The large field of view ASTRI/CTA Cherenkov mini-array

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for the ASTRI Collaboration and the CTA Consortium

Talk outline

The ASTRI SST-2M prototype

- Dual-mirror concept
- Innovative sensors and electronics
- End-to-end approach

The ASTRI/CTA mini-array

- First CTA seed
- Science cases
- Synergies with other instrumental set-ups

Conclusions

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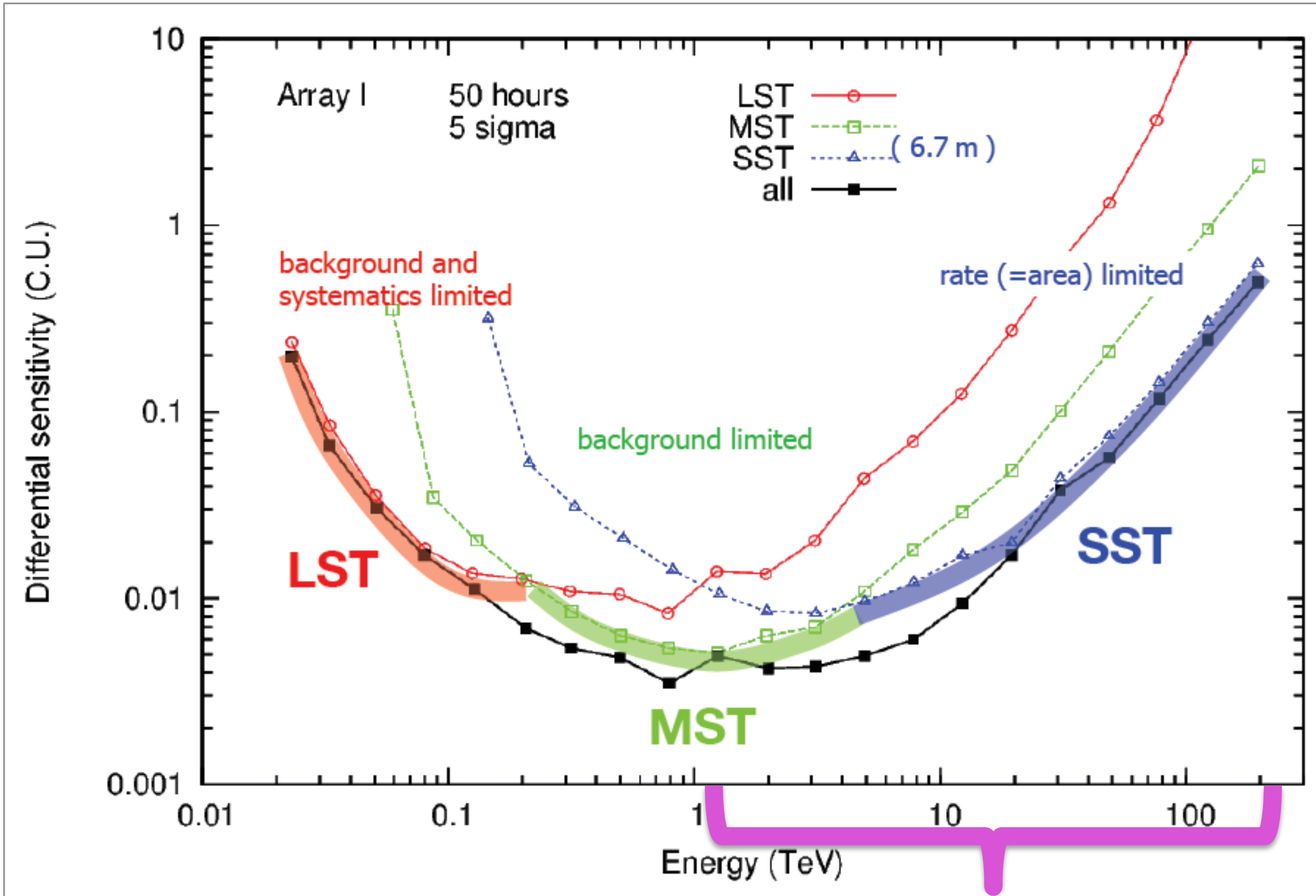
The CTA Project



The ASTRI project

ASTRI is an Italian "Flagship Project" funded by the Ministry of Education, University and Research (MIUR) and led by the Italian National Institute for Astrophysics (INAF).

The main goals of the project are the design, development and deployment, **within the CTA framework** of:

- **an end-to-end prototype** of the CTA small-size telescope in a dual-mirror configuration (ASTRI SST-2M) to be tested under field conditions at the INAF observing station on Mt. Etna (Sicily) at the end of **2014**;
- **a SST-2M mini-array** to be placed at the chosen CTA Southern Site starting in **2016**.

Dual-mirror concept

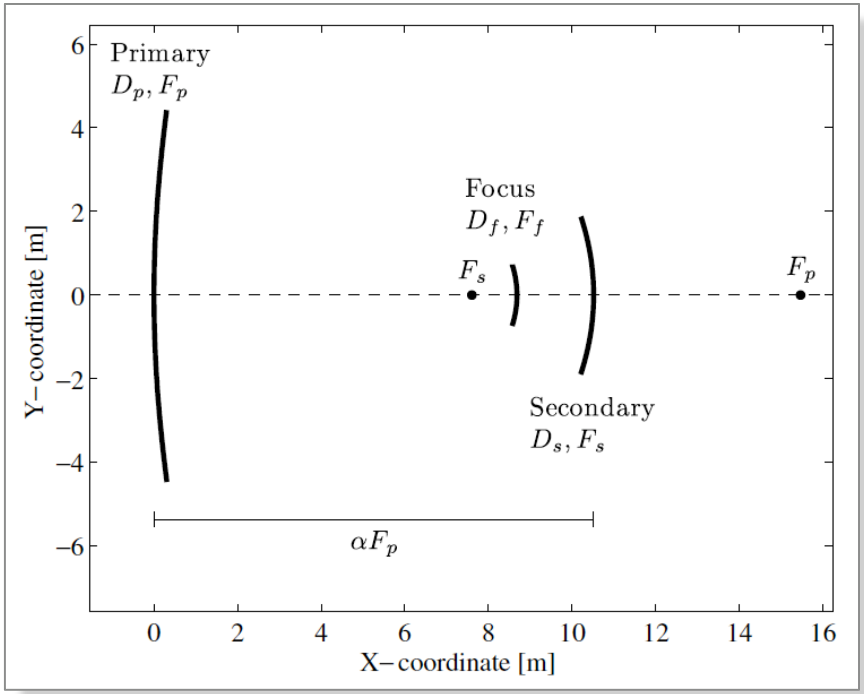
Small pixel size, large field of view, and controlled cost requirements are mutually incompatible within the Davies-Cotton telescope design paradigm.

