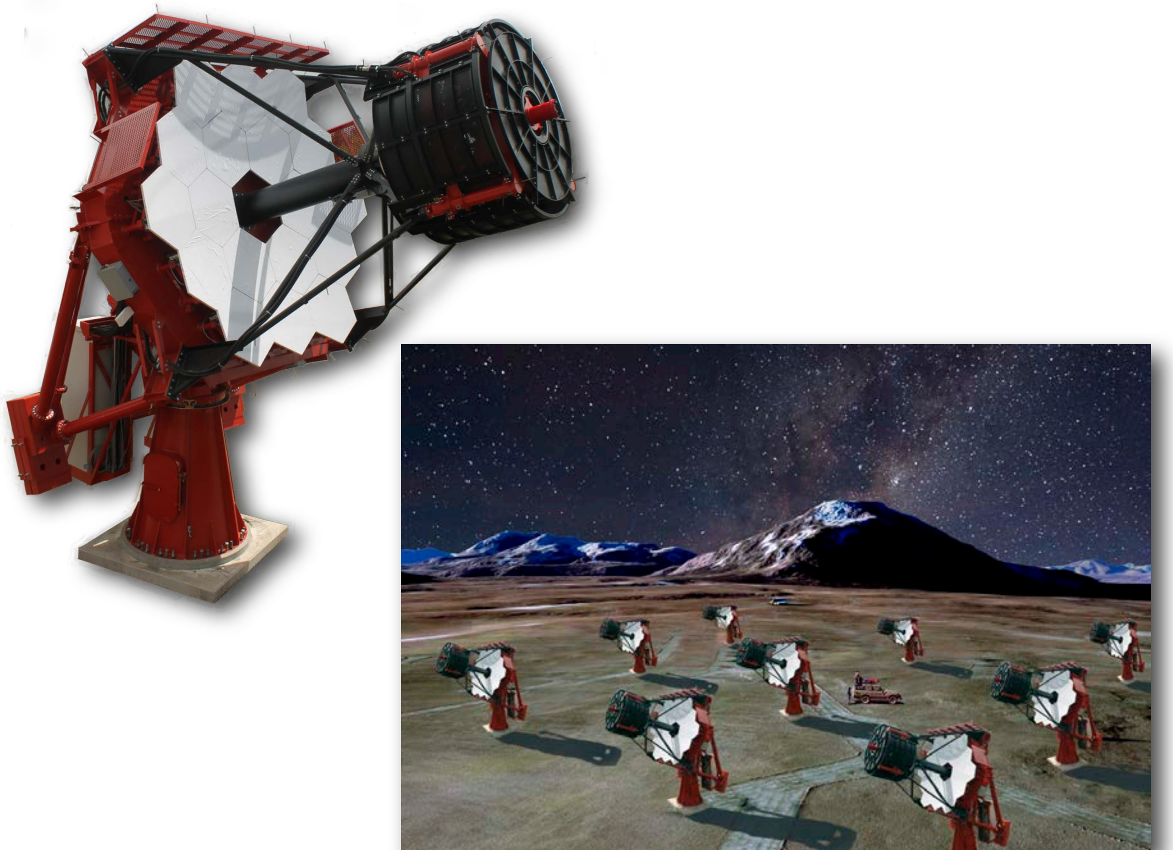

ASTRI Astrofisica con Specchi a Tecnologia Replicante Italiana

cta cherenkov telescope array

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

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

MIUR

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

The second phase of the ASTRI project: a mini-array of telescope precursors of the Cherenkov Telescope Array (CTA) at its southern site

S. Vercellone (INAF/IASF Palermo)
on behalf of the ASTRI Collaboration and the CTA Consortium

Outline

The ASTRI SST-2M end-to-end prototype
- Technological innovations
- Present status and preliminary results

The ASTRI mini-array of precursors
- Main performance
- Scientific cases
- Synergies with current and future facilities

Outlook and Conclusions

Outline

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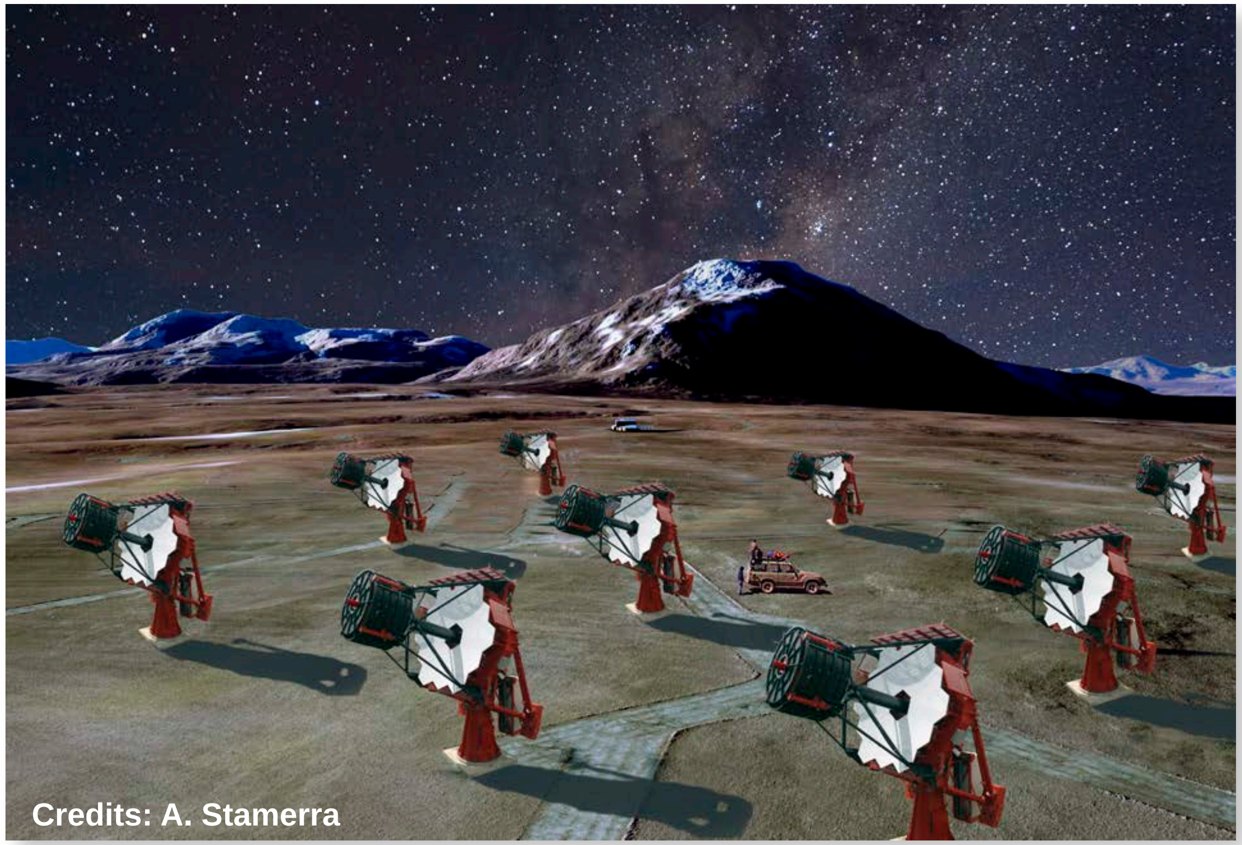
Outlook and Conclusions

The ASTRI Project

The INAF-led **ASTRI Project** has two main goals:

- an **end-to-end prototype** of the **CTA small-size telescope** in a dual-mirror, Schwarzschild-Couder configuration (ASTRI SST-2M), inaugurated on 2014 Sept. 24th and currently under test at the INAF observing station on Mt. Etna (Sicily);
- an **ASTRI mini-array** of precursors composed of **nine telescopes** proposed to be installed at the chosen CTA Southern site in 2016.


Credits: T. Abegg


Credits: A. Stamerra

The ASTRI Project in a nutshell

- Project funded in 2010-2014 by the Italian **MIUR "Progetto Bandiera"** (> 40 FTE)

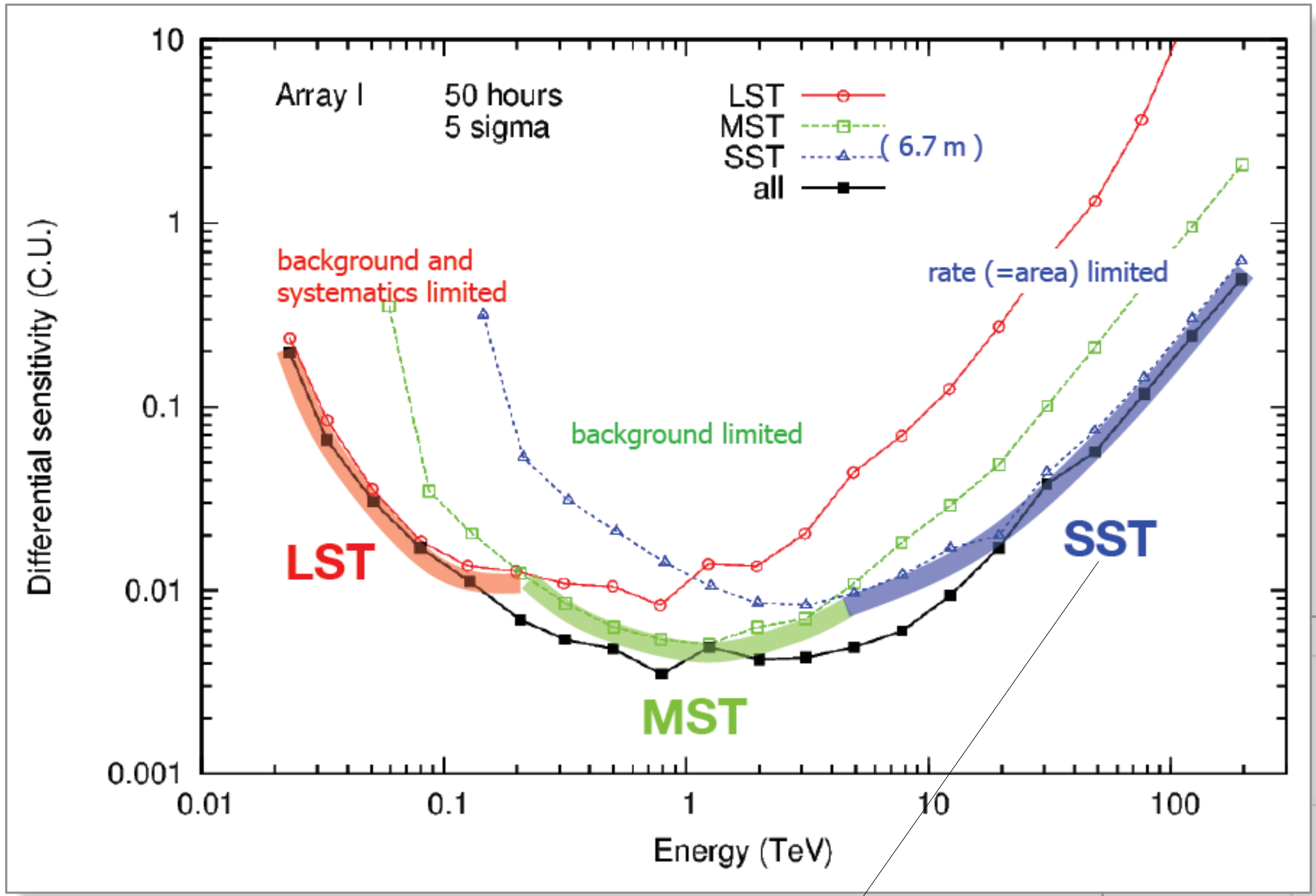
- Now the project continues with the support of **MIUR ("Progetto Bandiera extension") and MISE ("Industrial Astronomy" program)** with the participation of **Universities from South Africa and Brazil**

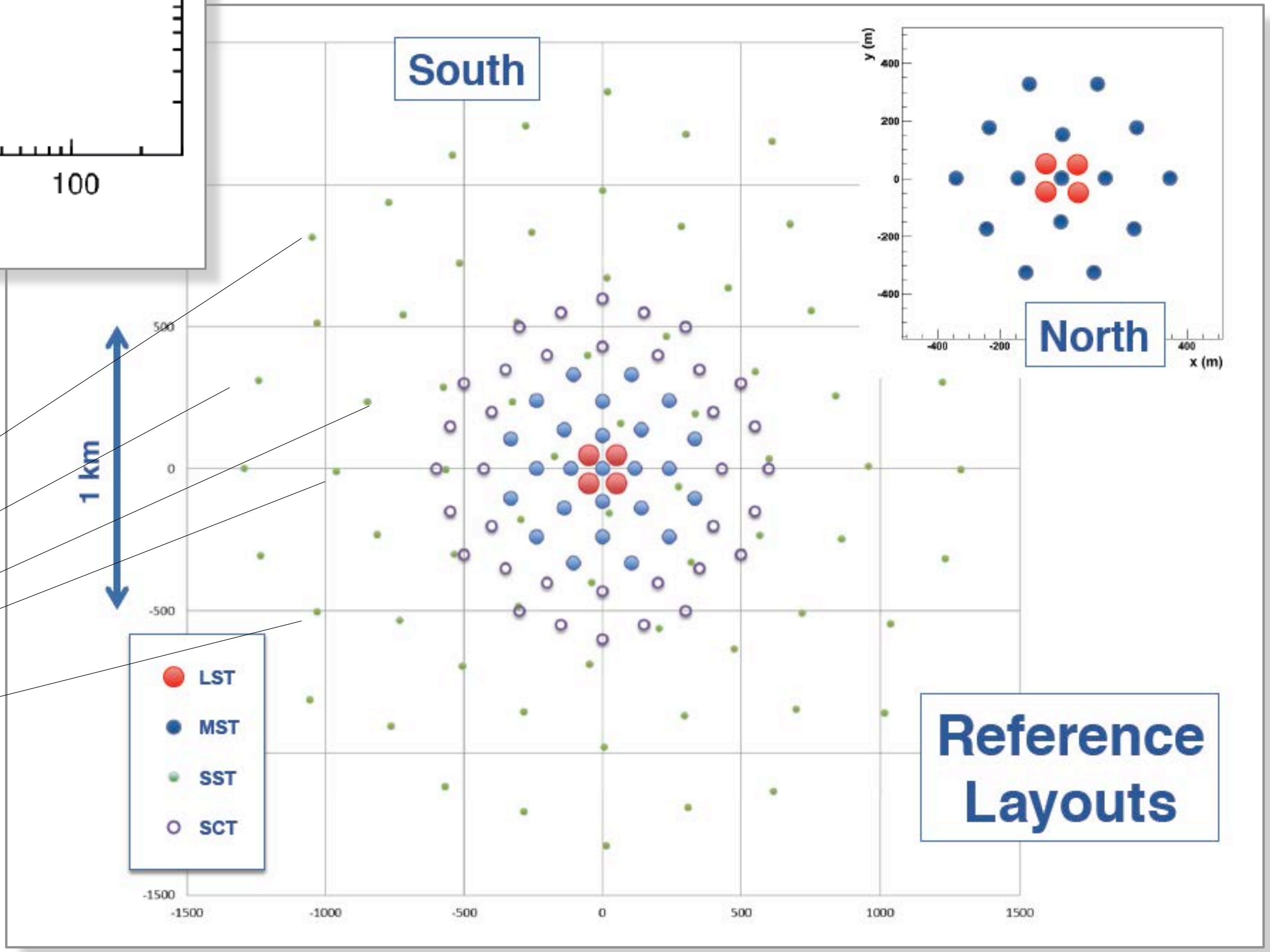
- **End-to-end SST-2M prototype:**
  - Validation and commissioning of the telescope via Cherenkov astronomical observation

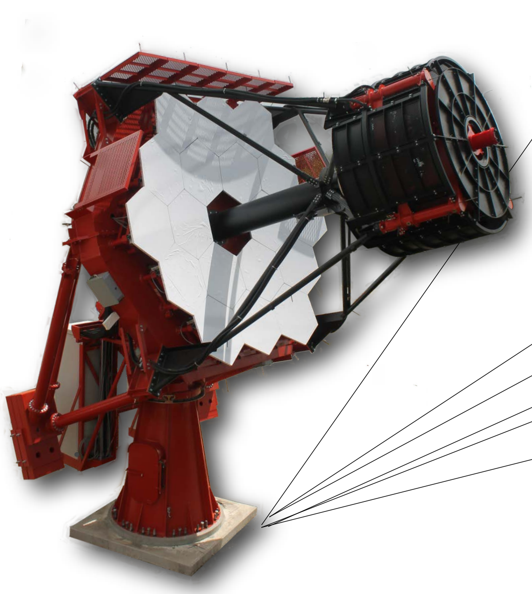
- **End-to-end implementation of a mini-array** (# ≥ 9) of SST-2M (pre-production) at the CTA southern site:
  - Validation and commissioning of the array (including trigger and SW) via Cherenkov astronomical observations, first CTA scientific data

- **Aiming at the construction of 35 out of the 70 SST units** of the CTA southern array

The ASTRI Project and CTA







The ASTRI SST-2M E2E prototype

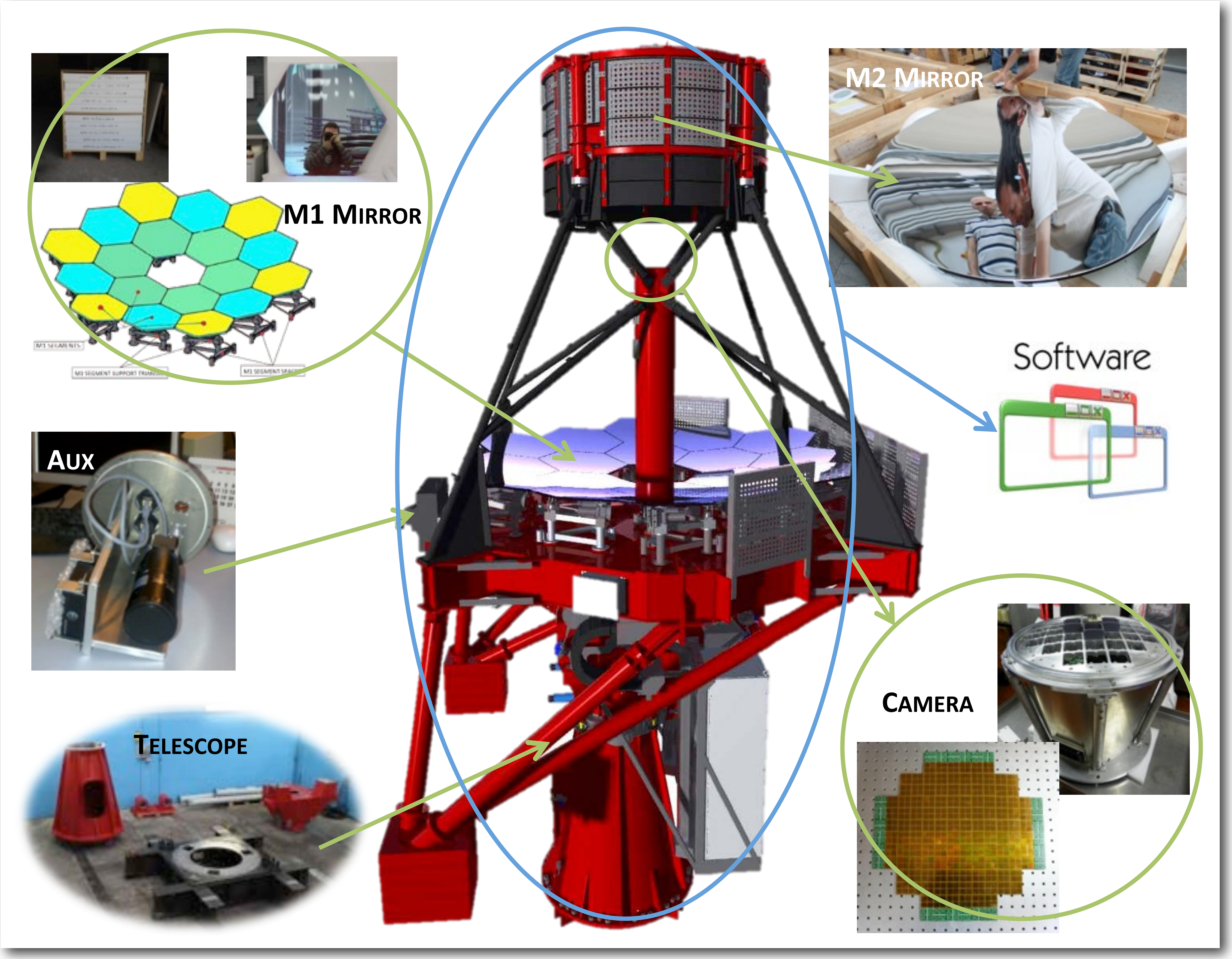
ASTRI SST-2M **innovative solutions**:

