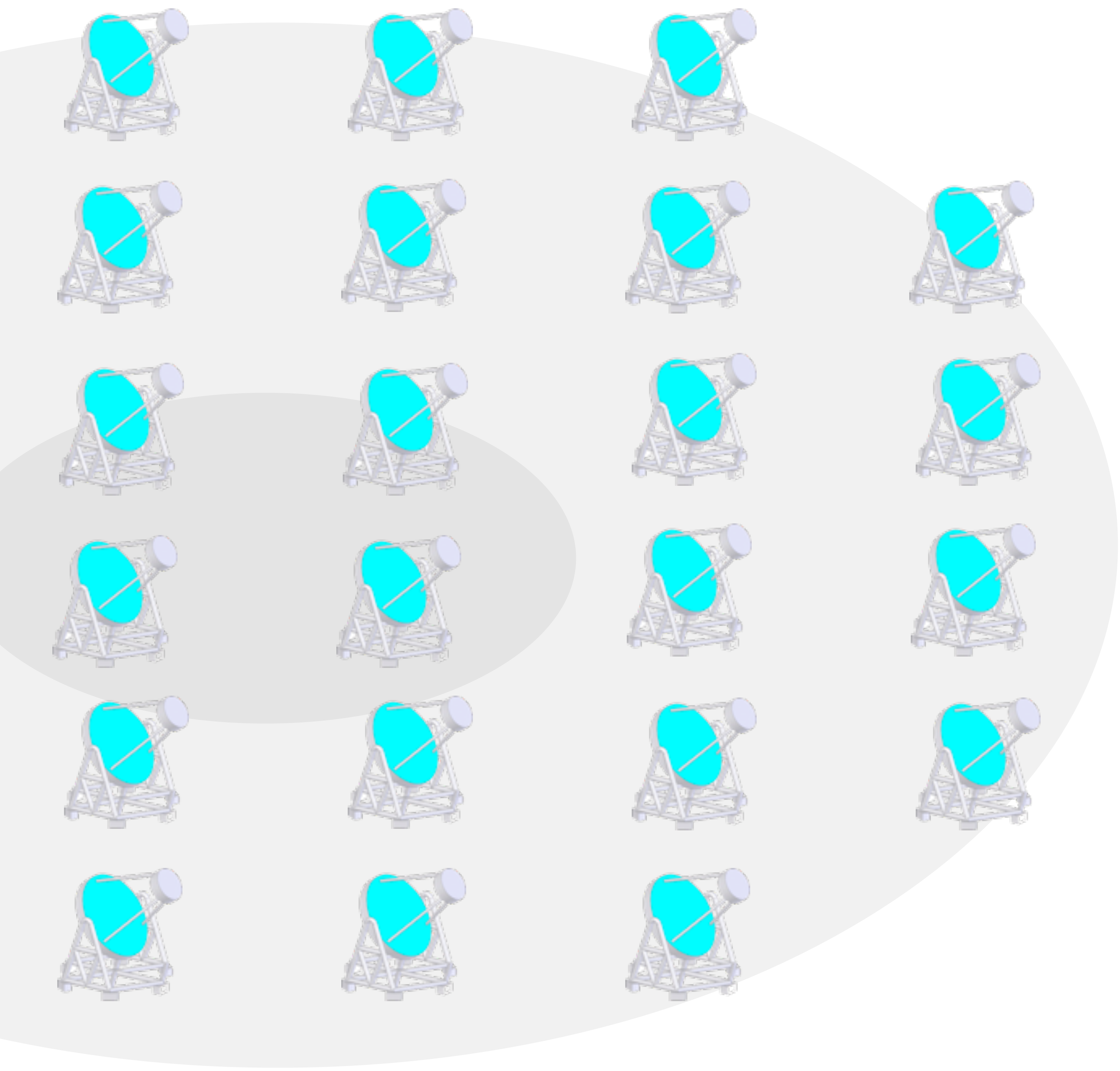




Boosting sensitivity & resolution: Arrays of Cherenkov telescopes







Core array:

mCrab sensitivity in 0.1–10 TeV range

Not to scale !

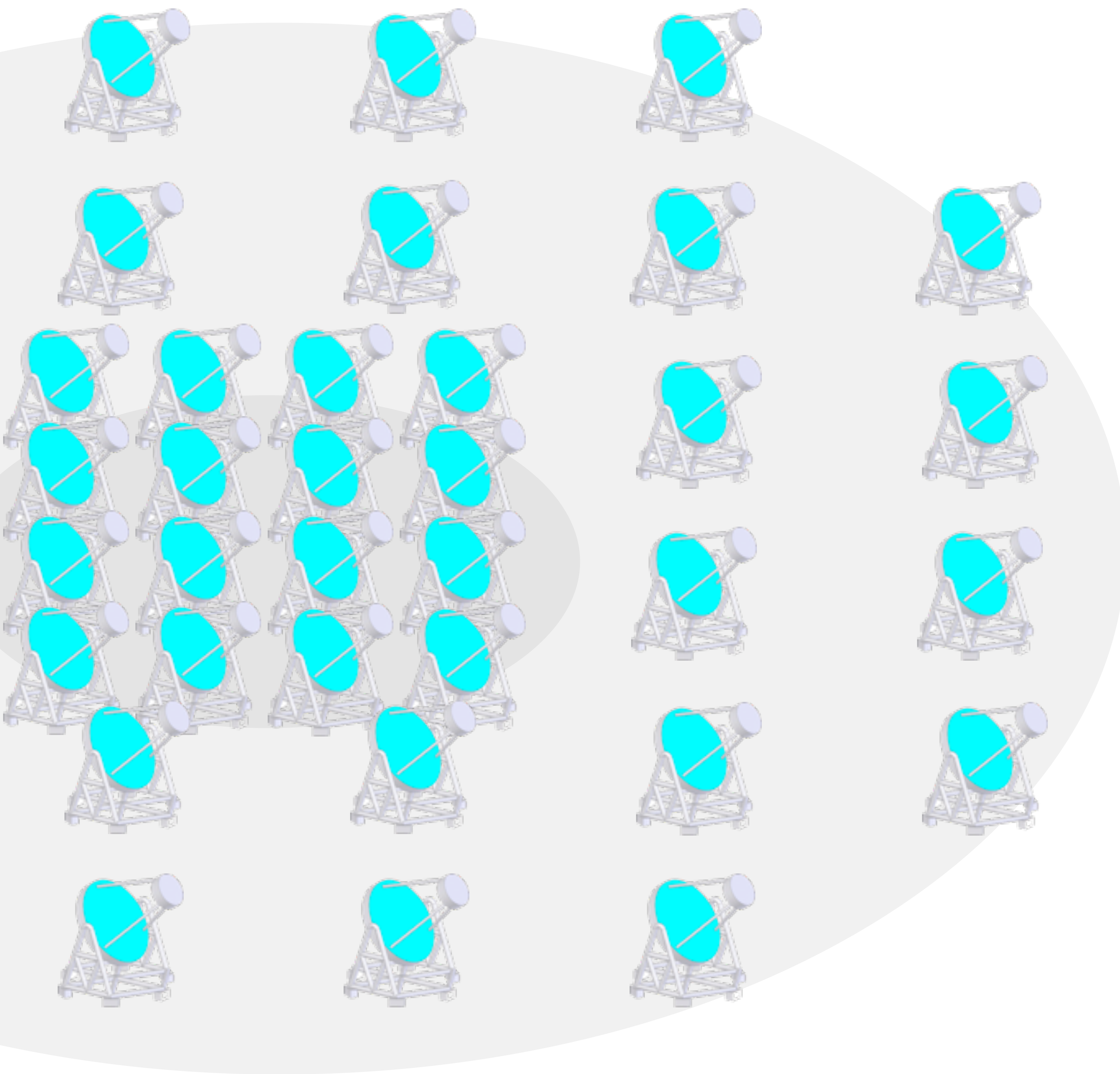
Low-energy section

energy threshold

of some 10 GeV

(a) bigger dishes or

Not to scale !



Low-energy section

energy threshold

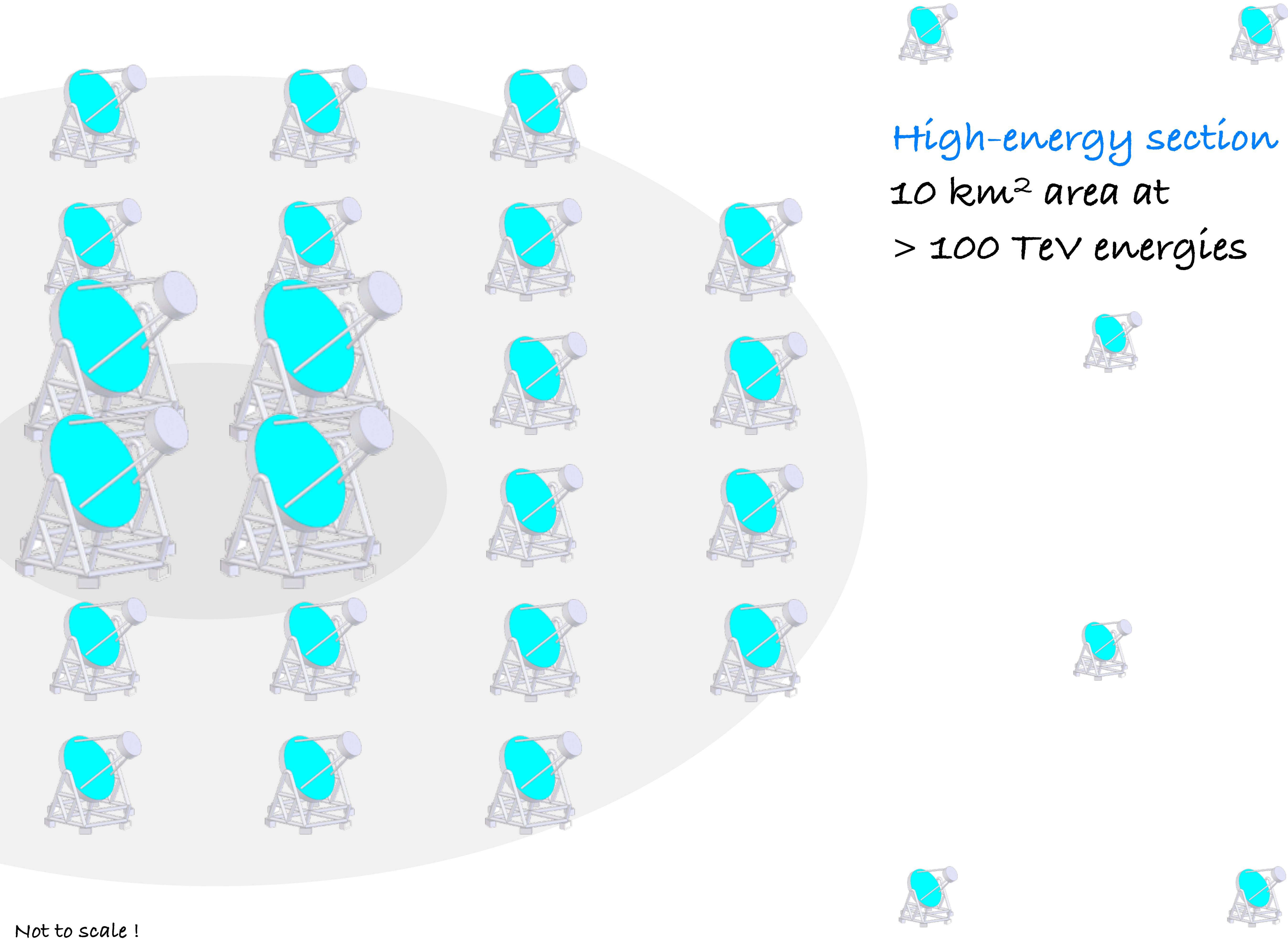
of some 10 GeV

(a) bigger dishes or

(b) dense packing /

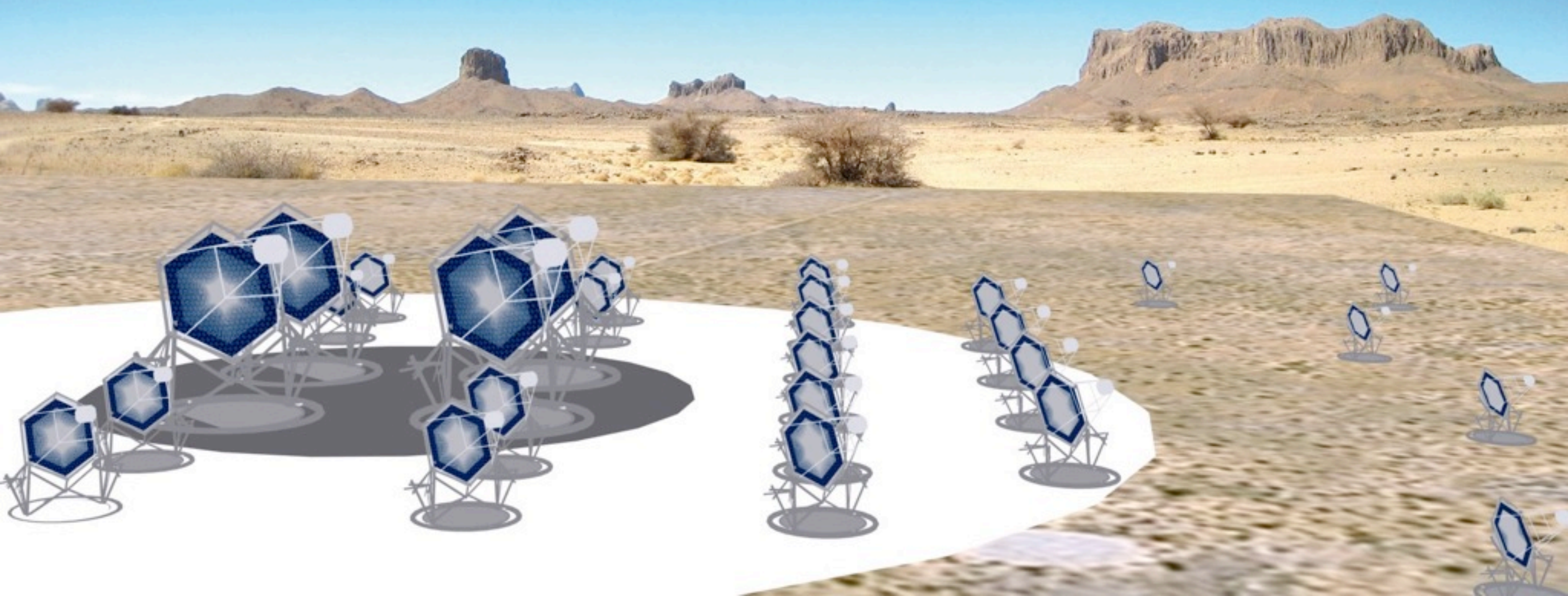
high-QE sensors

Not to scale !


