Science with ASTRI and the ASTRI/CTA Mini-Array

Giacomo Bonnoli (INAF - OA Brera)

Outline

✦ IACTs for newcomers:

a few glimpses

✦ The ASTRI SST-2M prototype:

a technological demonstrator with potential scientific output

✦ The ASTRI/CTA SST Mini-Array and its science:

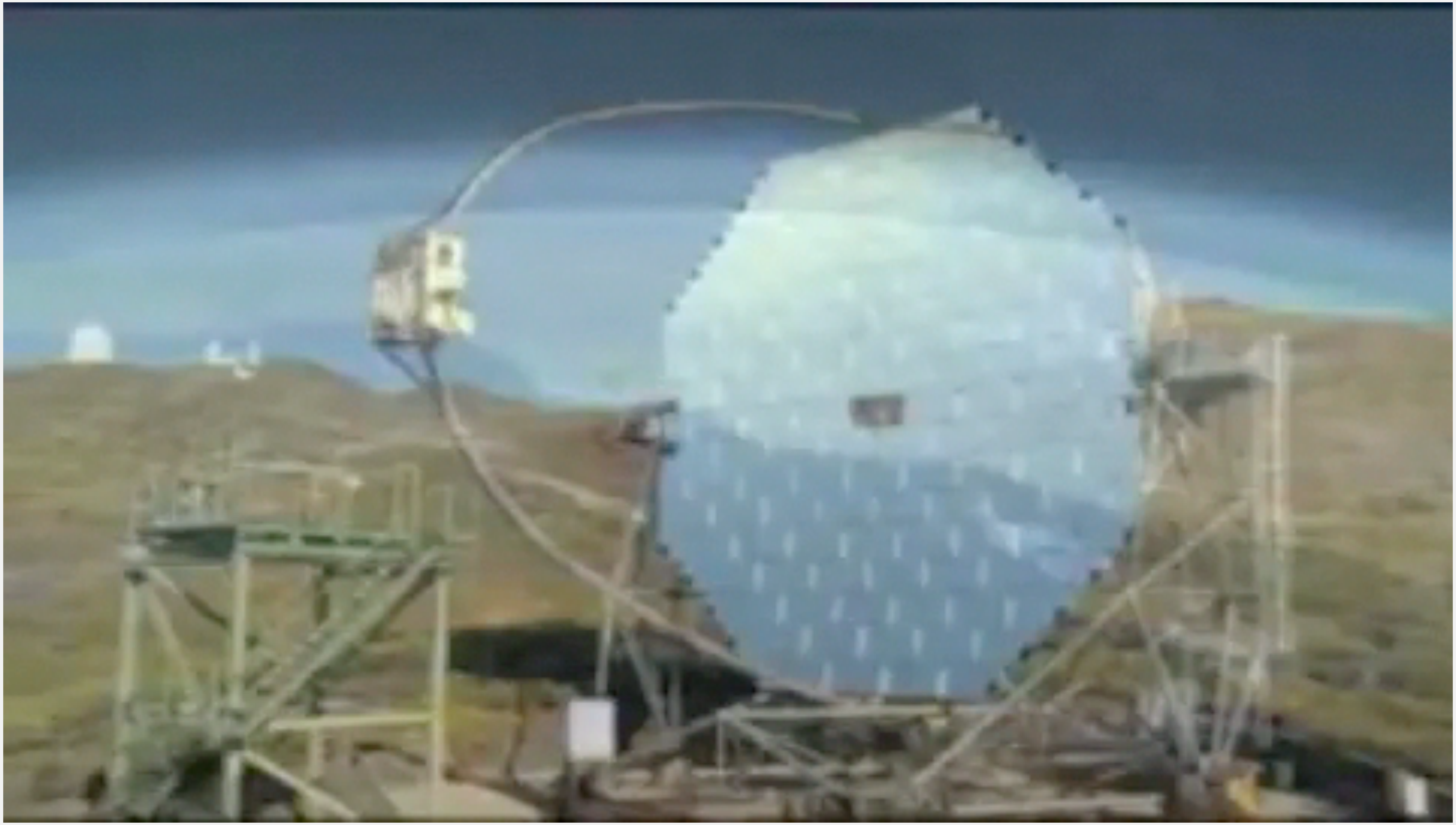
a first seed of the CTA array already taking up the challenge of TeV science

✦ Extreme HBLs:

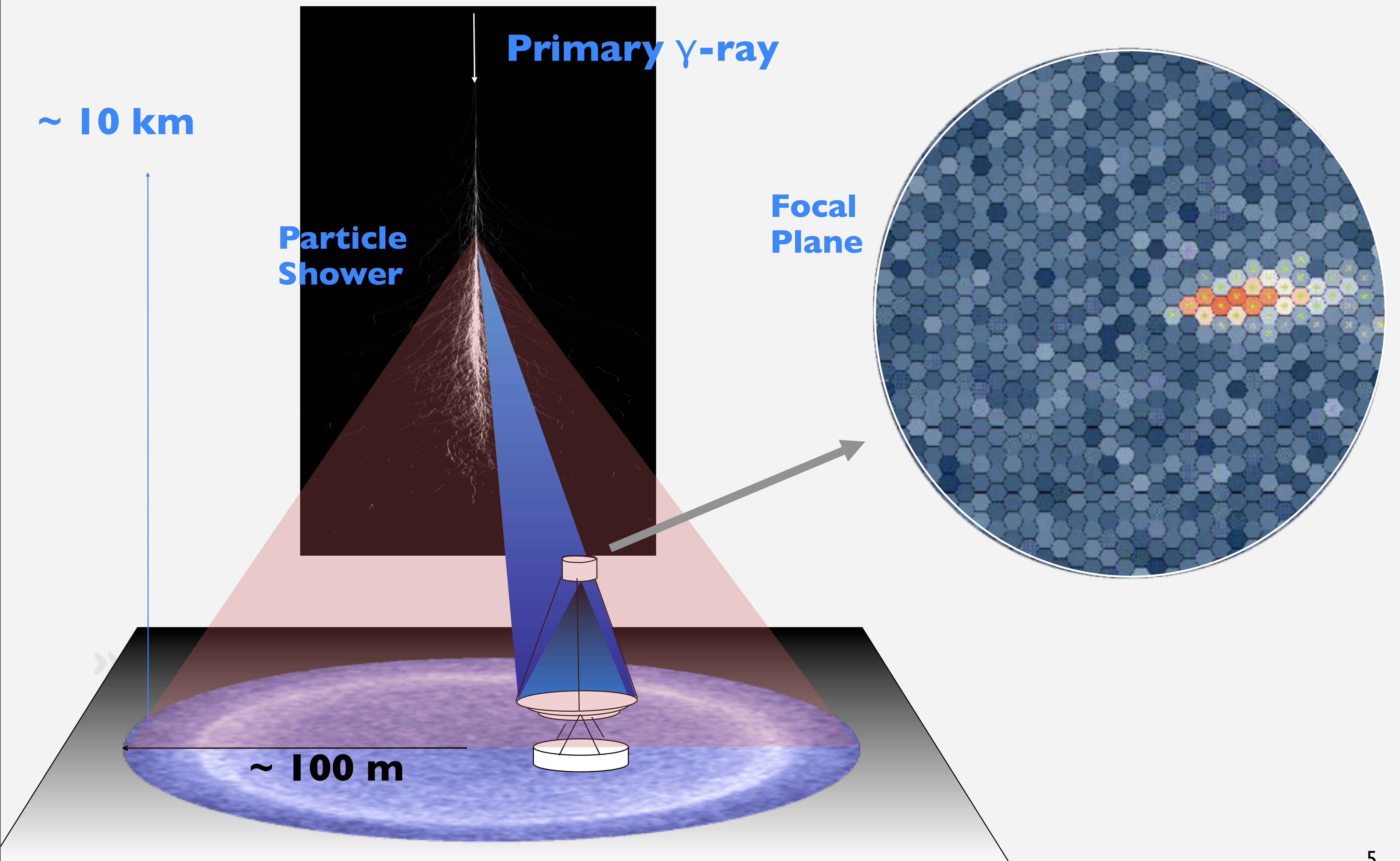
ideal candidate sources conveying intriguing physics

IACT for newcomers: a few glimpses

Principle of IACT detection



Imaging of an Extended Air Shower



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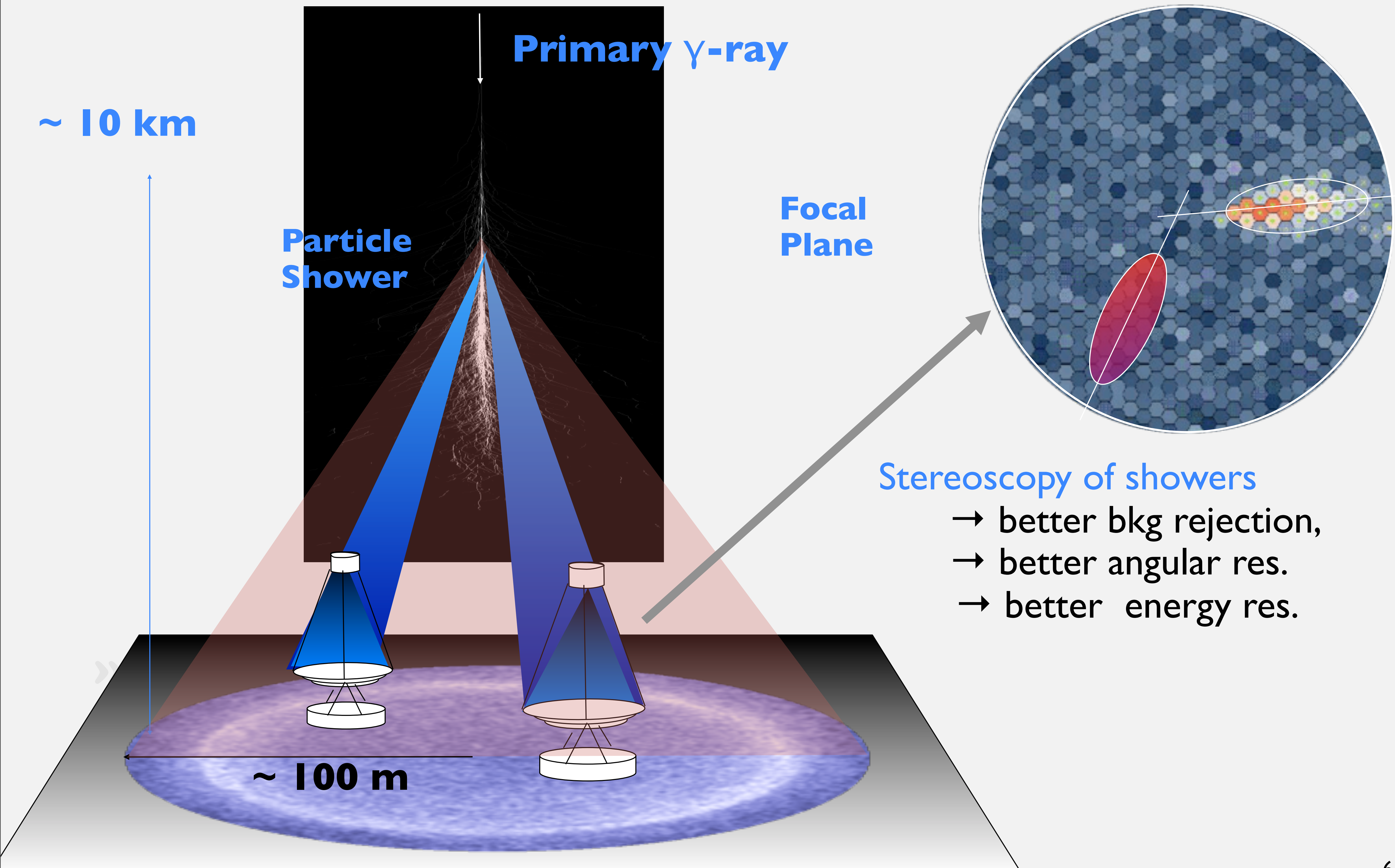
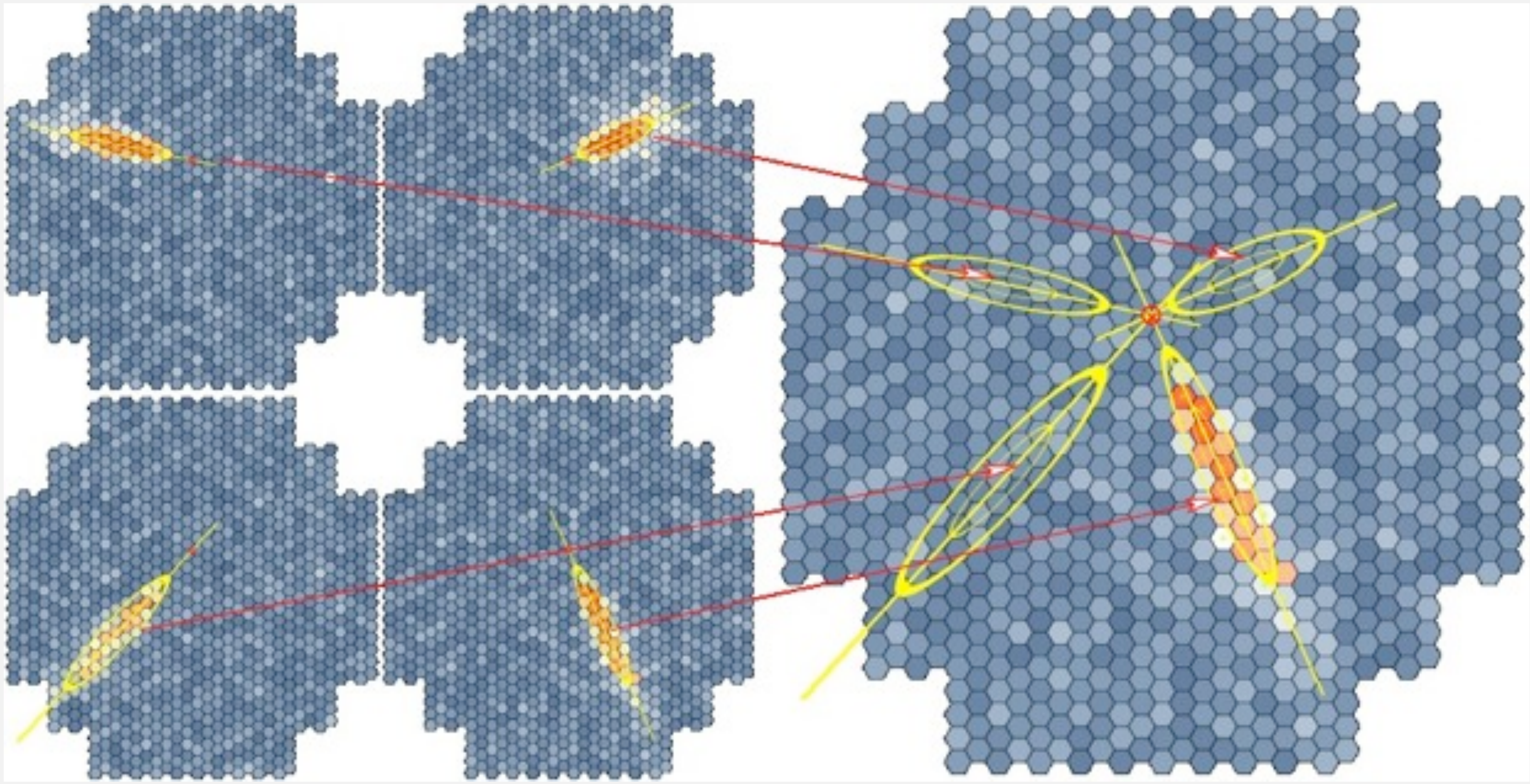
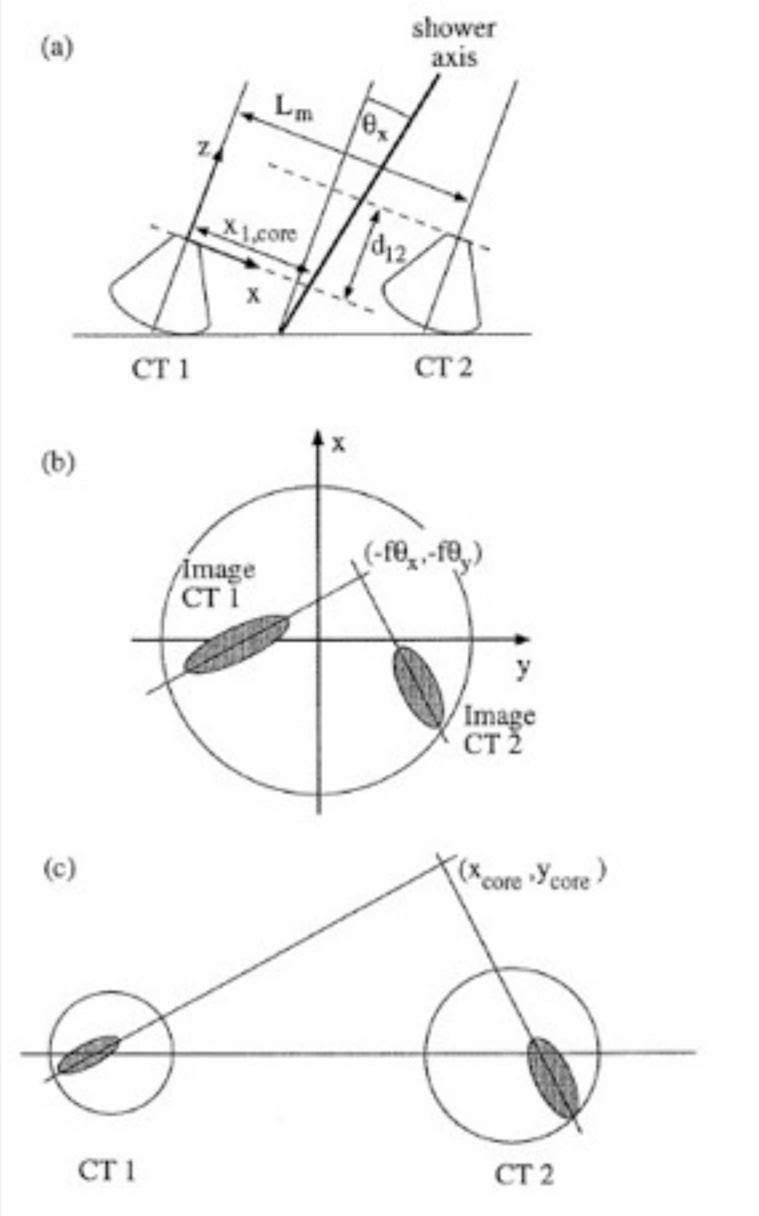


Stereoscopy of showers
→ better bkg rejection,
→ better angular res.
→ better energy res.

