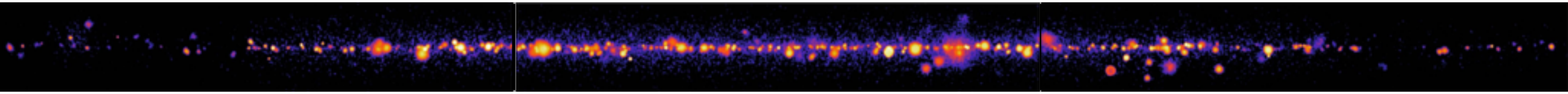
cherenkov telescope array



CTA Status & Perspectives

- A New Era in Gamma Ray Astronomy -

Johannes Knapp, DESY
for the CTA Consortium

Contents:

> Gamma-ray astronomy with
> Cherenkov telescopes
> Science Case
> The CTA concept
> CTA status & perspectives

Astro-Particle Physics

radio IR visible light UV X rays γ rays

the range of astroparticle physics

meV ... eV ... keV ... MeV ... GeV ... TeV ... PeV ... EeV ... ZeV

10^{-3} ... 1 ... 10^{3} ... 10^{6} ... 10^{9} ... 10^{12} ... 10^{15} ... 10^{18} ... 10^{21} eV

non-thermal processes

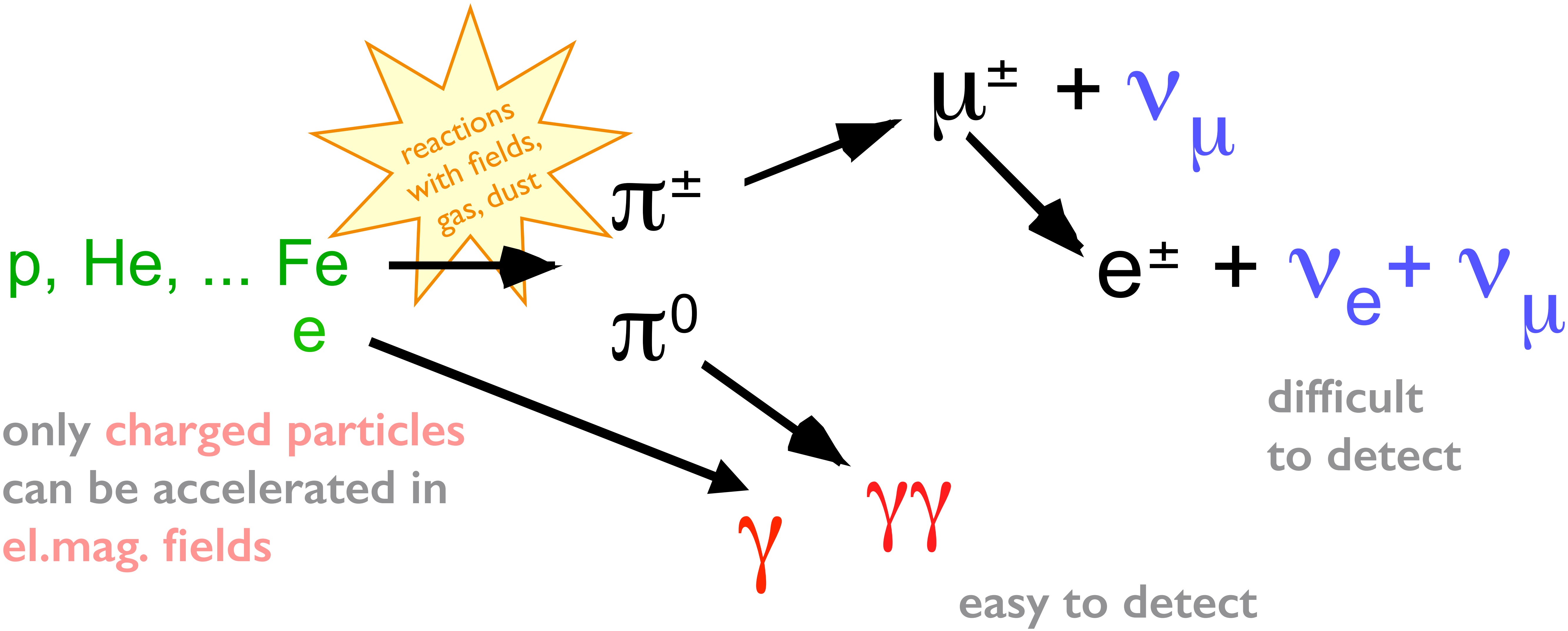
Photons: astronomy

charged: p, He, ... Fe, ... completely ionised nuclei

electrons

Neutrinos:

Cosmic rays, gamma rays and neutrinos come likely from the same sources



"multi-messenger astrophysics"

but gamma rays are currently the most "productive" messengers.

γ, ν

point back to sources
(good for astronomy)
but serious backgrounds

γ Rays:

pick them out of the CR background
point back at sources

< 100 GeV: direct observations on satellites

γ via direct identification

e.g. Fermi

> 100 GeV: indirect observations
via air showers

γ via shower shape, muon content

or via localised excess of events
from certain sky positions

IACTs

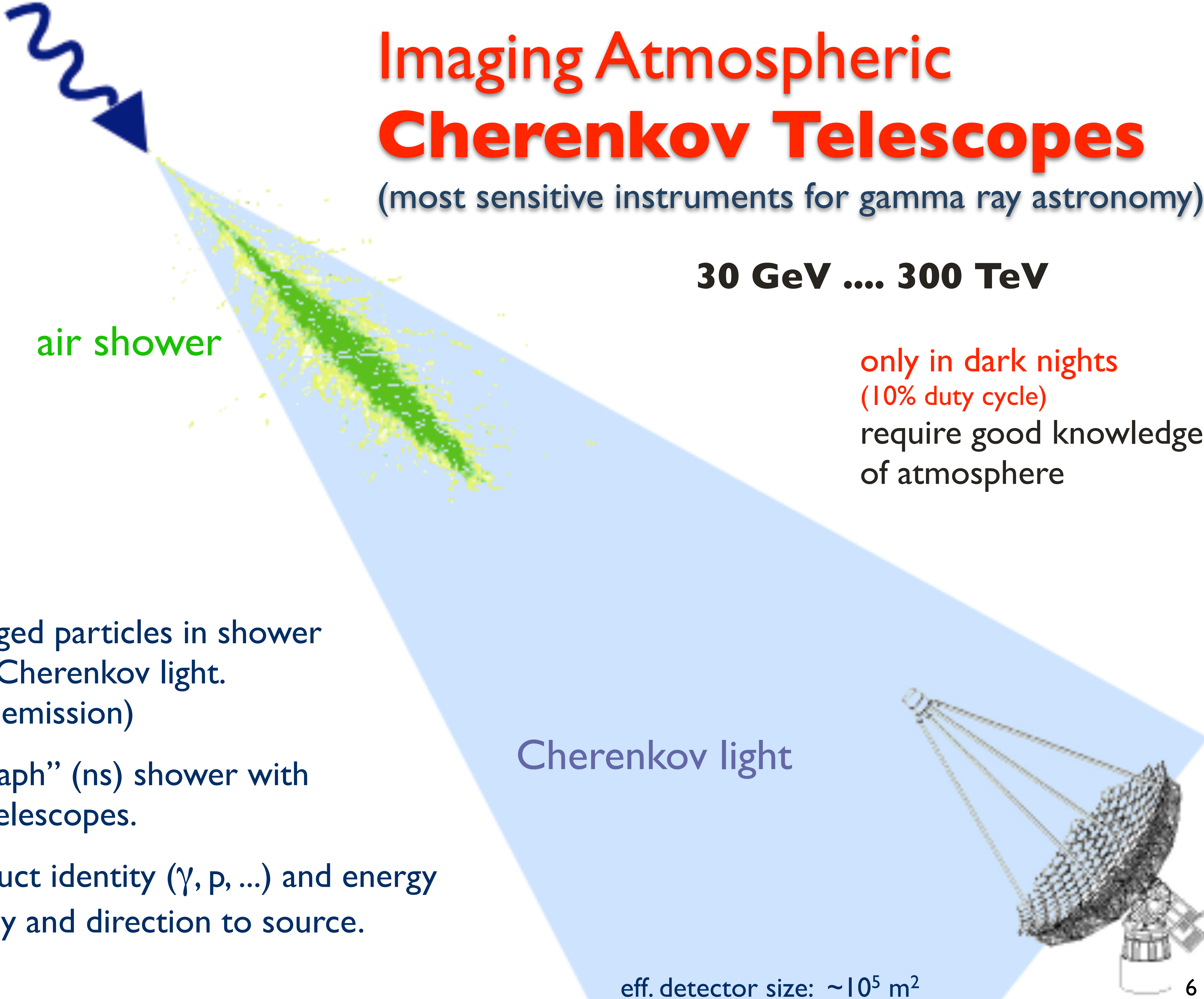
e.g. Tibet, Argo, HAWC, ...

Imaging Atmospheric **Cherenkov Telescopes**

(most sensitive instruments for gamma ray astronomy)

30 GeV .... 300 TeV

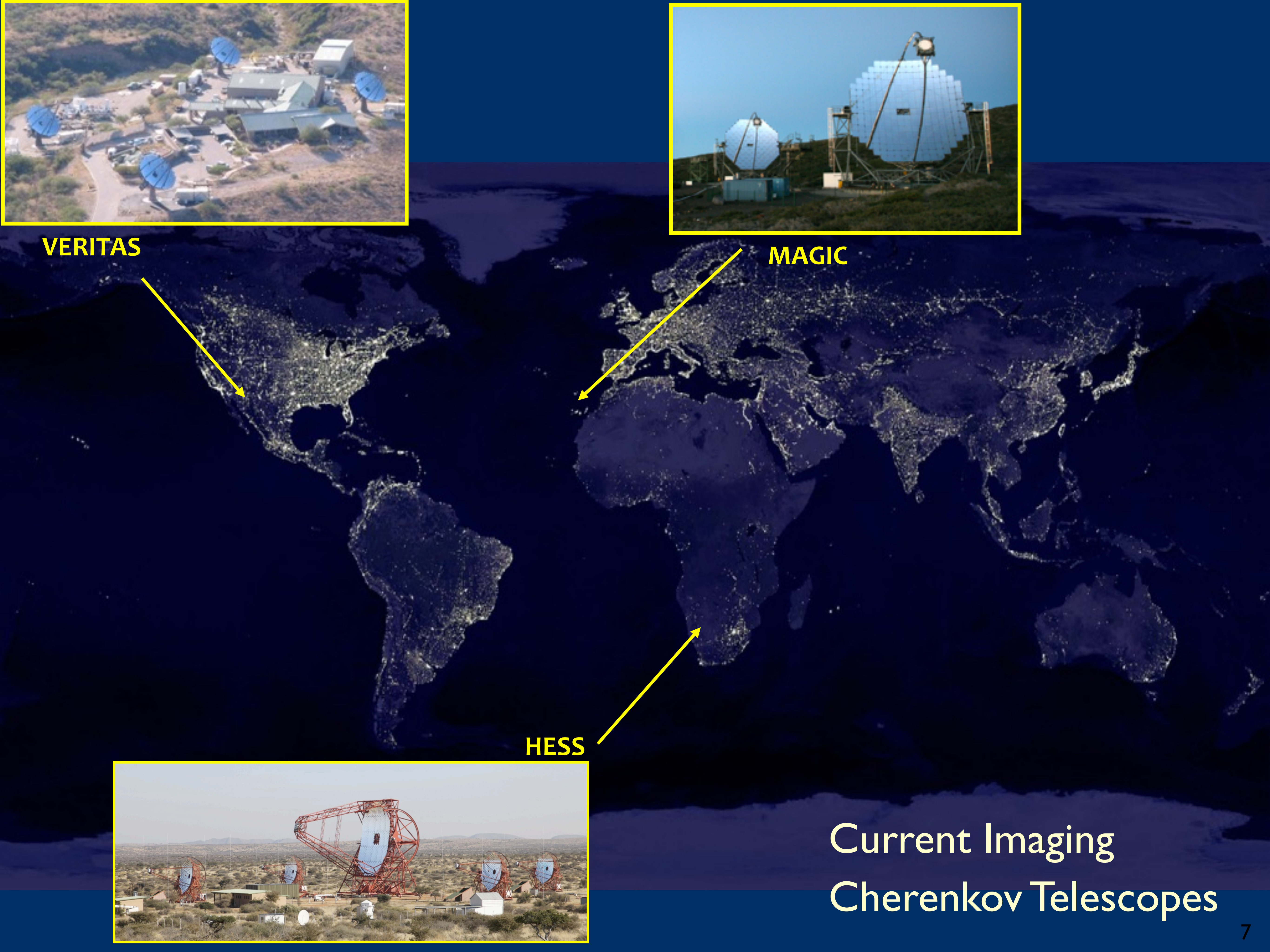
only in dark nights
(10% duty cycle)
require good knowledge of atmosphere



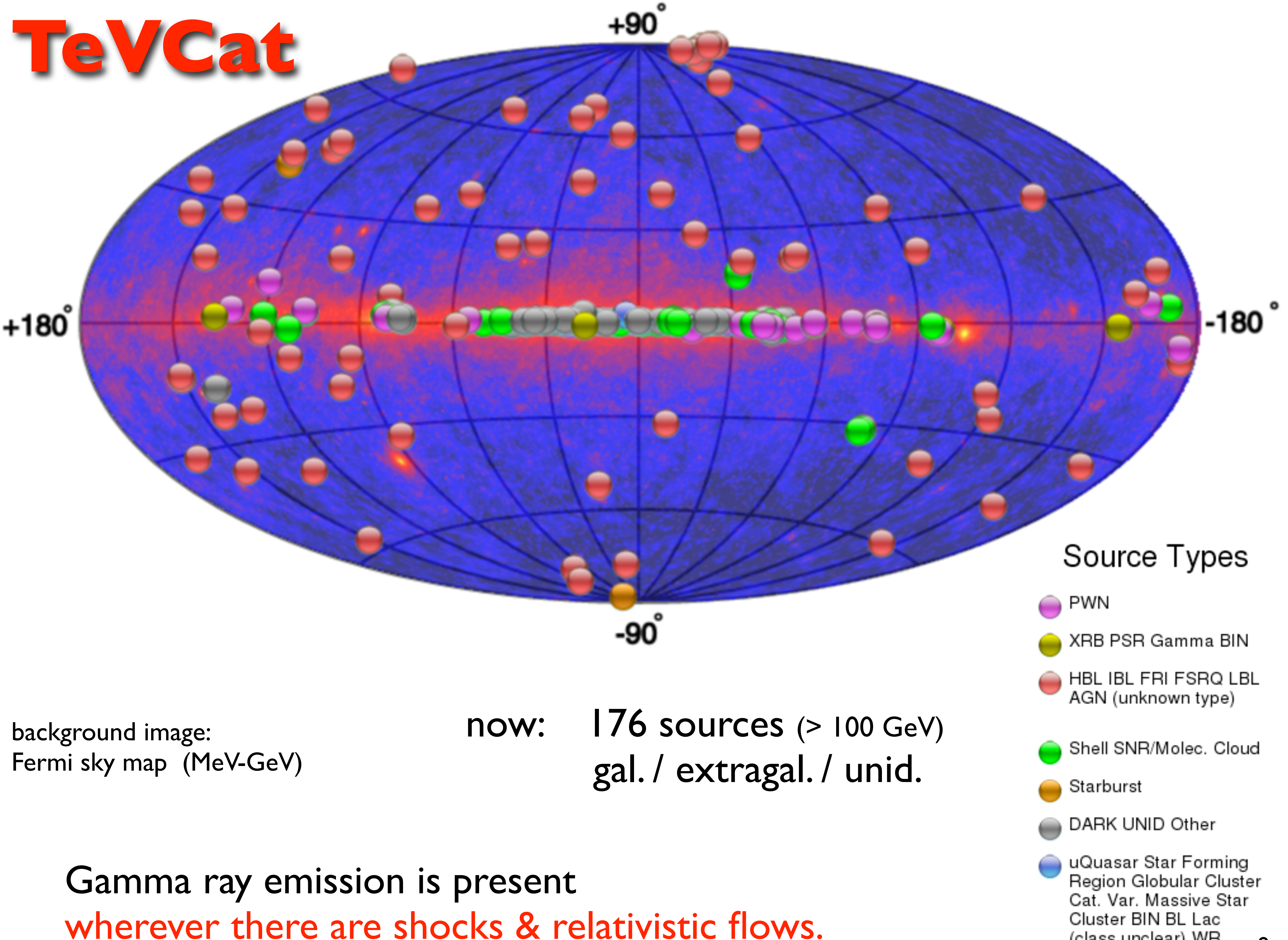
Fast charged particles in shower produce Cherenkov light. (forward emission)

“Photograph” (ns) shower with imaging telescopes.

Reconstruct identity (γ, p, ...) and energy of primary and direction to source.


VERITAS
MAGIC
HESS
Current Imaging
Cherenkov Telescopes

TeVCat



background image:
Fermi sky map (MeV-GeV)

now: 176 sources (> 100 GeV)
gal. / extragal. / unid.

Gamma ray emission is present
wherever there are shocks & relativistic flows.

Science Areas:

Cosmic energetic particles

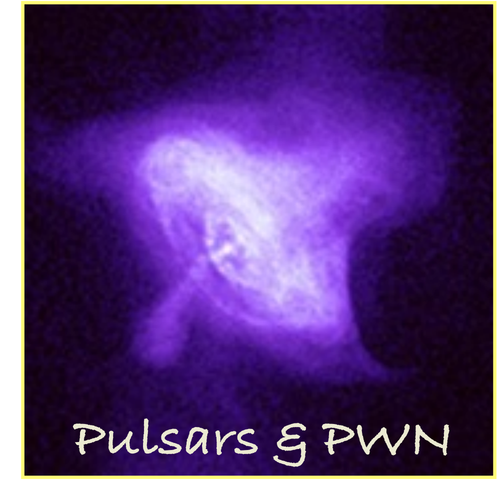
- Origin of the galactic cosmic rays
  - Also UHECR signatures
- Role of ultra-relativistic particles in in clusters of galaxies, AGN, Starbursts…
- The physics of (relativistic) jets and shocks

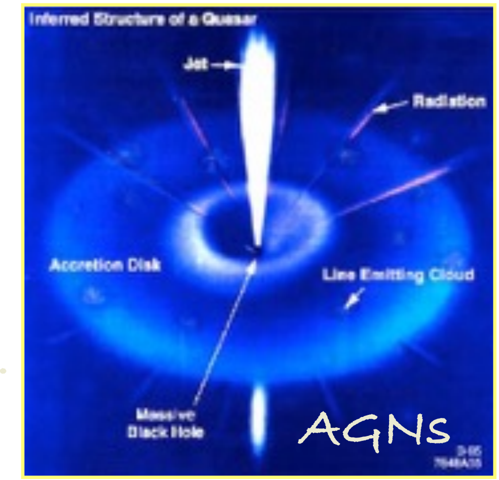
Fundamental Physics

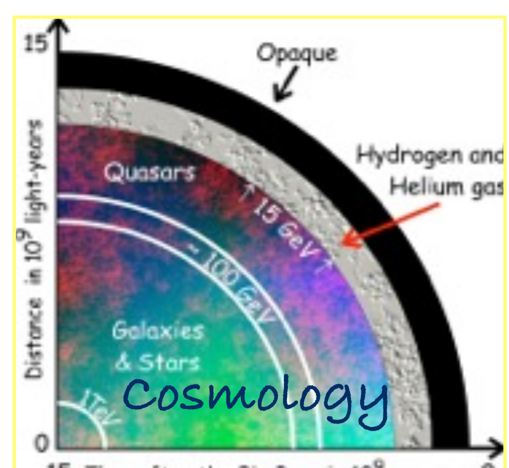
- Dark Matter annihilation / decay
- Lorentz Invariance violation

