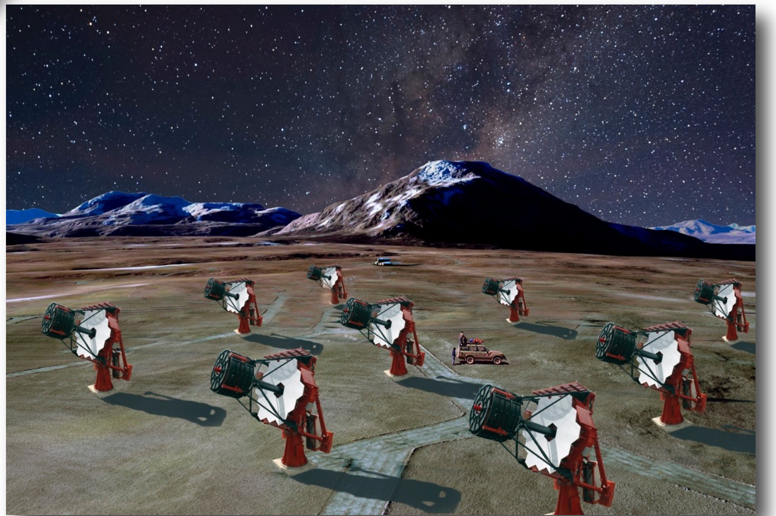
Astrofisica con Specchi a Tecnologia Replicante Italiana



INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Universidade de São Paulo
Instituto de Astronomia, Geofísica e Ciências A

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

n Etna Volcano to Andes: activities and plans for t implementation of ASTRI SST telescopes in the Cherenkov Telescope Array

A. Giuliani - G. Pareschi INAF – Milano

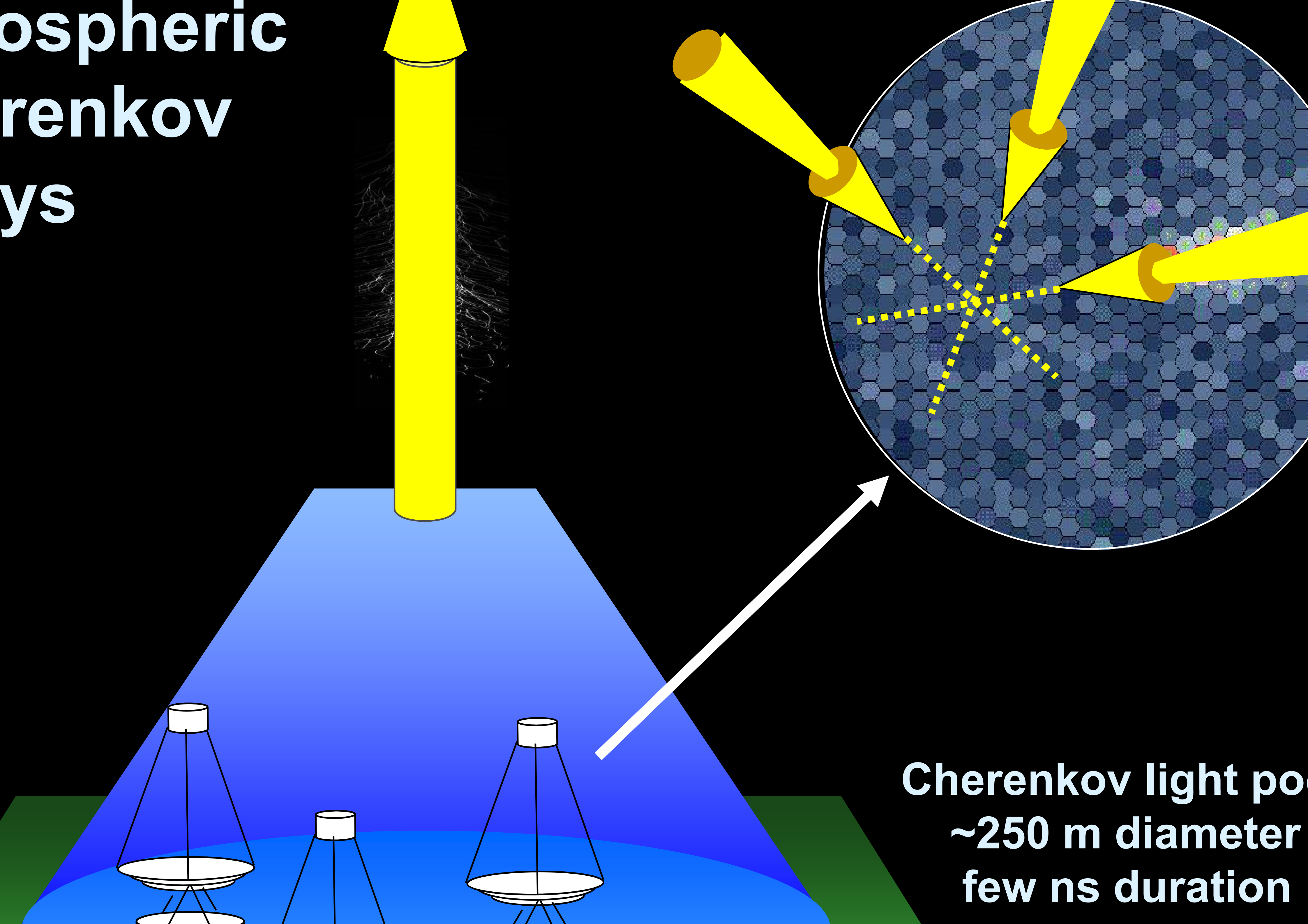
A few remarks on Ground Based Gamma Ray Astronomy & CTA

The ASTRI project

The ASTRI Telescope prototype

ASTRI mini-array: early science with CTA

ospheric
renkov
ys



Major IACT instruments

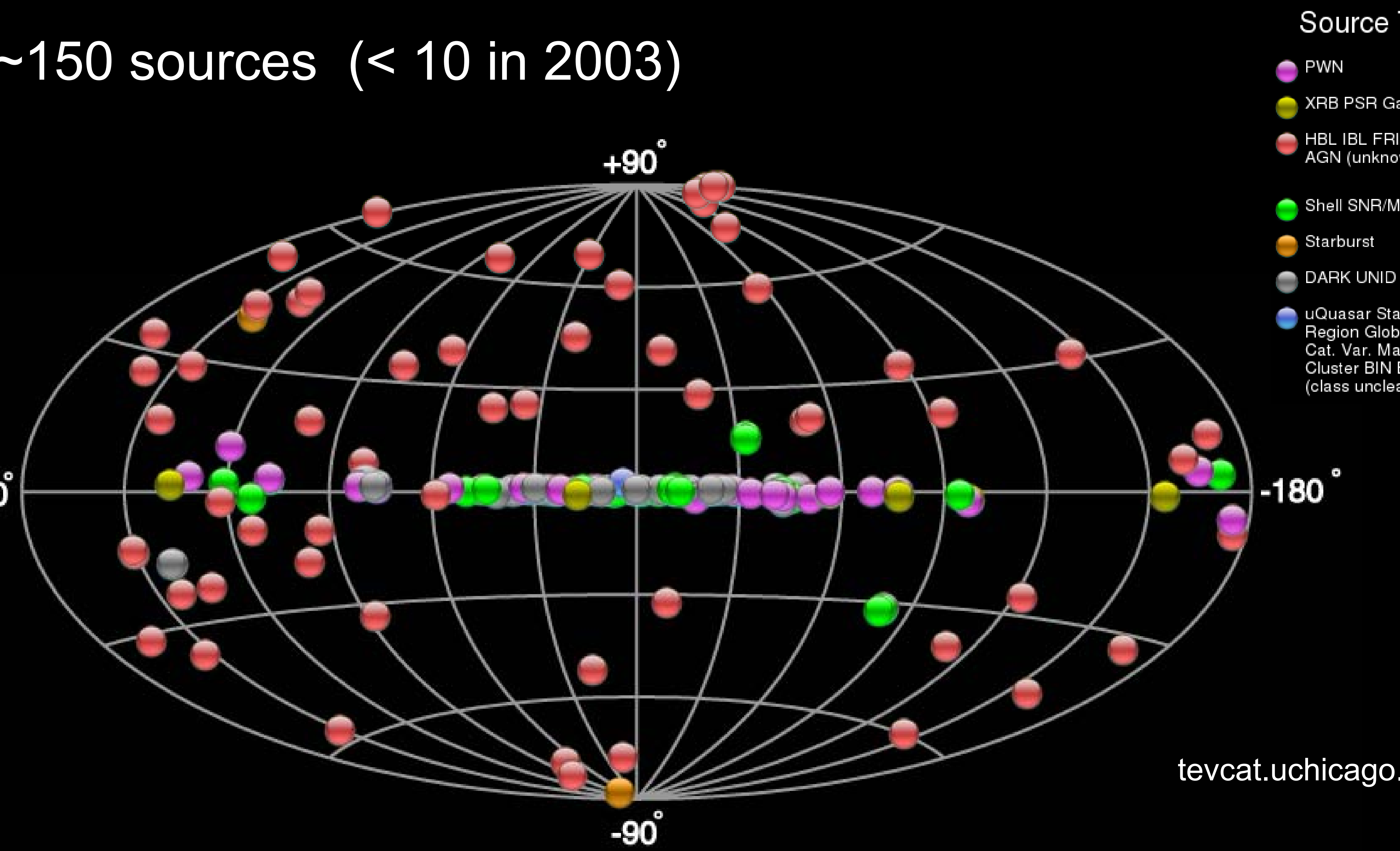
MAGIC Canary Islands 2200 m asl
2 x 17m telescopes. Magic I in operation since
2003, Magic II first light shown at ICRC09

TAS Arizona, USA 1800 m asl
elescopes of 12m diameter
y operational from fall 2007

MAGIC
VERITAS
HESS

HESS Namibia 1800 m asl
HESS I: 4 telescopes of 12m diamet
HESS II: 28 m diameter

~150 sources (< 10 in 2003)



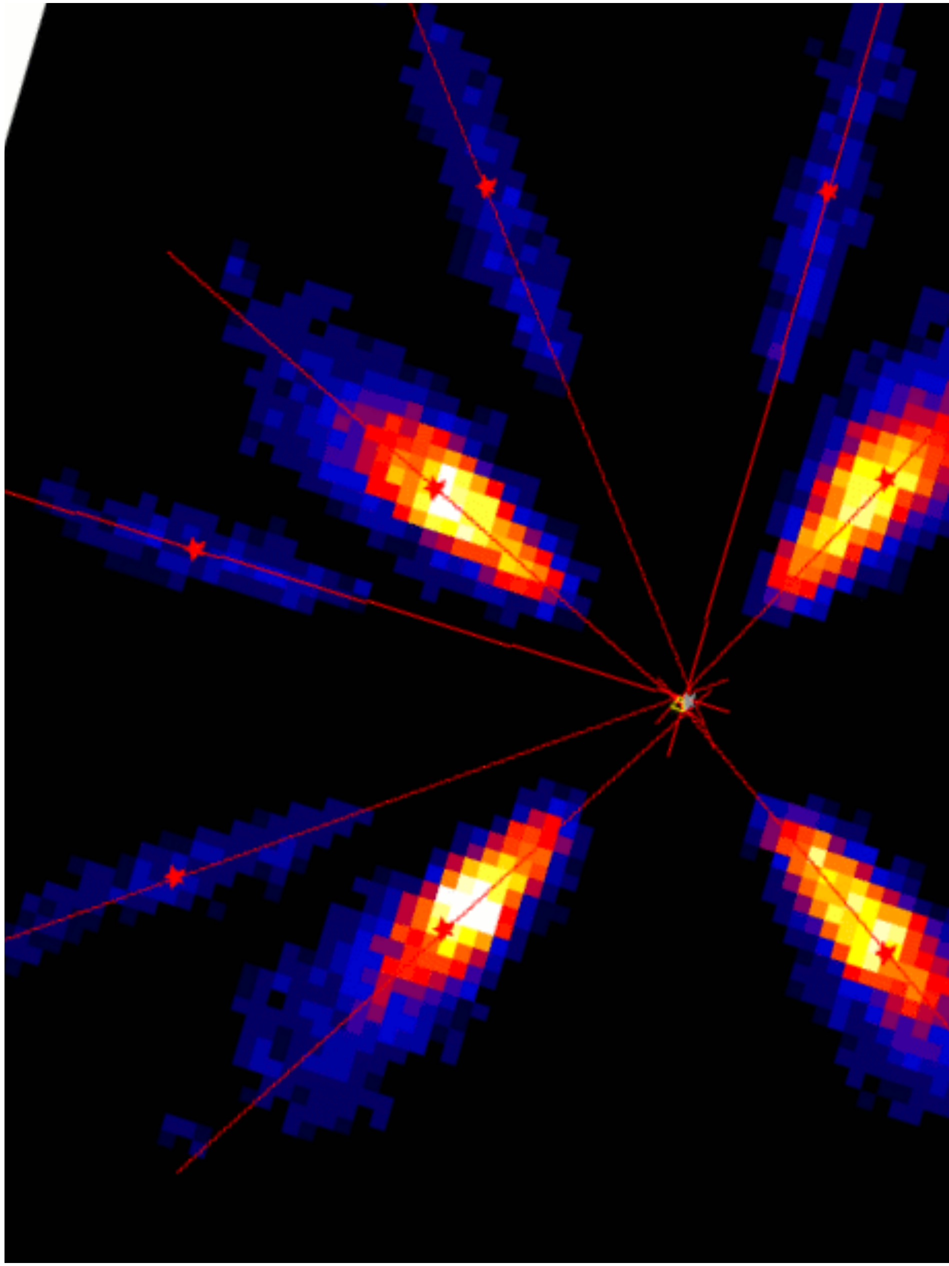
Detailed source information: Spectra, Images, Variability, MWL re events

- ore photons = better spectra, mages, fainter sources
  - ✓ Larger collection area for gamma-rays

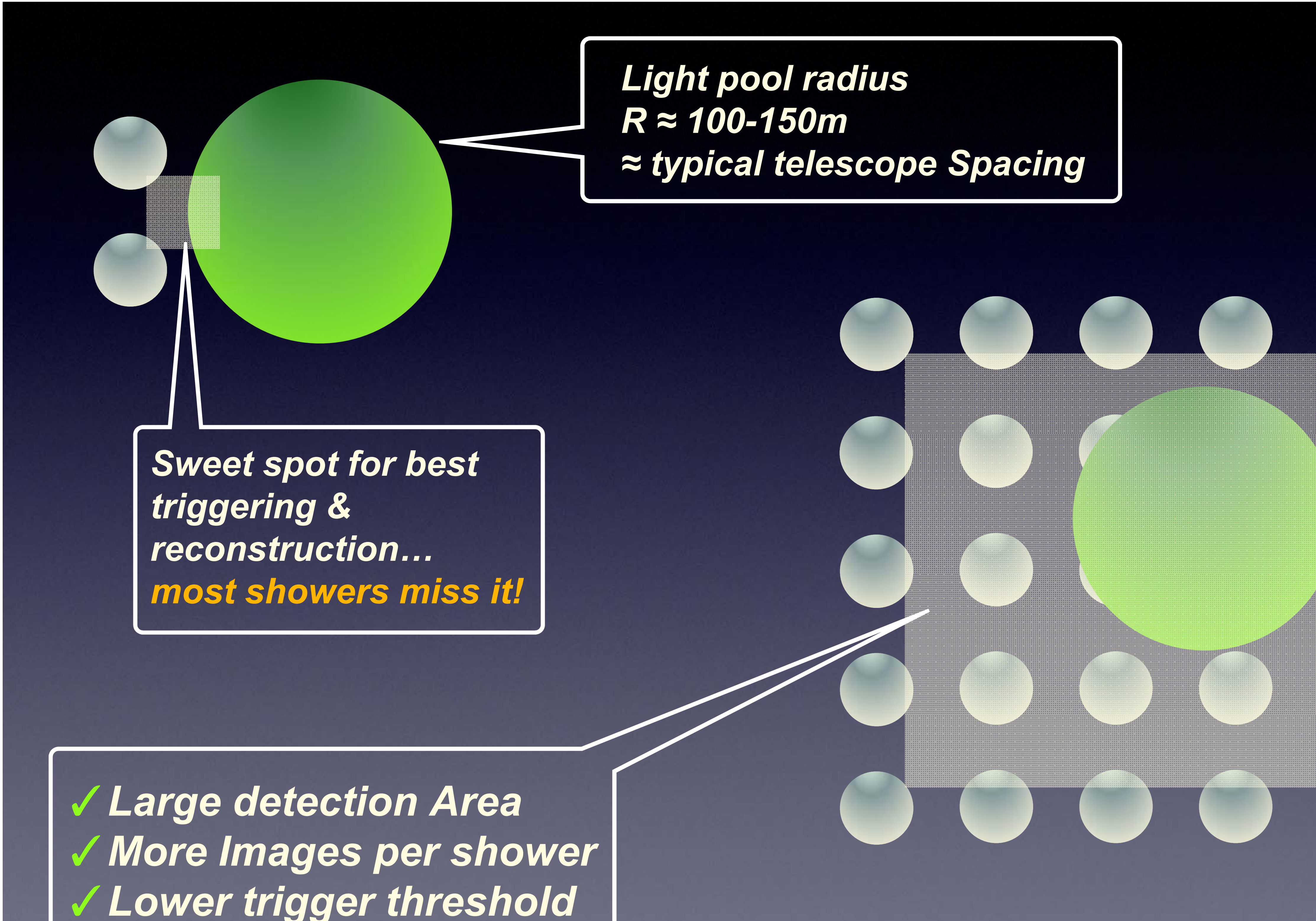
ter events

- ore precise measurements f atmospheric cascades and ence primary gammas
  - ✓ Improved angular resolution
  - ✓ Improved background rejection power

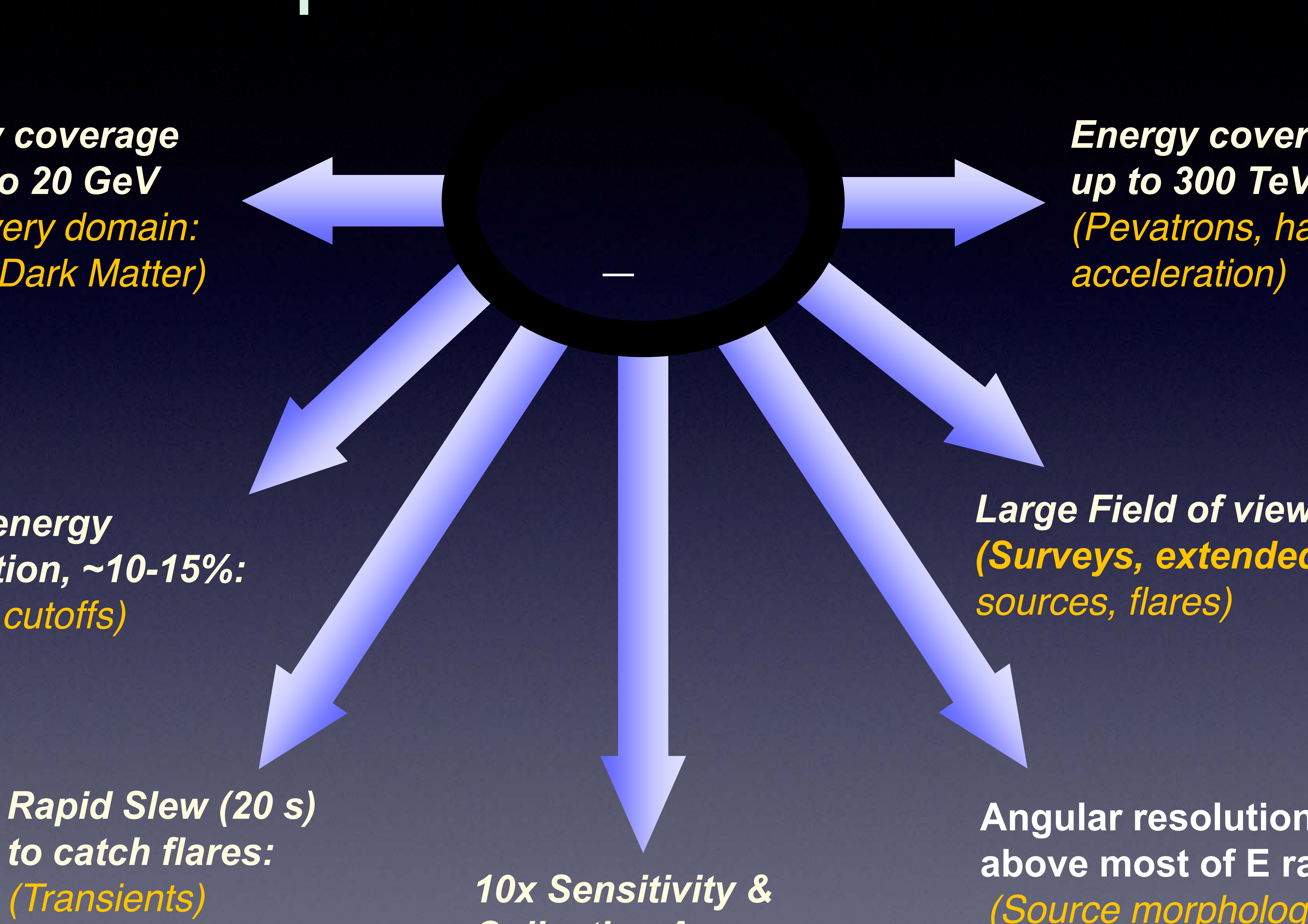
ore telescopes!



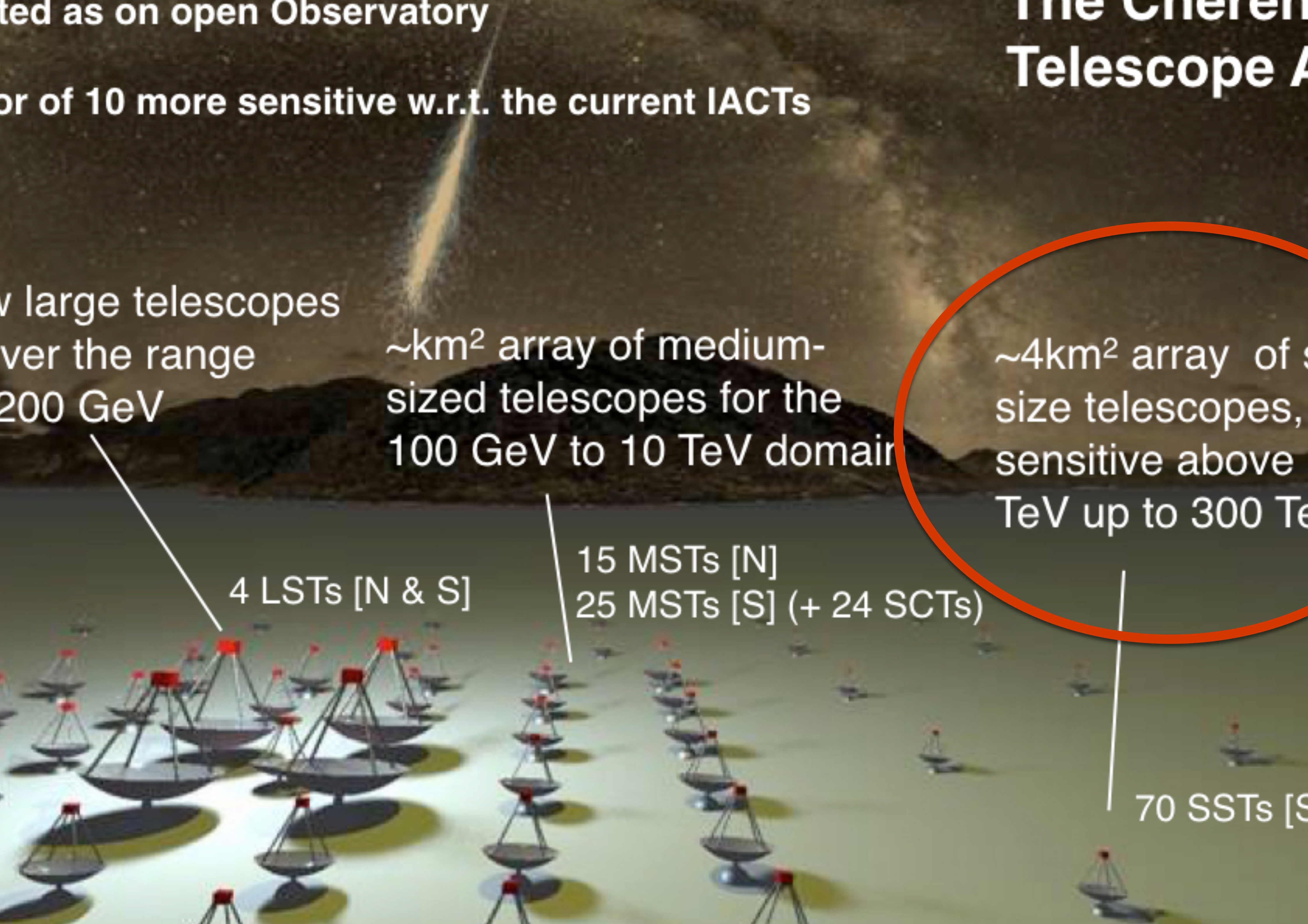

cta
cherenkov telescope array



Light pool radius
R ≈ 100-150m
≈ typical telescope Spacing
Sweet spot for best
triggering &
reconstruction…
most showers miss it!
✓ Large detection Area
✓ More Images per shower
✓ Lower trigger threshold



coverage
o 20 GeV
ery domain:
Dark Matter)
Energy cover
up to 300 Te
(Pevatrons, ha
acceleration)
energy
tion, ~10-15%:
cutoffs)
Large Field of view
(Surveys, extended
sources, flares)
Rapid Slew (20 s)
to catch flares:
(Transients)
10x Sensitivity &
Angular resolution
above most of E ra
(Source morpholog



ted as on open Observatory
Telescope
or of 10 more sensitive w.r.t. the current IACTs
large telescopes
ver the range
200 GeV
~km² array of medium-
sized telescopes for the
100 GeV to 10 TeV domain
~4km² array of
size telescopes,
sensitive above
TeV up to 300 Te
4 LSTs [N & S]
15 MSTs [N]
25 MSTs [S] (+ 24 SCTs)
70 SSTs

	LST "large"	MST "medium"	SCT "medium 2-M"	SST "small"
Number	**4 (S) 4 (N)**	**25 (S) 15 (N)**	**≤ 36 (S and N)**	**70 (S)**
Energy range	20 GeV to 200 GeV	100 GeV to 10 TeV	200 GeV to 10 TeV	**5 TeV – 300 TeV**
Effective mirror area	370 m^2	90 m^2	40 m^2	**> 5 m^2**
Field of view	> 4.5°	> 7°	> 8°	**> 9°**
Pixel size ~PSF θ_{80}	< 0.11°	< 0.18°	< 0.07°	**< 0.25°**
Positioning time	50 s, 20 s goal	90 s, 60 s goal	90 s, 60 s goal	**90 s, 60 s goal**
Target capital cost	7.4 M€	1.6 M€	< 2.0 M€	**600 k€**

ow energies

ergy threshold 20-30 GeV

23 m diameter

4 telescopes

(LSTs)

Medium energies

100 GeV – 10 TeV

9.5 to 12 m diameter

25 single-mirror telescopes

> 24 (up to 36) dual-mirror telescopes

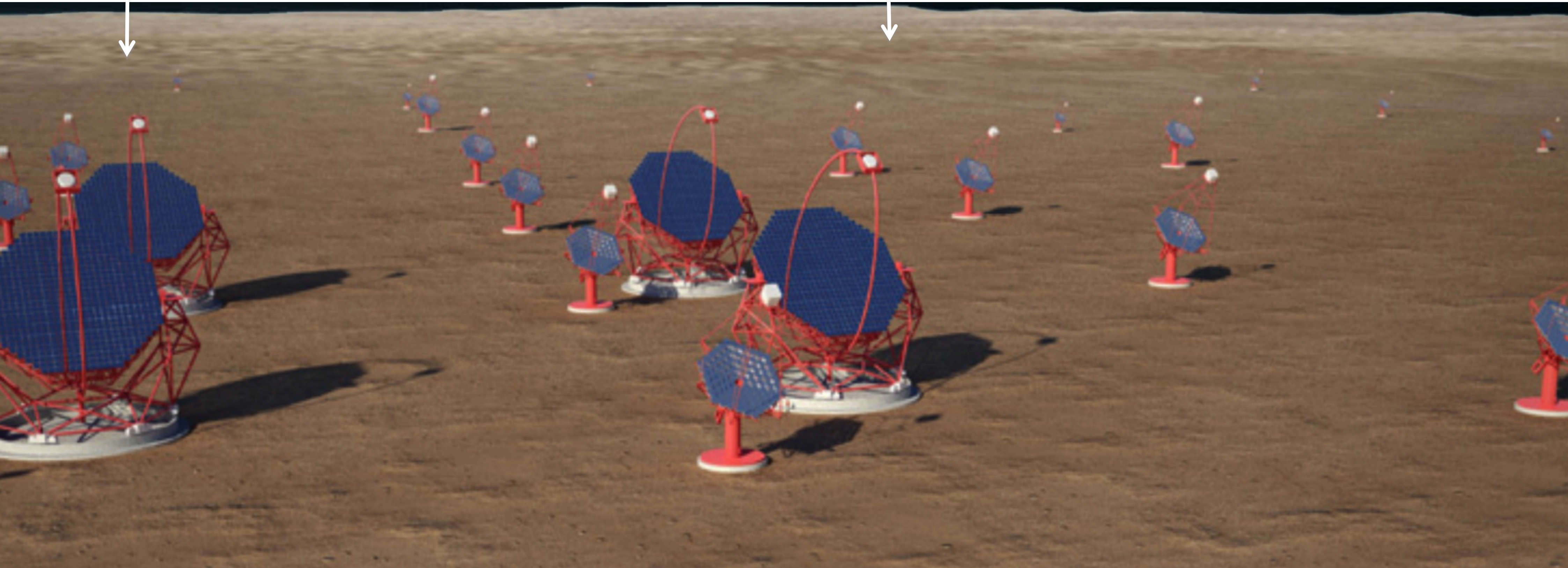
(MSTs/SCTs)

