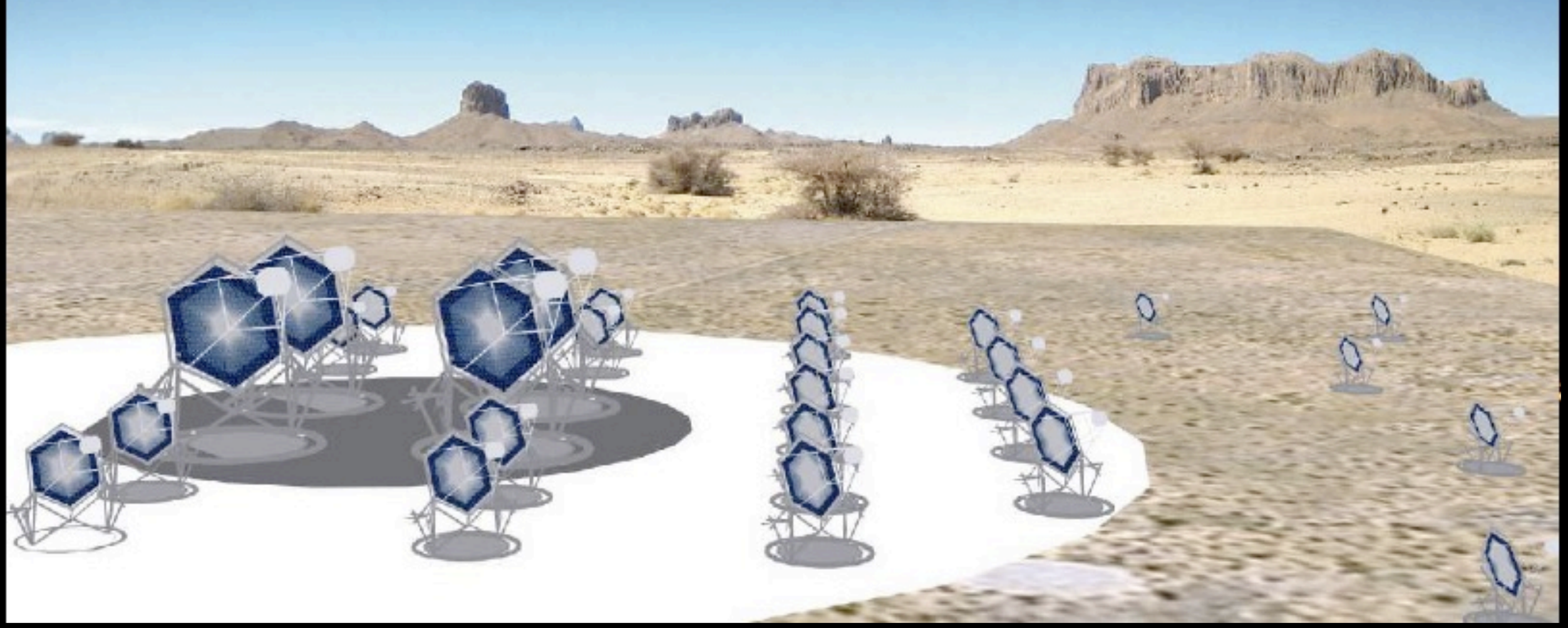
A project for a new generation of Cherenkov telescopes

M. Mariotti CTA consortium, SCINEGE '09, mariotti@pd.infn.it



overview

overview

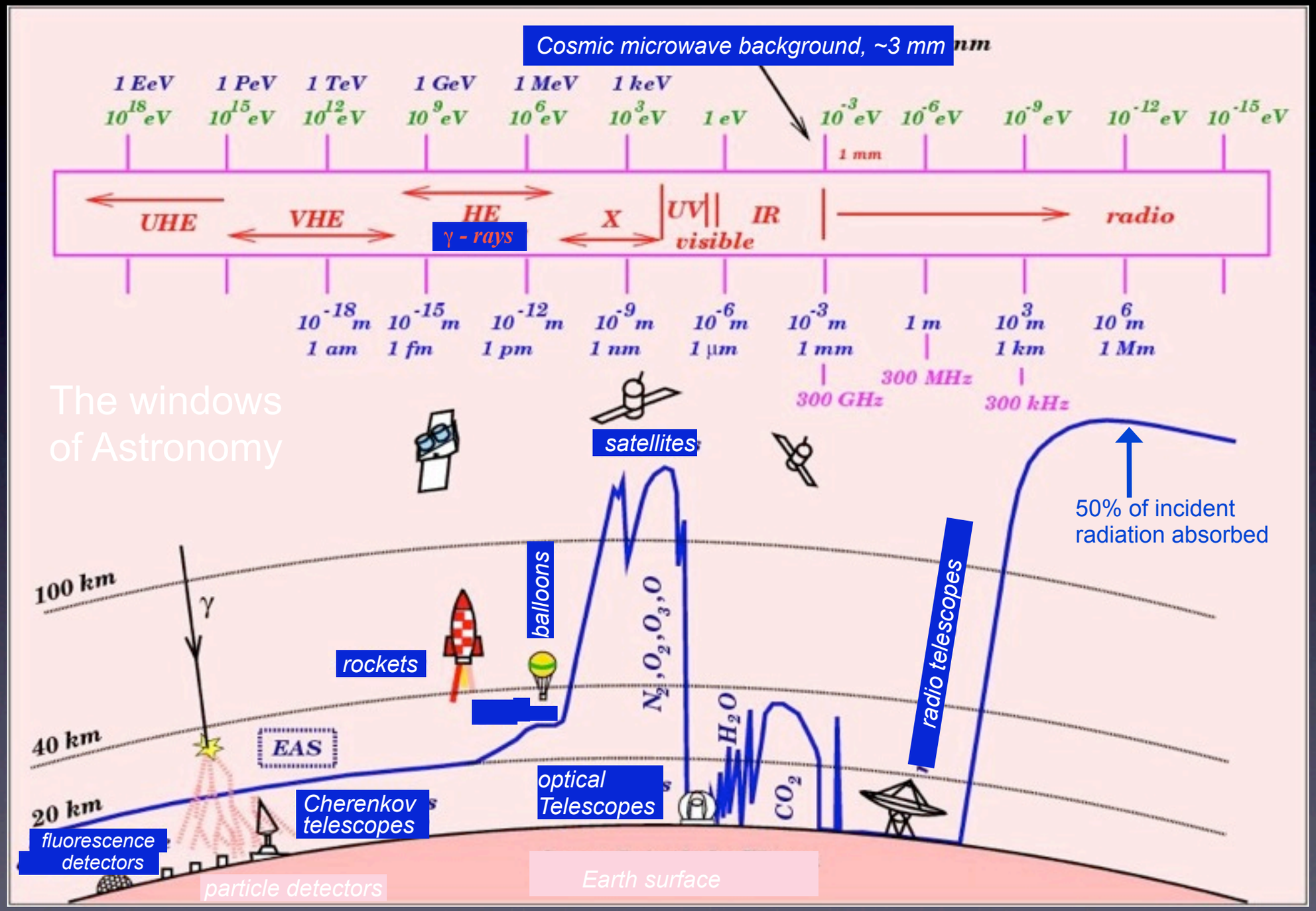
- Short review of current techniques
  - technological aspects
  - selected results

overview

- Short review of current techniques
  - technological aspects
  - selected results

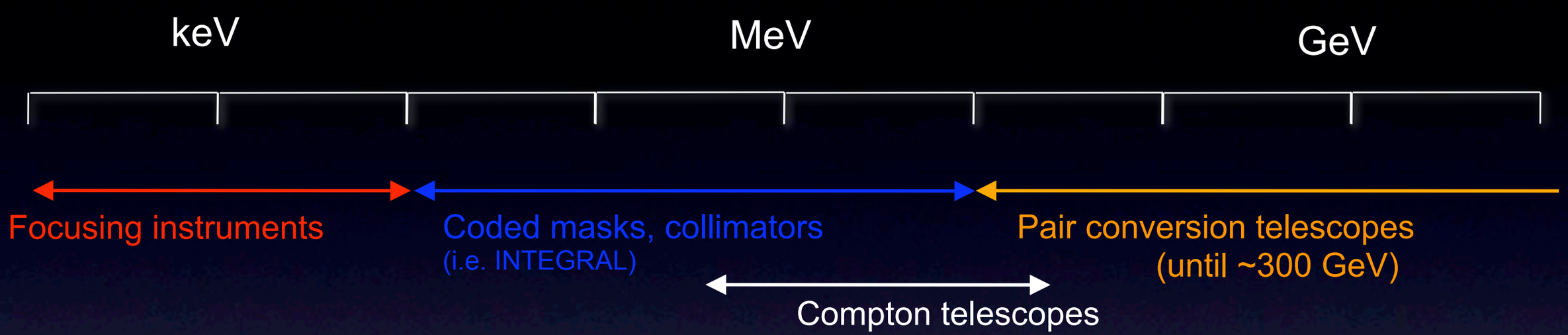
- A next generation IACTs
  - Physical motivations
  - CTA consortium
  - Technical solutions
  - Timeline

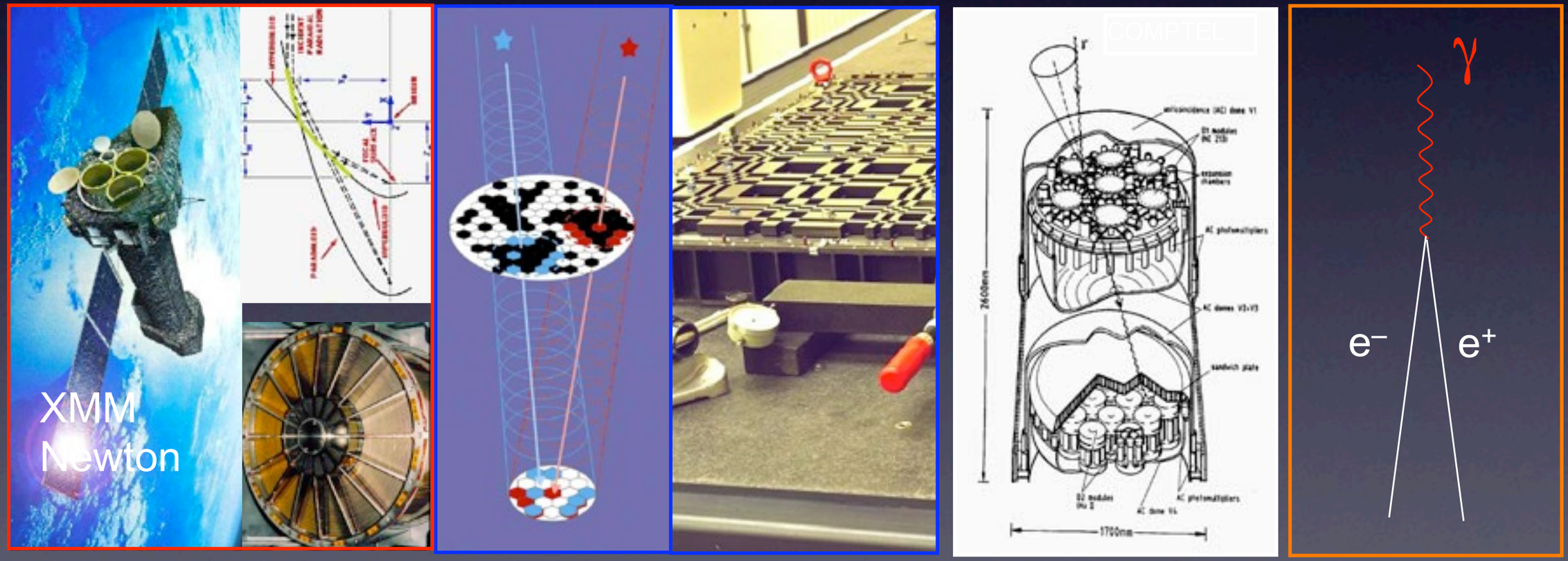
opacity of the atmosphere



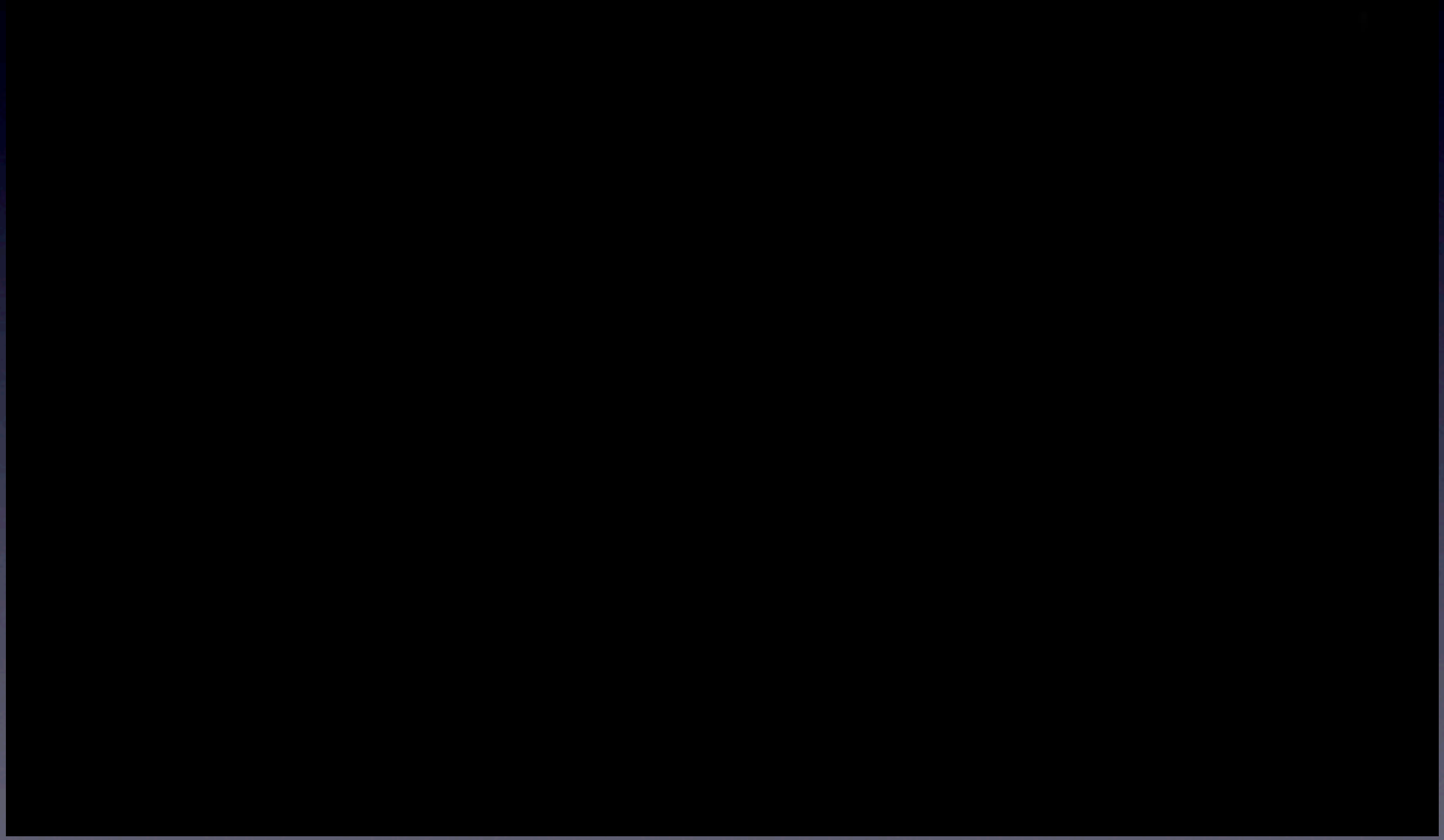
M. Mariotti, CTA - A project for a new generation IACTs, SCINEGE 09 (Assisi)

X-ray and γ-ray astronomy

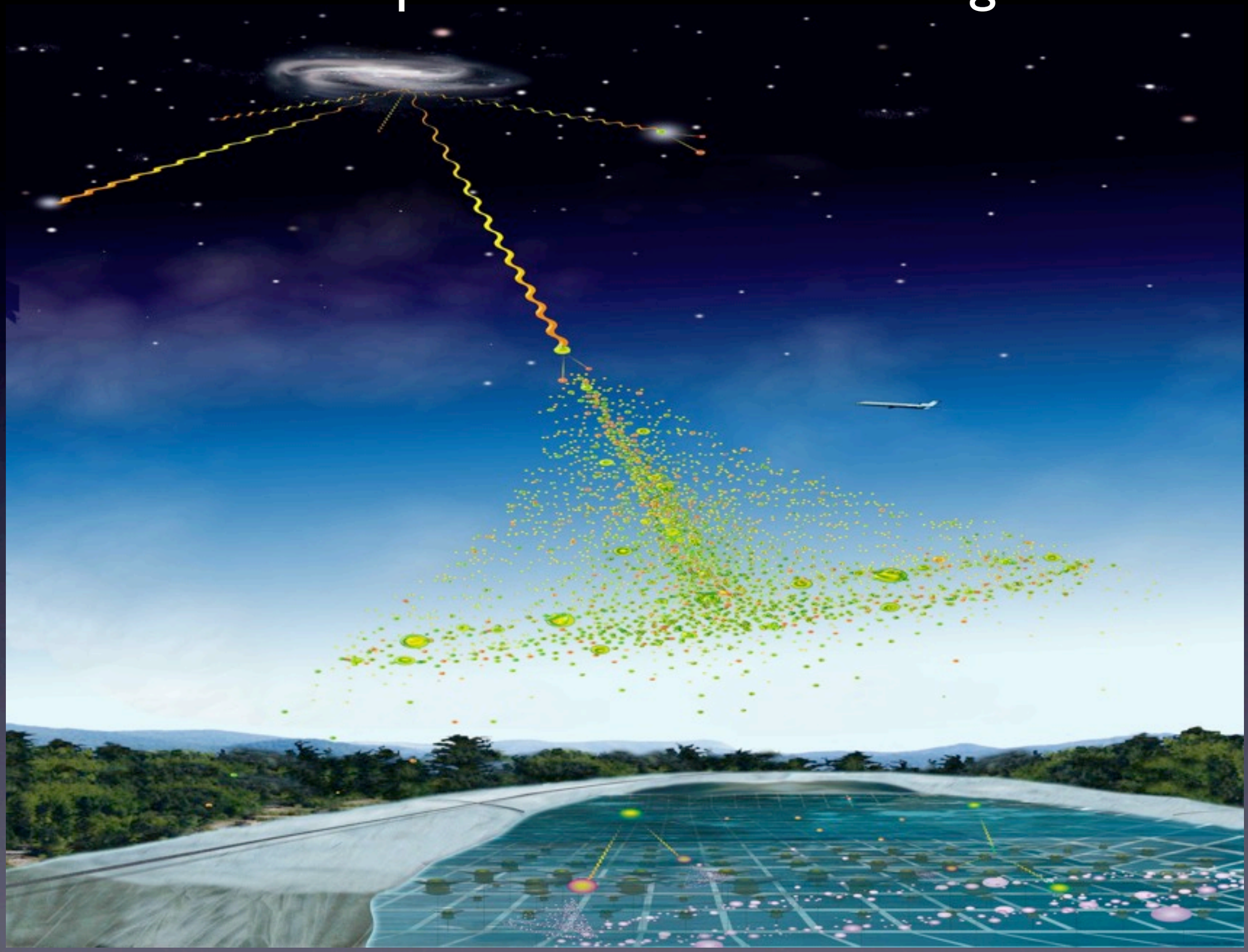




em shower + cherenkov light emission.



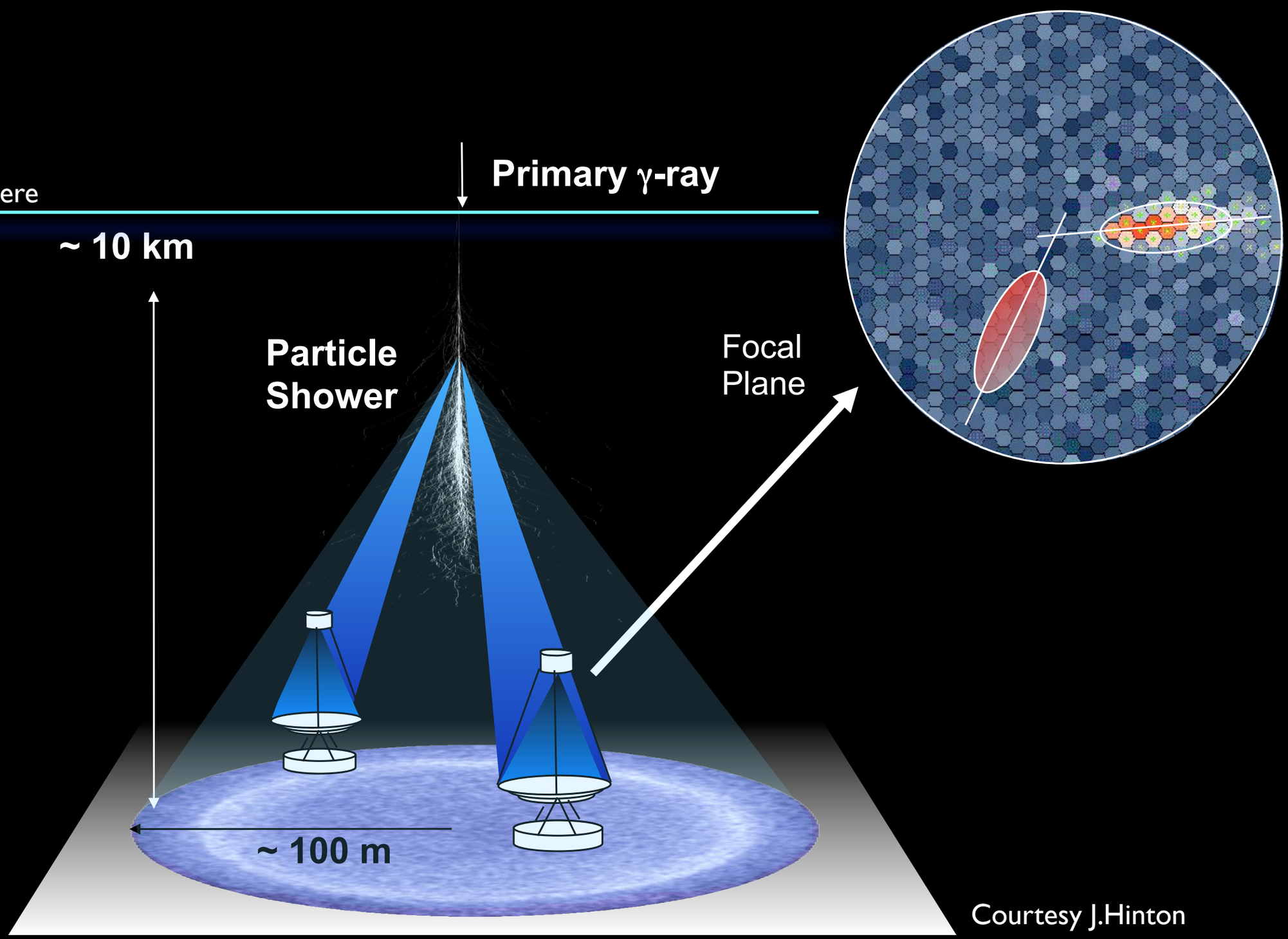
em shower: particles can reach the ground.



M. Mariotti, CTA - A project for a new generation IACTs, SCINEGE 09 (Assisi)

Current IACTs

IACT technique



Courtesy J.Hinton

Current major experiments

VERITAS (Arizona, USA)

Array 4 telescopes of 12m diam.
Central mast mounting
1800 m asl
>2007

Array 2 telescopes
17m diameters
2200 m asl
>2004

MAGIC (Canary Island, Spain)

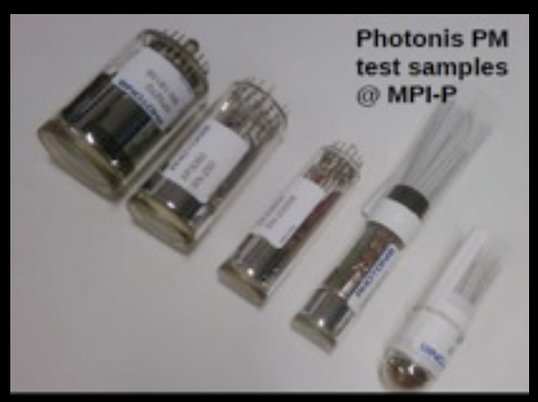
HESS (Namibia)

HESS I: Array 4 tel. of 12m
HESS II: 28m diameter (>2009)
1800 m asl
> 2003

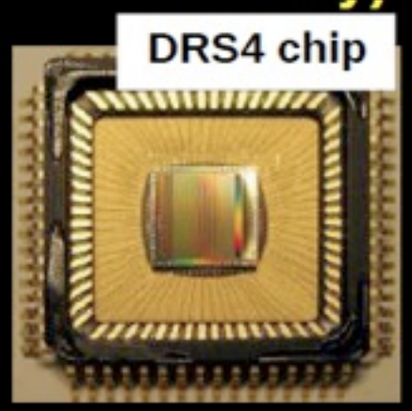
Well-proven technology...

