Probing the Very High Energy Universe with the Cherenkov Telescope Array

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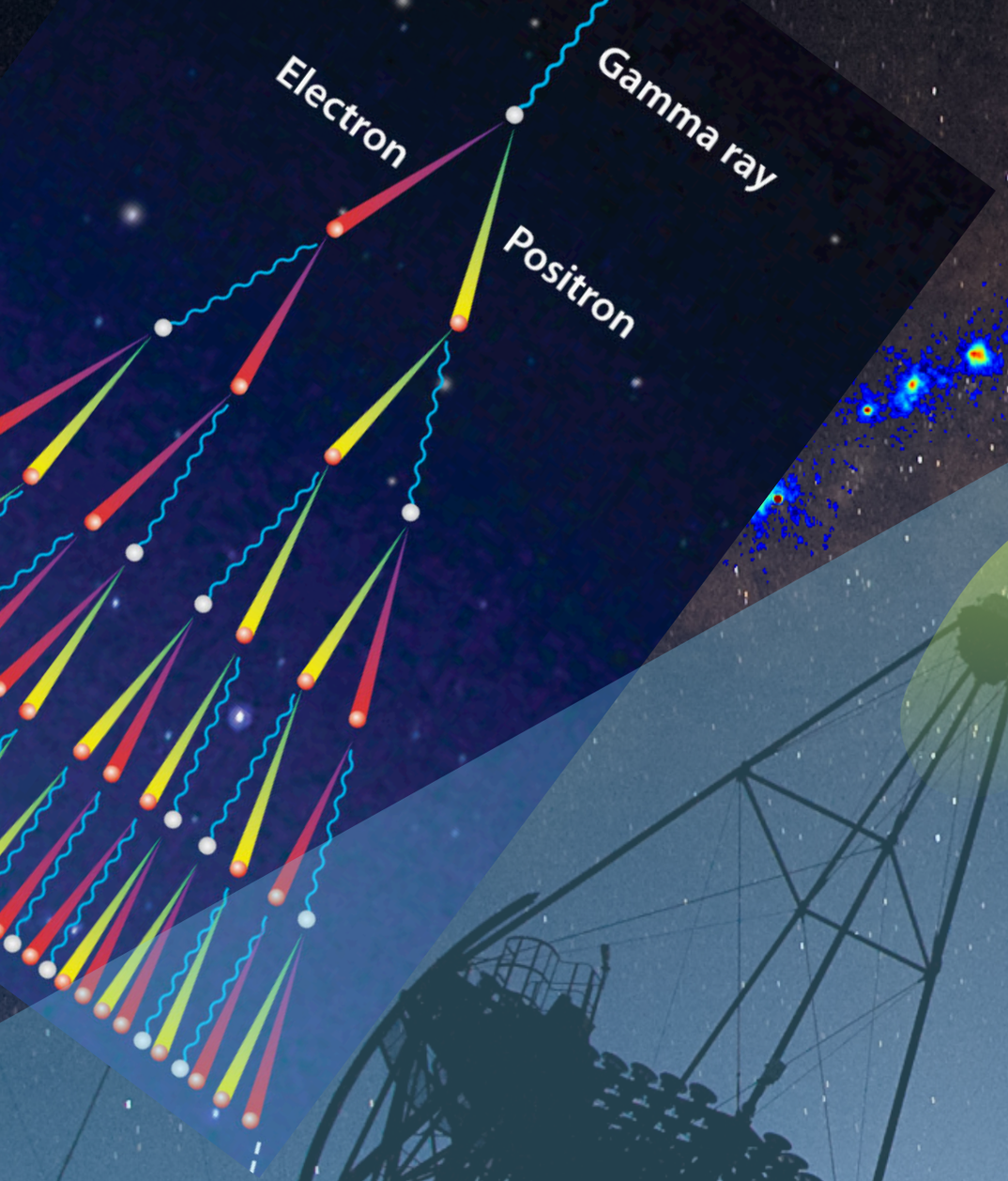
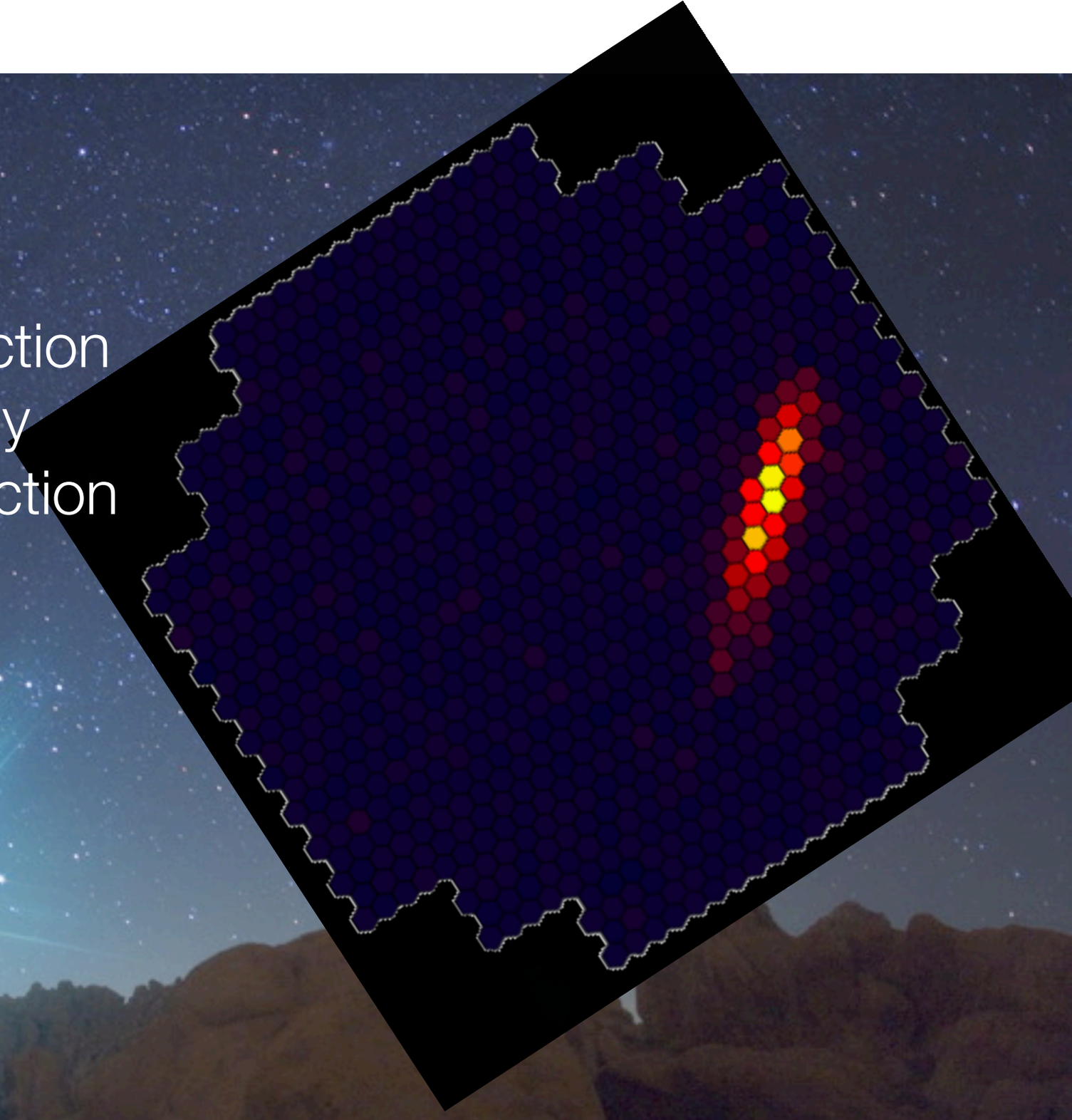
For the CTA Consortium
http://www.cta-observatory.org