New dual-mirror, Schwarzchild-Couder (SC) based aplanatic design has been proposed and developed [Vassiliev, Fegan & Brousseau, 2007, A.Ph., 28, 10]

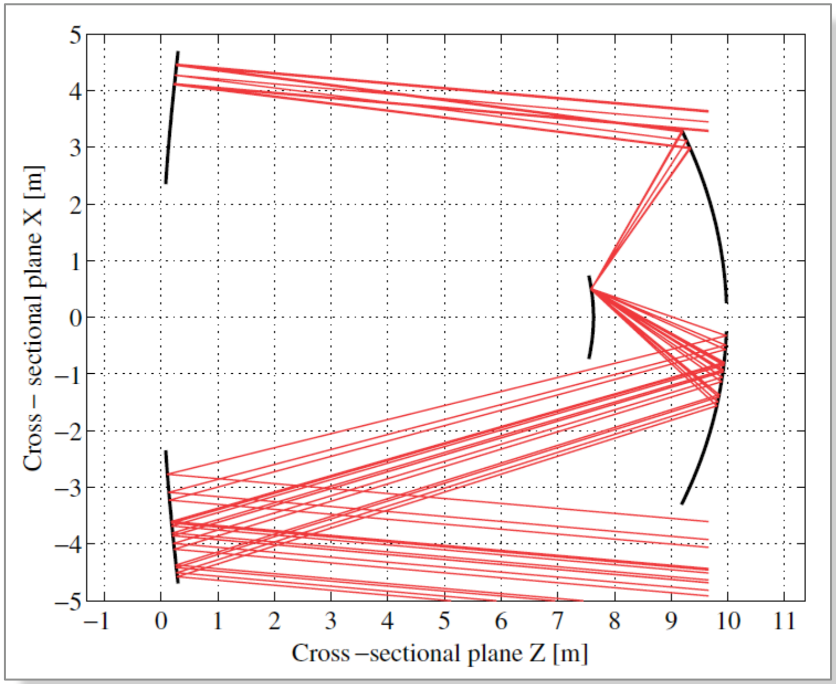
The dual-mirror layout allows us:

- to obtain a more compact and stiffer mechanical structure
- to reduce the dimension, the weight, and the cost of the camera at the focal plane of the telescope
- to adopt Silicon-based photo-multipliers as light detectors, thanks to the reduced plate-scale. SiPMs allow us to perform observations during Moon-light, increasing the observatory duty-cycle
- to have an optimal imaging resolution across a wide field of view

Dual-mirror concept



"Wide field aplanatic two-mirror telescopes for ground-based γ-ray astronomy"
Vassiliev, Fegan & Brousseau, 2007, A.Ph., 28, 10



In the SC telescope, the focal plane is located in-between two aspherical mirrors, close to the secondary mirror.