Dual-mirror optical layout
- first time for VHE IACTs
- reduces the plate-scale
- optimal PSF across the entire FoV

SiPMs photo-detectors
- small pixel-size
- can work during moonlight
- fast front-end and control electronics

Wide field-of view
- excellent for:
  - extended sources
  - surveys

ASTRI SST-2M end-to-end approach



ASTRI SST-2M characteristics

Energy threshold

- 1 TeV

Telescope characteristics

- Primary mirror = 4.3m
- Optical design = Schwarzchild-Couder
- M1 type = Segmented (18, 3 concentric rings)
- Secondary mirror = 1.8m (2.2m RoC)
- M2 type = Monolithic
- M1-M2 distance = 3m
- Effective area = 6m^2
- F/D1 = 0.5, F = 2.15m

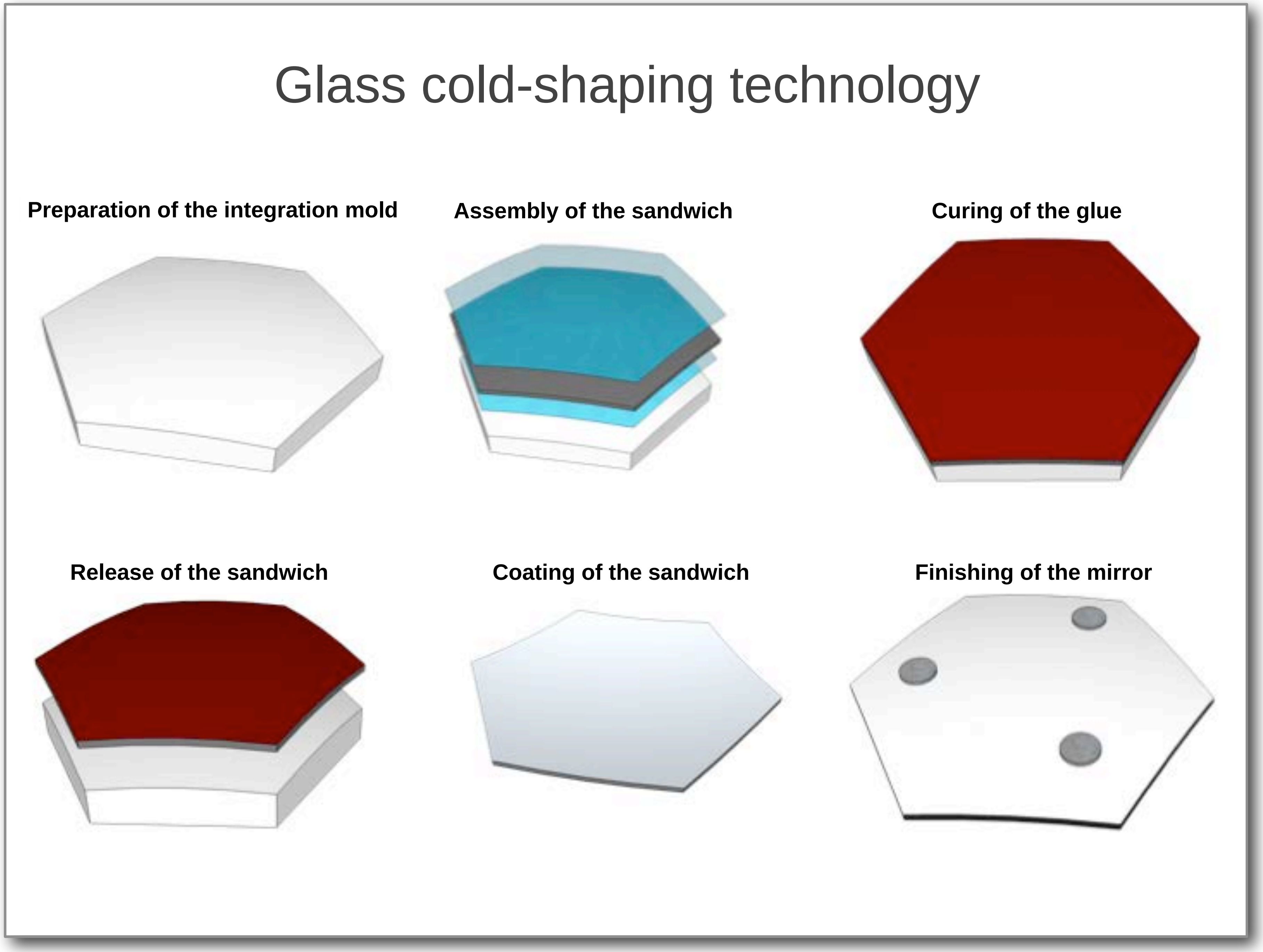
Camera characteristics

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

Innovation on mirrors - M1

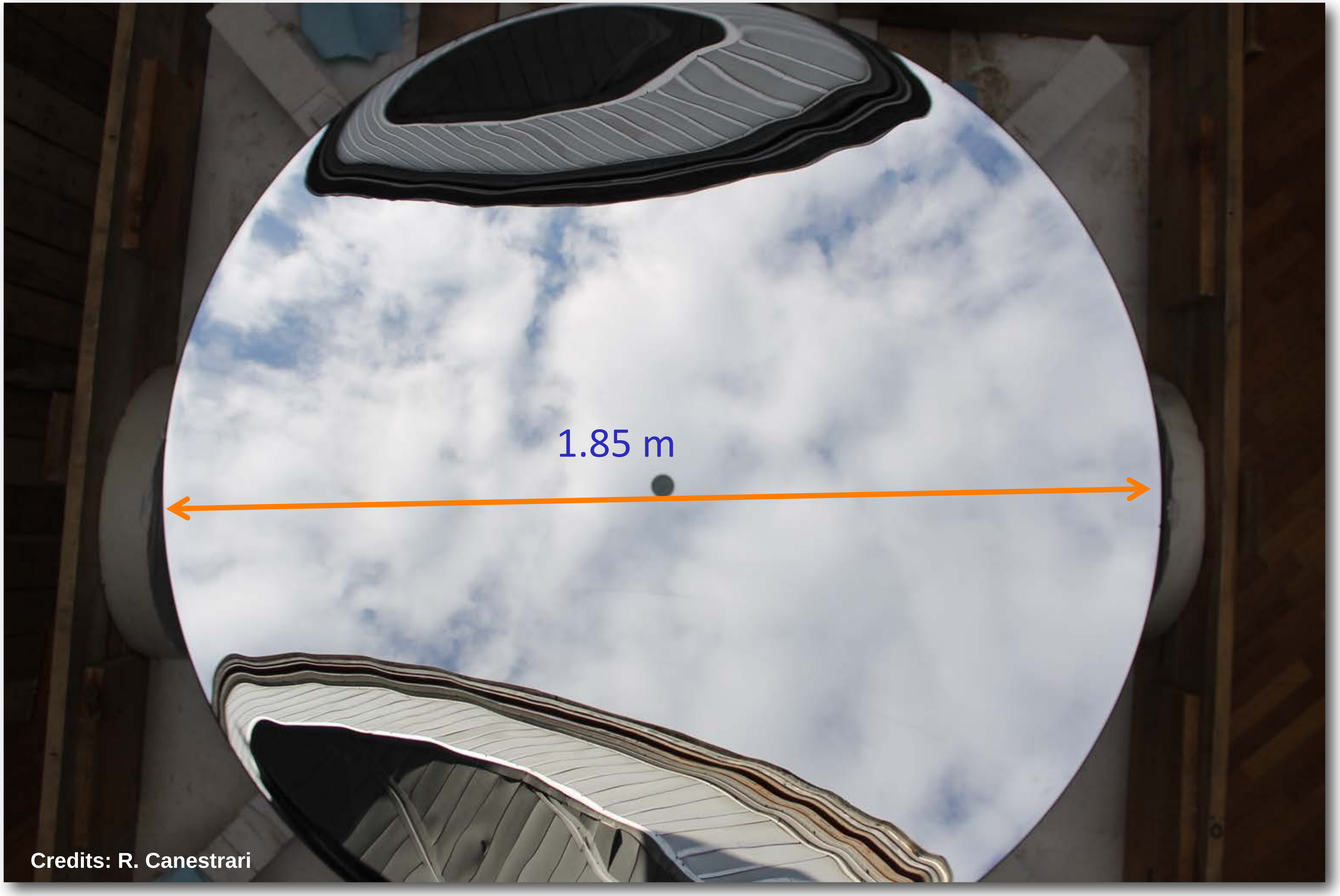
Manufacturing process: Glass cold-shaping

Structural implementation: sandwich panel with thin glass skins



Innovation on mirrors - M2

Hot shaping technique (collaboration with Flabeg, Germany)



Innovation on camera

Sensors: SiPMs & FEE ASIC

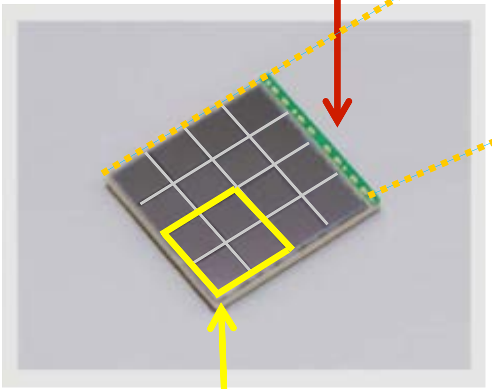
Modularity: Unit → PDM → Focal Plane

Credits: O. Catalano

SST-2M prototype SiPM

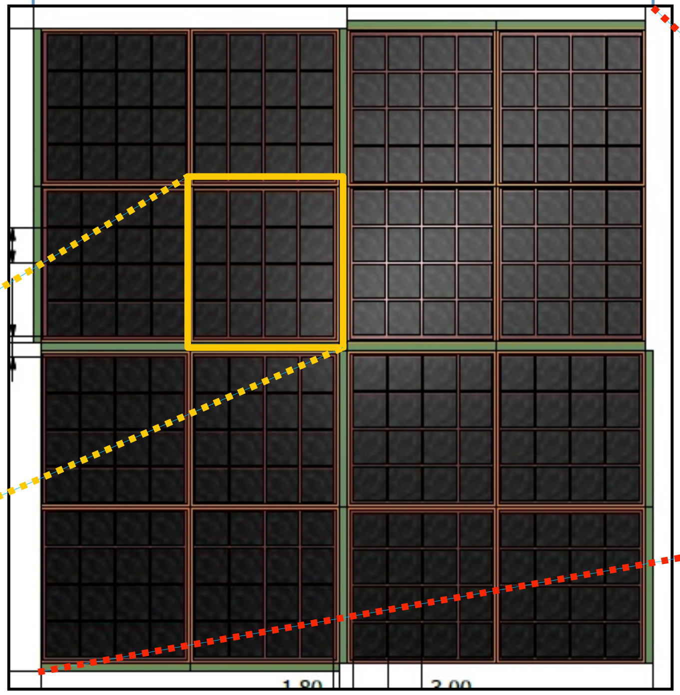
S11828-3344M1 the 'Unit'

geometrical dead area



Logical pixel
6.2×6.2mm
≡ 0.17°
(4 channels)

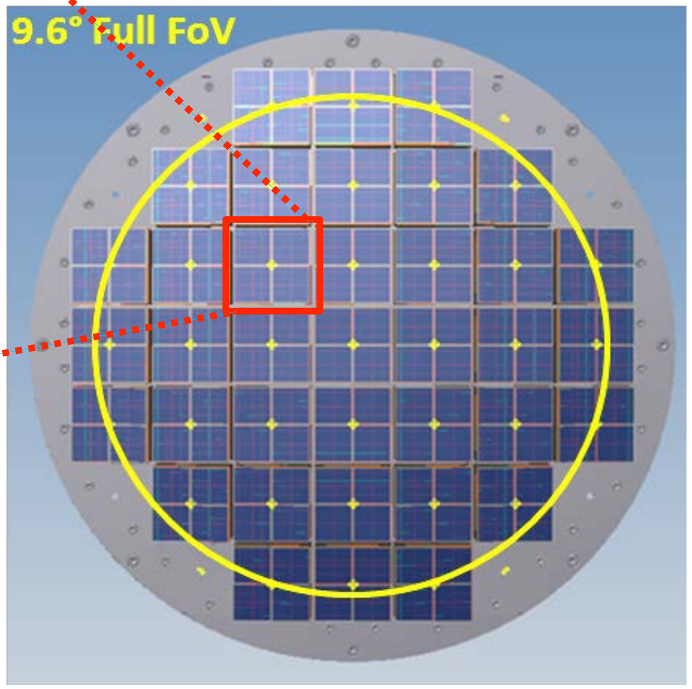
Photon Detection Module PDM



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

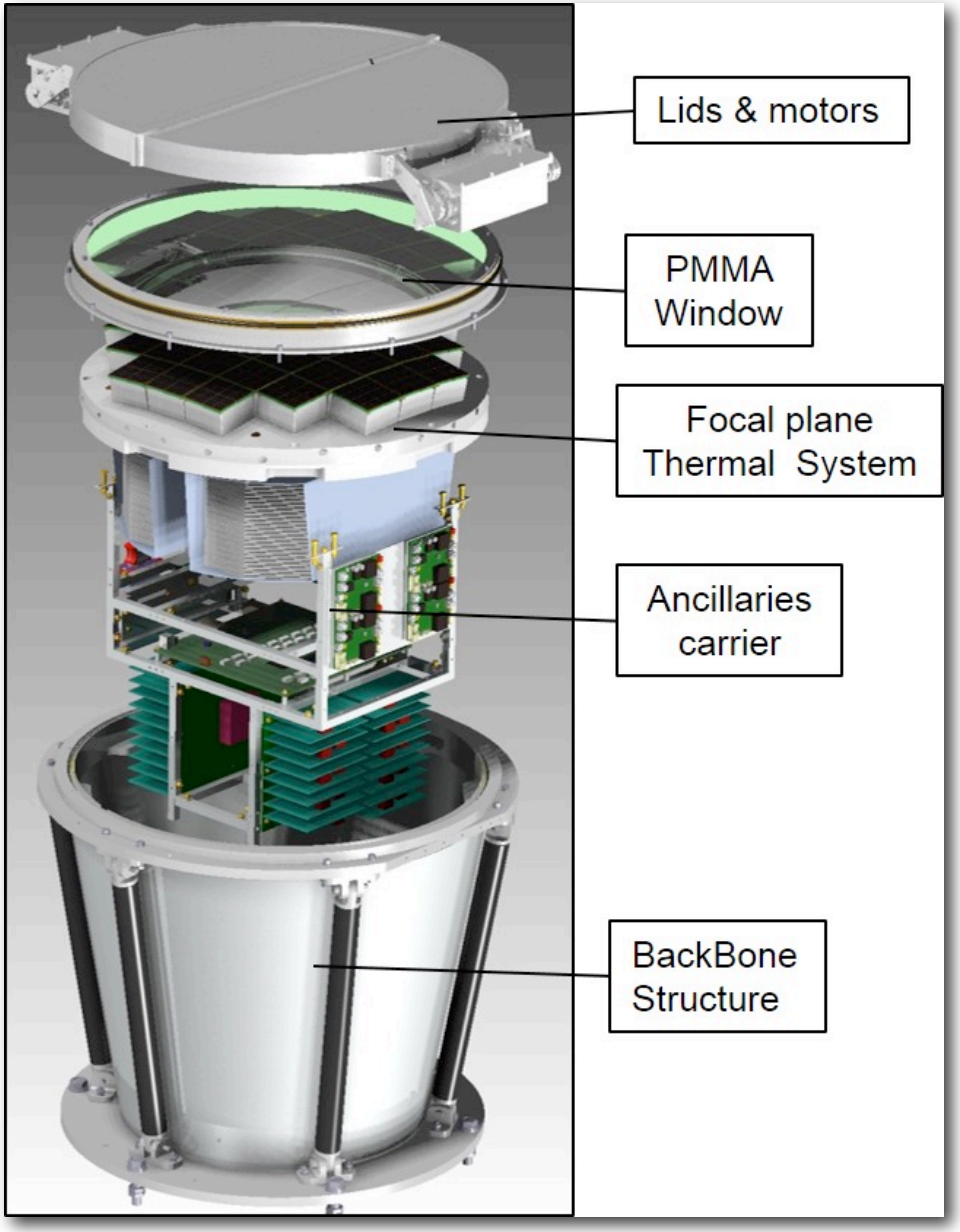
Each PDM works independently from the others

