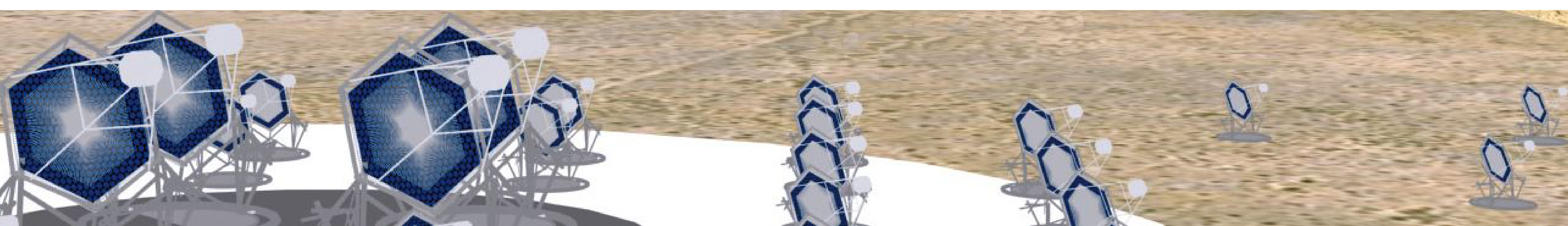
VHE Gamma Ray Astronomy with the

cta
cherenkov telescope array

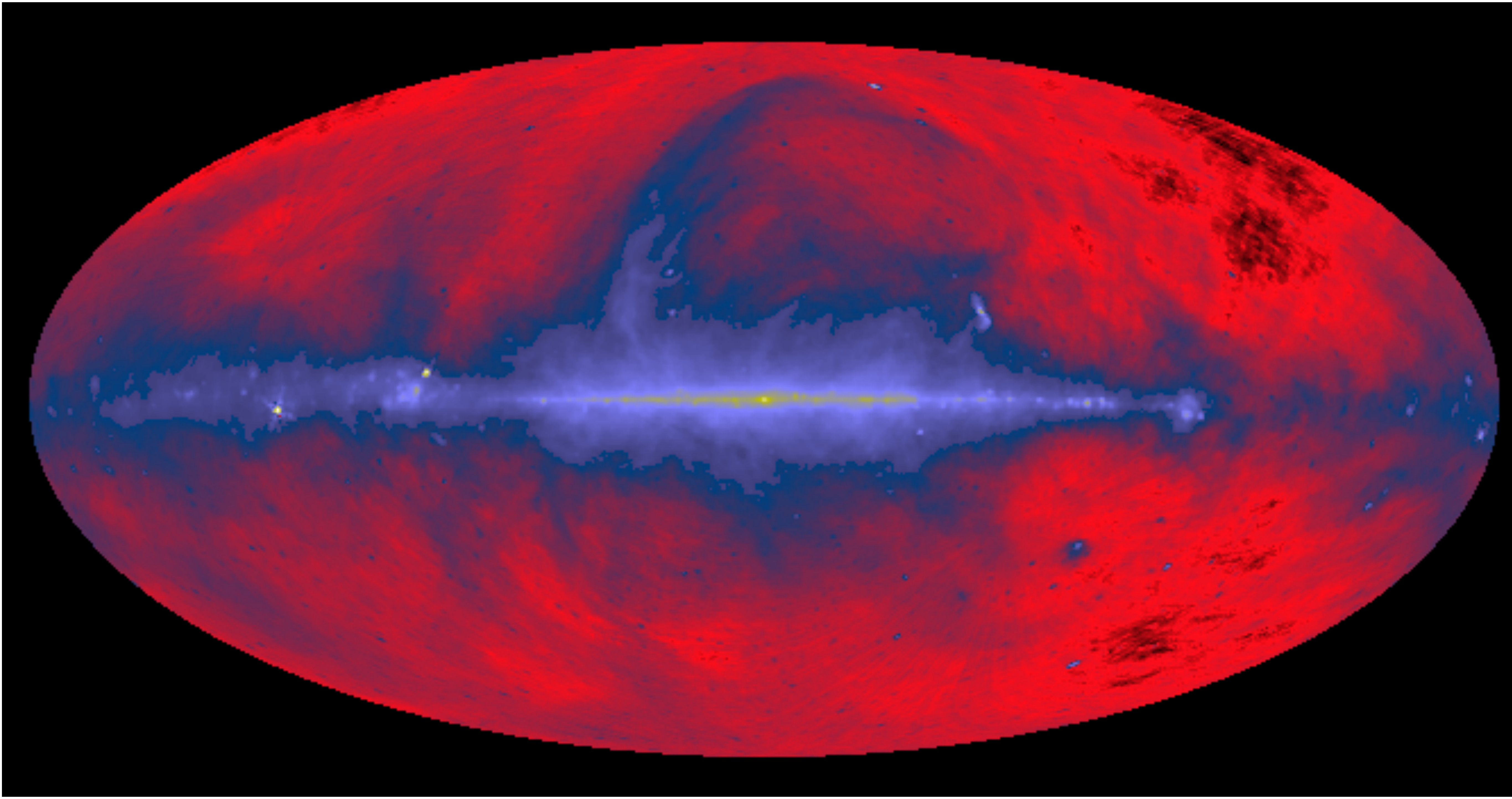
J Knapp, U of Leeds, UK
Ooty, Dec 2010



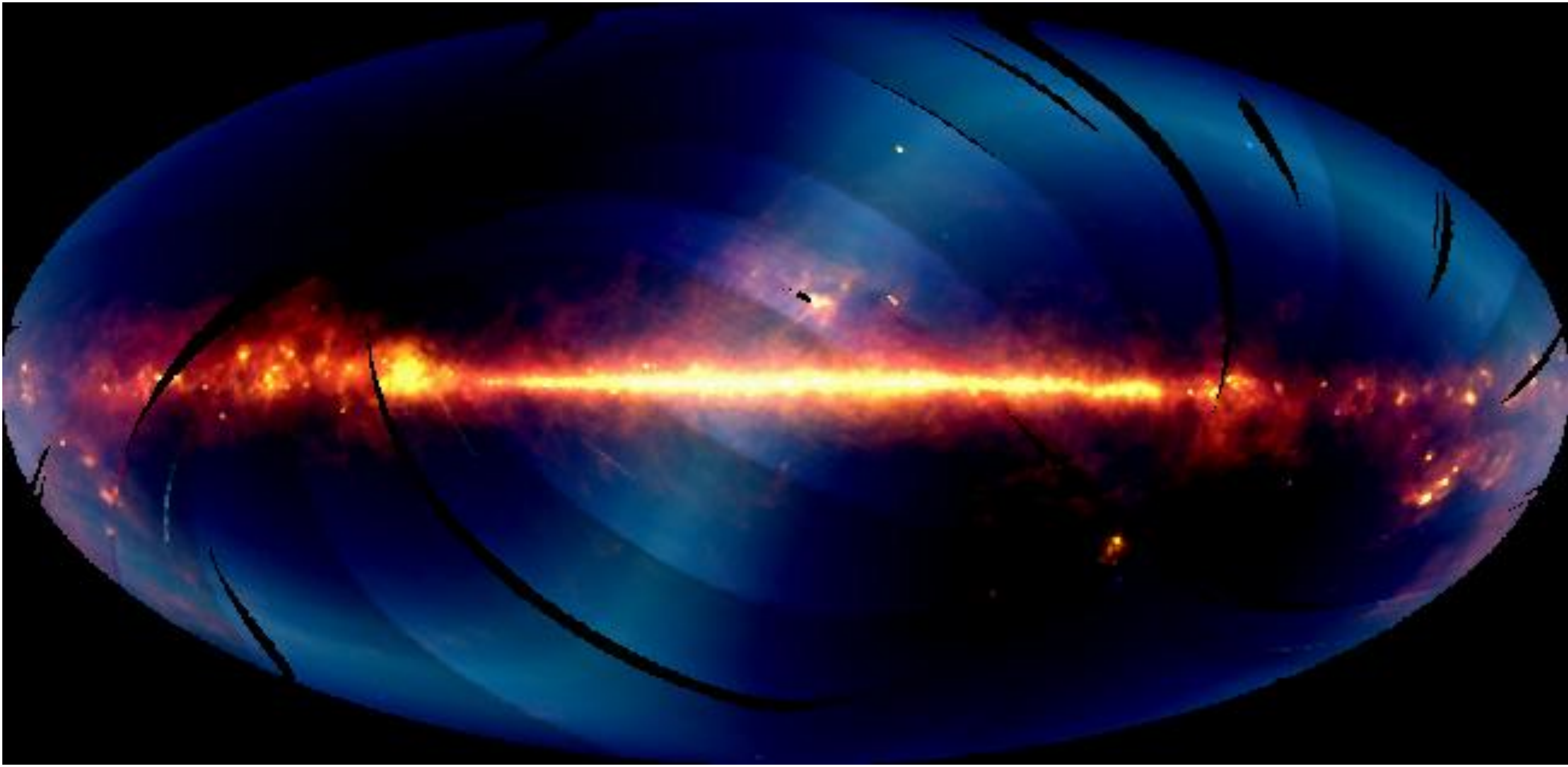
- The non-thermal universe
- Detecting VHE γ rays
- Science Case

- CTA

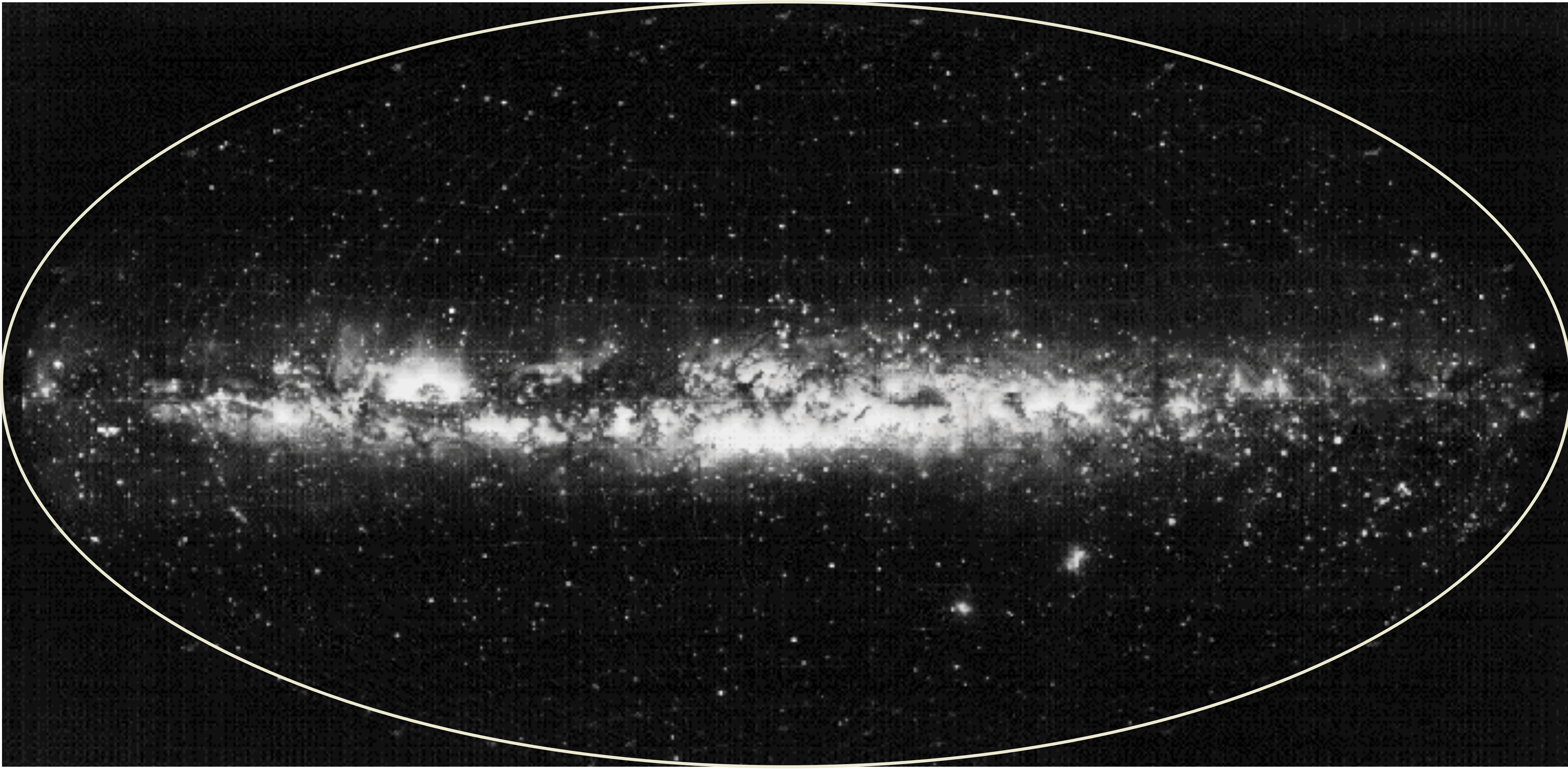
with many thanks to
J Hinton, W Hofmann, R White
for informations and slides



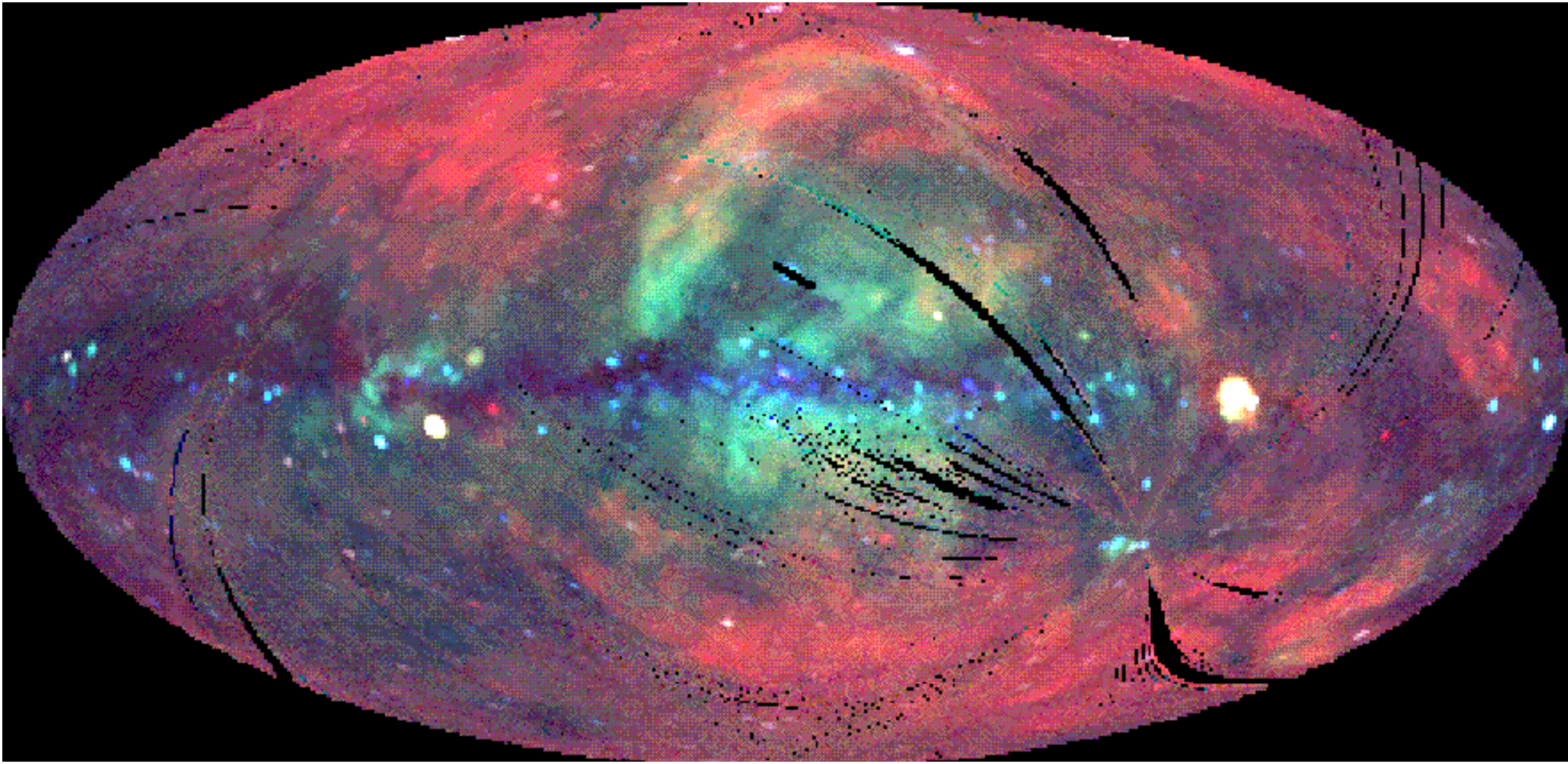
radio (10^{-6} eV)



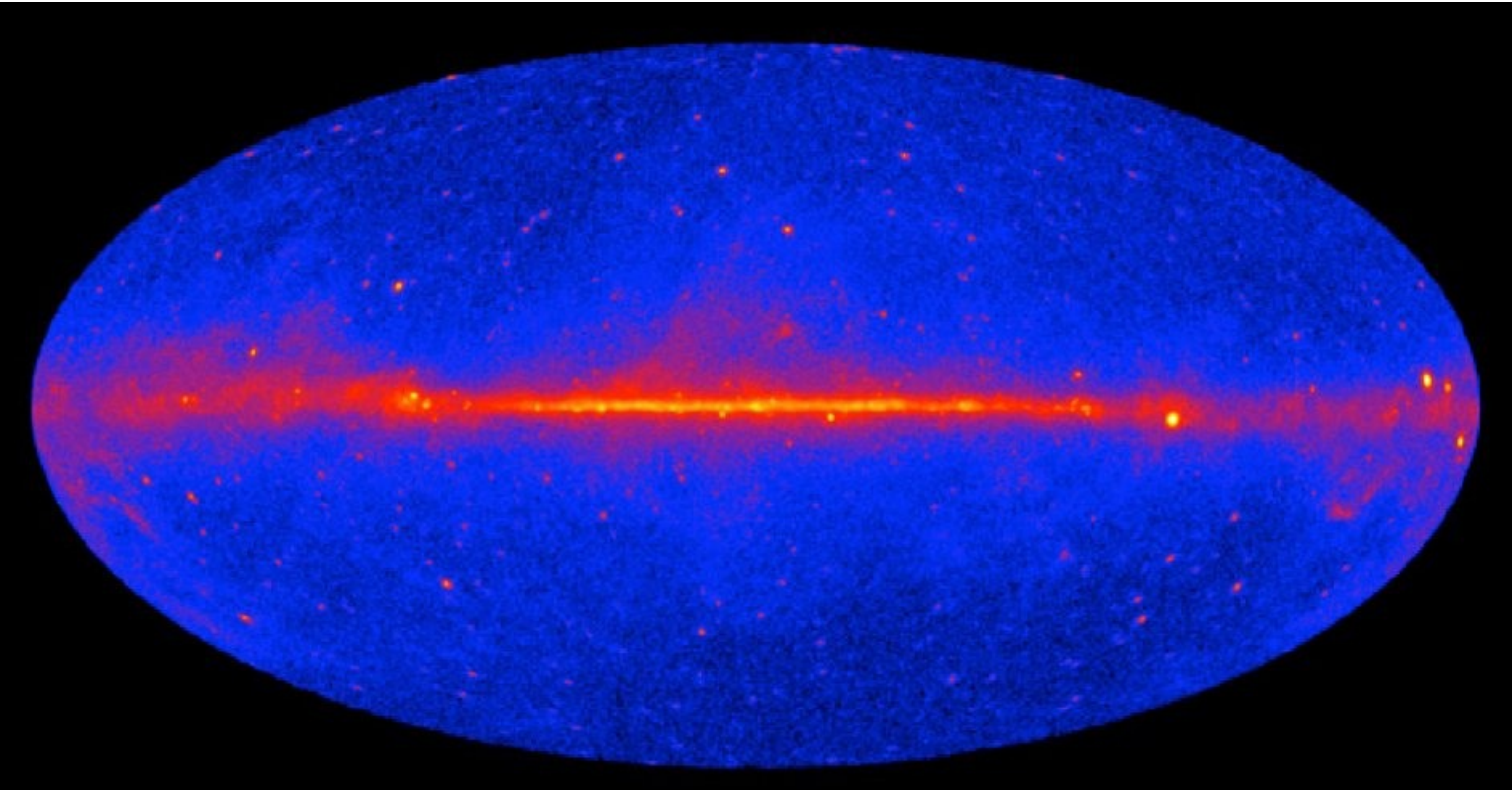
Infrared (10^{-2} eV)



visible (eV)

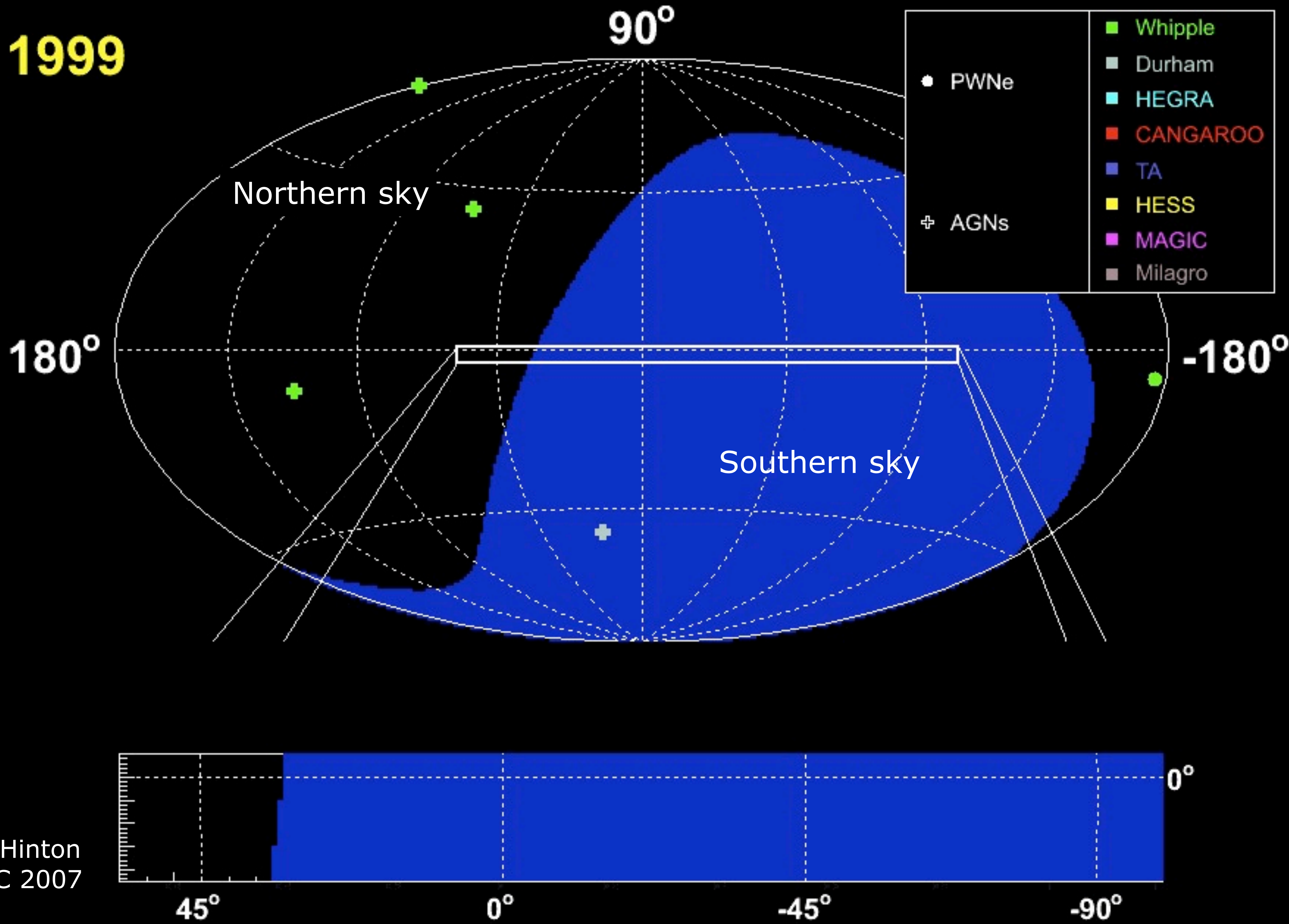


X-ray (keV)



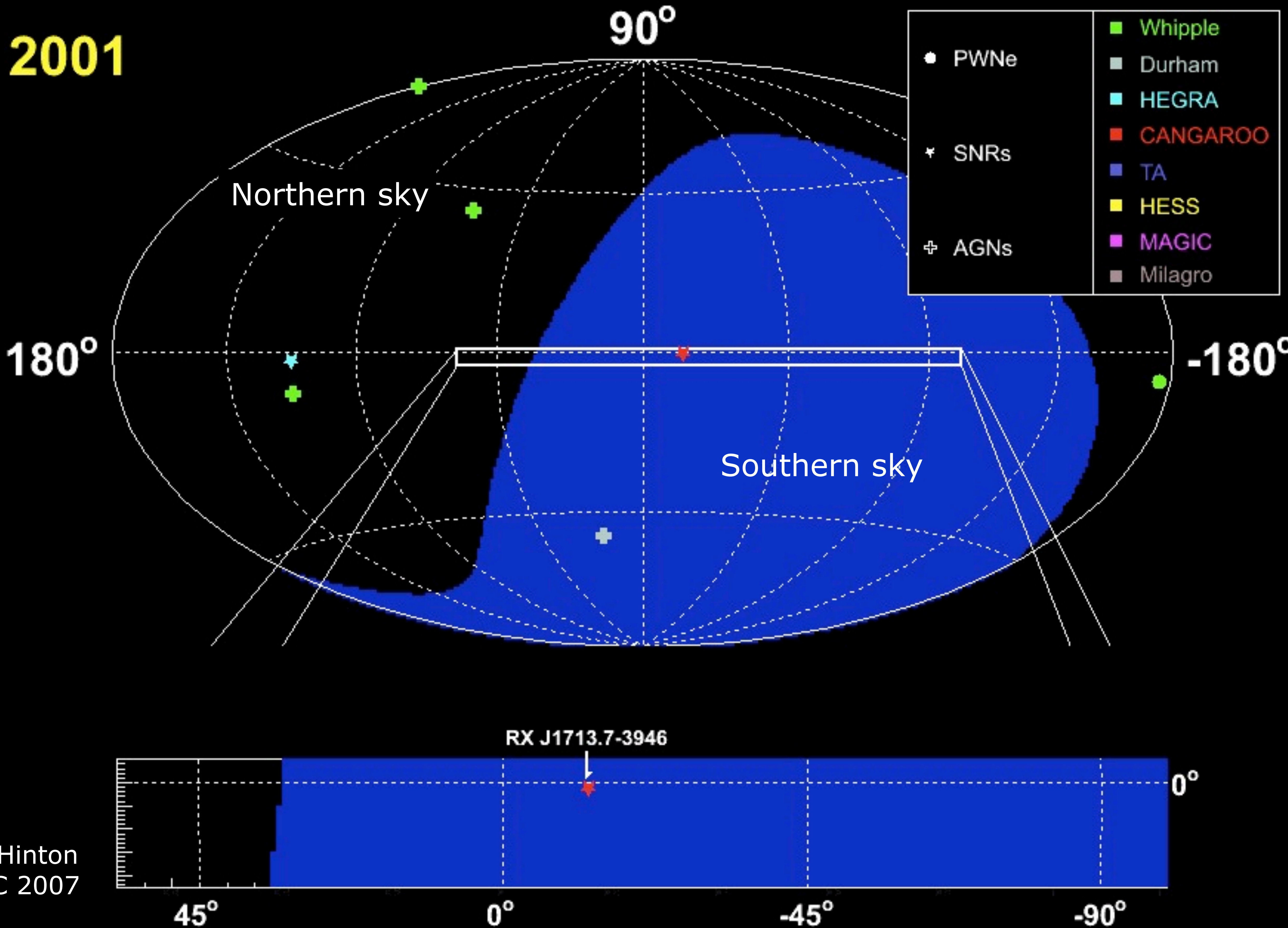
gamma rays (GeV)

VHE gamma rays (TeV)



Jim Hinton
ICRC 2007

VHE gamma rays (TeV)