No Cherenkov telescope adopted this optical system up to now

ASTRI SST-2M

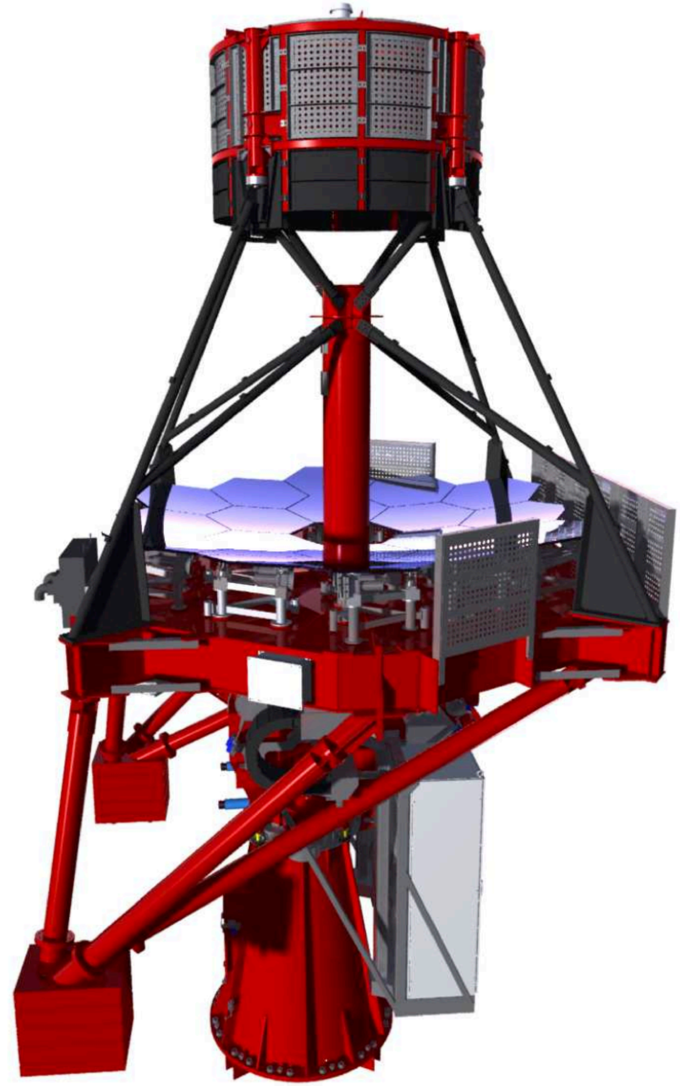
Energy threshold

- 1 TeV

End-to-end SST-2M Prototype

Telescope properties

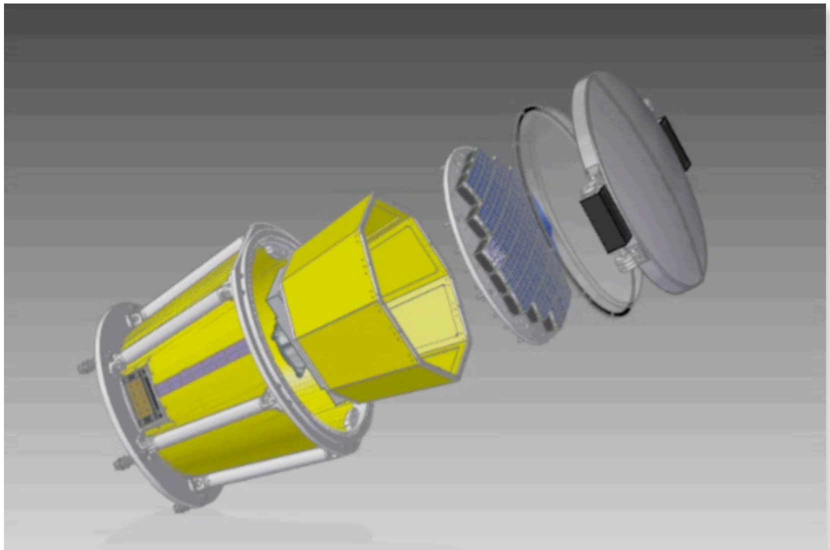
- Primary mirror = 4.3m
- Optical design = Schwarzchild-Couder
- M1 type = Segmented (18, 3 concentric rings)
- Secondary mirror = 1.8m (2.2m RoC)
- M2 type = Monolithic
- M1-M2 distance = 3m
- Effective area = 6.5m^2
- F/D$_1$ = 0.5, F = 2.15m

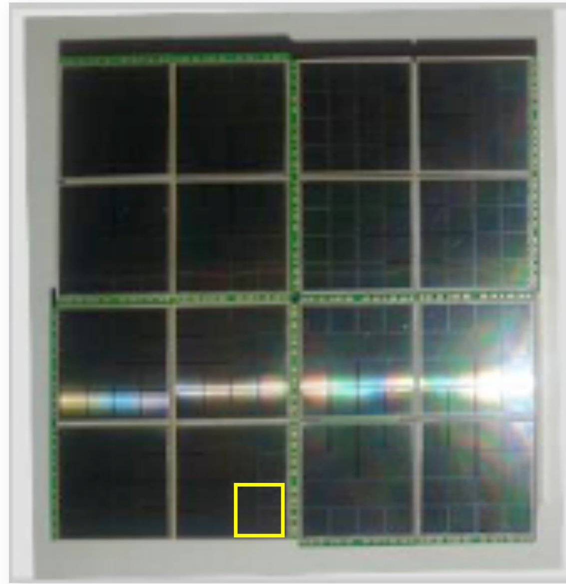


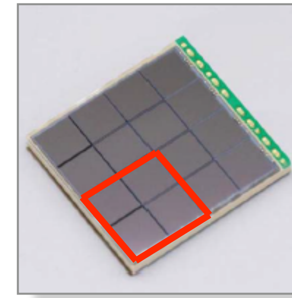
Camera properties

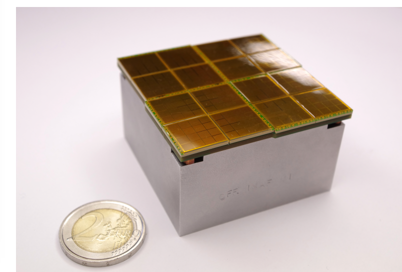
- Number of logical pixels = 1984
- Pixel size = 0.17° (plate scale = 37.5mm/°)
- Field of View = 9.6°
- Sensors type = SiPMs