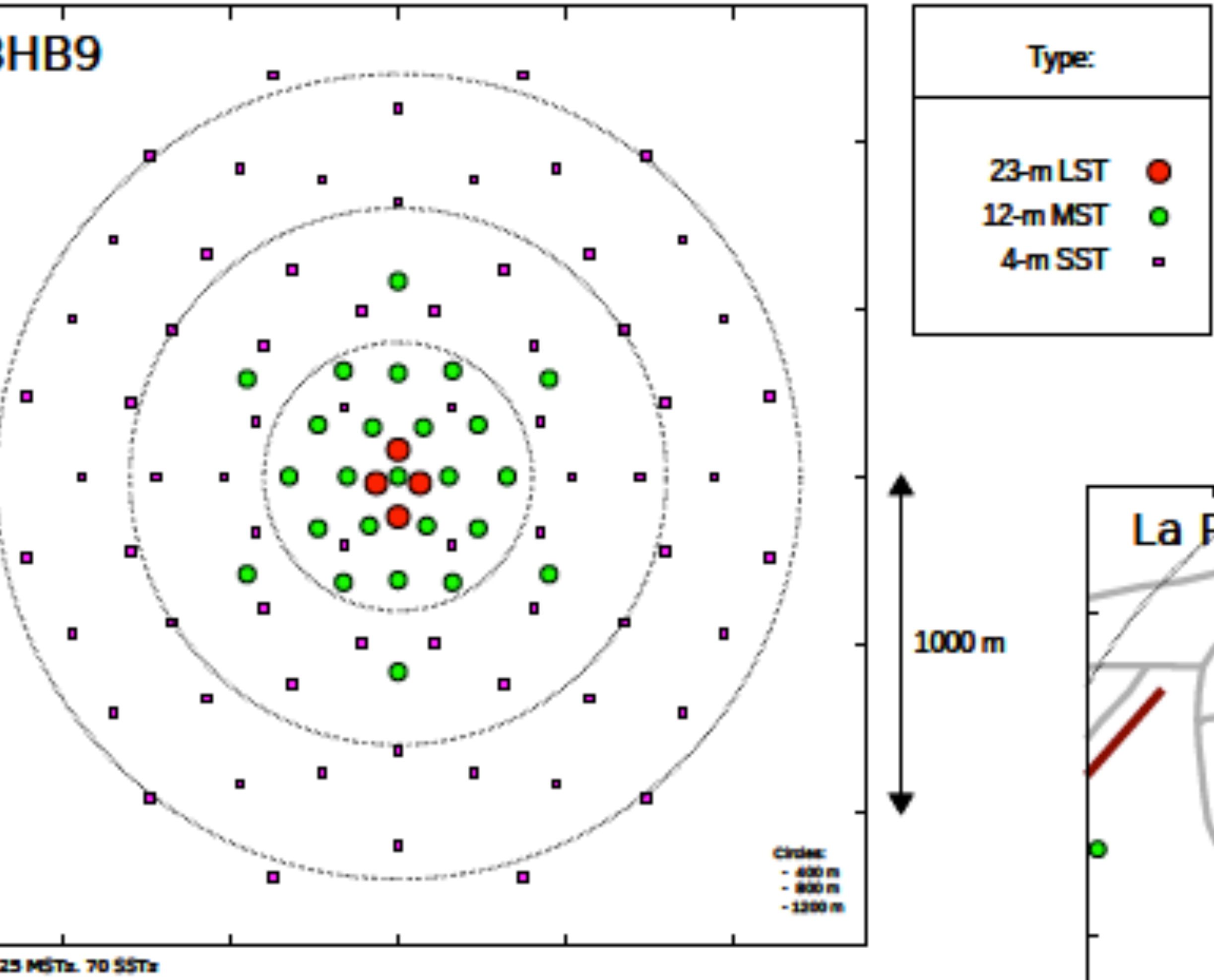
High energ

10 km^2 area at

4 m

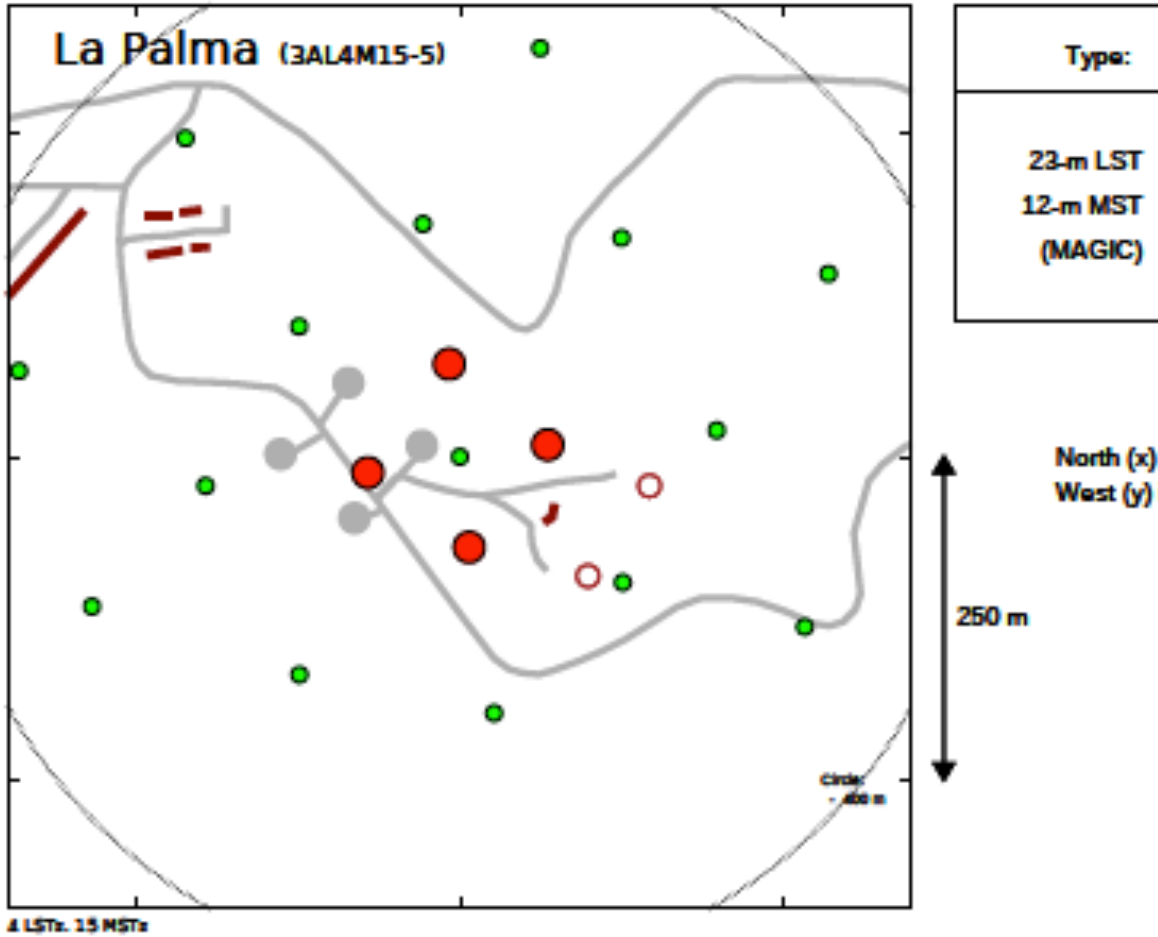
70 te



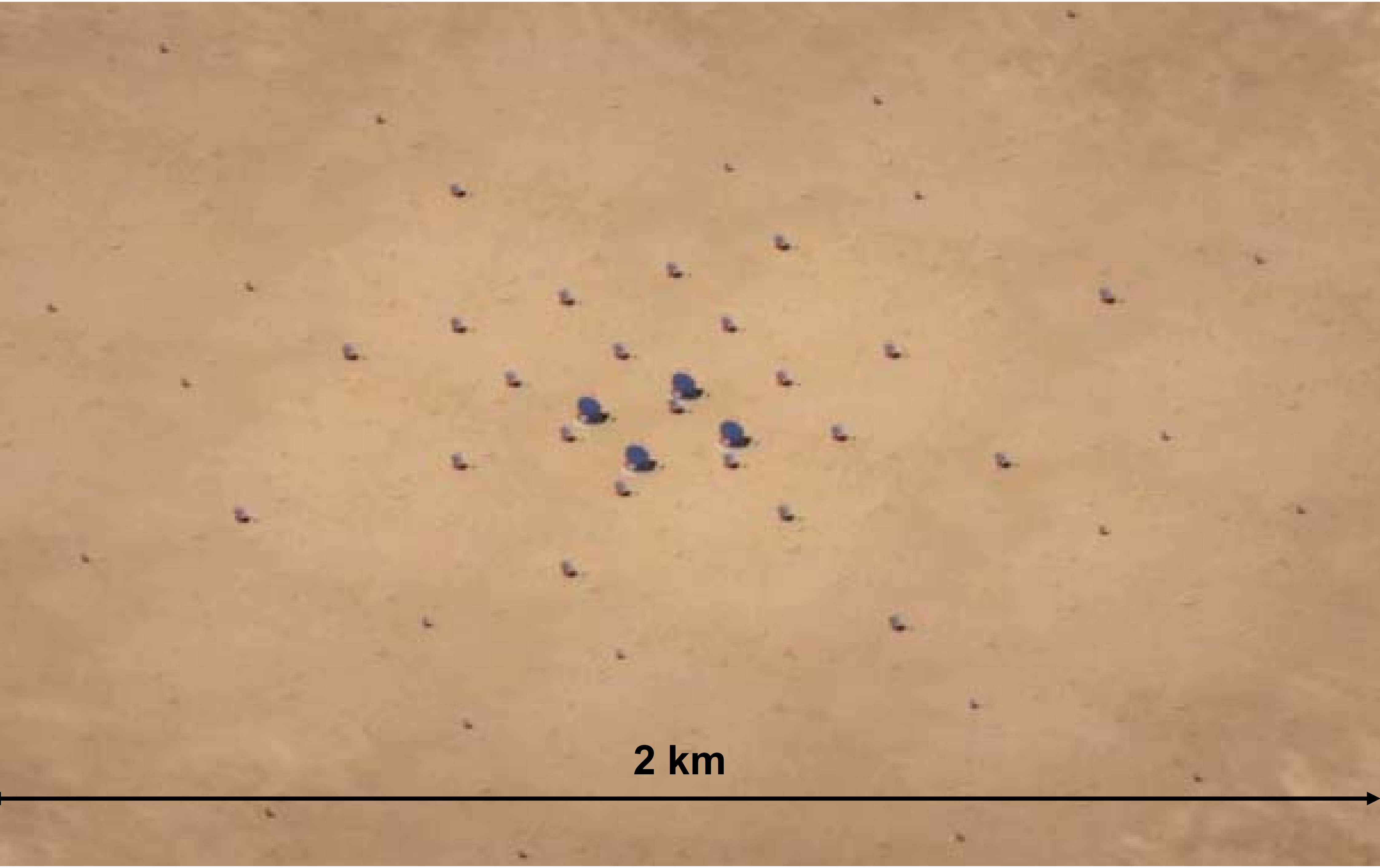


South:
4 LST
25 MST
70 SST

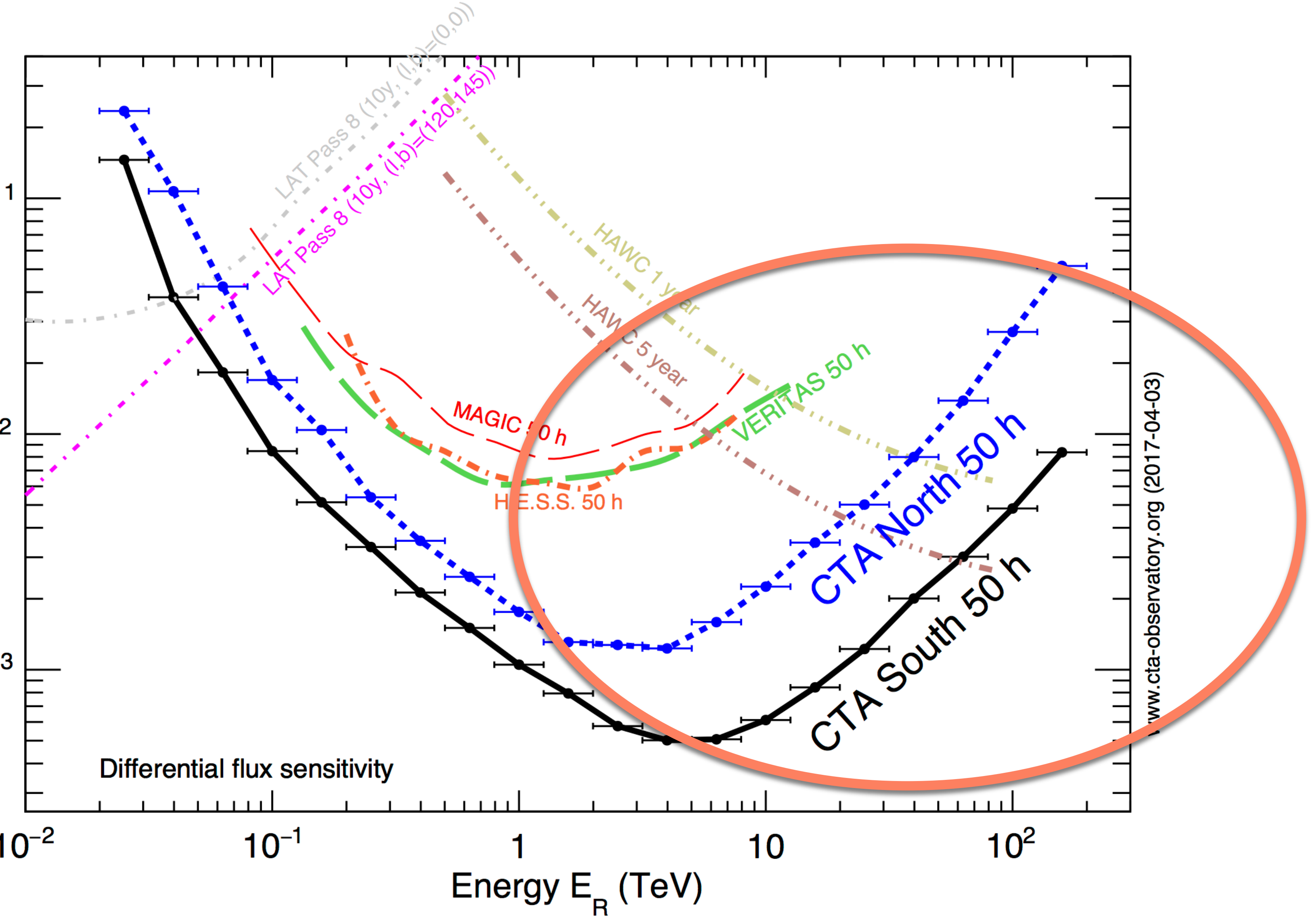
North:
4 LST
15 MST



Credits: The CTA Consortium


2 km

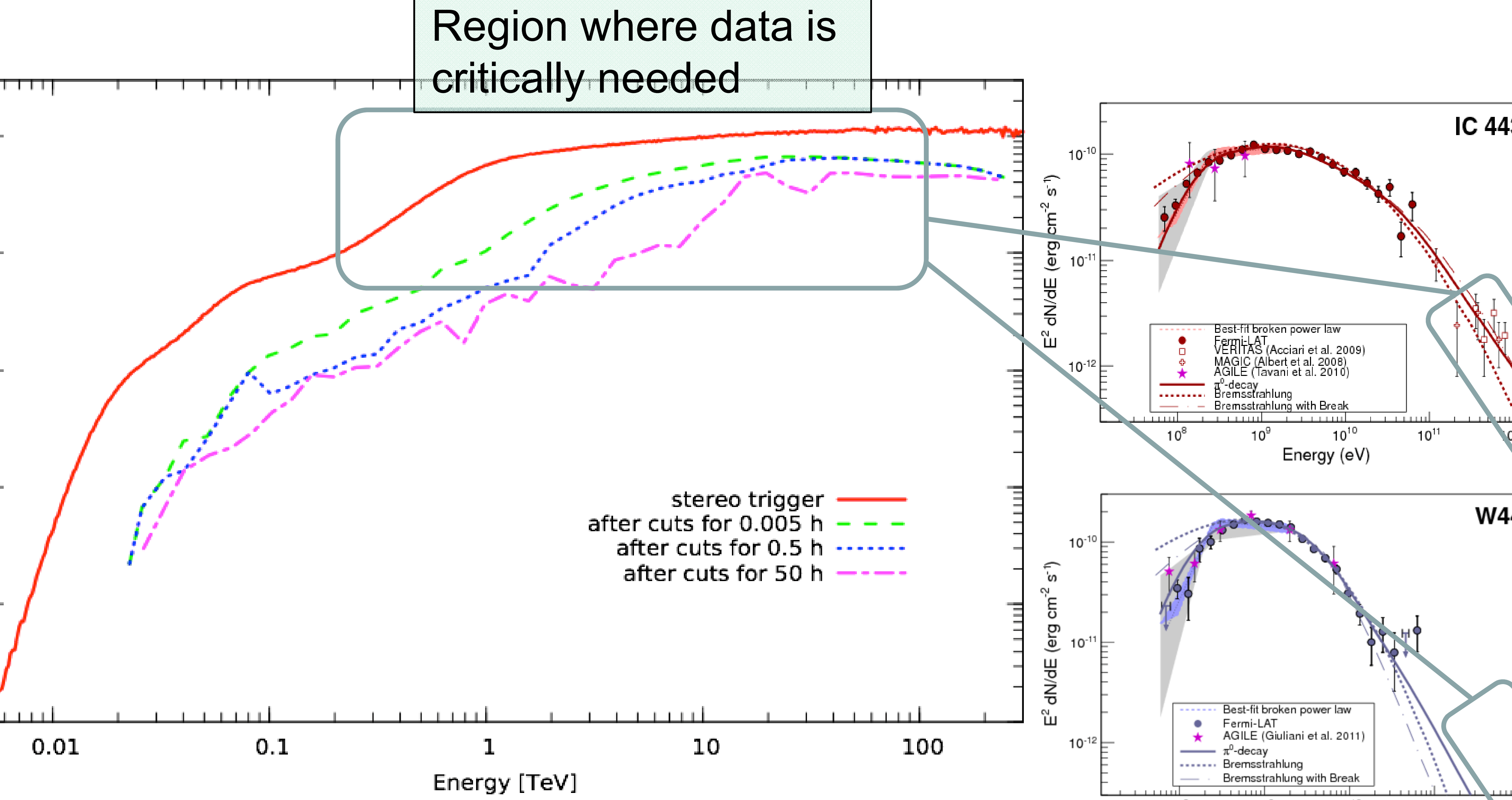
Differential Sensitivity



The CTA Consortium

A factor of **5-1(** **improvement** sensitivity in th domain of **abo** **100 GeV to so** **10 TeV.**

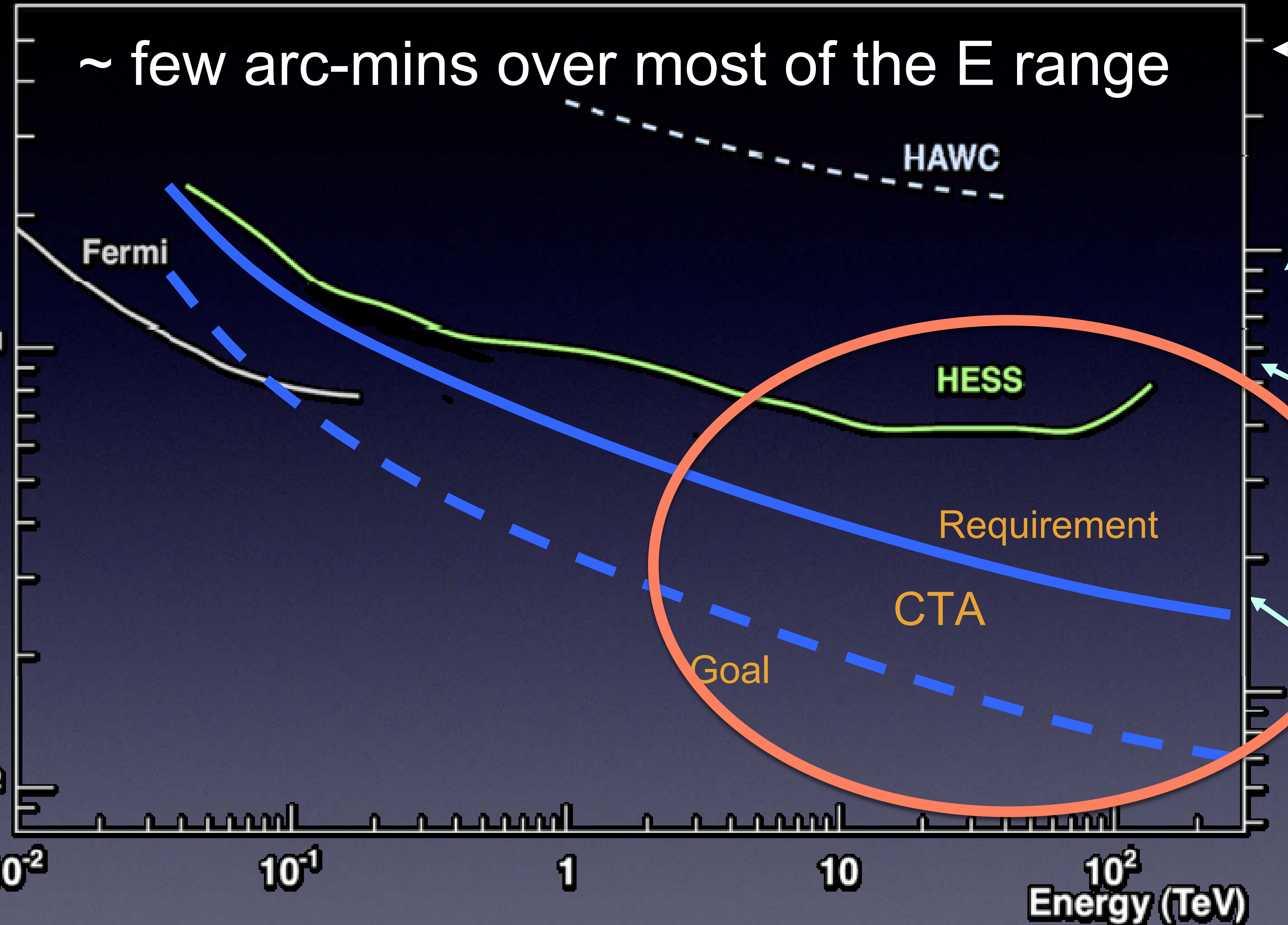
Extension of accessible energ range from **wel** **below 100 G** **to above 100** **TeV**.

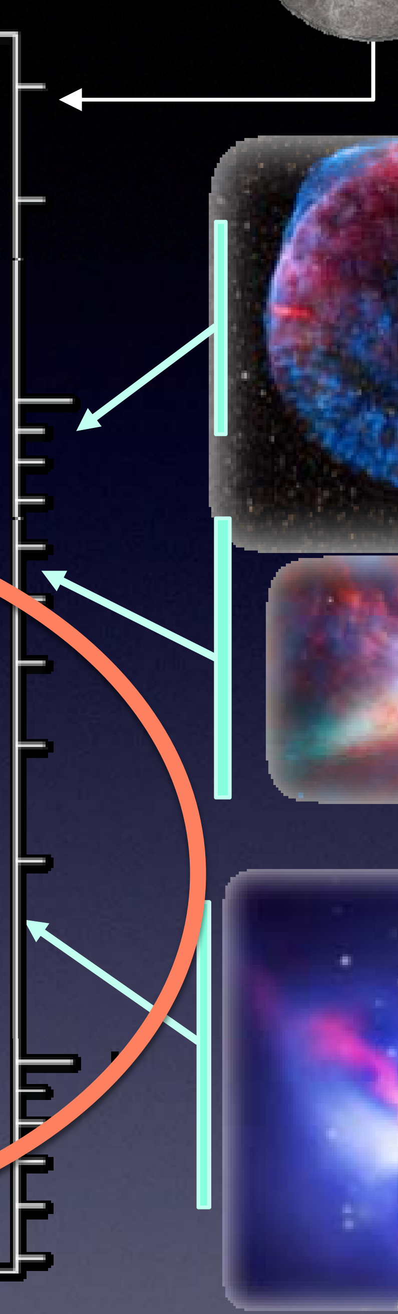


A_{coll} ~10^7 m^2 above 10 TeV (*importance of SSTs*)

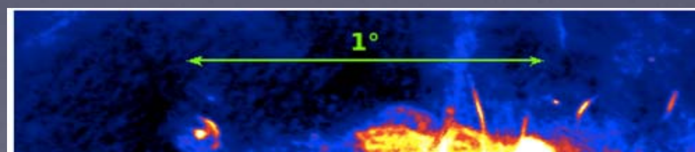
Crucial for:

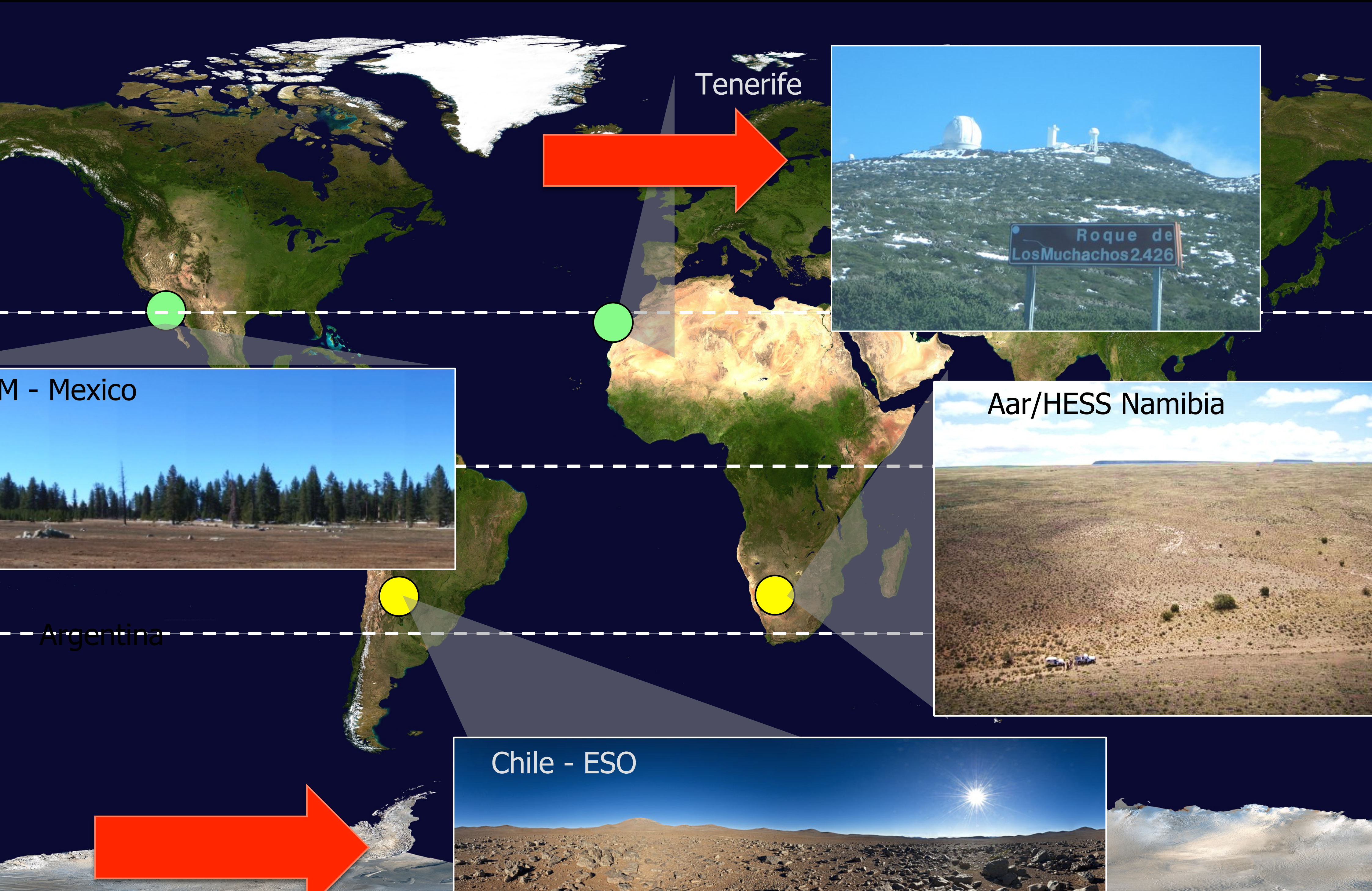
High-energy spectra, discovery of Pevatrons → Origin of CRs

