Prospects for Fundamental Physics and Cosmology with the Cherenkov Telescope Array

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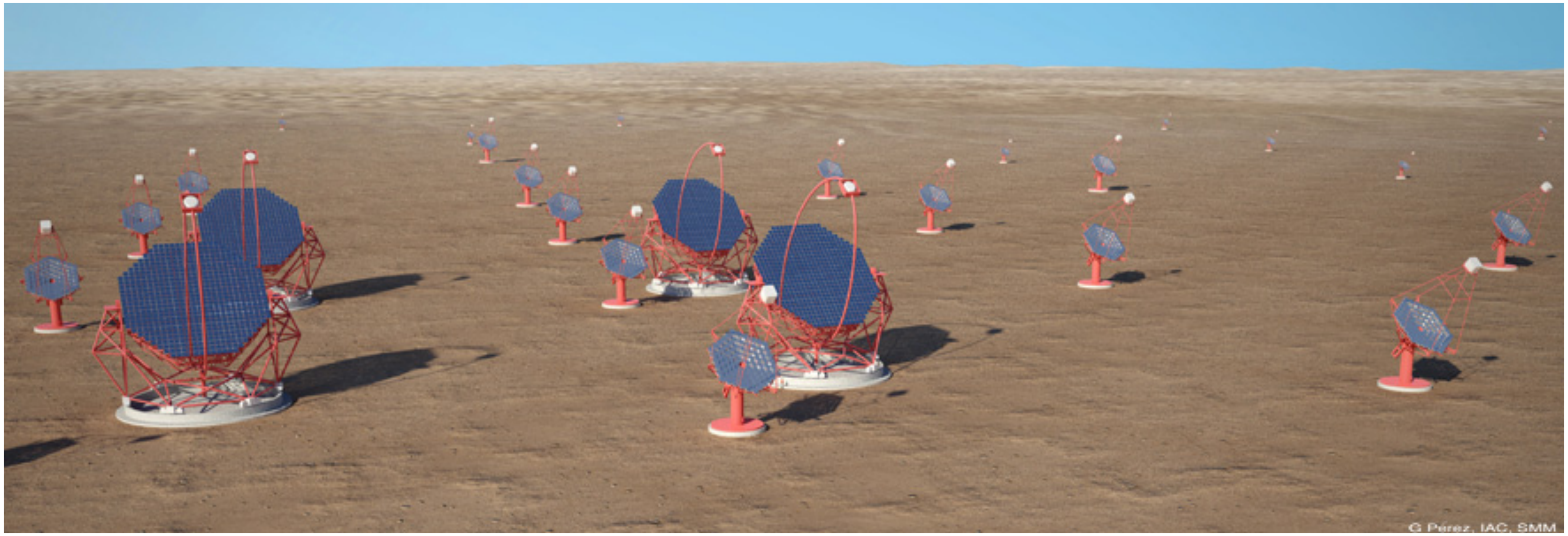
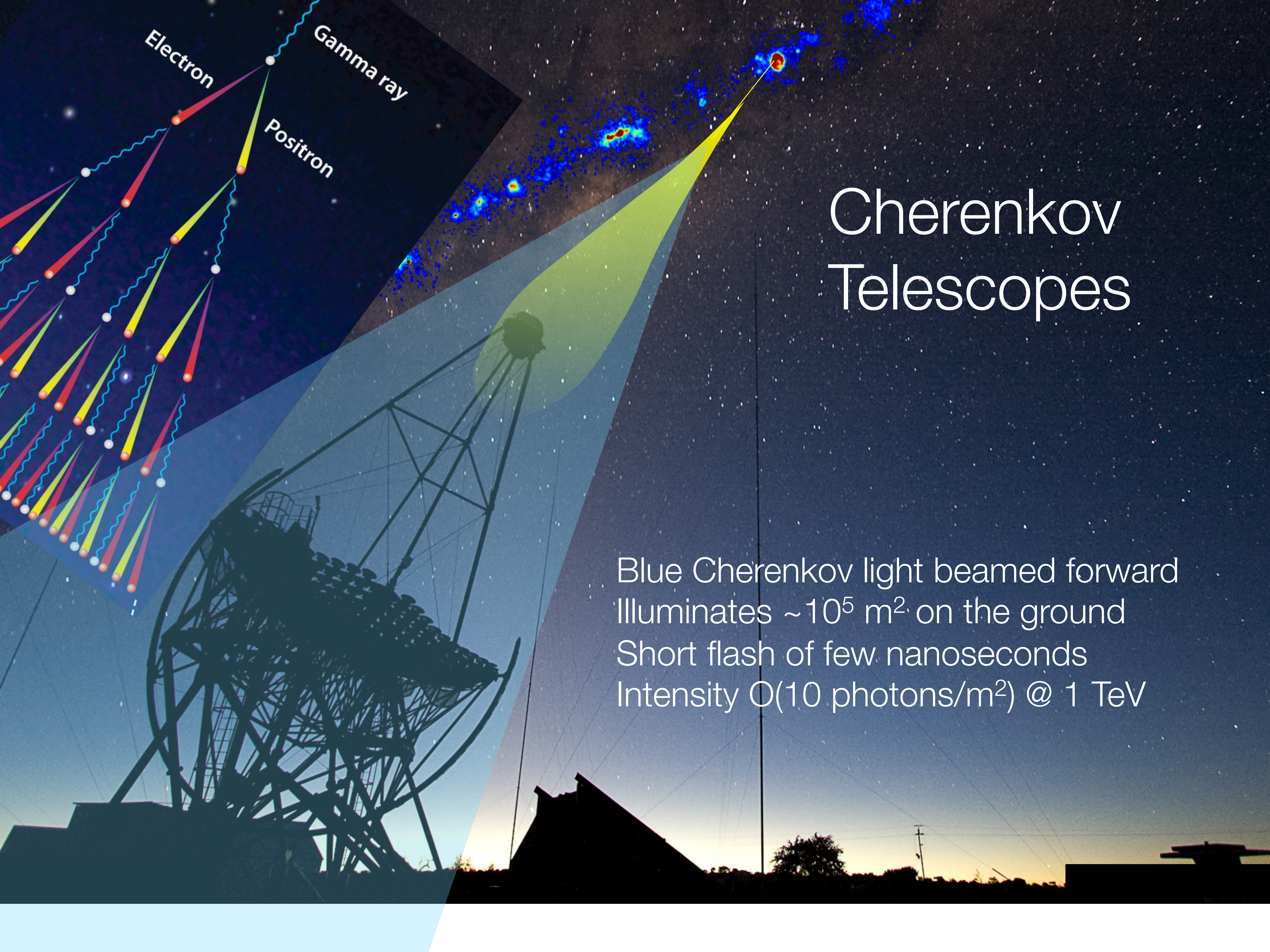
For the CTA Consortium
http://www.cta-observatory.org

The CTA Concept



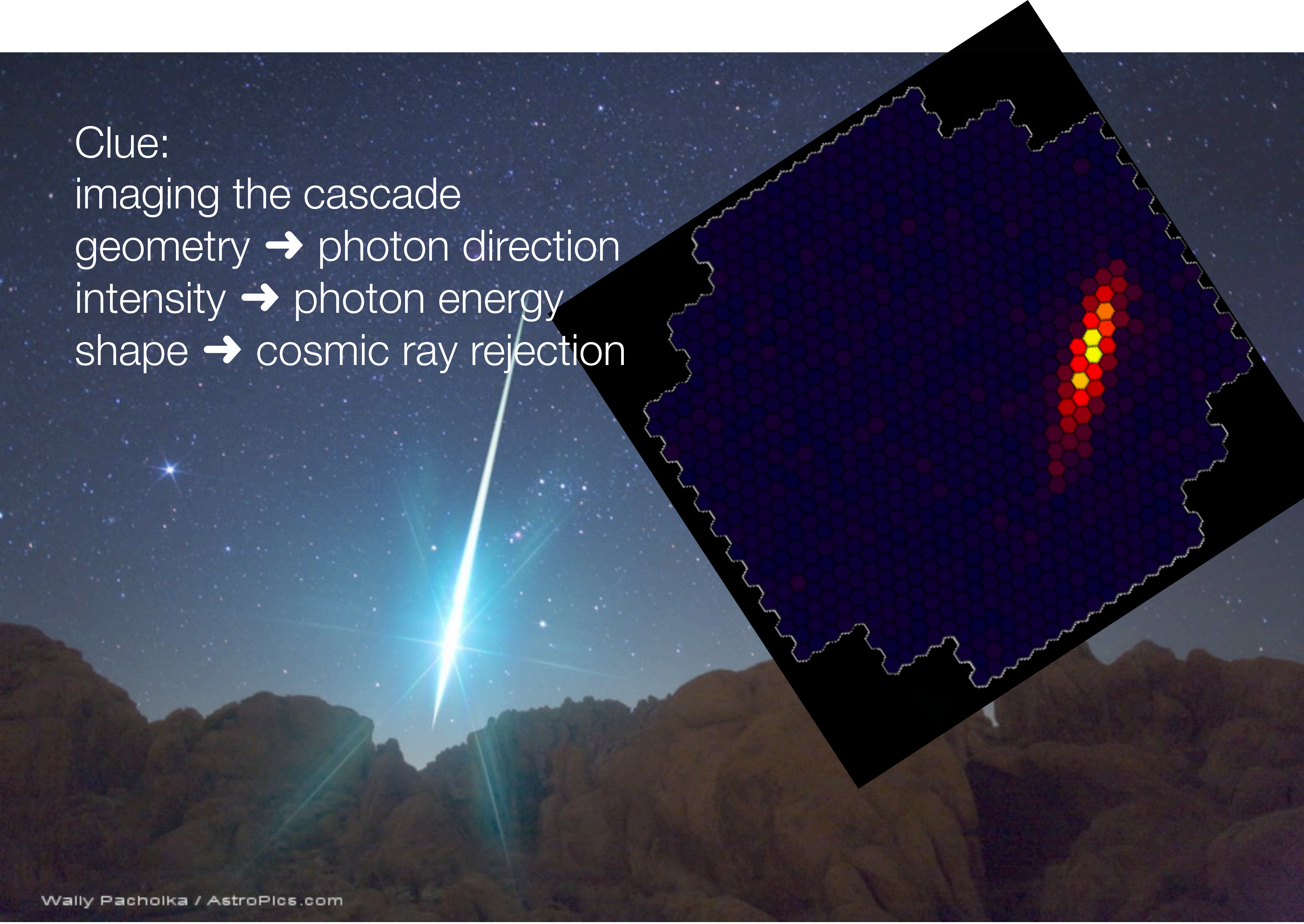
- Arrays in northern and southern hemispheres for full sky coverage
- 4 large (~23 m) telescopes in the center (LSTs)
  - Threshold of ~30 GeV
- ≥25 medium (9-12 m) telescopes (MSTs) covering ~1 km^2
  - Order of magnitude sensitivity improvement in 100 GeV–10 TeV range
- Small (~4 m) telescopes (SSTs) covering >3 km^2 in south
  - >10 TeV observations of Galactic sources
- Construction begins in ~2015