ASTRI camera



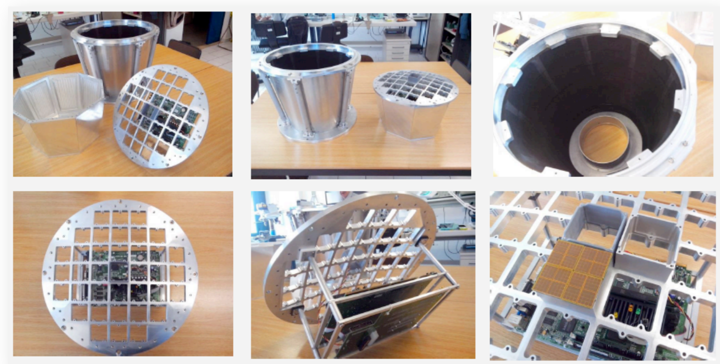




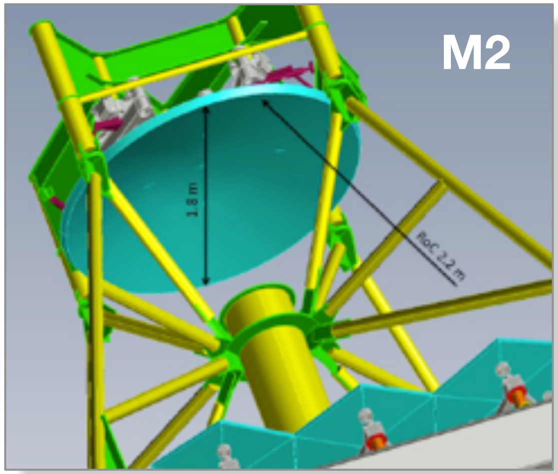


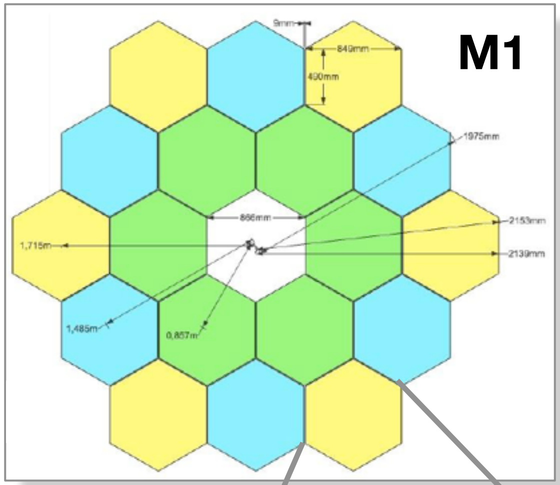
Take away numbers

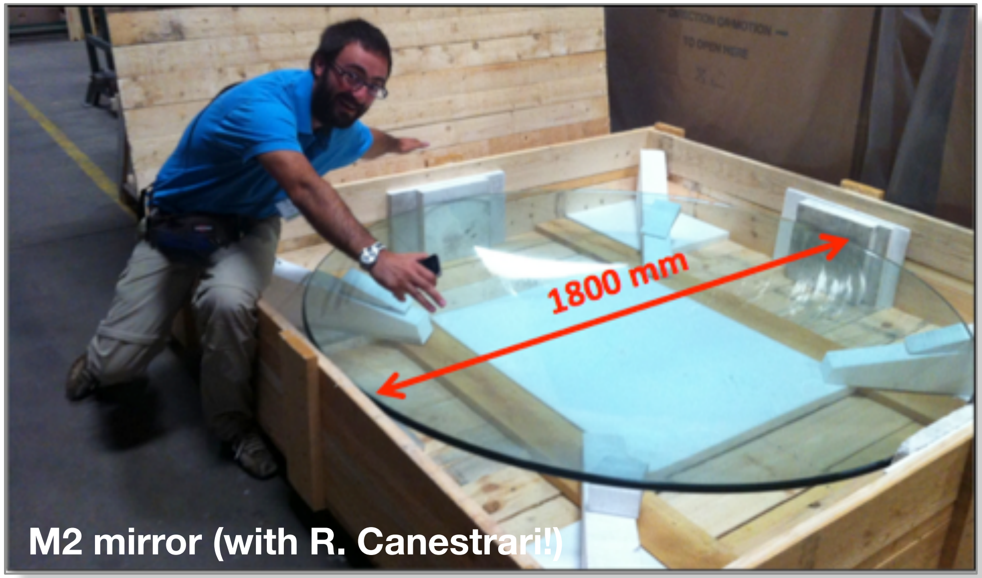
- All parts fully integrated in the camera body
- Logical pixel size = 6.2mm x 6.2mm
- Number of pixels = 1984
- Field of view = 9.6° (RoC = 1m)
- Weight ~ 50kg
- FFE ASIC = CITIROC [signal shaper]
- Photo-sensors = SiPMs (S11828-3344M, other sensors under test for the mini-array)



ASTRI mirrors



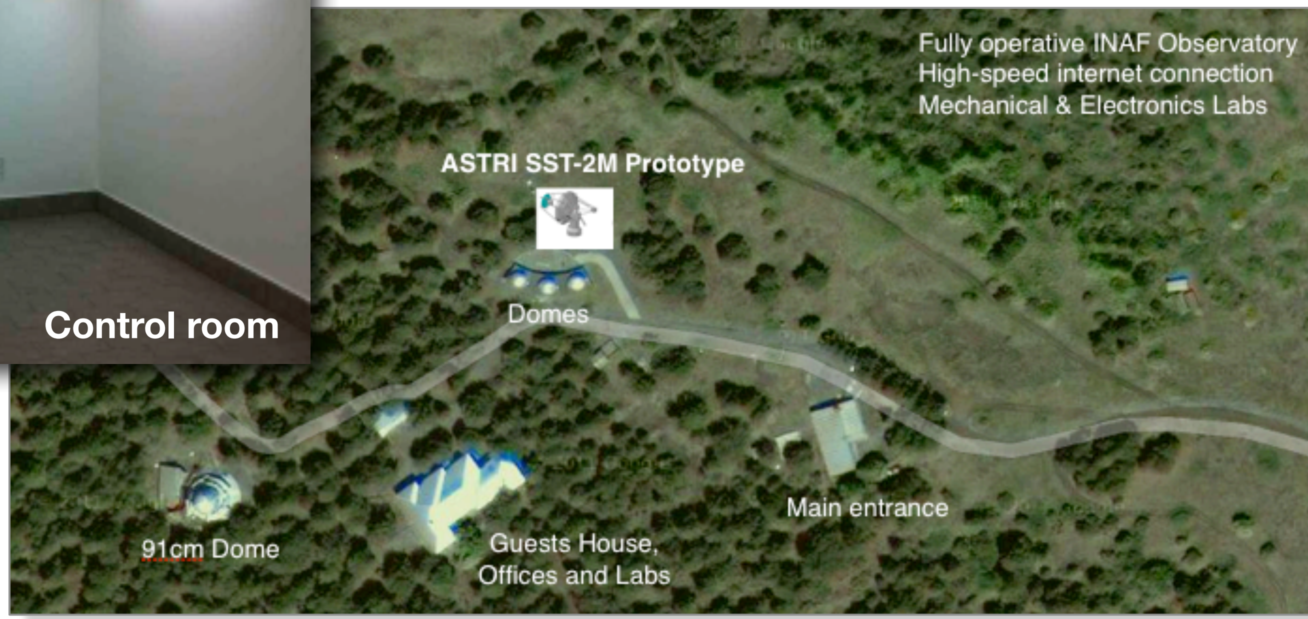




M2 mirror (with R. Canestrari!)

M1 external segment

ASTRI site



The ASTRI SST-2M prototype will be installed at the INAF Facility on Mt. Etna (Sicily) at 1735m a.s.l.. The location altitude and the end-to-end approach will allow us to perform observations of the Crab, MKN 501 and MKN 421.

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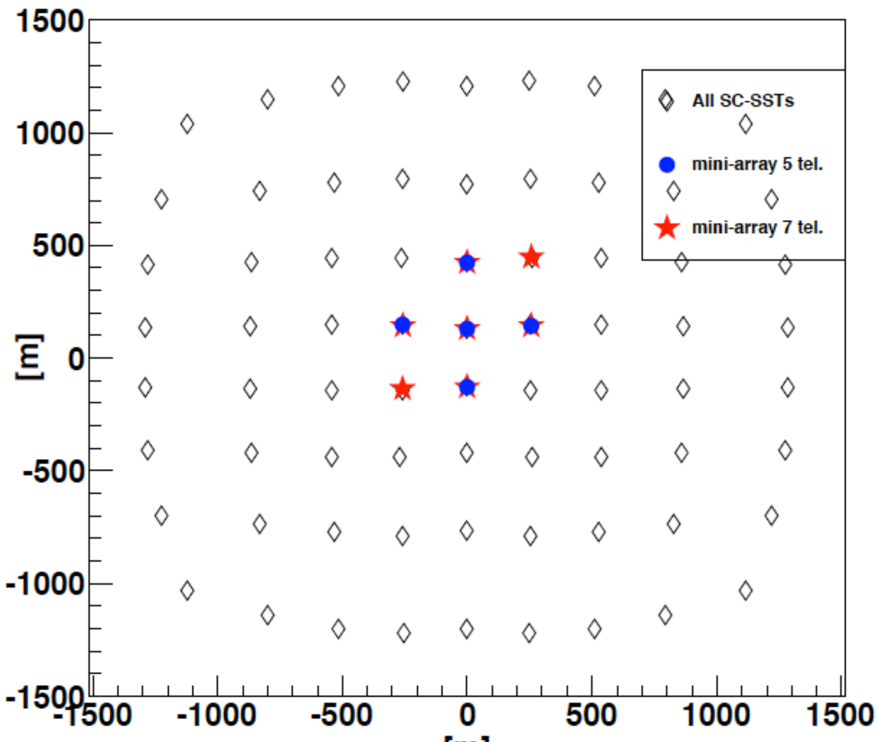
ASTRI/CTA mini-array