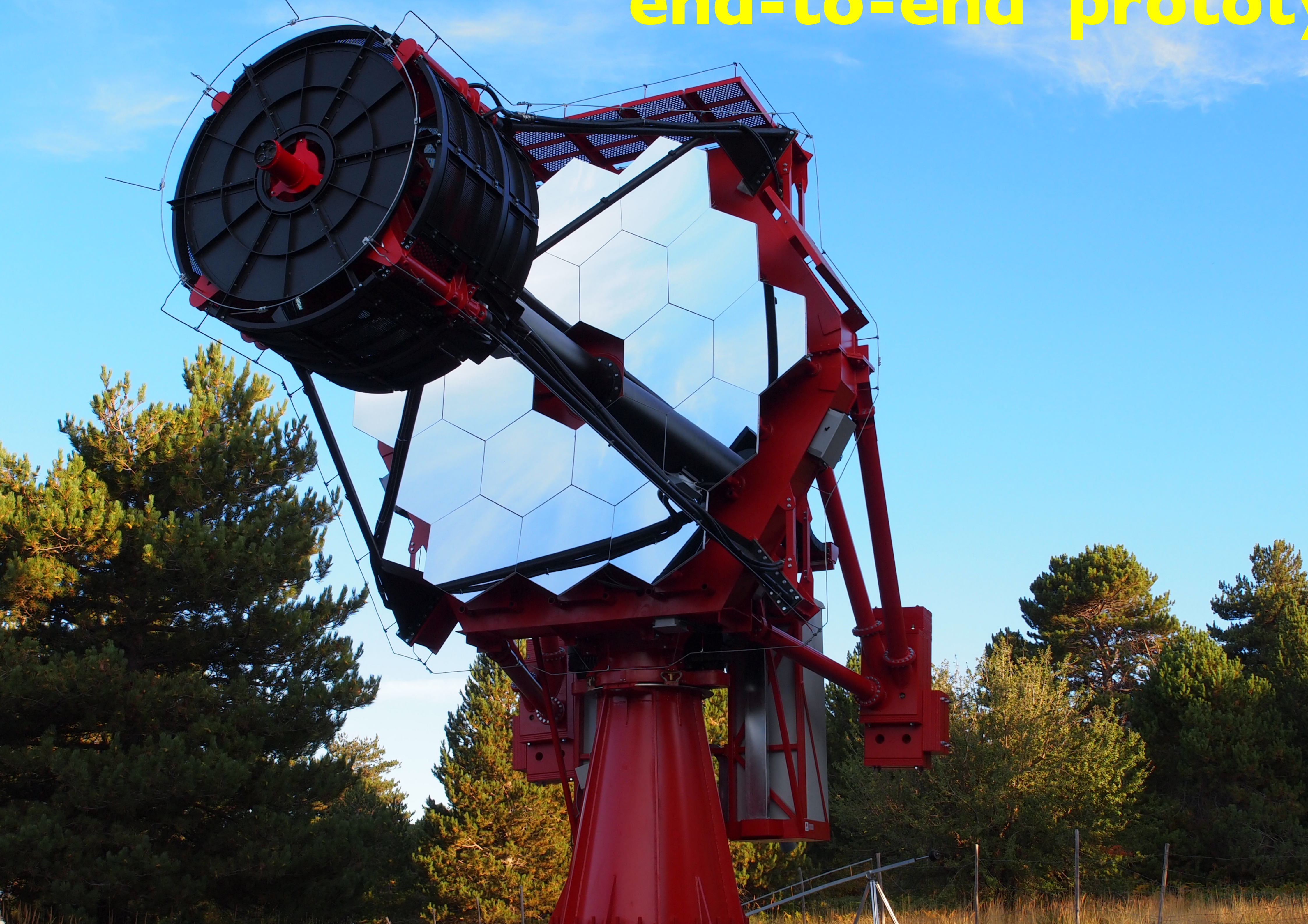




ngular resolution critical for
ource morphology and identification




Tenerife
Roque de
LosMuchachos 2.426
M - Mexico
Aar/HESS Namibia
Argentina
Chile - ESO


end-to-end prototy

End-to-end SST-2M prototype

- Validation and commissioning of the prototype via Cherenkov astronomical observations

End-to-end implementation of a mini-array

- ≥ 9 SST-2M (pre-production) at the CTA southern s
- Validation and commissioning of the ASTRI mini-array of pre-production CTA telescopes (including trigger and SW) via Cherenkov astronomical observations, first pre-production scientific data

Aiming at the construction of > 50 out of the 70 S-
units of the CTA southern array

Before ASTRI

nical Aspects

- Use of “new” SiPM sensors (➔ small pixels)
- Telescope design with inherent small plate scale & compact structure ➔ **double mirror**
- Replication technology for mirrors
- Monolithic Secondary mirror
- Fully compliant to the most demanding requirements (wind conditions,

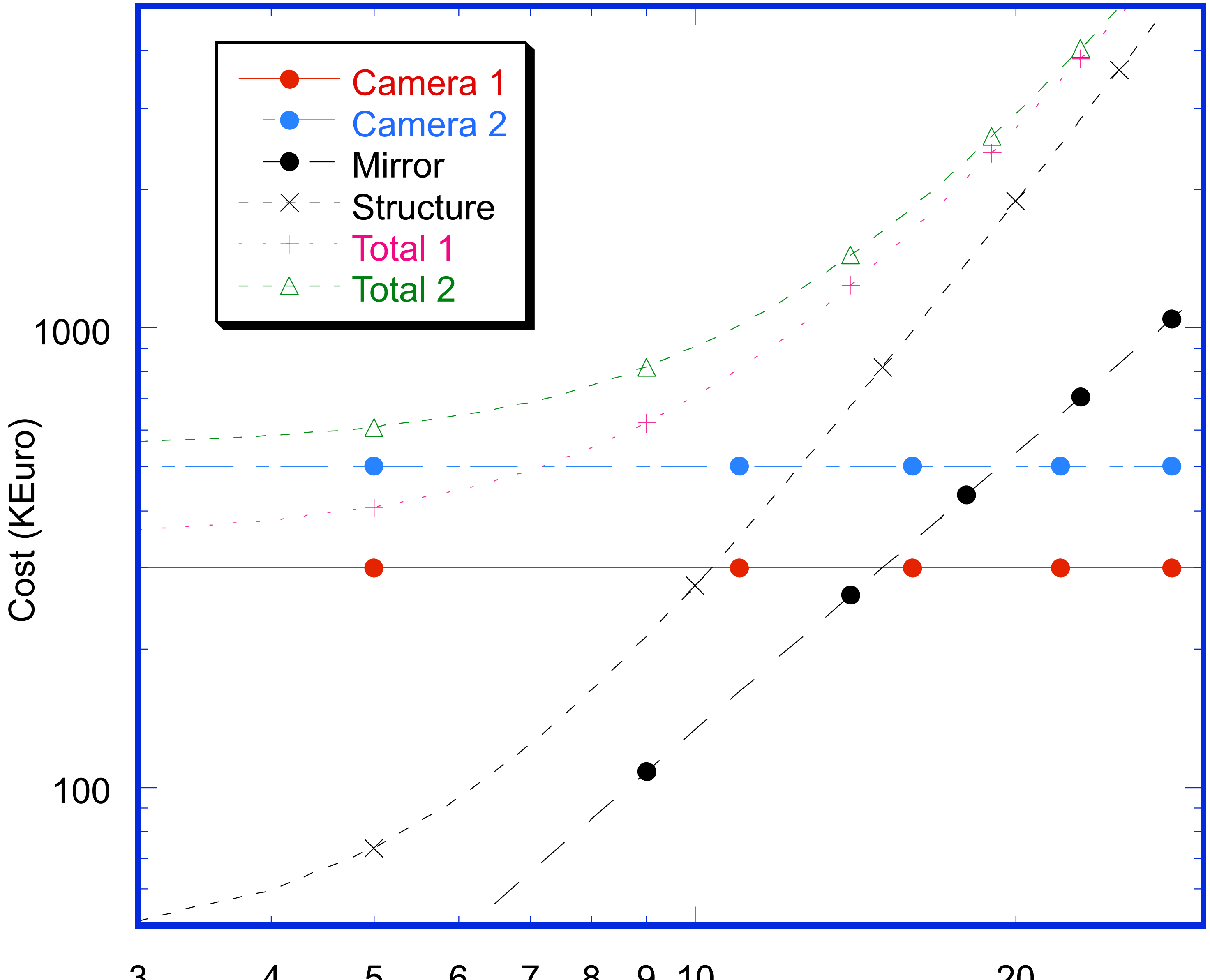
Programmatic Aspects

- E2E prototype (including ACTL, DAT Calibration subsystems) in a real astronomical site
- Design full compliant to the requiren
- Update of the design after the proto test and qualification and final site se
- Industrial involvement
- Array of a significant number of prec before the large final production

Telescope costs versus diameter

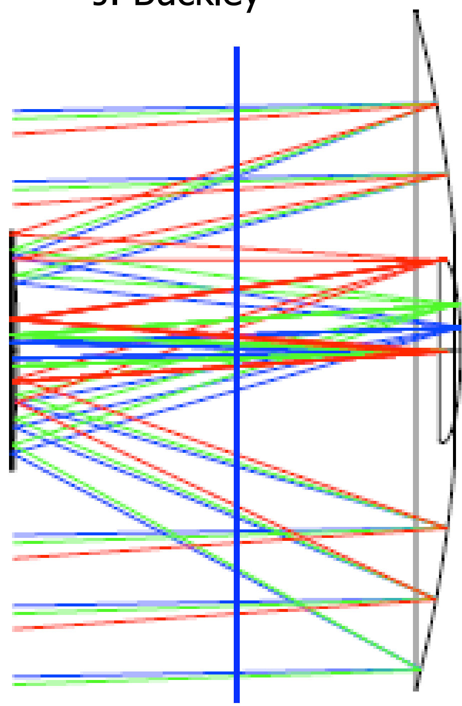
An advanced facility for ground-based high-energy gamma ray astronomy

… unless new
…mera technology
… available …
…ated image
…tensifiers??

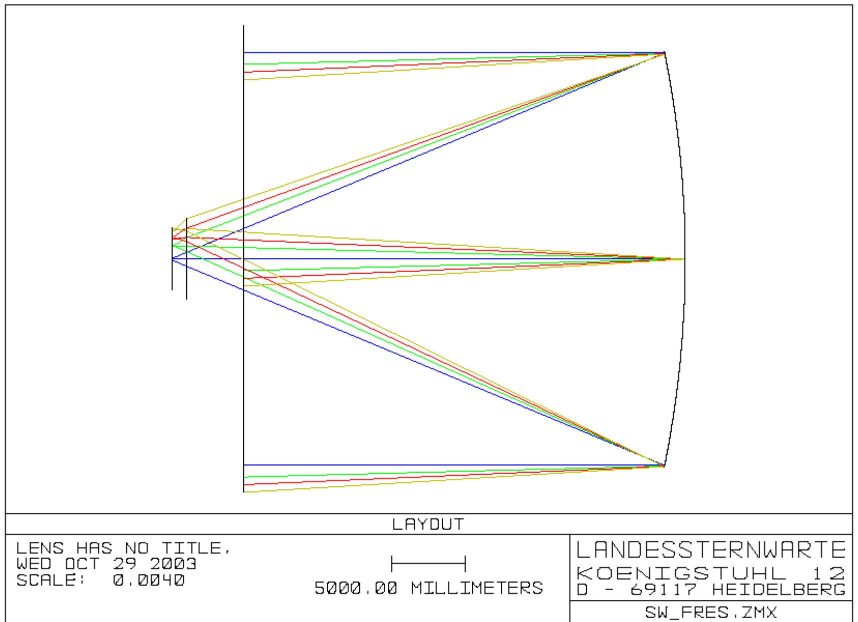


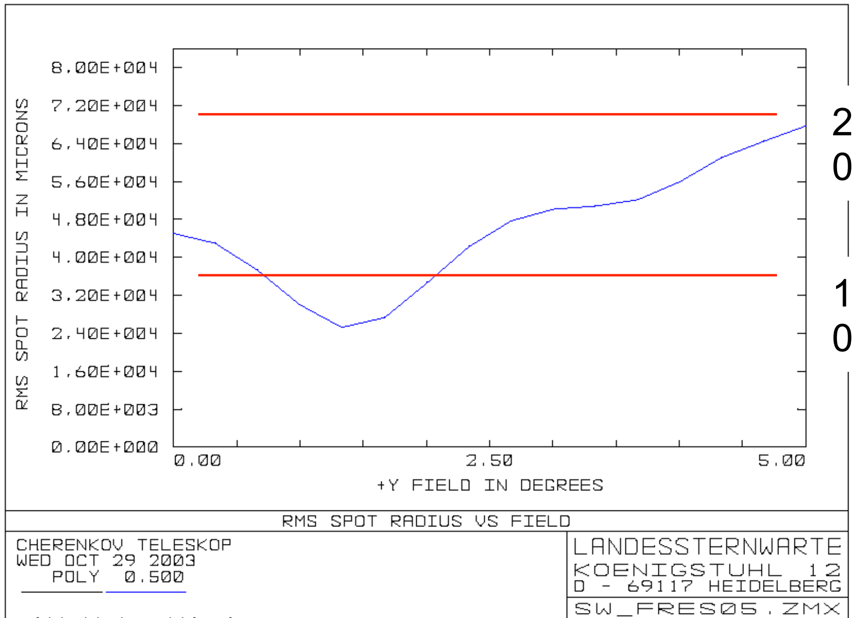
Camera field of view: Optics

J. Buckley



- Optics for wide fov
  - very large f/d
    - mechanically non-trivial
  - Dual-mirror optics with (large) secondary
    - cost, alignment, large effective focal length?
  - Frensnel corrector plate in front of camera
    - cost, transmission

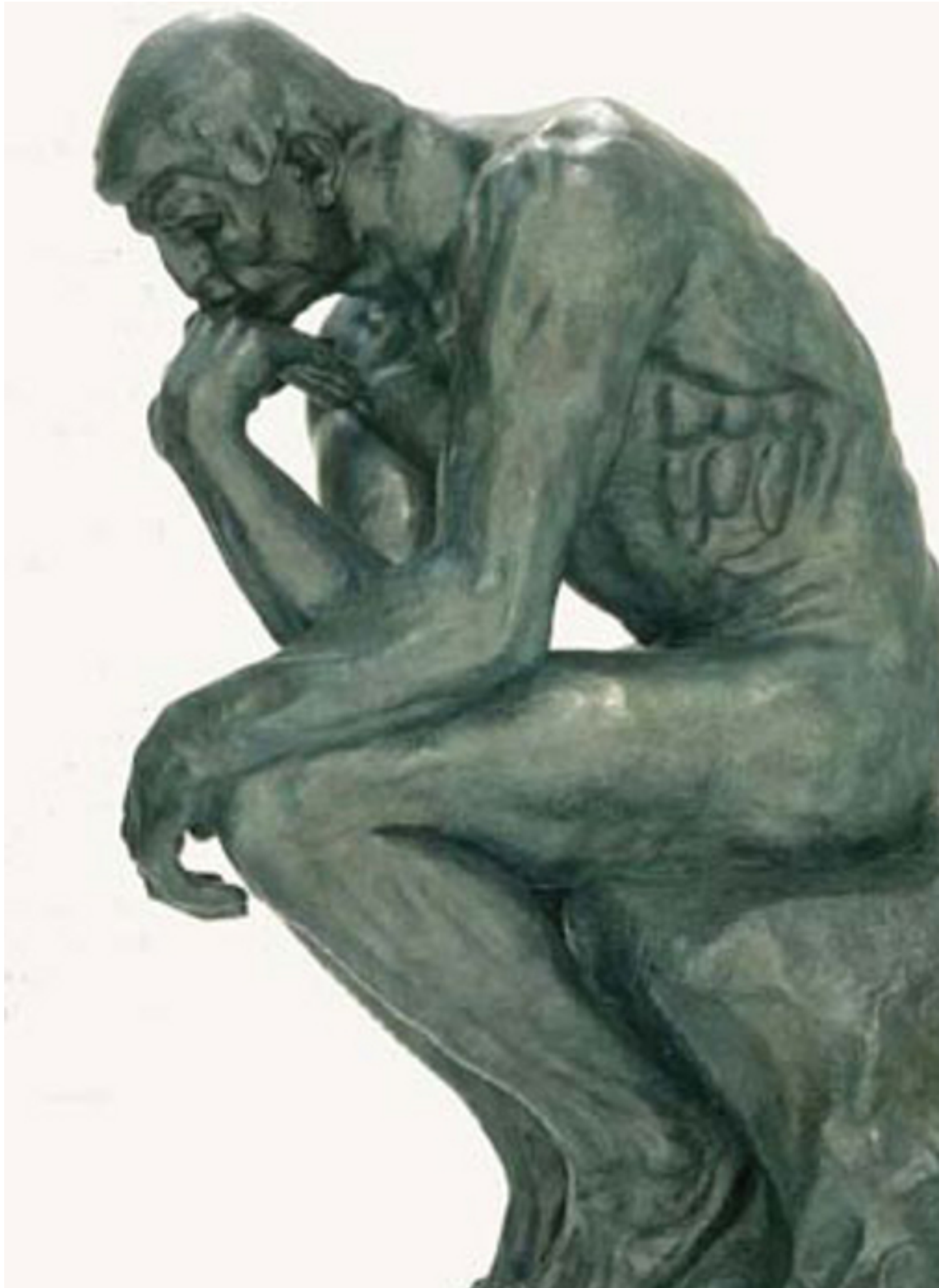




2 mrad
0.12°

1 mrad
0.06°

hinking ASTRI



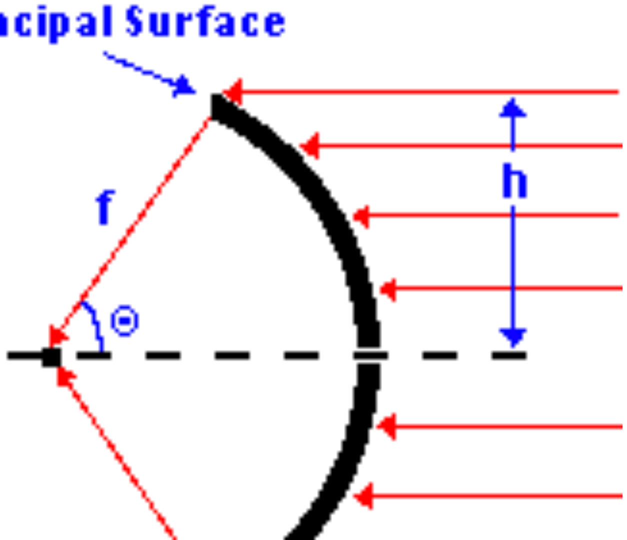
focusing mirrors

Coma: off-axis abberation caused by a different magnification of reflected rays, depending on the hitting position at the mirror surface

Typical blu
a focal sp
to co

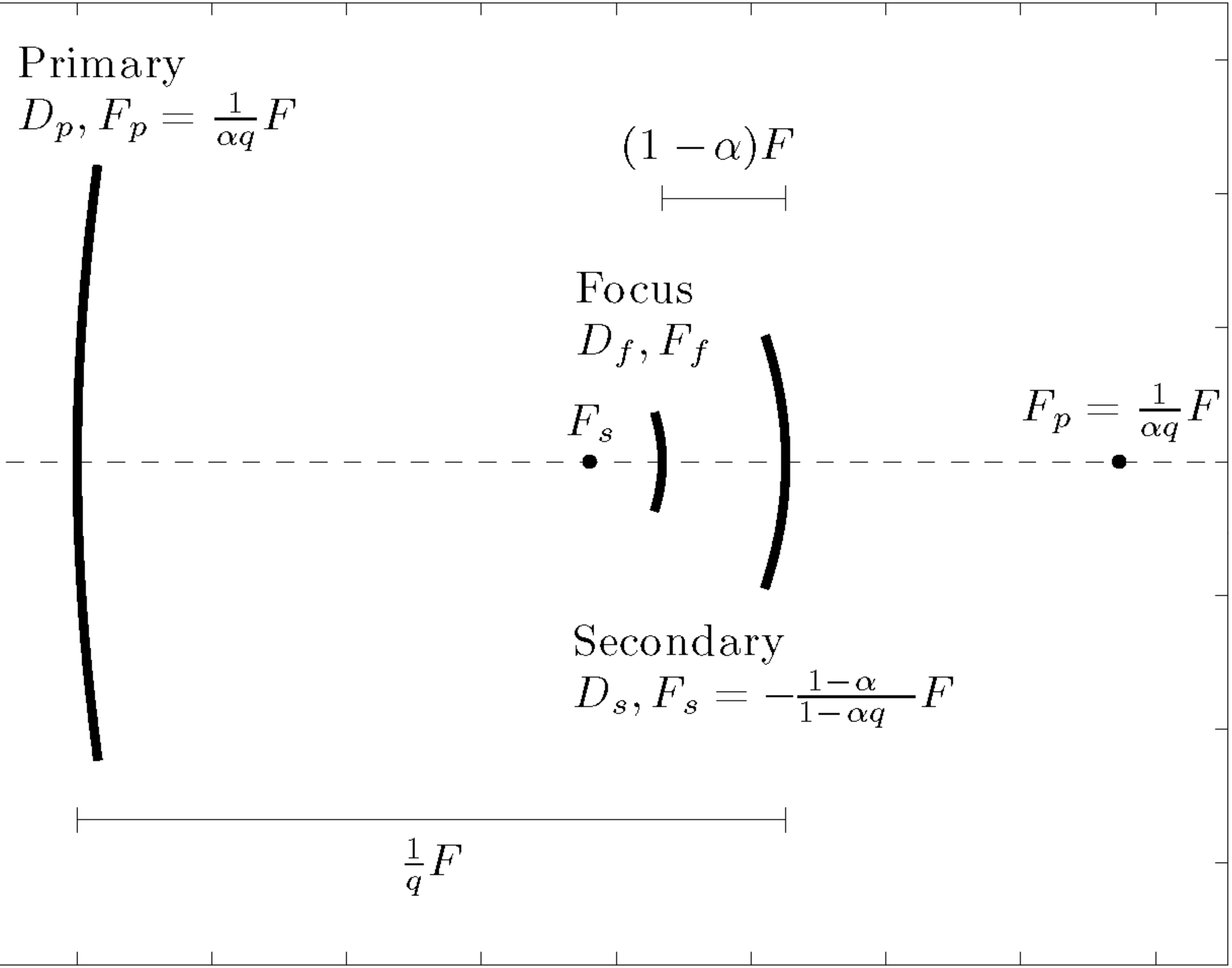
Coma free mirrors must satisfy the Abbe condition:

he surface defined by the intersection of each input ray with its esponding output ray (principal or Abbe surface) must be a sphe around the image, i.e.:



$$\frac{h_1}{\sin\theta_1} = \frac{h_2}{\sin\theta_2} = const.$$

adimir Vassiliev recovered the configuration for Cherenkov telescopes. Thanks!



Generalized Schwarzschil theorem:

"For any geom with reasonab separations b the optical ele it is possible t correct n prin aberrations wi powered elem (1905)

Karl Schw

Focal length **F** is fixed by geometrical and angular pixel sizes of Si

and **q** parameters are optmized for maximal light collectng area
mal PSF at the edge of **FoV**;

iameter of the primary is determined by **F**, α, **q** with second
vative being zero at the edge;

iameter of the secondary is determined by tolerable vignetting;

ocal plane is curved to minimize astigmtism.

**. Vassiliev, S. J. Fegan, P. F. Brousseau Astropart.Phys.
0-27,2007**

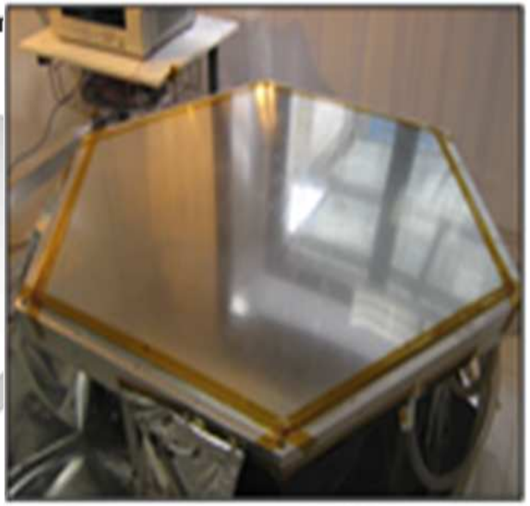
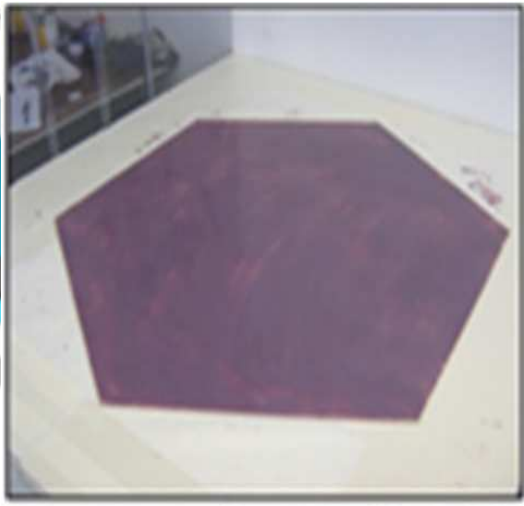
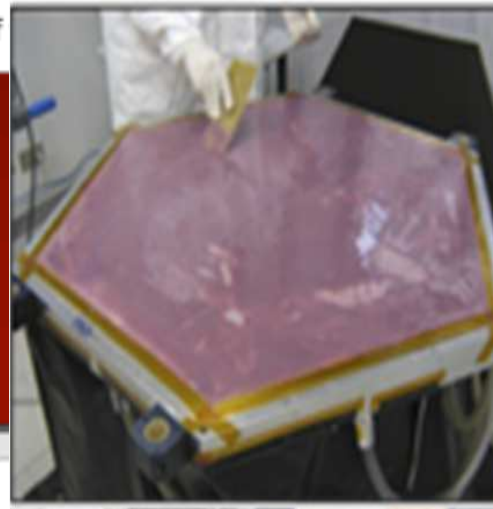
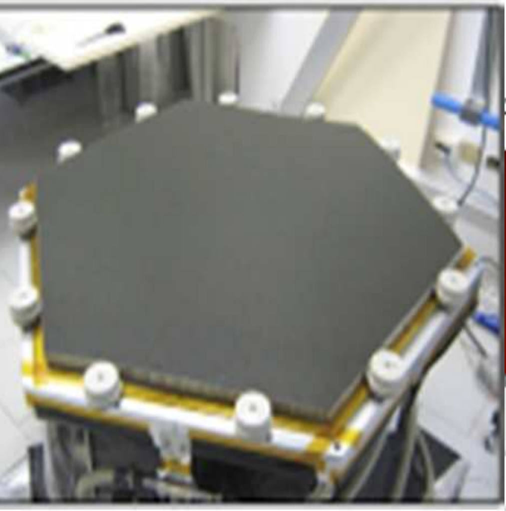
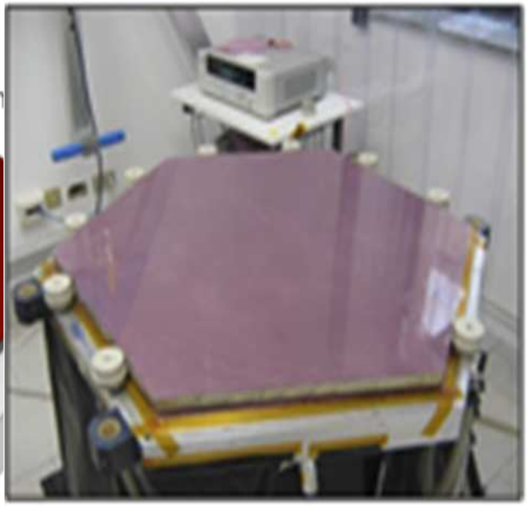
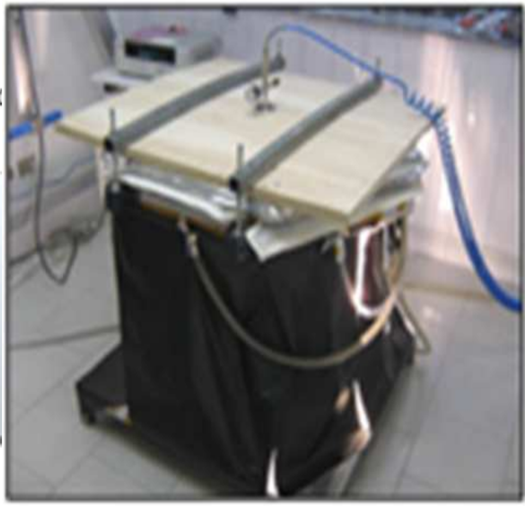
STRI - Astrofisica con Specchi a Tecnologia Replicante
aliana

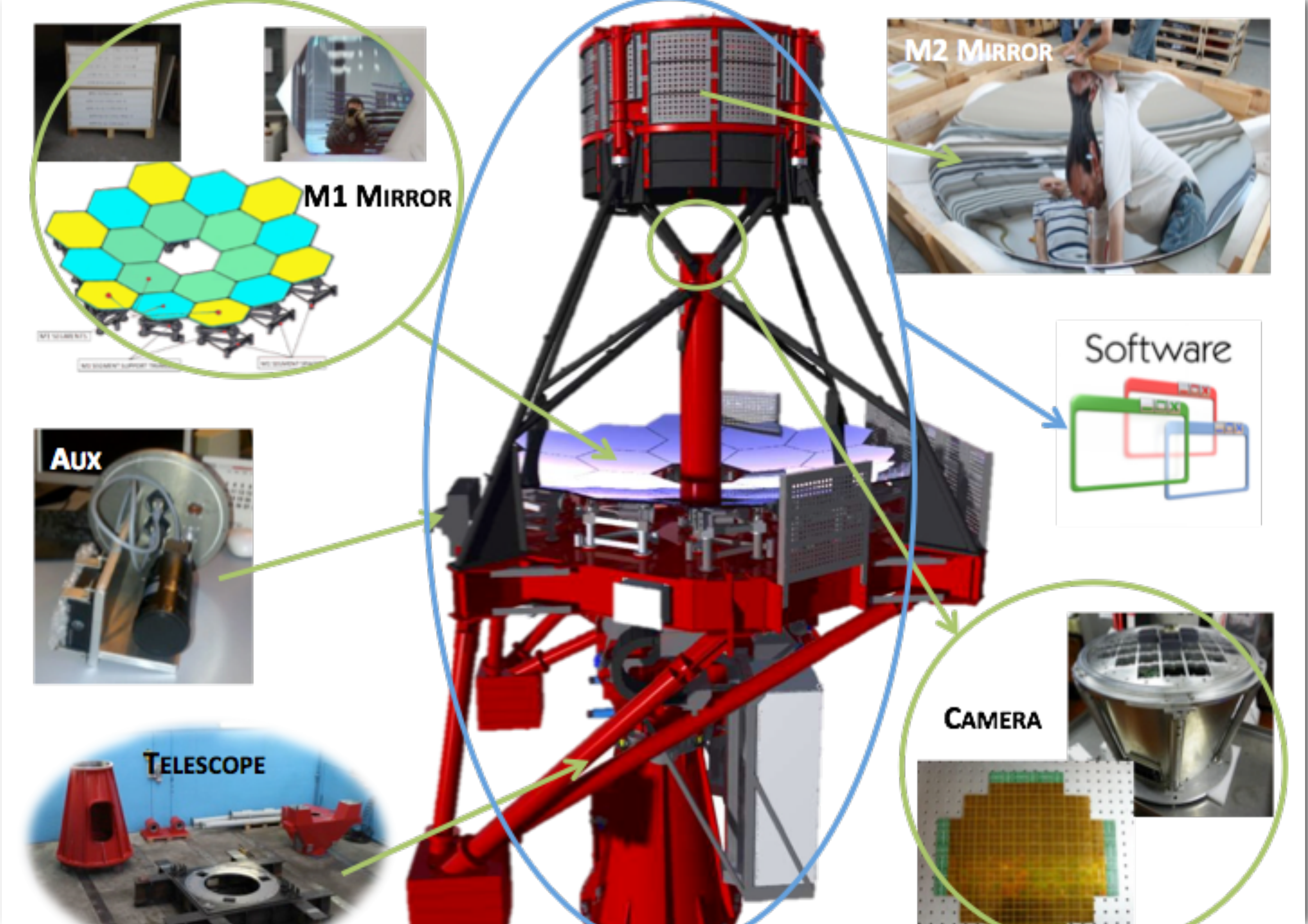
trophysics with Mirro

Name by Nanni Bignar

(a great scientist…. but a als
great “inventor” for success
acronyms, e.g. GEMINGA

