ASTRI Astrofisica con Specchi a Tecnologia Replicante Italiana

cta cherenkov telescope array

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The ASTRI mini-array and its scientific prospects in the framework of the Cherenkov Telescope Array

S. Lombardi for the ASTRI Collaboration & the CTA Consortium

Outline of the talk

✧ The ASTRI Project in the CTA context

✧ The ASTRI mini-array of telescopes at the CTA southern site

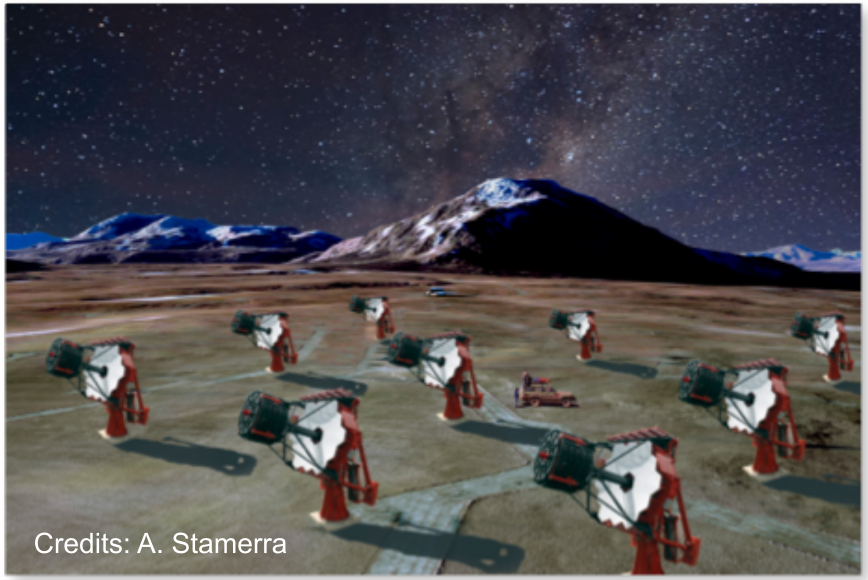
✧ Early science with the ASTRI mini-array

✧ Outlook and Conclusions

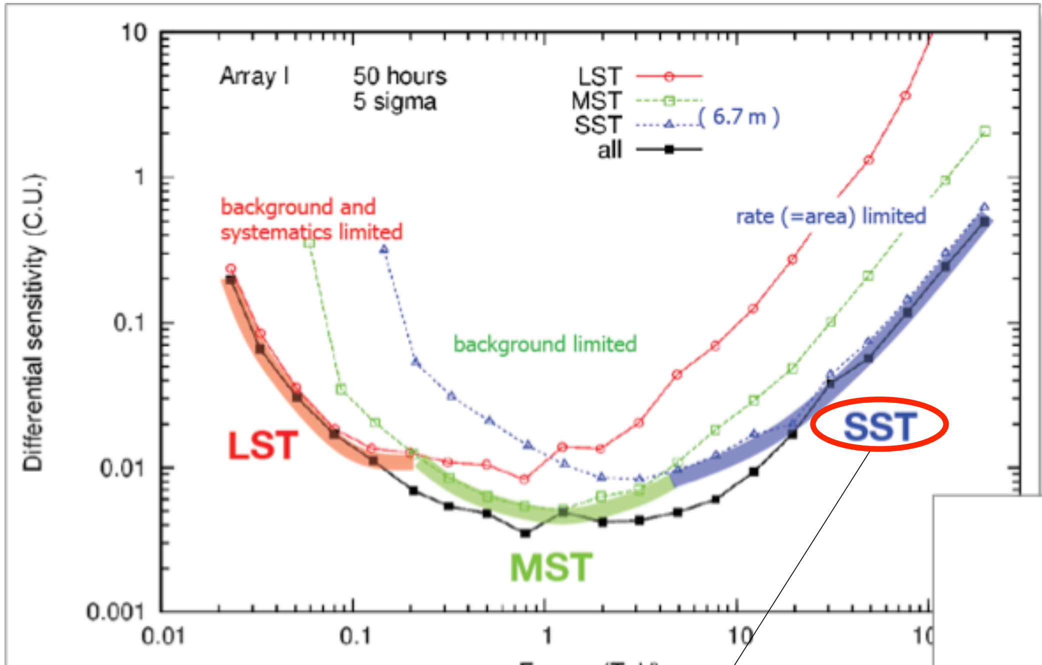
The ASTRI Project

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

- an **end-to-end prototype** of the **CTA small-size telescope** in a dual mirror configuration (ASTRI SST-2M), inaugurated on 2014 Sept. 24th and currently under testing at the INAF observing station on Mt. Etna (Sicily)
- an **ASTRI mini-array** composed of **nine telescopes** proposed to be installed at the chosen CTA Southern site in 2017

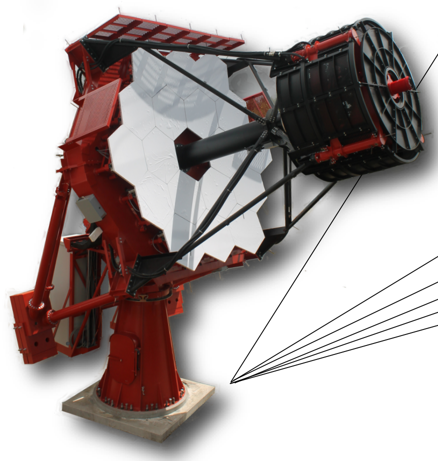


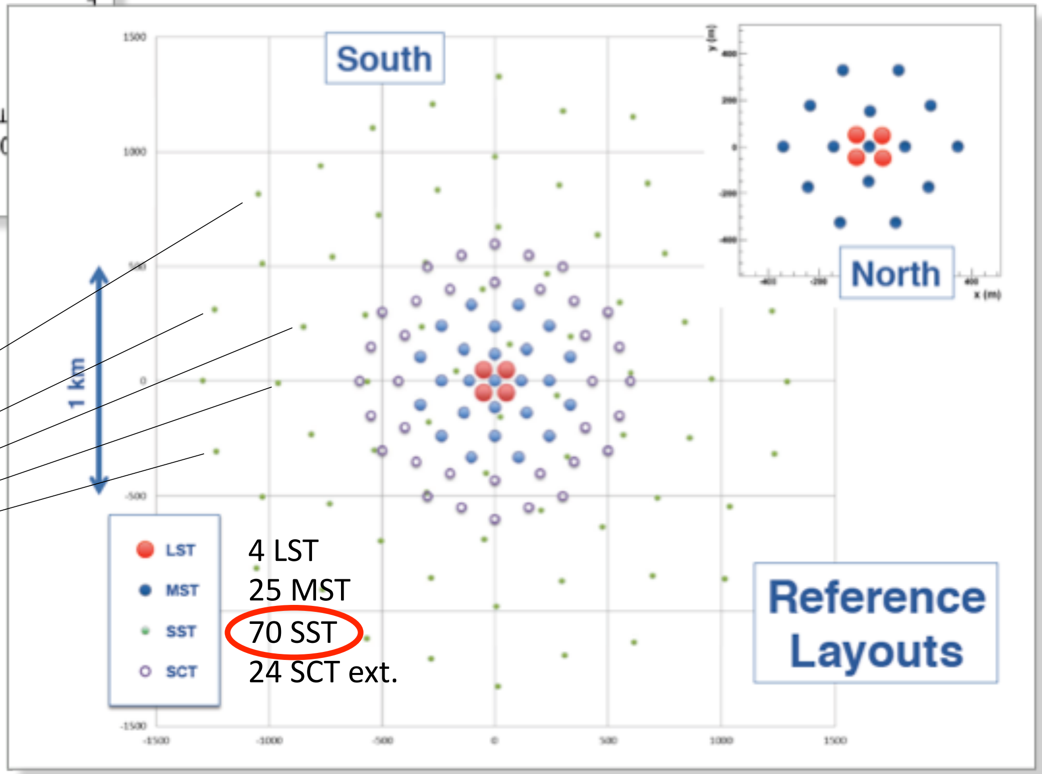
The ASTRI Project and CTA



Credits: CTA Consortium

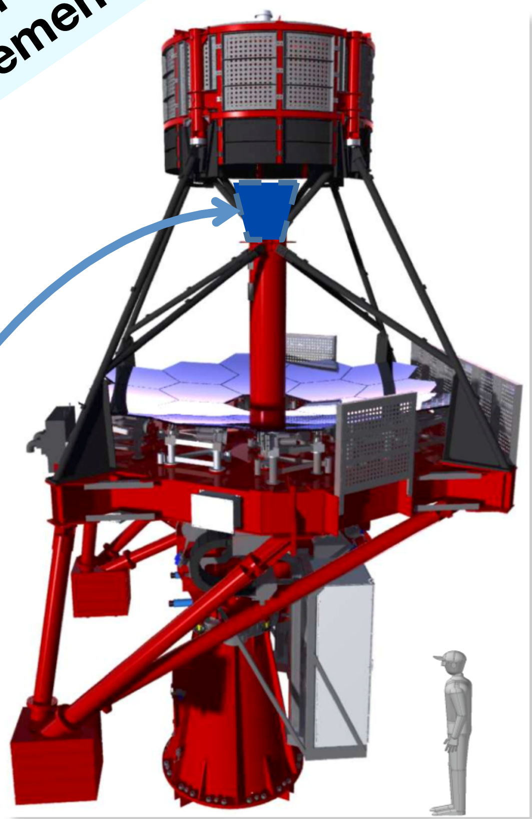
We aim at the production and deployment of about half of the CTA SST sub-array to explore the energy range above the TeV threshold

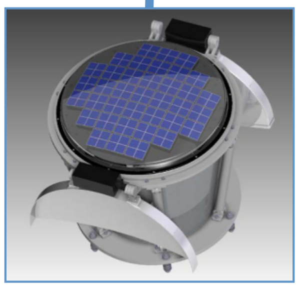




ASTRI SST-2M telescope features

Design fully compliant with CTA requirements





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

✧ **Dual-mirror optical layout**
- first time for VHE telescopes
- 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

The ASTRI SST-2M mini-array

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

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

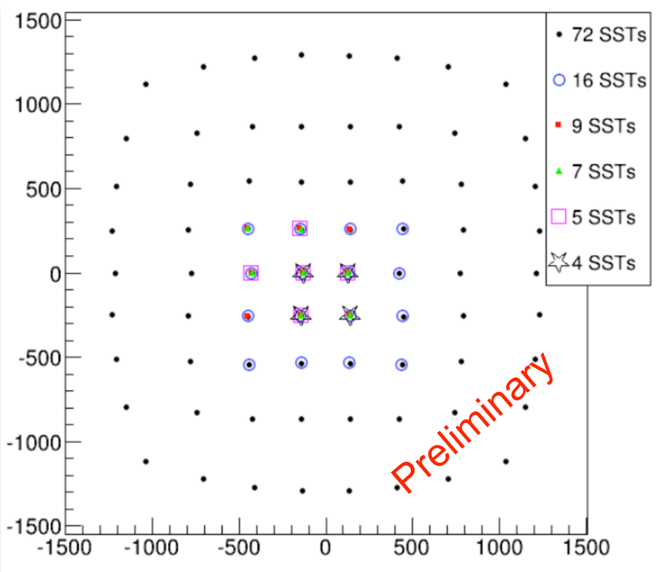
Proposed to be installed at the final southern CTA site as one of the CTA precursors (implementation in 2017)