Led by the Italian National Institute for Astrophysics
supported by the ASTRI and TeChe.it projects

Additional financial contributions from
North-West University, Potchefstroom, South Africa
Universidade de São Paulo, Brazil

Credits: A. Stamerra

ASTRI/CTA mini-array



Di Pierro et al, 2013

Limiting flux

- comparable or slightly better than H.E.S.S. above a few TeV for an array composed by 7 telescopes

Angular resolution

- a few (4-5) arcmin

Energy resolution

- of the order of 10-15 %

ASTRI/CTA mini-array

The ASTRI/CTA SST-2M mini-array can verify some array properties:

- **check of the trigger algorithms**
  - Preliminary MC simulations shows that a typical event will trigger a number O(5-7) of the whole CTA-SSTs 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 a few selected targets
- **do the first CTA science**
  - by means of a few solid detections during the first year

Galactic science

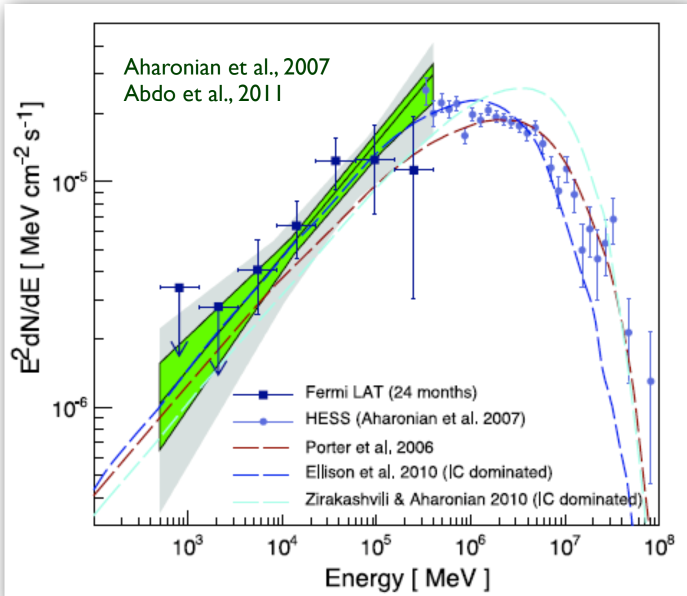
Supernova Remnants

- SNRs
- Pevatrons
- SNRs interacting with molecular clouds

PWNe

Gamma-ray binaries

Young SNRs



RX J1713.7–3946: young shell-like SNR

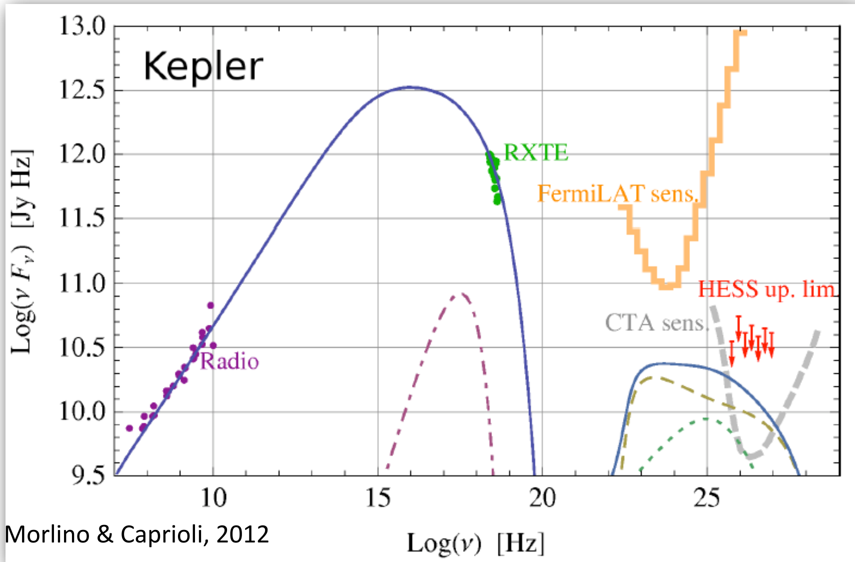
Fermi/LAT (24 months)
H.E.S.S. (combined 63 hours)

Significant emission (4.8 σ) E>30 TeV.

Broadband SED suggests a leptonic scenario.

The improved and uniform sensitivity within a few degrees and the comparable angular resolution of the ASTRI/CTA mini-array at E>10 TeV w.r.t. the current IACTs could allow us to investigate the VHE emission in the different regions of this source, studying their spectra.

SNRs/PeVatrons



Morlino & Caprioli, 2012

Tycho SNR would be the best candidate, but it is in the northern hemisphere.

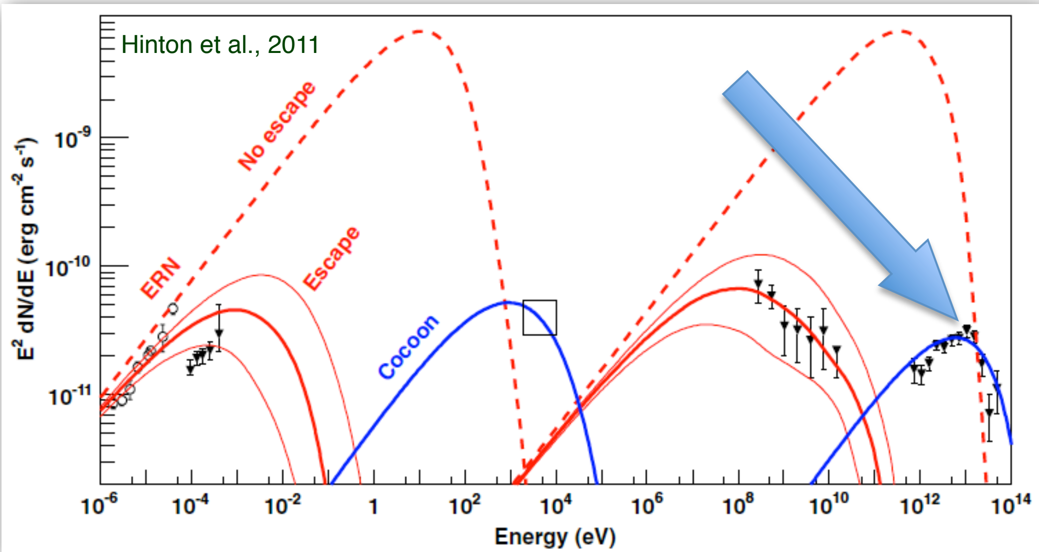
Kepler SNR is very similar w.r.t. Tycho SNR in terms of progenitor, age, radio flux and X-ray emission in thin filaments.

