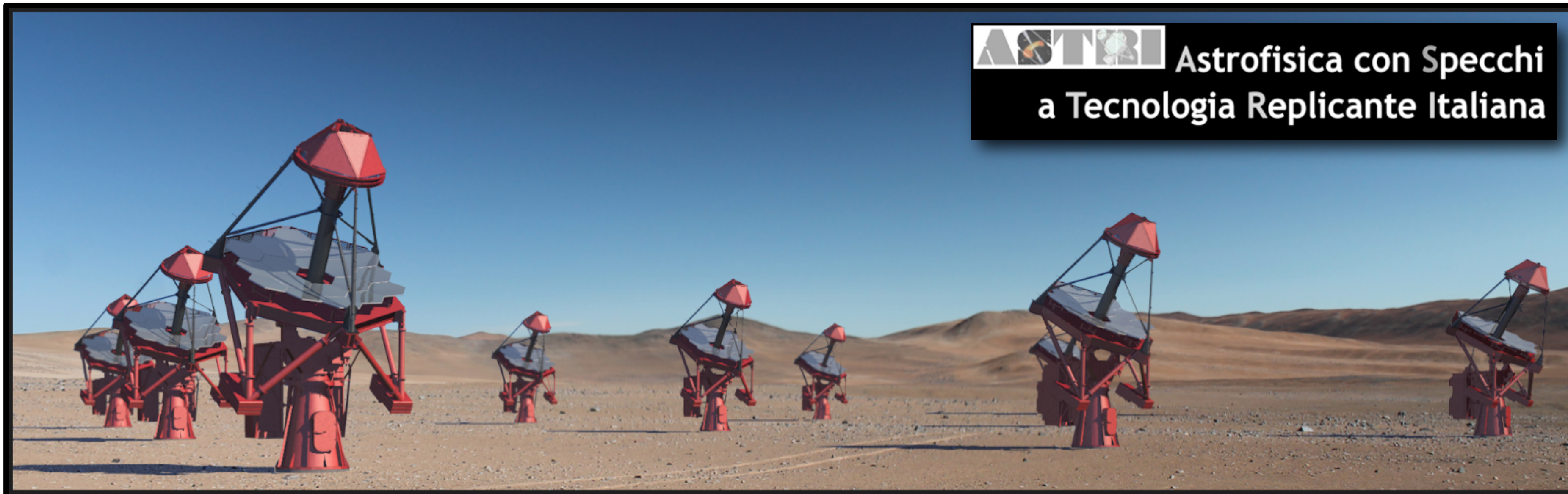


Science at very high energy with the ASTRI mini-array

Saverio Lombardi, INAF-OAR and ASI-SSDC, Rome, Italy

L.A. Antonelli, O. Catalano, G. Pareschi, S. Scuderi, S. Vercellone

for the ASTRI Project

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

Universidade de São Paulo

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

Fundación Galileo Galilei - INAF Telescopio Nazionale Galileo

Agenzia Spaziale Italiana

ASTRI Project (~40 FTE):

- Project born 10 years ago to consolidate the INAF technologies in the field of Cherenkov astronomy in view of future gamma-ray projects, including CTAO*
- Main sub-projects:
  - Development of an innovative end-to-end prototype of wide-field Small-Sized Telescope (4 m) class in dual-mirror configuration (SST-2M)
  - ASTRI mini-array @ Teide Observatory (Tenerife, Spain) in collaboration with Istituto de Astrofísica de Canarias (IAC), University of São Paulo, and North-West University
- Leading the consortium that will implement the SST telescopes @ CTAO southern site

***See talk by R. Zanin on Friday**

ASTRI SST-2M prototype: dedication to Horn D'Arturo

10th of November 2018

Dedication of ASTRI SST-2M prototype to **Guido Horn D'Arturo**
(inventor of the "segmented" astronomical mirrors)
➔ **ASTRI–HORN telescope**

ASTRI-Horn telescope

End-to-end prototype installed @ Serra La Nave Observatory (Mt. Etna, Italy)

Mainly a technological (HW&SW) demonstrator

Telescope *verification phase*: 2017 – 2019

<u>Telescope *scientific validation phase:* 2020</u>

Telescope characteristics:

- **<u>Optical design = Schwarzschild-Couder</u>**
- Primary mirrors (M1) = 4.3 m (segmented)
- Secondary mirror (M2) = 1.8 m (monolithic)
- F/D_1 = 0.5; F = 2.15 m
- M1-M2 distance = 3.0 m
- Average Effective Area = 5.0 m^2
- Optical PSF ≤ 0.19°

Camera properties:

- **<u>Sensor type = SiPMs</u>** (Hamamatsu)
- Unconventional low data-hungry Front-End electronics, based on fast peak detector
- Number of PDMs = 21(37*)
- Number of logical pixels = 1344(2368*)
- Pixel size = 0.19° (plate scale = 37.5 mm/°)
- Field of View = 7.6°(10.9°*)

*Nominal camera layout

Expected performance:

- Energy threshold ≈ 1 TeV
- Energy/Angular resolution < ~25% / < ~0.15°
- **Sensitivity ≈ 1 Crab @ 5 σ in few hours**

ASTRI-Horn telescope: operations and results

A&A 608, A86 (2017)
DOI: 10.1051/0004-6361/201731602

Astronomy & Astrophysics

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

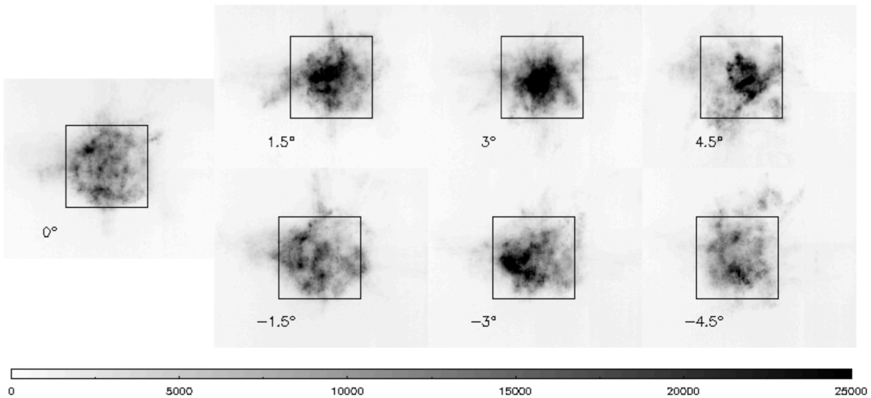
E. Giro[1,2], R. Canestrari[2], G. Sironi[2], E. Antolini[3], P. Conconi[2], C. E. Fermino[4], C. Gargano[5], G. Rodeghiero[1,6], F. Russo[7], S. Scuderi[8], G. Tosti[3], V. Vassiliev[9], and G. Pareschi[2]

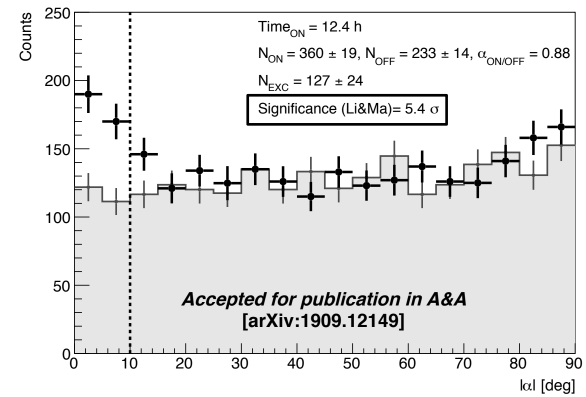
Astronomy & Astrophysics manuscript no. letter

Letter to the Editor

First detection of the Crab Nebula at TeV energies with a Cherenkov telescope in dual-mirror Schwarzschild-Couder configuration: the ASTRI-Horn telescope

