The Cherenkov Telescope Array

Ciro Bigongiari
INAF Osservatorio Astrofisico di Torino
for the CTA consortium

CRIS - Cosmic Ray International Seminar – 2015

Outline

- Very High Energy Gamma-ray Astronomy
  - Imaging Air Cherenkov Technique
- CTA project
  - Cherenkov telescopes
  - Expected performance
  - Science goals
- Conclusions

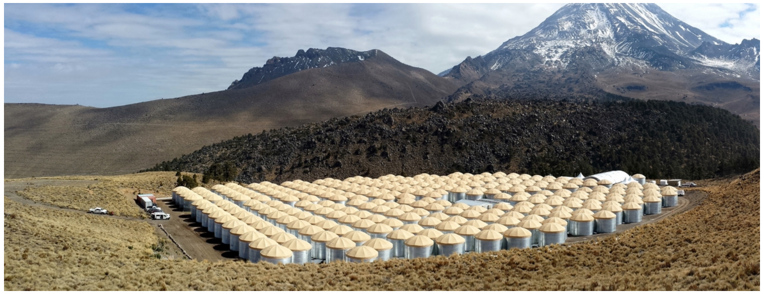
Gamma Ray Astronomy

Earth atmosphere is opaque for gamma rays

Indirect detection from ground

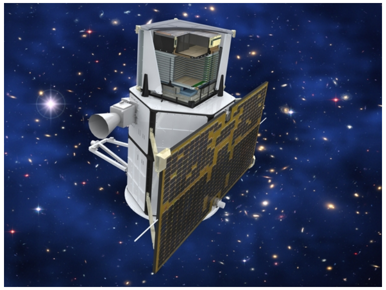
Current arrays of Imaging Air Cherenkov Telescopes
30 GeV < E < 30 TeV

Water Cherenkov Detectors
E > 30 TeV



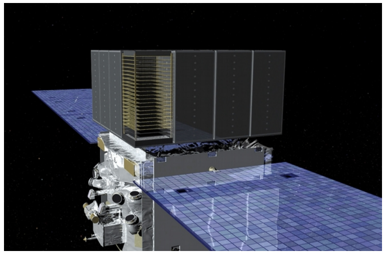
Direct detection from space

Integral
E < 10 MeV

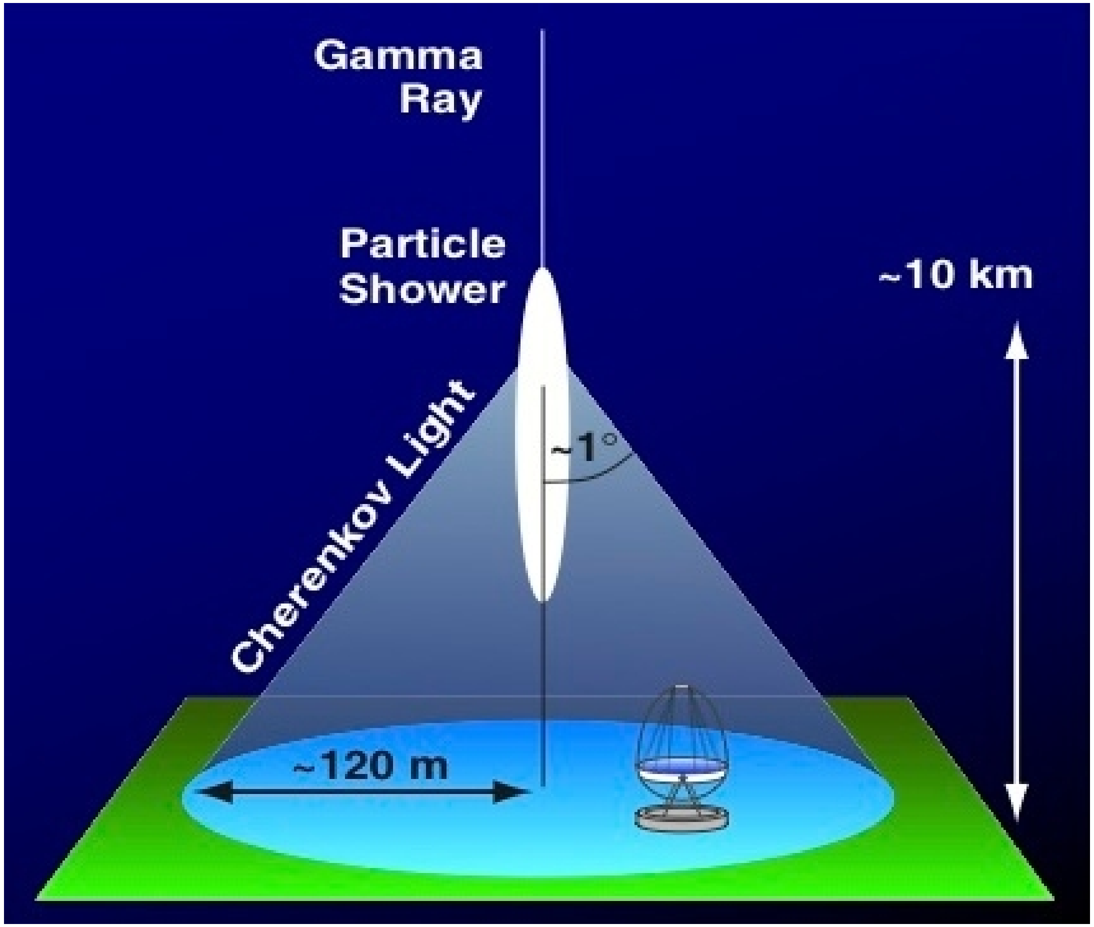


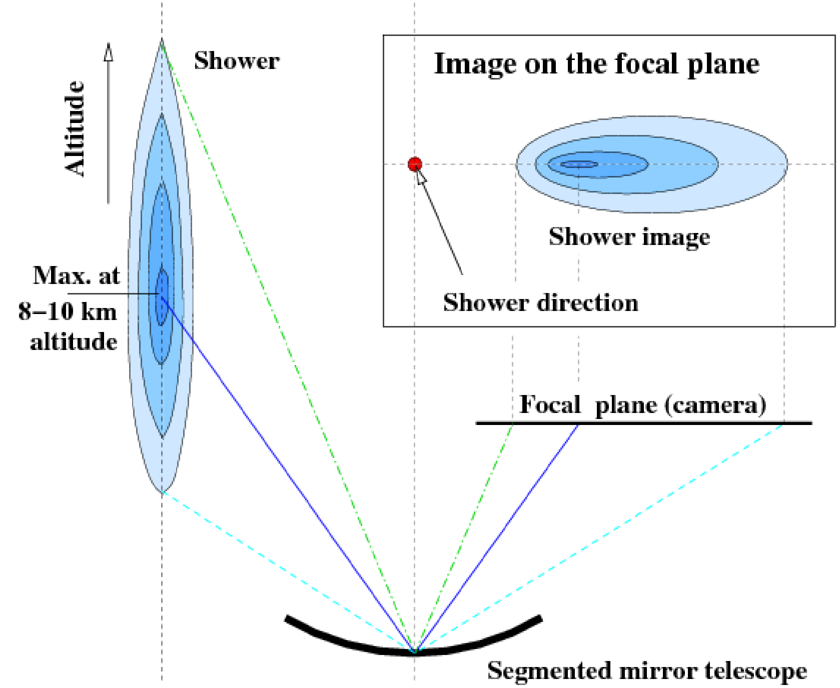
AGILE
30 MeV < E < 50 GeV

Fermi - LAT
100 MeV < E < 300 GeV



Imaging Air Cherenkov Technique





The Cherenkov light spreads over $O(10^4\ m^2)$
IACT collecting area is much larger than the one of satellite borne detectors ($\sim 1\ m^2$)

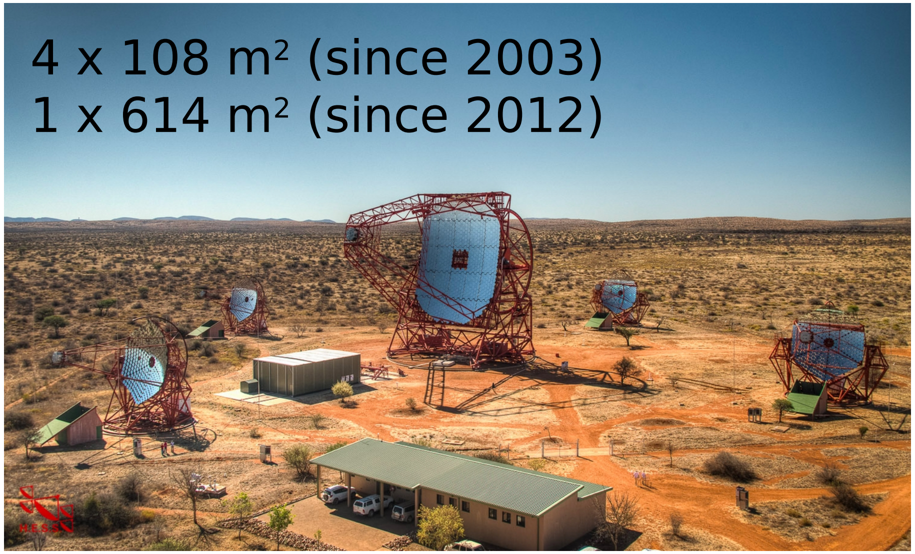
The collected light is focused on the telescope focal plane forming an image.

Size, shape and orientation of the image can be used to discriminate between gamma and hadronic primaries and to estimate primary direction and energy.

Present IACT Arrays

HESS (Namibia)

4 x 108 m^2 (since 2003)
1 x 614 m^2 (since 2012)



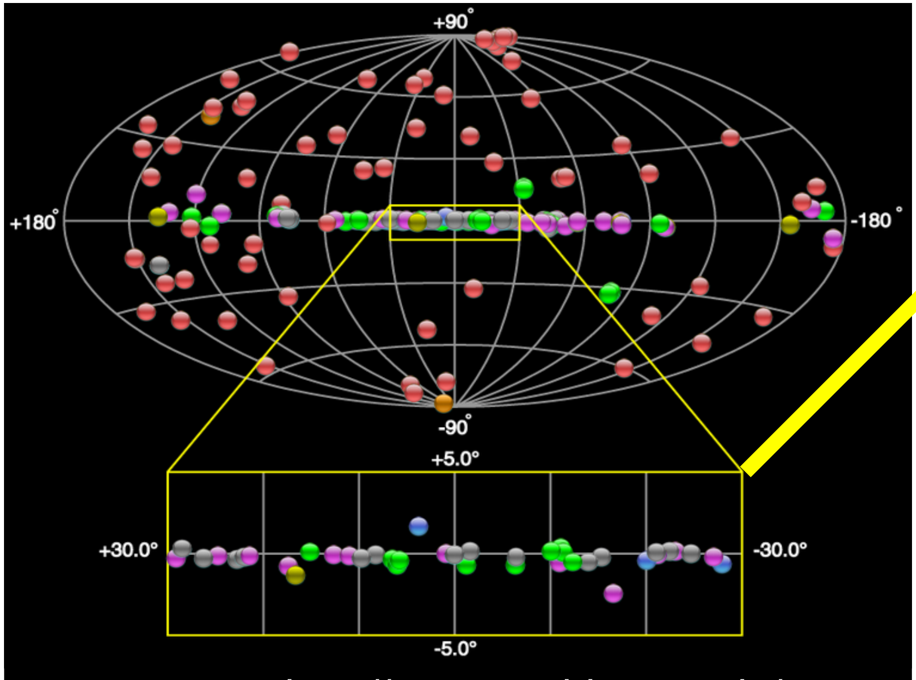
MAGIC (Spain)

2 x 236 m^2 (since 2003 / 2009)

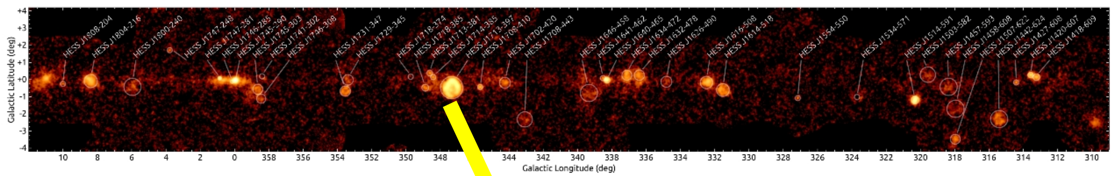
VERITAS (Arizona)

4 x 110 m^2 (since 2007)