Only upper limits from H.E.S.S. (13 hours): F[0.2-13 TeV] < 8.6×10^{-13} erg cm^{-2} s^{-1}

Theoretical models (Morlino & Caprioli, 2013) predict that the high energy emission from Kepler SNR should be only a factor 2-5 below the H.E.S.S. U.Ls.

The ASTRI/CTA mini-array could be able to investigate this young SNR by means of deep observations (>> 50hr).

PWN



PWN are excellent candidates for the study of particle acceleration and cooling in relativistic shocks.

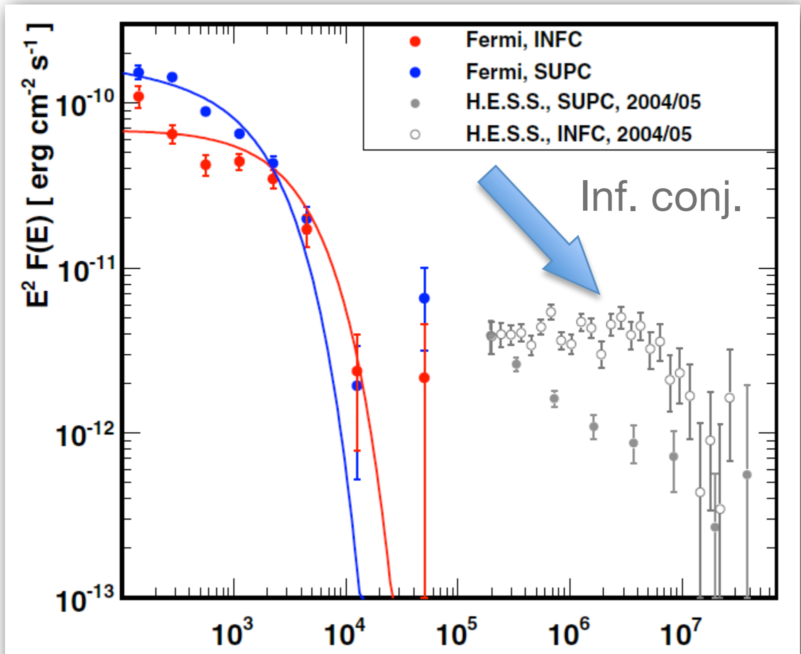
Vela-X is a bright and extended (~1 deg) source, which shows no signs of spectral softening at increasing distance from its parent's pulsar.

HESS J1825-137 is smaller (~0.2 deg), dimmer, and shows such a spectral softening.

Vela-X: VHE spectral maximum at ≈10 TeV.

ASTRI/CTA mini-array observations could provide constraints on the maximum energy achievable by the relativistic particles at the termination shock.

HMXB



Hadasch et al., 2012

LS 5039: HMXB in an eccentric orbit around a massive O-type star.

Orbital period is 3.9 days.

High energy emission modulation along the orbital period.

Sup. conj.: power law with Γ~2.53

Inf. conj.: power law with Γ~1.85 and exponential cut-off @ 8.7 TeV

Flux and spectral modulations ➔ phase-dependent gamma-ray absorption via pair production.

The ASTRI/CTA mini-array could investigate the spectrum of the TeV photons at different orbital phases, providing useful constraints on the gamma-ray emission and absorption.