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



Wally Pacholka / AstroPics.com

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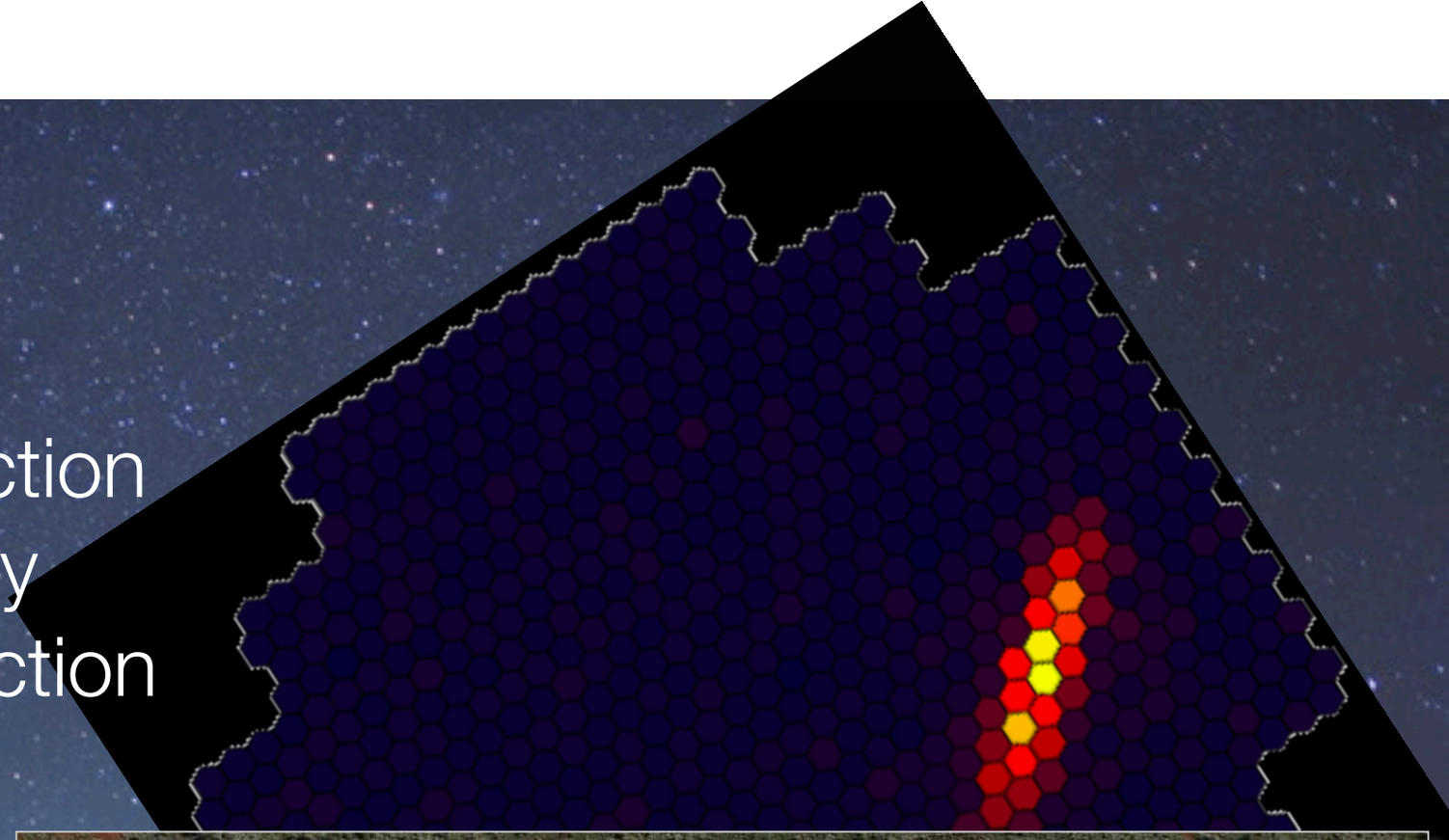
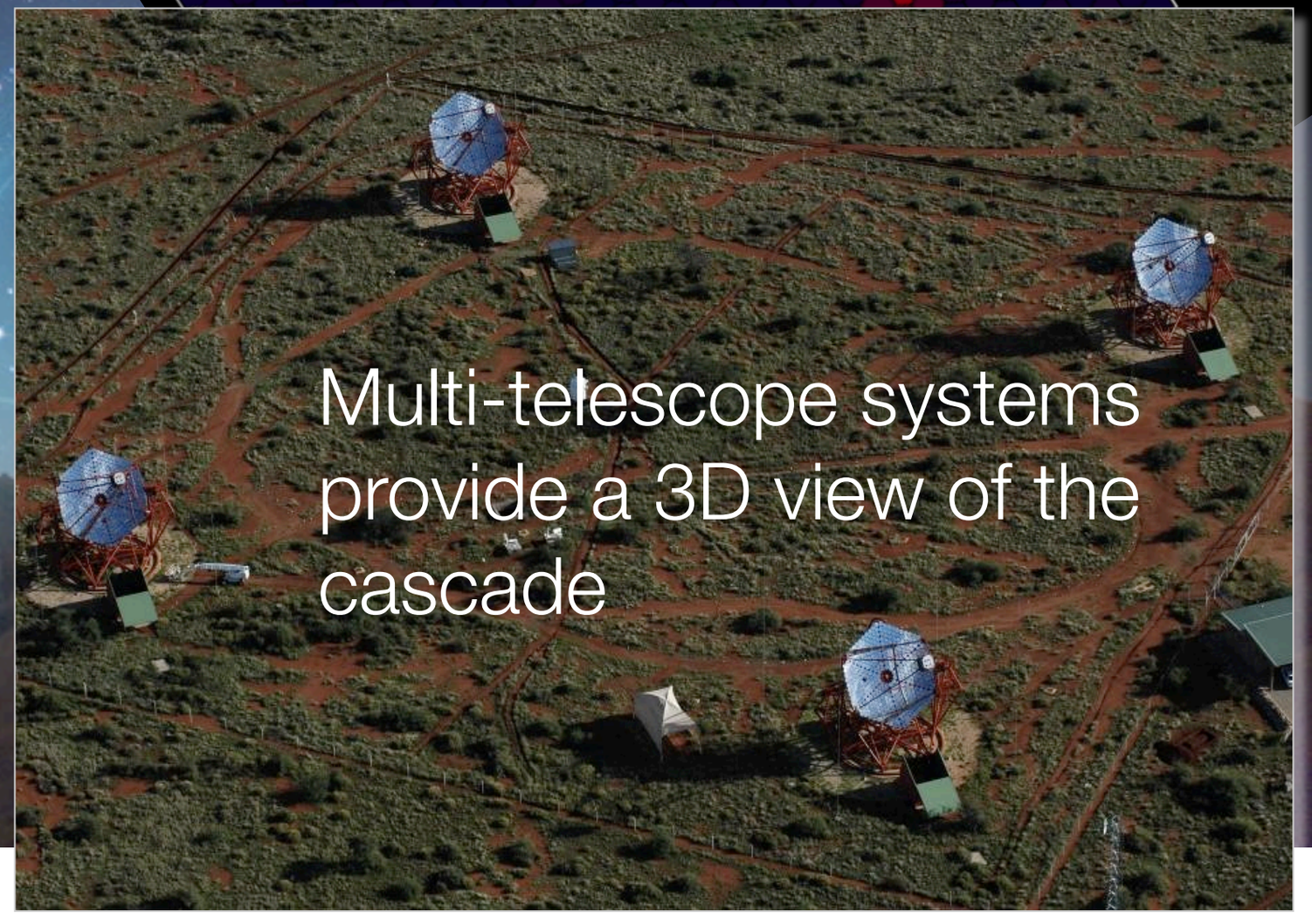
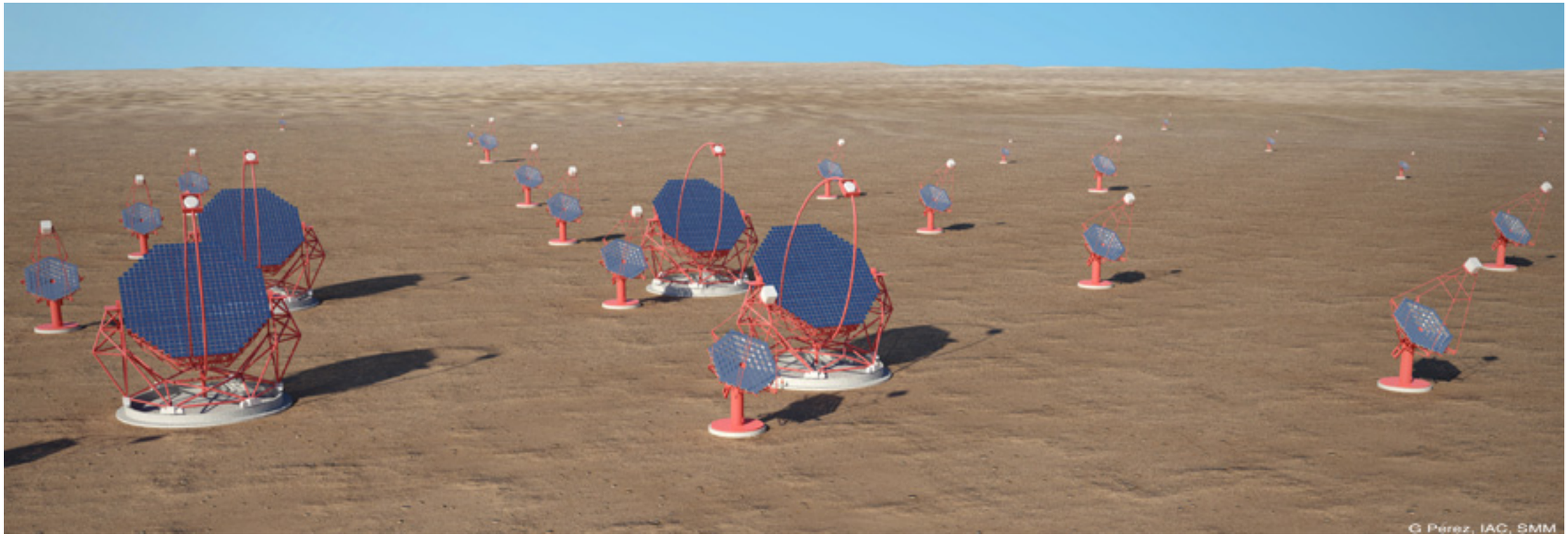




