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CTA: CHERENKOV TELESCOPE ARRAY

for the CTA consortium

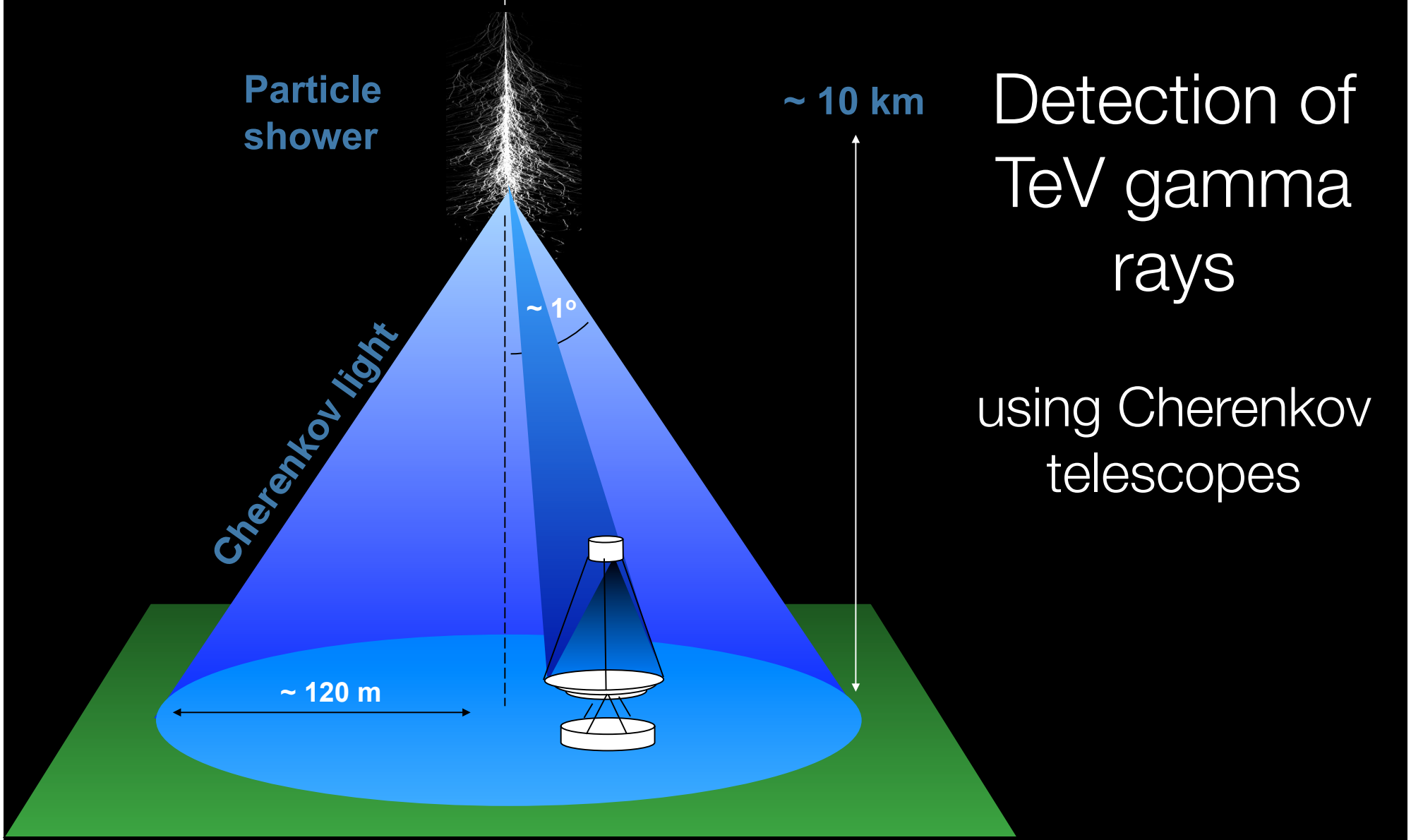
Thanks for material from Werner Hofmann and Manel Martinez

contents

- Very High Energy Gamma-Ray Astronomy
  - Observation technique
  - Major results
- CTA: concept
- Technical implementation
- Physics ahead
- Status of the project

Observation Technique

Gamma-ray



Detection of TeV gamma rays

using Cherenkov telescopes

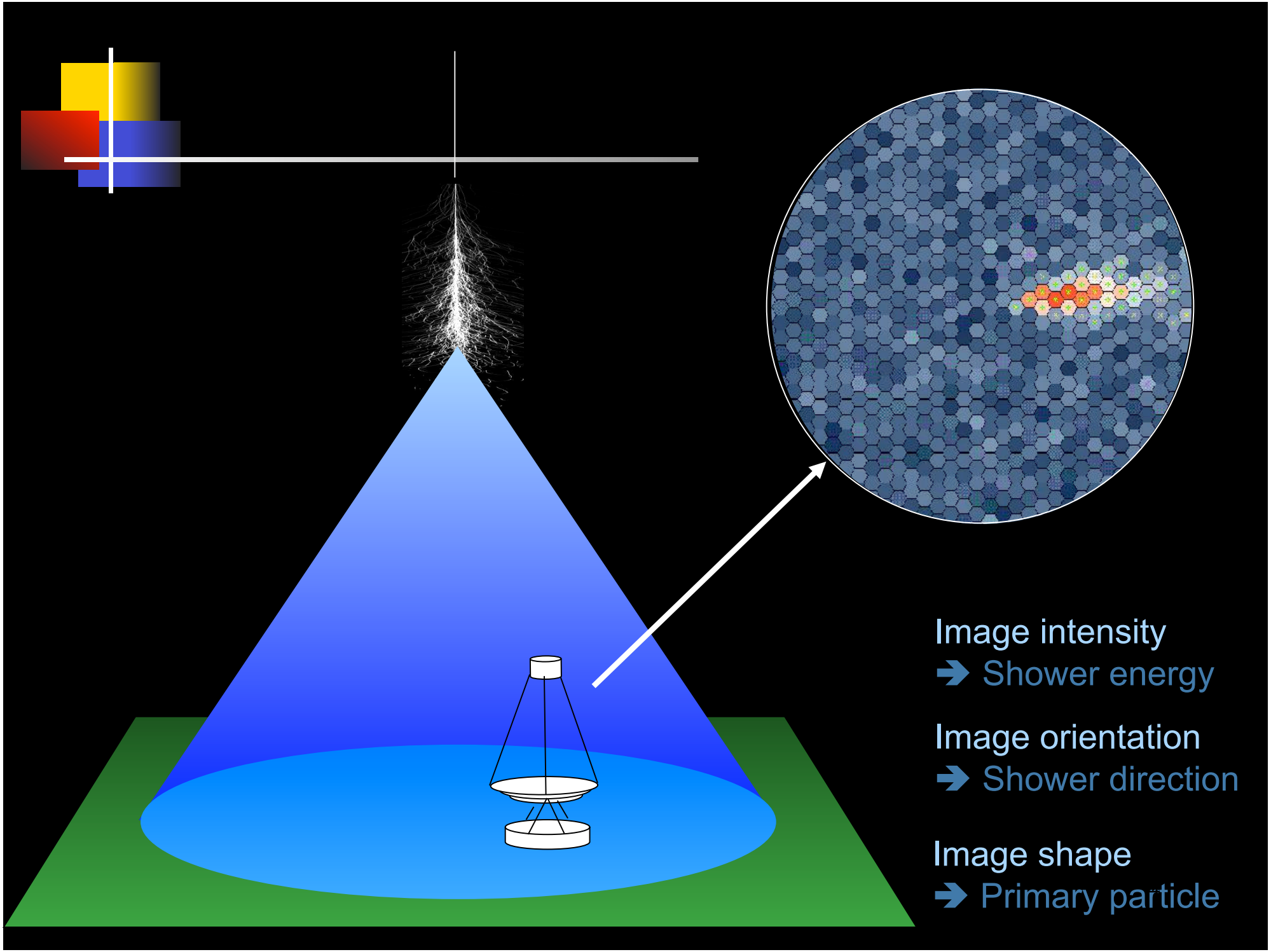
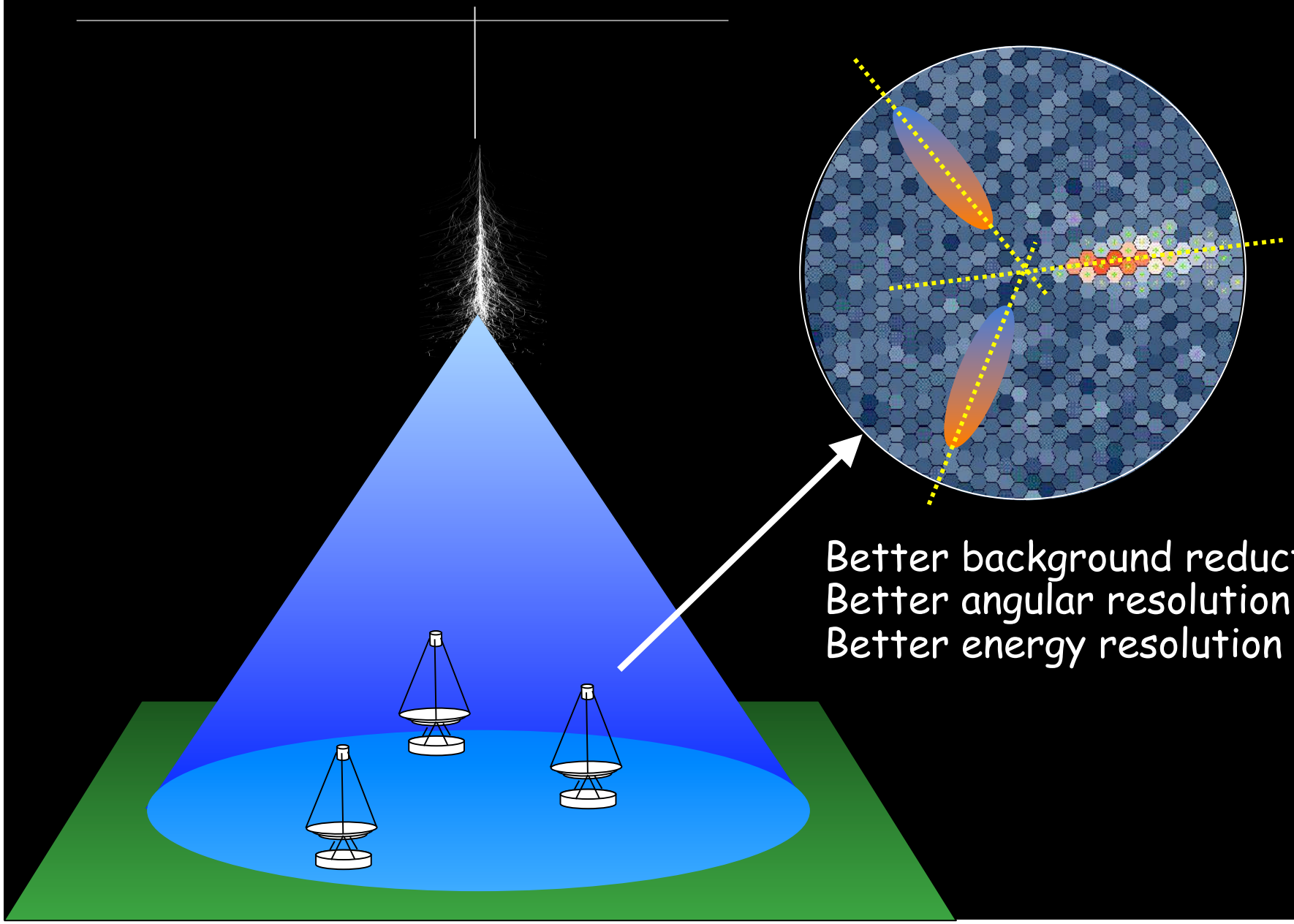


Image intensity
➔ Shower energy
Image orientation
➔ Shower direction
Image shape
➔ Primary particle

Systems of Cherenkov telescopes



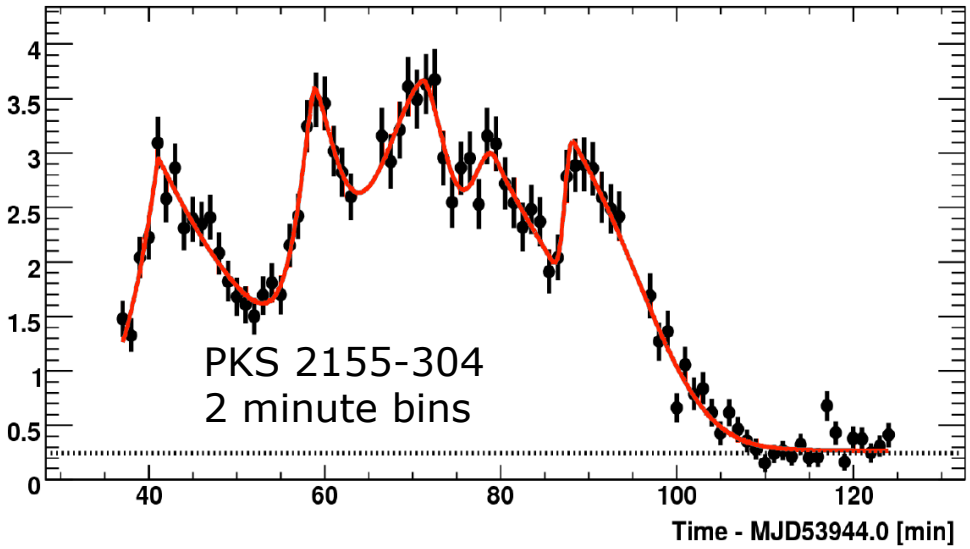
Better background reduction
Better angular resolution
Better energy resolution

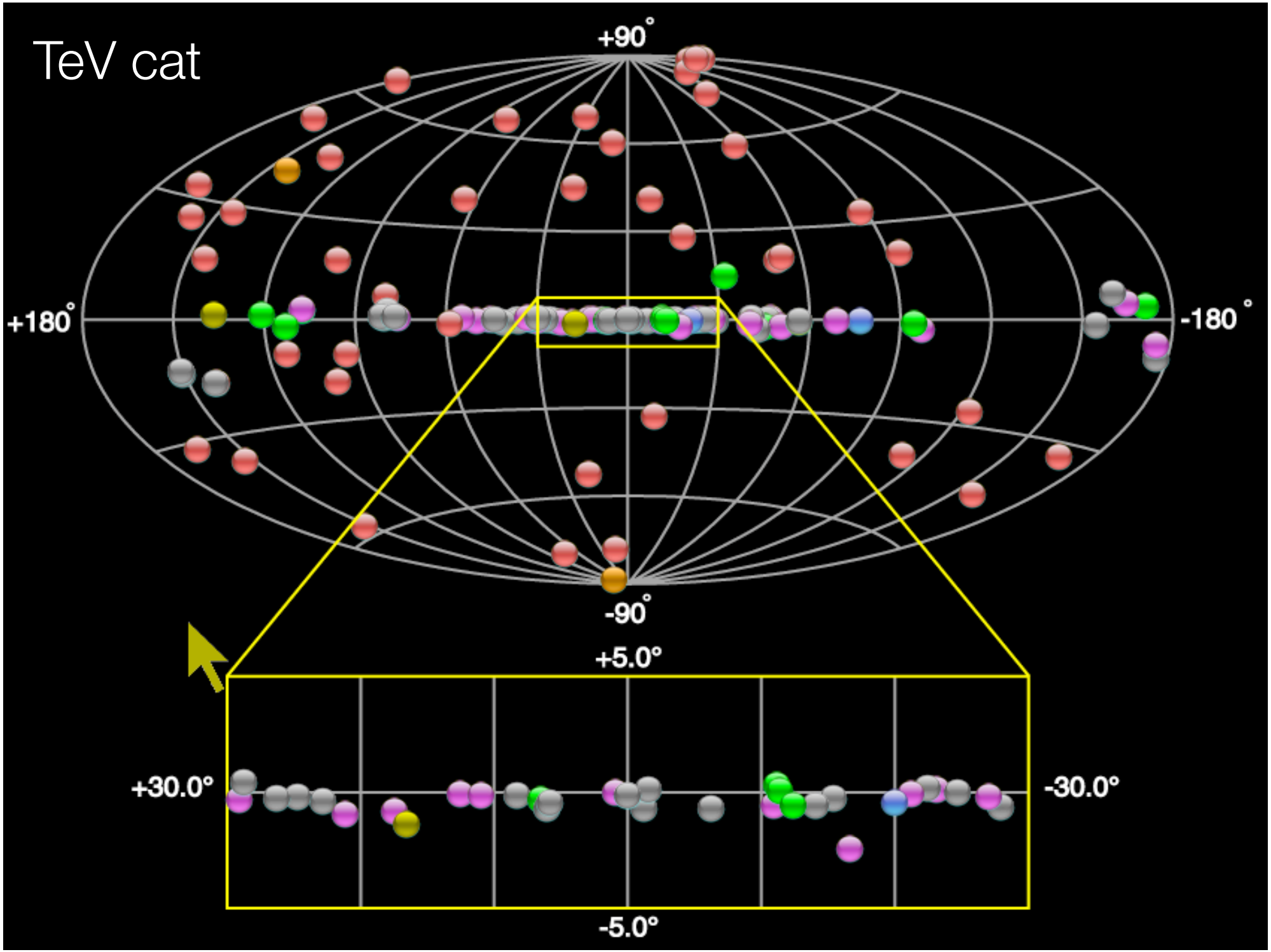
Current status: 3 major observatories

With instruments like H.E.S.S., MAGIC, VERITAS:

“Real astronomy”

- High sensitivity
  - 3 orders of magnitude dynamic range in flux between strongest and faintest sources
- Wide spectral range
  - >2 orders of magnitude coverage in energy, up to 10s of TeV
  - 10-15% energy resolution
- Resolved source morphology
  - ~5’ angular resolution
  - 10-20” source localization
- Survey capability
  - H.E.S.S. Galactic Plane Survey:
  - 2% Crab sensitivity
- Well-resolved light curves
  - Minute-scale variability of AGN

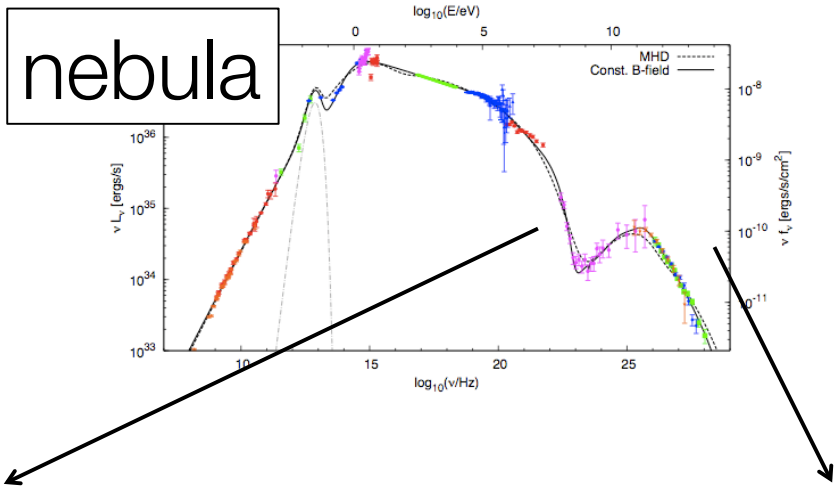


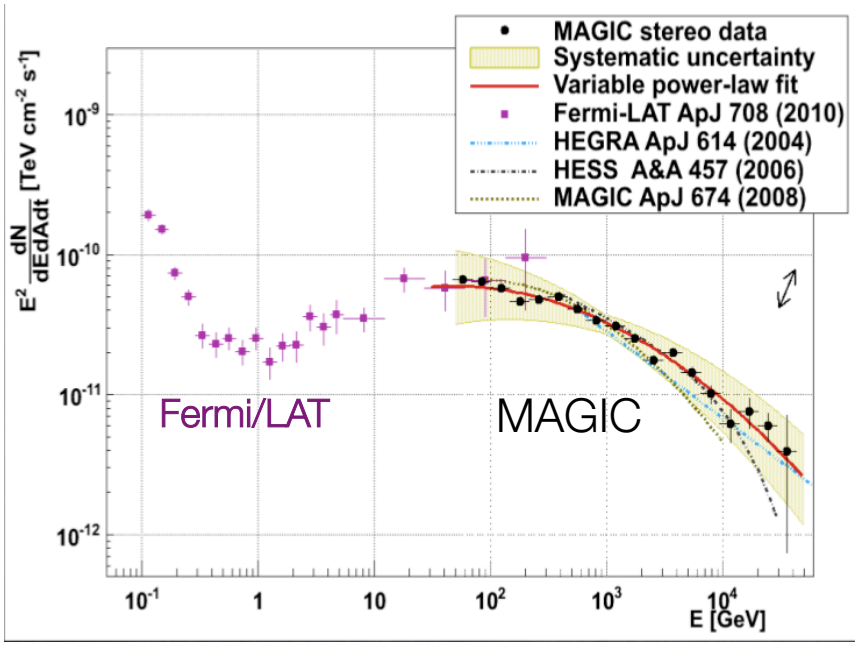

TeV cat
+90°
+180°
-180°
-90°
+5.0°
+30.0°
-30.0°
-5.0°

Spectra and Phasograms

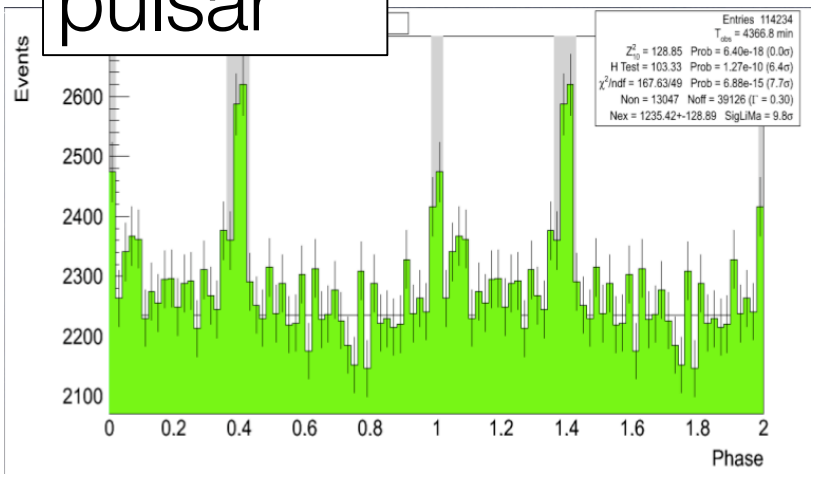
Crab Pulsar and Nebula is our standard candle:
- **Left over after supernova 1054**
- **2 kpc away**
- **Pulsar with 33.6 ms period**
- **Relativistic electrons (Γ up to ~10^9) extending up to a few pc -> Nebula**

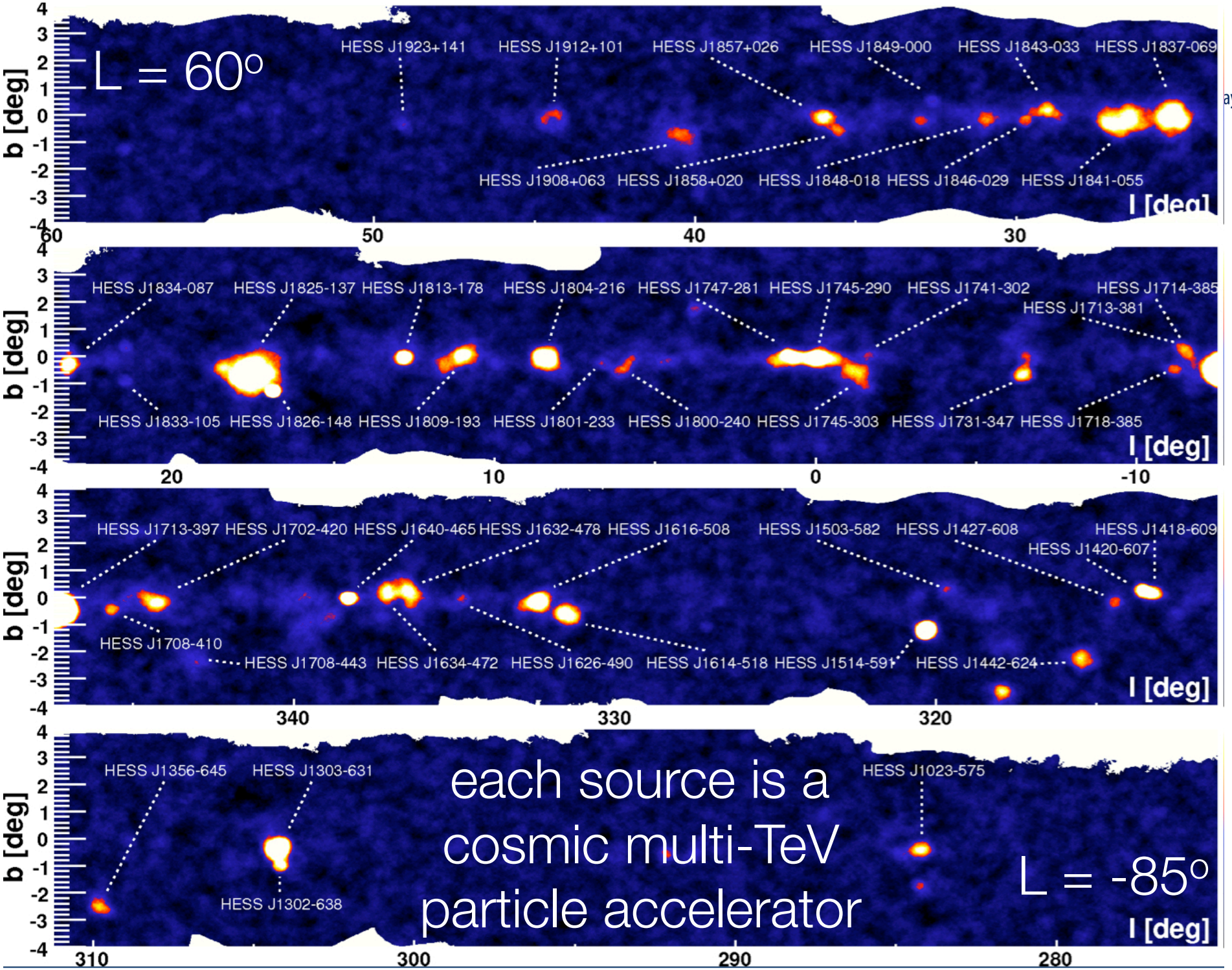
nebula





pulsar




L = 60°
HESS J1923+141
HESS J1912+101
HESS J1857+026
HESS J1849-000
HESS J1843-033
HESS J1837-069
HESS J1908+063
HESS J1858+020
HESS J1848-018
HESS J1846-029
HESS J1841-055
HESS J1834-087
HESS J1825-137
HESS J1813-178
HESS J1804-216
HESS J1747-281
HESS J1745-290
HESS J1741-302
HESS J1714-385
HESS J1713-381
HESS J1833-105
HESS J1826-148
HESS J1809-193
HESS J1801-233
HESS J1800-240
HESS J1745-303
HESS J1731-347
HESS J1718-385
HESS J1713-397
HESS J1702-420
HESS J1640-465
HESS J1632-478
HESS J1616-508
HESS J1503-582
HESS J1427-608
HESS J1418-609
HESS J1420-607
HESS J1708-410
HESS J1708-443
HESS J1634-472
HESS J1626-490
HESS J1614-518
HESS J1514-591
HESS J1442-624
HESS J1356-645
HESS J1303-631
HESS J1302-638
HESS J1023-575
each source is a cosmic multi-TeV particle accelerator
L = -85°
b [deg]
l [deg]

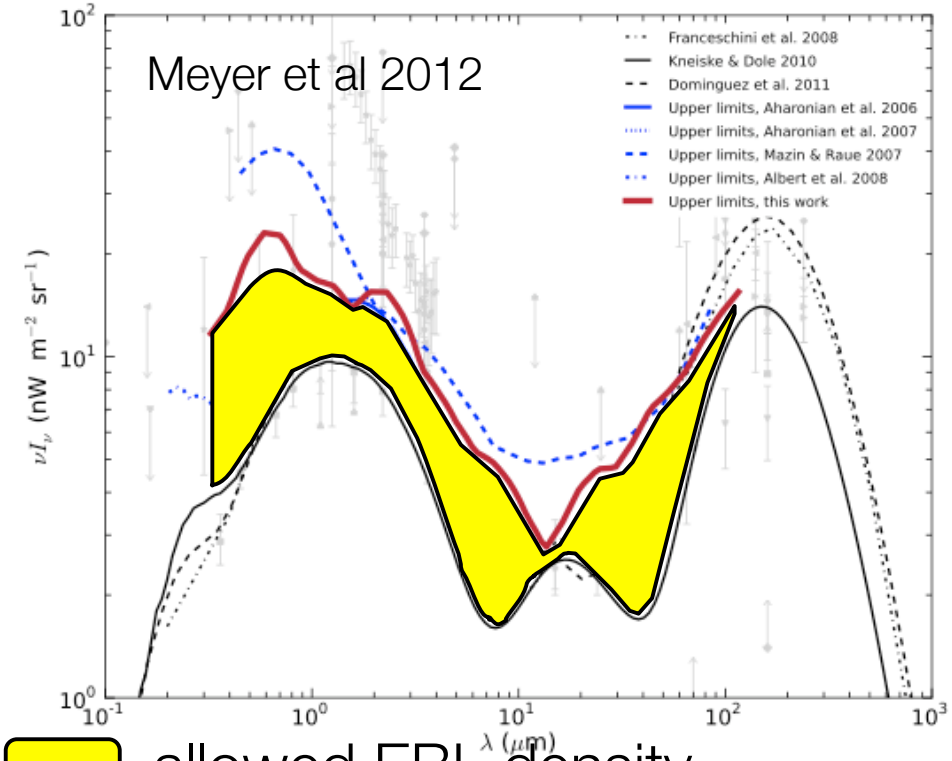
Propagation of Gamma-rays

- TeV gammas are partially absorbed on the way to the Earth:

$$\gamma_{TeV} + \gamma_{EBL} \rightarrow e^+ e^-$$

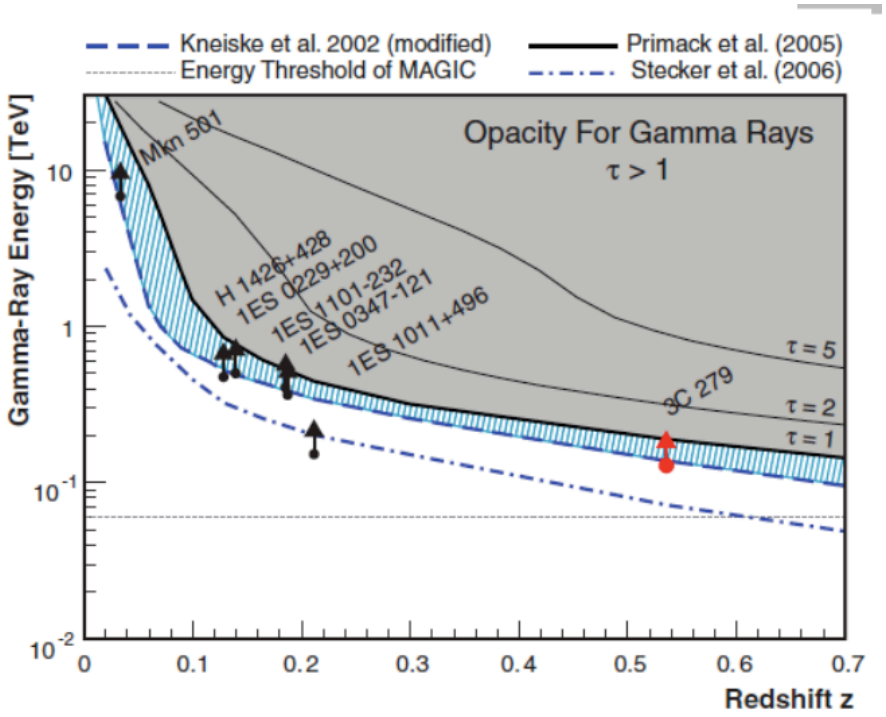
- This effect can be used to infer EBL density from measured AGN spectra

Extragalactic background light



allowed EBL density

Optical depth of Gamma-rays



Highly successful, but …

Some key object classes still elusive, e.g.