ASTRI Focal Plane



37 PDMs → Focal Plane
560×560mm
(1984 channels)

Innovation on camera

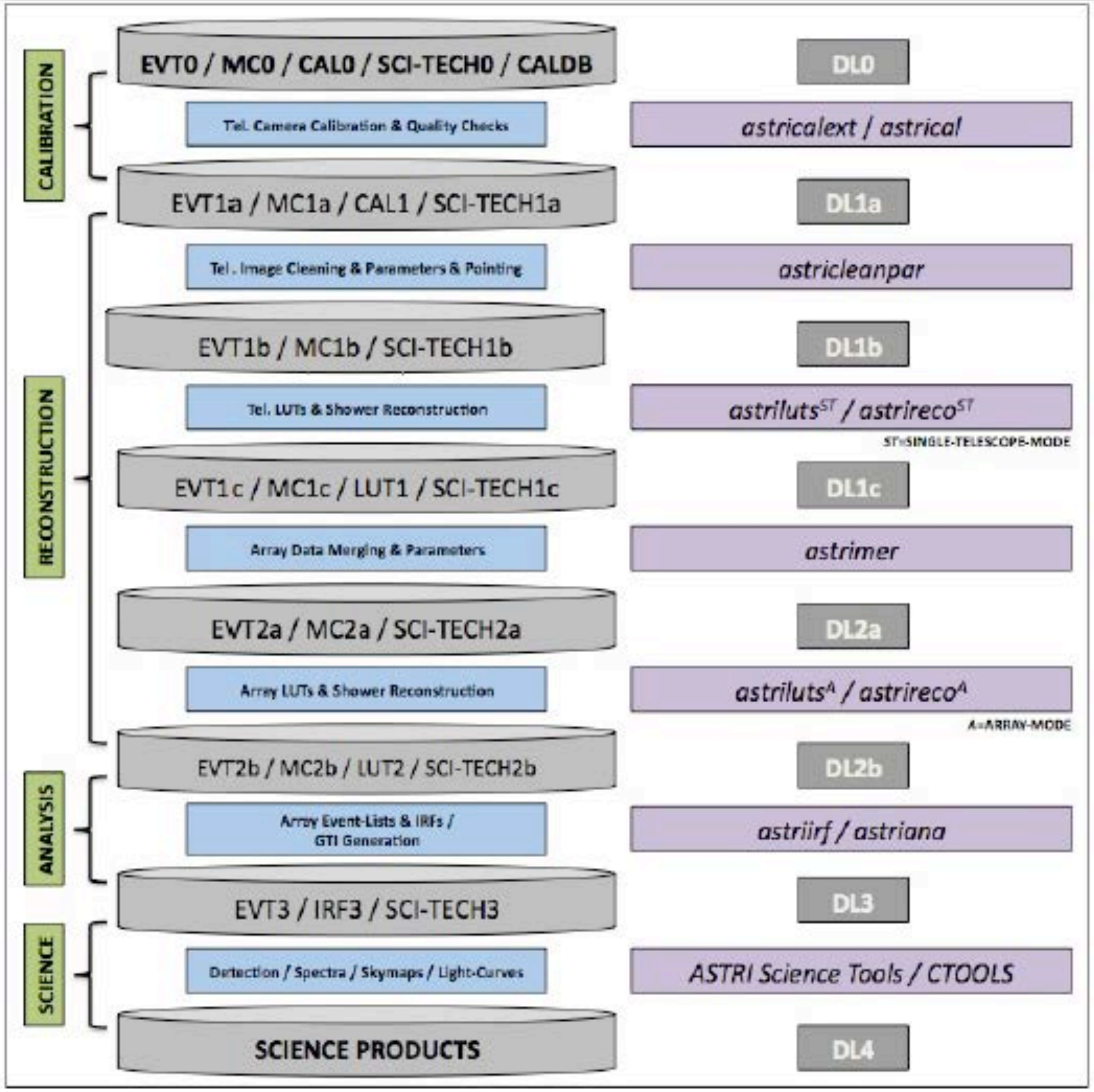


INAF intellectual property:
design of the CITIROC ASIC
[a signal shaper, not a sampler]

Credits: O. Catalano

Innovation on data management

Data flow and SW routines: can handle and process both the prototype and the mini-array data !

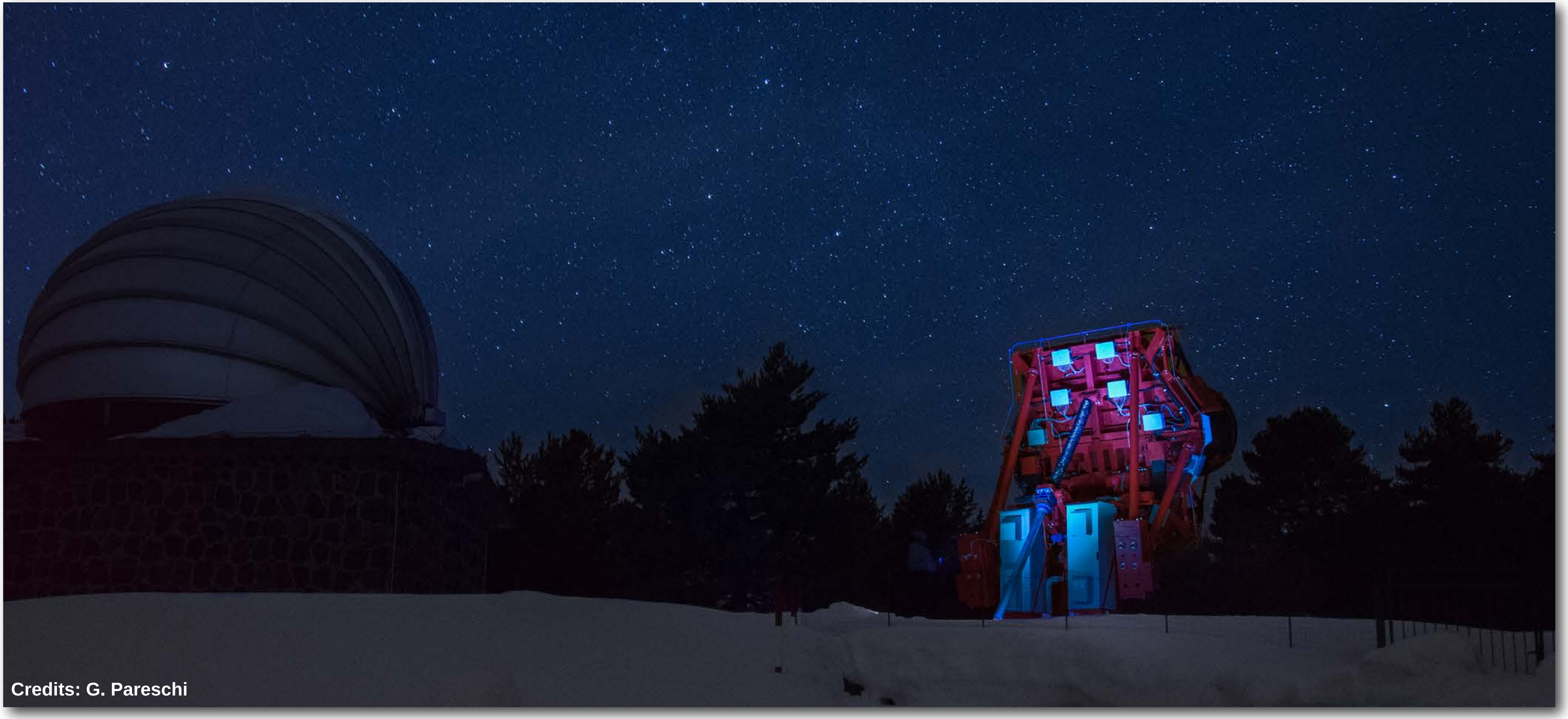


The ASTRI SST-2M Prototype and Mini Array Data Pipeline

- manages FITS data (from DL0 to DL3) adopting CFITSIO/CCFITS libraries;
- is written in C++ (Unix environment) / CUDA7 (for GPU/ARM coding);
- is developed in independent software modules linked by pipelines written in Python;
- will make use of *ad hoc* and official CTA Science Tools for final scientific results production (DL4).

Credits: A. Antonelli, S. Lombardi

Etna: an astronomical site...



...with a severe winter...

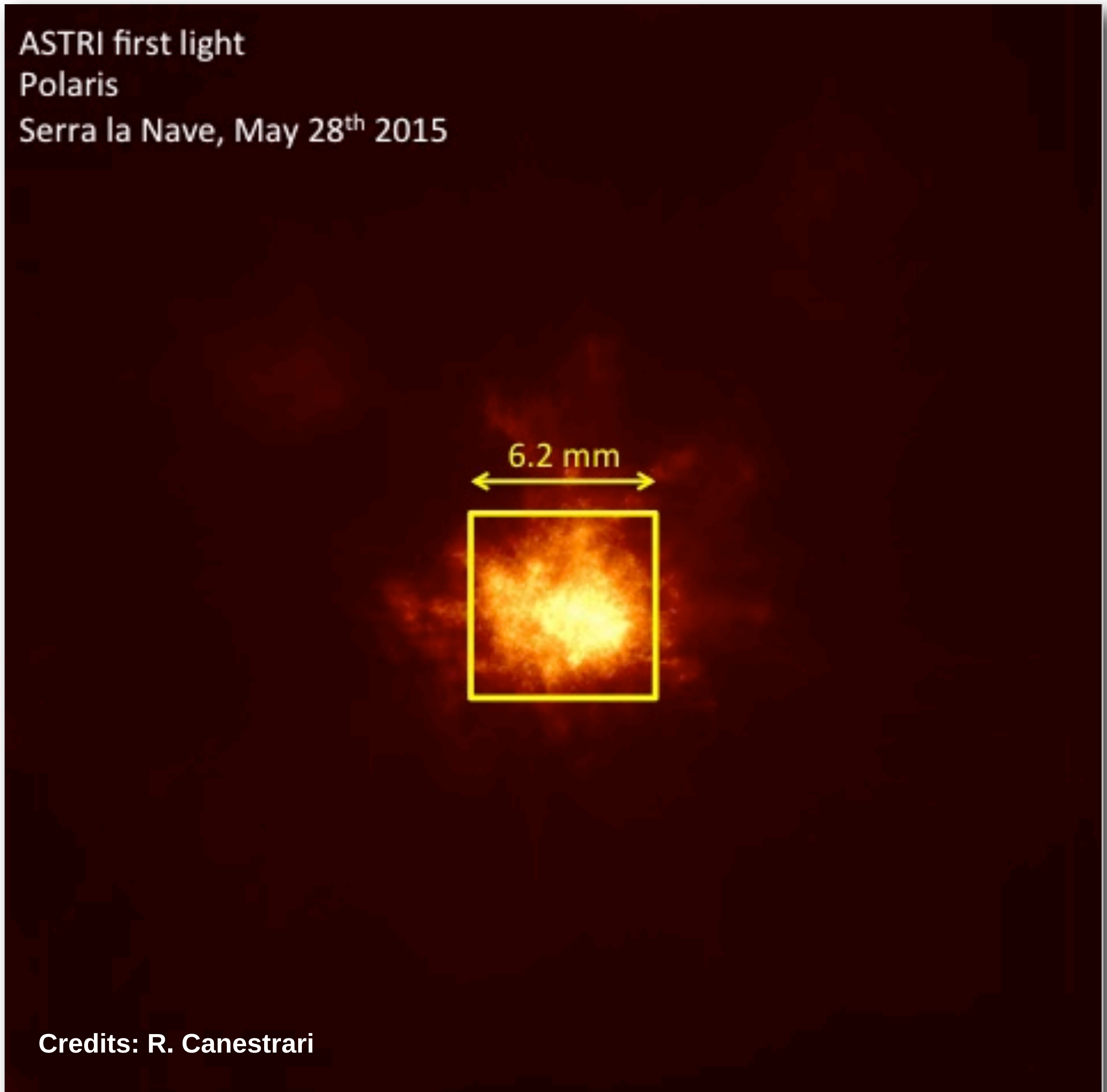
...and in a peculiar environment !

ASTRI SST-2M optical first light !

First light with a Schwarzchild-Couder telescope ever!

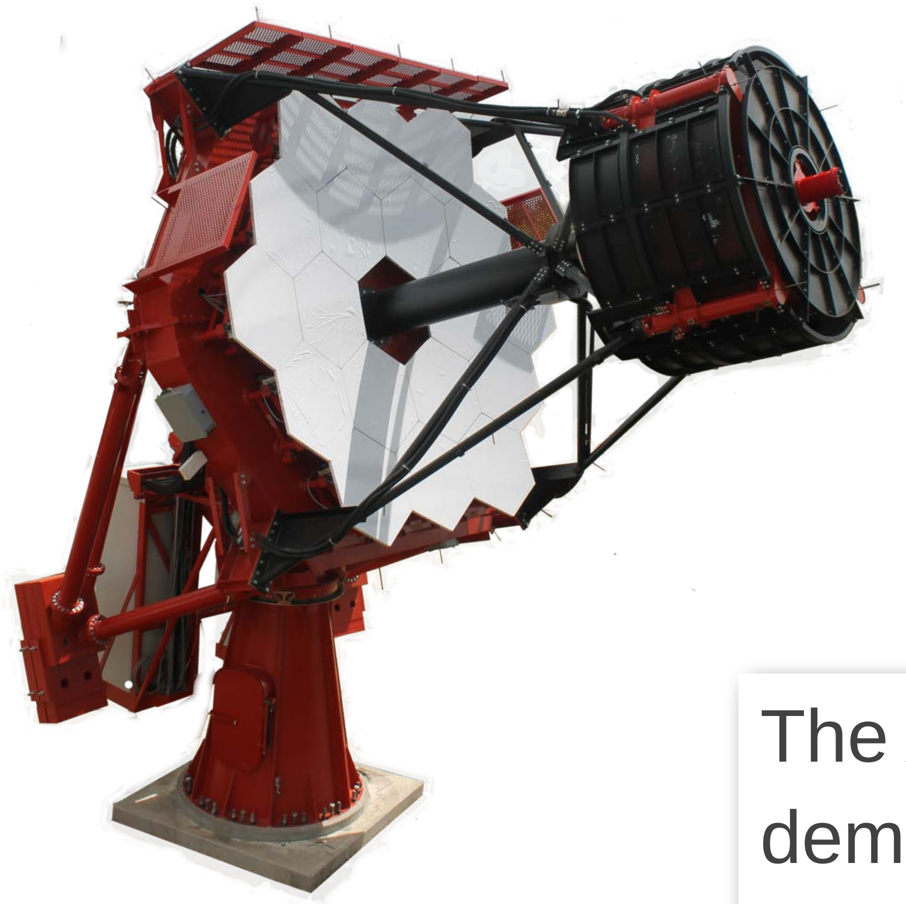
Performed without optimal mirror alignment

CTA requirements on PSF fully met !



"Optical Camera" equipped with a 36mm x 36mm CCD (about 1º FoV)

The ASTRI SST-2M end-to-end prototype



The ASTRI SST-2M prototype is mainly a technological demonstrator, but it will undergo **a science and performance verification phase.**

For E > 1 TeV we should be able to detect 1 Crab at 5σ in about a few hours, allowing us to perform the **first Crab and blazars observations with a Schwarzschild-Couder, SiPM-equipped telescope.**

The ASTRI SST-2M end-to-end prototype

- Technological innovations
- Present status and preliminary results

The ASTRI mini-array of precursors

- Main performance
- Scientific cases
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Outlook and Conclusions

The ASTRI mini-array

Led by the Italian National Institute for Astrophysics in collaboration with:

- **Universidade de São Paulo & FAPESP, Brazil**
- **North-West University, South Africa**

Credits: A. Stamerra

The ASTRI mini-array

The ASTRI mini-array can verify some CTA-SST sub-array properties:

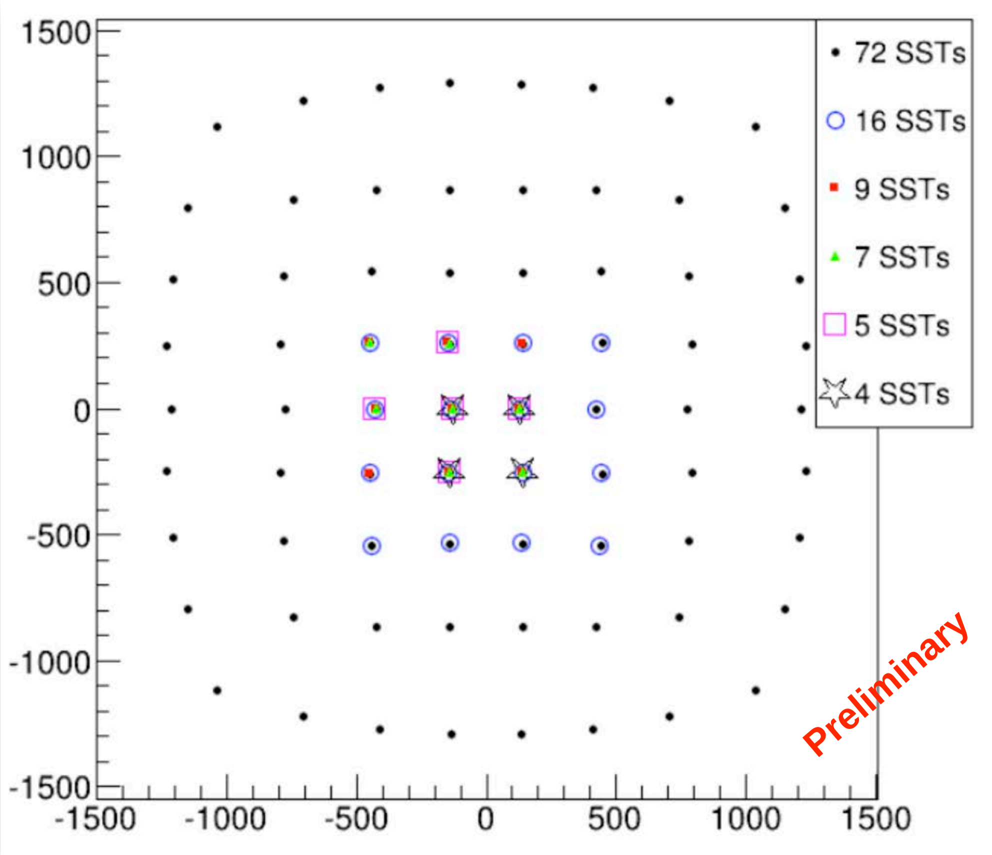
Check of the trigger algorithms
Preliminary MC simulations show that a typical event will trigger a number O(5-7) of the whole CTA-SST sub-array.