Cherenkov Telescopes



Blue Cherenkov light beamed forward
Illuminates ~10^5 m^2 on the ground
Short flash of few nanoseconds
Intensity O(10 photons/m^2) @ 1 TeV

Clue:
imaging the cascade
geometry ➜ photon direction
intensity ➜ photon energy
shape ➜ cosmic ray rejection



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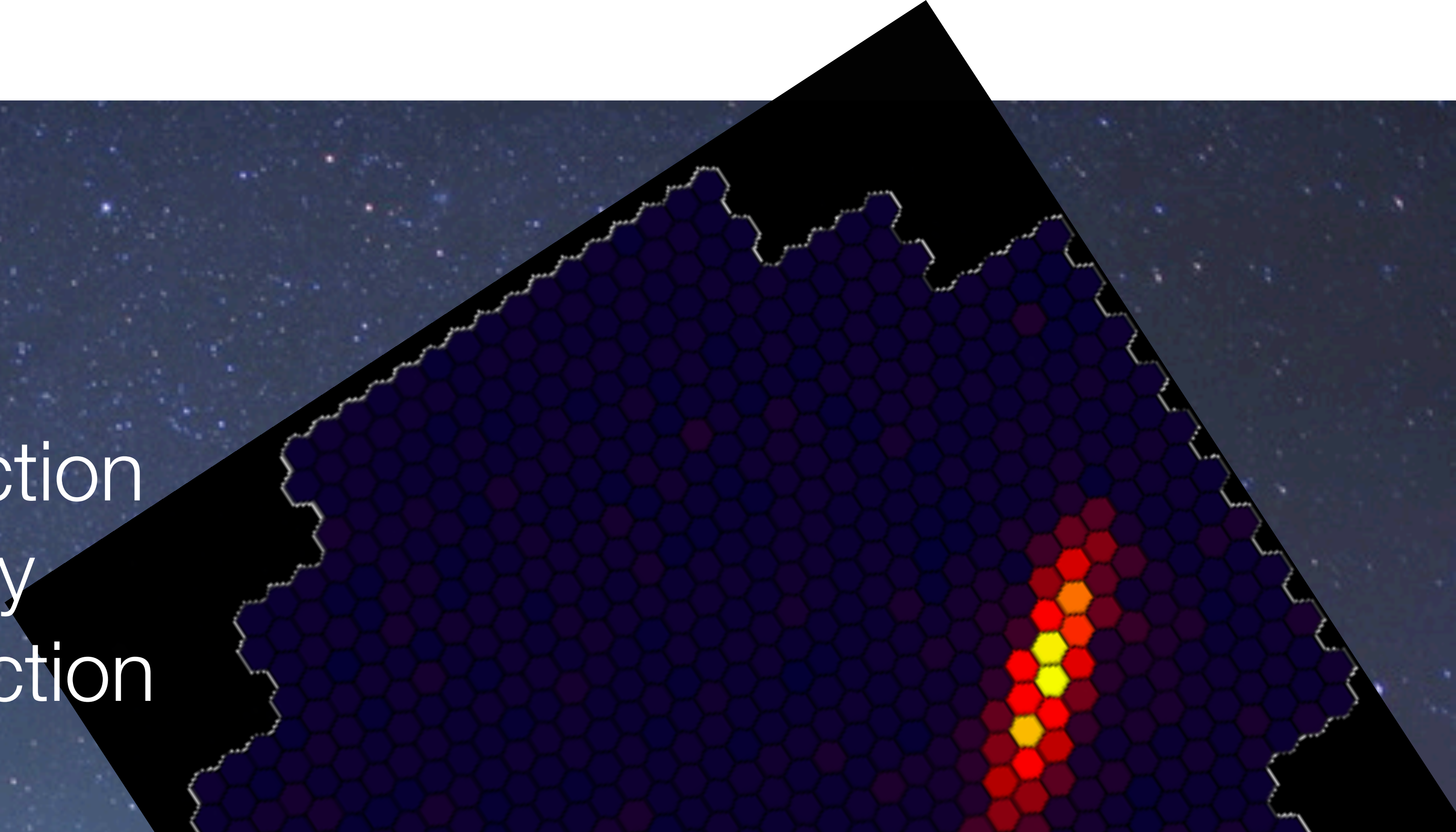
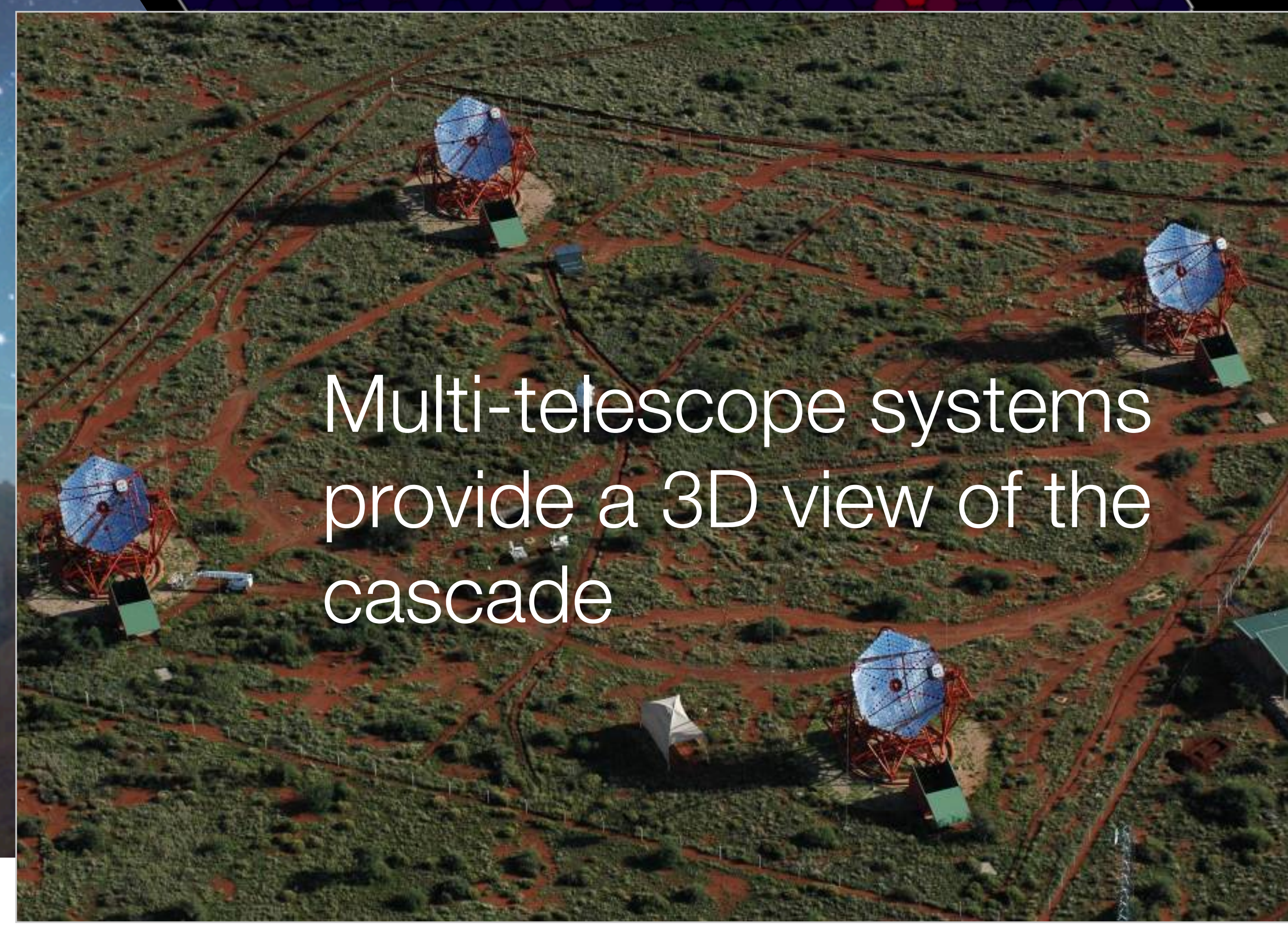
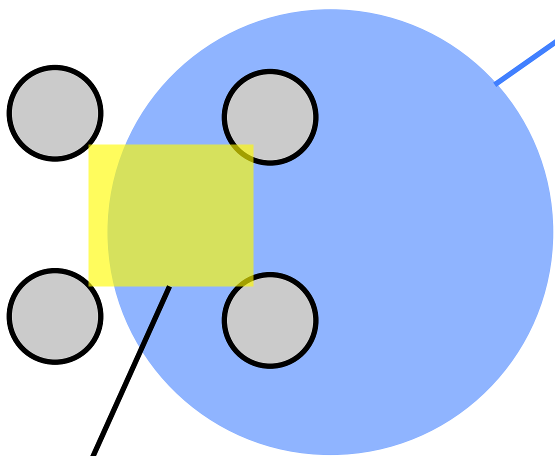




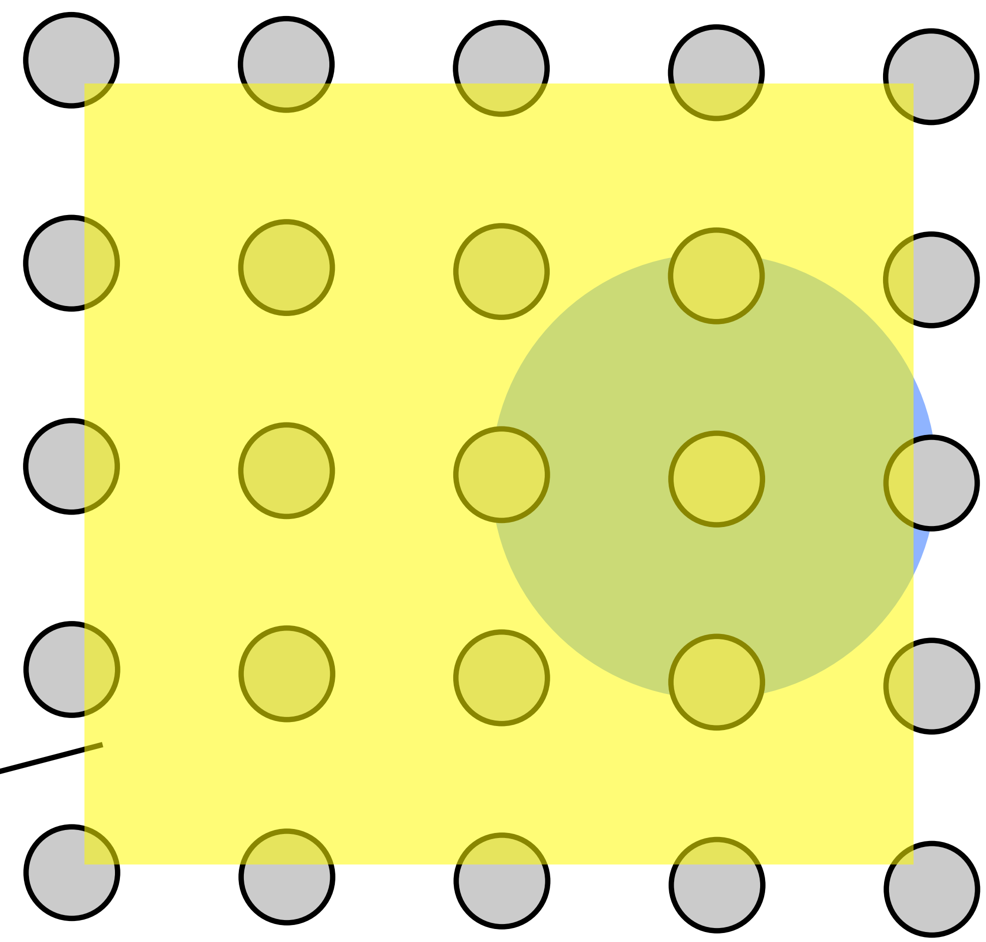
Multi-telescope systems provide a 3D view of the cascade