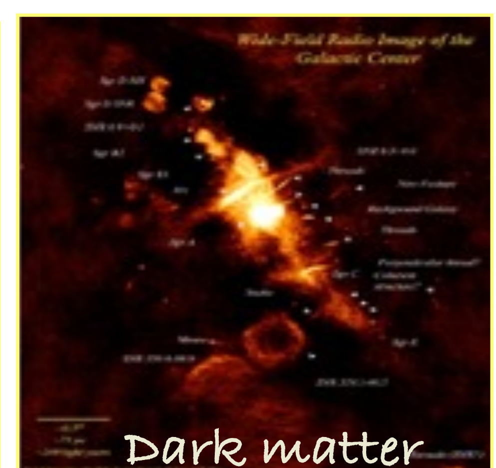
Cosmology

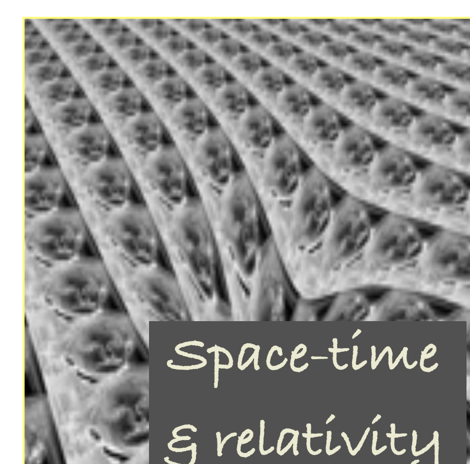
- cosmic FIR-UV radiation,
- cosmic magnetism











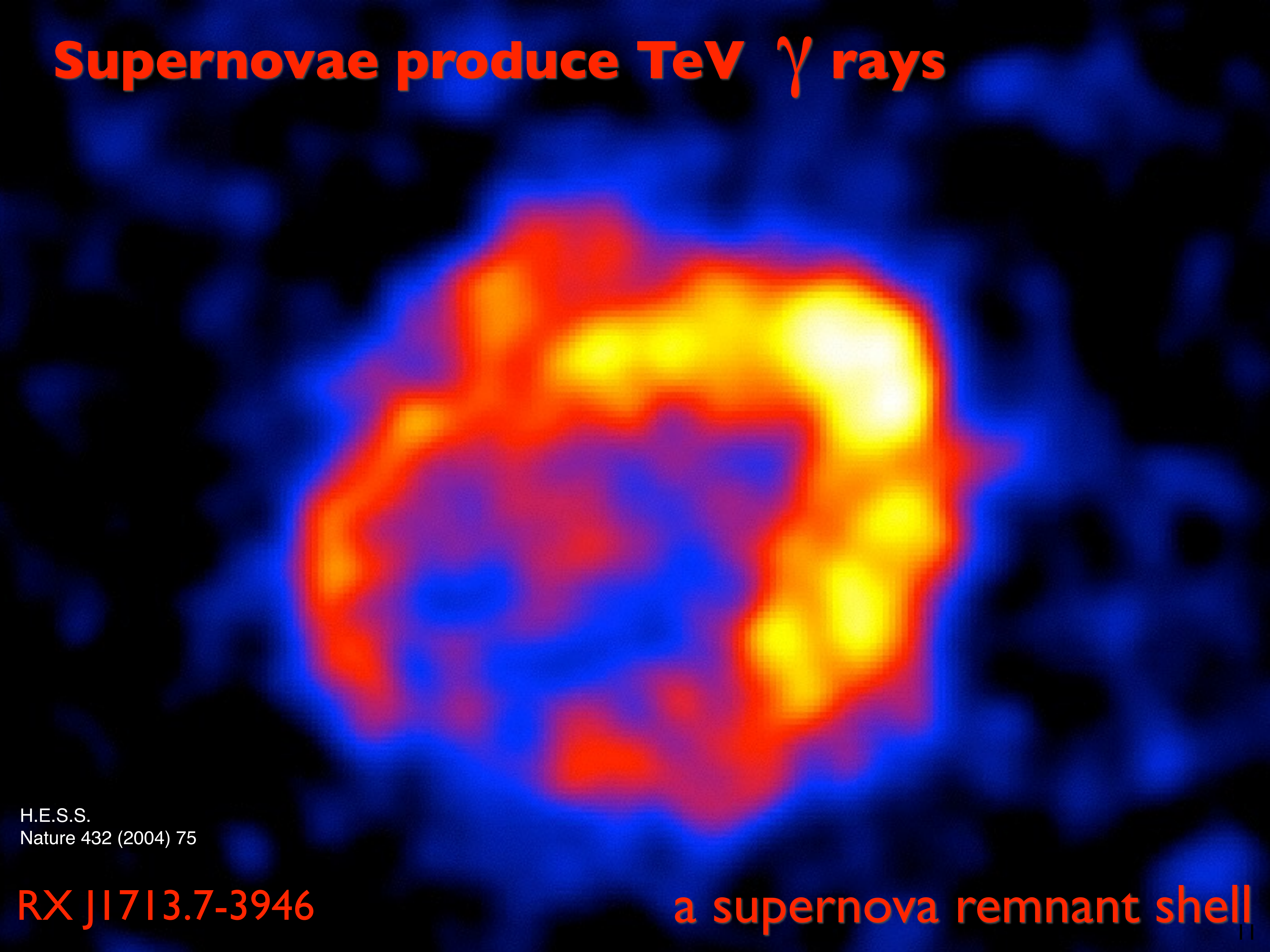
TeV astronomy highlights

from HESS, MAGIC and VERITAS
Descartes & Rossi Prize for HESS

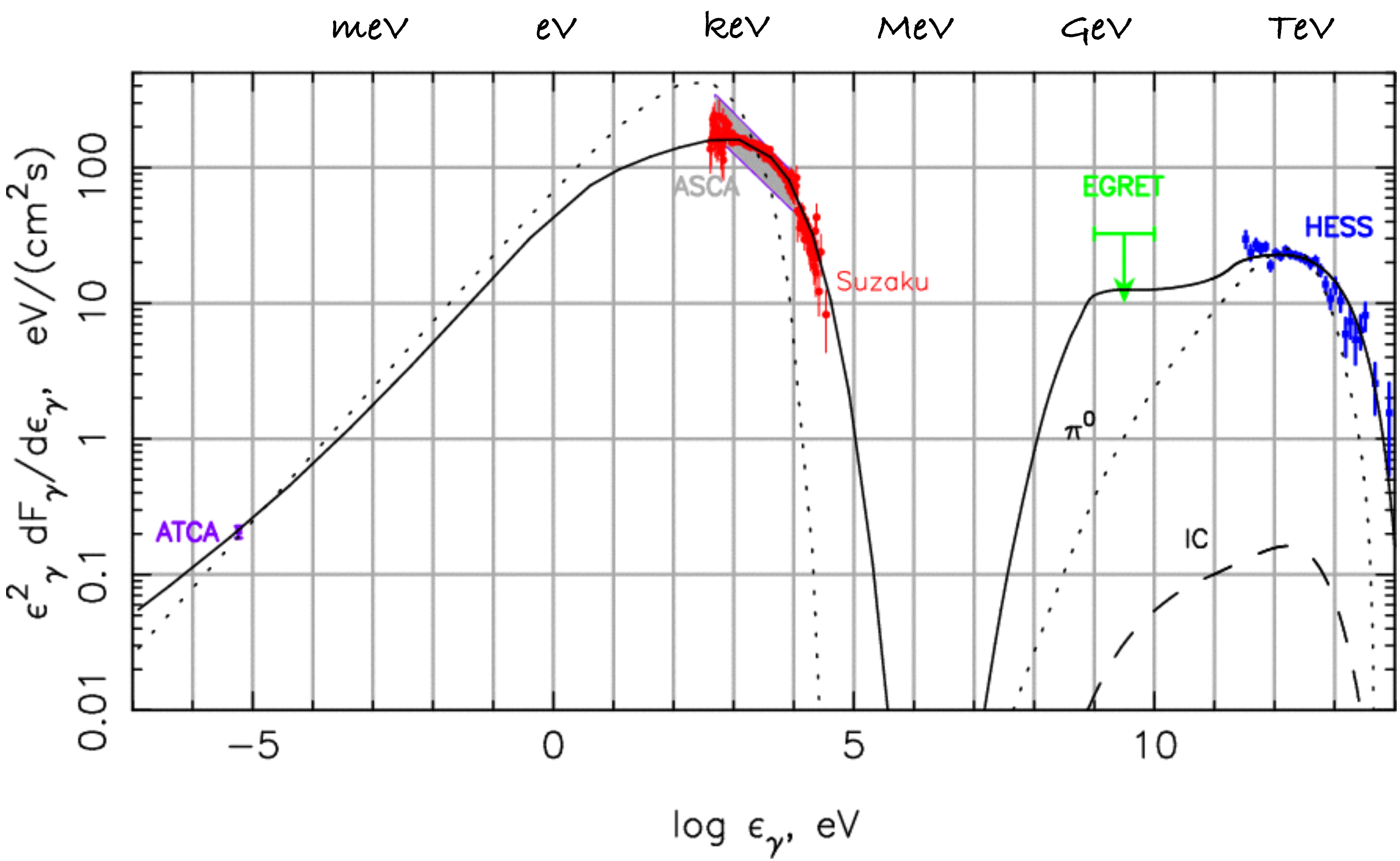
Supernova remnants:	Nature	432 (2004) 75		
Microquasars:	Science	309 (2005) 746	Science	312 (2006) 1771
Pulsars:	Science	322 (2008) 1221	Science	334 (2011) 69
Galactic Centre:	Nature	439 (2006) 695	Nature	531 (2016) 476
Galactic Survey:	Science	307 (2005) 1839		
LMC:	Science	347 (2015) 406		
Black Holes:	Science	346 (2014) 1080		
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 (2011) 161301
	PRL	114 (2015) 081301	PRL	110 (2013) 41301
Lorentz Invariance:	PRL	101 (2008) 170402		
Cosmic Ray Electrons:	PRL	101 (2008) 261104		

+ many papers in other journals
… a booming field.

Supernovae produce TeV γ rays

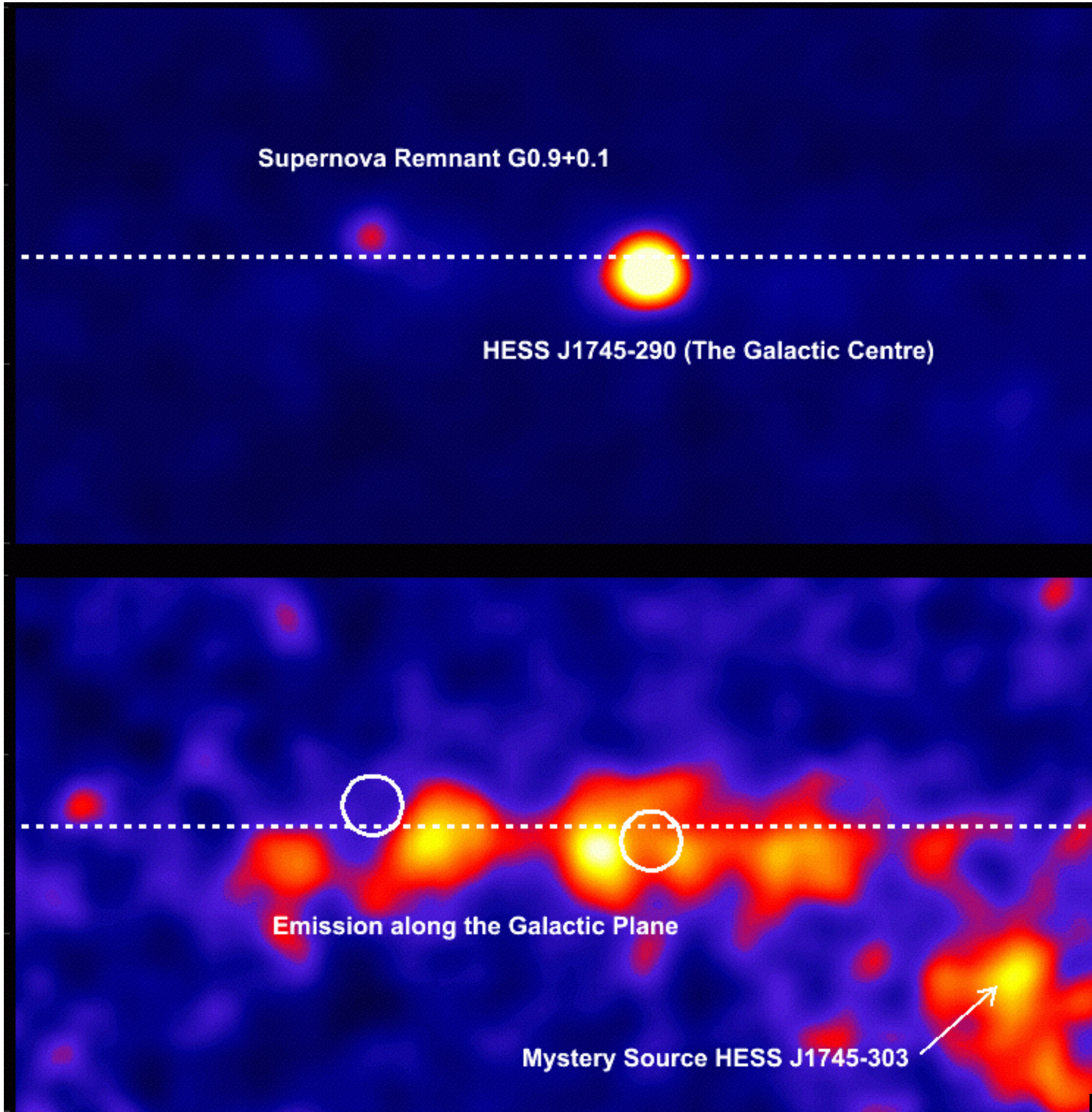


Supernova Remnant RX J1713.7-3946



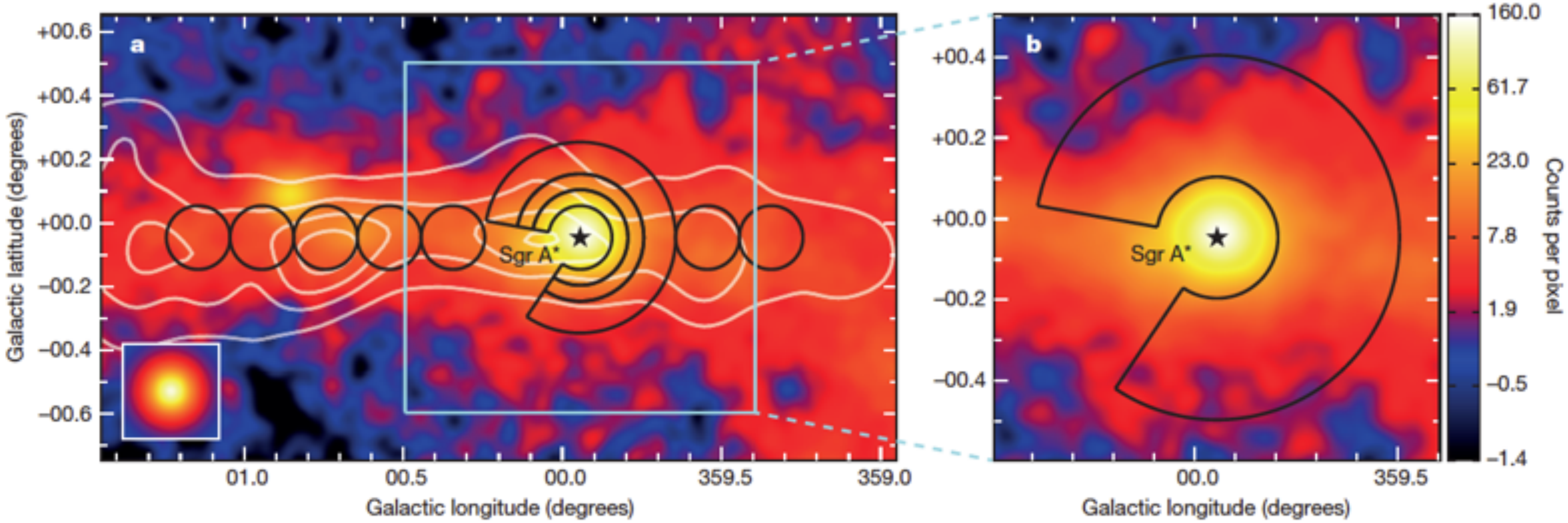
Galactic centre

H.E.S.S.
Nature 439 (2006) 695



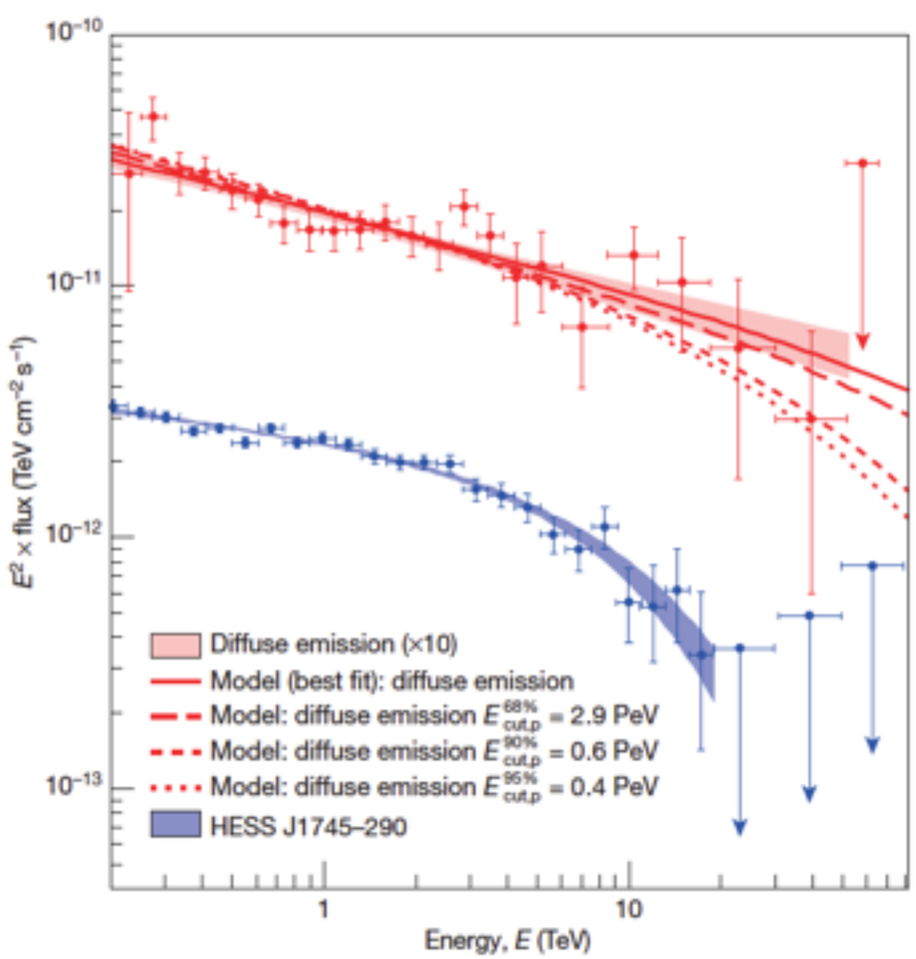
CRs interact with molecular clouds

A PeV-atron in our Galactic centre (?)