Stereo reconstruction

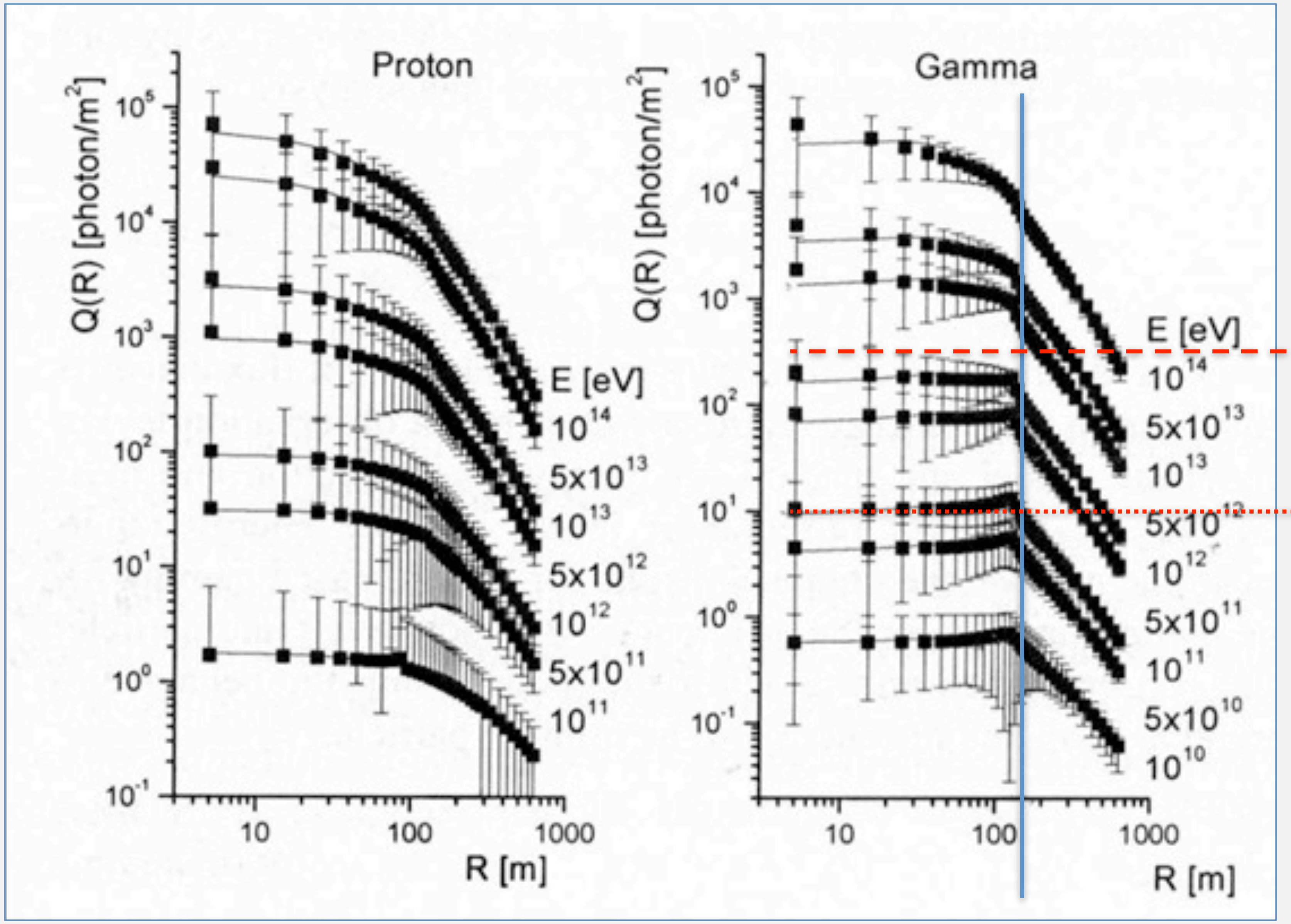




Intersection of major axes on the common FOV gives source position on the sky

Intersection of ground projections gives impact position (*core distance*)

Lateral distribution of EAS light



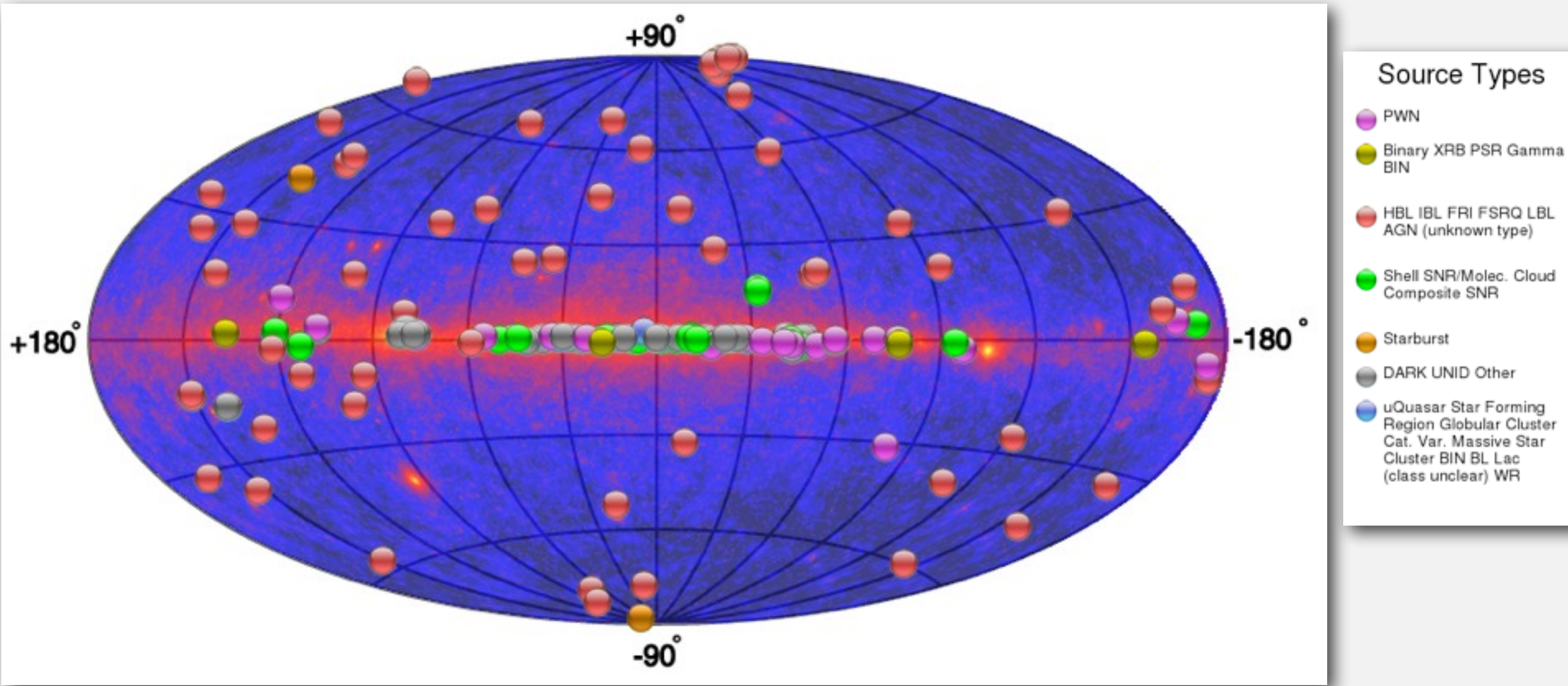
Especially at multi-TeV energy, showers can be imaged at large impact parameter, provided the FoV is wide enough to image the shower maximum;

This helps to obtain large collection area with given N of telescopes (large spacing compensates rarity)

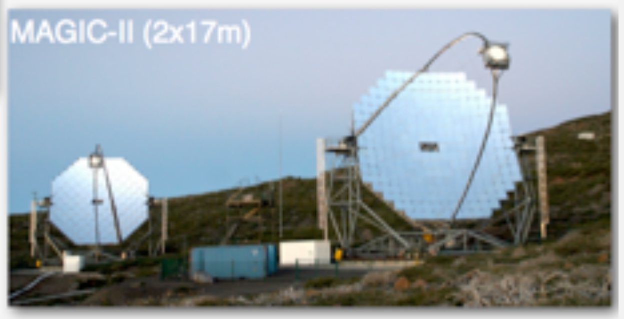
But need for precise measurement of impact parameter or prone to Energy degeneracy

This is crucial for a large FOV IACT such as ASTRI (9.6°corrected FOV), **poor DE/E in mono obs.**

The TeV sky

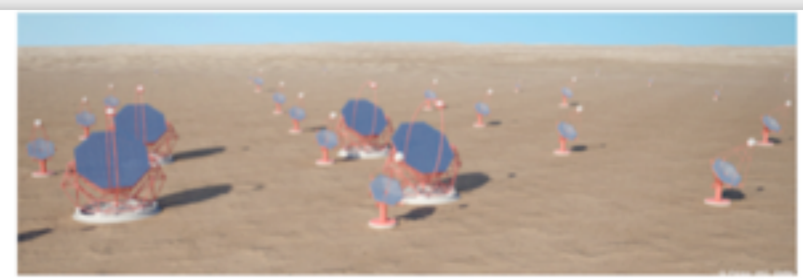

+90°
-90°
+180°
-180°
Source Types
PWN
Binary XRB PSR Gamma BIN
HBL IBL FRI FSRQ LBL AGN (unknown type)
Shell SNR/Molec. Cloud Composite SNR
Starburst
DARK UNID Other
uQuasar Star Forming Region Globular Cluster Cat. Var. Massive Star Cluster BIN BL Lac (class unclear) WR

Status



The present ...

and the future ...



- **Two arrays**, one in the northern and one in the southern hemisphere
  - To provide all-sky coverage (construction starting from 2015).
- **4 Large size-telescopes** (LSTs, ⦰~23m) at the center of the array
  - To lower the energy threshold down to E~30 GeV
- **25 Medium size-telescopes** (MSTs, ⦰~12m) covering about 1km^2
  24 Schwarzschild-Couder dual-mirror telescopes (SCTs, M1 ⦰~9.5m) only in the southern site
  - To improve by a factor of ten the sensitivity in the energy range 0.1 – 10 TeV
- **50-70 Small size telescopes** (SSTs, M1 ⦰~4m, A_{eff}~5-10m^2) only in the southern site, covering about 10km^2
  - To extend the energy range beyond 100 TeV.

The ASTRI prototype:

a technological demonstrator with potential scientific output

The ASTRI project

Principal Investigator G. Pareschi

Co-PIs O. Catalano & S.Vercellone
Program Manager M. Fiorini
System Engineer L. Stringhetti
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
OA Roma
OA Capodimonte
OA Catania

University Partners

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ASTRI SST-2M **concept**:
dual mirror
(Schwarschild-Couder)
large FoV (9.6°)

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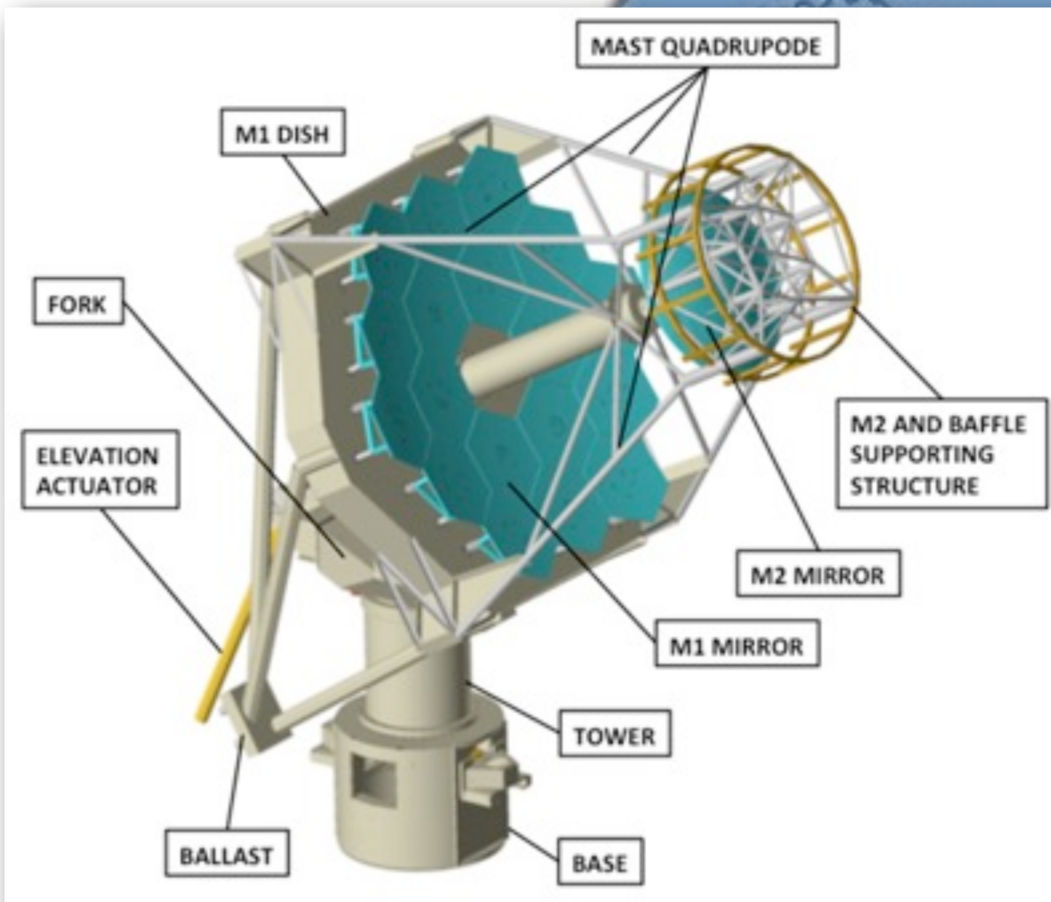

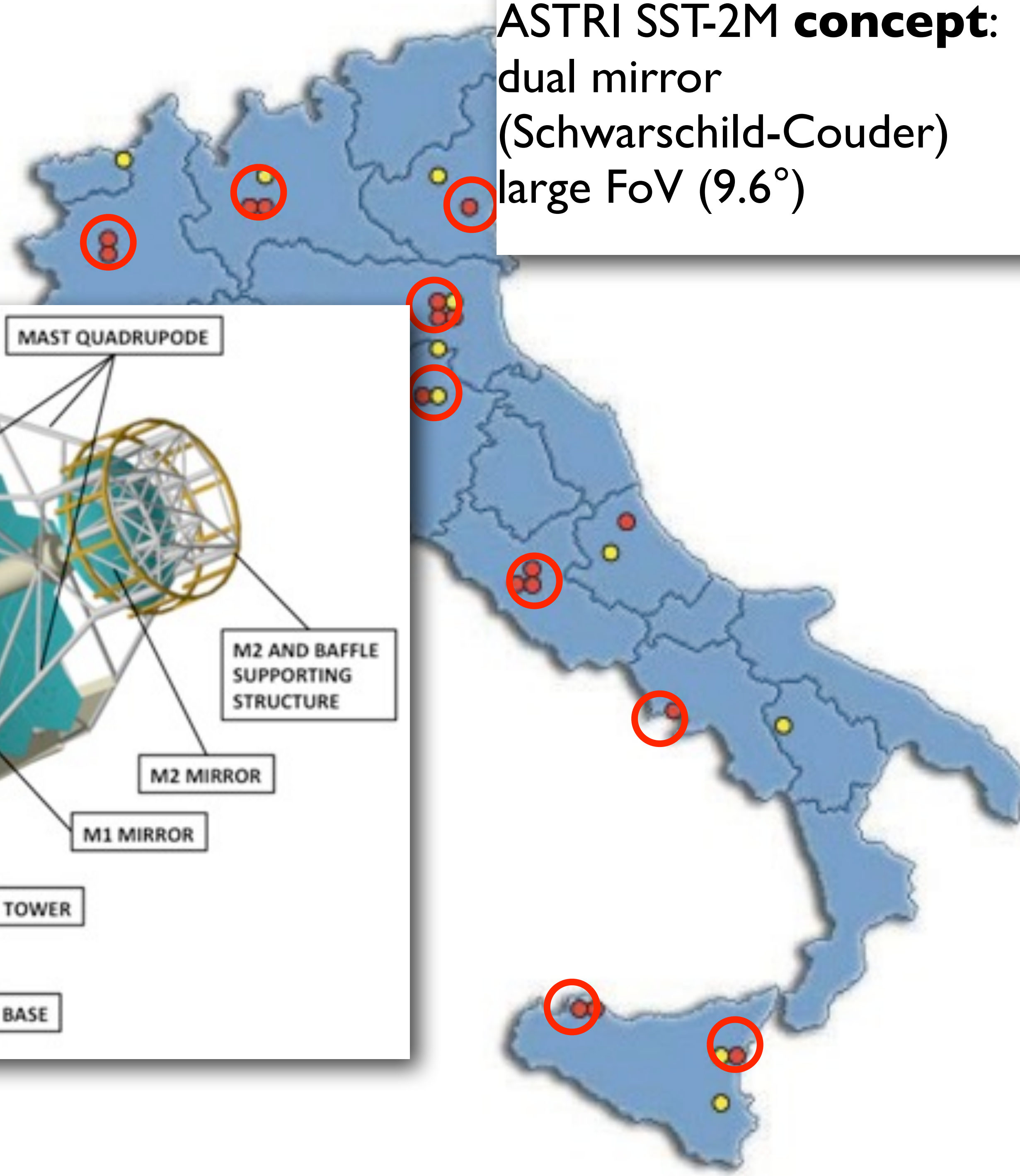

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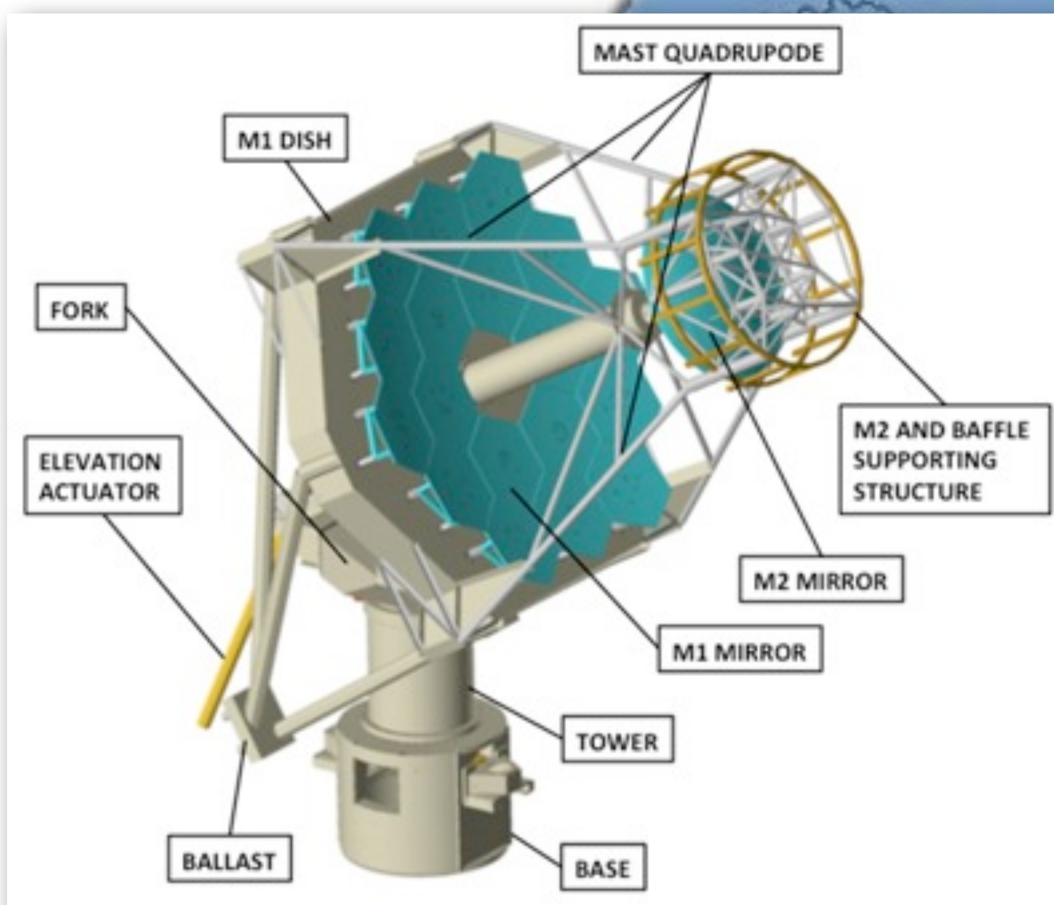