High-energy section
10 km² area at
> 100 TeV energies
Not to scale !

The Cherenkov Telescope Array

- A factor 10 more sensitive than current instruments
  - Plus - much wider energy coverage, substantially better angular and energy resolution & wider field of view
- A ~ € 150M International Project
  - Design 2008-2011, Prototyping 2011-13, Construction 2014-18
  - Baseline: 50-100 Cherenkov telescopes



Price Tag: € 100 + 50 M

South

North

What is the best instrument for this money?

↖ Science / €

Optimise performance (within budget),

(parameters: telescope size, type, pixel size, FoV, array layout)

design for mass production, long-term operation and low maintenance

i.e. cheap, reliable, modular ...

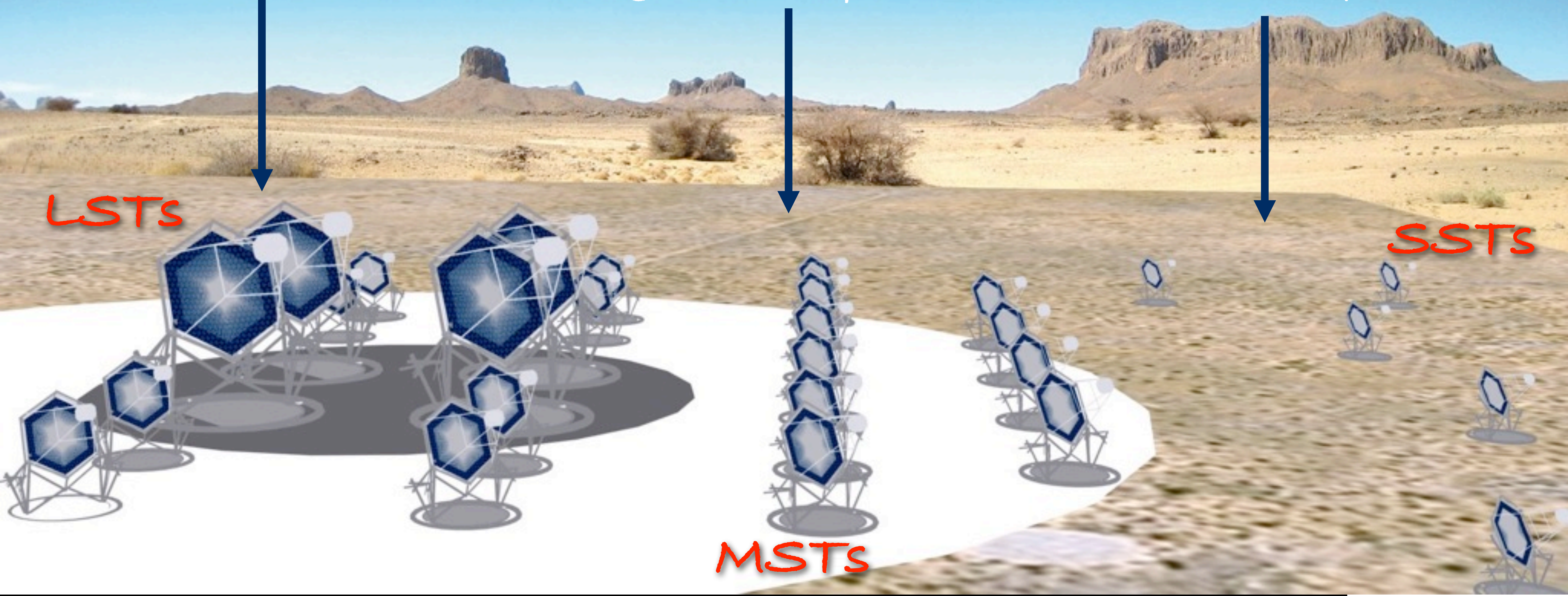
A real observatory with ≈ 100 telescopes.

Low-energy section
energy threshold
of 20-30 GeV
~24m telescopes

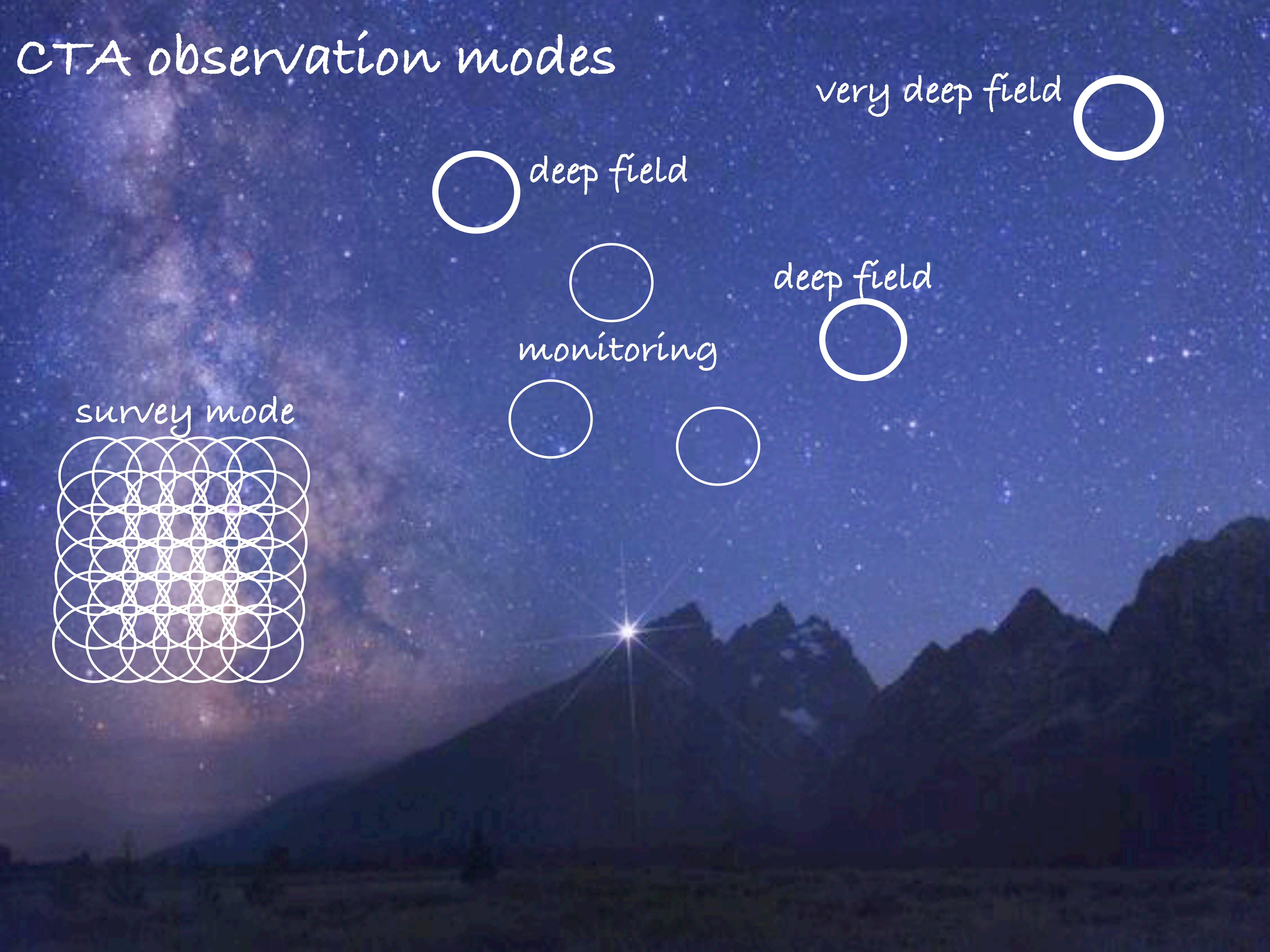
Medium Energies:
mCrab sensitivity
0.1–10 TeV
12m telescopes
(+9m SC option)

(South only)

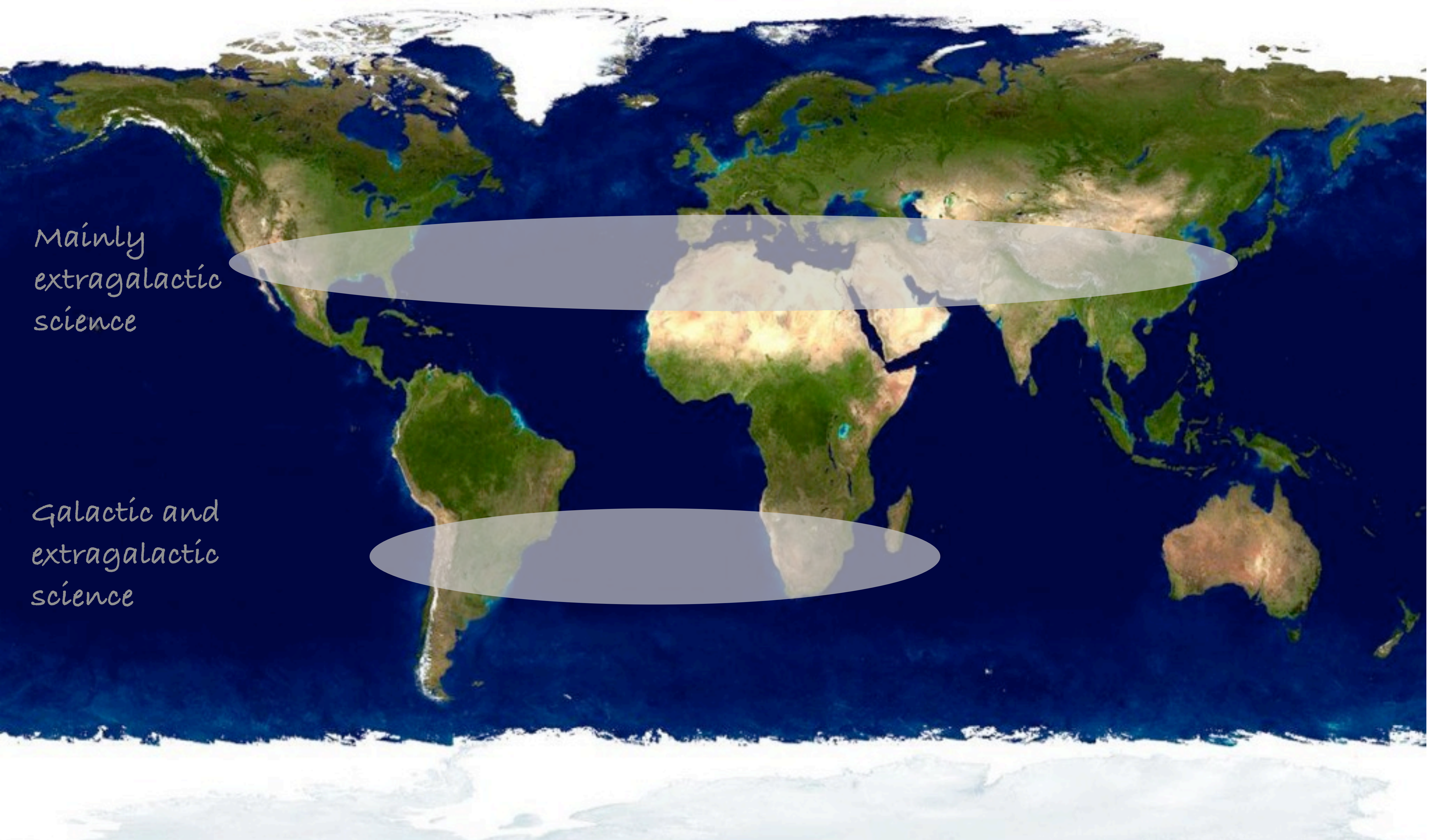
High-energy section
10 km² area for up to
energies ≈300 TeV
~5m telescopes



CTA observation modes



One observatory with two sites - operated by one consortium



Selection of sites by end 2012

10 km² (S) flat area 1.5-4.0 km altitude, minimum cloud cover, easiest access, ...