H.E.S.S..
Nature 531 (2016) 476

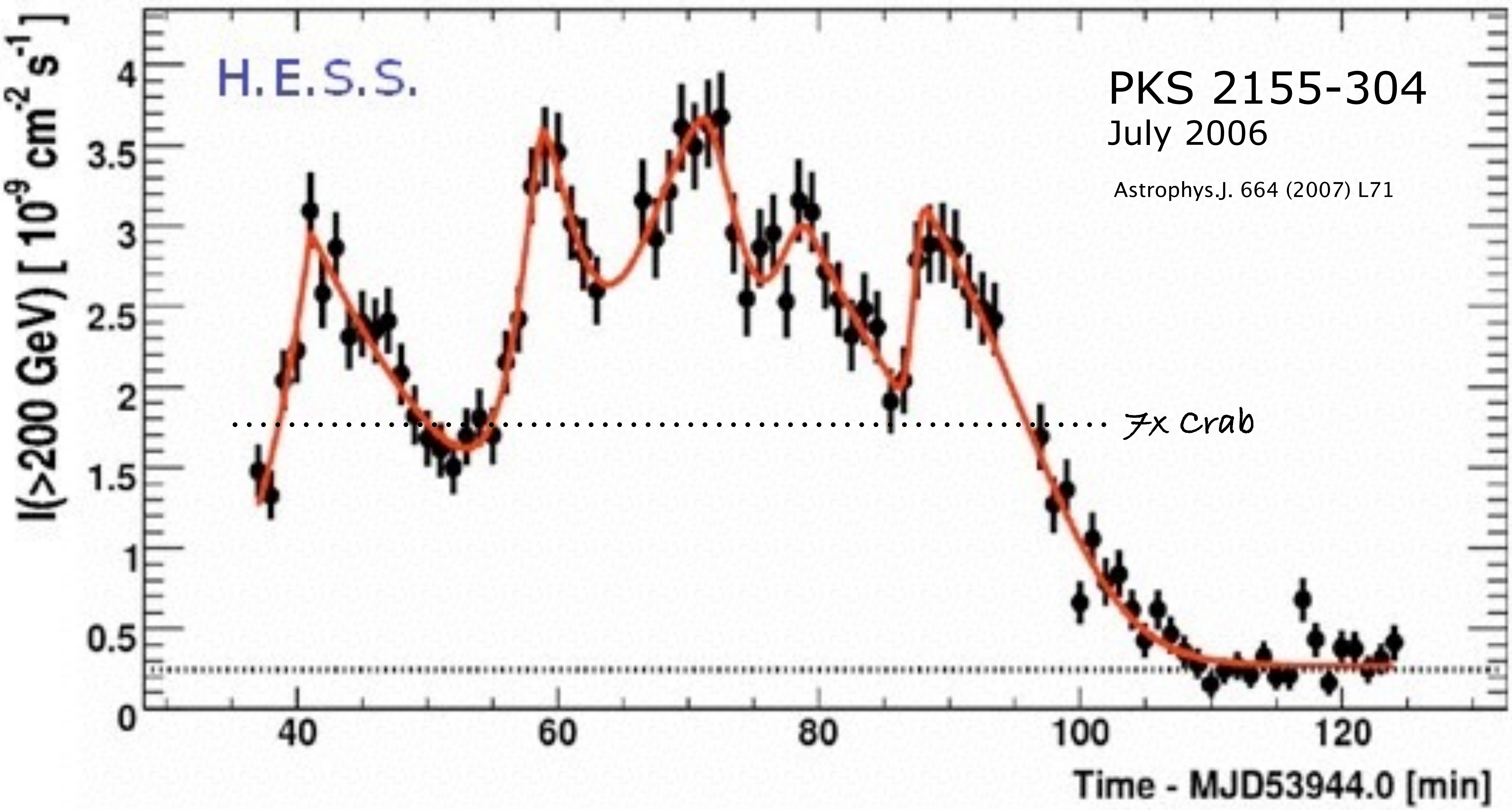
data from 2004-15



Very hard spectrum, no indication of cutoff

requires protons of ≥ 10^{15} eV,
i.e. a **PeV-atron**

Variability



BL Lac object $z = 0.116$

bursts on minute scales

$\Gamma \geq 100$ are required for a single zone SSC

Gamma Rays are ubiquitous:

many sources / source types
complex structures in space, time and energy

test extreme end of high-energy phenomena
complement observations at longer wavelengths
with other particles

The Imaging Atmospheric Cherenkov technique
is not yet at its limit:

Big improvements are possible with existing technology.

The future with

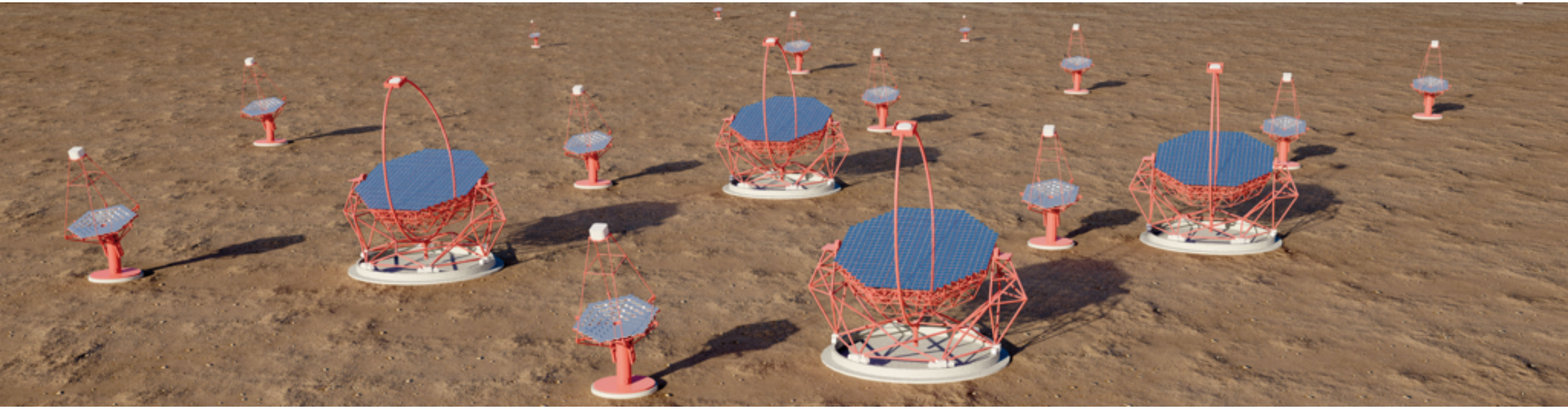
cta
cherenkov telescope array

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

CTA is the global, next-generation project
with largely enhanced performance and energy range
two observatories (South and North),

probing the **extreme universe** with huge potential for
high-energy astronomy and fundamental physics.

www.cta-observatory.org



full-sky coverage (2 observatories).

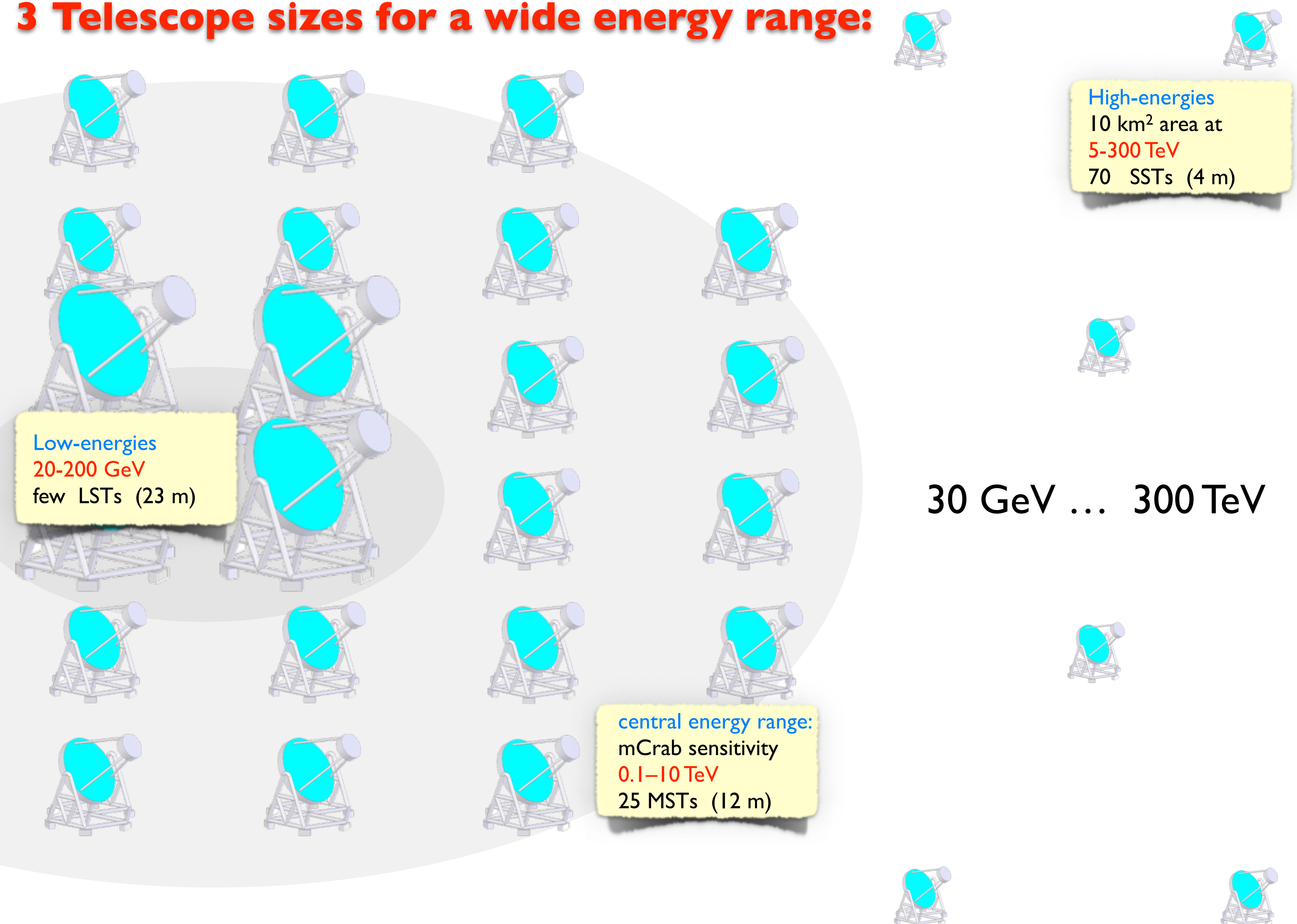
10x more sensitive than current instruments,

much **wider energy coverage** and **field of view**,

substantially **better angular** and **energy resolution.**

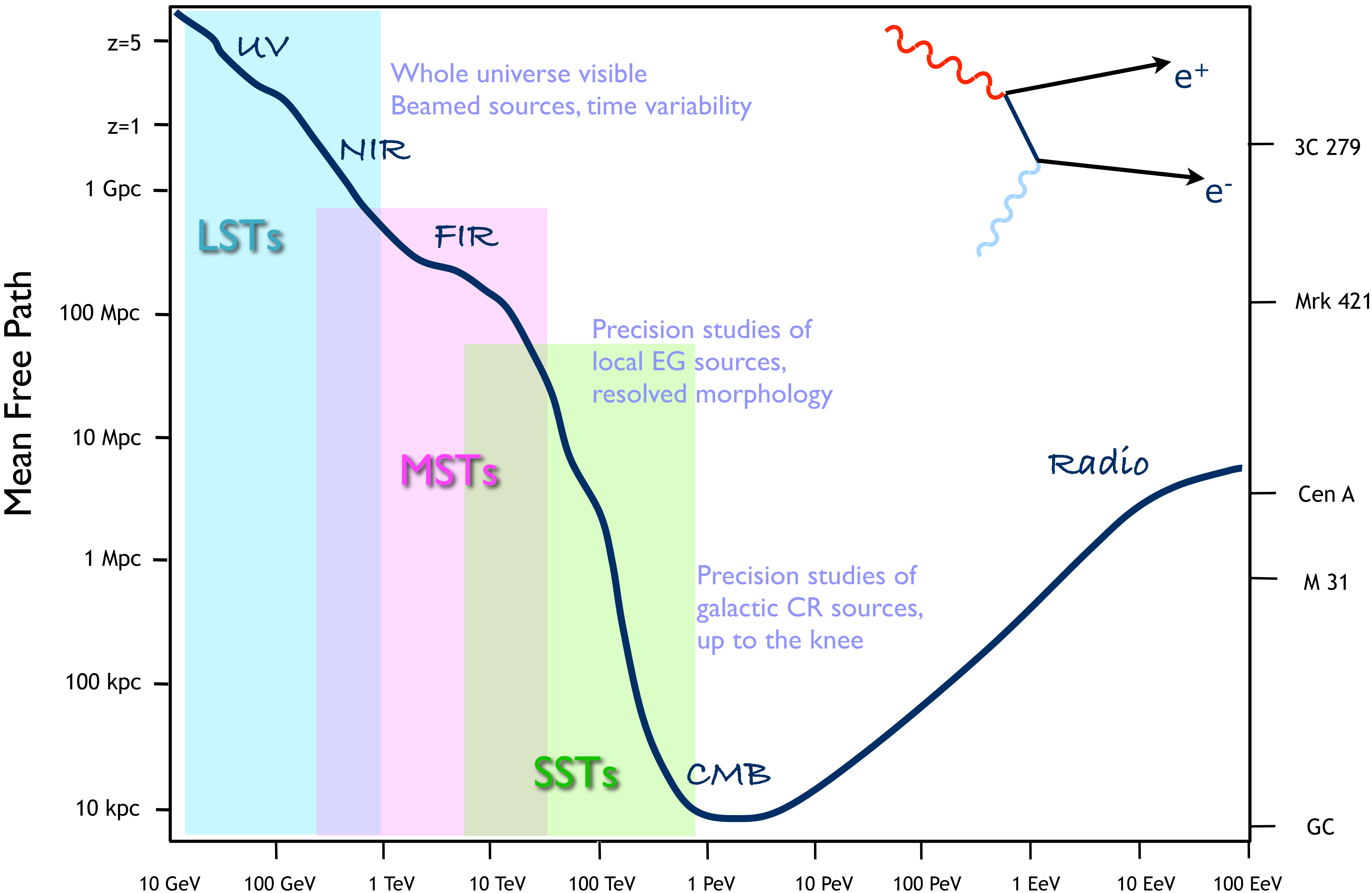
Telescopes + array control + data analysis + infrastructure +
≈ 300 M€ total invest + 100 M€ manpower

3 Telescope sizes for a wide energy range:

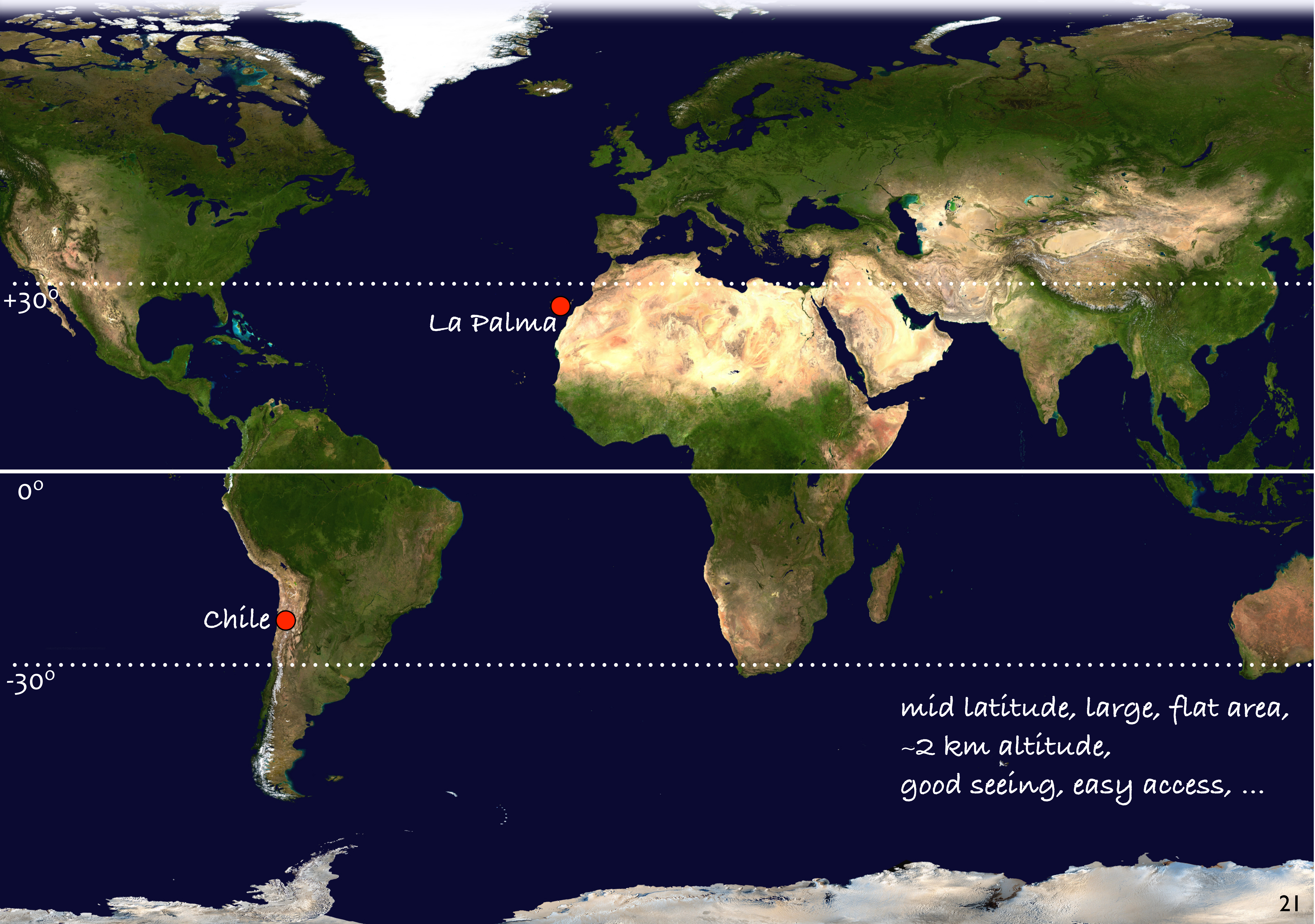


Not to scale !

The Gamma-Ray Horizon $\gamma_{VHE} + \gamma \longrightarrow e^+e^-$



One observatory with two sites

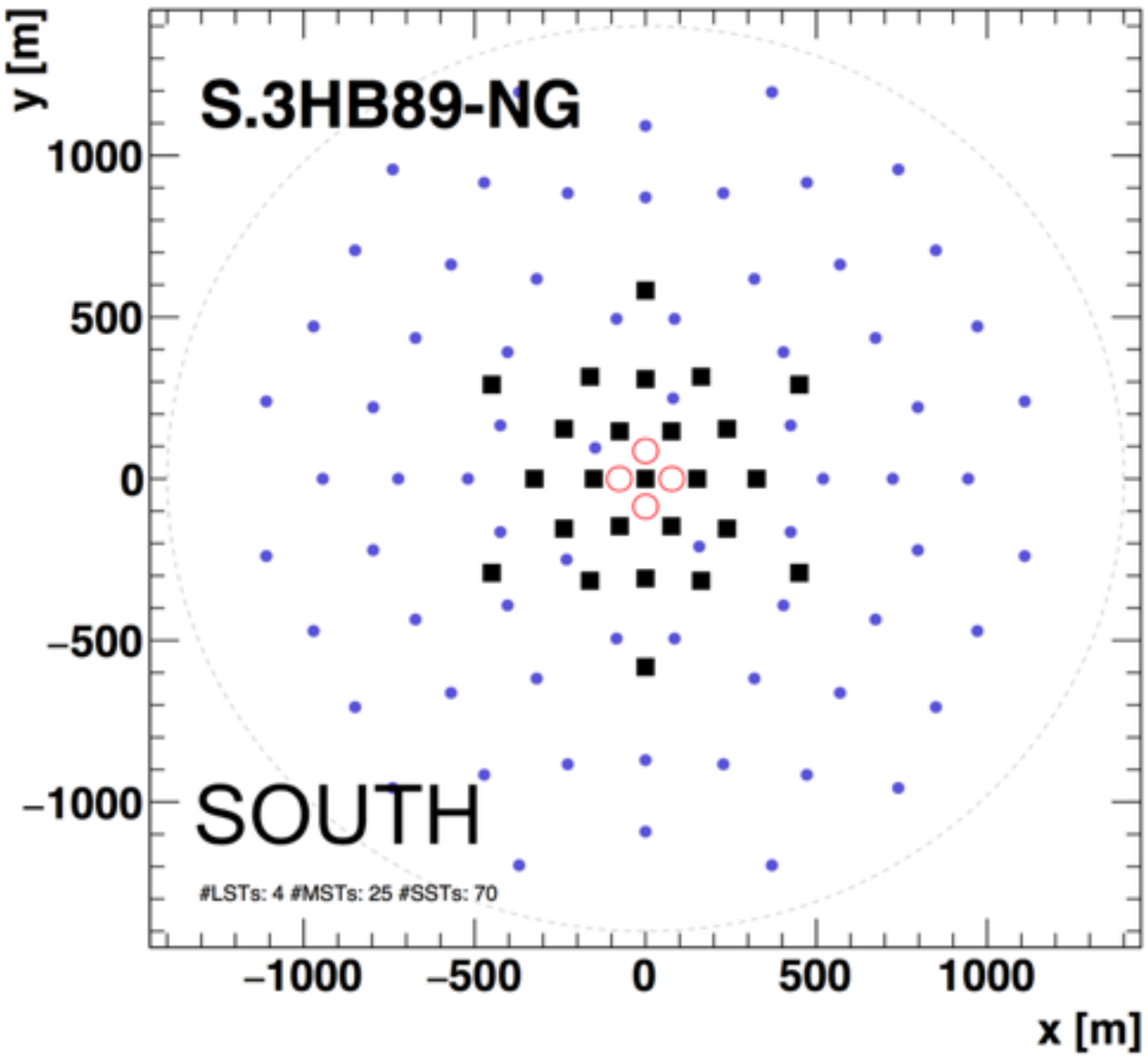


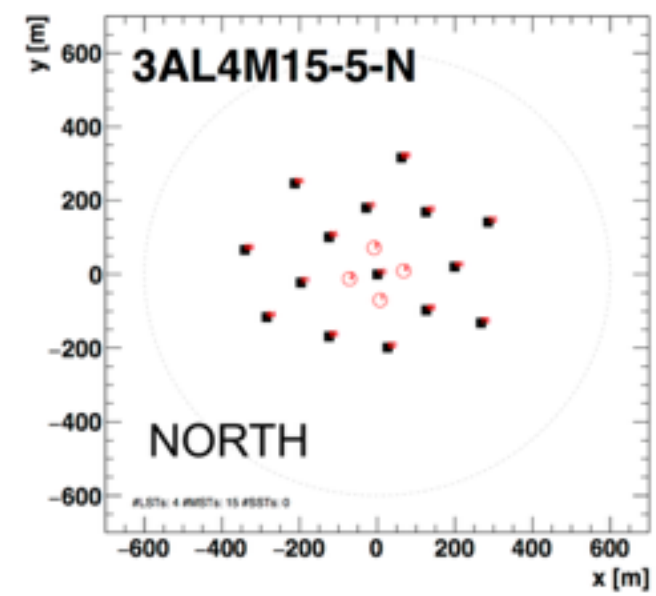
La Palma, Spain (near MAGIC site)