ASTRI SST-2M mini-array aims

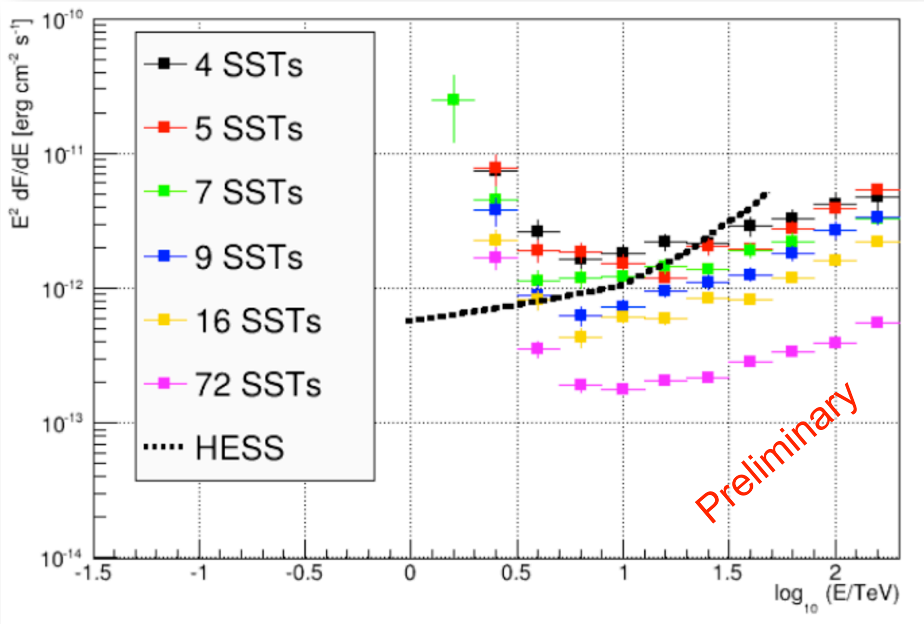
The ASTRI mini-array can verify some CTA-SST sub-array properties:

- **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
- **Check the array control and on/off-site data management systems**
- **Compare the mini-array performance with MC expectations**
  by means of deep observations of Crab
- **Do the first CTA precursor science**
  by means of a few solid detections during the first year

ASTRI SST-2M mini-array performance



Di Pierro et al., in prep.



✧ **Sensitivity**

slightly better than H.E.S.S. above few TeVs for an array composed of 9 telescopes

✧ **Angular resolution**

a few (4–5) arcmin

✧ **Energy threshold**

≥ few TeV

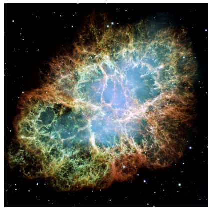
✧ **Energy resolution**

of the order of 10-15%

✧ **Wide field of view**

~10°

Supernova Remnants

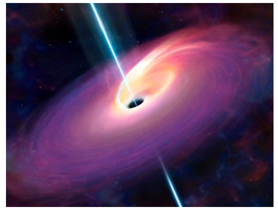


- SNRs
- Pevatrons
- SNRs interacting with molecular clouds

PWNe

Gamma-ray Binaries

Extreme BL Lacs

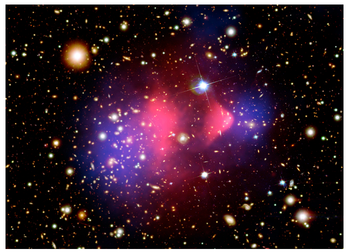


- Synchrotron peak > 1 keV
- Inverse Compton peak > 1 TeV

Less beamed AGNs

- Radio galaxies

Starburst Galaxies



Dark Matter and exotic physics

ASTRI SST-2M 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 and fully expolit the wide field of view
- **Extra-galactic science ➔** select a few promising targets
- **Fundamental physics ➔** GC and new optimal dwarf targets
- **Synergies with MSTs and LSTs** precursors are of paramount importance

SNR RCW 86

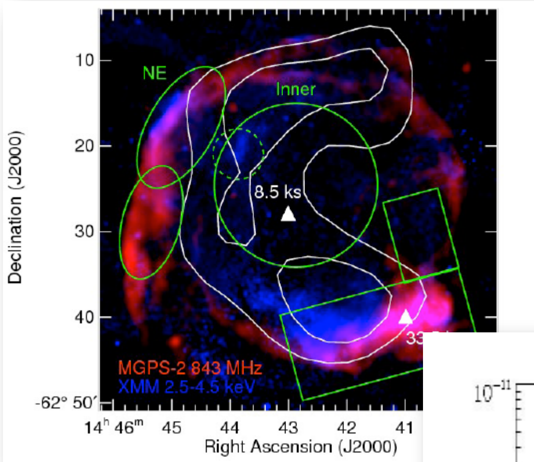
Fairly young SNR (2000 yrs)

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

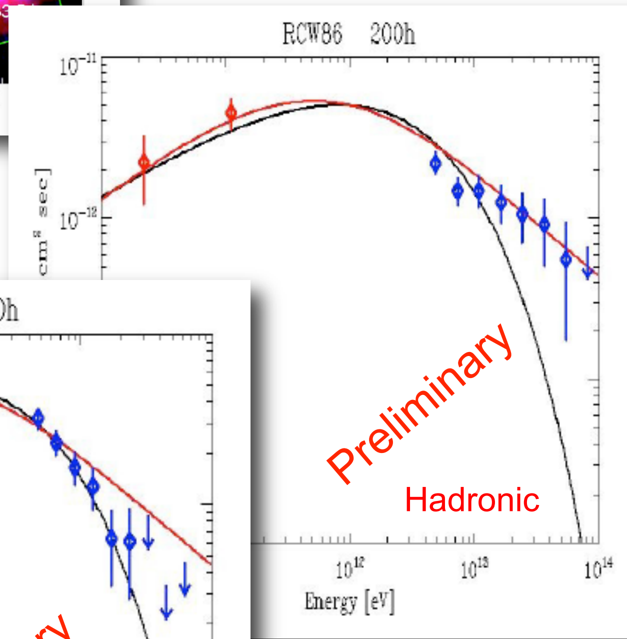
Debated origin:

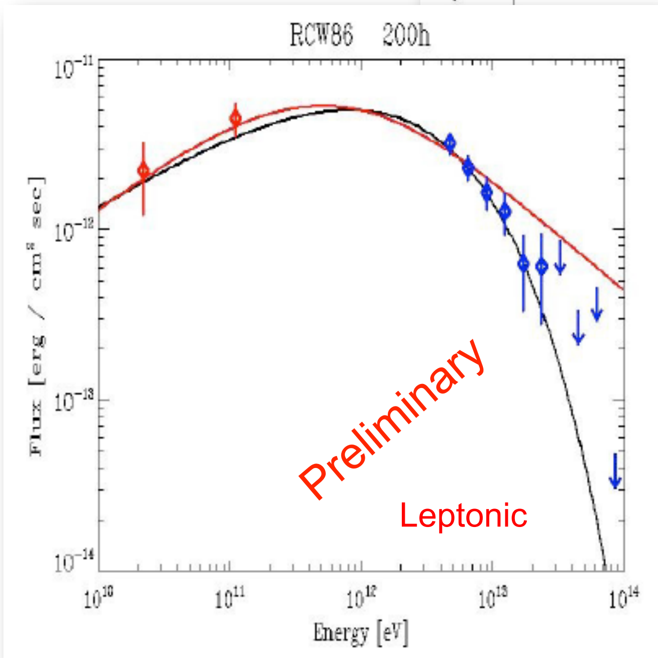
- interacting source with molecular clouds or
- RX J1713-like source ?

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



Giuliani et al., in prep.



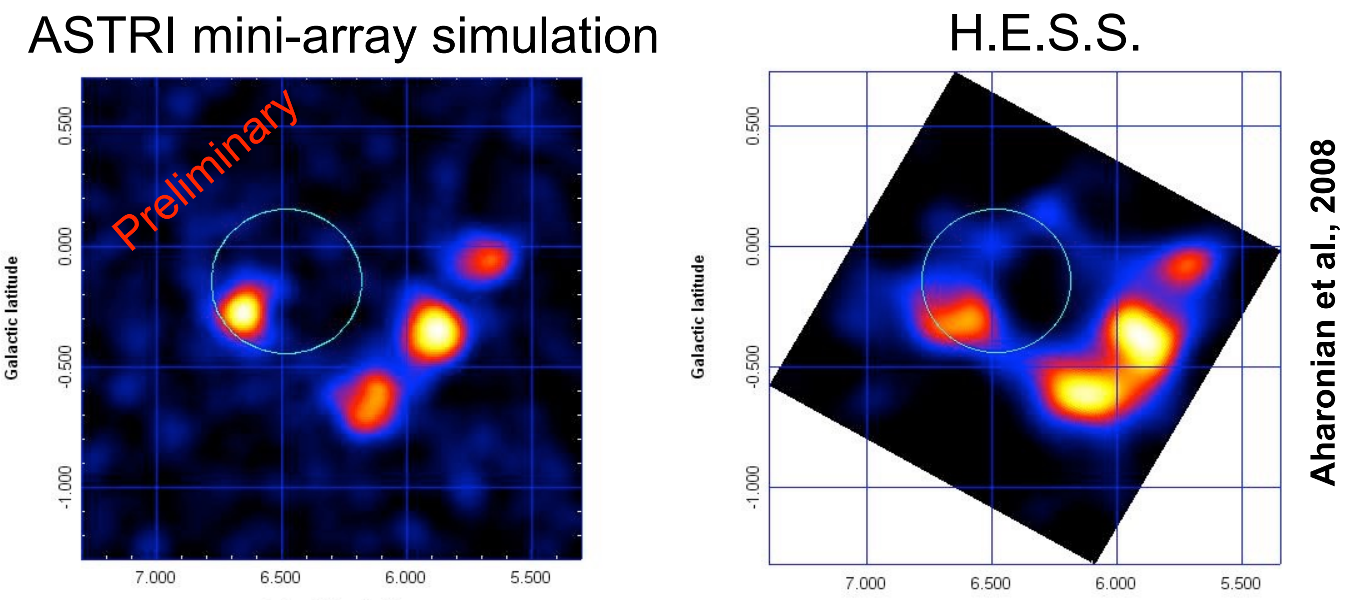


SNR W 28

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

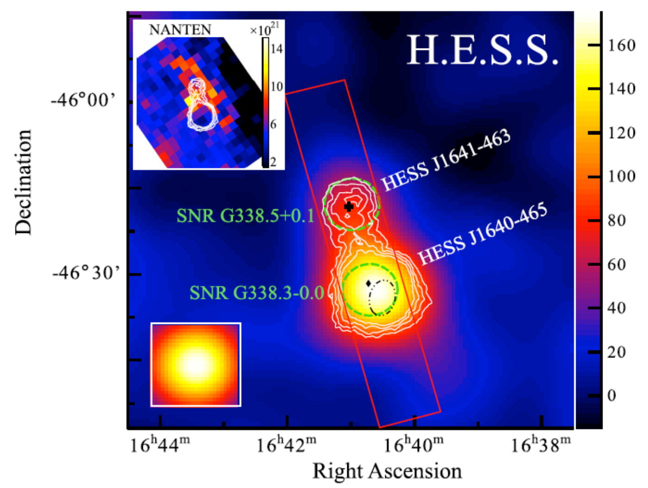
ASTRI mini-array can better resolve the source and study the diffusion of CR far from the SNR shell (blue circle)