Scientific Highlights



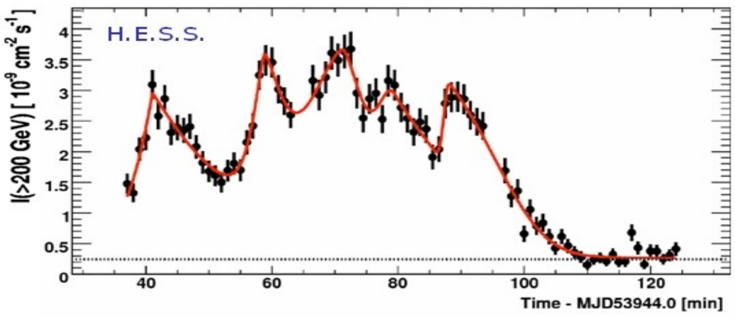
From TeVCat http://tevcat.uchicago.edu/



A. Donath et al. ICRC2015

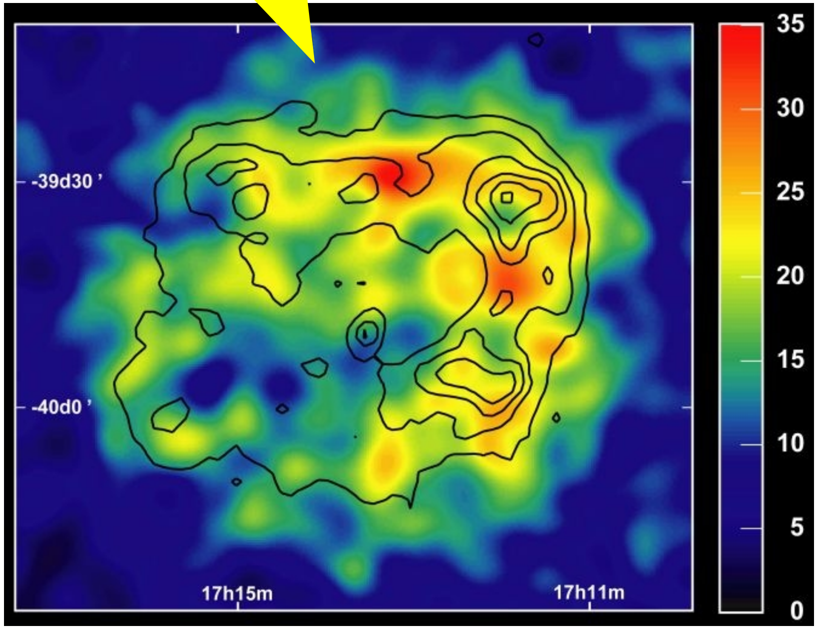
Detailed survey of the galactic plane

More than 160 sources detected, most of them in the last 10 years



Time resolved analysis of gamma emission down to few minutes scale

F.Aharonian et al. ApJ **664**, L71-L78,2007



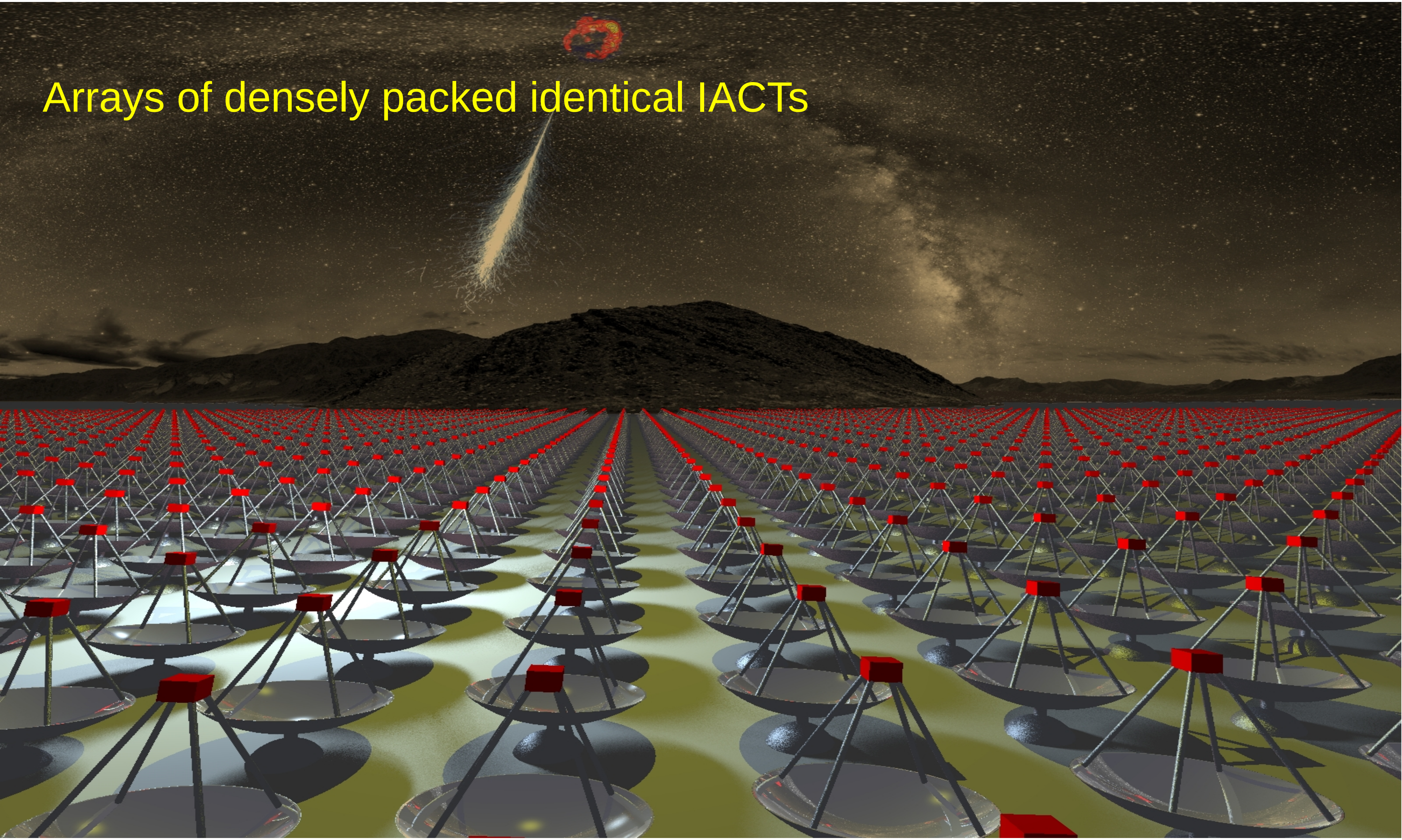
F.Aharonian et al., A&A **449,** 223-242,2006

Accurate morphological studies of extended sources

CTA Project

- Goals:
  - Increase the sensitivity by an order of magnitude
  - Extend the energy coverage ~20 GeV - ~300 TeV
  - Improve energy and angular resolution
  - Survey the full sky
  - Observe fast transient phenomena
- Solution
  - Two arrays of many IACTs
    - One in each hemisphere

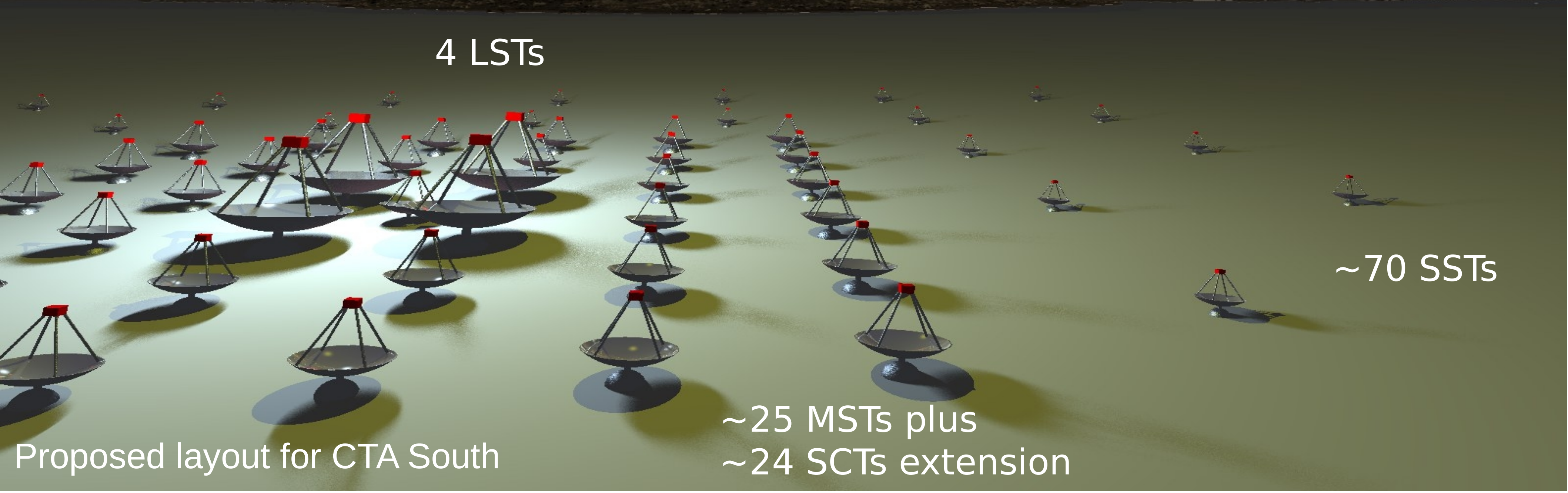
Ideal Solution



Feasible Solution

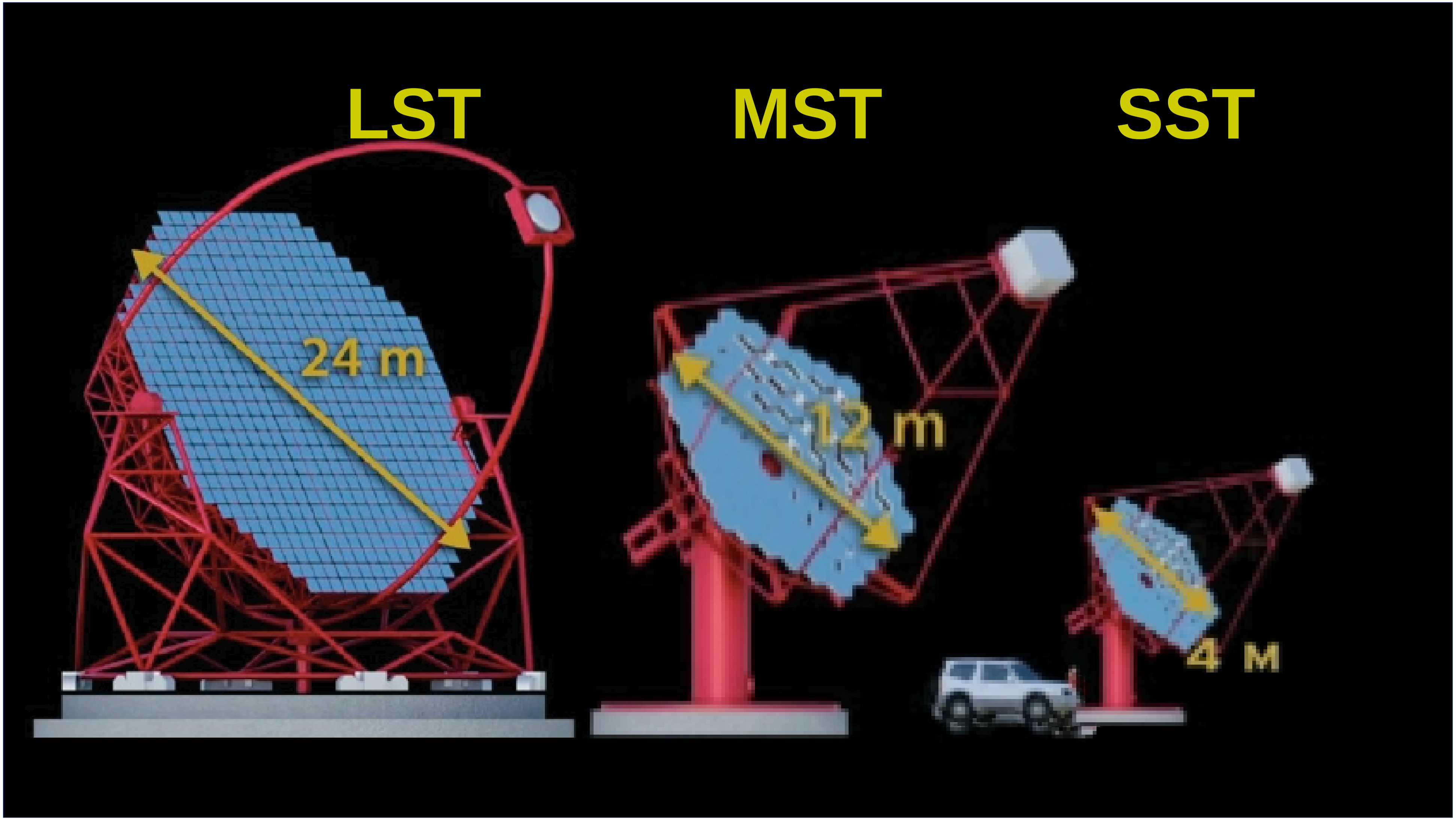
Science-optimization under budget constraints:

- Low-energy γ high γ-ray rate, low light yield
  ➜ require small ground area, large mirror area
- High-energy γ low γ-rate, high light yield
  ➜ require large ground area, small mirror area