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ICRC 2007

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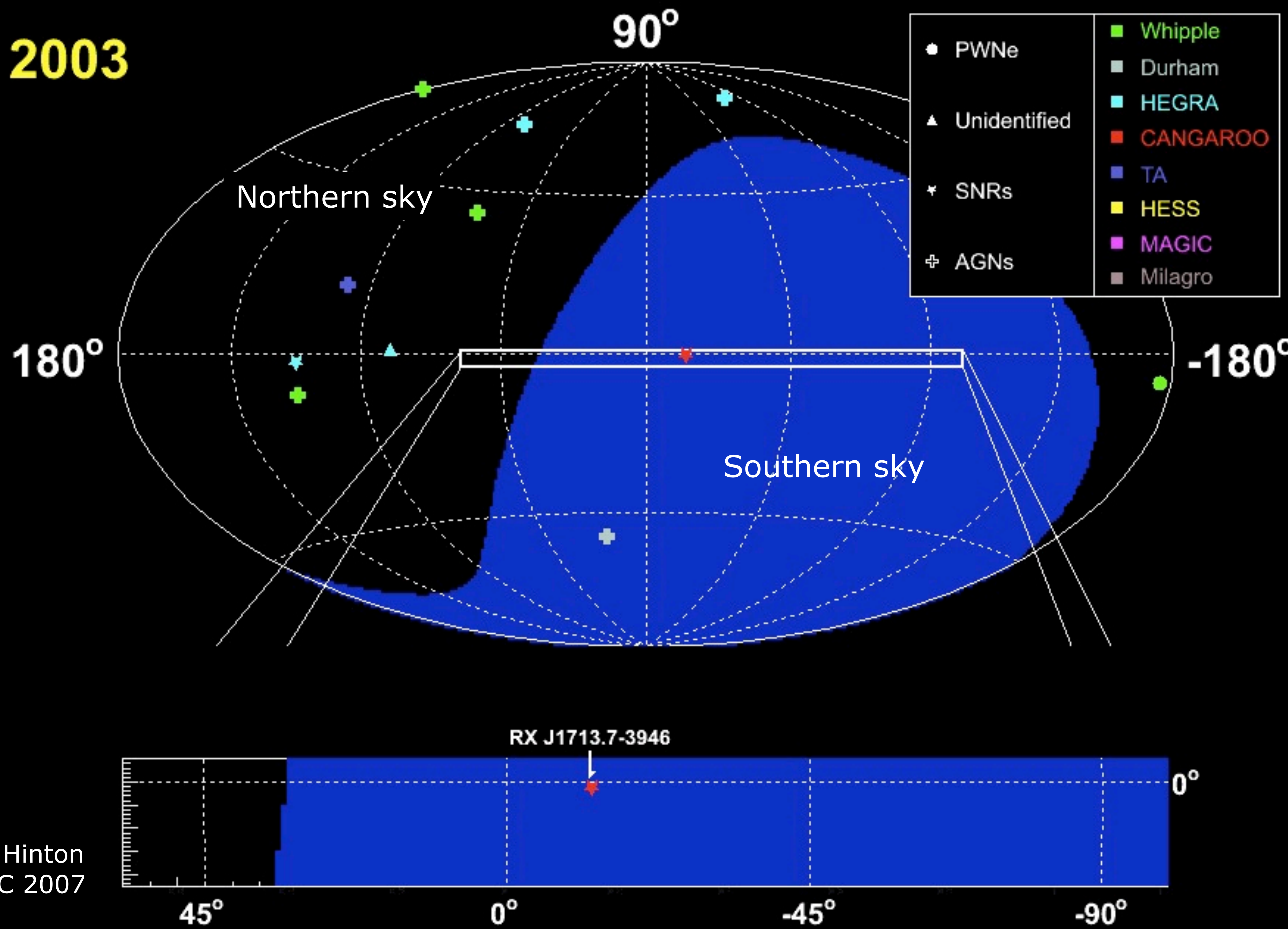

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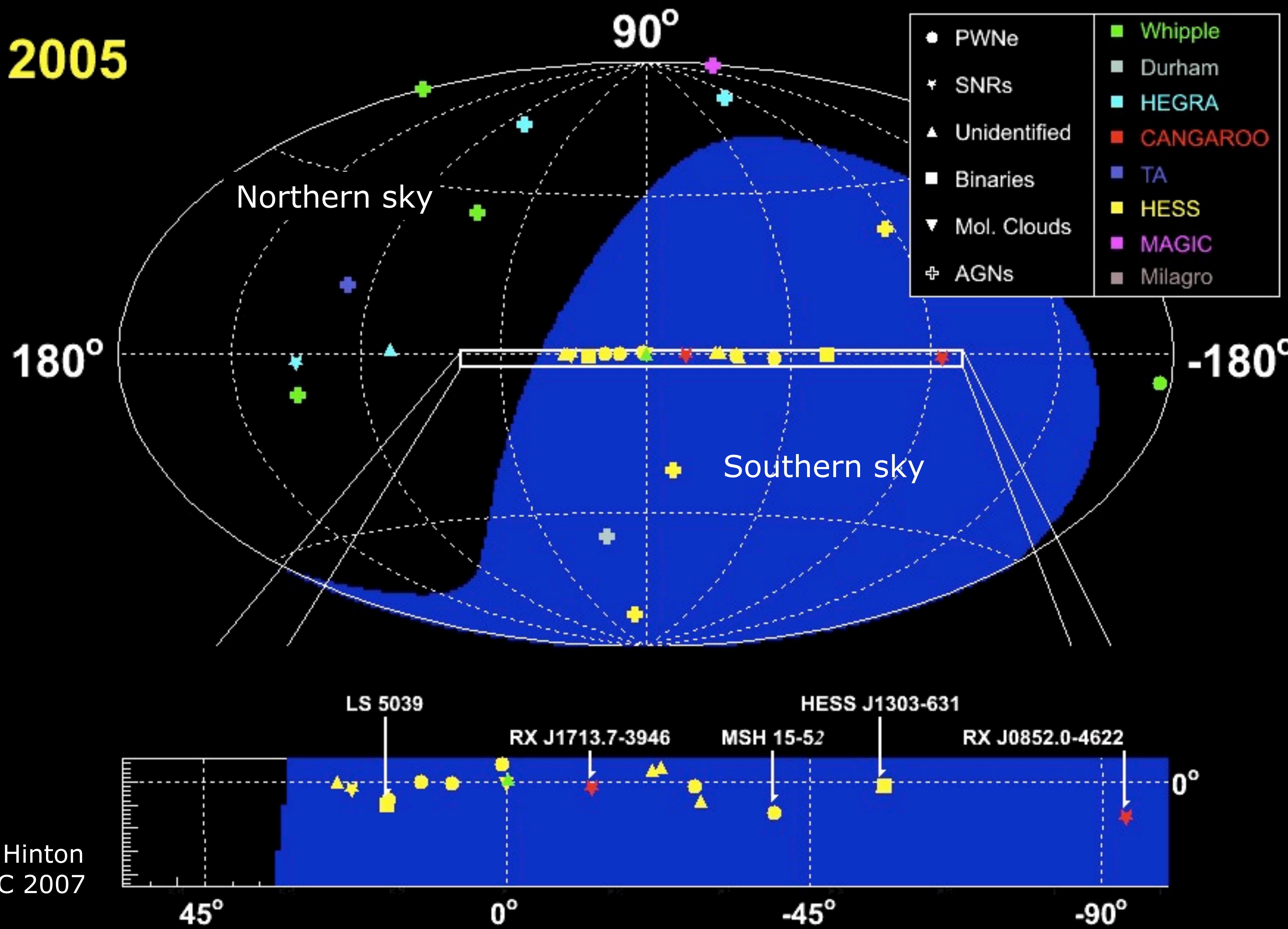
ICRC 2007

VHE gamma rays (TeV)



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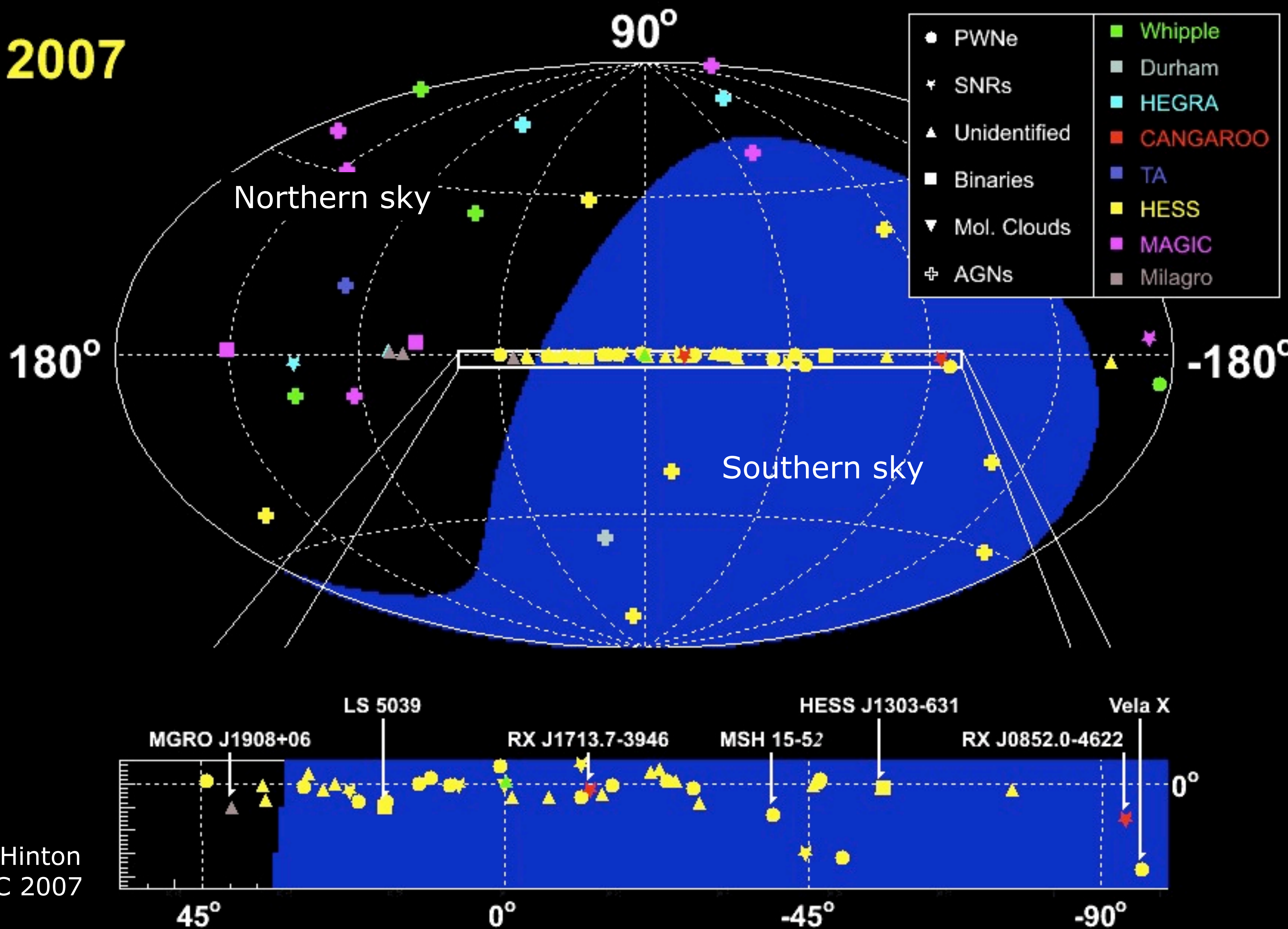
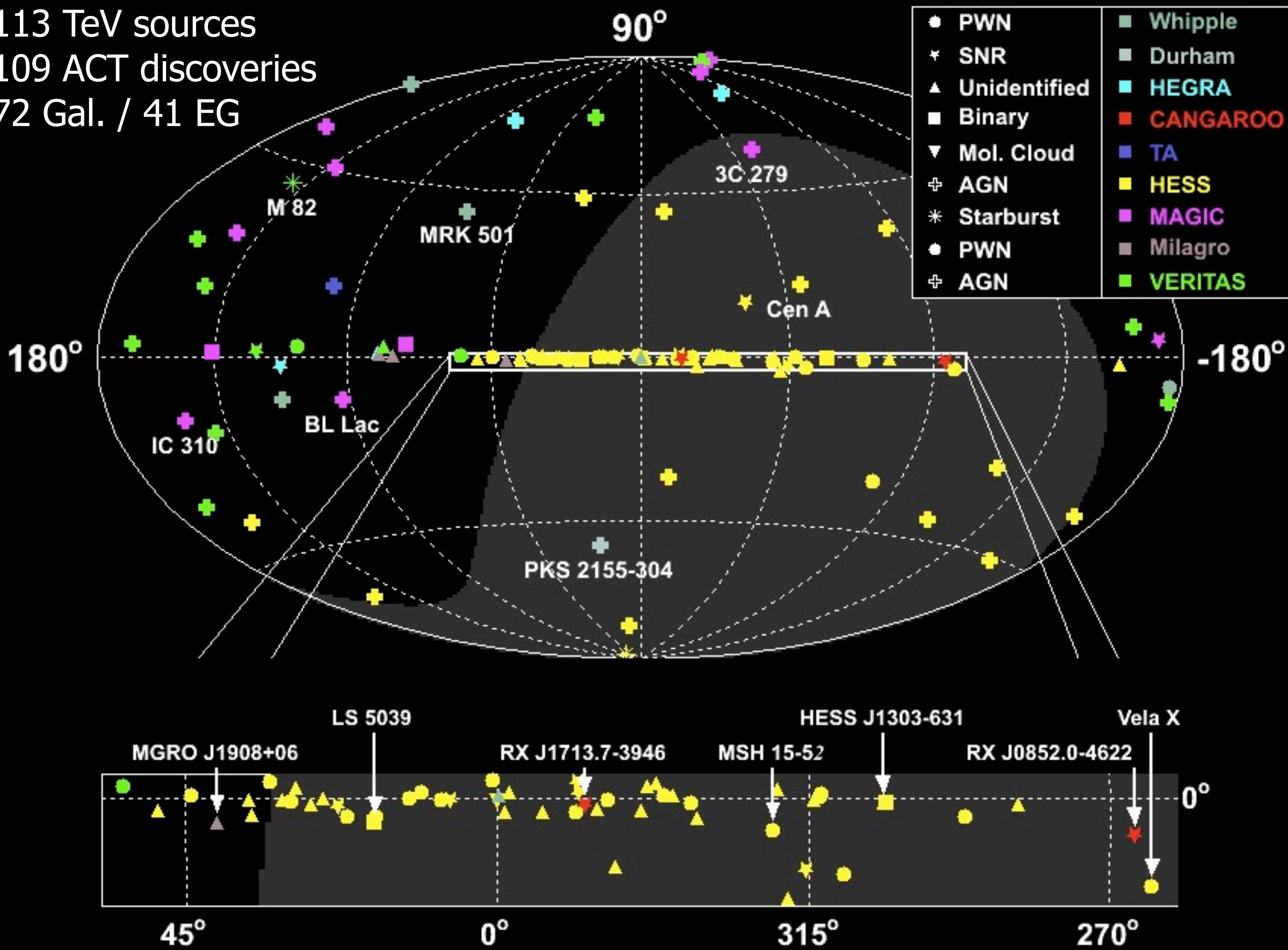
ICRC 2007

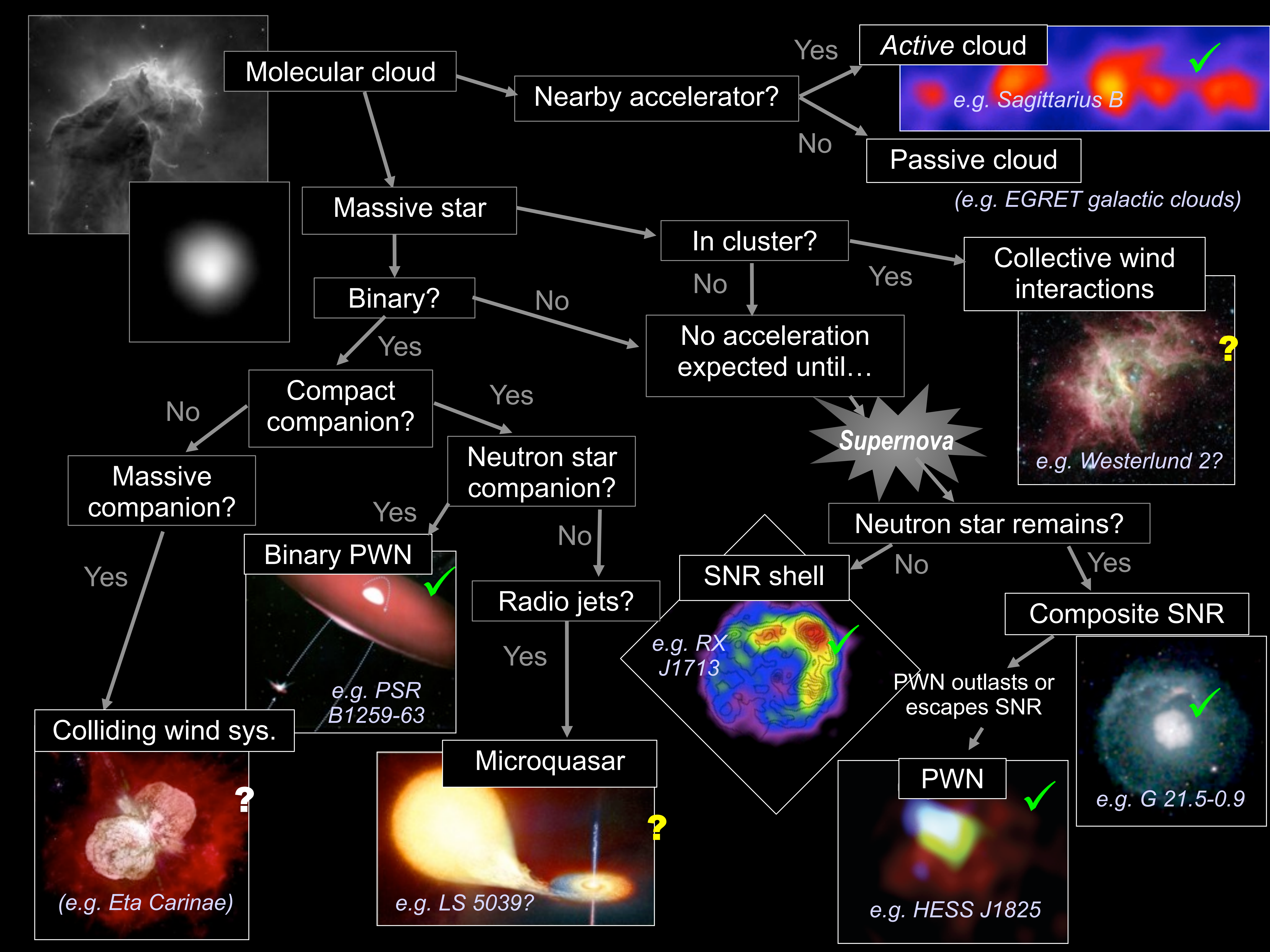
VHE gamma rays (TeV)



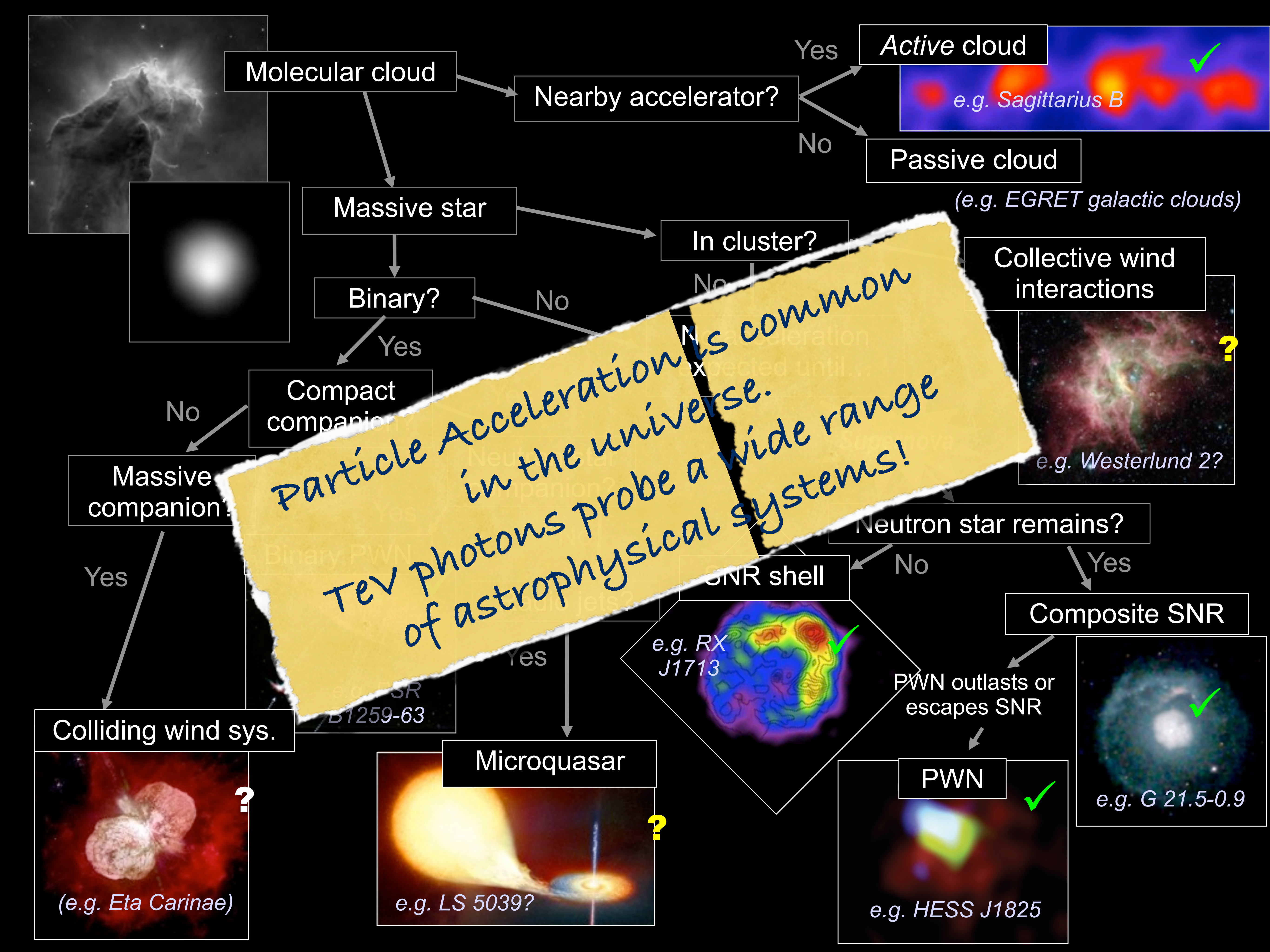
Jim Hinton
ICRC 2007

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





Molecular cloud
Nearby accelerator?
Yes
Active cloud
e.g. Sagittarius B
No
Passive cloud
(e.g. EGRET galactic clouds)
Massive star
In cluster?
Yes
Collective wind interactions
e.g. Westerlund 2?
?
No
No acceleration expected until…
Supernova
Binary?
No
Yes
Compact companion?
Yes
No
Massive companion?
Yes
Colliding wind sys.
(e.g. Eta Carinae)
?
Neutron star companion?
Yes
Binary PWN
e.g. PSR B1259-63
No
Radio jets?
Yes
Microquasar
e.g. LS 5039?
?
Neutron star remains?
No
SNR shell
e.g. RX J1713
Yes
Composite SNR
e.g. G 21.5-0.9
PWN outlasts or escapes SNR
PWN
e.g. HESS J1825



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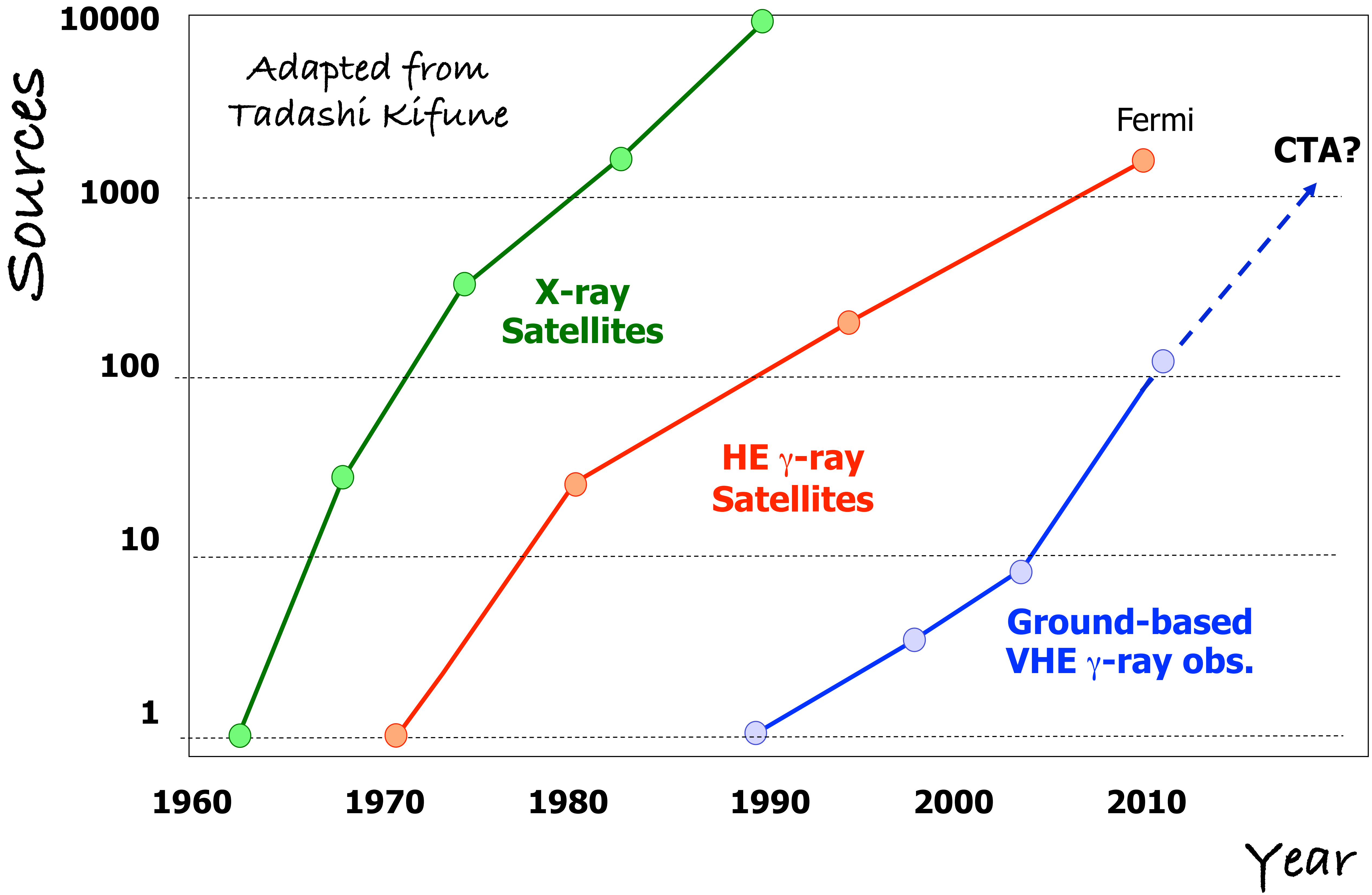
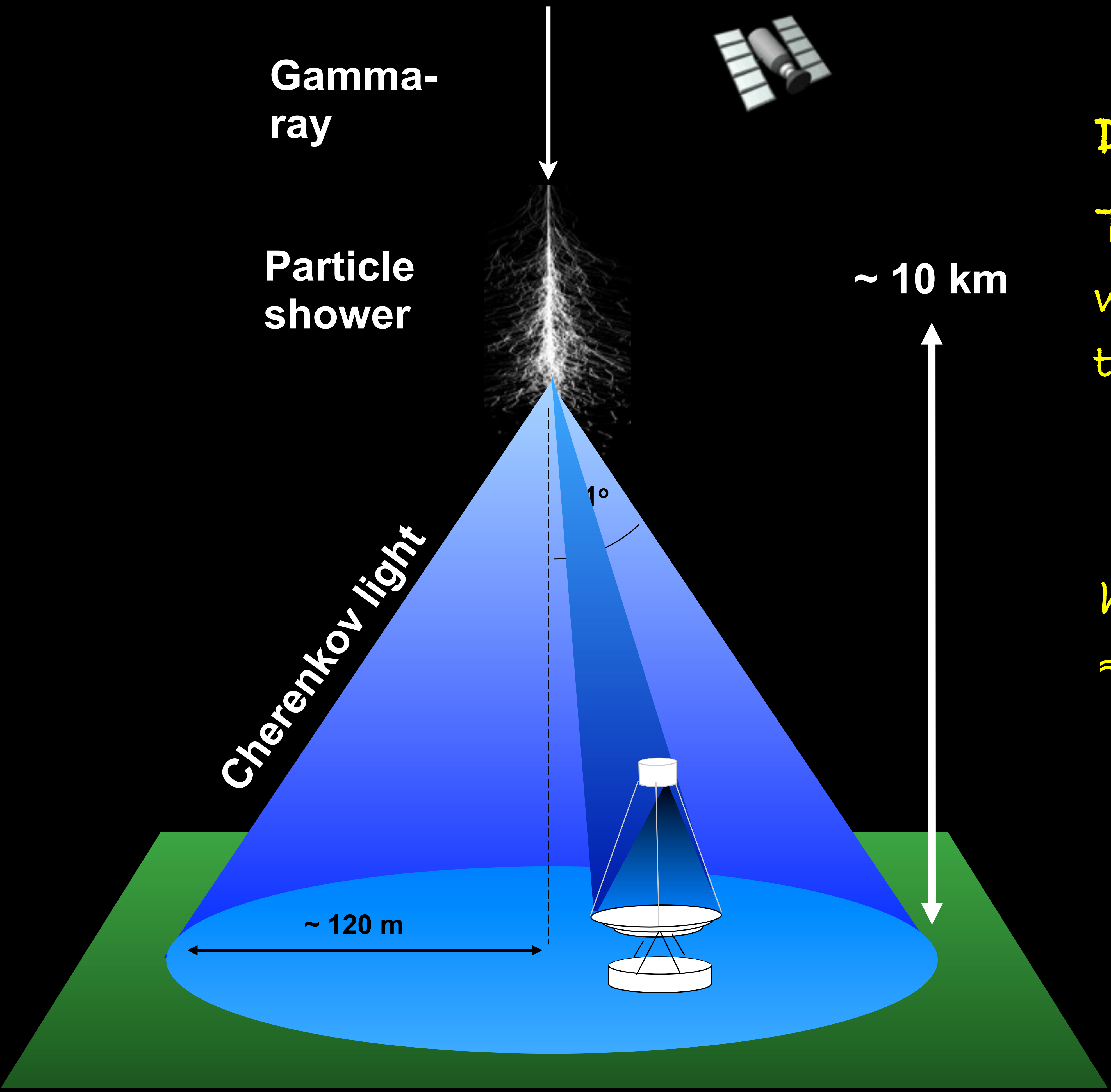
PWN
e.g. HESS J1825
e.g. G 21.5-0.9
Particle Acceleration is common in the universe.
TeV photons probe a wide range of astrophysical systems!