From current arrays to CTA



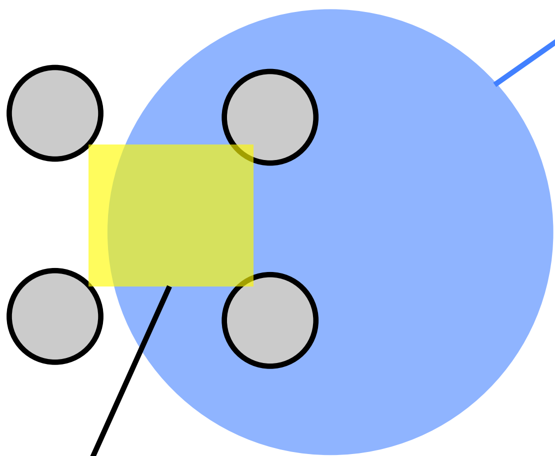
Light pool radius
R ≈100-150 m
≈ typical telescope spacing

Sweet spot for
best triggering
and reconstruction:
Most shower cores miss it!



Large detection area
More images per shower
Lower trigger threshold

From current arrays to CTA



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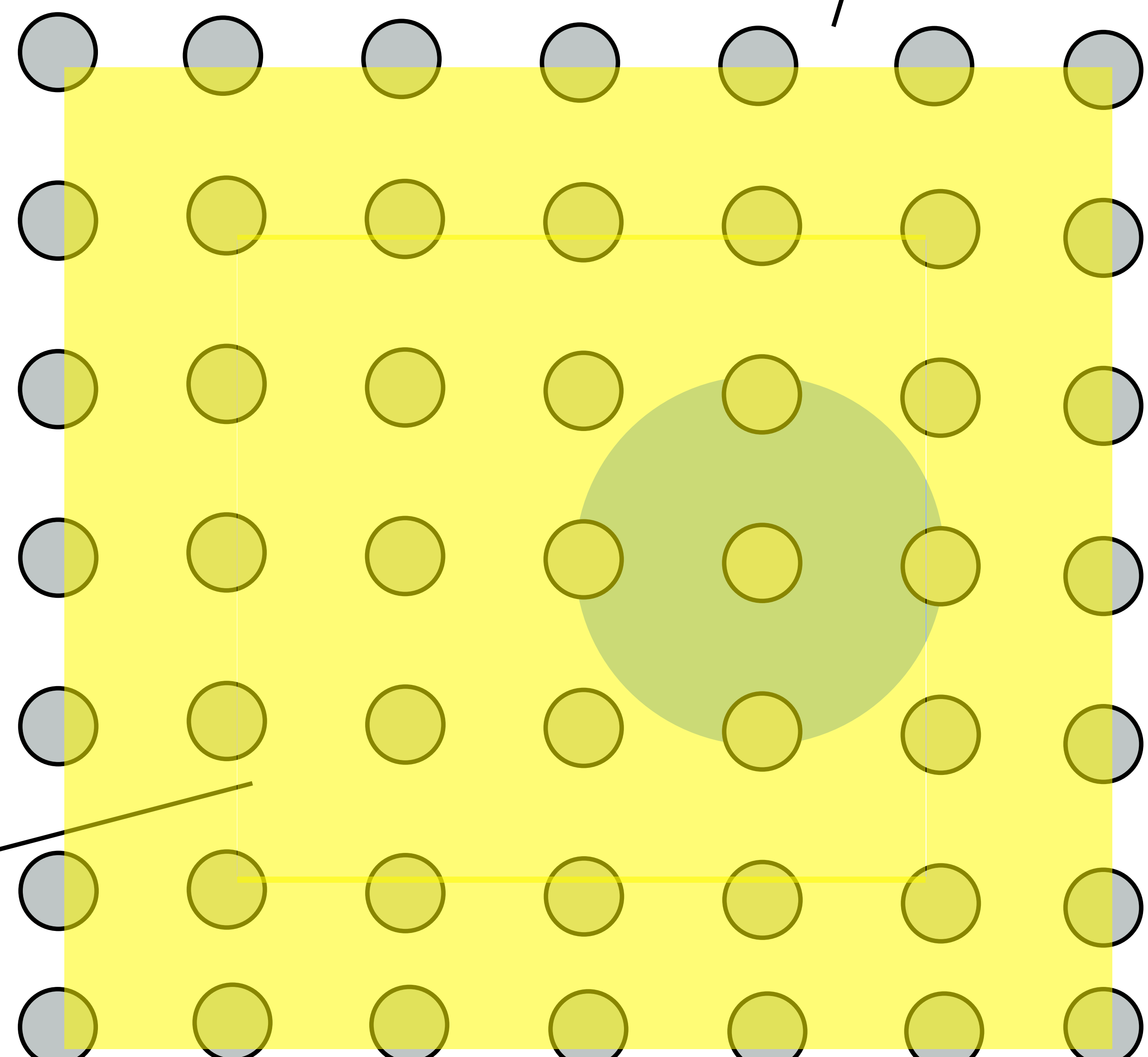
With US telescopes



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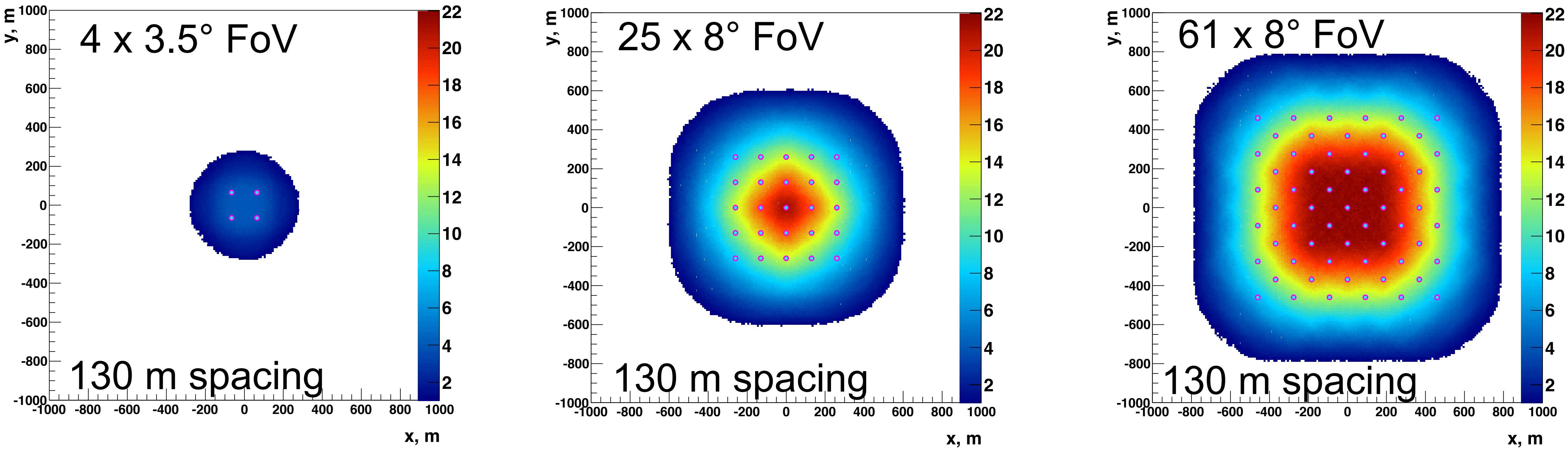
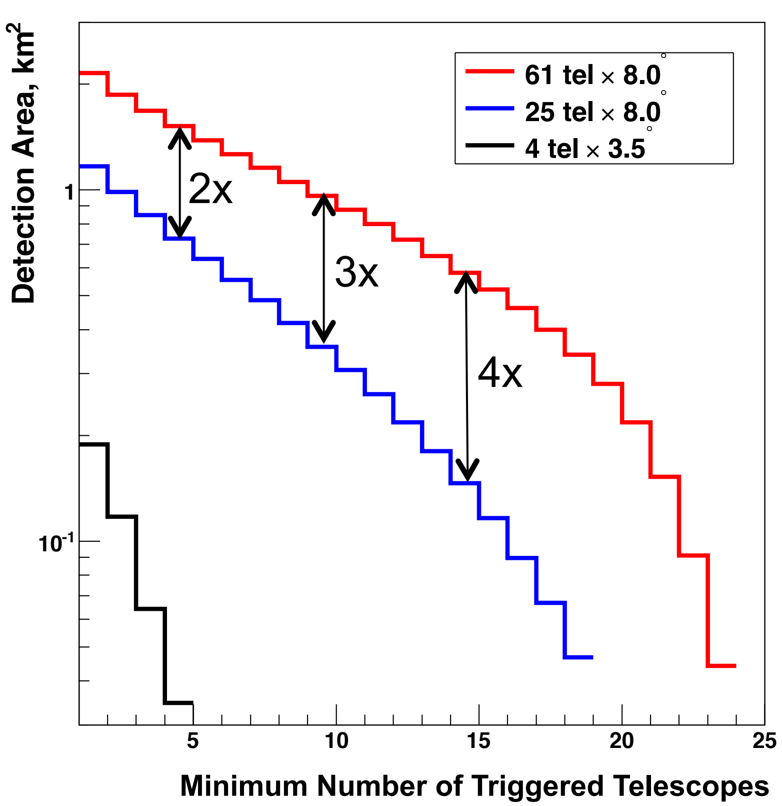
More images per shower
Lower trigger threshold

Why a large array?