- Mounting
  - Alt-azimuth mounting
  - Central mast or circular rail
  - Spherical or parabolic reflector (12-17m)

- Mirror
  - Tesselation of the surface
  - Extreme optical precision non required
  - Solid glass, aluminum, glass-aluminum replica



- Camera
  - ~1000 pixels
  - Photomultipliers (now...)
  - most expensive part of the telescope

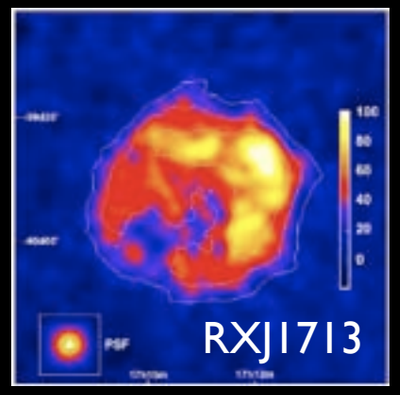


- Electronics/trigger
  - Cherenkov signal lasts few ns, fast electronics
  - Tbytes/night
  - Topological triggers for single telescopes
  - Central trigger for stereoscopy

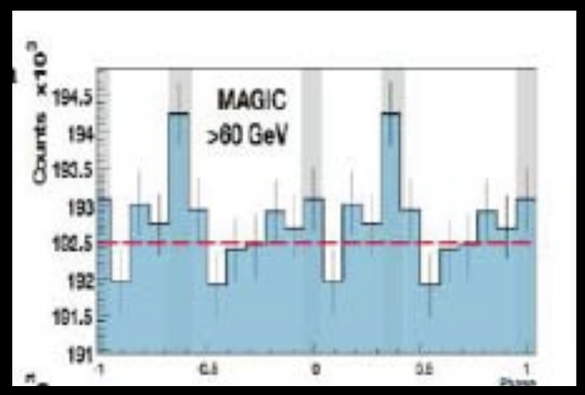
...and well-proven scientific outcome

...and well-proven scientific outcome

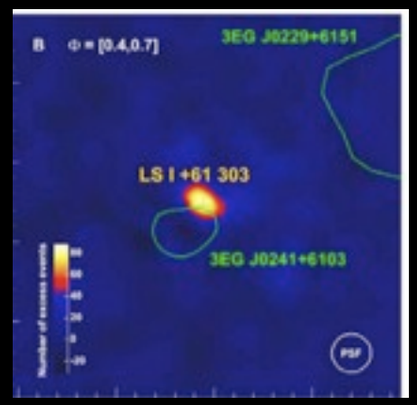
- Galactic targets



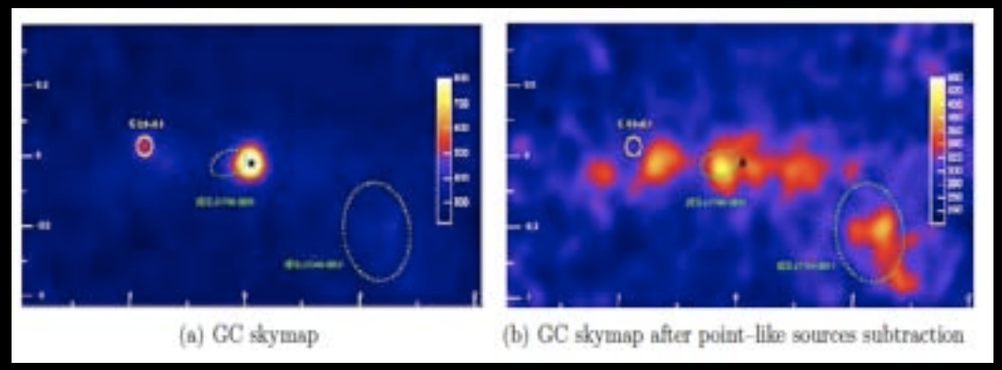
Y-morphology SNR



Pulsed Y from pulsars

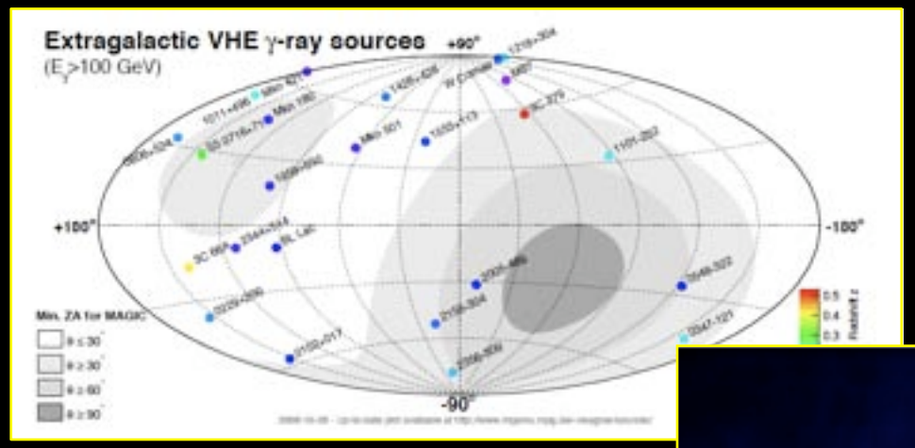


Periodic Y from binaries

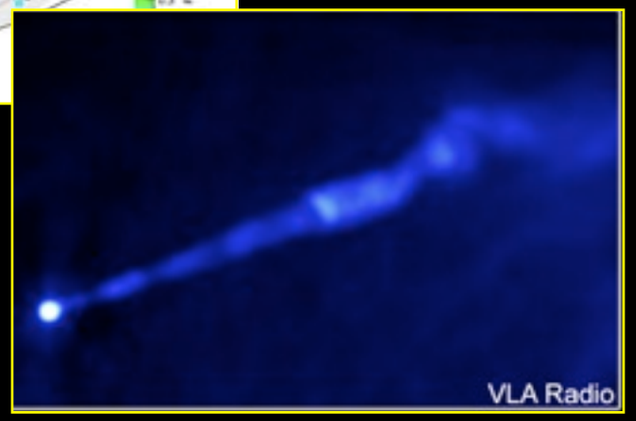


Diffuse and punctual Y from GCs

- Extragalactic targets

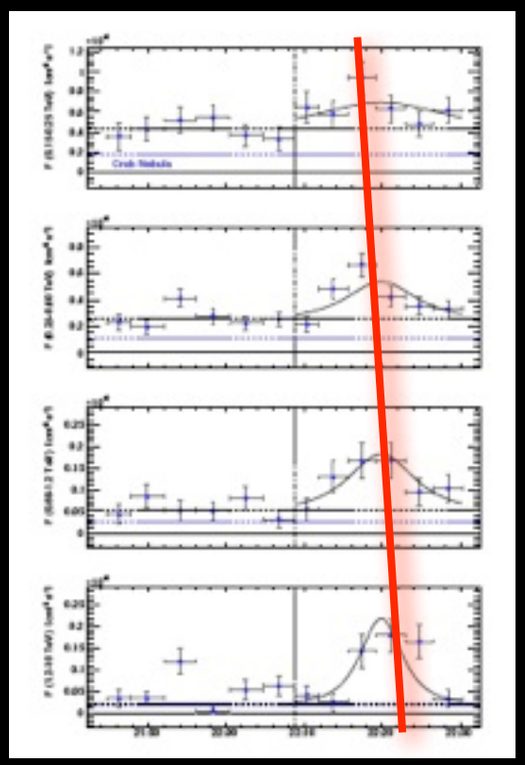


Growing catalog of blazar

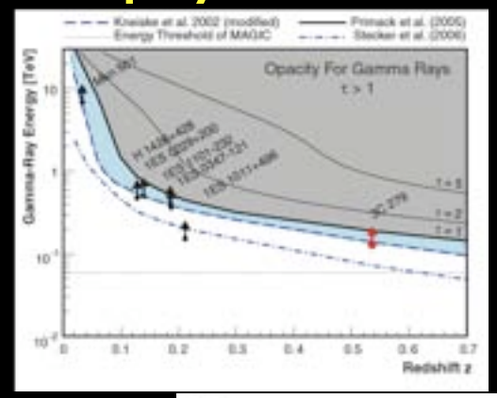


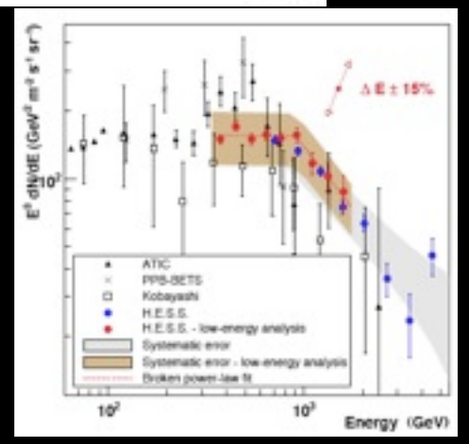
radiogalaxy M87

- Fundamental/CR physics Transparen



Delay vs energy





Electron-Positrons

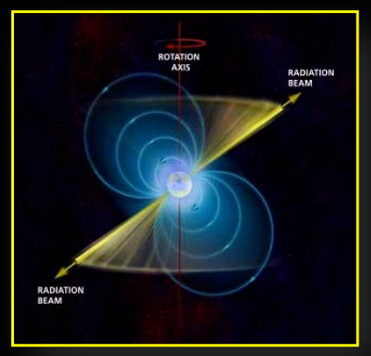
Towards a precision gamma-ray astronomy

Physics motivations / technical demands

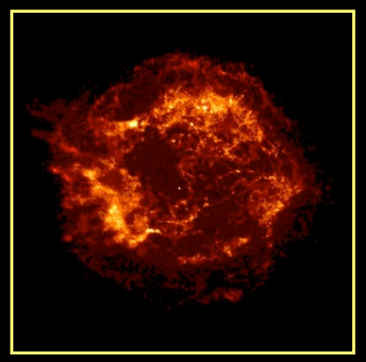
Scientific targets

Scientific targets

- Galactic targets

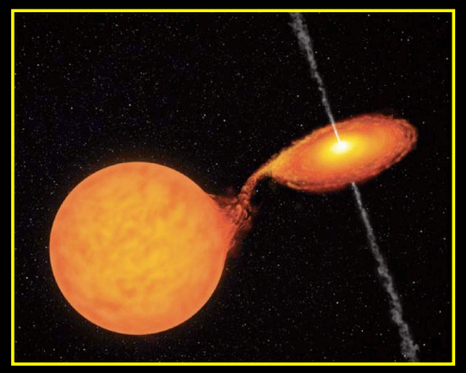


Pulsar

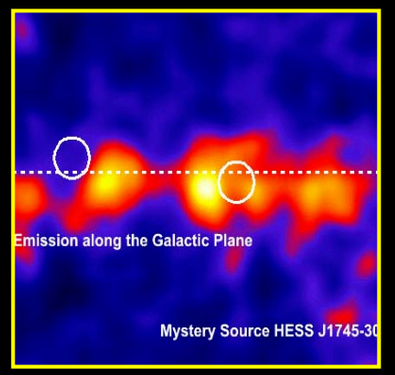


Supernova Remnants

Pulsar wind nebulae



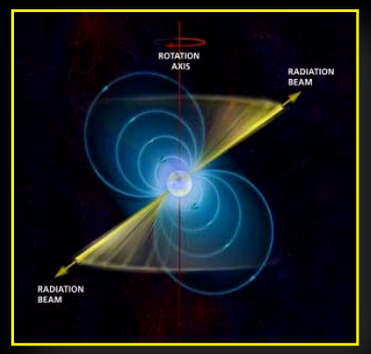
Micro-quasars



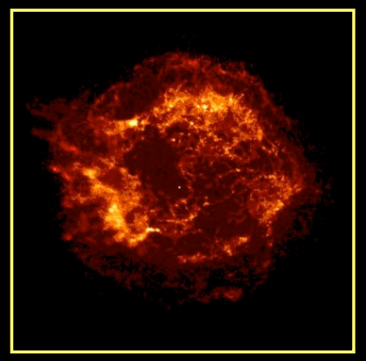
Galactic center

Scientific targets

- Galactic targets

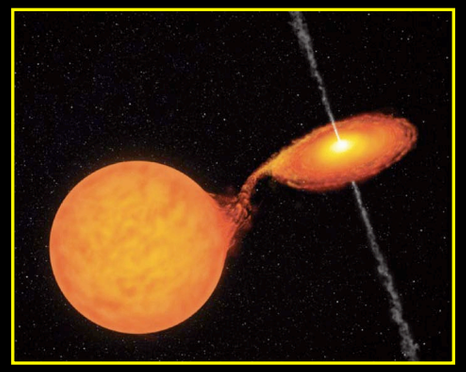


Pulsar

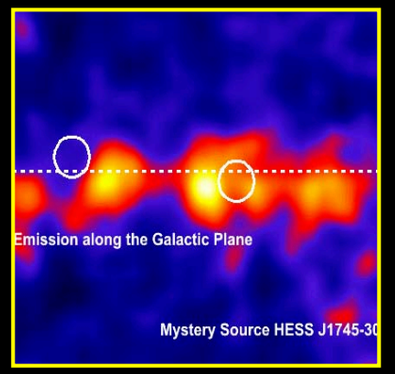


Supernova Remnants

Pulsar wind nebulae



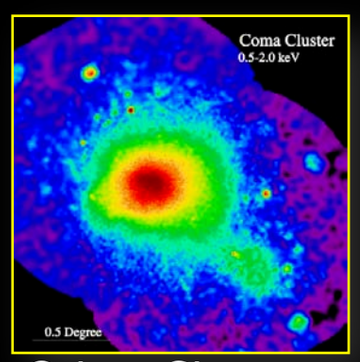
Micro-quasars



Galactic center

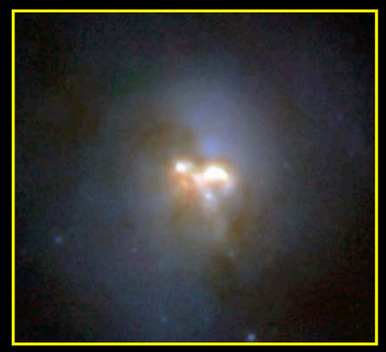
- Extragalactic targets

Active Galactic Nuclei



Galaxy Cluster

Starburst galaxies

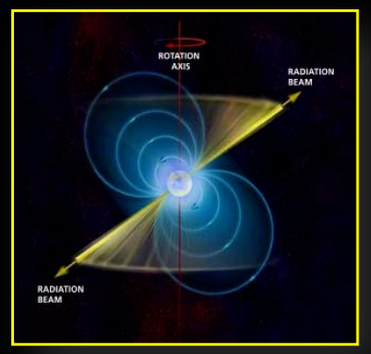


Merging Galaxies

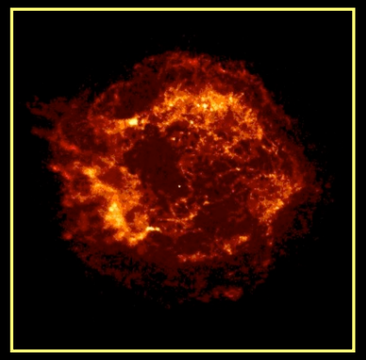
Gamma-ray Bursts

Scientific targets

- Galactic targets

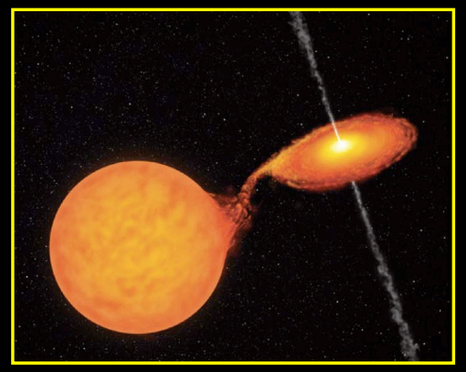


Pulsar

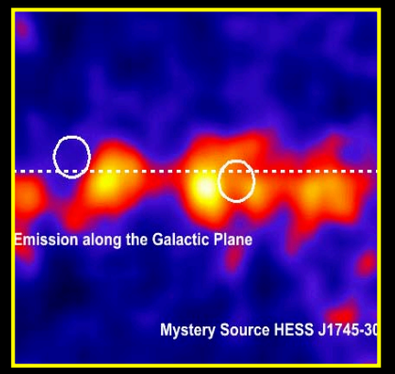


Supernova Remnants

Pulsar wind nebulae



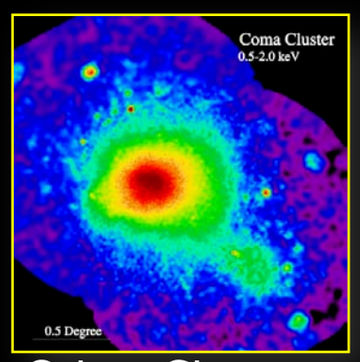
Micro-quasars



Galactic center

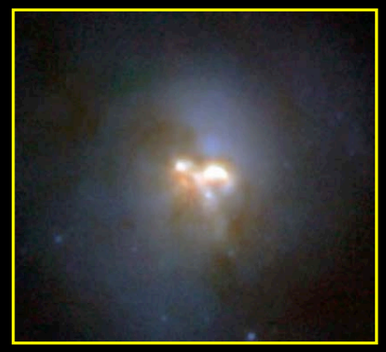
- Extragalactic targets

Active Galactic Nuclei



Galaxy Cluster

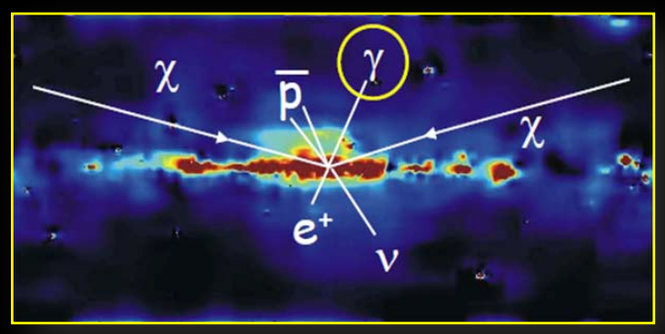
Starburst galaxies



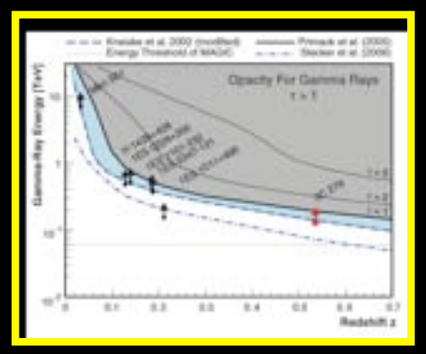
Merging Galaxies

Gamma-ray Bursts

- Fundamental physics



Dark Matter annihilation

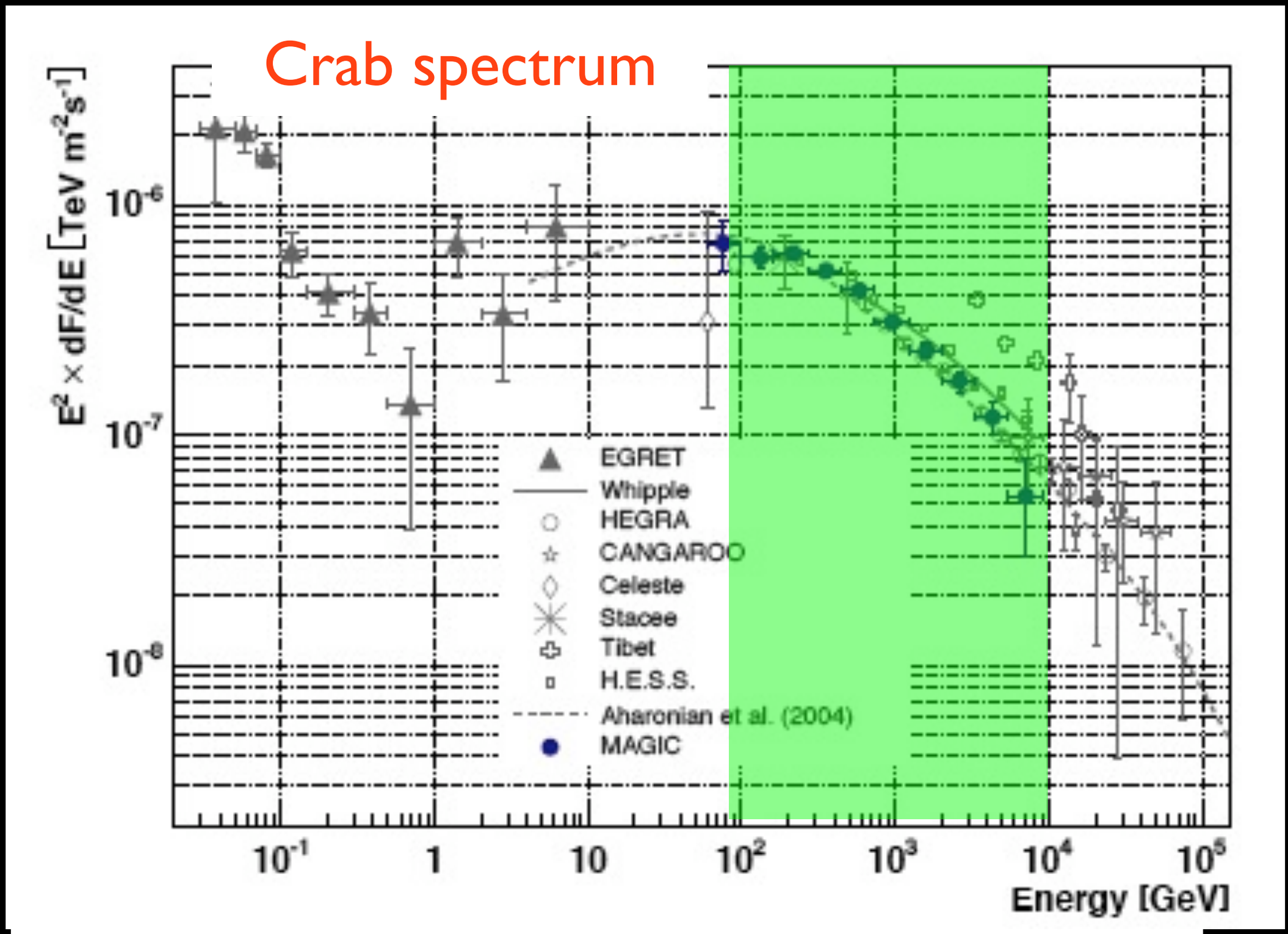


Universe transparency

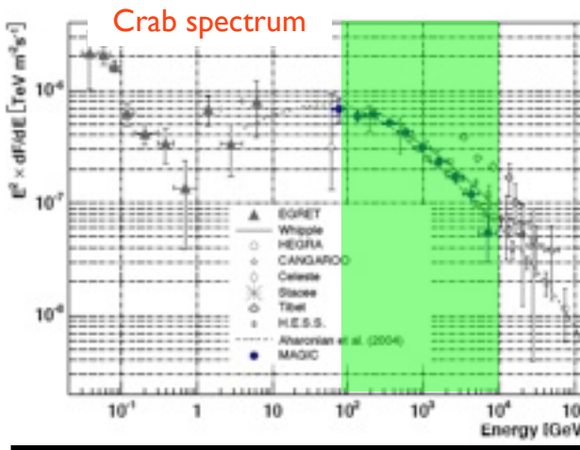
- CR physics
- Lorentz invariance
- Quantum gravity
- Axion-photons obsc

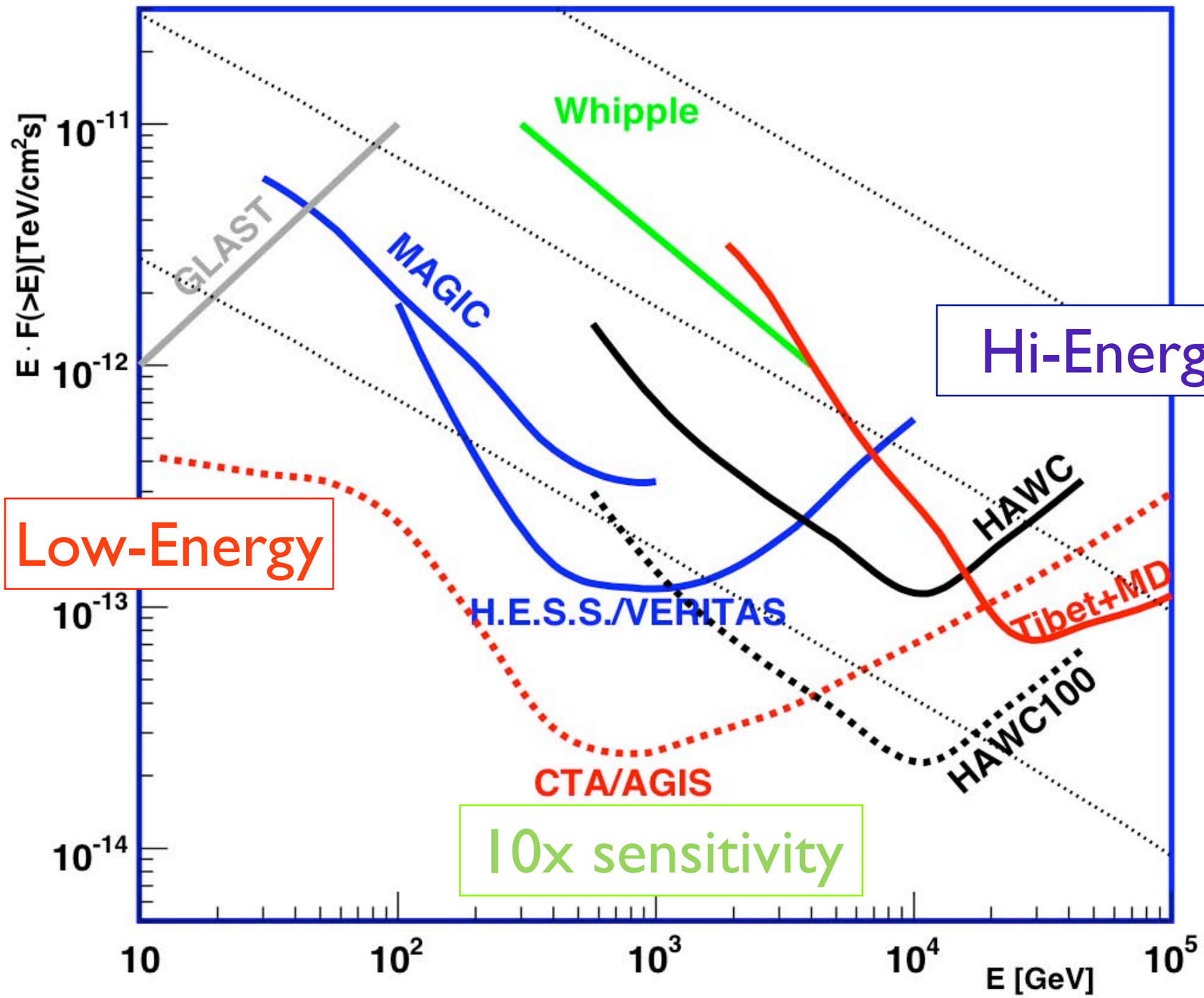
.....