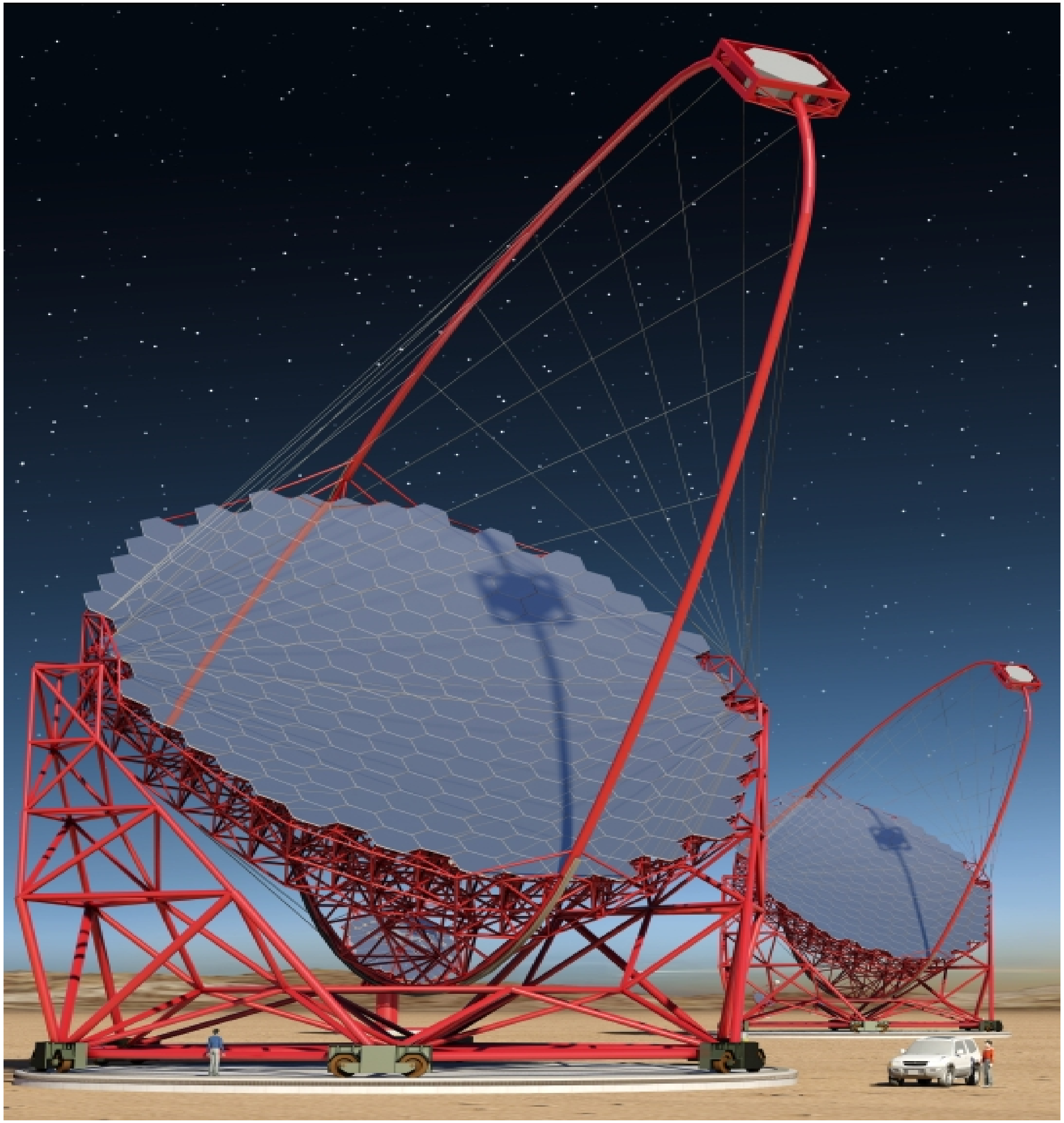
Proposed layout for CTA South

CTA Telescope Types



Three different sizes of telescope optimized for three different energy ranges

Large Size Telescope



LST
23 m diameter
389 m^2 dish area
28 m focal length
1.5 m hexagonal mirror facets

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

Carbon-fibre structure
for 20 s positioning

Active mirror control

4 LSTs on South site
4 LSTs on North site

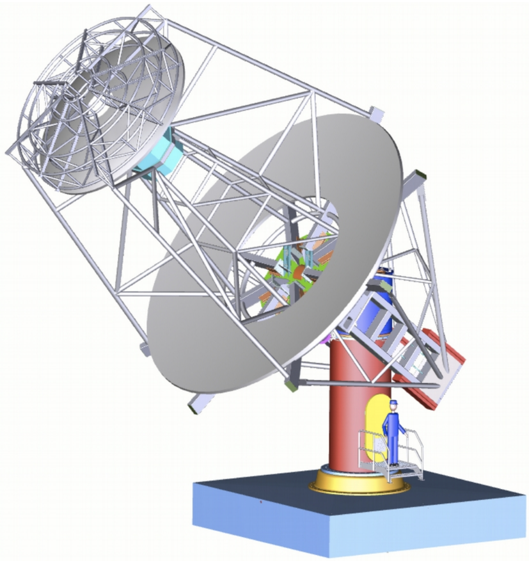
Prototype = 1st telescope

Medium Size Telescope

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

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

25 MSTs on South site
15 MSTs on North site



SCT (2-Mirrors)

Diameter -> 1M: 9.7m, 2M: 5.4 m
Total effective mirror area: 40 m^2
Focal Length: 5.6 m
SiPMT Camera with 0.07° pixels and >8° FoV

24 SCTs on CTA-South

Small Size Telescopes

SST
20 m^2 main dish area

~2.1 m (for 2M) and 5.6 m (for 1M) focal length
SiPM/MaPMT Cameras with ~0.17-0.25^o pixels and >9^o FoV

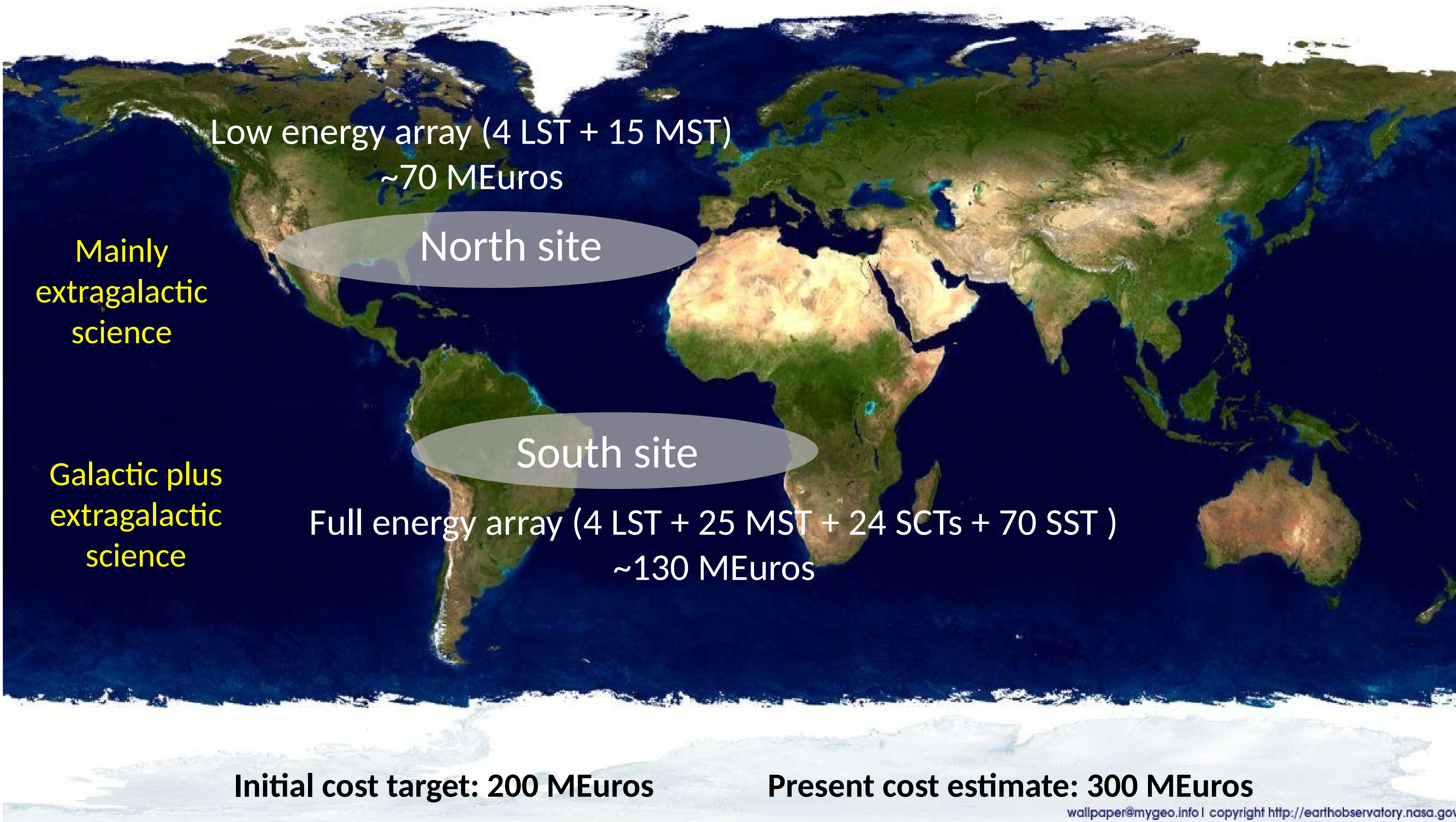
70 SSTs on South site
None on North site

ASTRI SST-2M

GCT-2M

SST-1M

Full-sky Coverage

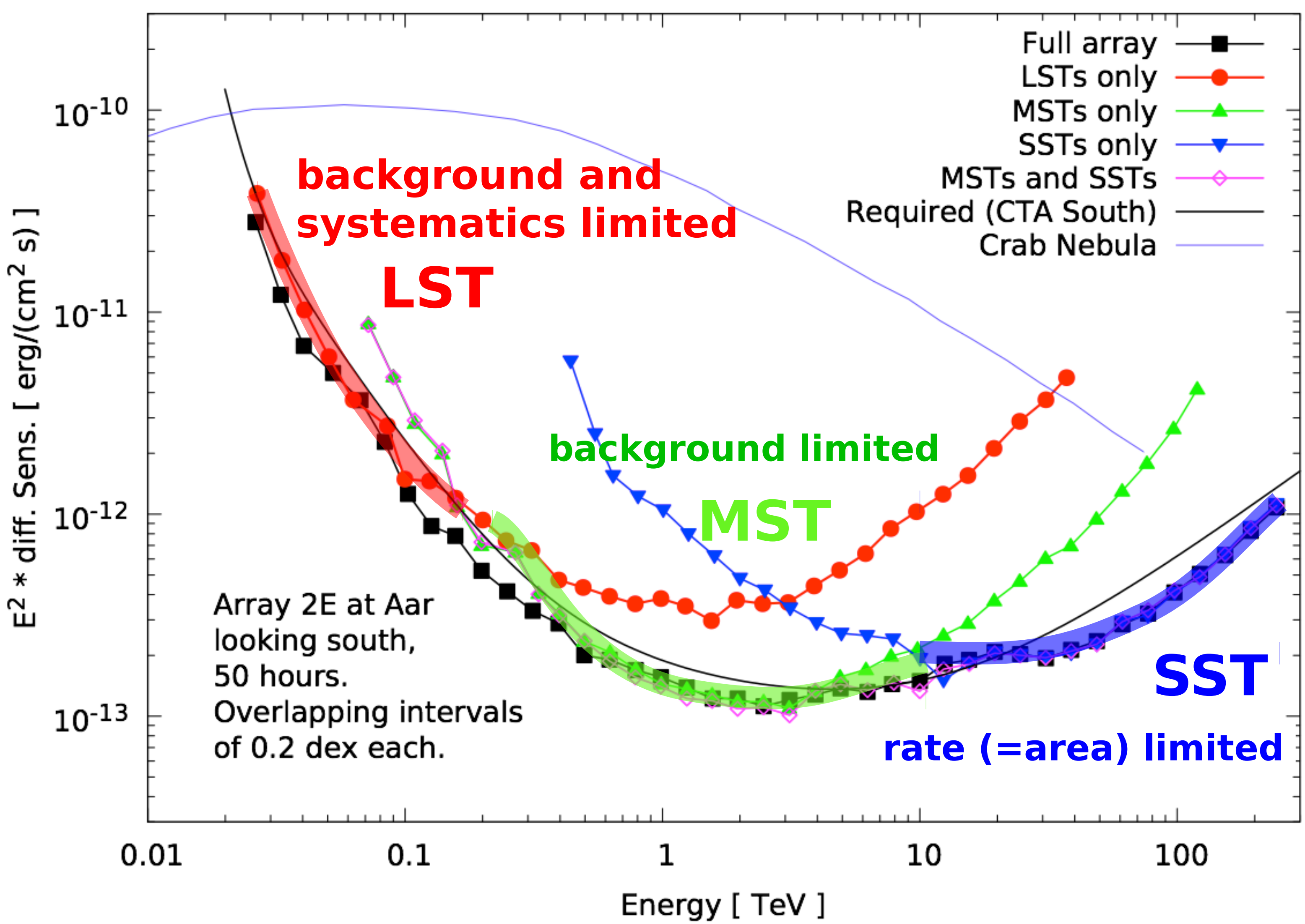


Site Selection

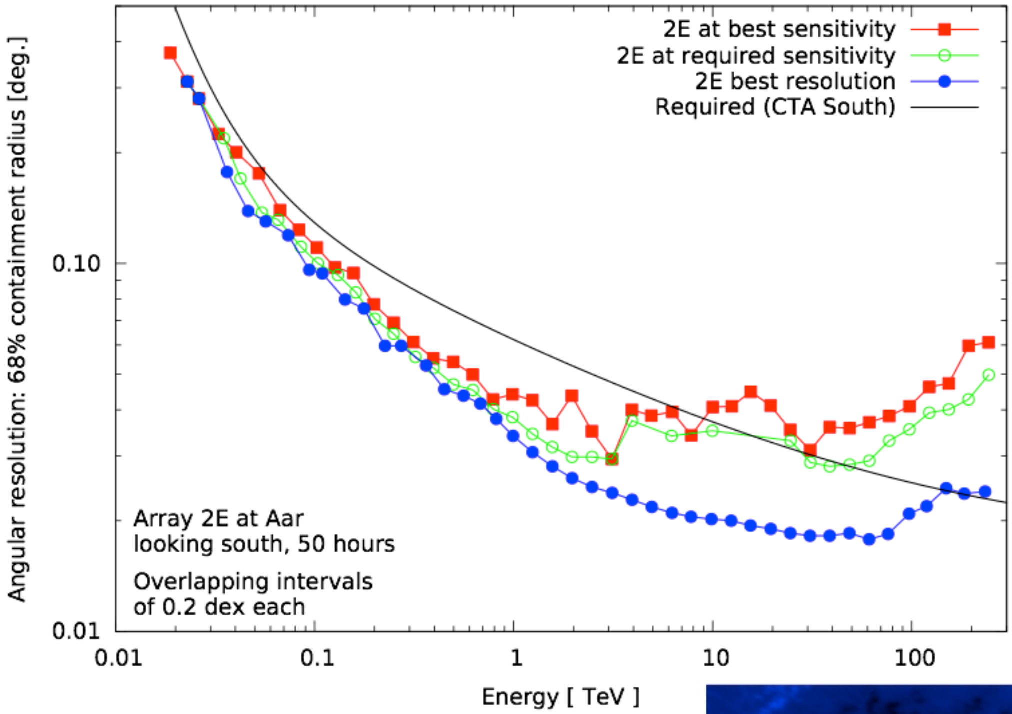
La Palma (Spain) and a site close to Cerro Paranal (Chile) are presently under negotiations to host CTA North and South respectively.