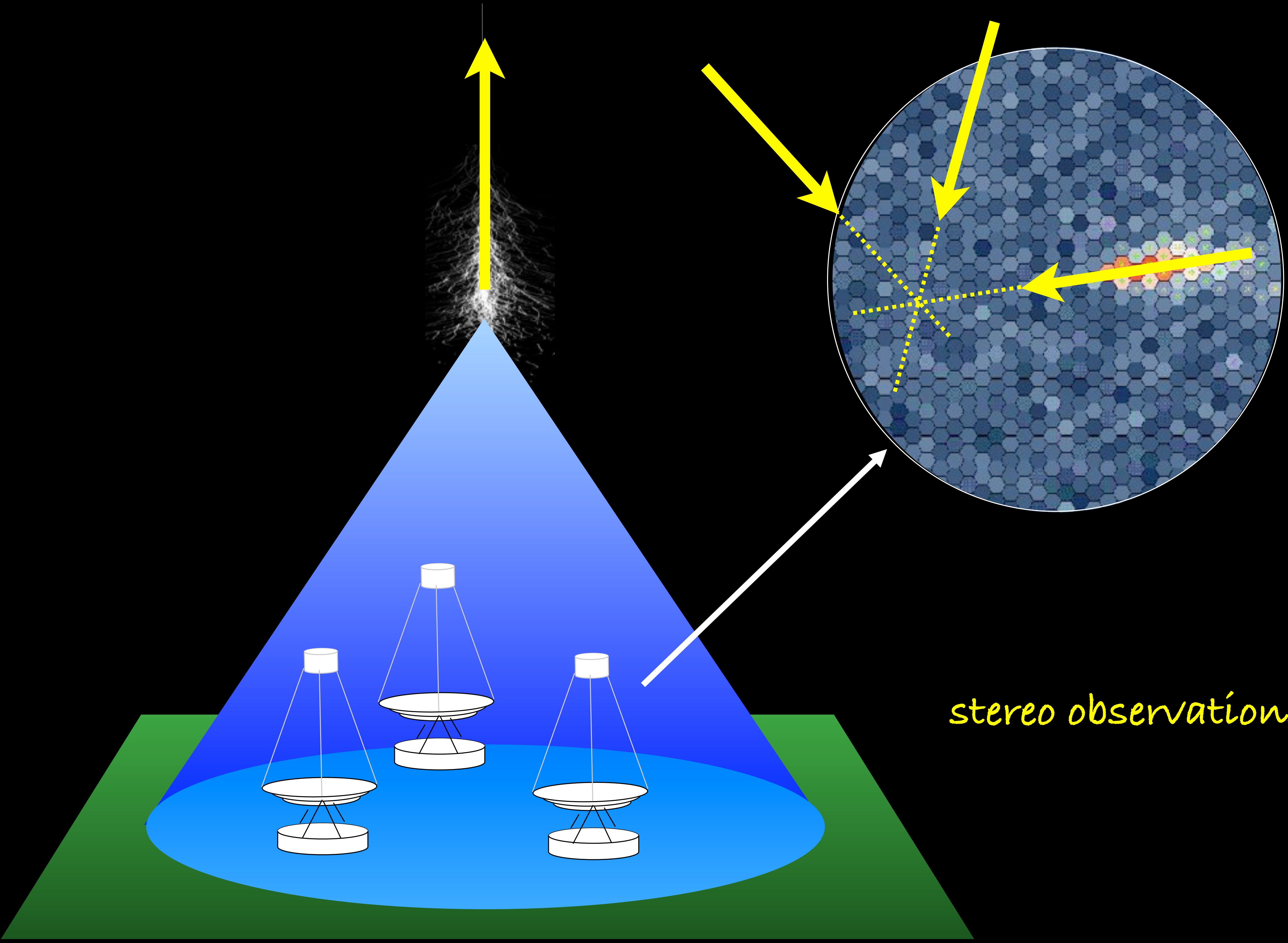
Source Numbers





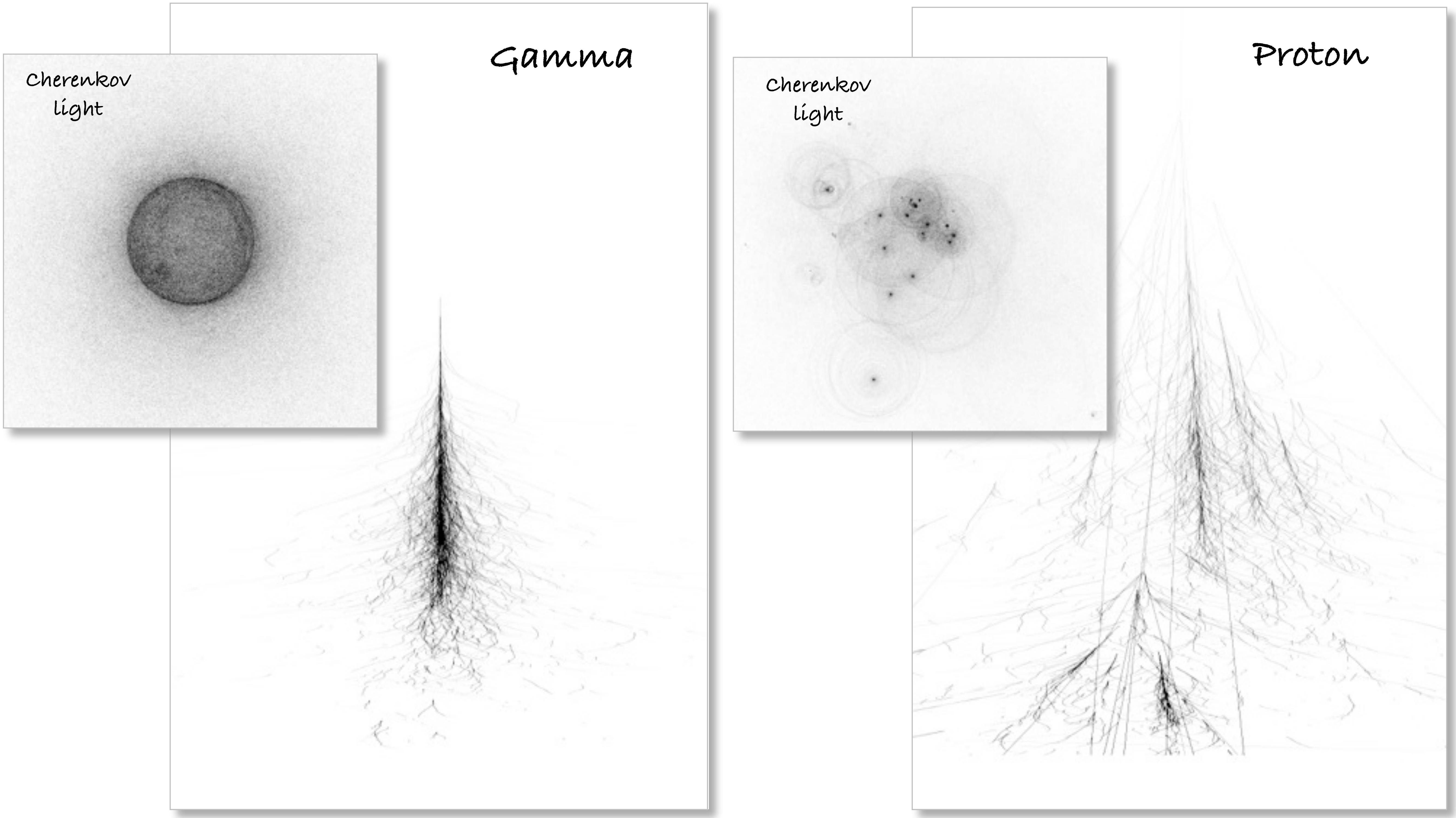
Detection of
TeV γ rays
with Cherenkov
telescopes

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

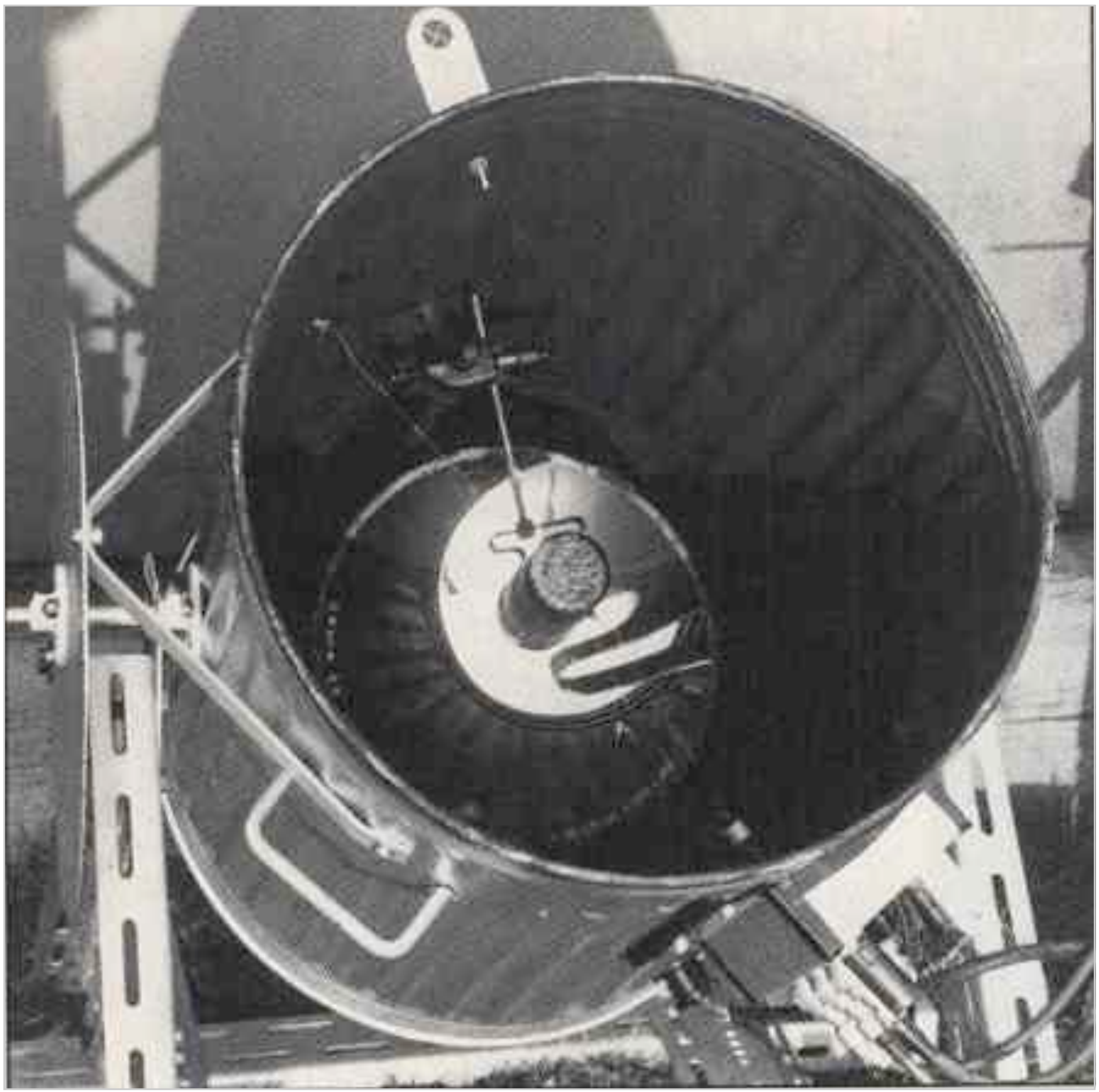


stereo observations

γ rays and Cosmic Ray background



The Early Days



February 21, 1953 NATURE

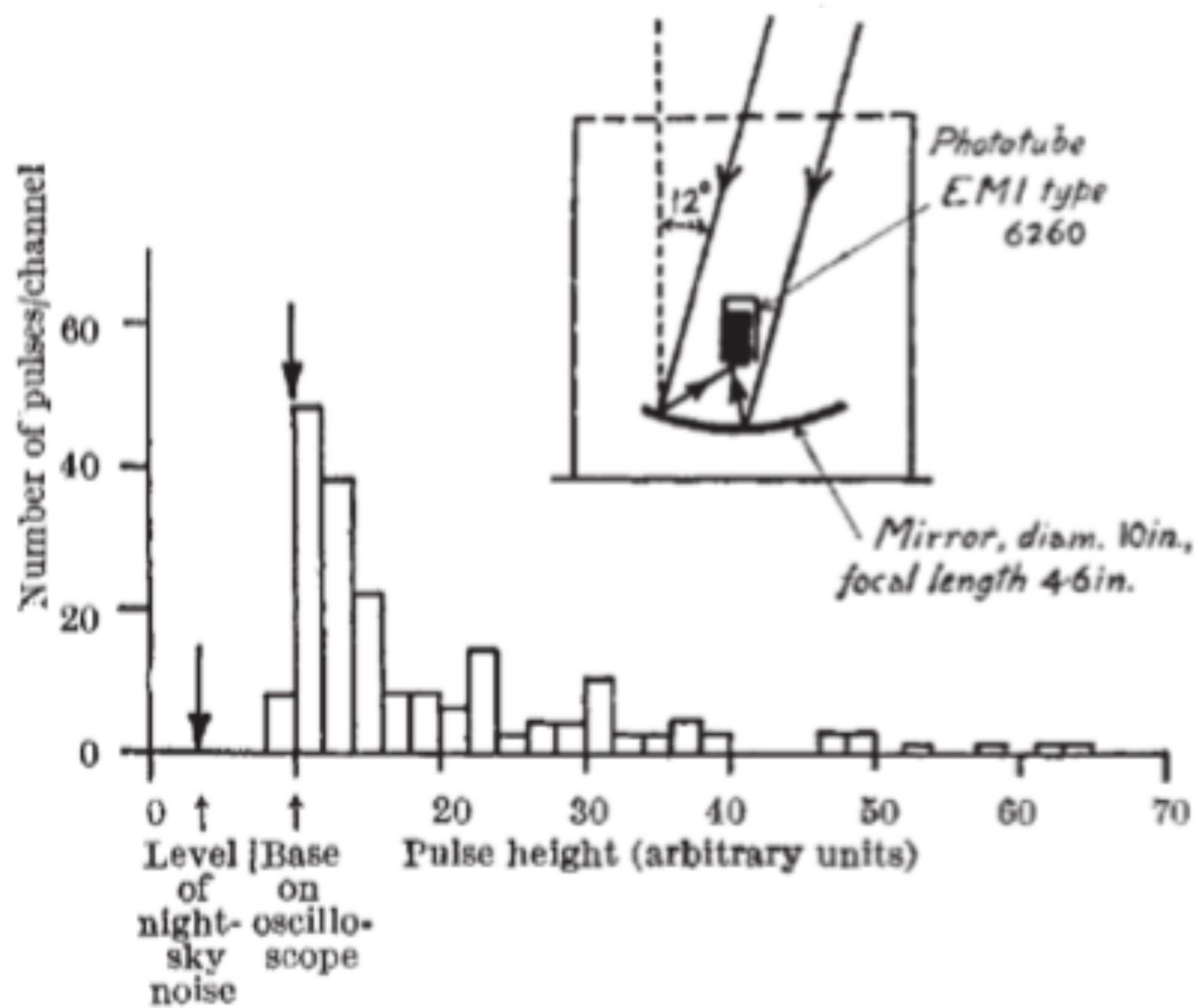
Light Pulses from the Night Sky associated with Cosmic Rays

In 1948, Blackett[1] suggested that a contribution approximately 10^{-4} of the mean light of the night-sky might be expected from Čerenkov radiation[2] produced in the atmosphere by the cosmic radiation. The purpose of this communication is to report the results of some preliminary experiments we have made using a photomultiplier, which revealed the

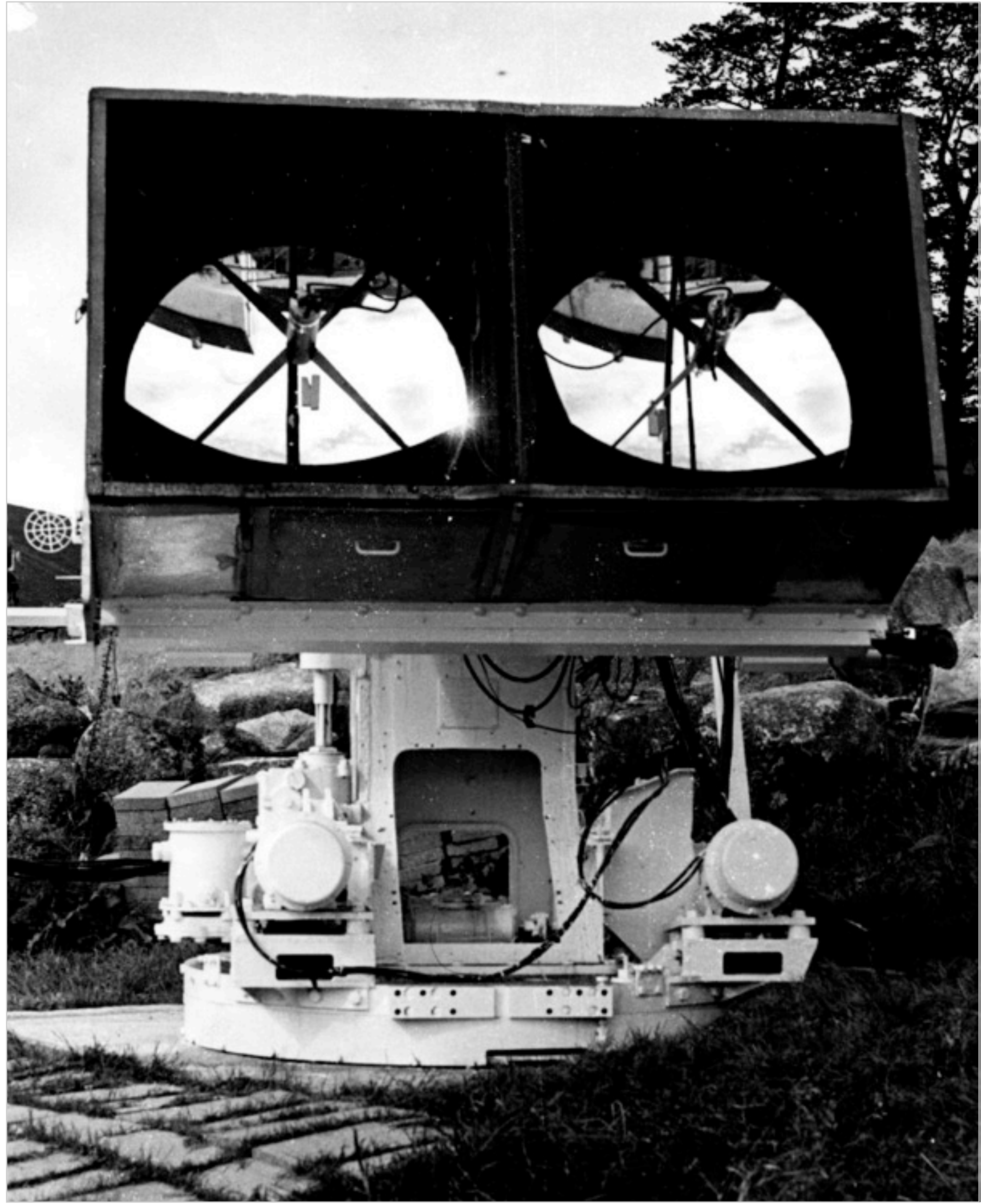
....

thank Mr. W. J. Whitehouse and Dr. E. Bretscher for their encouragement, and Dr. T. E. Cranshaw for the use of the extensive shower array.

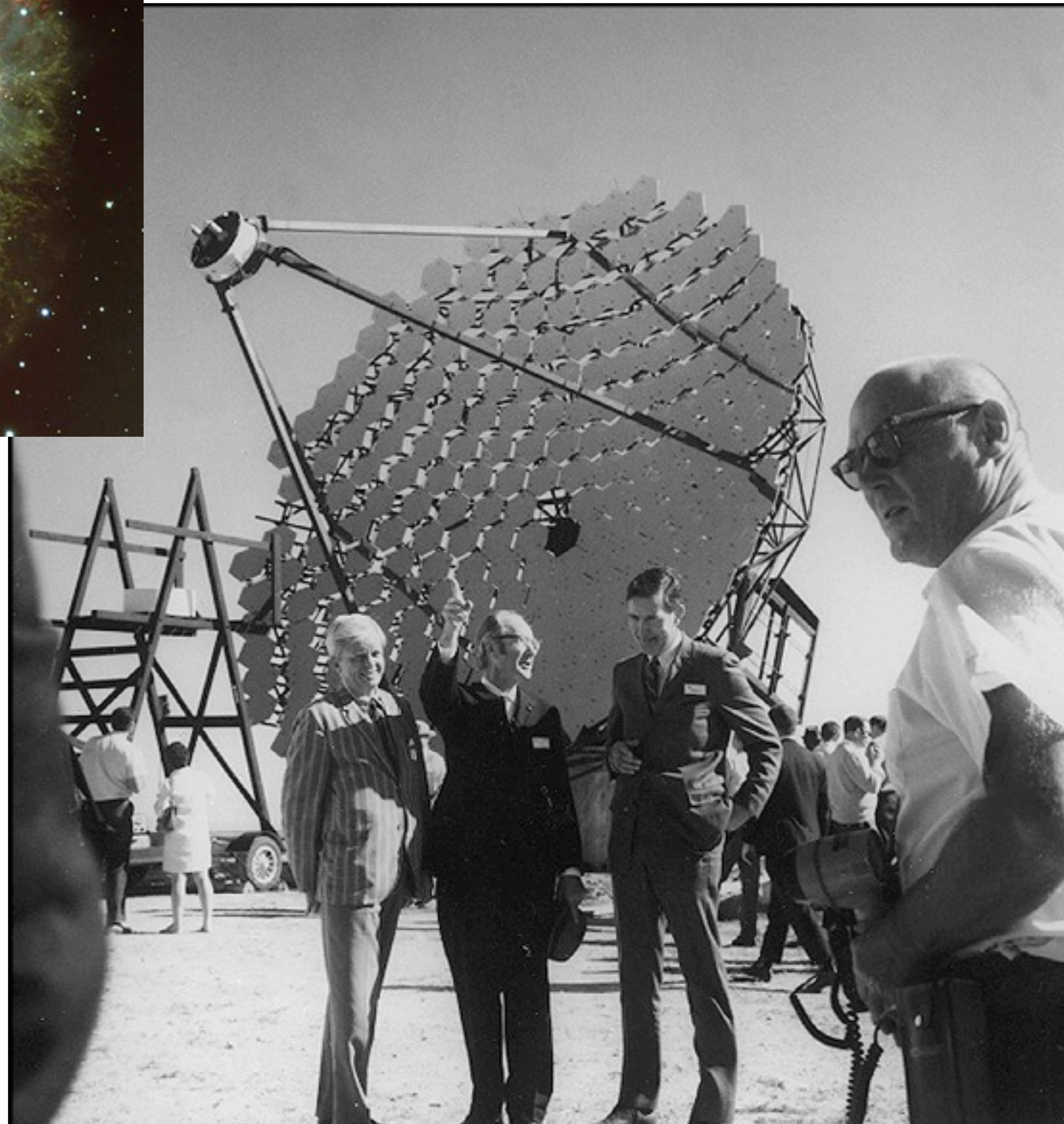
W. Galbraith
J. V. Jelley



Porter & Jelley
1962



10 m Whipple Telescope



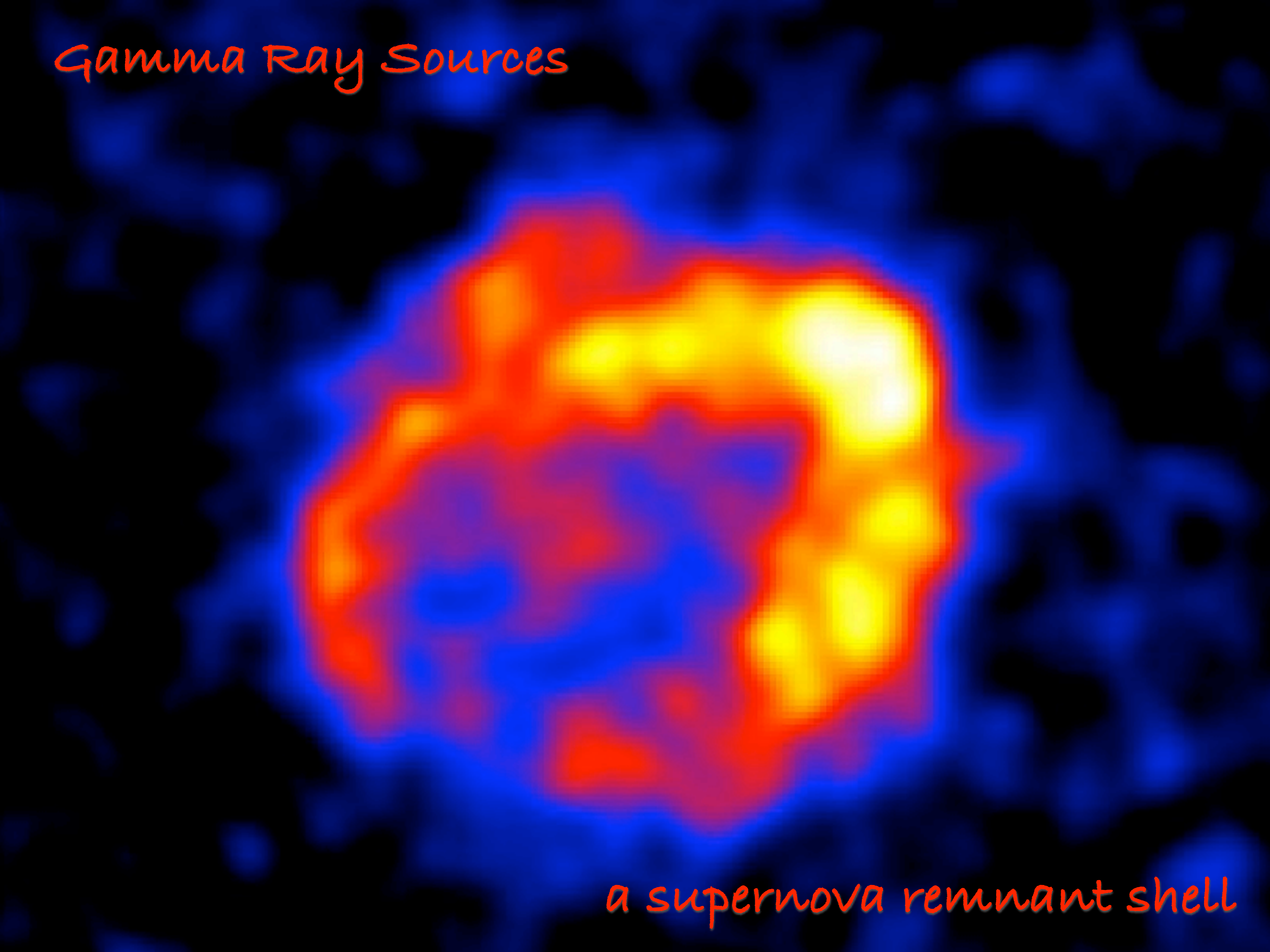
1989: Detection of the Crab Nebula

5σ signal in 50 h,
with 159 pixel camera and Hillas image analysis.