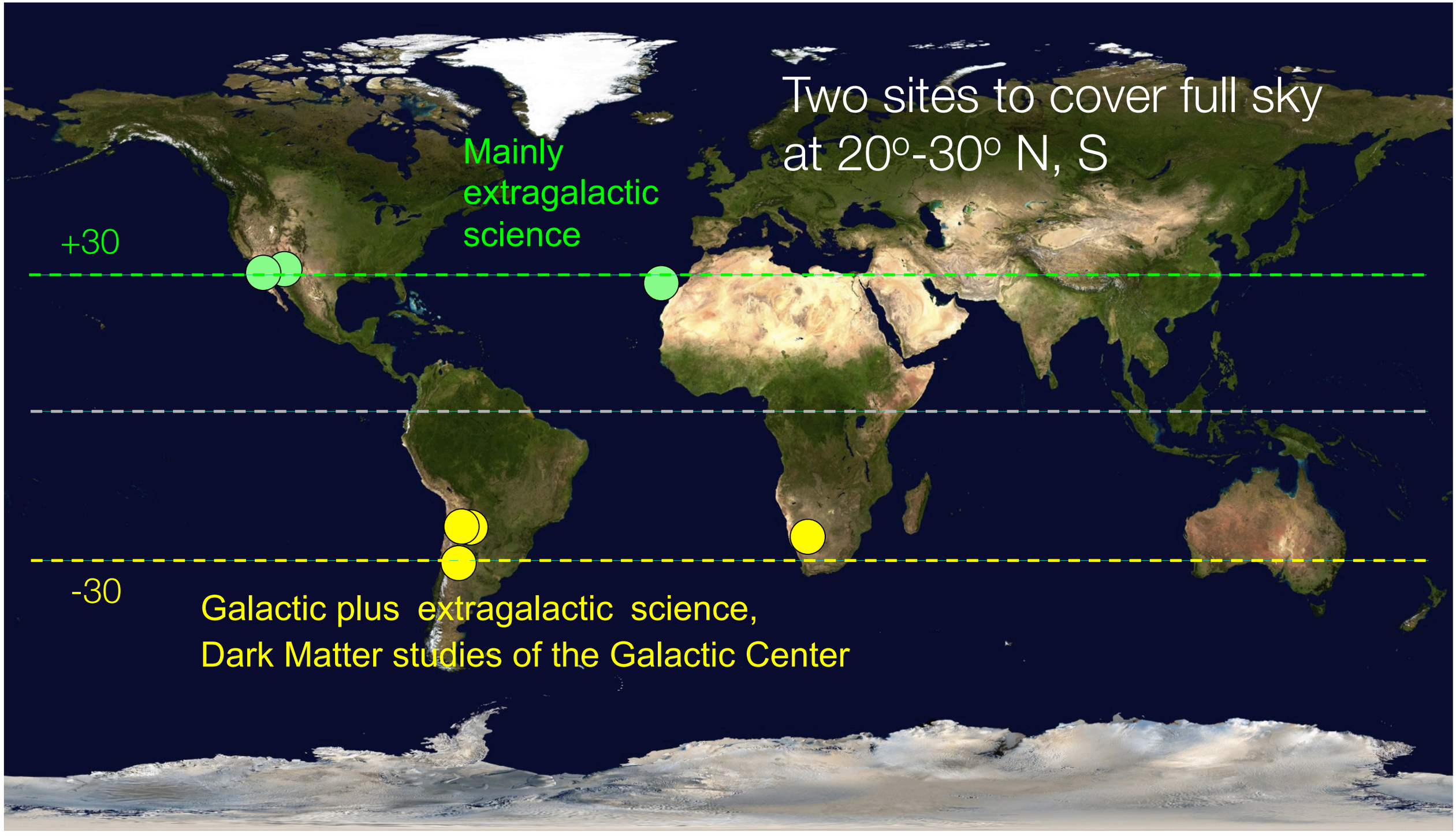
Multi-telescope systems provide a 3D view of the cascade