Paranal, Chile (ESO site, Atacama desert)

Baseline Arrays

South: 4 LSTs 25 MSTs 70 SSTs **North: 4 LSTs 15 MSTs**



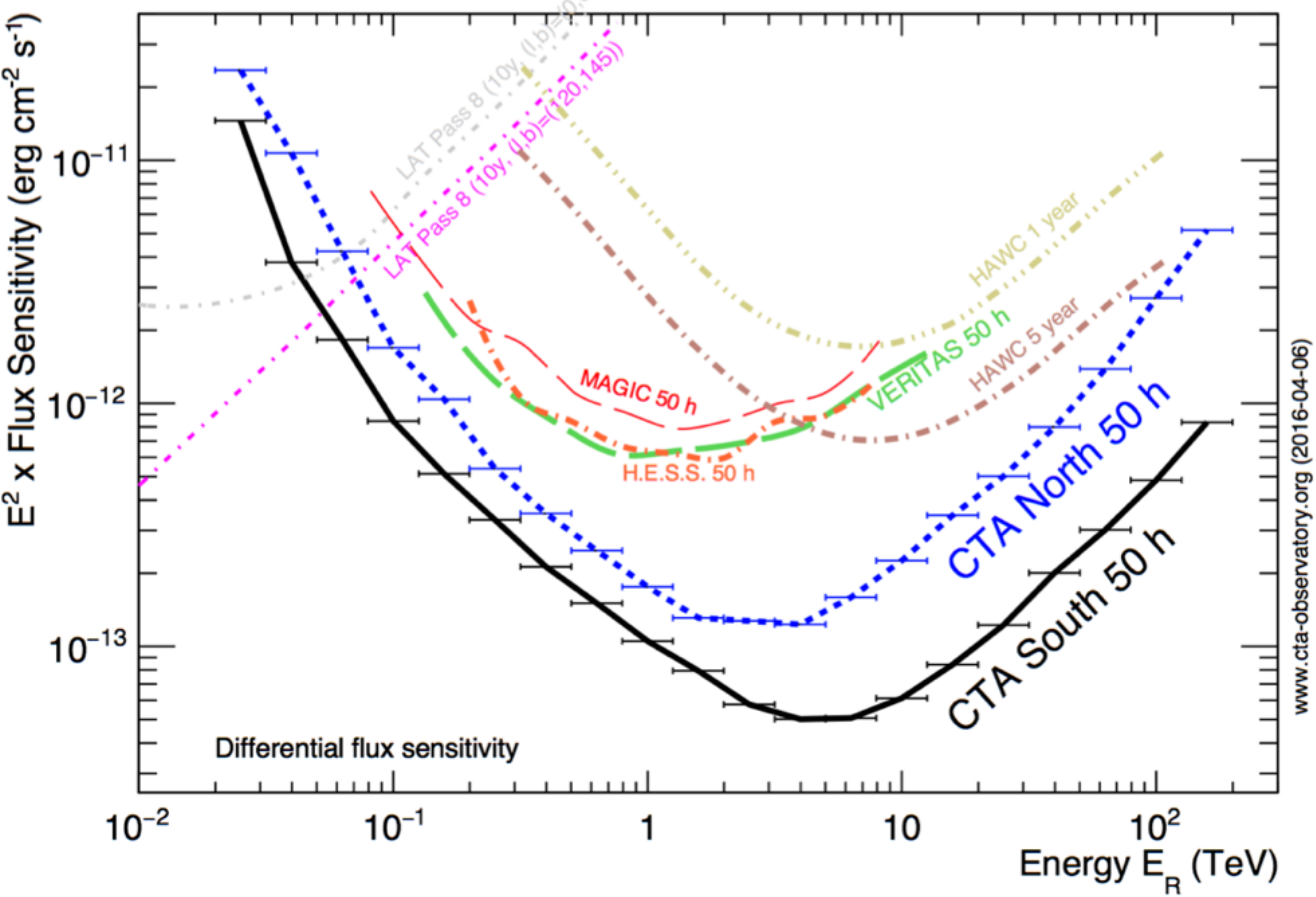


to scale

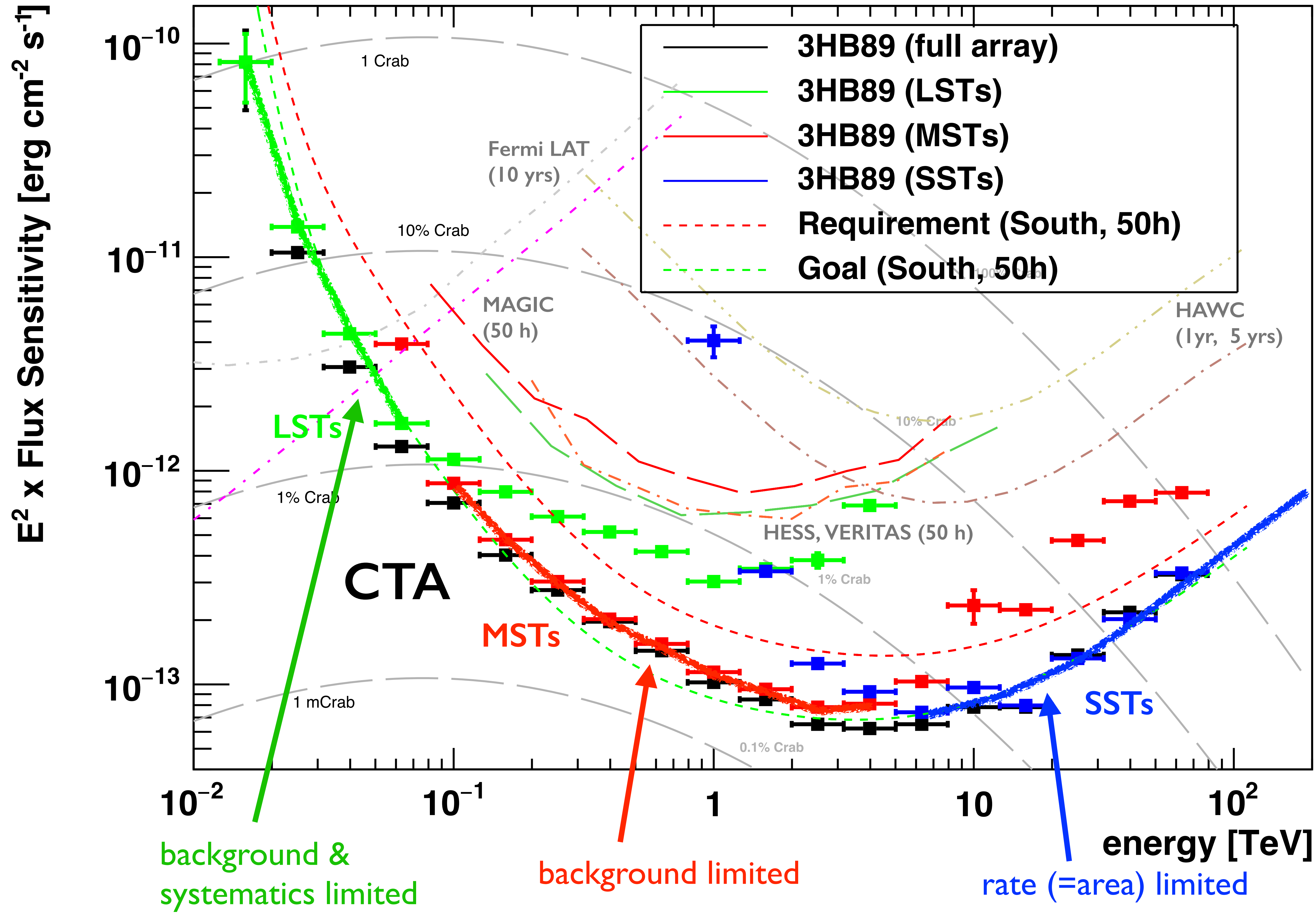
full energy range

mainly low energies

Sensitivity to point sources

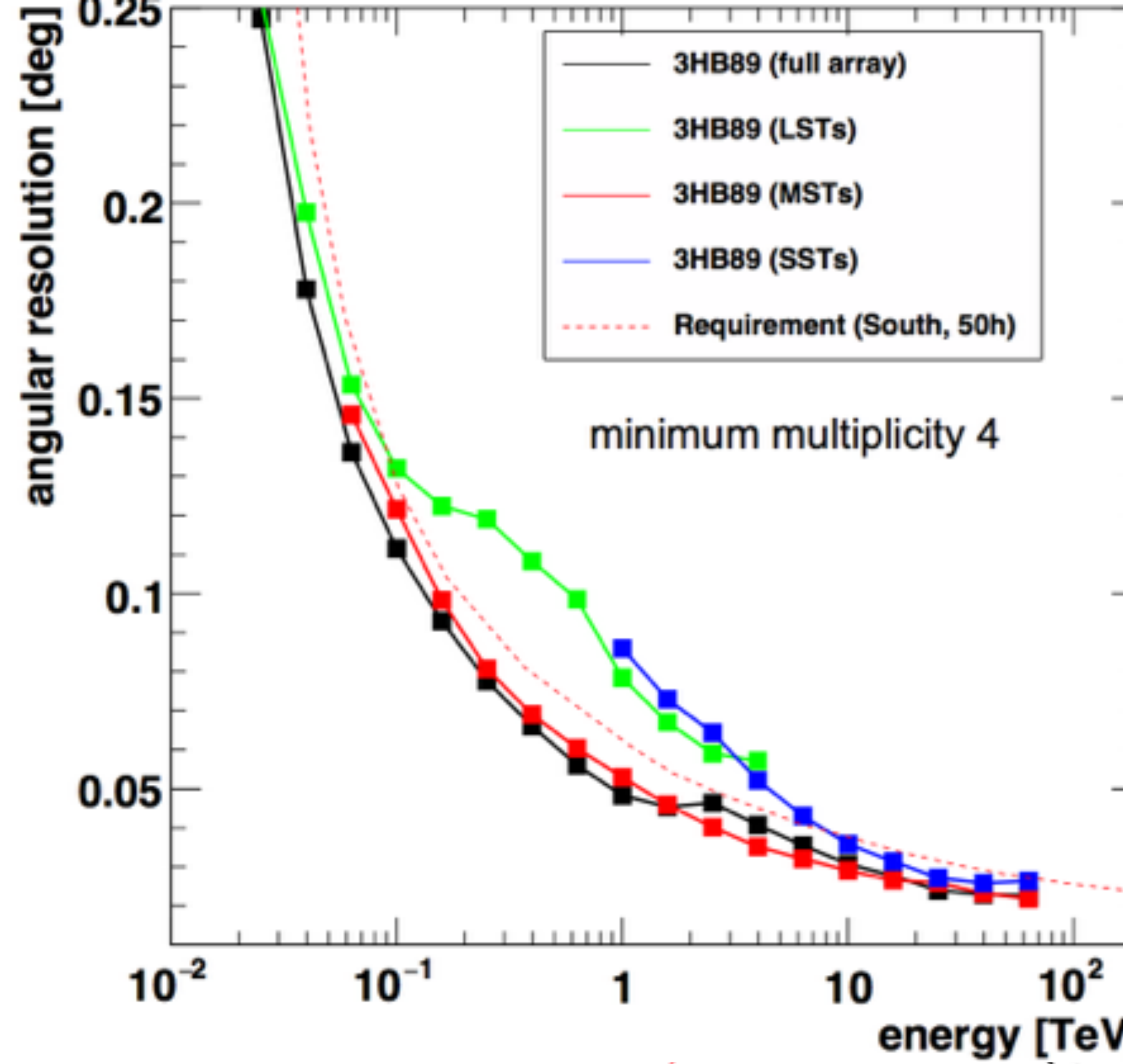


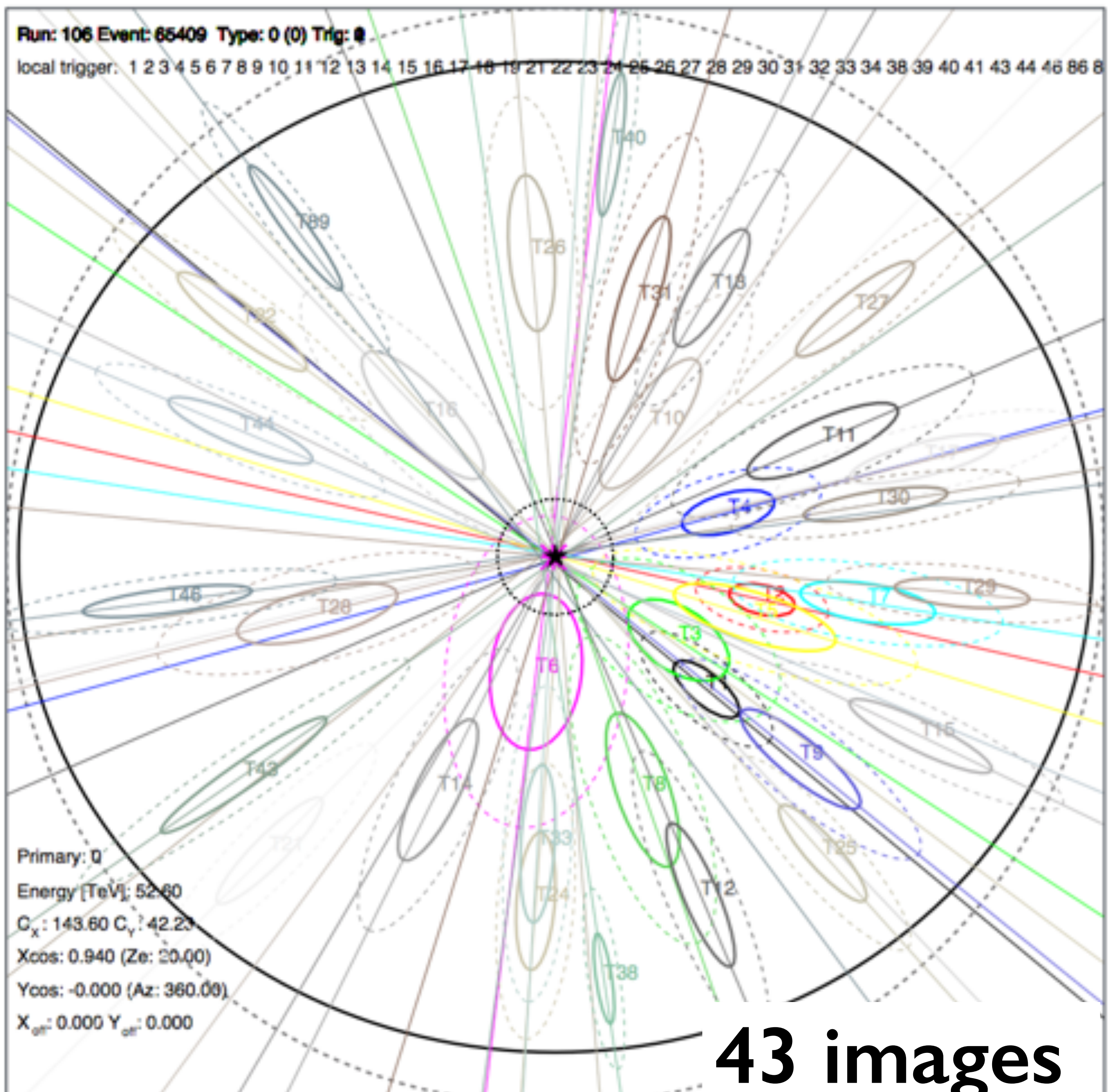
3 telescope sizes for a wide energy coverage



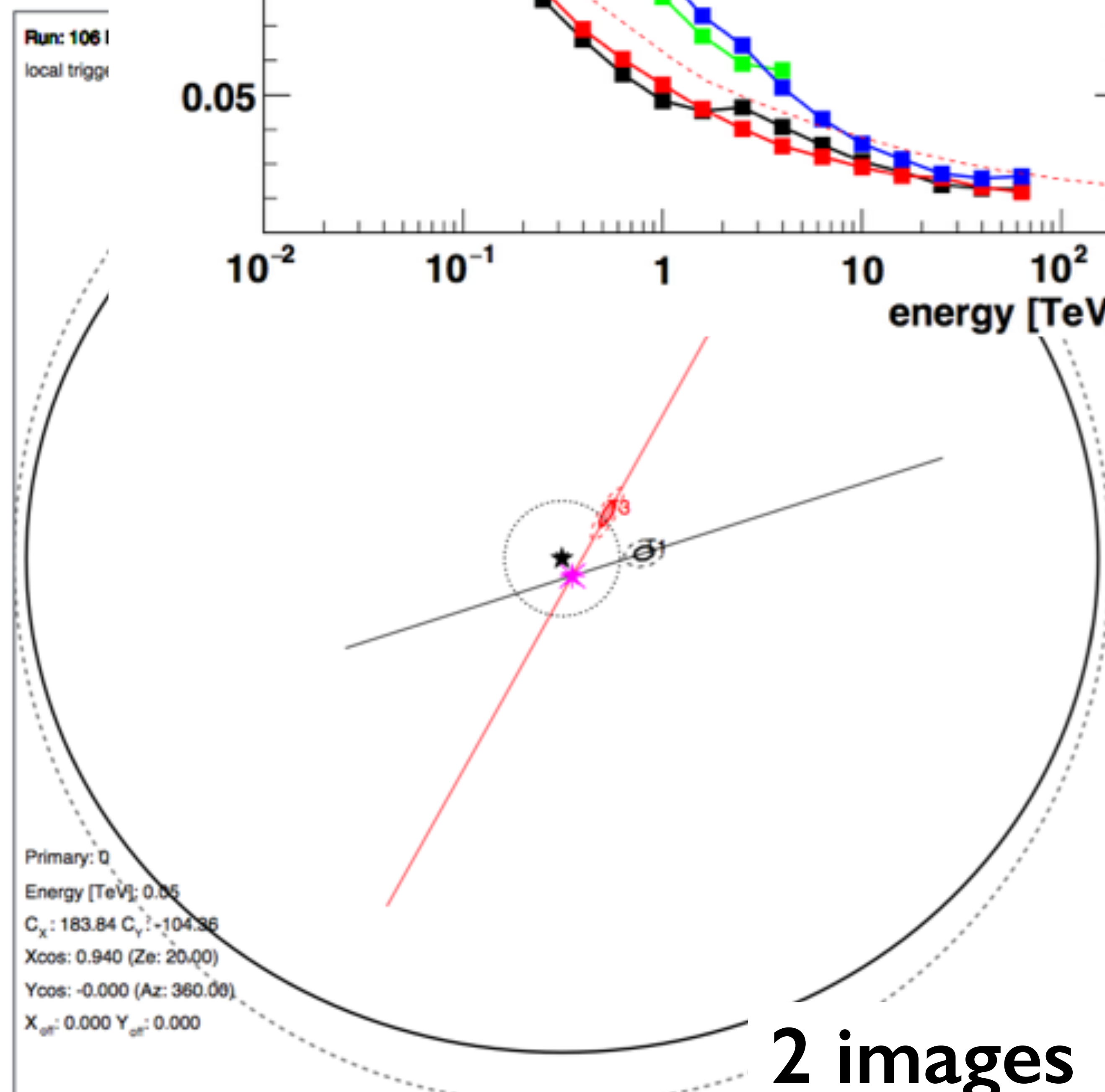
Angular Resolution:

< 0.1° for ≥ 5 images
or for E > 100 GeV (≥ 4 images)