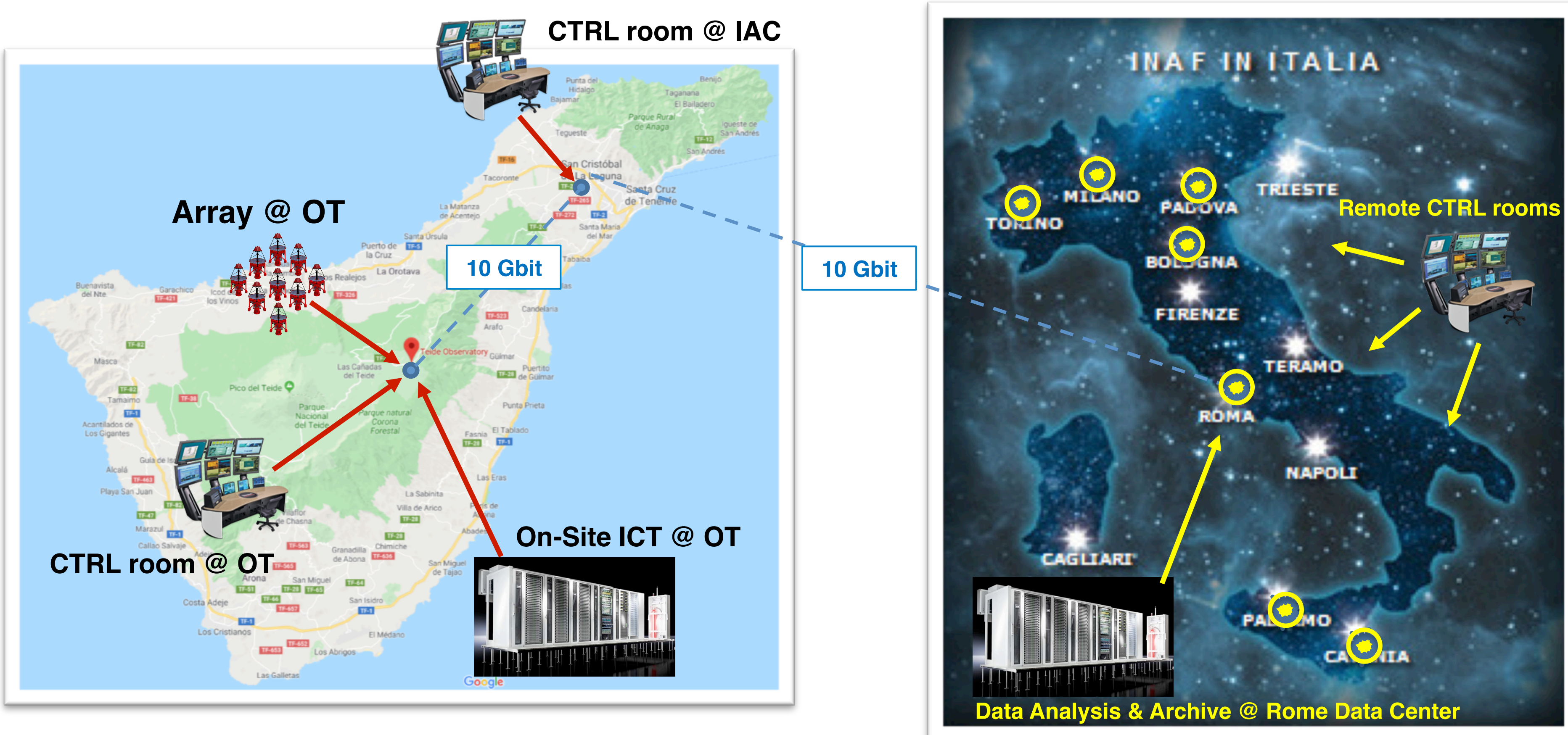
S. Lombardi[1,2,⋆], O. Catalano[3,⋆], S. Scuderi[4,⋆], L. A. Antonelli[1,2,⋆], and G. Pareschi[5,⋆] et al.





- **First optical validation** of a dual-mirror Schwarzschild Couder configuration (2016)
- **First detection of Crab Nebula** with a dual-mirror Cherenkov telescope (2018)
- **Full scientific validation** with new observations of bright gamma-ray sources (2020)
- **From 2020 onwards:**
  - Observations of a few bright sources (within MWL monitoring programs)
  - Test bench for implementation of new HW/SW technologies
  - Etna muon tomography and cosmic rays studies

ASTRI mini-array: general layout

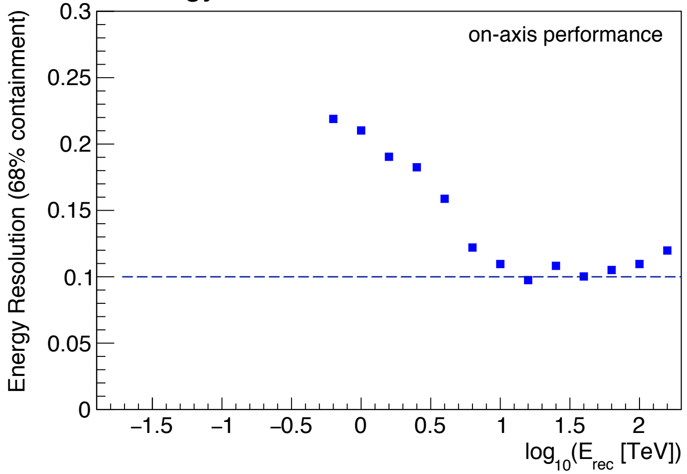


- **The ASTRI mini-array will be composed of 9 (improved) ASTRI-like SST-2M telescopes**
- **It is being developed so as to be operated remotely (after the commissioning phase)**
- **Low data size ➔ easy data transfer off-site ➔ off-line software trigger @ Data Center**
- **Implementation phase: *first telescope at site expected in fall 2020***

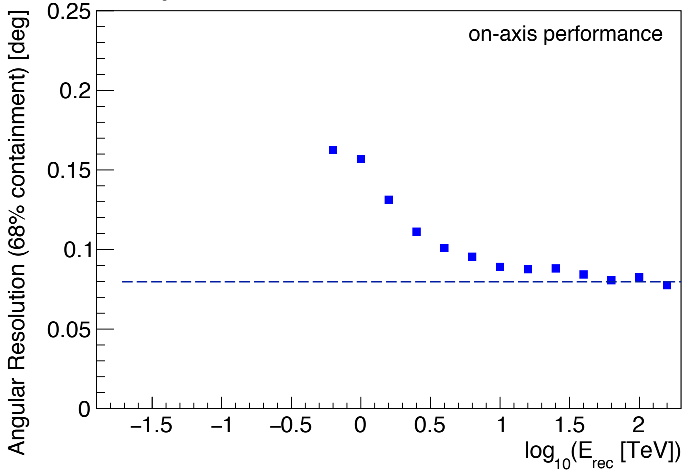
ASTRI mini-array: expected performance

- **Performance from simulation/analysis of 9 ASTRI-like telescopes @ CTA South**
- **Full simulations @ OT ongoing in order to assess more precise performance**

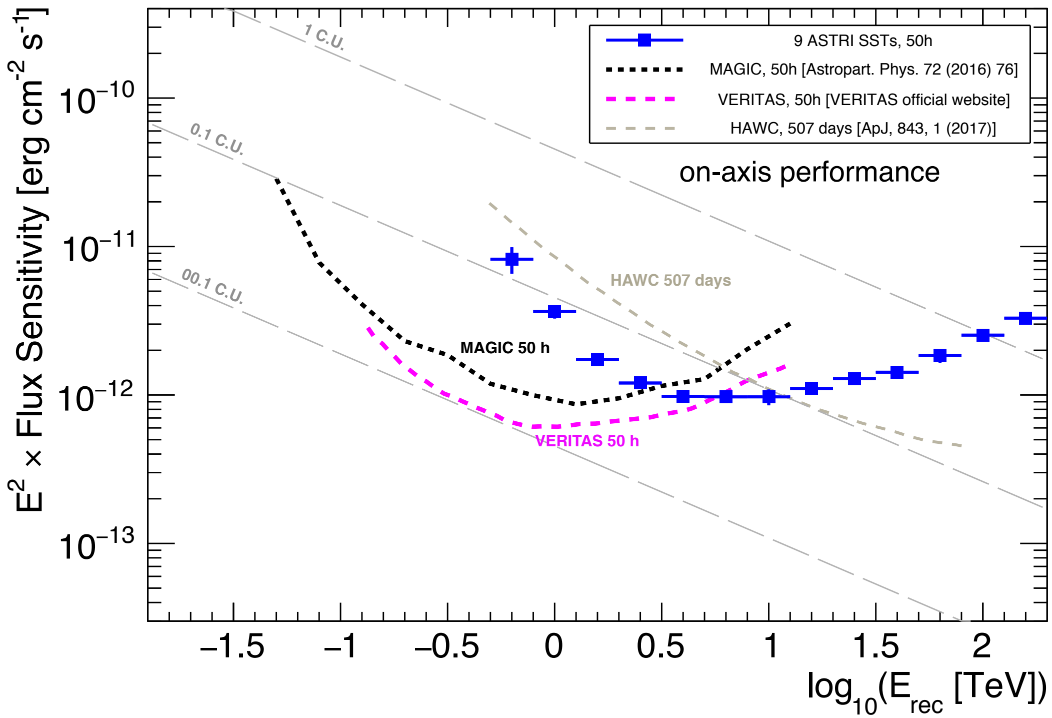
Energy resolution



Angular resolution



Differential flux sensitivity



Expected performance:

- Sensitivity: better than current IACTs (E > ~10 TeV)
- Energy/Angular resolution: < ~10% / < ~0.1° (E > ~10 TeV)
- Wide FoV (≥ 10°), with homogeneous off-axis acceptance

First ~2/3 years:

- Restricted number of targets / deep exposures (> ~200 h each) ➔ **core science program**
- Possibility of MoUs for joint observational programs with MAGIC, LSTs (before CTA North) and optical telescopes, like e.g. Galileo National Telescope (TNG)

Afterwards:

- Observing proposals from a wider scientific community
- Broader scientific cases, with main focus on the multi-TeV domain
- Comprehensive link between fundamental physics and galactic/extragalactic observations

Galactic targets:

- SNRs / PeVatrons / SNRs interacting with MCs
- PWNe / TeV Halos
- Gamma-ray binaries

Extragalactic targets:

- Extreme BL Lacs
- Radio galaxies
- Starburst galaxies

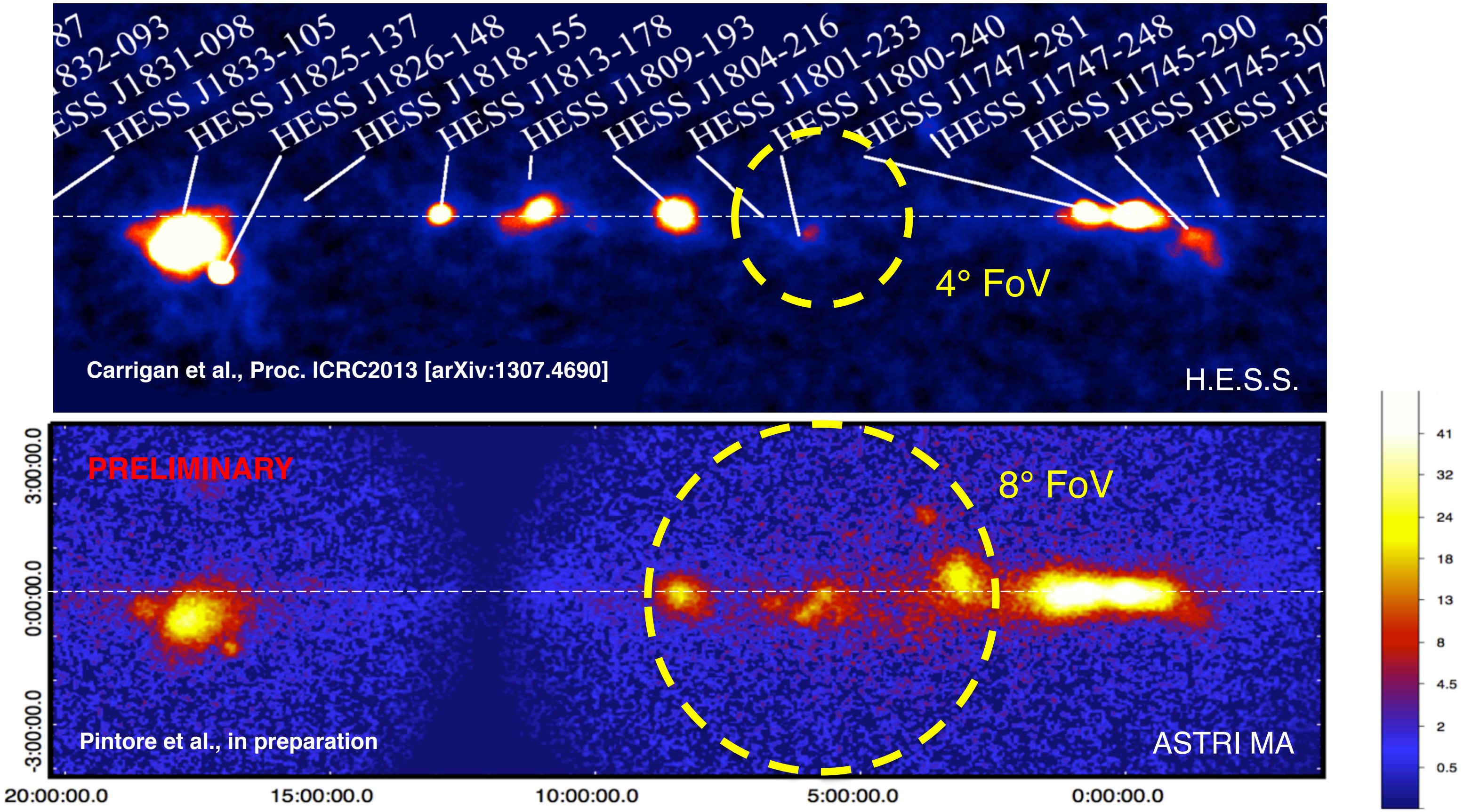
Fundamental physics:

- Lorentz invariance violation / Axion-like particles / Hadron beams in AGN jets
- EBL
- Dark Matter

ASTRI mini-array: key features

Large Field of View (≥ 10°), with homogeneous acceptance:

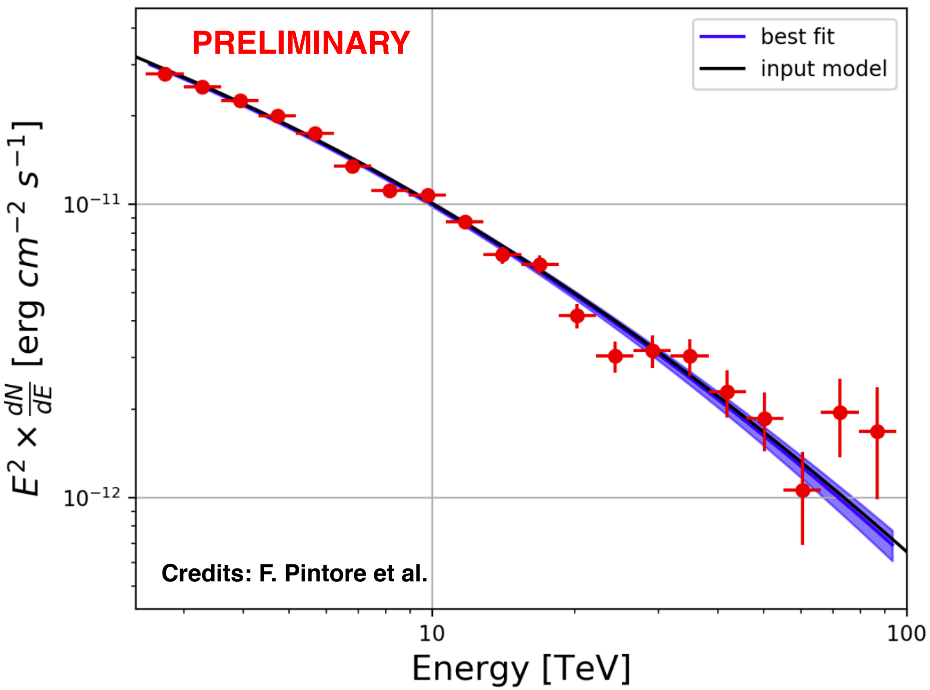
- Optimal for multi-target fields, surveys, and extended sources
- Enhanced chance for serendipity discoveries



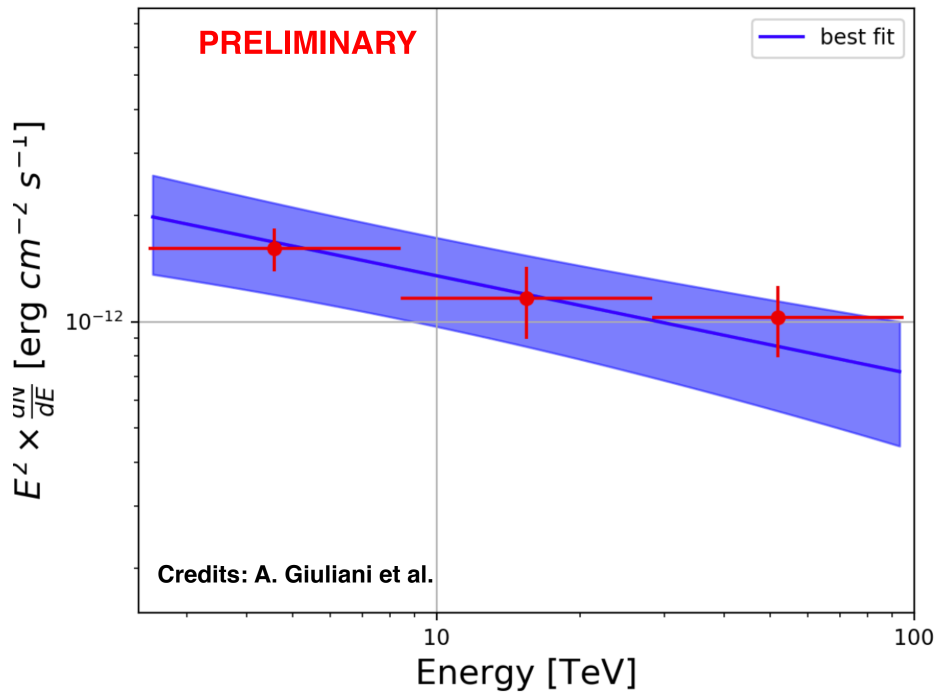
Simultaneous observation of several sources thanks to large FoV and spatially homogeneous acceptance

Expected sensitivity above ~10 TeV:

- Possibility to extend the spectra of already detected sources and/or measure cut-offs
- Possibility to characterized the morphology of extended sources at the highest VHE



Crab Nebula spectrum up to ~100 TeV in ~100 h
Important insights on the emission processes
at the highest VHE energies