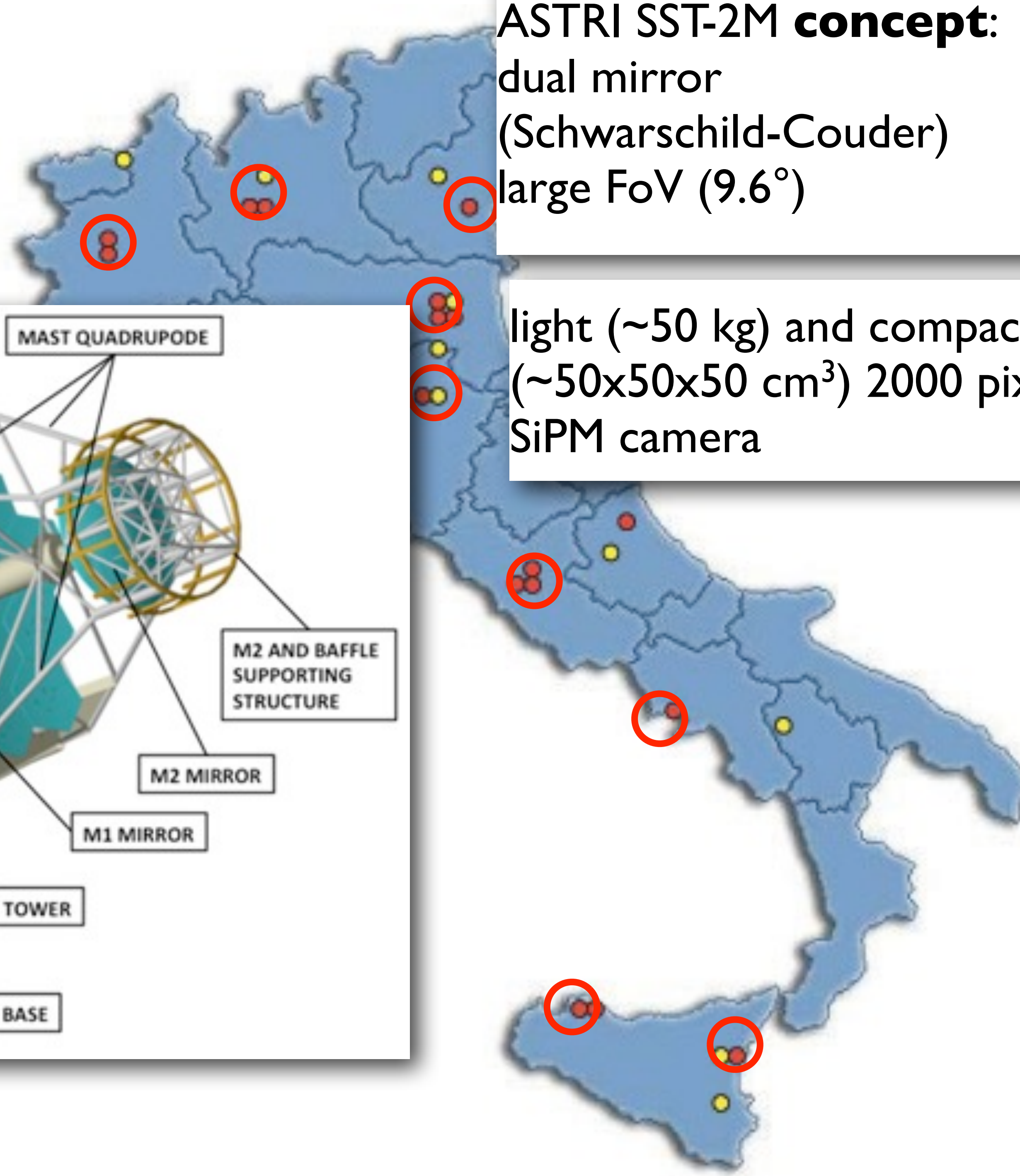

ASTRI SST-2M **concept**:
dual mirror
(Schwarschild-Couder)
large FoV (9.6°)

light (~50 kg) and compact
(~50x50x50 cm^3) 2000 pixel
SiPM camera

The ASTRI project

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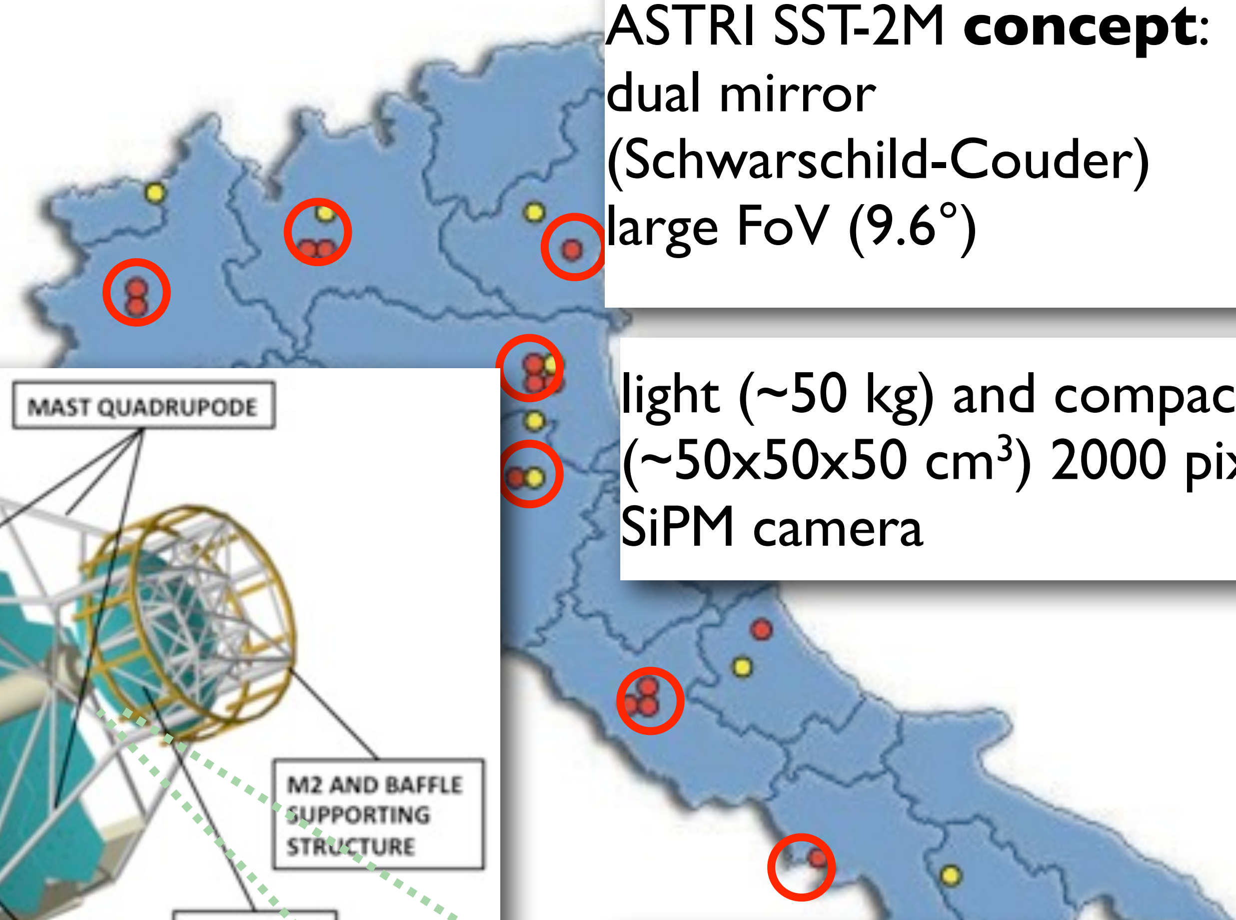

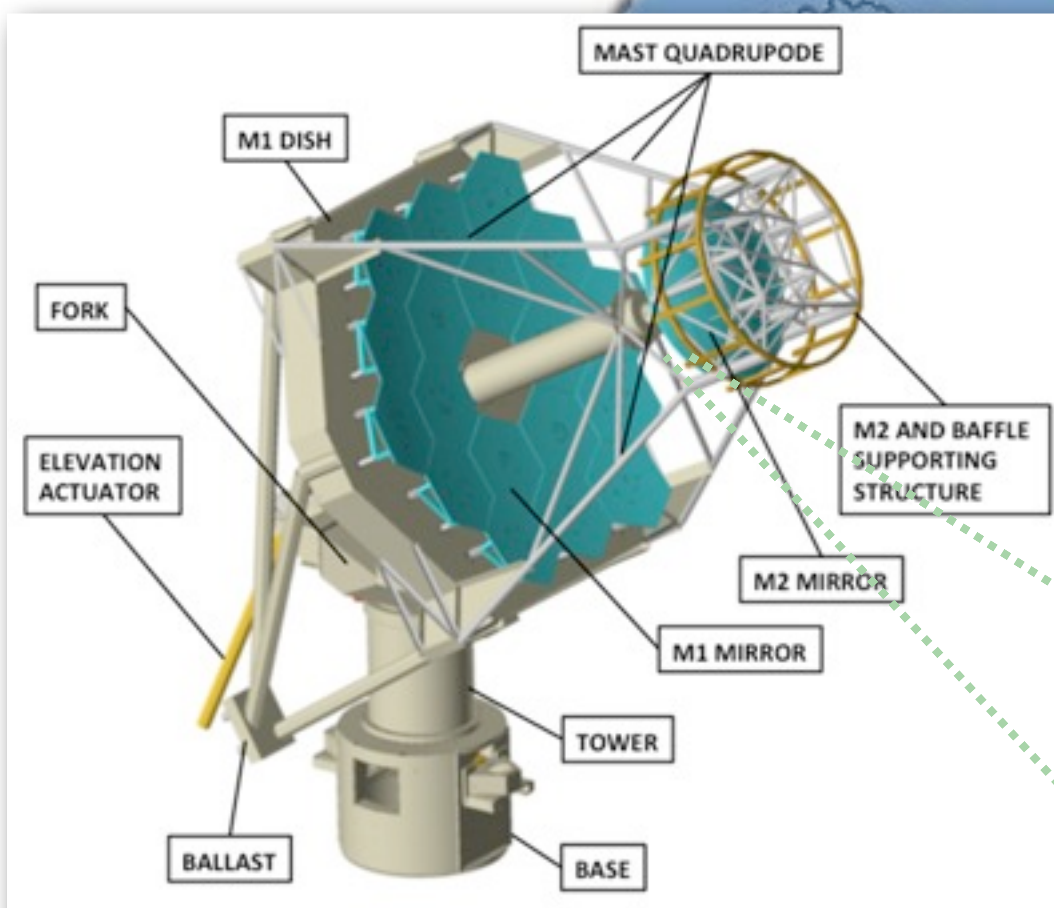

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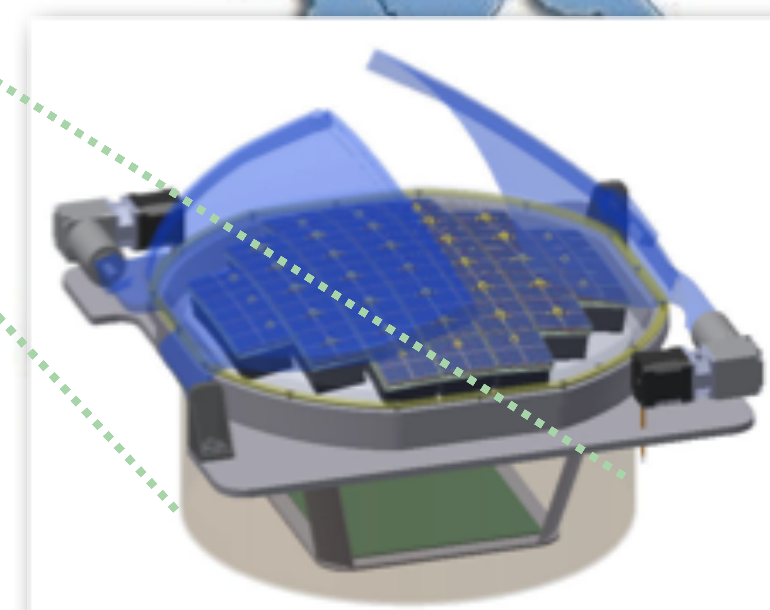


ASTRI site @ Serra La Nave (Mt. Etna)

INAF - Catania Astrophysical Observatory

The "M. G. Fracastoro" Mountain Station - Serra La Nave (Mt. Etna)

Altitude: 1735 m a.s.l.

Longitude: +14° 58'.4; Latitude +37° 41'.5

SVP starting beg. of 2015

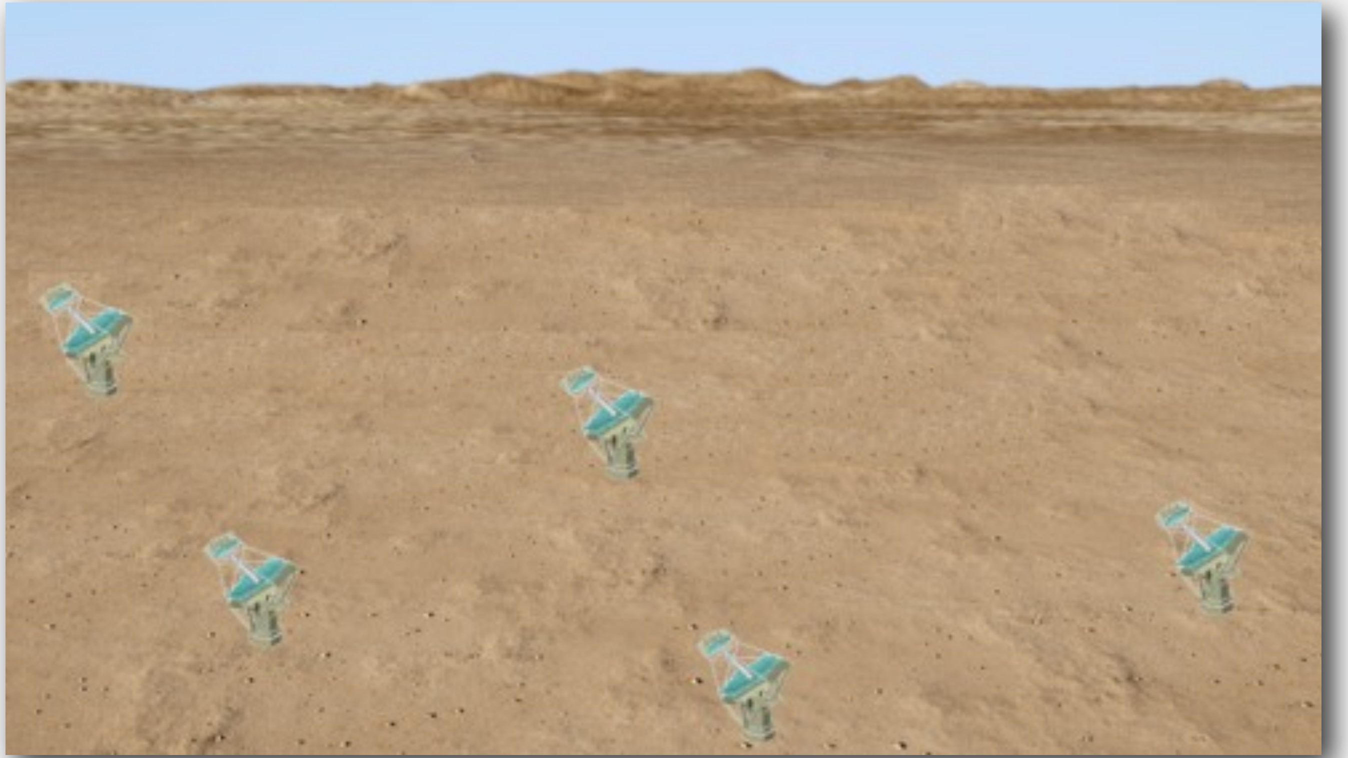
The ASTRI Prototype sensitivity

The ASTRI Prototype is a technological demonstrator, but some science is feasible.

- **Maximum sensitivity : E > 1 TeV (1 Crab @ 5σ in a few hours)**
  - In the range E > 10 TeV : (1 Crab @ 5σ in a few tens of hours)
- **First Crab observations with a SC, SiPM Telescope**
  - Cross-calibrations activities with current IACTs both based on PMTs & G-APDs.
- **Accessible sources from Sicily : Crab, Mkn 421, Mkn 501**
  - Intense flares (~5-**10** Crab, e.g., ATel #4976) could allow detections on a much shorter time-scale. (PKS 2155-304 @ 70° ZA)

The ASTRI/CTA SST Mini-Array:

a first seed of the CTA array already taking up the challenge of TeV science



The ASTRI/CTA mini-array concept

Our goal is the deployment and the operation of a **mini-array composed of seven SST-2M telescopes** at the final CTA southern site.

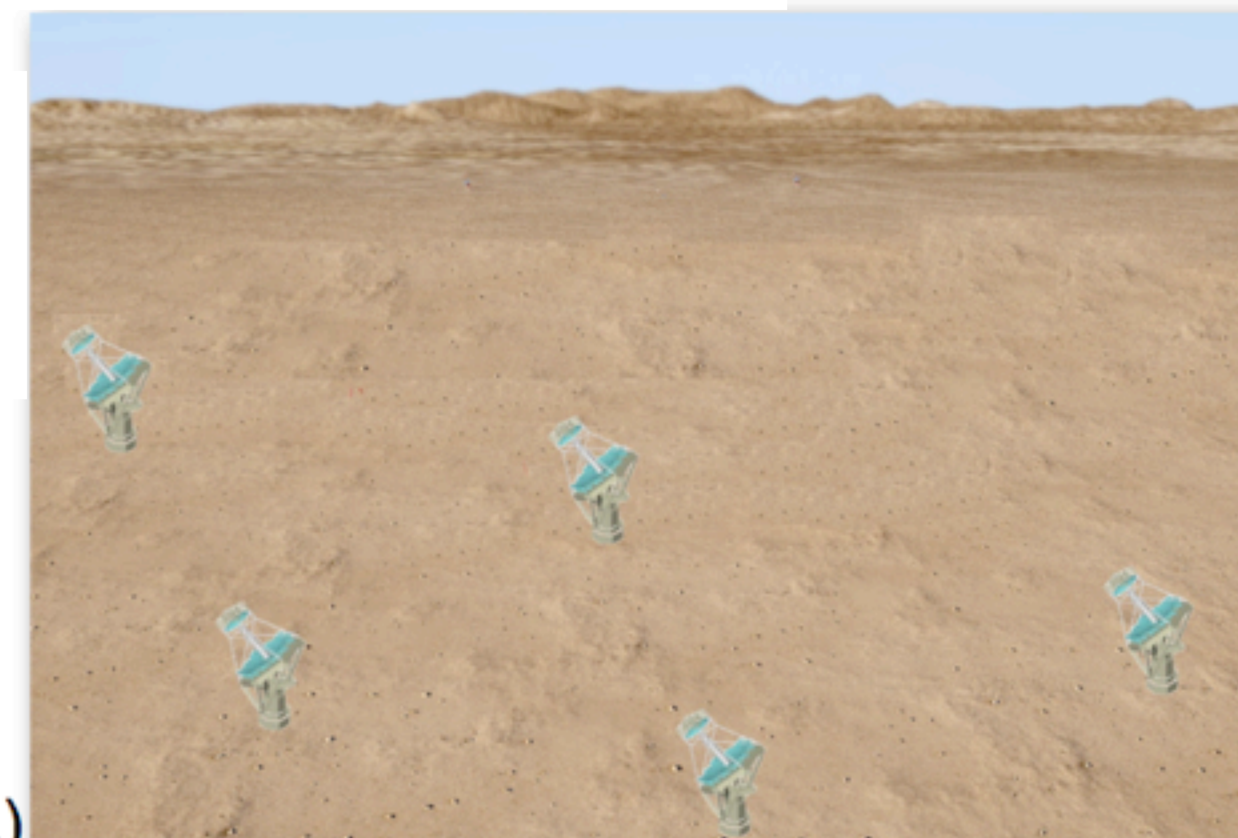
ASTRI /CTA mini array

CTA Southern site should be decided at the end of 2014.