- Galaxy clusters as cosmological storehouses of CRs
- Very high energy emission from GRB
- Dark Matter annihilation signatures

Some key mechanisms remain to be understood, e.g.

- Supernovae as sources of cosmic rays: do they provide sufficient peak energy & energy output?
- Cosmic ray escape from accelerators and propagation
- Energy conversion in pulsars

Energy range & angular resolution of current instruments insufficient to probe details

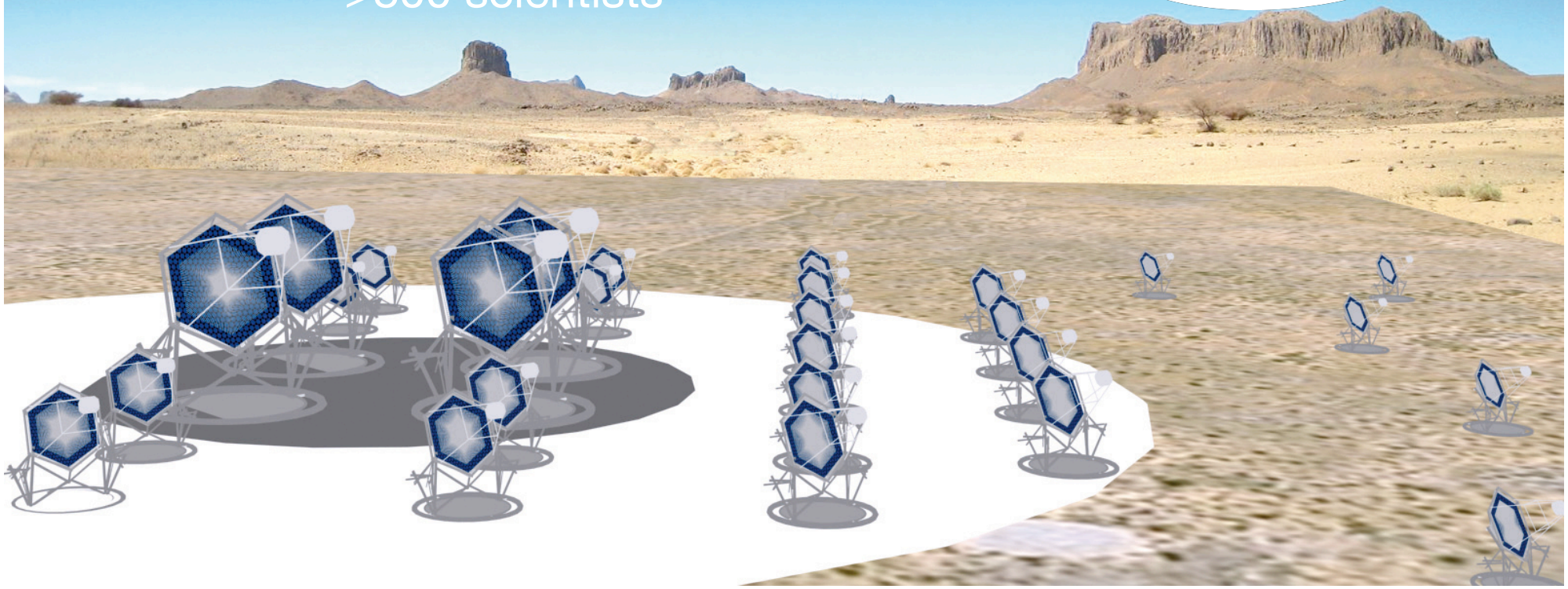
CTA concept

The future in VHE gamma ray astronomy:

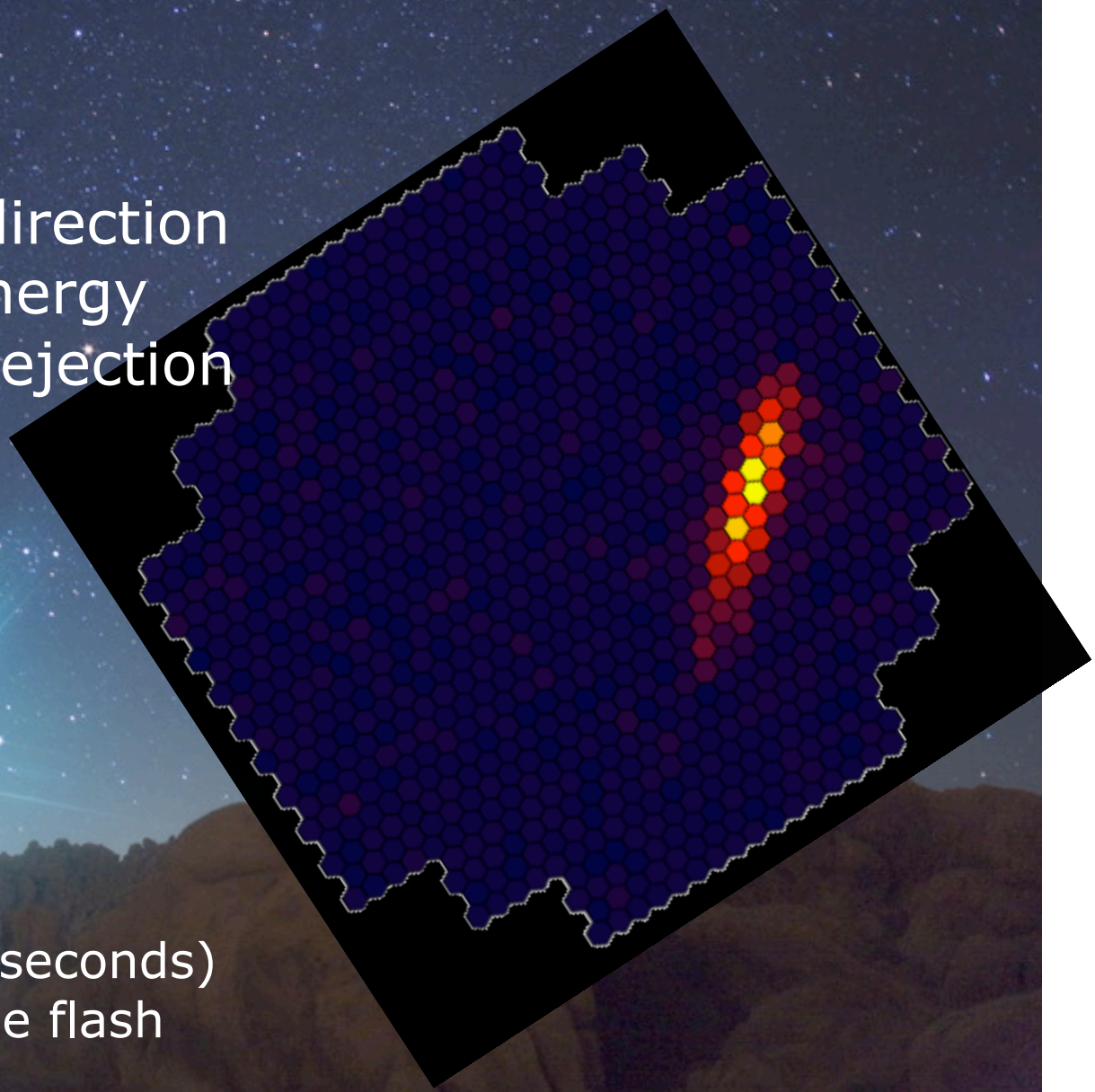
10 fold sensitivity of current instruments
10 fold energy range
improved angular resolution
two sites (North / South)
operated as observatory

World-wide cooperation
25 countries
132 institutes
>800 scientists

cta
cherenkov telescope array

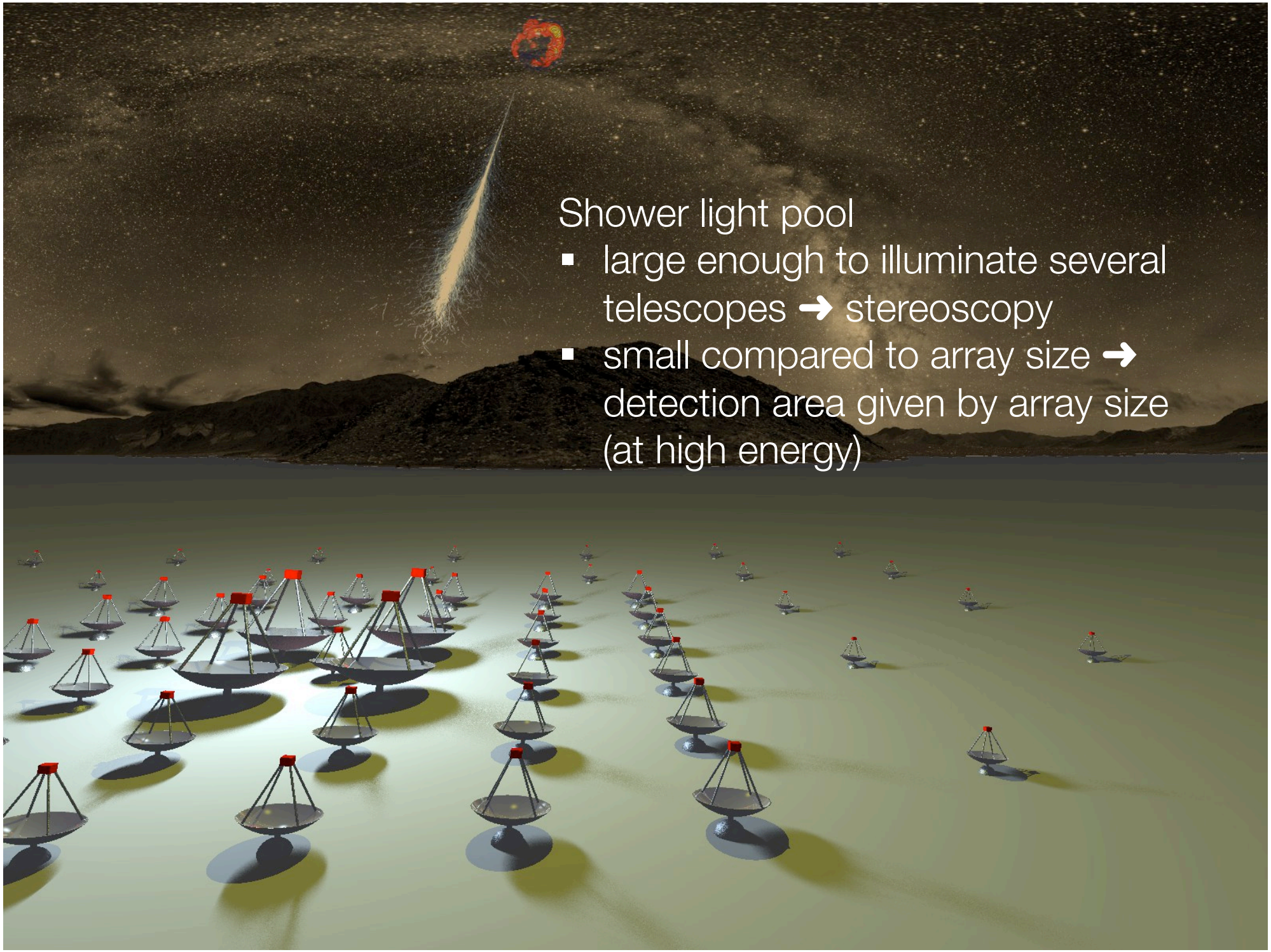


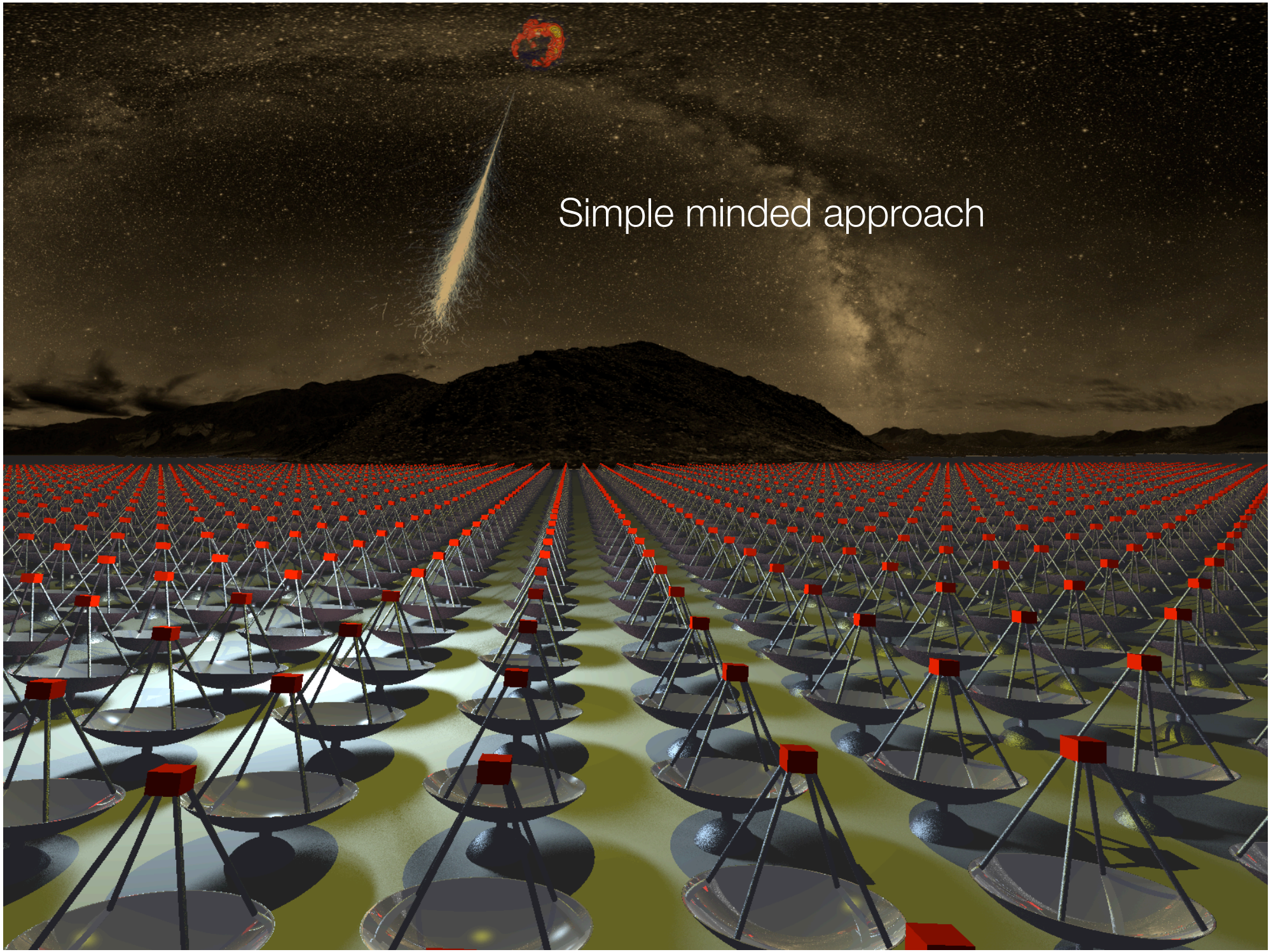
Reminder:
imaging the cascade
geometry ➜ photon direction
intensity ➜ photon energy
shape ➜ cosmic ray rejection



In reality: a short (nanoseconds)
faint (few 10 ph./m^2) blue flash

Wally Pacholka / AstroPics.com


Shower light pool
large enough to illuminate several telescopes ➜ stereoscopy
small compared to array size ➜ detection area given by array size (at high energy)