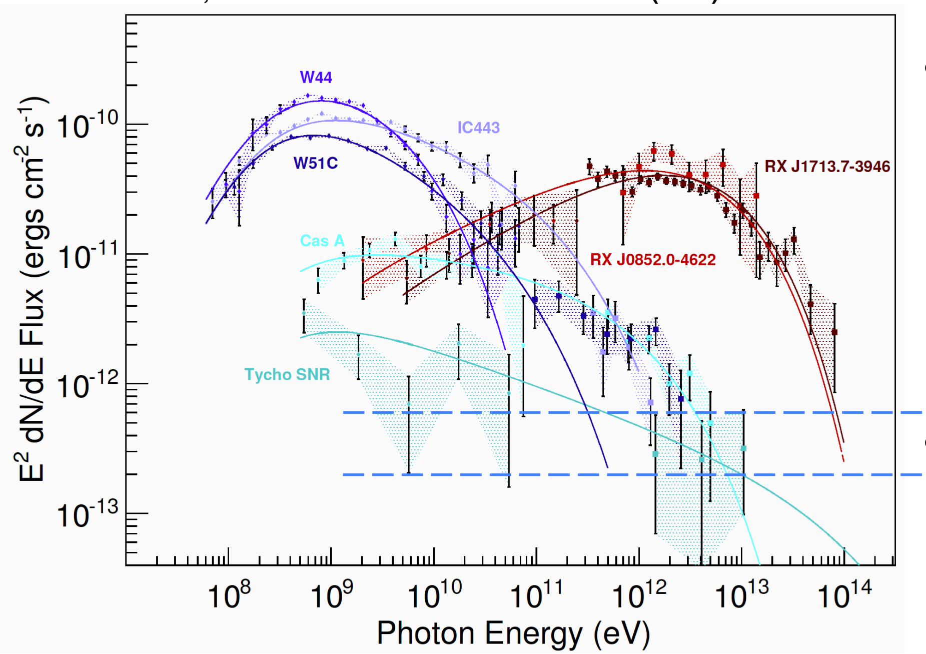


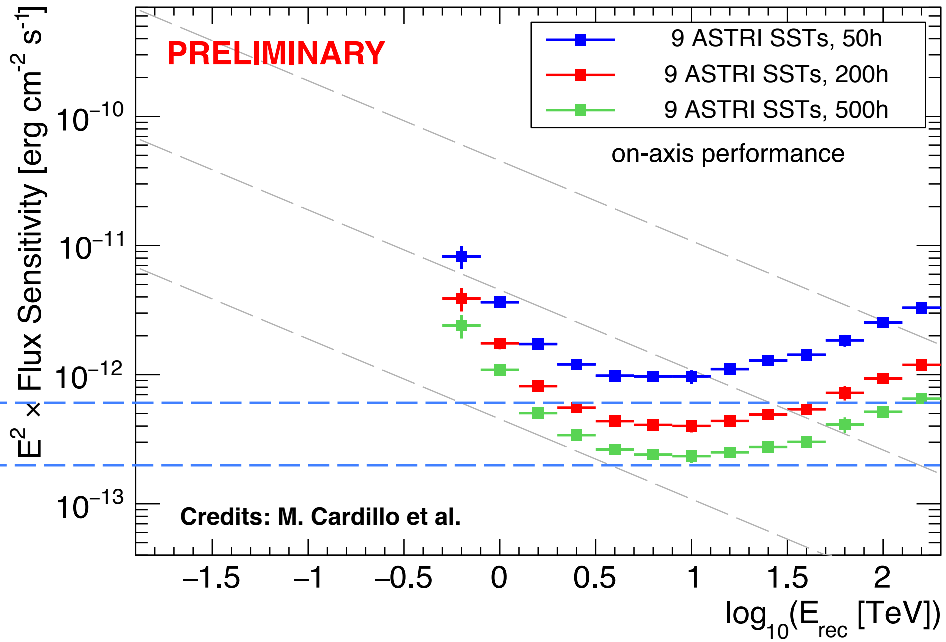
Geminga spectrum up to 100 TeV in ~300 h
Extension of morphological studies
at the highest VHE energies

Expected sensitivity above ~10 TeV:

- Possibility to extend the spectra of already detected sources and/or measure cut-offs
- Possibility to characterized the morphology of extended sources at the highest VHE

Funk, Annu. Rev. Nucl. Part. Sci. 65:245-277 (2015)

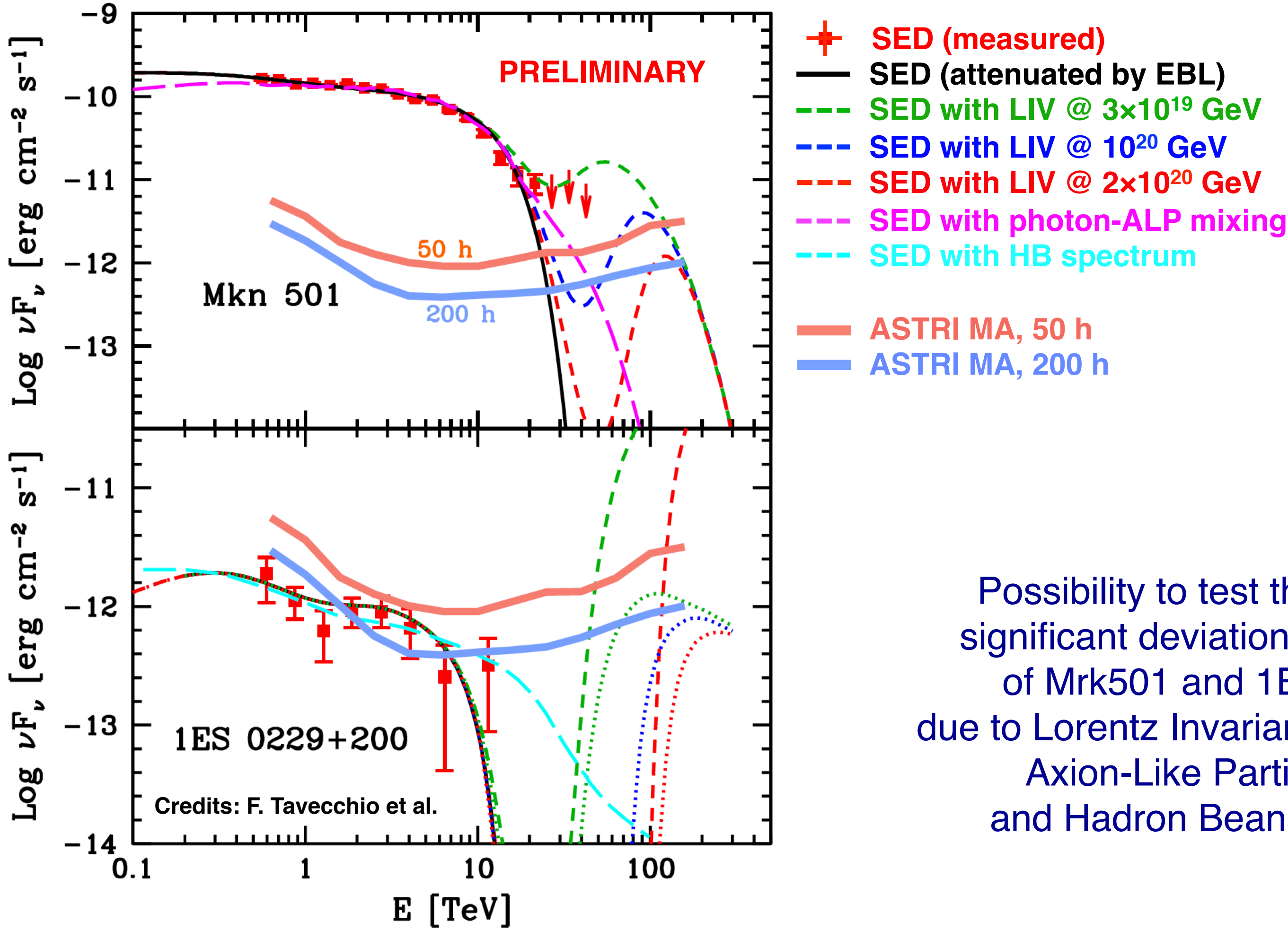




Possibility to better constrain the PeVatron spectrum in > few hundreds hours

Expected sensitivity above ~10 TeV:

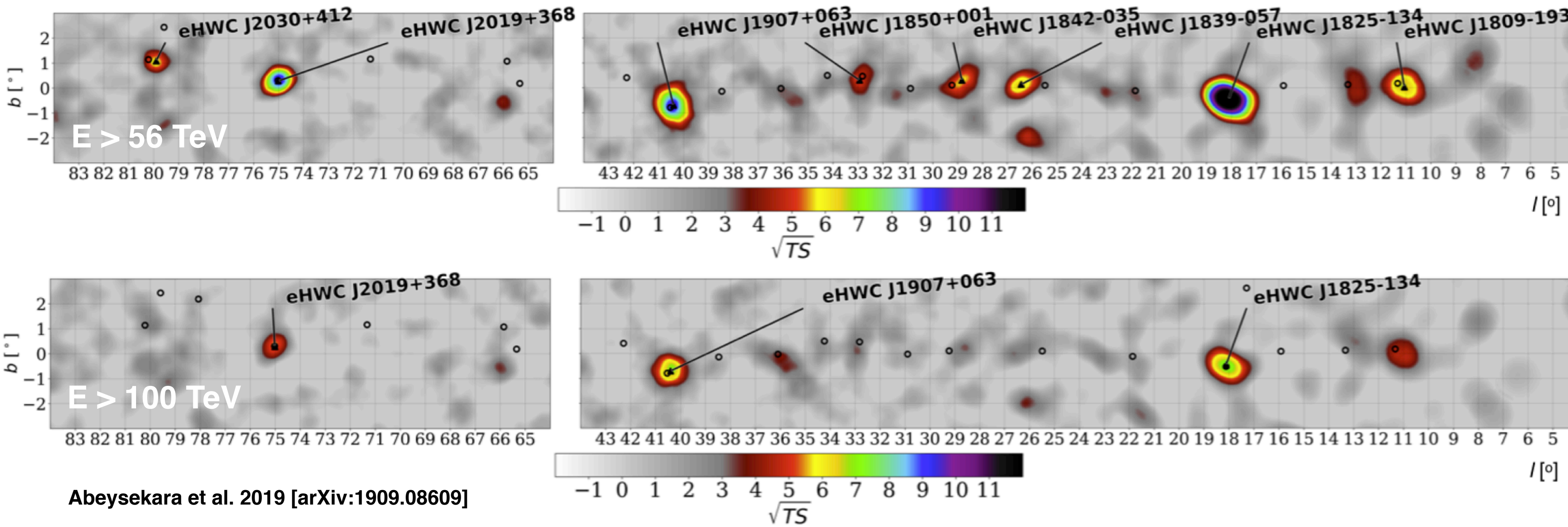
- Possibility to extend the spectra of already detected sources and/or measure ***new signatures***
- Possibility to characterized the morphology of extended sources at the highest VHE



Possibility to test the presence of significant deviations in the spectra of Mrk501 and 1ES 0229+200 due to Lorentz Invariance Violation (LIV) Axion-Like Particles (ALPs) and Hadron Beans (HB) effects

Synergies with current VHE Northern Arrays:

- Observations of HAWC sources with much higher angular/energy resolution
- Simultaneous observations with MAGIC and LSTs will be possible



Abeysekara et al. 2019 [arXiv:1909.08609]