San Pedro Martir (Mexico) and Aar (Namibia) are currently back-up solutions.

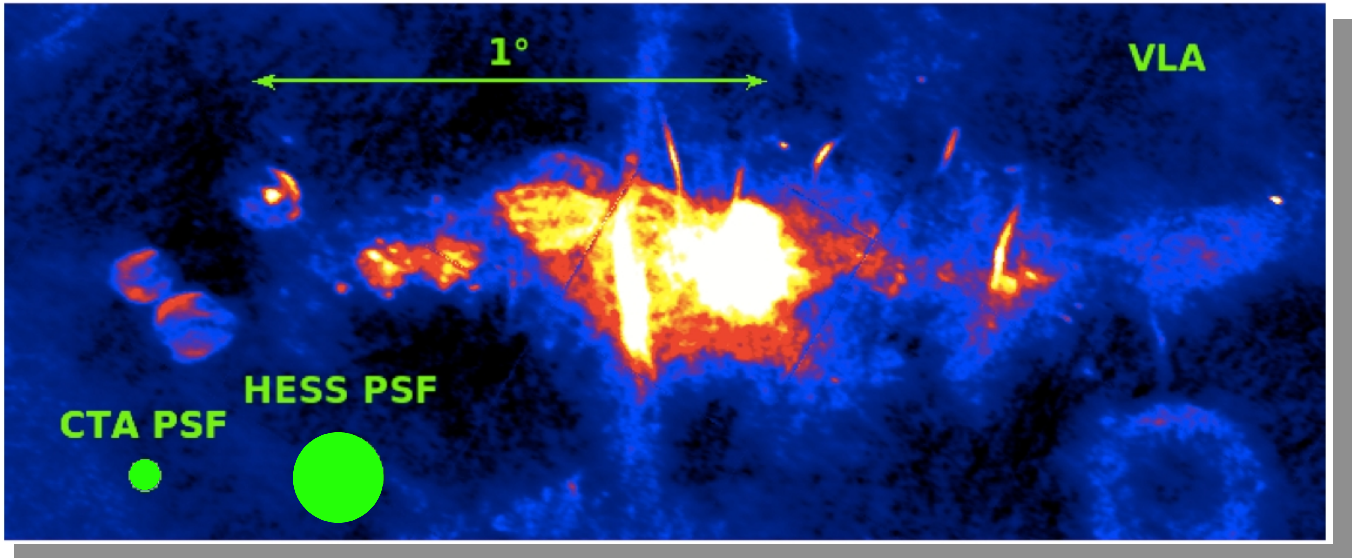
Sensitivity



Angular Resolution

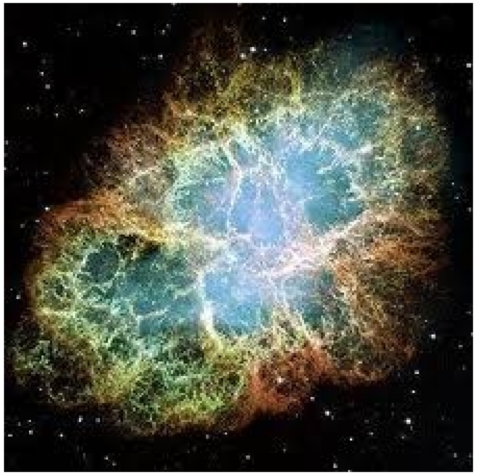


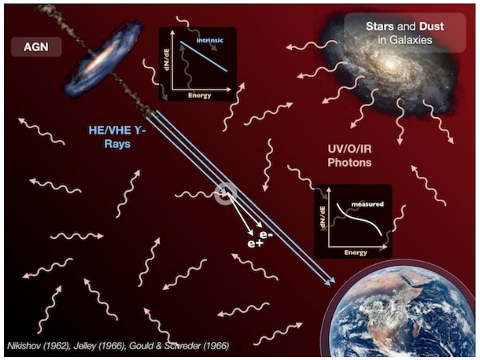
An highly improved angular resolution w.r.t. to previous IACT arrays will allow unprecedented morphological studies of gamma ray emission regions



Main Research Topics

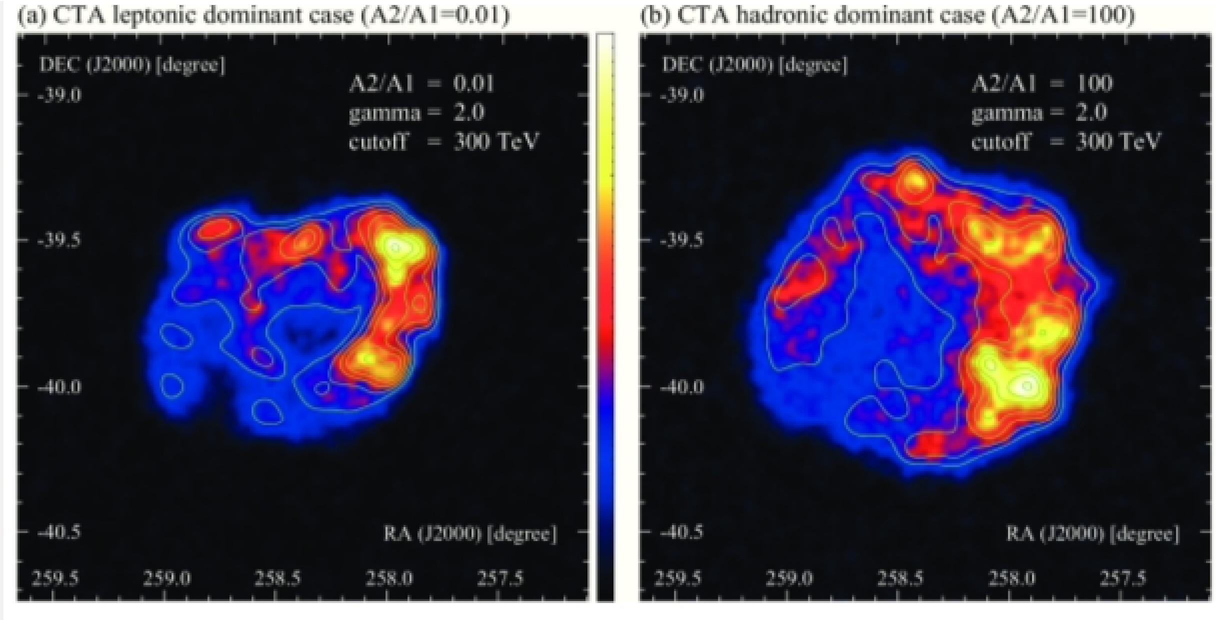
- Cosmic Rays
  - sites of acceleration in our galaxy and beyond
  - search for Pevatrons
  - CR interactions within galaxies & clusters
- Probing extreme environments
  - relativistic jets & winds in the vicinity of neutron stars & black holes
- Probing the intergalactic medium
  - B-fields, background radiation fields
- Physics frontiers
  - indirect DM searches (WIMPS, axions)
  - testing the invariance of the speed of light





Extreme Accelerators

- Where and how Galactic CR are accelerated up to PeV energies?
- Do young shell-type SNRs accelerate hadronic CRs up to PeV energies ?
- If so, what is the acceleration mechanism and how effective is it ?



CTA Timeline

Design Phase
up to 2010

Preparatory / Pre-construction Phase
2011-2015

Construction Phase
early 2016-2021

Operation Phase
Early op.: 2018-2021
Full op.: 2021-2050

- TDR √
- CDR √
- Site Decision

- Pre-Production telescopes (precursors) deployment
- Early Science

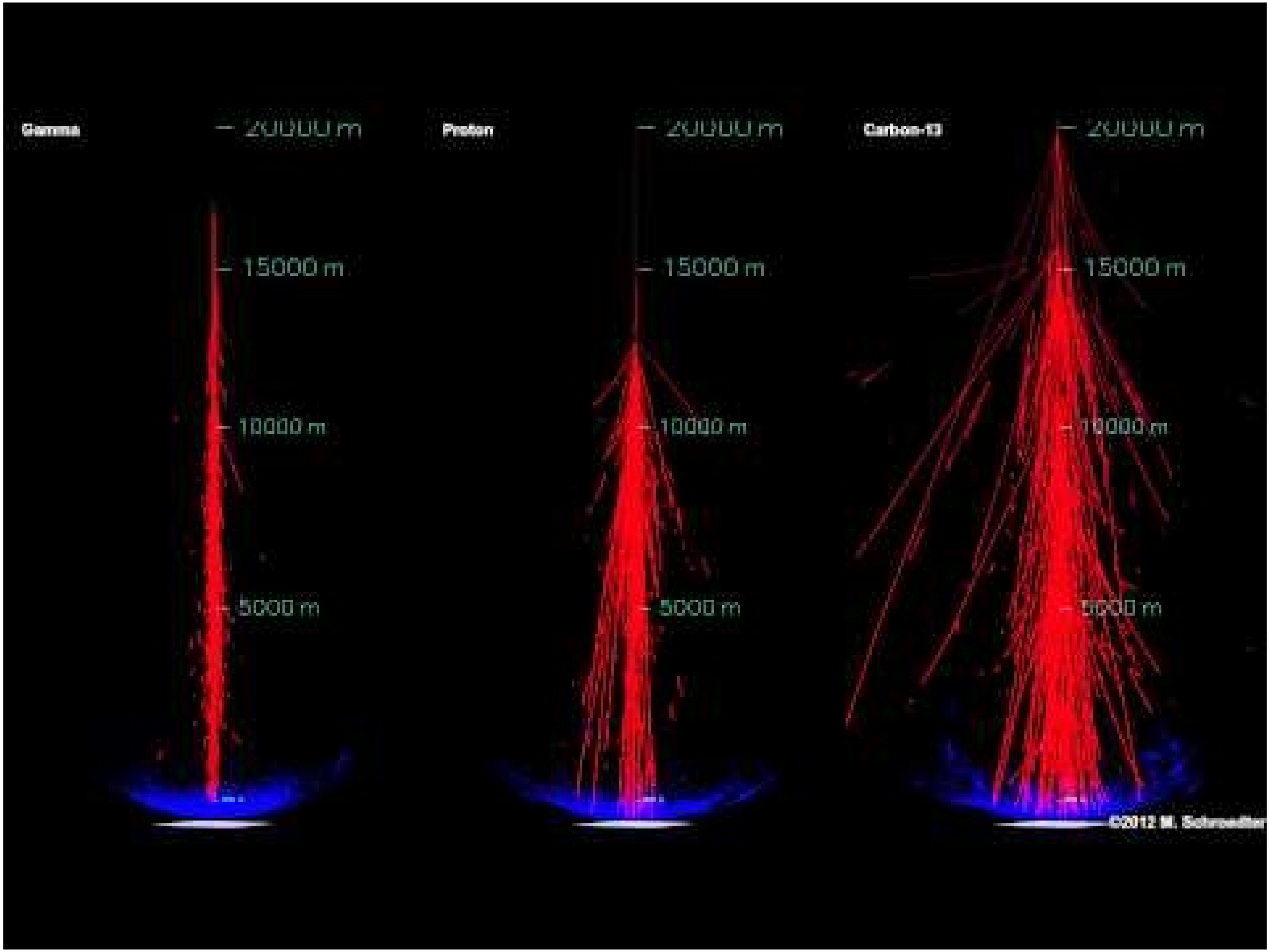
Conclusions

- CTA will be the next generation facility for VHE gamma-ray astronomy
- Major recent progress towards realizing the observatory
  - A CDR has recently taken place
  - Two sites have been selected for final negotiations
- CTA is heading up towards a funding agreement to start construction in 2016
- On track for completion ~2020
- Early science will be possible in few years with CTA precursors
- Will open up VHE astronomy to a wide community