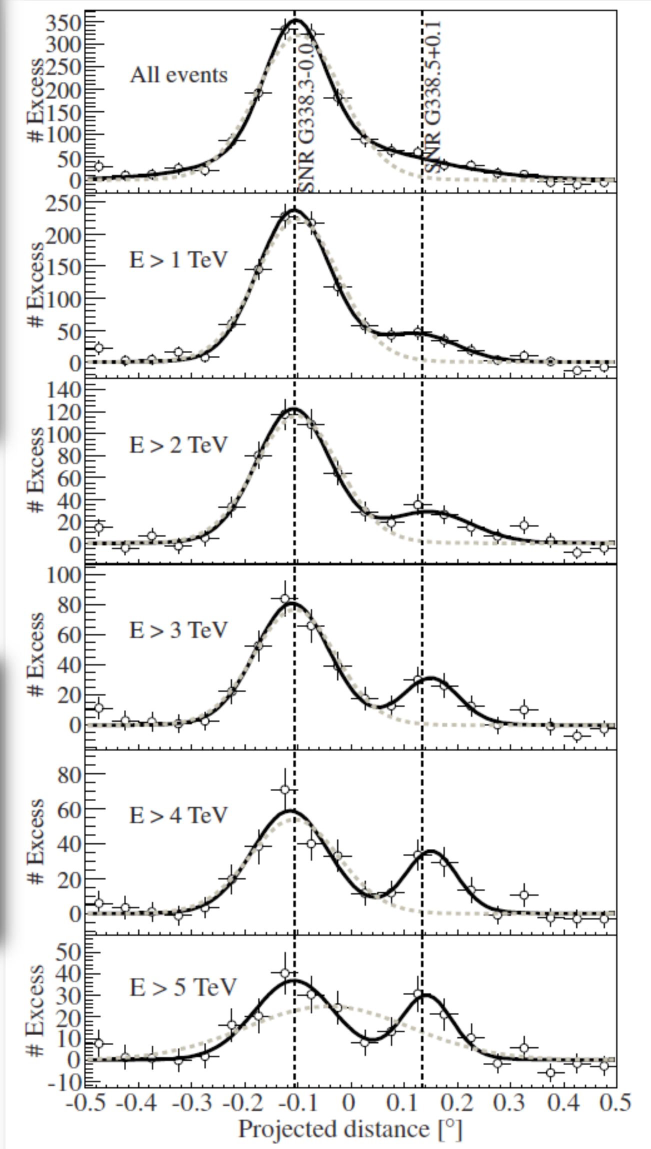
Giuliani et al., in prep.