The CTA Concept

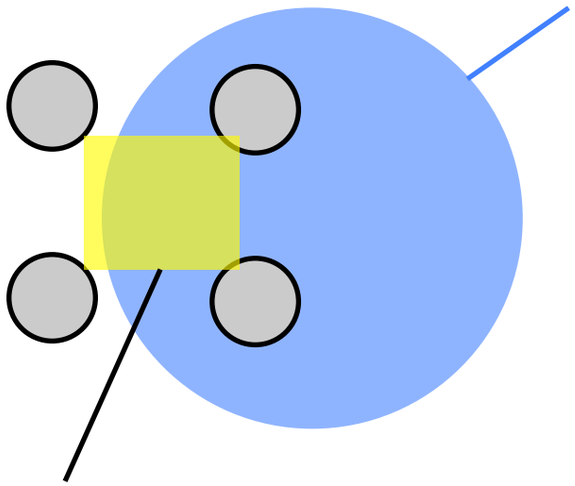


- Arrays in northern and southern hemispheres for full sky coverage
- 4 large (~23 m) telescopes in the center (LSTs)
  - Threshold of ~30 GeV
- ≥25 medium (9-12 m) telescopes (MSTs) covering ~1 km^2
  - Order of magnitude sensitivity improvement in 100 GeV–10 TeV range
- Small (~4 m) telescopes (SSTs)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