2014 - 2015 ➔ ASTRI/CTA mini-array re-assessment study phase

2016 ➔ ASTRI/CTA mini-array deployment phase

Currently:
- 3 units provided by ASTRI
- 1unit provided by a South African Consortium
- 3 units provided by a Brasilian Consortium (proposal almost accpt.)



The ASTRI/CTA mini-array expectations

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

✓ **check of the array trigger algorithms**

➡ we expect a number O(5-7) of CTA-SSTs will trigger. The ASTRI/CTA mini-array could be the *quanta* of the whole 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

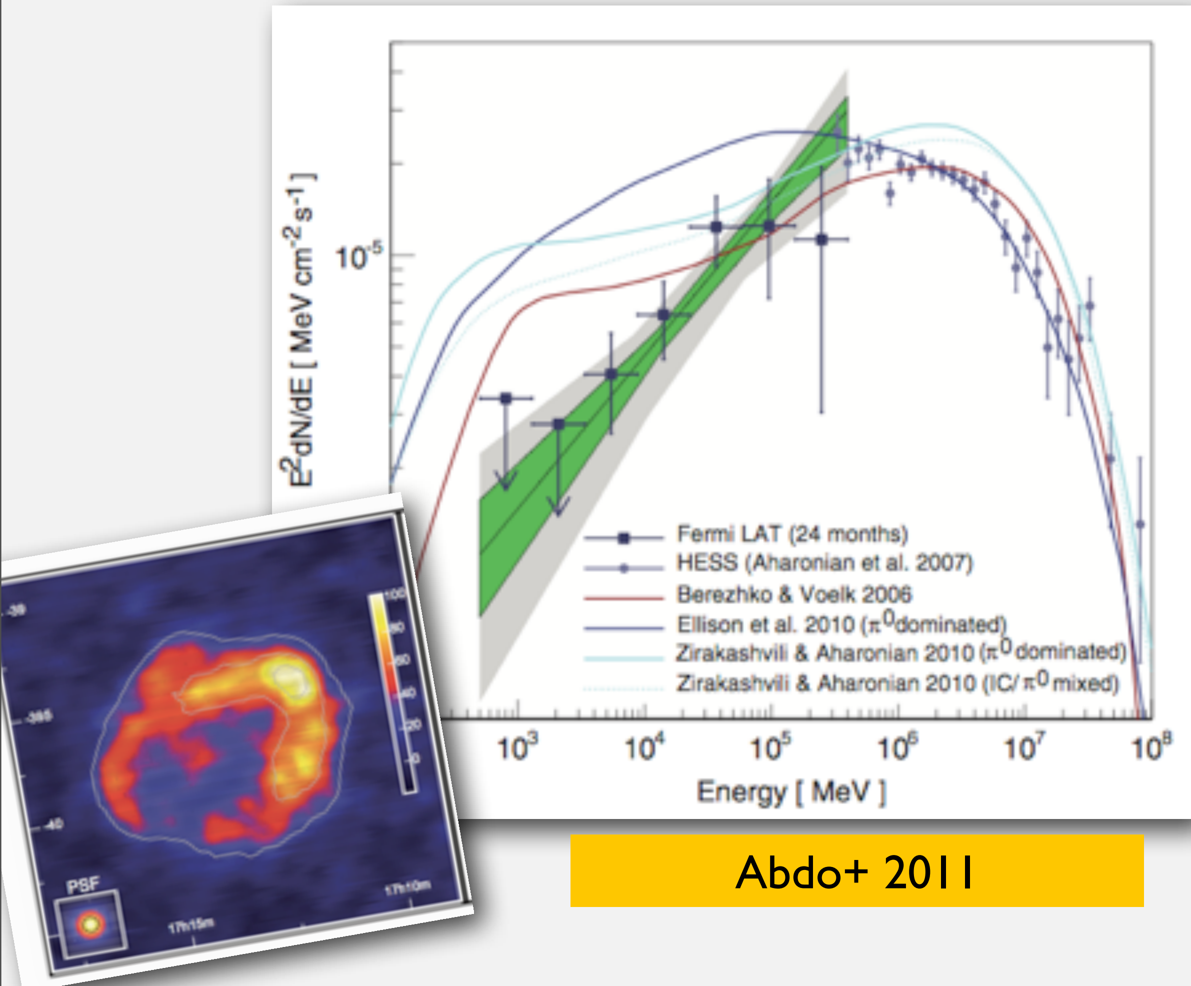
✓ **do the first CTA science**

➡ by means of a **few solid detections** during the first year

Galactic targets

- Supernova Remnants
  - SNRs
  - Pevatrons
  - SNRs interacting with molecular clouds
- PWNe
- Gamma-ray binaries

ASTRI/CTA Mini-Array & SNR



Abdo+ 2011

RX J1713.7−3946: young shell-like SNR

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

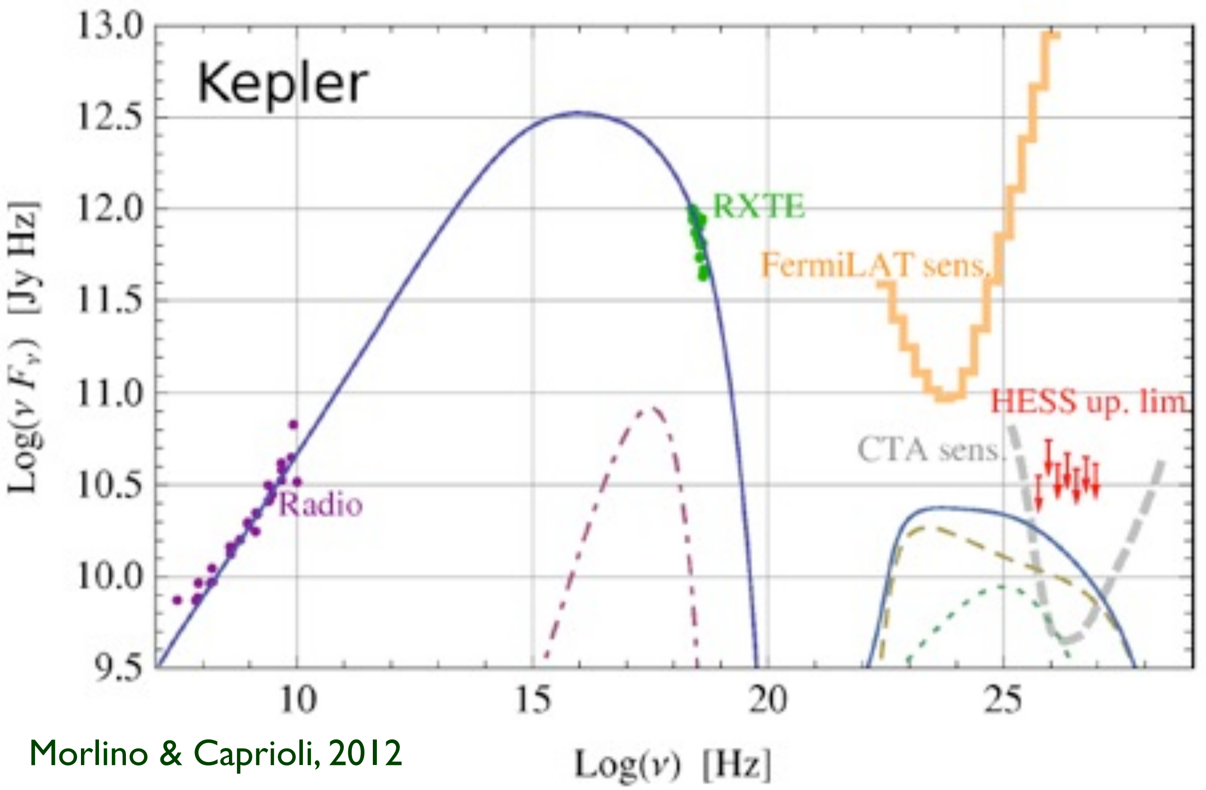
Significant emission (4.8σ) E>30 TeV.

Broadband SED suggests a leptonic scenario.

But....

- ✓ A clumpy circum-stellar medium (CSM) could produce an hadronic spectrum different from a simple spherical model.
- ✓ A detailed comparison between the proton distribution in the CSM and the high-resolution gamma-ray image is therefore a useful test of the hadronic scenario.
- ✓ The improved sensitivity 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.

ASTRI/CTA mini-array & Pevatrons



Morlino & Caprioli, 2012

Tycho SNR would be the best candidate, but it is not accessible from the CTA southern site.

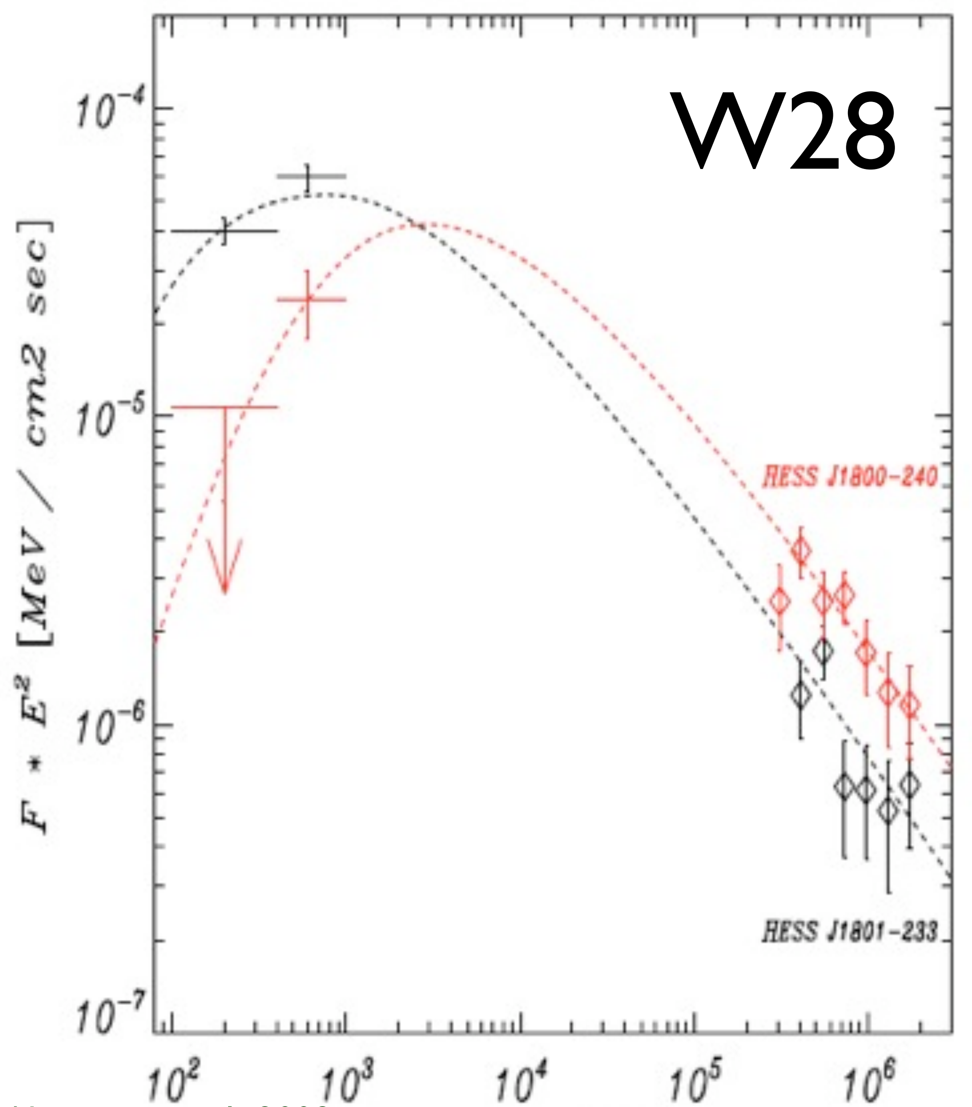
Kepler SNR is very similar w.r.t. Tycho SNR in terms of progenitor, age, radio flux and X-ray emission in thin filaments.

Only upper limits from H.E.S.S. (13 hours): $F_{[0.2-13\ TeV]} < 8.6\times10^{-13}$ 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 detect this young SNR by means of a deep observation (>>50hr), especially if conducted in conjunction with one (or, even better, two) medium size telescope units to be placed at the same CTA southern site, which could expand the energy range below a few TeV.

ASTRI/CTA mini-array & SNR/MC

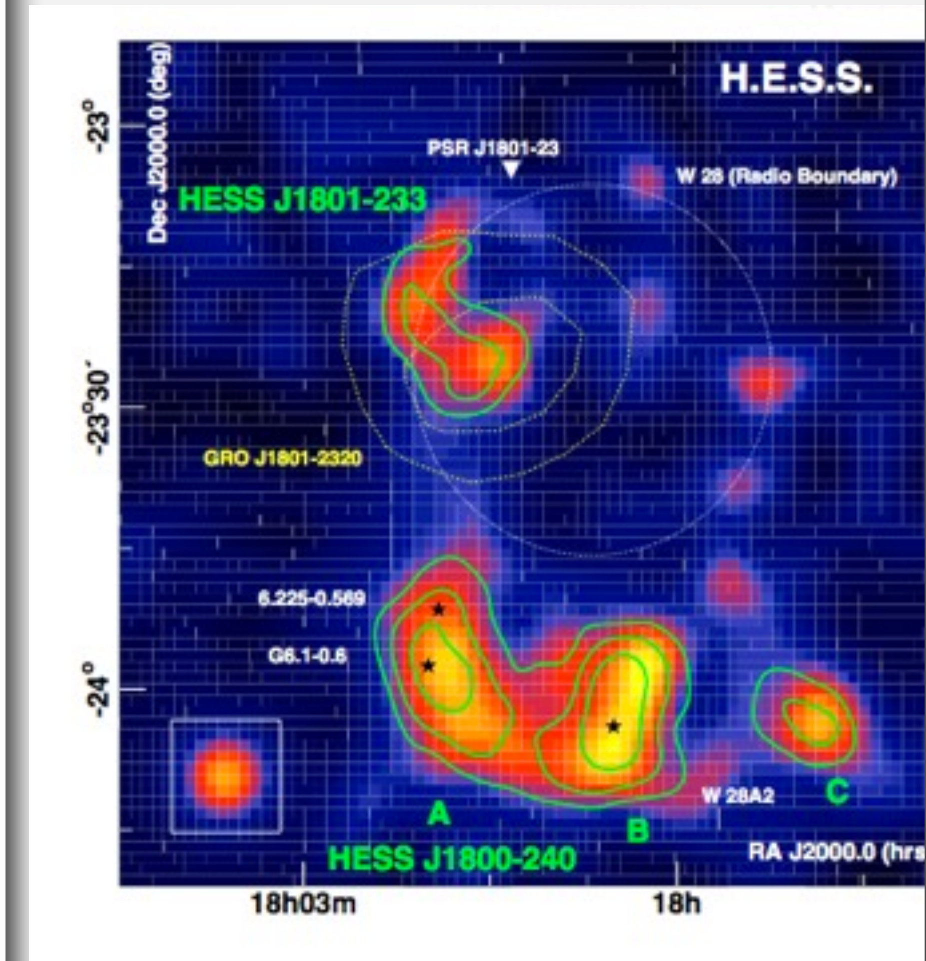


Aharonian et al., 2008
Giuliani et al., 2010

Middle-age SNRs interacting with Molecular Clouds (MC).

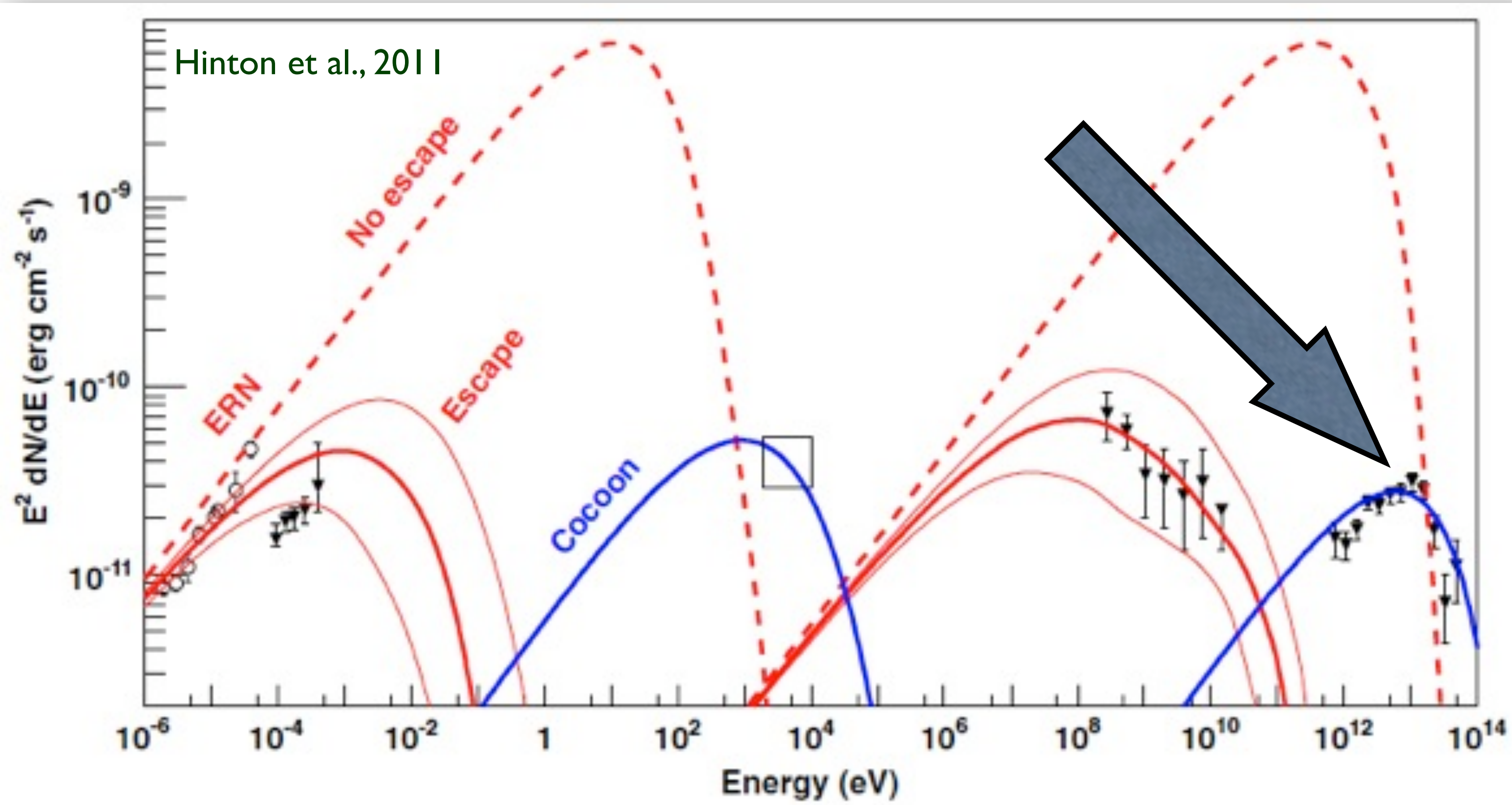
Several accessible by the ASTRI/CTA mini-array: W28, W30, W51...

More intense emission in the GeV energy range rather than in the TeV one.