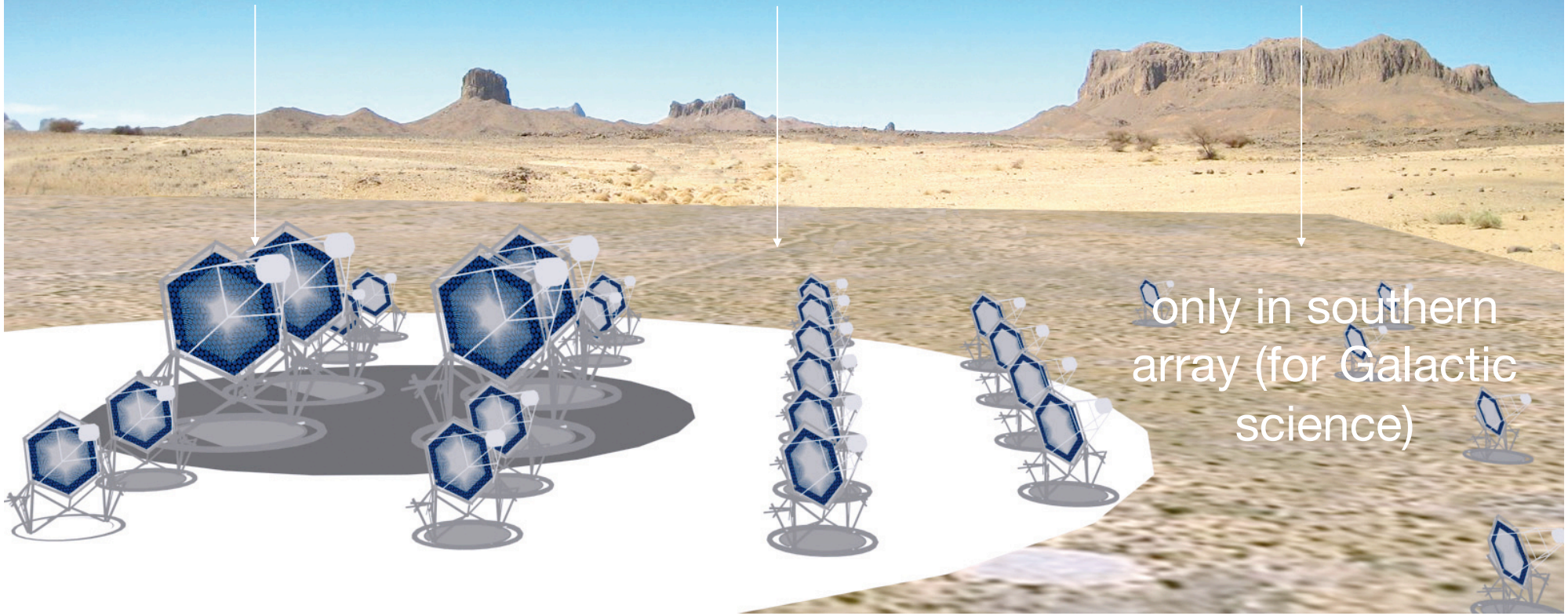

Simple minded approach

The Cherenkov Telescope Array concept

Low energy
Few 23 m
telescopes
4…5° FoV
~2500 pixels
~ 0.1°

Medium energy
About twenty 12 m
telescopes
6…8° FoV
~1500 pixels
~ 0.18°

High energy
Fifty + 4…7 m
telescopes
8…10° FoV
~1500…2000 pixels
~ 0.2°…0.3°

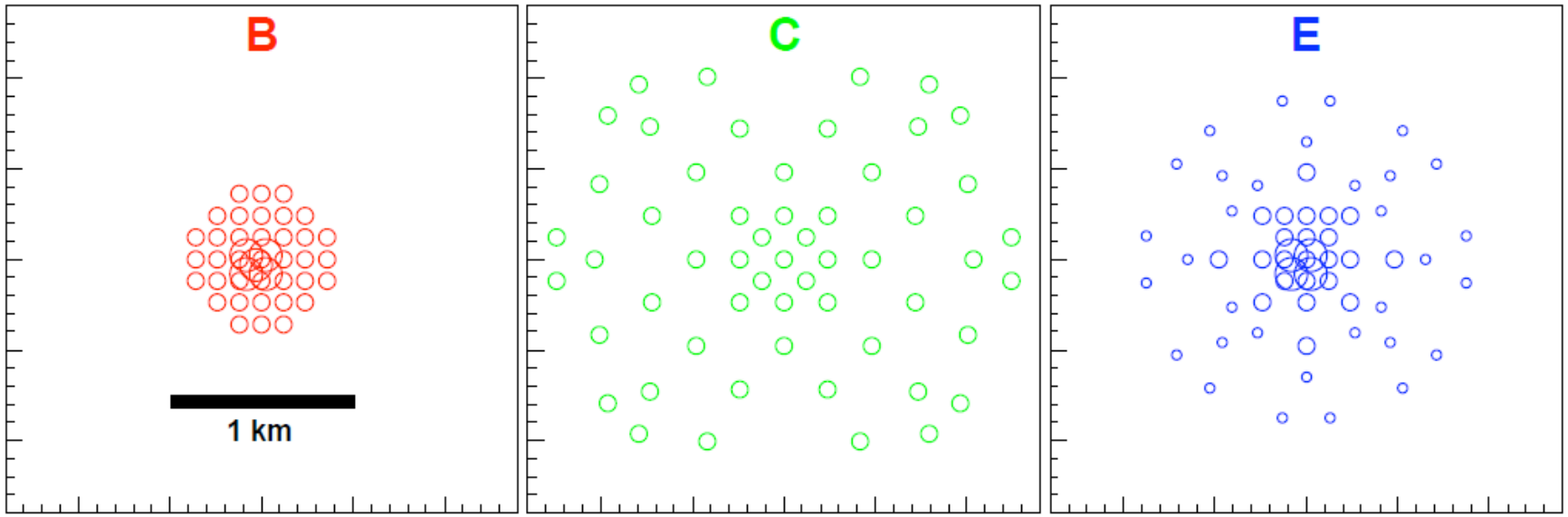


only in southern array (for Galactic science)

Technical implementation

Possible CTA configuration

Selection of different possible sub-arrays with estimated construction cost of ~80 M€ each



Densely packed array of 12 m and 24 m telescopes
→ focus on low Energy

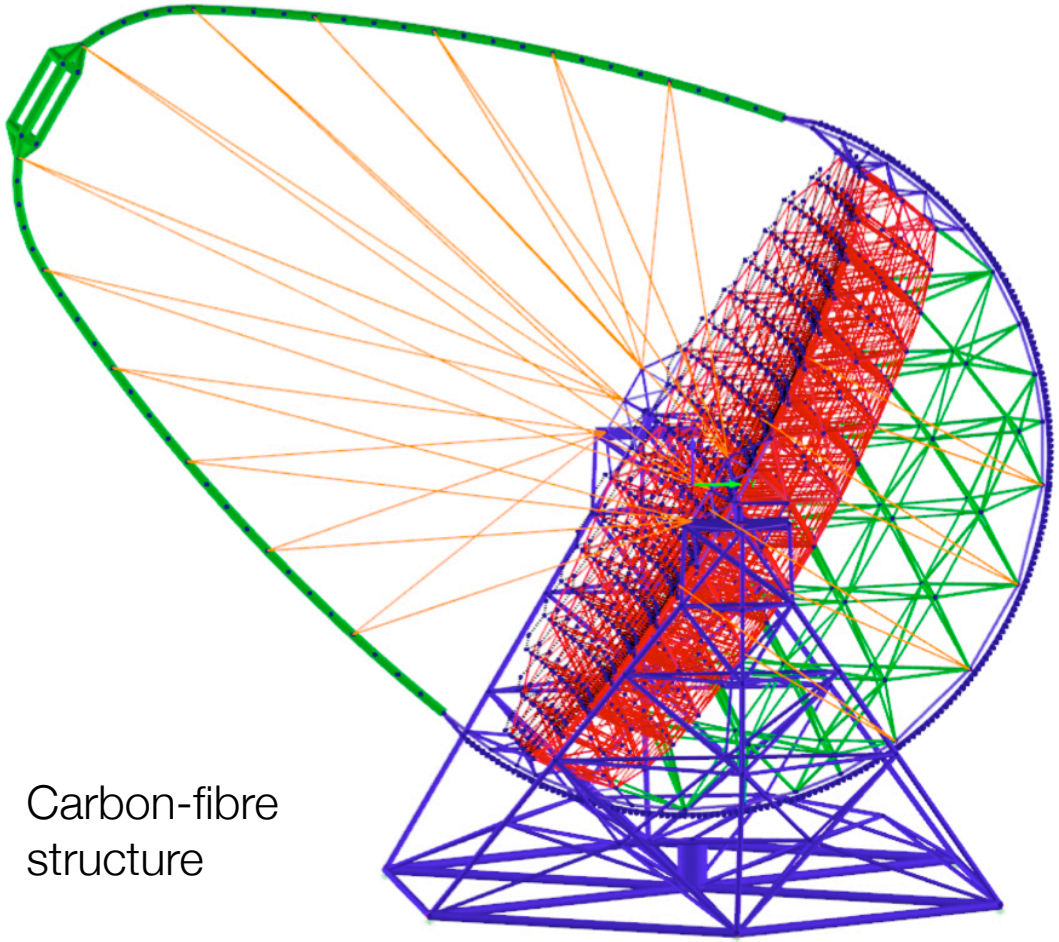
Wide spread array of 12 m telescopes
→ focus on mid and high Energy

Mixed array of 7, 12 and 24 m telescopes
→ Balanced sensitivity over large E-range

Design: 23 m Large Telescopes

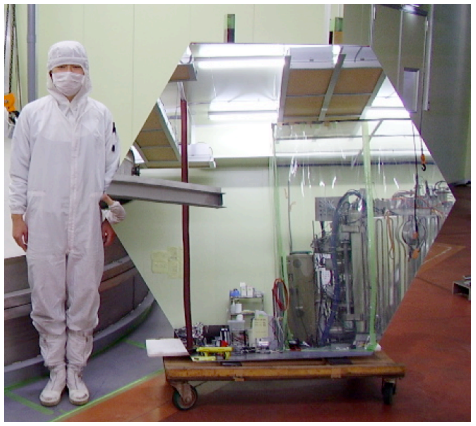
optimized for the range below 200 GeV

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

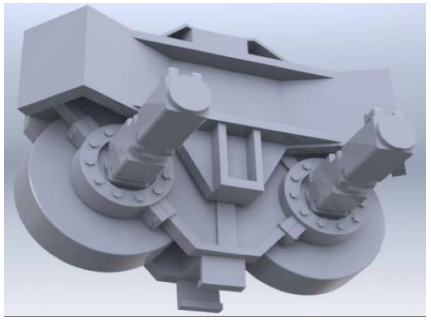


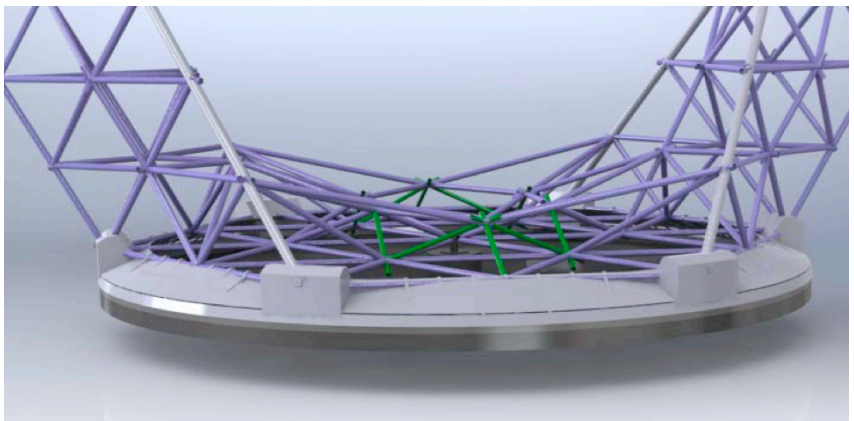
Carbon-fibre structure

400 m^2 dish area
1.5 m sandwich mirror facets



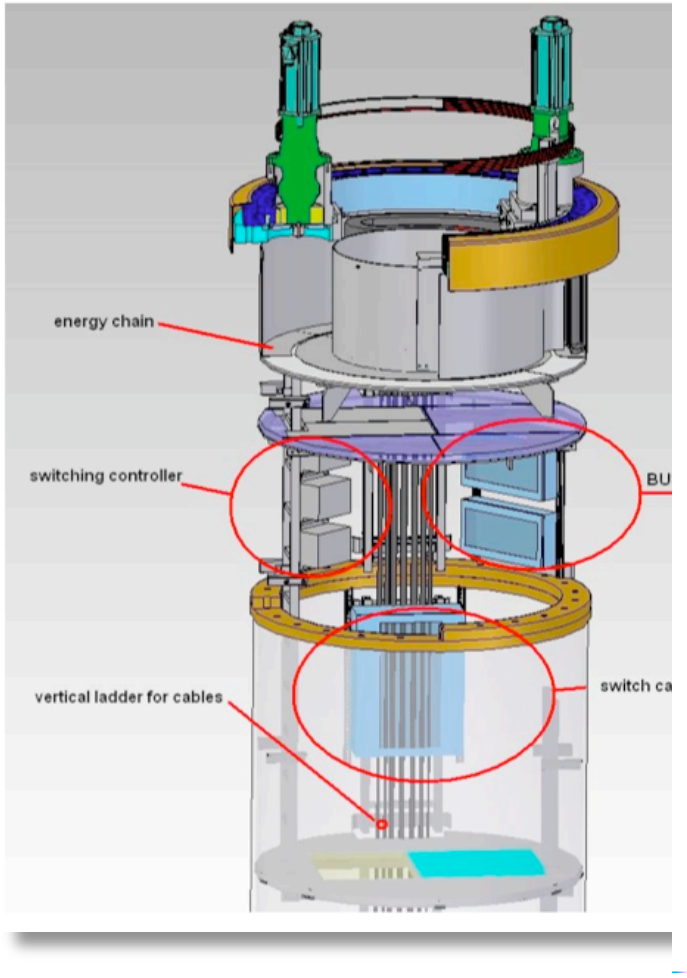
On (GRB) target in < 20 sec.