Check of the wide field-of-view performance
by detecting VHE showers with the core at a distance up to 500m

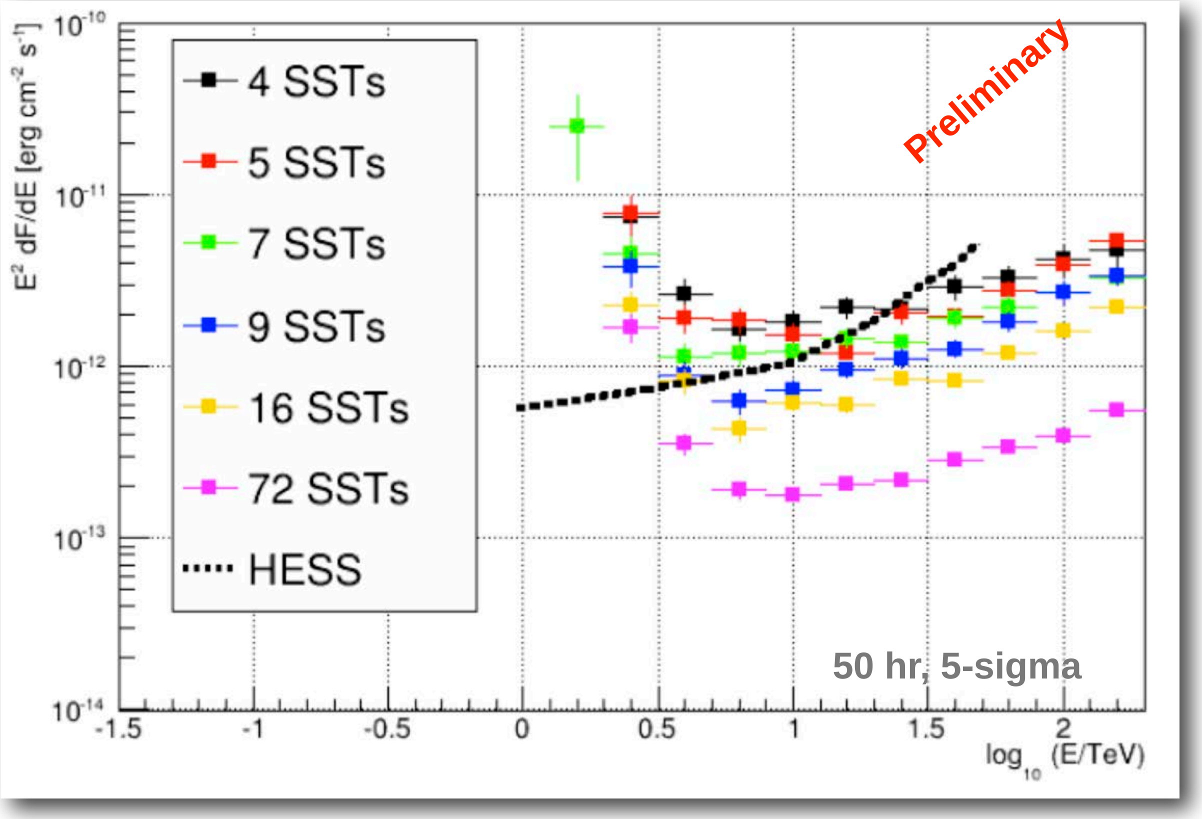
Compare the mini-array performance with the Monte Carlo expectations
by means of deep observations of the Crab

Do the first CTA precursor science
by means of a few solid detections during the first year

The ASTRI mini-array: a few facts



Di Pierro et al, 2015



Limiting flux

slightly better than the H.E.S.S. one above a few TeV for an array composed of 9 telescopes

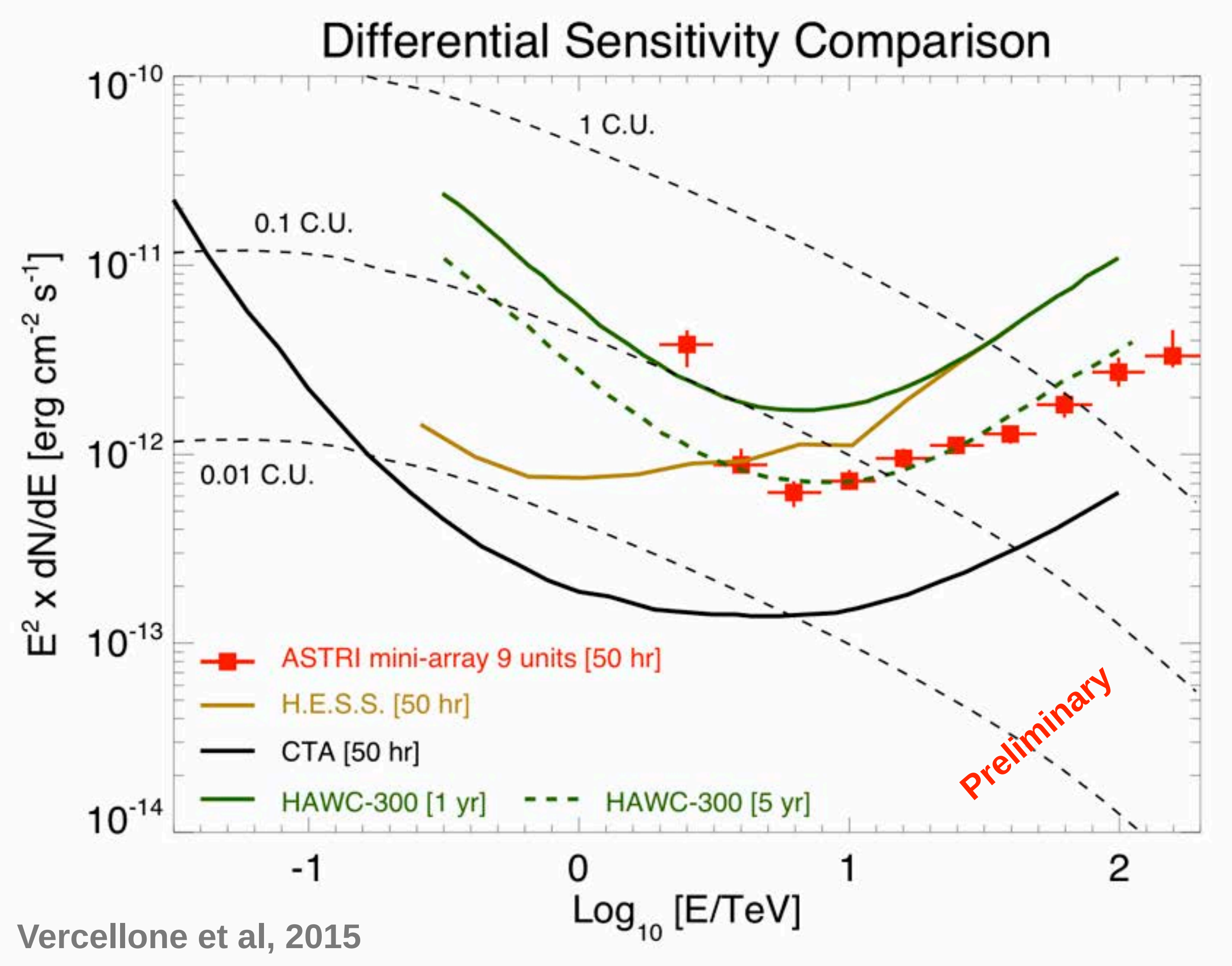
Angular resolution

a few (4-5) arcmin

Energy resolution

of the order of 10-15 %

Sensitivity comparison



The ASTRI mini-array will extend the differential sensitivity up to several tens of TeV and beyond, a never-explored energy range by IACTs.

We will have a better sensitivity at E>10 TeV for extended sources, favouring the study of their VHE emission at the very edges.

At time of the ASTRI mini-array operation, HAWC will have performed at least one year of operation, accumulating a sensitivity that, on selected sources, could be reached by the ASTRI mini-array in a few weeks of pointings.

The ASTRI mini-array can study, by means of deep observations, sky “hot-spots” detected by HAWC, similarly to the ones identified by the MILAGRO experiment.

The ASTRI mini-array targets

Supernova Remnants
- SNRs
- Pevatrons
- SNRs interacting with molecular clouds

PWNe

Gamma-ray binaries

Extreme BL Lacs
- Synchrotron peak > 1 keV
- Inverse Compton peak > 1 TeV

Less-beamed AGNs
- Radio-galaxies

Starburst galaxies

Dark Matter & exotic physics

ASTRI mini-array scientific rationale

- The aim is to **test both the SST-2M technological and scientific performance** at energies above a few TeV by means of **prolonged pointings**.

- **Galactic science ➔** choose sky regions containing multiple targets.

- **Extra-galactic science ➔** select a few promising targets.

- **Synergies with MSTs and LSTs** precursors are of paramount importance.

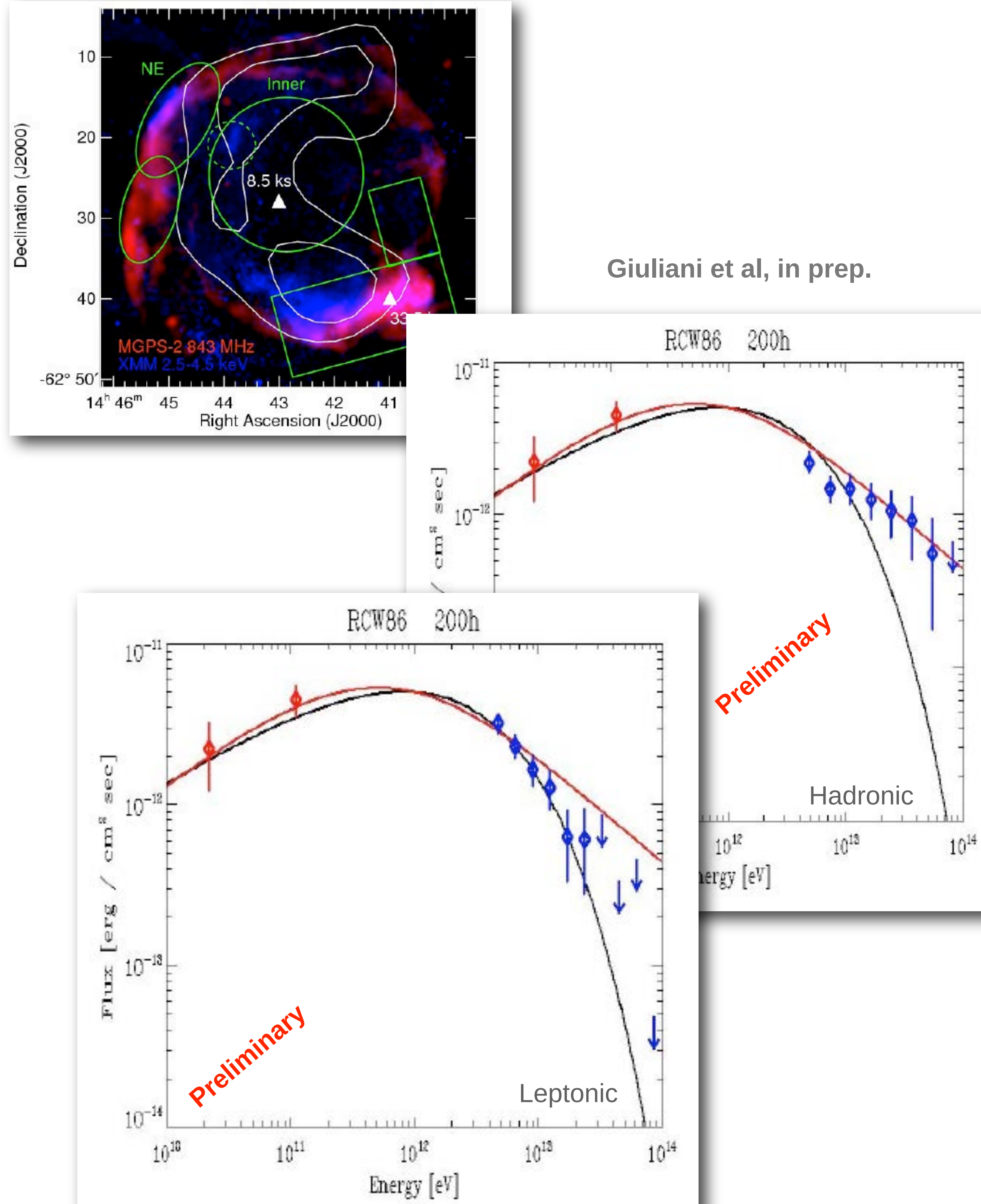
SNR RCW 86

Fairly young SNR (2000 yrs)

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

Debated origin:
- interacting source with molecular clouds or RX J1713-like source ?

ASTRI mini-array (blue points, simulated data) can discriminate between hadronic and leptonic scenario and (if hadronic) look for VHE(~5x10^{14} eV) CRs

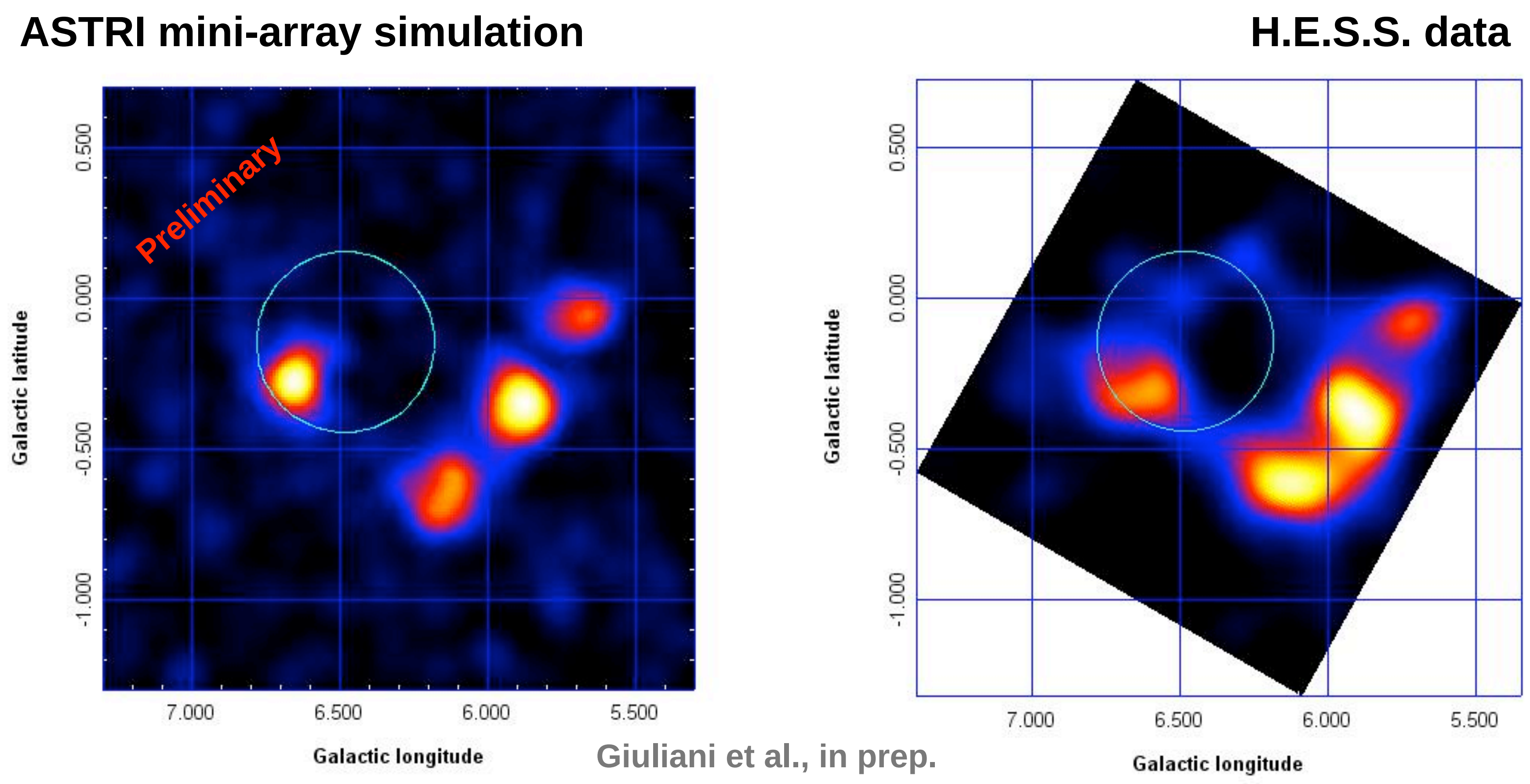


SNR W 28

Evolved SNR interacting with a giant MC, very bright @ TeV

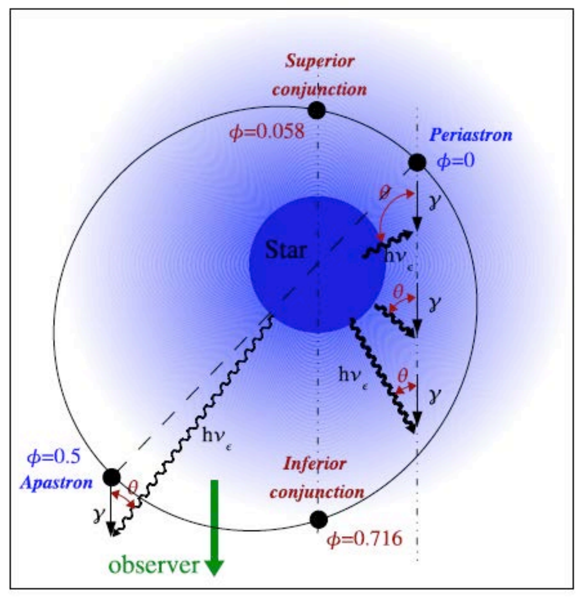
H.E.S.S. resolved this source in almost 4 point-like sources near the MC

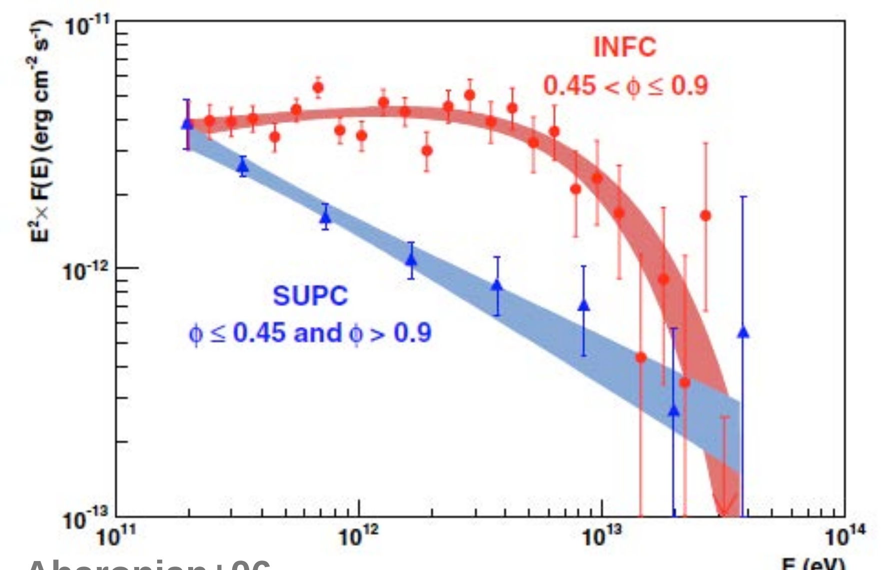
ASTRI mini-array can better resolve the source and study the diffusion of CR far from the SNR shell (blue circle)