CTA sensitivity

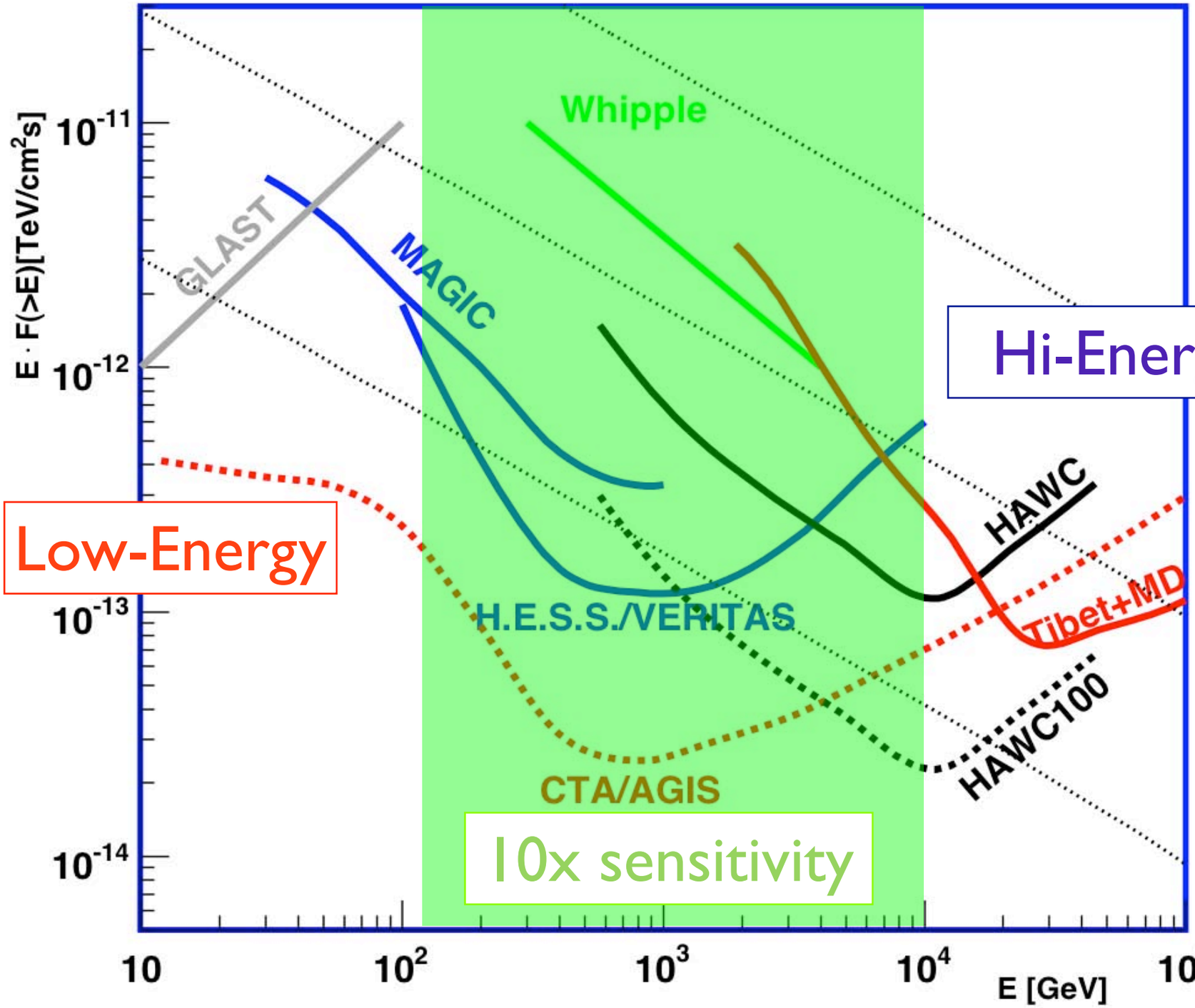


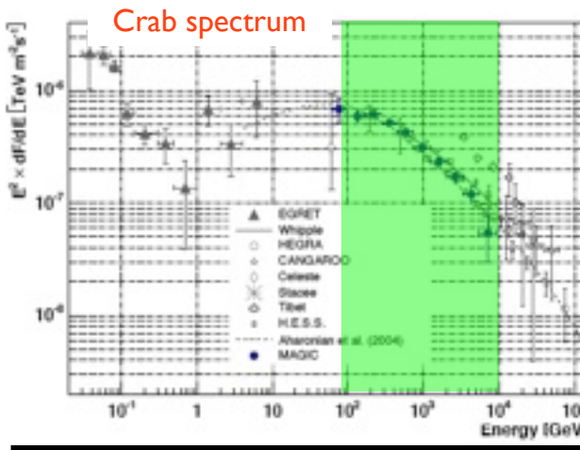
CTA sensitivity



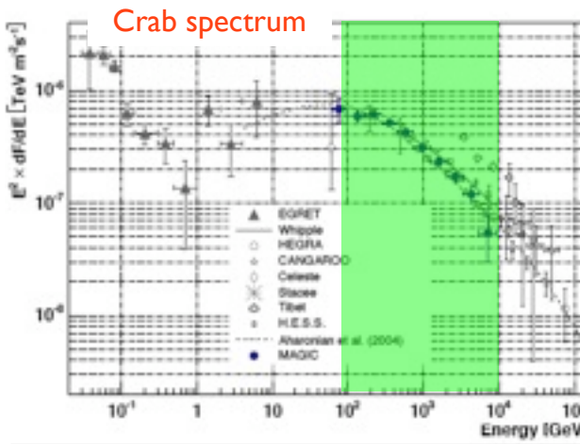


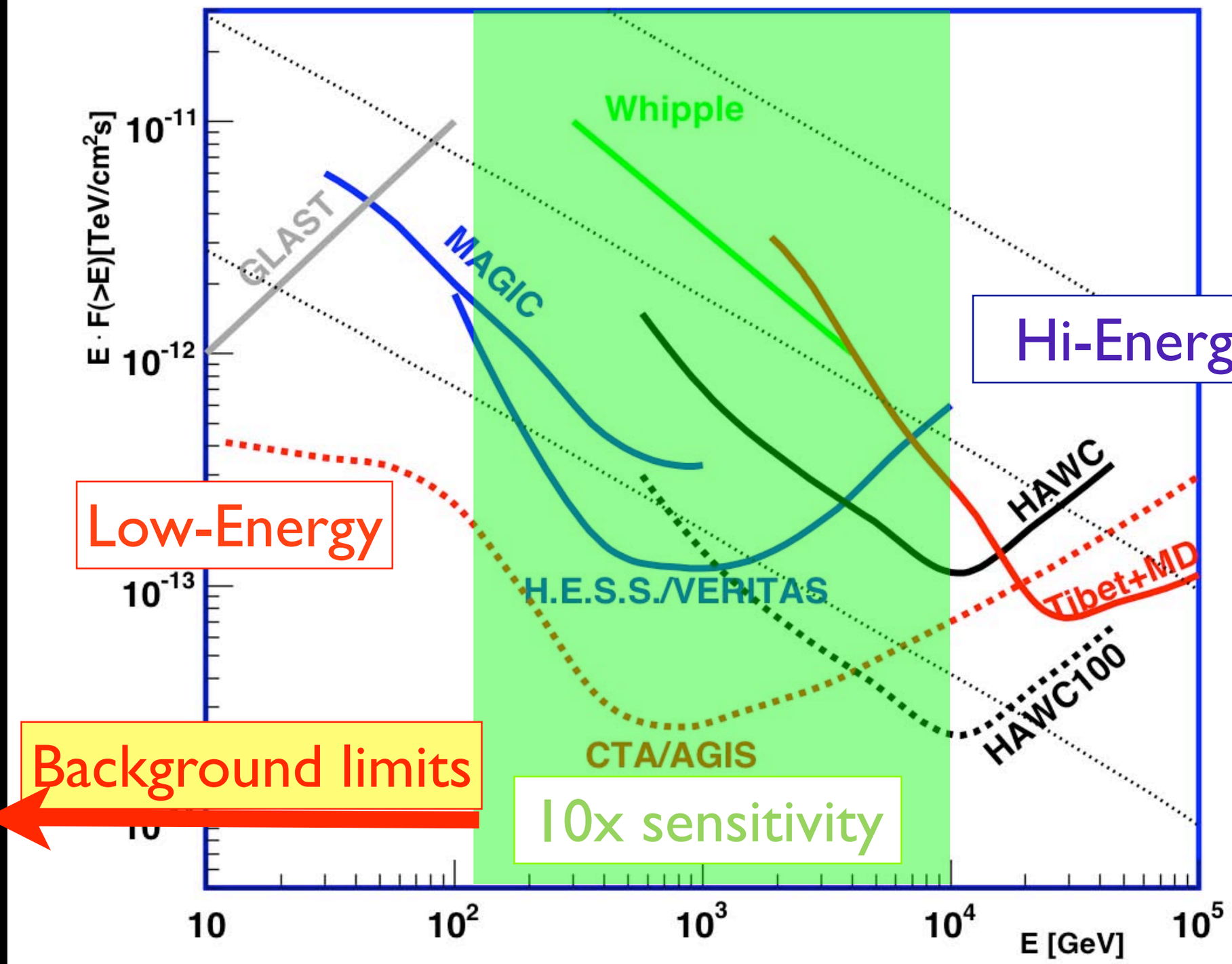
CTA sensitivity





CTA sensitivity





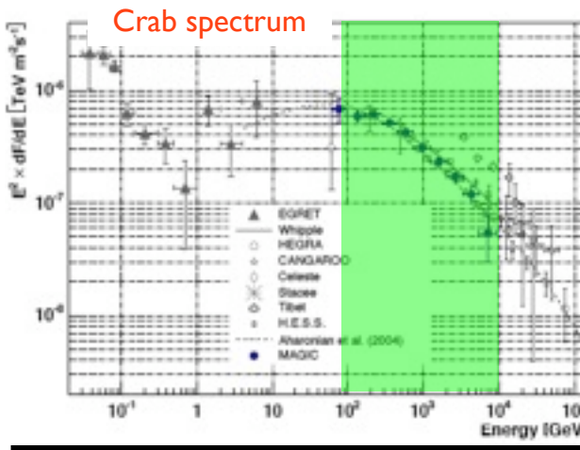
Hi-Energy

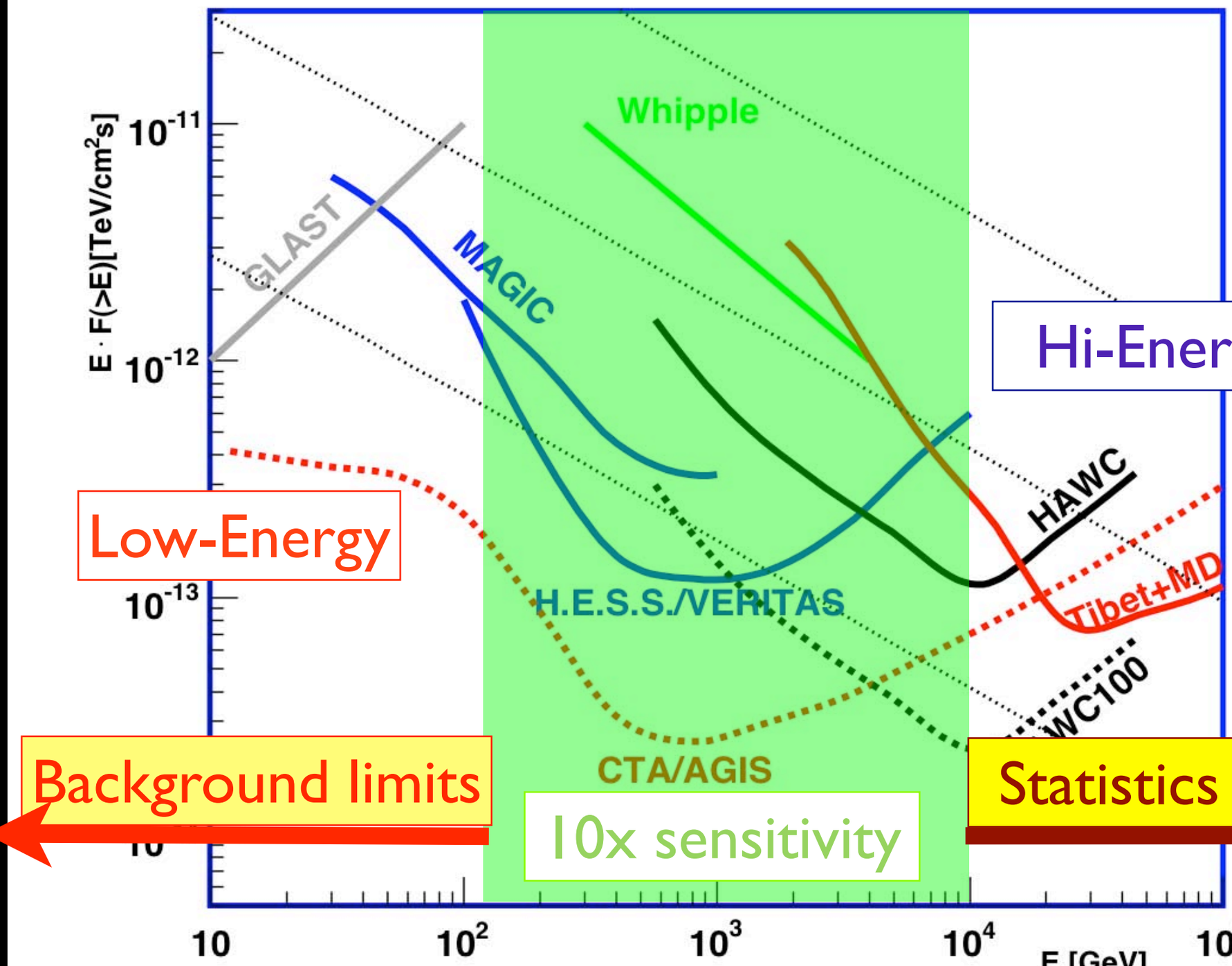
Low-Energy

Background limits

10x sensitivity

CTA sensitivity





Hi-Energy

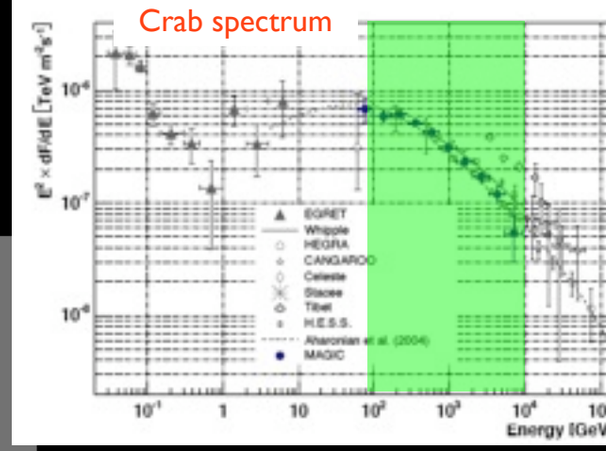
Low-Energy

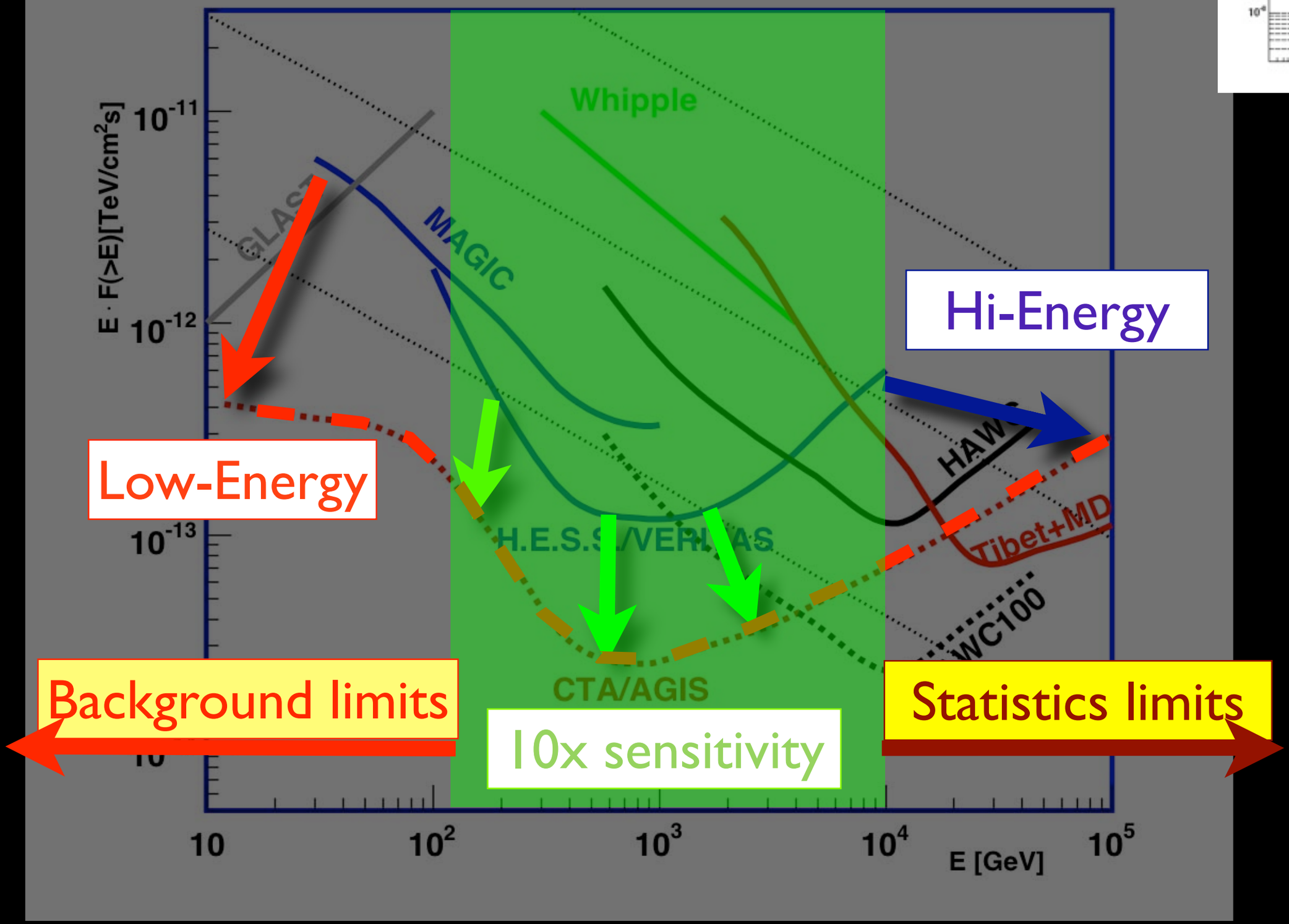
Background limits

Statistics limits

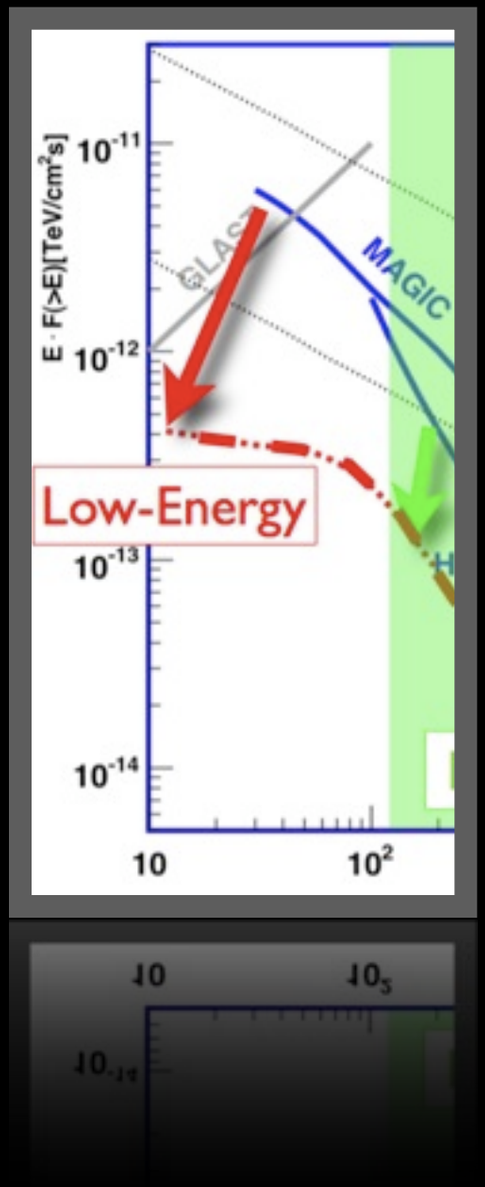
10x sensitivity

CTA sensitivity

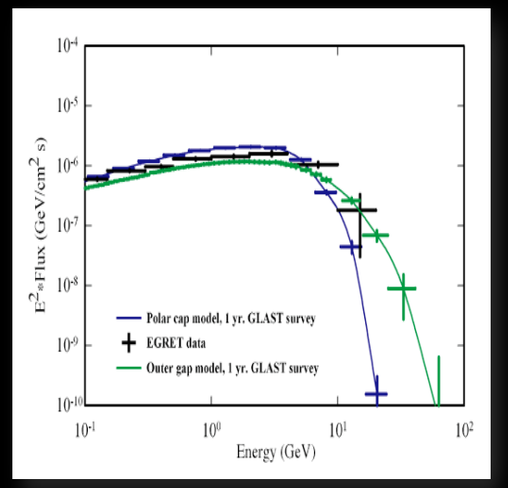


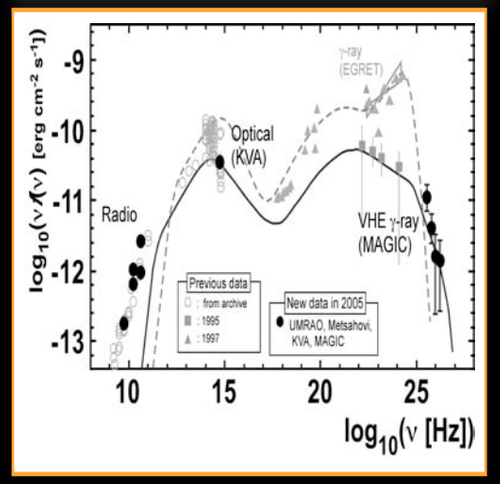


Low-energy physics (<50 GeV)