- ✓ These sources can be observed by the ASTRI/CTA mini-array with better spatial and energy resolution than what has been done before.
- ✓ Such systems can provide useful information on how particles escape from the remnant and propagate in their vicinity. Excellent synergy with Fermi/LAT

ASTRI/CTA mini-array & PWN

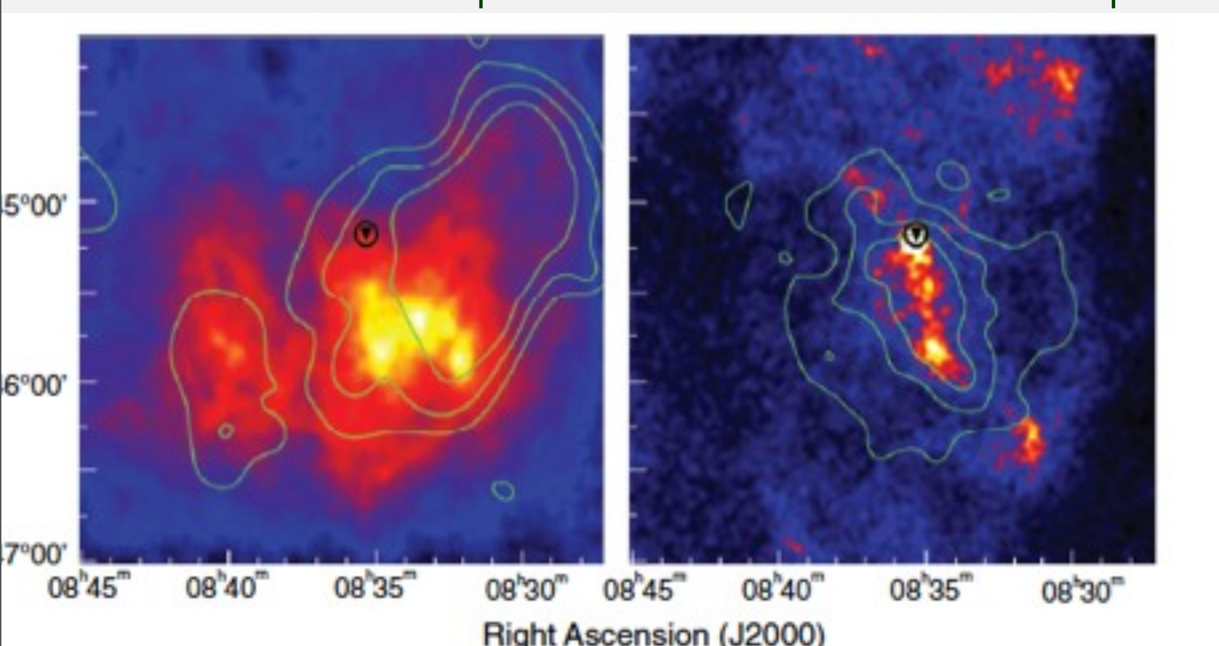


PWN are excellent candidates for the study of particle acceleration and cooling in relativistic shocks.

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.

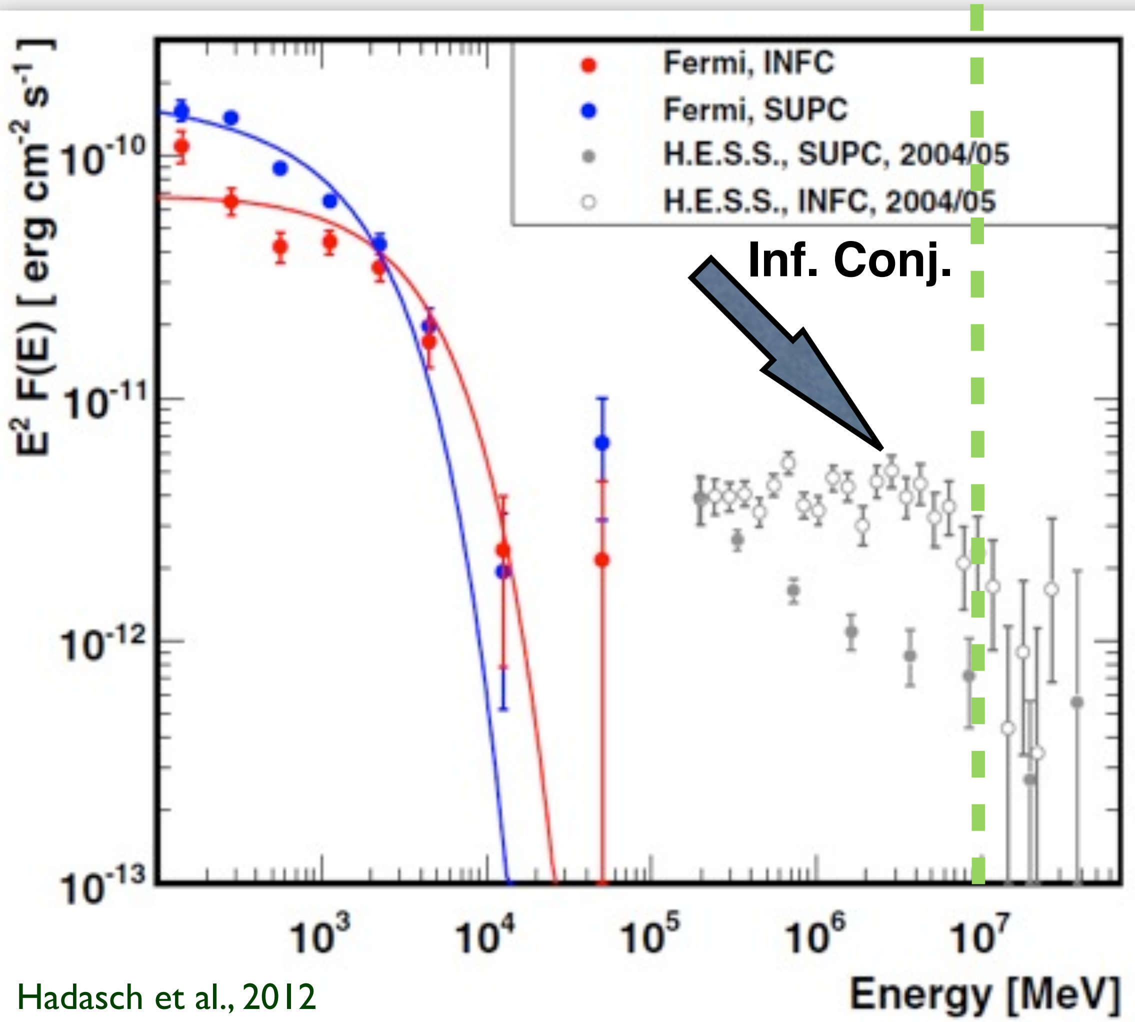
HESS J1825-137 is smaller (~0.2 deg), dimmer, and shows such a spectral softening.

LAT contours on VLA map   HESS contours on ROSAT map



- ✓ Vela-X: VHE spectral maximum at ≈10 TeV.
- ✓ ASTRI/CTA mini-array observations could provide stronger constraints on the maximum energy achievable by the relativistic particles at the termination shock

ASTRI/CTA mini-array & γ-ray binaries



Hadasch et al., 2012

LS 5039: HMXRB in a moderately eccentric orbit around a massive O-type star.

Orbital period is 3.9 days.

We observe high energy emission modulation at 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 mini-array could investigate the spectrum of the observed TeV photons at different orbital phases, providing useful constraints on the gamma-ray emission and absorption.

Extra-galactic targets

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

- Less-beamed AGNs
  - Radio-galaxies
  - Starburst galaxies

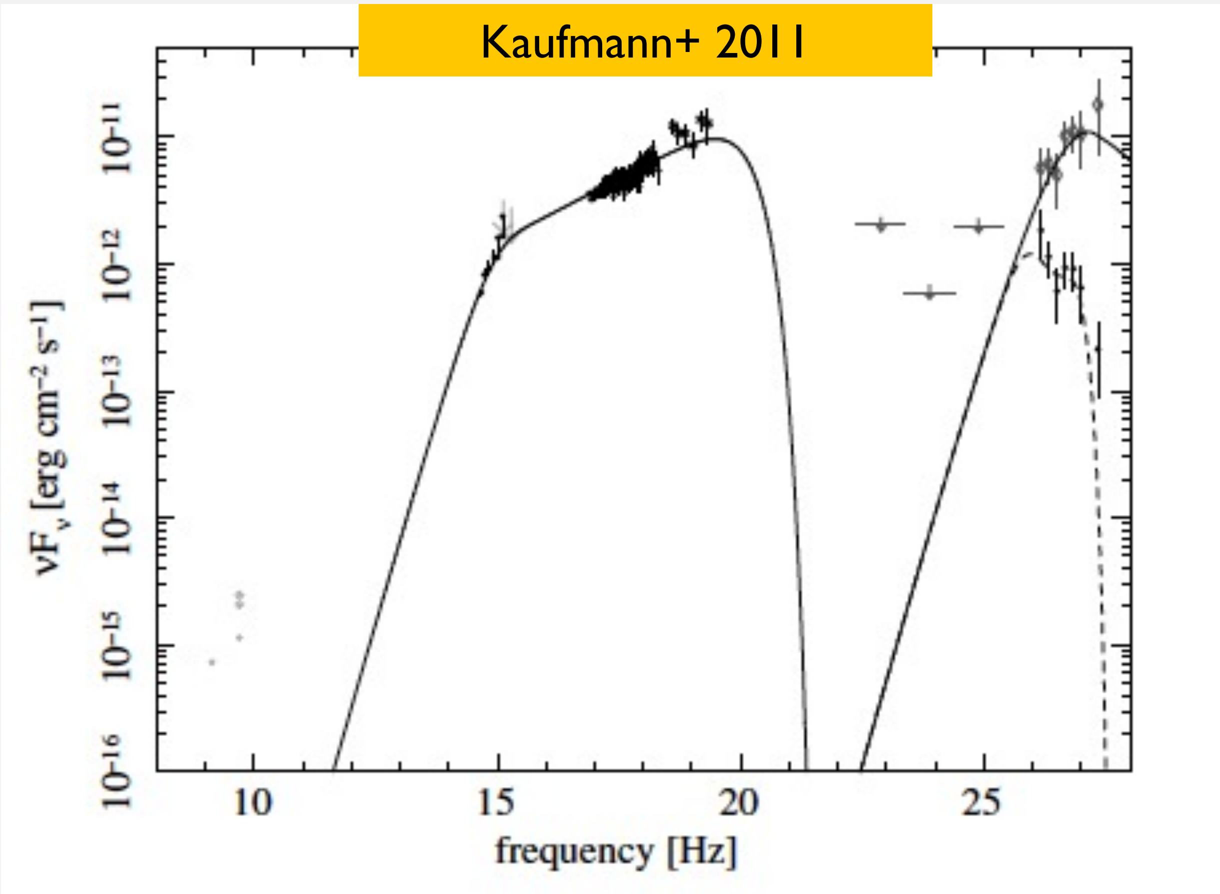
The archetypal EHBL: 1ES 0229+200

- BL Lac @ z= 0.14
- Hardly detected in HE gamma
- Detected by all current TeV instruments (HESS first)
- Synchrotron peak at few keV, low compton dominance, IC peaks at many TeV at the origin
- in SSC frame, evidence for high lower edge of electron energy distribution

Katarzynski+2006, Tavecchio+ 2009

- Deabsorbed IC peaks at multi TEV
- TeV beacon-probe for EBL and anomalies in opacity, UHECR beams
- TeV beacon-probe for IGMF

Neronov 2010
Tavecchio+ 2010



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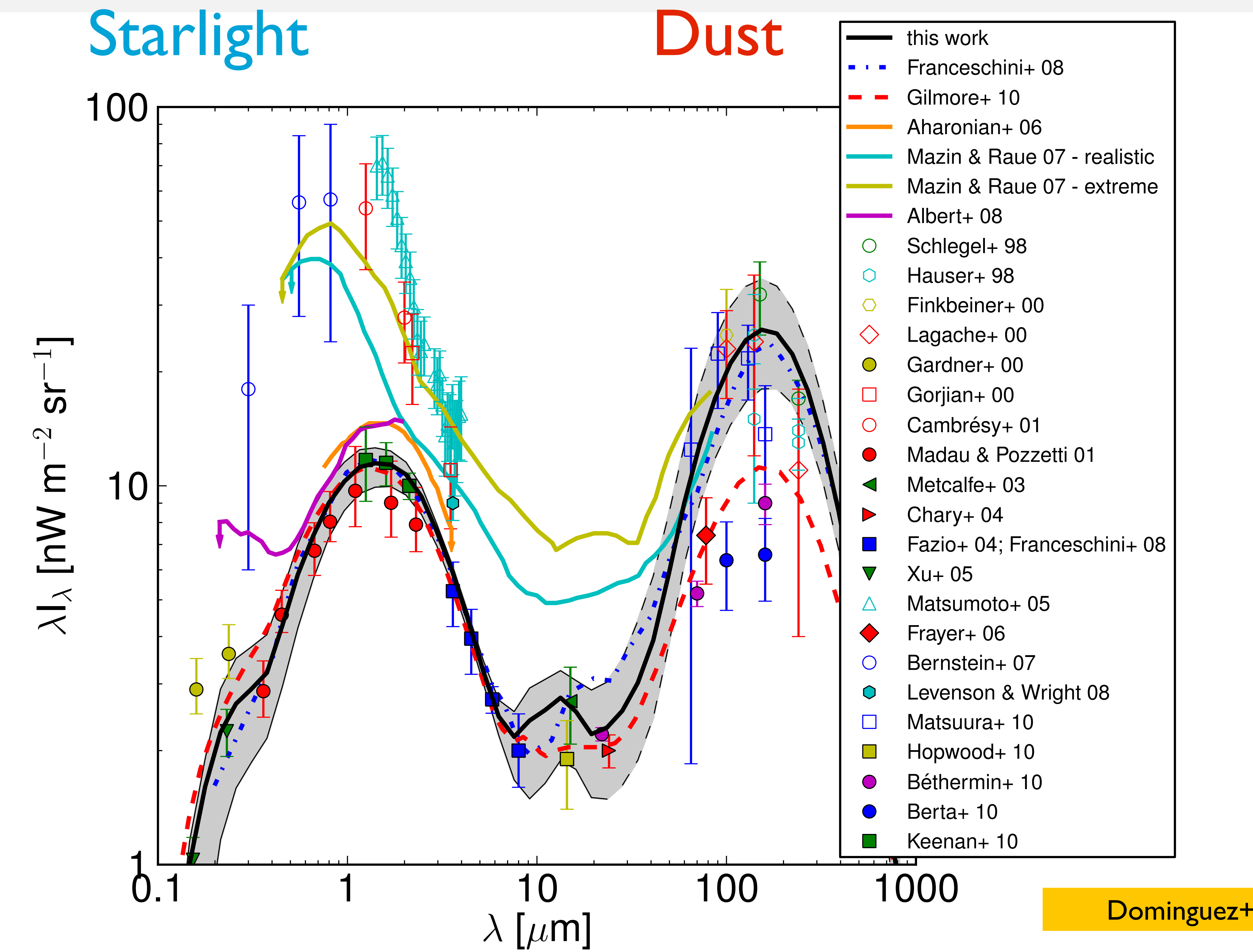
Why are EHBLs so interesting?

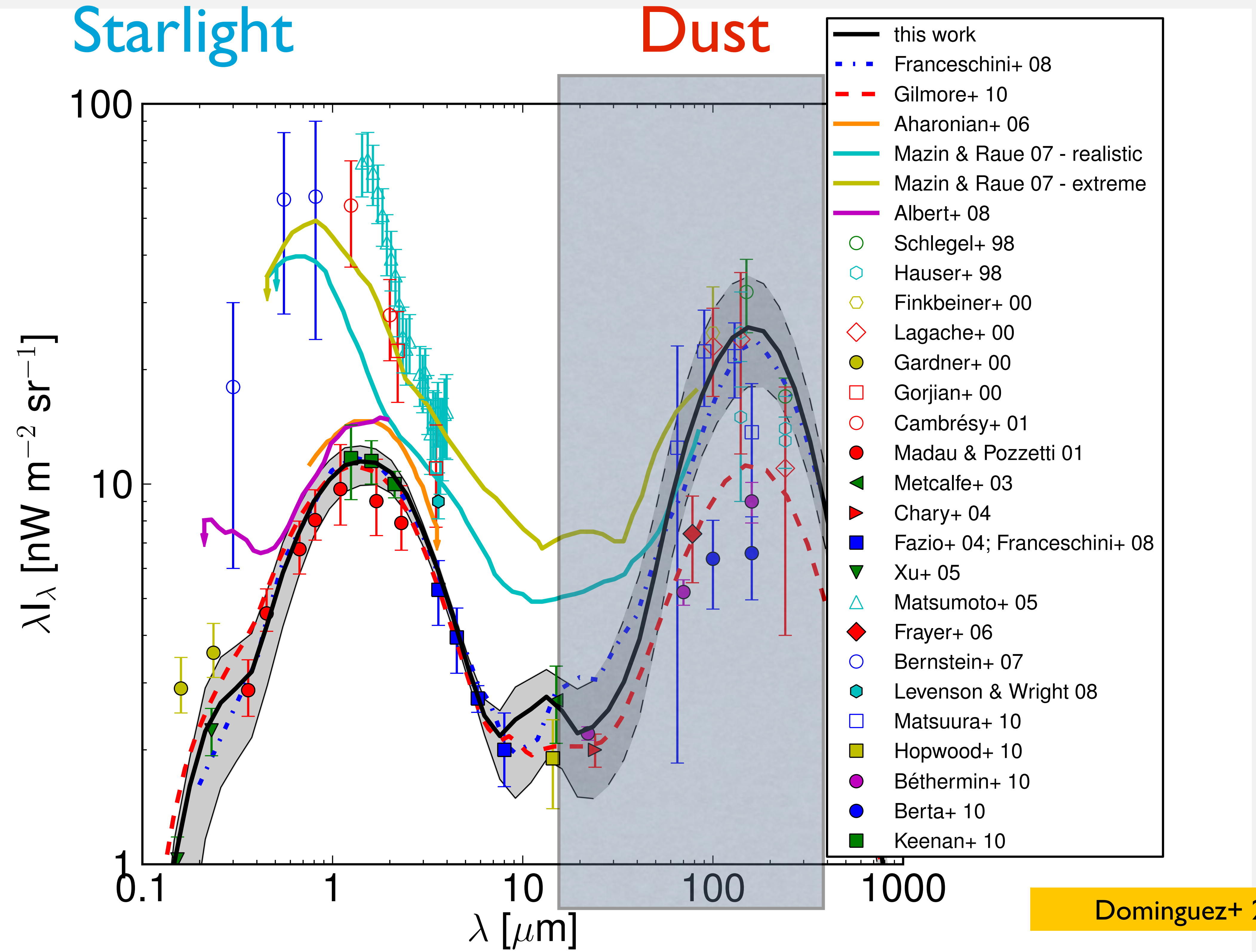
- Jet mechanism (high minimum el. energy assuming SSC) — Katarzynski+2006, Tavecchio+ 2009
- far-IR EBL-probes — Franceschini+ 2008, Dominguez+ 2011
- Anomalies in EBL opacity:
  - ALPs — Roncadelli+ 2007, Tavecchio+ 2012
  - Hadron beams — Essey & Kusenko 2010, Dermer+ 2012, Murase+ 2012
  - LIV — Fairbairn+ 2014, http://arxiv.org/abs/1401.8178
- parent population? “FR0” — Baldi & Capetti 2009
- HE gamma-ray background — Inoue & Ioka 2012. Bonnoli+ in prep
- IGMF probes — Neronov 2010, Tavecchio+ 2010