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

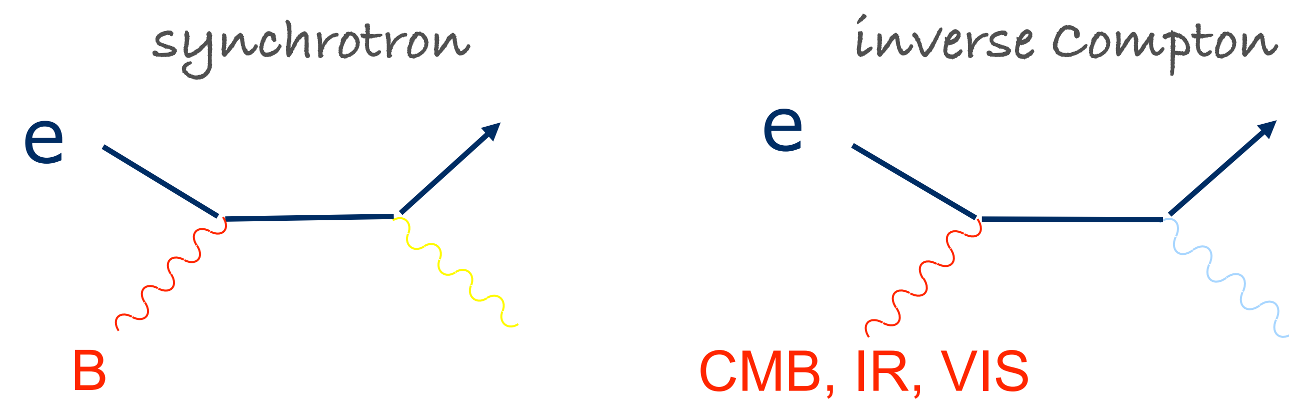

Current IACTs
VERITAS
Whipple
MAGIC
TACTIC
HESS
CANGAROO-III

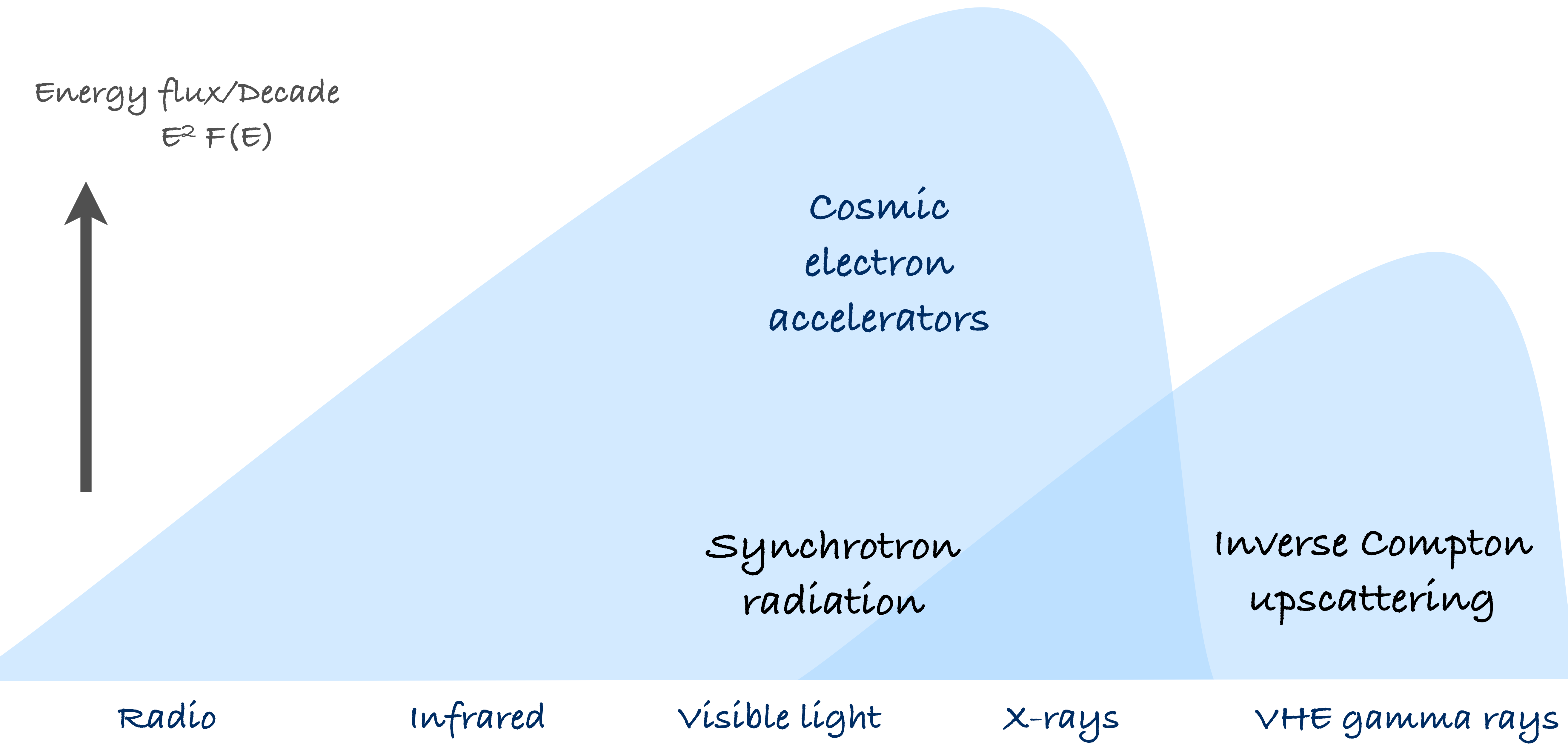
Gamma Ray Sources



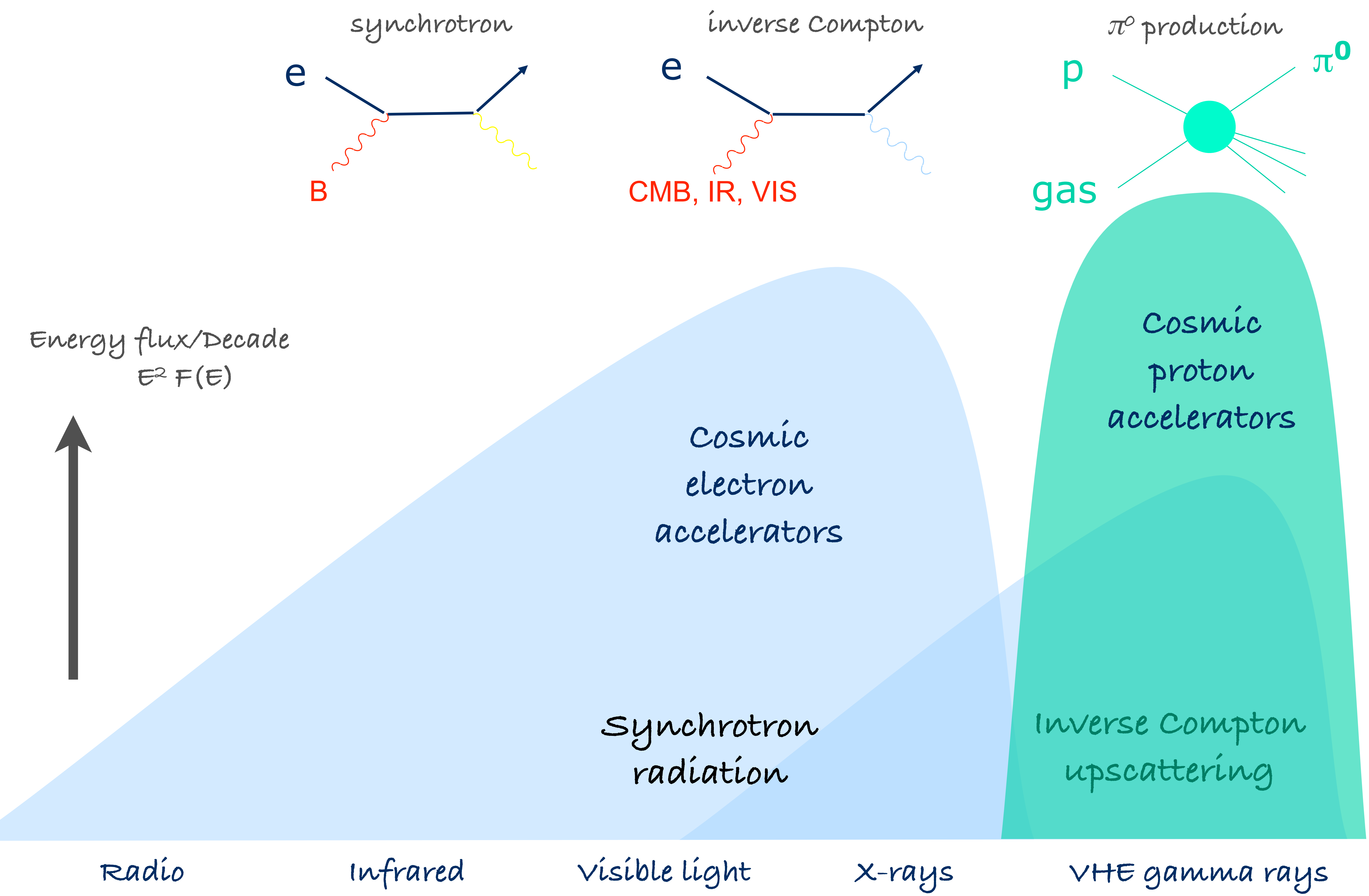
a supernova remnant shell

From particles to radiation





From particles to radiation



TeV Astronomy Highlights

Microquasars:	Science 309 (2005) 746
	Science 312 (2006) 1771
Pulsars:	Science 322 (2008) 1221
Supernova remnants:	Nature 432 (2004) 75
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:	Phys Rev Letters 96 (2006) 221102
Lorentz Invariance:	Phys Rev Letters 101 (2008) 170402
Cosmic Ray Electrons:	Phys Rev Letters (2009)

Results from HESS, MAGIC and VERITAS

How to do even better ?

A future 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

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

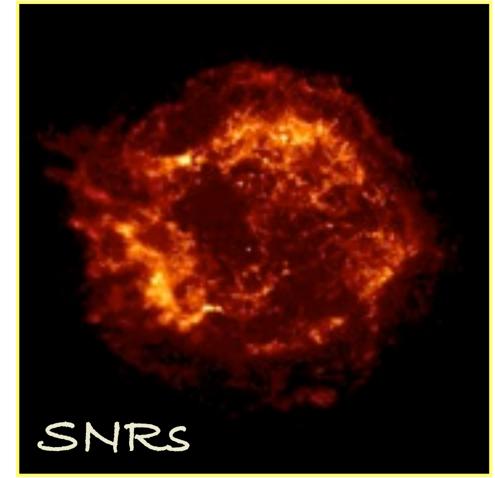
Dark Matter annihilation / decay

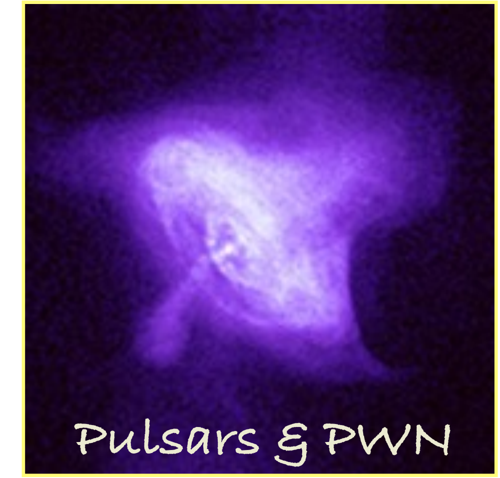
Lorentz Invariance violation

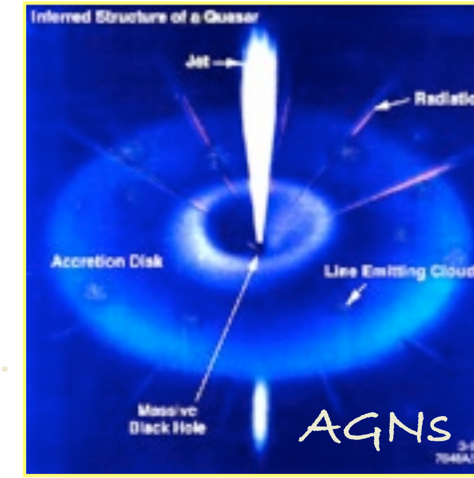
Cosmology

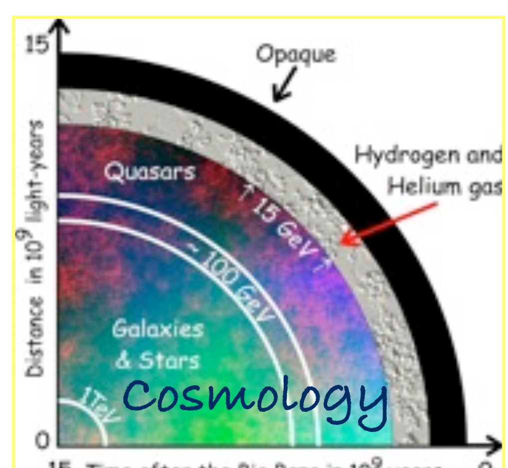
cosmic FIR-UV radiation,

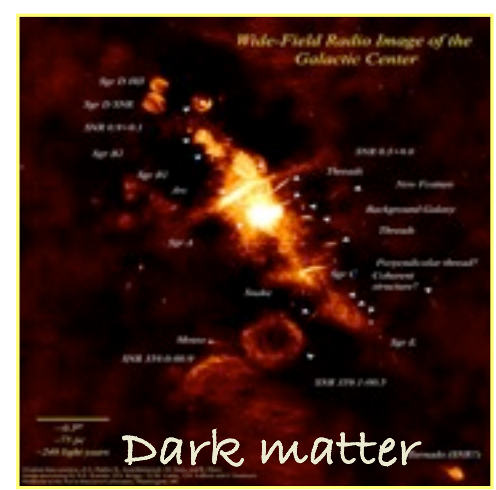
cosmic magnetism

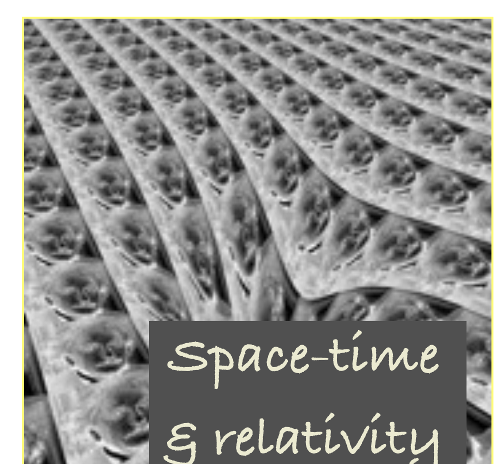












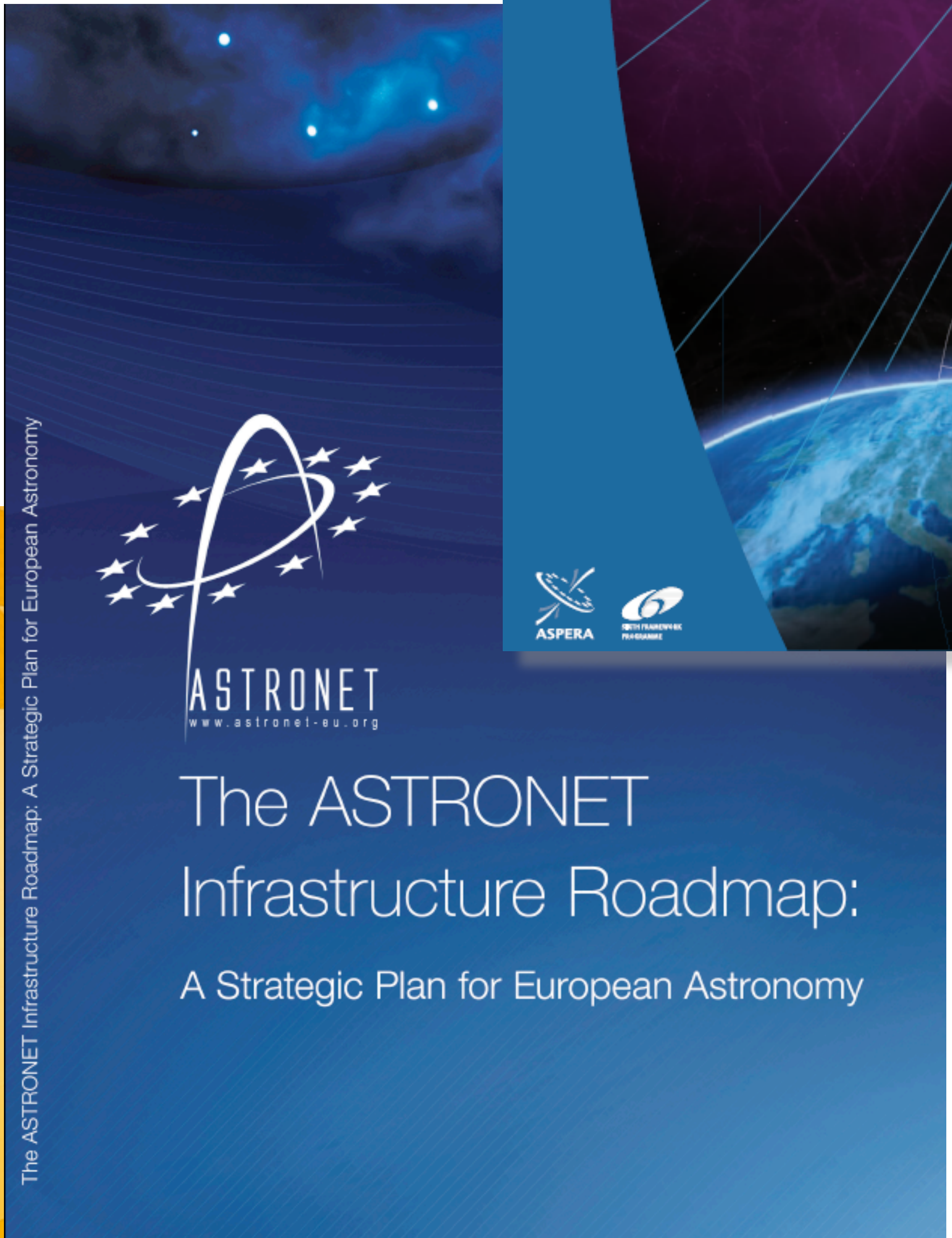
Wish list for CTA:

- Higher sensitivity at TeV energies (x 10)
  - more sources, details in extended sources
- Lower threshold (some 10 GeV)
  - pulsars, distant AGN, source mechanisms
- Higher energy reach (PeV and beyond)
  - cutoff region of Galactic accelerators
- Wider field of view
  - extended sources, surveys
- Improved angular resolution
  - structure of extended sources
- Higher detection rates
  - transient phenomena

Very Good reviews for CTA:

ASPERA:

ASTRONET:

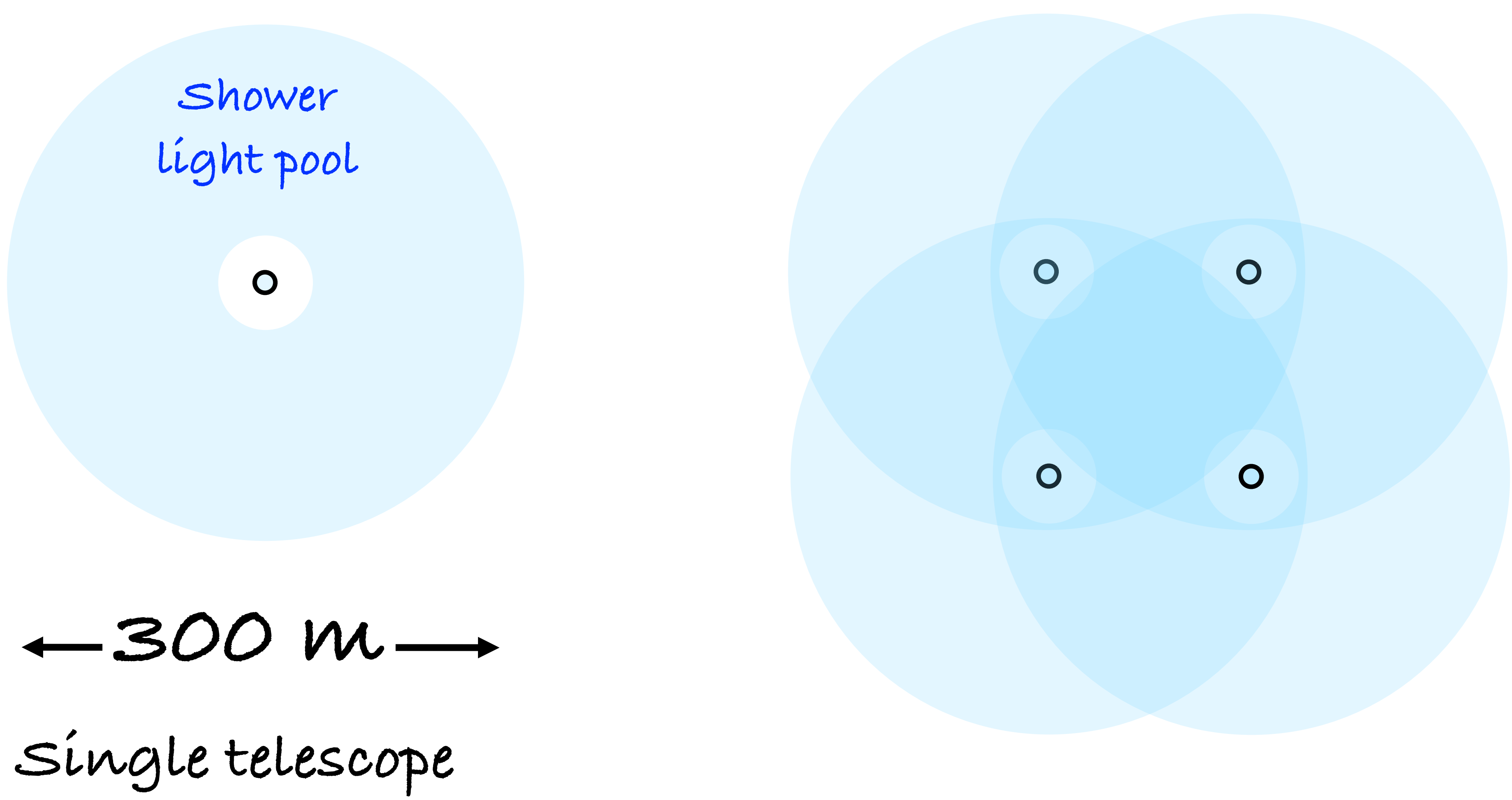


ESFRI:

Boosting sensitivity & resolution: Arrays of Cherenkov telescopes

Single telescope

Boosting sensitivity & resolution: Arrays of Cherenkov telescopes



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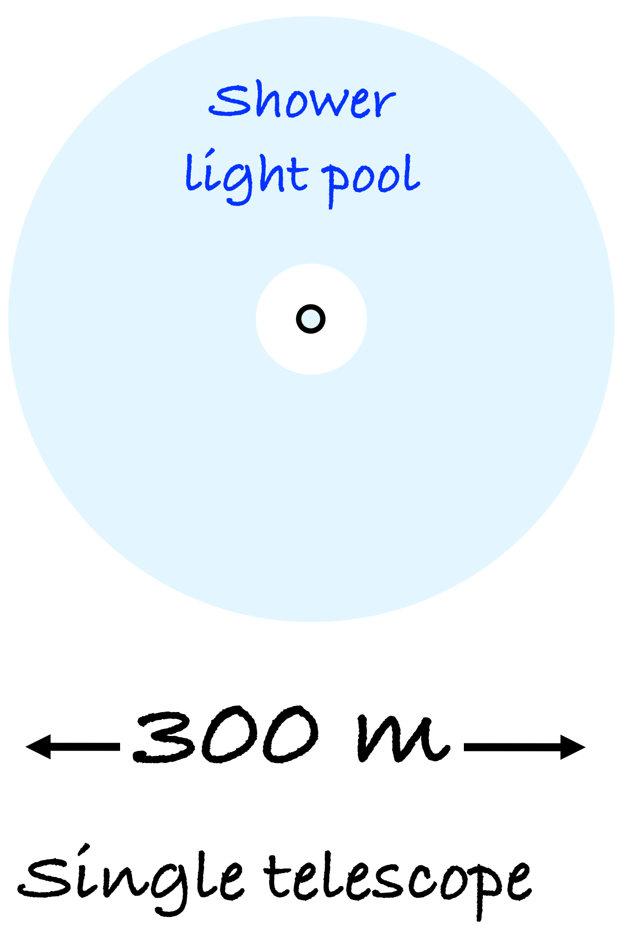
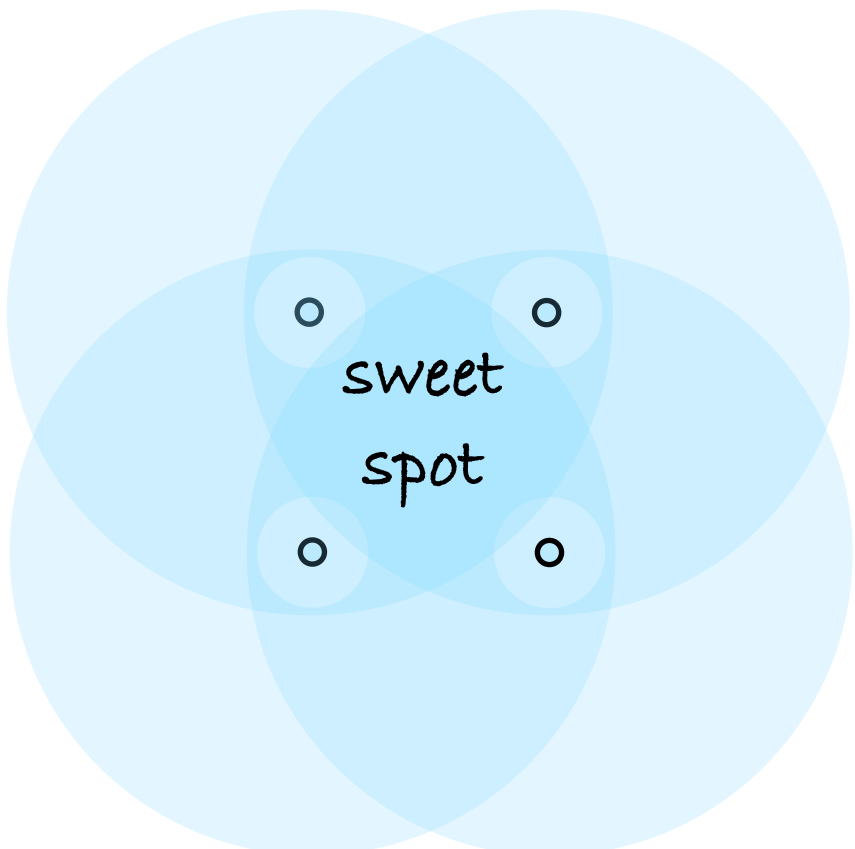
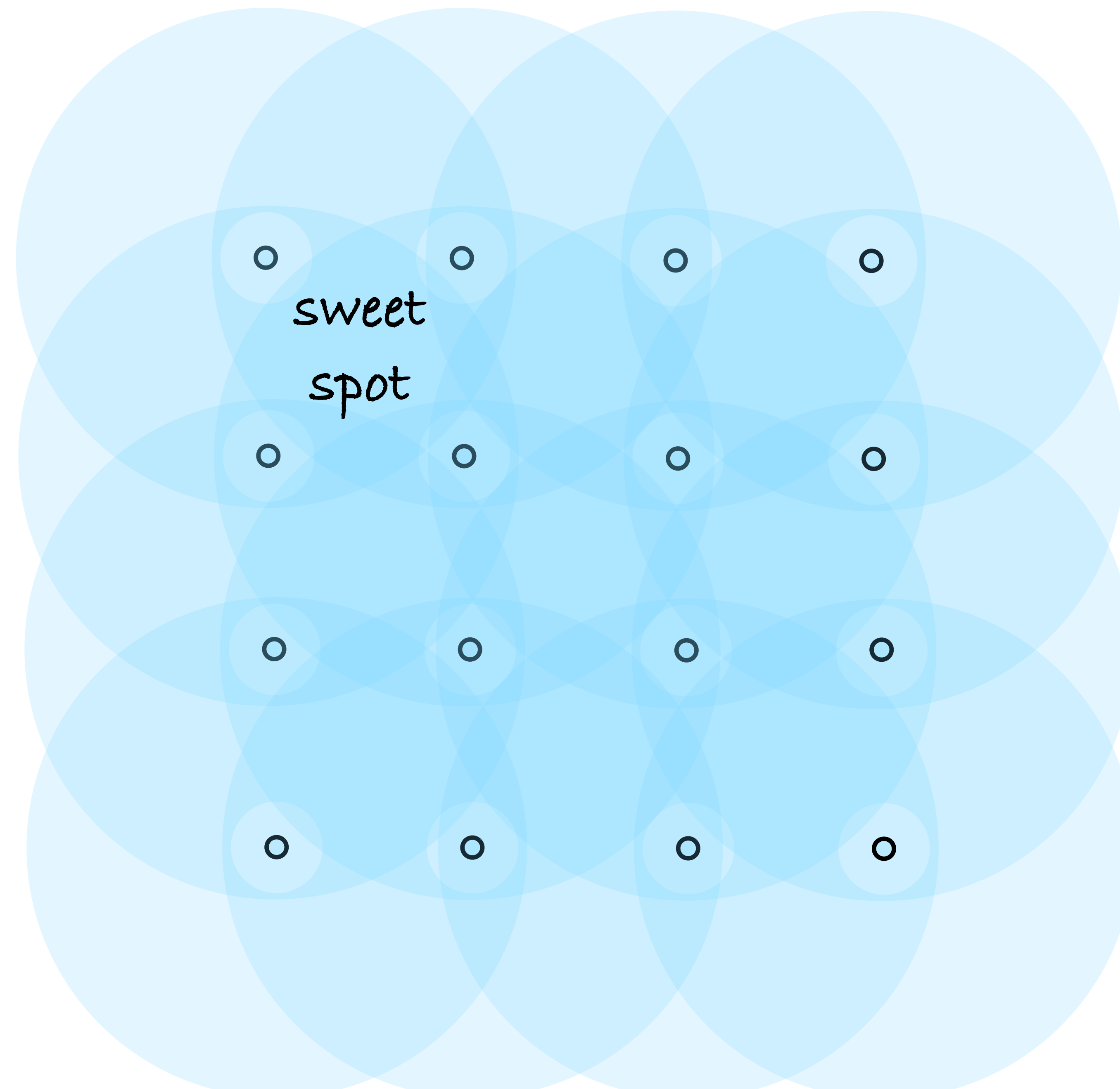