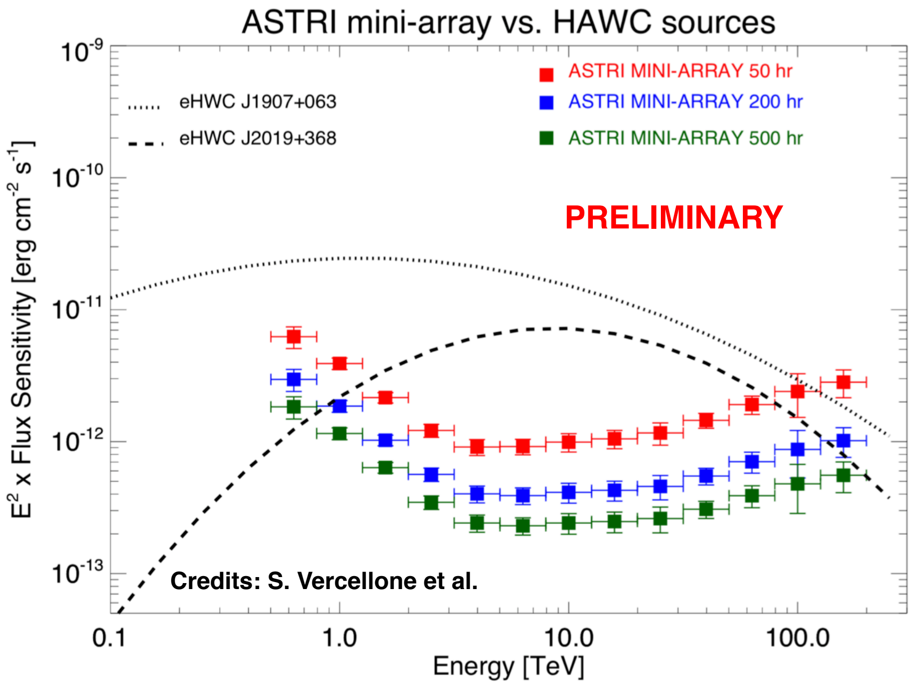
Source name	RA (^{o})	Dec (^{o})	Extension > 56 TeV (^{o})	F (10^{-14} ph cm^{-2} s^{-1})	$\sqrt{TS}$ > 56 TeV	nearest 2HWC source	Distance to 2HWC source(^{o})	$\sqrt{TS}$ > 100 TeV
eHWC J0534+220	83.61 ± 0.02	22.00 ± 0.03	PS	1.2 ± 0.2	12.0	J0534+220	0.02	4.44
eHWC J1809-193	272.46 ± 0.13	-19.34 ± 0.14	0.34 ± 0.13	$2.4^{+0.6}_{-0.5}$	6.97	J1809-190	0.30	4.82
eHWC J1825-134	276.40 ± 0.06	-13.37 ± 0.06	0.36 ± 0.05	4.6 ± 0.5	14.5	J1825-134	0.07	7.33
eHWC J1839-057	279.77 ± 0.12	-5.71 ± 0.10	0.34 ± 0.08	1.5 ± 0.3	7.03	J1839-065	0.96	3.06
eHWC J1842-035	280.72 ± 0.15	-3.51 ± 0.11	0.39 ± 0.09	1.5 ± 0.3	6.63	J1844-032	0.44	2.70
eHWC J1850+001	282.59 ± 0.21	0.14 ± 0.12	0.37 ± 0.16	$1.1^{+0.3}_{-0.2}$	5.31	J1849+001	0.20	3.04
eHWC J1907+063	286.91 ± 0.10	6.32 ± 0.09	0.52 ± 0.09	2.8 ± 0.4	10.4	J1908+063	0.16	7.30
eHWC J2019+368	304.95 ± 0.07	36.78 ± 0.04	0.20 ± 0.05	$1.6^{+0.3}_{-0.2}$	10.2	J2019+367	0.02	4.85
eHWC J2030+412	307.74 ± 0.09	41.23 ± 0.07	0.18 ± 0.06	0.9 ± 0.2	6.43	J2031+415	0.34	3.07

Synergies with current VHE Northern Arrays:

- Observations of HAWC sources with much higher angular/energy resolution
- Simultaneous observations with MAGIC and LSTs will be possible

Source	Moonless [h]	Dark [h]	Grey [h]	>100 TeV
eHWC J0534+220	344.0	55.7	8.0	
eHWC J1809-193	0.0	0.0	0.0	
eHWC J1825-134	0.0	0.0	0.0	✅
eHWC J1839-057	77.0	6.7	1.0	
eHWC J1842-035	137.0	13.3	2.0	
eHWC J1850+001	193.7	18.7	3.0	
eHWC J1907+063	257.0	28.0	7.3	✅
eHWC J2019+368	361.0	42.0	14.0	✅
eHWC J2030+412	353.7	43.0	17.3	

Moonless = no Moon Light
Dark = Moon Light < 40%
Grey = 40% < Moon Light < 70% (and target at > 90° from Moon)



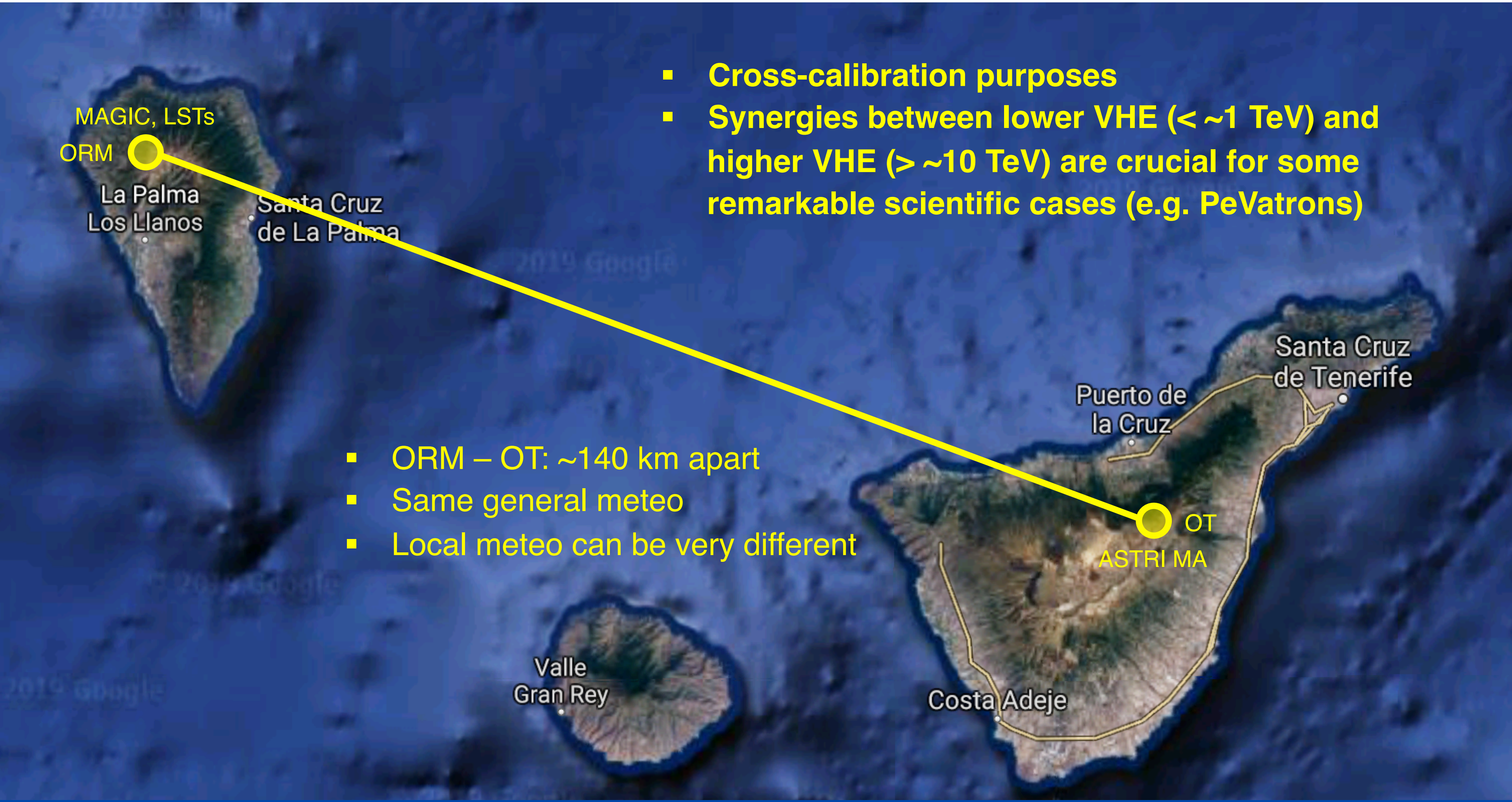
Maximum number of h / yr observable from Observatorio del Teide (Zenith angle < 35°)

Some HAWC sources detectable in < ~100 h (Detailed simulations, taking into account both morphological and spectral properties ongoing)

Synergies with current VHE Northern Arrays:

- Observations of HAWC sources with much higher angular/energy resolution
- Simultaneous observations with MAGIC and LSTs will be possible

- **Cross-calibration purposes**
- **Synergies between lower VHE (< ~1 TeV) and higher VHE (> ~10 TeV) are crucial for some remarkable scientific cases (e.g. PeVatrons)**



- ORM – OT: ~140 km apart
- Same general meteo
- Local meteo can be very different

Summary and outlook

ASTRI mini-array @ Teide Observatory is being implemented

- Key features: performance @ > ~10 TeV, ≥ 10° FoV (with homogeneous acceptance)
- Important synergies with Northern VHE facilities (MAGIC, LSTs, HAWC, …)
- Implementation phase:
  - *First telescope at site expected in fall 2020*
  - *First observations expected in 2022*

Core science program in the first ~2/3 years

(detailed strategy under definition)