Glass Cold-Shaping technology



M1 Mirror
M2 Mirror
Software
Aux
Telescope
Camera

ASTRI SST-2M **innovative solution**

Science !

e expect to detect **1 Crab**
x level sources at 5-sigma
a few hours at E > 1 TeV

e information:
cellone et al., 2015, arXiv:1508.00799

Dual-mirror optical layout

first time for VHE IACTs;

reduces the plate-scale;

optimal PSF across the entire Fo

SiPMs photo-detectors

small pixel-size;

can work during moonlight;

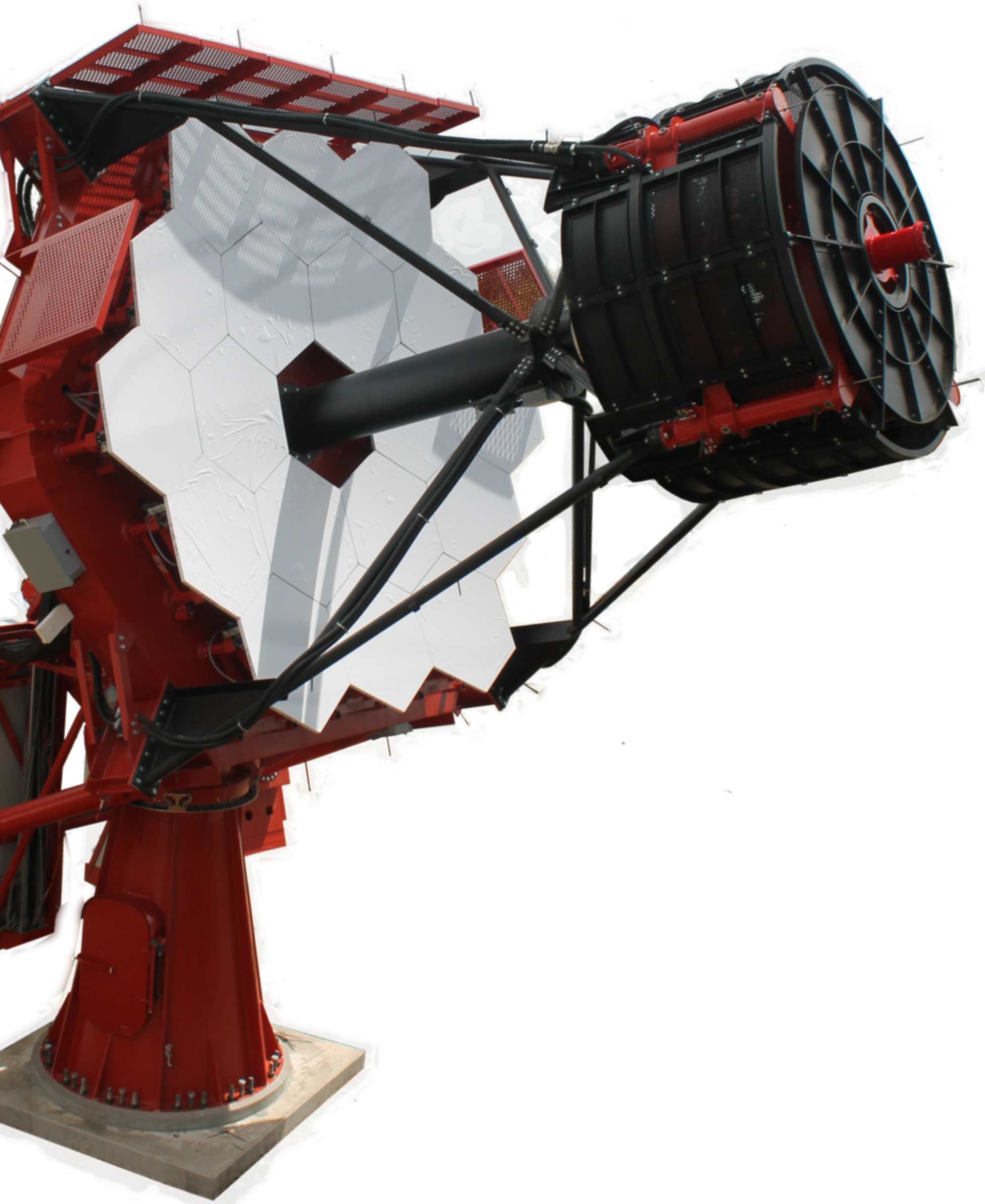
fast front-end and control electro

Wide field-of view (9.6°)

excellent for:

extended sources, surveys;

allows to extend the energy ra



Energy threshold

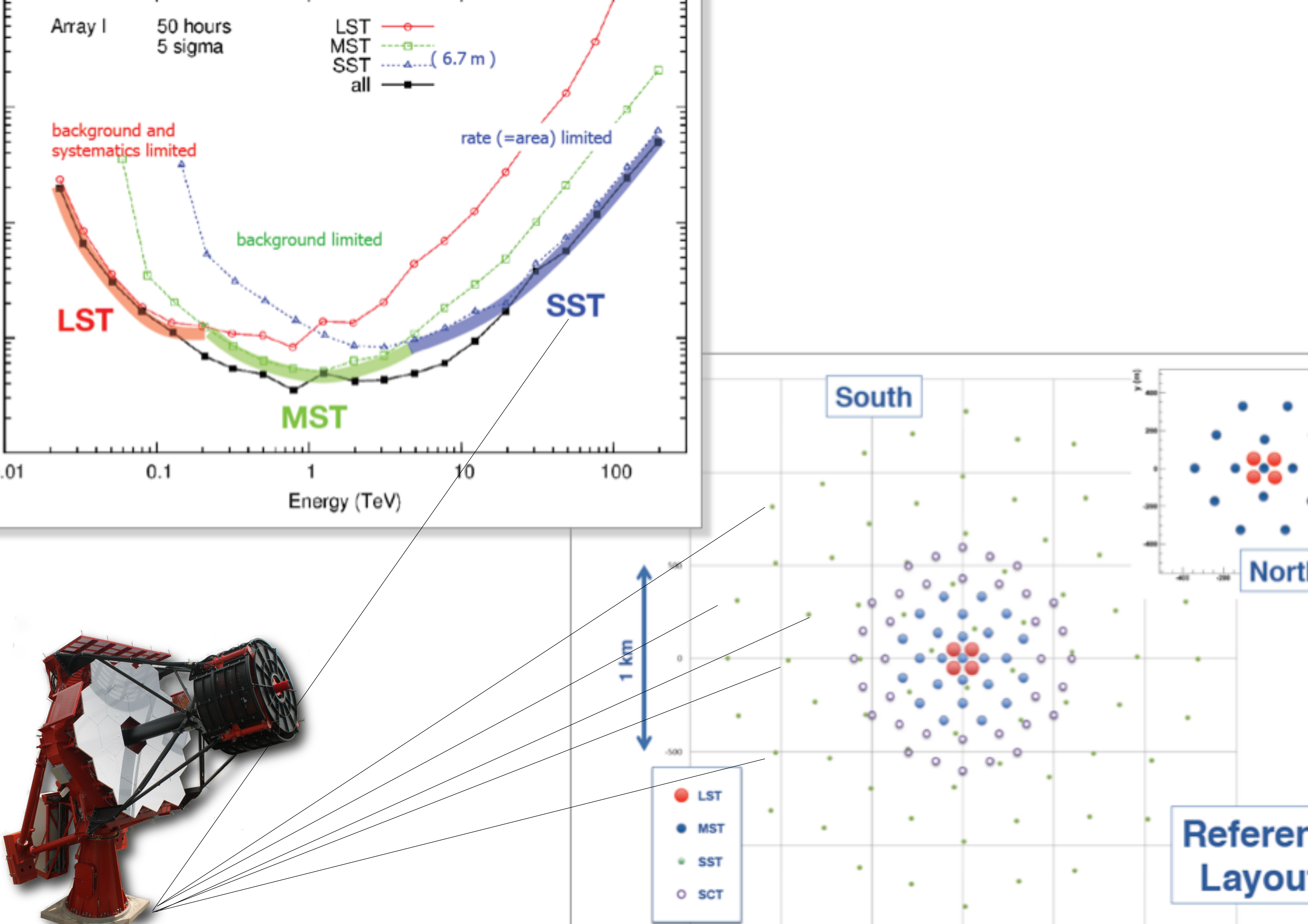
- 1 TeV

Telescope characteristics

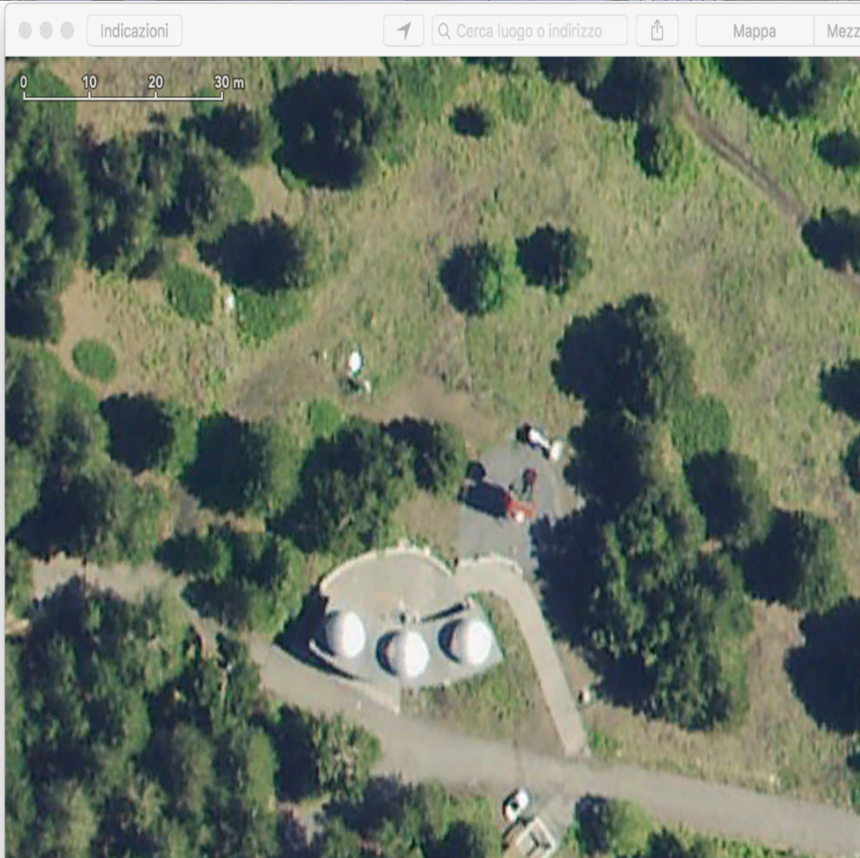
- Primary mirror = ⌀ 4.3m
- Optical design = Schwarzschild-Cou
- M1 type = Segmented (18, 3 corona
- Secondary mirror = ⌀ 1.8m (2.2m R
- M2 type = Monolithic
- M1-M2 distance = 3m
- Optical effective area = 6m^2
- F/D1 = 0.5, F = 2.15m

Camera characteristics

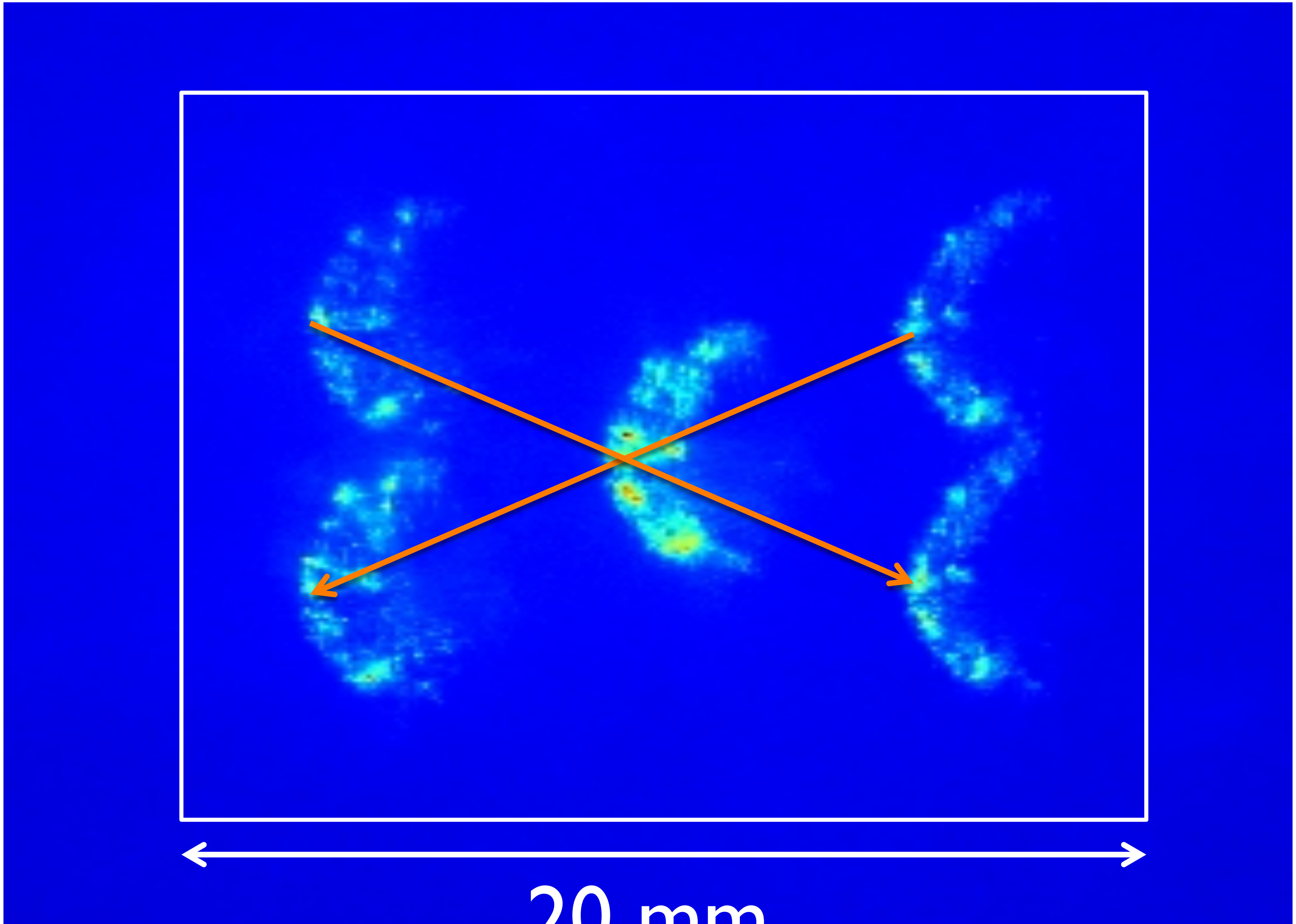
- Number of logical pixels = 1984
- Pixel = 0.17° (plate scale = 37.5mm
- Field of View = 9.6°
- Sensors type = SiPMs


Array I
50 hours
5 sigma
LST
MST
SST
(6.7 m)
all
background and
systematics limited
rate (=area) limited
background limited
LST
SST
MST
0.1
1
10
100
Energy (TeV)
South
North
1 km
LST
MST
SST
SCT
Referen
Layout

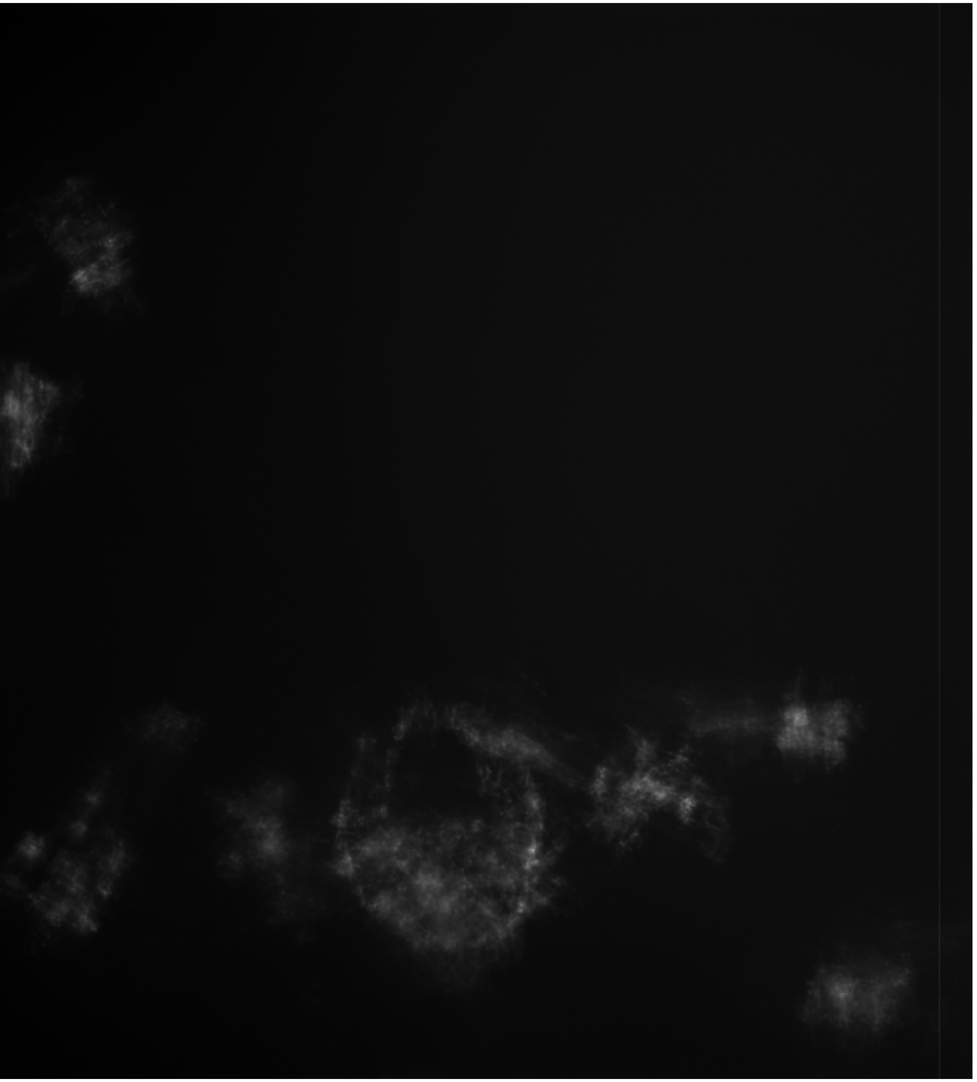
prototype is
at 1725 meters
e Etna volcano @
F - Catania
tain station in
La Nave



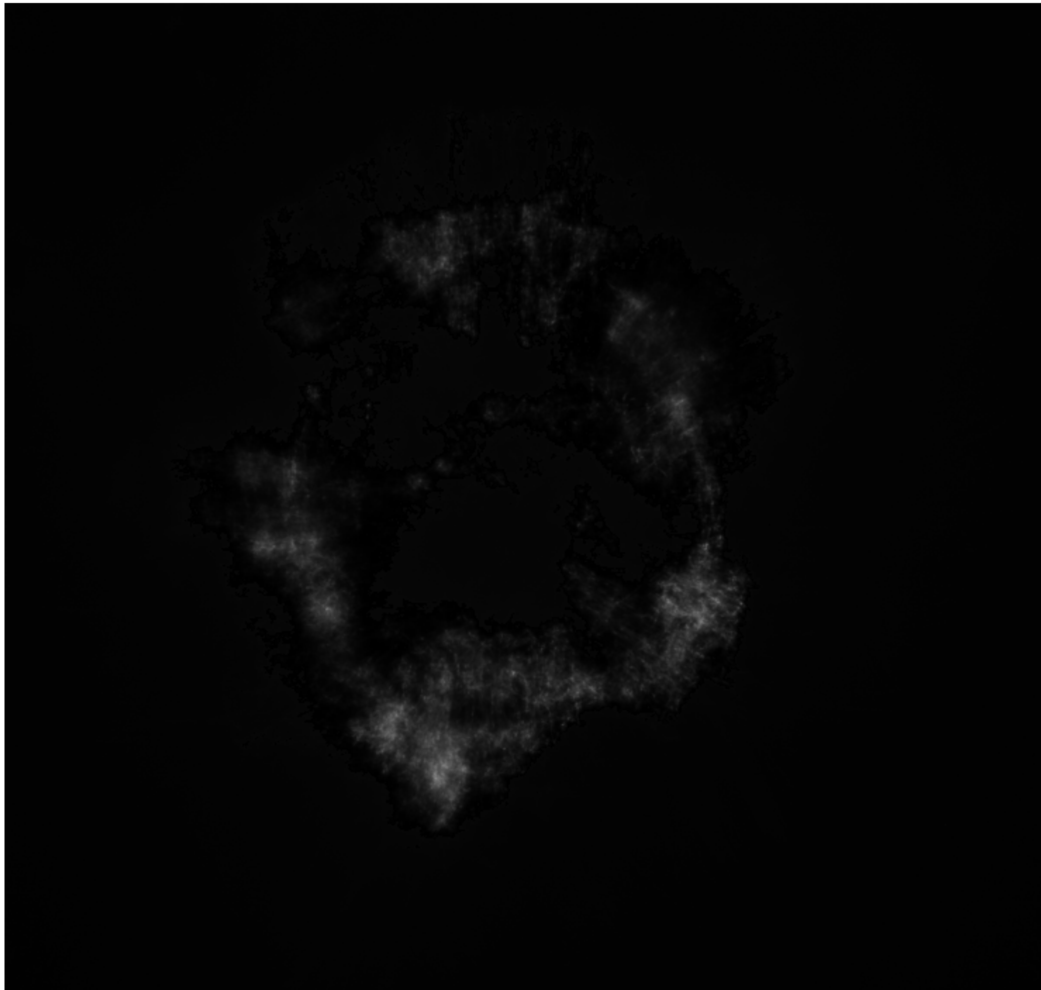
ain a calibration of the kinematic model of the actuators 5 images of a eac
nt for five fixed number of step displacements have been obtained.
about 1.4 arcsec/step has been calibrated.



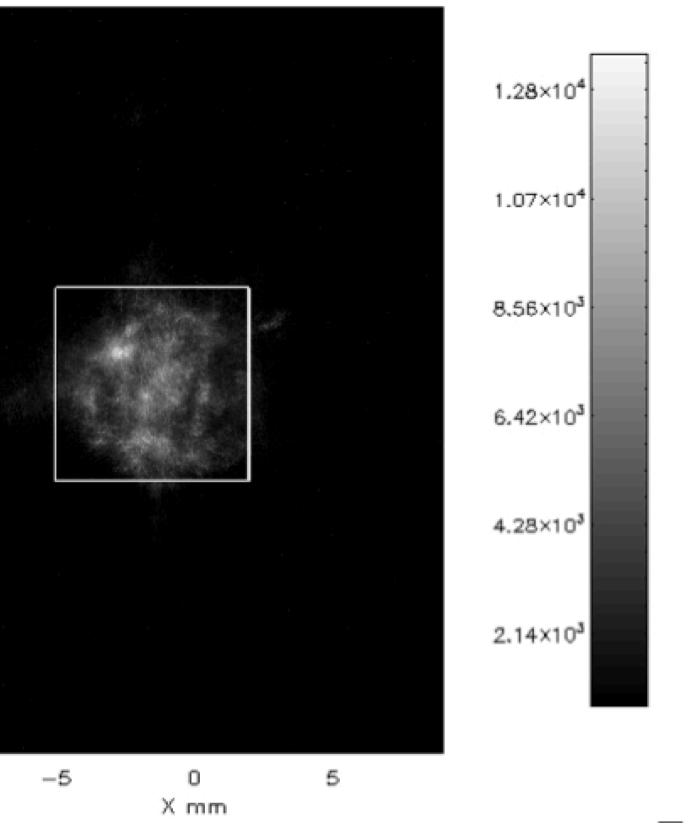
M1 segments



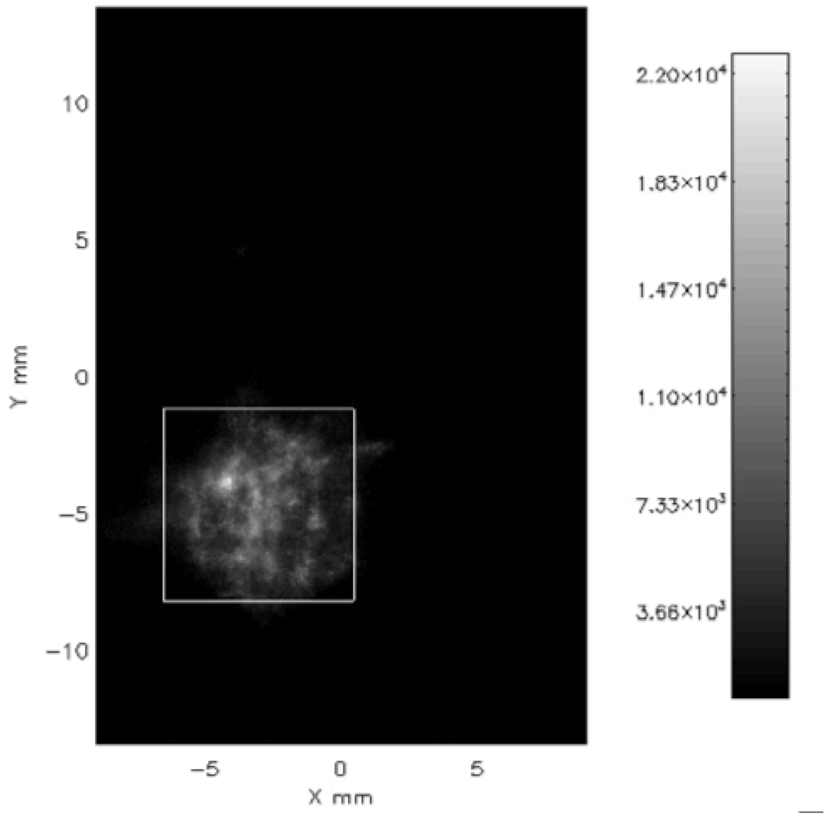
M2 mirror



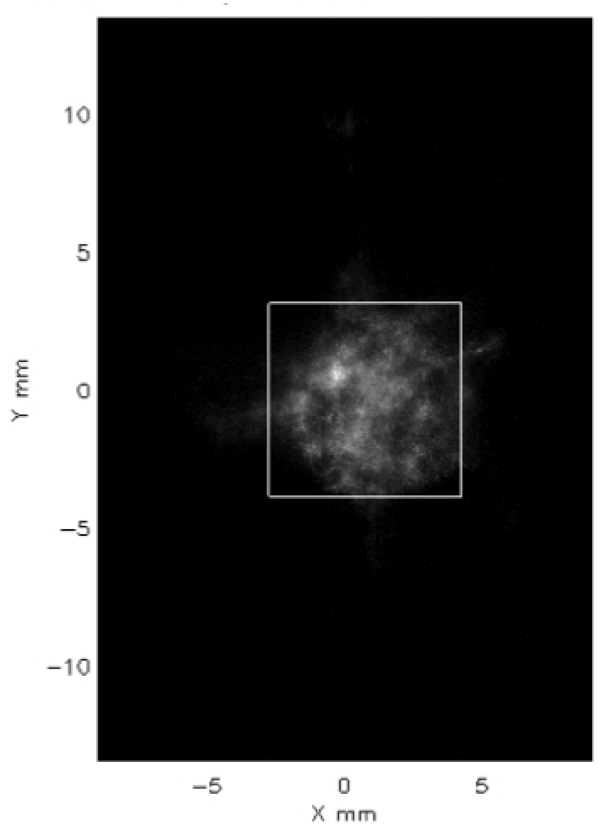
Acqusition of PSF for different elevations have been obatined. The PSF shows stability both in



l = 37 deg



El = 60 deg



El = 75 deg

, 1–6 (2017) Preprint 3 May 2017 Compiled using MNRAS LaTeX style file v3.0

optical validation of a Schwarzschild Couder telescope: the RI SST-2M Cherenkov telescope

Giro[1],* Rodolfo Canestrari[2], Giorgia Sironi[2],
Antolini[3], Paolo Conconi[2], Carmelo Gargano[4],
ele Rodeghiero[1,5], Federico Russo[6], Salvo Scuderi[7],
Tosti[3] and Giovanni Pareschi[2]

ervatorio Astronomico di Padova, vicolo dell' Osservatorio 5, 35122, Padova, ITALY
ervatorio Astronomico di Brera, via Emilio Bianchi 46, 23807, Merate (LC), ITALY
nto di Fisica e Geologia, Universitá di Perugia, via Pascoli, 06123, Perugia, ITALY
F Palermo, via Ugo La Malfa 153, 90146, Palermo, Italy
k Institute for Astronomy, Königstuhl 17, 69117, Heidelberg, GERMANY
ervatorio Astrofisico di Torino, via Osservatorio, 20, 10025, Pino Torinese (TO), ITALY
ervatorio Astrofisico di Catania, via S. Sofia, 78, 95125, Catania, ITALY

XX. Received YYY; in original form ZZZ

ABSTRACT

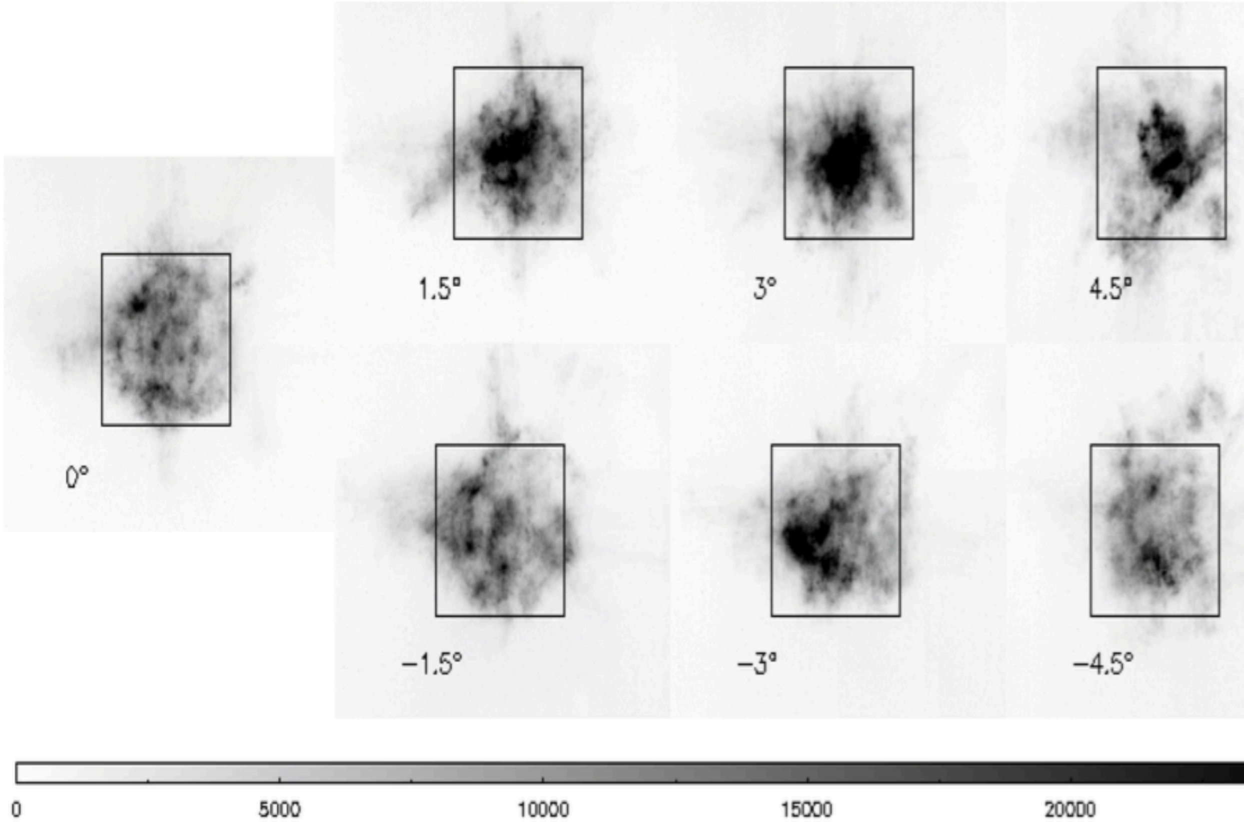
The optical qualification of the ASTRI SST-2M telescope in the full field of view is presented. The telescope has been developed as a demonstrator in the context of the upcoming Cherenkov Telescope Array (CTA). Its main innovation consists in the optical layout which, for the first time, implements the Schwarzschild–Couder configuration for a real working telescope. Moreover, ASTRI SST-2M also represents the first qualified example of a two mirrors telescope for Cherenkov Astronomy. This configuration permits to (i) maintain a high optical quality across a large FoV (about 10°), (ii) de-magnify the plate scale, (iii) exploit new technological solutions for focal plane sensors. We report the results of the first–light optical qualification. Test results validate the design specifications, opening a new scenario for Cherenkov Gamma ray Astronomy and, in particular, for the detection of high energy (1 -300 TeV) gamma rays and wide-field observations with CTA.