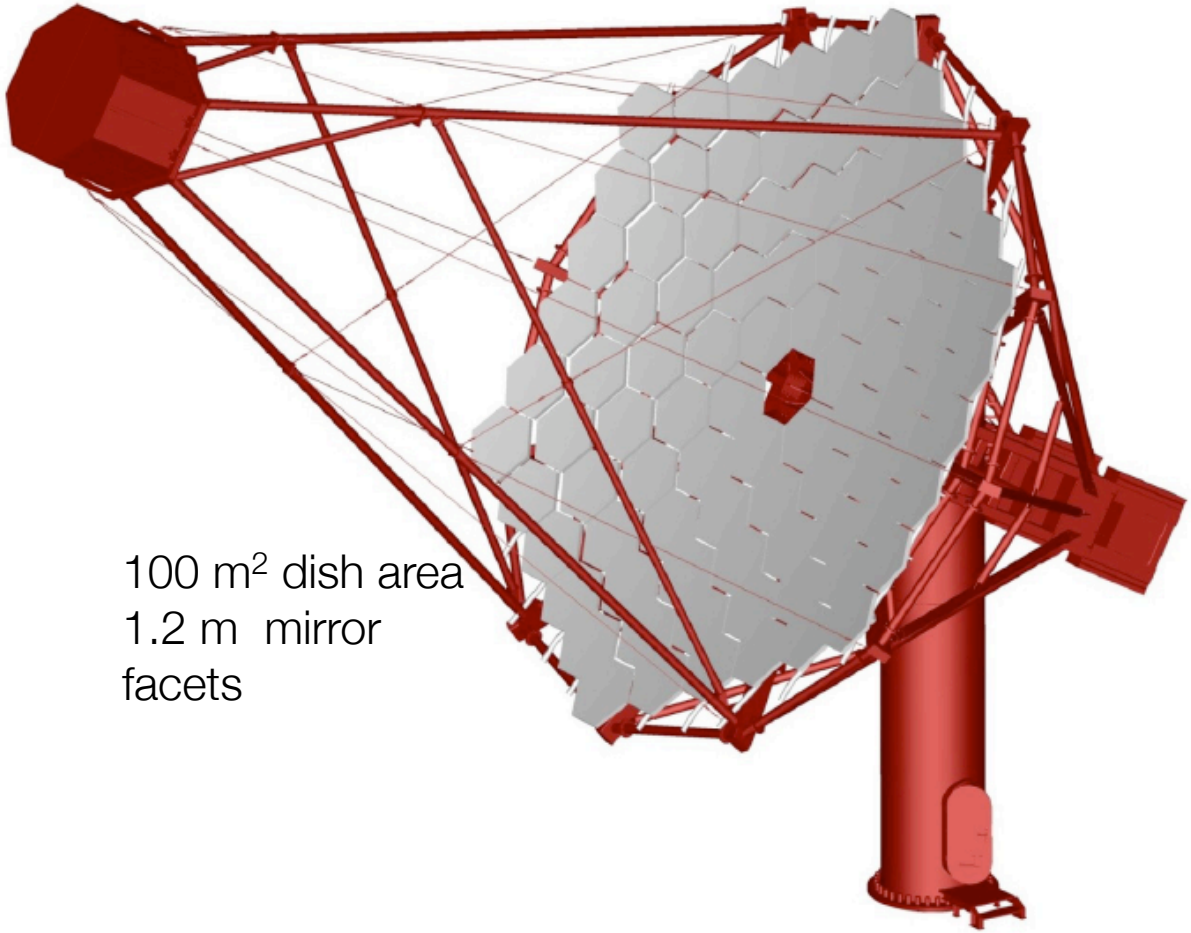


Design: Medium-Sized 12 m Telescope

optimized for the 100 GeV to ~10 TeV range



16 m focal length
7-8° field of view
0.18° pixels

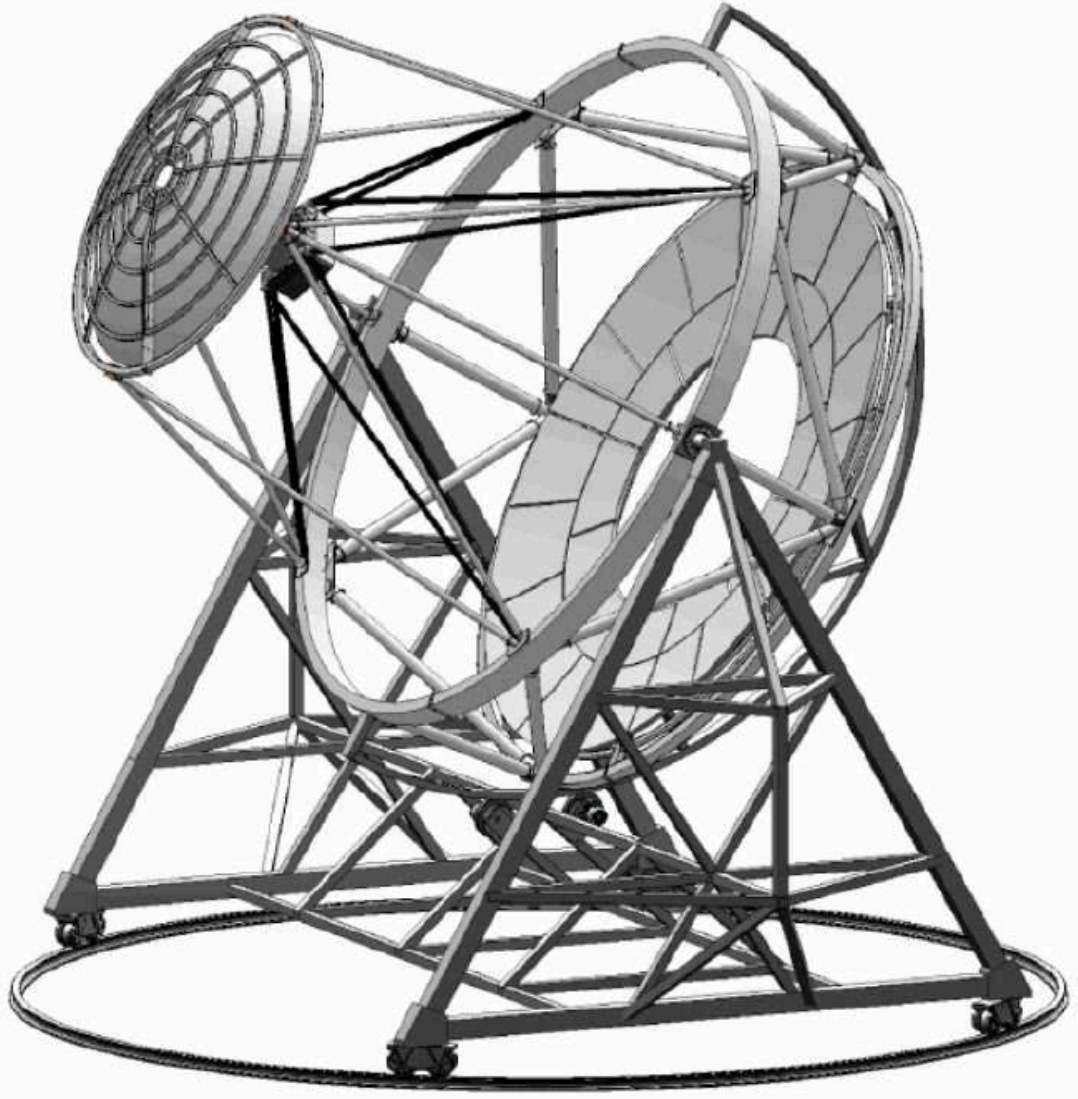


100 m^2 dish area
1.2 m mirror facets

Dual Mirror Option for medium telescope

Improved imaging
Small plate scale

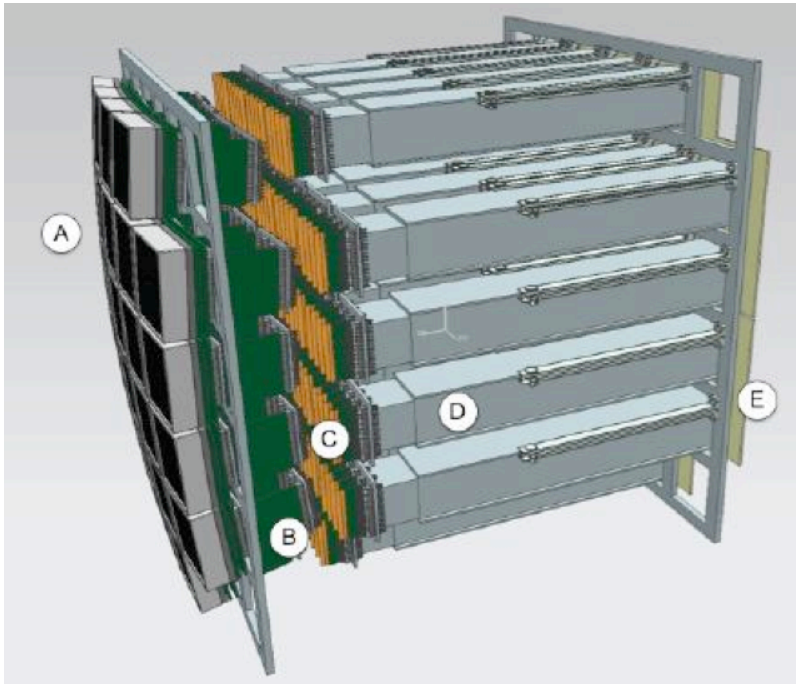
Discussed for
US-driven expansion
of MST array