On Simulations ...

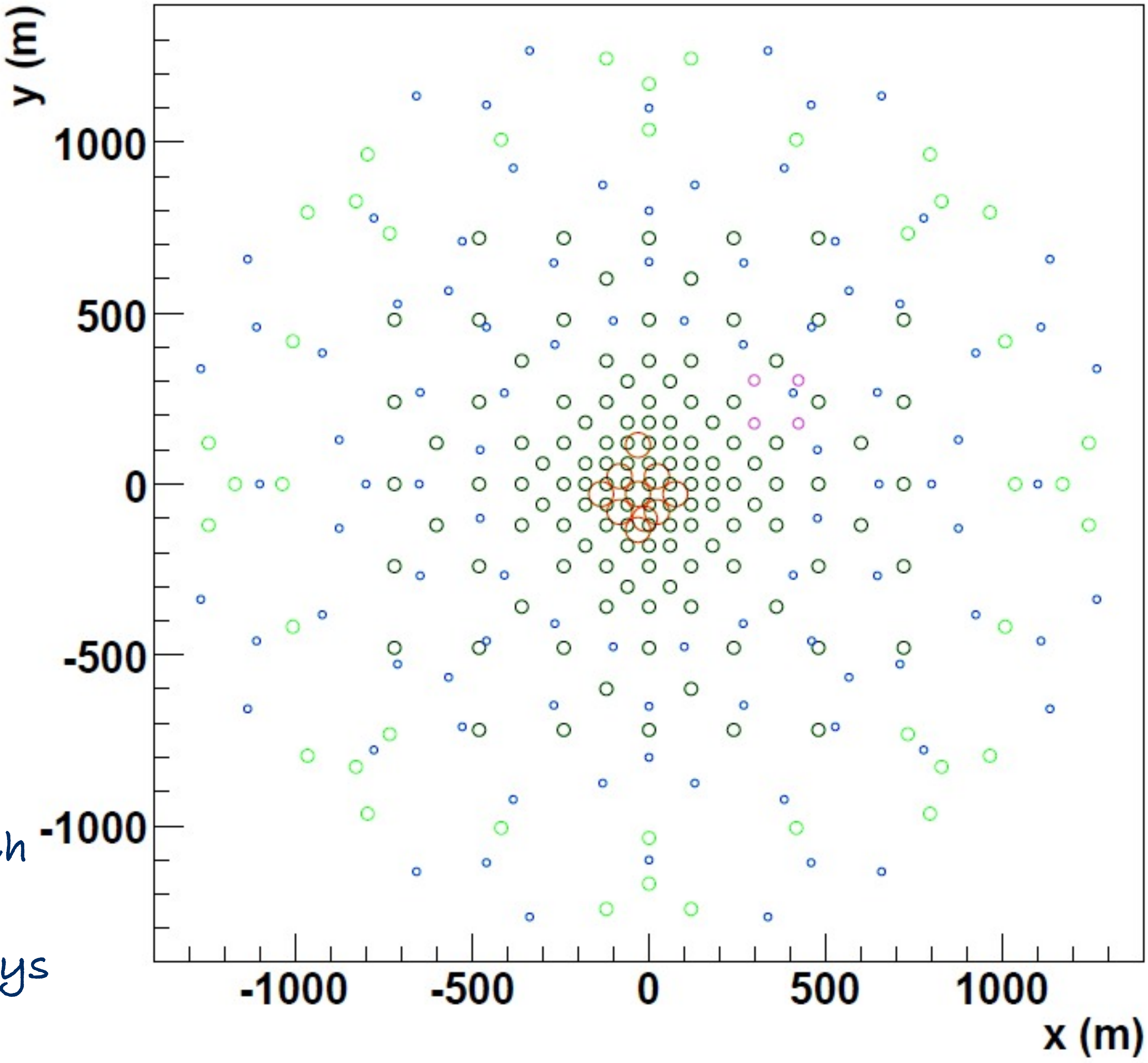
γ ray simulations are straight forward:

- energies are relatively low (i.e. sims are fast)
- γ ray showers can be simulated well (QED)
- hadronic background can be measured
  (i.e. no urgent need for sims of p, He, ...)

handshake between CORSIKA and detector simulations

> 10^9 showers can be simulated

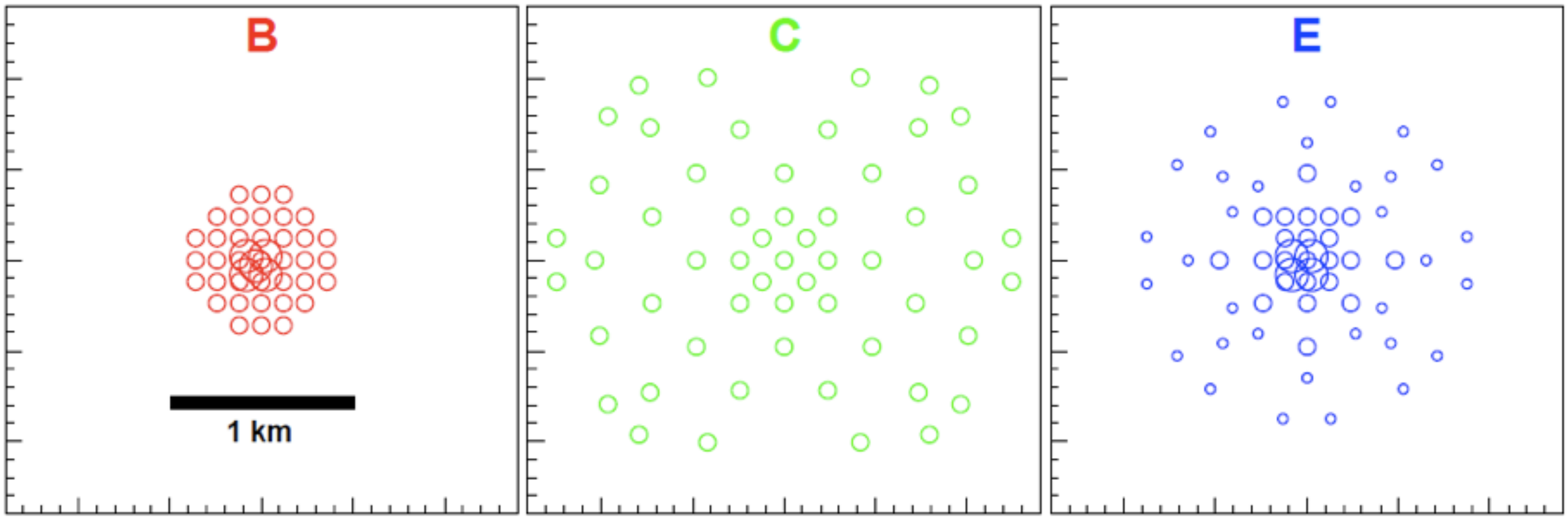
Performance Calculations



273 telescopes, subsets of which are actual candidate arrays

Examples of subarrays

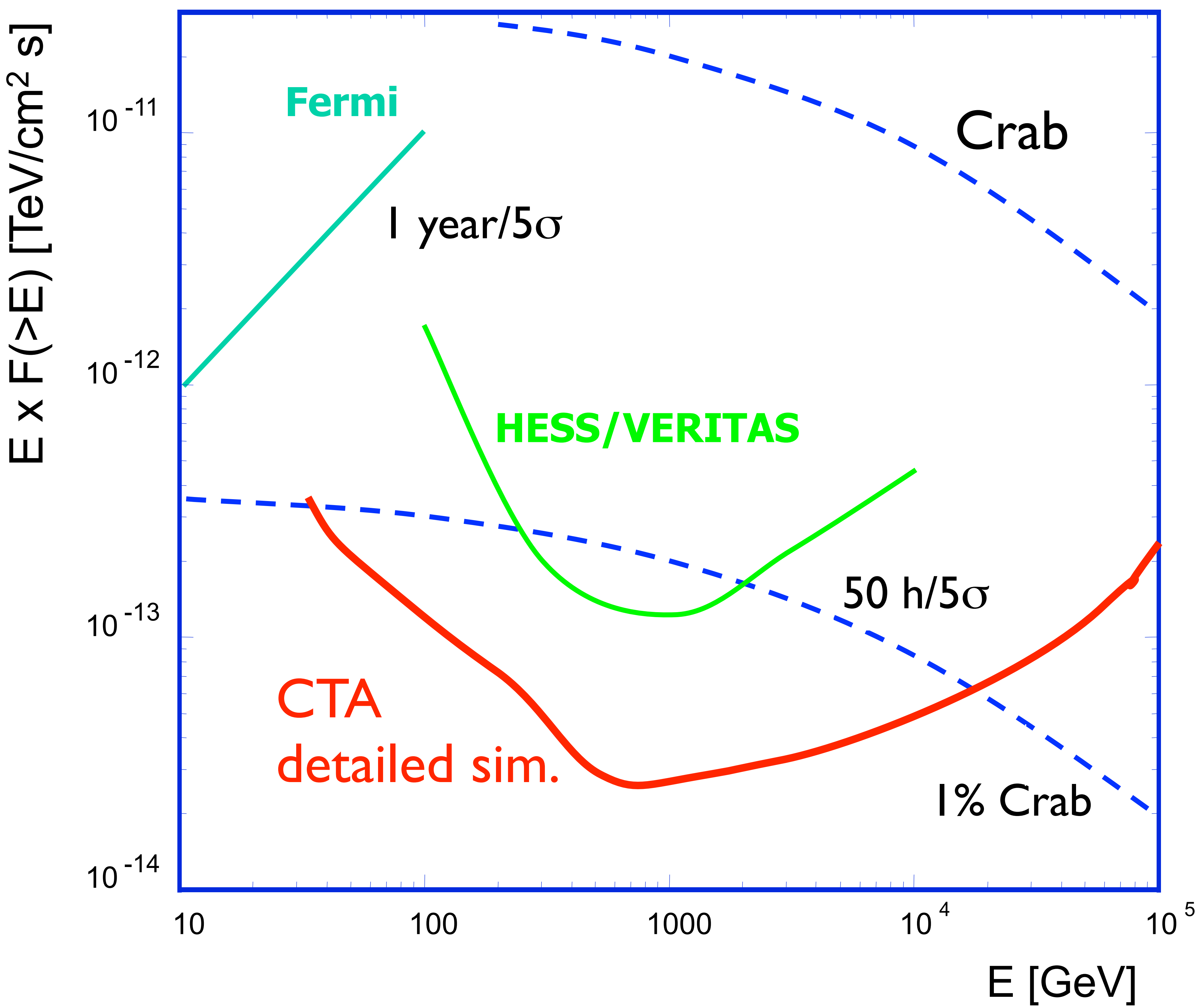
(of same cost)