EHBLs as far-IR EBL beacon probes



Dominguez+ 2011

EHBLs as far-IR EBL beacon probes



Dominguez+ 2011

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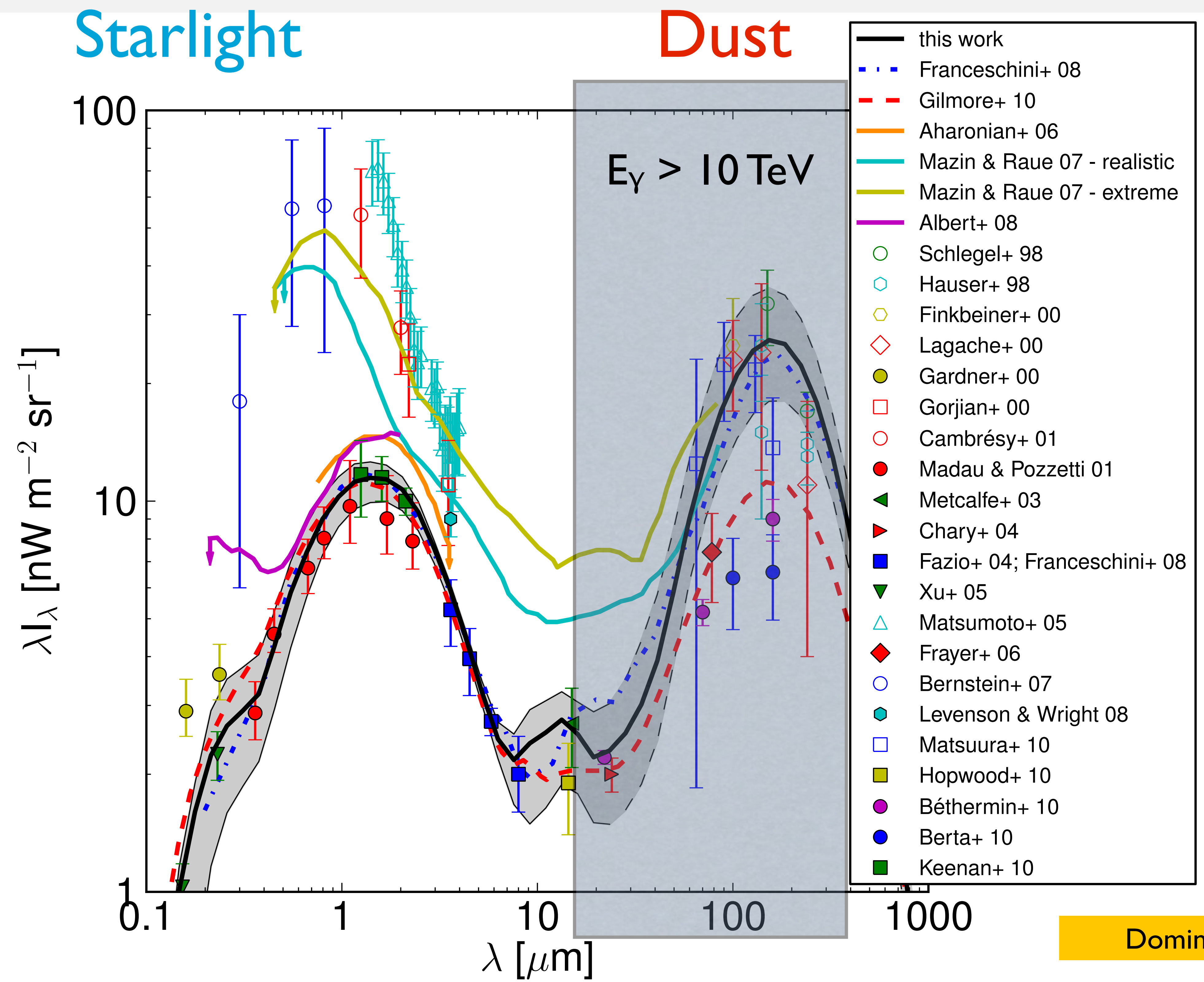
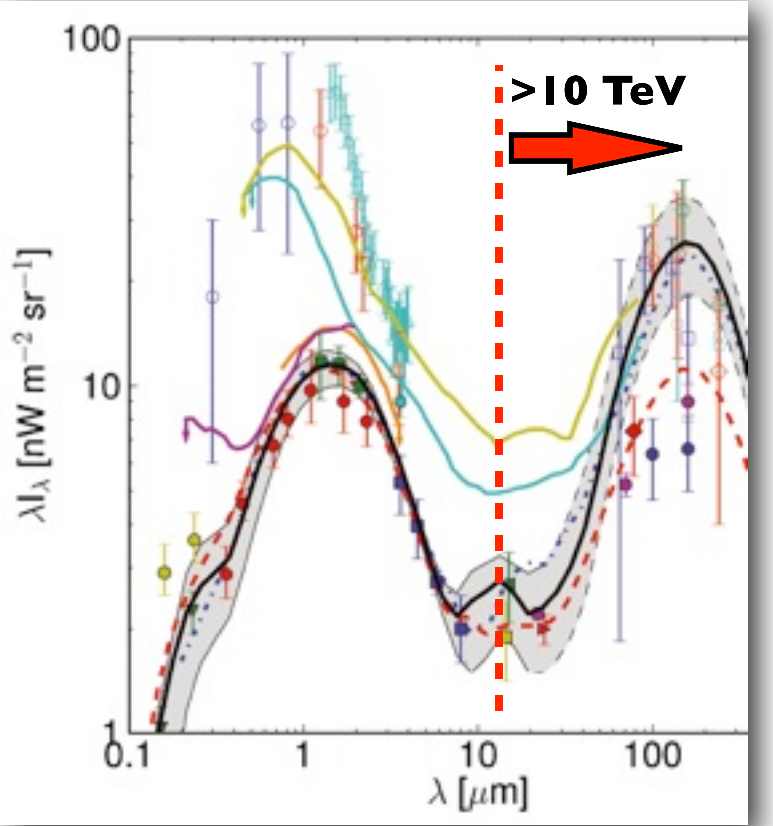


Dominguez+ 2011

ASTRI/CTA Mini-Array & FIR EBL

$\lambda_{max} = 1.24 \mu m (E/TeV)$

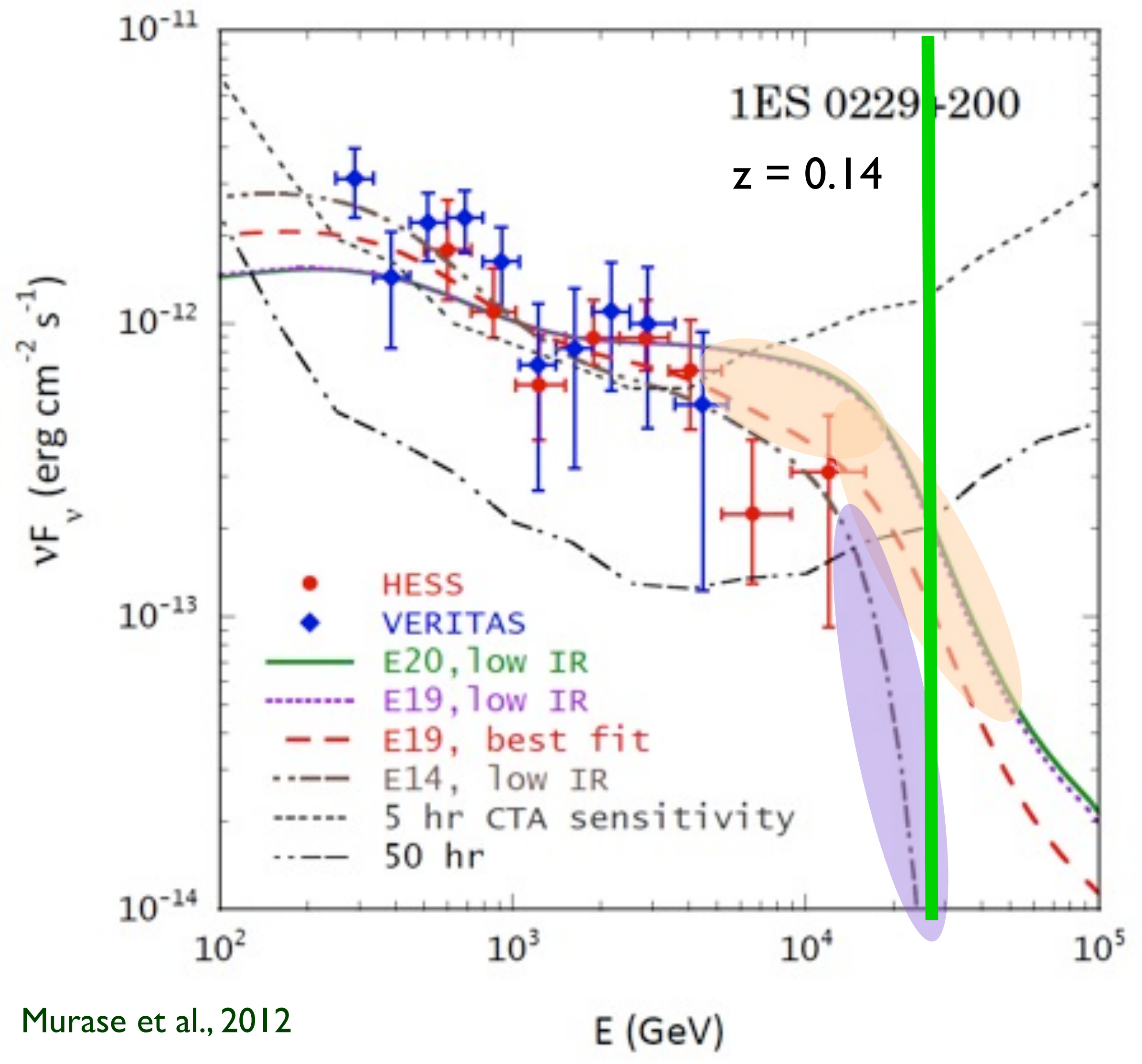


EBL studies with the ASTRI/CTA Mini-Array are ***difficult*** → only a few very close blazars can be used.

IR component: not well investigated up to now.

- ✓ Possible candidates should be nearby, hard, intense blazars. Among those observable form the Southern Hemisphere, we can consider MKN 421 (z = 0.03) and possibly M 87 (z = 0.0043), the latter one being less intense than the former.
- ✓ MKN 421 and M 87 will be observable from the CTA southern site at high zenith-angles, requiring ad-hoc Monte Carlo simulations in order to fully study their VHE properties.

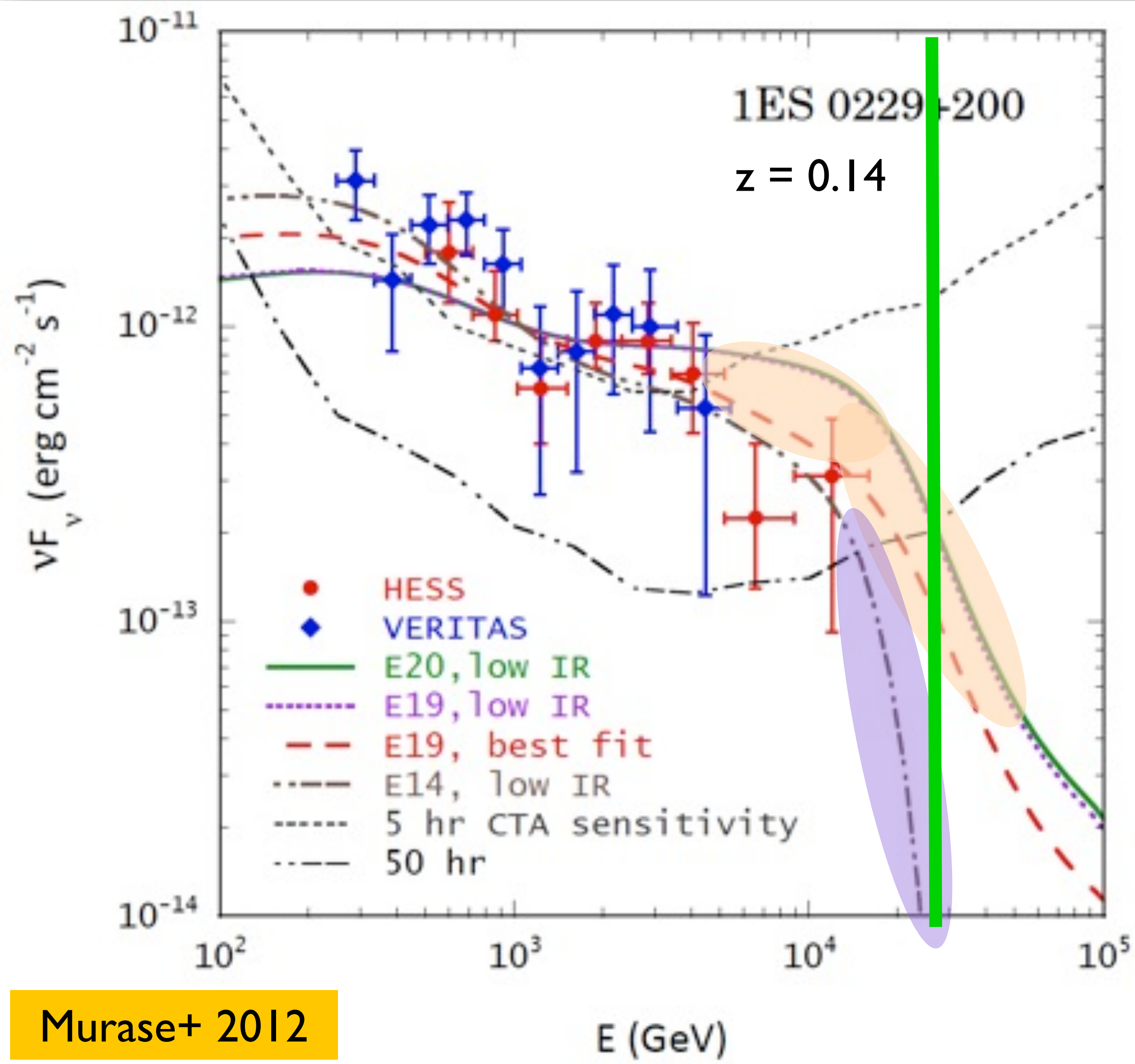
ASTRI/CTA mini-array & E-HBL



✓ 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.

UHECR beams



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.

Other good candidate: KUV 00311-1938 (z=0.61)

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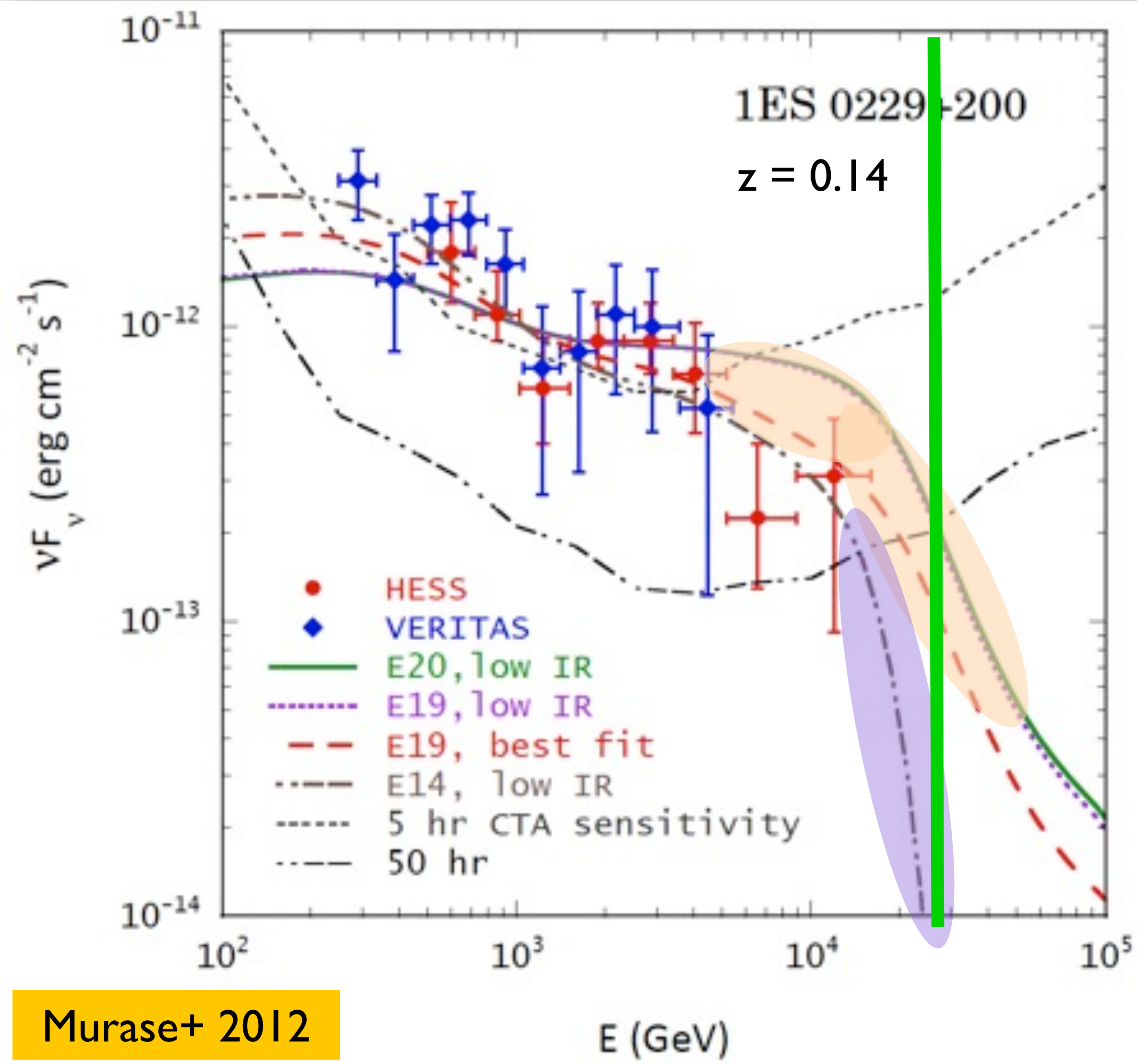