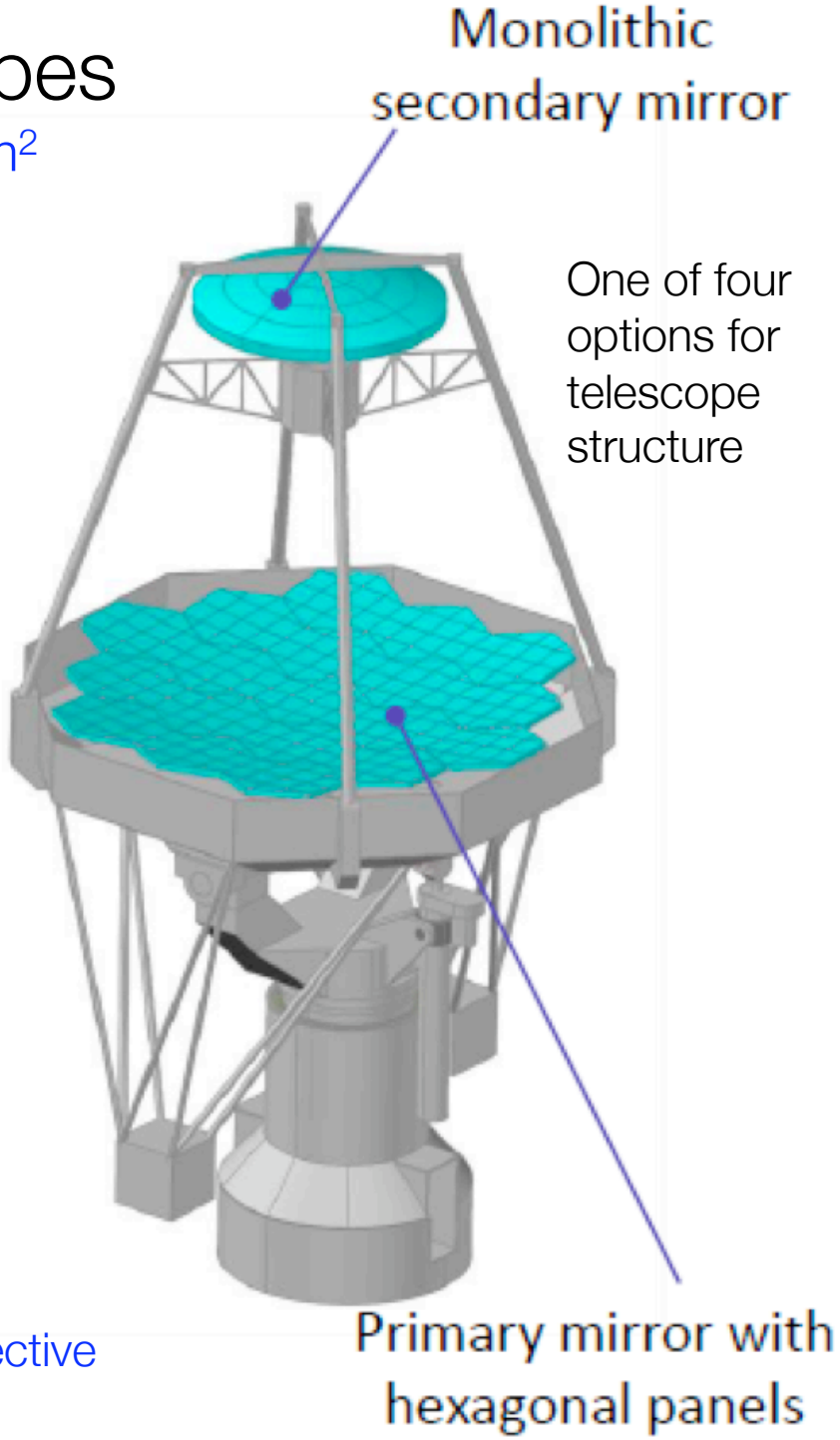
Design: Small 4-6 m Telescopes

cover the range above few TeV across 10 km^2

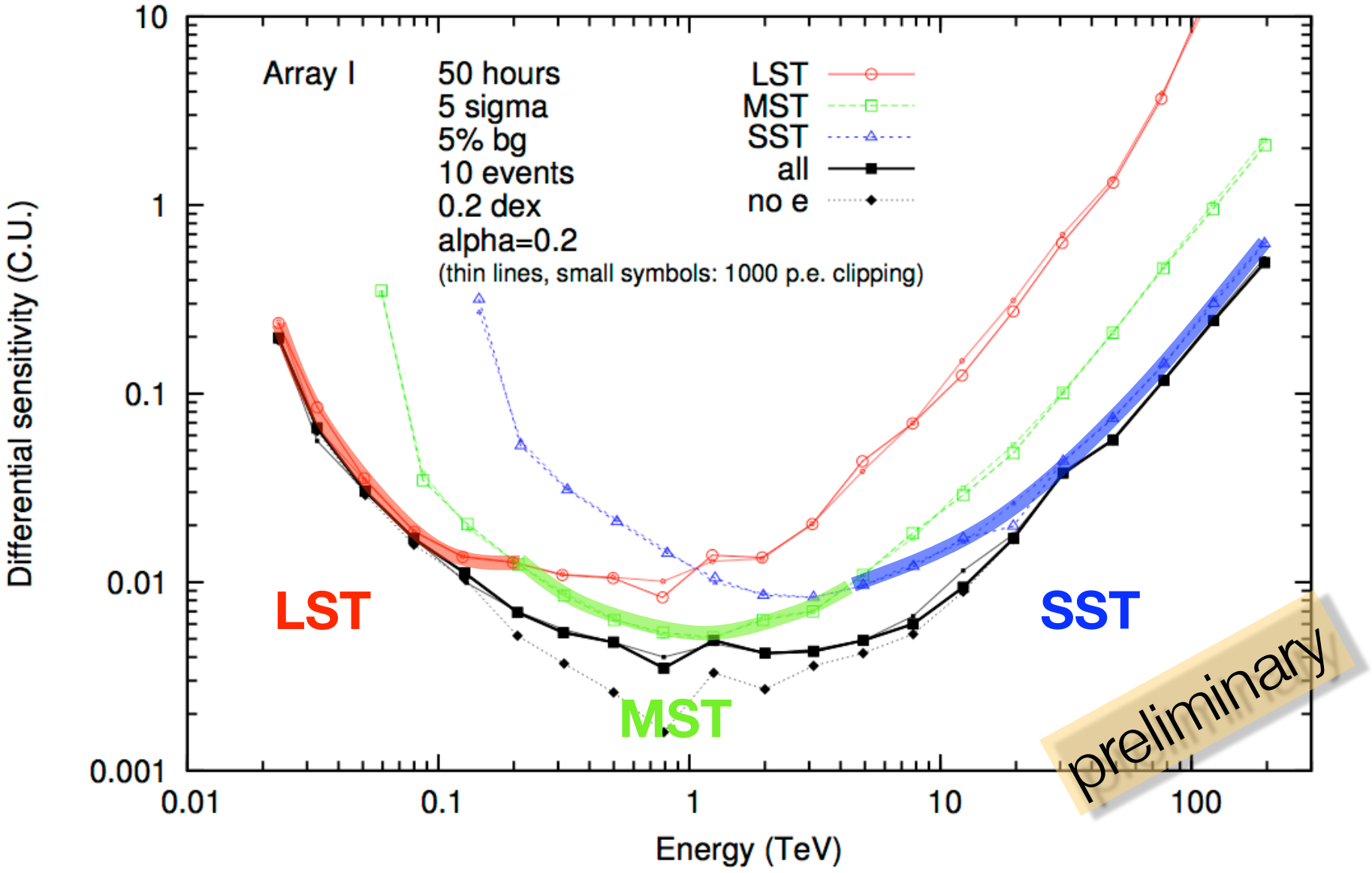
Multi-Anode PMT camera option



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

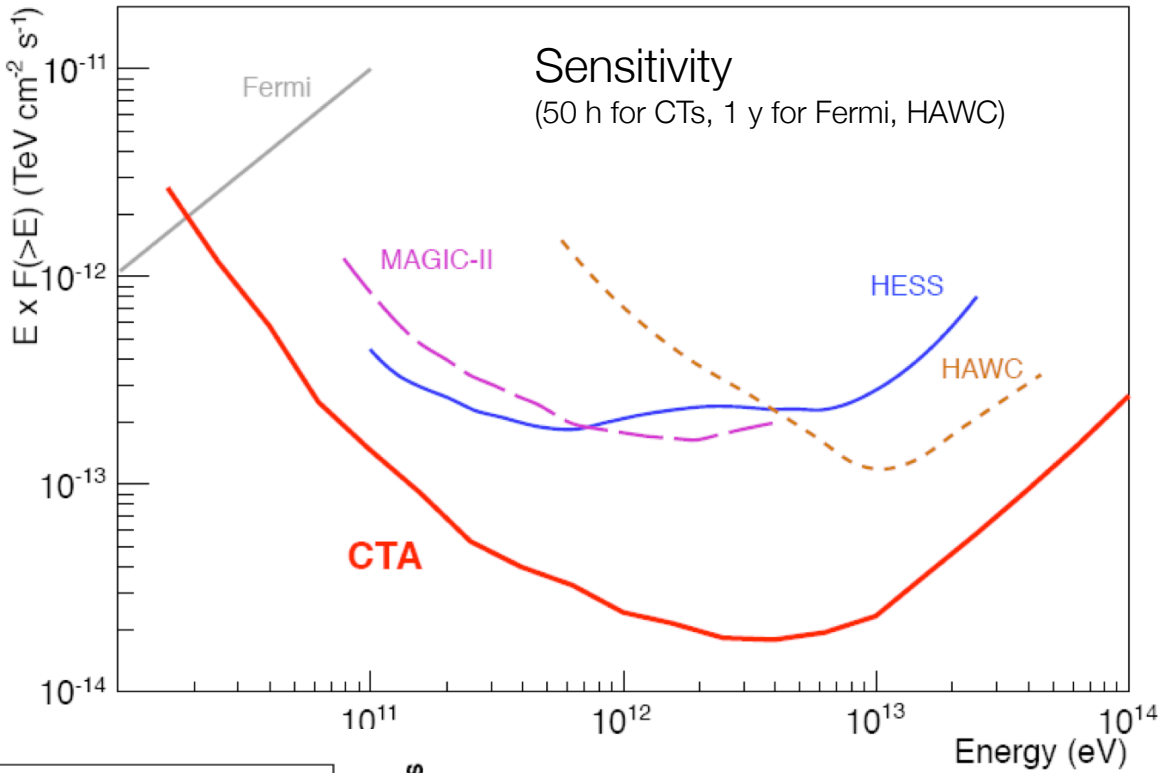


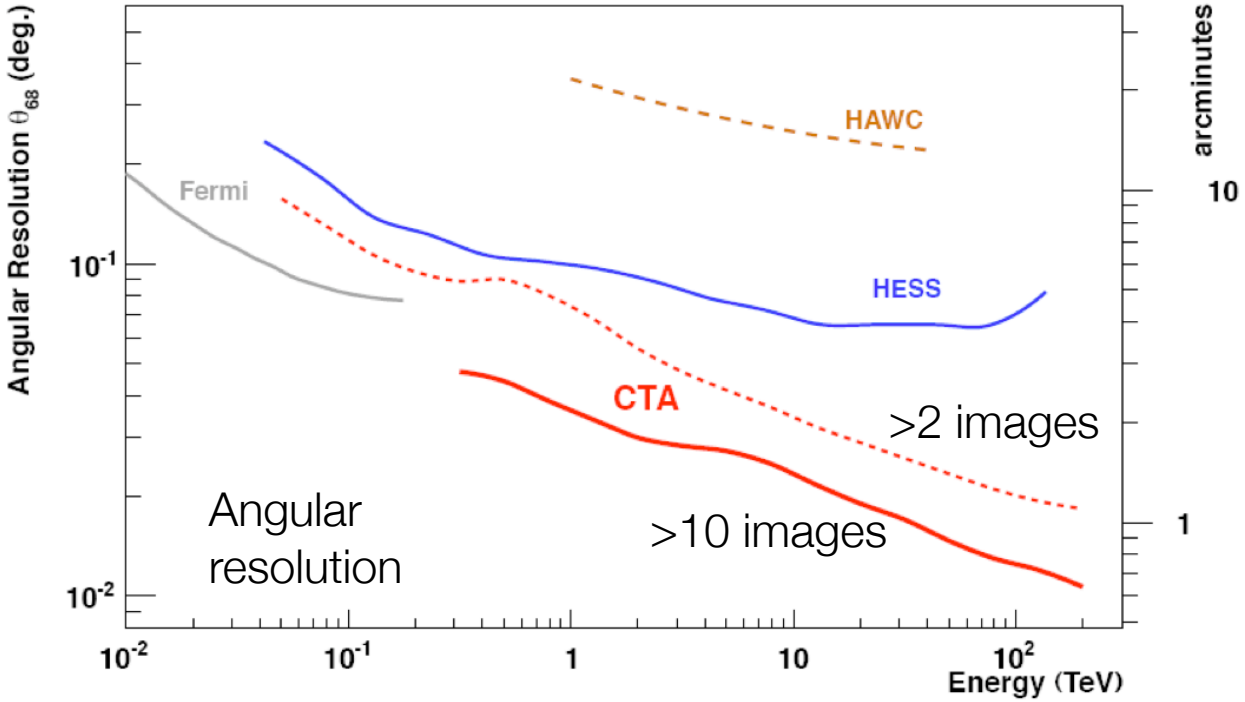
Sensitivity



Performance

Significant improvements due to new analysis algorithms



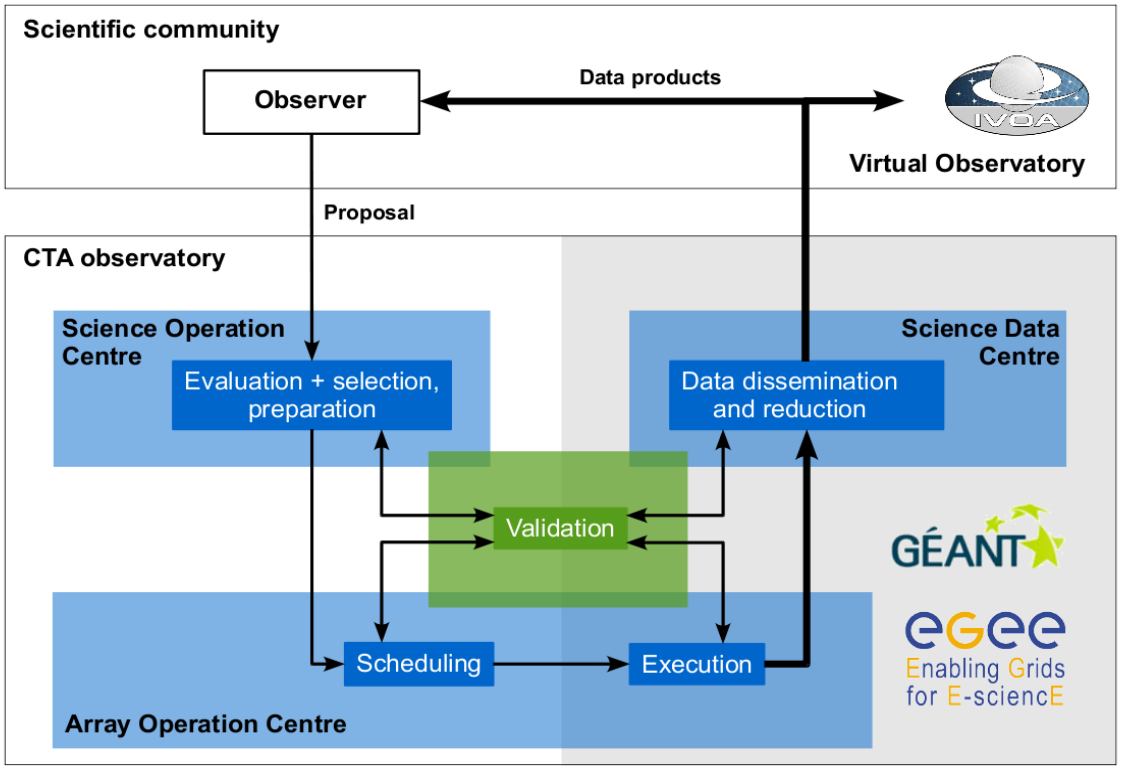


Up to factor 10
compared to HESS or MAGIC

Arc-minute scale angular resolution at high energies

CTA, an open observatory

- Large number of detectable objects main motivation to operate CTA as an open observatory
  - Provide tools for data dissemination and data analysis
- Large number of users from astronomy, astroparticle and particle physics, cosmology, …

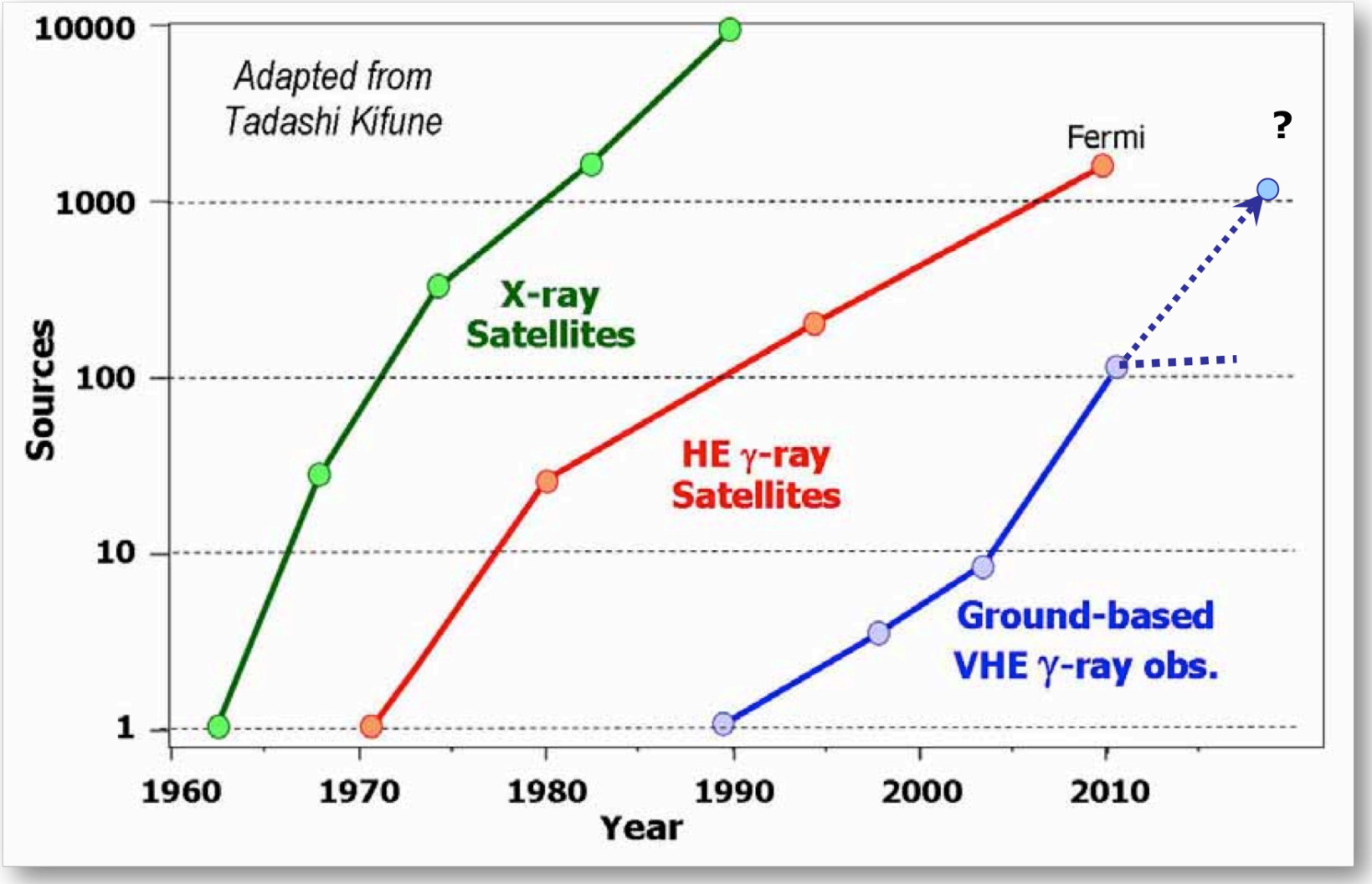


Physics ahead

Very subjective highlights

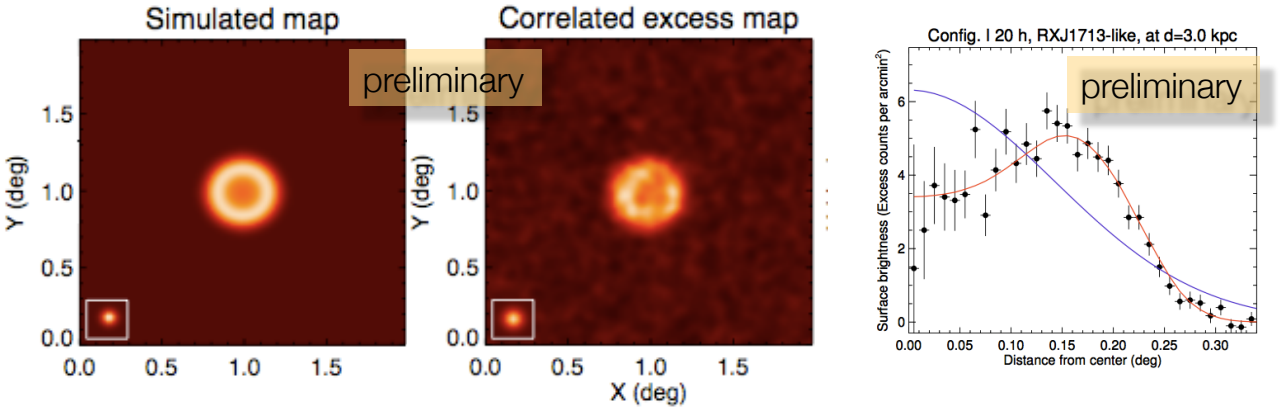
Number of sources

Kifune plot

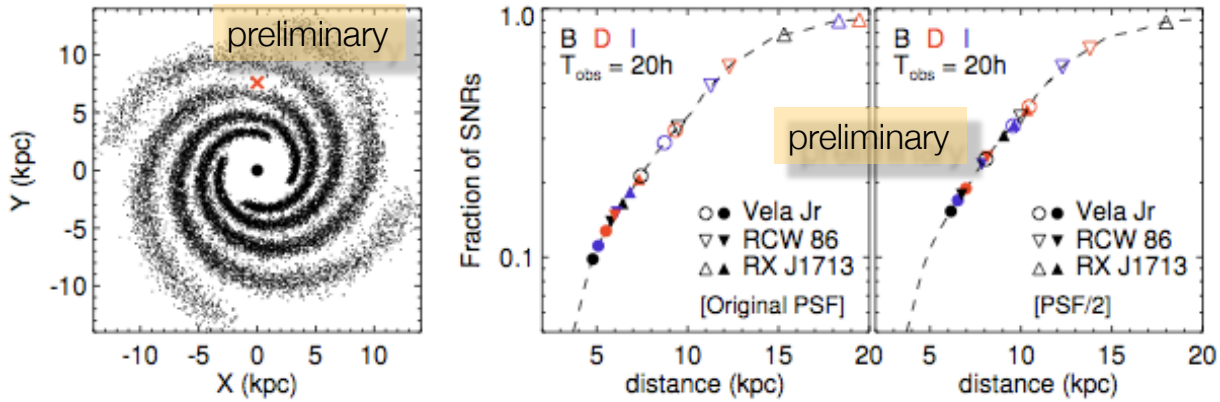


Cosmic ray accelerators

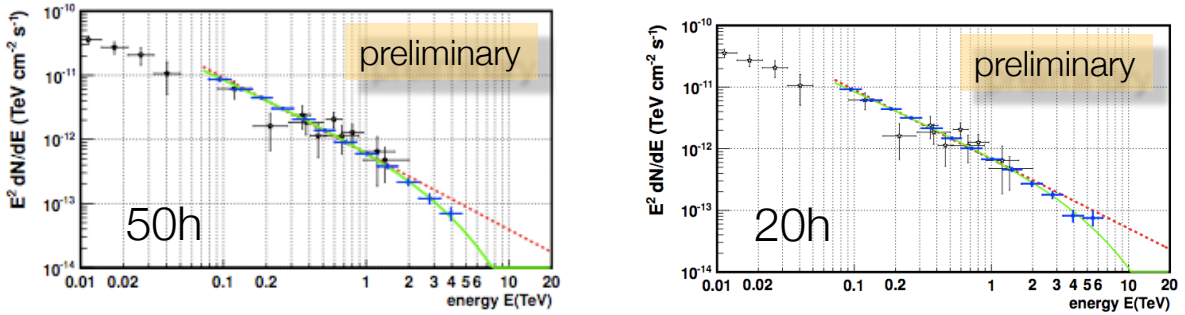
- Through much better imaging (angular resolution)