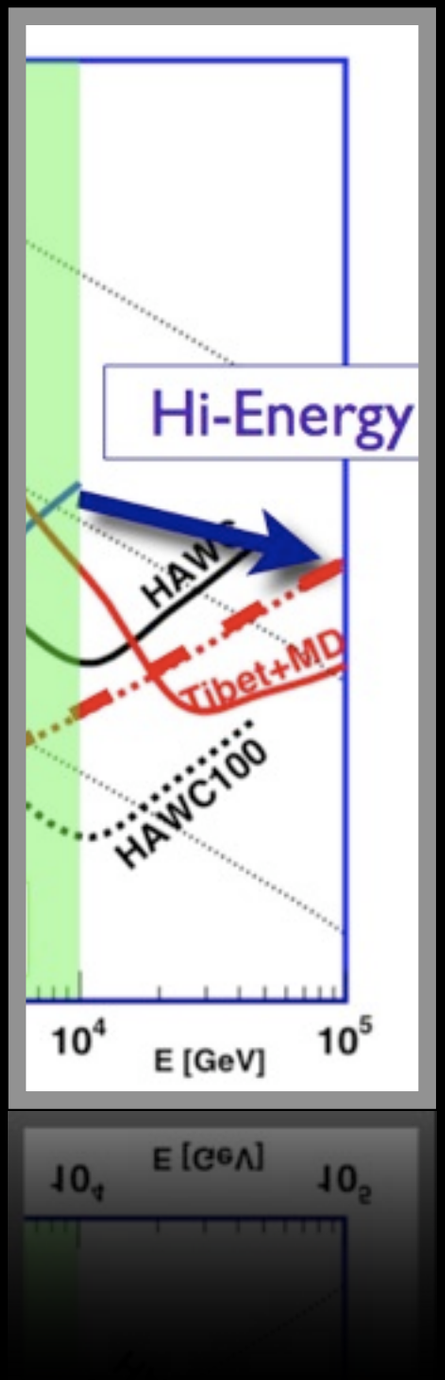


- Galactic objects
  - Investigate Pulsar models: pulsars have different cutoffs (below ~60 GeV) according to acceleration close or far from surface
  - VERY FERMI DEPENDENT!
  - Synchrotron emission from PWNs: PWNs emit synchrotron ~50 GeV gamma-rays from ultra-relativistic winds
    - Investigate acceleration mechanisms
  - hadronic/leptonic acceleration at SNRs: there are spectral differences below 100 GeV
- Extragalactic objects
  - Steep-spectrum blazars.
  - Complete Fermi catalog at VHE
  - overlap with Fermi on all unidentified >GeV sources: disantangle EBL/intrinsic cutoff, infer extragalactic distance by absorption (dark energy measurements)
- Other
  - increase probability of observation of low-mass DM candidates

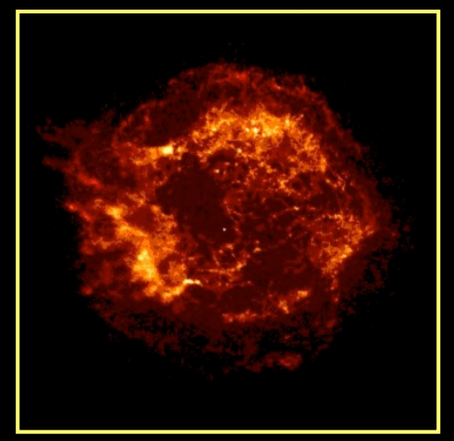




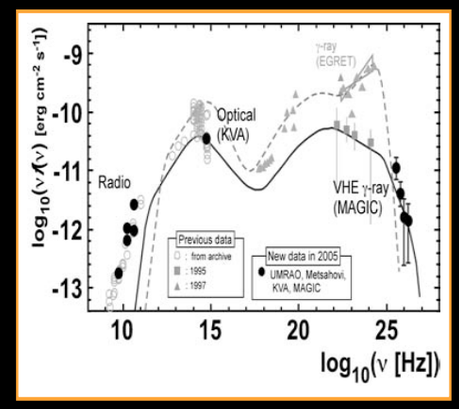
High-energy physics



- Galactic sources
  - Acceleration mechanism in SNRs (again): Above 50 TeV, hadronic/leptonic acceleration mechanism at SNRs differ
  - the nature of ultra-relativistic jets of micro-quasars
  - the nature of binary-systems
- Extragalactic
  - Infrared EBL with nearby blazars

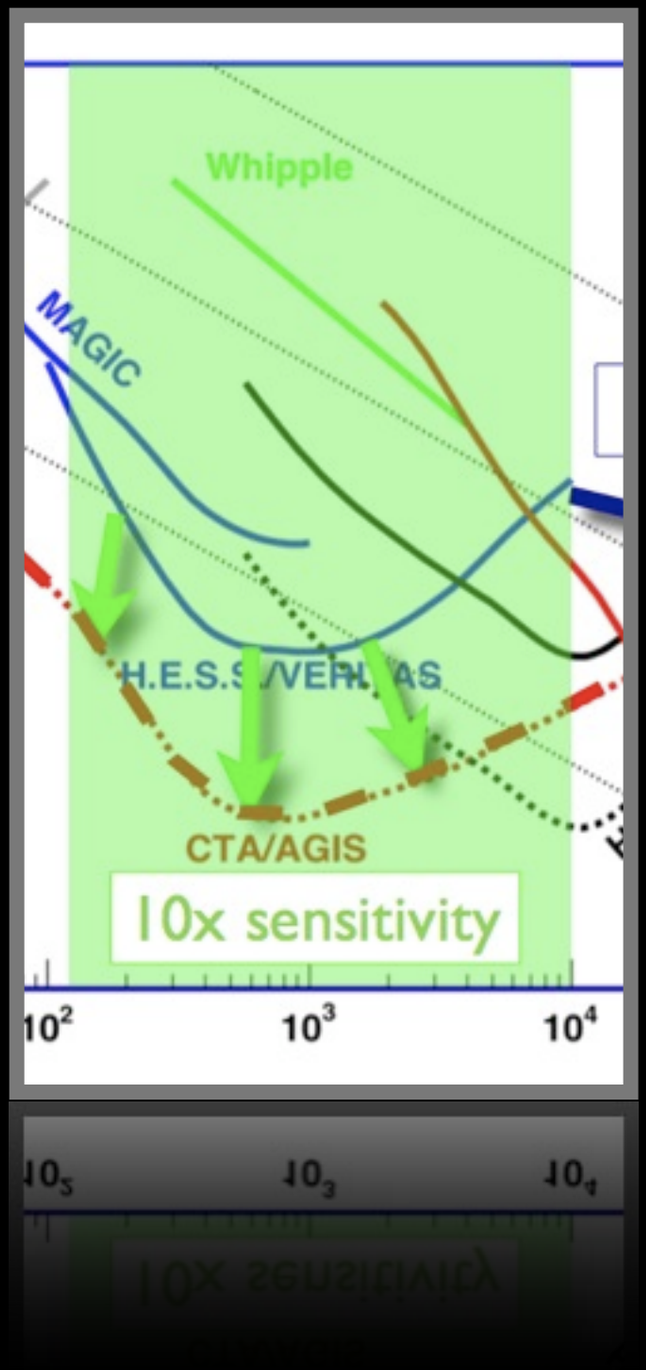


Supernova Remnants



- Other
  - Lorentz invariance between HE/LE photons nearby blazars
  - Probing the knee in cosmic-ray spectrum

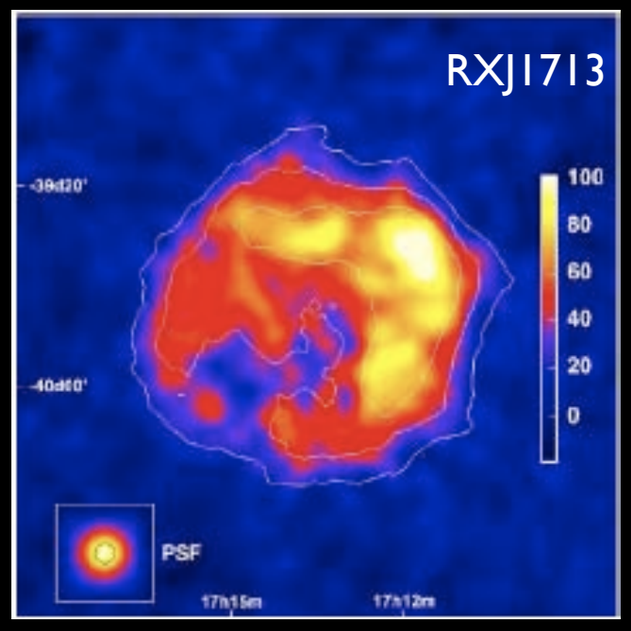
Improve sensitivity

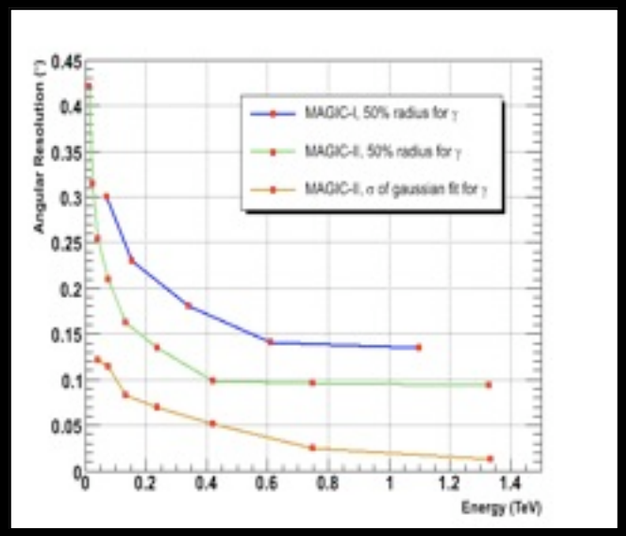


- The most fundamental of all tasks
- Give birth to precision VHE TeV astronomy

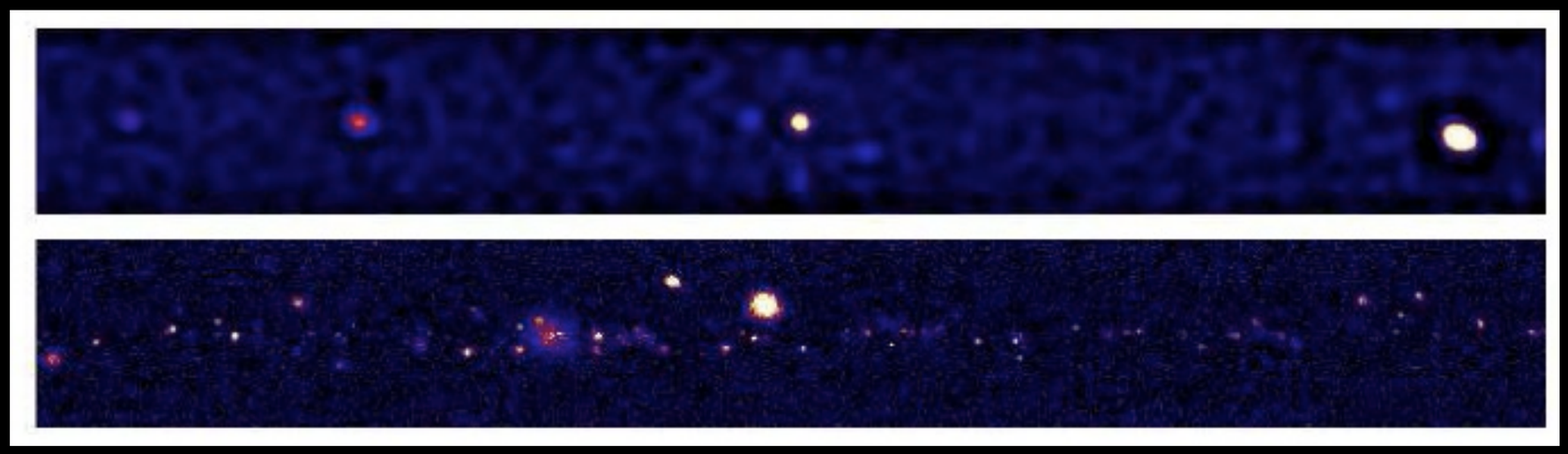
- Morphological studies on galactic targets
  - local interaction with gas/matter
  - discrimination hadronic/leptonic mechanisms
  - interaction with globular clouds
- Variability studies
  - sub-min scale variation (pulsar, binaries, AGNs, Lorentz invariance)
  - possibility to make follow-up obs. (binaries,blazar)
- Consolidate TeV astronomy
  - ~1000 new sources expected
  - acceleration sites of extragal. CRs (gal. merges, gal. clusters, IR gal., ...)
  - VHE model for AGNs
  - GRBs...

Improve angular resolution

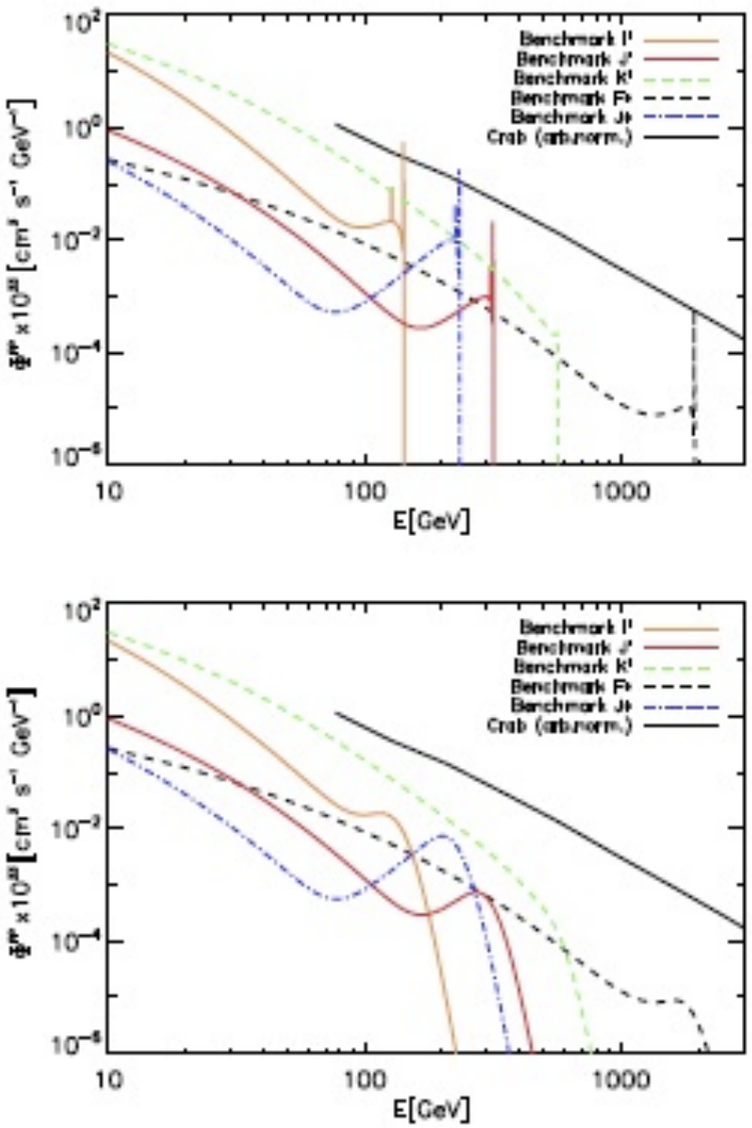




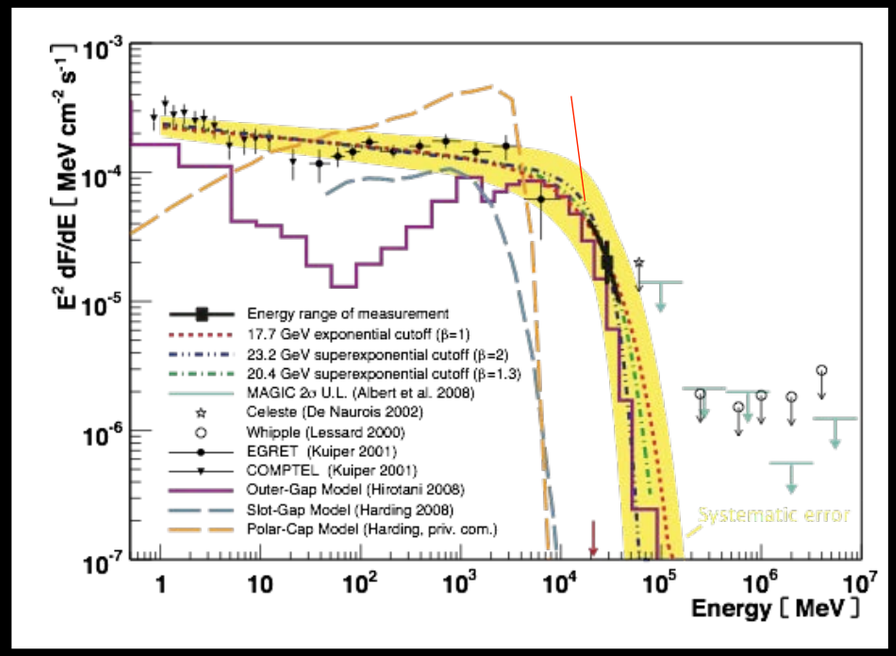
- Both at the center and on the entire FOV
- Galactic objects
  - avoid source confusion due to the improved sensitivity.
  - hadrons and leptons have different free-streaming lengths and gamma-emission is strongly shaped by local interactions
  - Improved angular resolution (arcsec scale) coupled with MW campaing will give key information to discriminate acceleration mechanisms
  - SNRs, PWNs, Binaries, Micro-quasar, GC
- Complete a preciser multi-wavelengths scenario



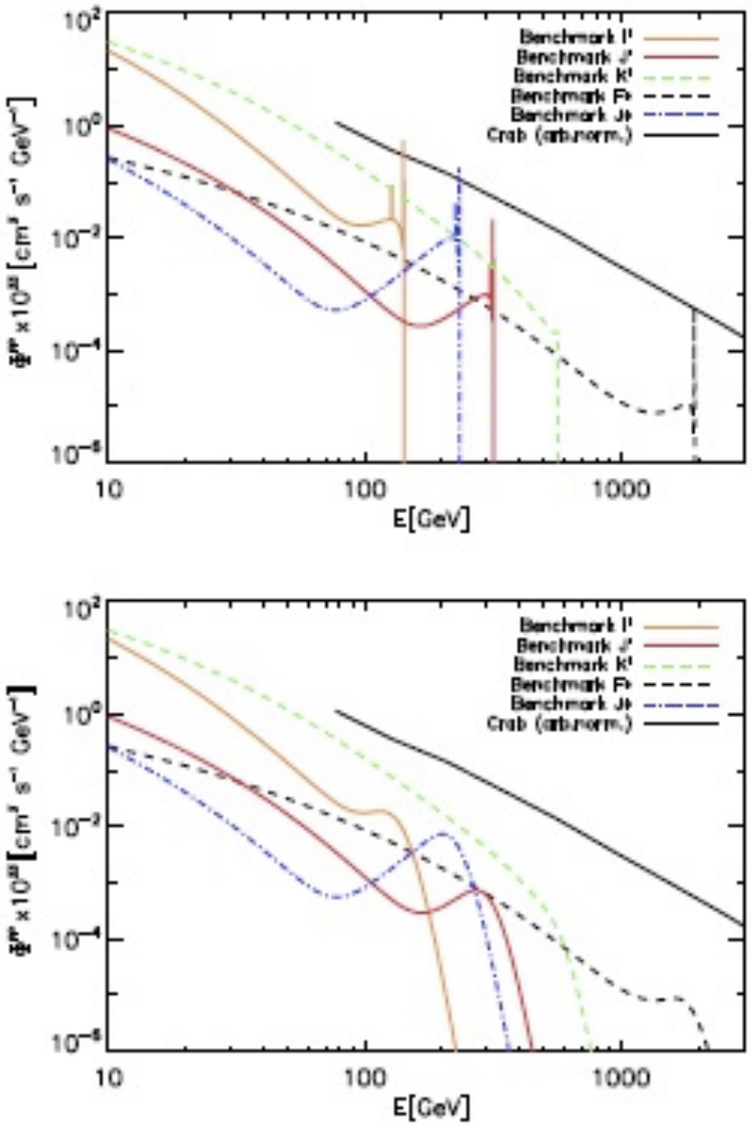
Improve energy resolution



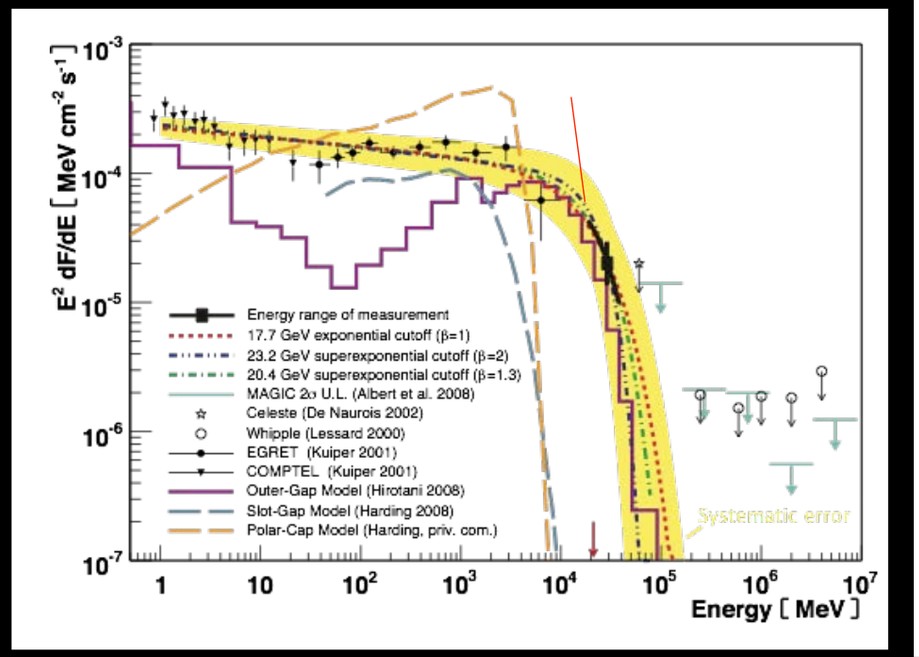
- Increase capability to observed cutoffs
  - Pulsar,
  - EBL-absorbed AGNs
  - DM spectral features
  - Lorentz invariance