- Restricted number of targets / deep exposures (> ~200 h) ➔ strong scientific cases
  - Galactic sources: wide FoV ➔ multi-target fields
  - Extragalactic sources: survey of a few promising targets at > ~10 TeV scale
  - Fundamental physics: studies on LIV, EBL, Axion-Like Particles, …
  - Science beyond VHE astronomy also envisaged ➔ Stellar Intensity Interferometry

Contribution to pave the way to the highest energy observations @ CTA southern site


THANK YOU

Backup Slides

ASTRI-Horn telescope

End-to-end prototype installed @ Serra La Nave Observatory (Mt. Etna, Italy)

Mainly a technological (HW&SW) demonstrator

Telescope *verification phase*: 2017 – 2019

Telescope *scientific validation phase:* 2020

Dual-mirror optical layout

- First time for Cherenkov Telescopes
- Schwarzschild-Couder optical design
- Optimal PSF across the entire field of view

Silicon photo-multipliers camera

- Small pixel-size
- Can work during moonlight

Wide filed-of-view (> ~10°):

- Important for survey and multi-target fields
- Important for extended sources

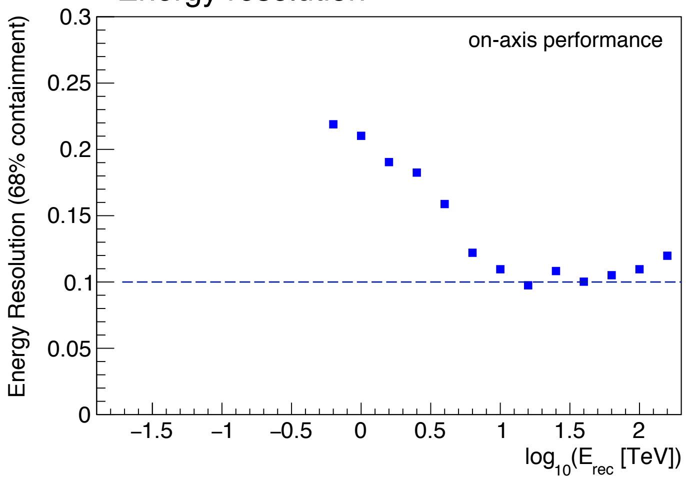
Expected performance:

- Energy threshold ≈ 1 TeV
- Energy/Angular resolution < ~25% / < ~0.15°
- **Sensitivity ≈ 1 Crab @ 5 σ in few hours**

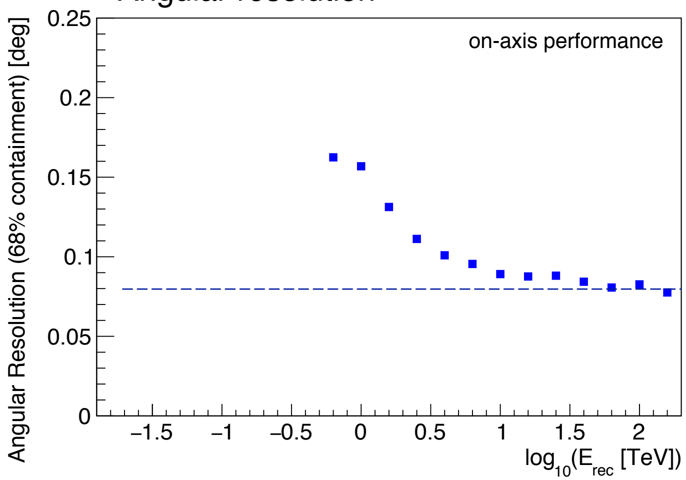
ASTRI mini-array: expected performance

- **Performance from simulation/analysis of 9 ASTRI-like telescopes @ CTA South**
- **Full simulations @ OT ongoing in order to assess more precise performance**

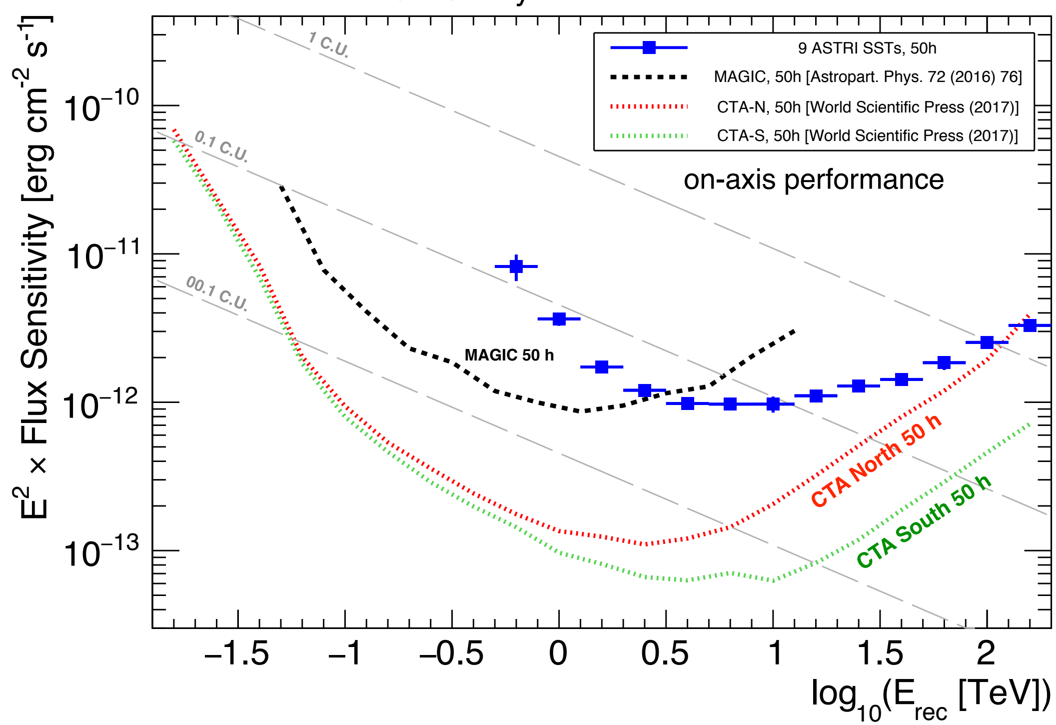
Energy resolution



Angular resolution



Differential flux sensitivity



Expected performance:

- Sensitivity: better than current IACTs (E > ~10 TeV)
- Energy/Angular resolution: < ~10% / < ~0.1° (E > ~10 TeV)
- Wide FoV (≥ 10°), with homogeneous off-axis acceptance

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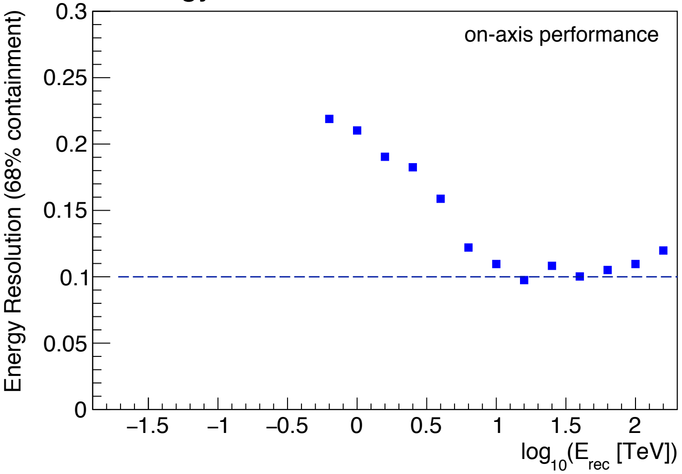
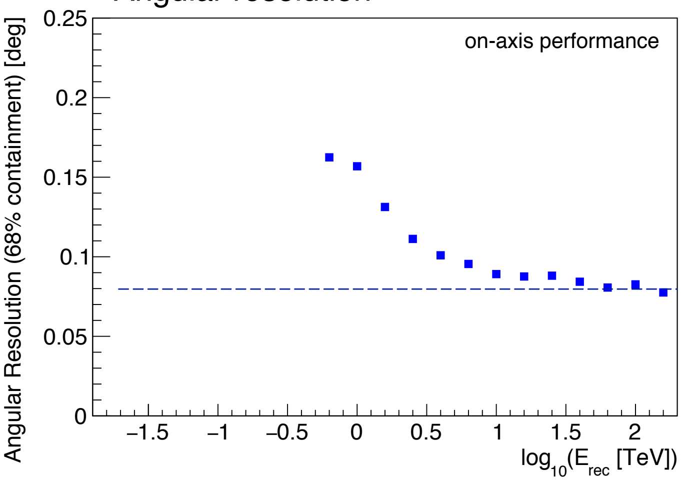
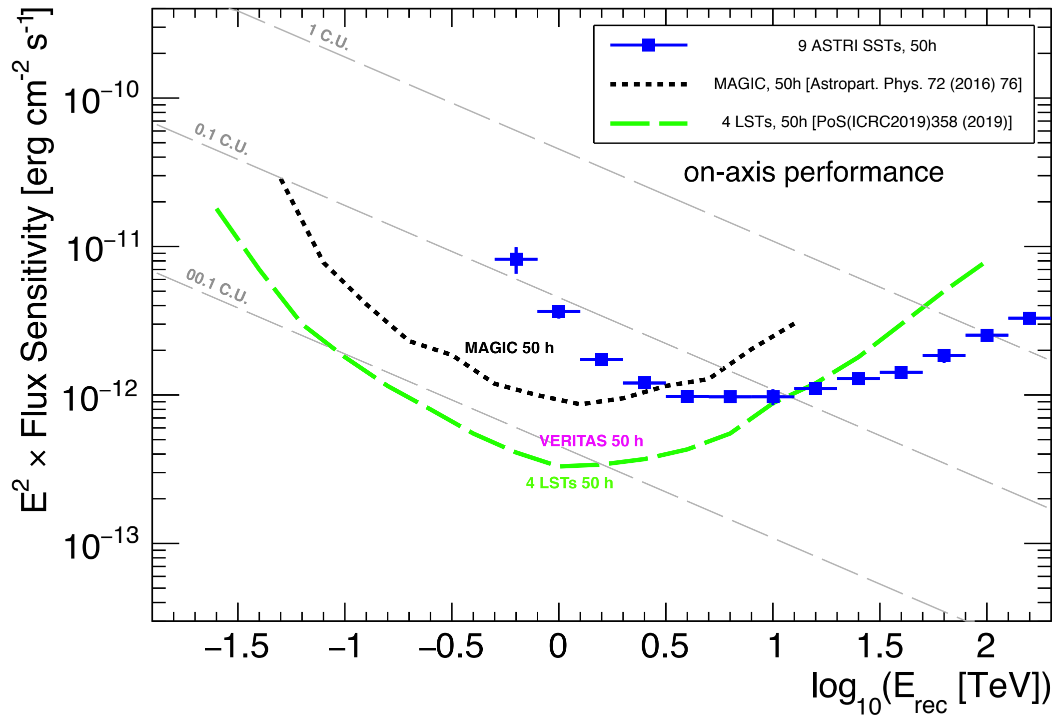