Key words:
Geometric optics – Mirror system design – dual mirror telescope – Cherenkov – IACT

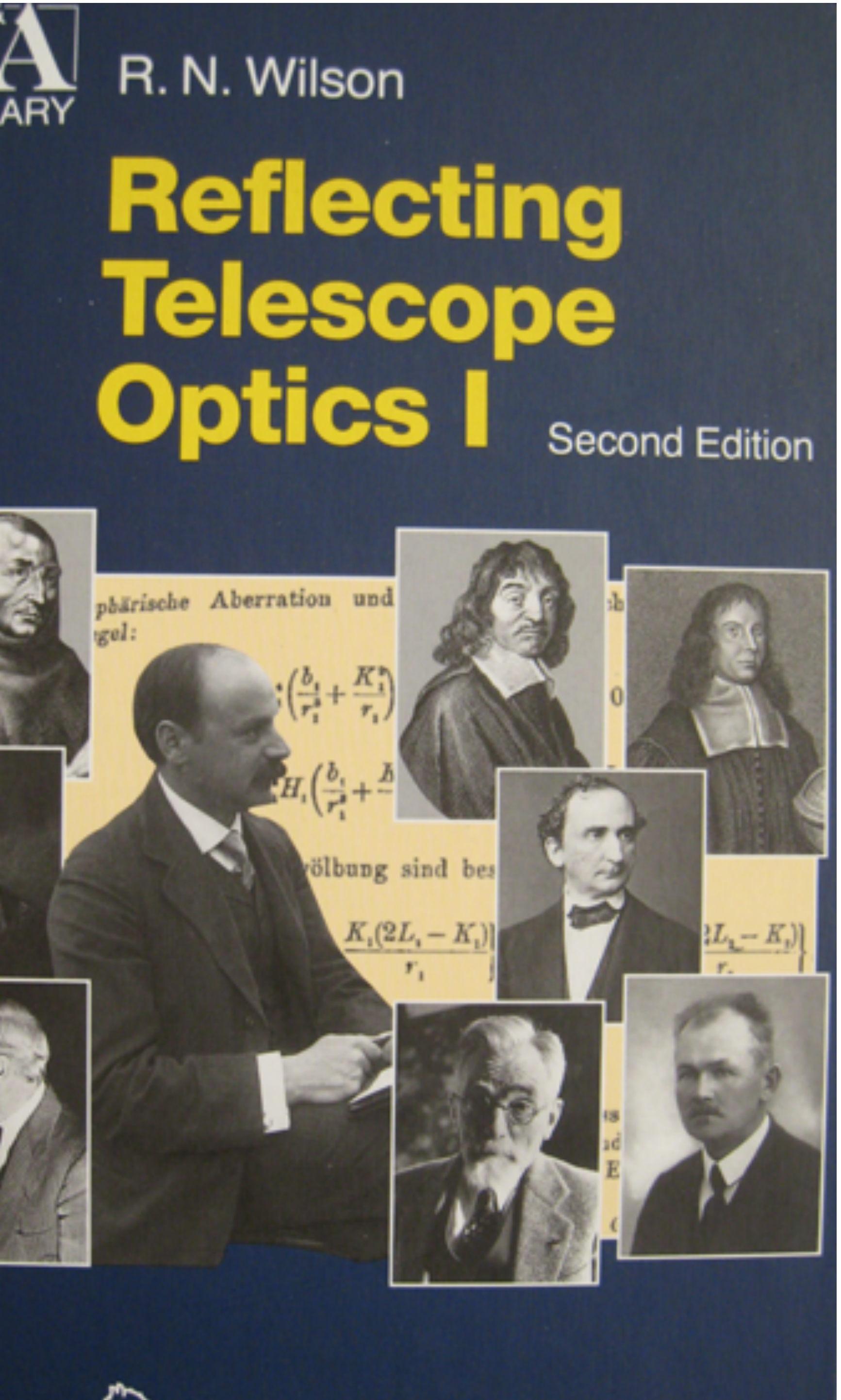
DUCTION

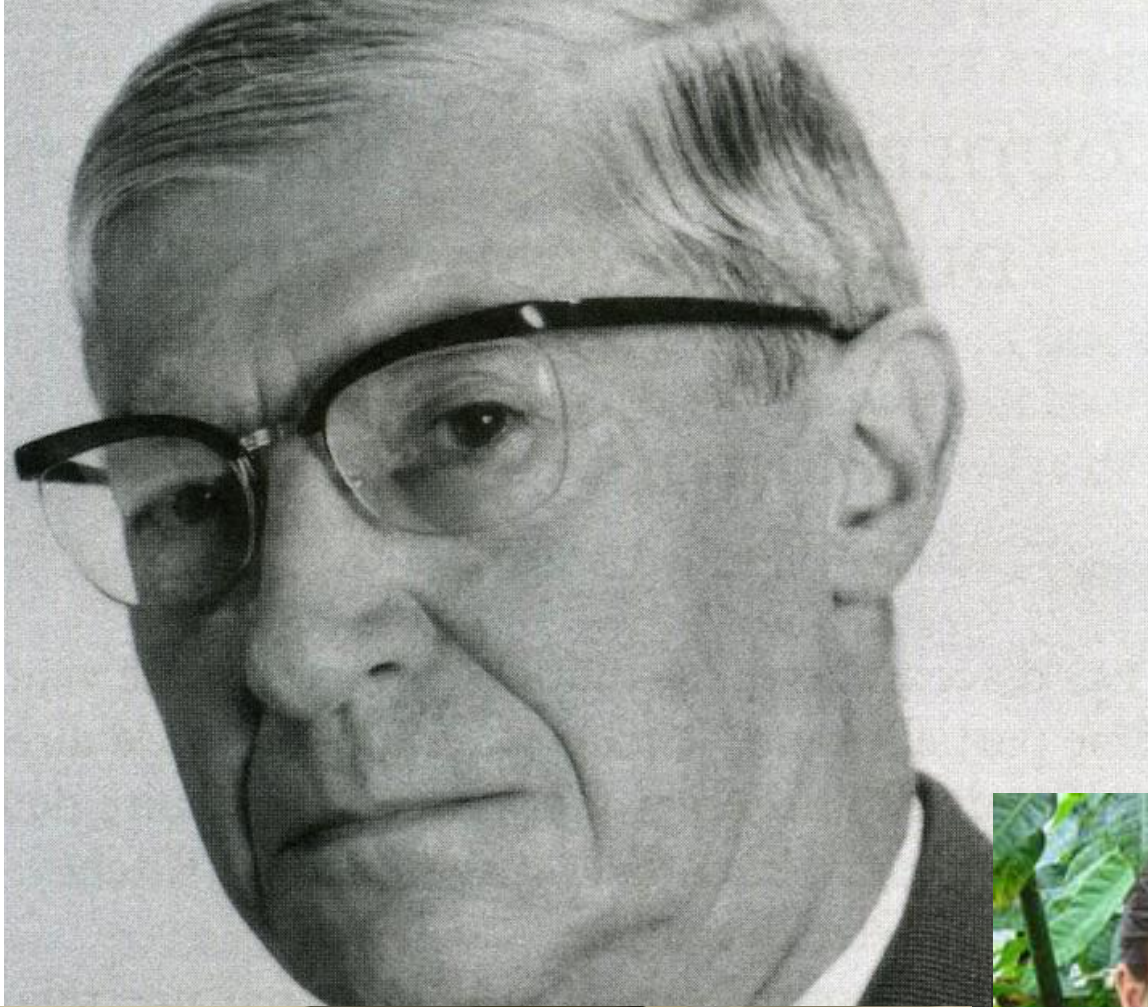
e German astrophysicist Karl Schwarzschild proposed r a two–mirror telescope eliminating much of the op- tion across the Field of View (FoV) (Schwarzschild his paper he proposed a method to design an op- n free of both spherical and coma aberrations by wo aspherical mirrors described by radial polynomi- gnition of Schwarzschild's contribution to optics de- the analytical solutions for two-mirror telescopes are Schwarzschild aplanats". In 1926 Couder enhanced ild's solution adding a curved focal plane to reduce atism (Couder 1926), and this kind of configuration me of Schwarzschild–Couder (hereafter SC). More recently, Lynden-Bell (Lynden-Bell 2002), starting from this pioneering work, proposed a solutions for an exact optics aplanatic telescopes operating in the visible.

In order to limit the coma aberration effects in X-ray microscopy, Wolter was the first who applied the Schwarzschild's approach to get aplanatic grazing incidence optics for X-rays (Wolter 1952*a* and 1952*b*). Wolter's approach has been later on adopted for the design of X–ray astronomical telescopes based on grazing incidence optics and a number of X-ray telescopes were realized (Aschenbach 1985 and 2009). Following the approach initially suggested by Burrows, Burgh and Giacconi (Burrows et al. 1992), Conconi (Conconi et al. 2010) showed that different Wolter–like designs could be obtained expanding as a power series the primary and secondary mirrors' profiles in order to increase the angular resolution at large off-axis positions, at the expenses of the on-axis performances. Also the



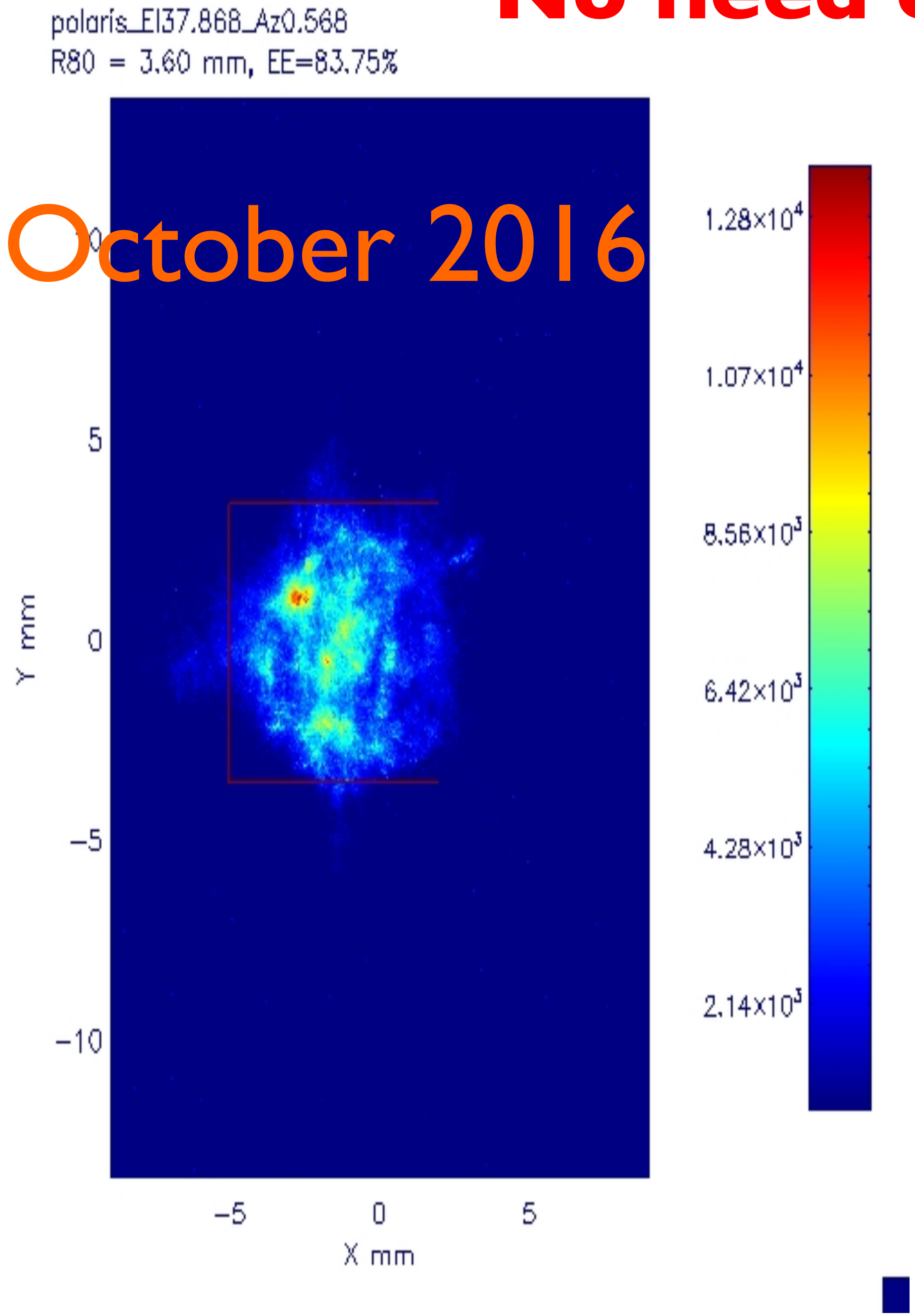
- **Submitted to A & A**

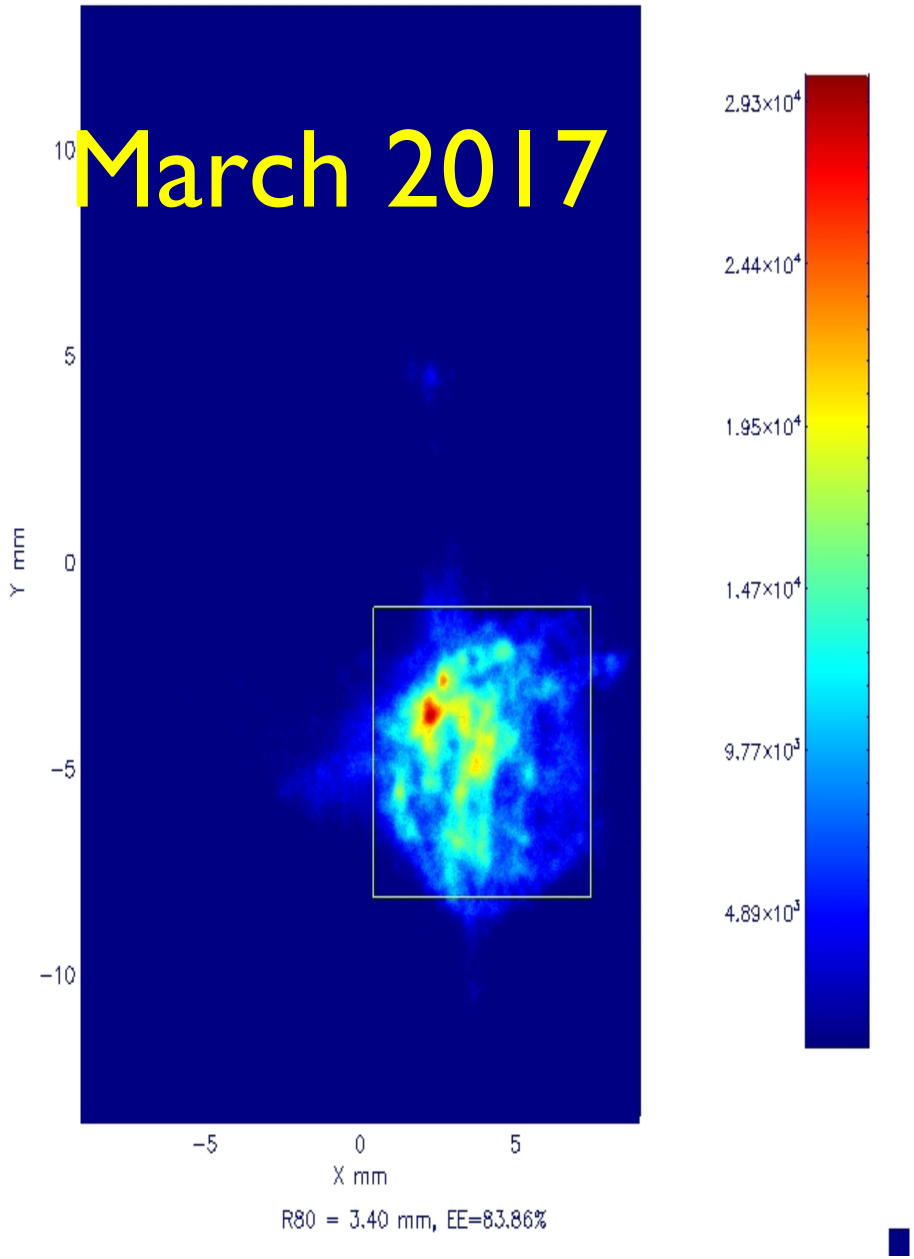

R. N. Wilson
Reflecting Telescope Optics I
Second Edition



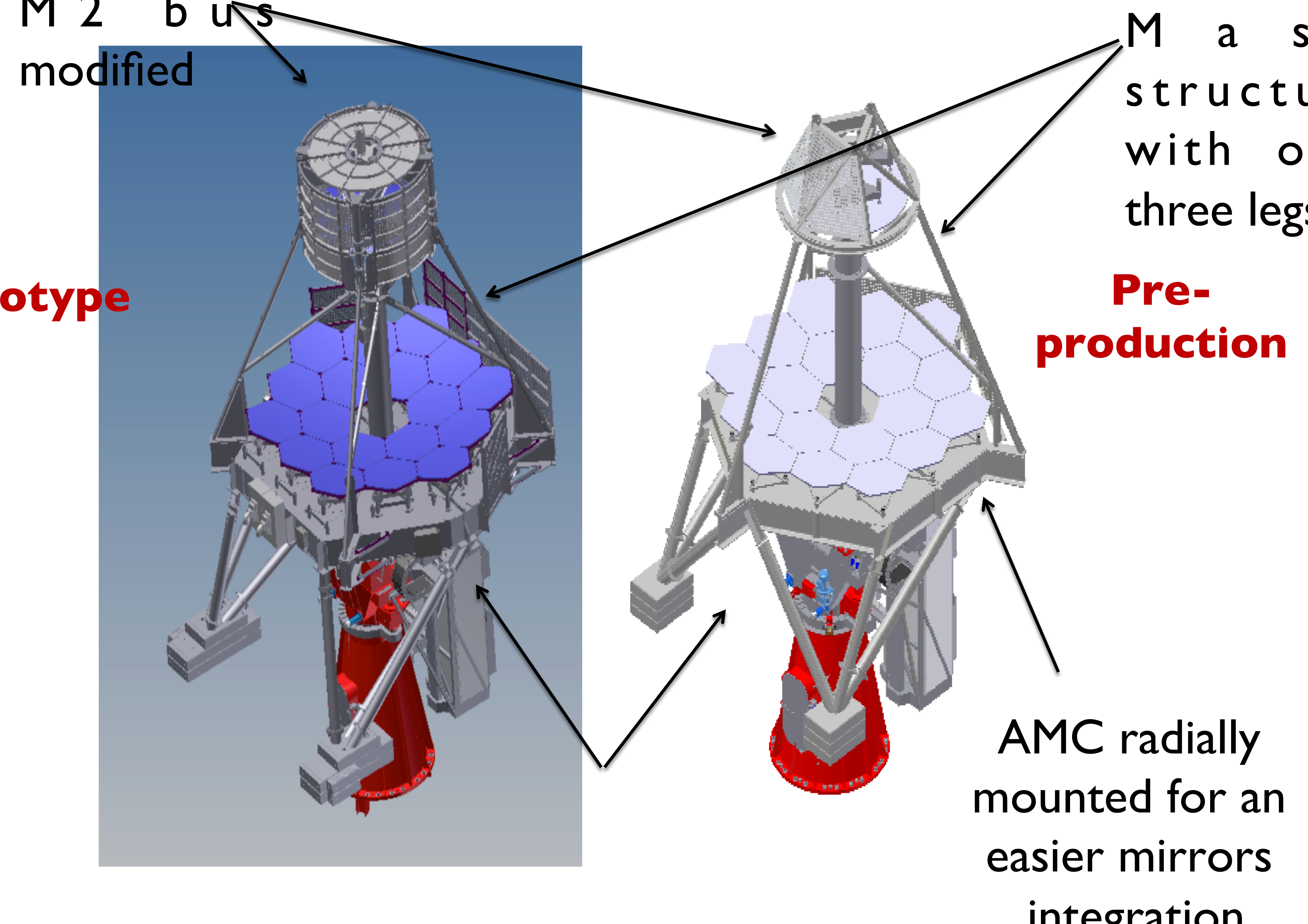
er 6 months the PSF showed an impressive stability

No need of actuators!





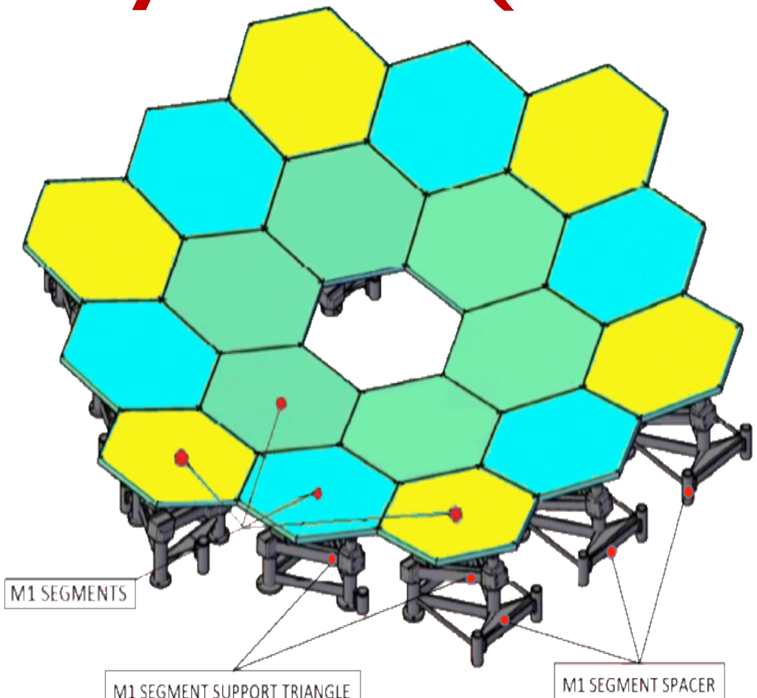
Right image is acquired with double exposure time because of the weather partially cloudy

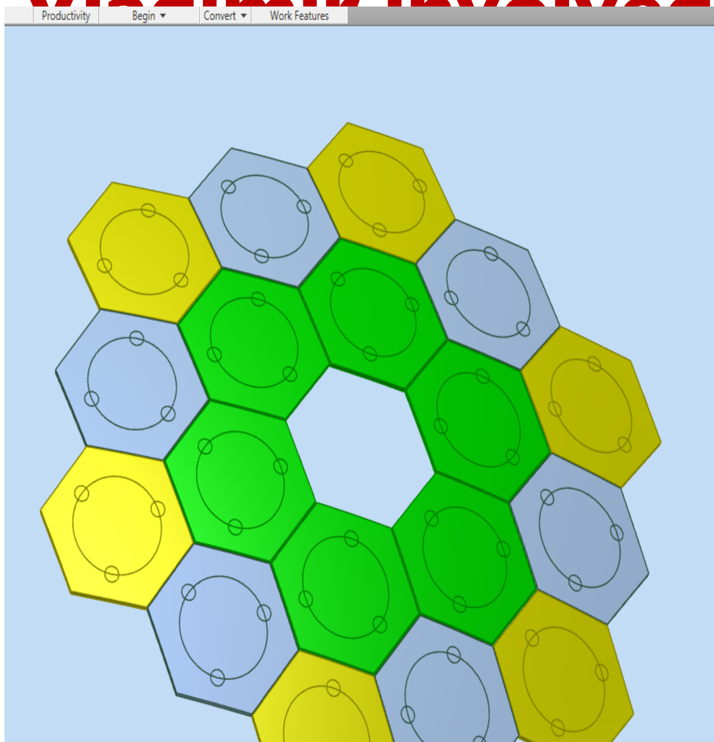

M 2 b u s
modified
otype
M a s
structu
with o
three leg
Pre-
production
AMC radially
mounted for an
easier mirrors
integration

urement of ASTRI primary mirrors (9 set + 1 spare)

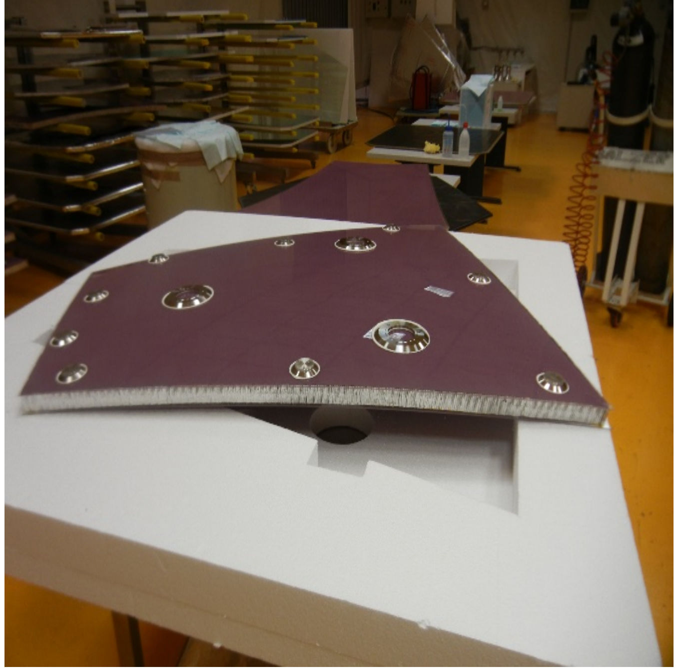
- **Contract assigned to Media Lario**
  - **KOM 27th Jan**
  - **PPR 10th March**
  - **Beginning of Qualification phase 5th May**
  - **End of Qualification phase 30th July**

Complementary activities: procurement of 2 complete sets of MST mirrors and 1 set SCT econdary mirror (Markus and Vladimir involved)