Extra-galactic science

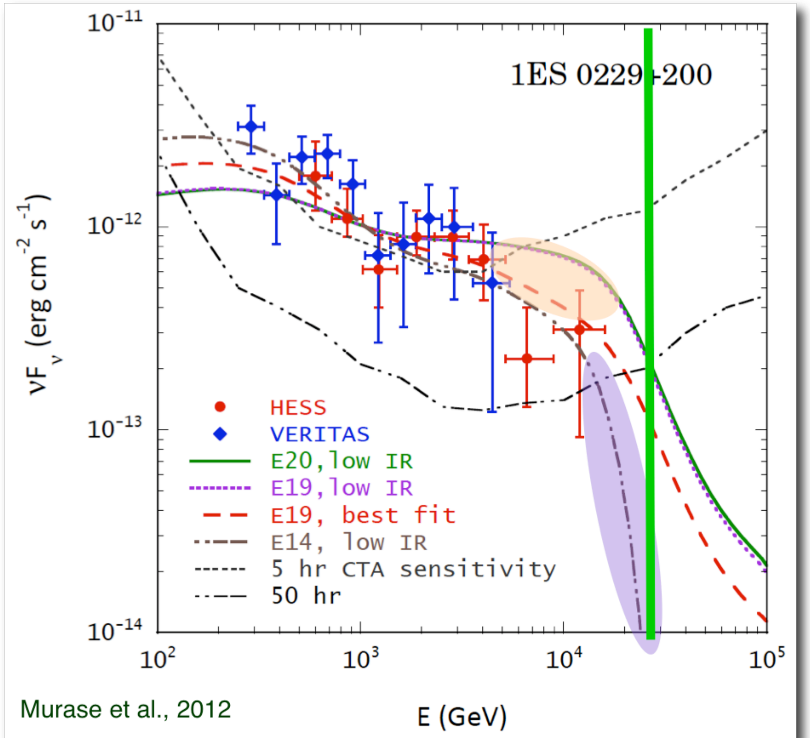
Extreme BL Lacs

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

Less-beamed AGNs

- Radio-galaxies
- Starburst galaxies

E-HBLs



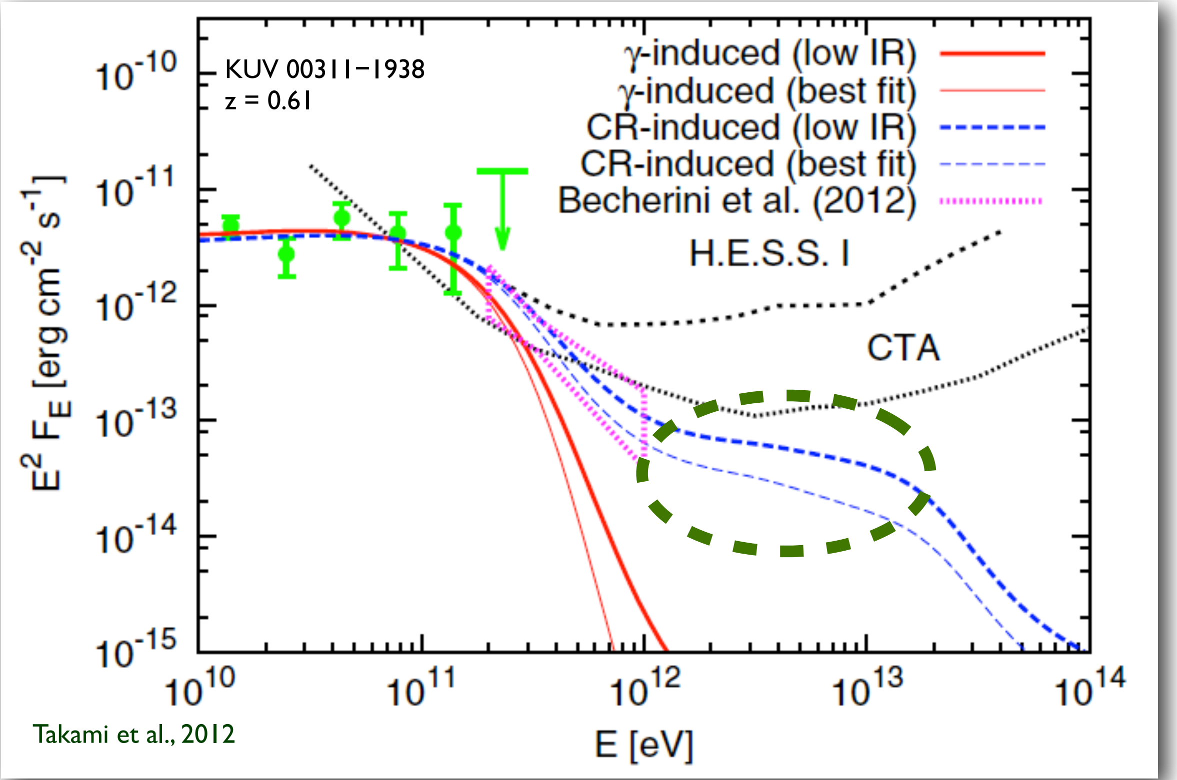
1ES 0229+200 SED can be fit by both the γ-ray-induced cascade and proton-induced cascade emissions.

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.

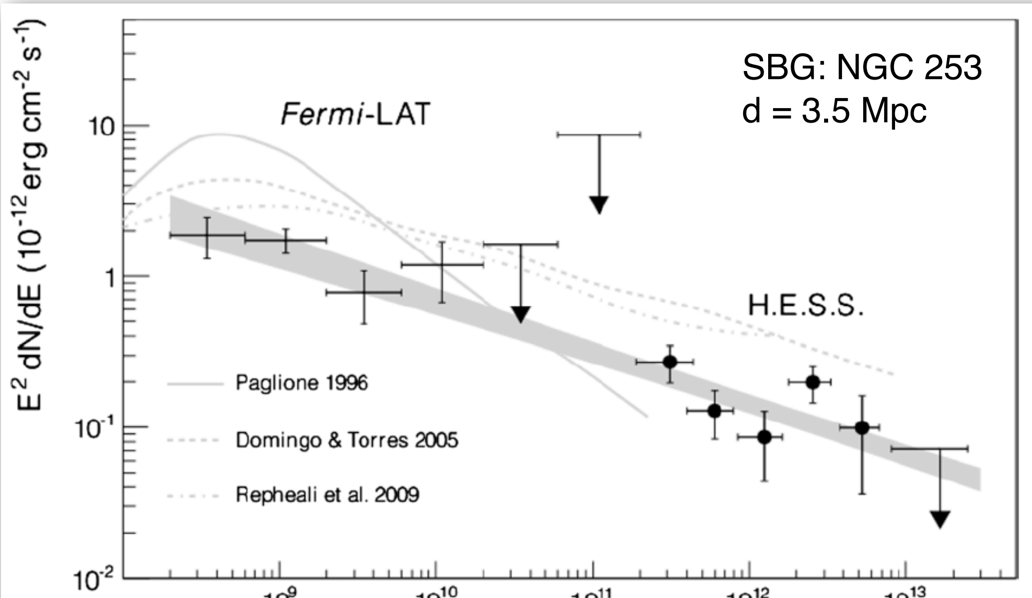
A detection of >25 TeV γ-rays from 1ES 0229+200 is only compatible if the γ-rays are hadronic in origin. Very deep ASTRI/CTA mini-array observation are required.

E-HBLs



KUV 00311-1938: detections of E-HBLs above a few TeV could provide useful constraints on the physical mechanisms responsible for the VHE emission.

SBGs/RGs



Abramowki et al., 2012

Starburst Galaxies:
NGC 253: challenging, about 200hr of observation.

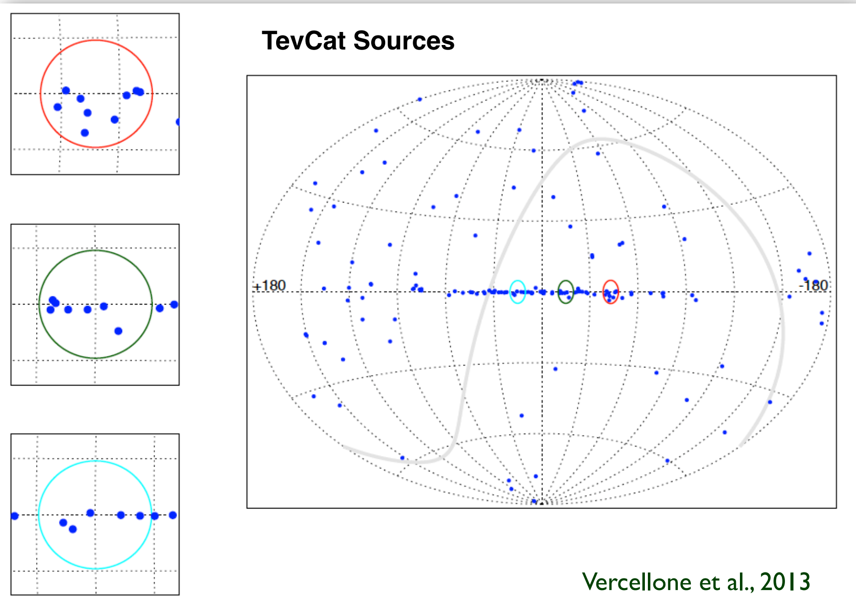
NGC 4945: no detection so far, but a good candidate.