Boosting sensitivity & resolution:
Arrays of Cherenkov telescopes

Single telescope



Boosting sensitivity & resolution: Arrays of Cherenkov telescopes

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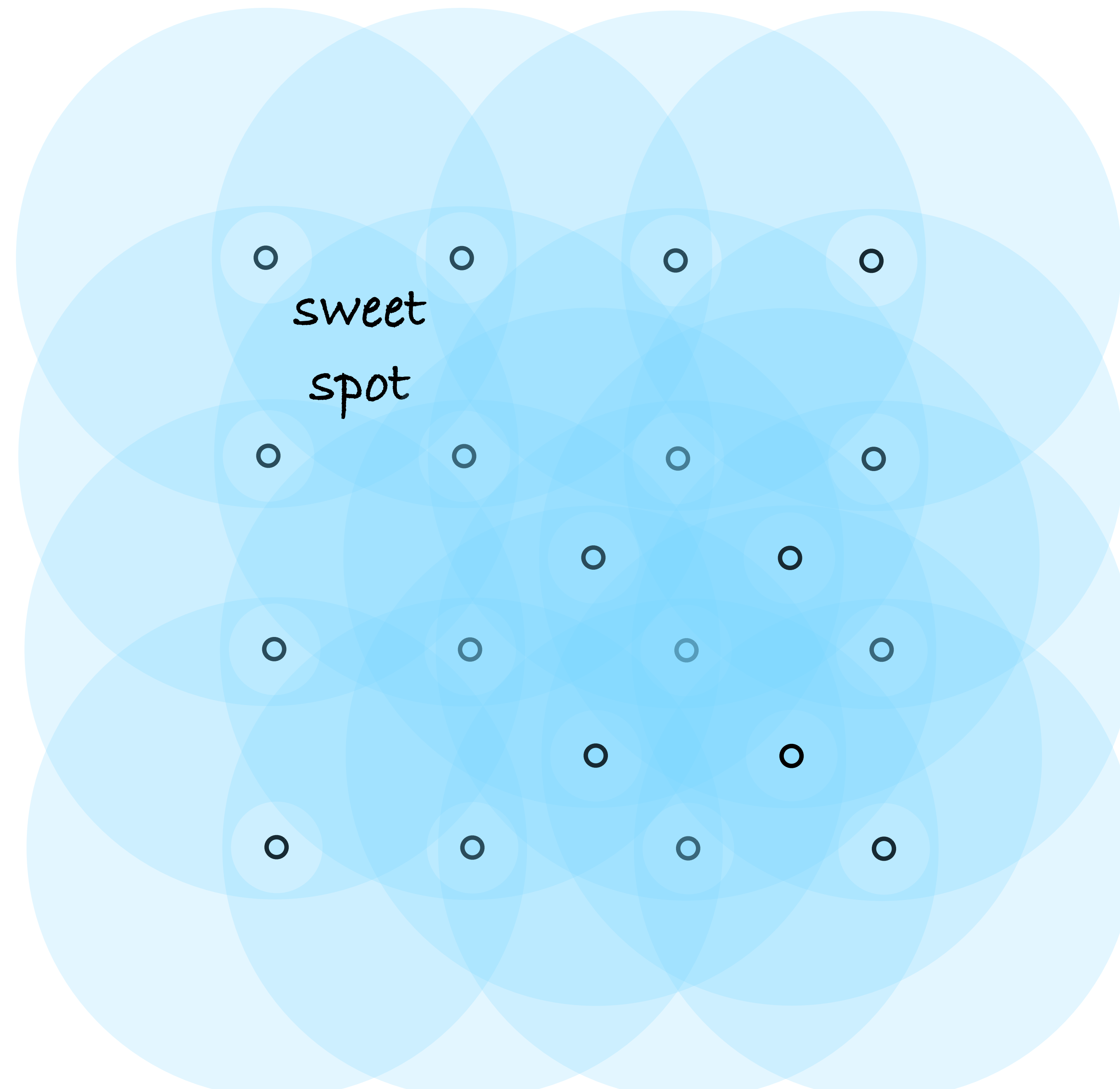
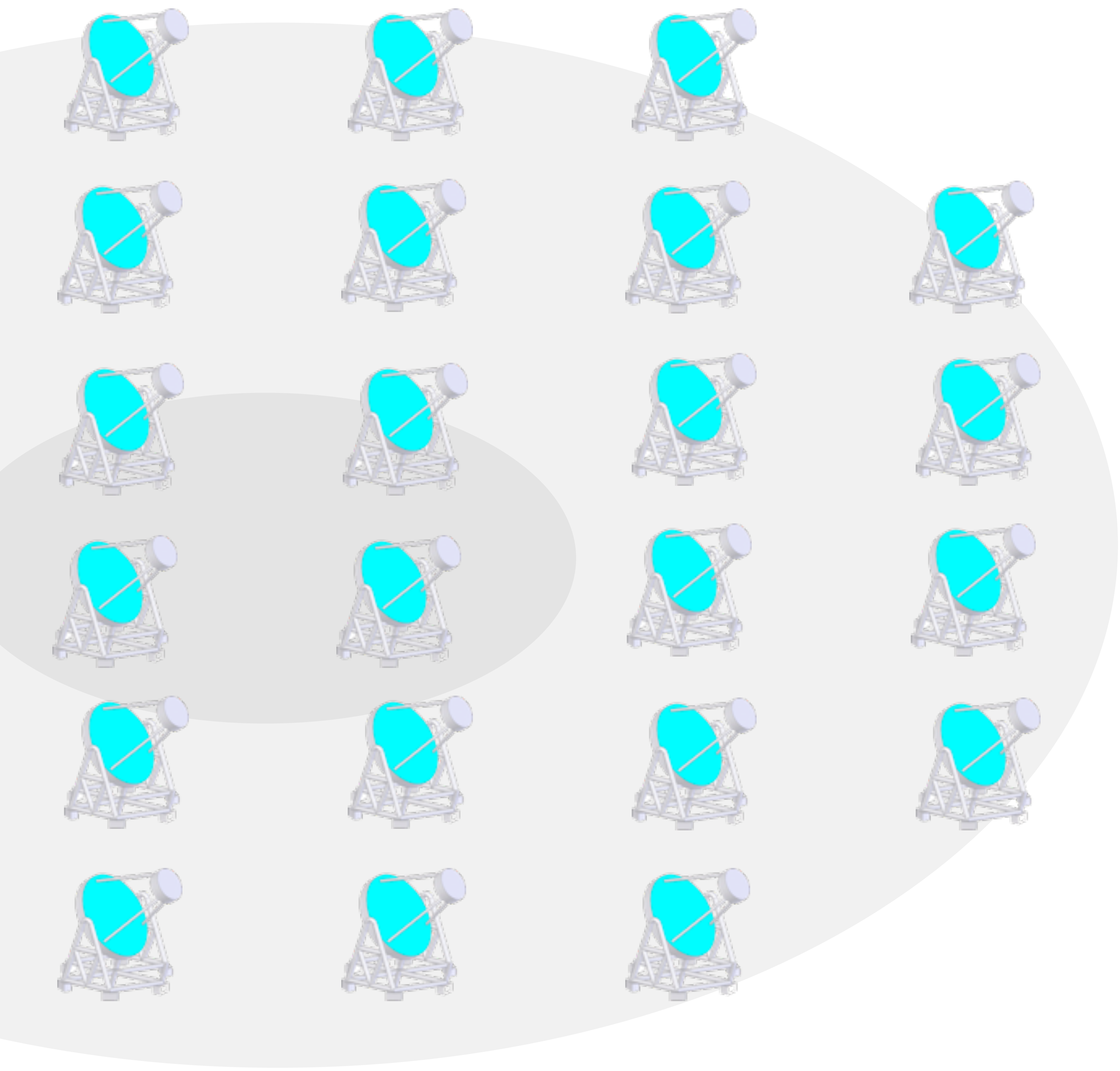




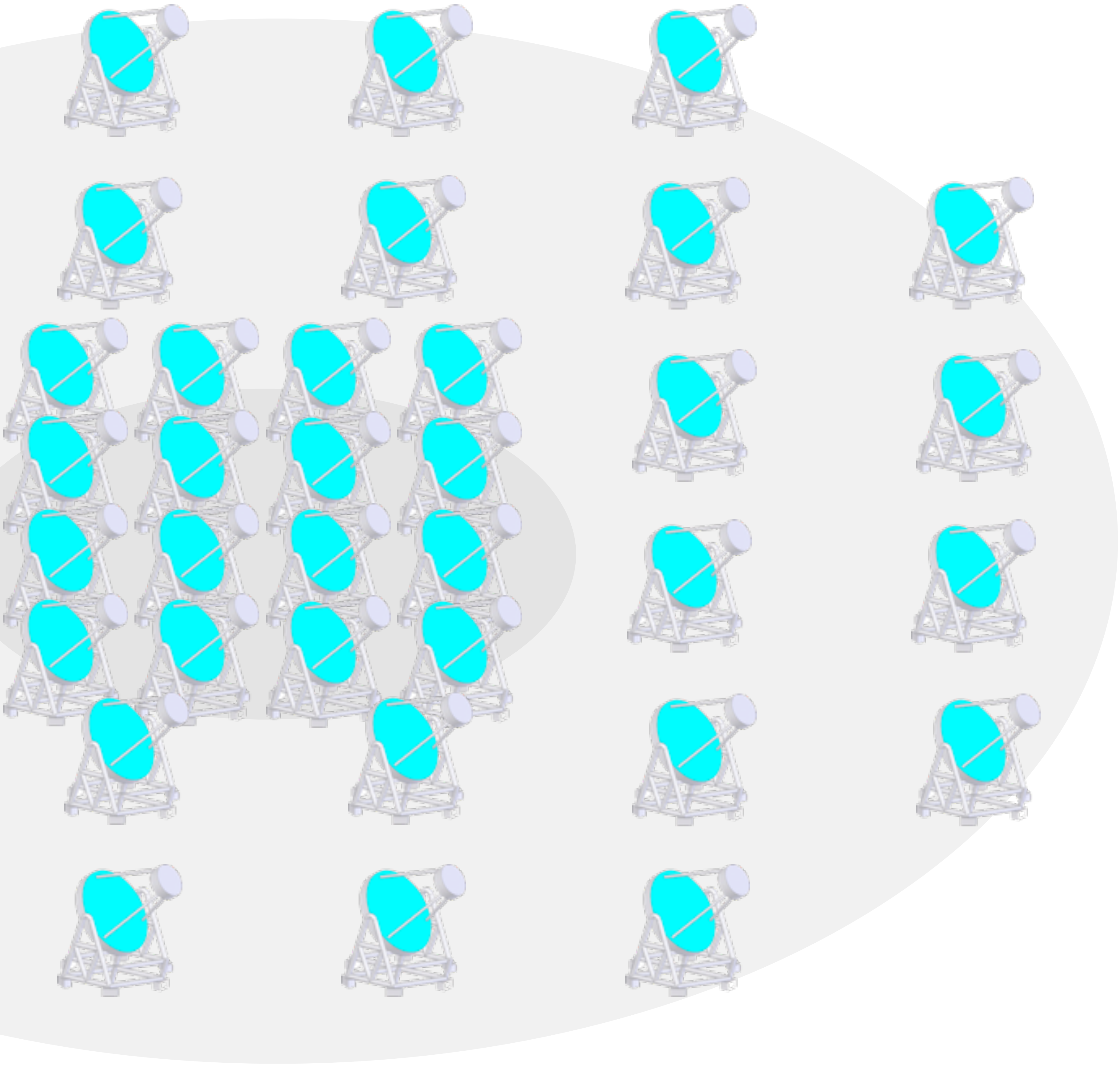
Core array:
mCrab sensitivity
in 0.1–10 TeV range

Not to scale !

Low-energy section

energy threshold
of some 10 GeV
(a) bigger dishes or

Not to scale !



Low-energy section

energy threshold

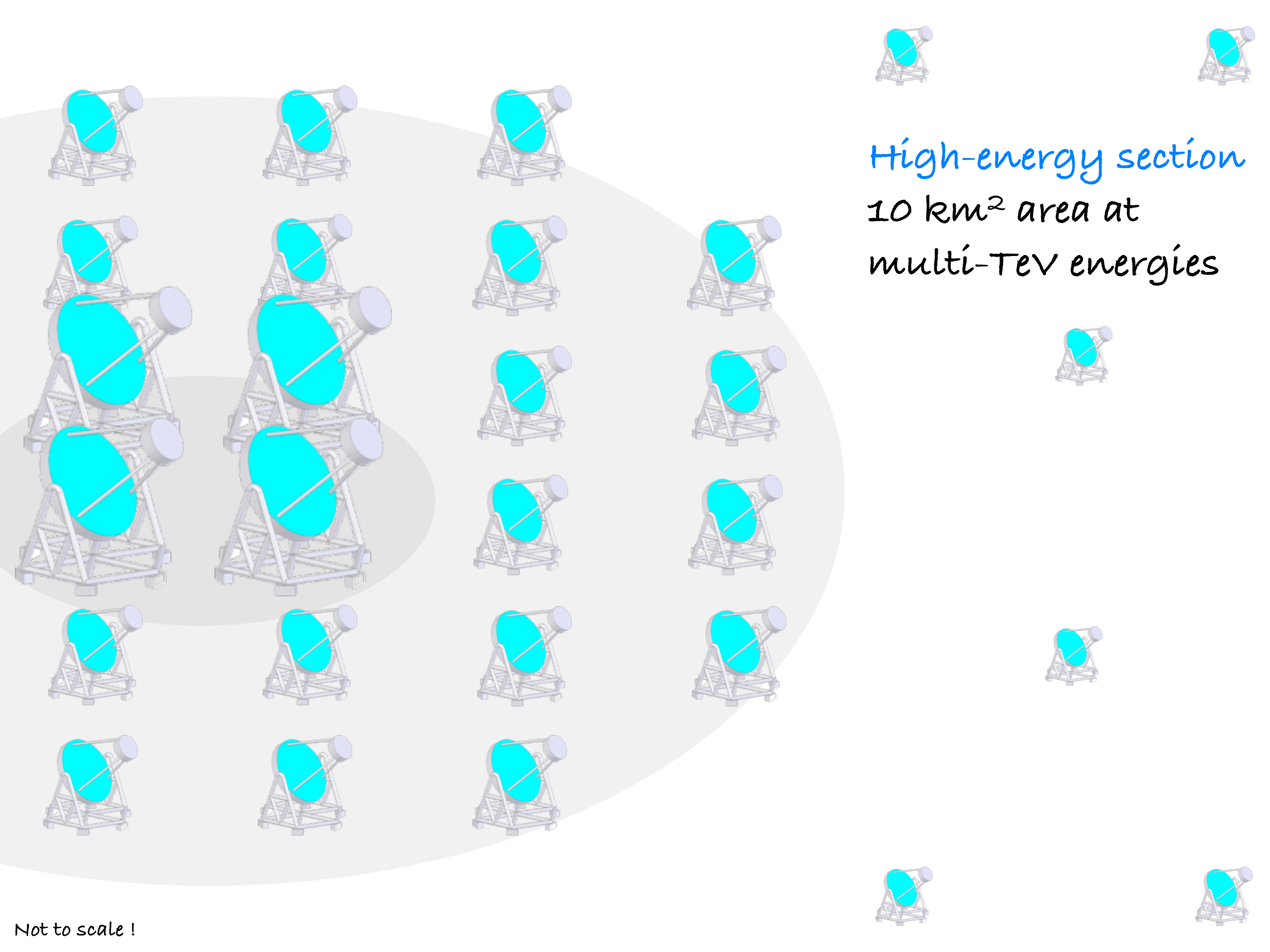
of some 10 GeV

(a) bigger dishes or

(b) dense packing /

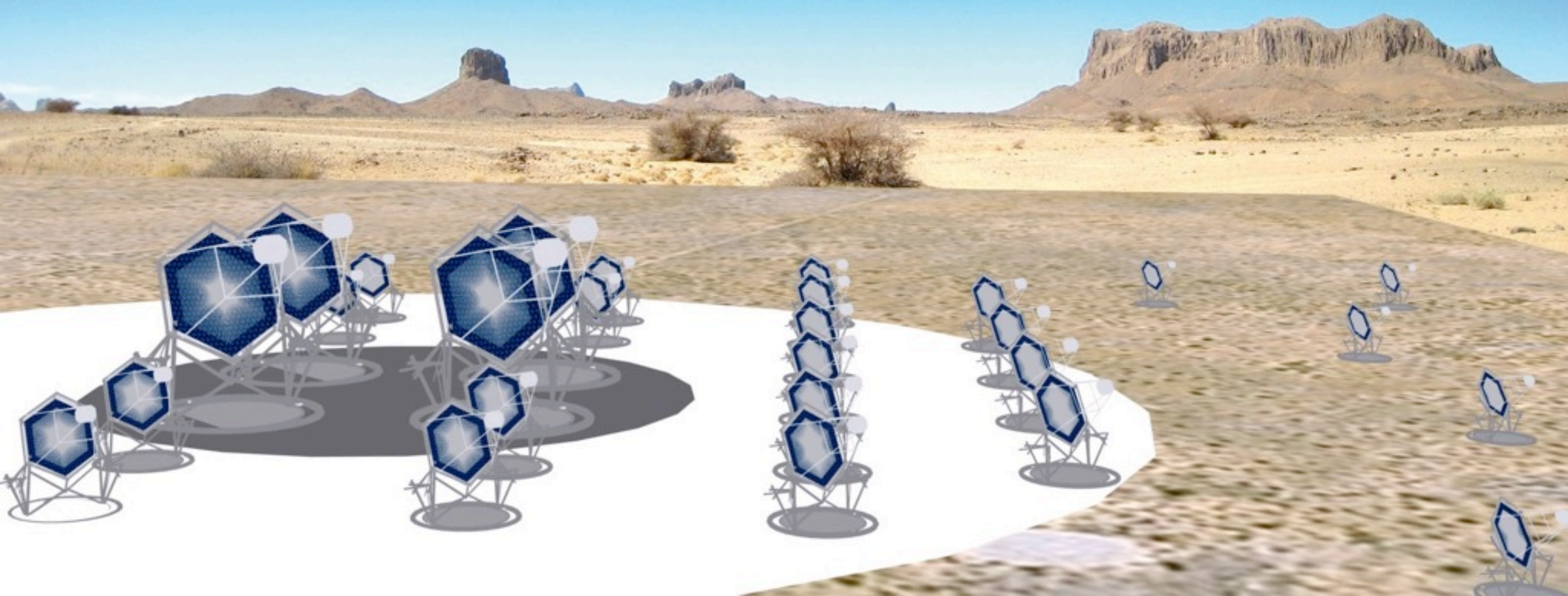
high-QE sensors

Not to scale !


High-energy section
10 km² area at multi-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 2013-18
  - Baseline: 50-100 Cherenkov telescopes



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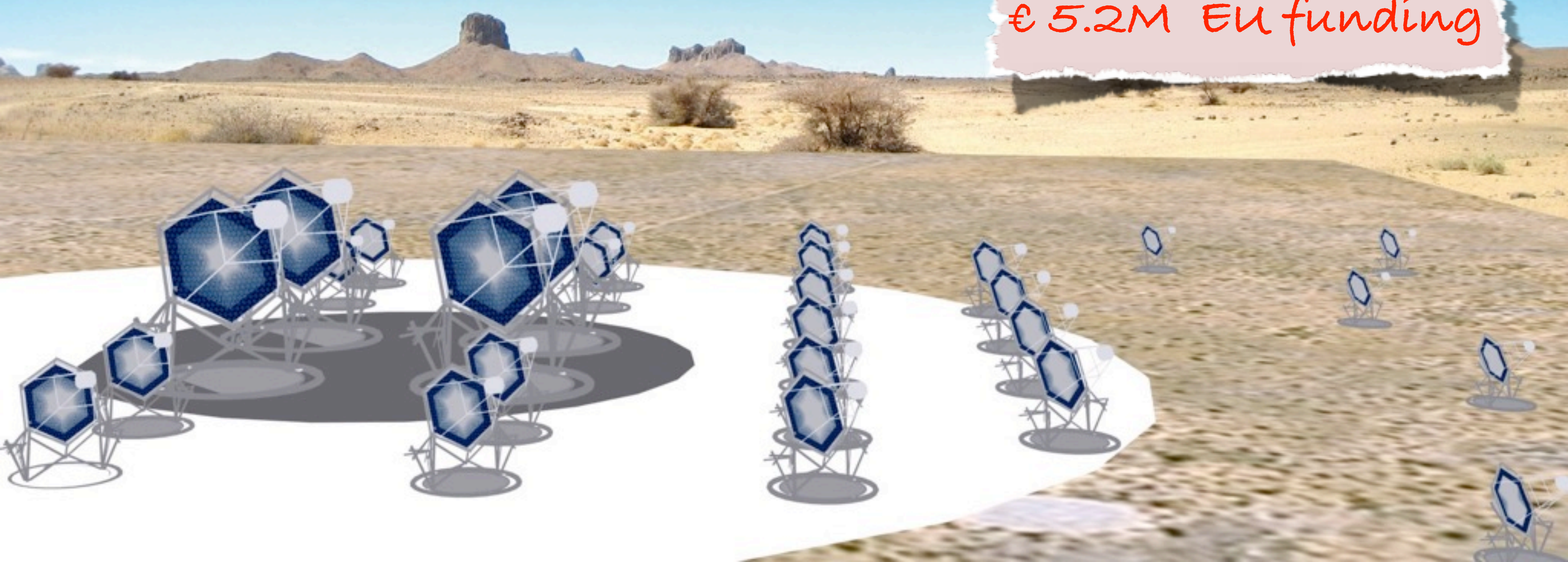
€ 5.2M EU funding



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 ...

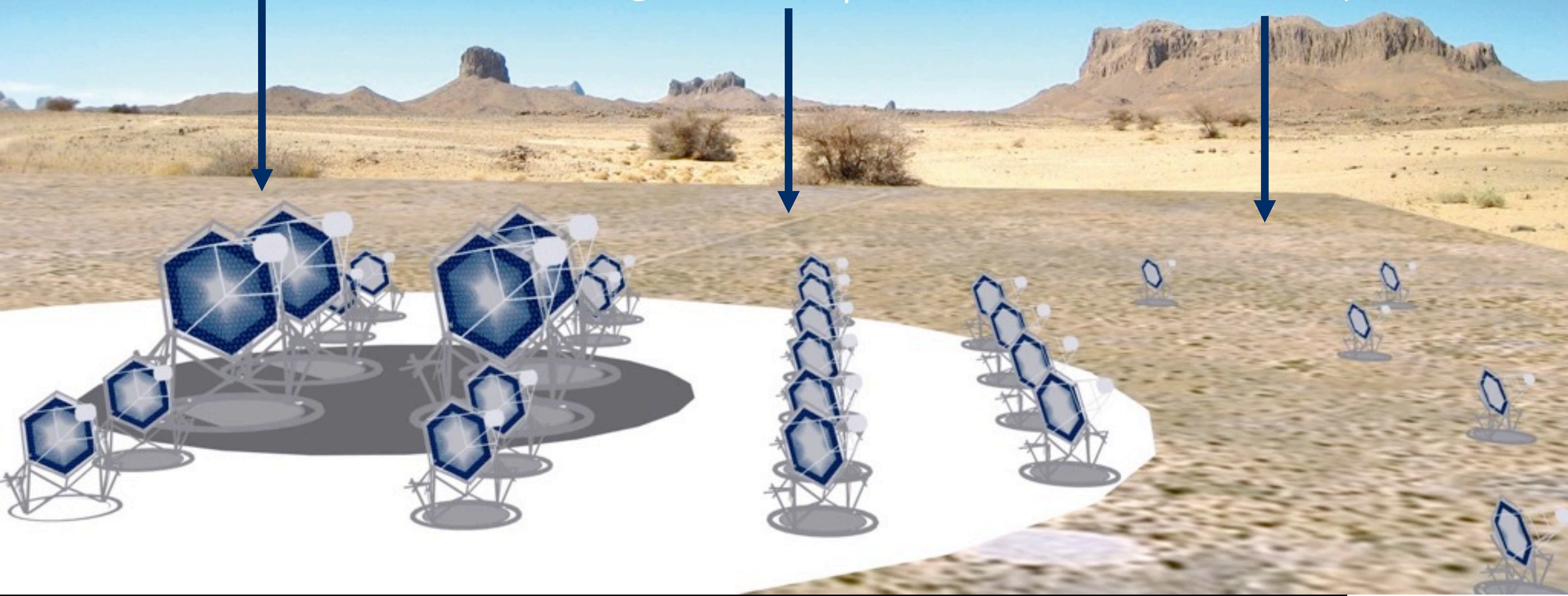
A real observatory with ≈ 100 telescopes.