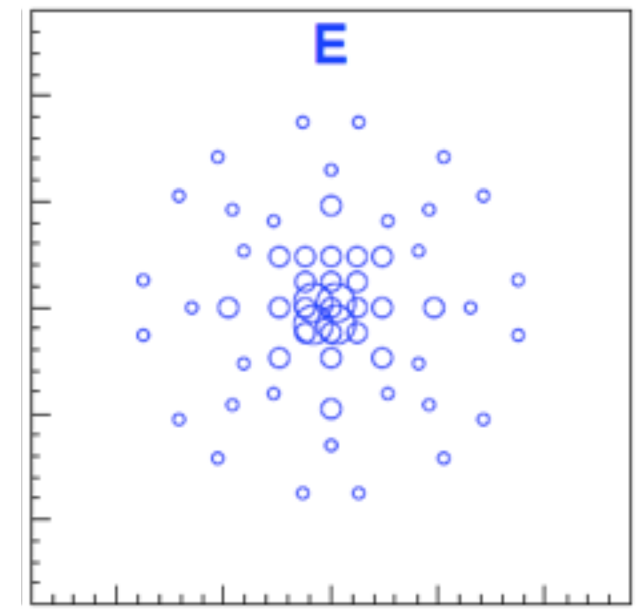


dense array of 12 & 24 m tels.	low density array of 12 m telescopes	array of 7, 12 and 24 m telescopes
+ low E	+ high/medium E	+ good sensitivity across full energy range
- high E	- low E	

main trade-off: quantity vs quality of events

Point Source Sensitivity

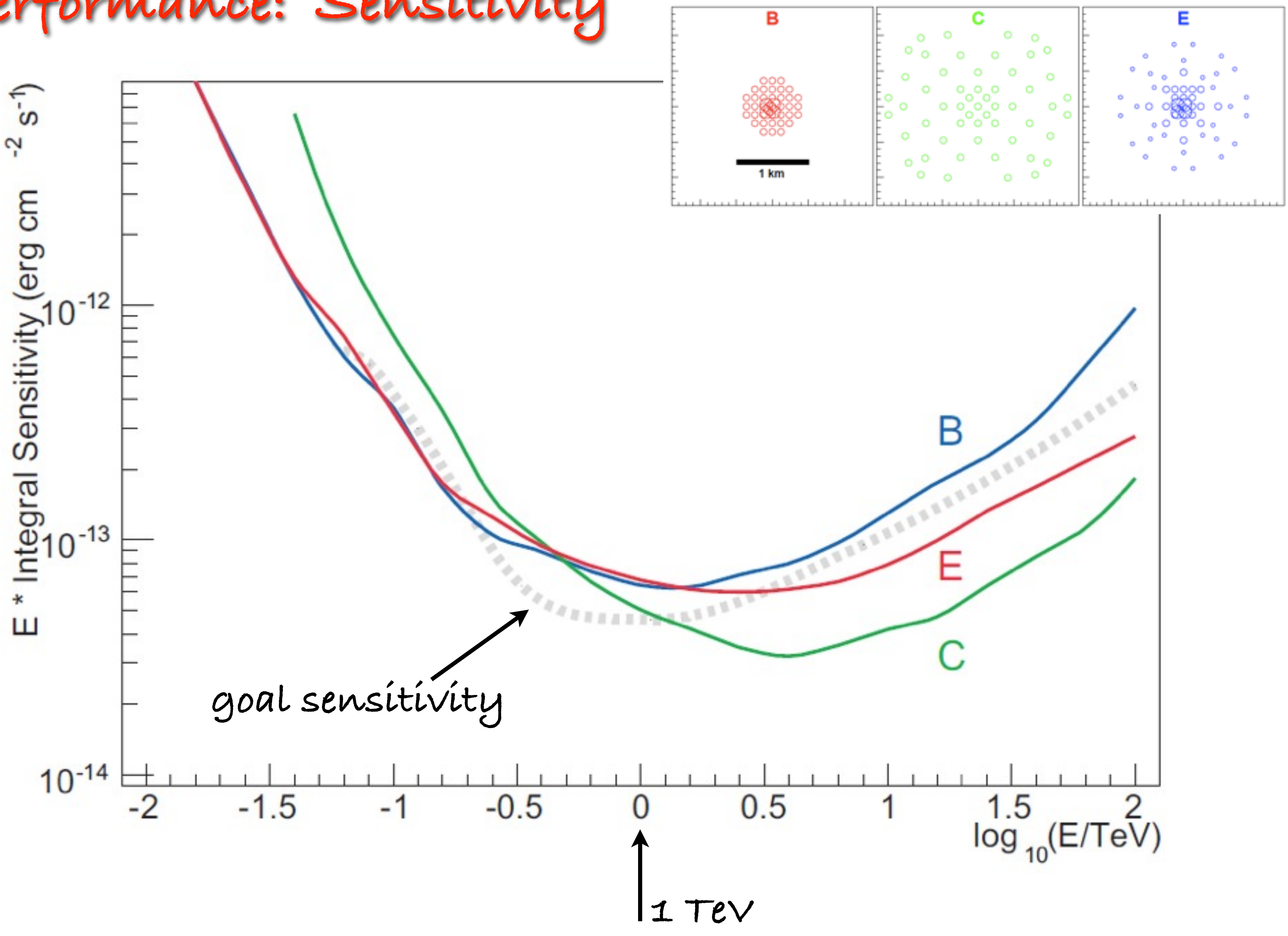


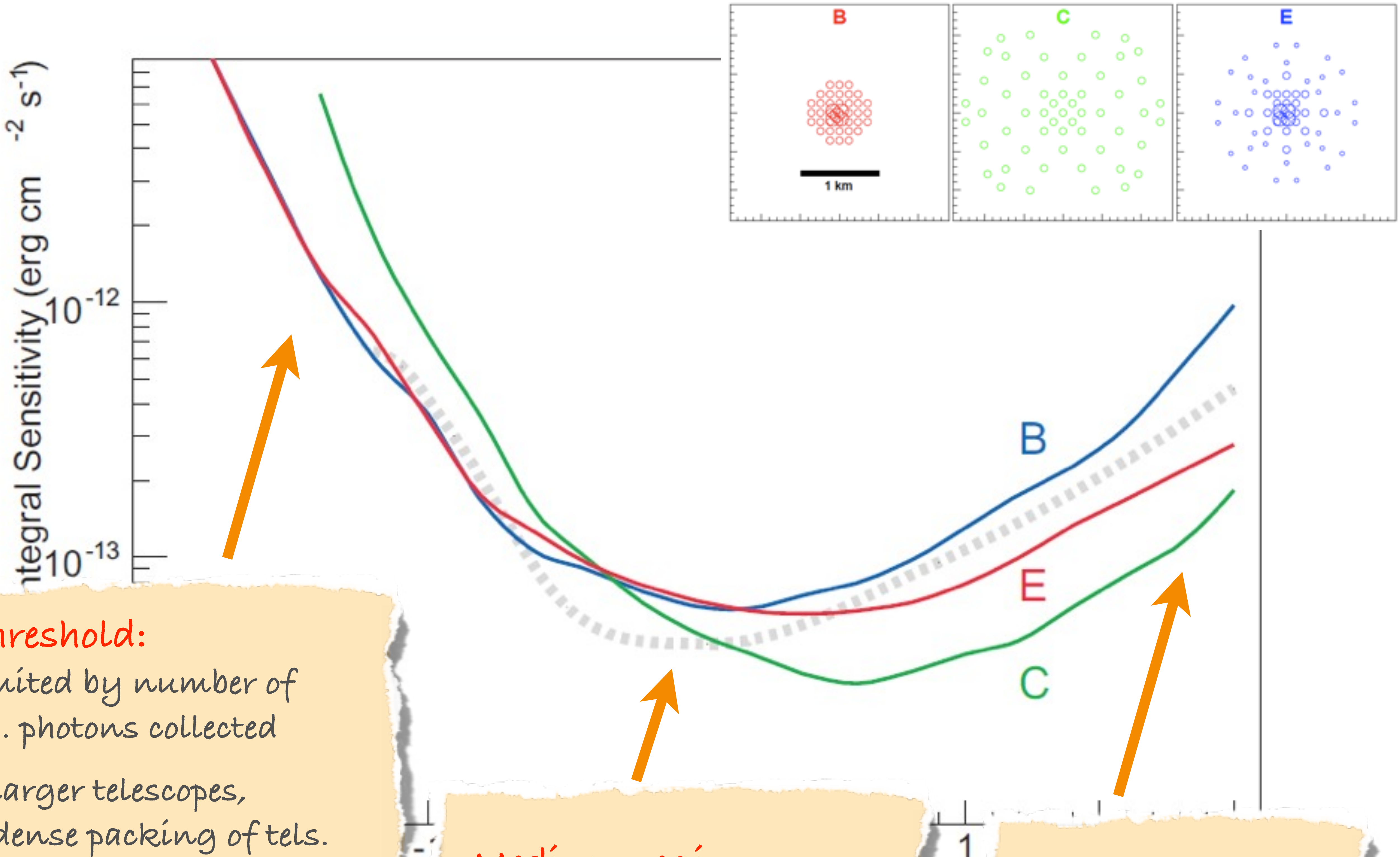


array "E" :
59 telescope config.
(analysis & layout
not optimised yet)

€80M nominal cost

Performance: Sensitivity





Threshold:
limited by number of Ch. photons collected

- larger telescopes,
- dense packing of tels.
- better photo detectors

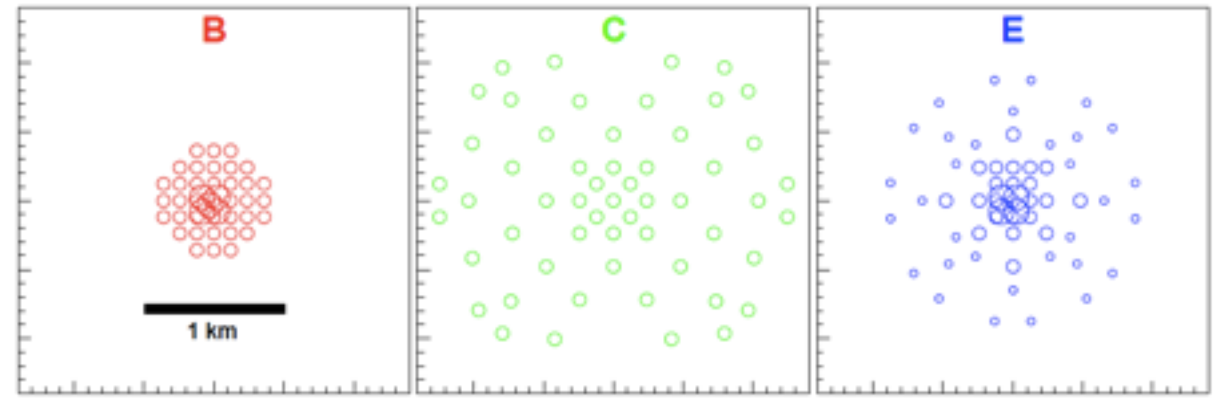
Medium region:
limited by signal / BG

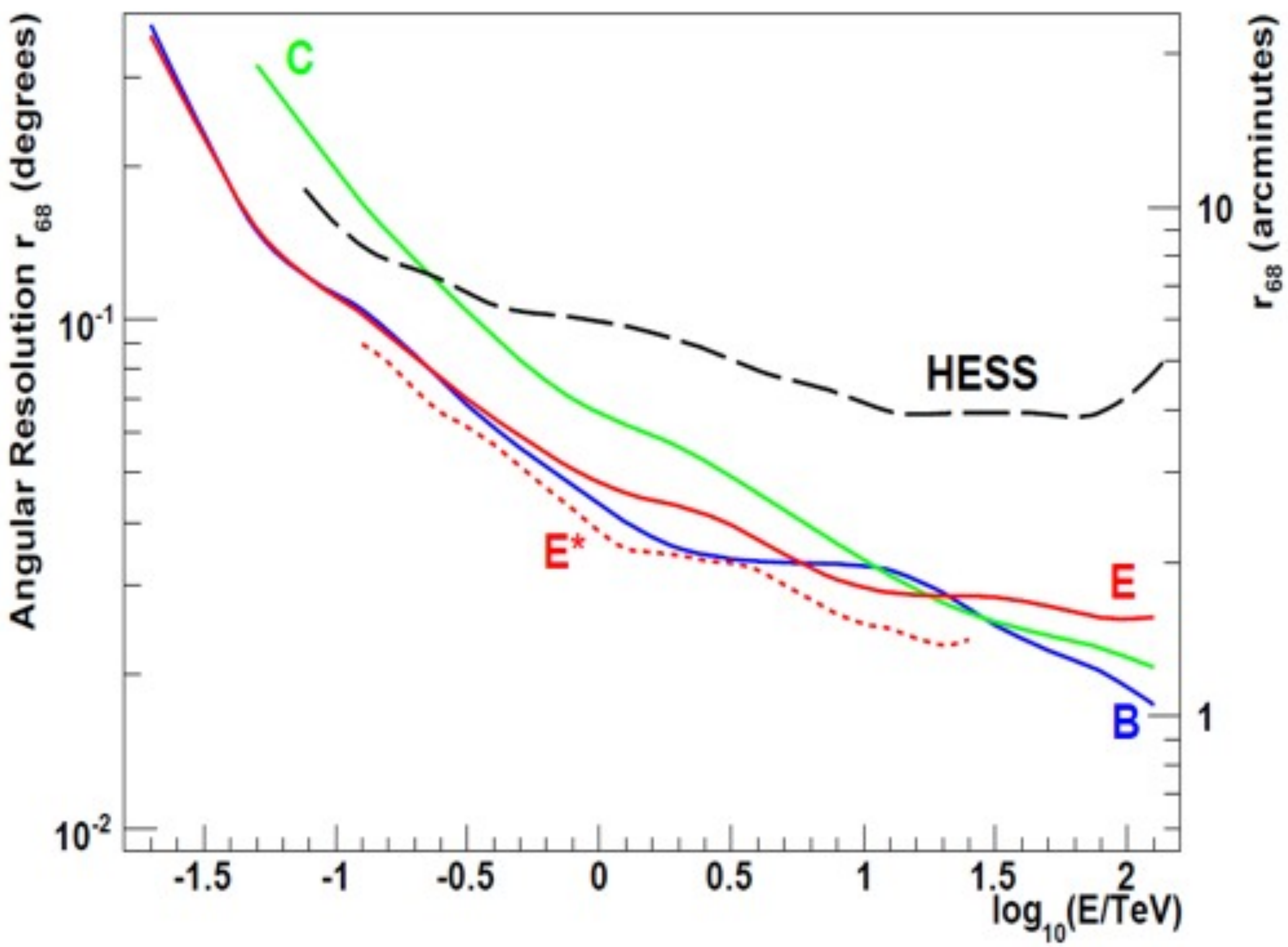
- better BG rejection,
- improved ang. resolution,
- better photon statistics