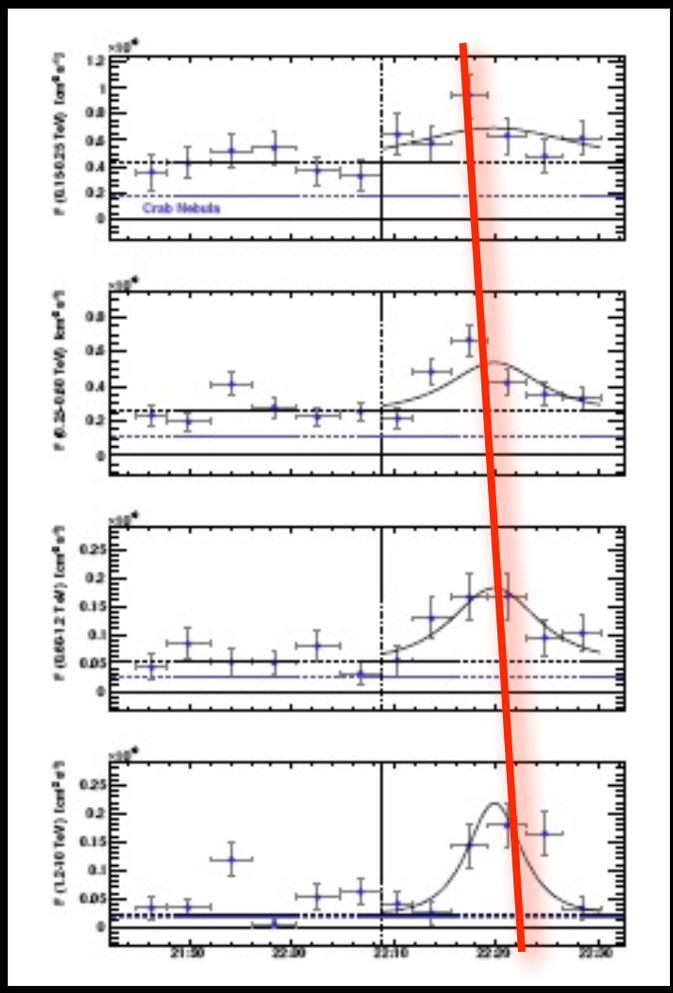


Improve energy resolution



- Increase capability to observed cutoffs
  - Pulsar,
  - EBL-absorbed AGNs
  - DM spectral features
  - Lorentz invariance



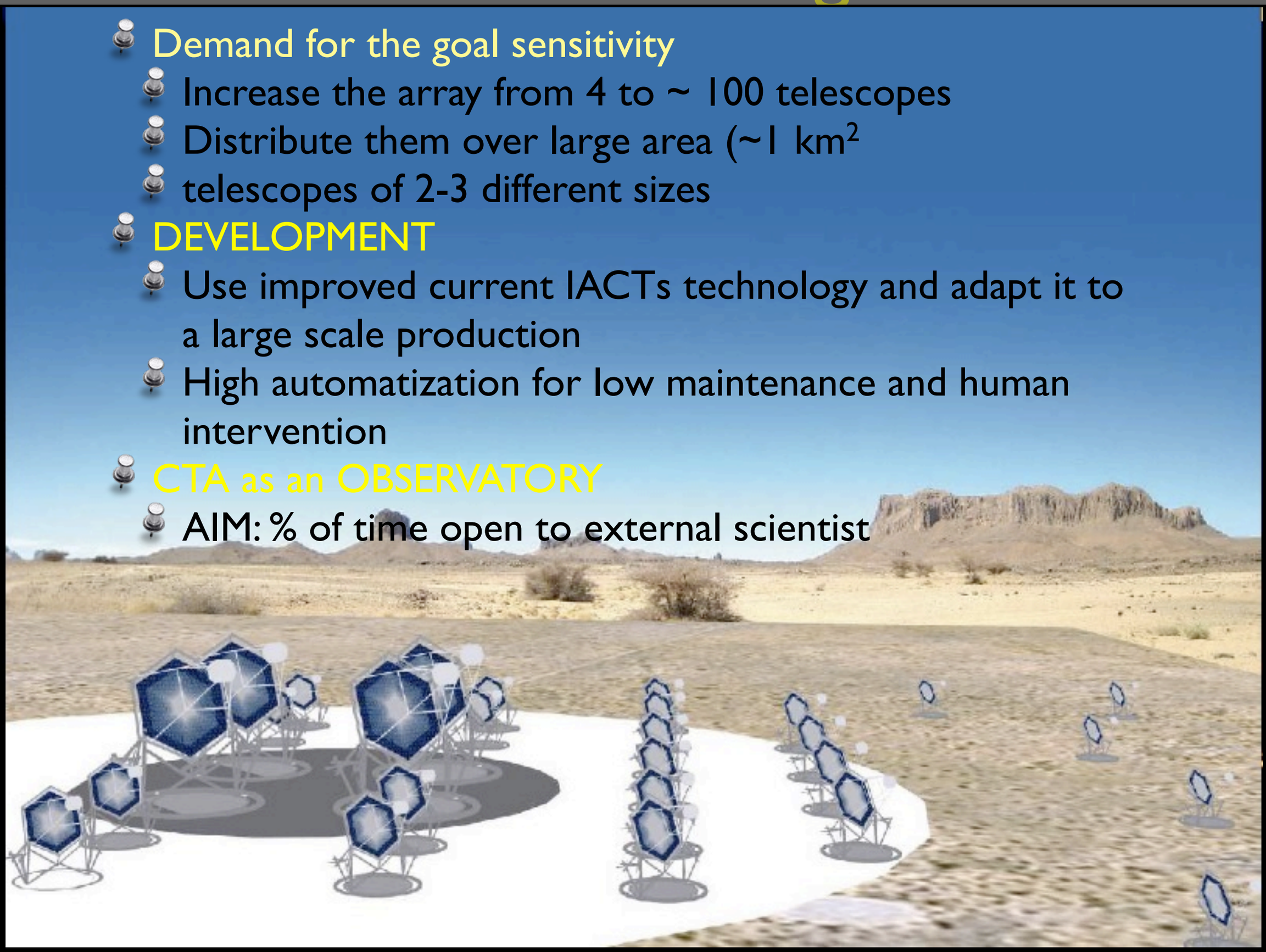


CTA

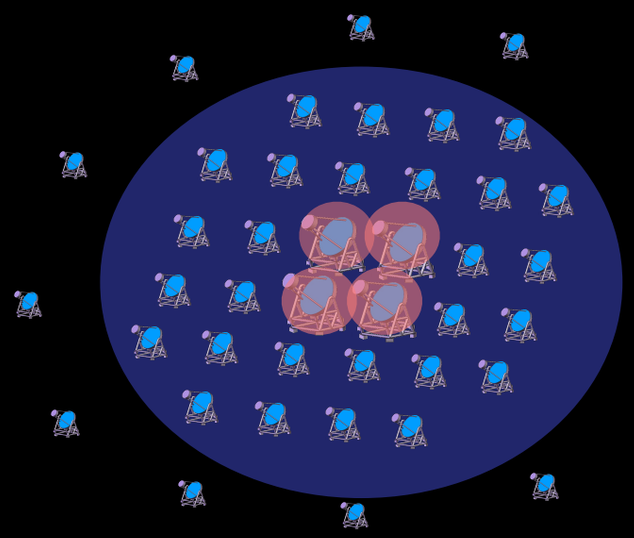
Technical demands

General design

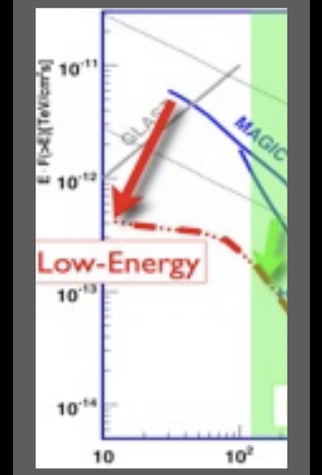
- Demand for the goal sensitivity
  - Increase the array from 4 to ~ 100 telescopes
  - Distribute them over large area (~1 km^2
  - telescopes of 2-3 different sizes
- DEVELOPMENT
  - Use improved current IACTs technology and adapt it to a large scale production
  - High automatization for low maintenance and human intervention
- CTA as an OBSERVATORY
  - AIM: % of time open to external scientist



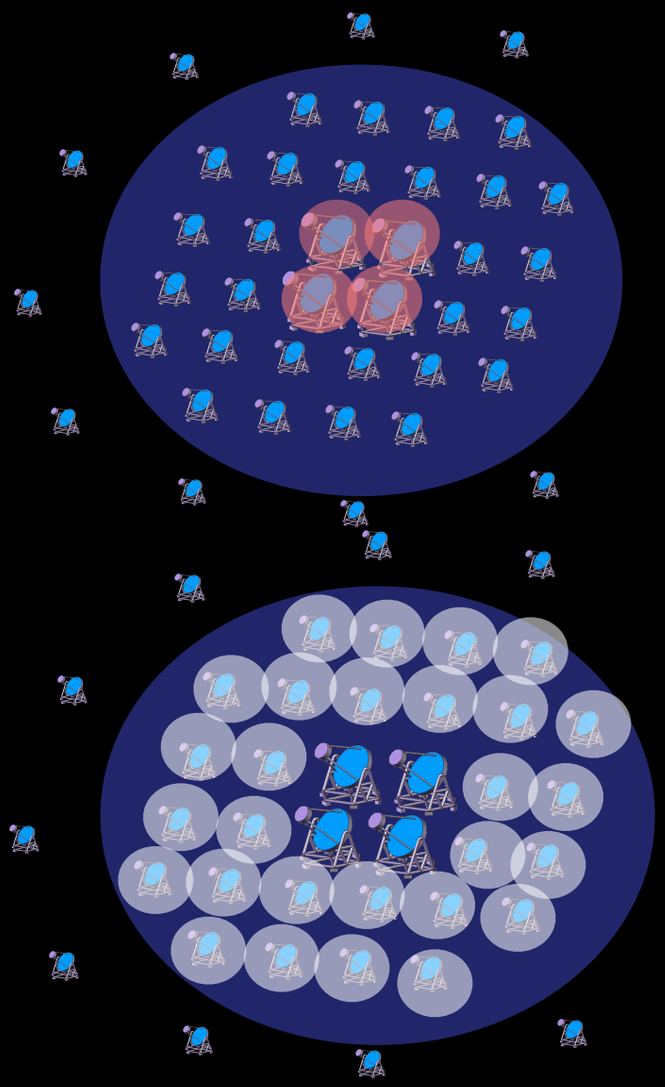
Basic design



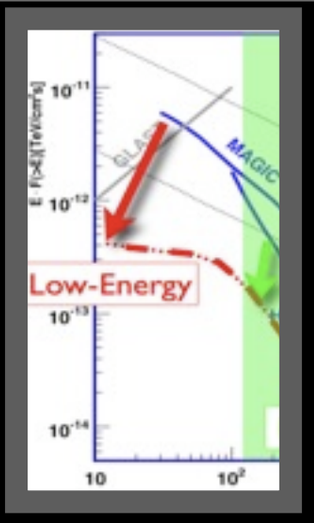
- Few Large Size Telescopes should catch the sub-100 GeV photons
  - Large reflective area
  - Parabolic profiles to maintain time-stamp
  - Contained FOV
  - Challenging technology on all sides



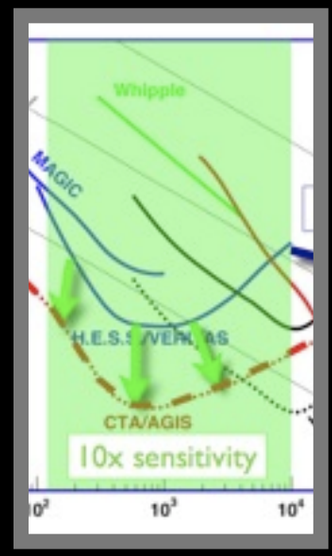
Basic design



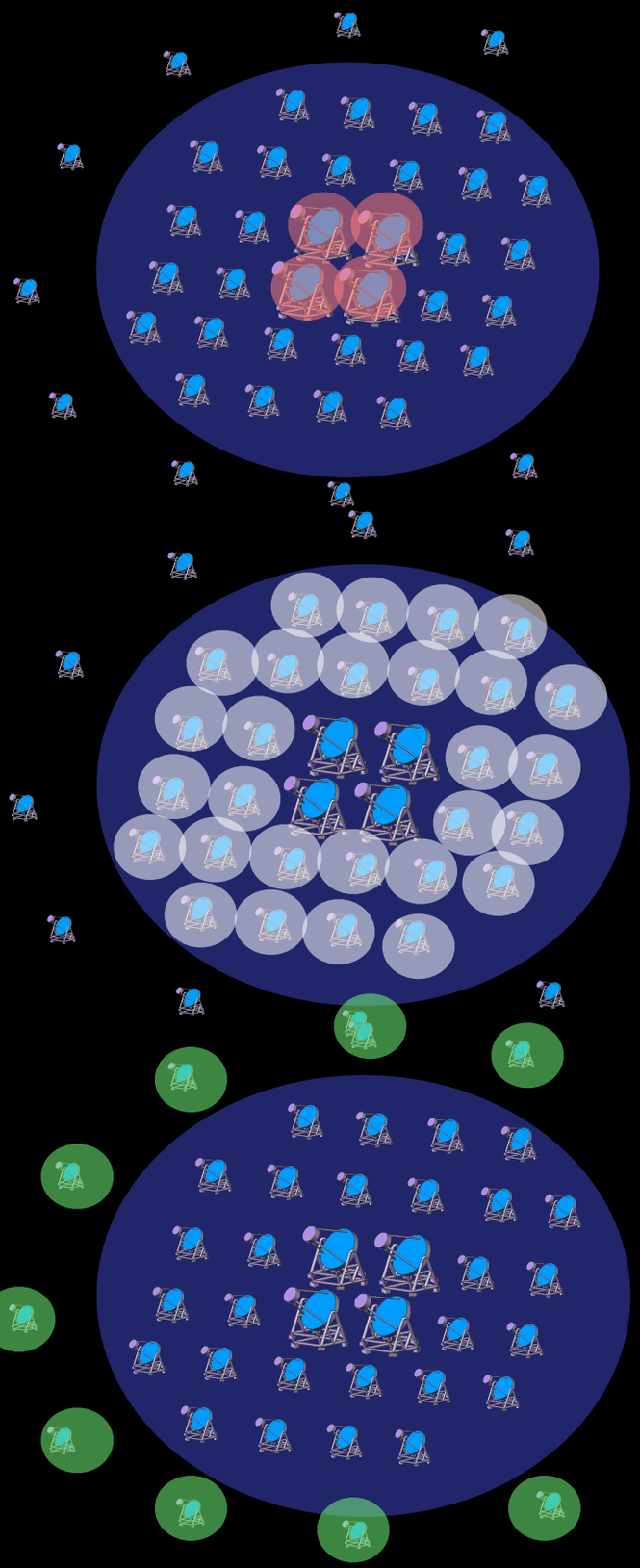
- Few Large Size Telescopes should catch the sub-100 GeV photons
  - Large reflective area
  - Parabolic profiles to maintain time-stamp
  - Contained FOV
  - Challenging technology on all sides



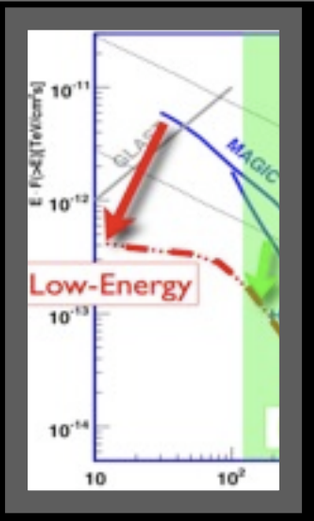
- Several Medium Size Telescopes perform 100 GeV-50 TeV search
  - well-proven techniques (HESS, MAGIC)
  - goal is to reduce costs and maintenance
  - core of the array
  - act as VETO for LSTs



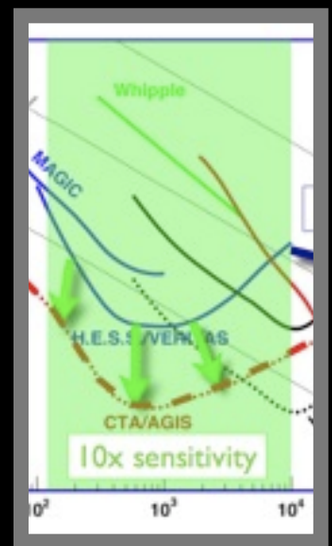
Basic design



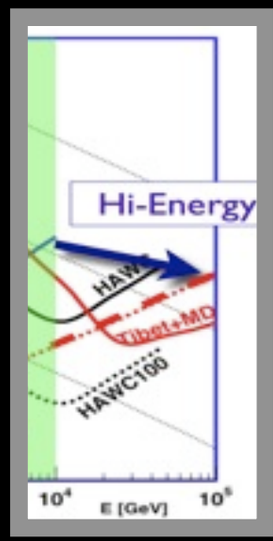
- Few Large Size Telescopes should catch the sub-100 GeV photons
  - Large reflective area
  - Parabolic profiles to maintain time-stamp
  - Contained FOV
  - Challenging technology on all sides



- Several Medium Size Telescopes perform 100 GeV-50 TeV search
  - well-proven techniques (HESS, MAGIC)
  - goal is to reduce costs and maintenance
  - core of the array
  - act as VETO for LSTs

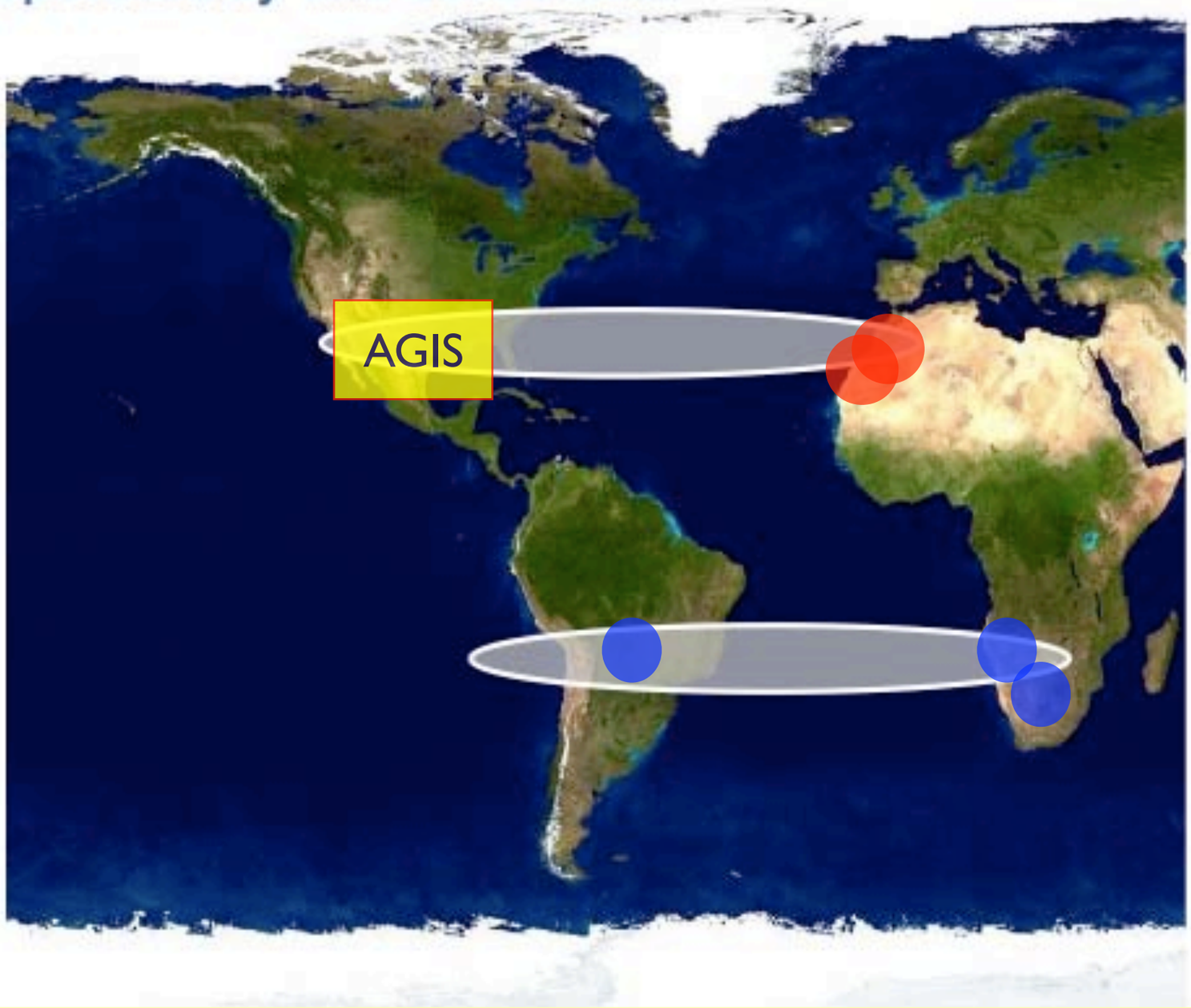


- Several Small Size Telescopes perform ultra-50 TeV search
  - very simple construction
  - price should be small compared to full observatory
  - (maybe use only MST with larger FOV)



Sites

One observatory with two sites
operated by one consortium



Northern Array (50 ME)

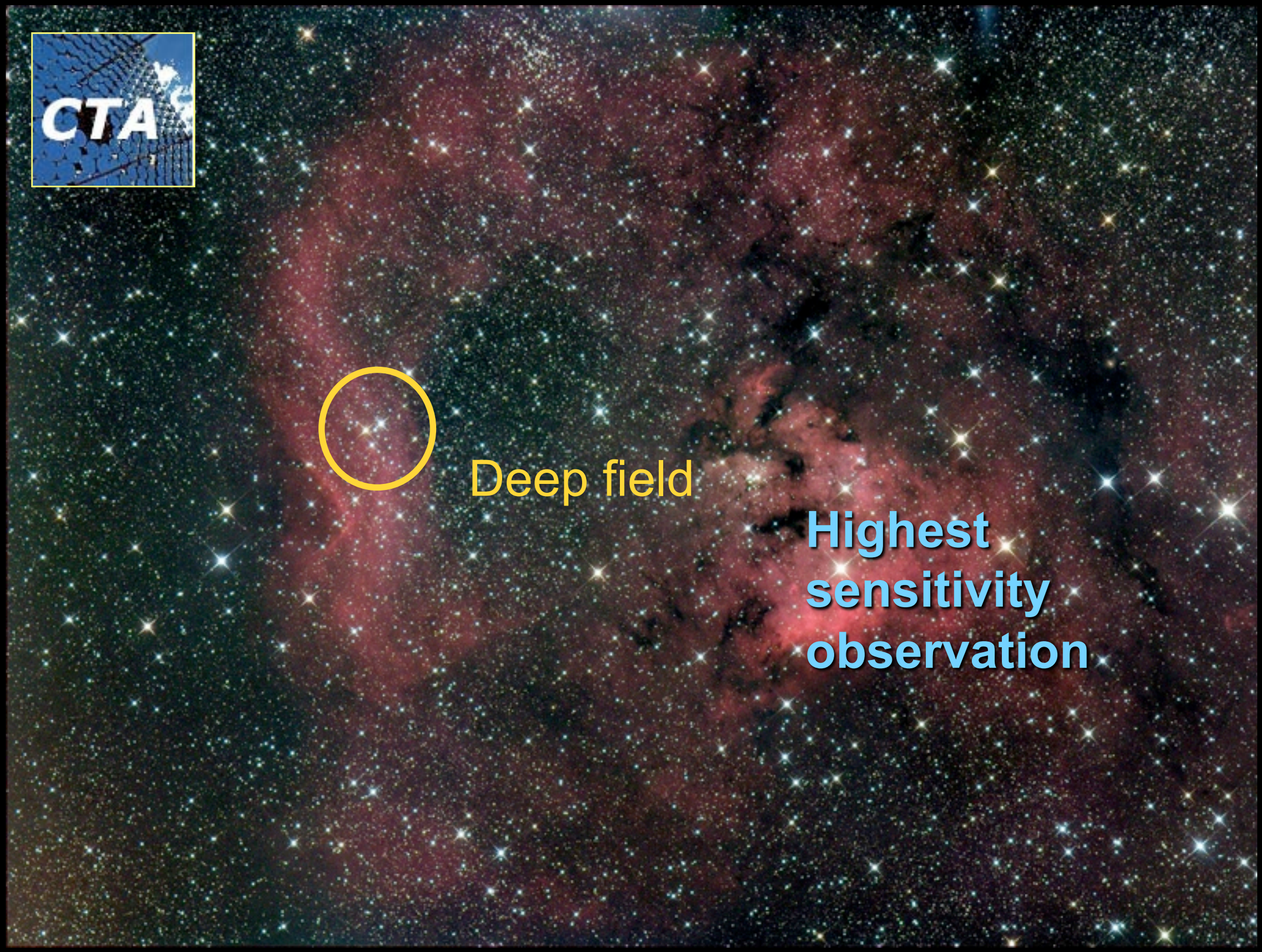
→ complementary to SA for full sky coverage
→ Energy range some 10 GeV …. ~1 TeV
→ Small field of view
Mainly extragal. Sources

Southern Array (100 ME)