Sites: Candidates

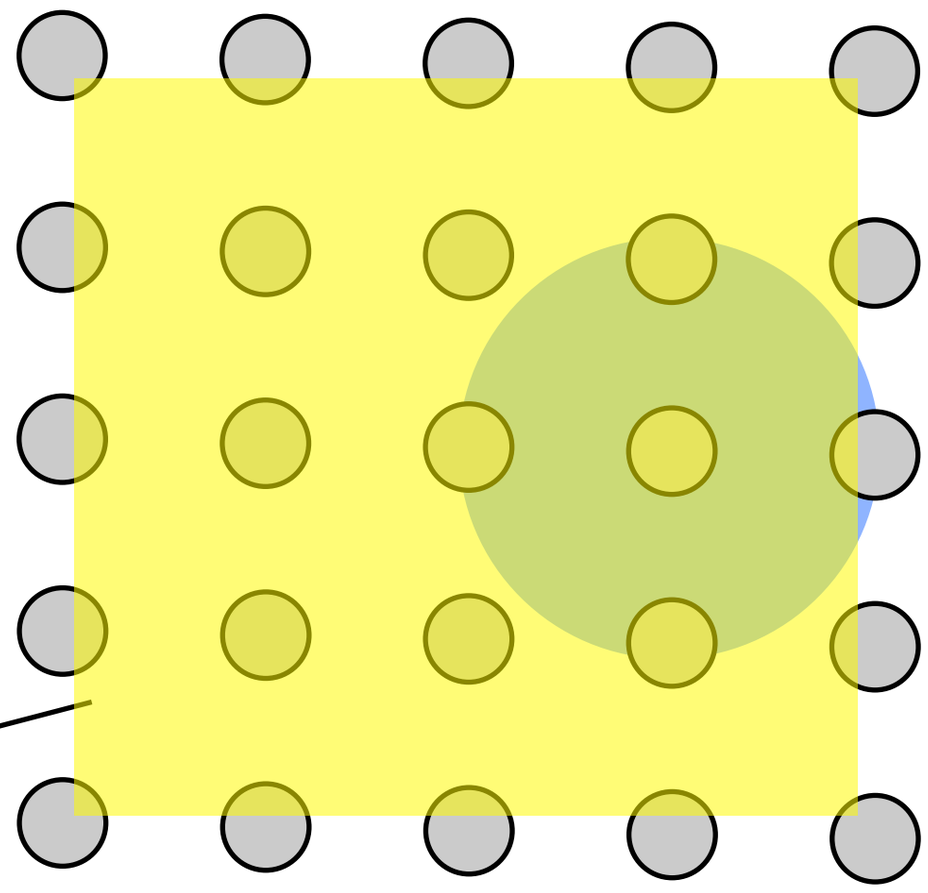


From current arrays to CTA



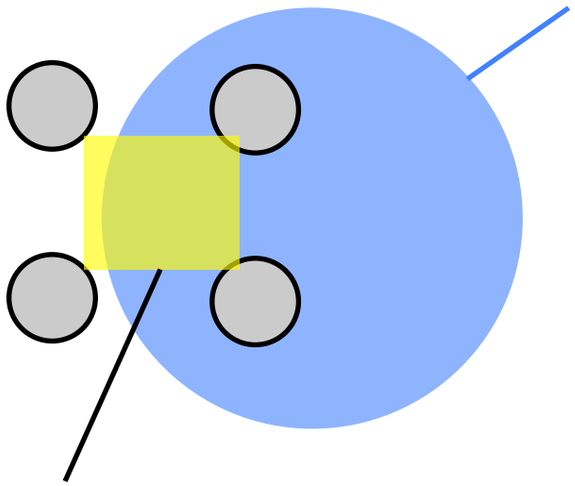
Light pool radius
R ≈100-150 m
≈ typical telescope spacing

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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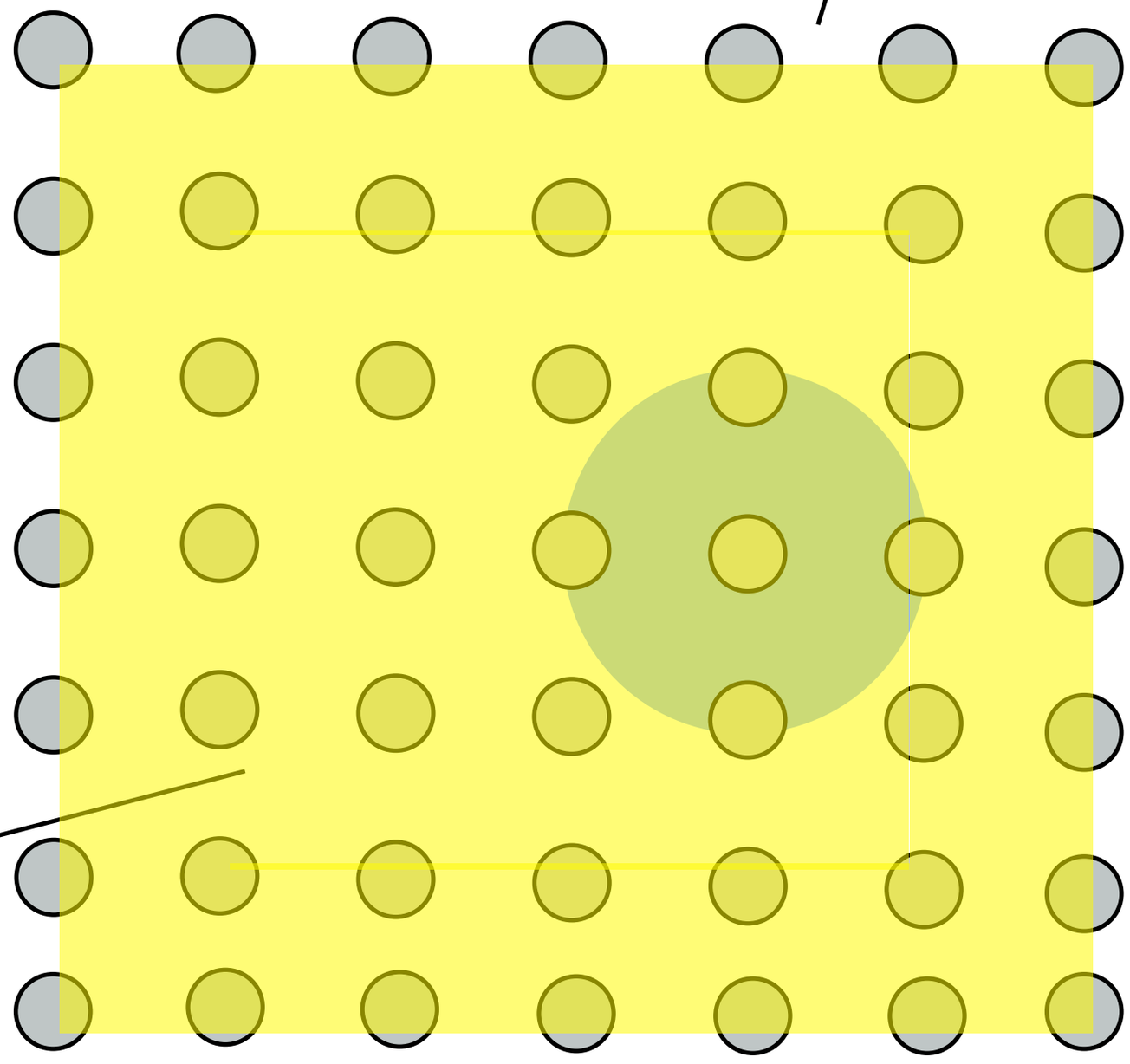
With US telescopes