43 images

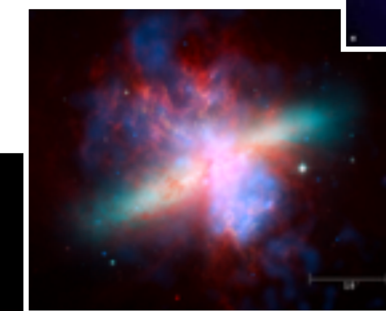


2 images

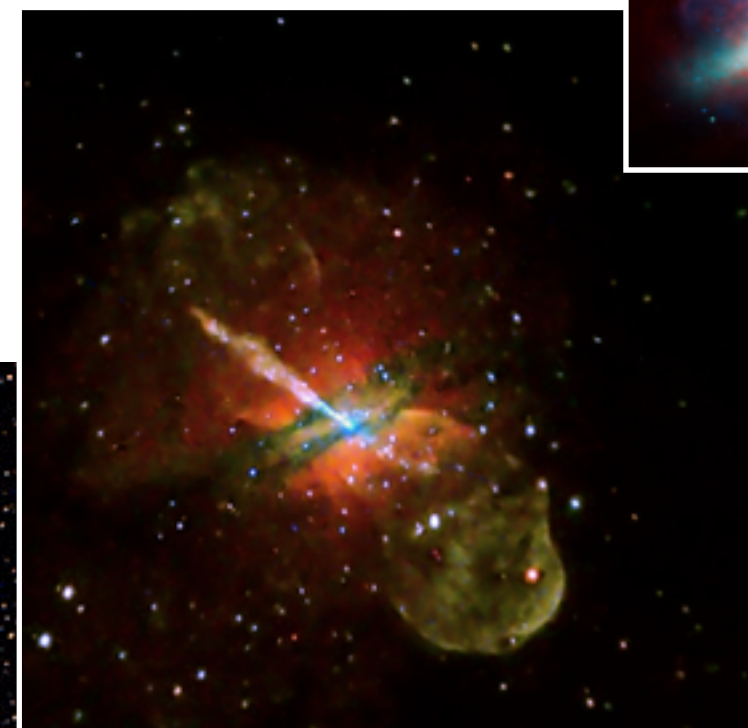
… allows study of morphologies

Hydra A

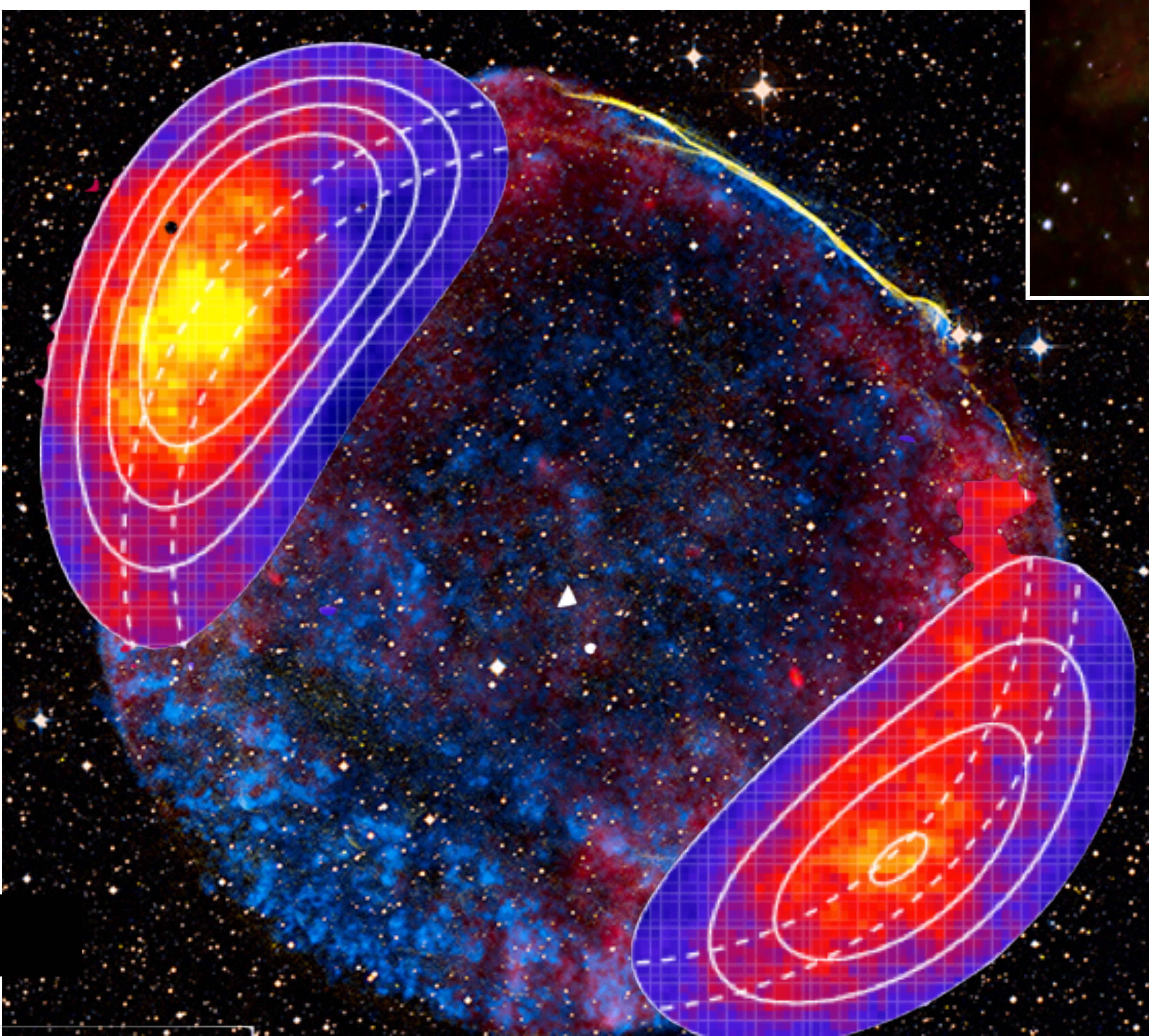
M 82

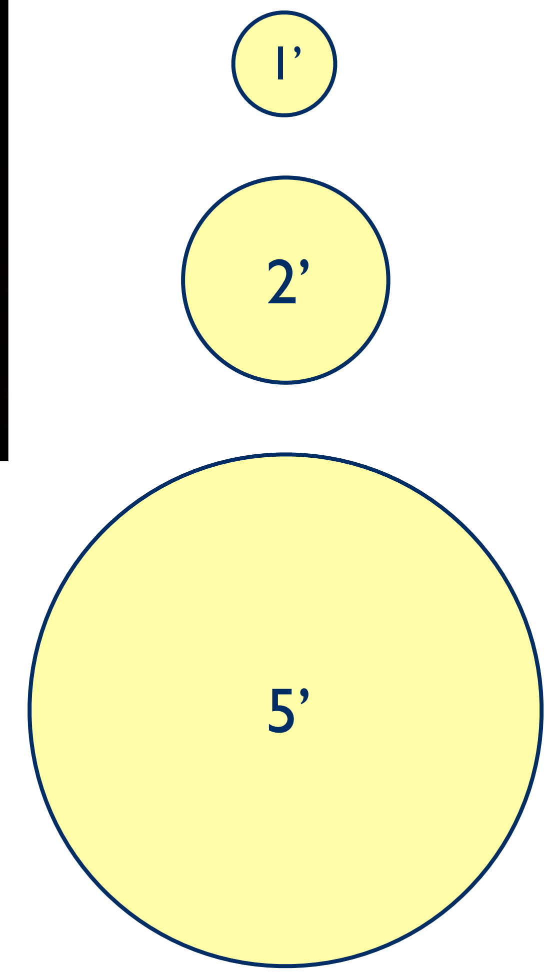


Cen A

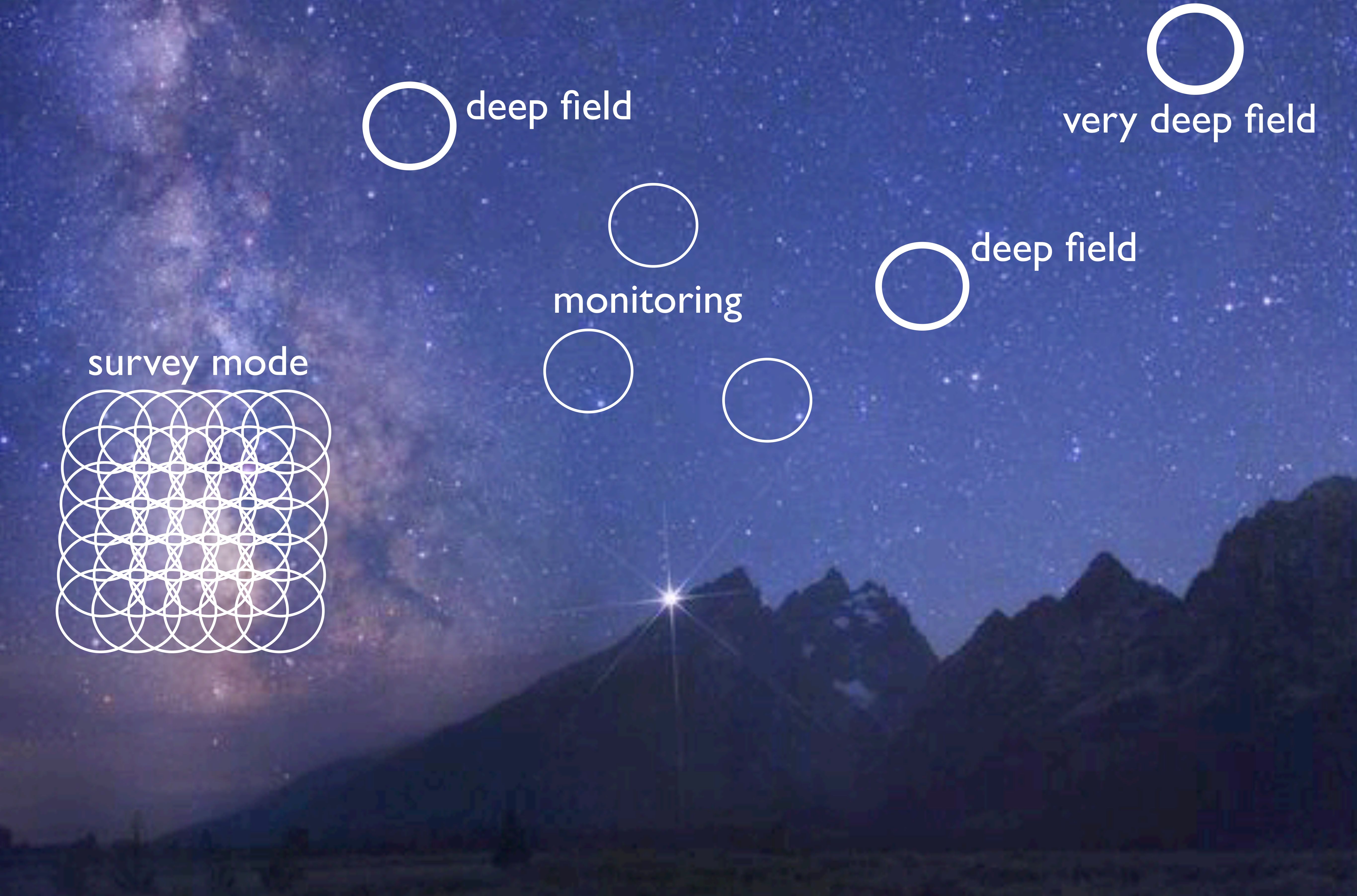


SN 1006



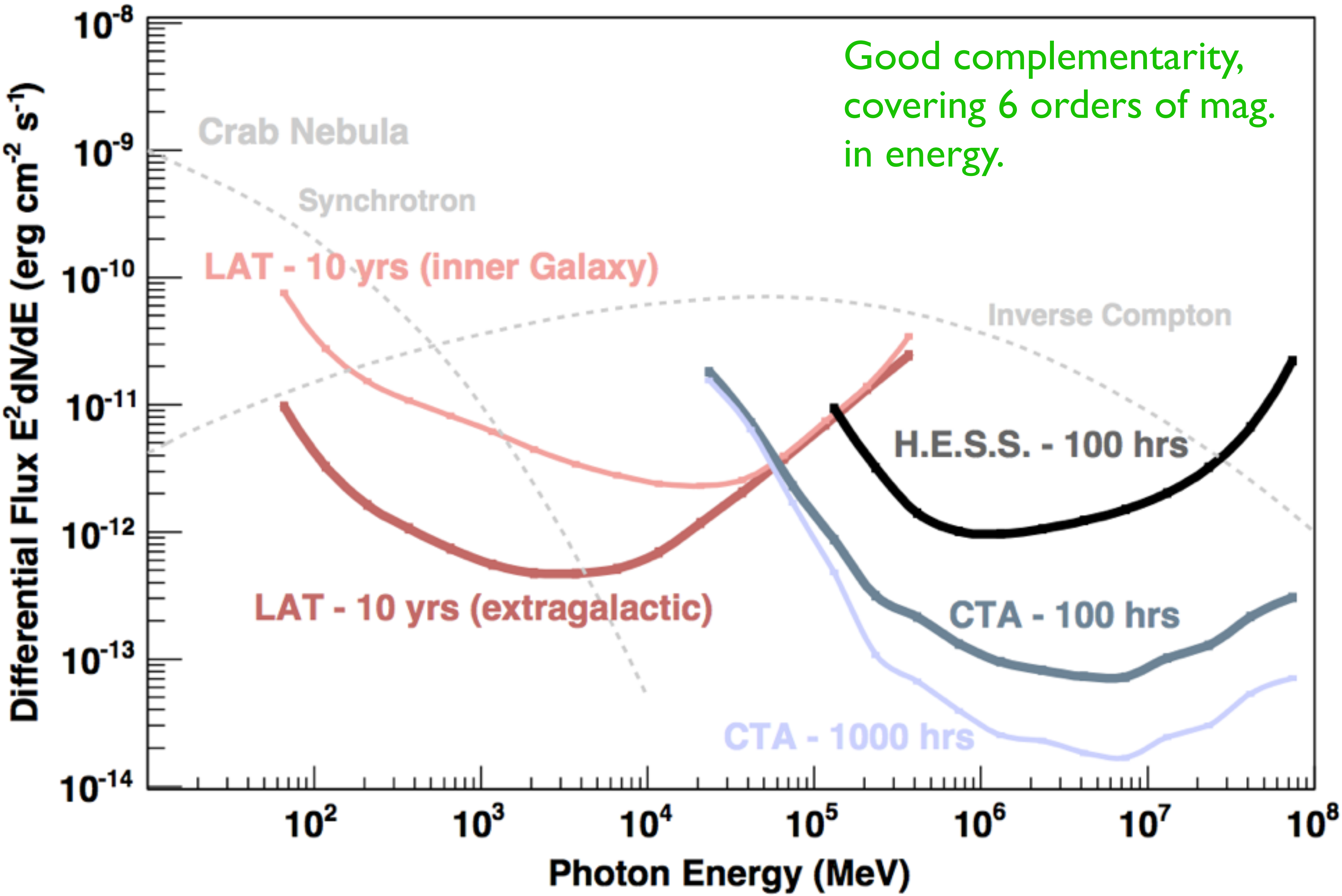


CTA observation modes



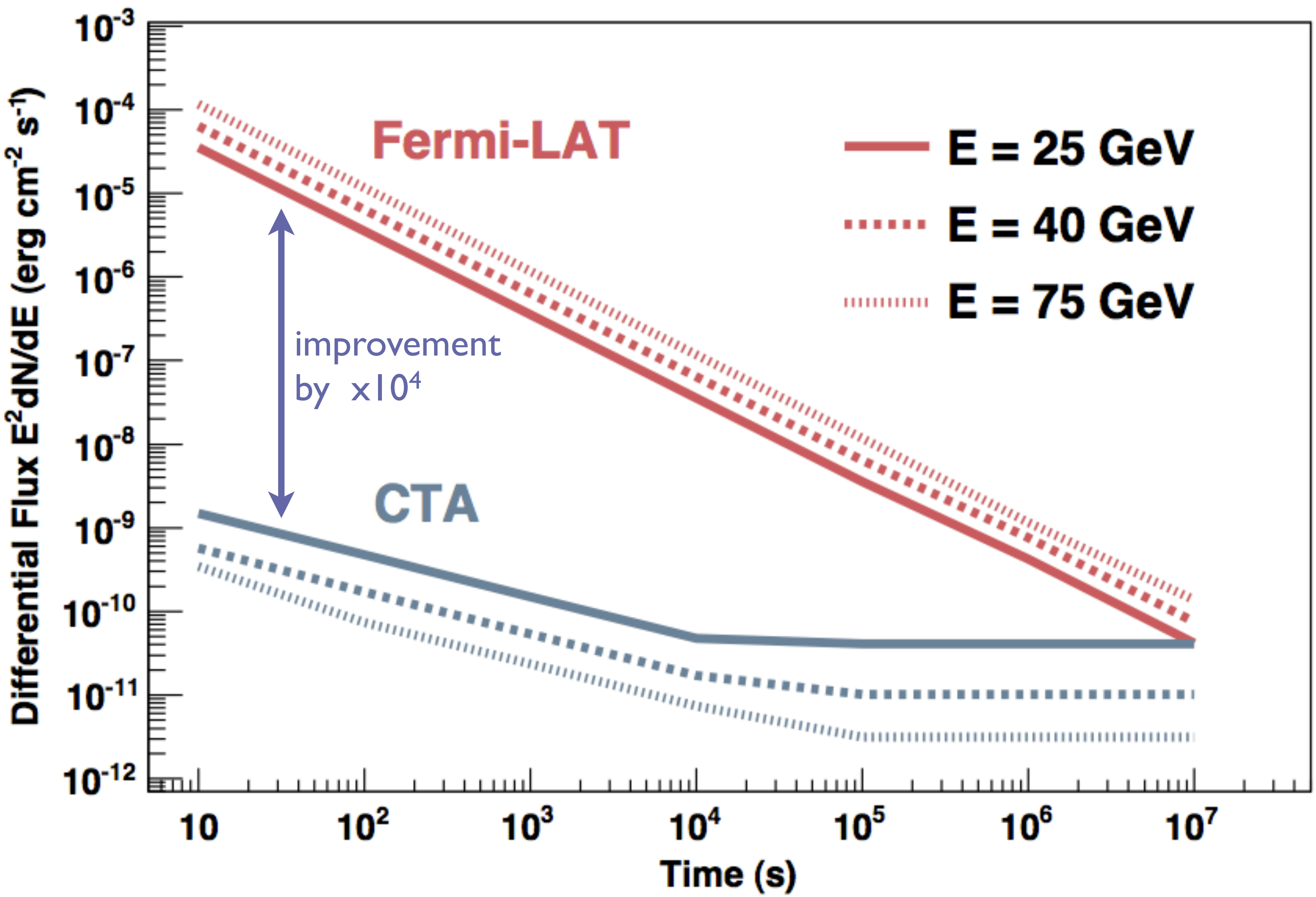
CTA and Fermi

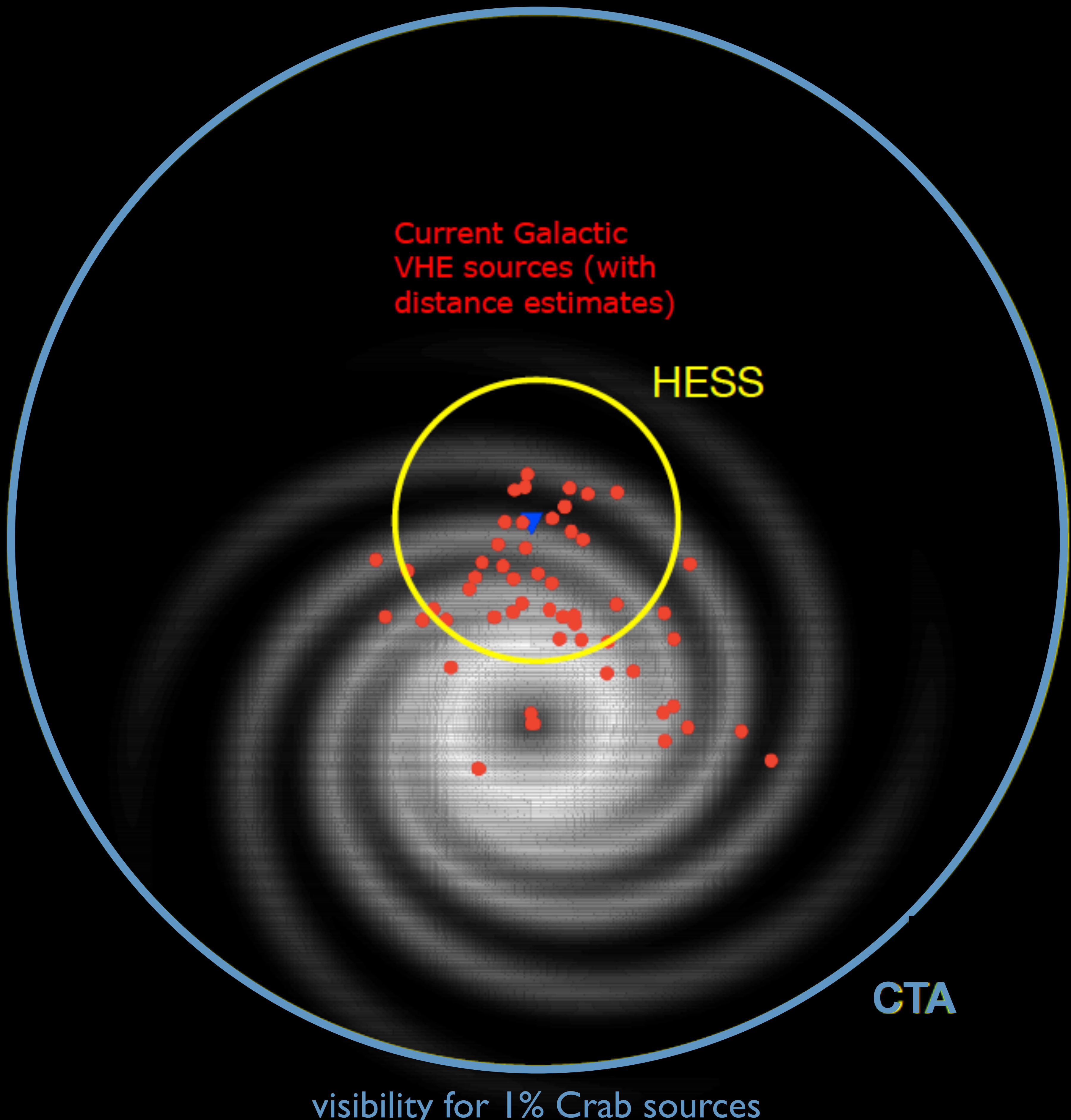
(Steady sources)



Variability and Short-Timescale Phenomena

(flares, GRBs, ... all sorts of transients)





CTA will be the
ultimate instrument …

… for surveys
~400x faster than H.E.S.S.