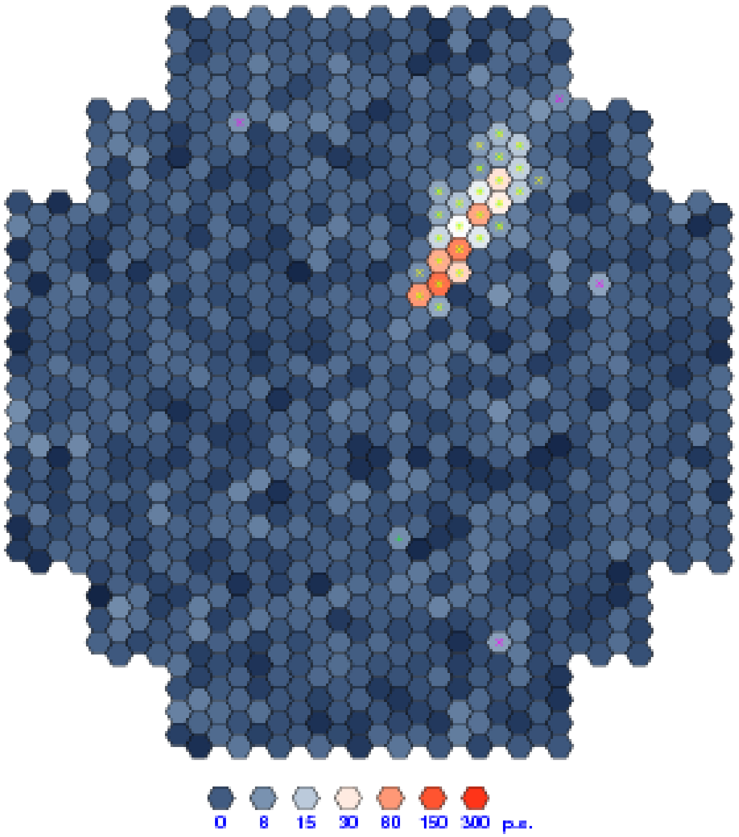
Backup

Backup

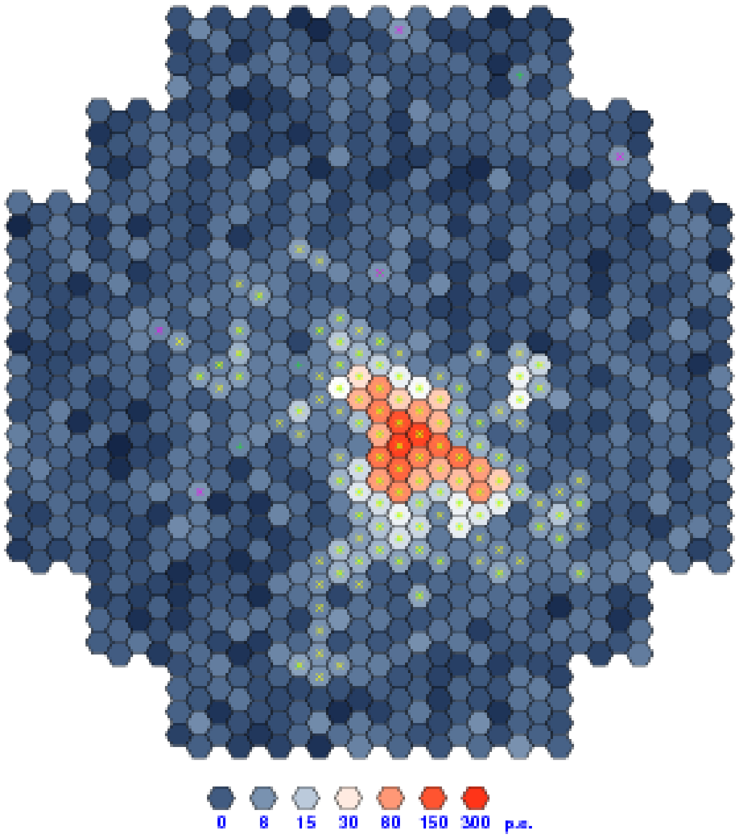
Atmospheric Showers



Cherenkov images



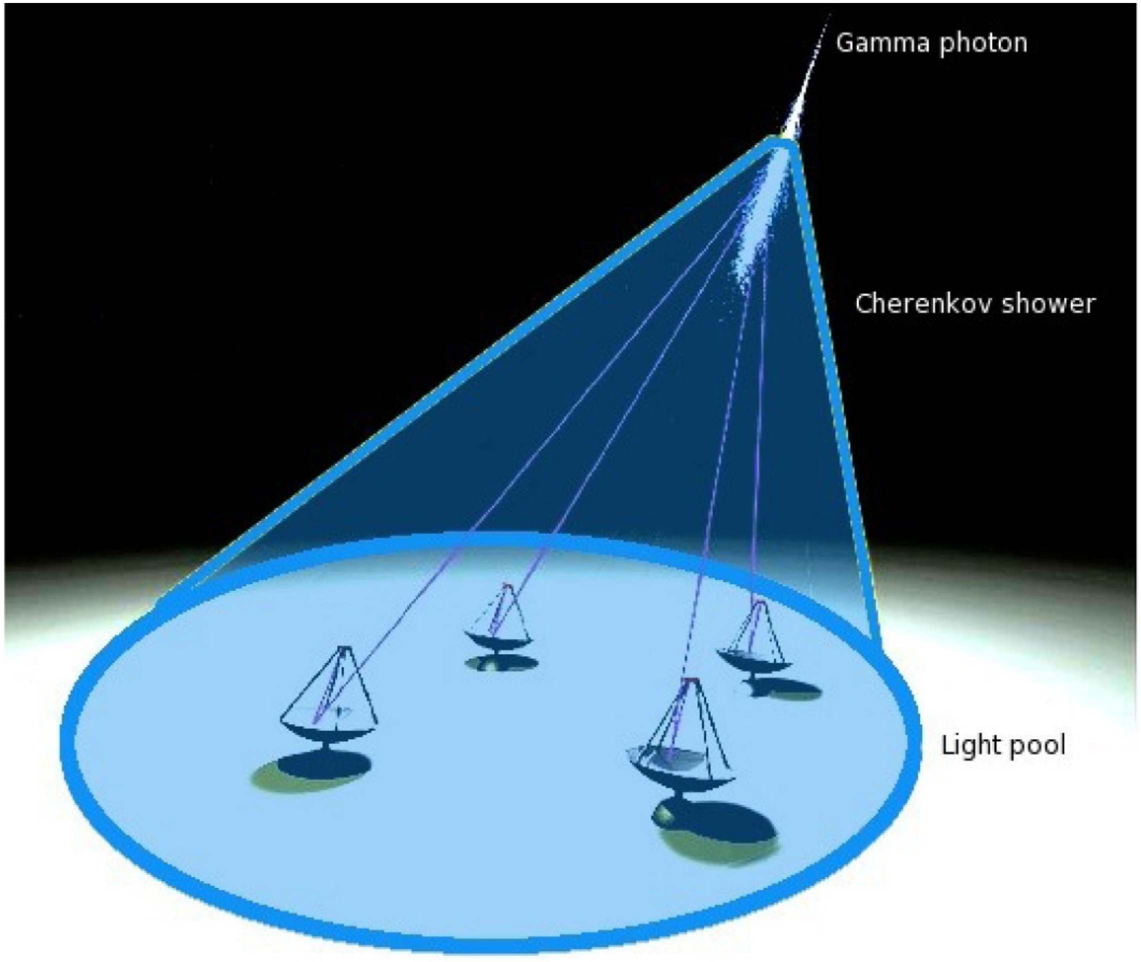
1.0 TeV gamma shower

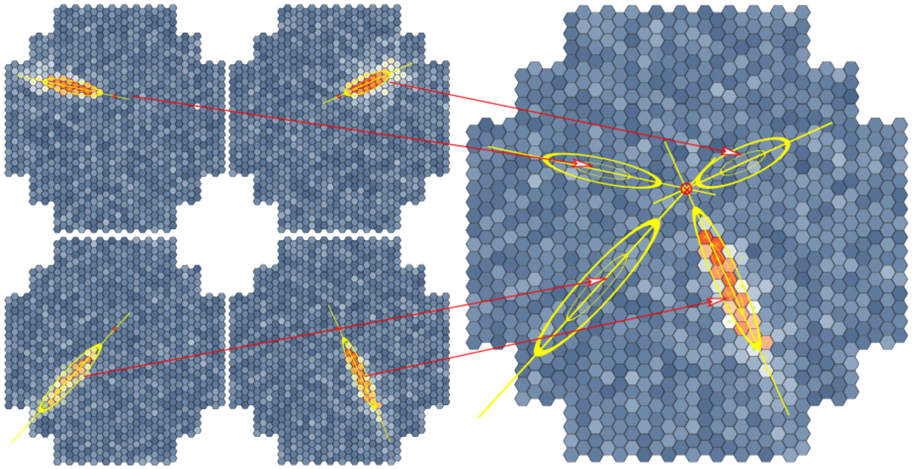


2.6 TeV proton shower

Images of gamma initiated atmospheric showers are usually more compact and regular

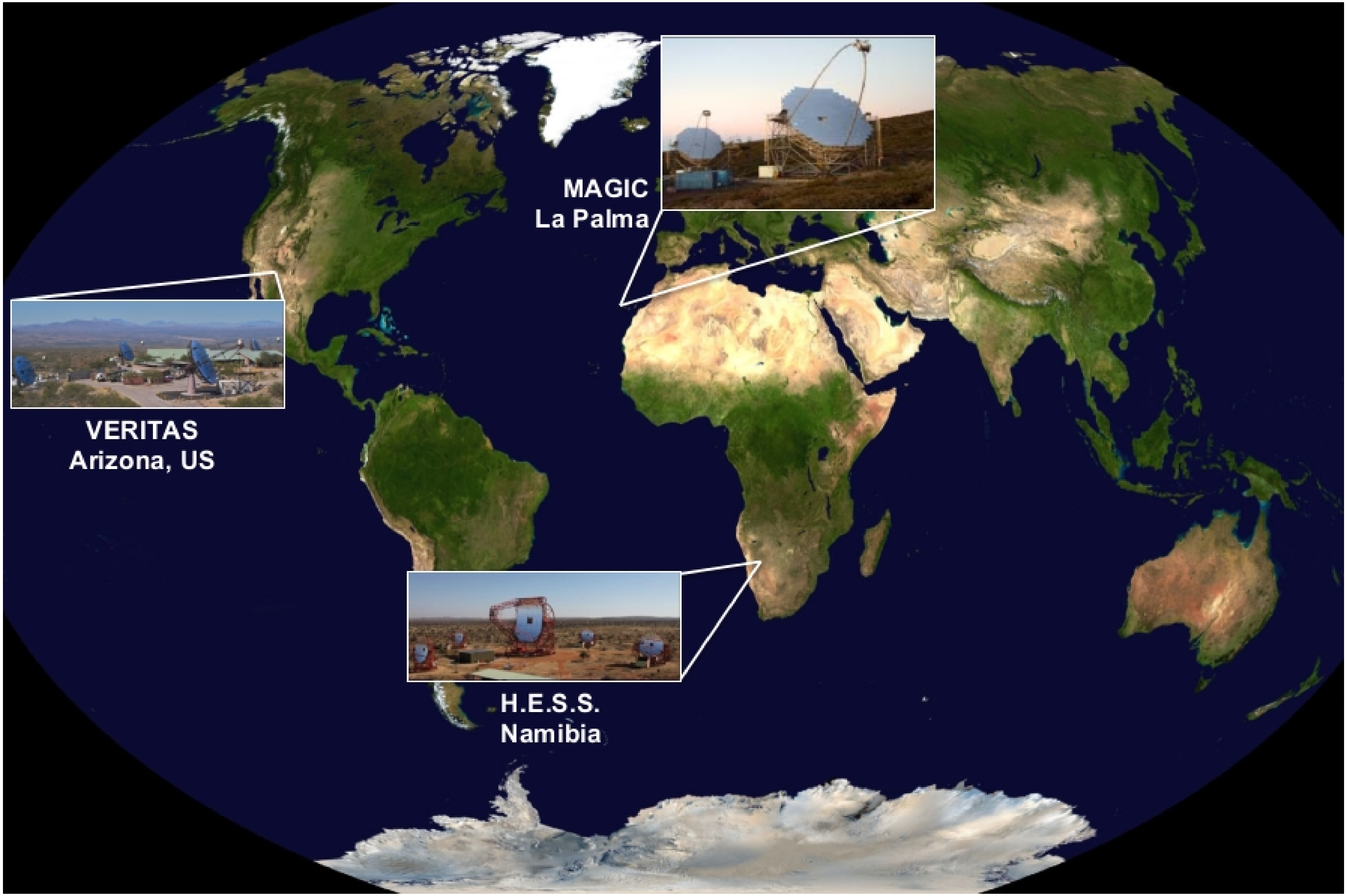
Stereo reconstruction





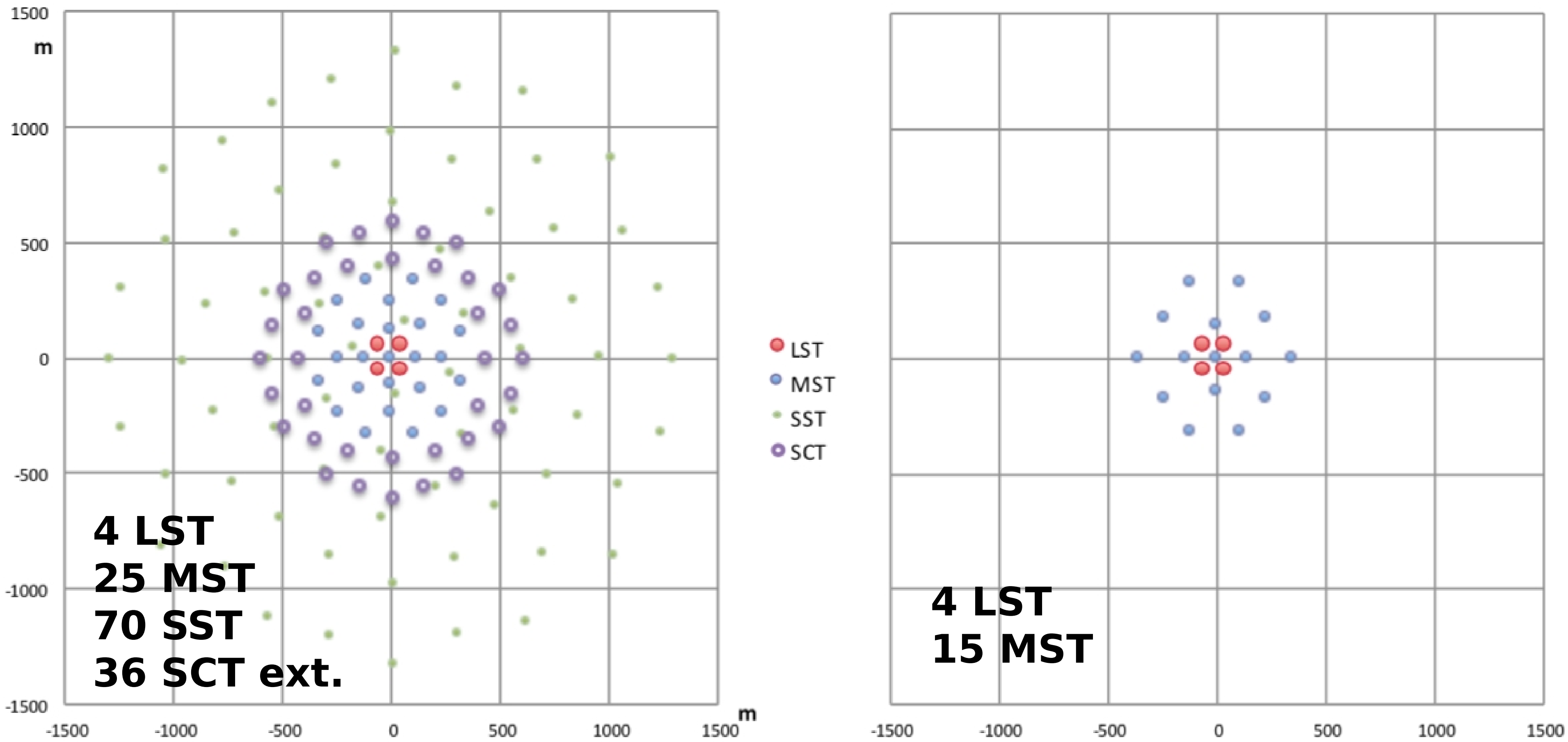
The stereoscopic view of the atmospheric shower allows a much better estimation of the primary direction and energy