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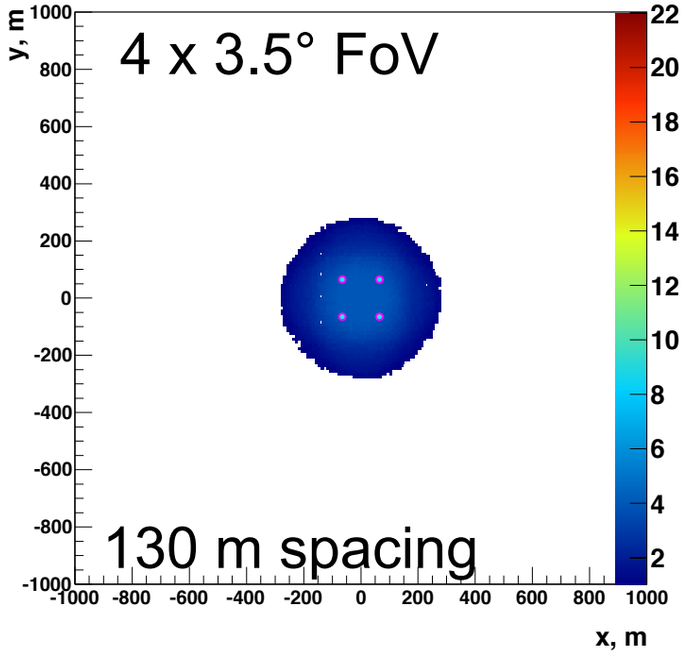
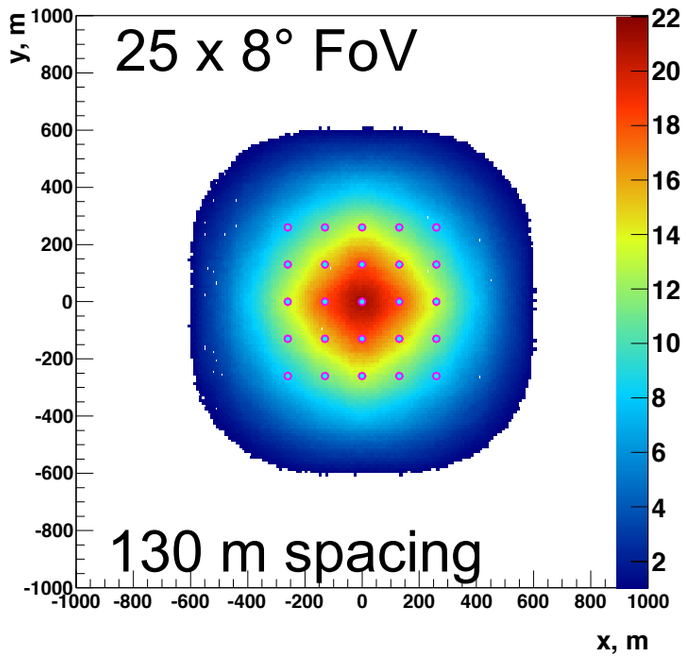
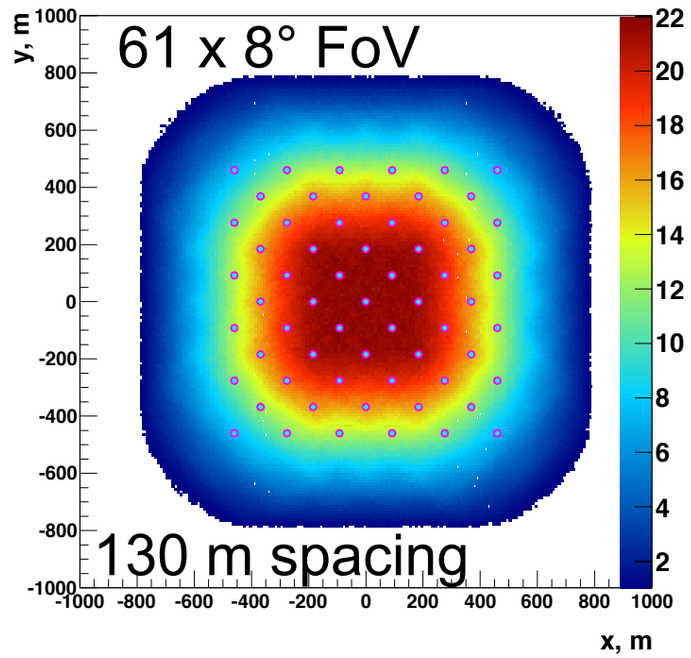
More images per shower
Lower trigger threshold