Angular resolution



Differential flux sensitivity



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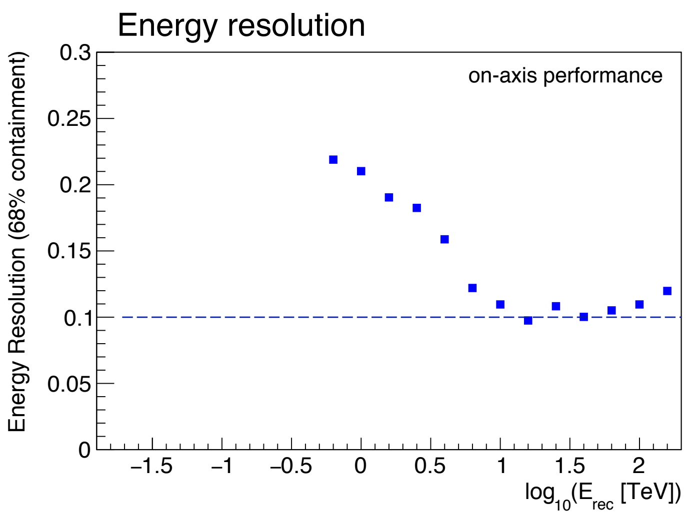

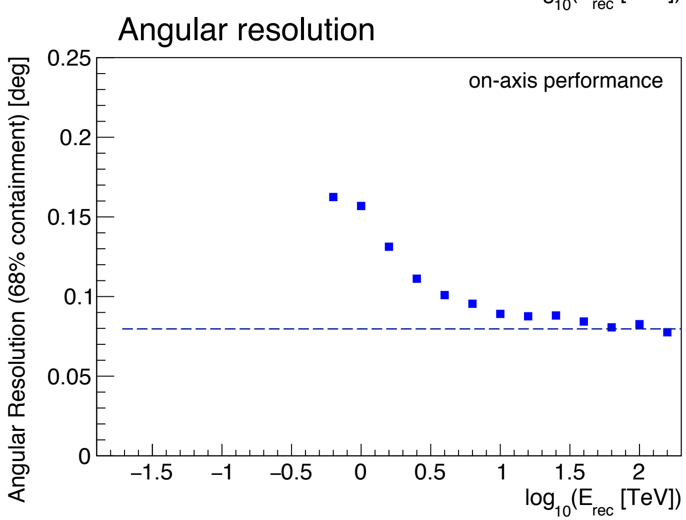

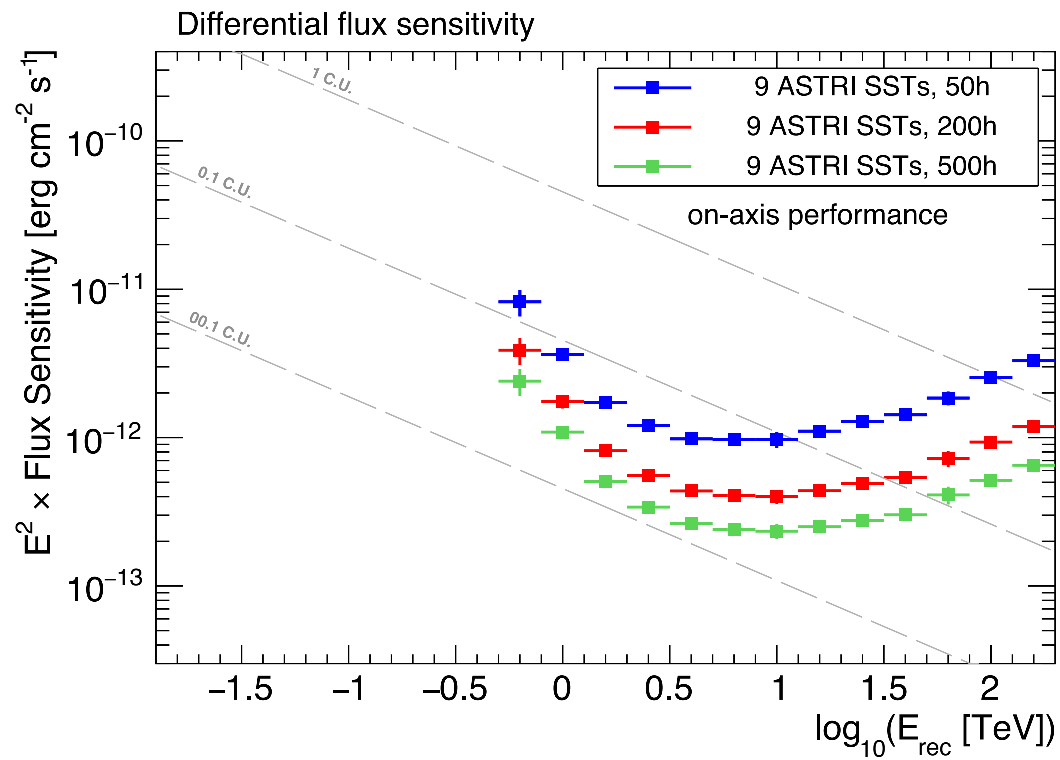

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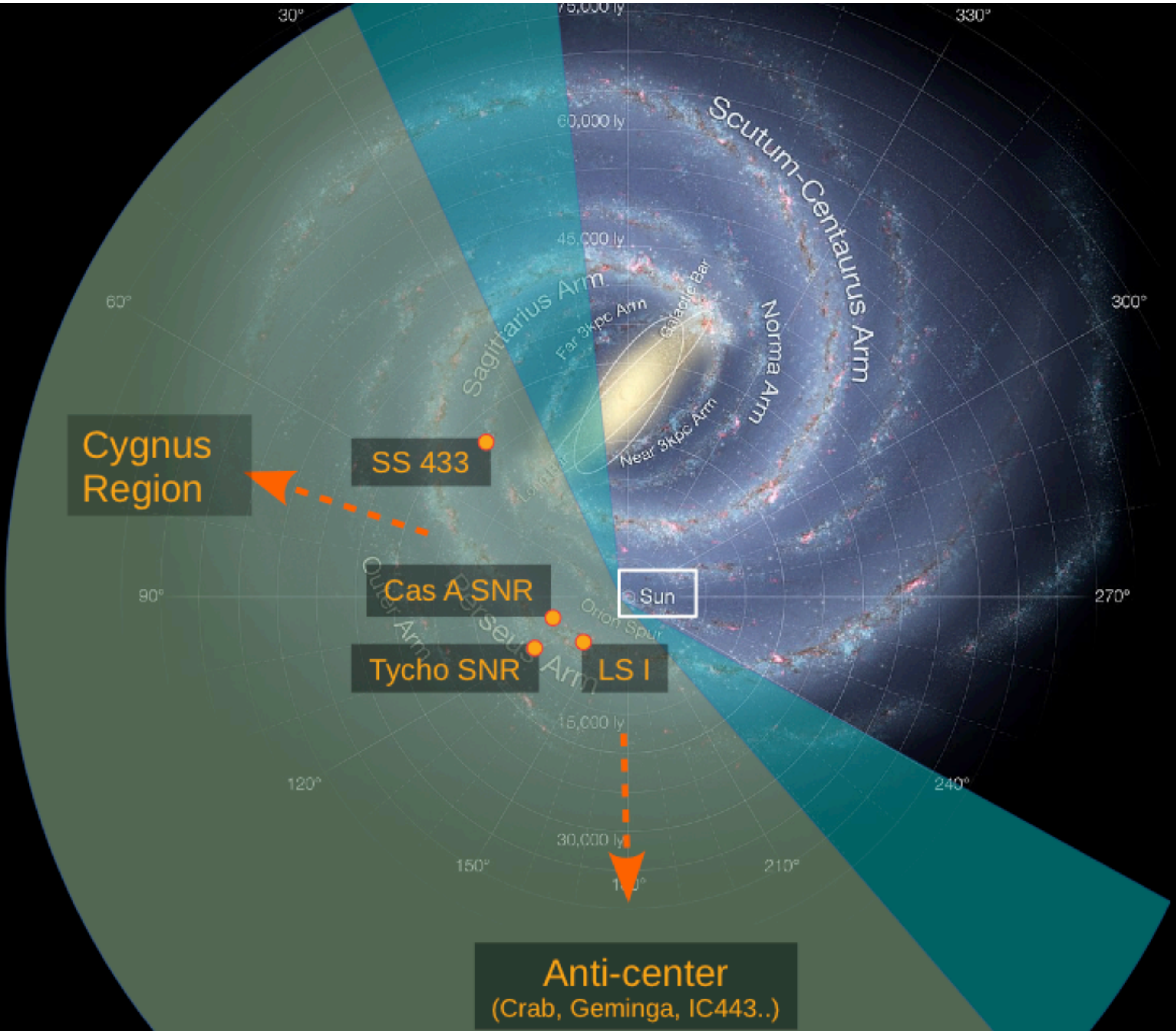
Galaxy regions visibility from Teide



Galaxy regions observable from Tenerife :

- Zenit An. < 40°
- Zenit An. < 60°

Credits: A. Giuliani et al.