Gamma-ray unidentified: HESS J1641-463

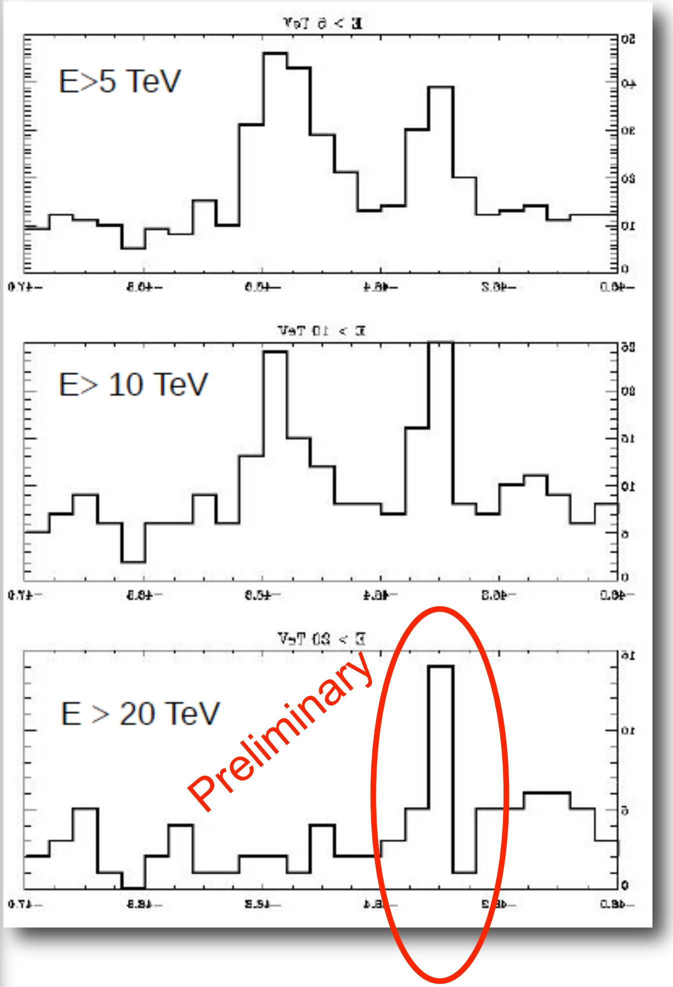
Abramowski et al., 2014



Abramowski et al., 2014



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

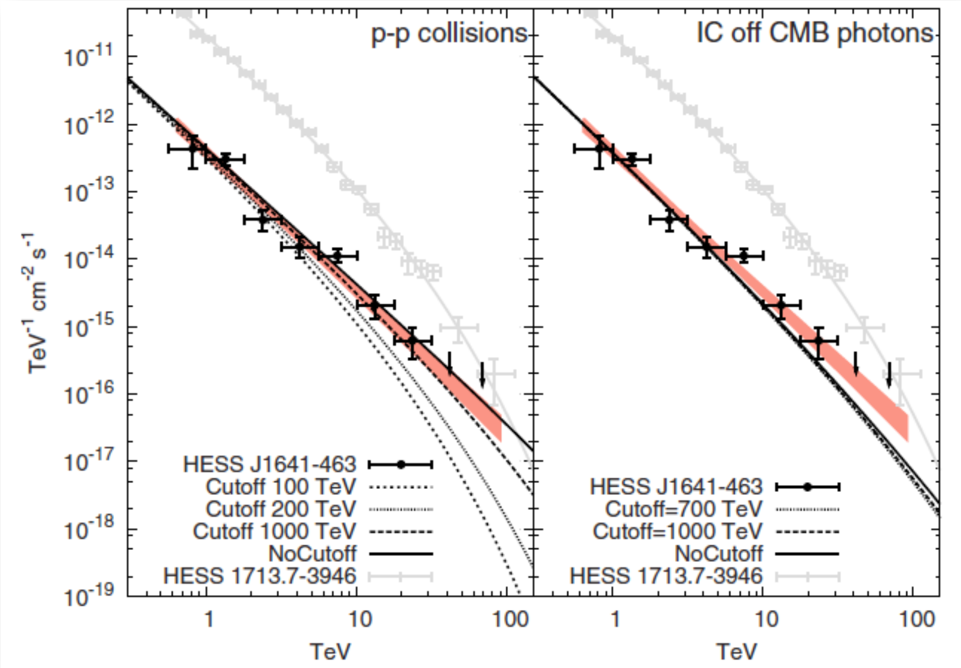


Very hard source $\Gamma \sim 2.1$

ASTRI mini-array 200 hrs simulation

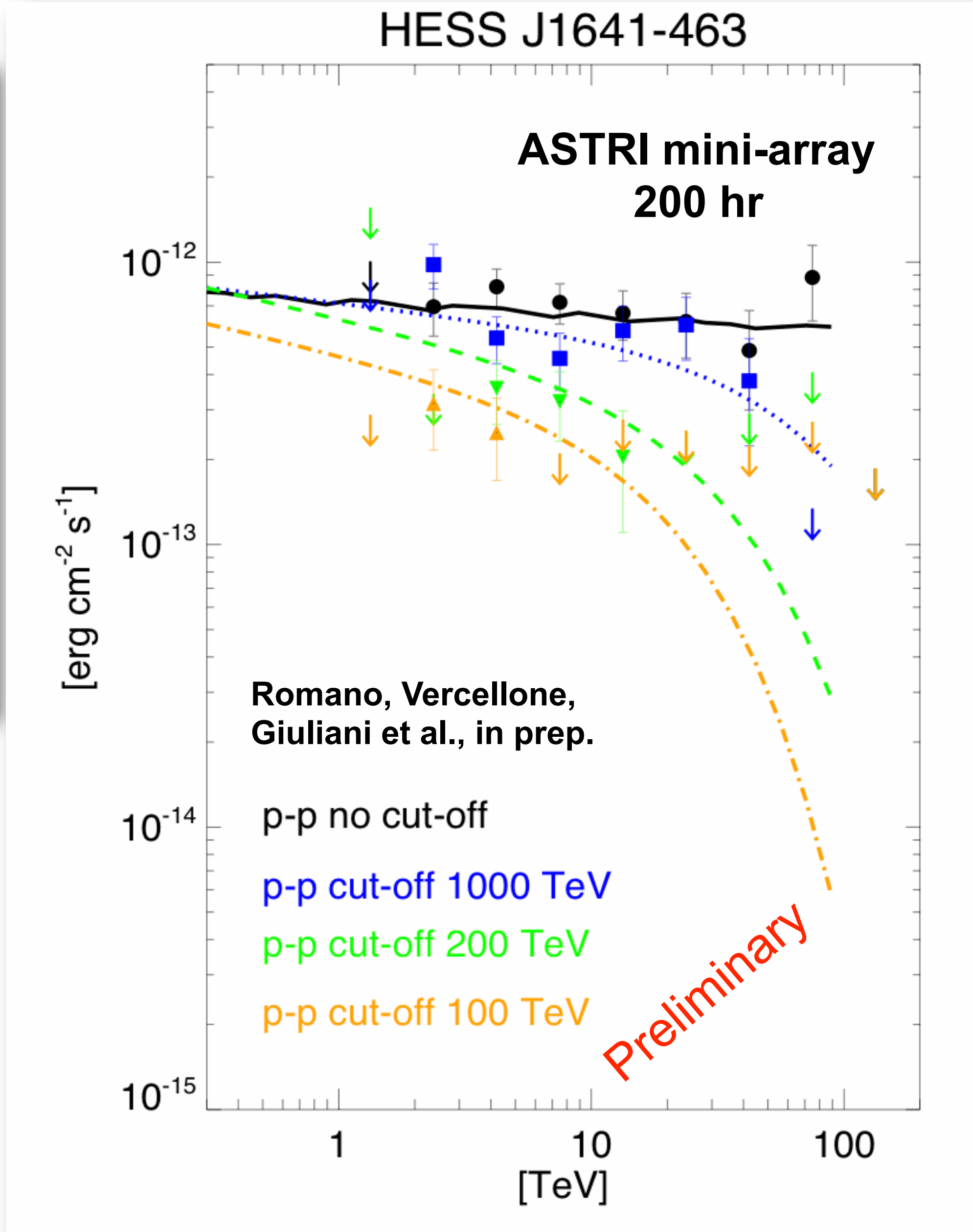
Gamma-ray unidentified: HESS J1641-463

Abramowski et al., 2014

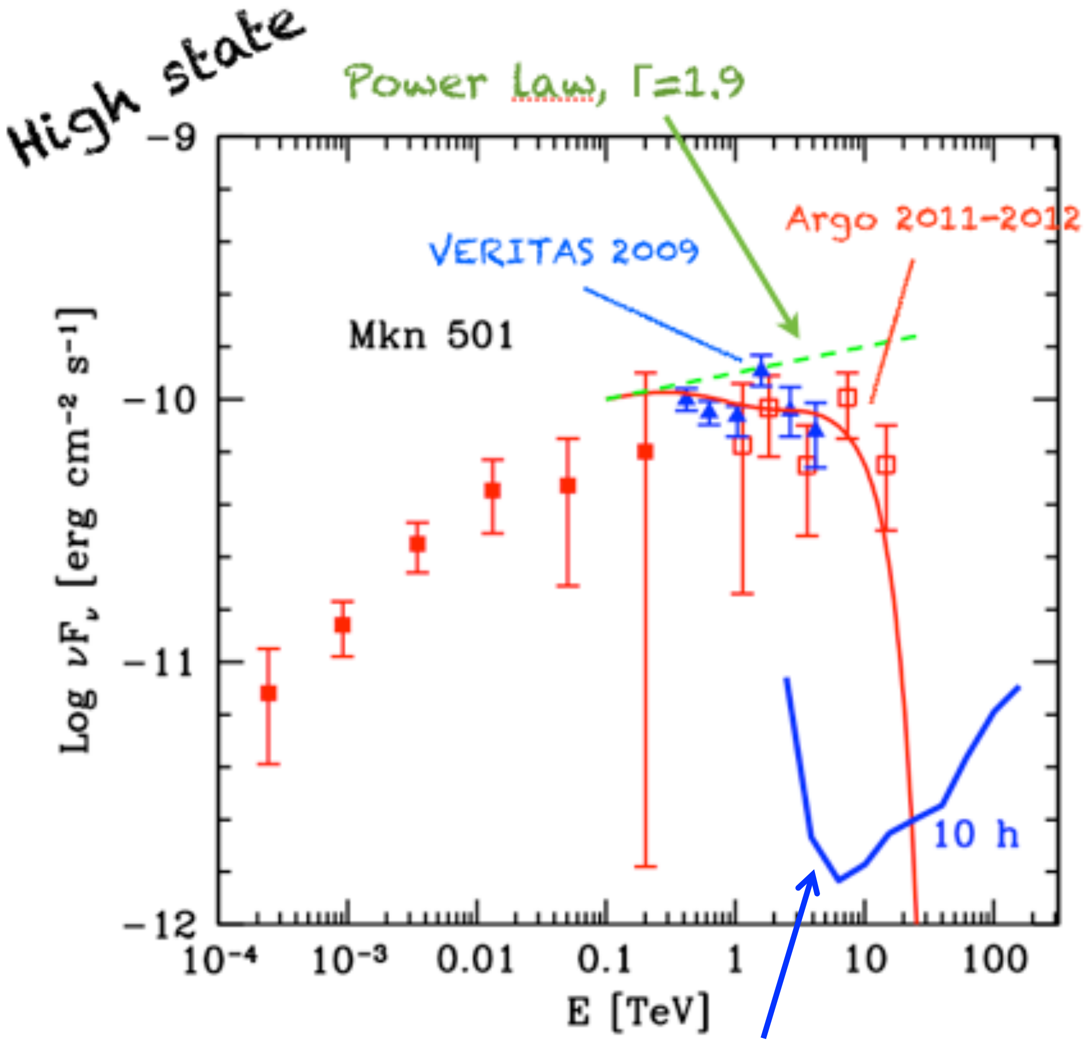


We can investigate:

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



Mrk501: flares and spectral properties



Differential sensitivity for a mini-array composed of 9 ASTRI SST-2M telescopes in 50 h

Mkn 501

Low quiescent flux

Relatively small duty cycle

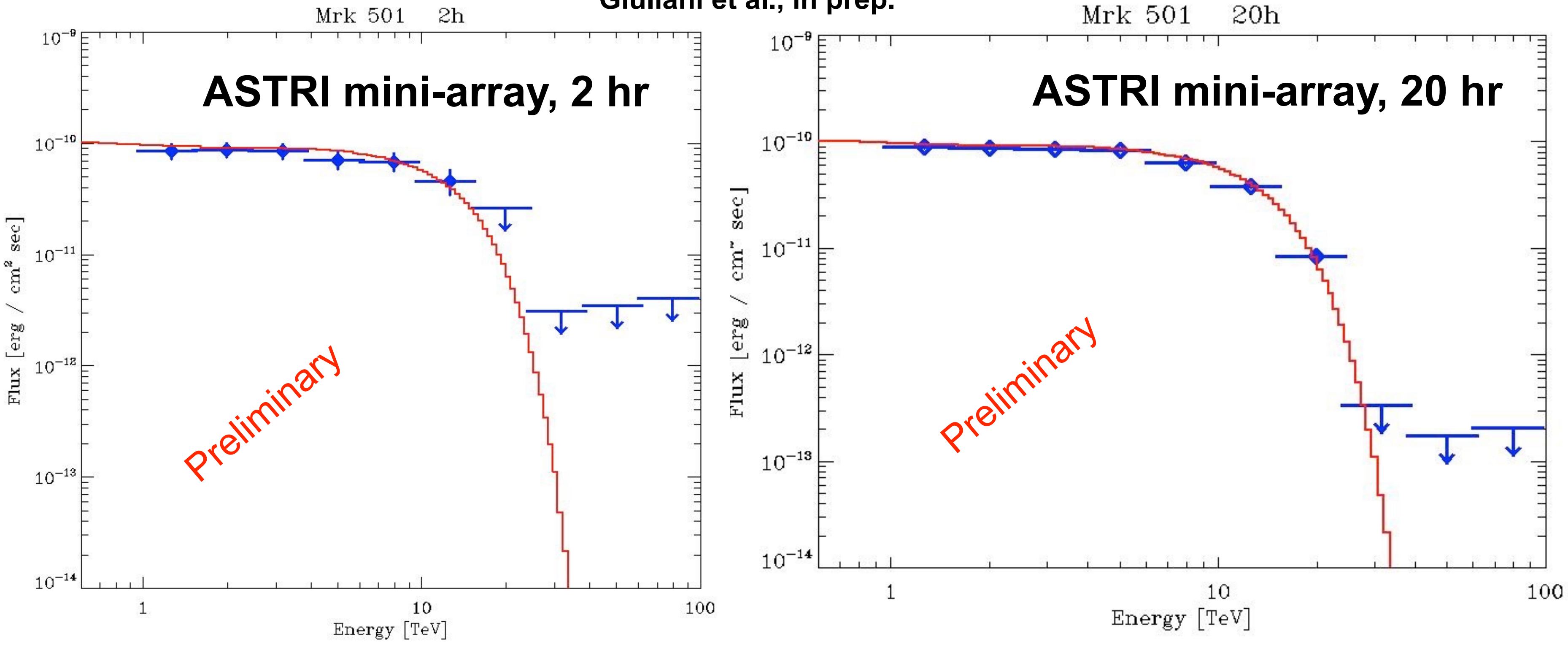
Large fluxes (~10 CU)

Prolonged (weeks) flares

Hard spectra

Mrk501: flares and spectral properties

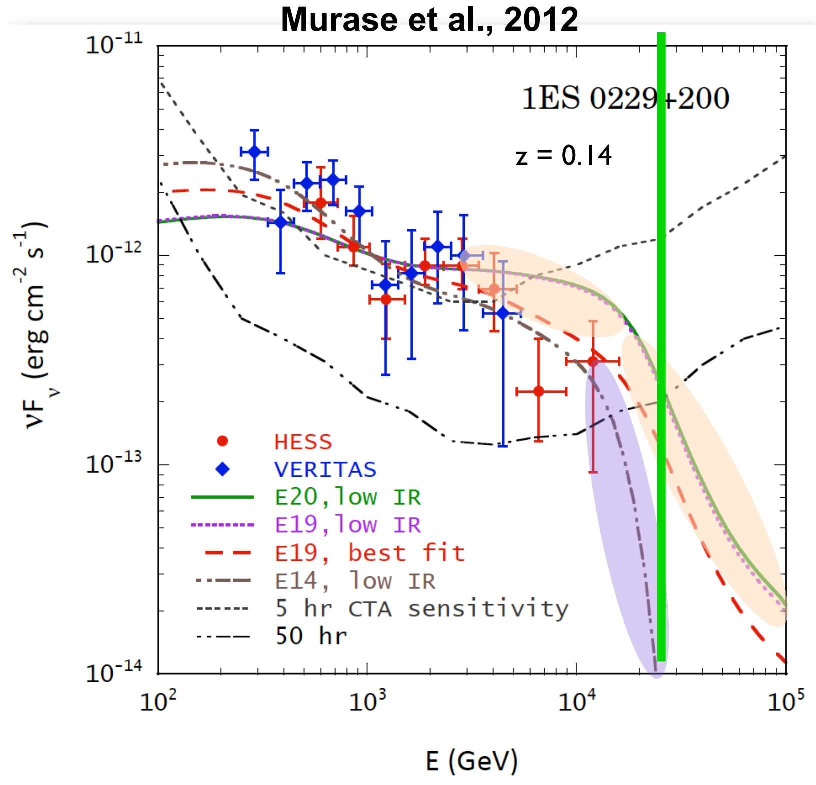
Bonnoli, Tavecchio,
Giuliani et al., in prep.



Observations up to 20 TeV, grazing the EBL "wall"

Need MWL triggers, fast reaction and (from CTA-S) observations at large ZA

Extreme BL LACs: probe of extreme physics

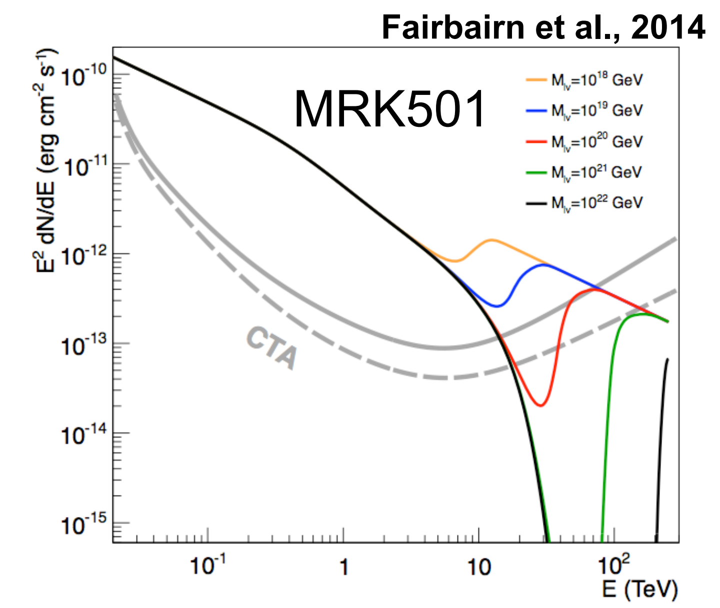


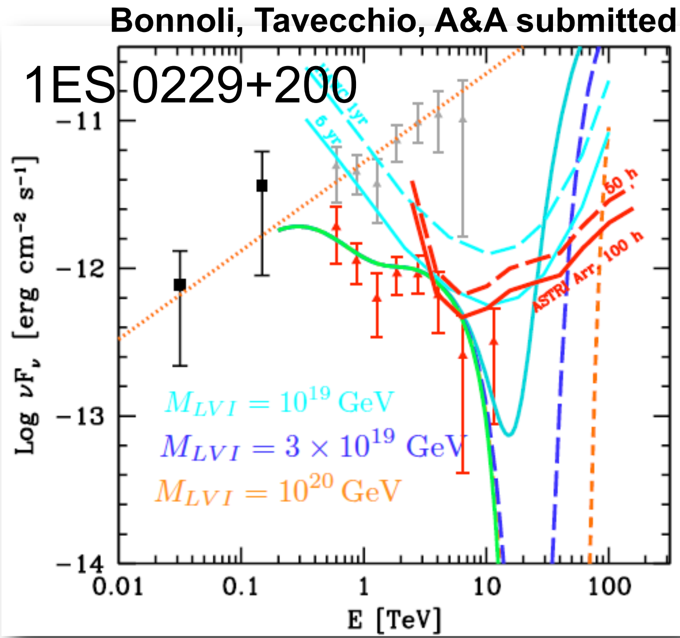
1ES 0229+200 E-HBL SED can be fit by both the **γ-ray-induced cascade** and **proton-induced cascade** emissions