- Through detecting all bright SNR in the galaxy and resolving many

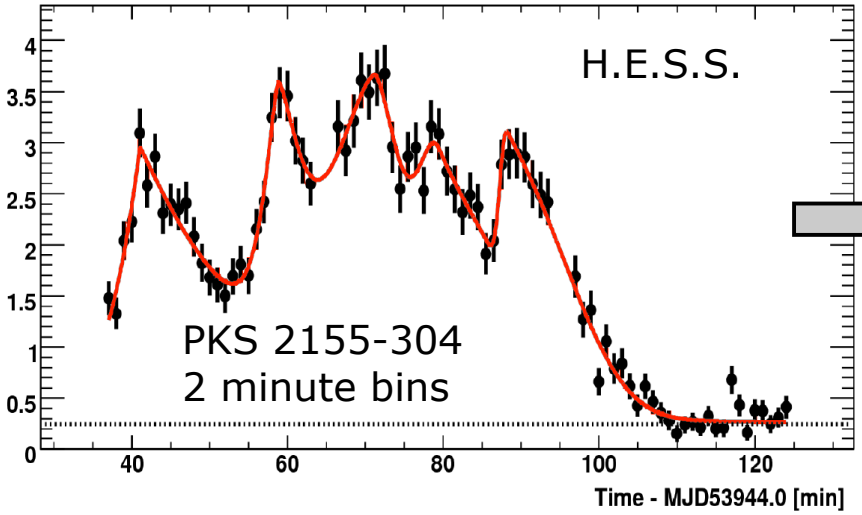


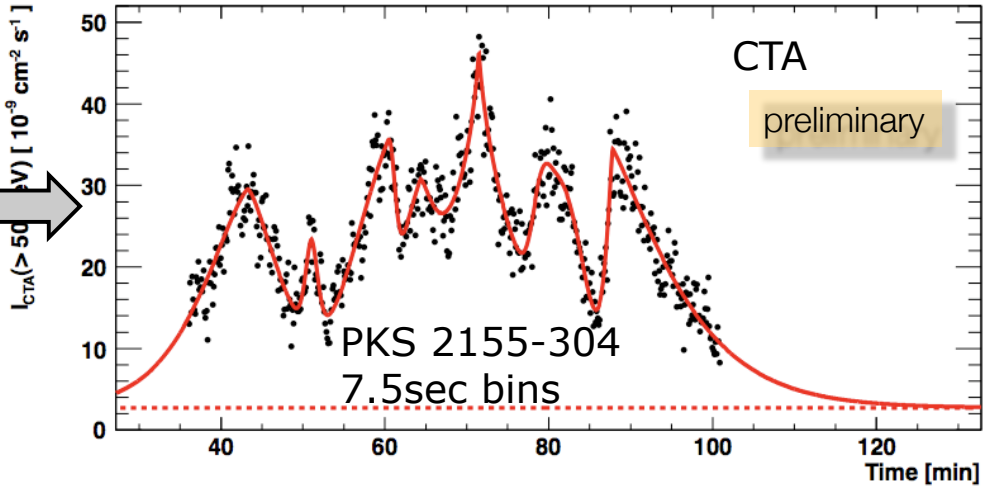
- Through spectral studies (e.g. finding energy cutoffs)

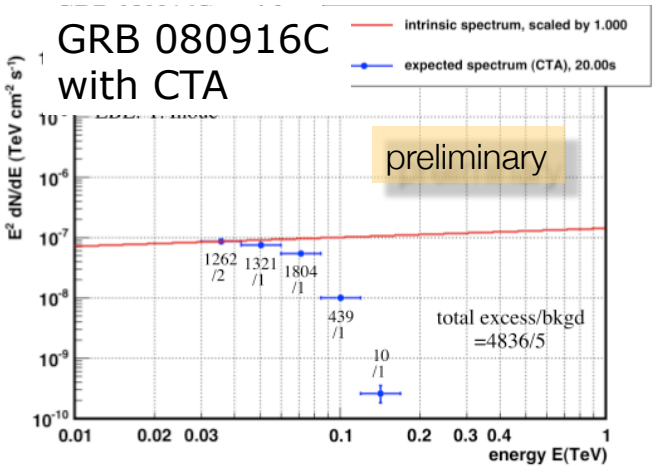


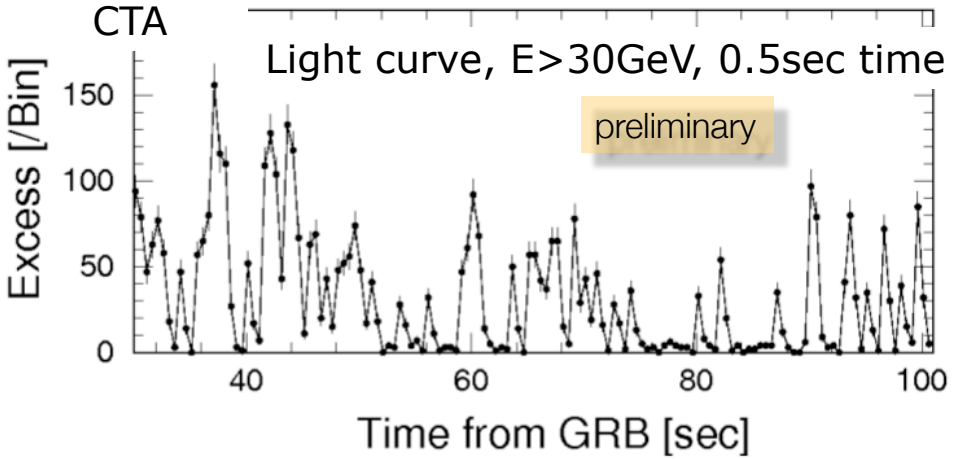
AGNs and GRBs (fast variability!!)

- Expect a quantitative jump in: Population studies, detecting sources at z>2, enormous progress in modeling of the emission, origin of variability



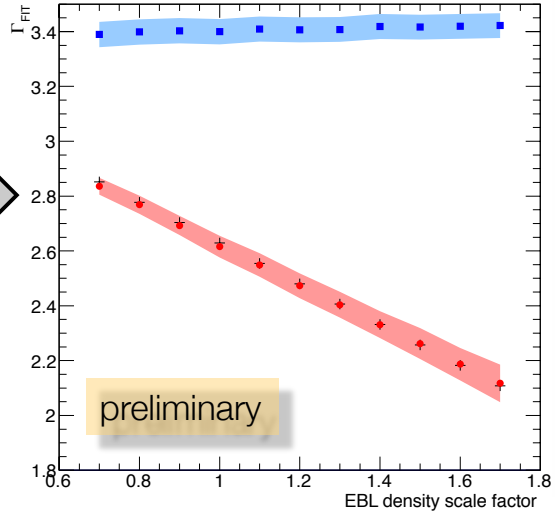


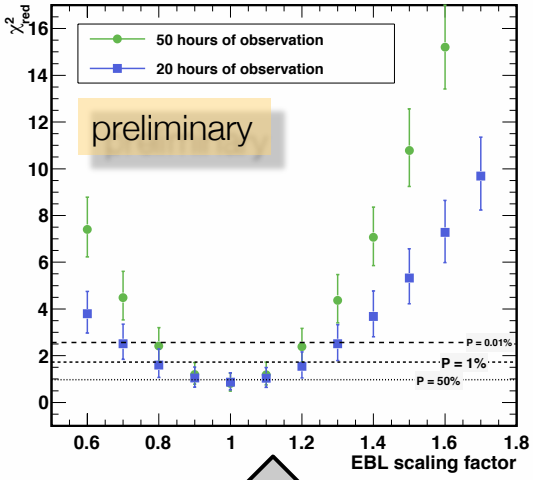




Extragalactic Background light and Cosmology

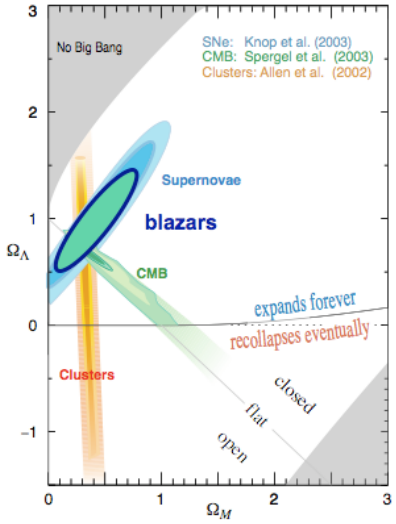
- Simultaneous measurement of absorbed and unabsorbed parts of the energy spectrum





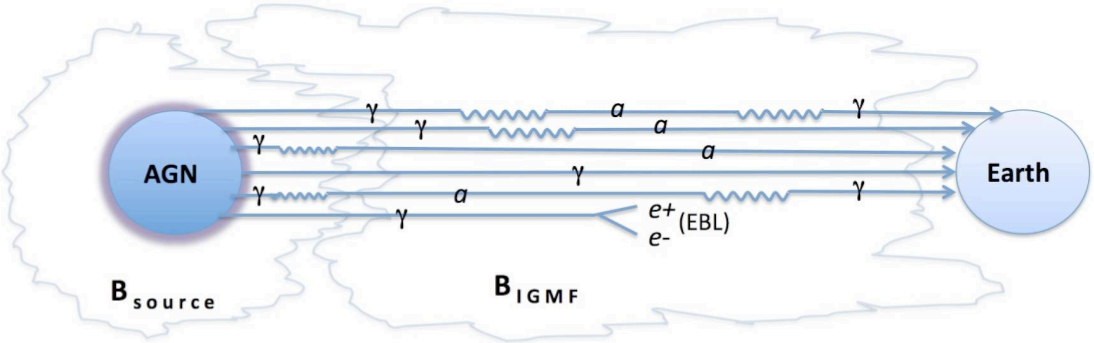
- Measuring EBL through resolved spectral features

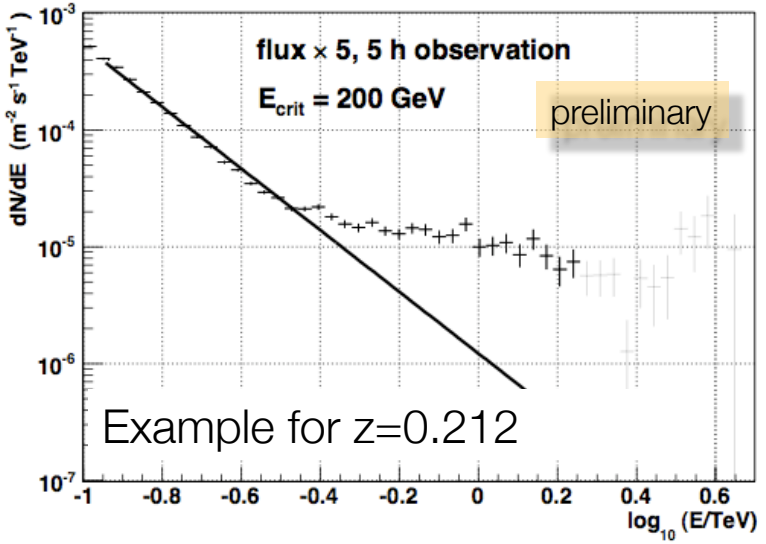
- Once EBL is measured, use it to independently measure distance to sources and test cosmological model



Fundamental physics

- Search of axion-like particles

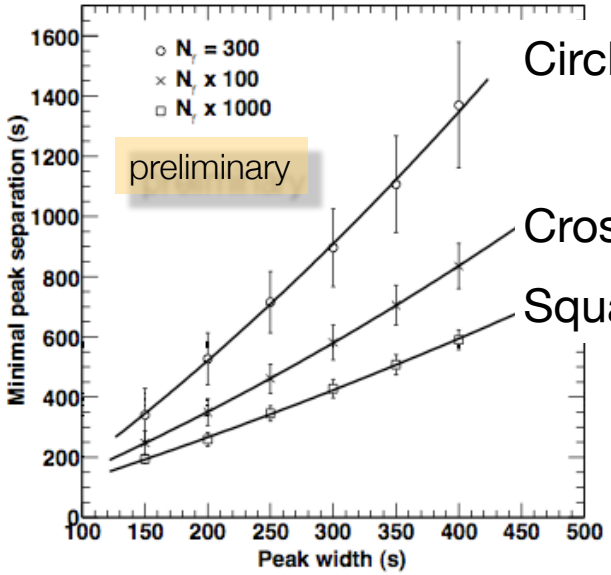




- High Energy Violation of Lorentz Invariance

$$\Delta t \simeq \left(\frac{\Delta E}{\xi_\alpha E_{\mathrm{Pl}}} \right)^\alpha \frac{L}{c}$$

with α=1 or 2



Circle: HESS-like

Crosses: CTA

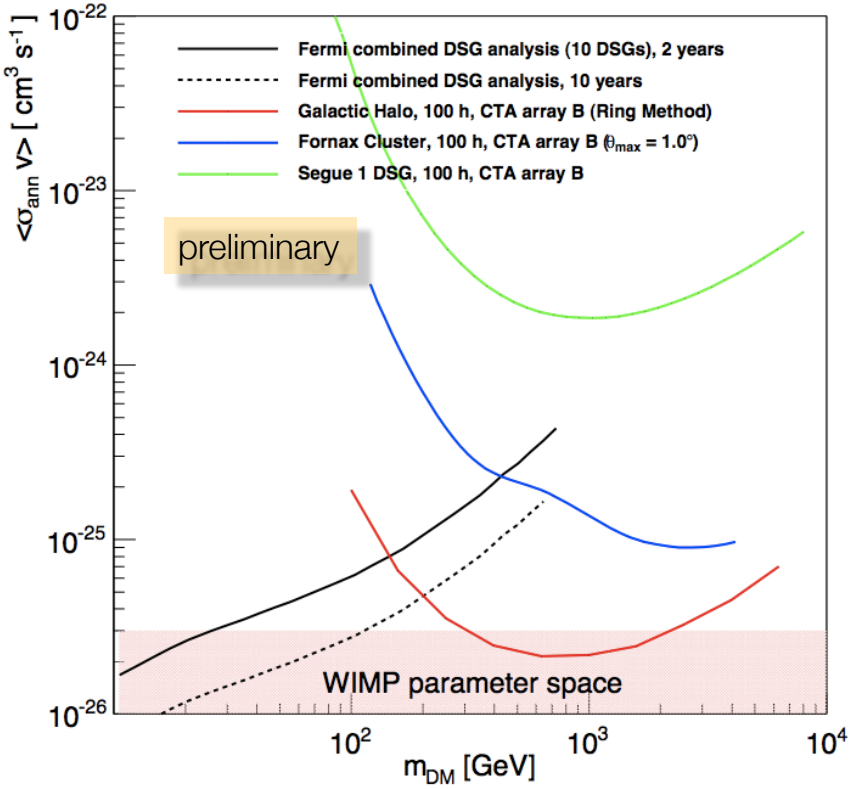
Square: ideal

Dark matter

$$\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = B_F \cdot \frac{1}{4\pi} \underbrace{\frac{\langle\sigma_{ann} v\rangle}{2\, m_\chi^2} \sum_i BR_i \frac{dN_\gamma^i}{dE_\gamma}}_{\text{Particle Physics}} \cdot \underbrace{\widetilde{J}(\Delta\Omega)}_{\text{Astrophysics}}$$

Many candidates to look at:

- Dwarf galaxies
- Galaxy clusters
- Galactic halo (most promising?)
- Galactic center



Might well be within the reach!