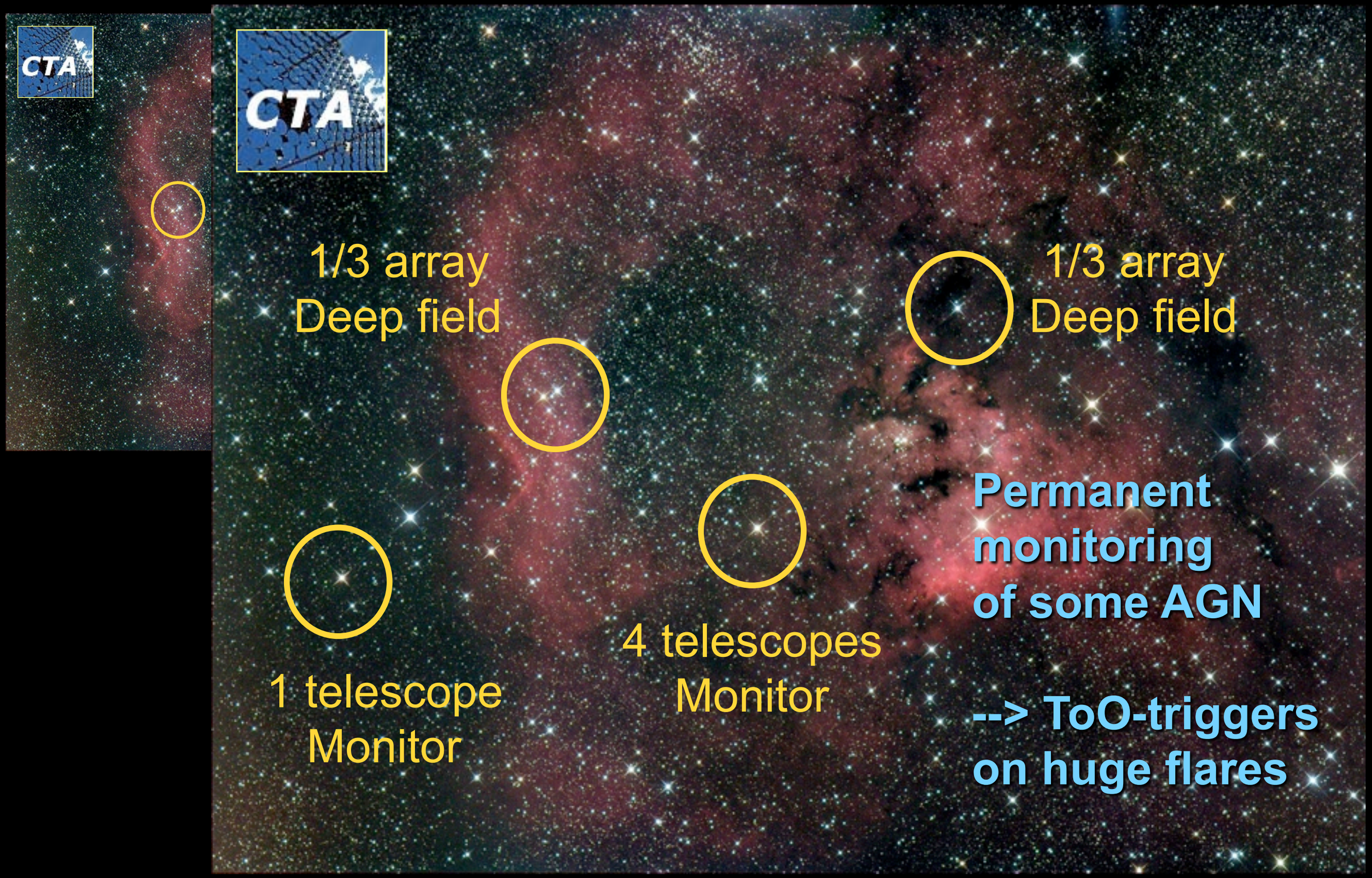
→ Full energy and sensitivity coverage some 10 GeV …. 100 TeV
→ Angular resolution: 0.02 … 0.2 deg
→ Large field of view
Galactic + Extragal. Sources

Observation modes

Observation modes



Observation modes



Observation modes

Wide FOV Scan

Systematic scan of some good part of the sky

4 telescope Monitor

Observation modes

Deep field

Highest sensitivity observation

1/3 array Deep field

1/3 array Deep field

1 telescope Monitor

4 telescopes Monitor

Permanent monitoring of some AGN

--> ToO-triggers on huge flares

Wide FOV Scan

Systematic scan of some good part of the sky

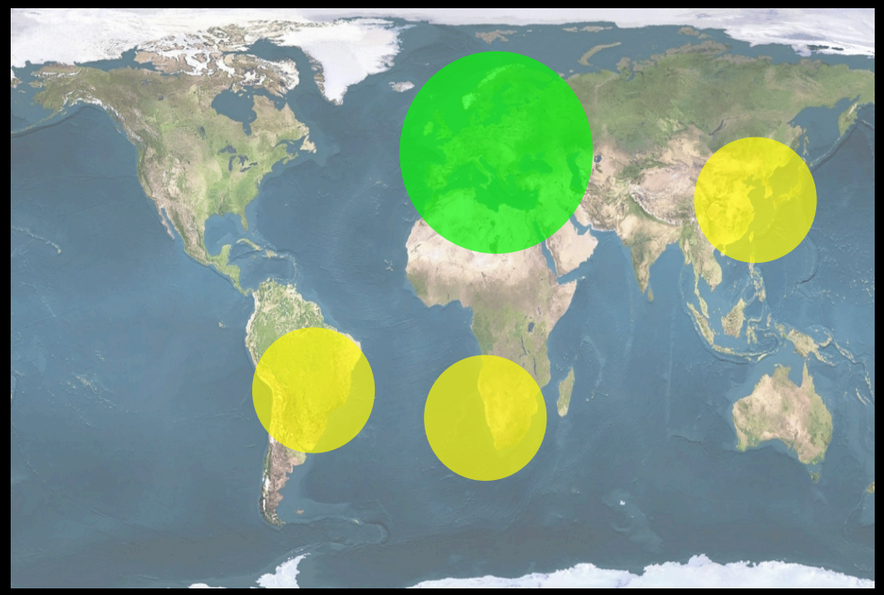
4 telescope Monitor

CTA Project

Structure, ideas, calendar

Members and structure

Members and structure



- Partners:
  - HESS+MAGIC collaborations + European (all) + world interest (Japan, Argentina)
  - coordination/discussions with US AGIS (Advanced Gamma-ray Imaging System) scientists, who work on a project
  - already ~50 institutes, ~14 countries (~ 300 scientists)
  - Regular meetings since 2007.
  - Project run as observatory

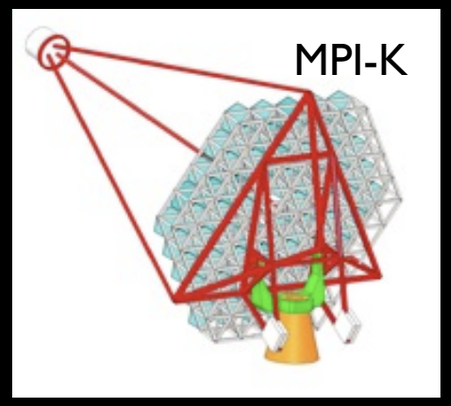
	WP	Work Package	Coordinators
1	MGT	Management of the design study Spokesperson search under way...	
2	PHYS	Astrophysics and astroparticle physics	Diego Torres – ICREA & Institud de Ciencies, Barcelona
3	MC	Optimisation of array layout, performance studies, and analysis algorithms.	Jim Hinton – University of Leeds Giovanni Lamanna – LAPP IN2P3/CNRS
4	SITE	Site evaluation and site infrastructure	R. Paoletti – University of Siena
5	MIR	Design of telescope optics and mirror	Mosé Mariotti – University of Padova
6	TEL	Design of Telescope structure, drives, and control systems	Michael Panter – MPIK Heidelberg
7	FPI	Focal Plane Instrumentation, photodetectors, light-guides, mechanics	Razmik Mirzoyan – MPIP Munich
8	ELEC	Read-out electronics and trigger	Pascal Vincent – LPNHE IN2P3/CNRS
9	ATAC	Atmospheric monitoring, associated science, and instrument calibration	Manel Martinez – IFAE Barcelona
10	OBS	Observatory operation and access	Aimo Sillanpää – Tuorla Obs./Turku Univ. Stefan Wagner – Landessternewarte Heidelberg
11	DATA	Data handling, processing, management, and access	Christian Stegmann – ECAP Erlangen Adrian Biland – ETH Zürich
12	QA	Quality assurance and risk assessment	Michael Punch – APC IN2P3/CNRS

- Structure
  - Spokesman: W. Hoffman (MPI-K, Heidelberg),
  - Co-spokesman: M. Martinez (IFAE, Barcelona)
  - Work-Packages:
    - Physics,
    - MC,
    - Telescope and Mirrors,
    - Focal Plane Instrumentation,
    - Electronics,
    - etc.

Telescopes

- Small Size Telescope (SST)

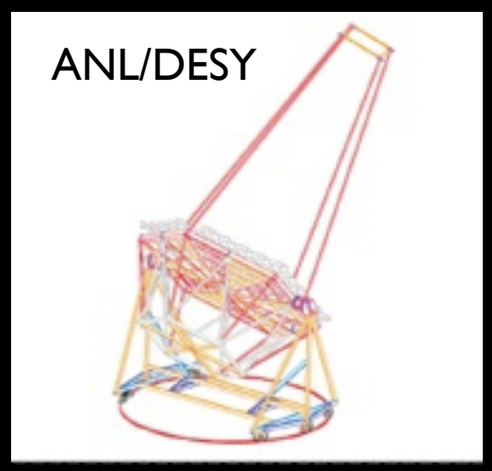
2 projects

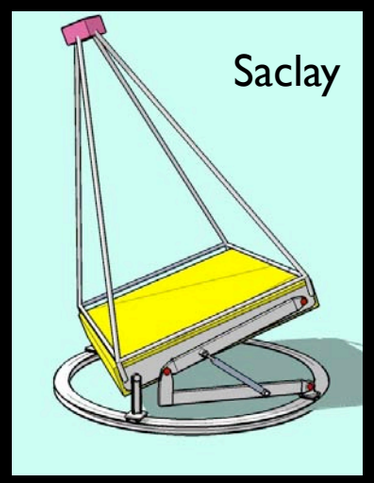


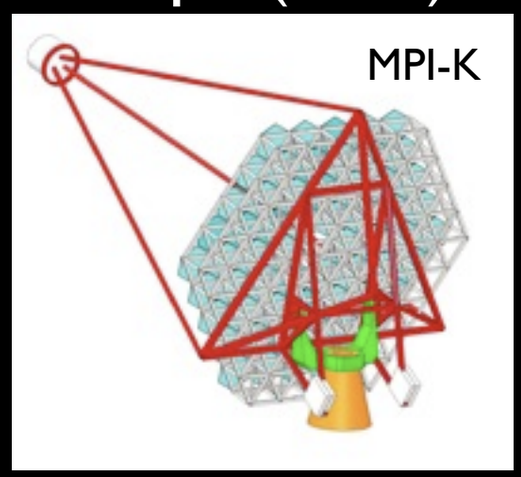
Different designs under competition

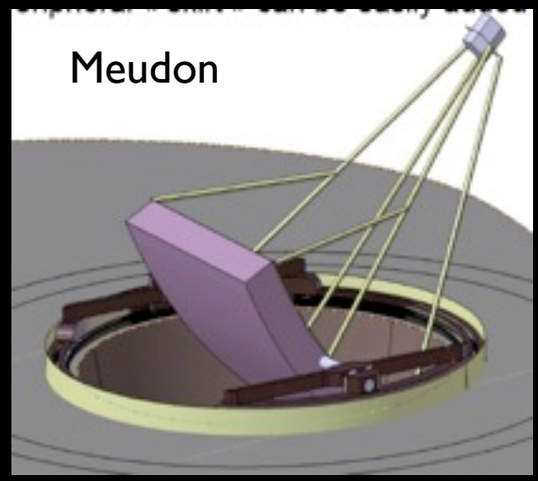
- Medium Size Telescope (MST)

4 projects
BASELINE



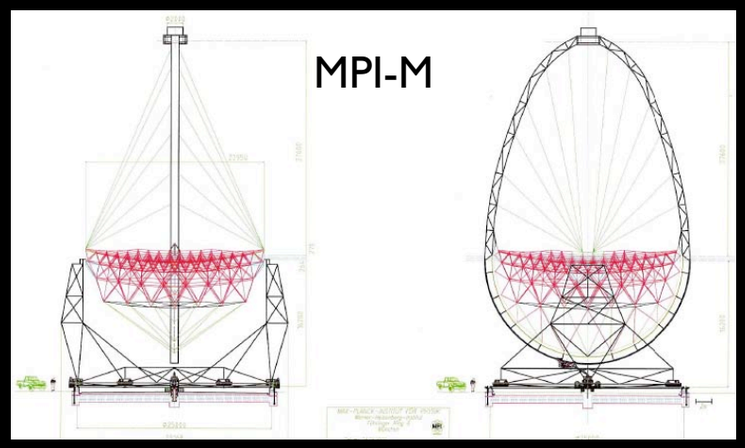






- Large Size Telescope (LST)

1 project



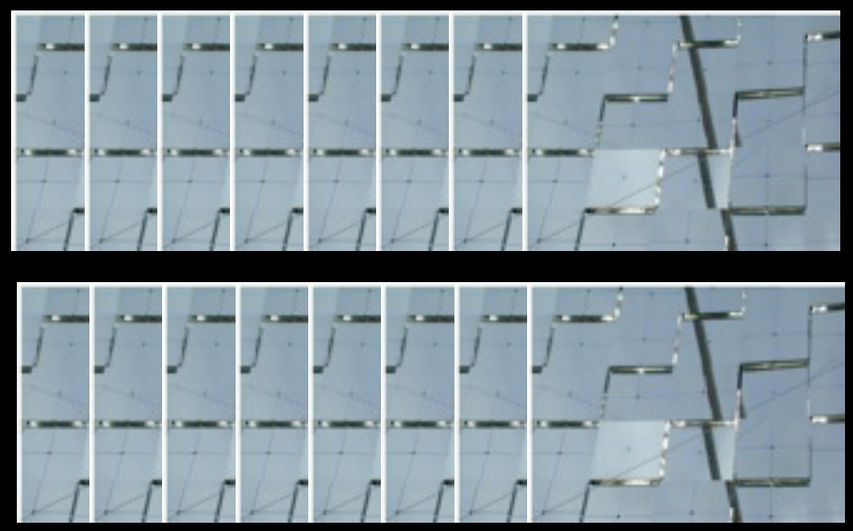
Mirrors

- Sizeable part of costs
- Challenges
  - 10,000 m^2
  - Produce them in time!
  - Replica techniques to be proven

Mirrors

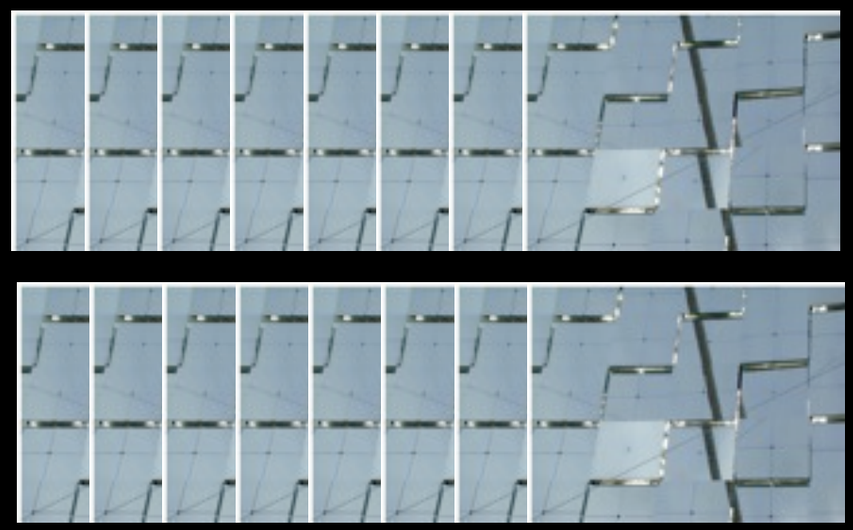
- Sizeable part of costs
- Challenges
  - 10,000 m^2
  - Produce them in time!
  - Replica techniques to be proven

Mirrors

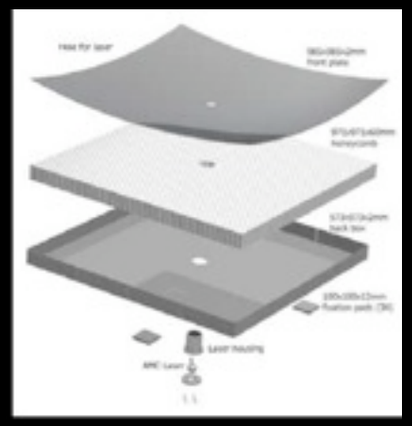


- Sizeable part of costs
- Challenges
  - 10,000 m^2
  - Produce them in time!
  - Replica techniques to be proven

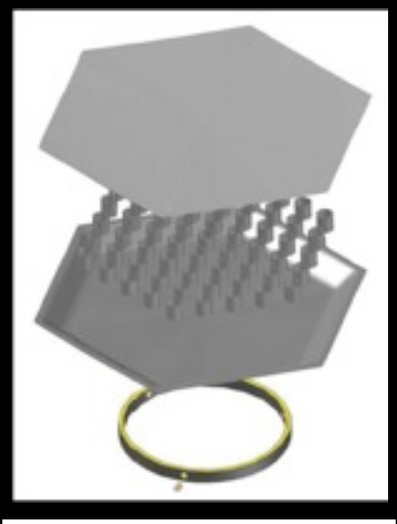
Mirrors



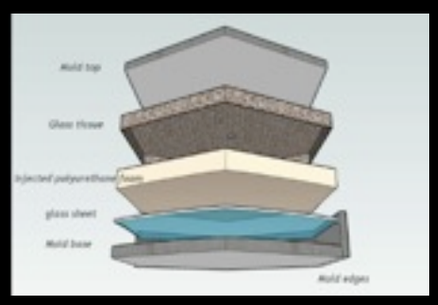
- Sizeable part of costs
- Challenges
  - 10,000 m^2
  - Produce them in time!
  - Replica techniques to be proven



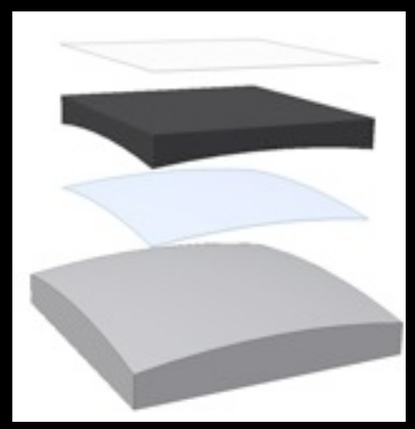
- Aluminum-sandwich
  - Maintain optical properties
  - Costly



- Composites
  - technology not proven



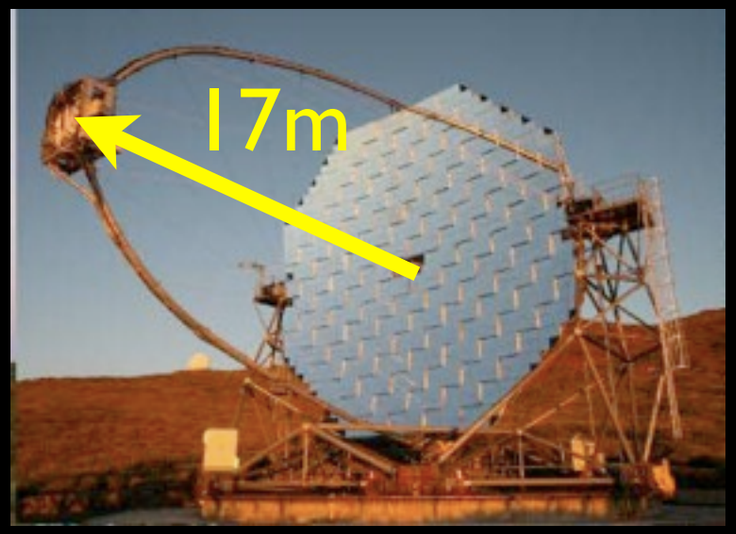
- Foam glass replica
  - Dew formation?
  - Cheap



- Cold-slumped glass replica
  - MAGIC II
  - Not proven technology

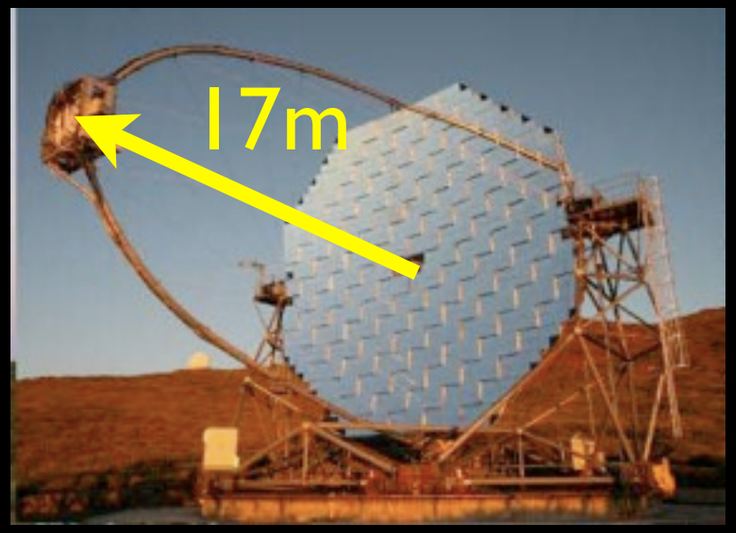
Camera/pixels

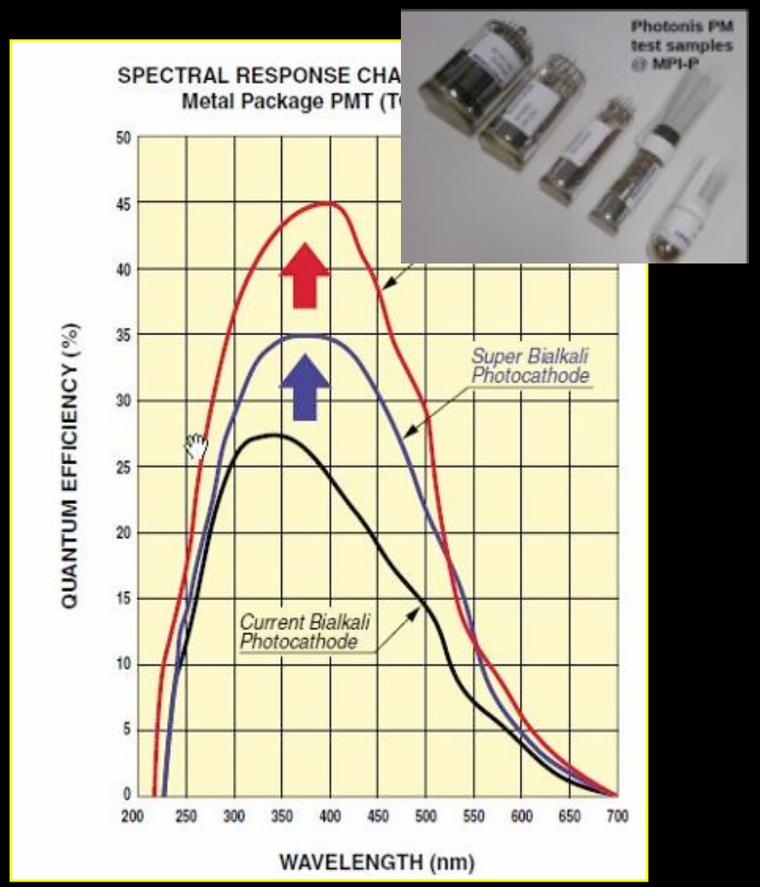
- Expensive
- Camera composed of 1000-2000 pixels
- Electronic inside the camera
- Keep low weight



Camera/pixels

- Expensive
- Camera composed of 1000-2000 pixels
- Electronic inside the camera
- Keep low weight