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

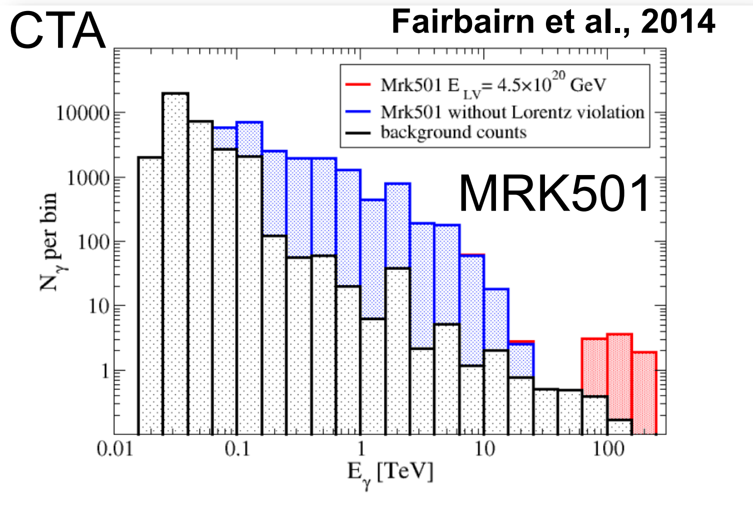
- ✧ At higher energies, however, UHECR-induced cascade emission becomes harder than γ-ray-induced cascade emission
- ✧ A detection of >25 TeV γ-rays from 1ES 0229+200 is consistent with an hadronic γ-ray emission (an alternative explanation in the next slide)
- ✧ Probe of gamma-ray absorption by the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

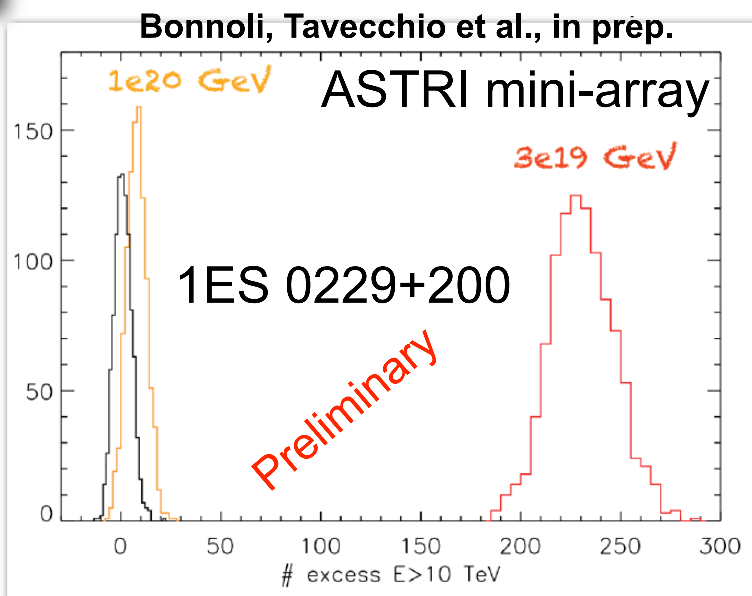
LIV and E-HBL





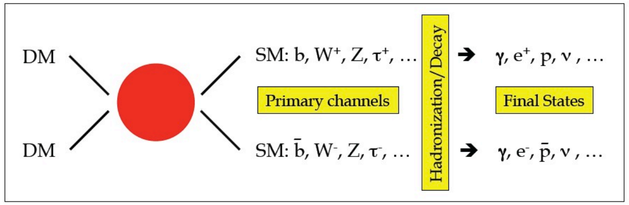
LIV effects studied for different values of the Lorentz-violating scales (M_{LIV})





Dark Matter searches

- ✧ Likely scenario for cold DM: weakly-interacting massive particles (WIMPs)
- ✧ WIMPs mass range: O(10 GeV) - O(100 TeV)
- ✧ WIMPs annihilation ➔ indirect detection (in γ-rays)

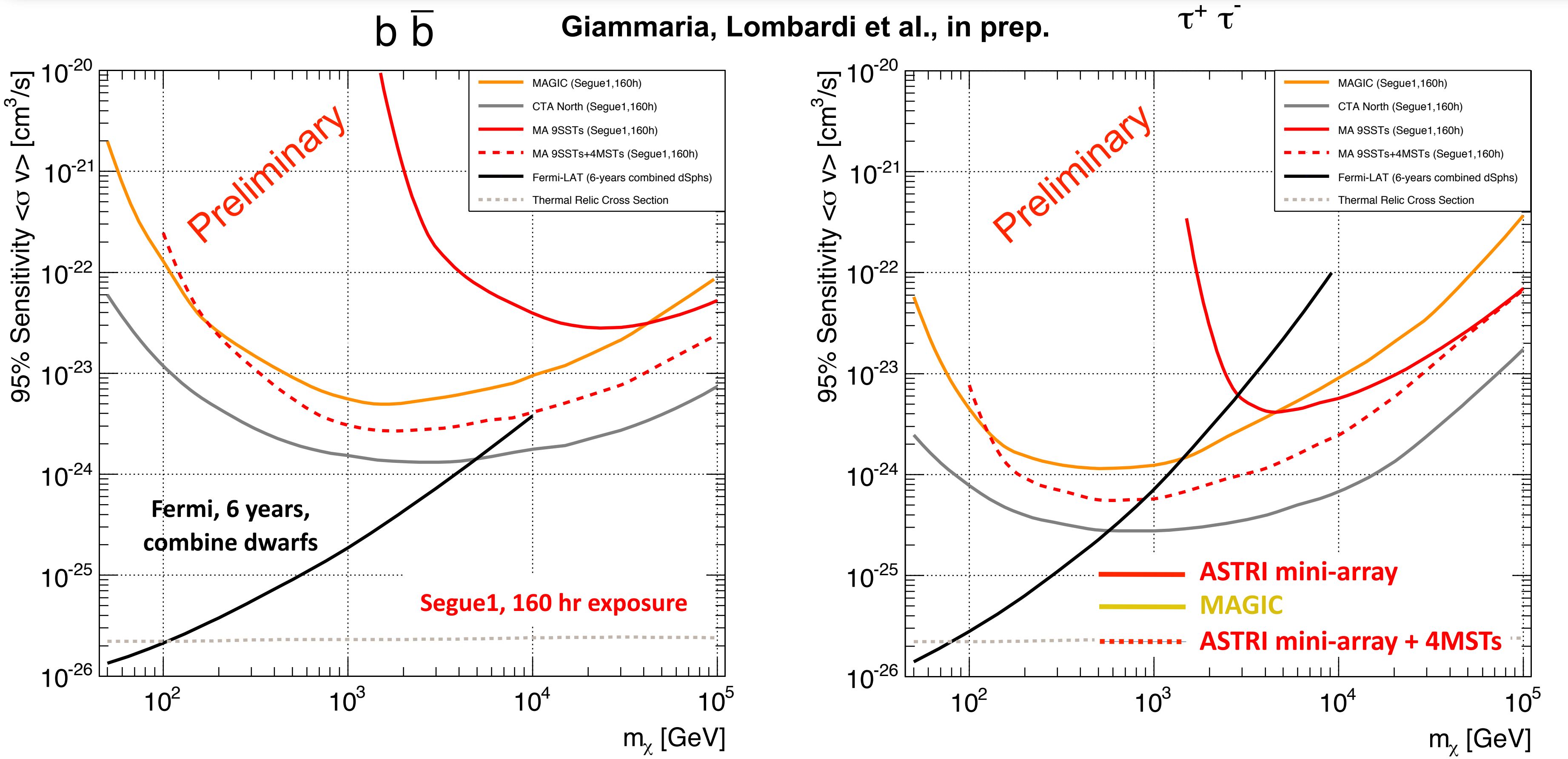


TARGETS:

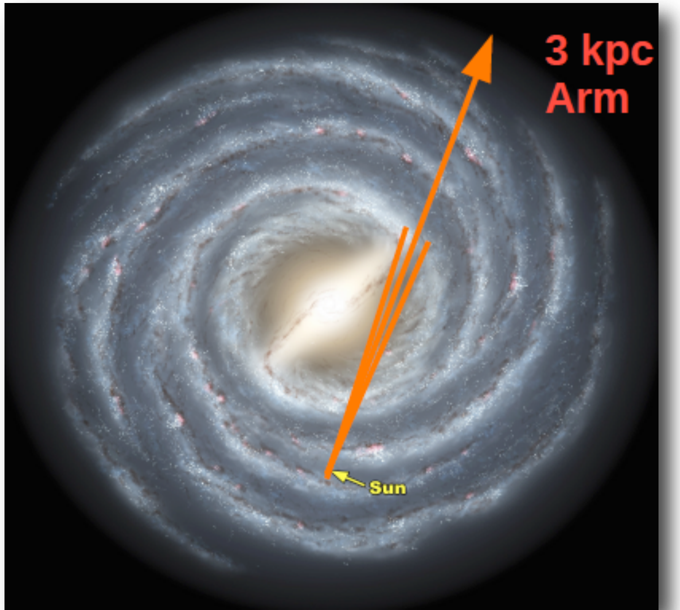
- *Galactic center?*
  - \+ Highest *J-factor*
  - − Very high astroph. bkg
  - − Uncertainties on inner DM distribution
  - − Southern Hemisphere
- *Galactic halo?*
  - \+ High *J-factor*
  - − Not fully-free from astroph. bkg
  - − Extended
  - − Southern Hemisphere
- *Galaxy Clusters?*
  - \+ Huge 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 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

Dark Matter searches

- ✧ Preliminary prospects for indirect Dark Matter searches (>~5 TeVs) with ASTRI mini-array
- ✧ First comparative studies with known target (Segue1 dwarf, 160 hr exposure)
- ✧ ASTRI mini-array + 4MSTs ➔ very interesting scenarios
- ✧ Refined simulations/analysis + new targets (southern dwarfs and GC) in progress