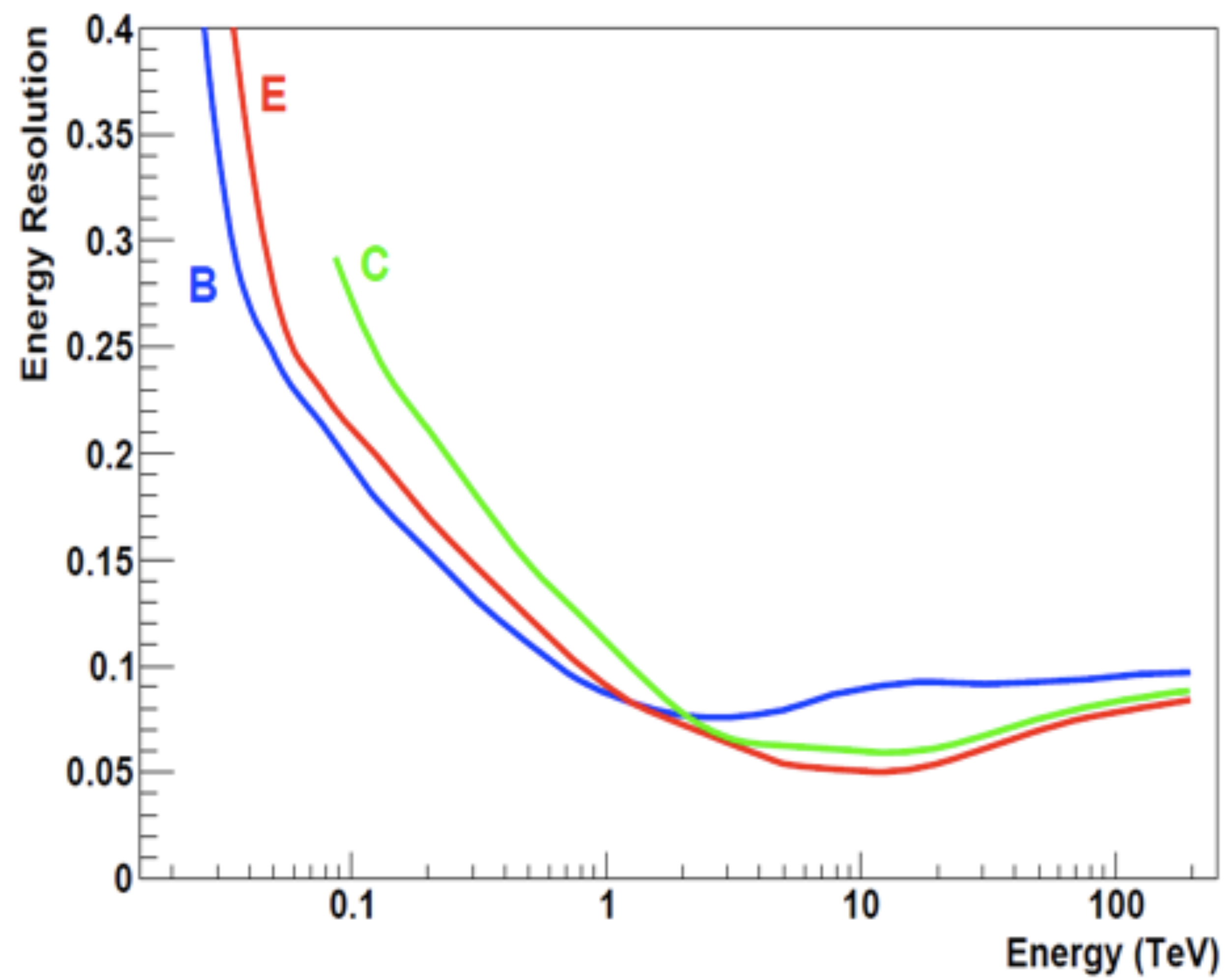
High energies:
limited by statistics

- large array

Performance: angular and energy resolution





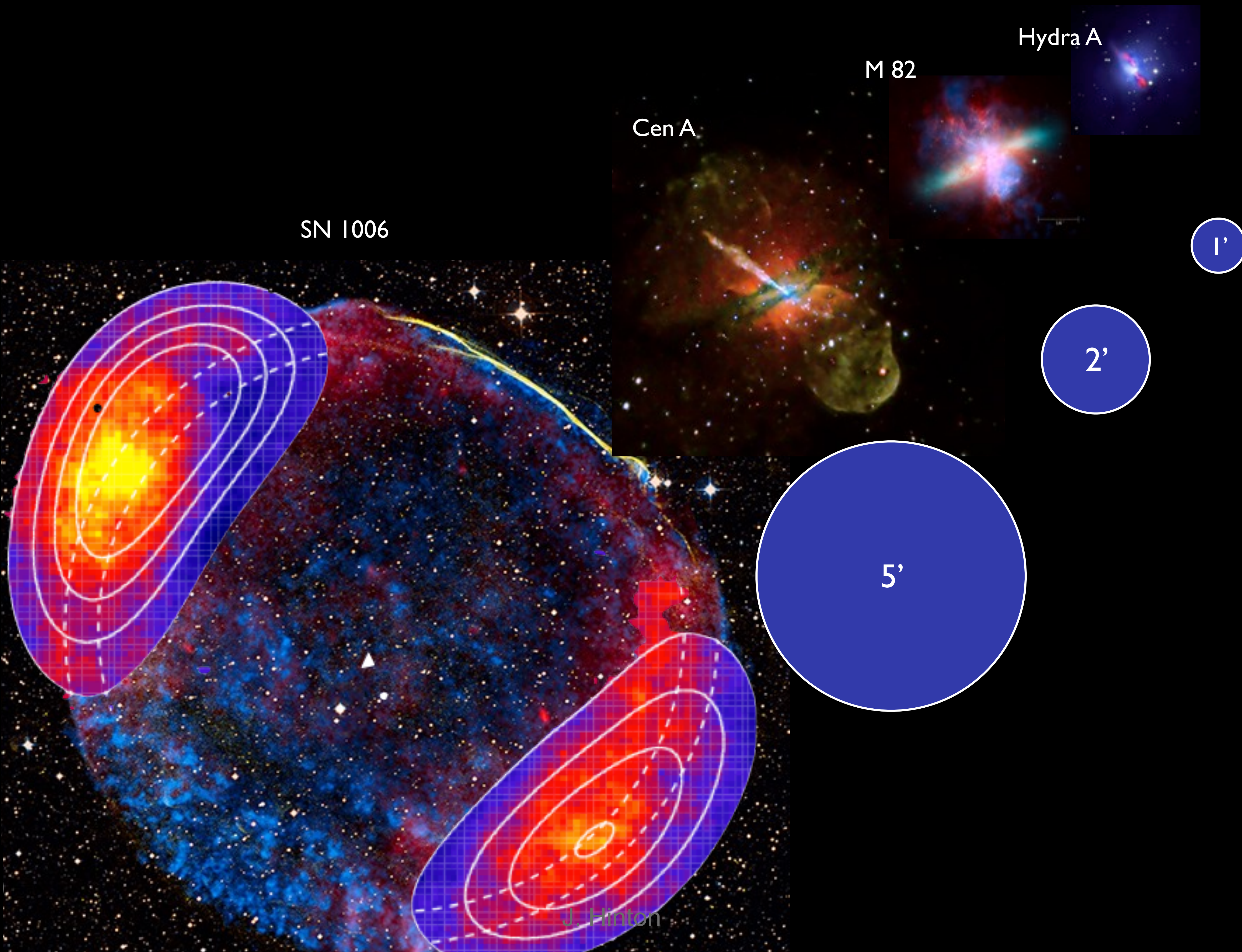


1-2′ for E > 1 TeV

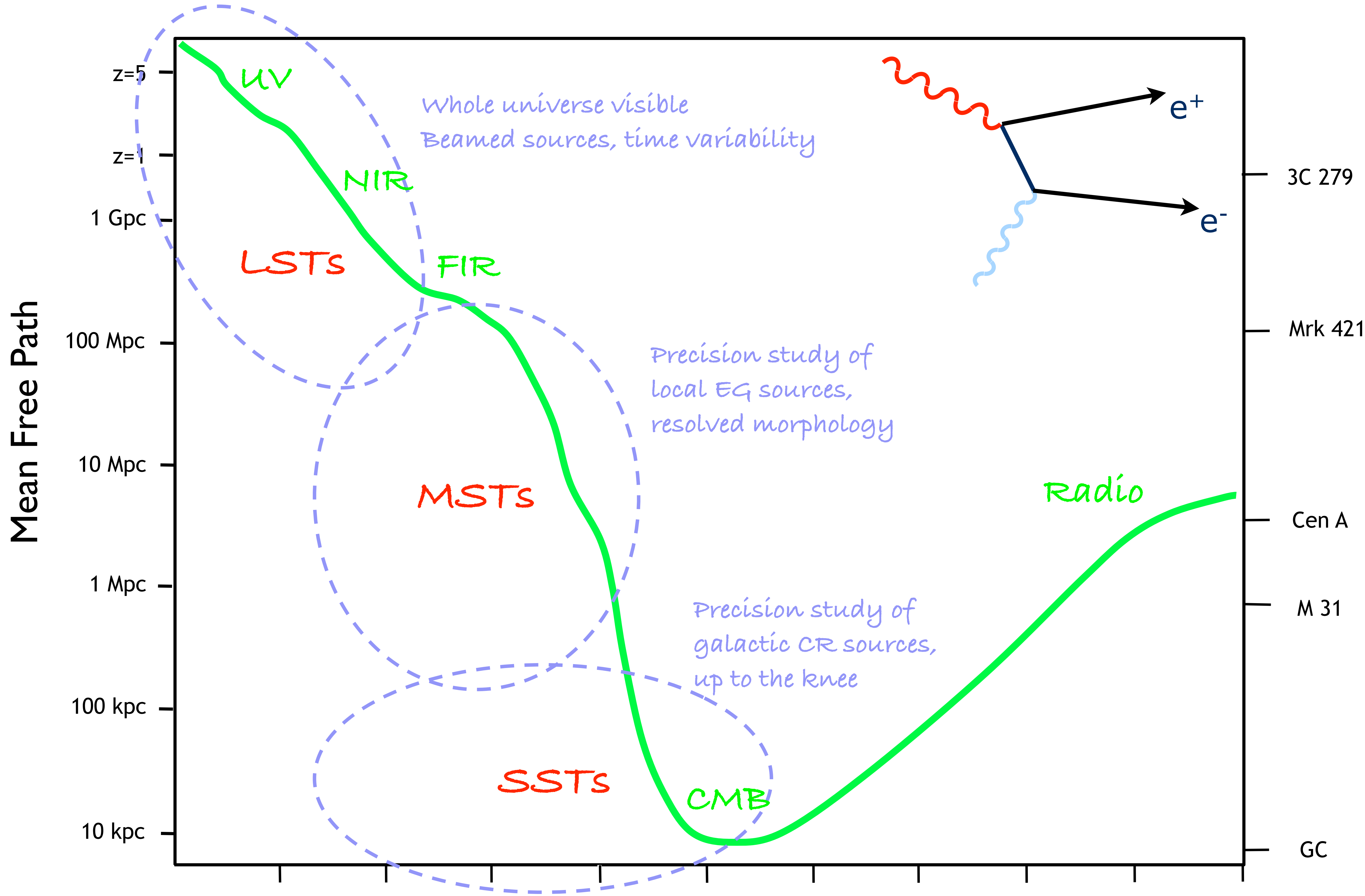
(fundamental limit: ~ 10″)

<10% for E > 1 TeV

Angular Resolution



The Gamma Ray Horizon $\gamma_{TeV} + \gamma_{IR} \rightarrow e^+e^-$



Performance:

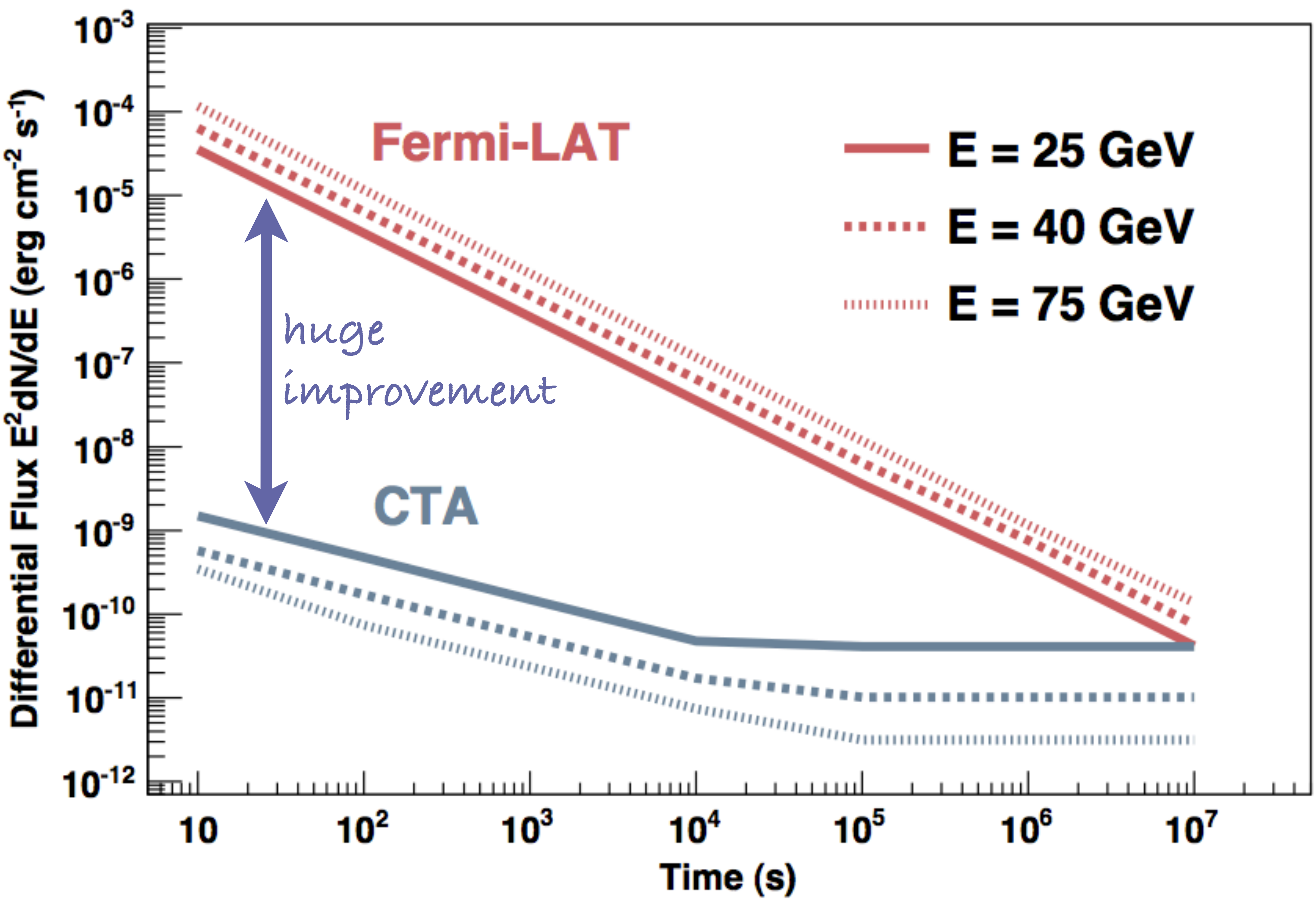
Energy TeV	Area km^2	Ang.Res arc min	E.Res %	FOV °
0.03	0.003	12	30	4-5
0.3	0.1	4	13	6-8
3	1	2	8	7-9
30	3	1.5	7	8-10

Improvement (relative to HESS) :

Diffuse continuum:	≈ x 5
Angular resolution for point sources:	≈ x 2
FoV for surveys:	≈ x 2
Energy resolution for lines:	≈ x 1.5
all-sky survey for point-like emission line sources:	≈ x 30
pointed observation of a 0.5° continuum source:	≈ x 5

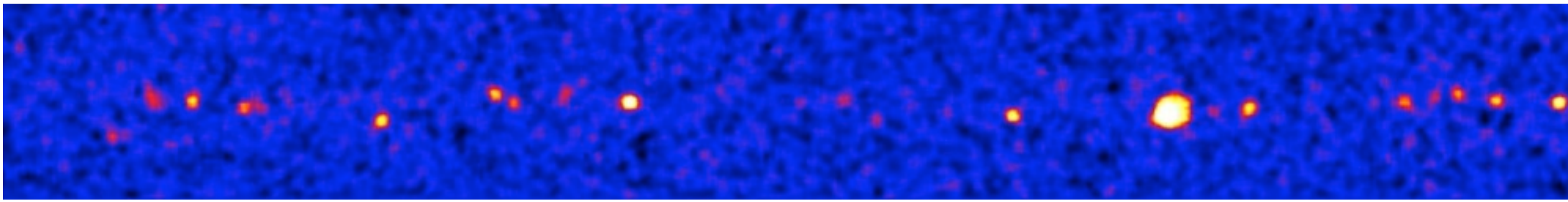
Variability and Short-Timescale Phenomena

(flares, GRBs, ...)

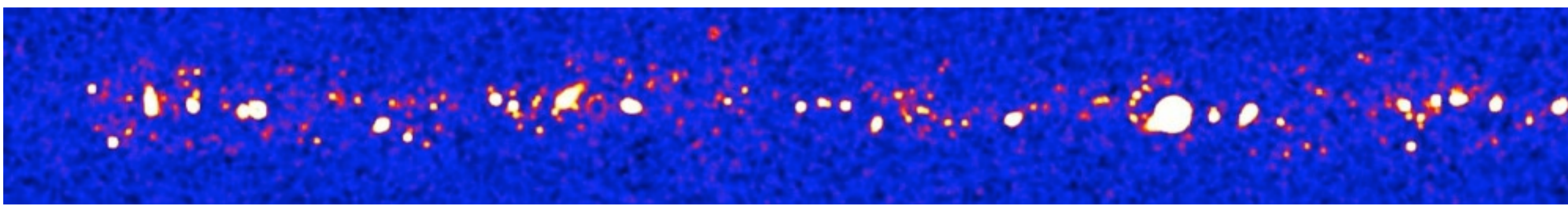


Funk, Hinton 2012

CTA expectation:



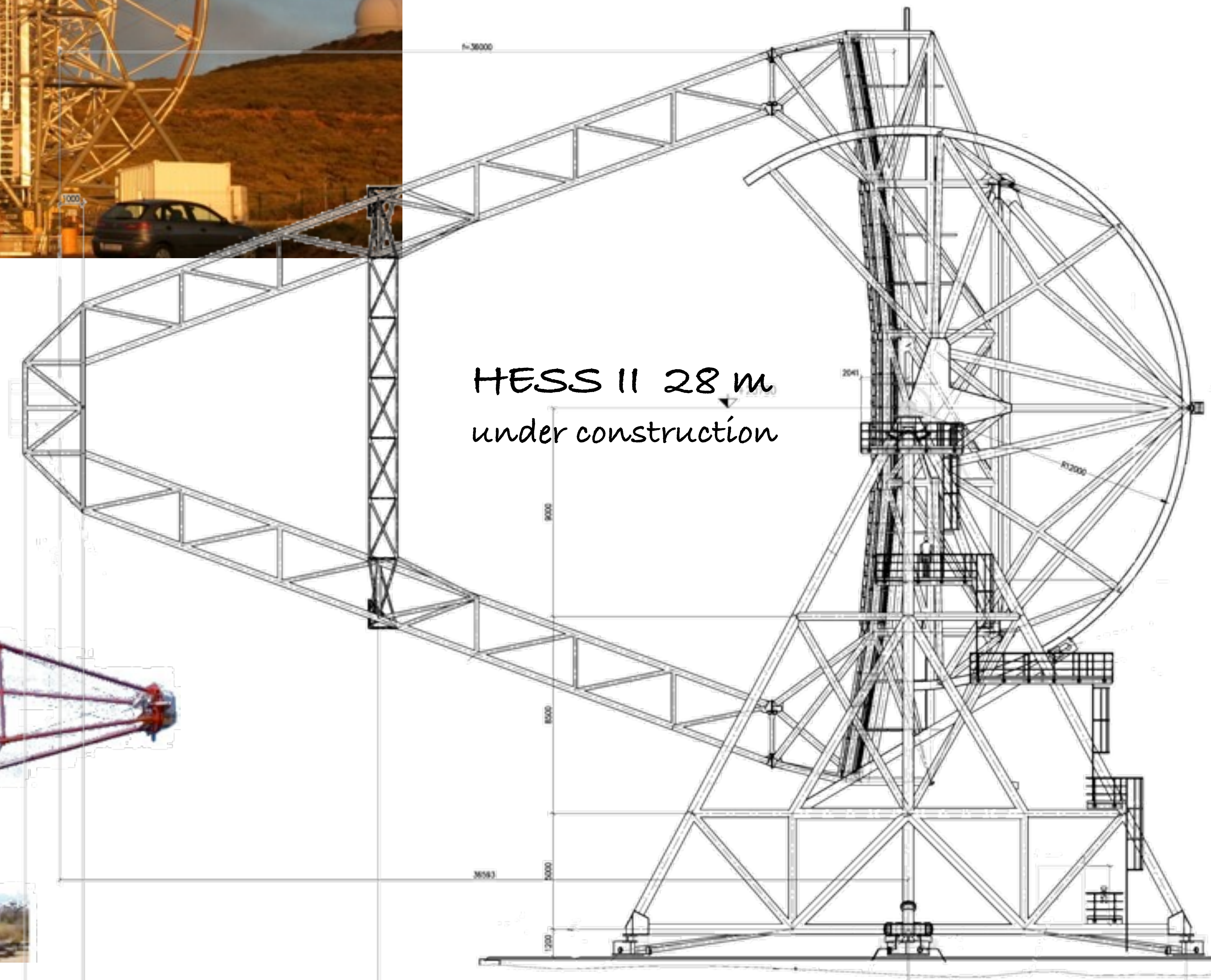
HESS ~500 h



CTA expectation: >1000 sources

Building blocks could be ...