Figures from Slava Bugaev



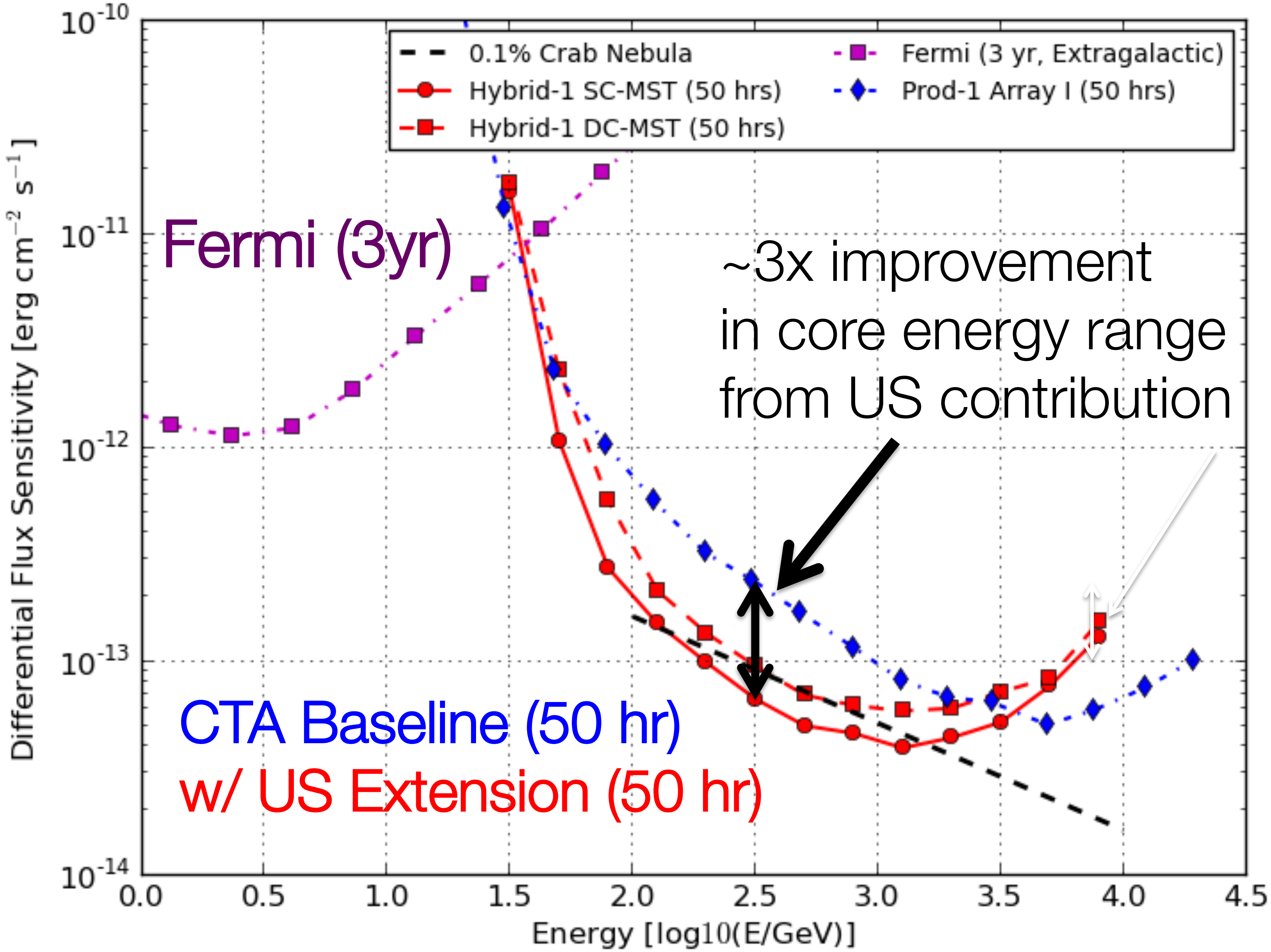


Color scale: number of triggered telescopes for 500 GeV showers

Sufficiently large and capable MST array is the primary goal of the US groups

- Double the size of the southern array
- Developing novel design w/ secondary mirror & <0.07° optical psf

Differential Sensitivity



CTA Baseline (Prod-1): See K. Bernlohr et al. 2012, arXiv:1210.3503
w/ US Extension (Hybrid-1): See T. Jogler et al. 2012, arXiv: 1211.3181

Recommended by several relevant roadmaps …

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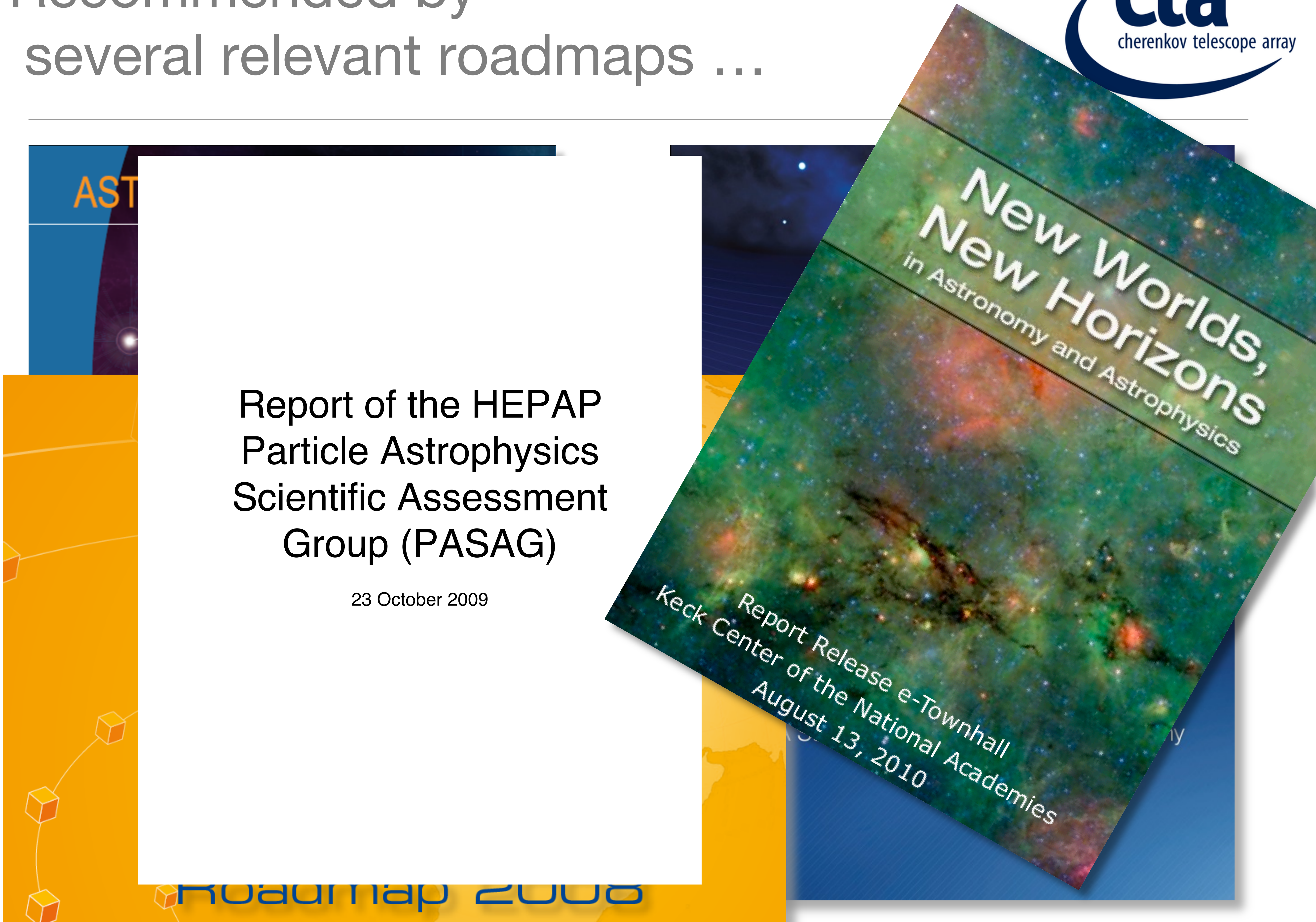
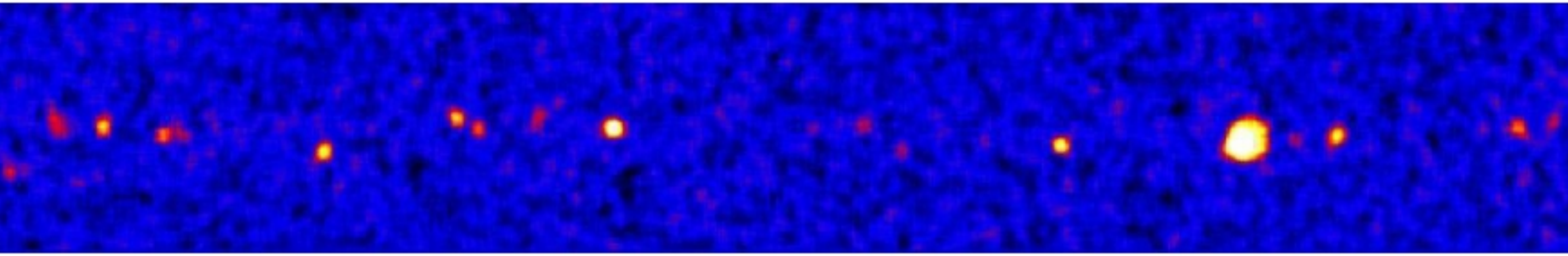
cta
cherenkov telescope array

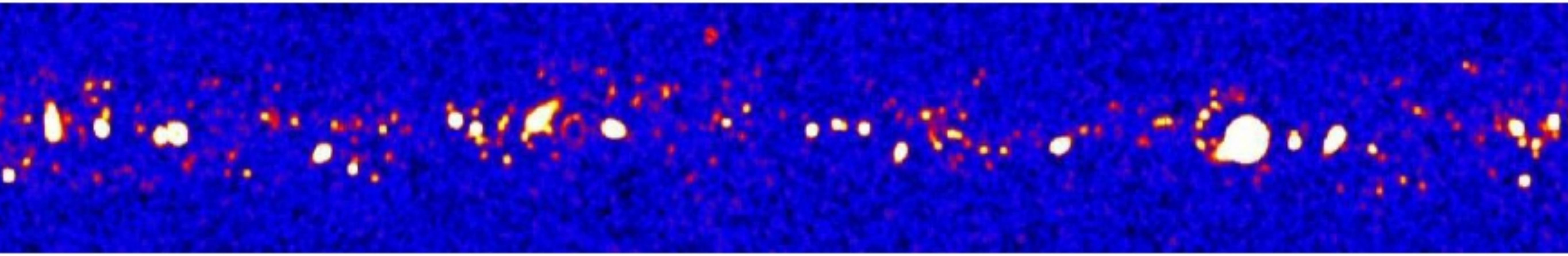


Simulated Galactic Plane surveys

H.E.S.S.