Present IACT arrays



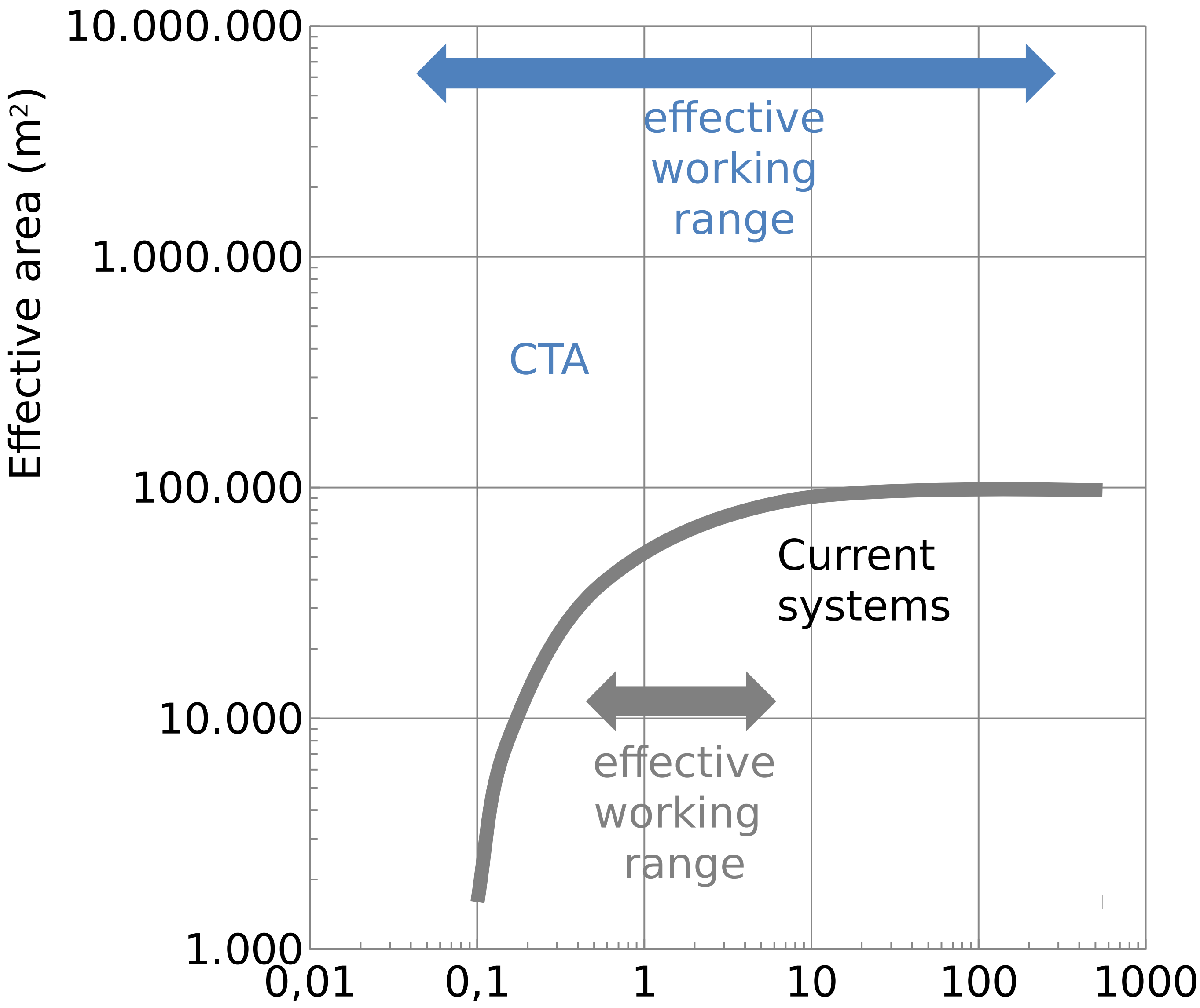
Prototypes

Baseline Layouts

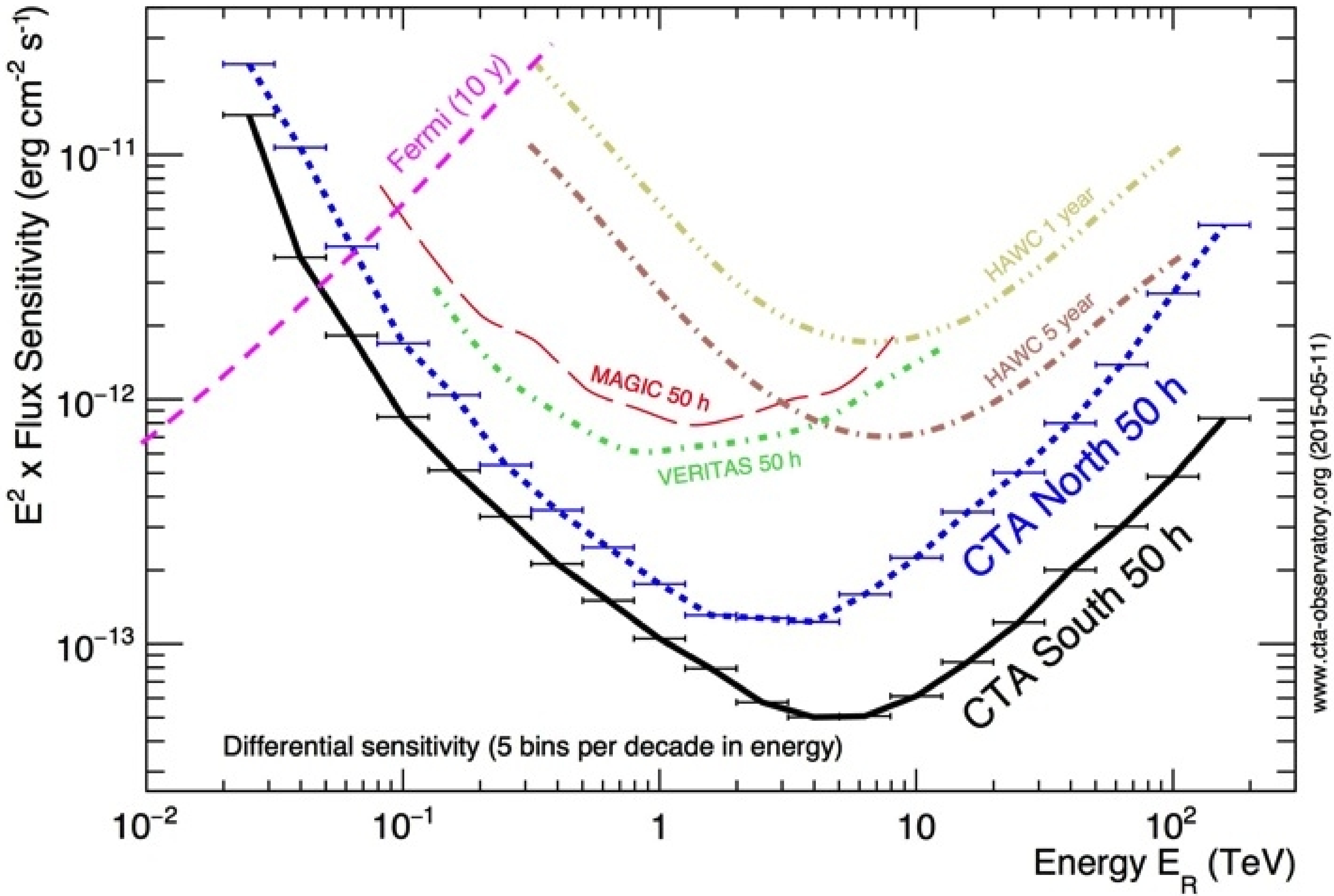


CTA-South **CTA-North**

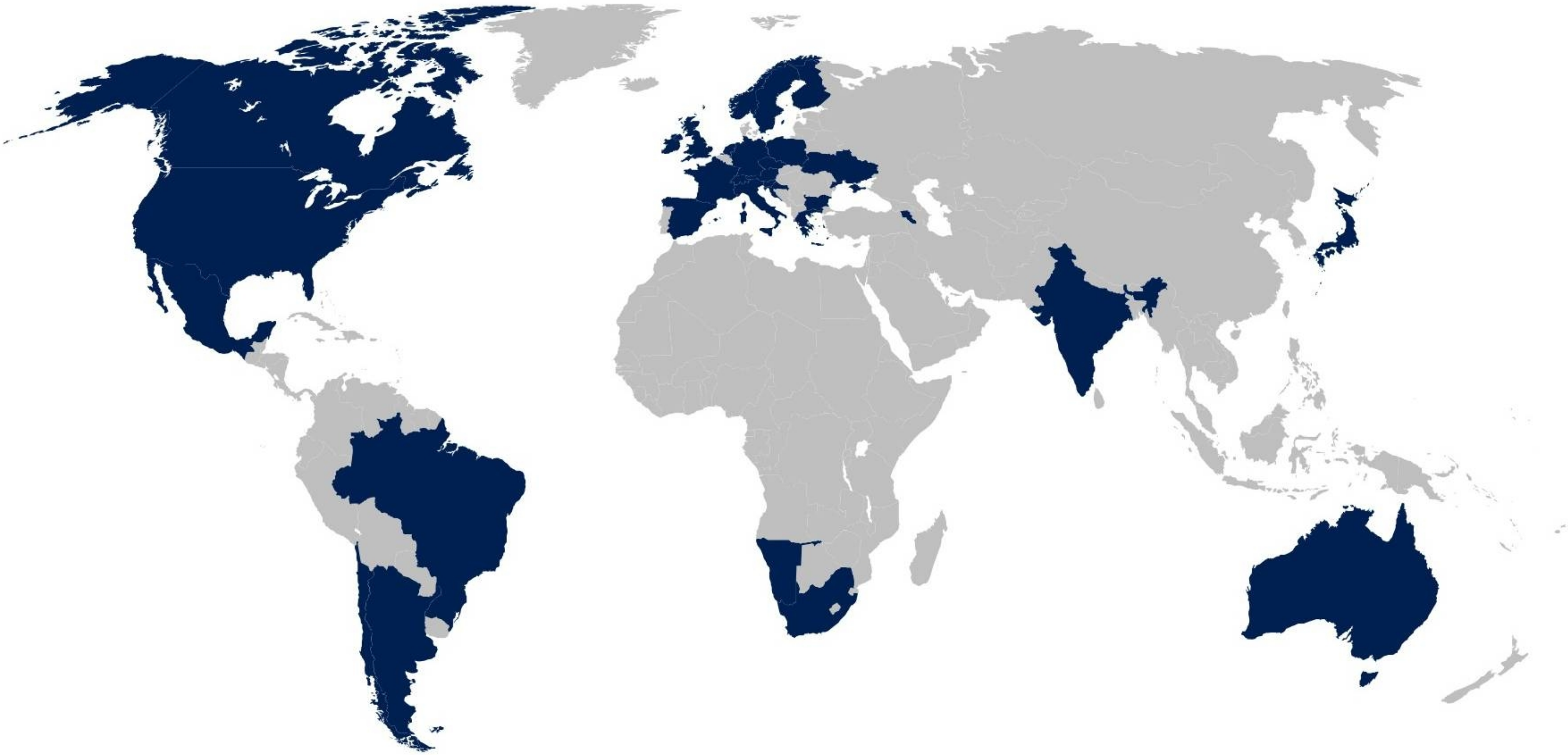
Energy Coverage



Sensitivity Comparison



CTA Consortium



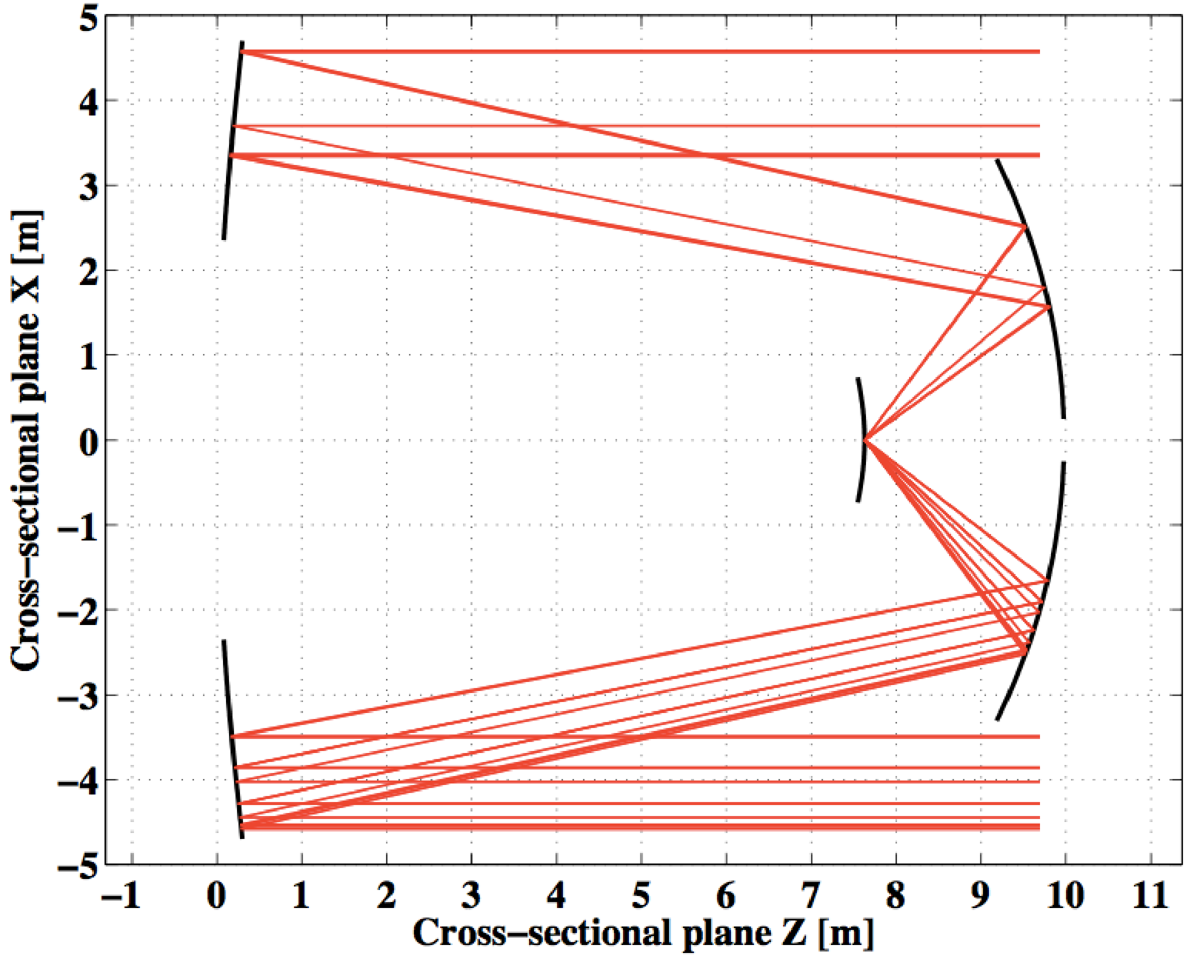
31 Countries
194 Institutes
> 1200 Members

CTA History

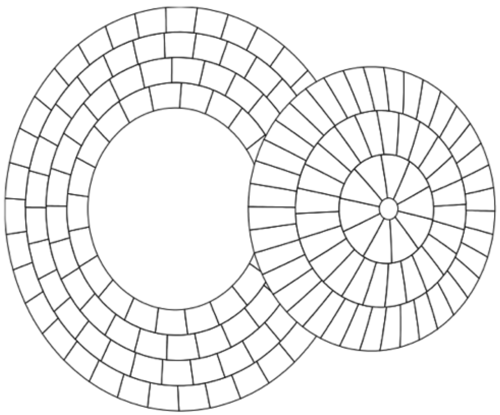
- 2006 Meeting in Heidelberg of Spokesmen of HESS (W. Hofmann), MAGIC (M. Martinez), VERITAS (S.Swordy) and CANGAROO (T. Kifune) to discuss the future of the field.
- 2006 Meeting in Berlin to define the initial concept:
  - One order of magnitude improvement in sensitivity
  - Extended energy range
  - Improved energy and angle resolution
  - South and North observatories
    - Array of telescopes
    - Different telescope size
- 2008 Meeting in Barcelona: birth of the CTA Consortium (~400 people)
- 2009 CTA Consortium Memorandum of Understanding -> First Spokesmen Election: W.Hofmann and M.Martinez
- 2010 "Design Concepts for CTA" Publication -> CDR
  - CTA included in ESFRI road-map

- 2011 CTA RB established thorough a DoI signed by 13 Countries.
  - 3-year EU-Prep Phase Funding for preparing TDR
  - Site evaluation studies start
- 2013 First prototypes of telescope elements