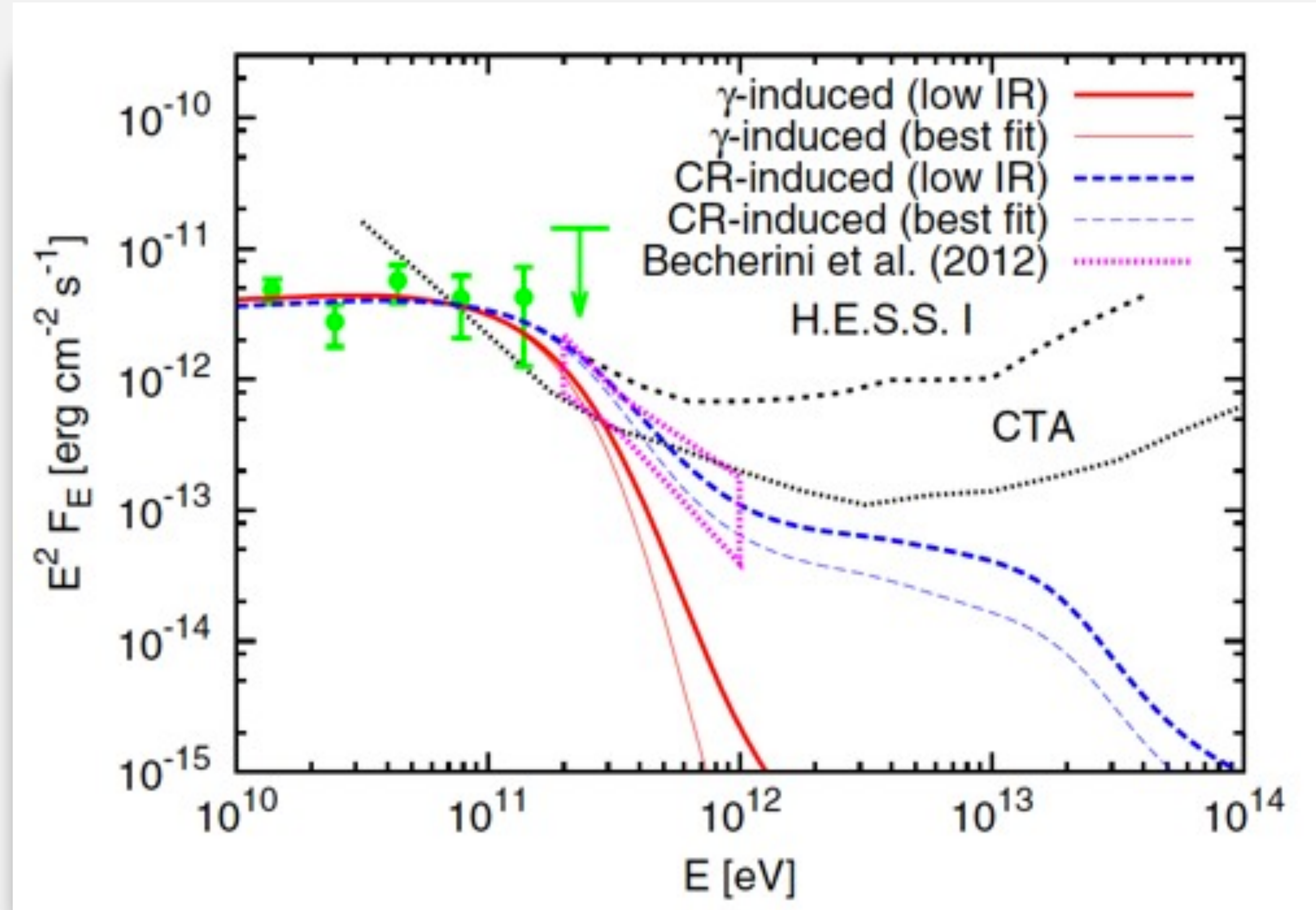

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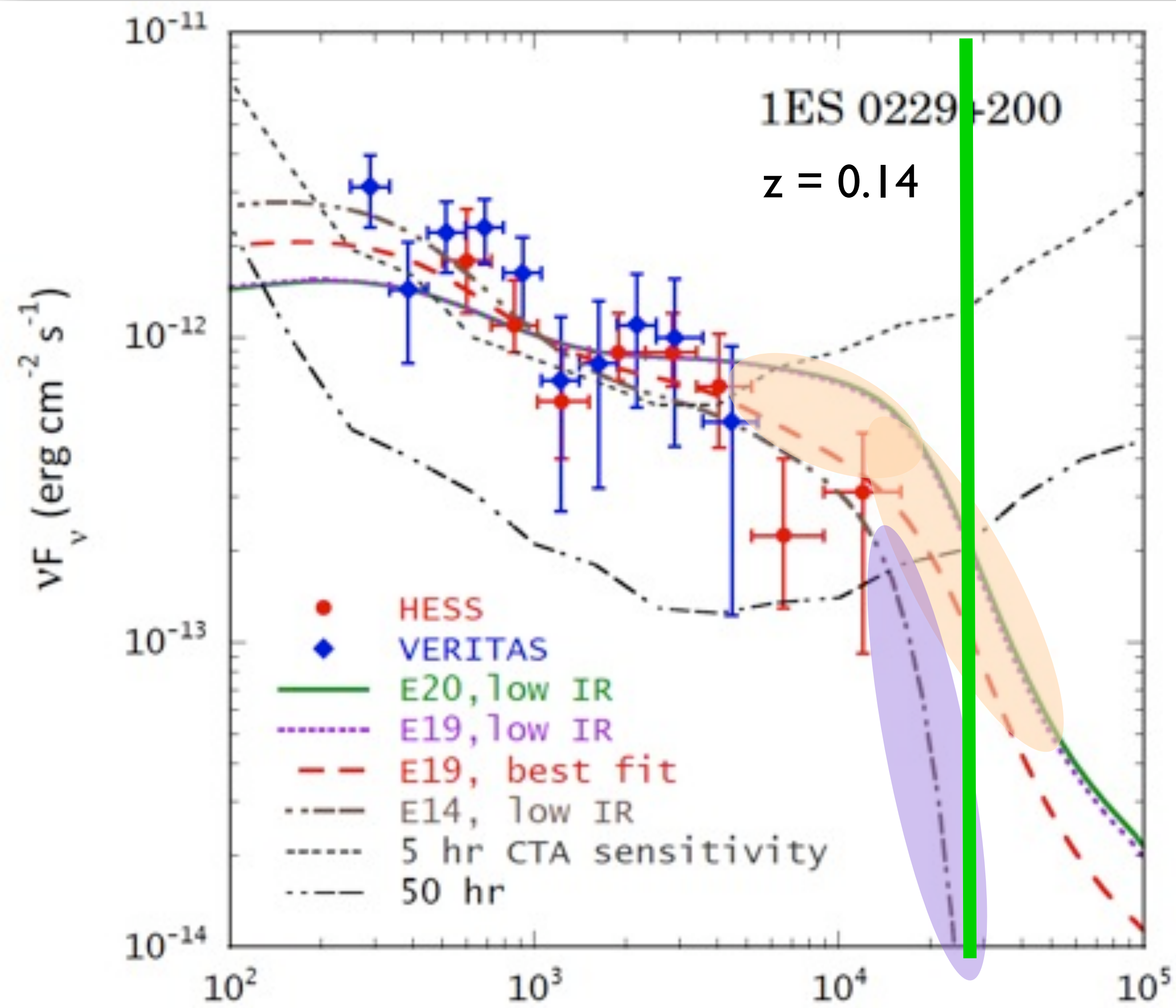
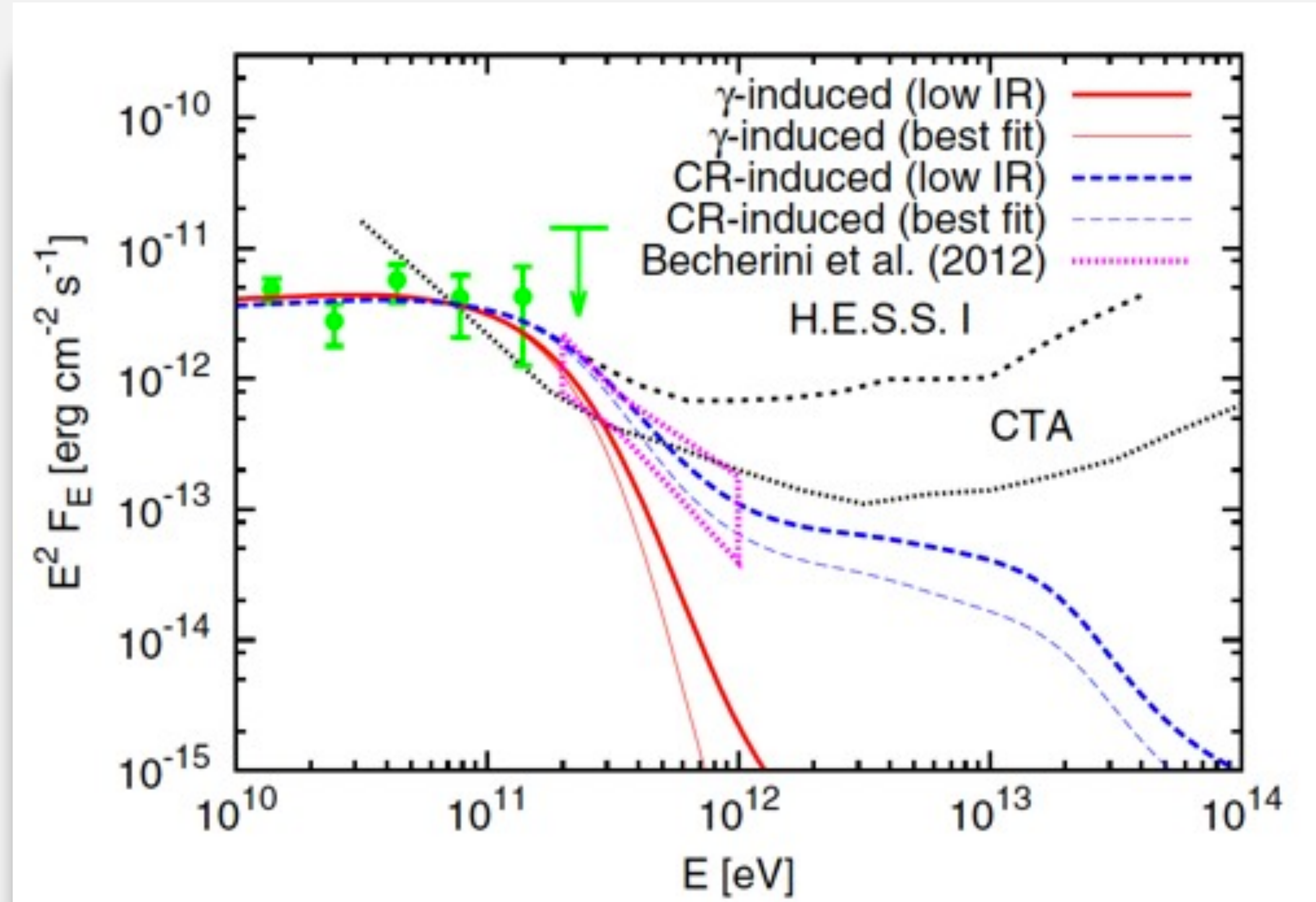


Murase+ 2012



Takami+ 2013

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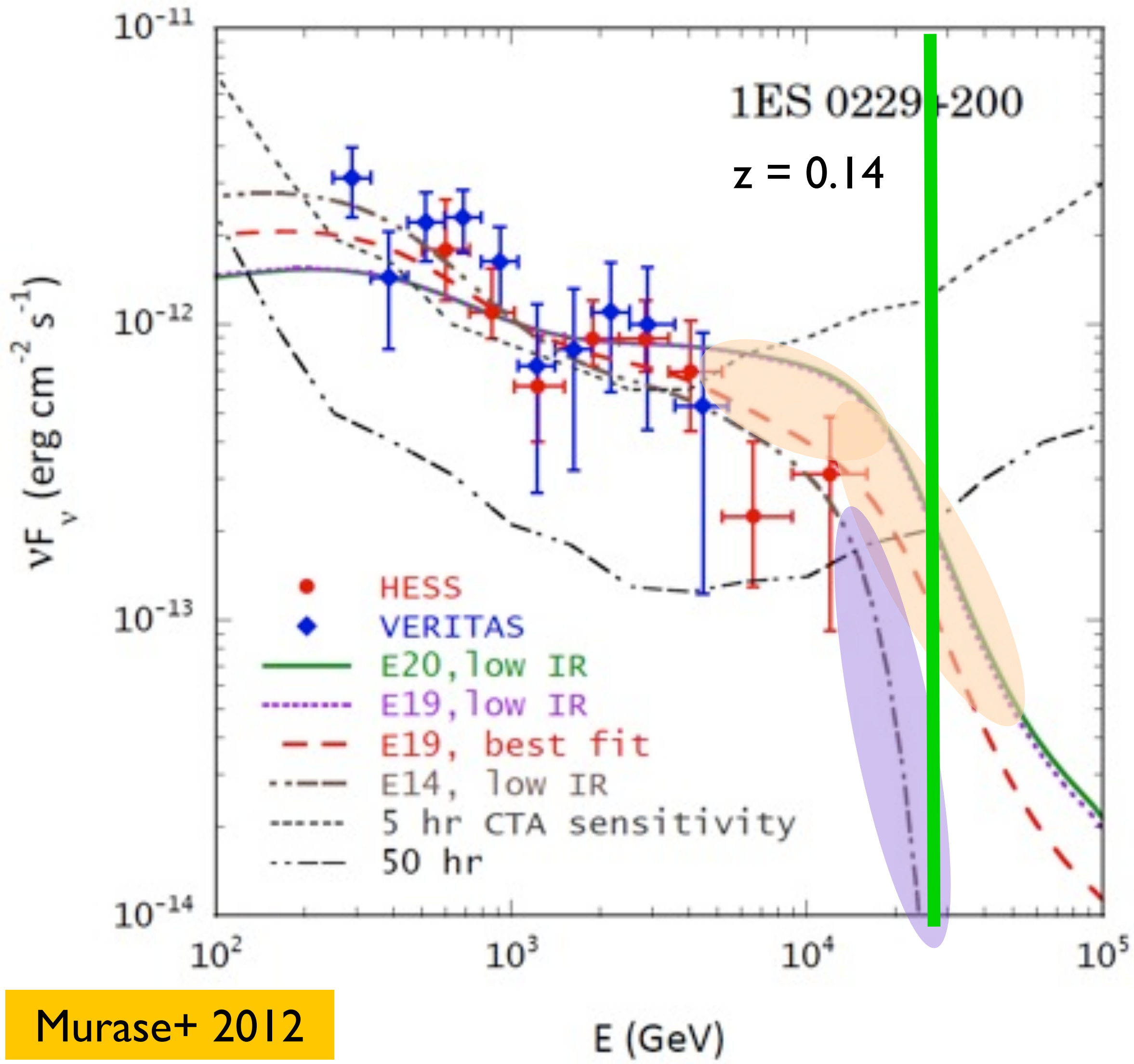
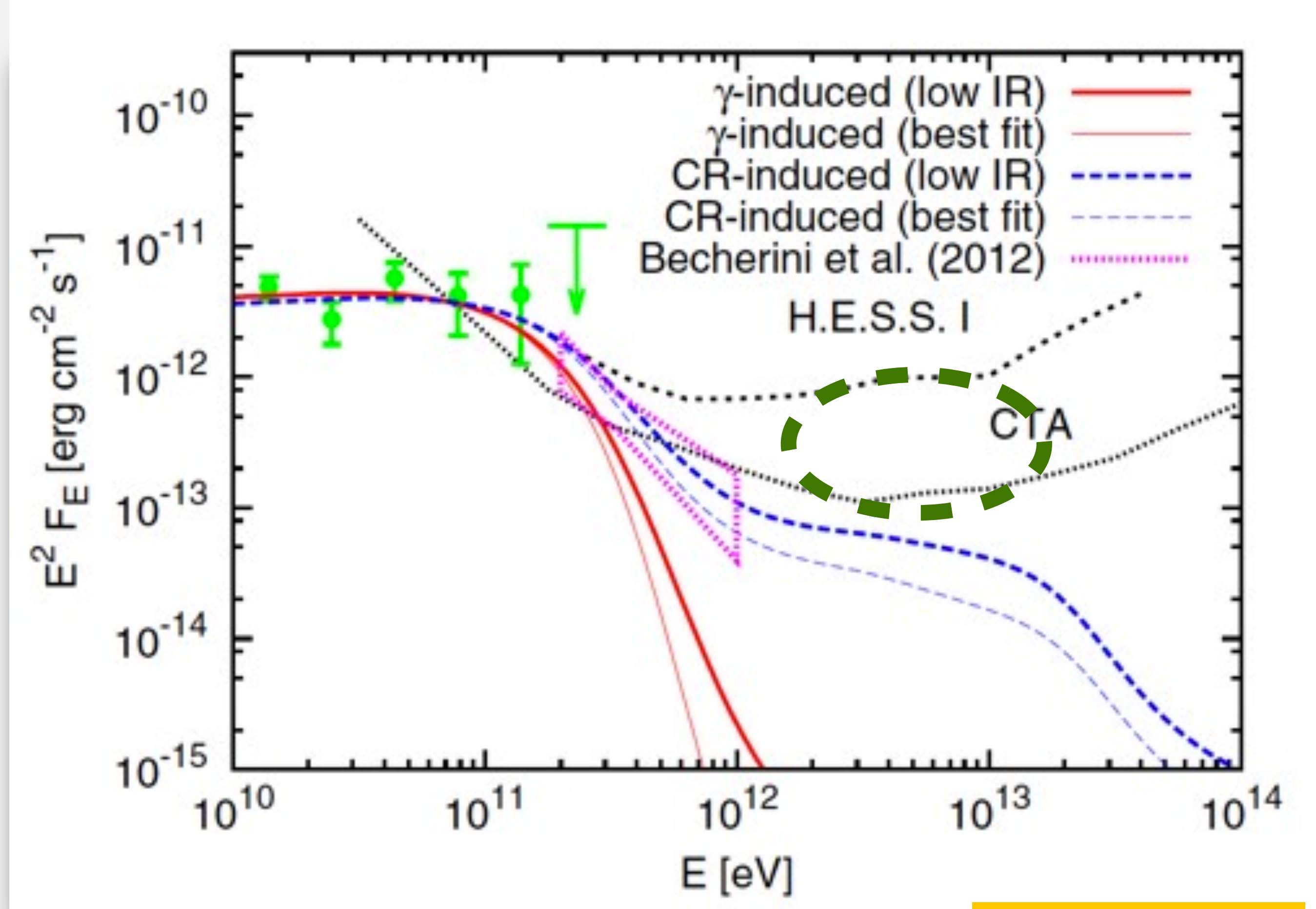
✓ A detection of >25 TeV γ-rays from 1ES 0229+200 is only compatible if the γ-rays are hadronic in origin. Very deep ASTRI/CTA mini-array observation are required.