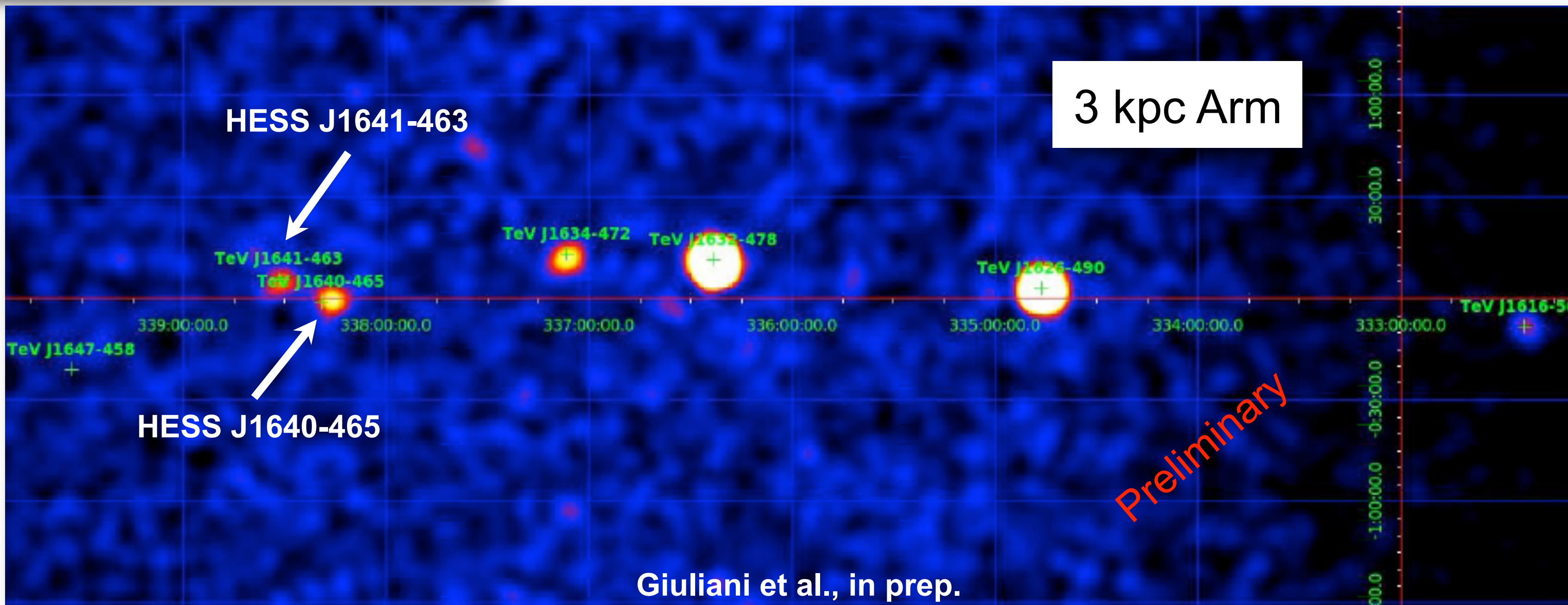


The wide field of view and our galaxy



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

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



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 beginning of 2016

- **The ASTRI mini-array** is proposed to be a *precursor* for the whole CTA-S 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 (both Galactic and extra-Galactic) will allow us to obtain several solid detections during the first year and to pursue some fundamental physics searches

- **Excellent synergies** with the other CTA precursors (MSTs, LSTs) and with several observing facilities from 2017 and beyond http://www.brera.inaf.it/astri/

Thanks!

Credit: R. Canestrari

Backup

The ASTRI Project in a nutshell

- **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 telescopes** of the CTA southern array

The ASTRI SST-2M E2E prototype

End-to-end prototype

mainly a technological (HW&SW) demonstrator, but foreseen a science and performance verification phase (early 2016)

(first Crab and blazars observations @1TeV with S-C, SiPM-equipped telescope!)

✧ Telescope characteristics:

- Optical design = Schwarzchild-Couder
- Primary mirrors = 4.3m (segmented)
- Secondary mirror = 1.8m (monolithic)
- $F/D_1 = 0.5$; F = 2.15m
- M1-M2 distance = 3m
- Effective Area = 6.5m^2

✧ Camera properties:

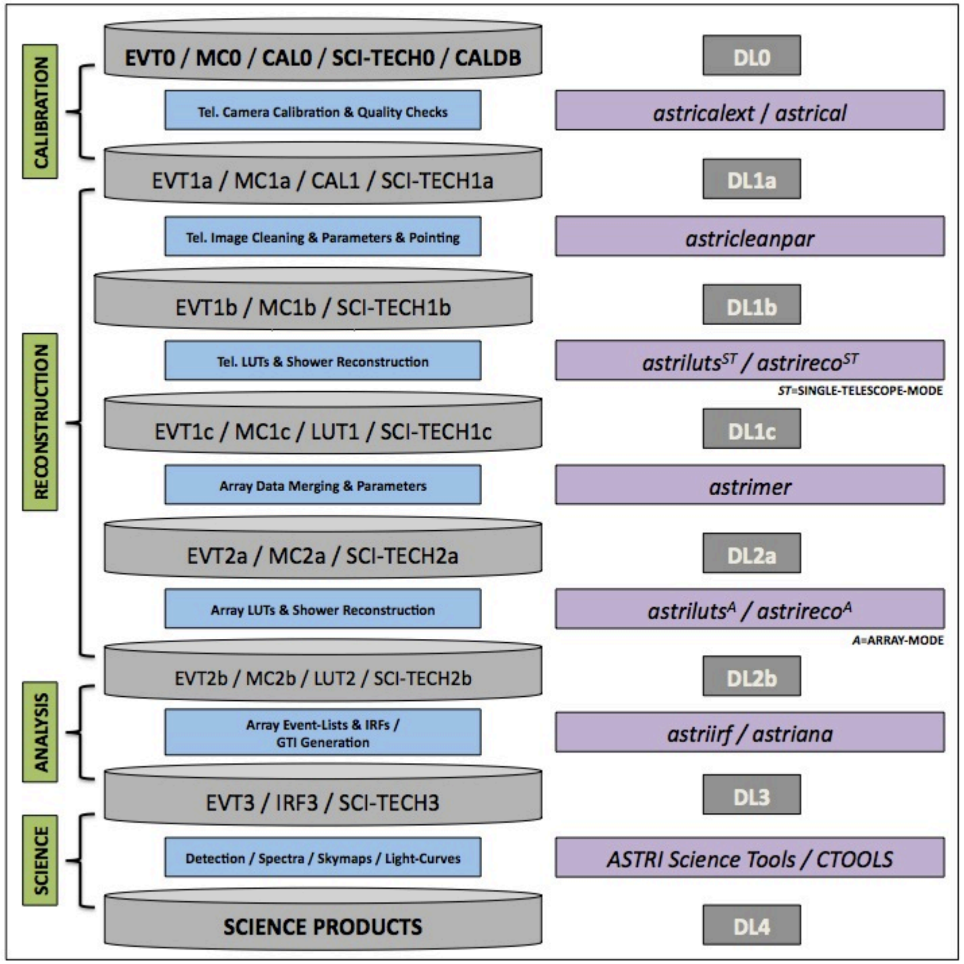
- Sensor type = SiPMs
- Number of logical pixels = 1984
- Pixel size = 0.17° (plate scale = 37.5mm/°)
- Field of View = 9.6°

✧ Expected performance:

- **Energy threshold ≥ 1TeV**
- **Energy/Angular resolution ≈20% / ≤0.15°**
- **Sensitivity ≈ 1 Crab @ 5σ in few hours**

ASTRI SST-2M E2E approach

End-to-end (E2E) prototype (including array control, data management and calibration subsystems) in a real astronomical site.
Data pipeline and archive can handle both prototype and mini-array data

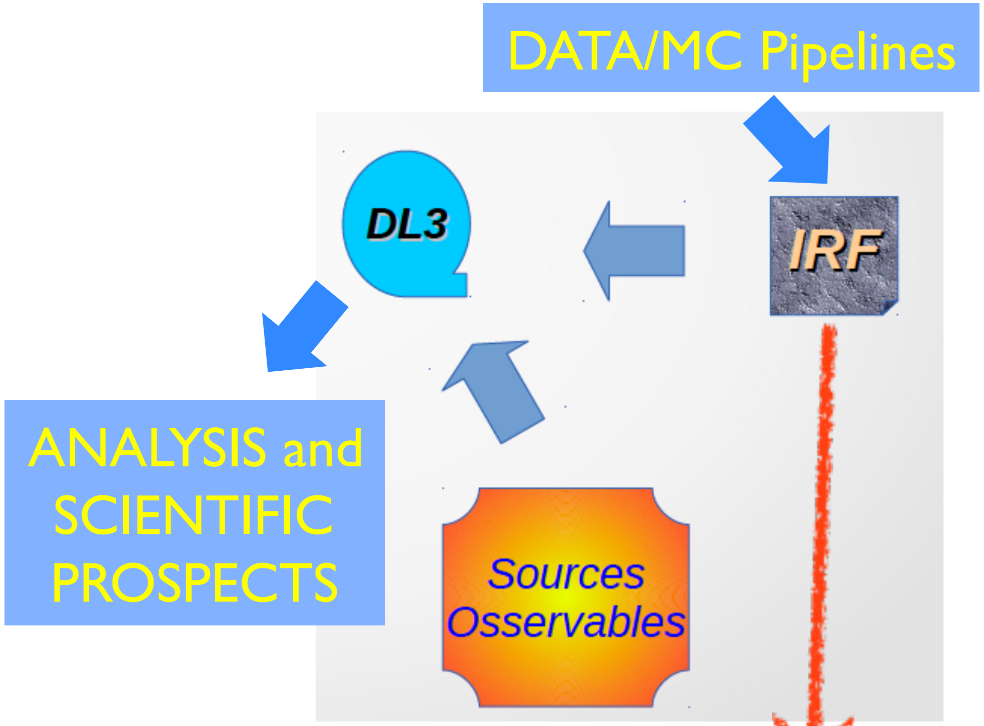


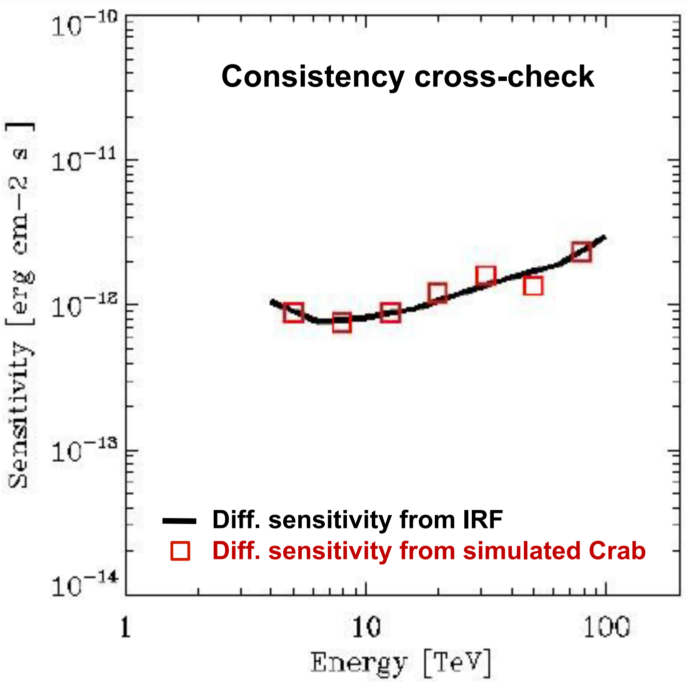
The ASTRI SST-2M prototype and mini-array Data Pipeline:

- 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**;
- makes use of ***ad hoc* and official CTA Science Tools** for final science products (DL4).

ASTRI simulation tools

Simulated data achieved by the ASTRI scientific simulator based on Instrument Response Functions (IRFs) for 9 SSTs from CTA prod2 for a Southern site. Reasonably conservative IRFs, since optimizations for ASTRI and for the analysis are not yet fully implemented.