CTA, for same exposure

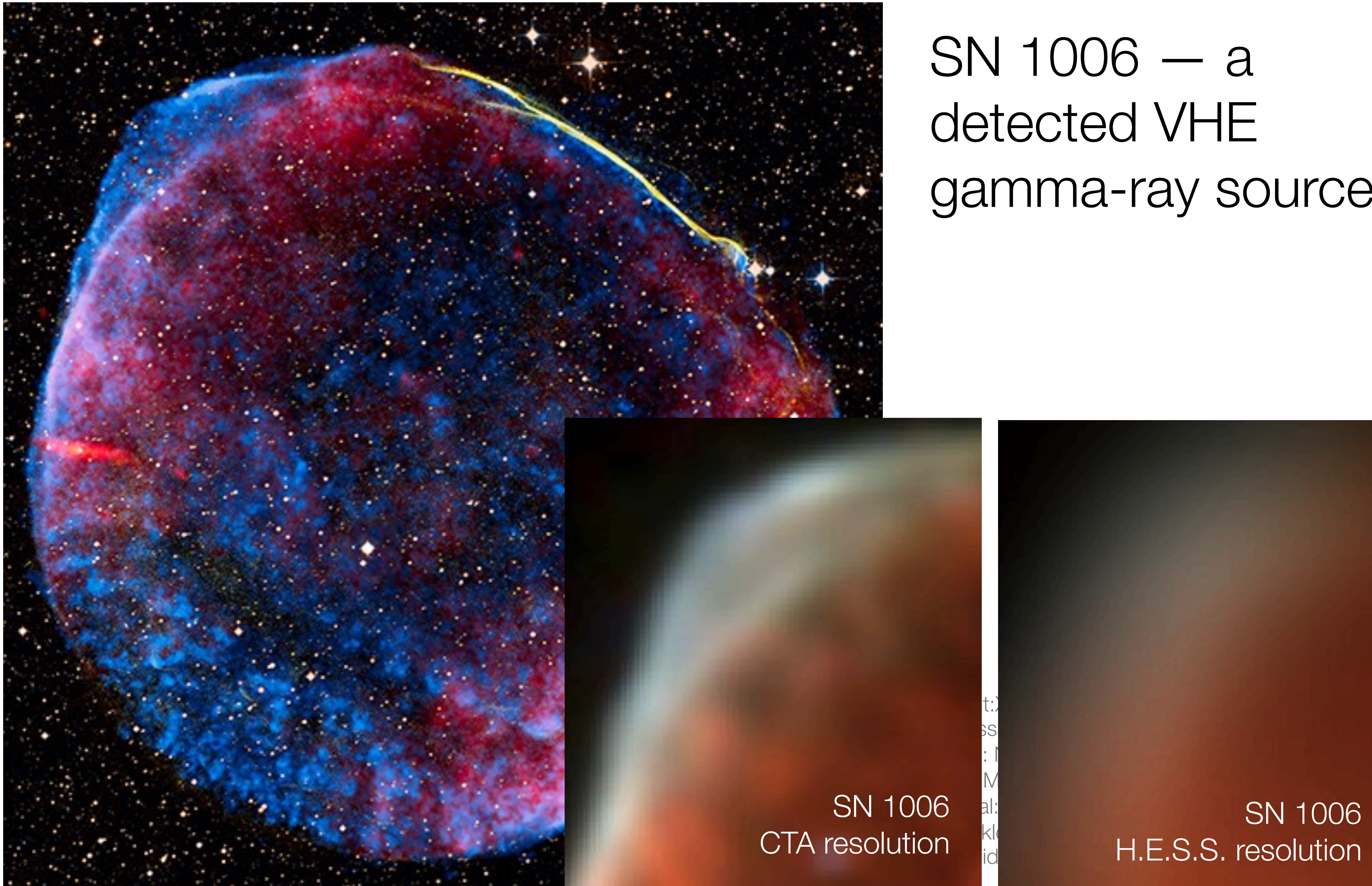


Expect ~1000 detected sources over the whole sky

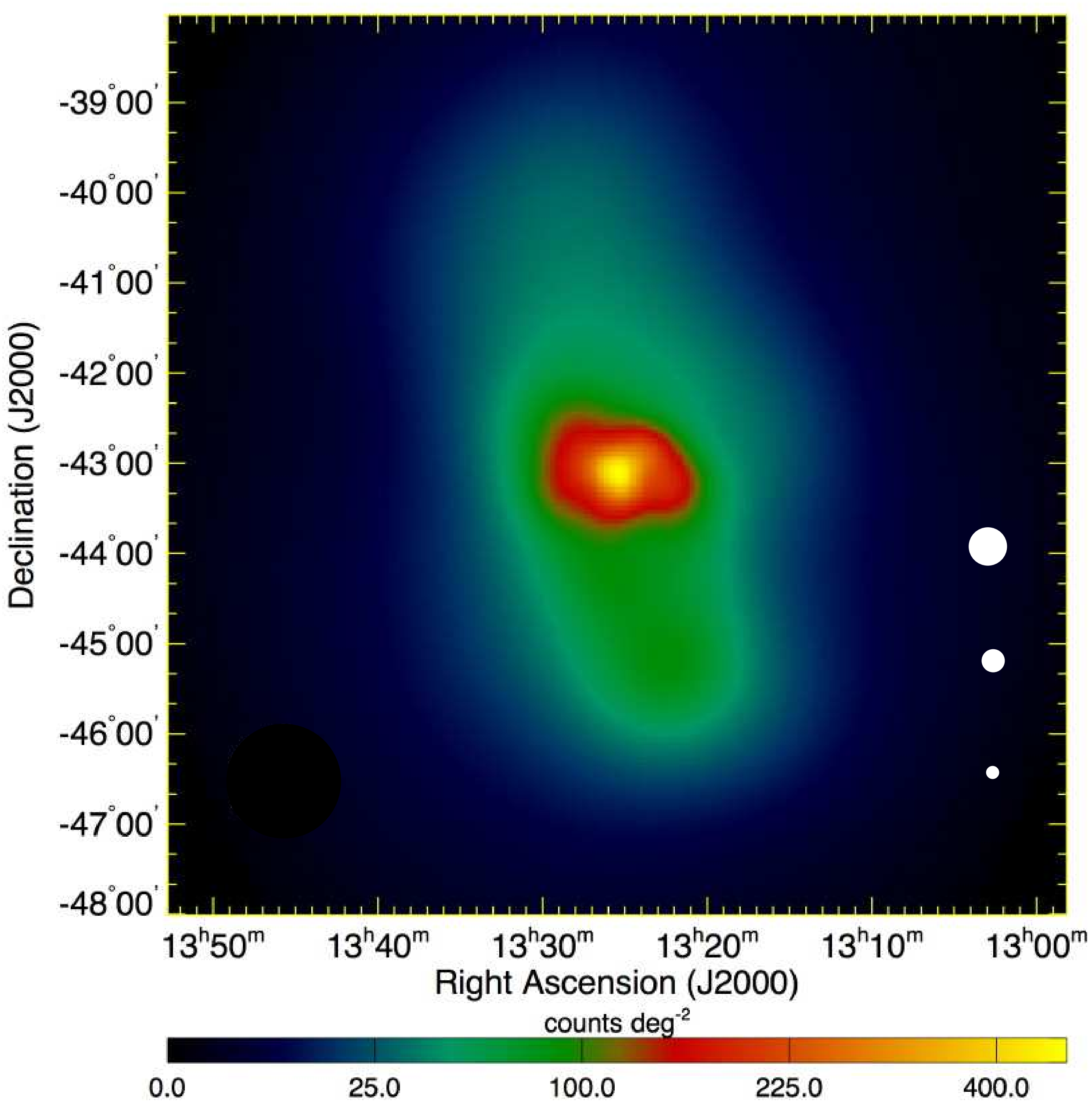
Funk et al., *Amer. Inst. Phys. Conf. Proc.* 1085, 886 (2008)

Resolving complex sources

SN 1006 — a detected VHE gamma-ray source



Resolving extragalactic sources: Cen A



Fermi LAT >200 MeV background-subtracted counts map of Cen A

Abdo et al. 2010, *Science* **328**, 725

Fermi LAT PSF at 10 GeV

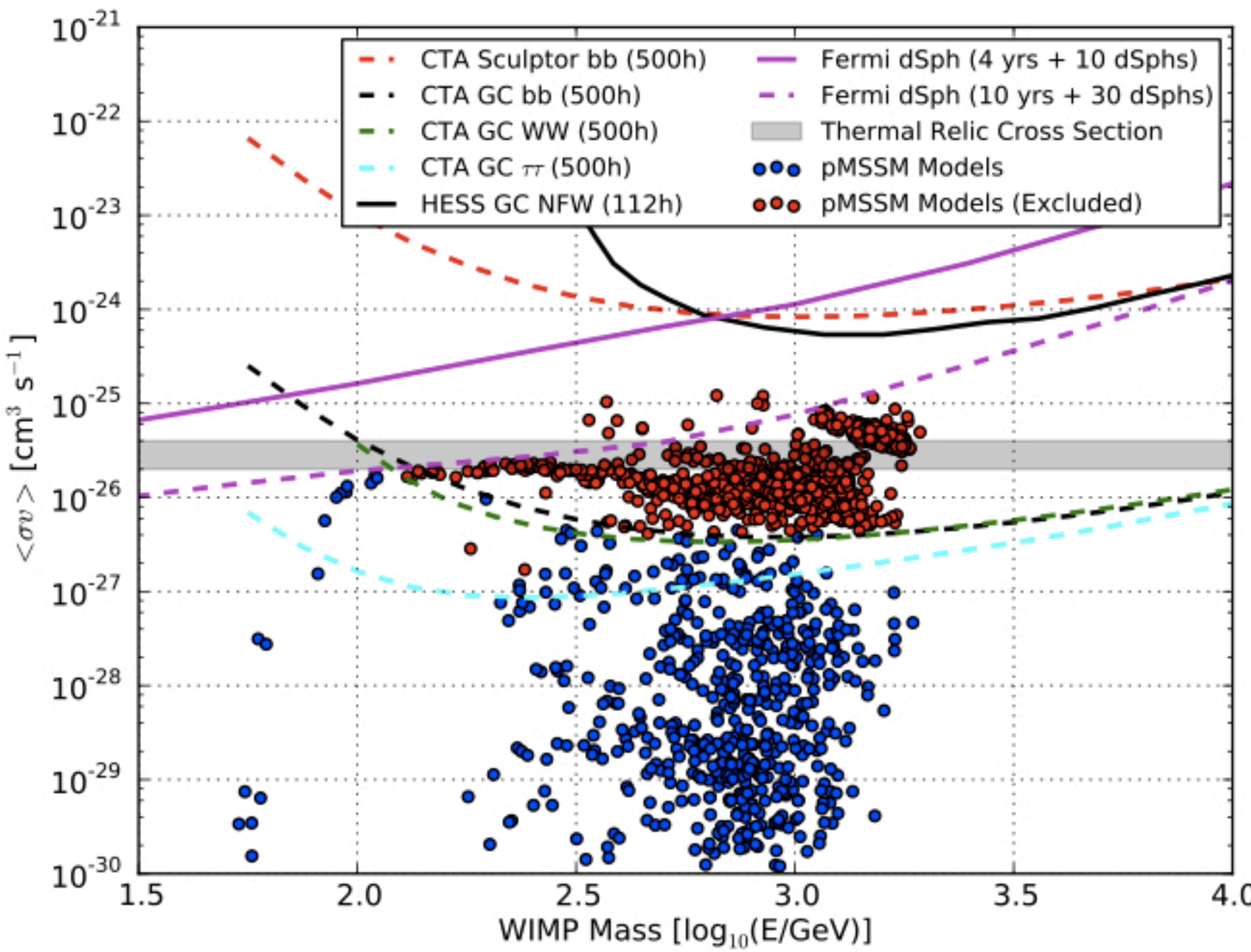
CTA PSF at 100 GeV (≥2 images)