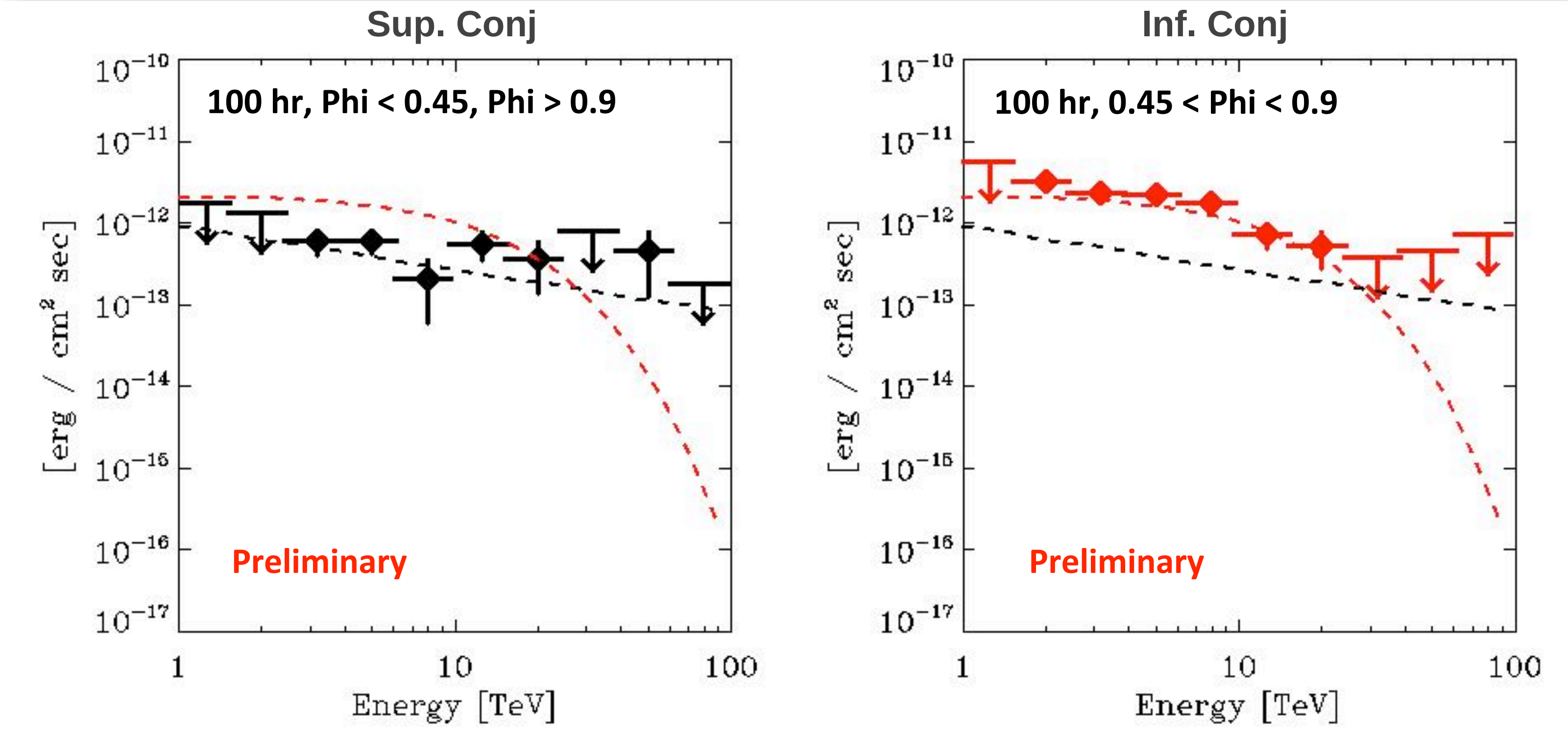
Giuliani et al., in prep.

μ-QSO: LS 5039





Aharonian+06



Romano, Vercellone, Giuliani et al., in prep.

H.E.S.S. spectrum not well constrained above 10 TeV.

It can be studied simultaneously with PWN HESS J1825-137.

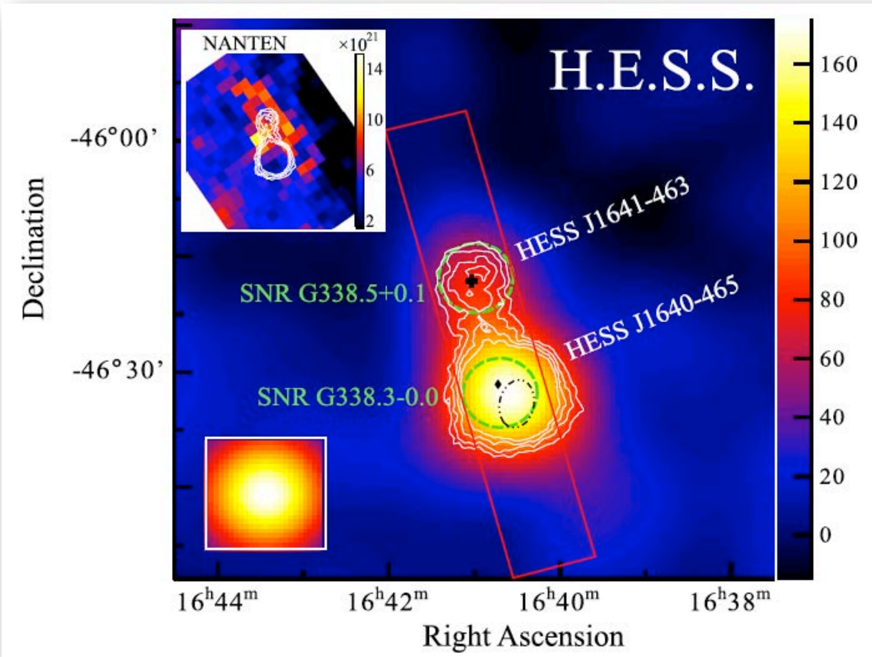
ASTRI mini-array 100+100 hrs simulation

We can investigate:

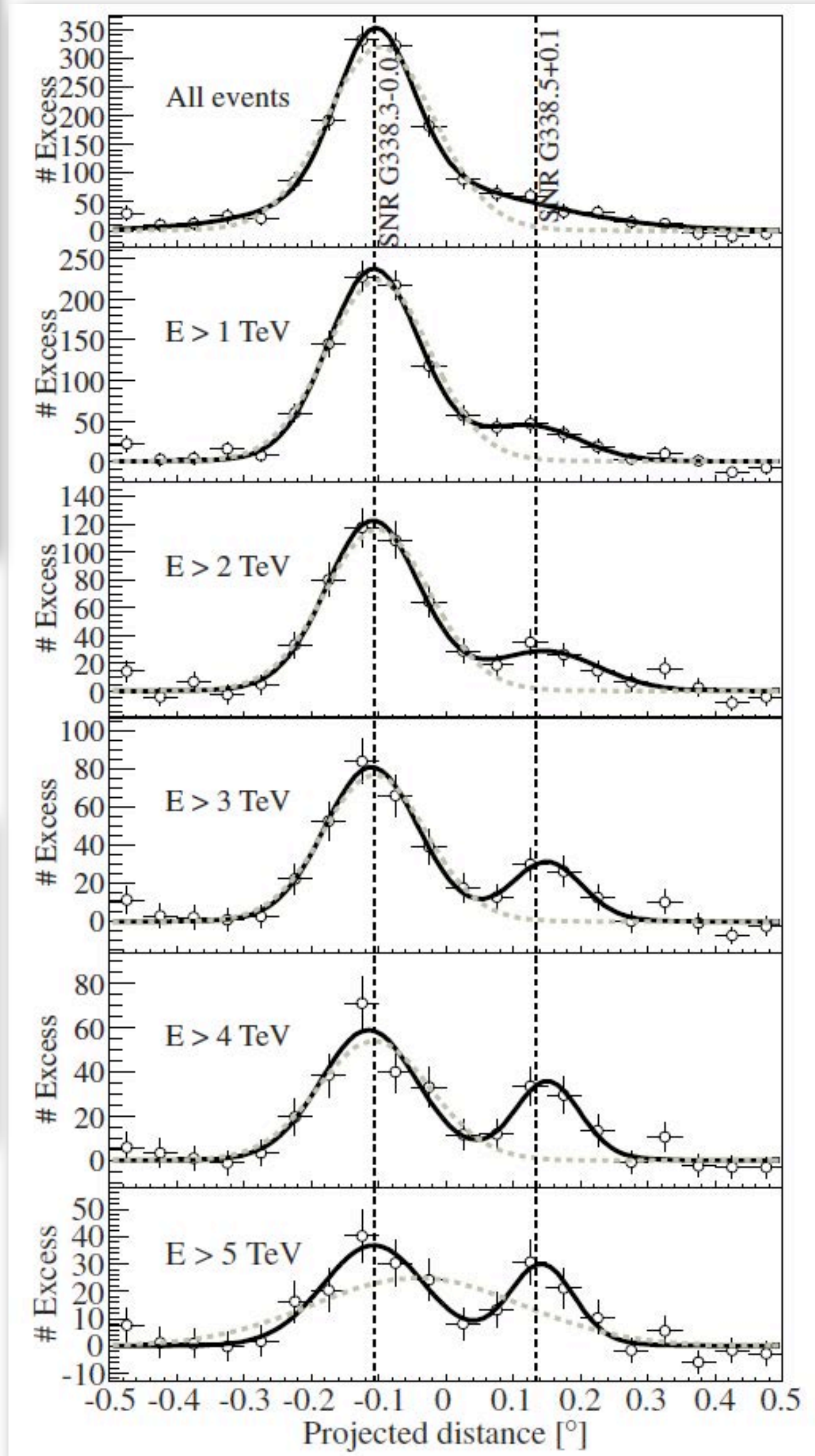
- phase-dependent gamma-ray absorption/emission;
- phase-dependent spectral modulation.

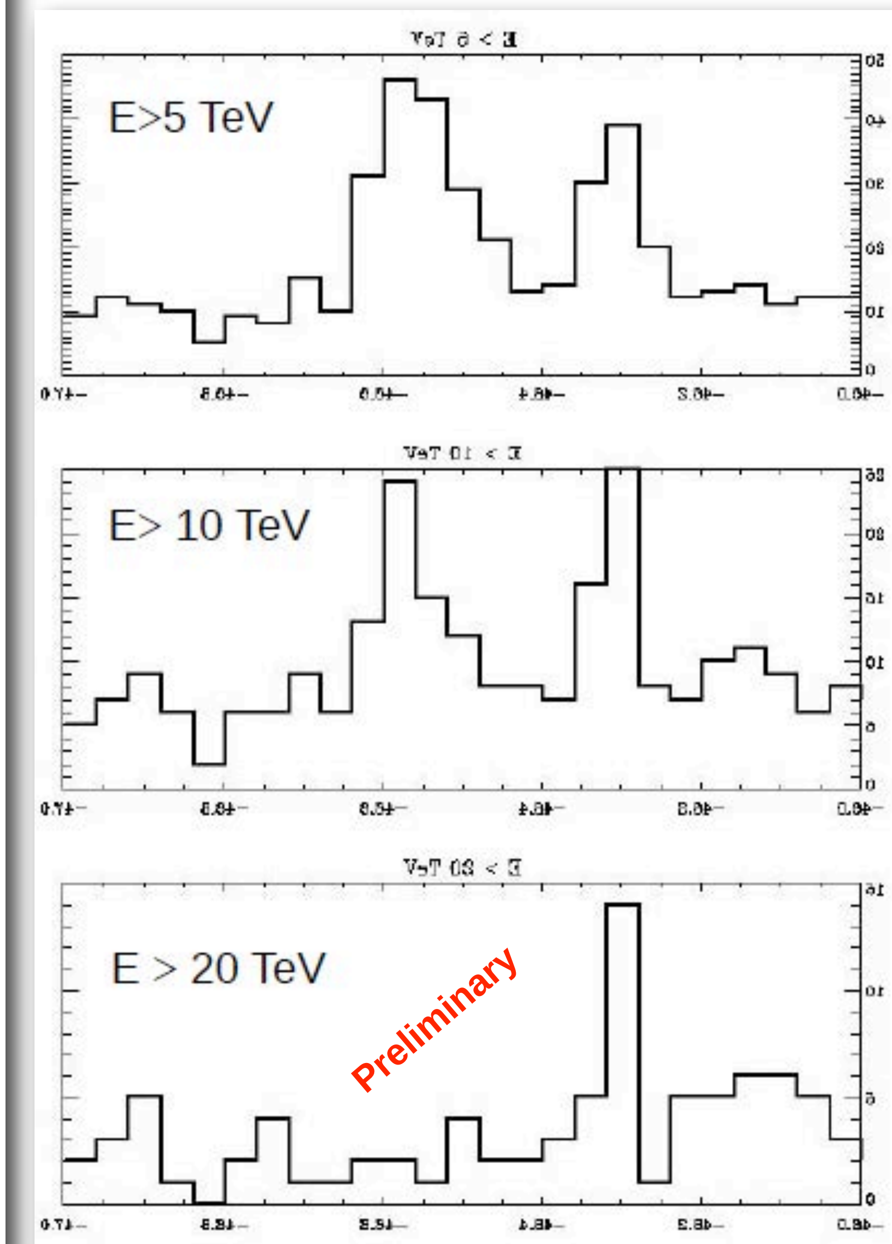
γ-ray UNID: HESS J1641-463

Abramowski +14



Abramowski +14



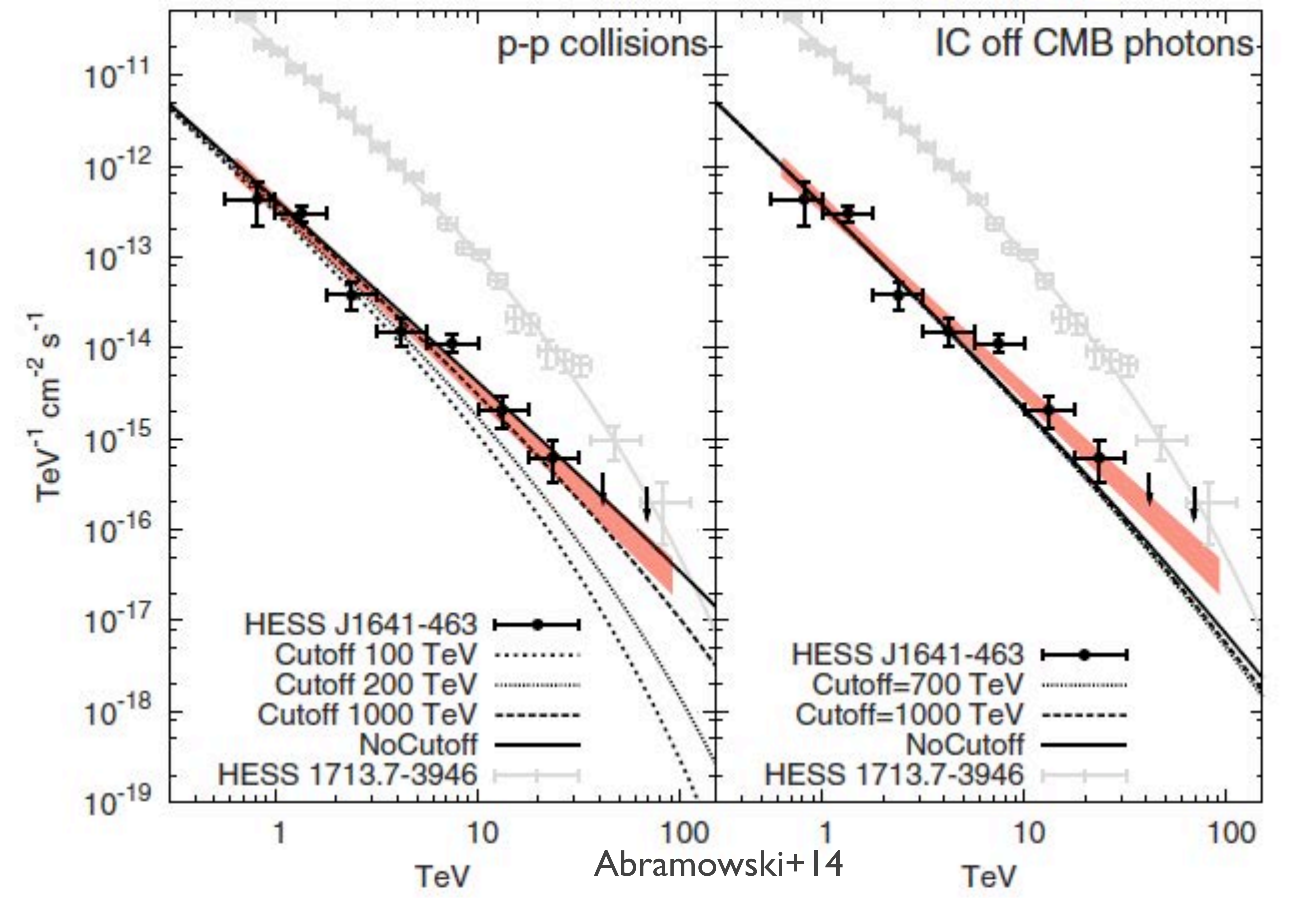


Romano, Vercellone, Giuliani et al. in prep.