  - PTDR completed -> PDR review successfully passed
  - Astroparticle Physics Journal special issue on CTA Physics
- 2014 Creation of CTAO GmbH
  - First prototypes of complete telescopes mechanics
  - Site selection narrowing down
- 2015 **TDR completed -> CDR has taken place**
  - Site selection for final negotiations
  - Funding agreement being prepared for starting construction

Dual Mirror Telescopes



Vassiliev, Fegan, Brousseau
Astropart.Phys.28:10-27,2007



- Reduced plate scale
- Reduced psf
- Uniform psf across f.o.v.

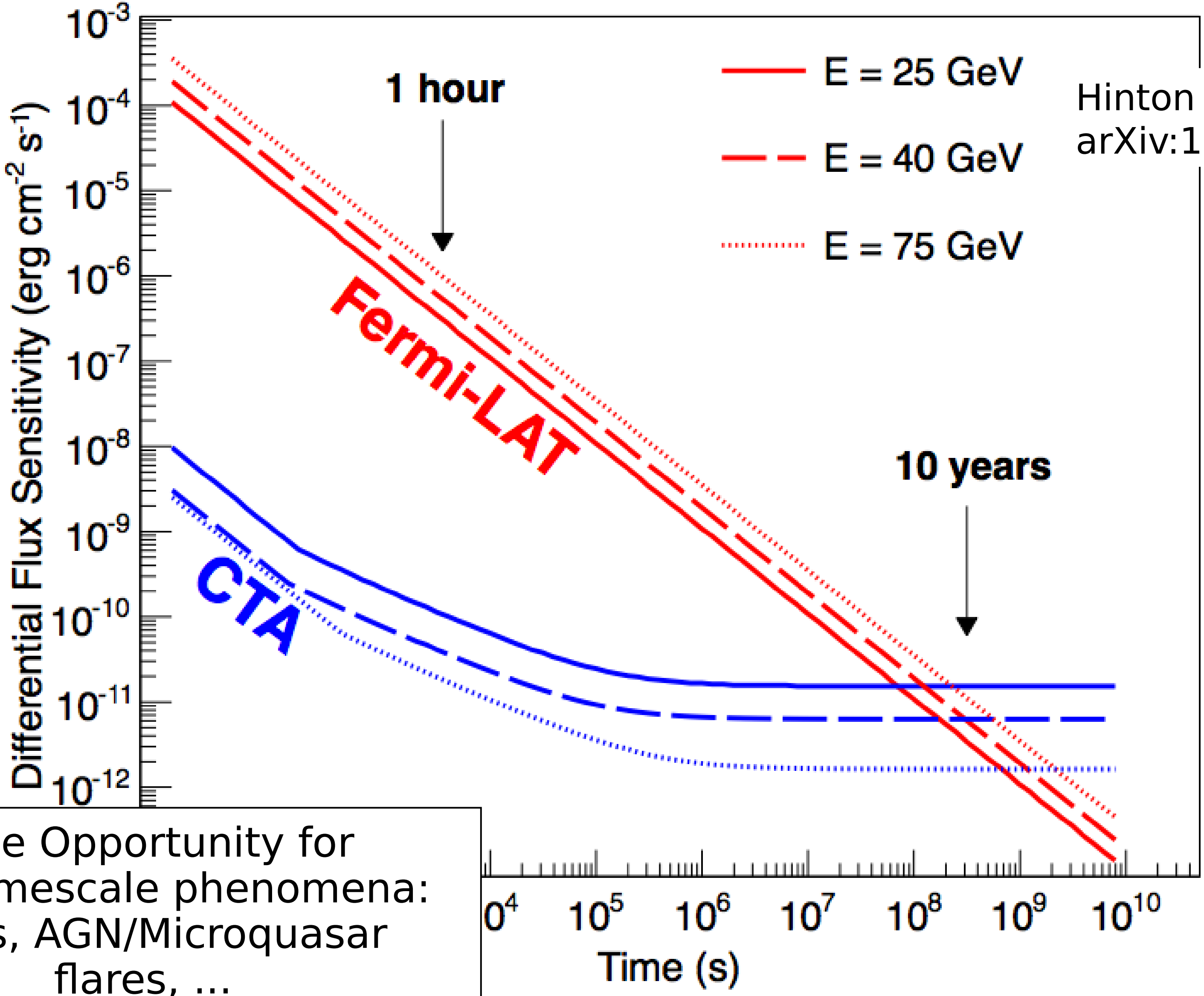
➜ Cost-effective small telescopes with compact sensors (SST-2M)

➜ Higher-performance telescopes with small pixels (SCT)

Sites

Country	Location	Latitude [deg]	Elevation [m]
Argentina	El Leoncito	31.7 S	3600
Argentina	El Leoncito B	31.7 S	1600
Argentina	San Antonio	24.0 S	2700
Chile	ESO area	24.3 S	2500
Namibia	Aar	26.2 S	1700
Namibia	H.E.S.S. site	23.3 S	1800
Mexico	San Pedro Martir	31.0 N	2400
Spain	Tenerife	28.3 N	2300
Spain	La Palma	28.8 N	2200
US	Meteor Crater	35.0 N	1700
US	Yavapai Ranch	35.1 N	1700

Transient

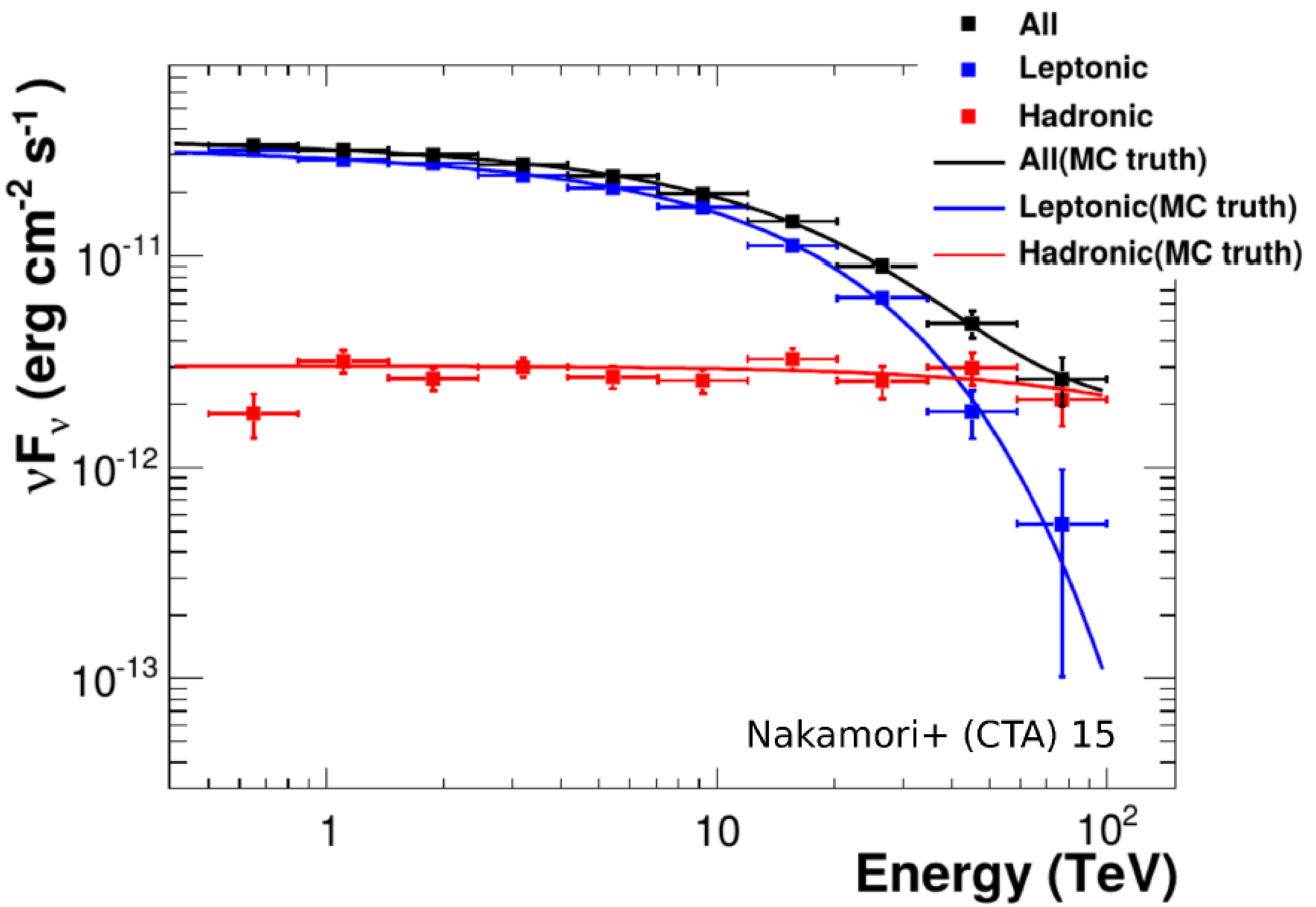


Hinton & Funk
arXiv:1205.0832

Huge Opportunity for short-timescale phenomena: GRBs, AGN/Microquasar flares, ...