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 at
multi-TeV energies
~5m telescopes



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High-energy section
10 km² area at
multi-TeV en
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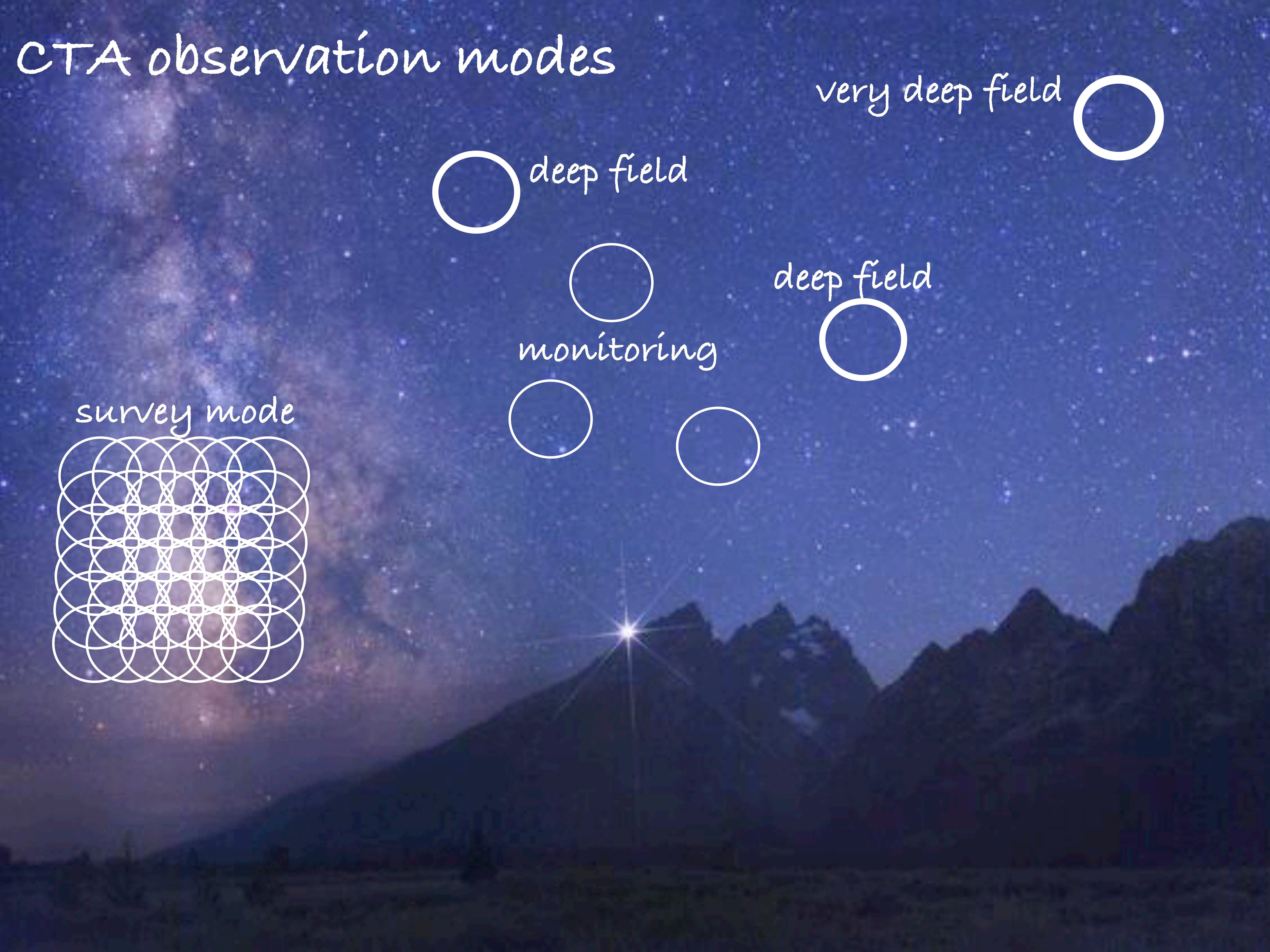
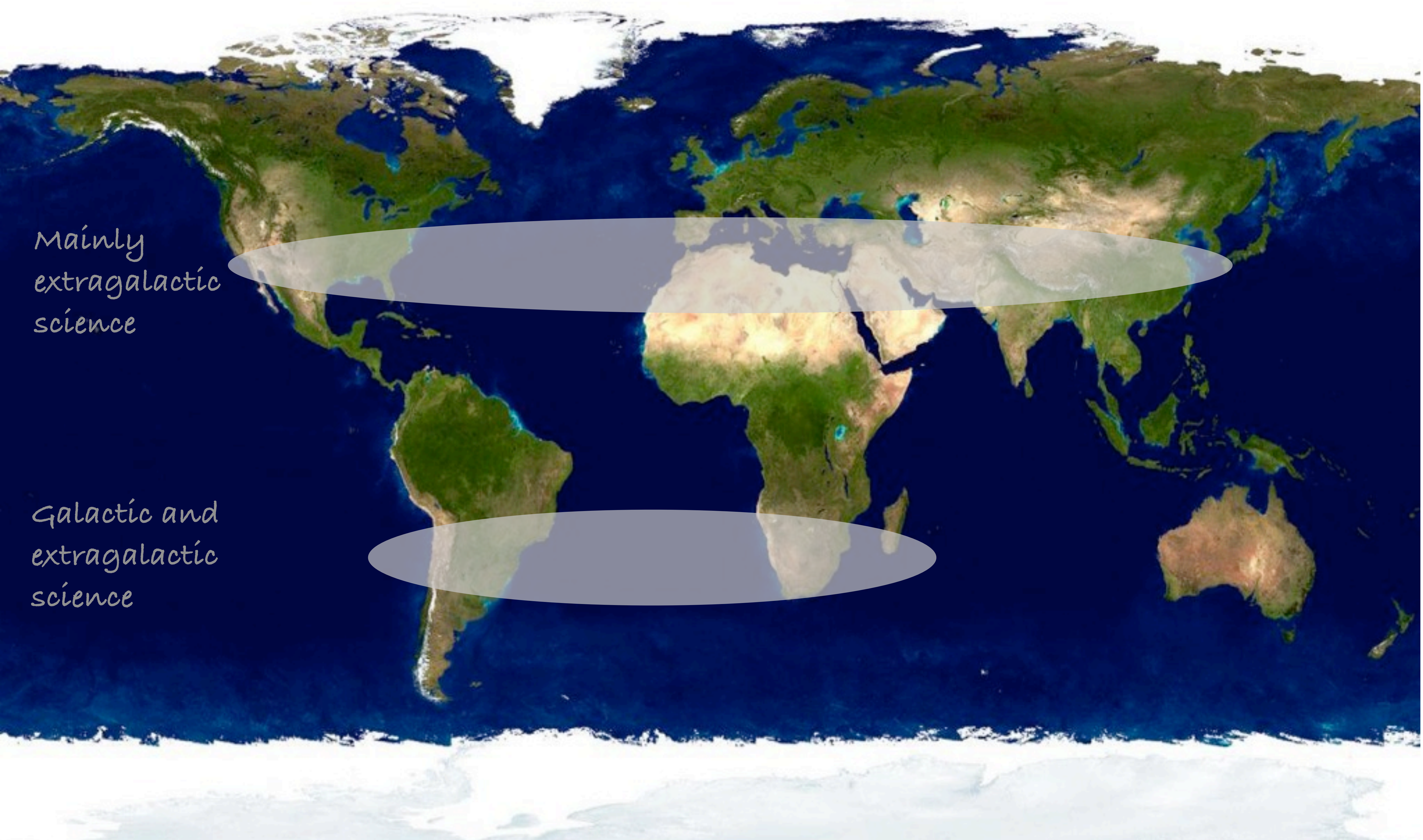
CTA observation modes



One observatory with two sites - operated by one consortium



Selection of sites by 2012

10 km^2 (S) flat area 1.5-4.0 km altitude, minimum cloud cover, easiest access, ...

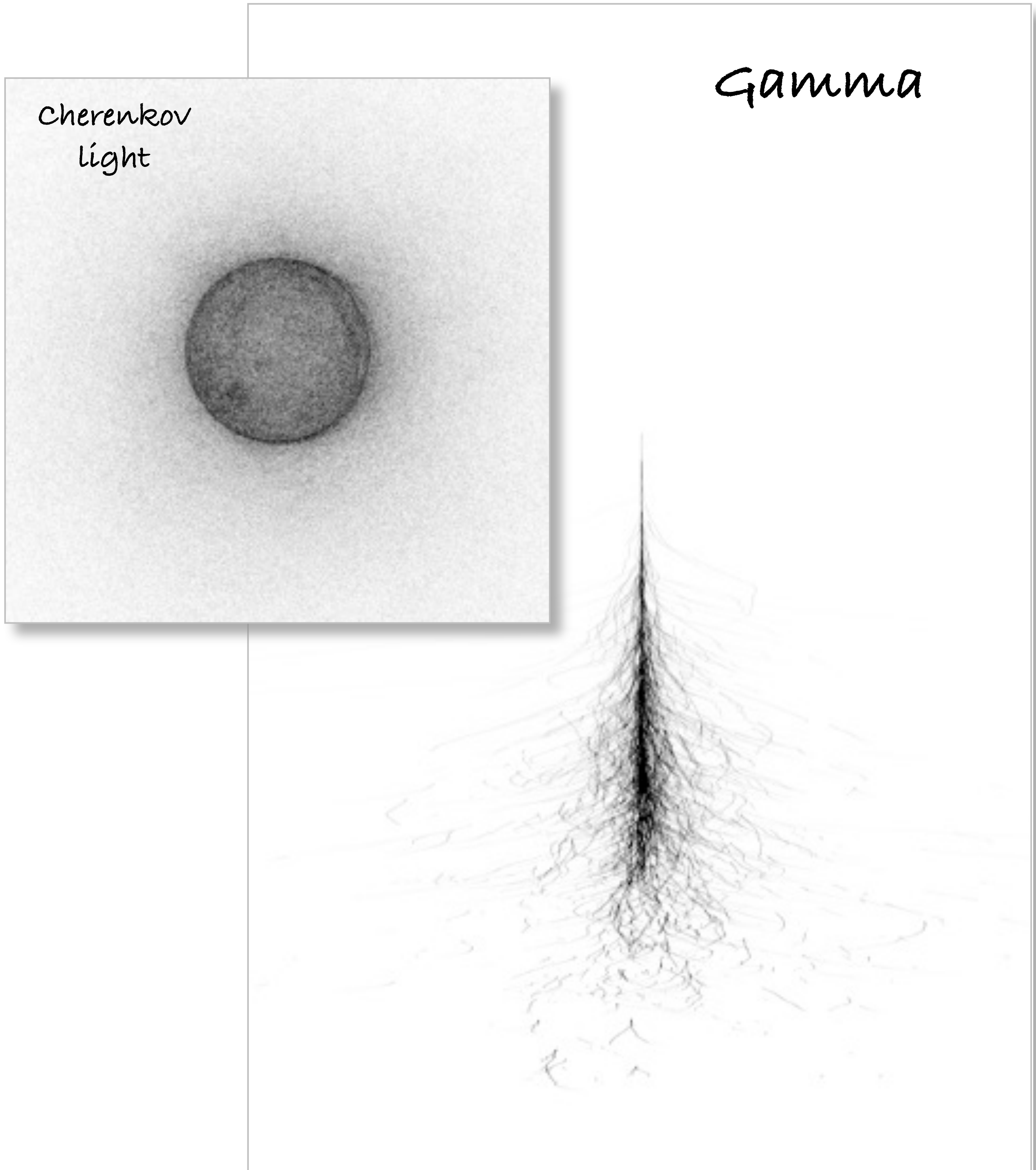
On Simulations ...

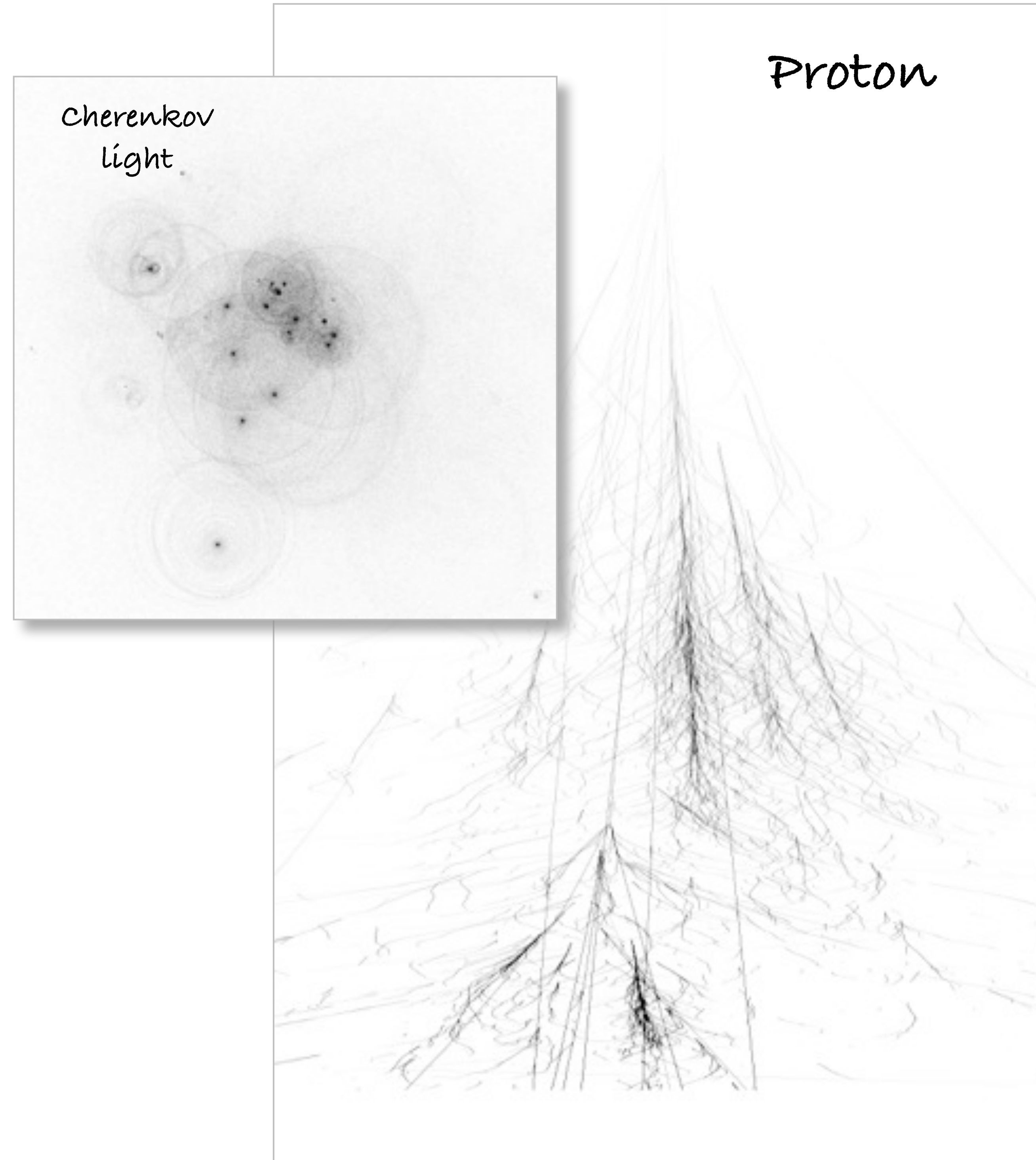
γ ray simulations are straight forward:

- 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, ...)

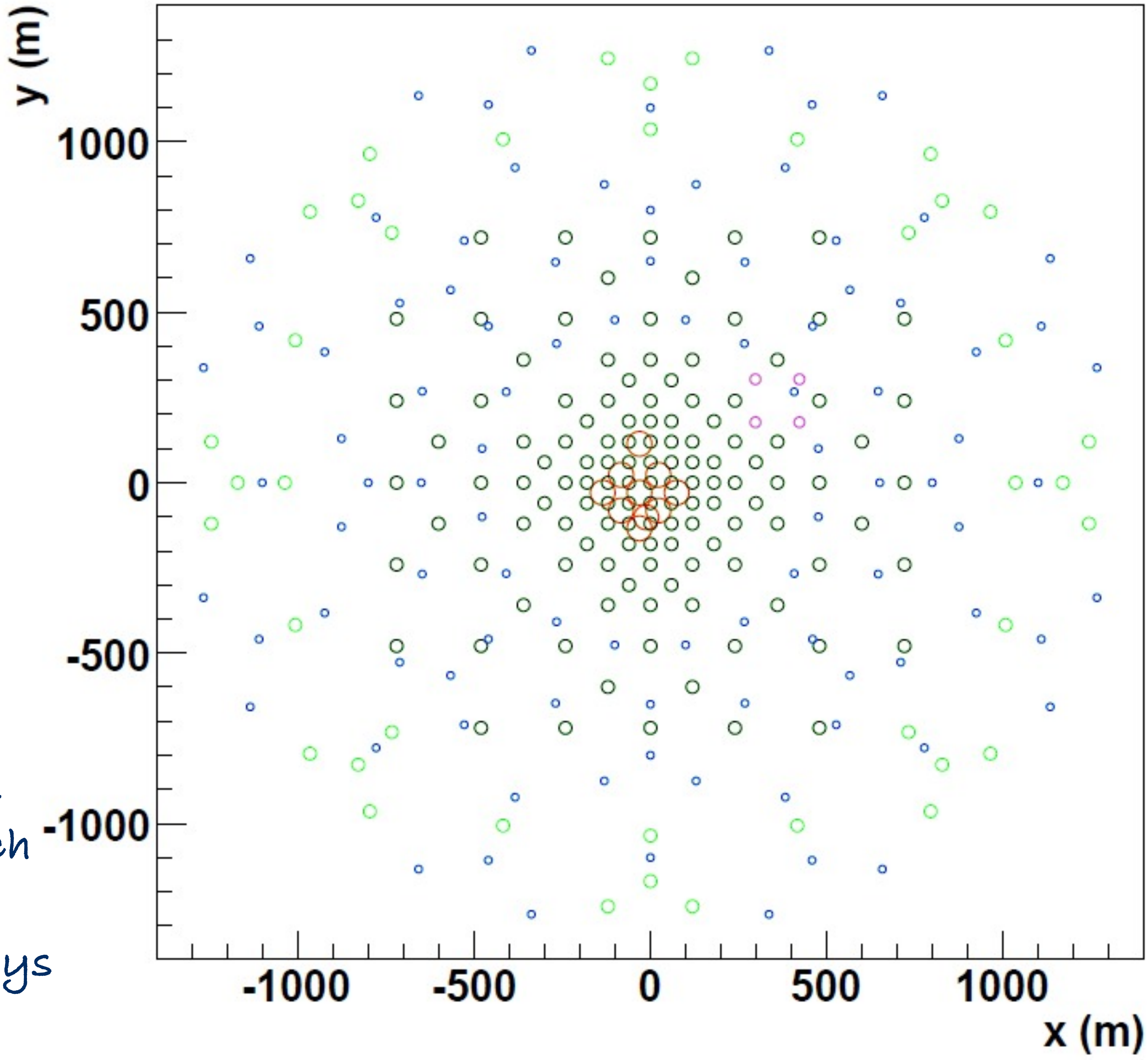
handshake between CORSIKA and detector simulations
already $\sim 10^9$ showers simulated

γ rays and Cosmic Ray background





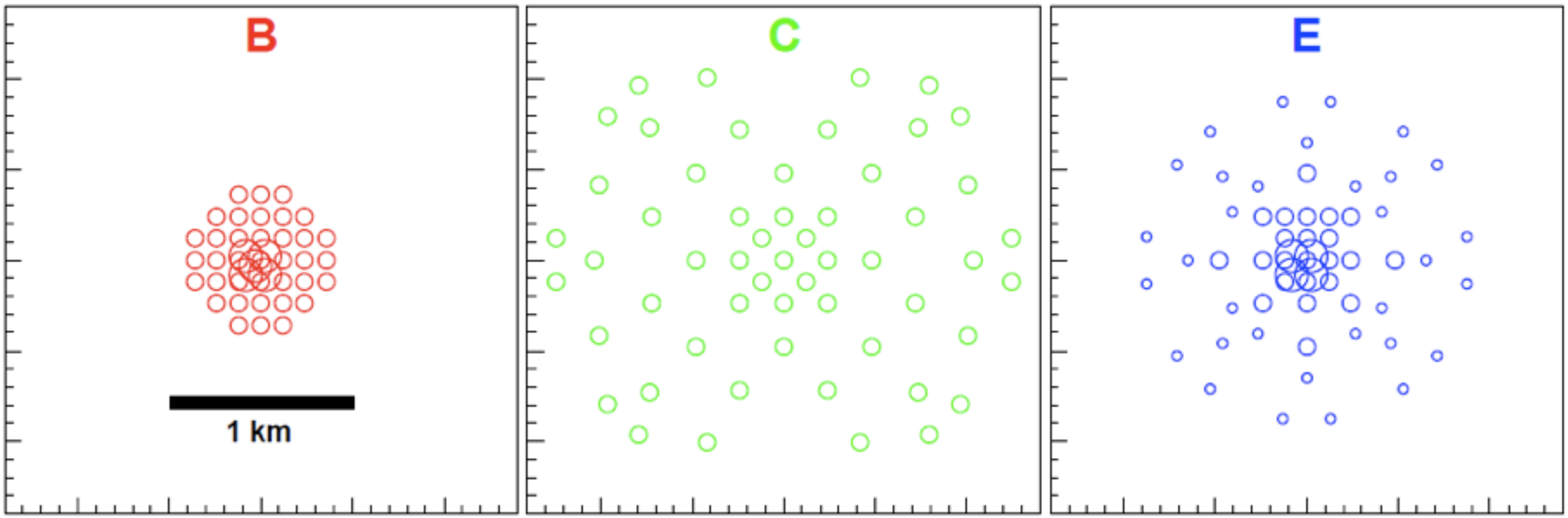
Performance Calculations



273 telescopes, subsets of which are actual candidate arrays

Examples of subarrays

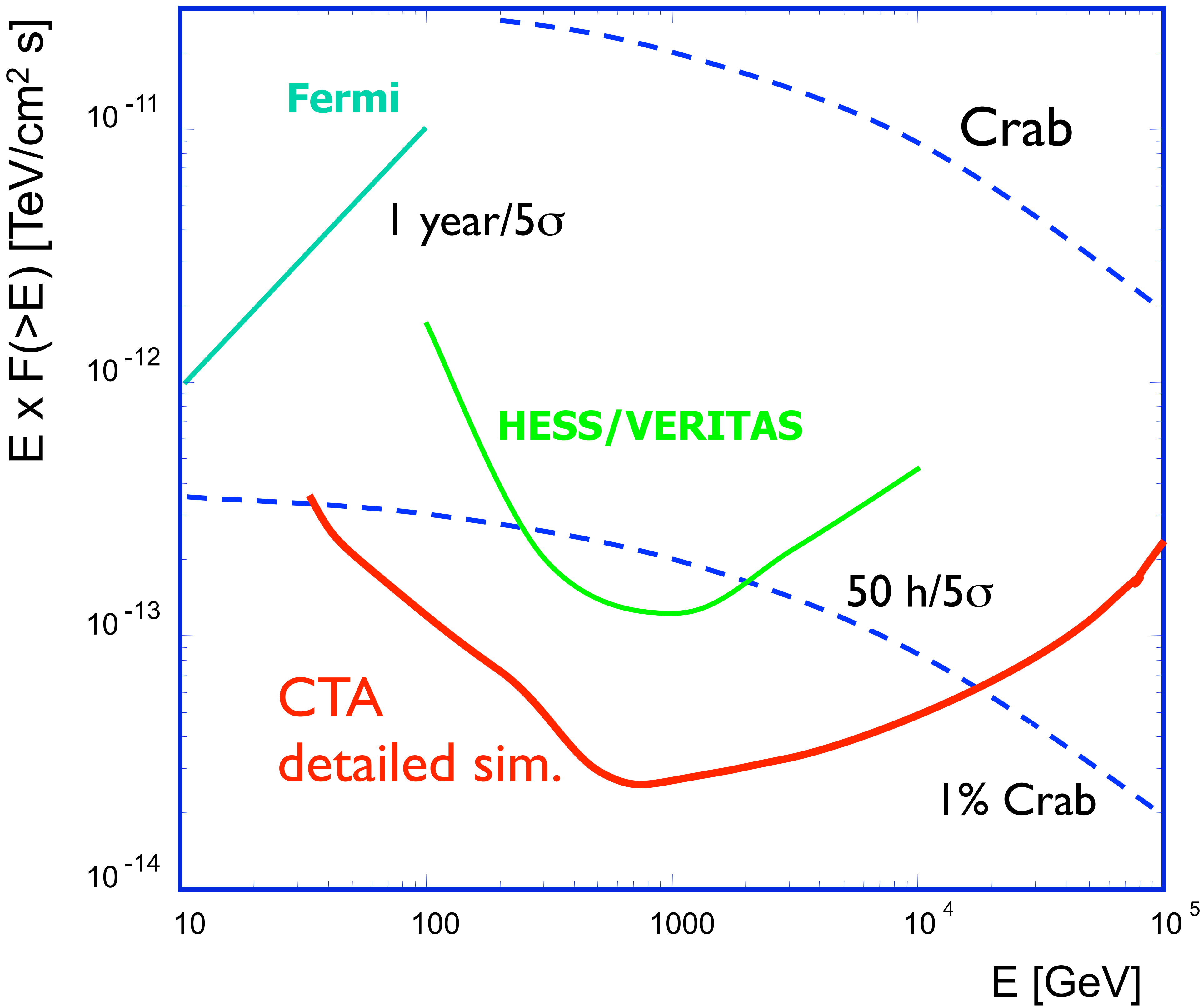
(of same cost)

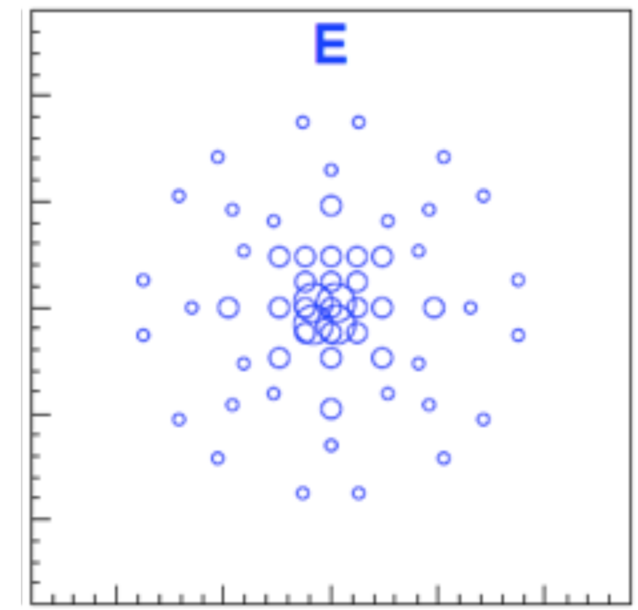


dense array of 12 & 24 m tels.	low density array of 12 m telescopes	array of 7, 12 and 24 m telescopes
+ low E - high E	+ high/medium E - low E	+ good sensitivity across full energy range

main trade-off: quantity vs quality of events

Point Source Sensitivity

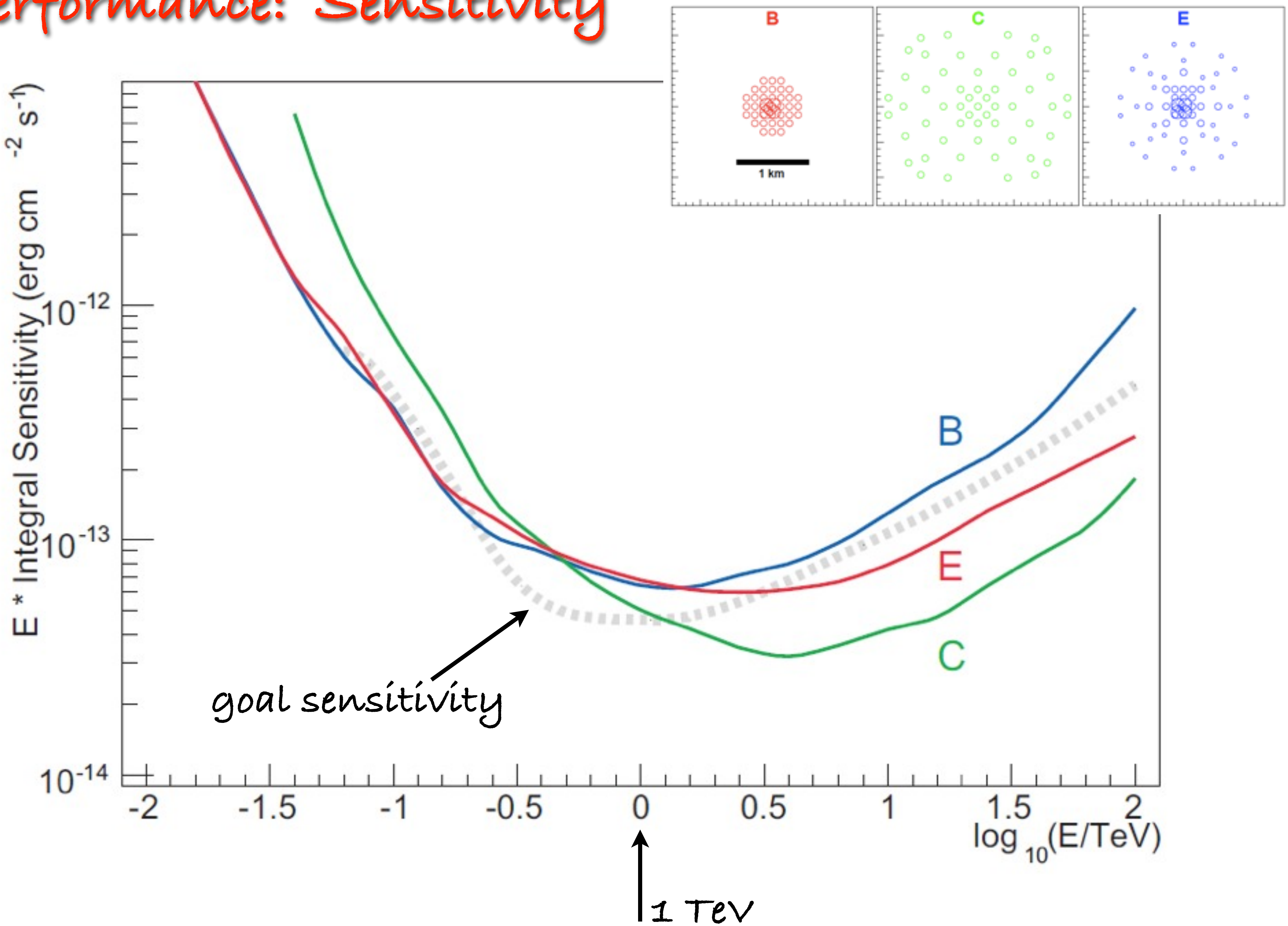


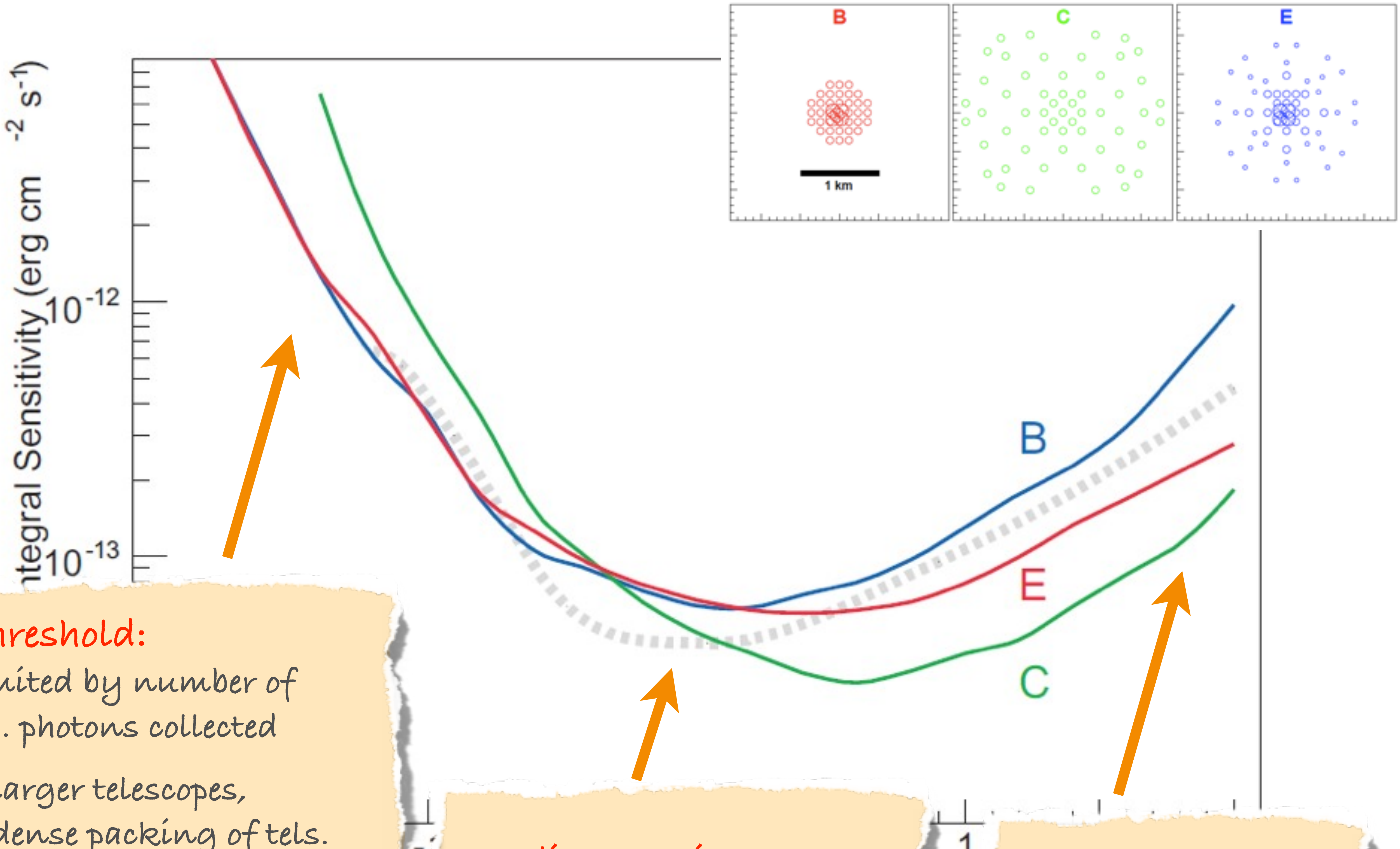


array "E":
59 telescope config.
(analysis & layout
not optimised yet)