to scale



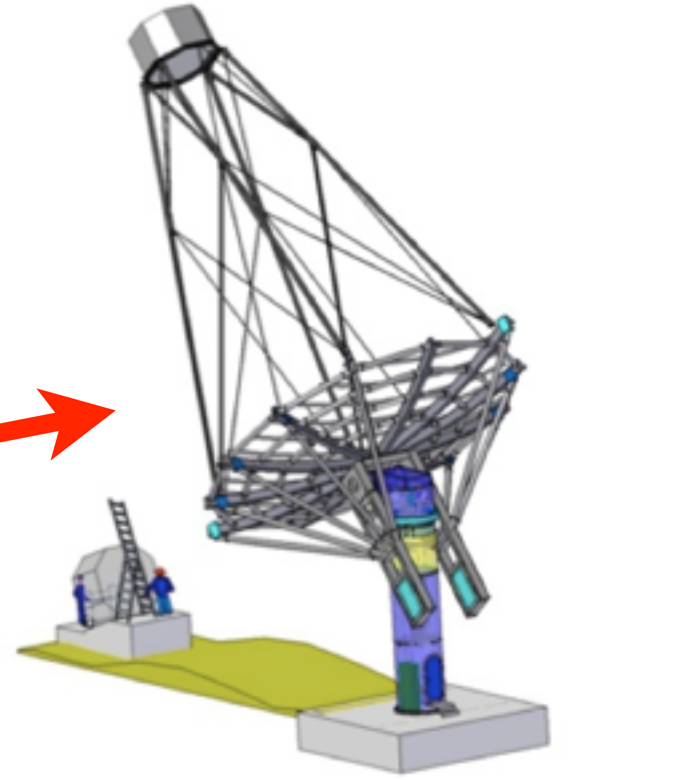
HESS I 12 m

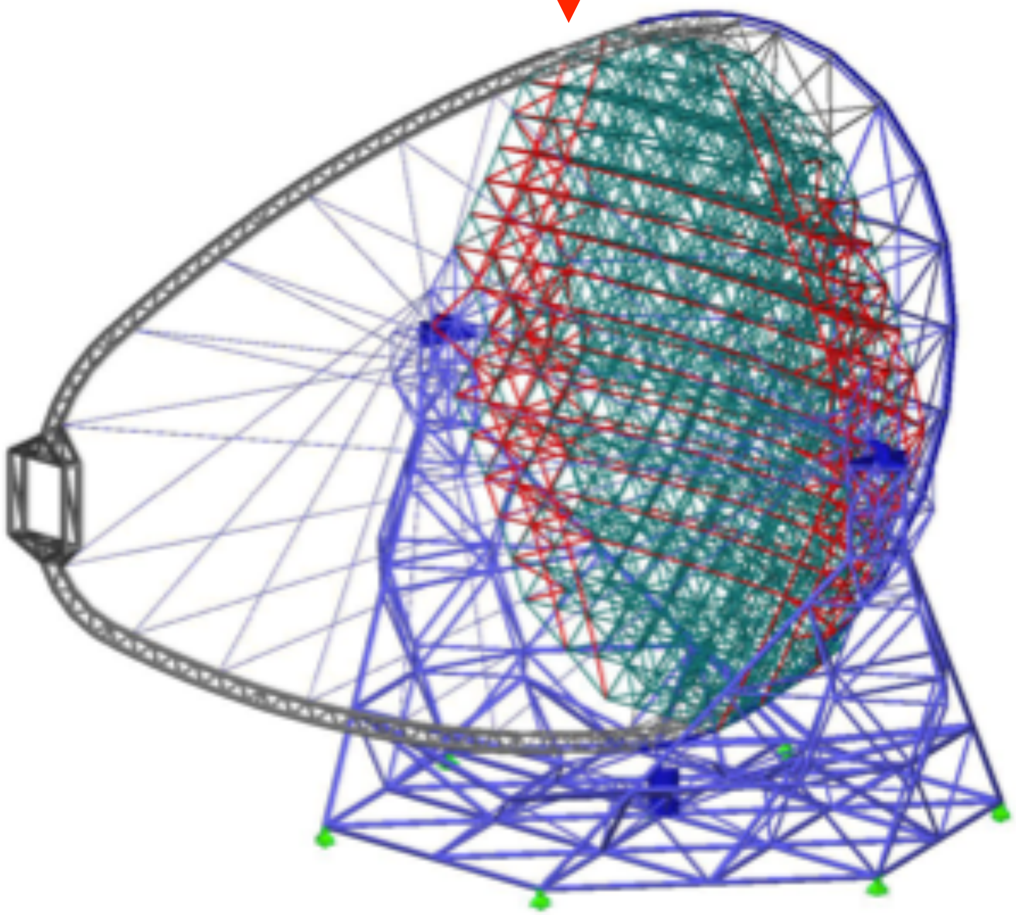
HESS II: 28 m diameter

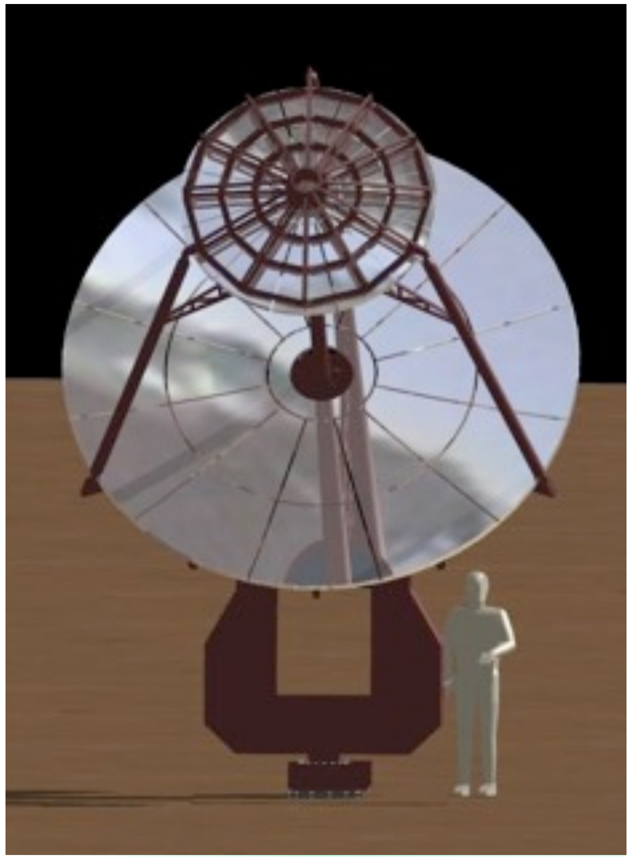
Truck

Options for LST, MST

& SST

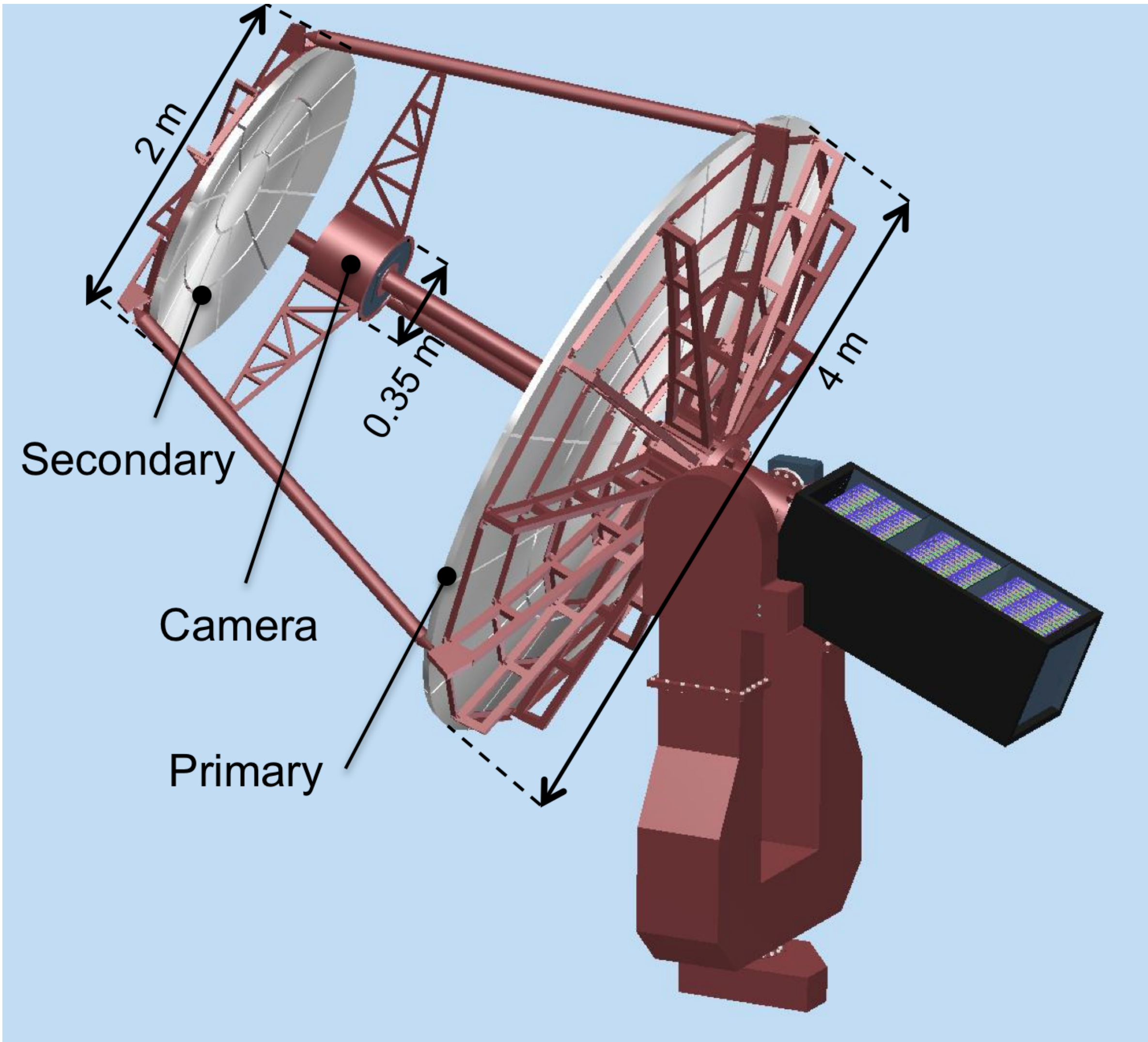


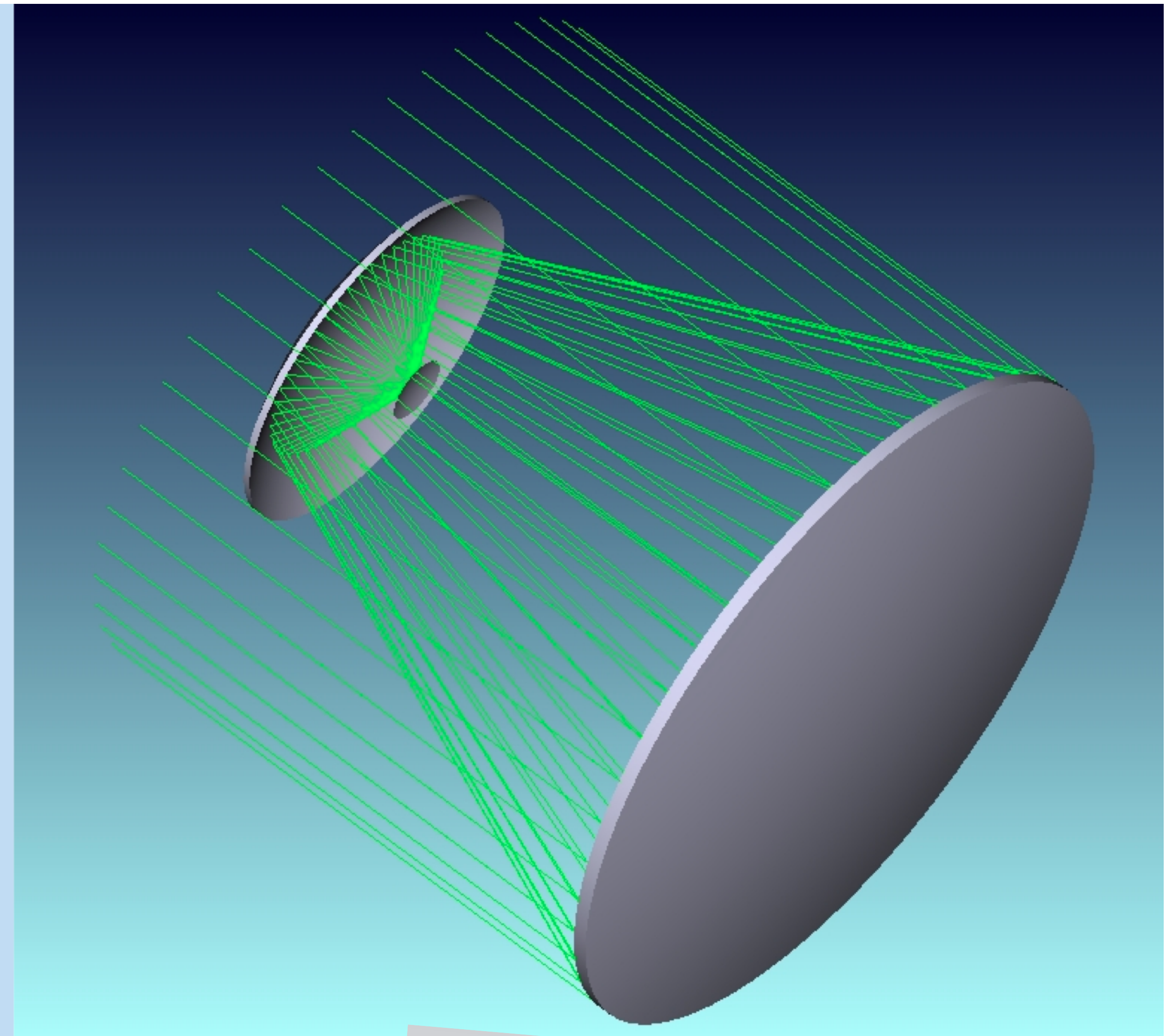




SST dual mirror design:

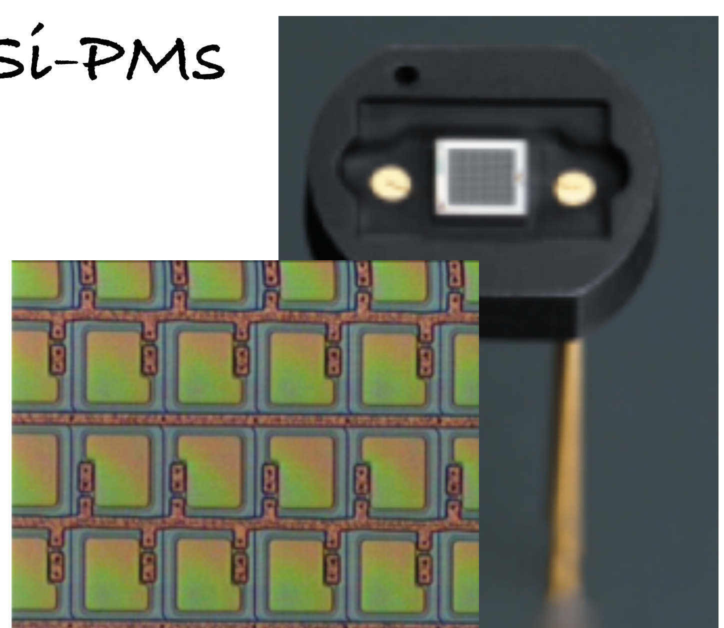
10° FOV, small plate scale, much cheaper camera