ASTRI mini-array: scientific operations and targets

First ~2/3 years:

- Restricted number of targets / deep exposures (> ~200 h each) ➔ **core science program**
- Possibility of MoUs for joint observational programs with MAGIC, LSTs (before CTA North) and optical telescopes, like e.g. Galileo National Telescope (TNG)

Afterwards:

- Observing proposals from a wider scientific community
- Broader scientific cases, with main focus on the multi-TeV domain
- Comprehensive link between fundamental physics and galactic/extragalactic observations

Galactic targets:

- Crab Nebula, Tycho, GC, …
- HESS J1813-178, Geminga, HESS 1825-137, …
- SS433, LS 5039, ...
- HAWC unidentified sources

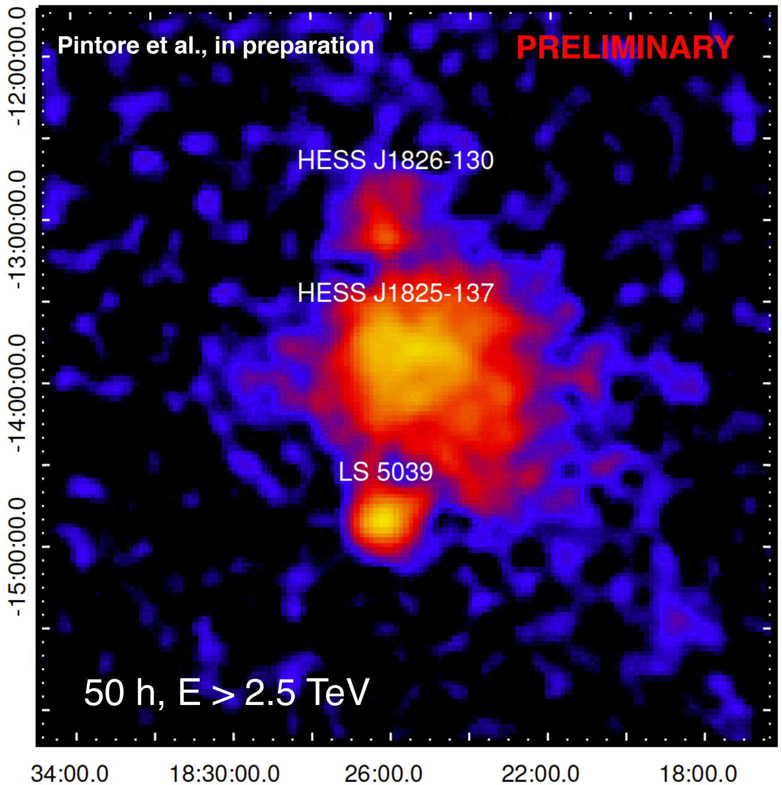
Extragalactic targets:

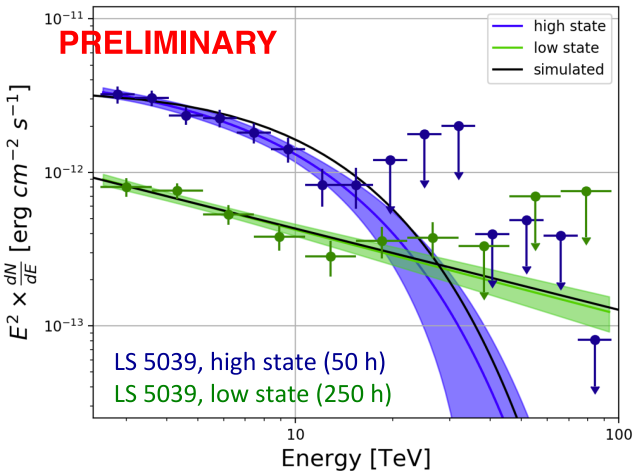
- Mrk421, Mrk501
- IC310, M87
- M82, NGC 1068

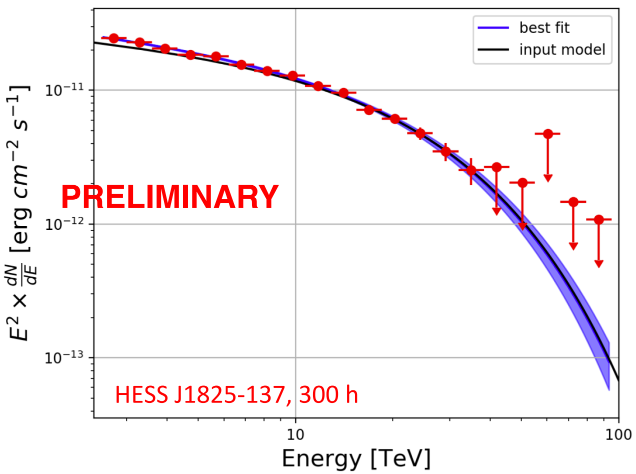
Fundamental physics:

- Mrk501, 1ES 0229+200
- IC310, M87
- dSphs (Ursa Major II, …), GH/GC

- **Large Field of View (≥ 10°), with homogeneous acceptance:**
  - Optimal for multi-target fields, surveys, and extended sources
  - Enhanced chance for serendipity discoveries







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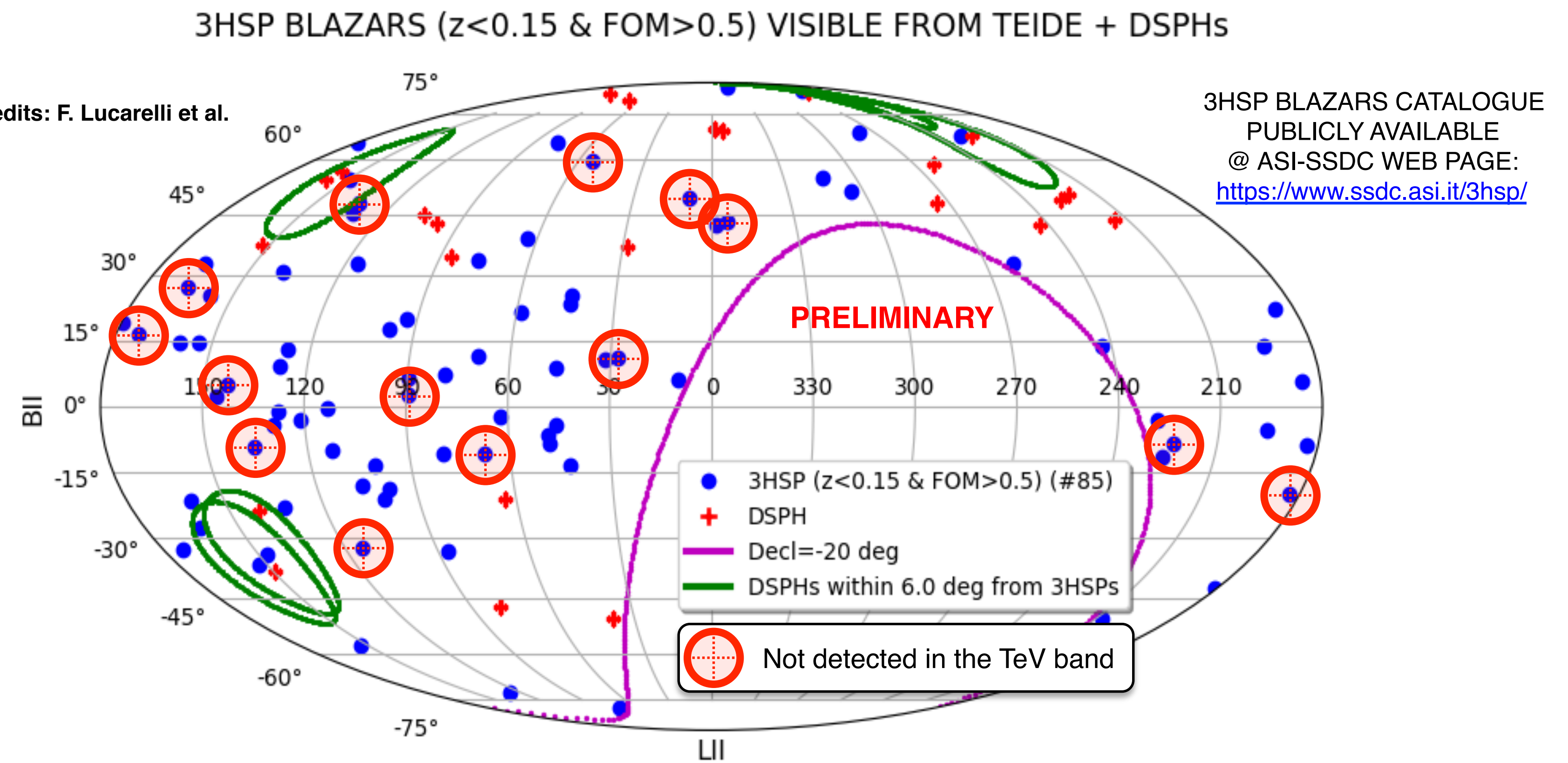

Possible observation with enhanced sensitivity at the TeV band of so far undetected high synchrotron peak (HSP)

Multiple sources (e.g. HSPs and dwarf spheroidals) may be observed with single pointings, maximizing the duty cycle of the system