€80M nominal cost

Performance: Sensitivity





Threshold:
limited by number of Ch. photons collected

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

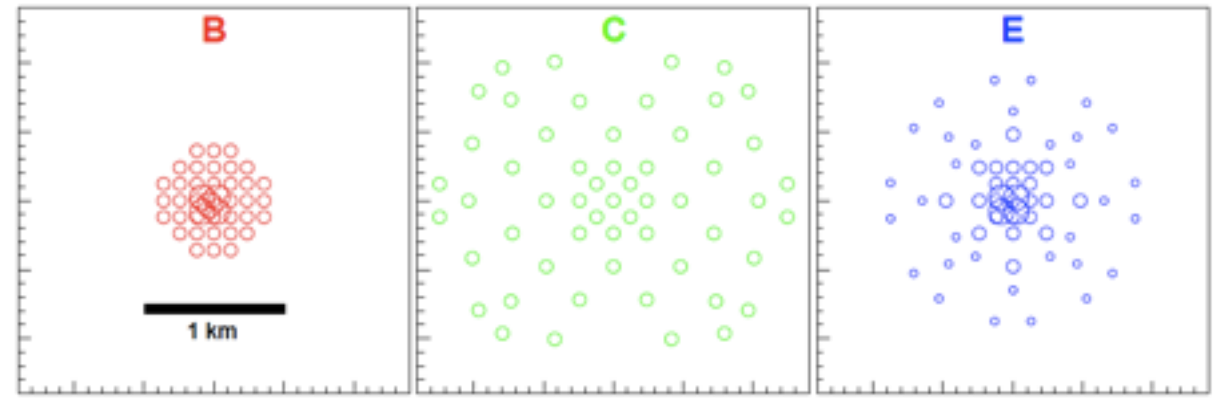
Medium region:
limited by signal / BG

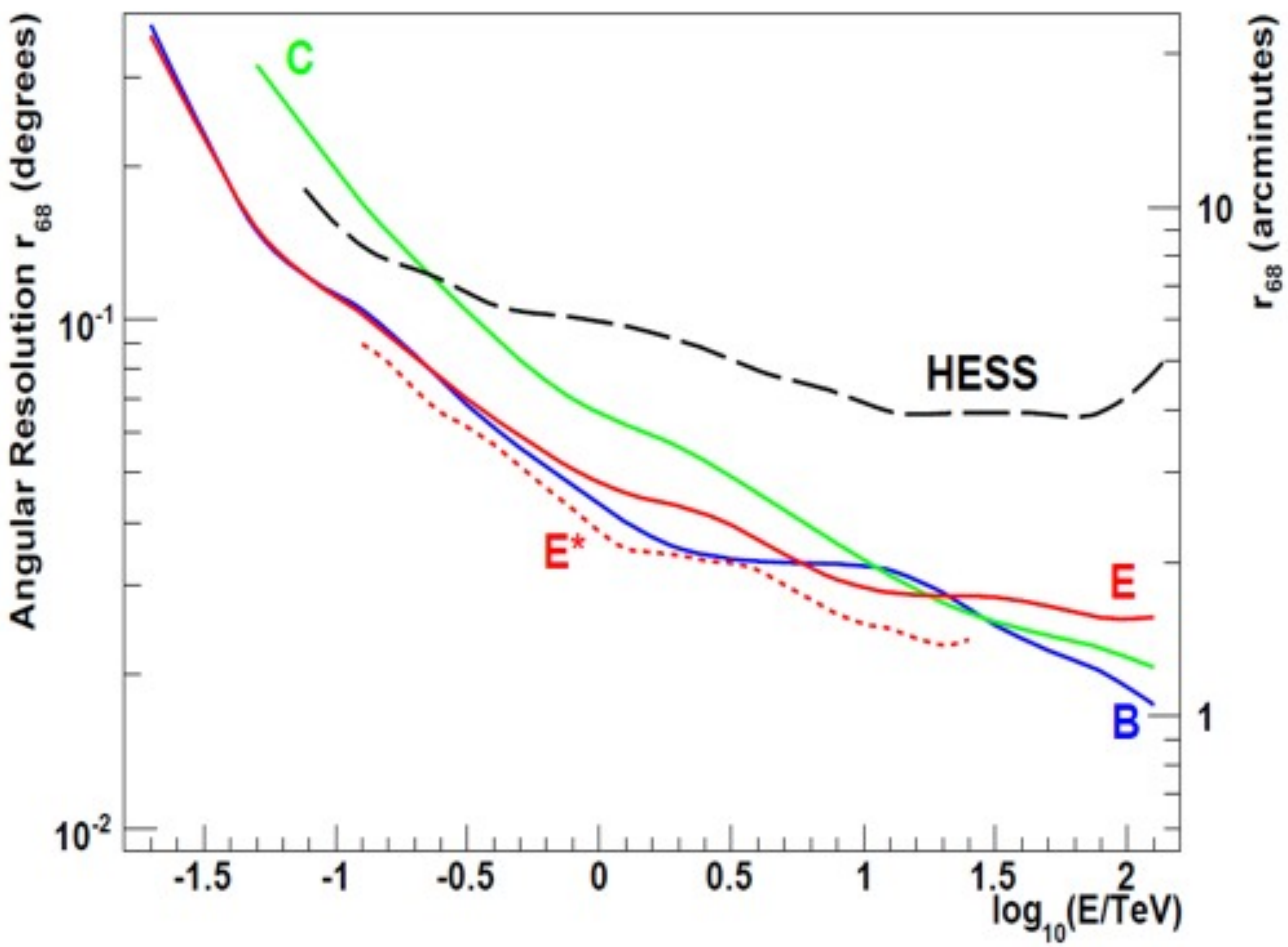
- better BG rejection,
- improved ang. resolution,
- better photon statistics

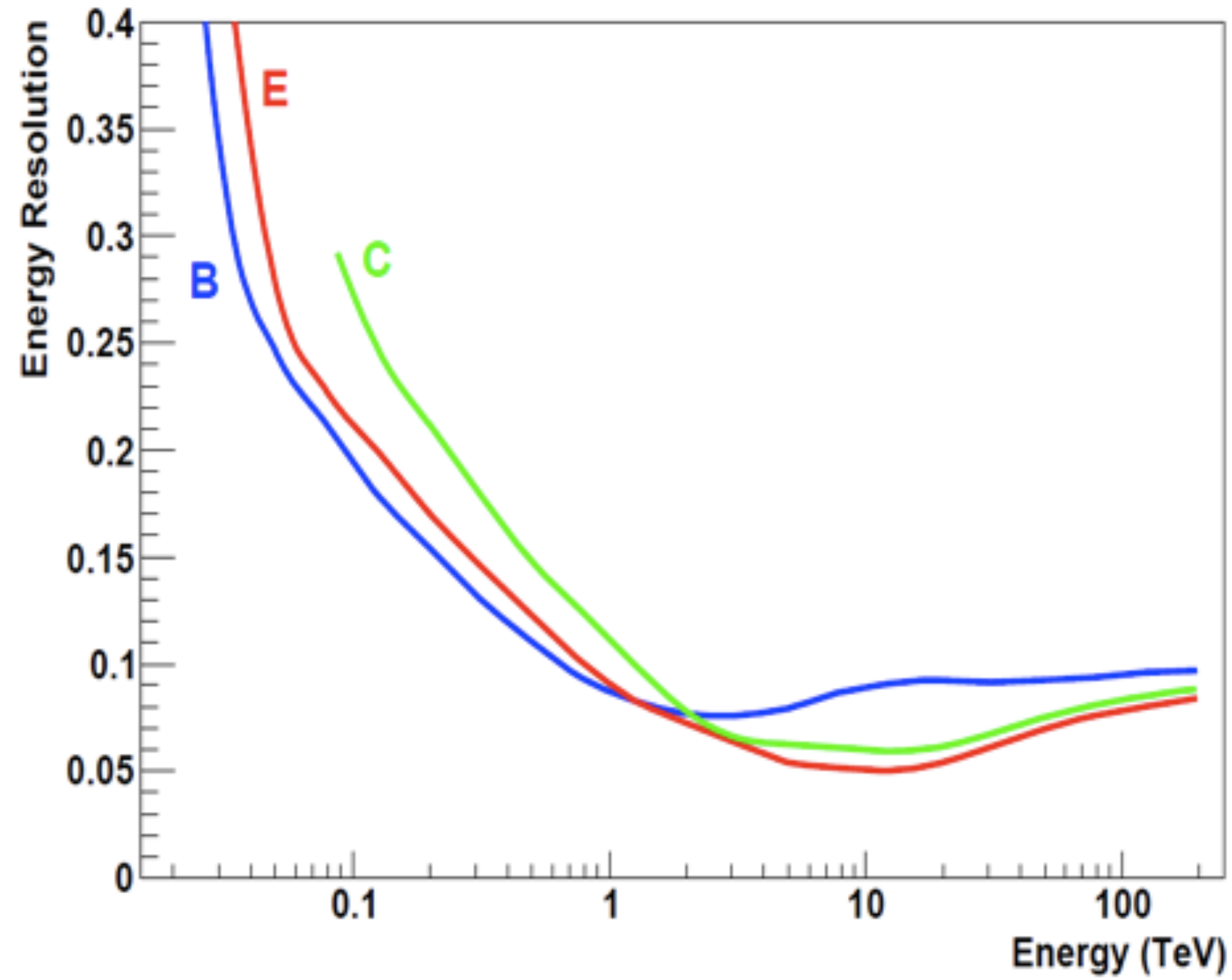
High energies:
limited by statistics

- large array

Performance: angular and energy resolution





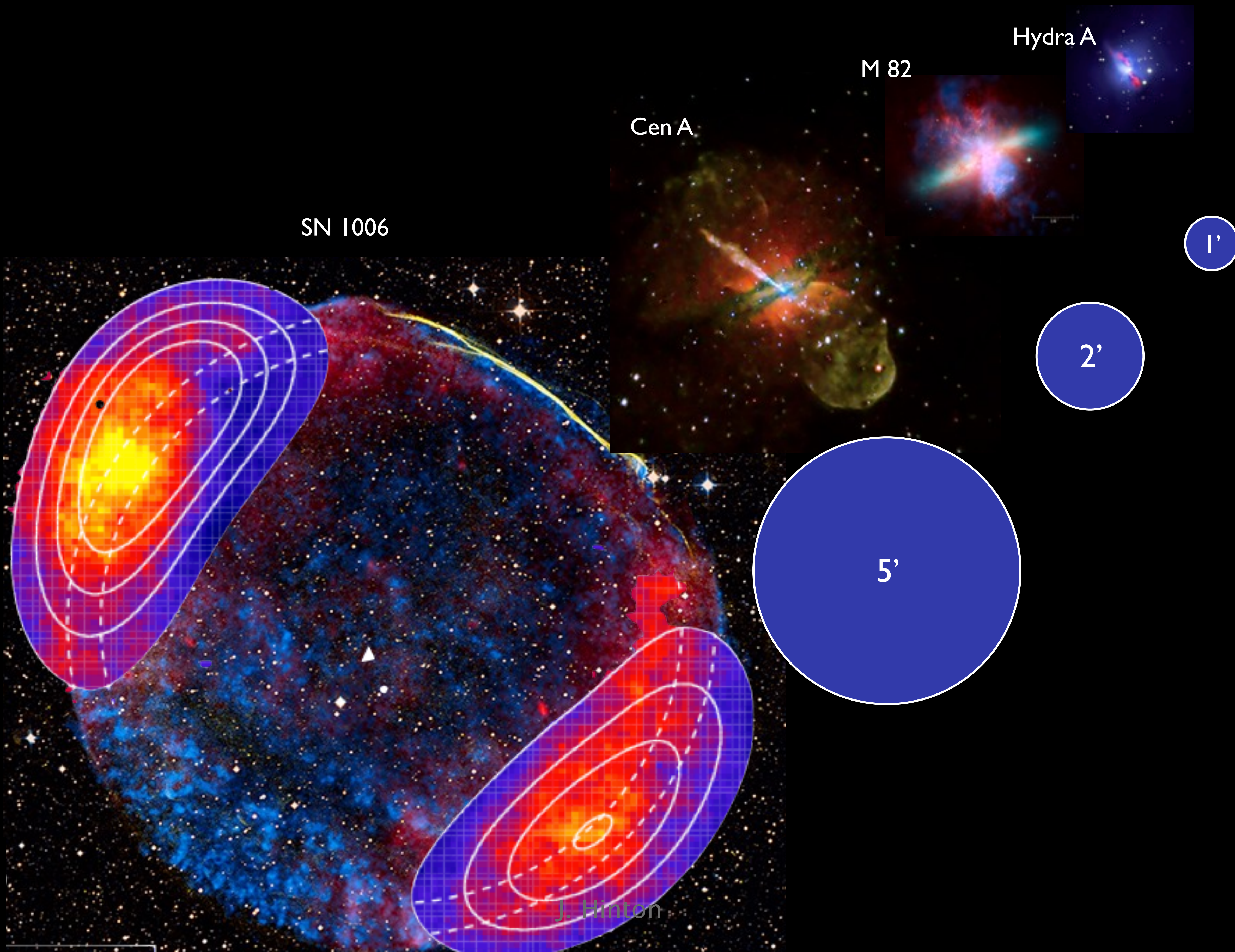


1-2′ for E > 1 TeV

(fundamental limit: ~ 10″)

<10% for E > 1 TeV

Angular Resolution



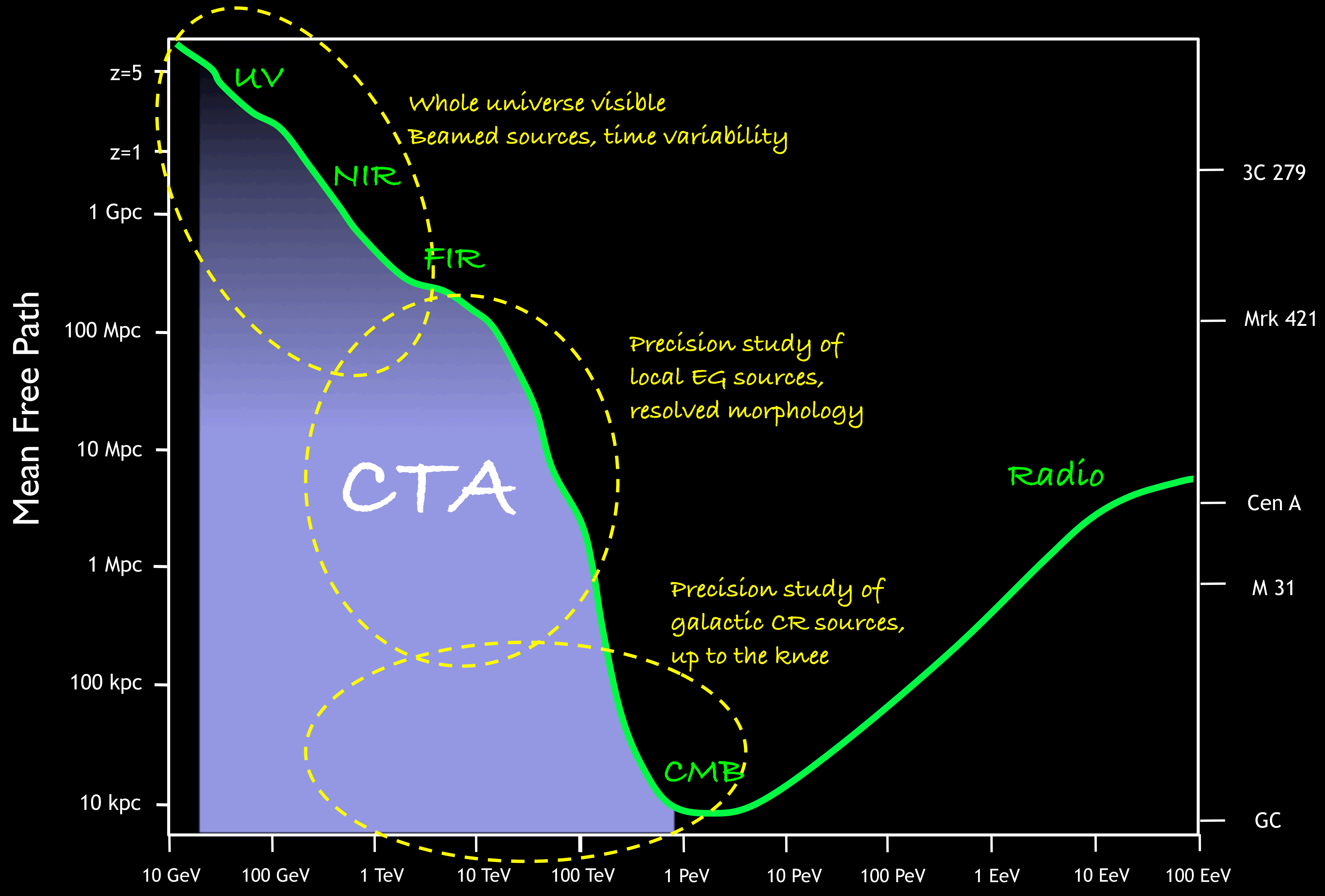
Performance:

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

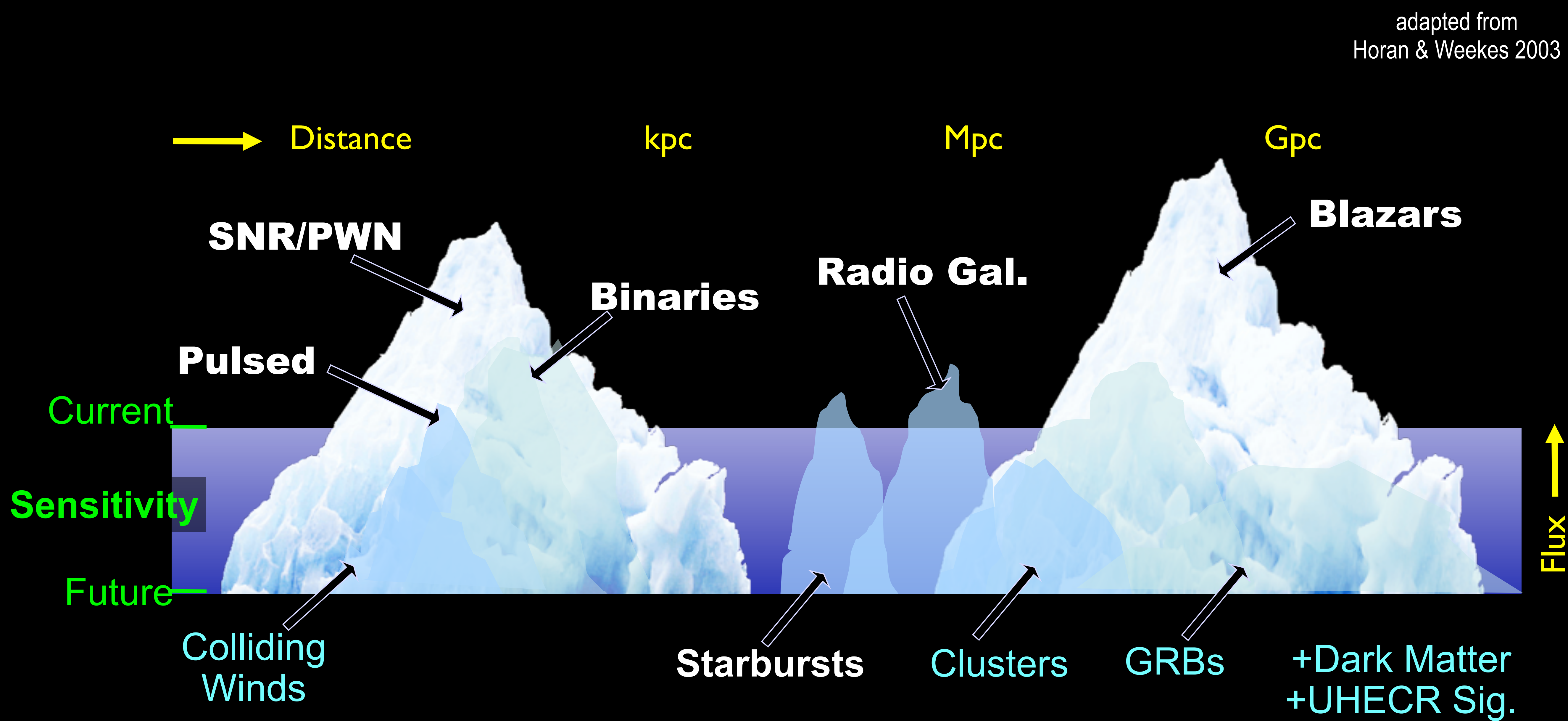
Improvement (relative to HESS) :

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

The Gamma Ray Horizon $\gamma + \gamma \longrightarrow e^+e^-$

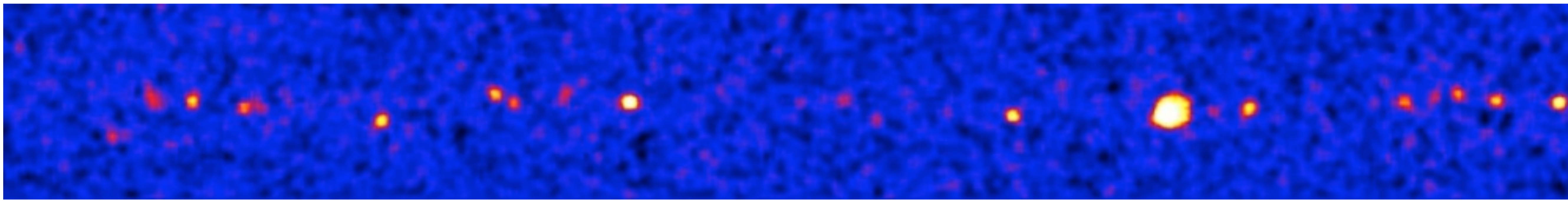


Science Potential

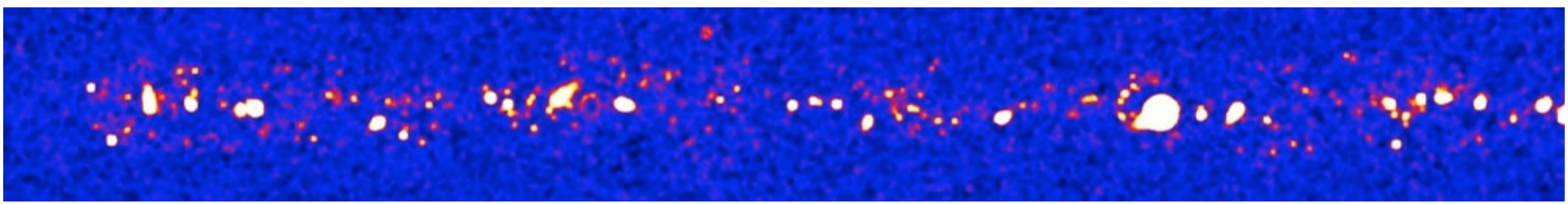


- Current instruments are sensitive enough to reveal a rich panorama, but this is clearly only the tip of the iceberg
- Broad and diverse program for CTA, combining guaranteed astrophysics with significant discovery potential

CTA expectation:



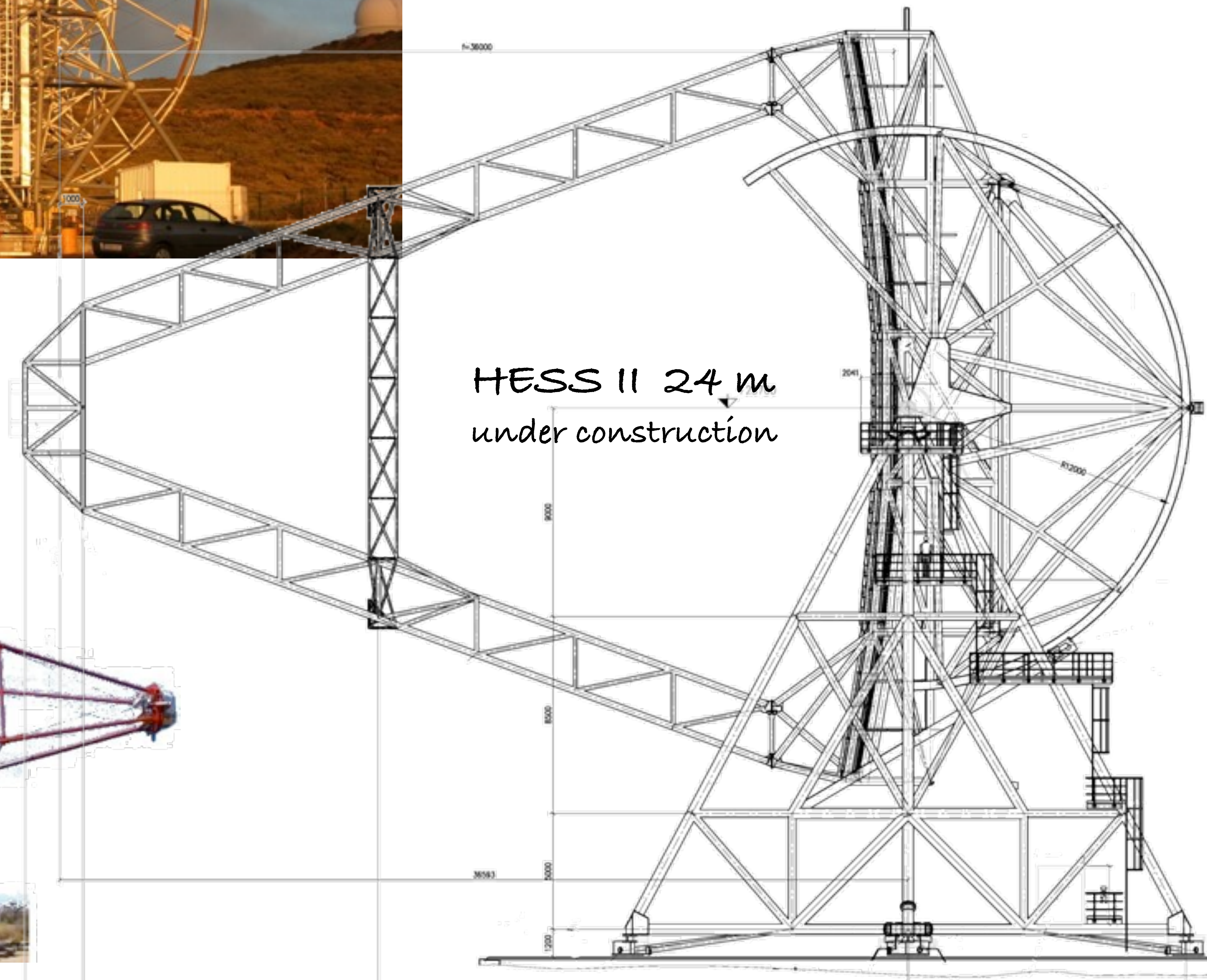
HESS ~500 h



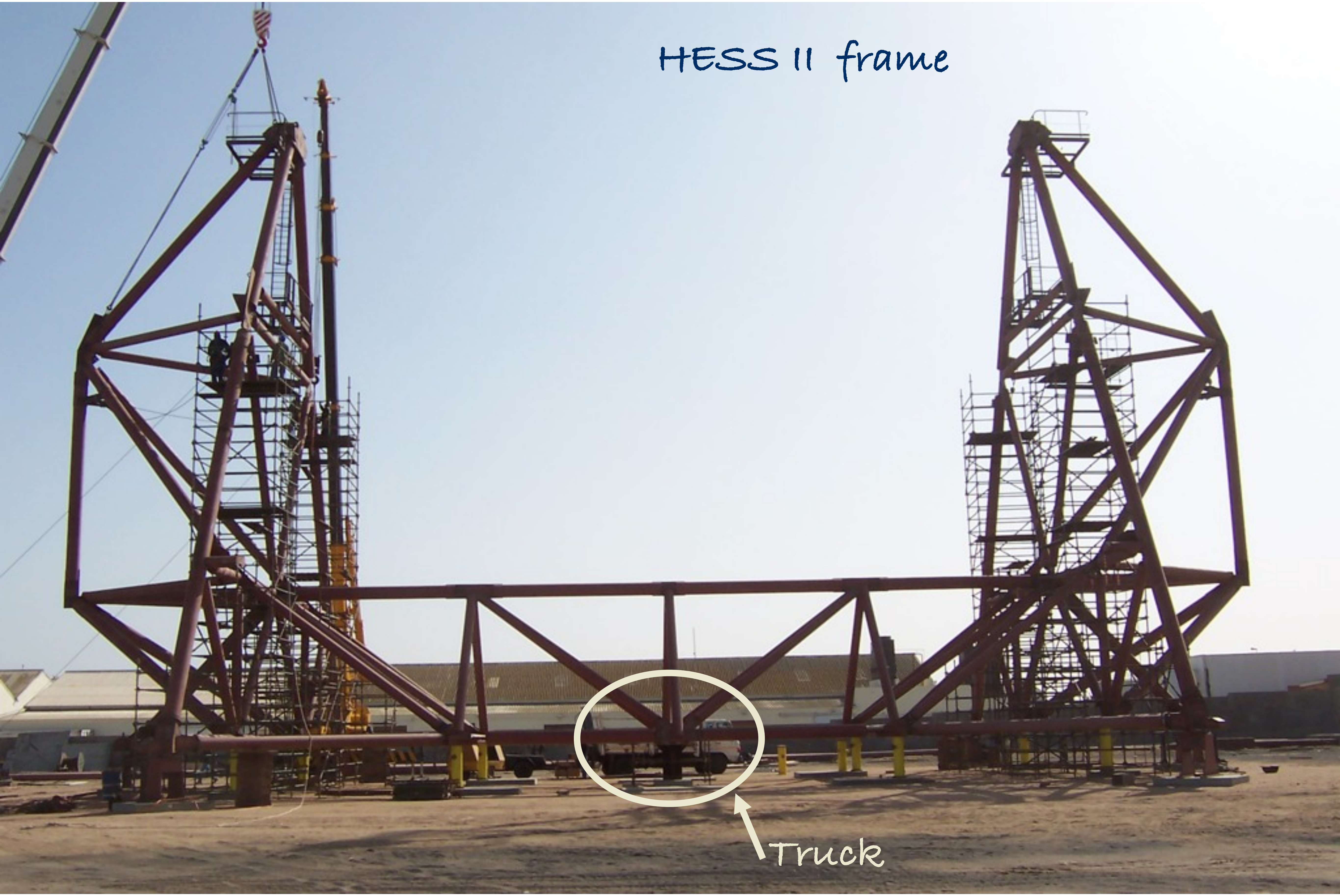
CTA expectation: 1000 sources

Building blocks could be ...

to scale



HESS I 12 m


HESS II frame
Truck

HESS I : ~1.5 M€/tel HESS II : ~11 M€/tel MAGIC : ~5 M€/tel

This would exceed target cost by 1.5 - 2 x

We need to be cheaper !!!

Instrument reliability to be increased by > 10x

for high data quality and to limit operating costs

We believe we can build even better telescopes

wider field of view, better resolution,

improved photo sensors & electronics

Lacking tools to operate a user facility and to handle data

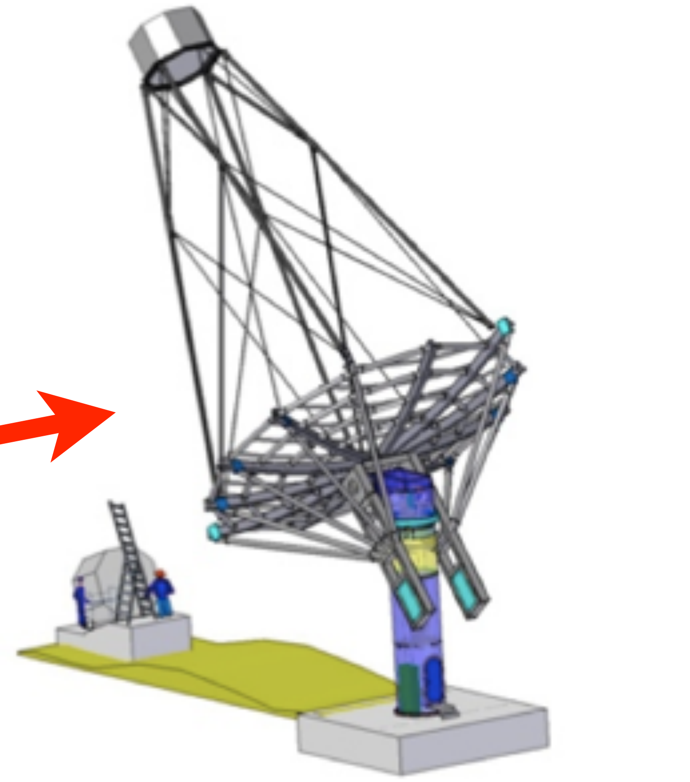
Observation scheduling & system control

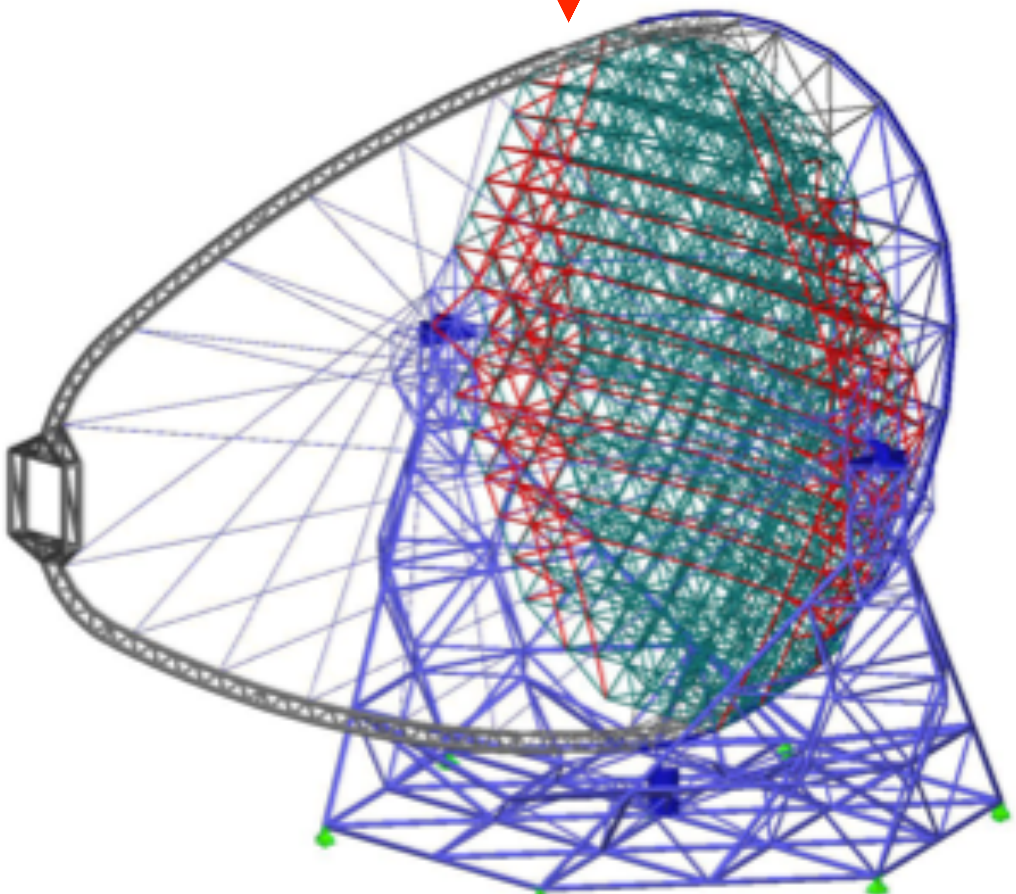
Science data centre and data access tools

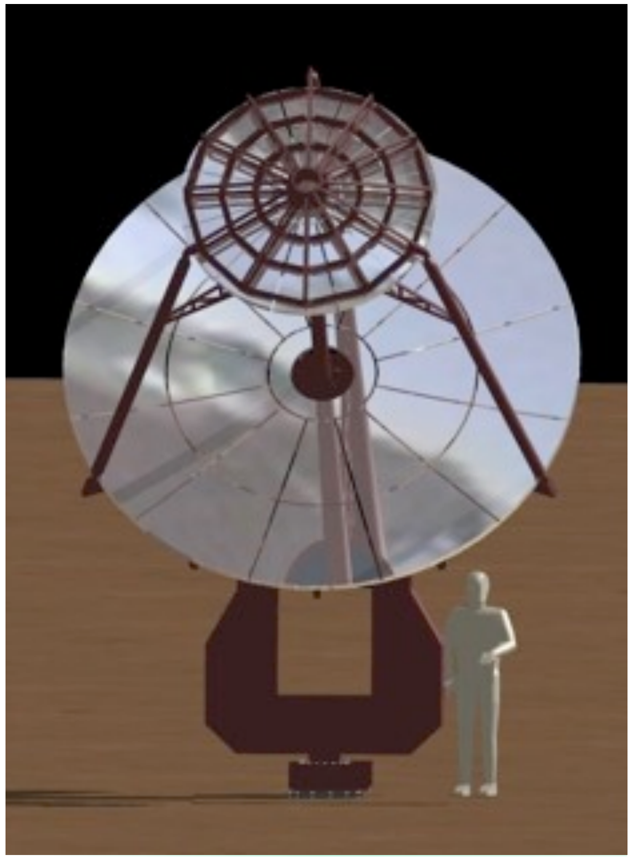
significant effort needed to optimise design

Options for LST, MST

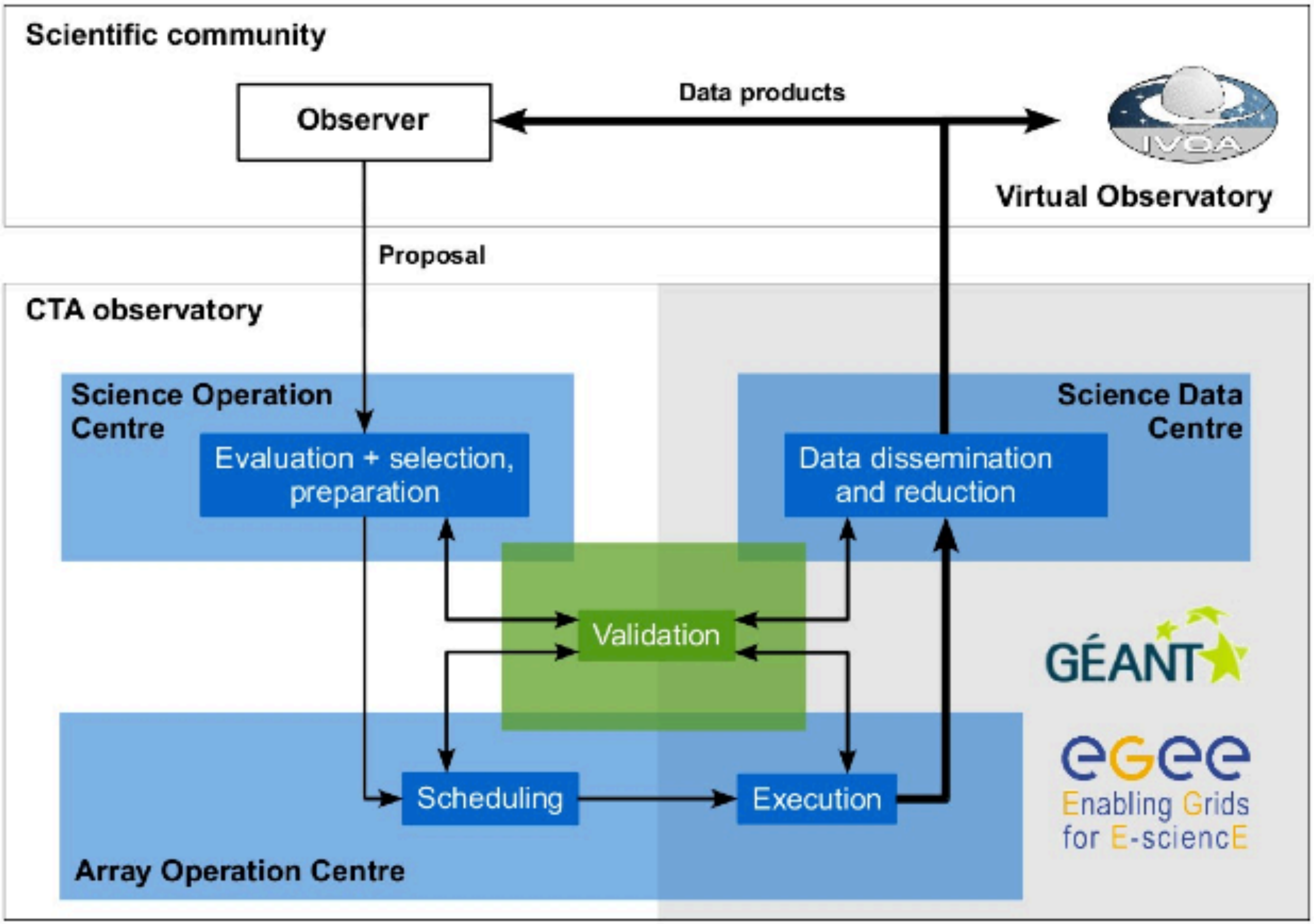
& SST







CTA as an open observatory



The Preparatory Phase

Preparing for CTA

Organisation (Governance, Finance, Legal...)

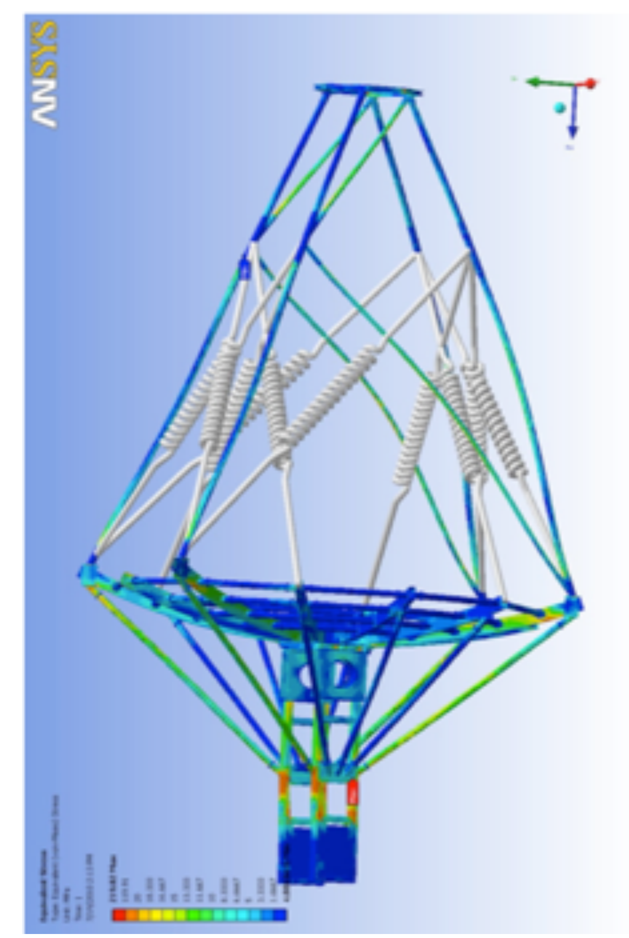
Construction (Finalise Design/Implementation plans, Site selection/development)

Operation (Observatory, Data, ...)

Technical work

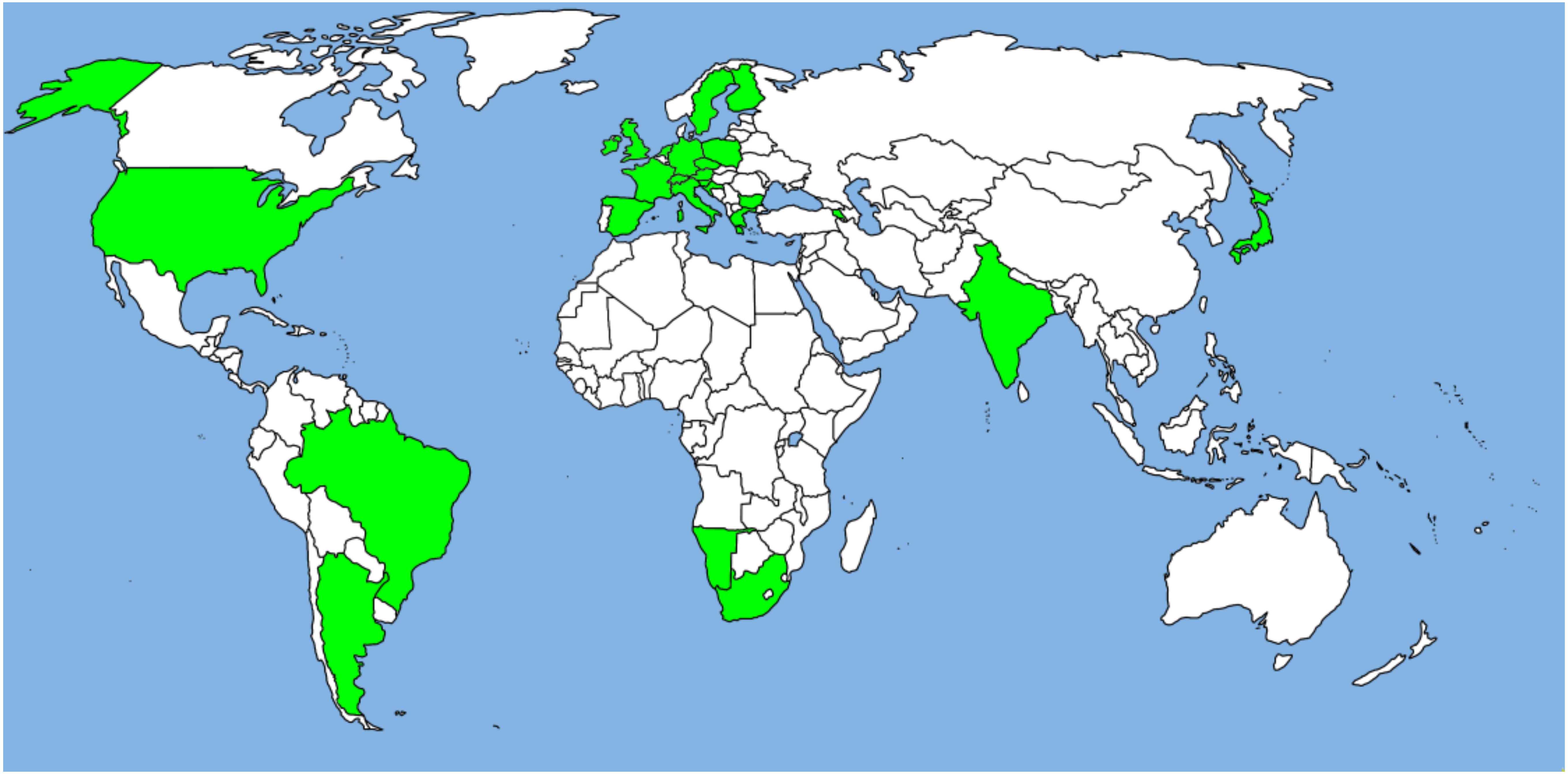
Science-based optimisation of the observatory, detailed design work, layout, hardware options, mechanical and electronic engineering

Monte-Carlo simulations, data analysis development, physics/astrophysics studies



CTA Members: 25 Countries

>700 scientists and engineers from >100 insitutions



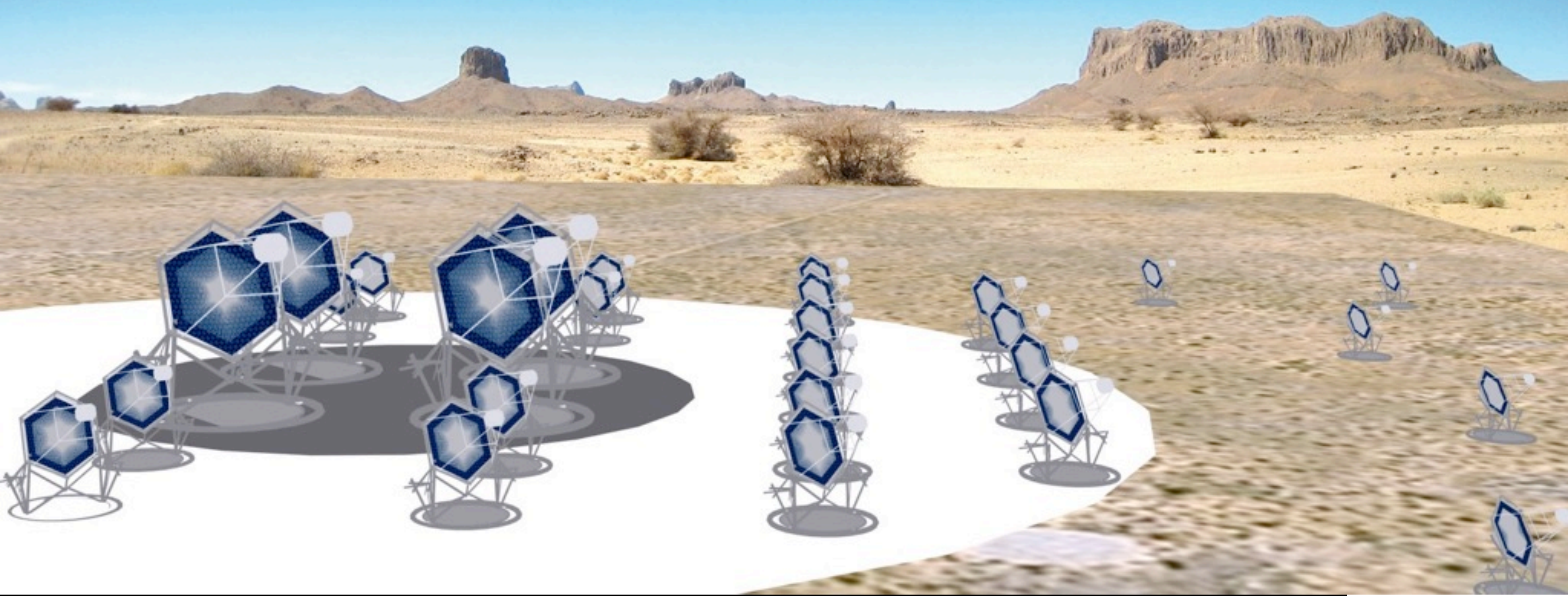
Argentina, Armenia, Austria, Brazil, Bulgaria, Czech Republic, Croatia, Finnland, France, Germany, Greece, India, Italy, Ireland, Japan, Namibia, Netherlands, Poland, Slovenia, Spain, South Africa, Sweden, Switzerland, UK, USA

Conclusions

CTA is the global next generation project

... a precise and sensitive probe of the extreme universe

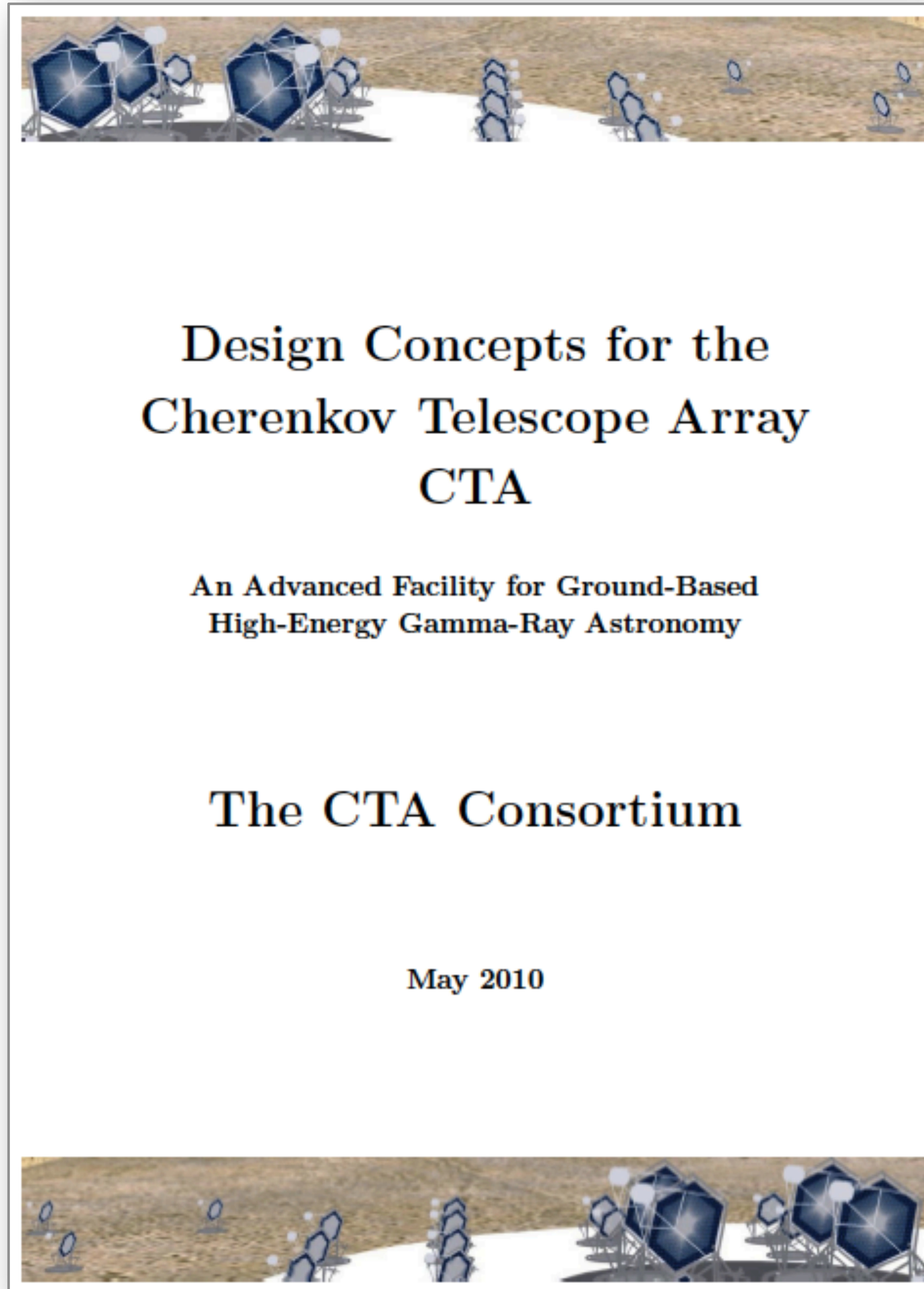
It has a huge potential for extreme astronomy and fundamental physics with TeV photons



More Details:

general info:
www.cta-observatory.org

arXiv:1008.3703
120 pages



Design Concepts for the
Cherenkov Telescope Array
CTA

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

The CTA Consortium

May 2010