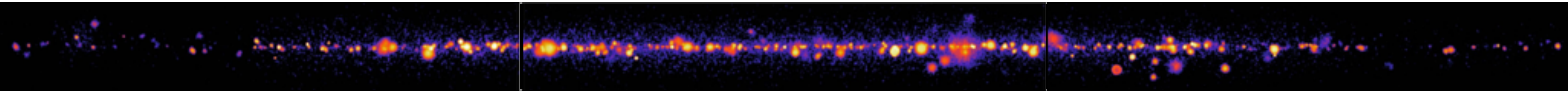
… for transients
at 25 GeV,
10^4x better than Fermi

Multi-Messenger Physics:

Radio	LOFAR, SKA, ALMA, …
optical	VLT, GMT, eELT, LSST, …
X-rays	SWIFT, XMM, SVOM, …
Gamma rays (keV-GeV)	Fermi, DAMPE, …
(TeV)	HAWC, **CTA**
neutrinos	IceCube/Gen2, KM3net
gravitational waves	Adv Ligo, KAGRA, Ligo-India

many complementary / contemporary experiments

CTA prognosis: a rich harvest …

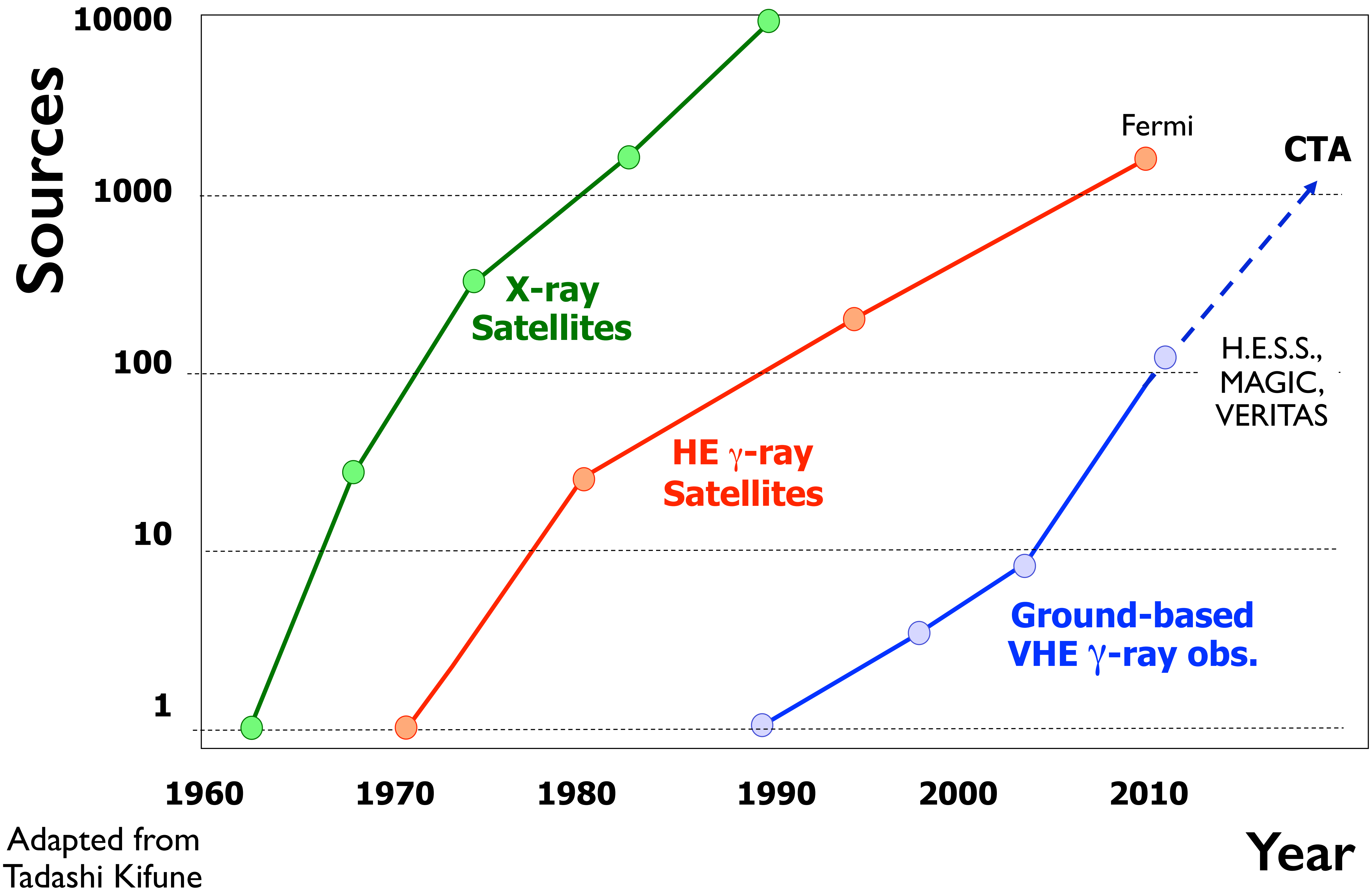


galactic disc: long. ±90 deg
lat. ±5 deg

galactic + extragalactic: ≥ 1000 sources

Source Number

Ground-based
gamma ray astronomy
becomes “mainstream”.