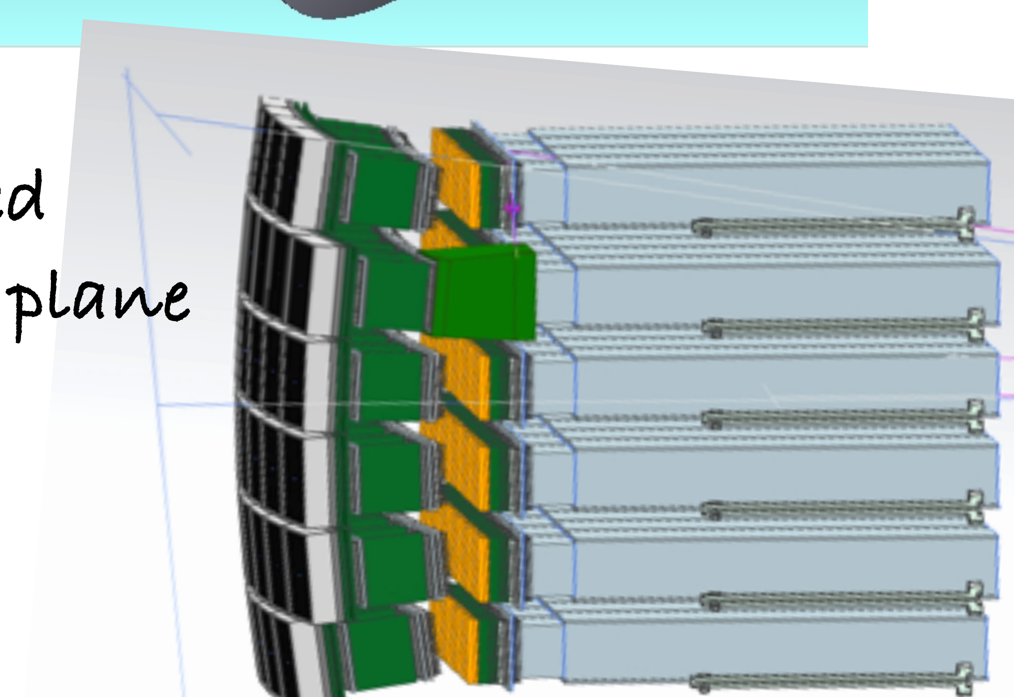


MA-PMs

Si-PMs

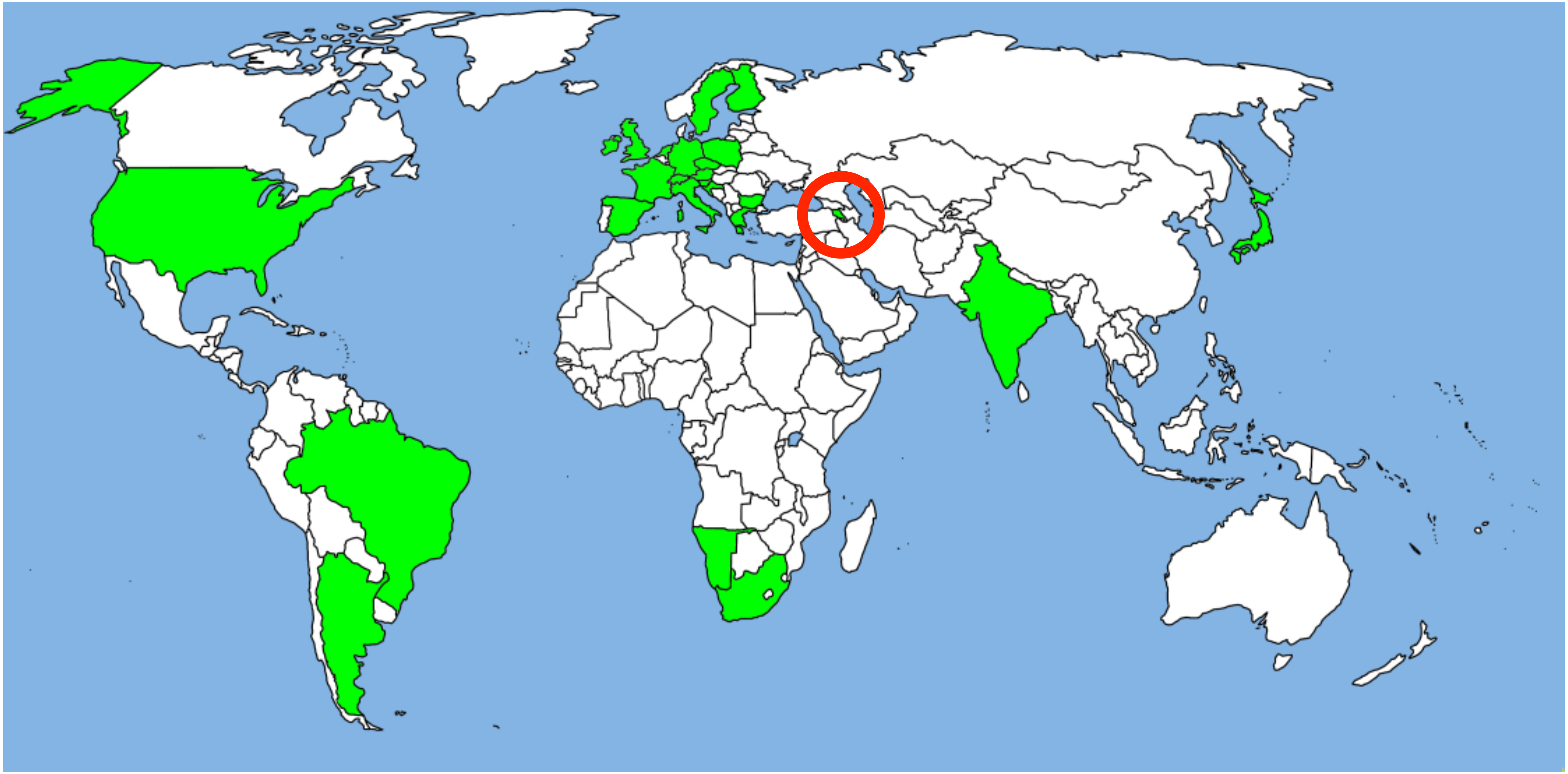


curved focal plane



CTA Members: 27 Countries

>1000 scientists and engineers from >100 institutions



Argentina, Armenia, Austria, Brazil, Bulgaria, Czech Republic, Croatia, Finland, France, Germany, Greece, India, Italy, Ireland, Japan, Mexico, Namibia, Netherlands, Norway, Poland, Slovenia, Spain, South Africa, Sweden, Switzerland, UK, USA

Armenian members:

Vardan Sahakian
Ashot Akhperjanian
Gagik Papyan
Levon Pogosyan

(unfortunately
in the moment not
very active)

Armenia

YEREVAN PHYSICS INSTITUTE, established in: 2 Alikhanyan Brothers St., Yerevan 0036, Armenia, represented by Prof. Ashot Chilingarian, Director of Yerevan Physics Institute, or an authorized representative.

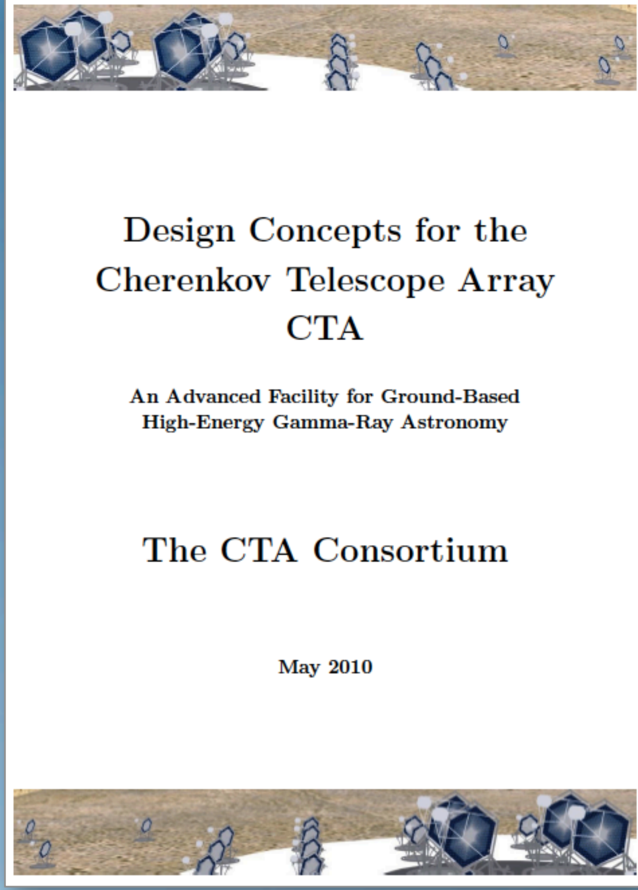
Ashot Chilingarian	Yerevan 14.01.10	
Name of Signatory	Place & Date	Signature

More Details:

general info:
www.cta-observatory.org

arXiv:1008.3703
120 pages

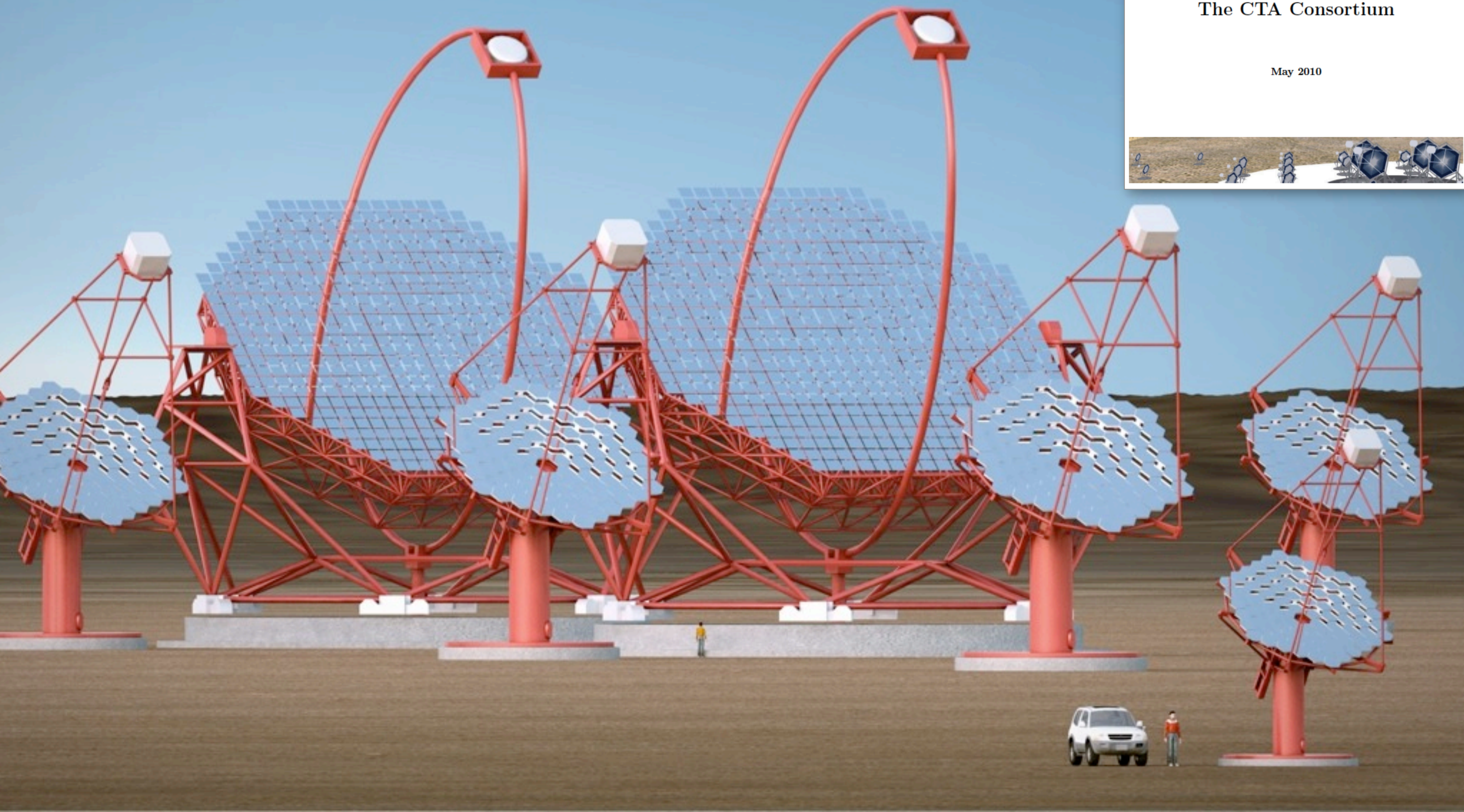
Exp. Astronomy
32 (2011) 193-316


Design Concepts for the
Cherenkov Telescope Array
CTA

An Advanced Facility for Ground-Based
High-Energy Gamma-Ray Astronomy

The CTA Consortium

May 2010



γ rays in Astroparticle Physics

range from 10^{-6} - 10^{20} eV

pose many exciting questions for research in the next decades ...

Cherenkov Telescopes are the best means of studying γ-rays at energies >20 GeV

CTA is the much improved next-generation instrument to reach >1000 sources.

… and some of it began …

… and some of it began … exactly here.

Summary (of all our lectures)

- Astroparticle Physics is an exciting field.
- Highest energy particles are rare & difficult to detect

  ... but new experiments / techniques / models
  allow detection of these particle and identification of their sources.
- The most-energetic CRs, gamma rays & neutrinos
  come likely from the same, most violent environments
  in the universe.

  (Multi-messenger approach for improved understanding)
- Three new windows in Astronomy:

  TeV gamma rays, UHECRs, Neutrinos
- Bright future with many challenges for
  bright young theorists and experimentalists.

Astroparticle Physics still poses many puzzles.

The experimental findings and theoretical ideas do not (yet) form a coherent and clear image.
The situation may seem messy.

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Steven Weinberg,
Four golden lessons (for young physicists)
Nature 426 (2003) 389

"My advice is to go for the messes
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Experiments & analyses are challenging and require **bright young students** (*i.e. you ?*) to answer some of the most exciting questions in physics.