Very hard source Γ ~ 2.1

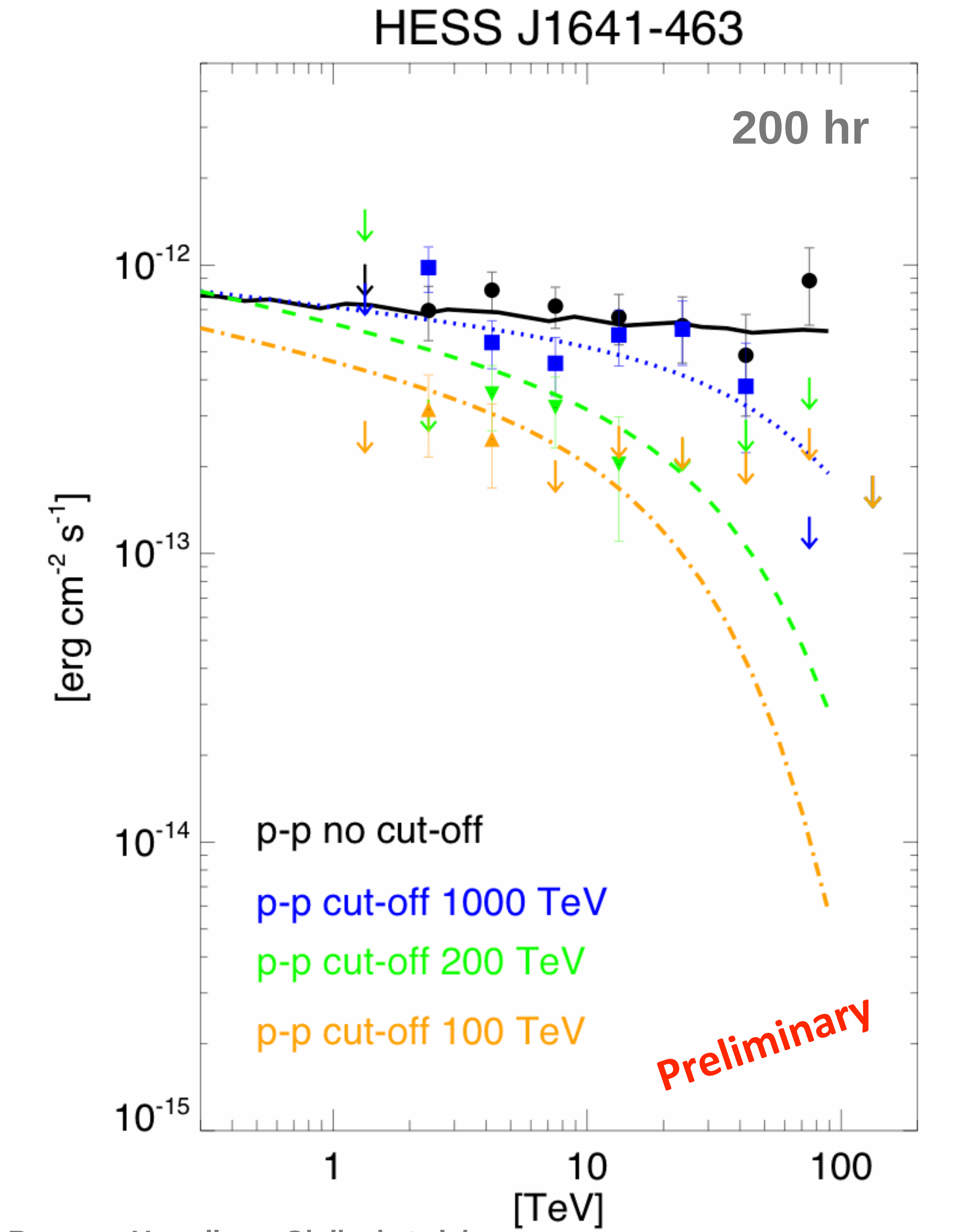
ASTRI mini-array 200 hrs simulation

γ-ray UNID: HESS J1641-463



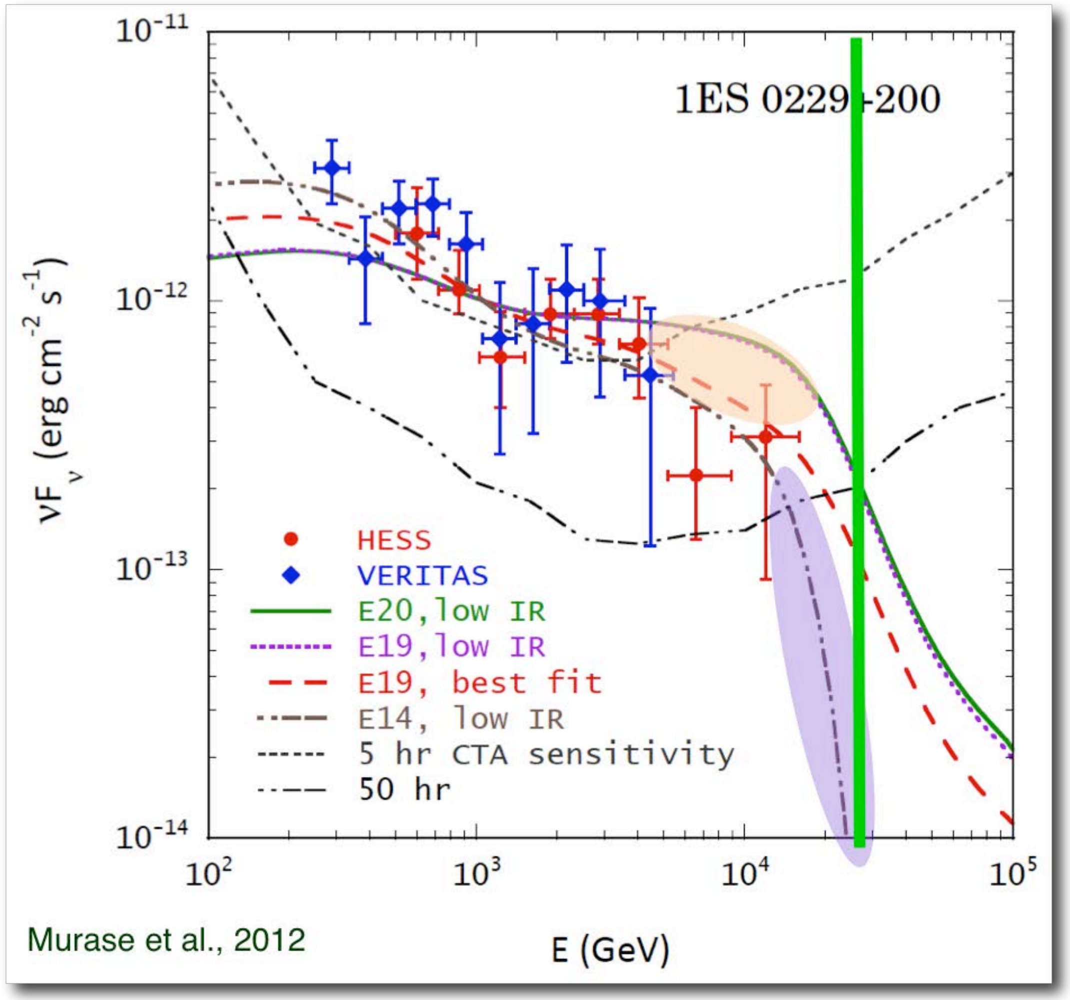
We can investigate:

- **presence of a spectral cut-off (and its energy)**
- **nature of this source**



Romano, Vercellone, Giuliani et al. in prep.

Extreme BL Lacs: probes of extreme physics



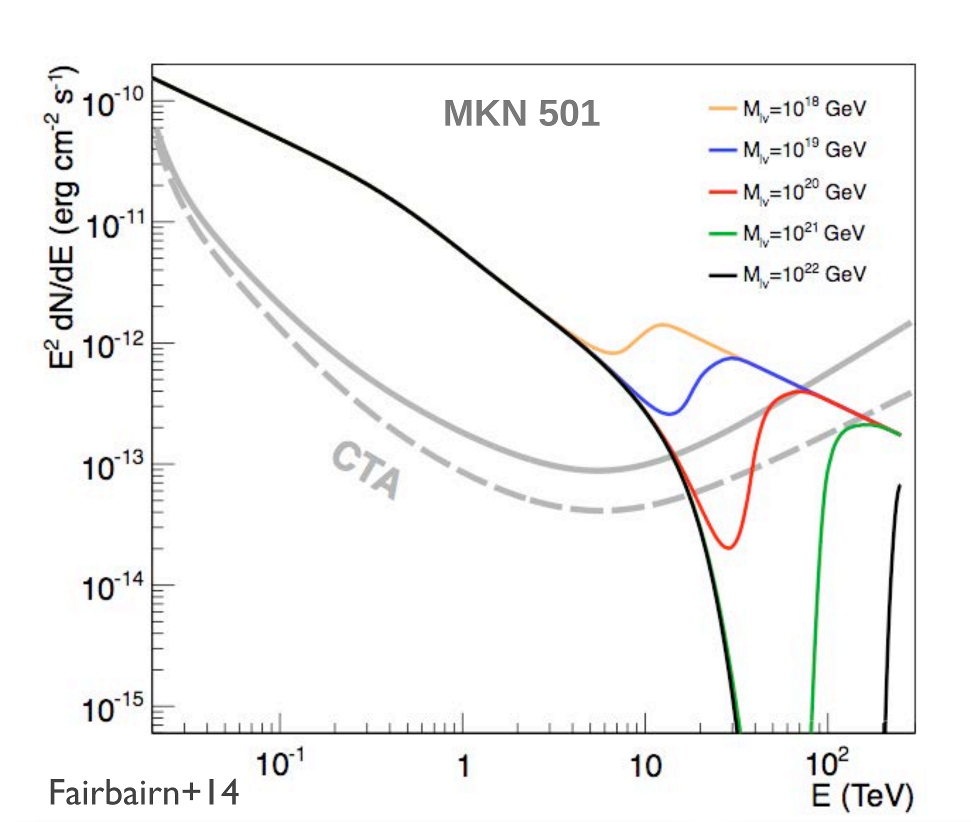
1ES 0229+200 E-HBL SED can be fit by both the **γ-ray-induced cascade** and **proton-induced cascade** emissions.

Because of the uncertainty in EBL models, it is not easy to distinguish between the two possibilities at ~1-10 TeV energies.

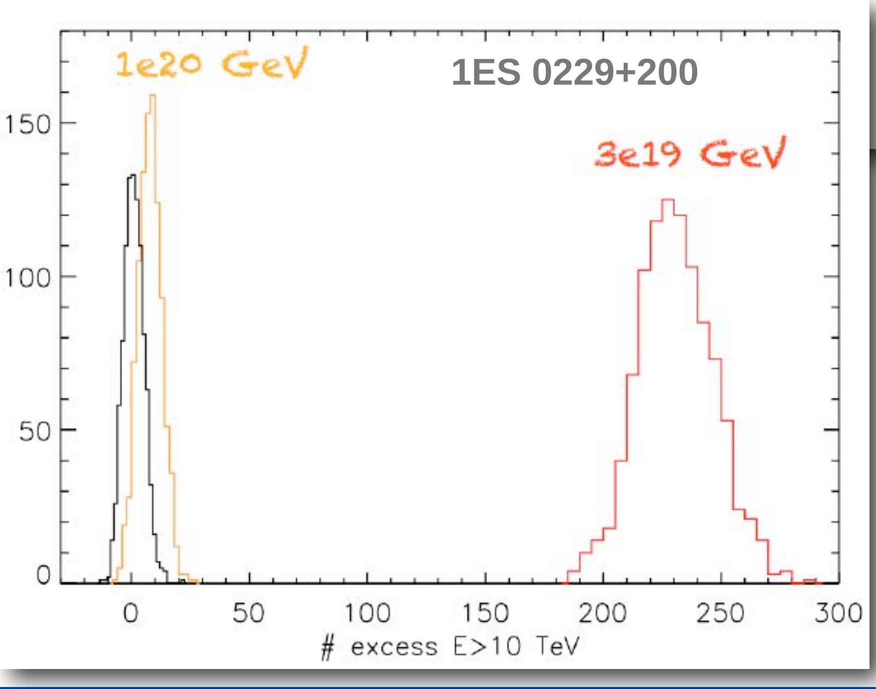
- At higher energies, however, UHECR-induced cascade emission becomes harder than γ-ray-induced cascade emission.
- A detection of >25 TeV γ-rays from 1ES 0229+200 is consistent with an hadronic γ-ray emission (an alternative explanation in the next slide).
- Probe of gamma-ray absorption by the far-infrared EBL

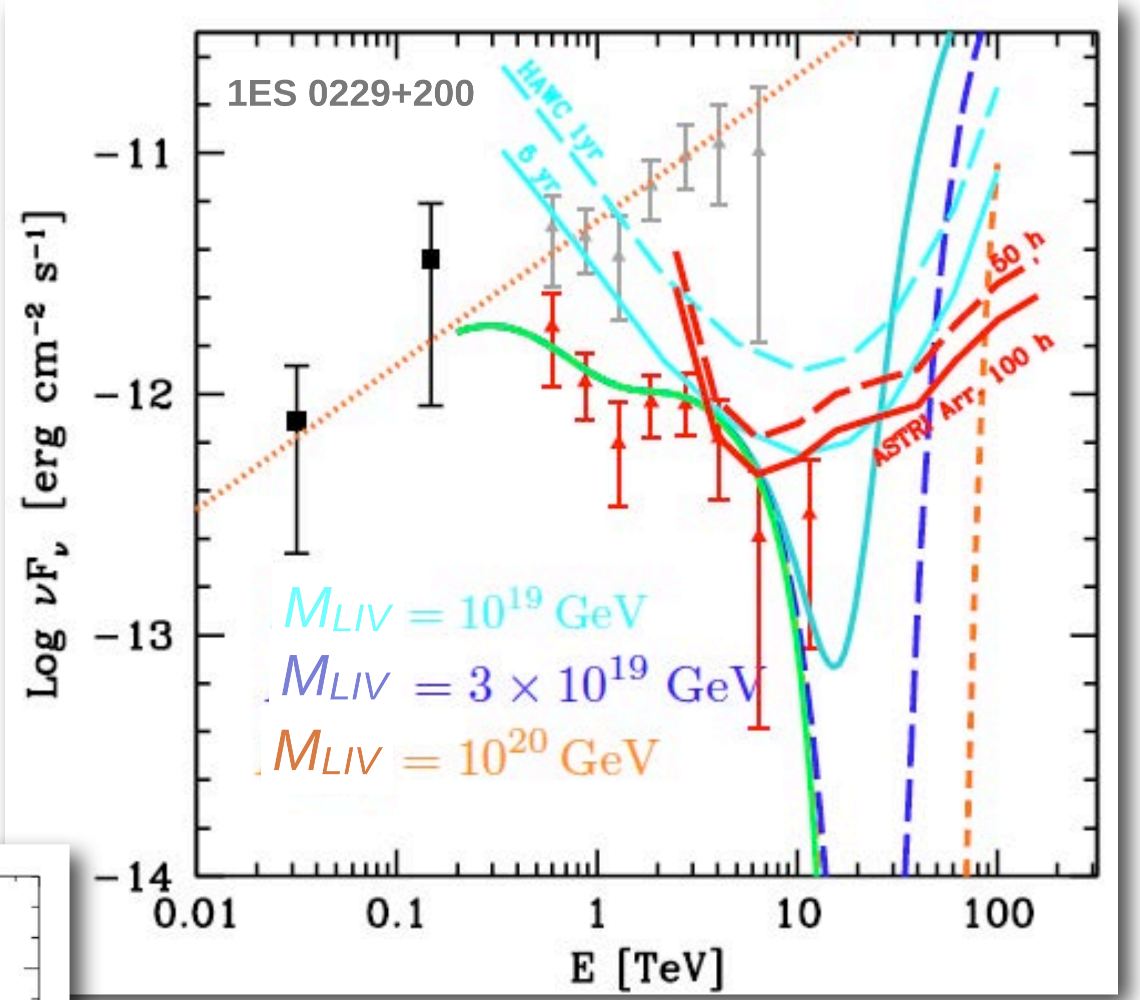
LIV and E-HBL

Lorentz invariance violation induces suppression of the EBL opacity.



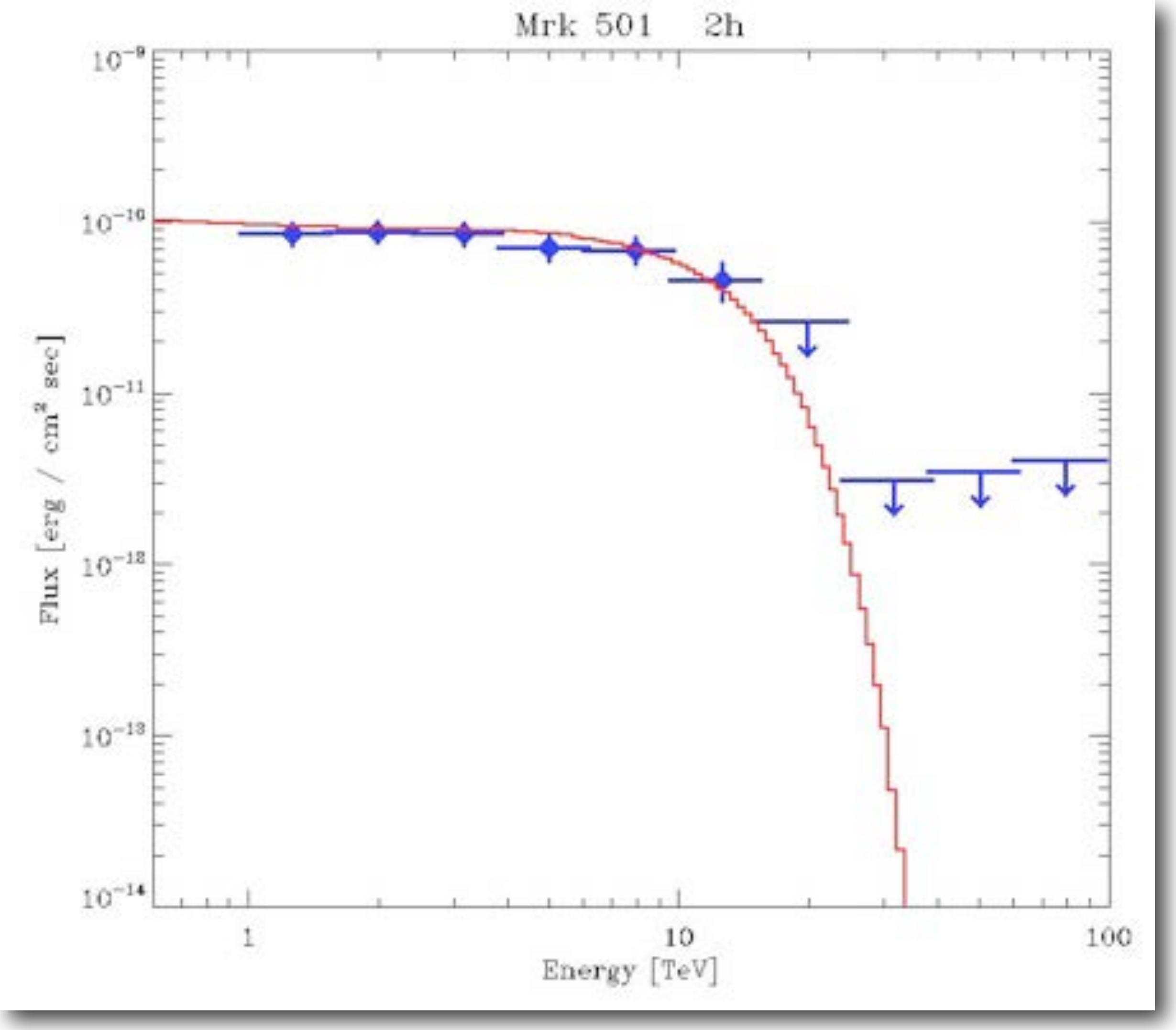
Application to MKN 501 for different values of the Lorentz-violating scales (M_{LIV}).