Status and plans

Design study phase concluded in Fall 2010

➜ Design Concepts for the Cherenkov Telescope Array (arXiv:1008.3703)

FP7-supported Preparatory Phase: Fall 2010 – Fall 2013

➜ Technical design, sites, construction and operation cost

➜ Legal, governance and finance schemes

➜ Small + medium-sized telescope prototypes

Aim for

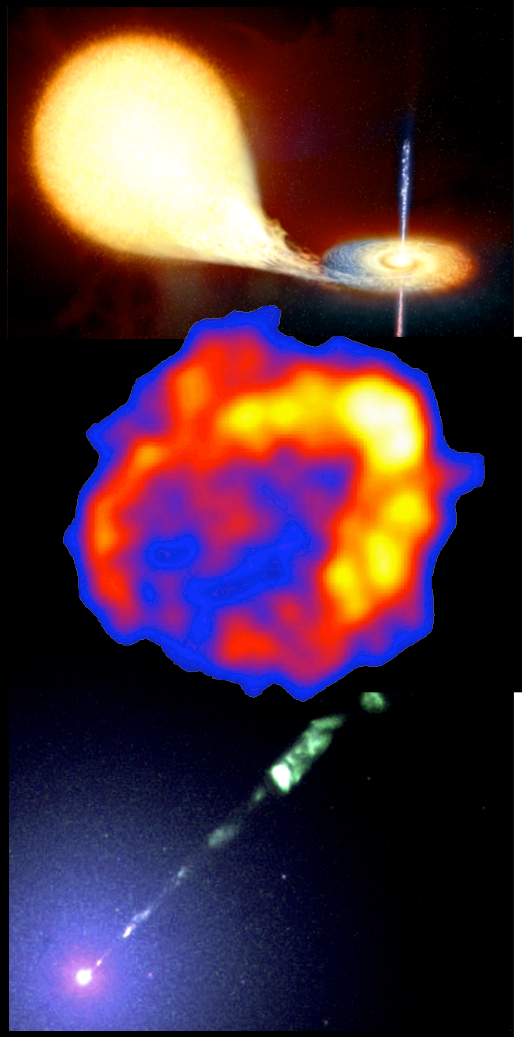
- start of deployment in early 2014
- first data in 2016/17
- base arrays complete in late 2018
- expanded mid-energy array driven by US

BACKUP

TeV Astronomy: Highlights

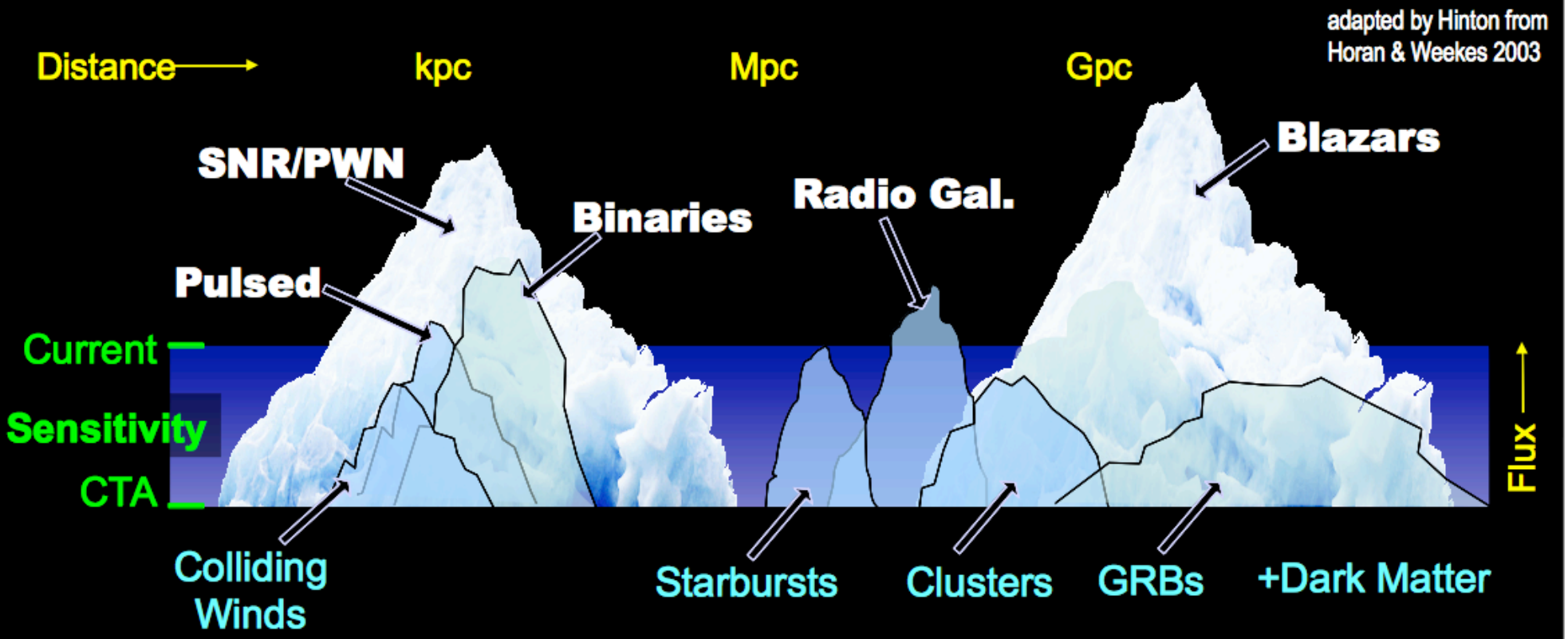
Over 350 publications in high-impact journals:

- *Microquasars*: Science 309, 746 (2005), Science 312, 1771 (2006)
- *Pulsars*: Science 322, 1221 (2008)
- *Supernova remnants*: Nature 432, 75 (2004)
- *The Galactic Centre*: Nature 439, 695 (2006)
- *Galactic Survey*: Science 307, 1839 (2005)
- *Starbursts*: Nature 462, 770 (2009), Science 326,1080 (2009)
- *AGN*: Science 314,1424 (2006), Science 325, 444 (2009)
- *EBL*: Nature 440, 1018 (2006), Science 320, 752 (2008)
- *Dark Matter*: Phys Rev Letters 96, 221102 (2006)
- *Lorentz Invariance*: Phys Rev Letters 101, 170402 (2008)
- *Cosmic Ray Electrons*: Phys Rev Letters (2009)



Results from **HESS**, **MAGIC** and **VERITAS**

Science Potential



- Current instruments have passed the critical sensitivity threshold and reveal a rich panorama, but this is clearly only the tip of the iceberg
- What big science questions remain ?

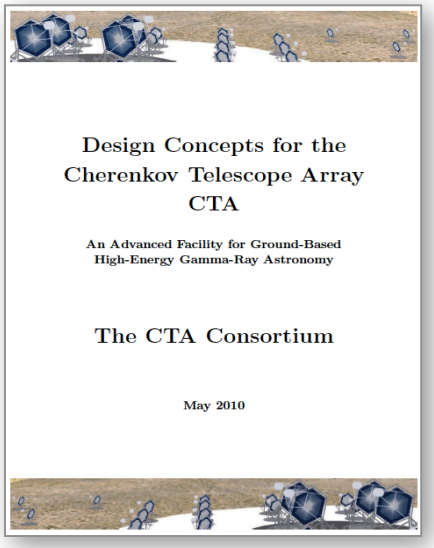
Tentative timeline towards the *CTA* observatory

	07	08	09	10	11	12	13	14	15
Array layout									
Telescope design									
Component prototypes									
Telescope prototype									
Array construction									
Partial operation									

Design

Prototype

Array



Design Study
2007-2010

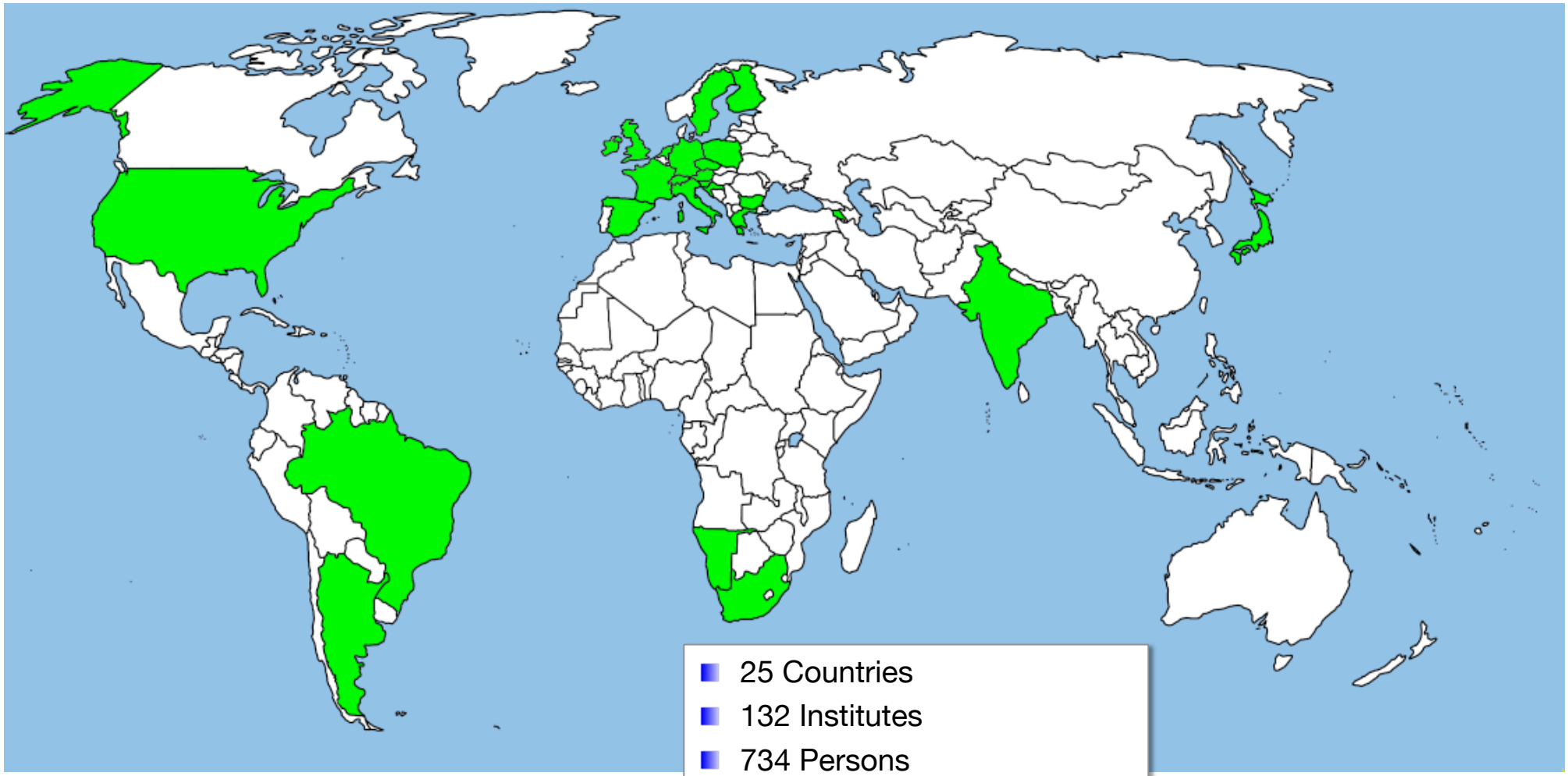
Preparatory Phase
2010-2013

Array Construction
2014-2018

Design Concepts for CTA
(arXiv:1008.3703v1)

"Production-Ready"
Technical Design Report

CTA



- 25 Countries
- 132 Institutes
- 734 Persons
- 220 FTEs

Goals of Prep Phase

- Provide a technical design
- Provide site choices
- Define organizational, legal, financial framework
- Provide reliable costs for construction and operation
- Develop funding scenario
- Prepare science exploitation

- **Get agencies to sign**

CTA-PP budget:
5.2 M€ from FP7
+ support by local agencies >10 M€

Telescope characteristics

Wavelength range
- 300 – 600 nm

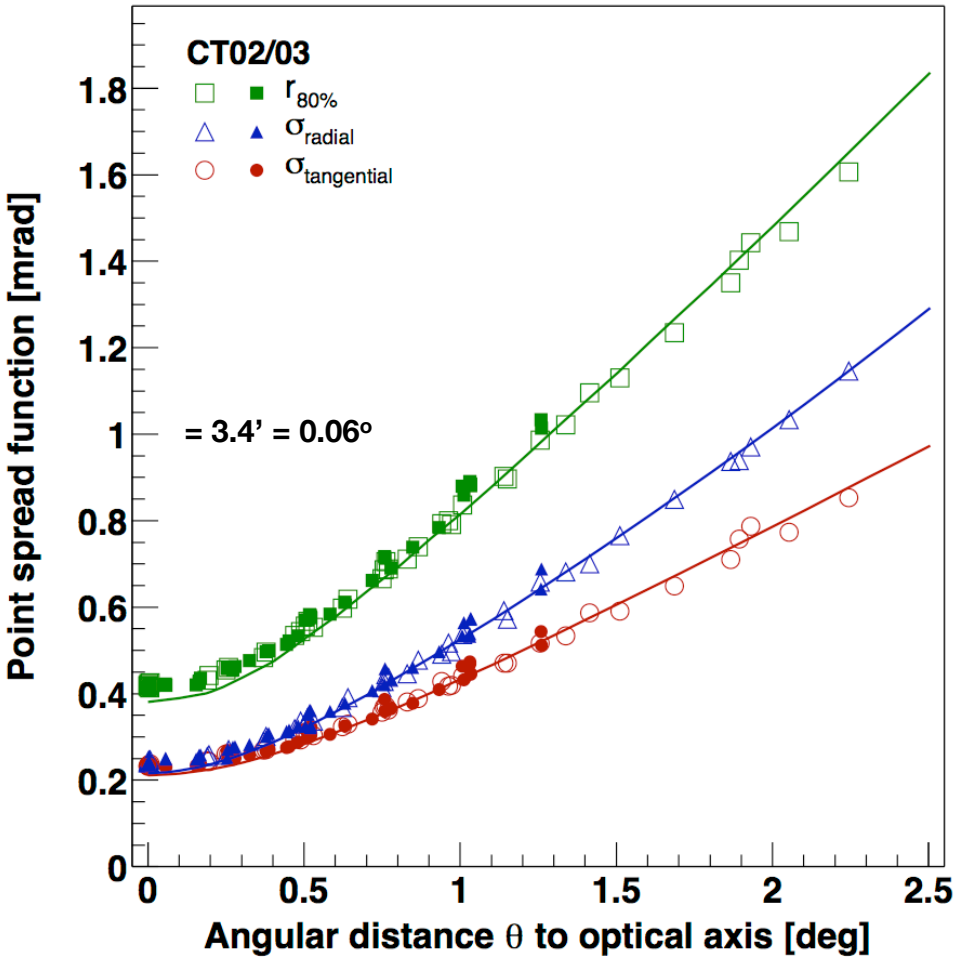
Mirror PSF
- O(1') on axis, worse off axis

Pixel size
- 0.1° – 0.2°

Source localization
- 5" – 10" for source centroid

Image rate
- kHz

Exposure time
- single image: O(10 ns)
- typical source: 10 – 50 h



Differences to optical and radio telescopes: what does not matter (much)

Seeing: Pixel size of CT's is 0.1^{o} – 0.2^{o}
Don't care about seeing

Water vapor: no significant scattering or absorption of Cherenkov light
Don't care as long as it is vapor

Tracking, shaking: no need to point / track very precisely as long as one knows where the telescope points during the 10 ns exposure