CTA PSF at 300 GeV (≥10 images)

(68% containment)

Expect to detect hundreds of AGN

Dark matter searches with CTA



Constraints

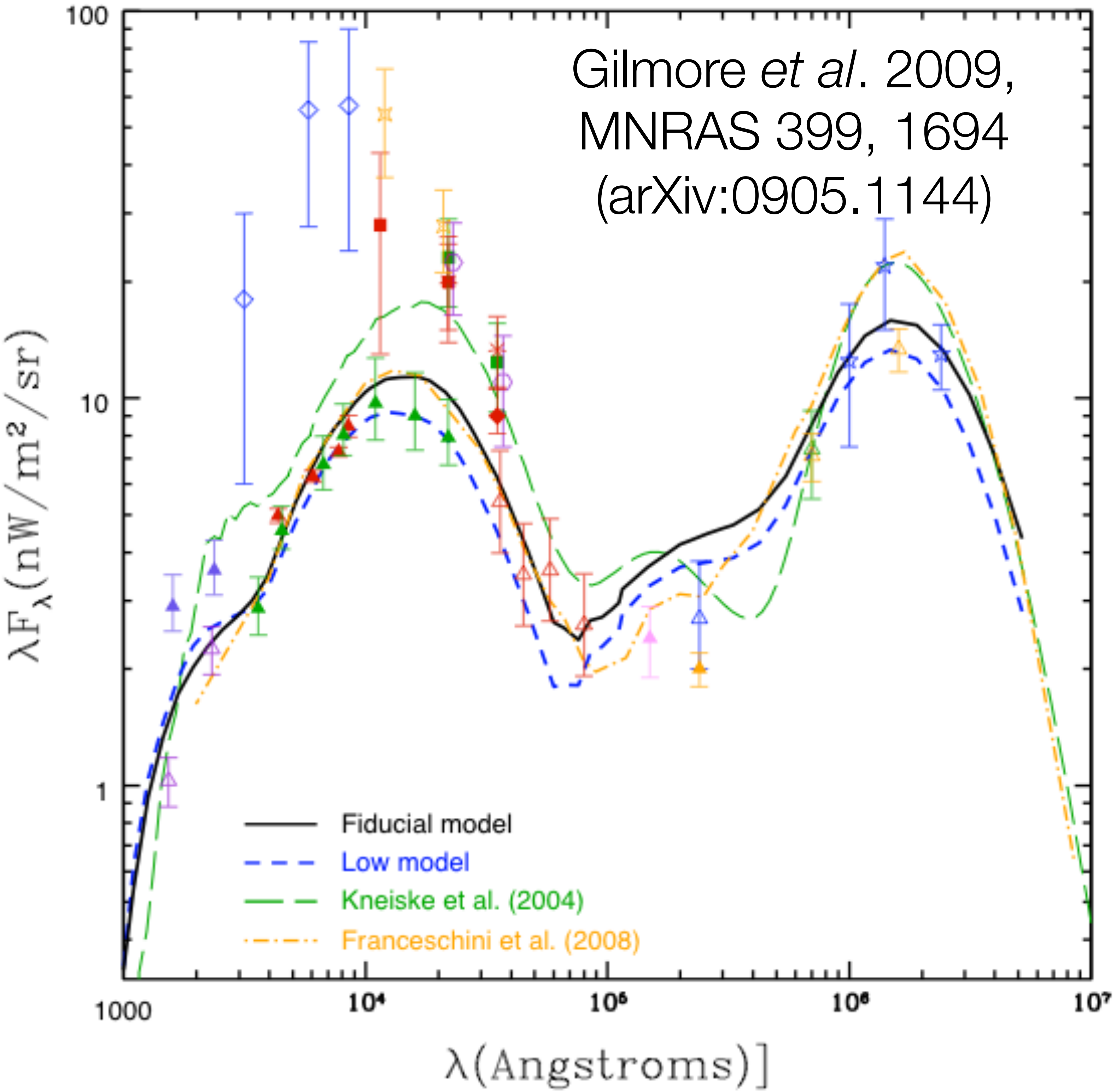
$\Omega_{DM}h^2 > 0.1$

XENON100 (2011)

CMS+ATLAS (2012)

More details in following talk by Matthew Wood

Extragalactic Background Light



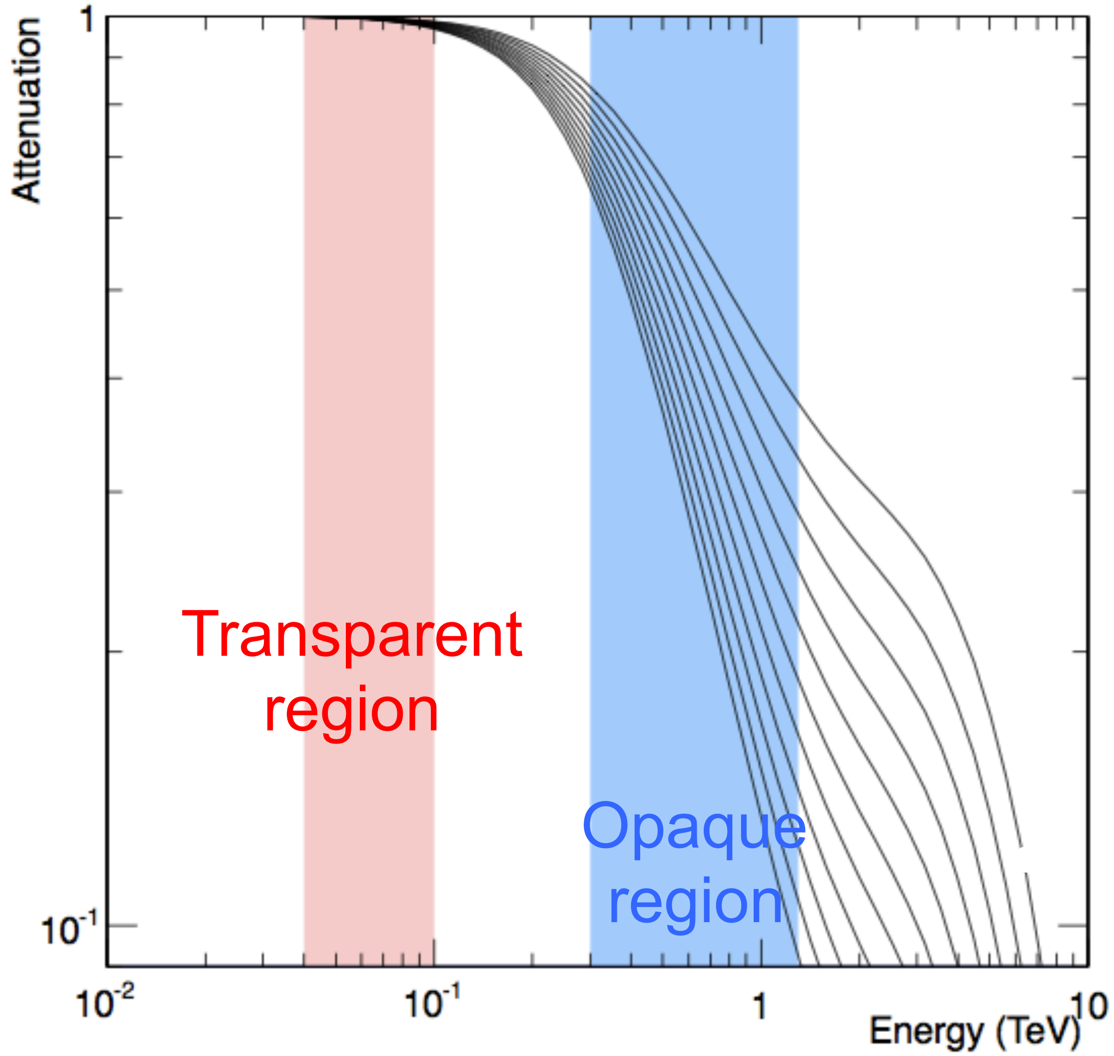
$\gamma_{\text{High Energy}} + \gamma_{\text{EBL}} \rightarrow e^+ e^-$