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IRF for ON AXIS

log(E)	Area	r68	r80	ERes.	BG Rate	Diff Sens
-2.0	0.0	0.0000	0.0000	0.0000	0.00000000	0.000000e+00
-1.8	0.0	0.0000	0.0000	0.0000	0.00000000	0.000000e+00
-1.6	0.0	0.0000	0.0000	0.0000	0.00000000	0.000000e+00
-1.4	0.0	0.0000	0.0000	0.0000	0.00000000	0.000000e+00
-1.2	0.0	0.0000	0.0000	0.0000	0.00000000	0.000000e+00
-1.0	0.0	0.0000	0.0000	0.0000	0.00000000	0.000000e+00
-0.8	0.0	0.0000	0.0000	0.0000	0.00000000	0.000000e+00
-0.6	0.0	0.0000	0.0000	0.0000	0.00000000	0.000000e+00
-0.4	0.0	0.0000	0.0000	0.0000	0.00000000	0.000000e+00
-0.2	0.0	0.0000	0.0000	0.0000	0.00000000	0.000000e+00
-0.0	0.0	0.0000	0.0000	0.0000	0.00000000	0.000000e+00
0.2	7045.3	0.1355	0.1764	0.1368	0.00000000	0.000000e+00
0.4	39824.7	0.1075	0.1518	0.1222	0.00000000	0.000000e+00
0.6	141911.7	0.0799	0.1064	0.1183	0.00001621	1.051026e-12
0.8	282517.1	0.0698	0.0907	0.1033	0.00001652	7.613567e-13
1.0	372093.3	0.0635	0.0827	0.1020	0.00001679	8.118874e-13
1.2	493827.6	0.0613	0.0808	0.1088	0.00001610	9.494925e-13
1.4	557620.2	0.0645	0.0914	0.1097	0.00001427	1.217832e-12
1.6	661707.3	0.0737	0.1131	0.1214	0.00001078	1.533251e-12
1.8	781255.9	0.0938	0.1428	0.1186	0.00000547	1.912365e-12
2.0	510052.9	0.1155	0.1809	0.1219	0.00000211	3.002351e-12

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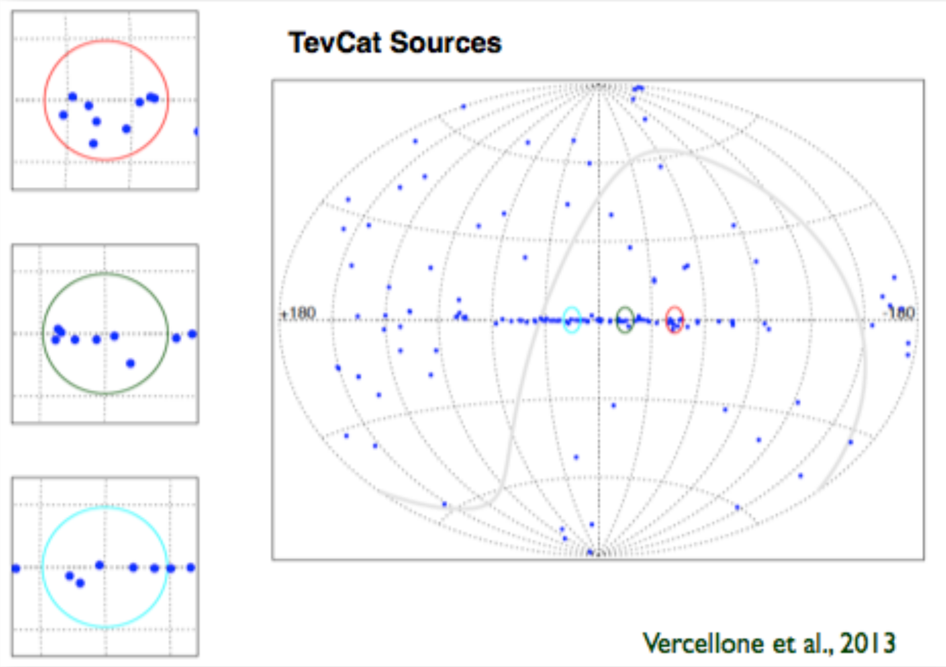
The wide field of view



The ASTRI mini-array will have a larger field of view wrt the current IACT ones

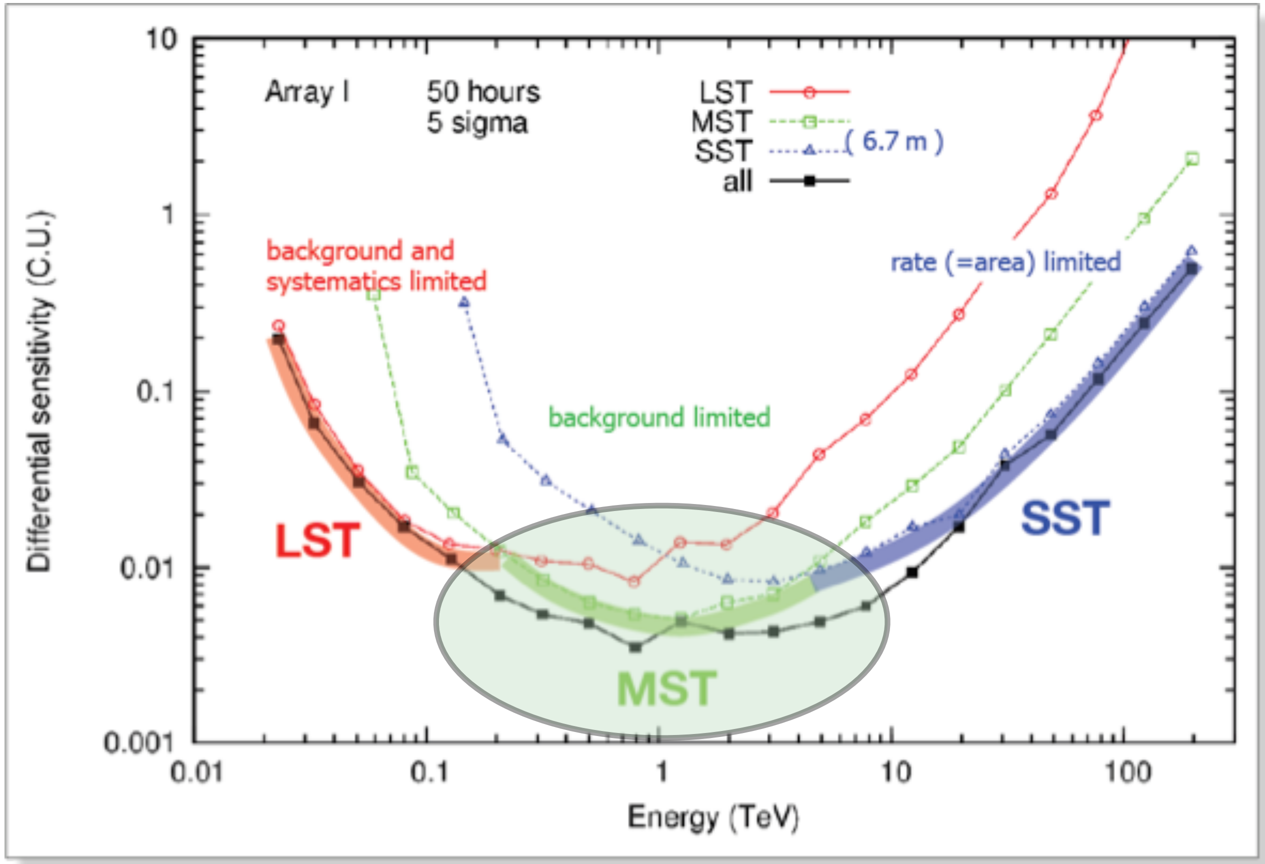
Although the actual sensitivity will substantially drop for off-axis sources, **a few targets can be monitored simultaneously**

Close (angular distance < 3°) and bright (about 10^{-12} erg cm^{-2} s^{-1} above a few TeV) sources can be observed pointing in a "smart" direction:

HESS J1825-137-------- LS 5039
Vela-X---------------------- Vela Junior
RX J1713.7-3946-------- HESS J1718-385.

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

Synergy with MSTs



Courtesy of the CTA Consortium

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

- ✧ **test trigger performance among different kinds of telescopes**
- ✧ decrease the energy threshold (crucial for e.g. Dark Matter searches)
- ✧ obtain a better energy coverage below 1 TeV