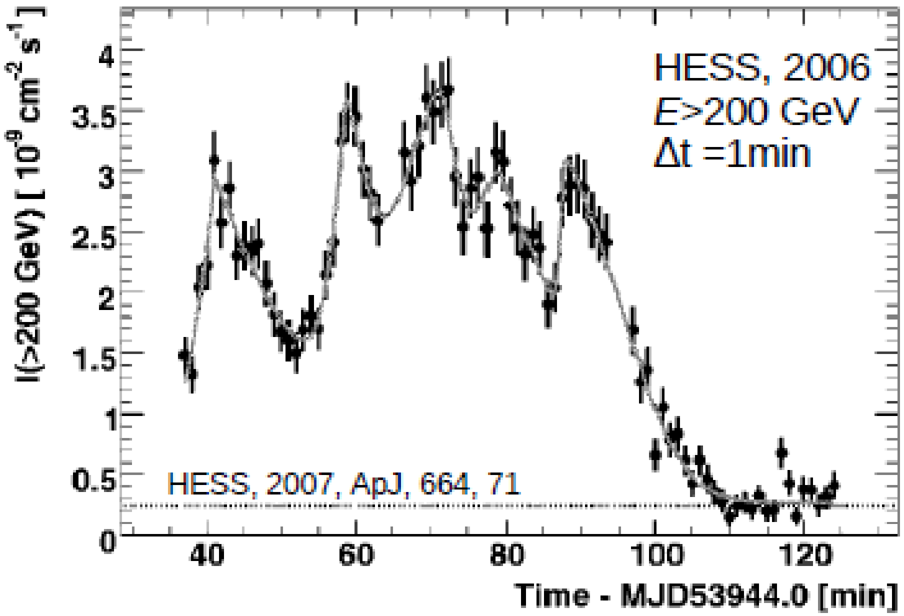
Spectral Studies

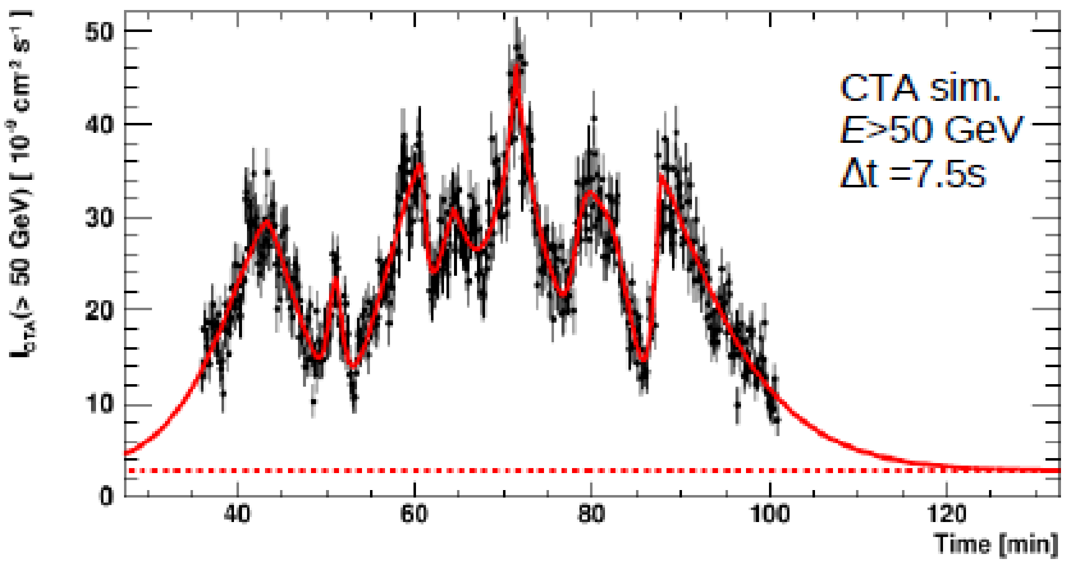
RX J1713.7-3946



The improved sensitivity, the better energy resolution and the extended energy coverage will allow CTA to discriminate between a pure leptonic or a leptonic+hadronic acceleration mechanismi

Fast Transient

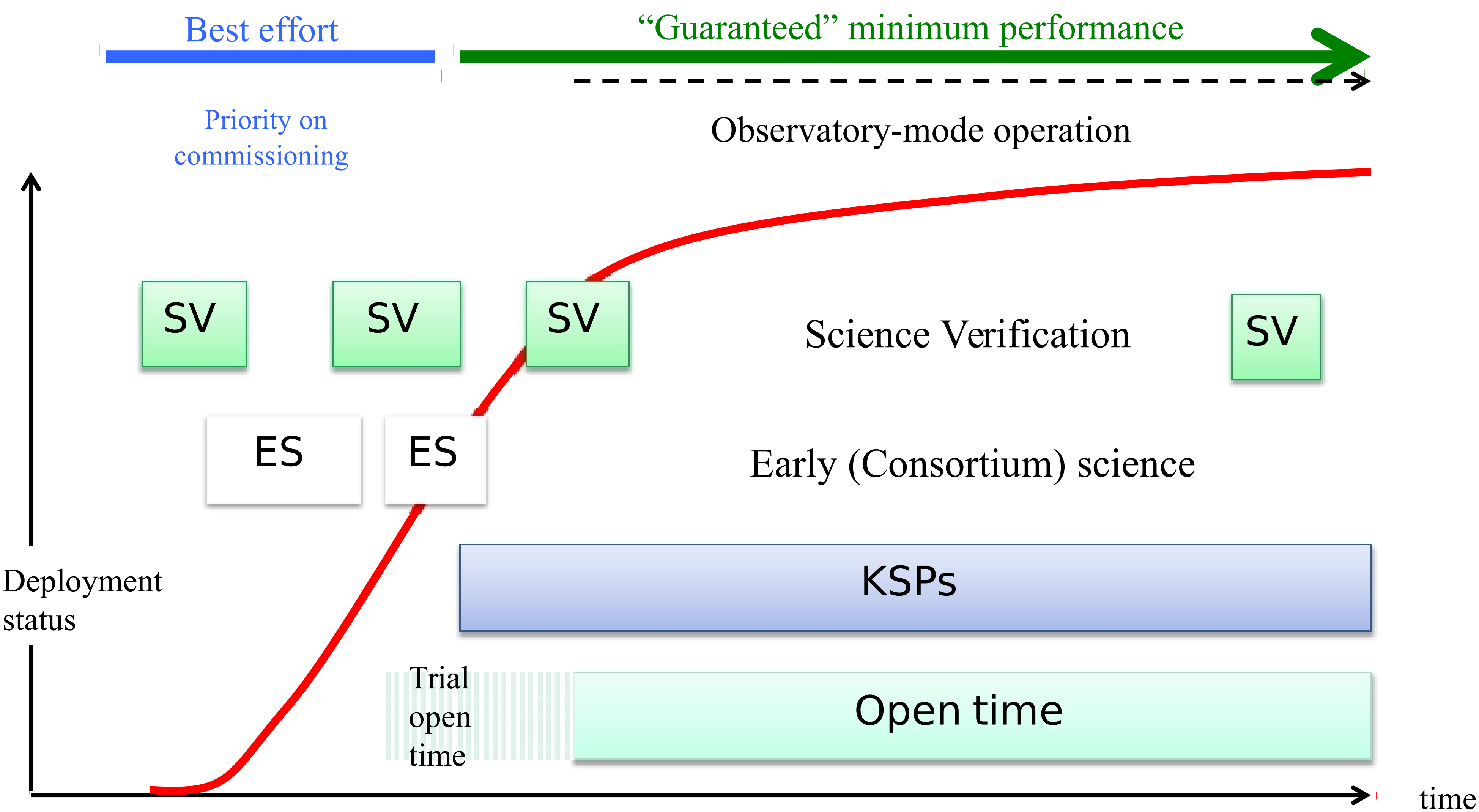




•Consider PKS 2155's 2006 flare
– Power-law extrapolation of the HESS power spectrum, assuming red-noise at high frequencies
•Large effective area and energy range allows binning on timescales of ~7s!
•Allows for smaller variability timescales to be observed.
•Allows for better definition of flare rise and fall timescales.

CTA's sensitivity allows for unprecedented temporal resolution

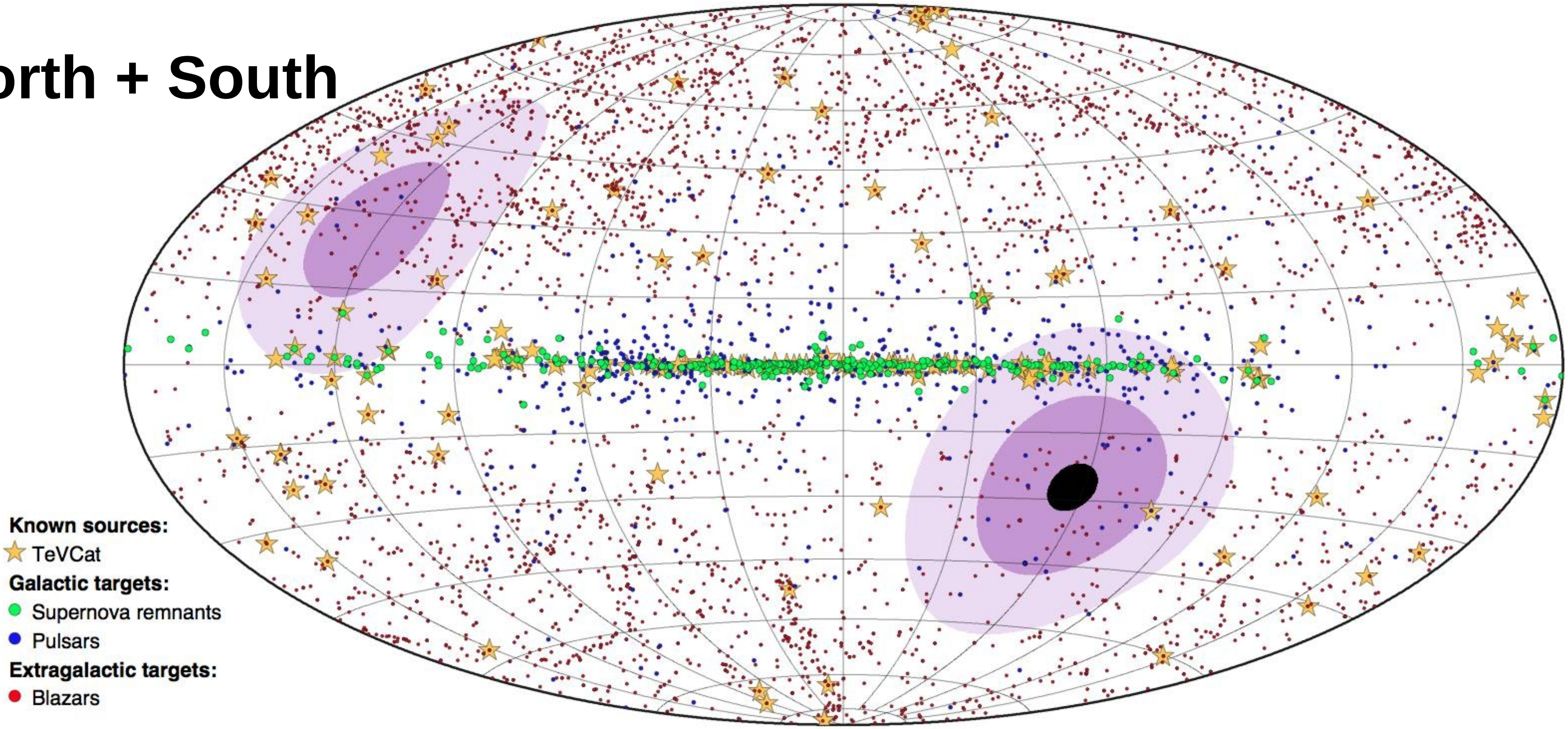
CTA Observation plans



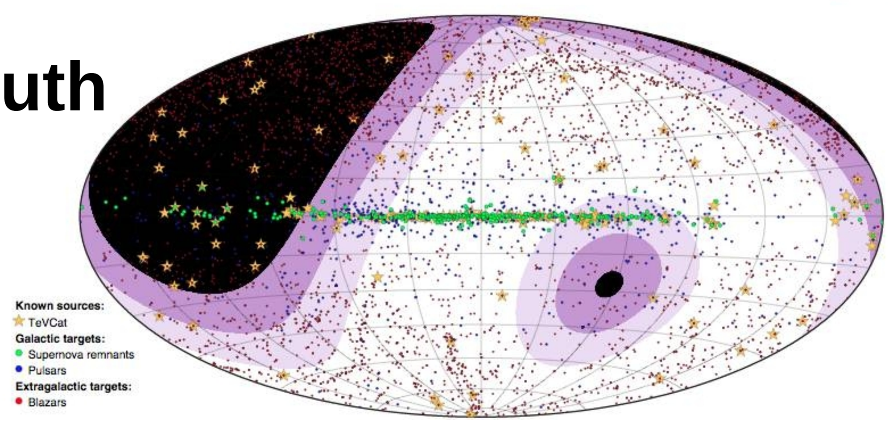
Detailed scheduling still to be decided

Sky Coverage

North + South



South



North