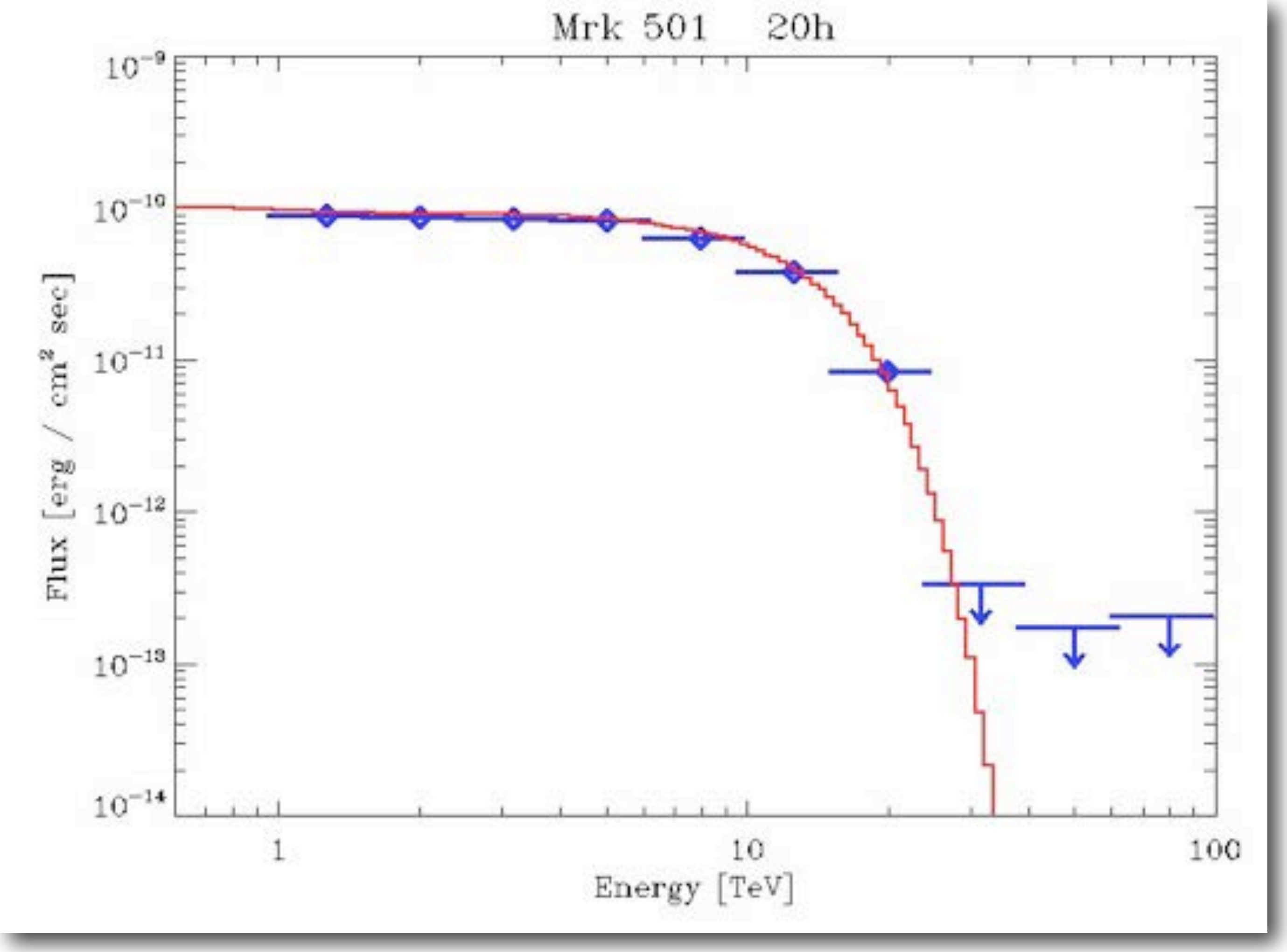


Bonnoli, Tavecchio, Giuliani et al. in prep.

MKN 501: flares and spectral properties



Bonnoli, Tavecchio, Giuliani et al. in prep.



- MKN 501 2009 flare.
- 2 hr vs 20 hr ➔ need MWL trigger and (from CTA-S) high ZA simulations and operations

Indirect search of DM in dSphs

- Likely scenario for cold DM: weakly-interacting massive particles (WIMPs)
- WIMPs mass range: O(1 GeV) - O(100 TeV)
- WIMPs annihilation ➔ indirect detection

POSSIBLE TARGETS

- *Galactic center?*
  + Highest *J-factor*
  − Very high astroph. bkg
  − Uncertainties on inner DM distribution
  − Southern Hemisphere

- *Galactic halo?*
  + High *J-factor*
  − Not fully-free from astroph. bkg
  − Extended
  − Southern Hemisphere

- *Galaxy Clusters?*
  + Huge amount of DM
  − High astroph. bkg
  − Extended
  − High uncertainties on *J-factors*

- *DM Clumps?*
  + Free from astroph. bkg
  + Nearby and numerous
  − To be found!
  − Bright enough?

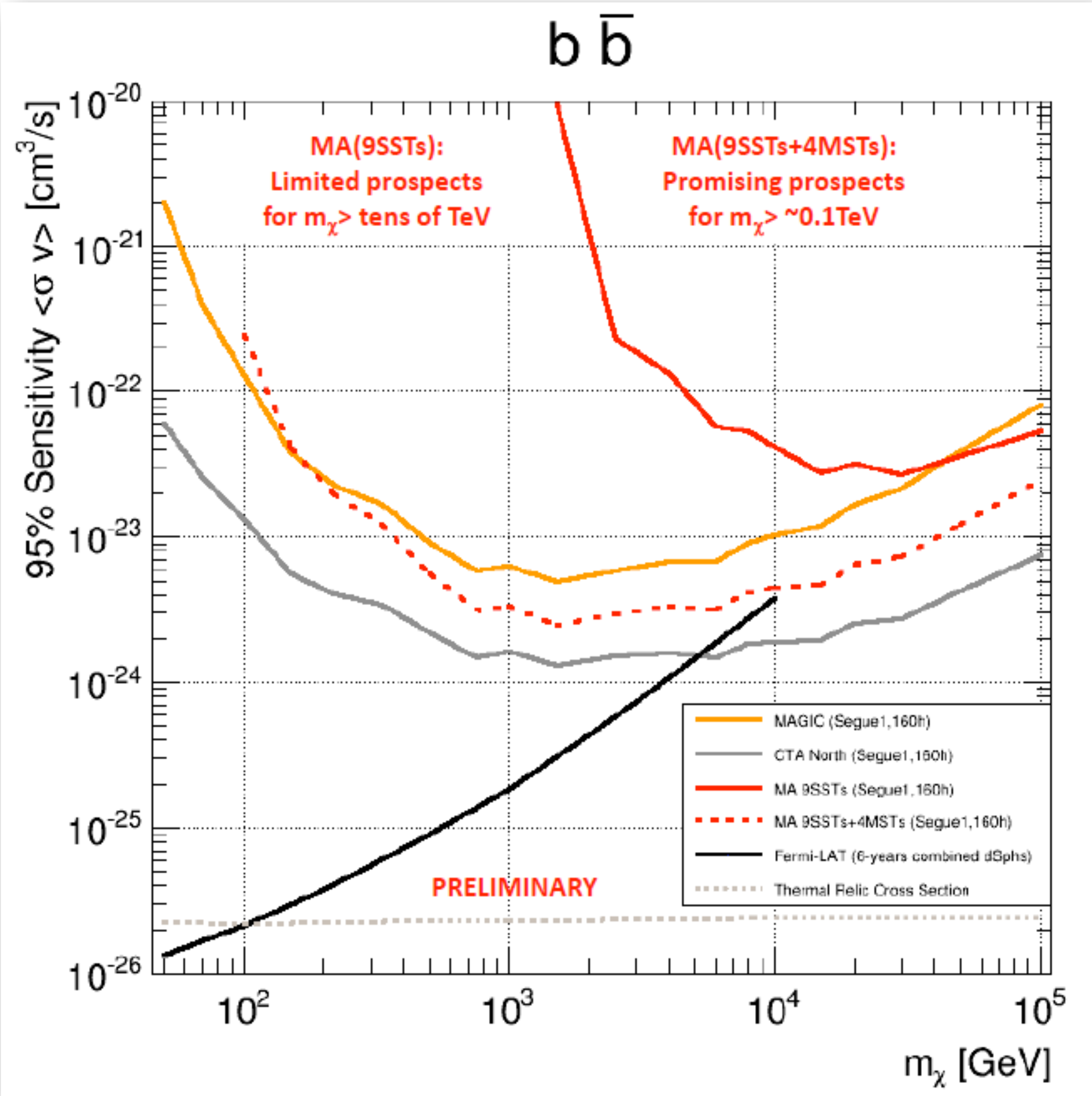
- *Dwarf Spheroidal Galaxies?*
  + DM dominated (high M/L ratios)
  + Free from astroph. bkg
  + Close (<~100 kpc)
  + Slightly extended at most
  + Less uncertainties on *J-factors*
  − *J-factors* ~100 lower than for GC

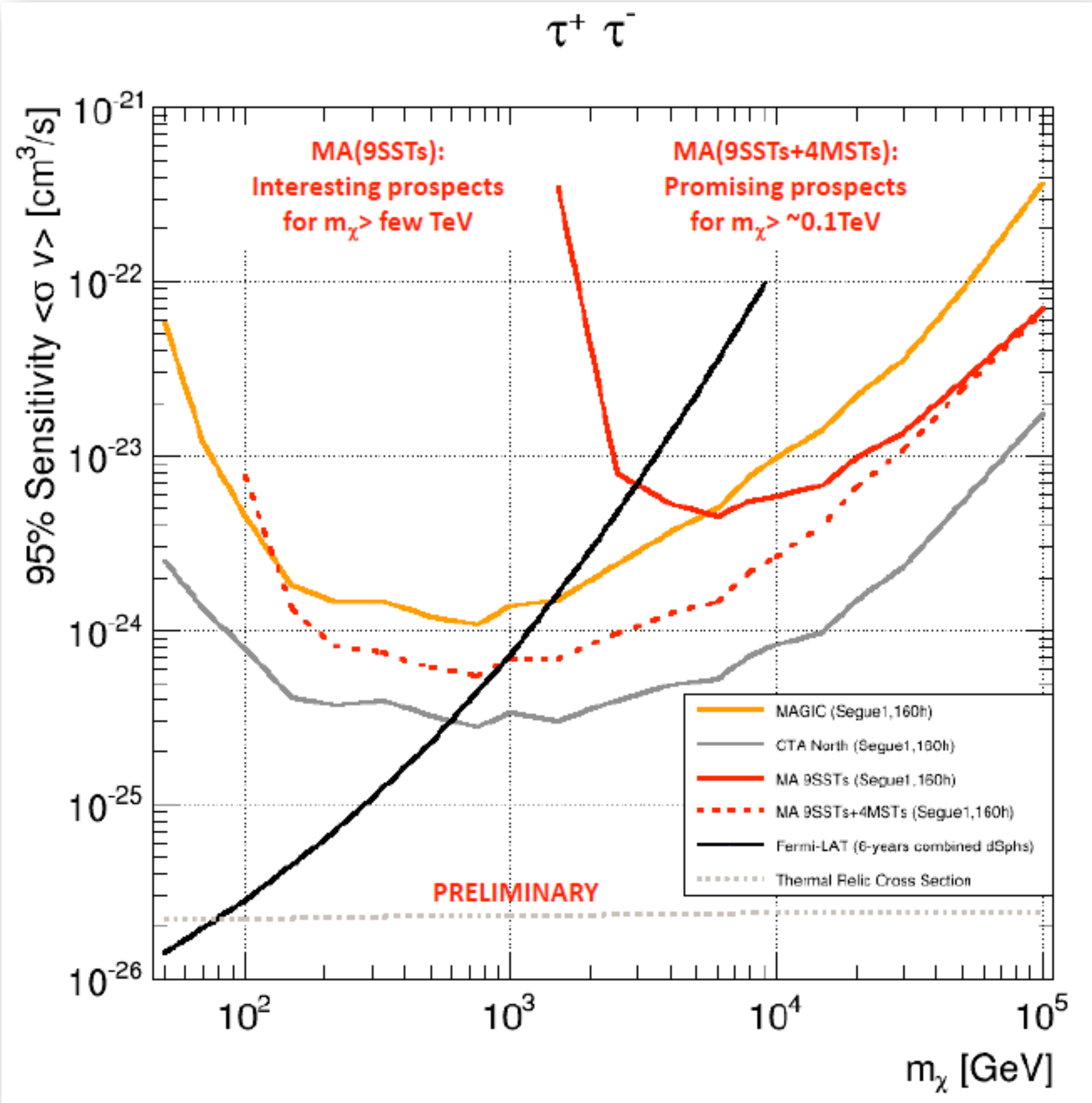
Giammaria, Lombardi, Antonelli, Brocato, et al., in prep.

Indirect search of DM in dSphs

Segue 1: 160 hr on target ➔ constraints only!

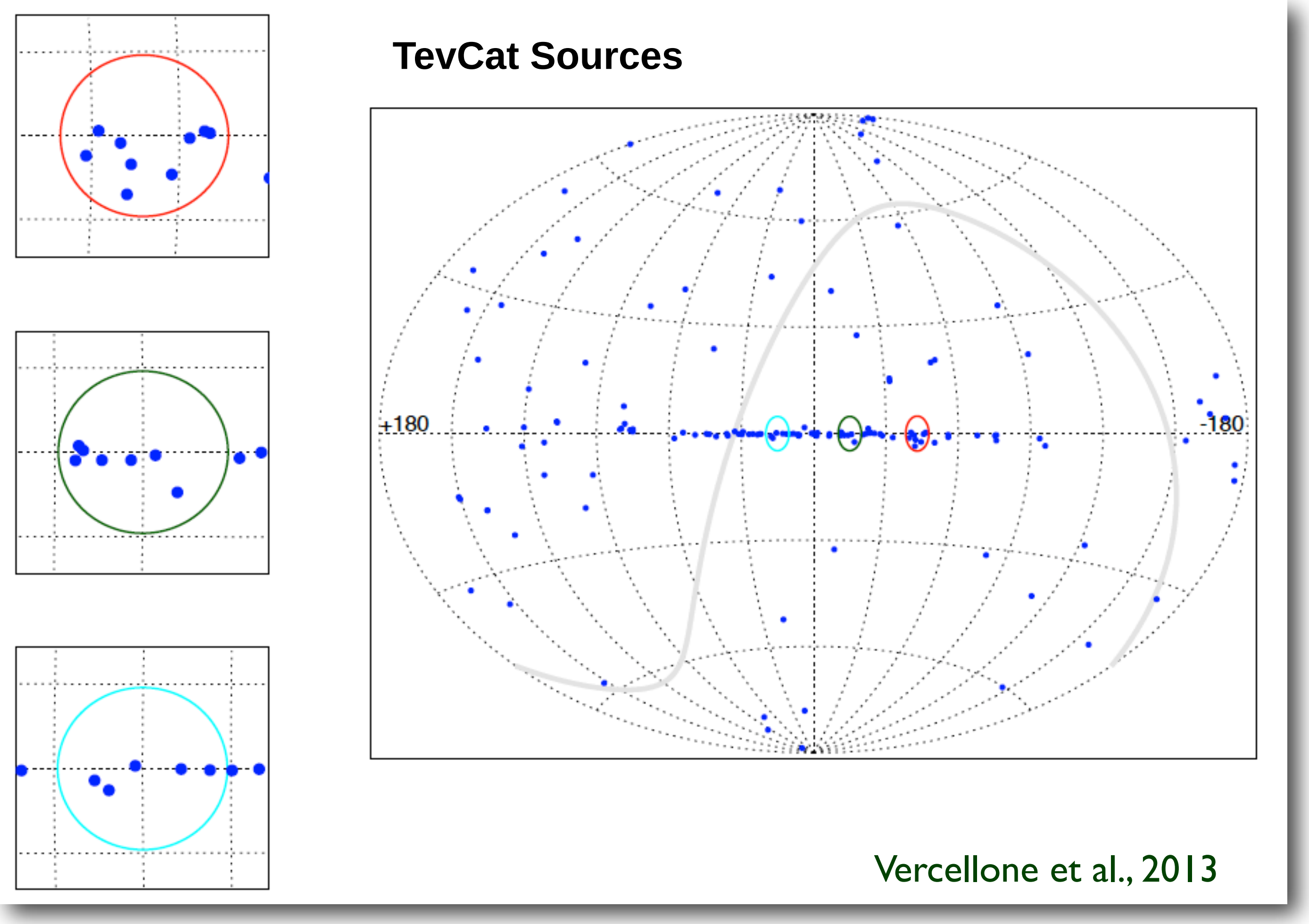
- Ultra-faint dSph Galaxy, 23 kpc from Earth
- M ~ $6 \times 10^5\ M_\odot$, M/L ~ 3400 $M_\odot/L_\odot$
- Einasto DM profile
- J-factor=1.1×10^{19} GeV^2 cm^{-5}





Giammaria, Lombardi, Antonelli, Brocato, et al., in prep.

The wide field of view

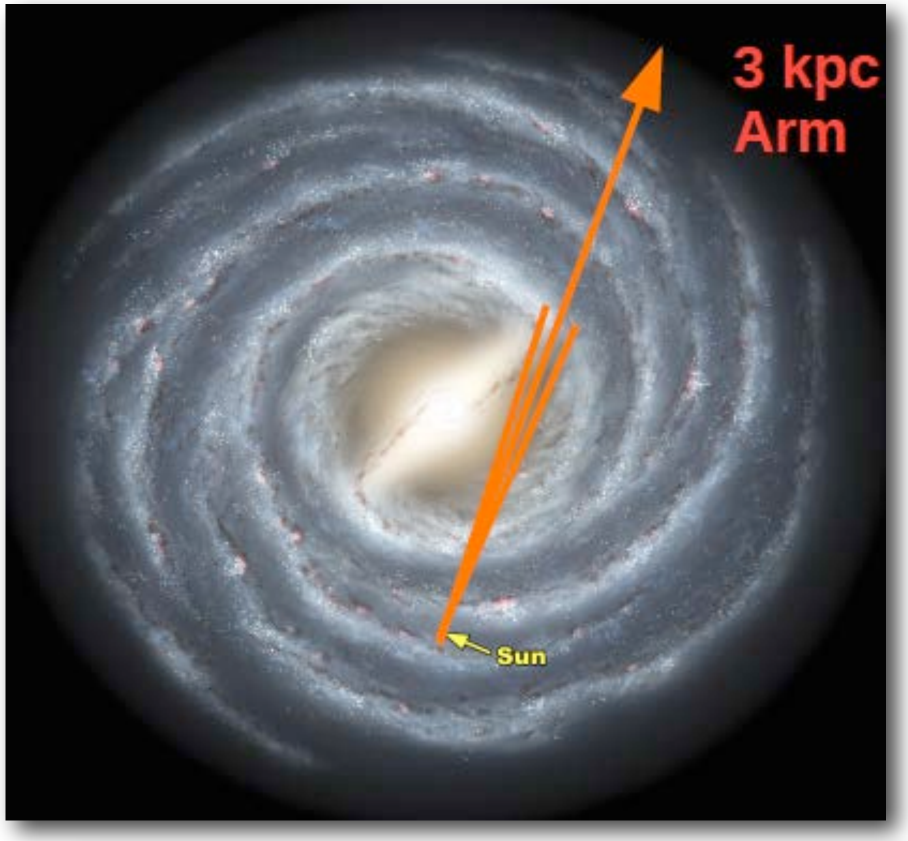


The ASTRI mini-array will have a **larger field of view** w.r.t. the current IACT ones.

Although the actual sensitivity will substantially drop for off-axis sources, **a few targets can be monitored simultaneously.**

Detections of serendipitous strong flares (a few Crab units) from hard spectrum sources will be possible as well.