The ASTRI Project and the E2E prototype

Principal Investigator G. Pareschi

Co-PIs O. Catalano & S.Vercellone

INAF/CTA Responsible P. Caraveo

INAF Institutions

IASF Milano
IASF Bologna
IASF Palermo
INAF HQ Roma
OA Brera
OA Torino
OA Padova
OA Bologna
OA Arcetri
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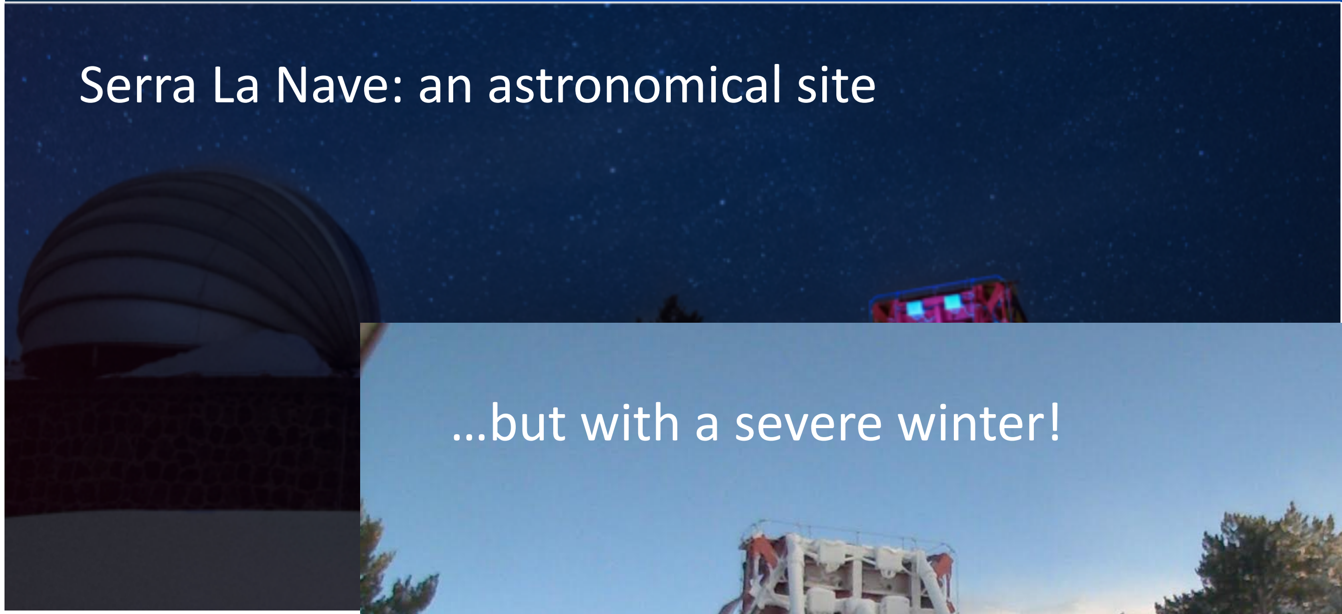
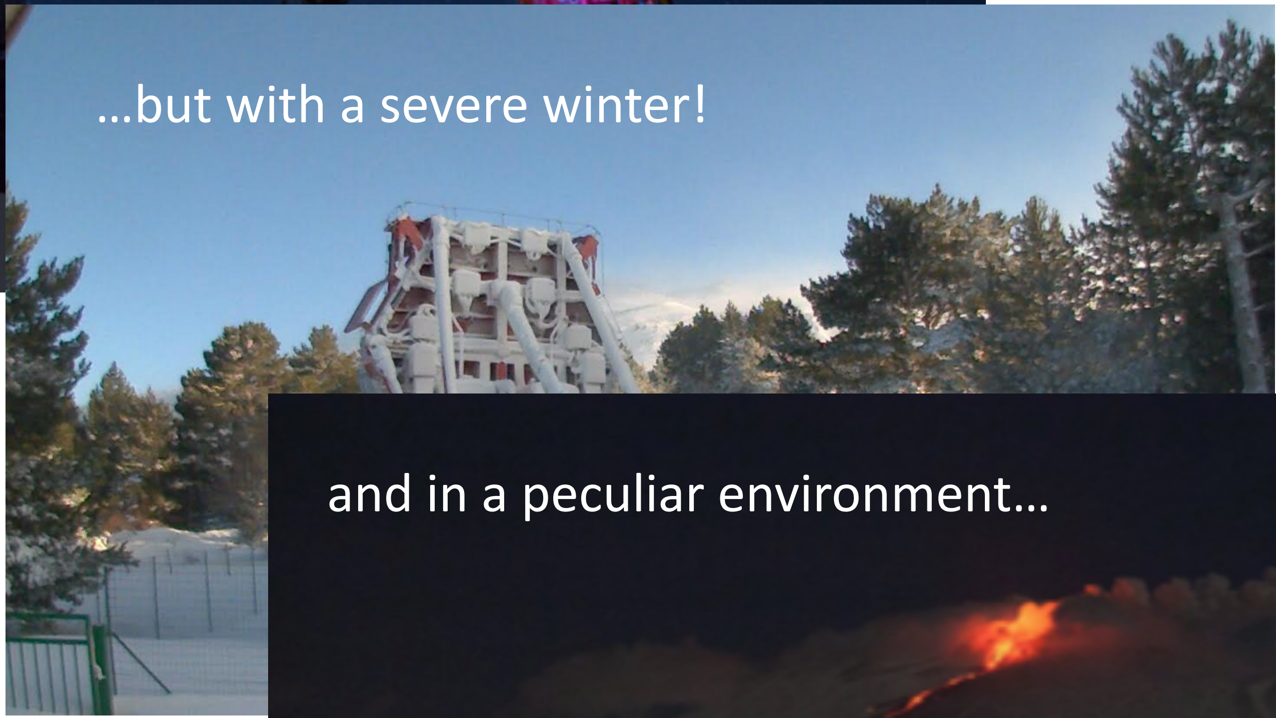
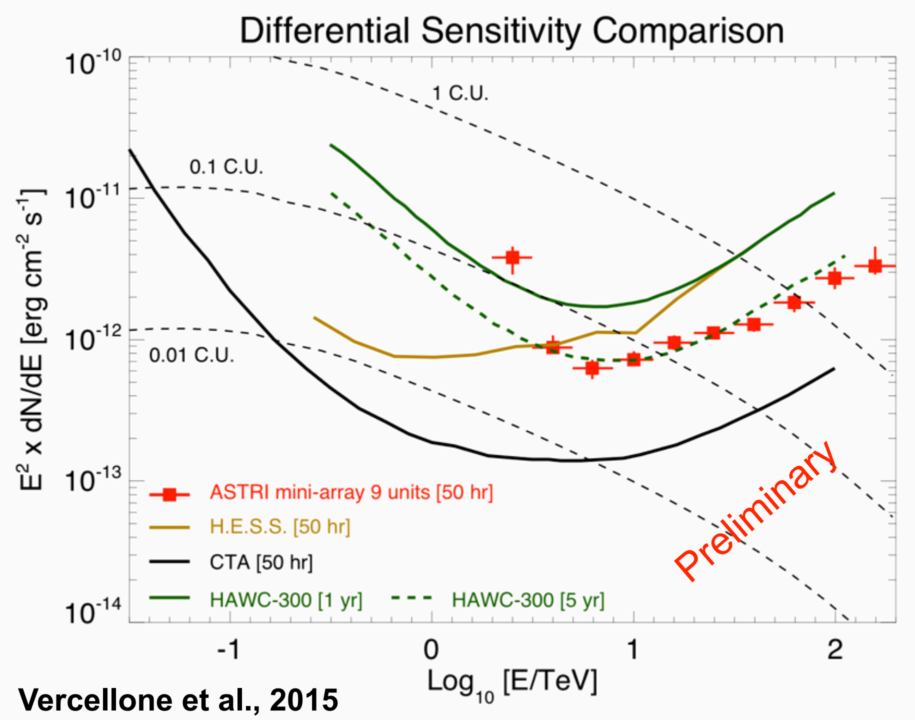
OA Capodimonte
OA Catania

University Partners : Univ. of Padova and Univ. of Perugia

The ASTRI SST-2M prototype astronomical site







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

It will have a better sensitivity at E>10 TeV for extended sources, favoring 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

LIV and E-HBL

LIV induces an effective mass for the photon

$$\beta_\gamma = 1 - \left(\frac{E_\gamma}{M_{LVn}}\right)^n \quad ; \quad m_\gamma^2 = -\frac{E_\gamma^{2+n}}{M_{LVn}^n},$$

Delays

Modification of threshold for pair production at high E

LIV induces suppression of EBL-opacity

Fairbairn+ 2014

ASTRI mini-array

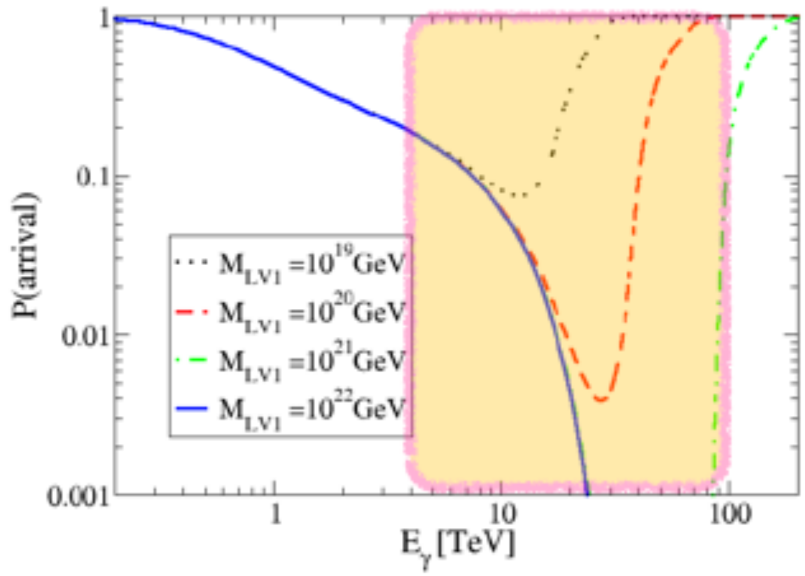
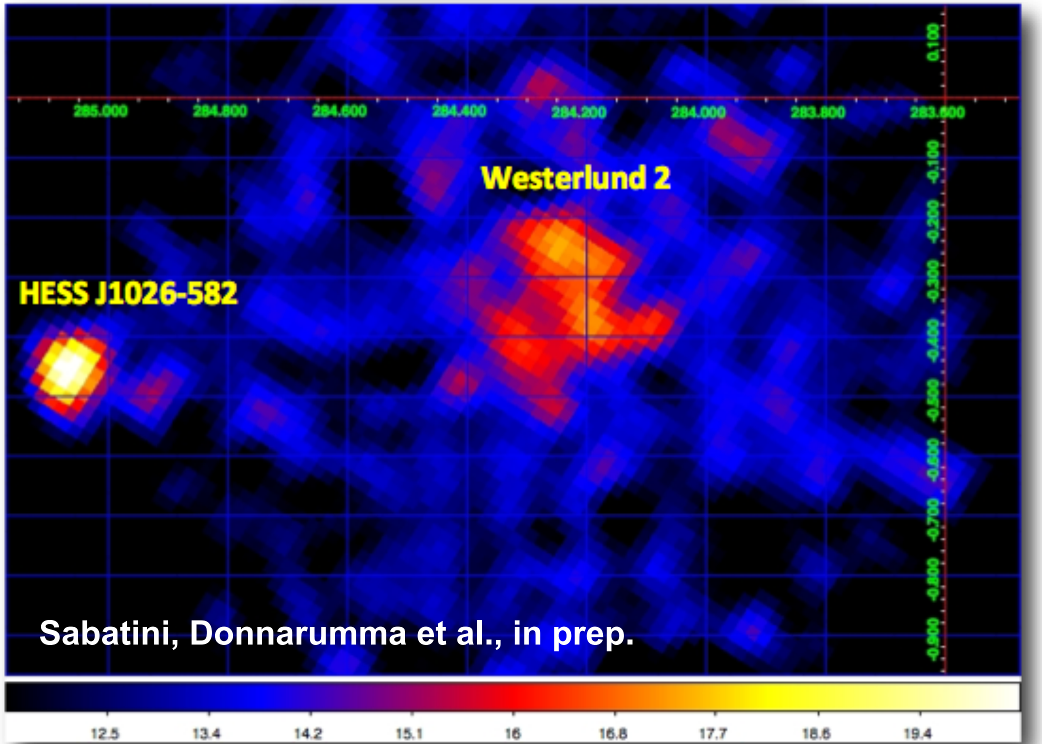


Figure 2. *The arrival probability of a photon emitted from a hypothetical source at redshift $z = 0.05$ as a function of energy. The different curves represent different values of the Lorentz-violating scale M_{LV1}. VHE photons with energies $\gtrsim 100$ TeV can travel through the CMB effectively unimpeded.*

The wide field of view and our galaxy

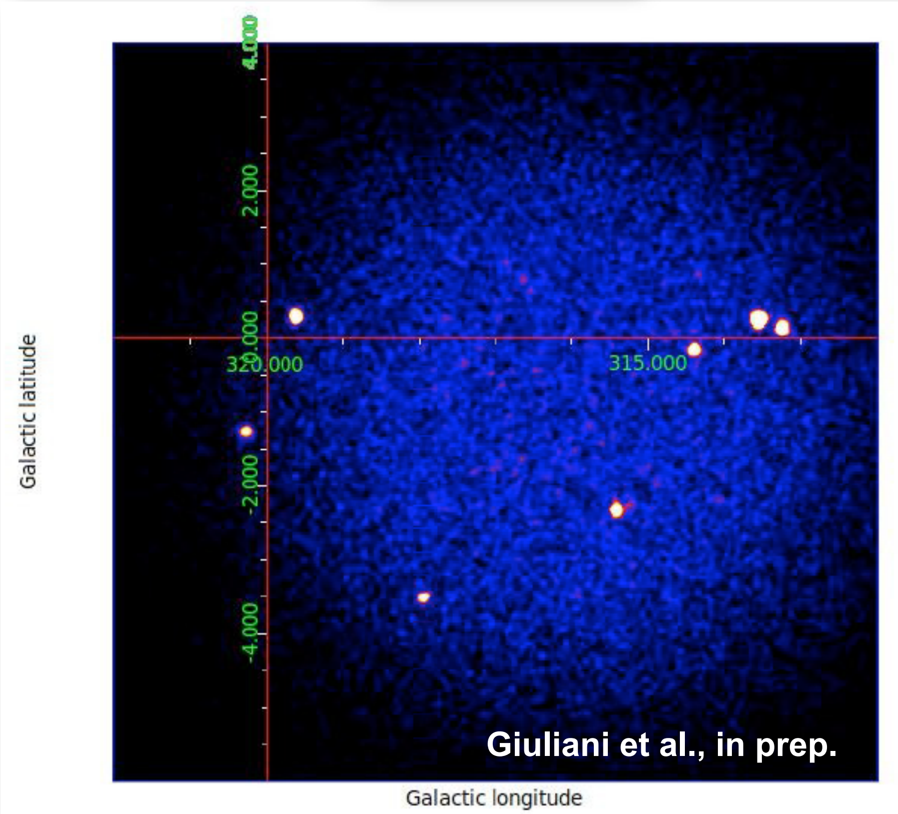
Eta Carinae region

270 hr



Crux Arm

200 hr



MWL facilities