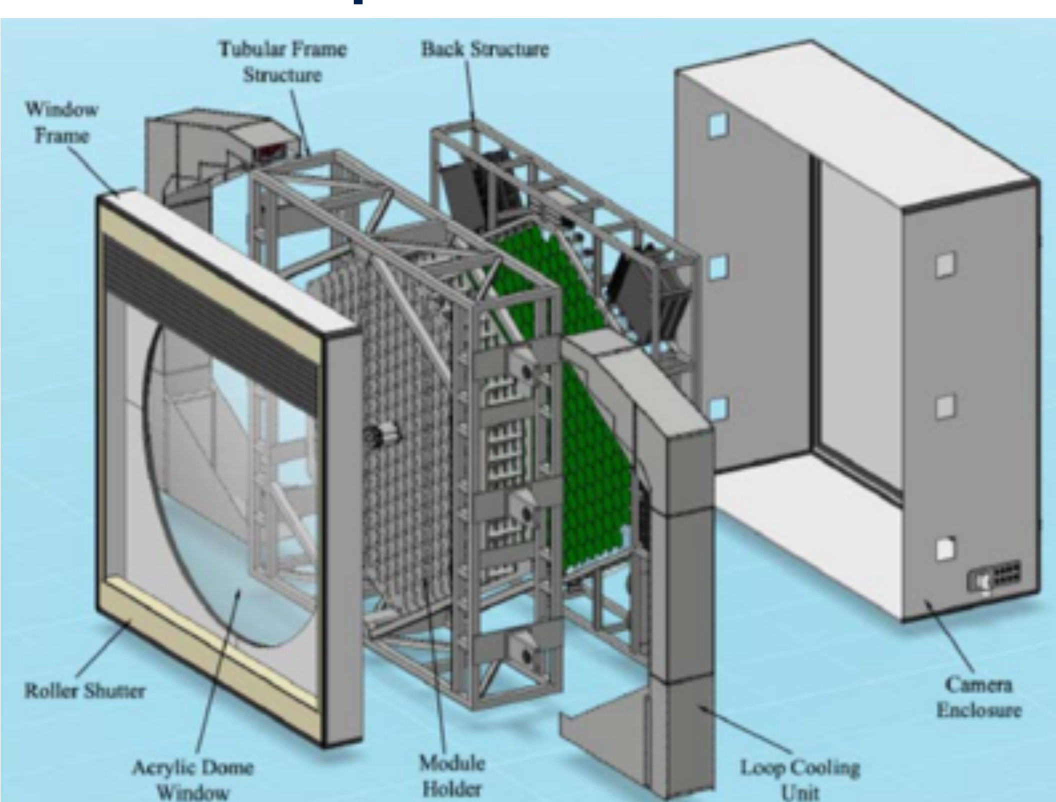


Adapted from
Tadashi Kifune

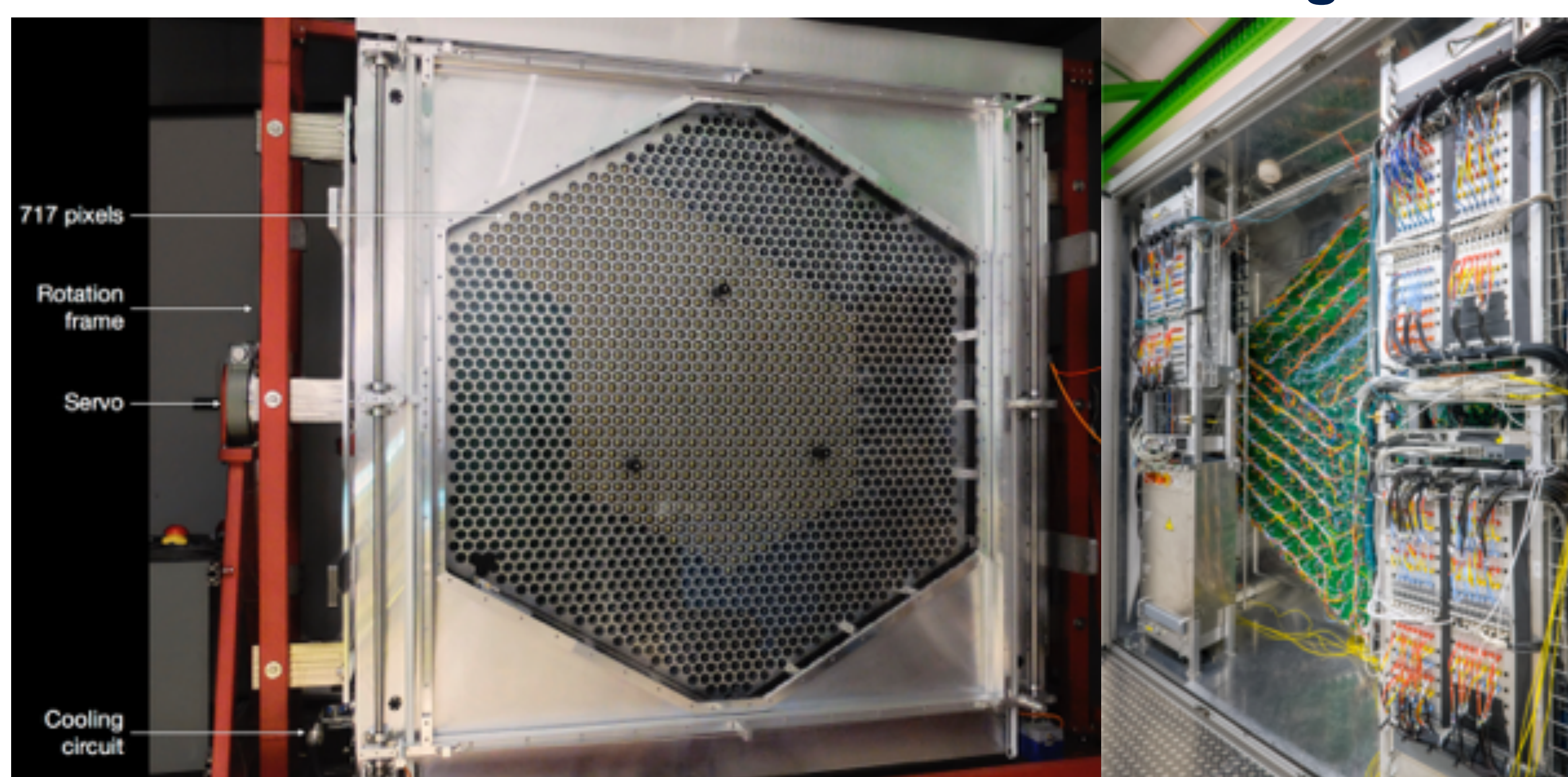
MST Prototype

DESY Zeuthen

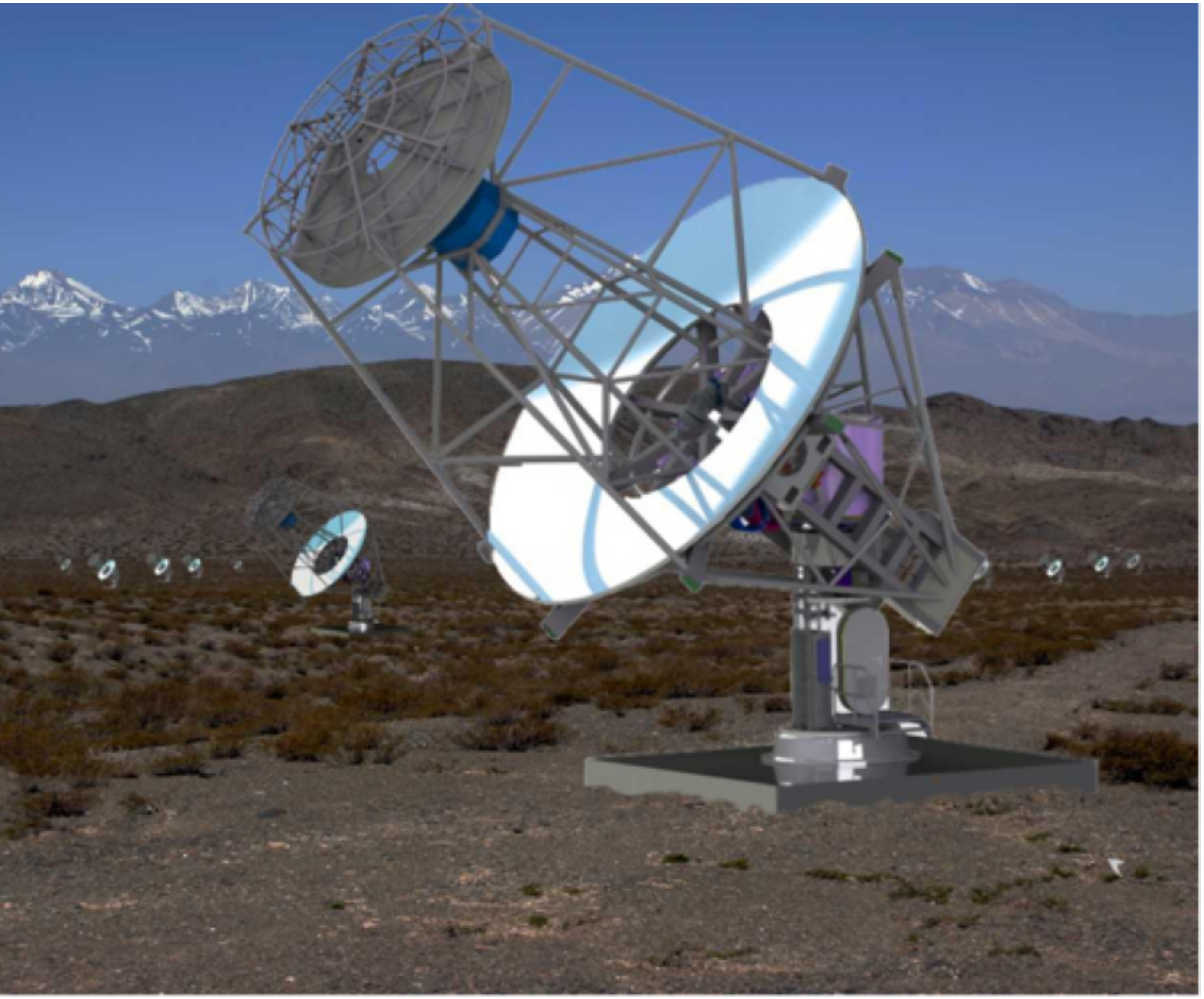
France / Spain

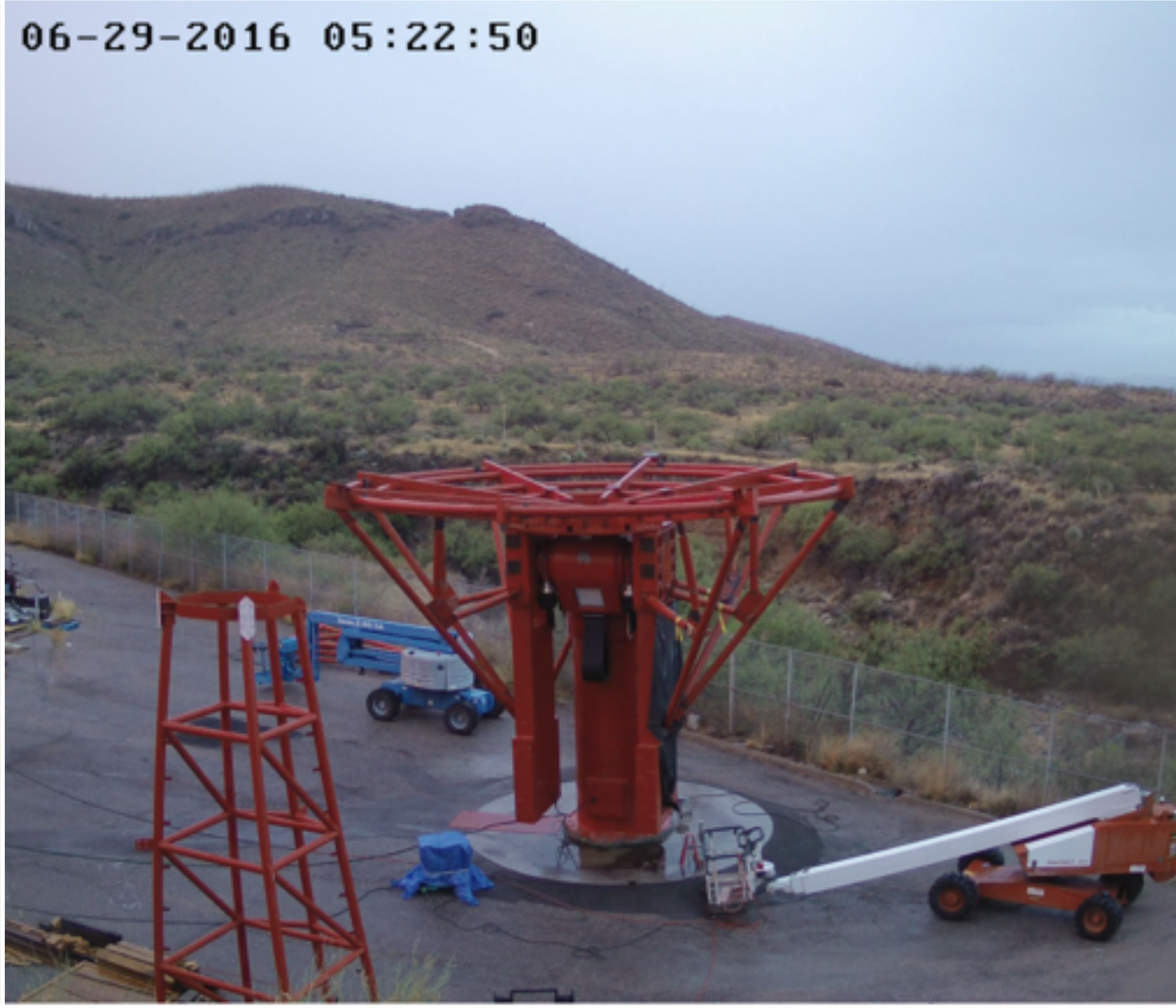


MPIK Heidelberg



MST Schwarzschild-Couder dual mirror USA

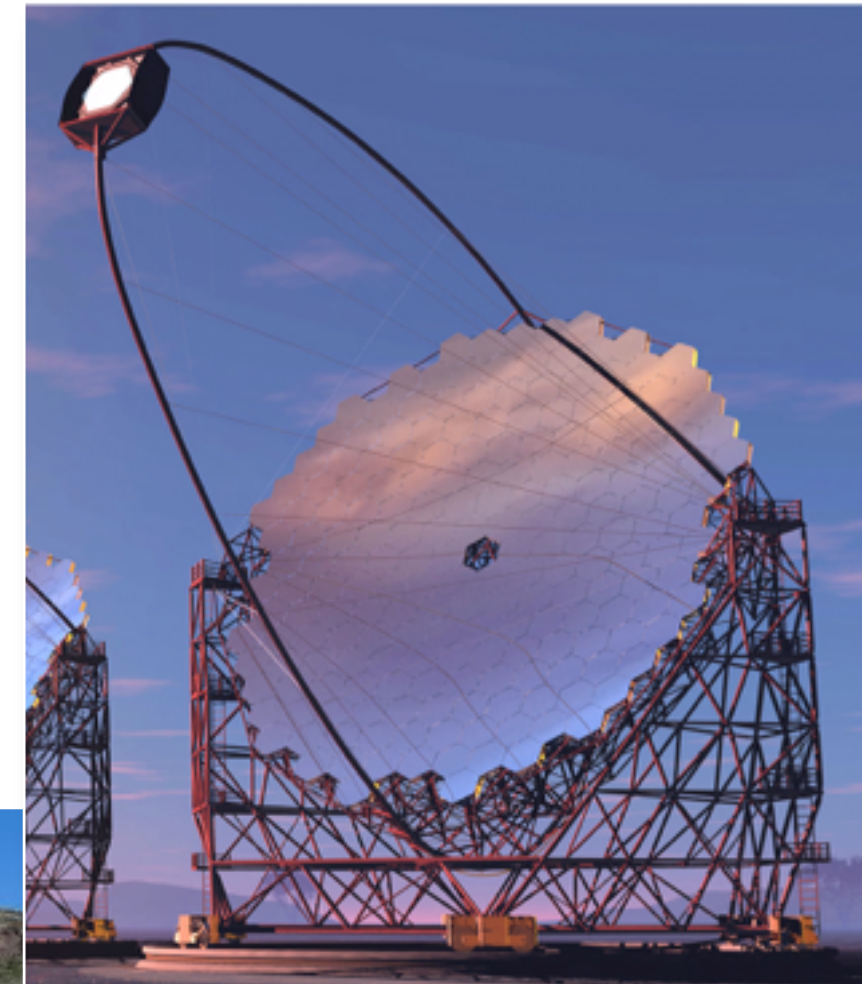




9.7 m primary
5.4 m secondary
5.6 m focal length, f/0.58

11328 x 0.07° SiPMT pixels

Large Size Telescope Prototype



Ground breaking on La Palma

SST Prototypes

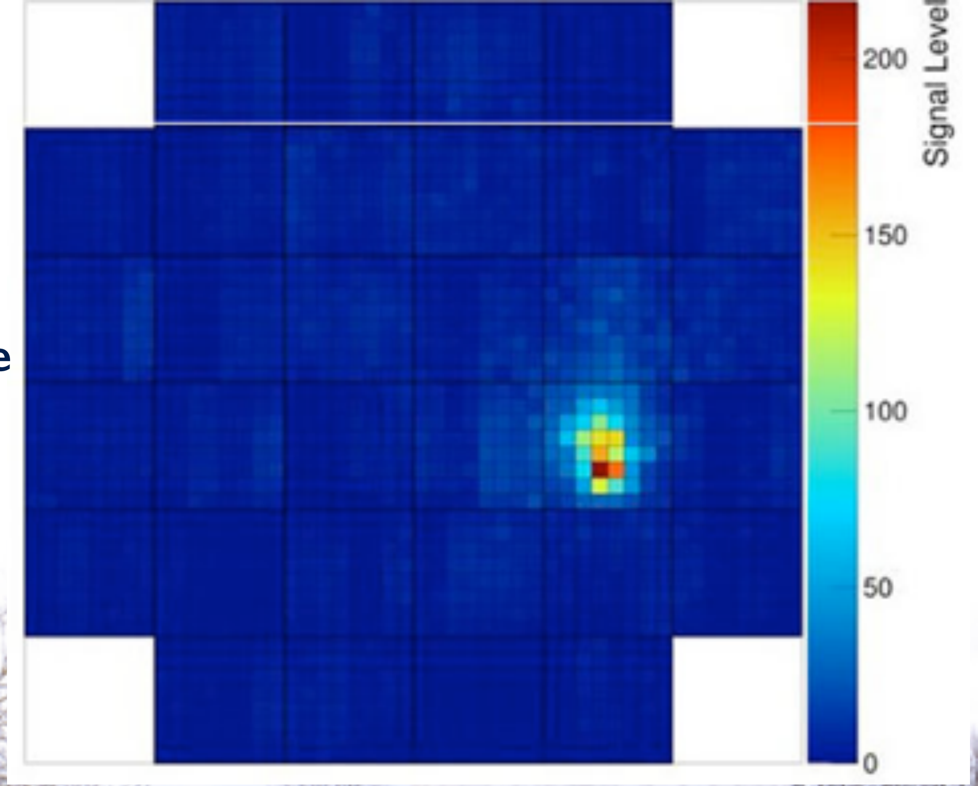
dual mirror telescope

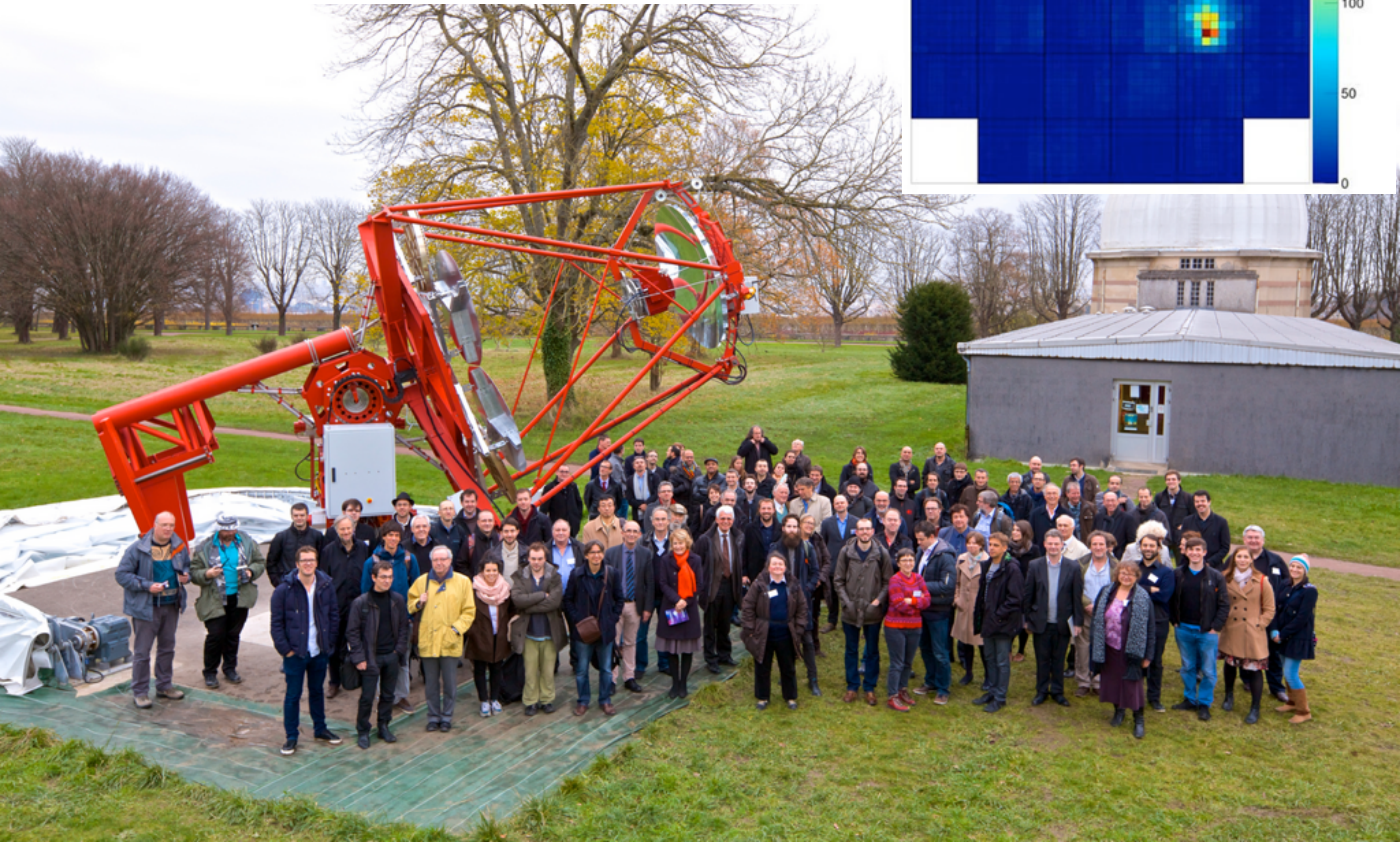
at Cracow

on Sicily

SST Prototype at Meudon

First images from a
dual mirror telescope

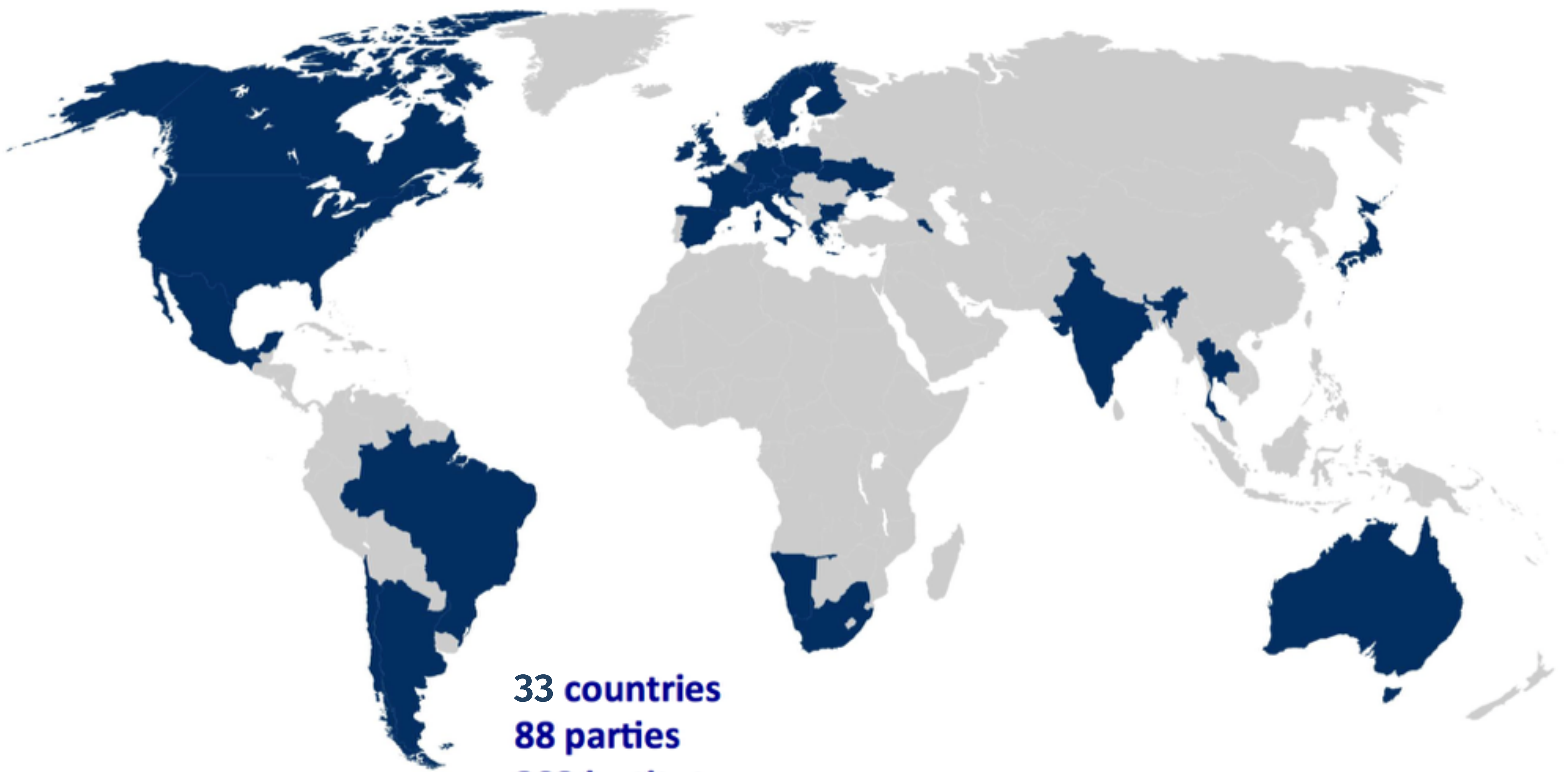




Tels. technical data

Telescope	Large	Medium		Small		
	LST	MST	SCT	SST-1M	ASTRI SST-2M	GCT SST-2M
Number North array	4	15	TBD	0		
Number South array	4	25	TBD	70		
Optics						
Optics layout	Parabolic mirror	Davies-Cotton	Schwarzschild-Couder	Davies-Cotton	Schwarzschild-Couder	Schwarzschild-Couder
Primary mirror diameter (m)	23	13.8	9.7	4	4.3	4
Secondary mirror diameter (m)	–	–	5.4	–	1.8	2
Eff. mirror area after shadowing (m^2)	368	88	40	7.4	6	6
Focal length (m)	28	16	5.6	5.6	2.15	2.28
Focal plane instrumentation						
Photo sensor	PMT	PMT	silicon	silicon	silicon	silicon
Pixel size (degr.), shape	0.10, hex.	0.18, hex.	0.07, square	0.24, hex.	0.17, square	0.15-0.2, square
Field of view (degr.)	4.5	7.7/8.0	8.0	9.1	9.6	8.5 - 9.2
Number of pixels	1855	1764/1855	11328	1296	1984	2048
Signal sampling rate	GHz	250 MHz / GHz	GHz	250 MHz	S&H	GHz
Structure						
Mount	alz-az, on circular rail	alt-az positioner	alt-az positioner	alt-az positioner	alt-az positioner	alt-az positioner
Structural material	CFRP / steel	steel	steel	steel	steel	steel
Weight (full telescope, tons)	100	85	~85	9	15	8
Max. time for repositioning (s)	20	90	90	60	80	60

CTA Consortium



33 countries
88 parties
202 institutes
1308 members (438 FTE)

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

CTA Consortium: ⇄ CTAO GmbH:

institutes from 33 countries
>1300 persons

have the relevant know-how

deliver components as
in-kind contributions
(investments and man-power)

do the science

CTA legal entity

(all contractual matters,
Shareholders: countries who fund CTA,
Council makes decisions)

manages construction and
operation of CTA

runs project office, headquarters, science
data centre and the observatory sites

Founded in summer 2014

Shareholders:

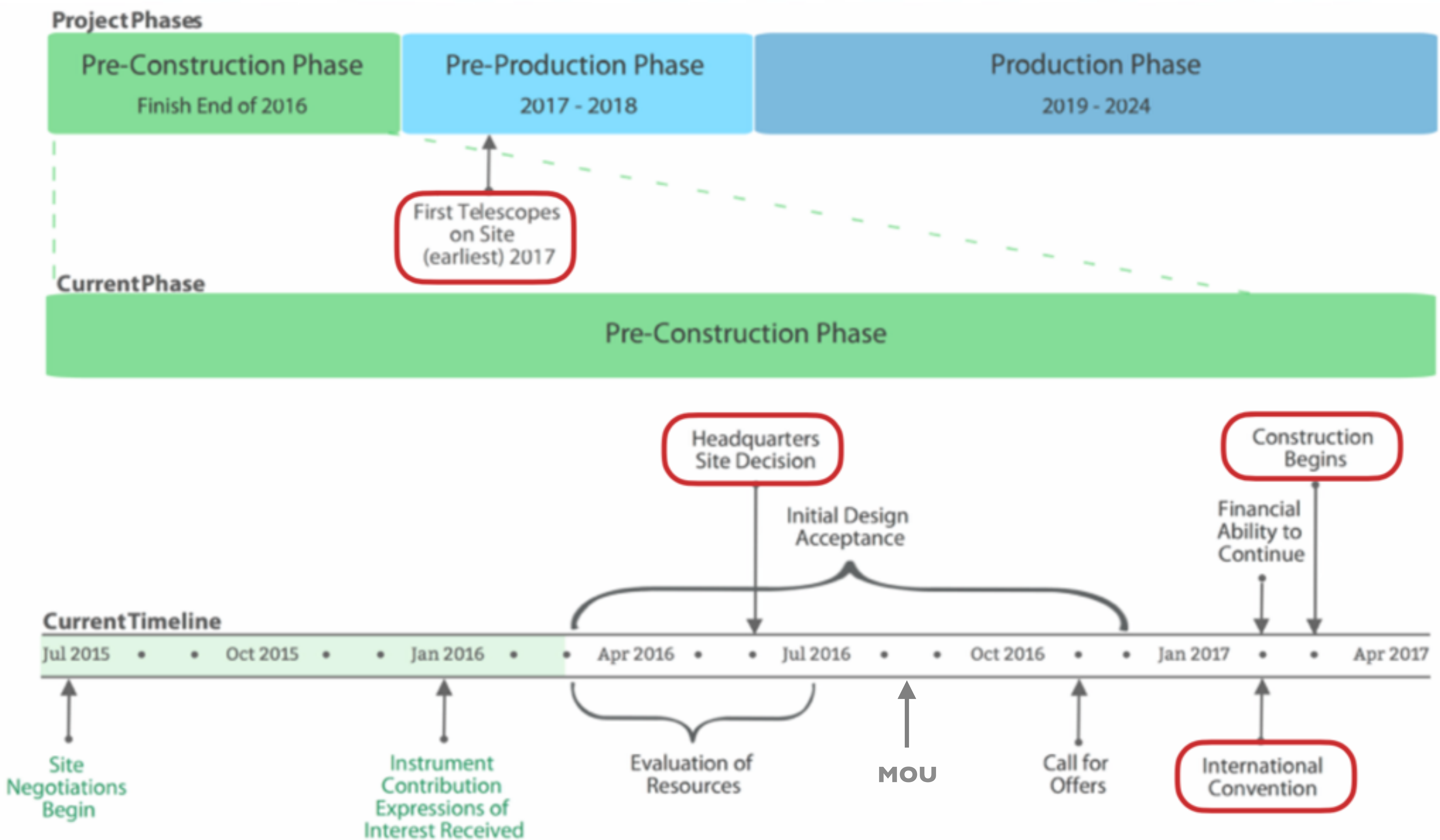
- Austria (Univ. Innsbruck)
- Czech Rep. (Acad. of Sciences)
- France (CNRS, CEA)
- Germany (DESY, MPG)
- Italy (INAF)
- Japan (ICRR)
- Spain (IAC)
- Switzerland (Univ. Zürich)
- UK (STFC)

list is growing

Associated:

- Netherlands
- South Africa
- Sweden

Timeline:


Project Phases
Pre-Construction Phase
Finish End of 2016
Pre-Production Phase
2017 - 2018
Production Phase
2019 - 2024
First Telescopes on Site (earliest) 2017
Current Phase
Pre-Construction Phase
Headquarters Site Decision
Construction Begins
Initial Design Acceptance
Financial Ability to Continue
Current Timeline
Jul 2015
Oct 2015
Jan 2016
Apr 2016
Jul 2016
Oct 2016
Jan 2017
Apr 2017
Site Negotiations Begin
Instrument Contribution Expressions of Interest Received
Evaluation of Resources
MOU
Call for Offers
International Convention

CTA Headquarters and Science Data Centre

decision: 14 June 2016

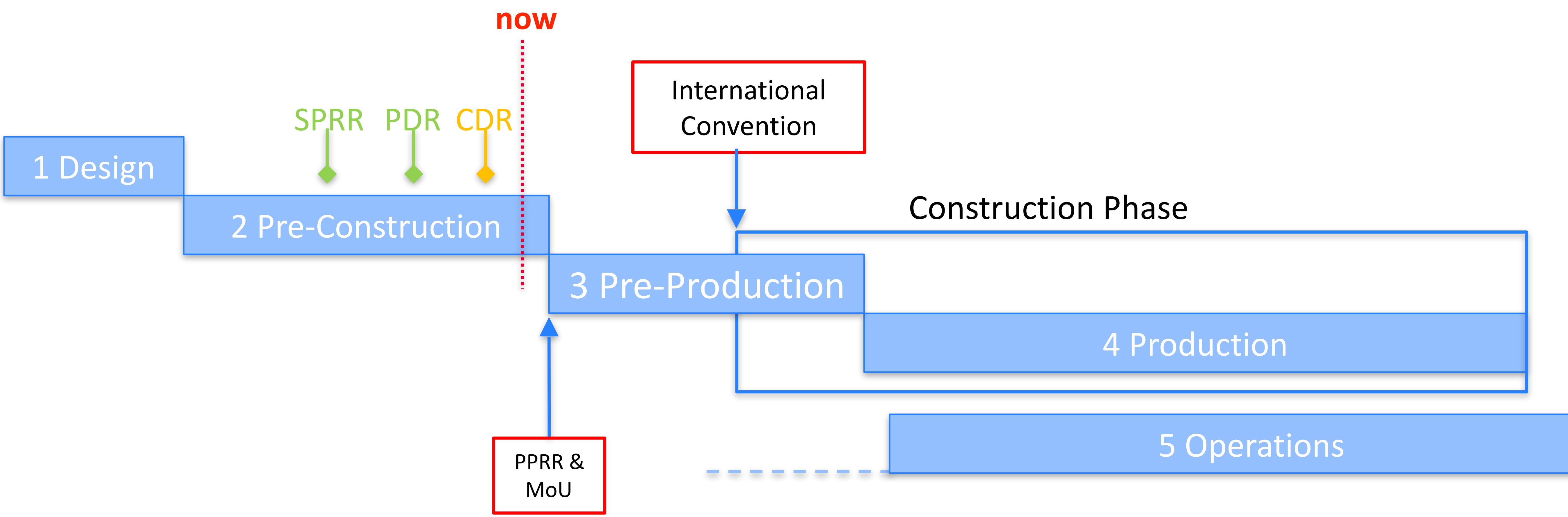
CTA Headquarters
for Admin and observatory operations

INAF Bologna, Italy

CTA Science Data Centre
for science operations and science products

DESY Zeuthen/Berlin, Germany

CTA Phases



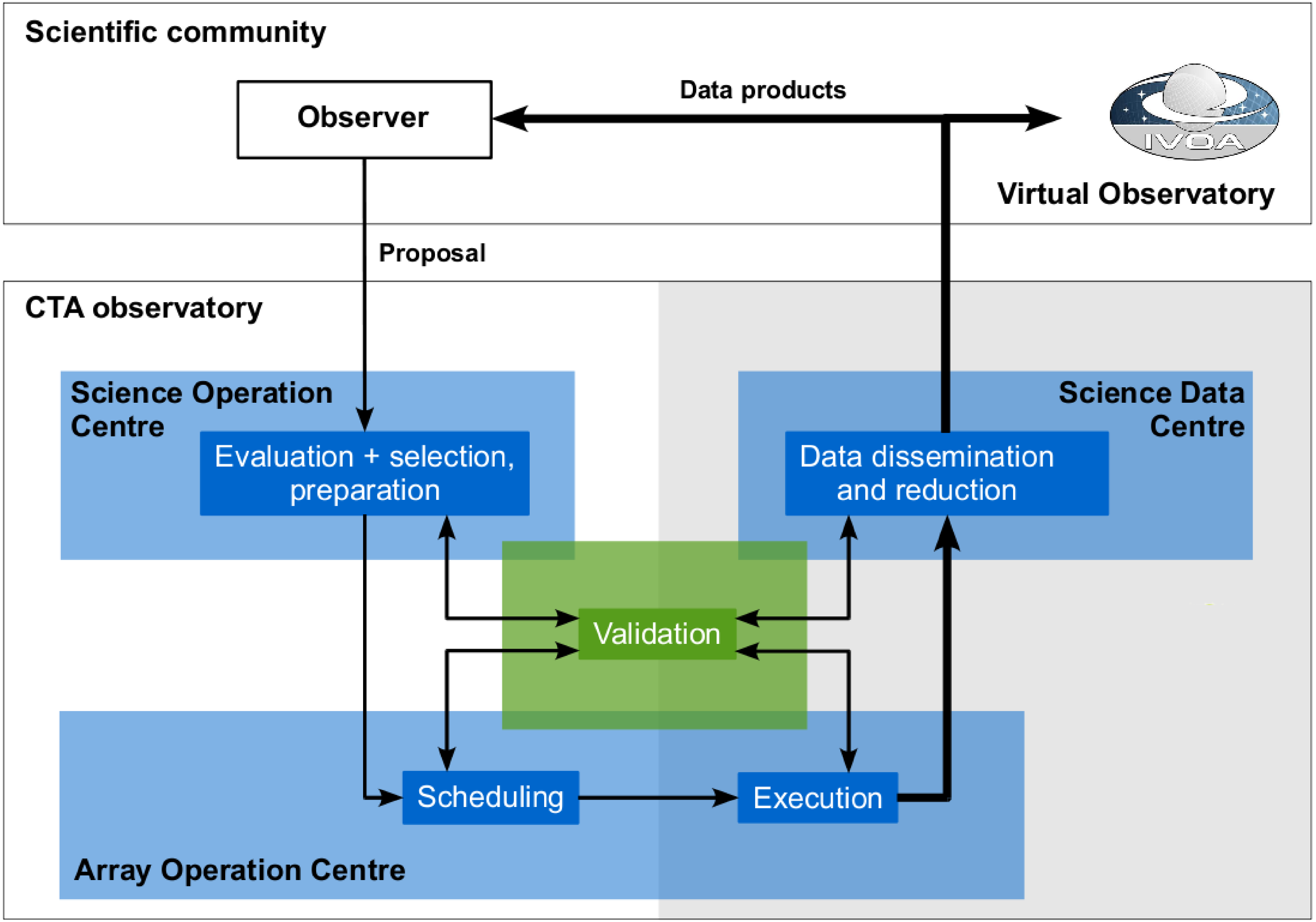
We are (still) in the Pre-construction Phase.
Current priorities:
- Prepare site(s) for pre-production telescopes
- Get pre-production telescopes on site

MoU in preparation to allow start of pre-construction in 2017, followed soon by **International Convention**.

Pre-production phase (~10% telescopes)
- Final 'learning phase'
- 'Consortia' install telescopes
- CTAO oversees/helps/learns

Production phase (~90% telescopes)
- 'mass production phase'
- CTAO installs telescopes using contractors
- 'Consortia' oversee/help

CTA as an "Open Observatory"



initial proprietary time (≈50%): for "Key Science Projects"
open for proposals (from scientist of participating countries)

Science Preparations

CTA science working groups:

1 Galactic science
- SNRs
- PWNs
- pulsar
- binaries
- other gal. sources

2 Cosmic Rays
- molecular clouds
- diffuse emission
- normal galaxies
- starburst galaxies
- galaxy clusters
- cosmic nuclei
- cosmic electrons

3 Extragalactic Science
- blazers
- non-blazer AGNs
- other extragalactic sources
- intergalactic mag fields
- extragalactic background light

4 Transient
- galactic transients
- extragalactic transients
- GRBs
- multi-messenger studies

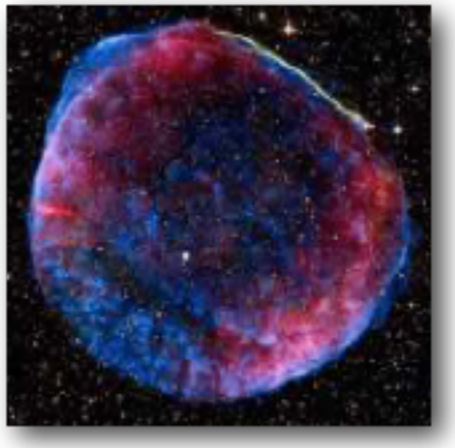
5 Dark Matter & exotic physics
- dark matter
- axions
- Lorentz invariance violation

6 Intensity interferometry

Main Science Themes:

Cosmic Particle Acceleration

- Particle acceleration
- Particle propagation
- Impact of rel. particles on their environment



Probing Extreme Environments

- Processes close to neutron stars and black holes
- Processes in relativistic jets, winds and explosions
- Cosmic voids

Physics frontiers

- Nature & distribution of Dark Matter
- Lorentz-Invariance at high energies
- Axion-like particles
- Exotics

Use of Observation Time ?

initially: commissioning

proprietary time for Consortium members contributing to construction of CTA
~50% for a few years, pooled together for "Key Science Projects"

open time (for scientists from CTA countries), proposal driven
~50% growing with time

All data become public after a proprietary period (~1yr)

CTA Key Science Projects

Criteria for KSPs:

1. Excellent scientific case with clear advance beyond the state of the art
2. The production of legacy data-sets of high value to a wider community
3. Clear added value of doing it as a KSP (rather than as part of the open-time observation)
   - need of large observing times (which are difficult to obtain in the open time)
   - need of a coherent approach across multiple targets or pointings
   - need of consortium expertise due to technical difficulty of the required analysis

CTA Key Science Projects

		Key Science Projects									
Theme	Question	Dark Matter Programme	Galactic Centre Survey	Galactic Plane Survey	LMC Survey	Extra-galactic Survey	Transients	Cosmic Ray PeVatrons	Star-forming Systems	Active Galactic Nuclei	Galaxy Clusters
Understanding the Origin and Role of Relativistic Cosmic Particles	1.1 What are the sites of high-energy particle acceleration in the universe?		✔	✔✔	✔✔	✔✔	✔✔	✔	✔	✔	✔✔
	1.2 What are the mechanisms for cosmic particle acceleration?		✔	✔	✔		✔✔	✔✔	✔	✔✔	✔
	1.3 What role do accelerated particles play in feedback on star formation and galaxy evolution?		✔		✔				✔✔	✔	✔
Probing Extreme Environments	2.1 What physical processes are at work close to neutron stars and black holes?		✔	✔	✔			✔✔		✔✔	
	2.2 What are the characteristics of relativistic jets, winds and explosions?		✔	✔	✔	✔	✔✔	✔✔		✔✔	
	2.3 How intense are radiation fields and magnetic fields in cosmic voids, and how do these evolve over cosmic time?					✔	✔			✔✔	
Exploring Frontiers in Physics	3.1 What is the nature of Dark Matter? How is it distributed?	✔✔	✔✔		✔						✔
	3.2 Are there quantum gravitational effects on photon propagation?						✔✔	✔		✔✔	
	3.3 Do Axion-like particles exist?					✔	✔			✔✔	

Surveys

Targets

Summary:

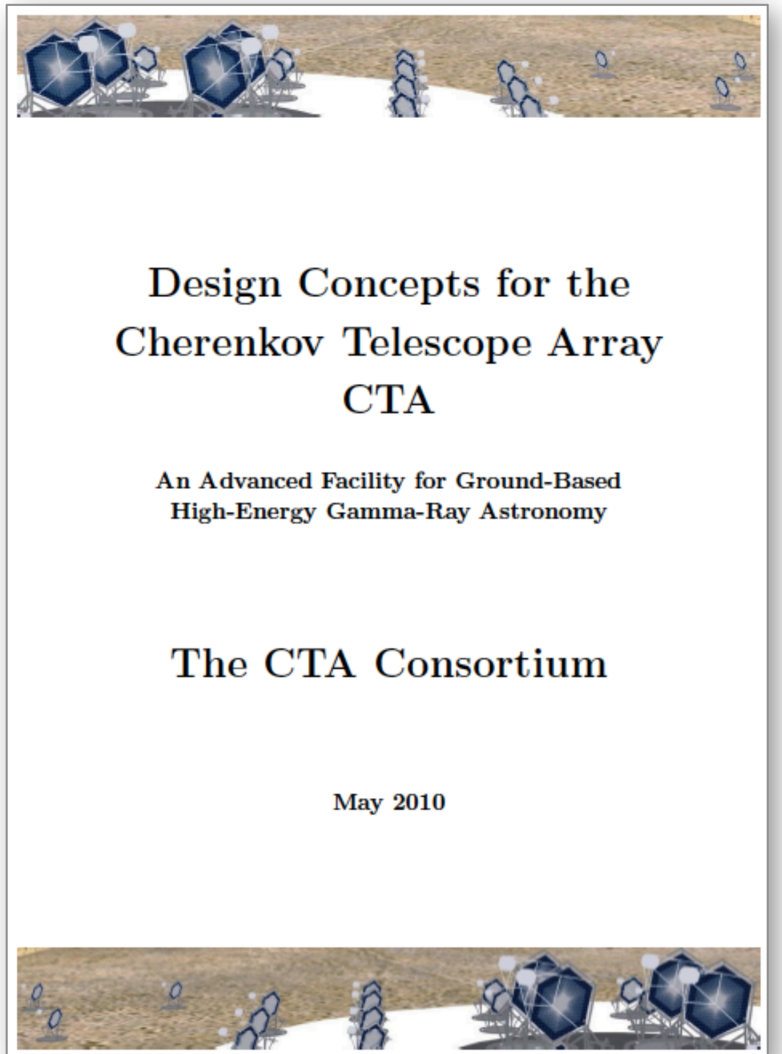
CTA is a new, powerful observatory for ground-based gamma-ray astronomy

- has a huge science potential (for a moderate price)
- offers an attractive mix of discovery potential and a wealth of "guaranteed" good astrophysics,
- complements data from other wavelengths / messengers
- is almost production ready,
- first funding is in hand / construction start very soon ...

CTA will considerably advance our knowledge on high-energy astrophysics and cosmic accelerators.

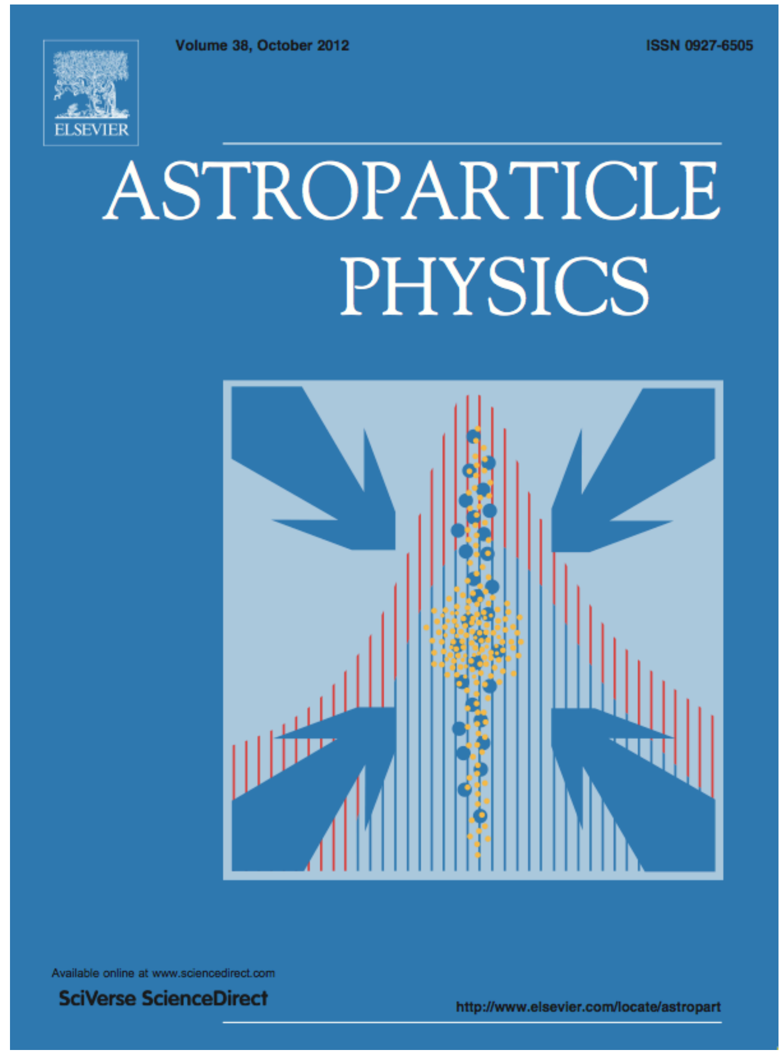
More Details:

general info: www.cta-observatory.org



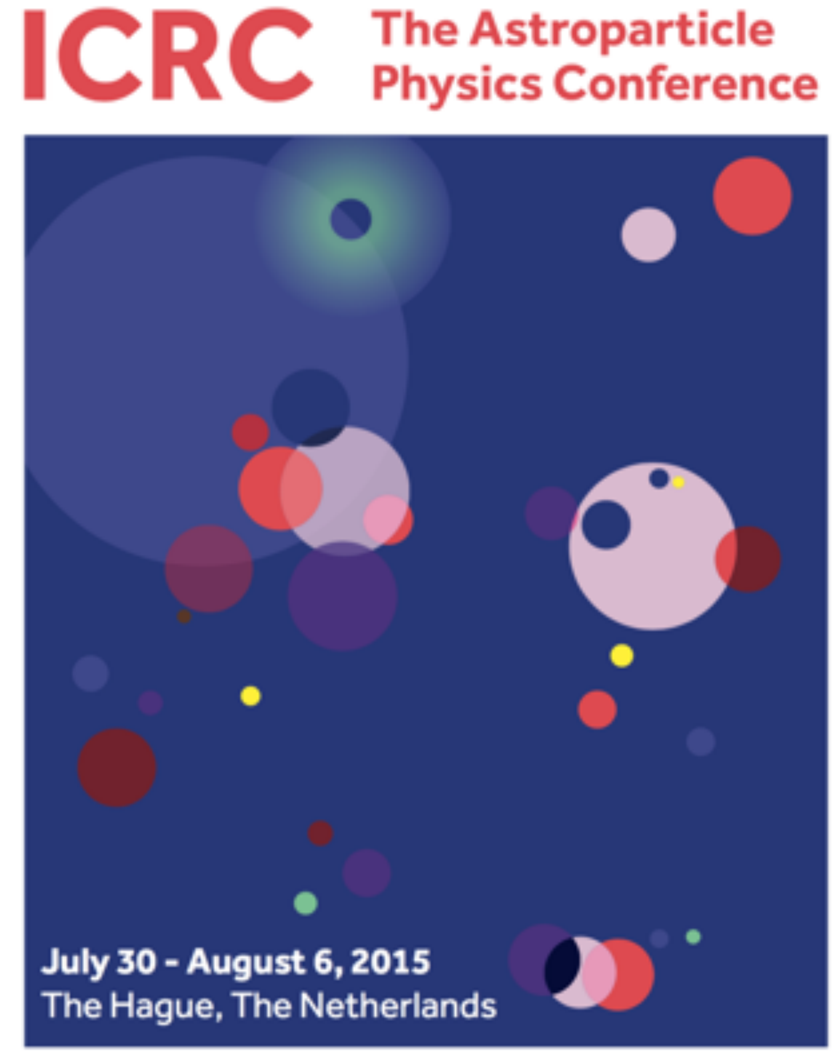
“Design Concepts for the Cherenkov Telescope Array”

120 pages
Exp. Astronomy 32 (2011) 193-316



“Seeing the High-Energy Universe with the Cherenkov Telescope Array”

24 articles, 356 pages
Astroparticle Physics 43 (2013) 1-356



CTA Contributions to the 34th ICRC 2015, Den Haag

60 papers
arXiv:1508.05894

Key Science Projects soon to be published