Radio Galaxies:
M 87: high Zenith angle.

SBGs ➔ studies of the cosmic ray sources within the starburst region. Excellent synergy with *Fermi*/LAT.

RGs ➔ studies of the short time-scale variability of such intense and low-redshift class of objects above a few TeV during periods of high-flux states.

Wide field of view

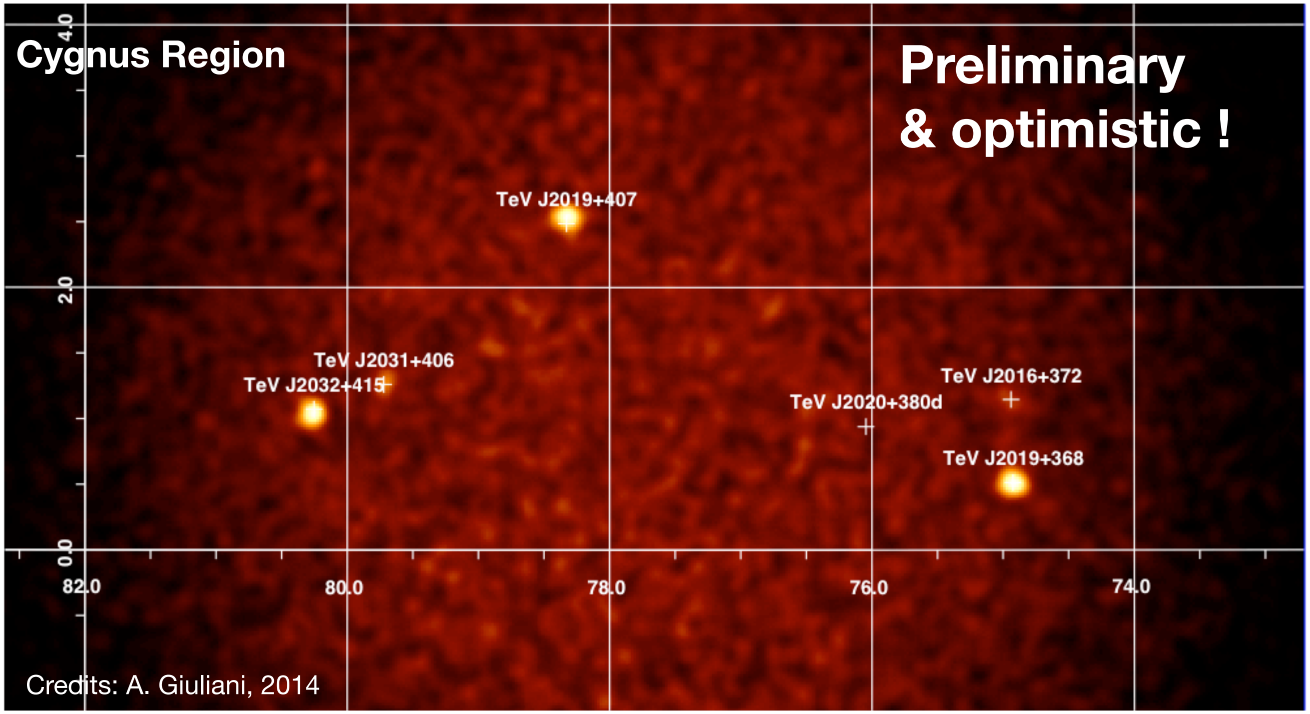


The ASTRI/CTA mini-array will have a larger field of view w.r.t. the current IACT ones.

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

- Close (angular distance < 3^{o}) 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.
- Several GeV *Fermi*/LAT sources lie within the central region of each pointings.

Field of view simulations



- Preliminary ASTRI/CTA mini-array simulation of the Cygnus region.
- The simulation is centered on Galactic coordinates of (l,b) = (77.7, 1.0)
- Net observing time of 150 hours
- Energy greater than 3 TeV
- Source parameters (position, flux, spectral index) from ASDC

Synergies

- ***"Given the similar sensitivities, how to compare with H.E.S.S. ?"***

- CTA requires that at about 3^{o} off-axis the sensitivity should be not less than half of the on-axis one. Therefore, we will have a better sensitivity at the edge of very extended sources (e.g. RX J 1713.7-3946). Moreover, we can check both technological aspects (e.g., PSF, off-axis sensitivity, etc...) and scientific ones (VHE emission at the very edges, spectral properties in different region of the source, etc...).

- We are free to choose just a few (2-3) targets and devote to them very long exposures, e.g. T>200-300 hr each target.

- Long exposures will help also for E-HBLs (e.g., KUV 00311-1938) in order to improve the determination of the possible hadronic origin of its VHE emission by means of detections at E > 10TeV.

- We extend our sensitivity up to 100 TeV and beyond, a never-explored energy range by IACTs.

Synergies

- ***"Given the similar energy range, how to compare with HACD ?"***
- The lower imaging energy threshold of current and future HACD (~100 GeV) and the wider energy range of the ASTRI/CTA mini-array (beyond 100 TeV) will allow a direct comparison of scientific data (spectra, light-curves, integral fluxes) of those sources which could be monitored simultaneously (e.g., Crab Nebula, MKN 421 [at high ZA], MGRO J1908+06).
- The region near the Galactic Center will be accessible by both the ASTRI/CTA mini-array and future EAS. Thanks to the wide field of view of the ASTRI/CTA mini-array (9^o in diameter) a large portion of the sky will investigated simultaneously.
- The high-energy boundary of both EAS and the ASTRI/CTA mini-array will allow to study the VHE (E>10 TeV) emission from extended source such as SNRs and PWN, and to investigate the presence of spectral cut-offs.

Conclusions

- **CTA will be a 10-fold improvement** in sensitivity for VHE studies, an analogous to the advance from EGRET to Fermi/LAT.
- **The ASTRI SST-2M prototype**, will be inaugurated on September 2014 during the CTA Consortium Meeting in Sicily, and will perform the first Crab observations with a Schwarzchild-Couder telescope equipped with SiPMs in 2015.
- **The ASTRI/CTA mini-array** will constitute a seed for the whole CTA array, allowing us to investigate innovative technological solutions.
- **CTA early science** performed by means of ASTRI/CTA mini-array observations of a few selected targets will allow us to obtain a few solid detections during the first year.
- **Excellent synergies** with ground- (e.g., HAWC, LHAASO, …) and space-based (*Fermi*, *Swift*) observatories from 2016 and beyond.

Thank you !