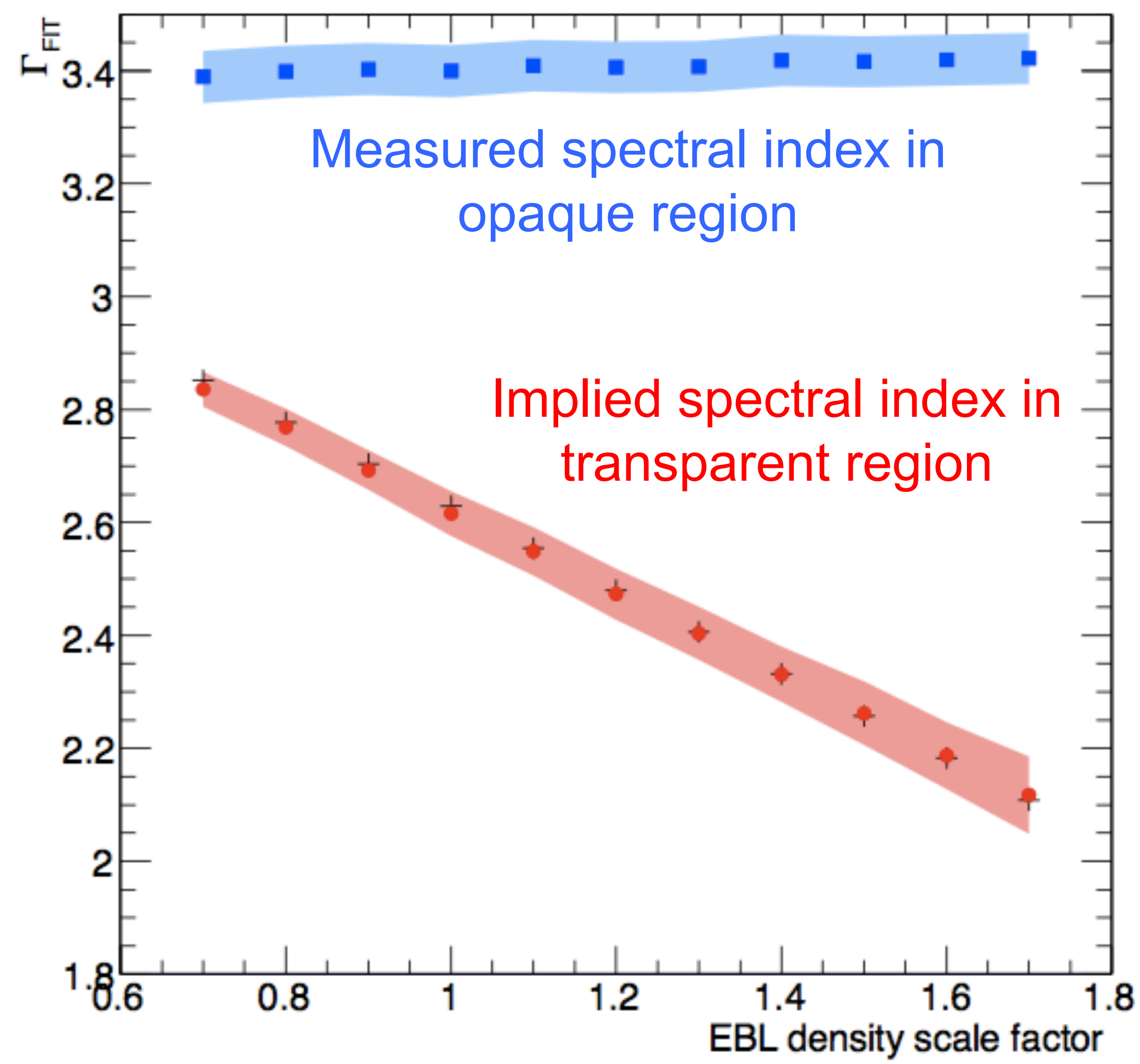
Difficult to measure EBL because of foreground sources

Test of cosmology

Attenuation by 1/e (*i.e.* $e^{-\tau}$ with $\tau = 1$) for
z ~ 1.2 at 100 GeV
z ~ 0.1 at 1 TeV

Photon Propagation through the Cosmos

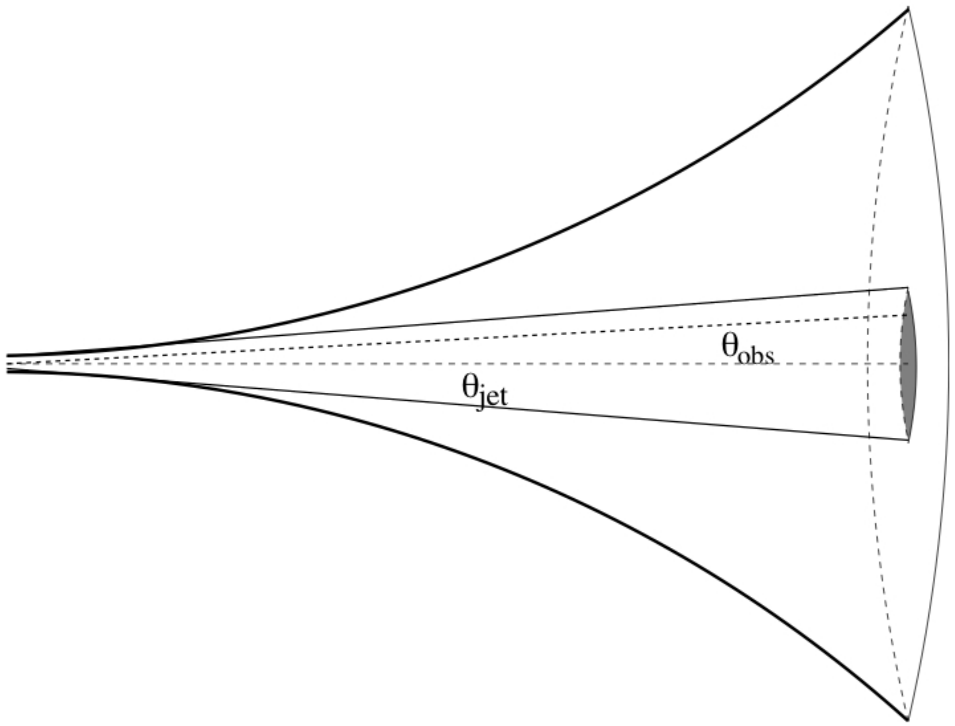


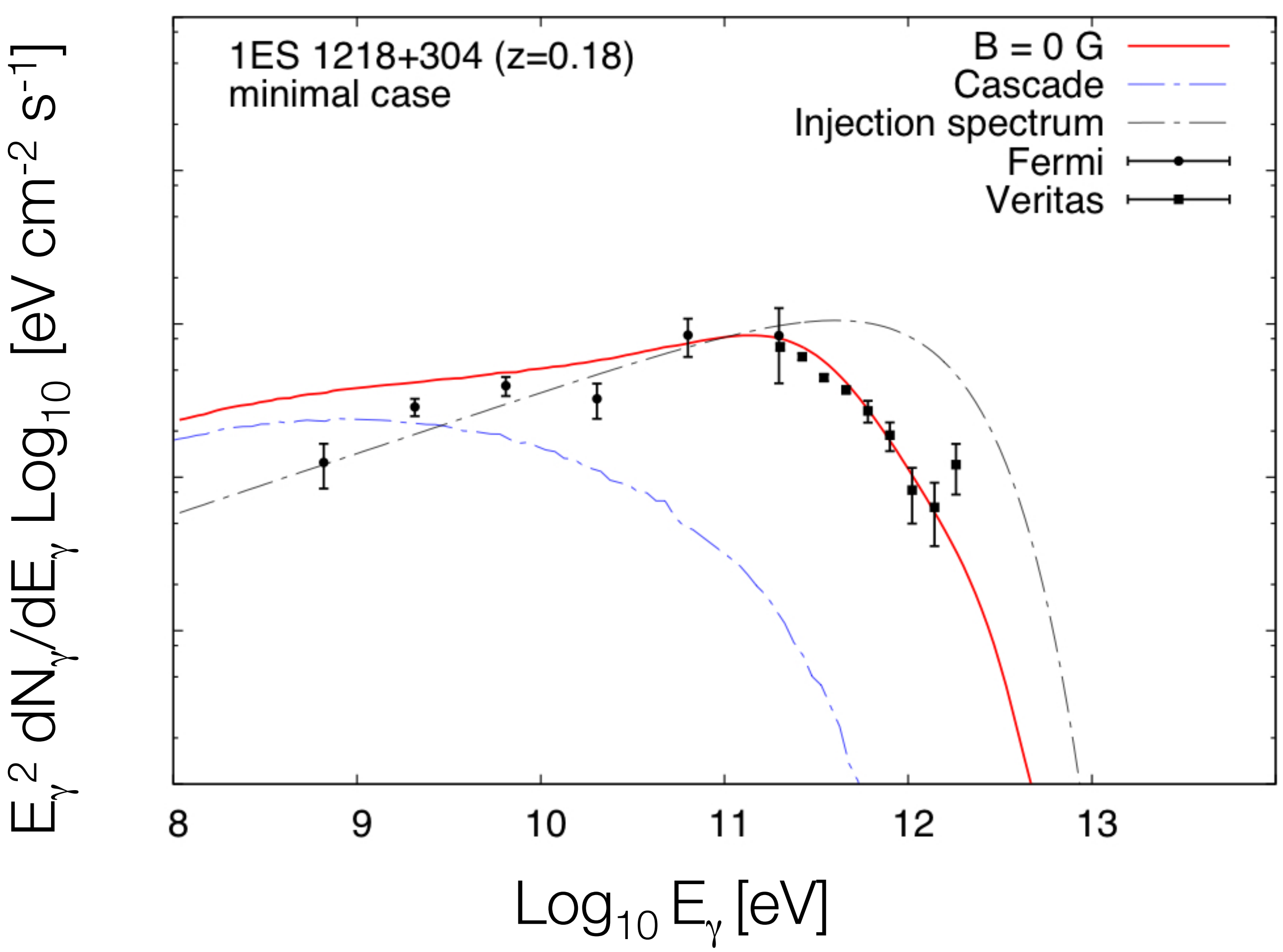


Spectral index Γ from fit to $dN/dE \sim E^{-\Gamma}$
EBL model of Franceschini et al. 2008