UHECR beams



Murase+ 2012



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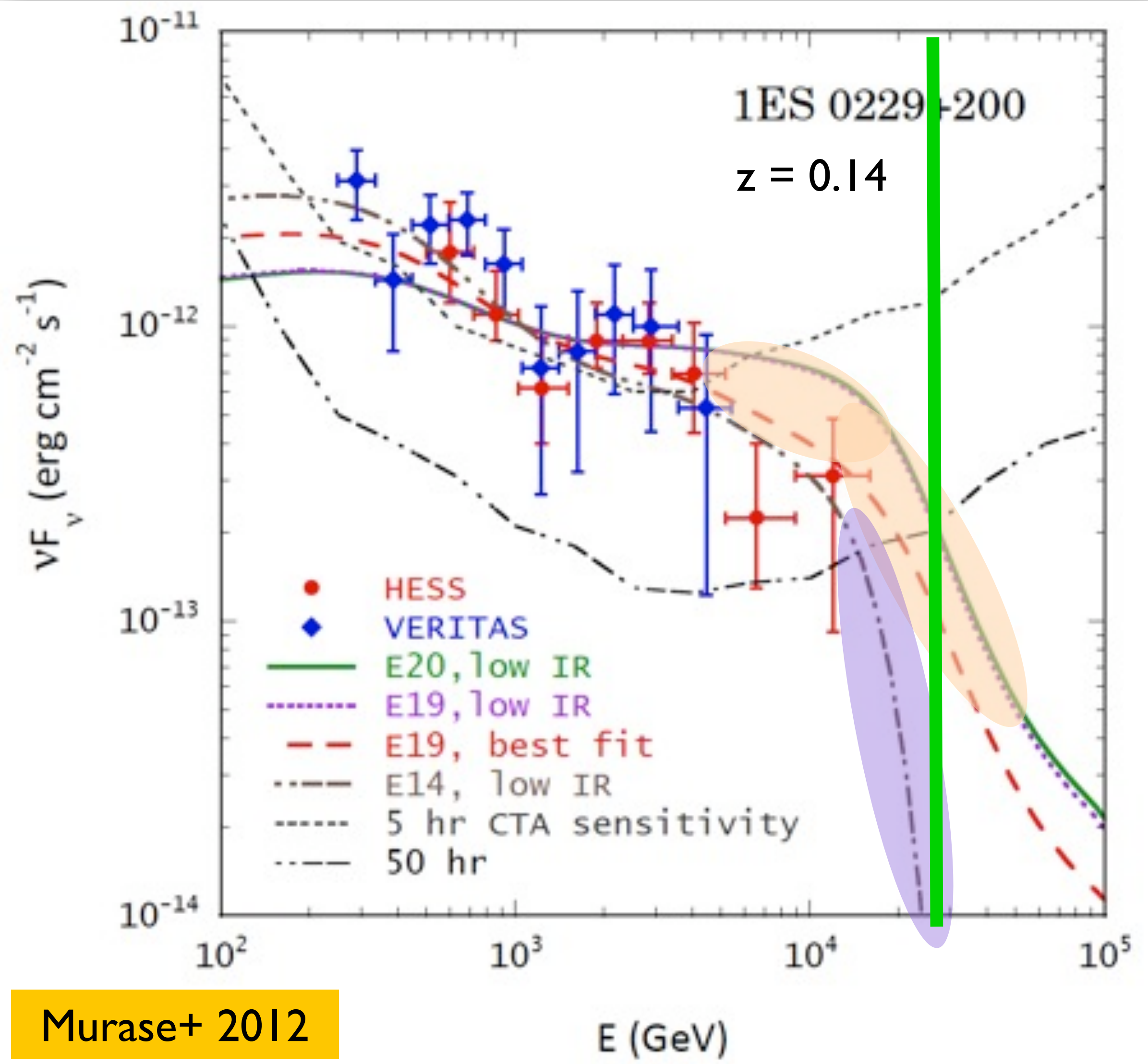
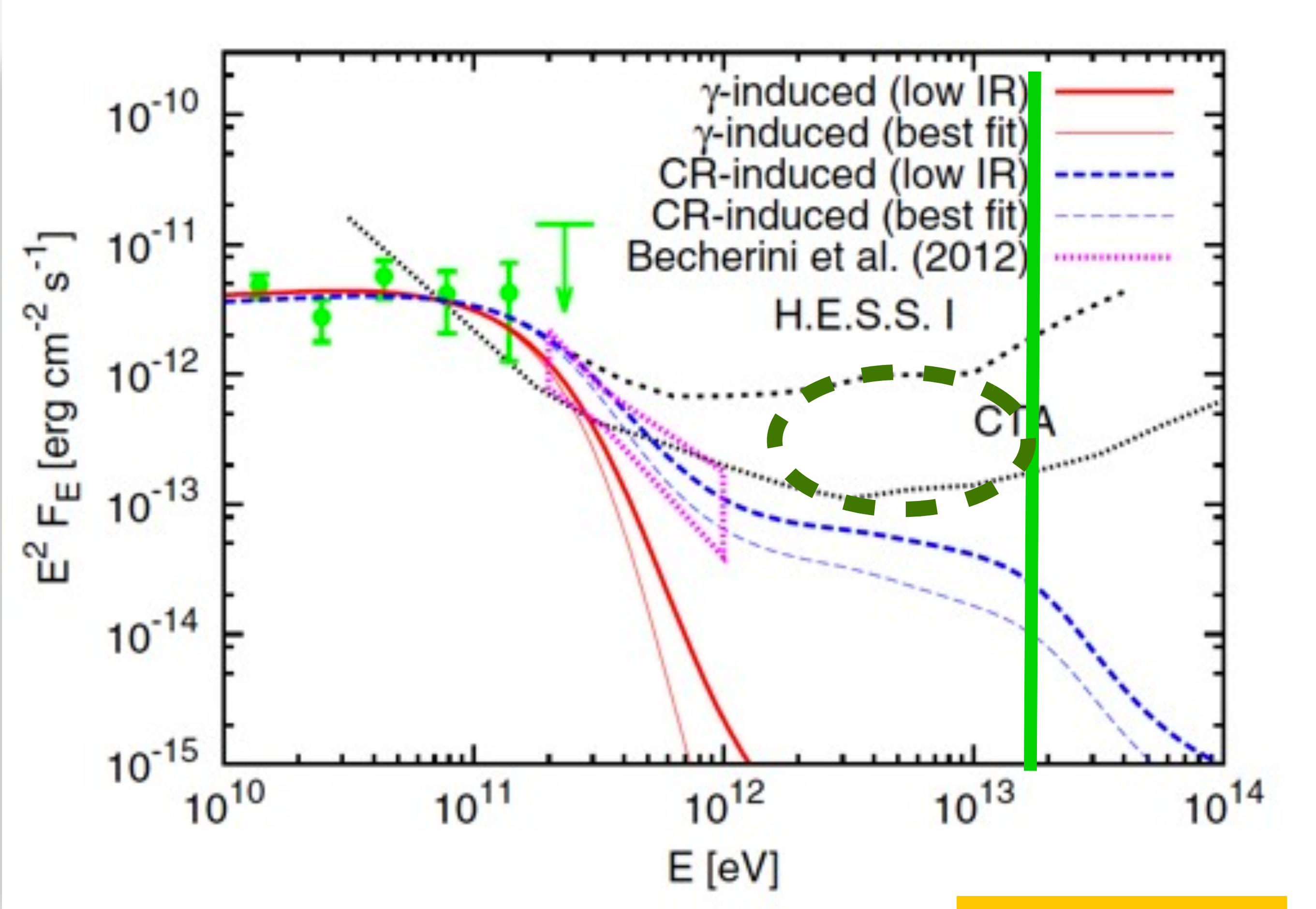


Murase+ 2012



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LIV and anomalies in EBL opacity

ASTRI Mini-Array

Mrk 501

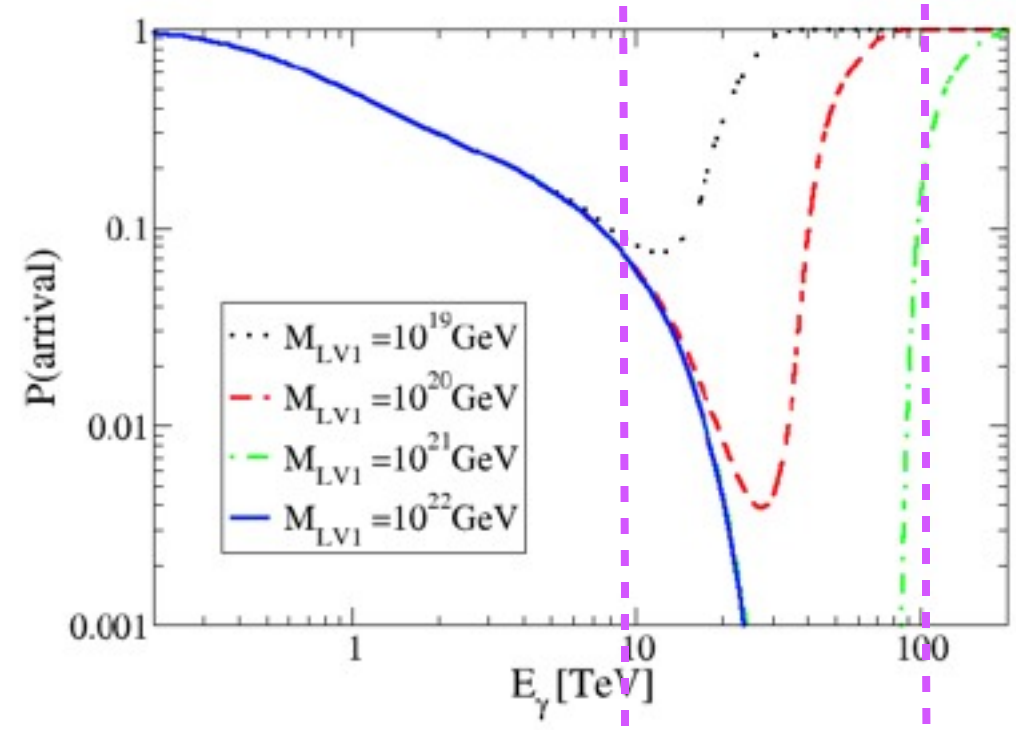
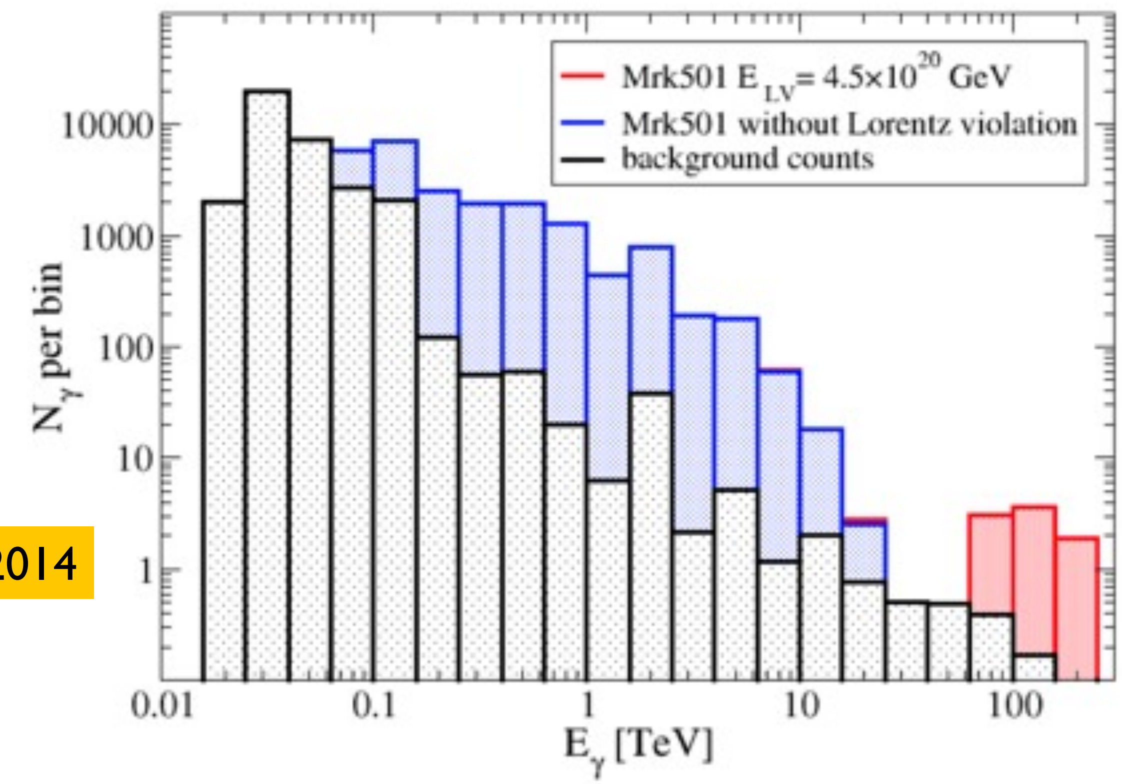


Figure 2. *The arrival probability of a photon emitted from a hypothetical source at redshift $z = 0.05$ as a function of energy. The different curves represent different values of the Lorentz-violating scale M_{LV1}. VHE photons with energies $\gtrsim 100$ TeV can travel through the CMB effectively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

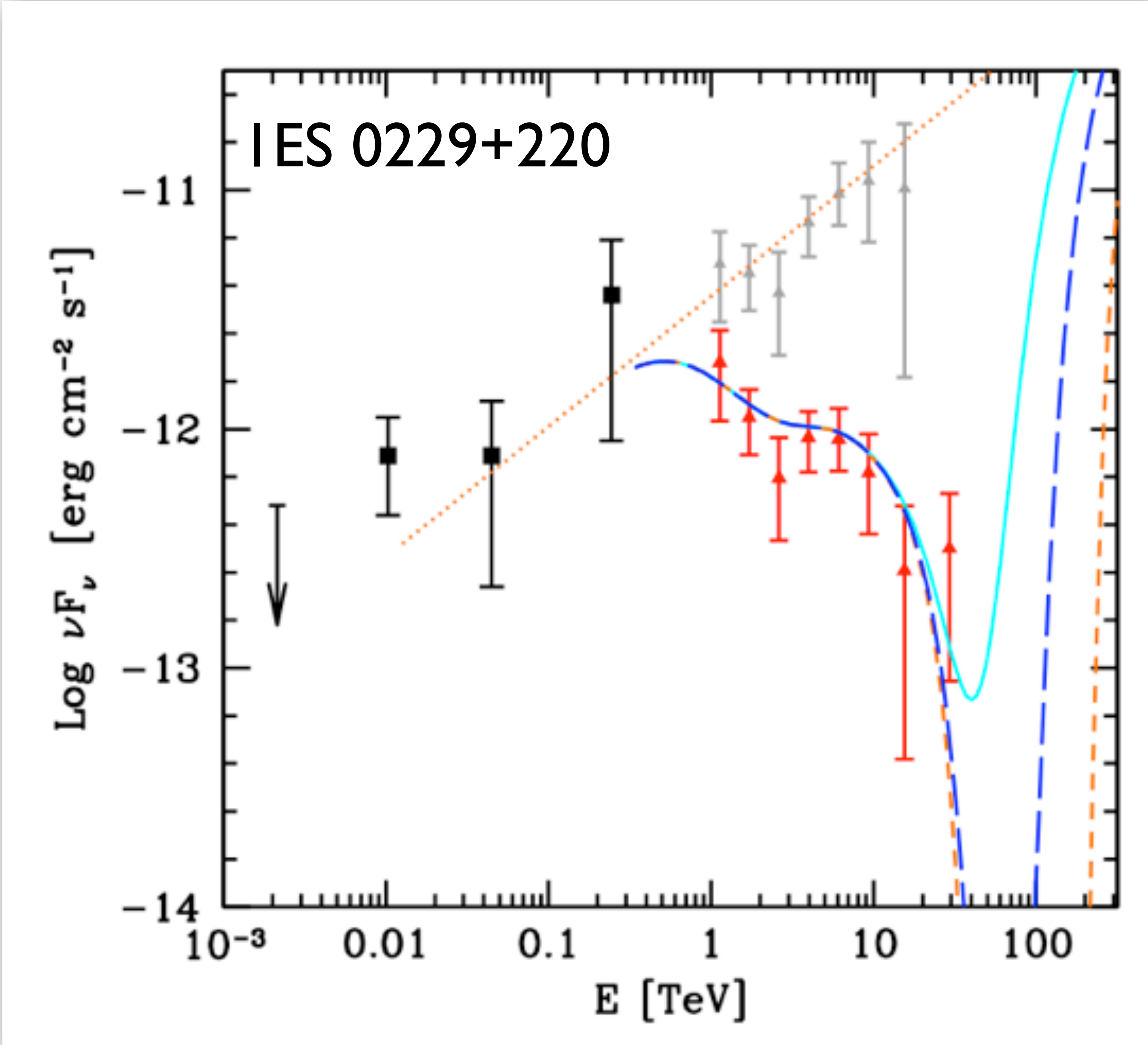
Fairbairn+ 2014



LIV induces suppression of EBL-opacity $\propto (E/M_{LVn})^n$.

LIV and anomalies in EBL opacity

A better source...



Fermi/LAT
Vovk et al. 2012

HESS
Aharonian et al. 2007

HESS De-absorbed
with Dominguez+ 11

$M_{LVI} = 10^{19}$ GeV

$M_{LVI} = 3 \times 10^{19}$ GeV

$M_{LVI} = 10^{20}$ GeV

Tavecchio+ in prep.

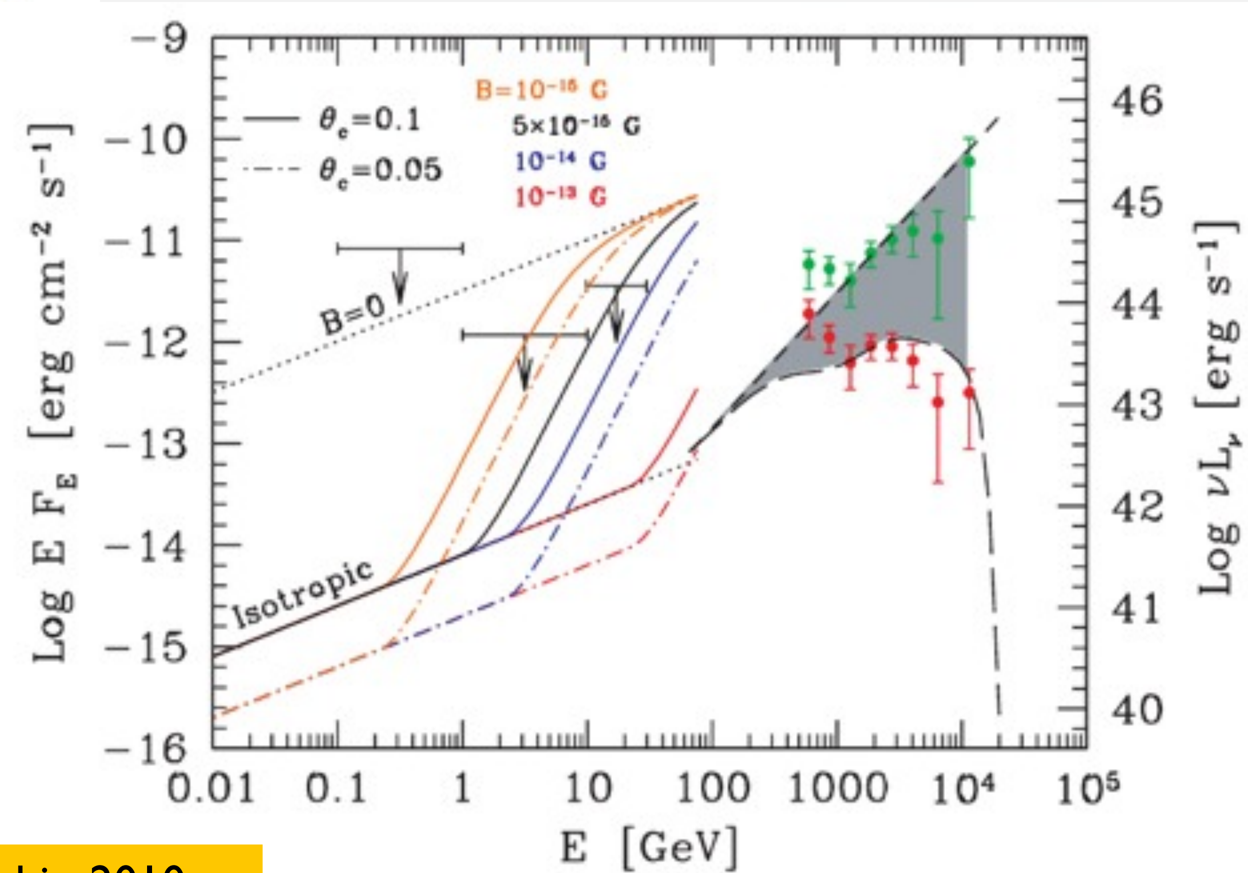
EHBL as IGMF beacon probes

Evidence for Strong Extragalactic Magnetic Fields from Fermi Observations of TeV Blazars

Andrii Neronov* and Ievgen Vovk

Neronov & Vovk 2009

Magnetic fields in galaxies are produced via the amplification of seed magnetic fields of unknown nature. The seed fields, which might exist in their initial form in the intergalactic medium, were never detected. We report a lower bound $B \geq 3 \times 10^{-16}$ gauss on the strength of intergalactic magnetic fields, which stems from the nonobservation of GeV gamma-ray emission from electromagnetic cascade initiated by tera–electron volt gamma rays in intergalactic medium. The bound improves as $\lambda_B^{-1/2}$ if magnetic field correlation length, λ_B, is much smaller th megaparsec. This lower bound constrains models for the origin of cosmic magnetic fields



Tavecchio 2010

EHBLs because of:

- large multi-TeV power to reprocess
- low GeV intrinsic (pure reprocessed)

Best of the bunch

- ✓ **Young SNR RX J1713.7–3946**: 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...).
- ✓ **SNR/MC W28**: useful information on how particles escape from the remnant and propagate in their vicinity. Excellent synergy with Fermi/LAT.
- ✓ **E-HBL KUV00311-1938 & 1ES 0229+200**: detection of E>20 TeV γ-rays from is only compatible if the γ-rays are hadronic in origin. Very deep ASTRI/CTA mini-array observation are required.

Summary

- ✓ The **ASTRI SST-2M prototype**, operational starting at beginning of 2015 will perform the **first Crab observations with a Schwarzchild-Couder telescope equipped with SiPMs.**

- ✓ The **ASTRI/CTA mini-array** will constitute a ***seed* for the whole CTA array**, allowing us to probe technological solutions.

- ✓ **ASTRI/CTA mini-array deep observations of a few selected targets** will allow us to obtain a few solid detections during the first year, and to perform the **CTA early science**.

- ✓ The **ASTRI/CTA mini-array** will exploit excellent **synergies with *Swift* and *Fermi*** (in operation in 2016 and beyond).


"That's all Folks!"