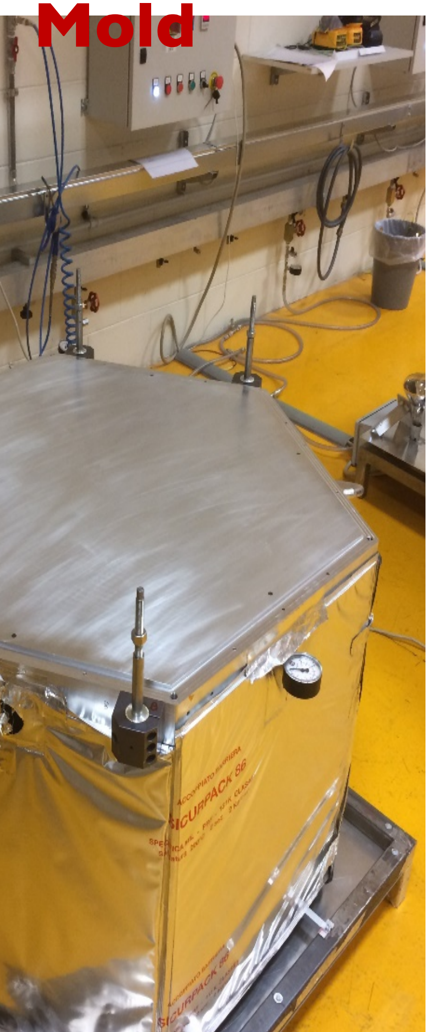




Courtesy of Media Lario

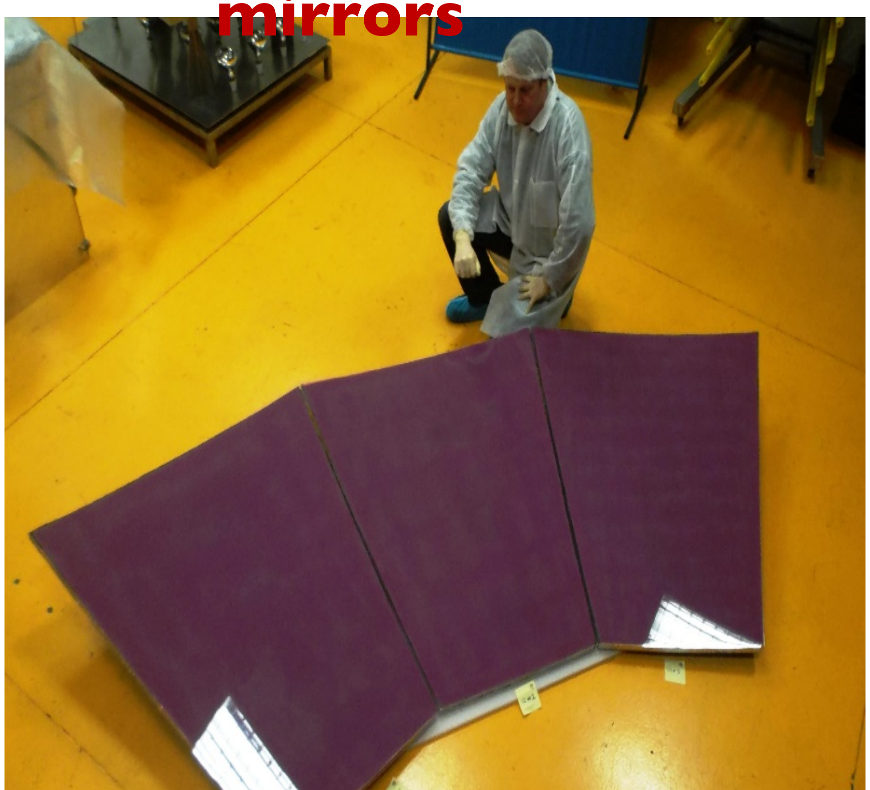


TRI CORI Mold



MST optical bench

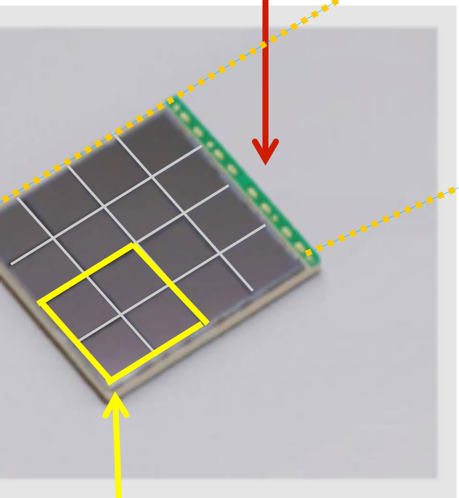
pSCT S2 mirrors



Modularity: Unit, PDM, Focal Plane

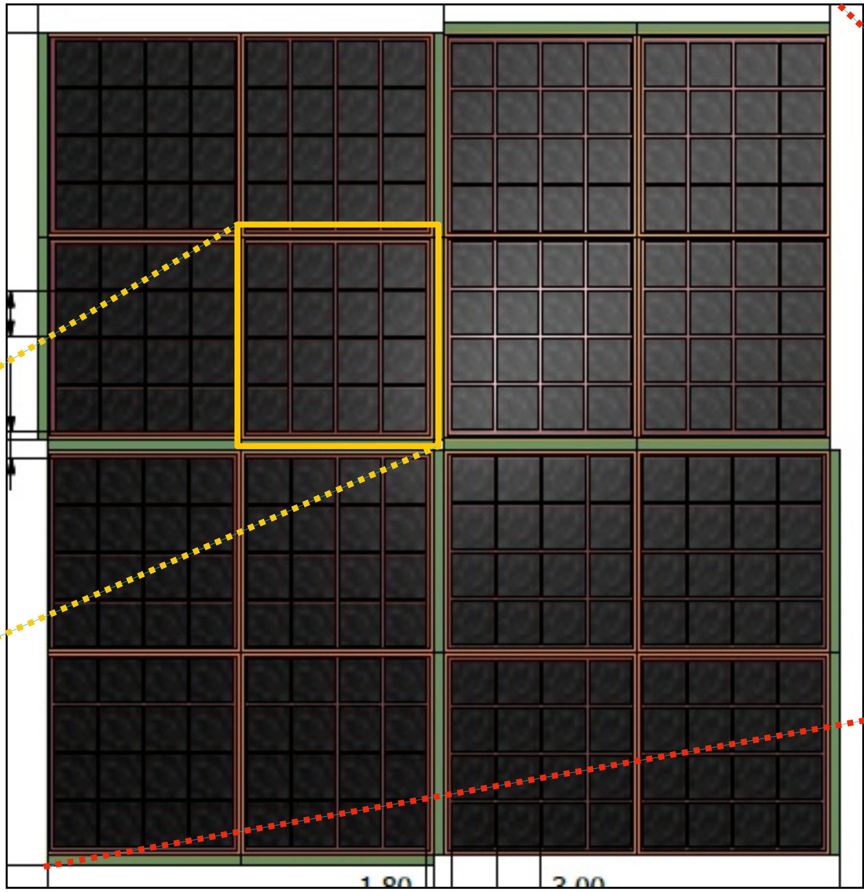
328-3344M1
he 'Unit'

metrical
d area



ogical pixel
.2×6.2mm

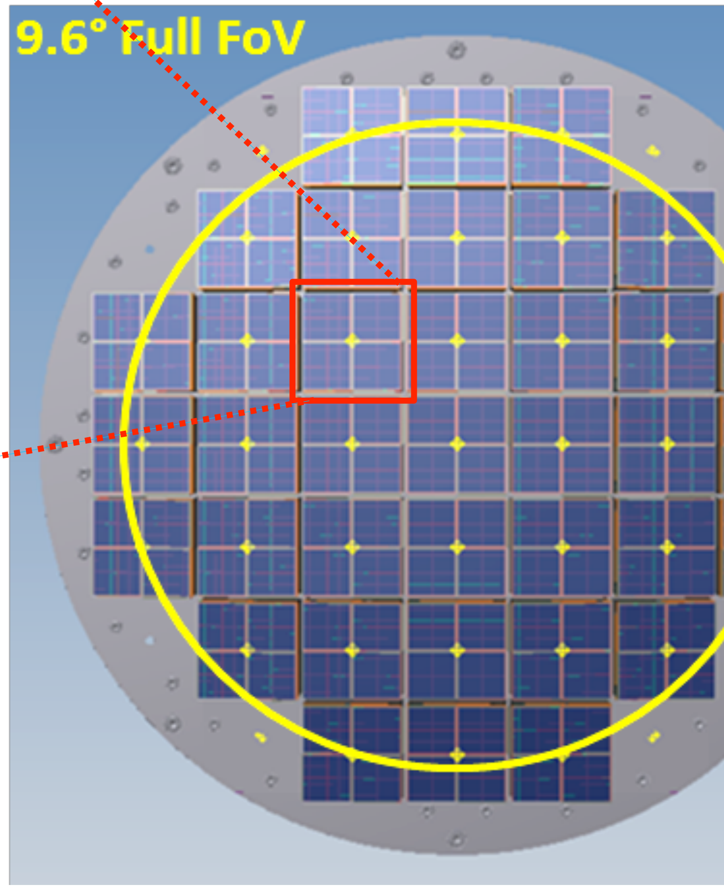
Photon Detection Module
PDM



4×4 Units → 1 PDM
56×56mm
(64 channels)

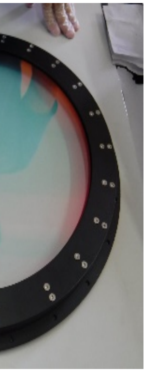
Each PDM works independently from the others

ASTRI Focal Plane

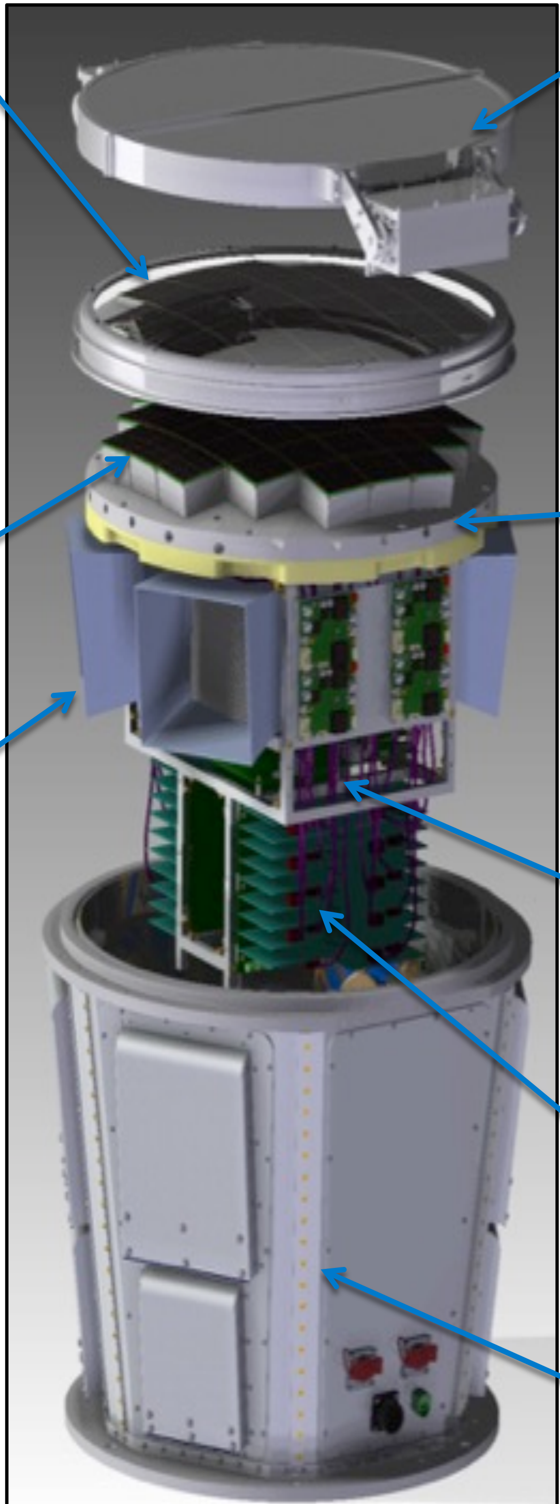


37 PDMs → Focal Pla
560×560mm

ront window



Assembling in lab

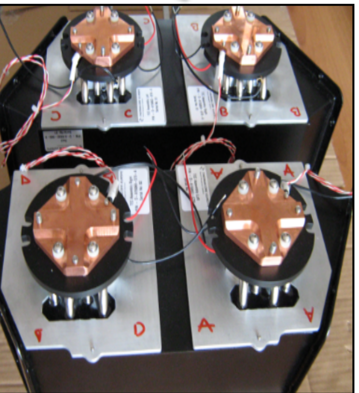


Lids

Photon Detection Module

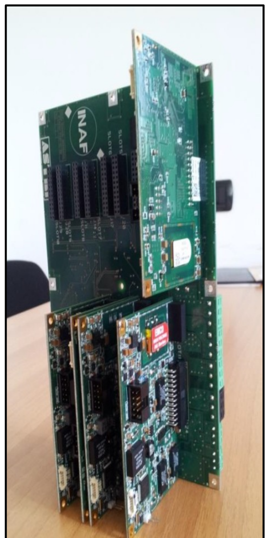
Focal Plane Support Structure

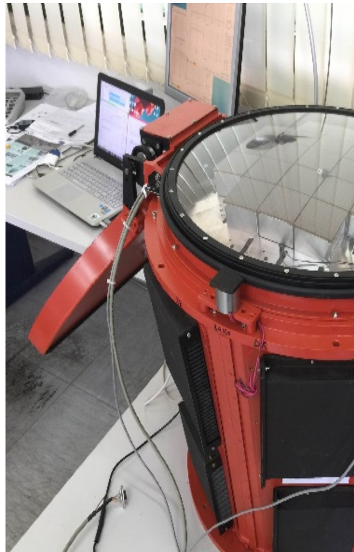
Thermal Control System



Back-End Electronics

Voltage Distributi on Board





Back-Bone Structure

PDM: CITIROC ASIC

The first batch of CITIROC ASICs is ready

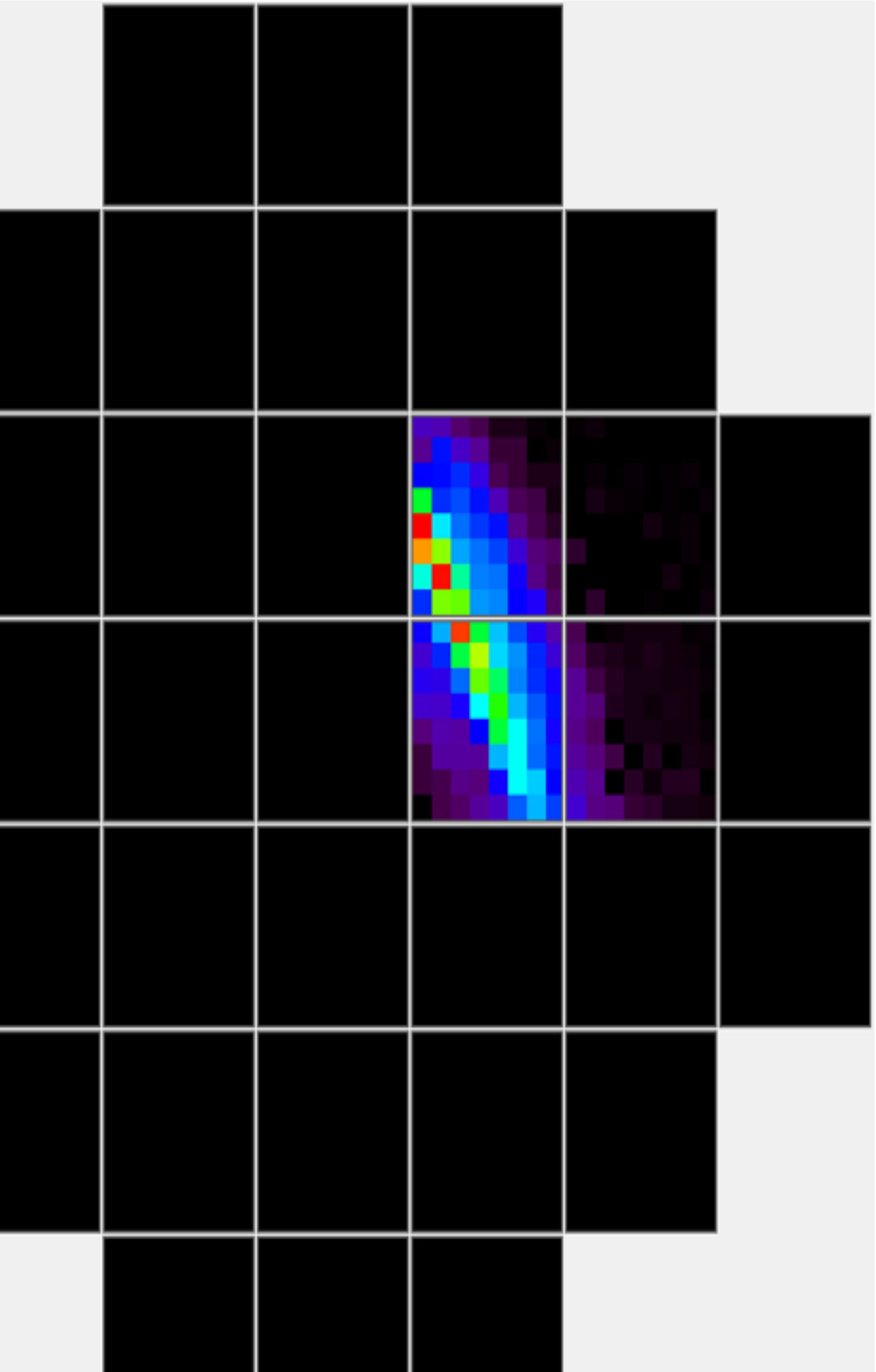
INAF has the Intellectual Property of the design

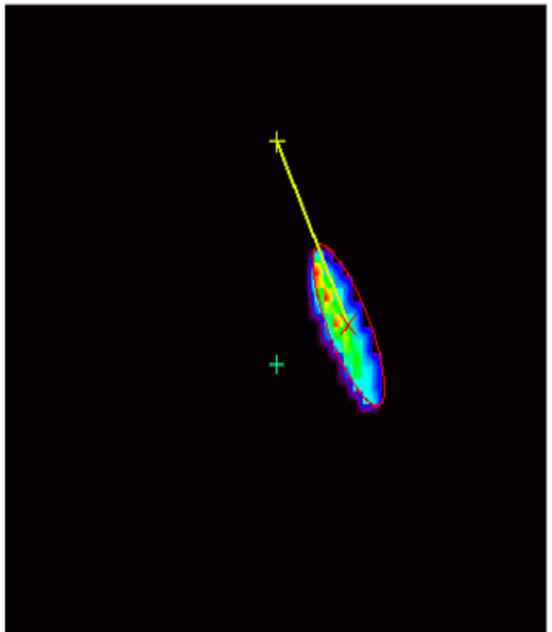
CITIROC is available as:

- LQFP160 case
- Naked die 4.1 x 4.1 mm^2

he camera has been moved and ccessfully integrated at the lescope before Easter (from 3rd 9th April) for a run of gineering tests.

22 – 26 May run





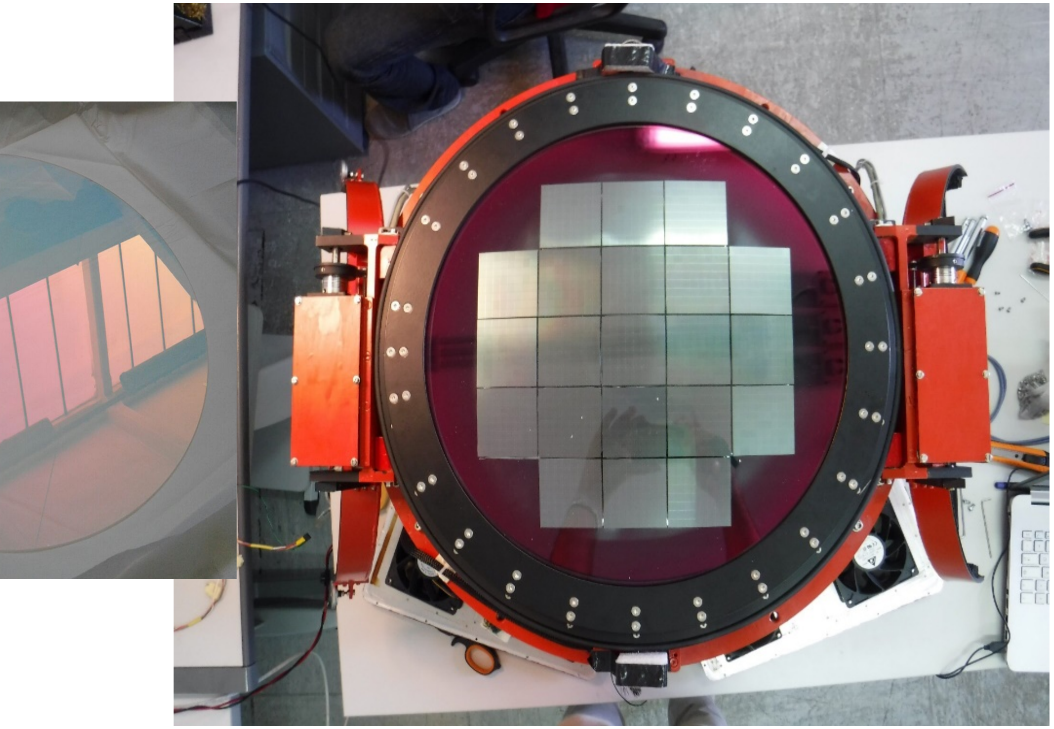
Camera settin

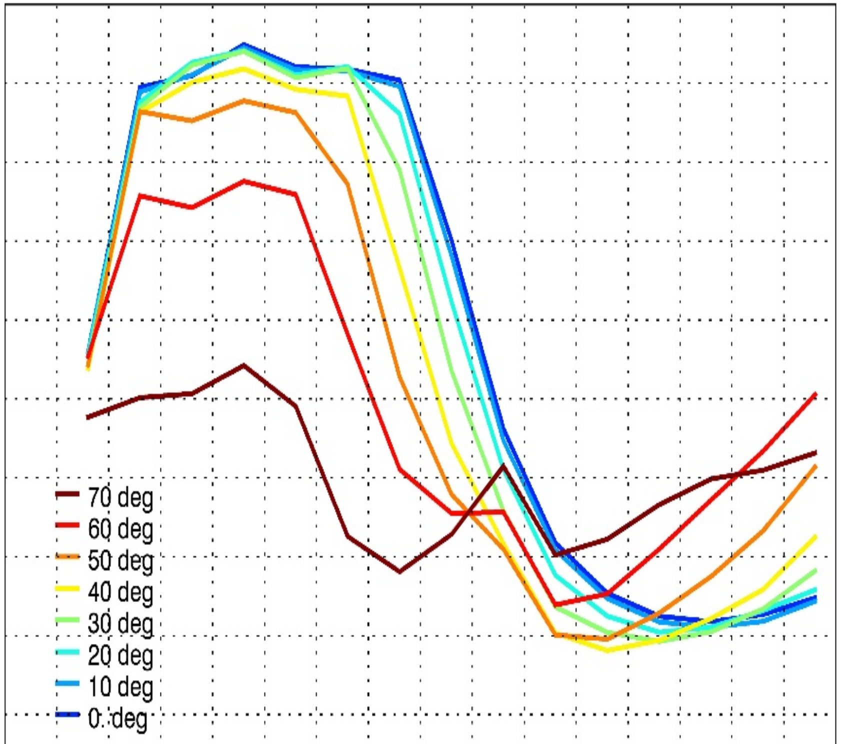
- 3 dataset with 4
  and 8 PDM in us
  trigger enabled
  one PDM only
- Topological trig
  contiguous pix
  with at least 7
  pixel.
  - Data readou
    through softwa
    very slow trig
    rate

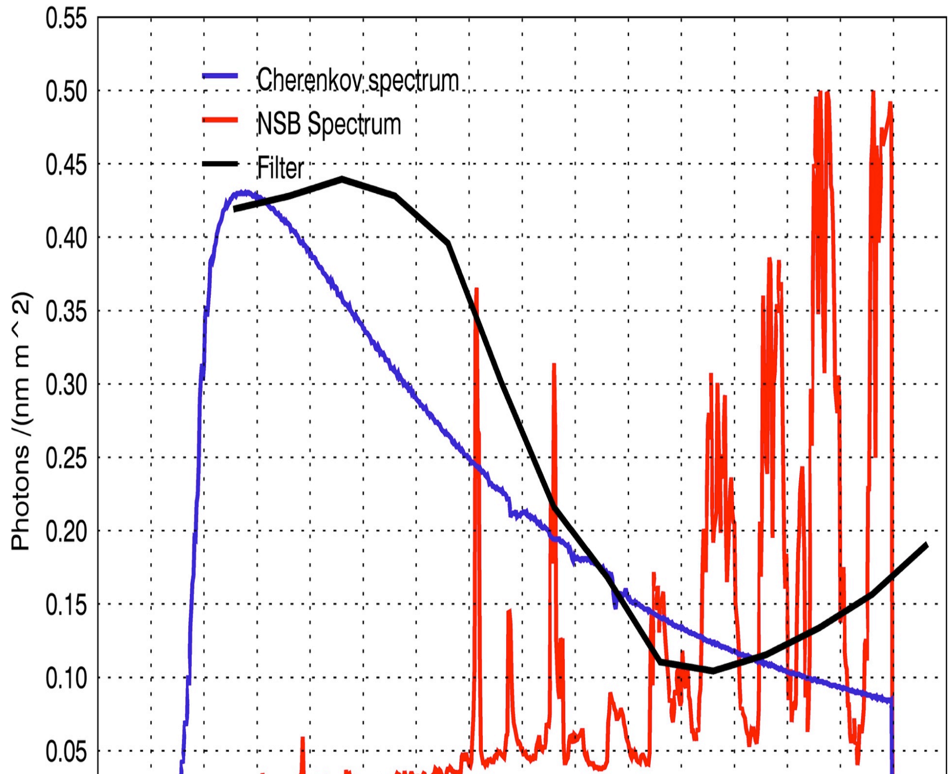
improvements

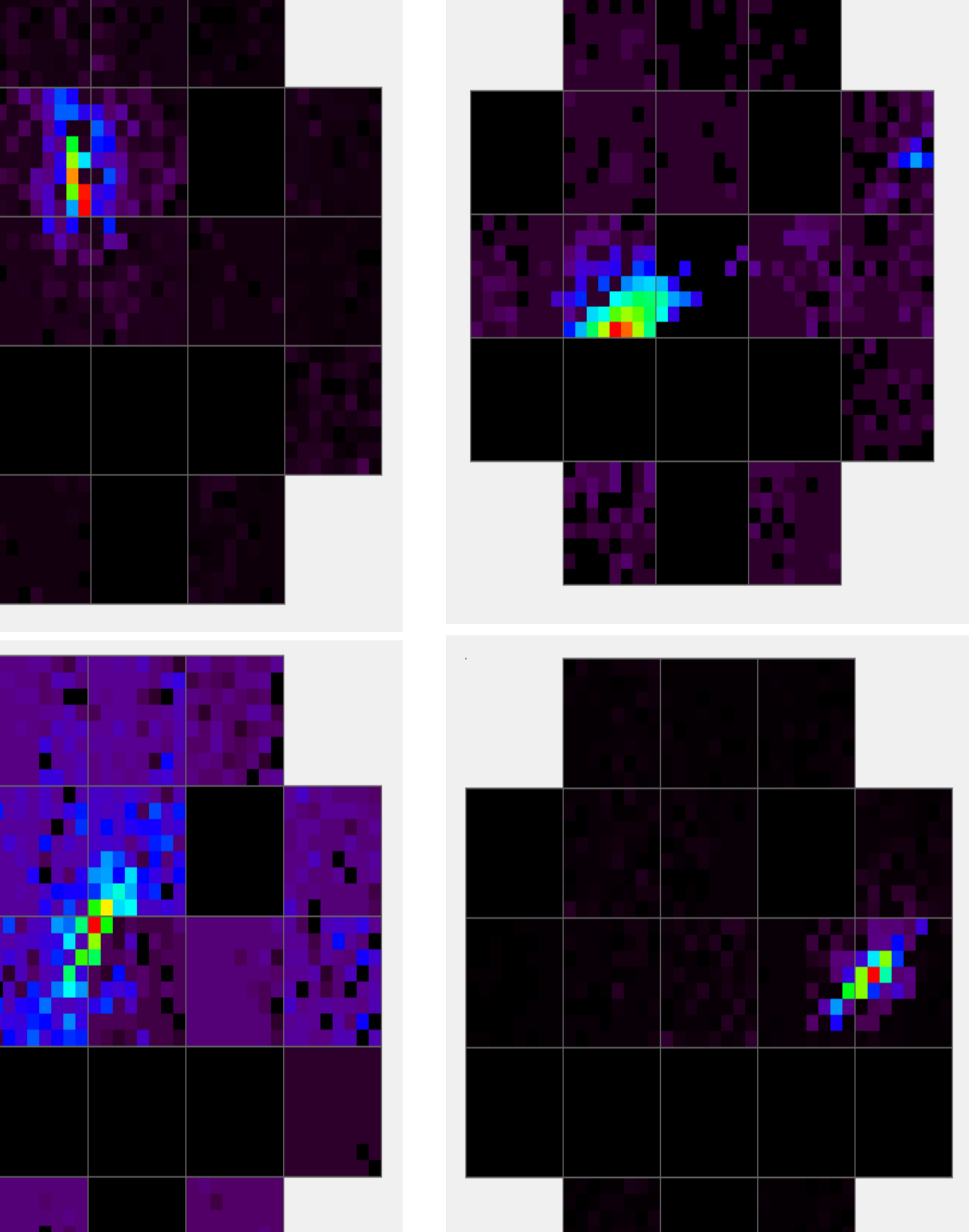
- 1Hz read out rate
- Remote programming

- PMMA window replaced by multila
filters
- Partial debug of voltage distributio
board
- Replacement of back end electron
- Debug of ancillary systems (LIDs,
Thermal Control)