D. Mazin et al. (2013), *Astropart. Phys.* 43, 241

The EBL and Intergalactic B Fields

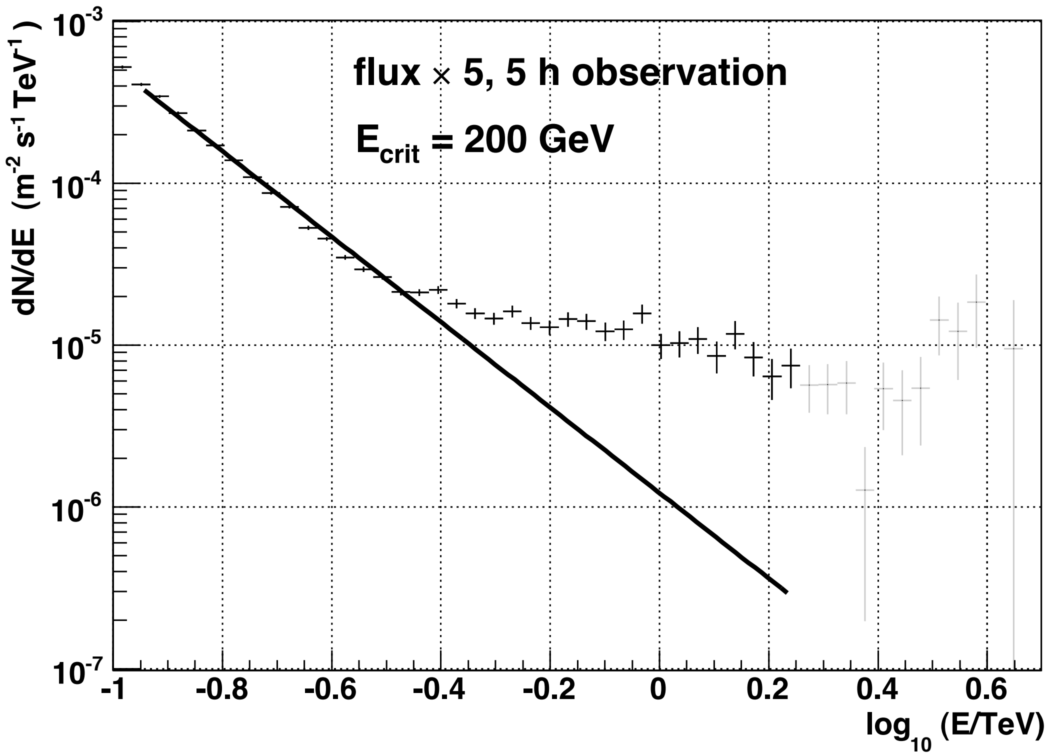




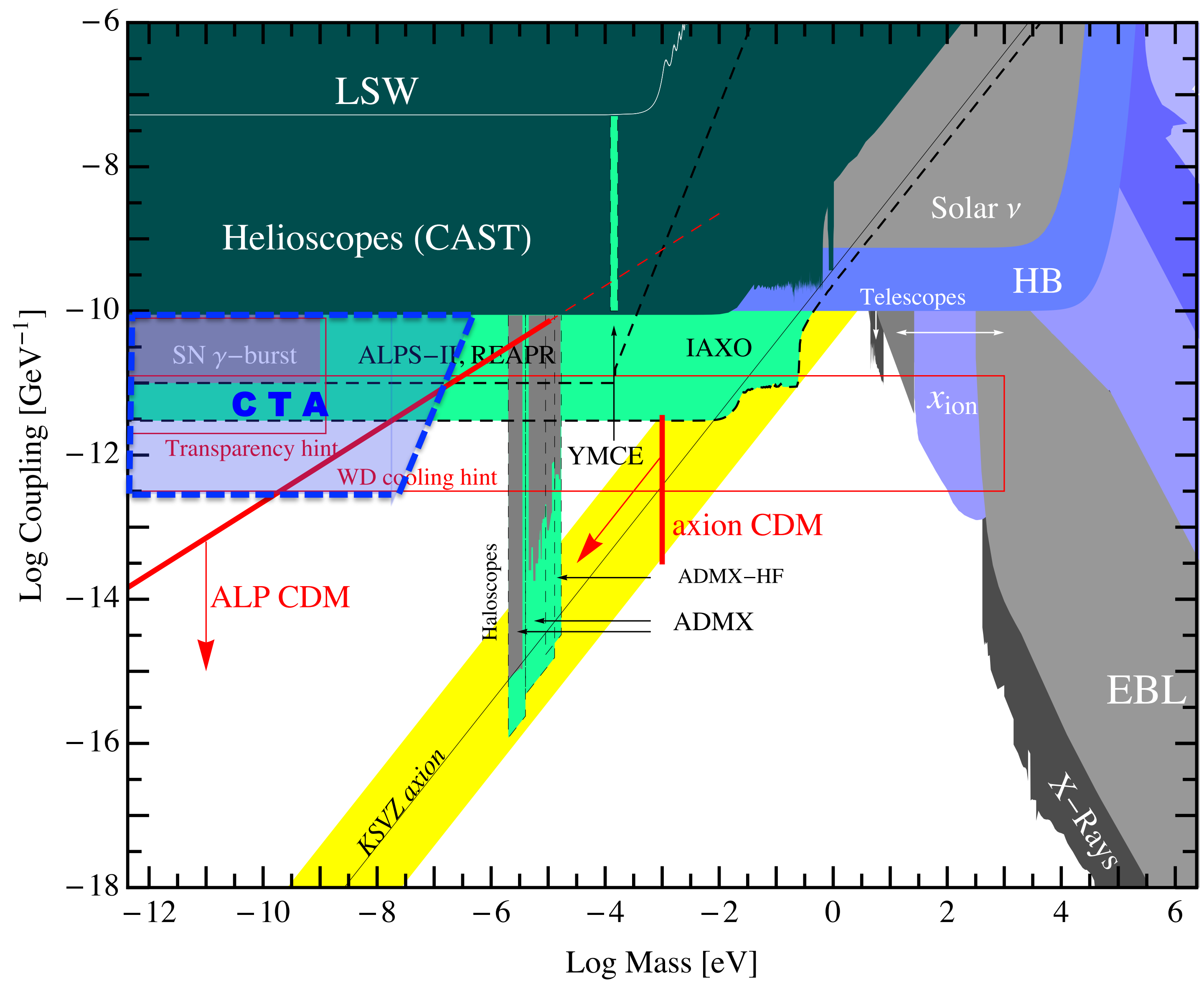
- Electrons produced by
  $\gamma_{\text{High Energy}}+\gamma_{\text{EBL}} \rightarrow e^+ e^-$
  Compton scatter off EBL to produce more photons
- Amount that the cascade fans out depends on intergalactic magnetic field (IGMF) strength
- Observable effects:
  - Pair halo
  - Spectral distortion
  - Large time delays between prompt and reprocessed photons

Figures from Taylor *et al*. 2011, arXiv: 1101.0932

Axion-like Particles (ALPs)



Simulated CTA observation
Bright flare from 4C 21.35
0.1 nG IGMF
EBL of Dominguez et al. 2011

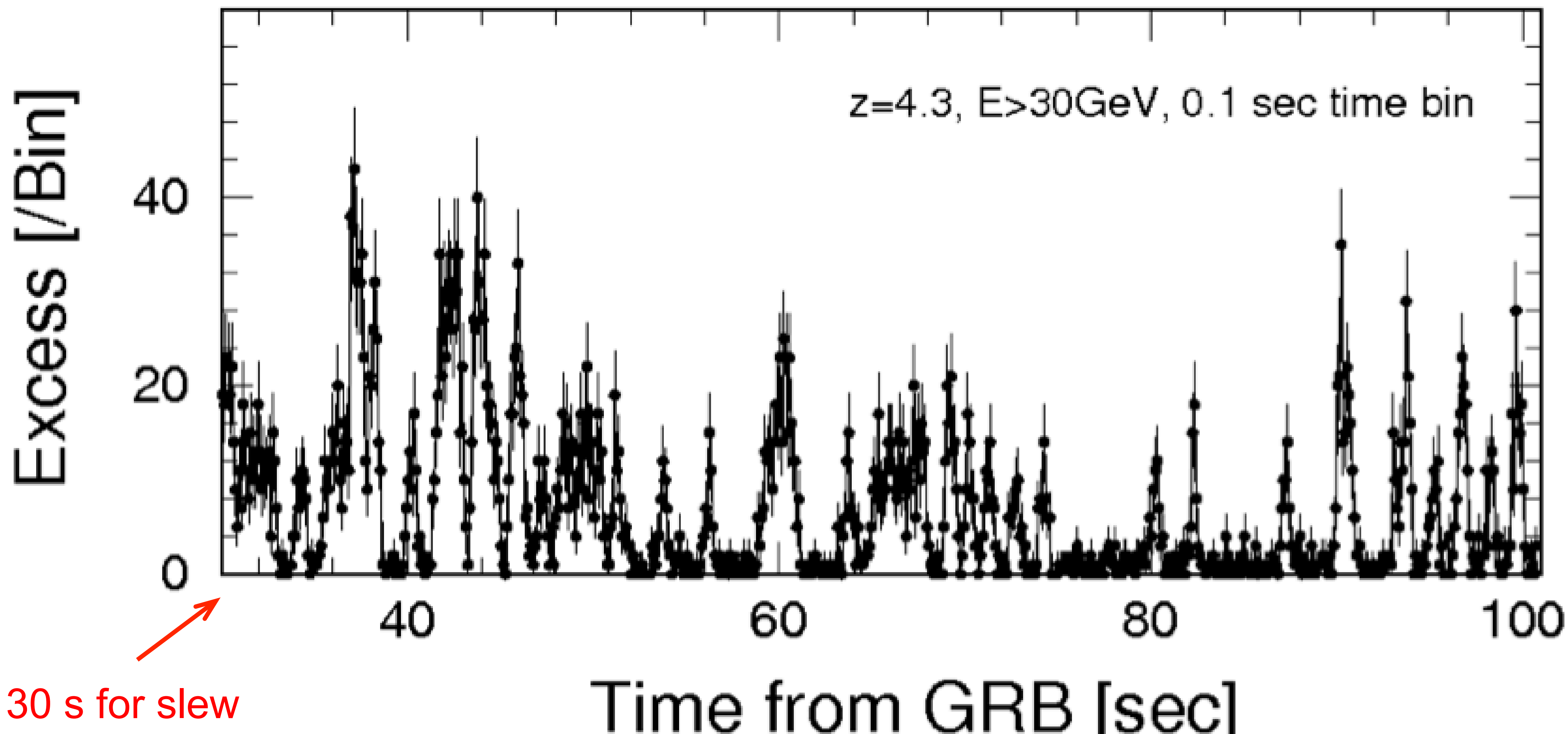


Caveat: Other astrophysical processes, e.g. UHECR cascades, can also lead to spectral hardening

Left figure: Doro et al., *Astropart. Phys.* 43, 189; arXiv:1208.5356
Right figure: Sanchez-Conde et al., in prep., adapted from Ringwald, 2012, arXiv:1209.2299

A simulated GRB (E > 30 GeV)

CTA Simulation of GRB 080916C seen by GBM + LAT



from
Gamma-Ray Burst Science in the Era of Cherenkov Telescope Array
(Astroparticle Physics special issue article)
Susumu Inoue et al.

More details on LIV in talk tomorrow by Nepomuk Otte

White Papers Contributed to Snowmass Study

Tests of Lorentz Invariance Violation to Probe Quantum Gravity
Prospects for Indirect Detection of Dark Matter with CTA
Fundamental Physics from Charged Particle Measurements with the Cherenkov Telescope Array
The Hunt of Axionlike Particles with the Cherenkov Telescope Array
The Extragalactic Background Light (EBL): A Probe of Fundamental Physics and a Record of Structure Formation in the Universe
Particle Acceleration in Relativistic Jets
Search for Dark Matter Sub-Halos in the Gamma-ray Band
The Impact of Astrophysical Particle Acceleration on Searches for Beyond-the-Standard-Model Physics
Gamma Ray Signatures of Ultra High Energy Cosmic Ray Line-of-sight Interactions

Key CTA Contributions to the Cosmic Frontier

- 10-fold improved sensitivity for VHE studies of the cosmos
  - ✓ "Routine" astrophysics is the foundation for recognizing new fundamental physics
- Sensitive searches for dark matter in its cosmic home
- Tests of cosmology
  - ✓ Extragalactic background light (EBL)
  - ✓ Intergalactic magnetic fields (IGMF)
- γ-ray propagation over cosmic distances
  - ✓ Tests of Lorentz invariance (LIV)
  - ✓ Search for signatures of axion-like particles (ALP)