The wide FoV and our Galaxy



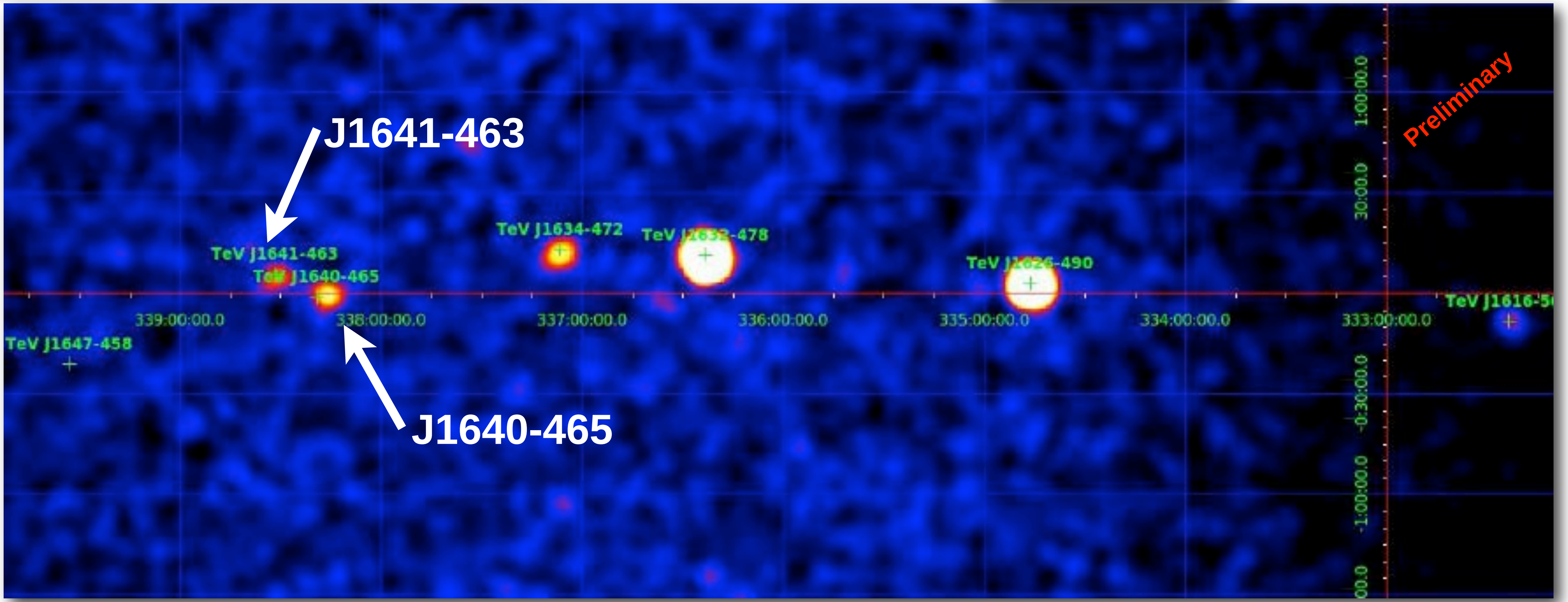
ASTRI mini-array 200 hrs simulation for E > 10 TeV

- This region can be monitored in the period [Feb. - Sept., ZA < 35deg] for more than 400 hrs
- Several sources can be investigated during a single pointing

200 hr

3 kpc Arm

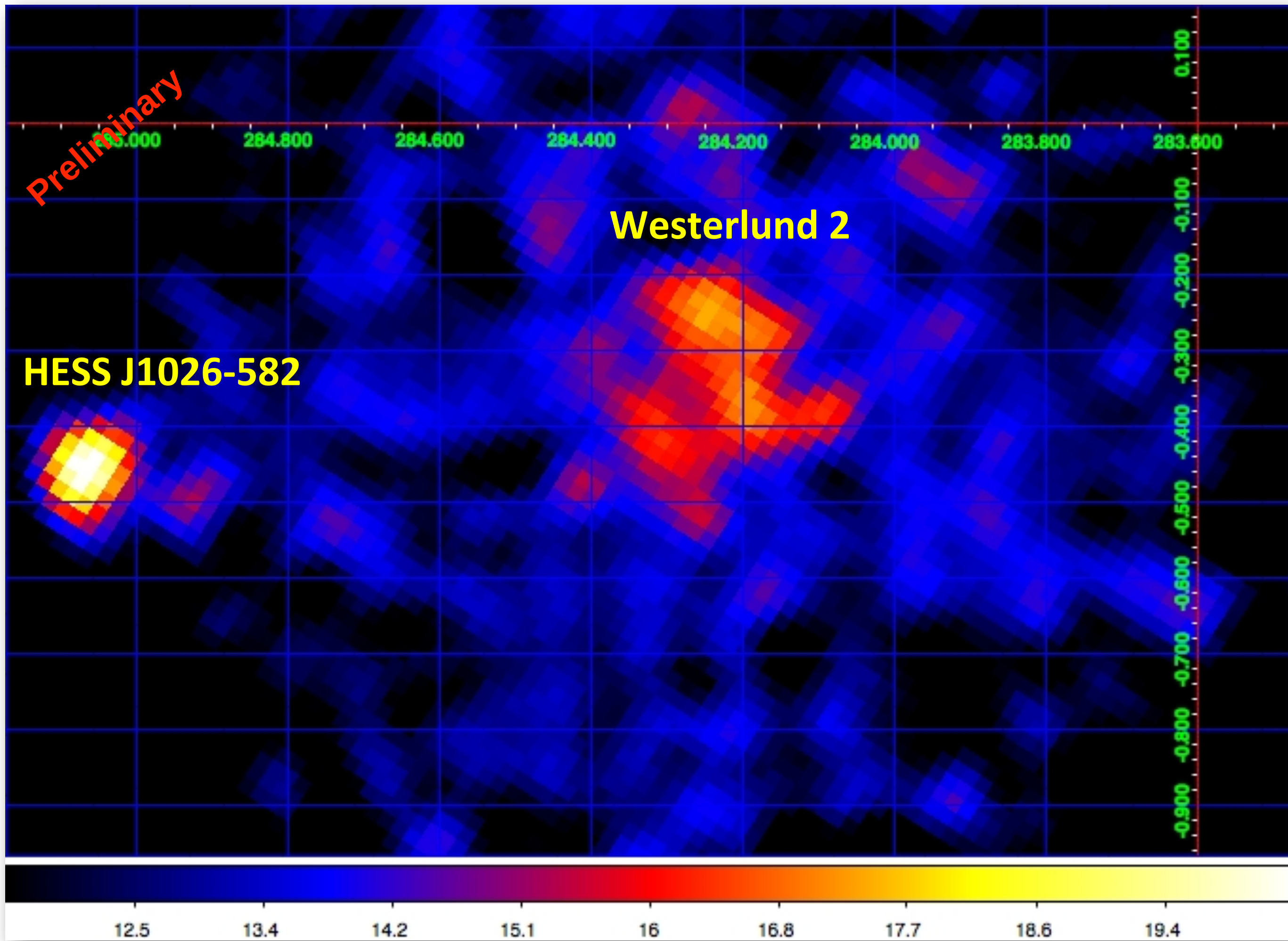
Giuliani et al., in prep.



The wide FoV and our Galaxy

eta-Car region

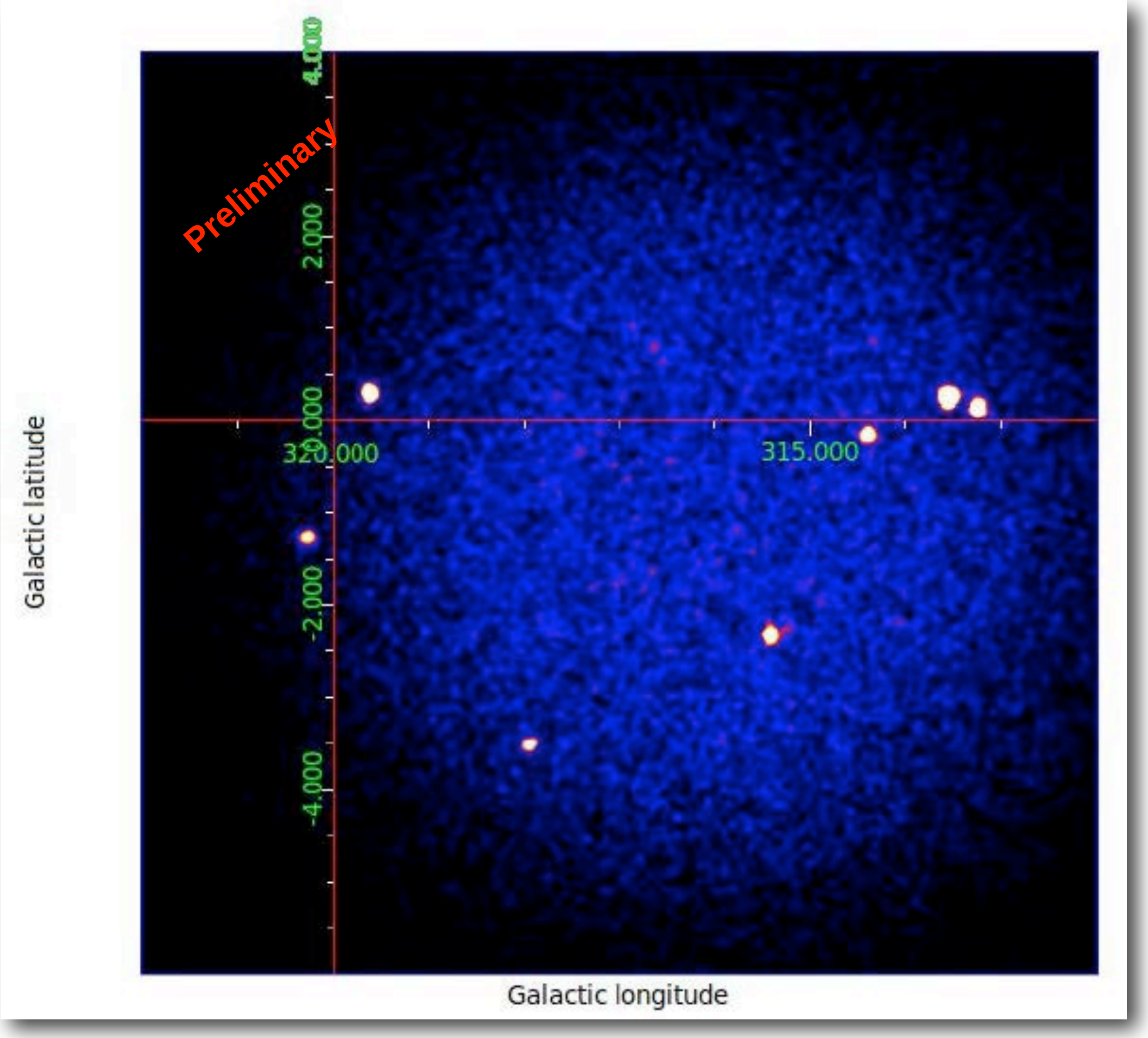
270 hr



Sabatini, Donnarumma et al., in prep.

Crux Arm

200 hr



Giuliani et al., in prep.

Outline

The ASTRI SST-2M end-to-end prototype

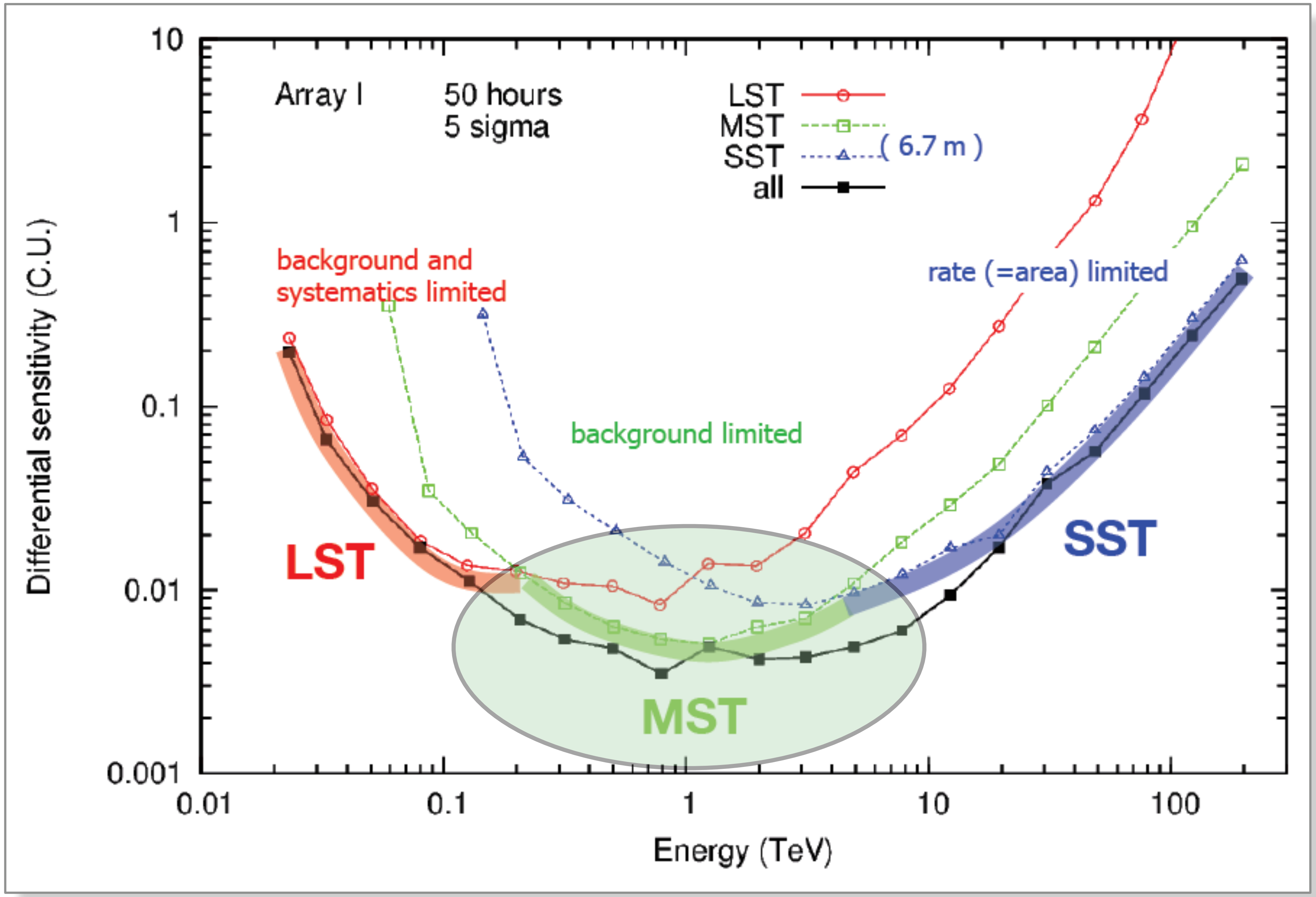
- Technological innovations
- Present status and preliminary results

The ASTRI mini-array of precursors

- Main performance
- Scientific cases
- Synergies with current and future facilities

Outlook and Conclusions

Synergy with MST

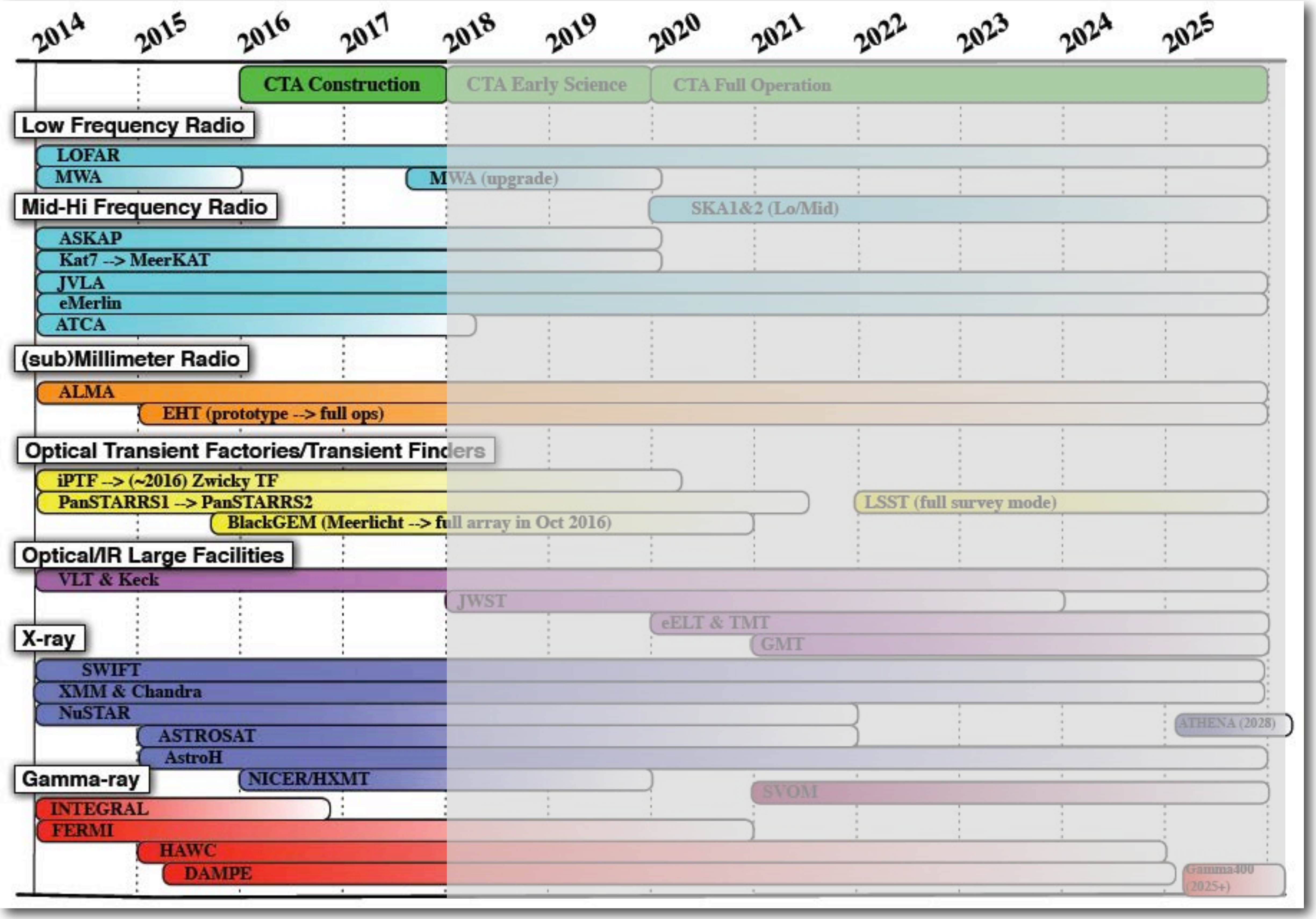


Courtesy of The CTA Consortium

Adding a couple of MST units to the ASTRI mini-array could be useful in order to:

- **test trigger performance among different kinds of telescopes;**
- improve the energy threshold;
- obtain a better energy coverage below 1 TeV.

MWL facilities



S. Markoff - TDR CTA Science

Summary

- **The ASTRI SST-2M prototype**, inaugurated on September 24th 2014, will perform the first observations with a Schwarzschild-Couder telescope equipped with SiPMs at the end of 2015.

- **The ASTRI mini-array** will constitute a *precursor* for the whole CTA array, allowing us to investigate innovative technological solutions.

- **CTA precursor early science** performed by means of ASTRI mini-array observations of a few selected targets will allow us to obtain several solid detections during the first year.

- **Excellent synergies** with other CTA precursors (MSTs, LSTs) and with several observing facilities from 2017 and beyond.

http://www.brera.inaf.it/astri/

Credit: R. Canestrari