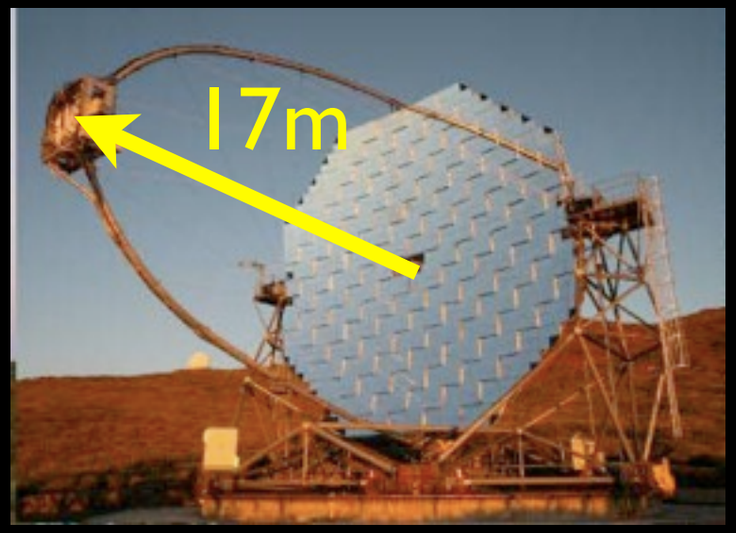


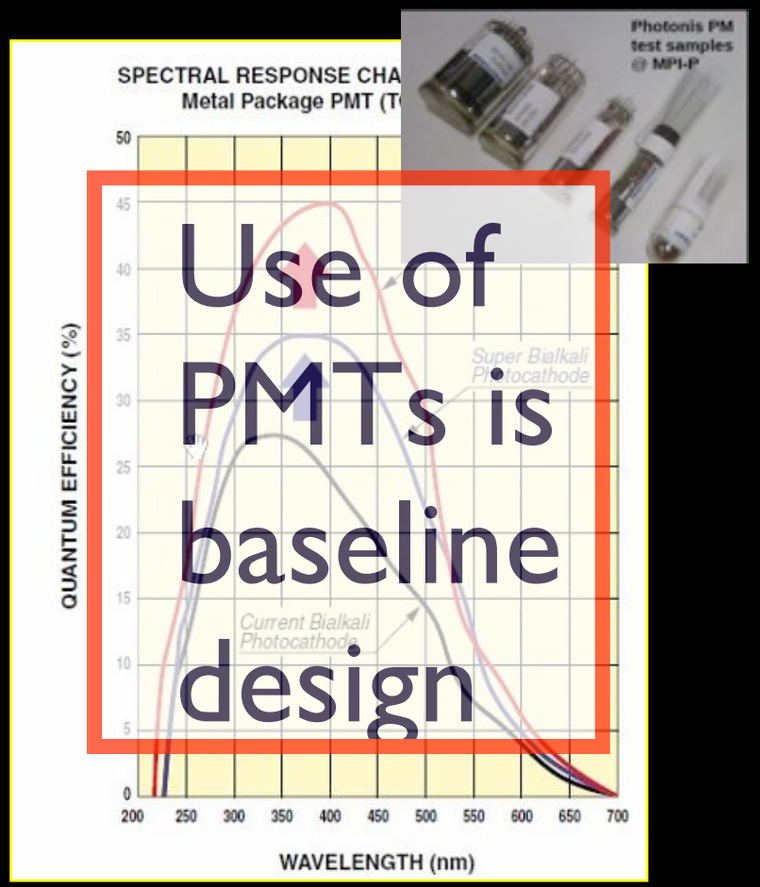


PMT=40% PDE

Camera/pixels

- Expensive
- Camera composed of 1000-2000 pixels
- Electronic inside the camera
- Keep low weight



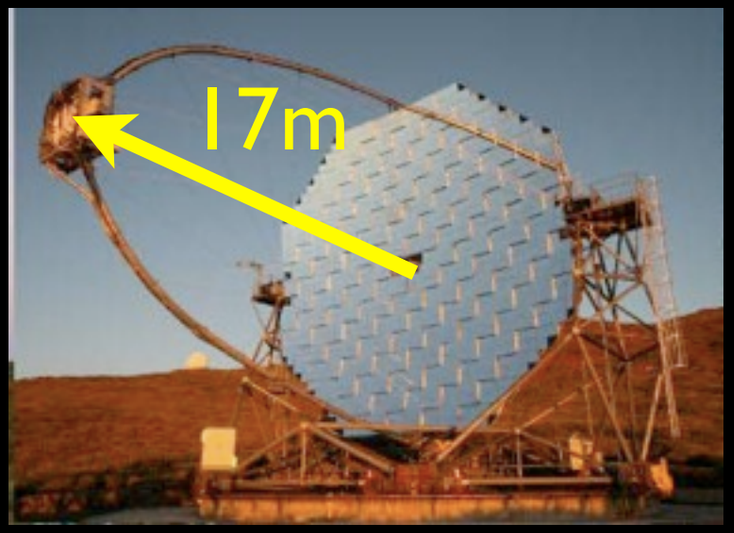


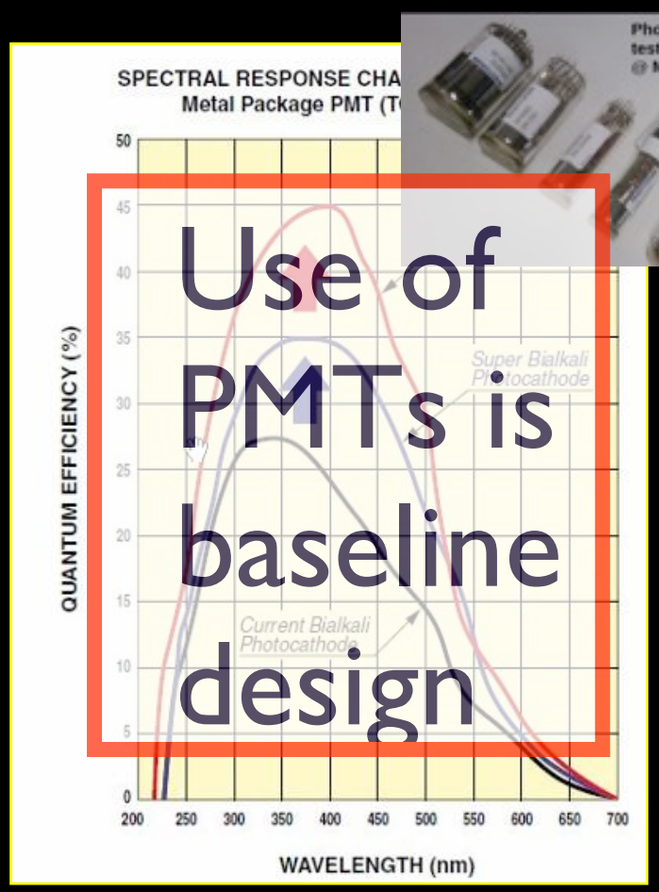
Use of PMTs is baseline design

PMT=40% PDE

Camera/pixels

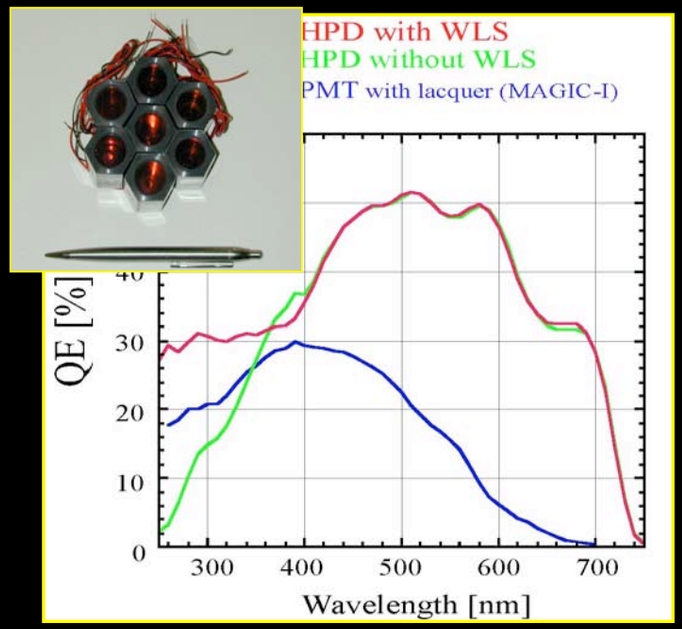
- Expensive
- Camera composed of 1000-2000 pixels
- Electronic inside the camera
- Keep low weight





Use of PMTs is baseline design

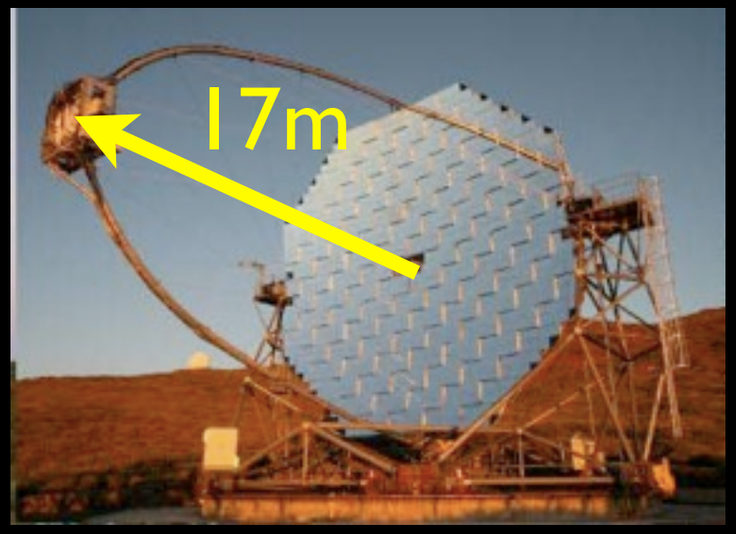
PMT=40% PDE

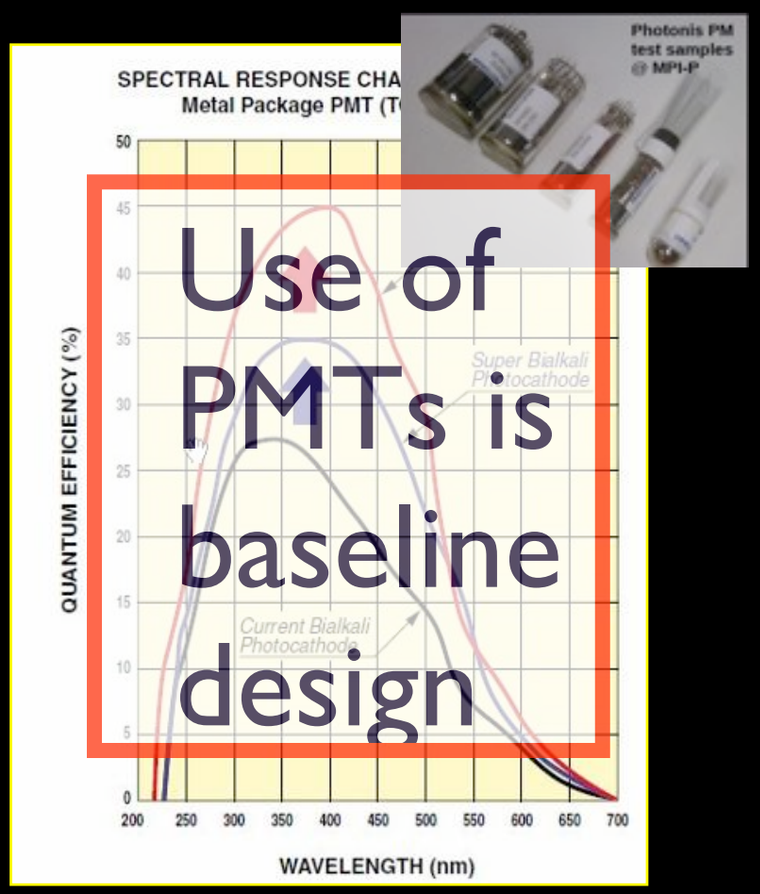


GaAsP HPD= 50% PDE

Camera/pixels

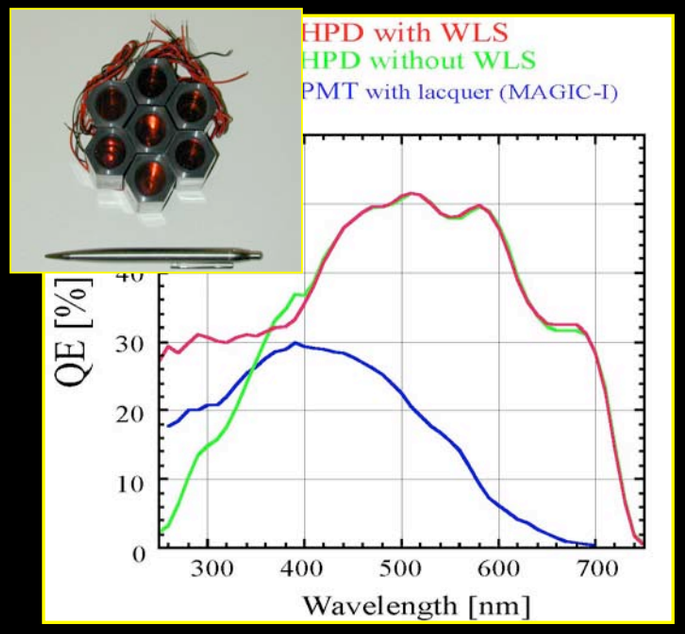
- Expensive
- Camera composed of 1000-2000 pixels
- Electronic inside the camera
- Keep low weight