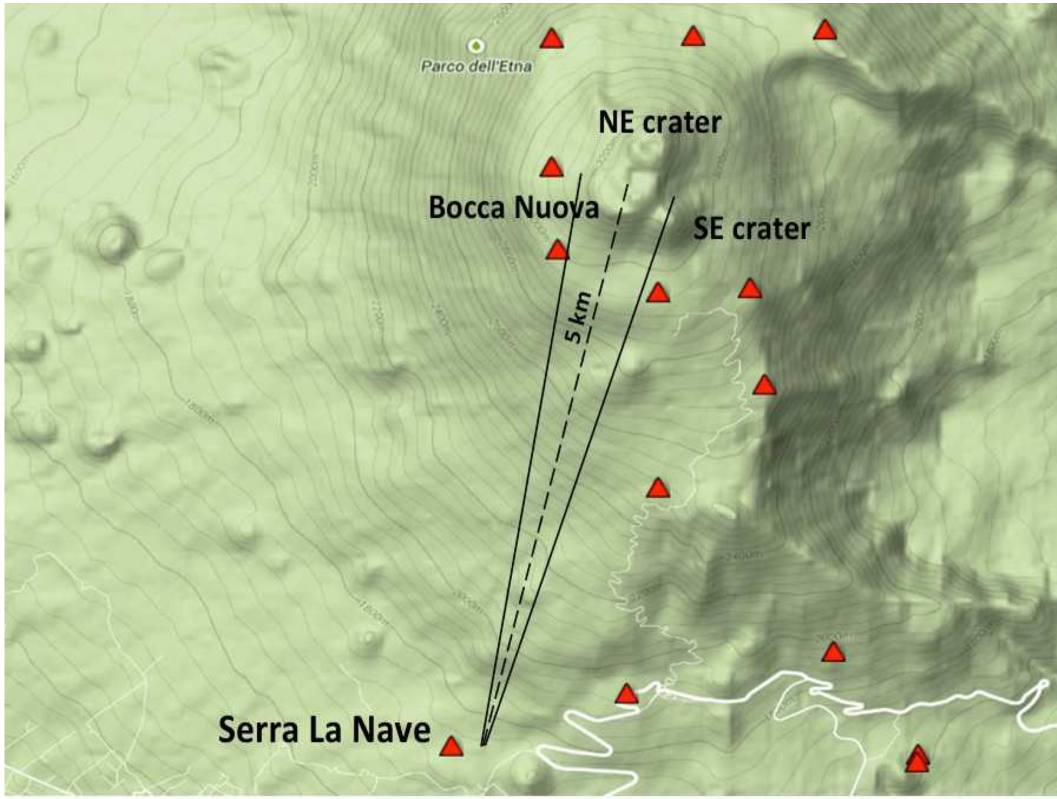
Camera settings

- **Dataset with 14 PD in use and trigger enabled for all PDM**
- **Topological trigger: contiguous pixels w at least 7 pe/pixel.**
- **Data readout: 1 Hz rate**

Observational Pla

- **Pointed observatio on sky**
- **Muons coming from volcano**
- **Tracking observatio on selected sources**
  - **MRK 421**


muon


Parco dell'Etna
NE crater
Bocca Nuova
SE crater
5 km
Serra La Nave

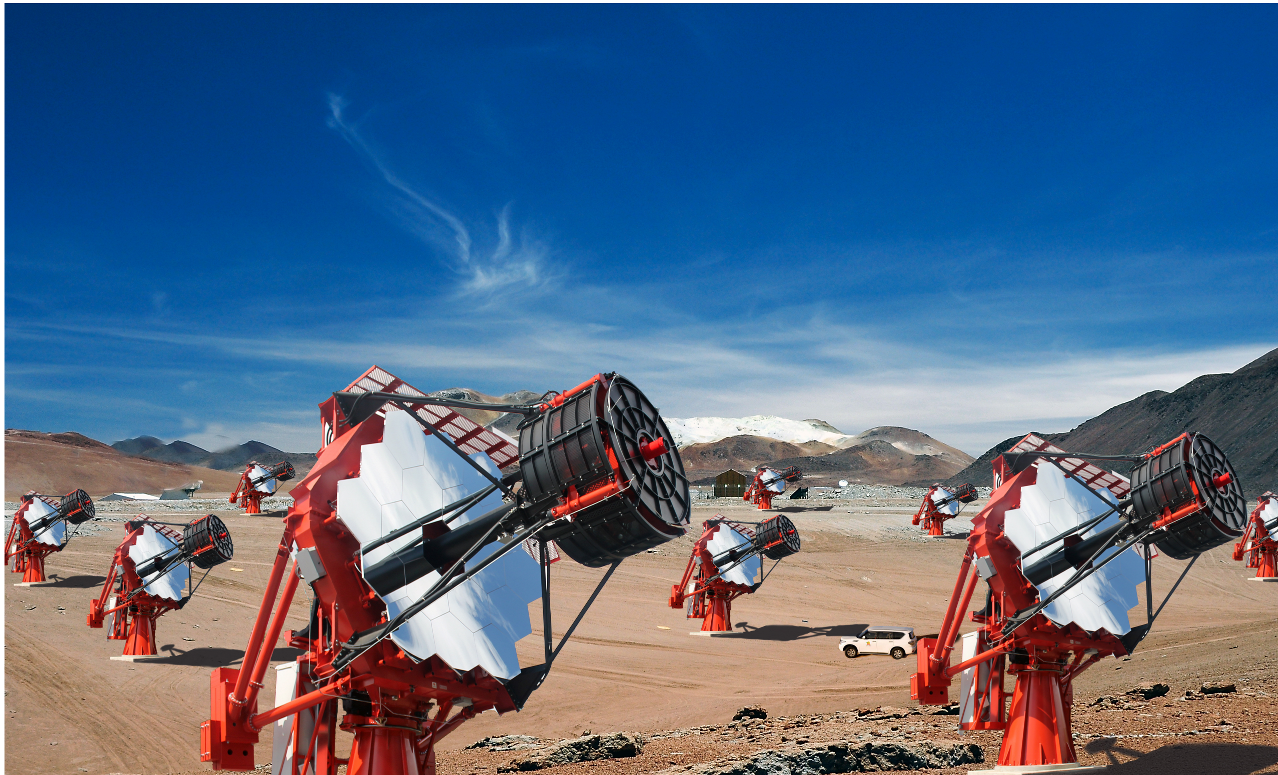
A reduced array

ASKAP – Austraulia (SKA precursosr)

KAT7 – South Africa (SKA precursor)

pal is the deployment and the operation
nini-array composed of a few
2M telescopes at the final CTA
ern site.

t concept...




by INAF in collaboration with:
Universidade de São Paulo & FAPESP, Brazil
North-West University, South Africa
INFN (trigger facility and SW)
250-300m

aim is to **test both the SST-2M technological and scienti** **ormance** at energies above a few TeV by means of **prolon** **ntings.**

actic science ➔ choose sky regions containing multiple targ

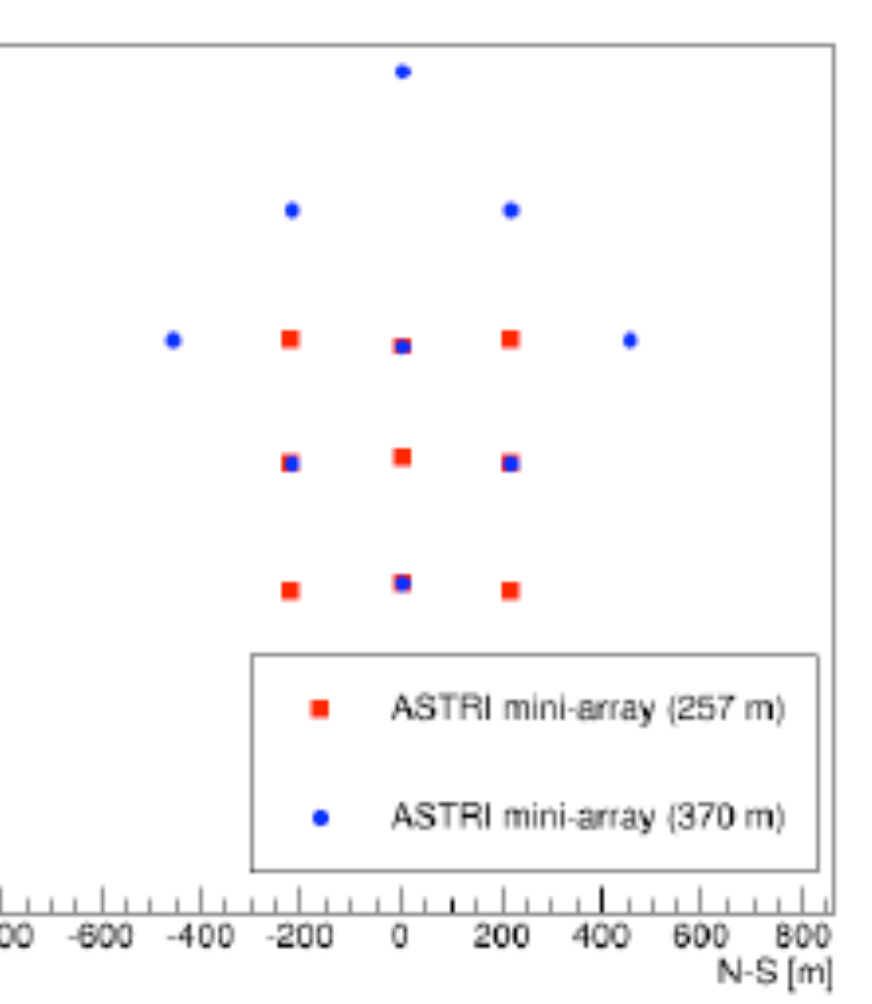
a-galactic science ➔ select a few promising targets.

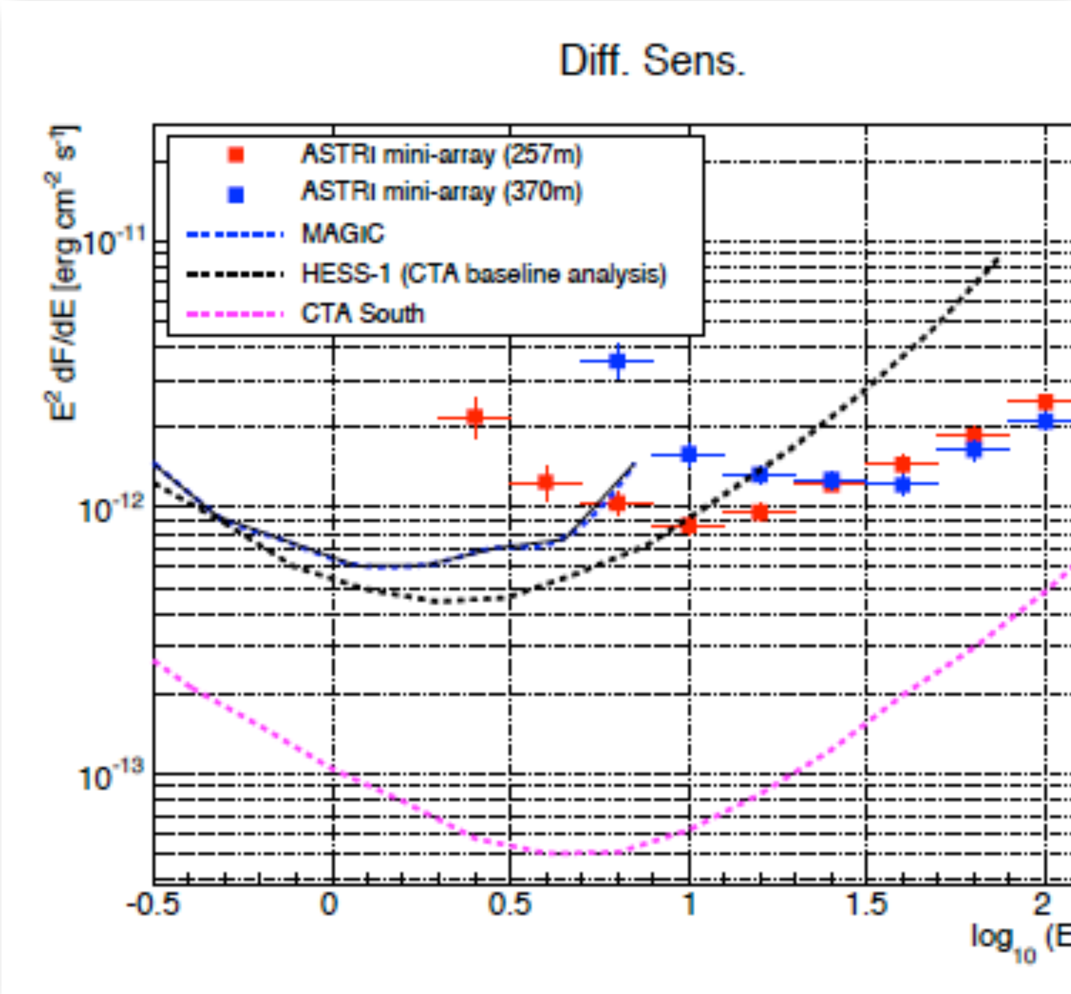
damental Physics ➔ nearby blazars, GC, and dSphs.

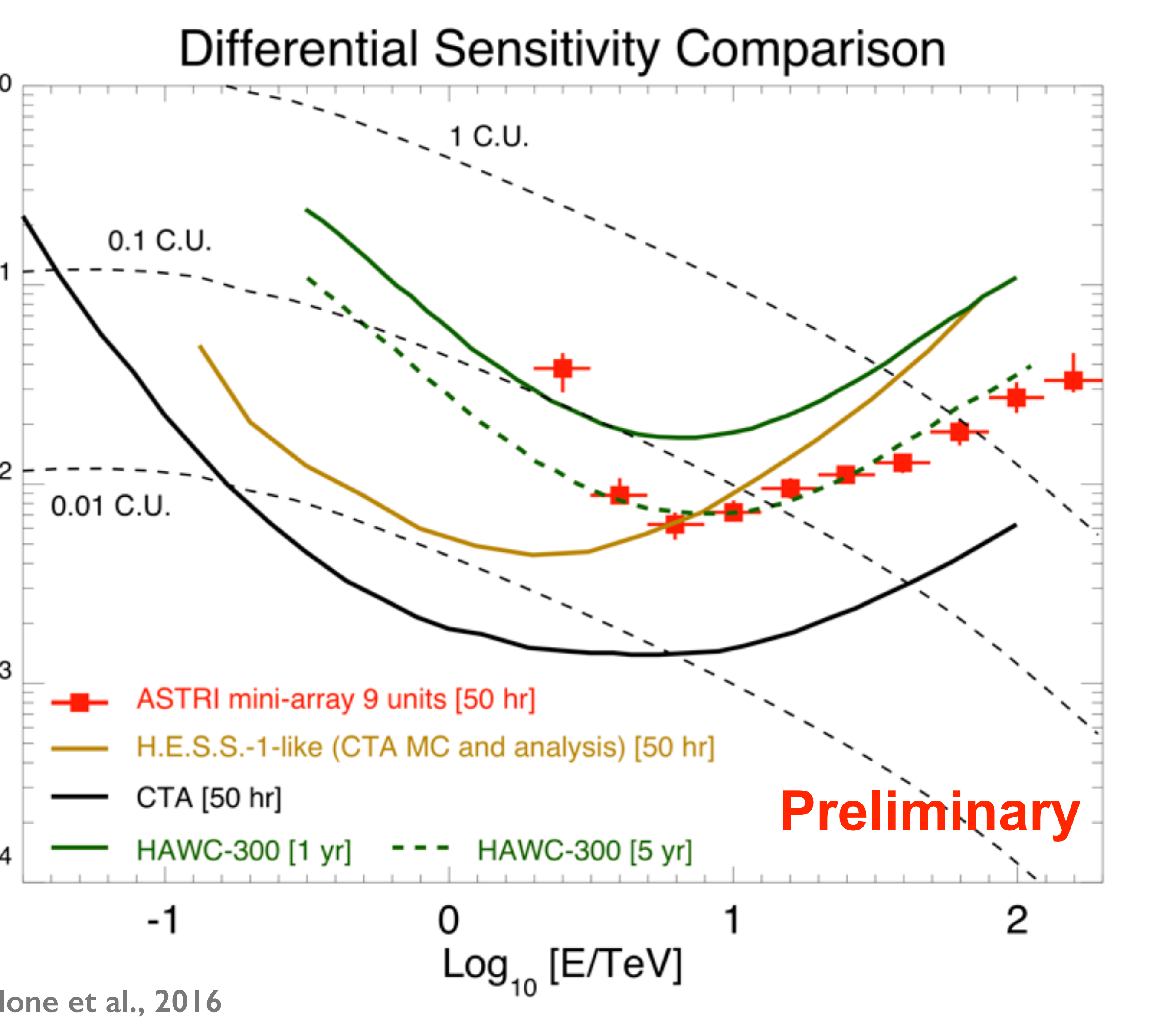
ergies with facilities dedicated to transient follow-ups are of mount importance.

te Carlo activities cover (at least) the following topics:

nvestigation of the mini-array performance
ptimisation of the SST array layout
roduction of the IRFs for the scientific simulations







Limiting flux

slightly better than curr
generation of IACT above f
(~10) TeV for an array
composed by 9 telescopes

Angular resolution

a few (4-5) arcmin

Energy resolution

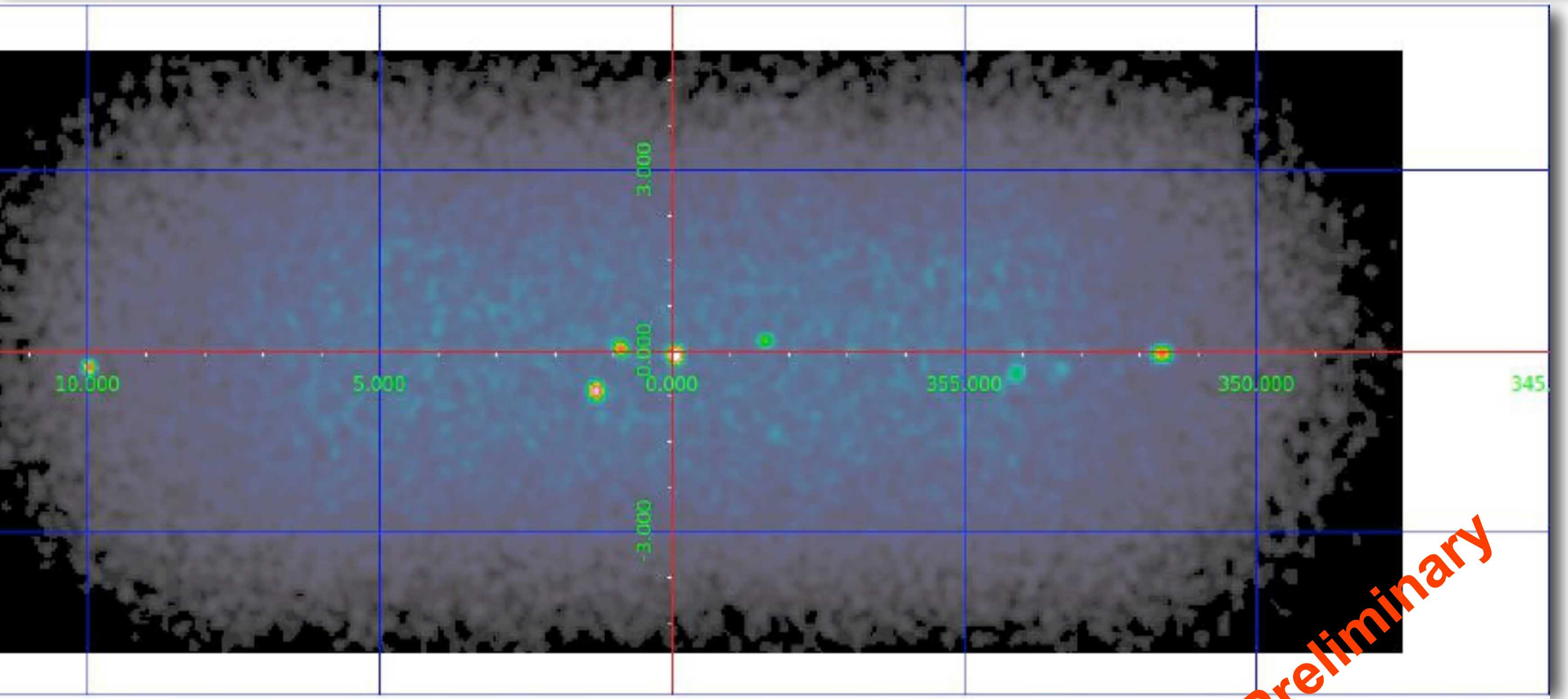
of the order of 10-15 %

**RI SST pre-production CTA telescopes will have a bette
sitivity at E >10 TeV for extended sources with respect to**

eveloped a fast scientific simulator, ***ASTRIsim***, which can simulate both p
nd extended sources, and which makes use of the IRFs computed by the
e Carlo code.

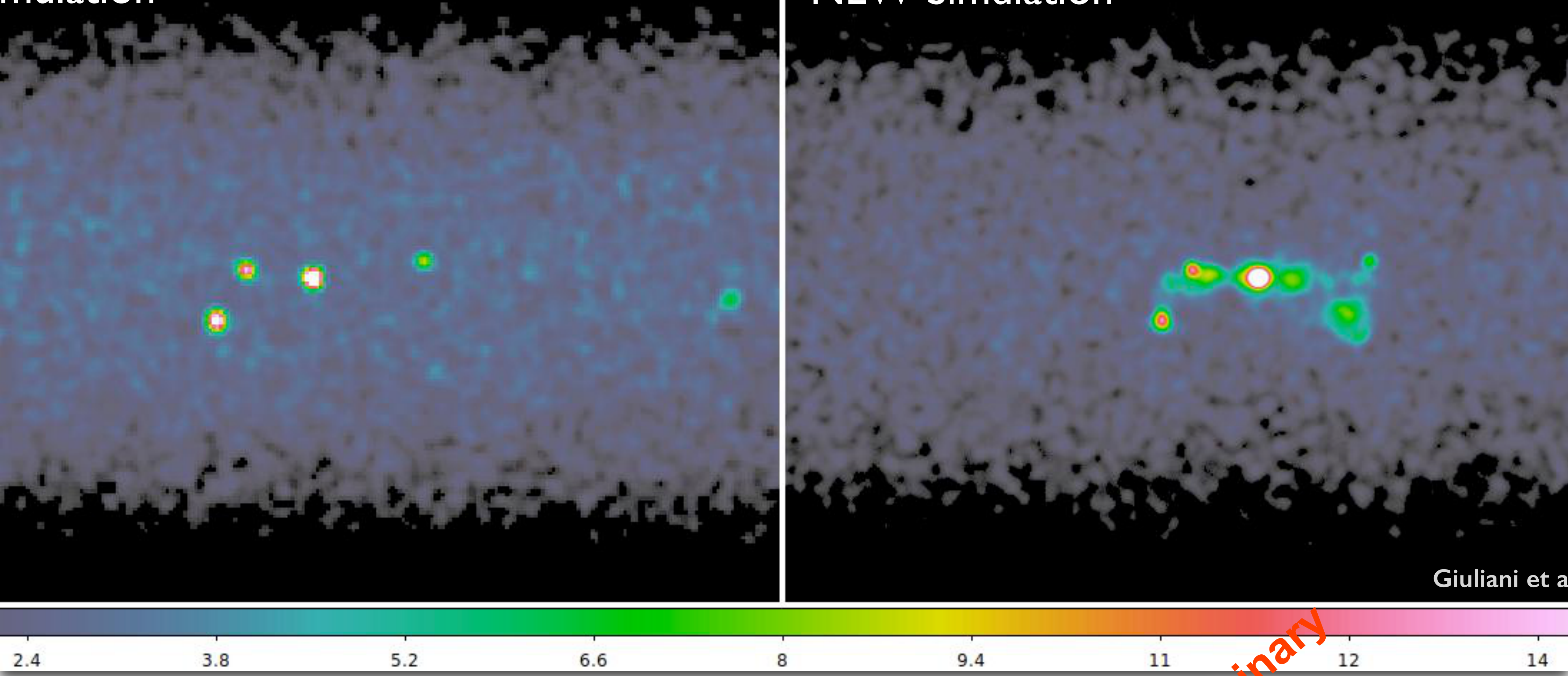
alogue of Cherenkov sources has been compiled, which is used as a star
for the *ASTRIsim* tool.

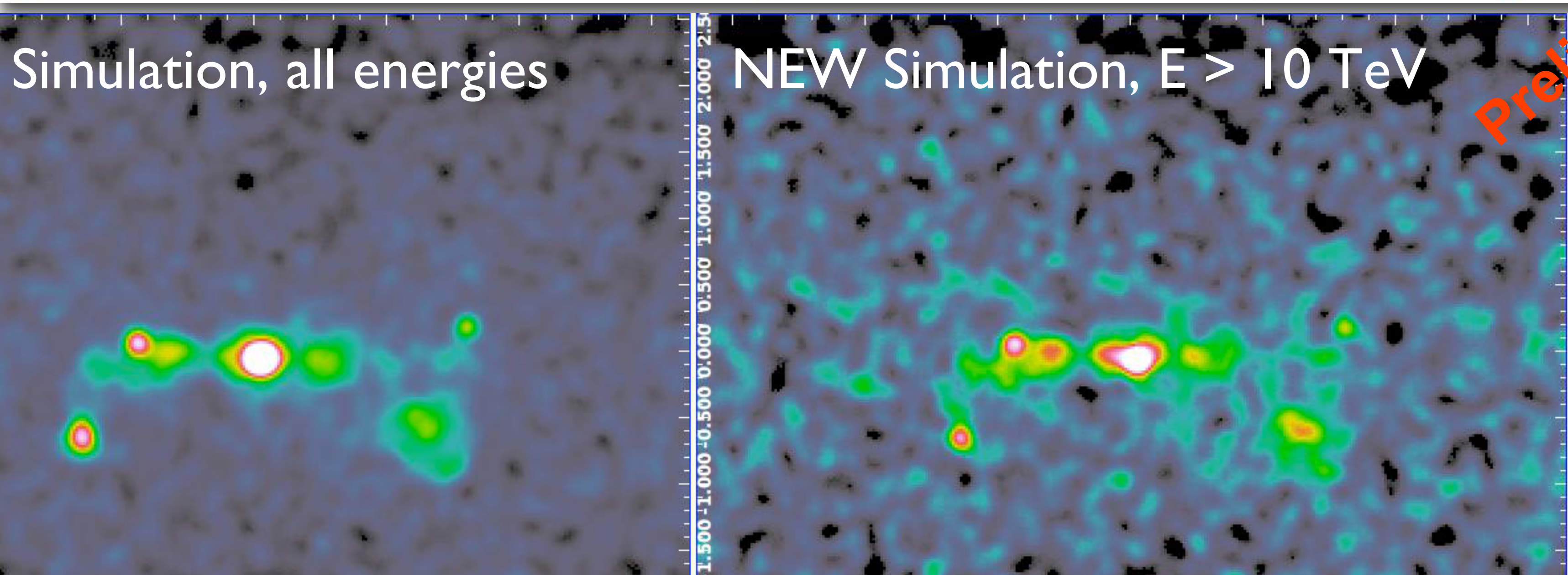
ASTRIsim output is fully compliant with the standard CTA analysis tools
ols). Dedicated analysis tools (spectra, significance,...) have also been
loped and integrated in the *ASTRIsim* SW suite.