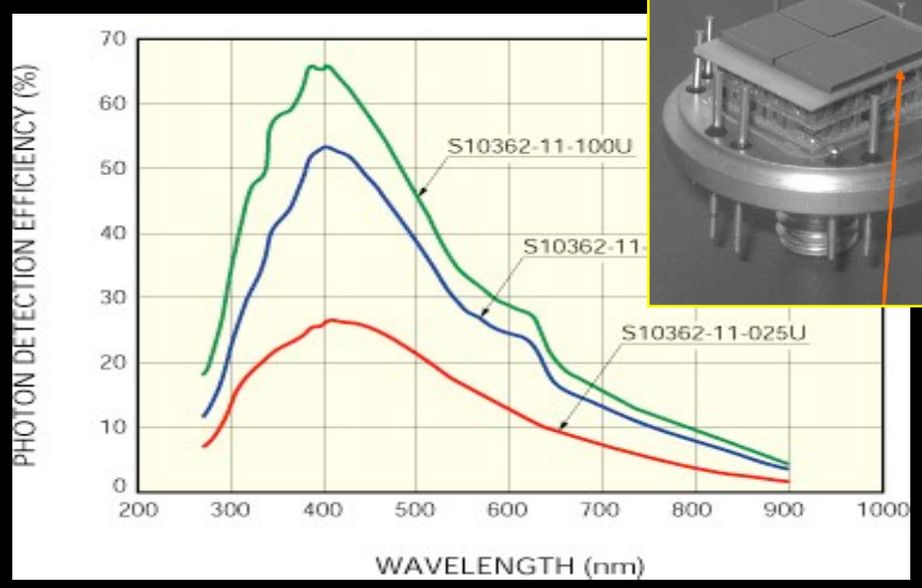


Use of PMTs is baseline design

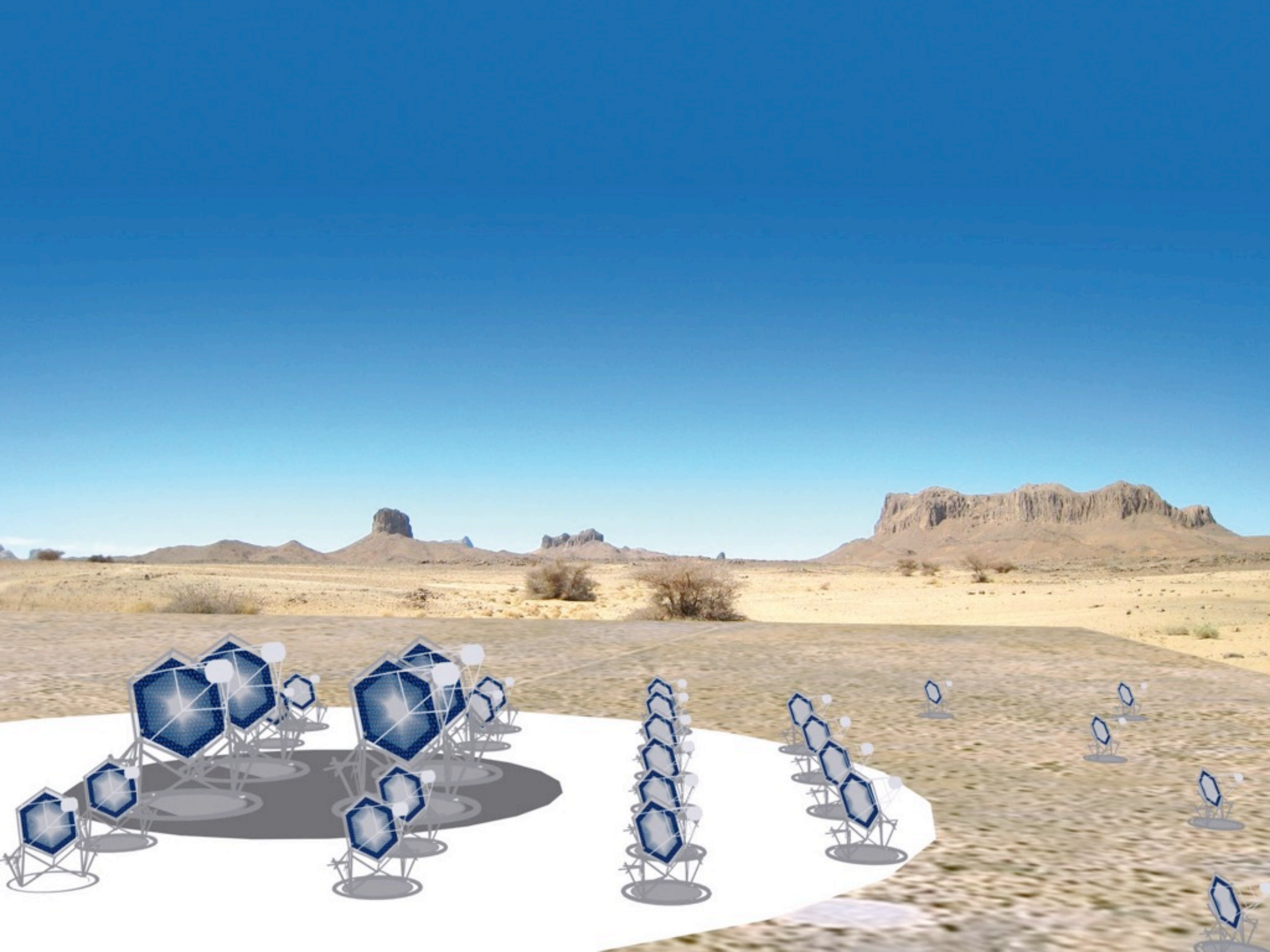
PMT=40% PDE



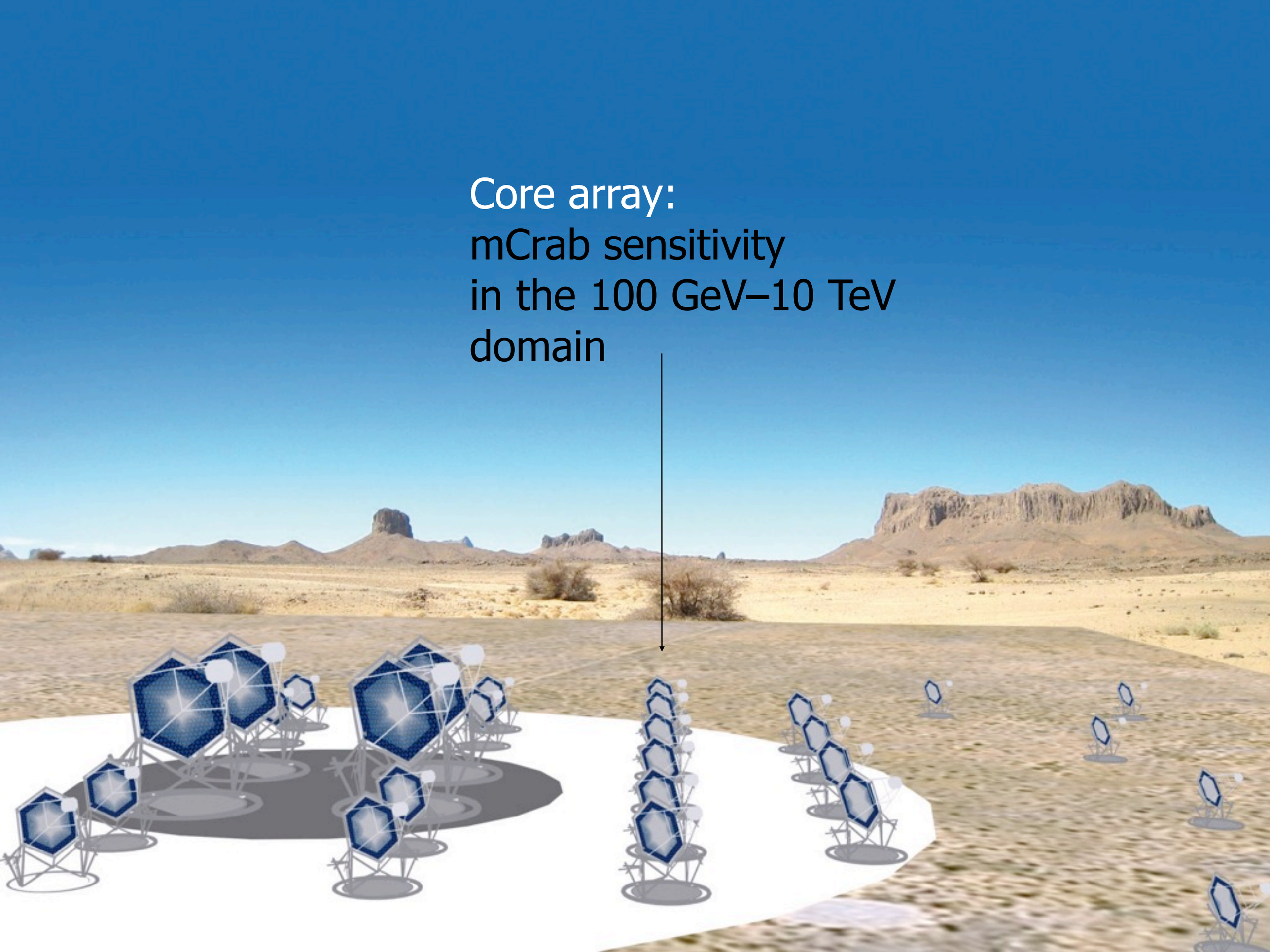
GaAsP HPD=
50% PDE



G-APD
60% PDE

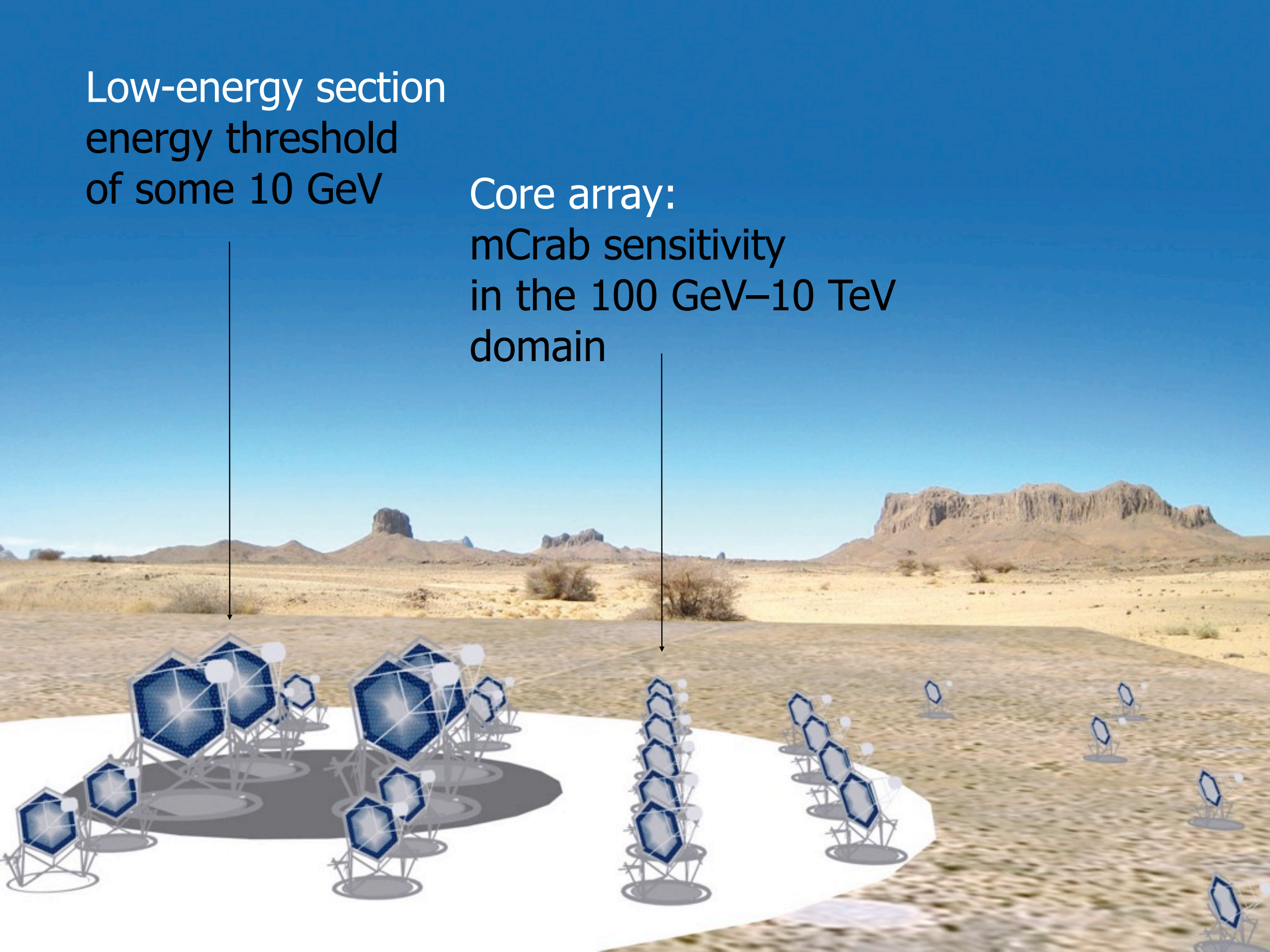


Core array:
mCrab sensitivity
in the 100 GeV–10 TeV
domain



Low-energy section
energy threshold
of some 10 GeV

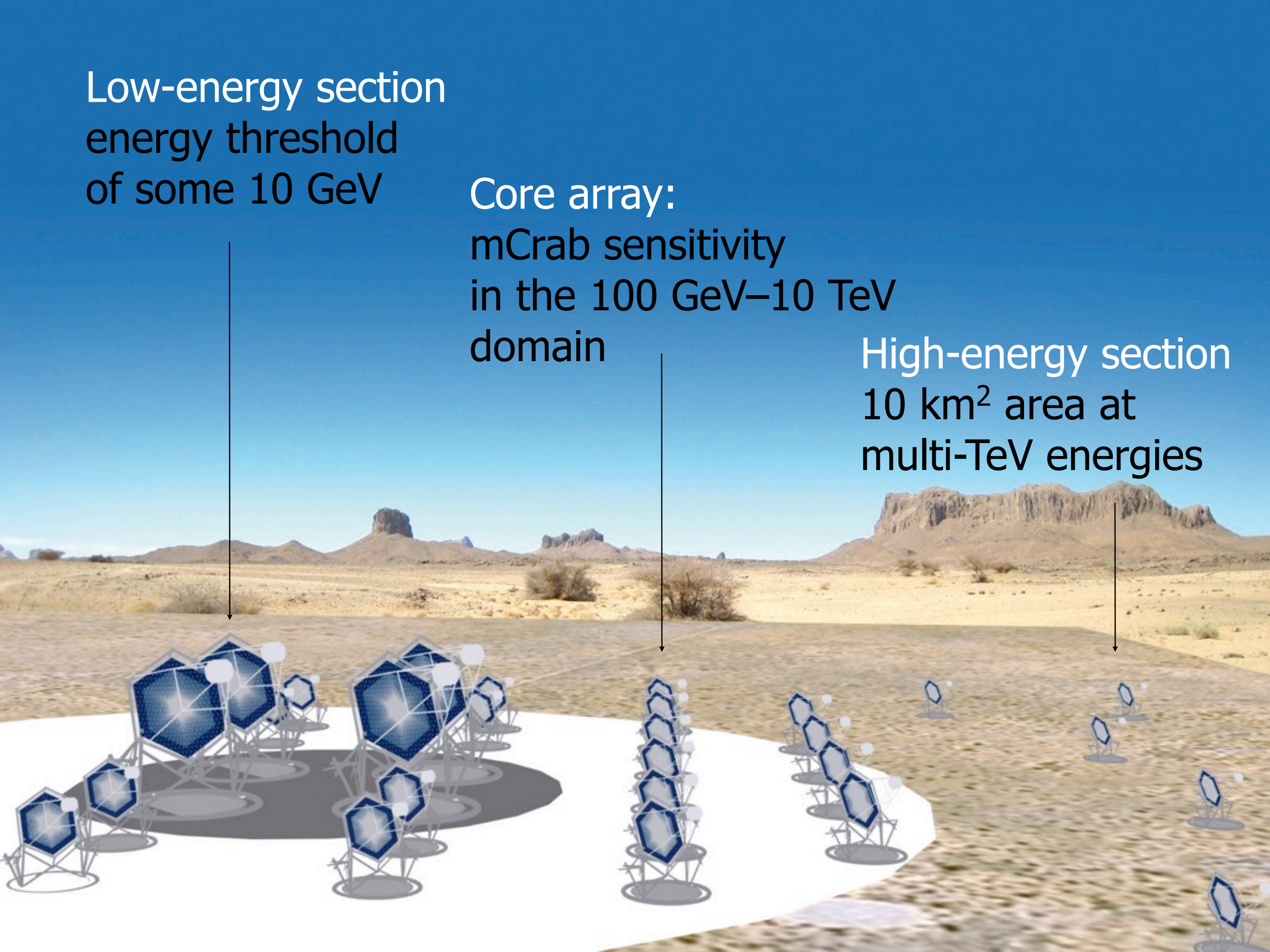
Core array:
mCrab sensitivity
in the 100 GeV–10 TeV
domain



Low-energy section
energy threshold
of some 10 GeV

Core array:
mCrab sensitivity
in the 100 GeV–10 TeV
domain

High-energy section
10 km^2 area at
multi-TeV energies



Advanced Gamma-ray Imaging System

(artist view by J. Buckley, Wash.U.)

Science goal: to be finalized by WP

Budget: ~130M$, "Moderate Initiative"

Observatory: ~1km² array of mid-IACTs

IACTs: 150-50 identical telescopes (+…)

CT Aperture: 5-15 m (#CTs & aperture TBD)

Technology: demonstrated AC technique

R&D: Novel Camera, OS , Trigger, DAQ

OS & Camera:

a) Prime focus telescope + PMTs (baseline for cost estimates based on VERITAS scaling)

b) Aplanatic telescope + MAPMTs or II&CMOS

c) Catadioptric (?)

Field of View: 5-12° (TBD through simulations, based on science goals, and cost study)

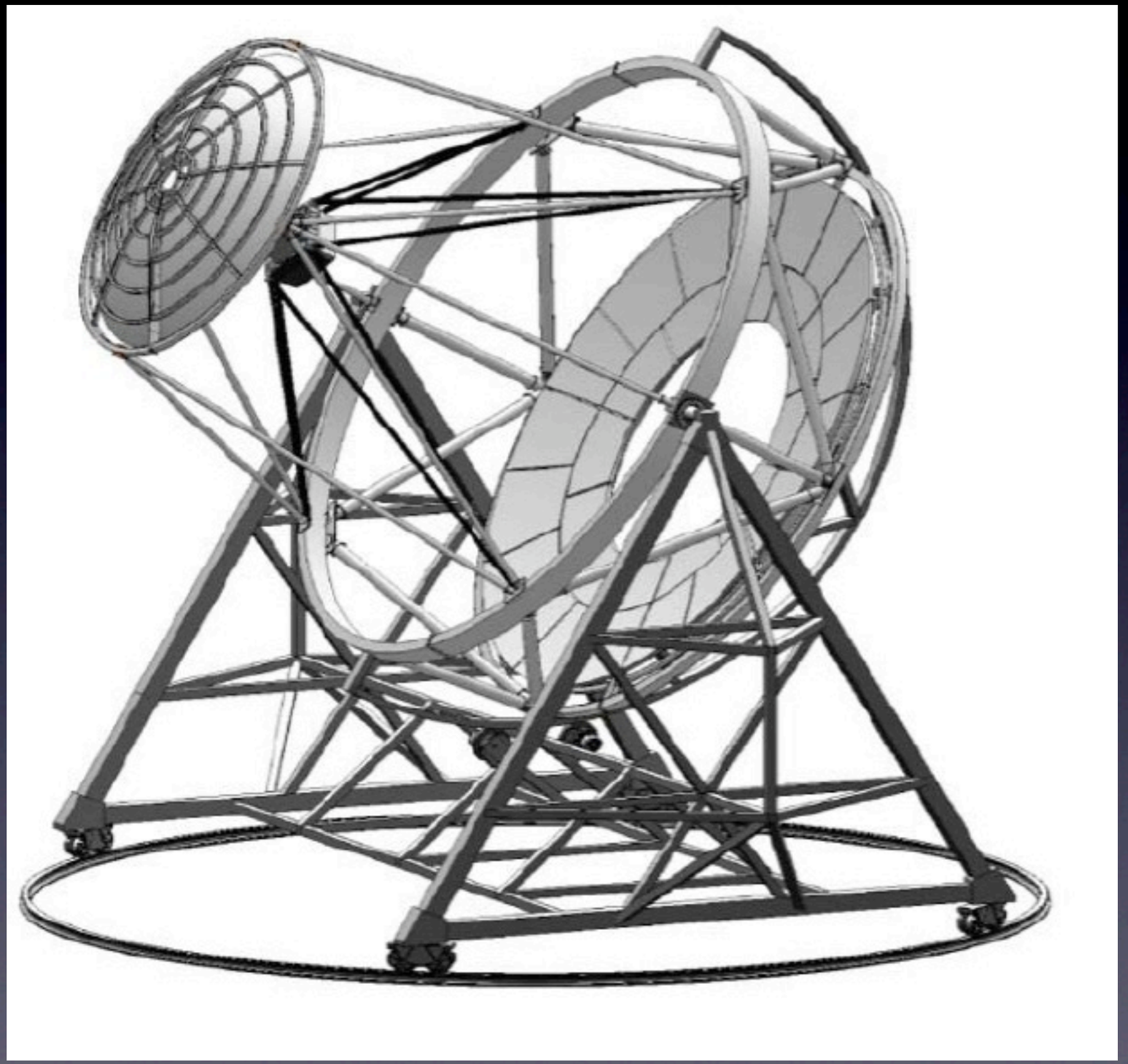
AGIS design

Dual-mirror optics provides Improved spot size over large fov

Reduced plate scale allowing use of 14 k 0.06o multi-anode PMT pixels

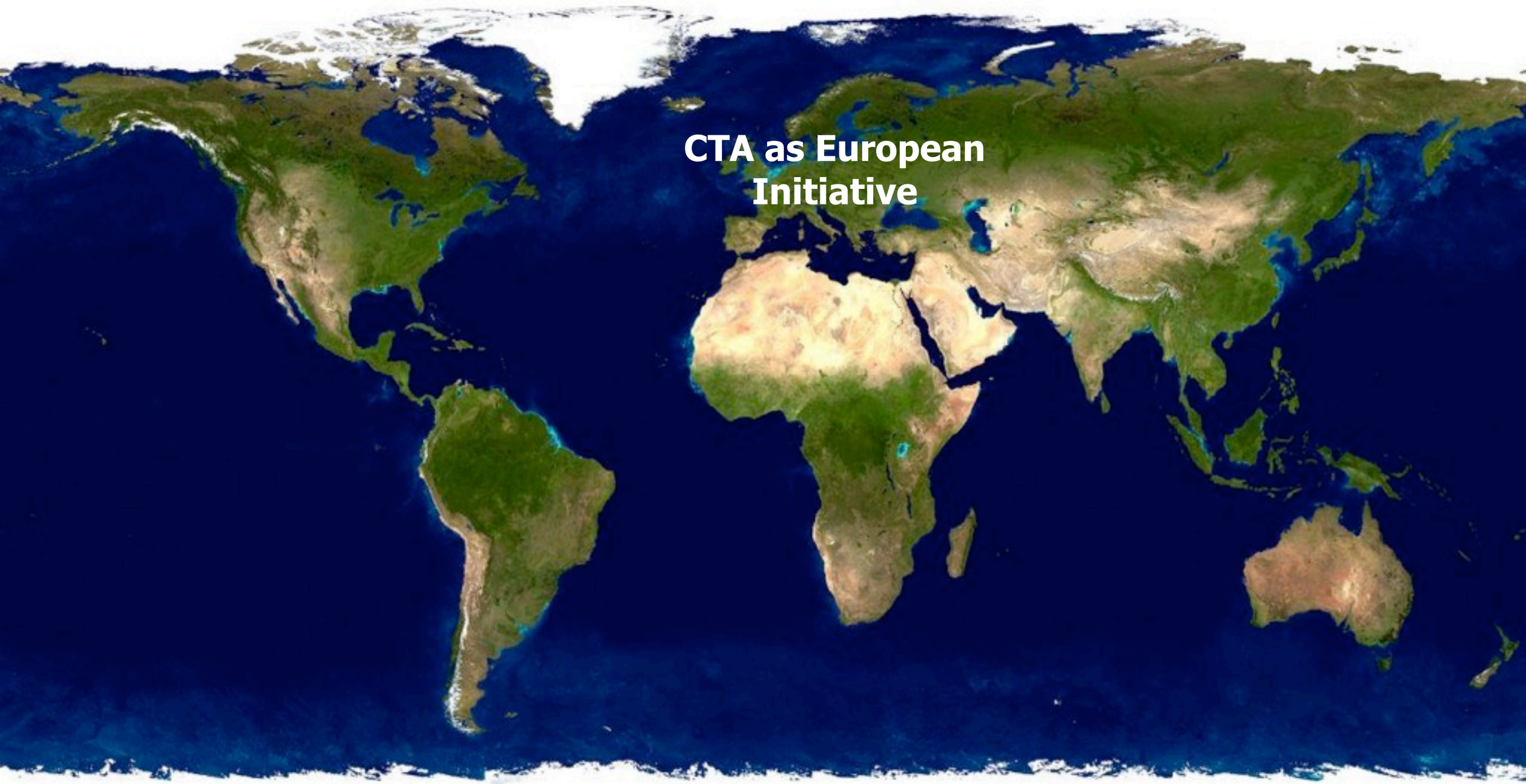
Without any question the better telescope (assuming that it can be made to work)

But also the better telescope system ? Depends on cost



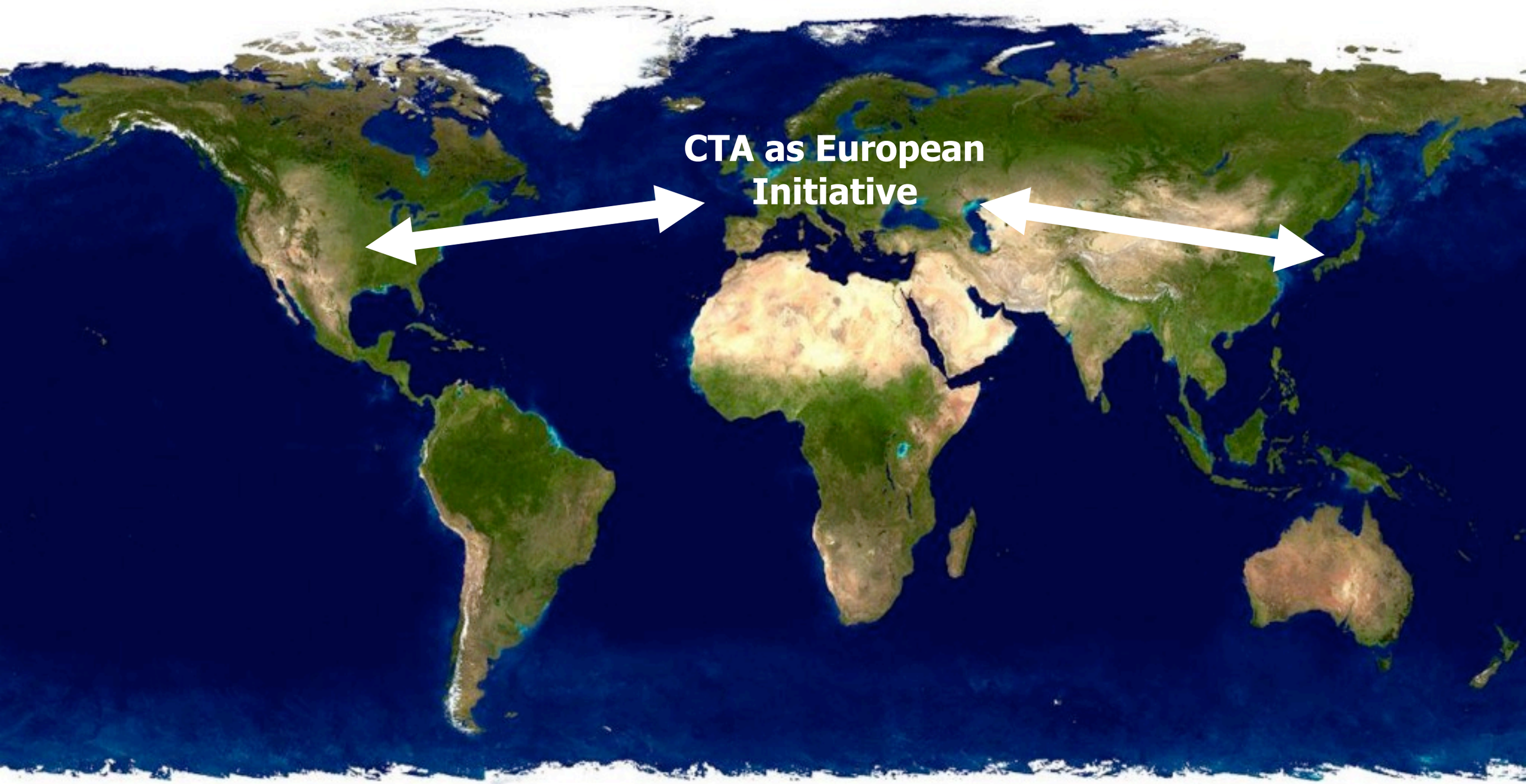
Cherenkov Telescope Array

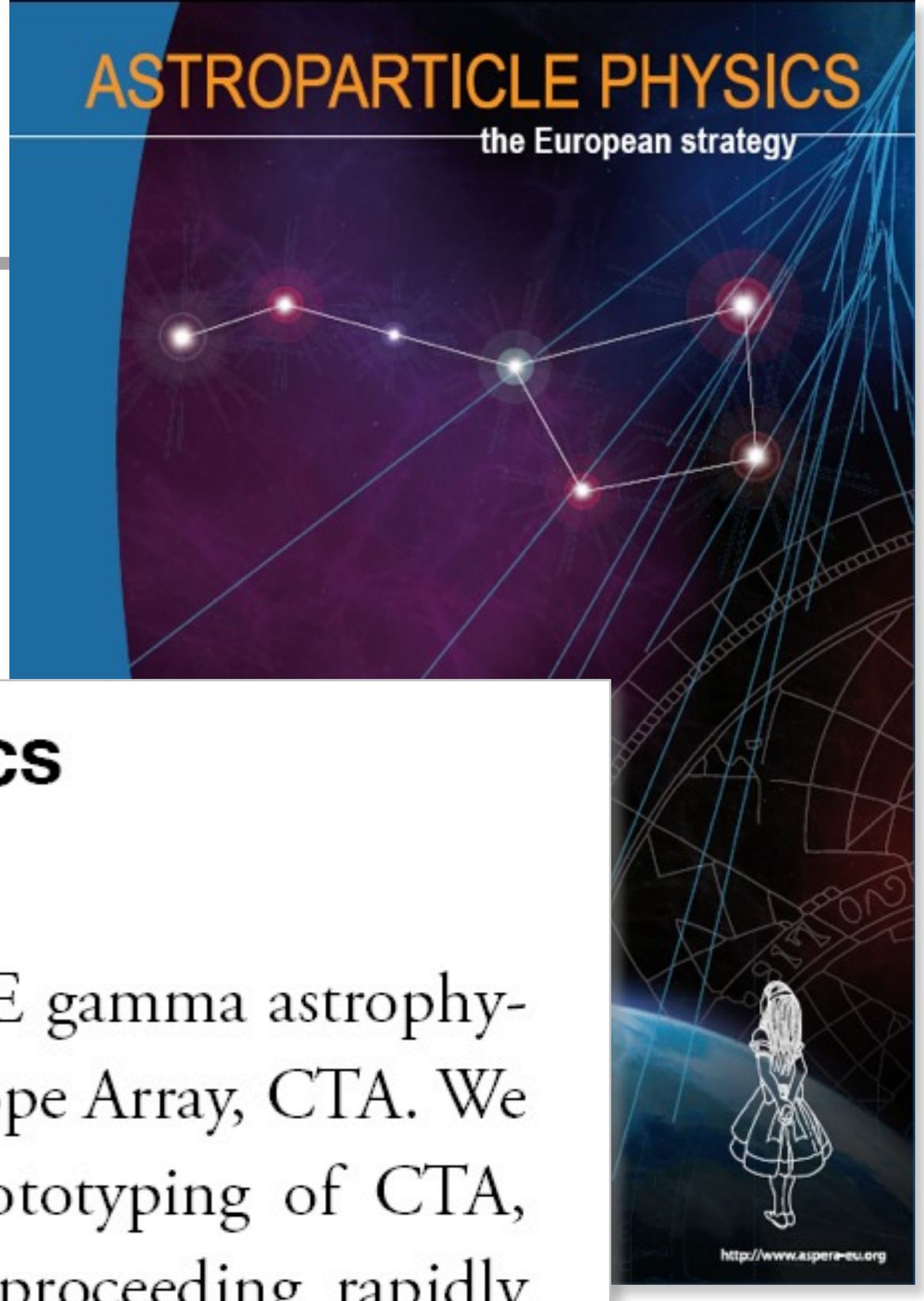
An advanced facility for ground-based high-energy gamma ray astronomy



Cherenkov Telescope Array

An advanced facility for ground-based high-energy gamma ray astronomy





Gamma Astrophysics

The priority project for VHE gamma astrophysics is the Cherenkov Telescope Array, CTA. We recommend design and prototyping of CTA, the selection of sites, and proceeding rapidly towards start of deployment in 2012.

CTA as an observatory

- CTA will be also an astrophysical observatory, open to the community, with professional operators, AOs, support for DA etc.
- Data will be public after some time (1 y?)
- Significant guaranteed time (~50%) for construction consortium

CTA will most likely combine HEP and astrophysics worlds

- Observatory operation
- Significant contribution to construction by institutes to reduce required investment

Tentative Timeline

FP7 DS application

	6	7	8	9	10	11	12	13
Array layout								
Telescope design								
Component prototypes								
Telescope prototype								
Array construction								
Partial operation								

Tentative Timeline

FP7 DS application

"Kick-off": Barcelona, Jan 24-25

	6	7	8	9	10	11	12	13
Array layout								
Telescope design								
Component prototypes								
Telescope prototype								
Array construction								
Partial operation								

Design

Tentative Timeline

FP7 DS application

"Kick-off": Barcelona, Jan 24-25

	6	7	8	9	10	11	12	13
Array layout								
Telescope design								
Component prototypes								
Telescope prototype								
Array construction								
Partial operation								

Design

Prototype

Tentative Timeline

FP7 DS application

"Kick-off": Barcelona, Jan 24-25

	6	7	8	9	10	11	12	13
Array layout								
Telescope design								
Component prototypes								
Telescope prototype								
Array construction								
Partial operation								

Design

Prototype

Array

Tentative Timeline

FP7 DS application

"Kick-off": Barcelona, Jan 24-25

	6	7	8	9	10	11	12	13
Array layout								
Telescope design								
Component prototypes								
Telescope prototype								
Array construction								
Partial operation								

Design

Prototype

Array

Concep. Design

Detailed Design

Summary

- In 5+ years from now,
  - CTA will open the era of precision VHE gamma-ray astronomy fo Galactic and extragalactic objects
  - CTA may answer long-standing questions on cosmic-rays:
    - Where galactic and extra-galactic CR are accelerated
    - How CR are accelerated (hadrons/leptons, jets, magnetic irregularities, etc....)
  - CTA may answer fundamental physics
    - DM
    - Dispersion effects (Lorentz invariance),
    - Universe transparency,
    - photon-axion oscillation,...

- For a new generation of IACTs, it is important to:
  - Extend energy range from few tens of GeV to 100 TeV
  - Improve sensitivity and energy resolution
  - Larger FOV and better angular resolution
  - Operate as observatory
  - Multi-wavelength observations

Thanks!