ASTRI mini-arra
simulation of the
Galactic Center
~240 hr, 5 point

Giuliani et al., 201





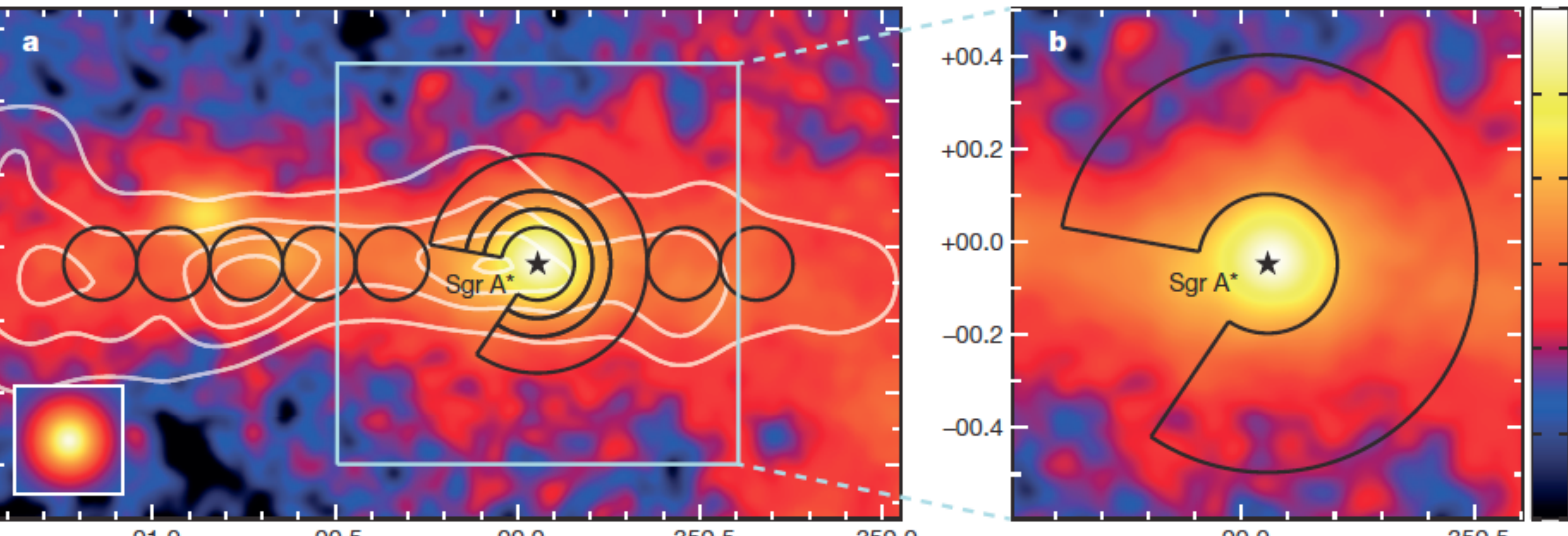
ASTRI mini-arra
simulation of the
Galactic Center
~240 hr, 5 point

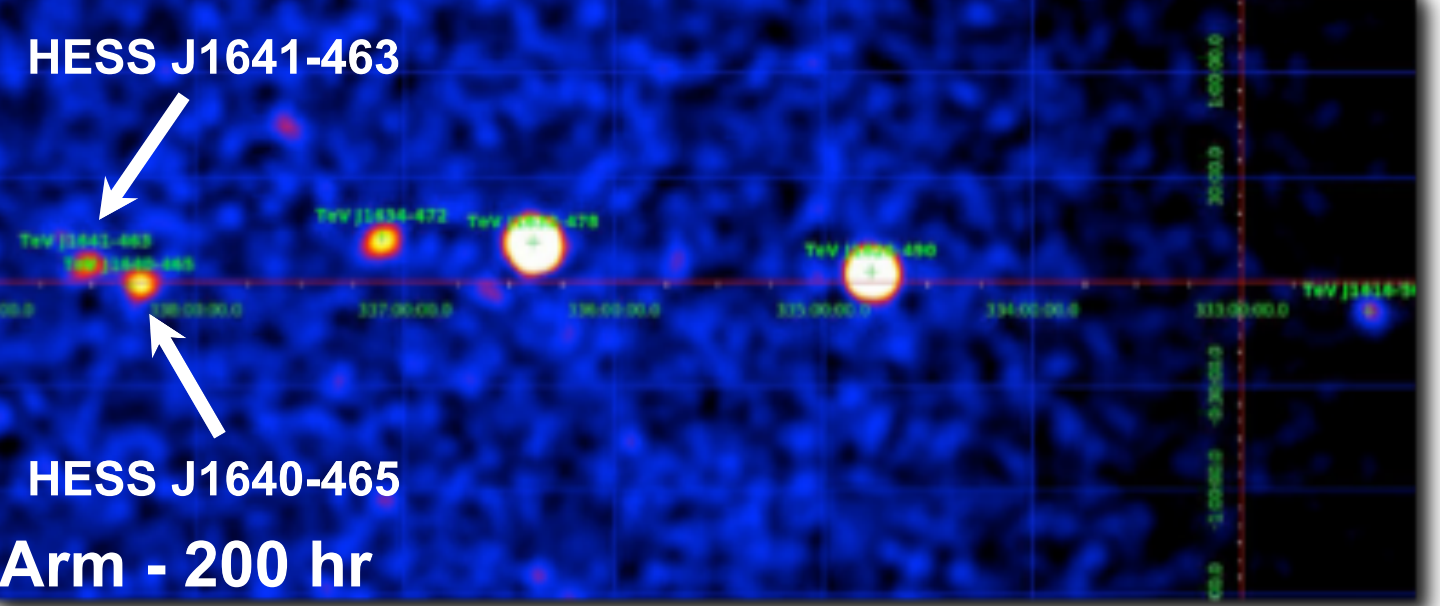
ETTER

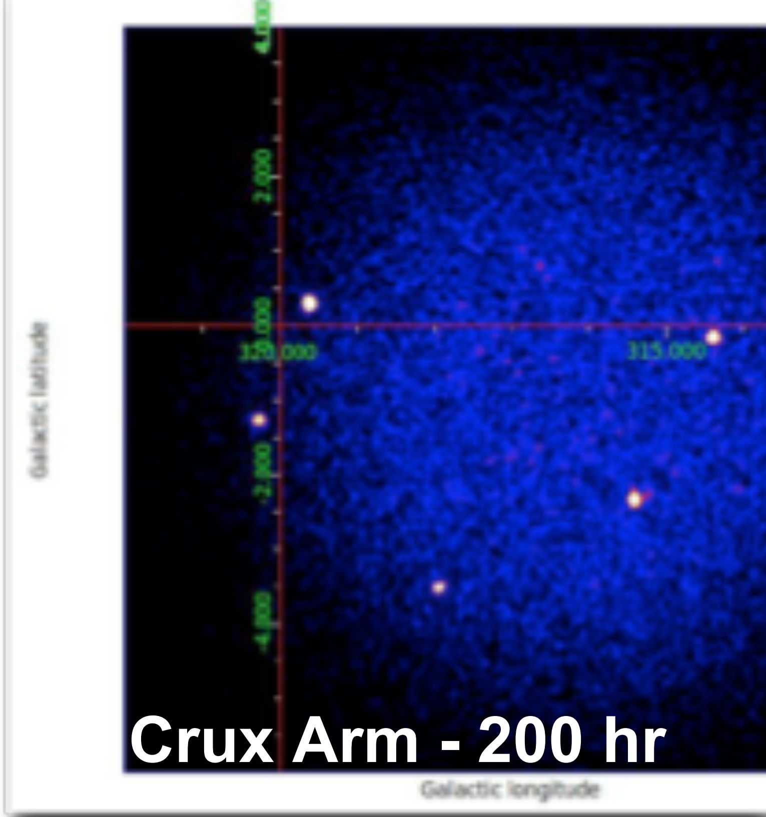
doi:10.1038/nature1

celeration of petaelectronvolt protons in the
actic Centre

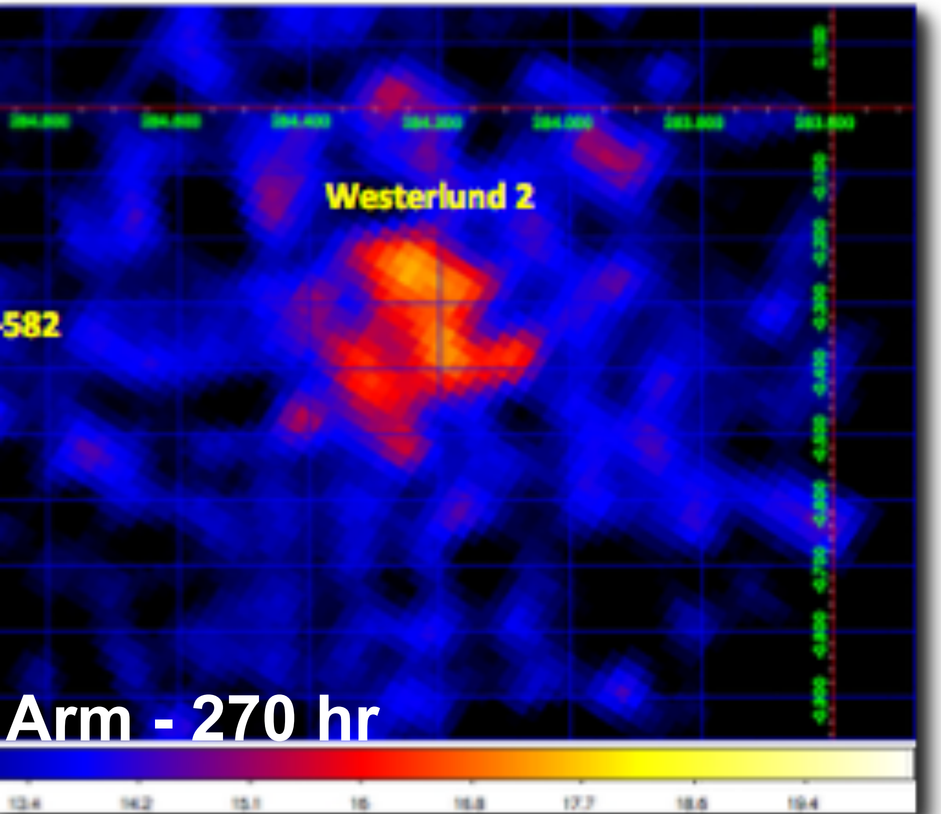
ollaboration*







Preliminary



Deep observations of Galactic Arms
Simulation based on the current performanc
the ASTRI mini-array of pre-production CTA
telescopes (by means of a dedicated SW).

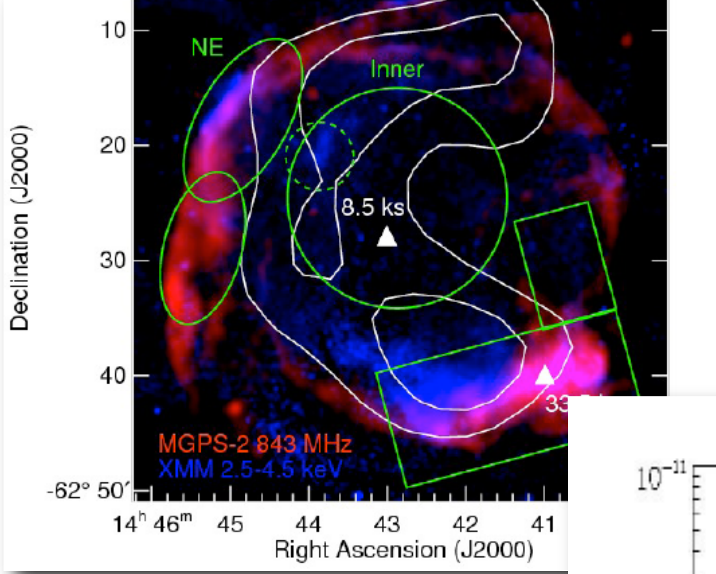
RCW 86

y **young** SNR (2000 yrs)

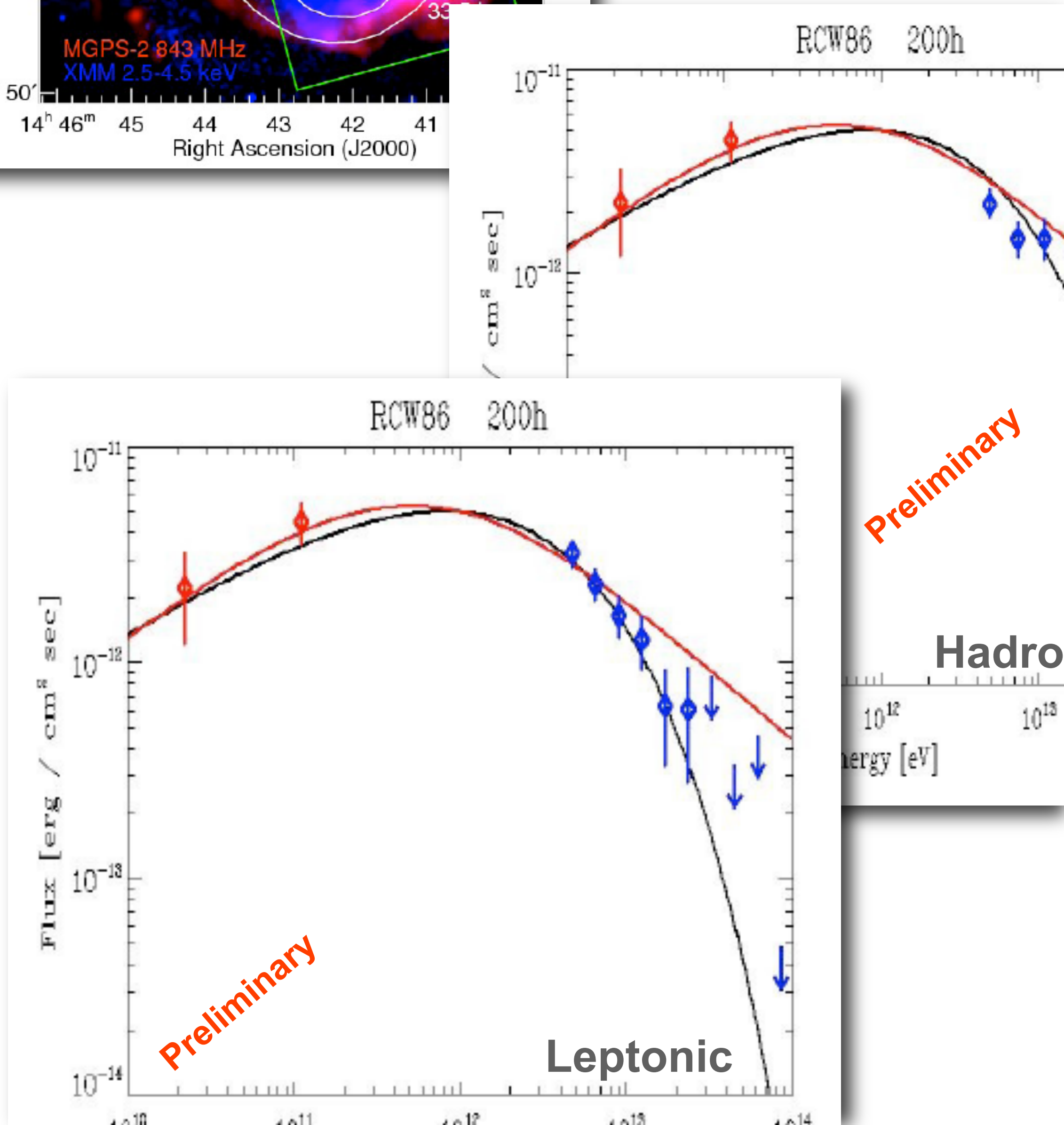
in Radio, X, GeV (*Fermi*),
(H.E.S.S.)

ted origin:
eracting source with
cular clouds or
J1713-like source ?

RI mini-array (blue points,
nulated data) can
criminate between
dronic and leptonic
enario and (if hadronic) look
VHE($\sim 5 \times 10^{14}$ eV) CRs



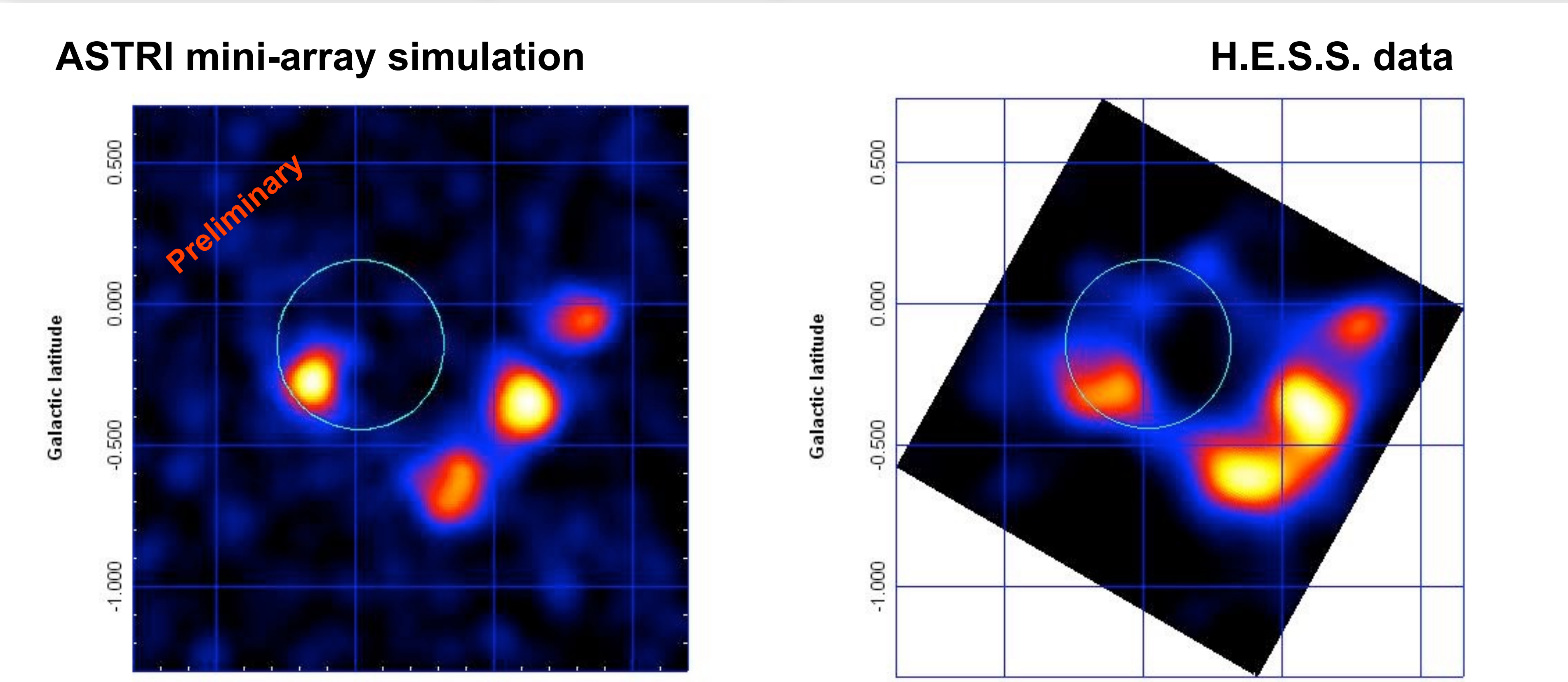
Giuliani et al, in prep



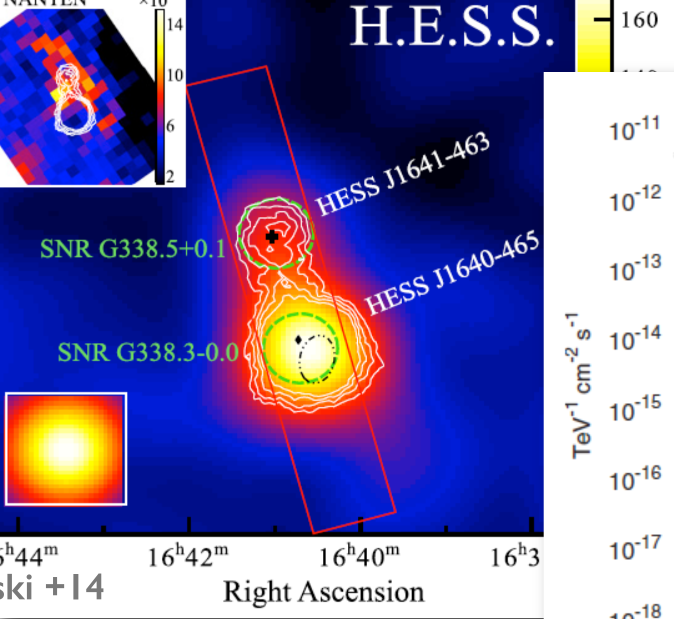
lved SNR interacting with a giant molecular cloud (MC), very bright a
energies

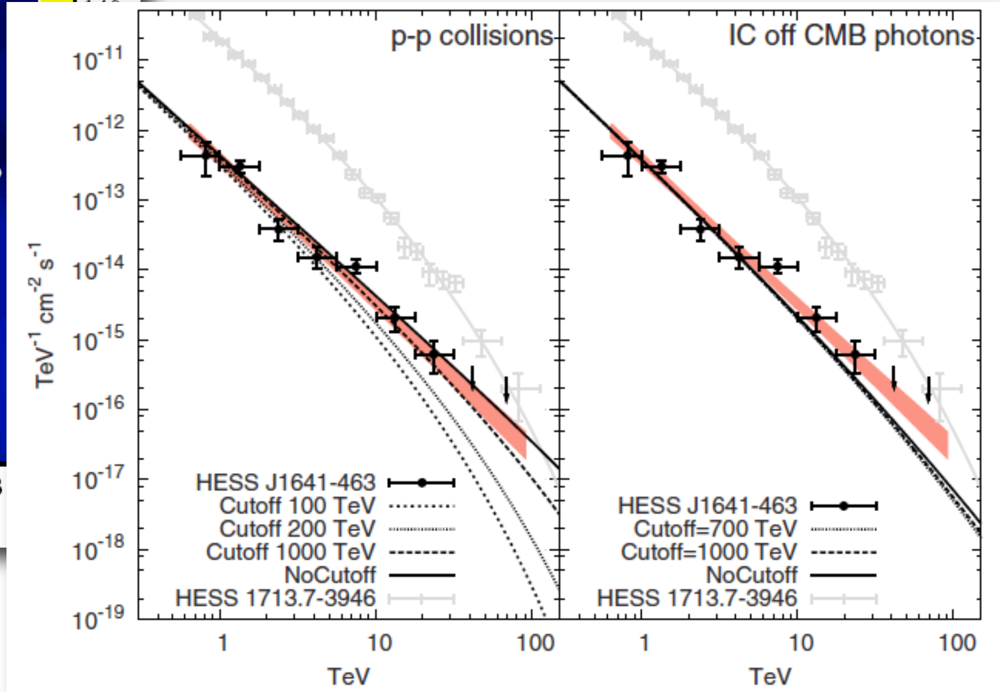
S.S. resolved this source in almost 4 point-like sources near the MC

RI mini-array can better resolve the source and study the diffusio
ar from the SNR shell (blue circle)



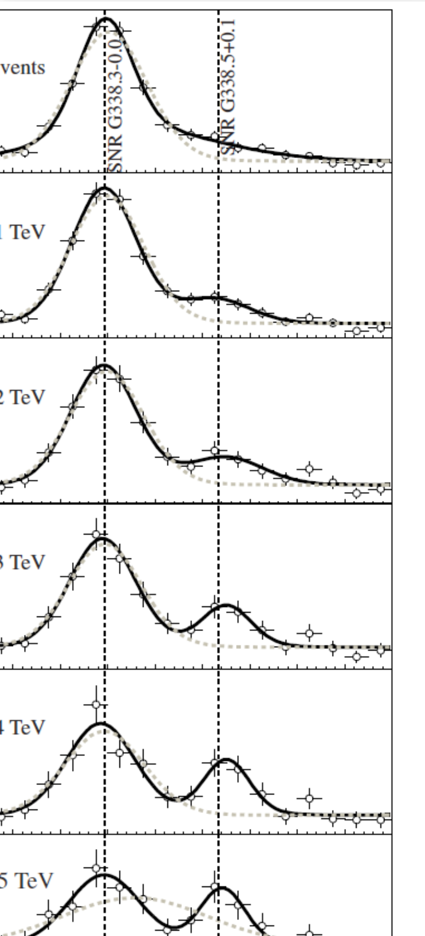
Abramowski+ 14

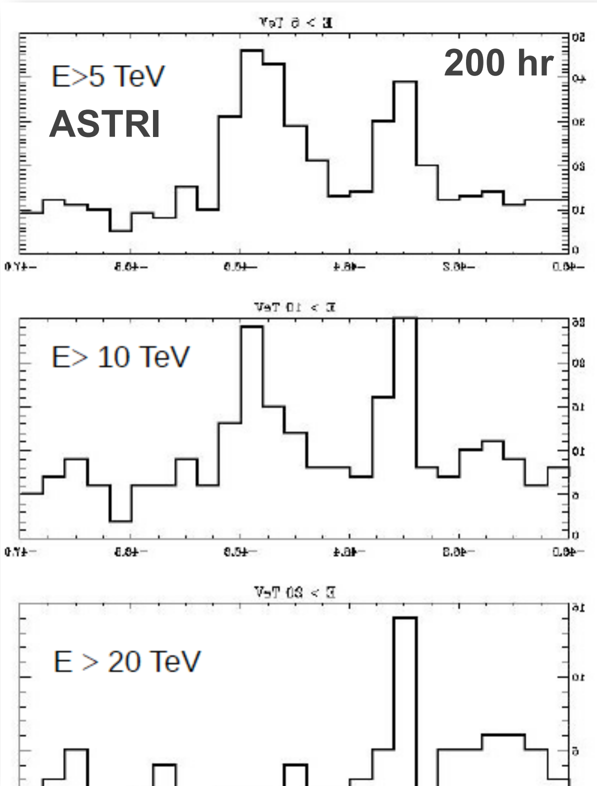




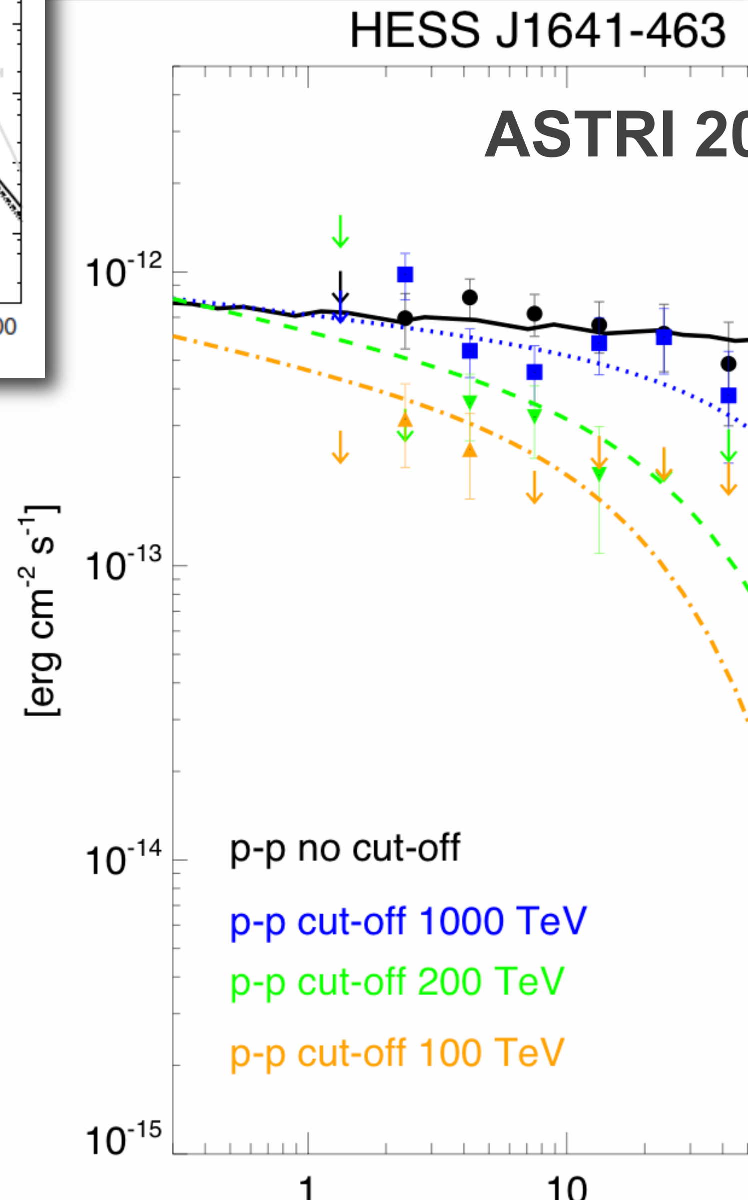
Hard source Ph. Ind
Uncertain nature

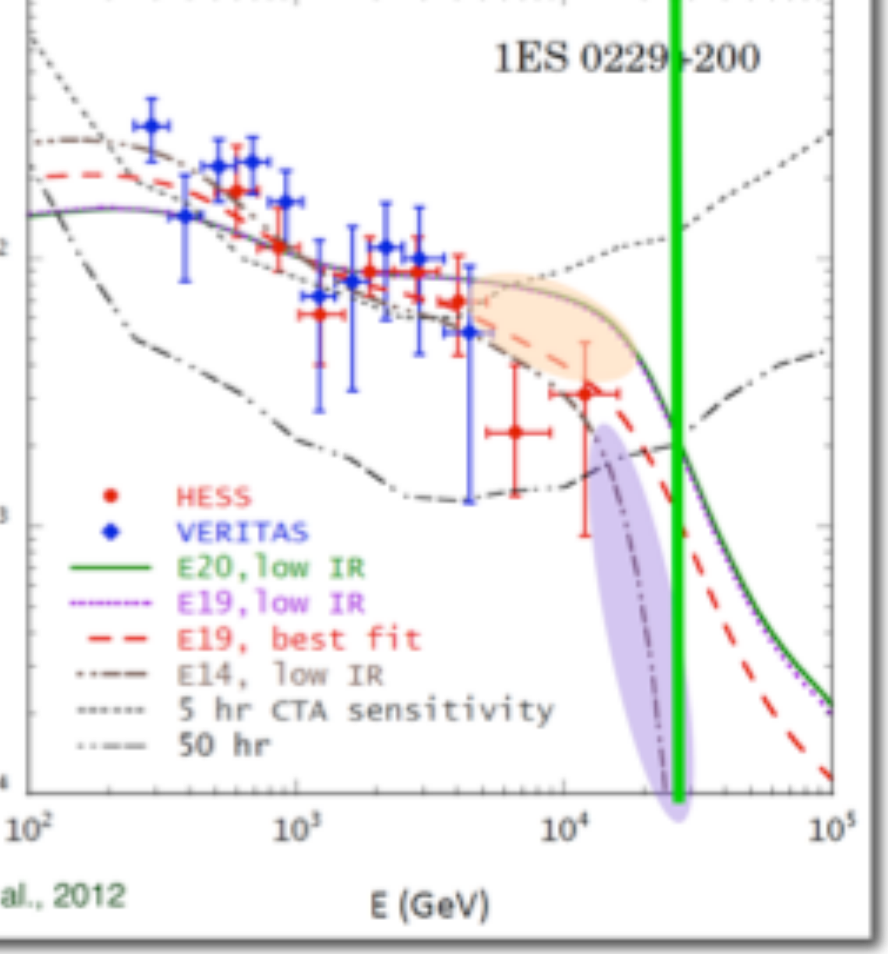
Simulations by the A
Science Team





Preliminary





E-HBLs are characterized by:

- extremely low radio luminosity;
- luminous and hard X-ray emission;
- synchrotron peak above 10 keV;
- low variability at TeV energies.

1ES 0229+200 E-HBL SED can be fit b
both the **gamma-ray-induced cascad**
and **proton-induced cascade** emissio

gher energies, however, UHECR-induced cascade emission become
er than gamma-ray-induced cascade emission.

tection of >25 TeV gamma-rays is consistent with an hadronic
ma-ray emission

e ASTRI SST-2M prototype, commisioning phase E2E almost
mpleted.

e ASTRI mini-array will constitute one of the *pre-production* set of
escopes for the whole CTA array, allowing us to investigate innovati
chnological solutions.

TA early science performed by means of ASTRI mini-array observat
a few selected sky regions will allow us to obtain several solid detect
ring the first year.

cellent synergies with other pre-production CTA telescopes (SSTs,
STs, LSTs) and with several observing facilities from 2017 and beyo

ptical stability of the PSF tested in different seaso
conditions. No need for realignment after about 6
months

herenkov Camera @ SLN –> Next week run with s
observations

NSB filter for the camera at the telescope. PSF insi
specification and shift about 2 mm in the focal plan
position as foreseen by simulations.

SW: next release of the control software in a mont

uxiliaries: UVScope & Illuminator under test and te

unt Etna showing satisfaction for the cam