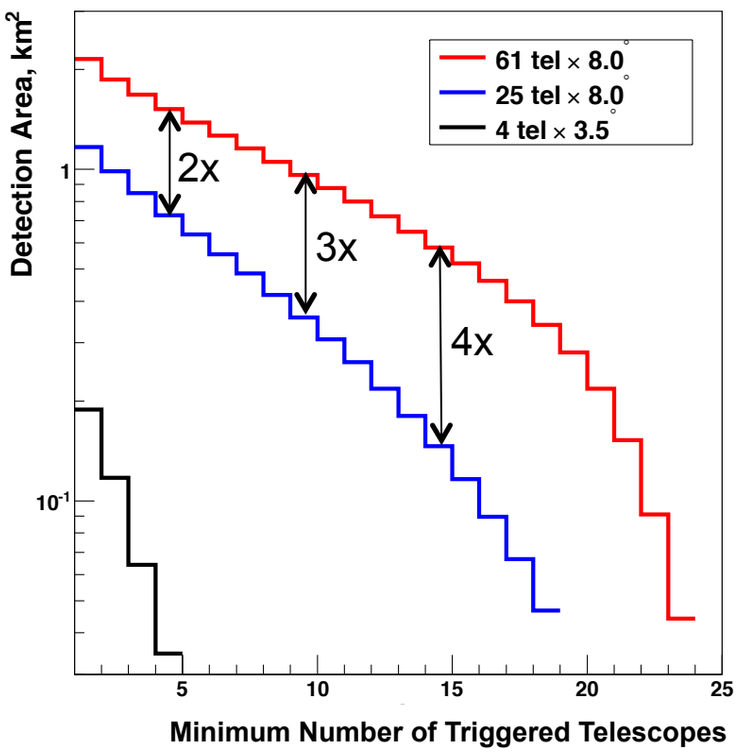
Why a large array?

Figures from Slava Bugaev









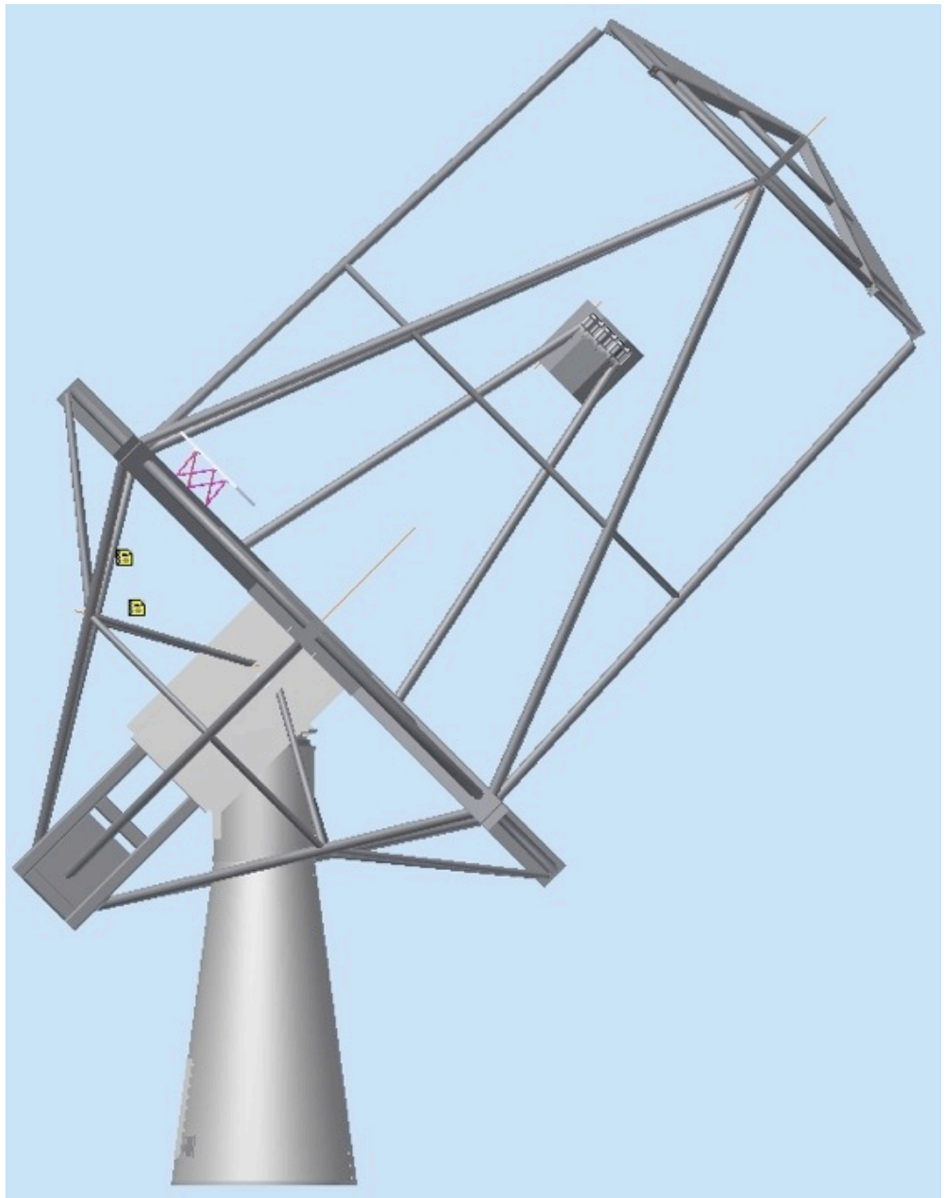
Color scale: number of triggered telescopes for 500 GeV showers

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

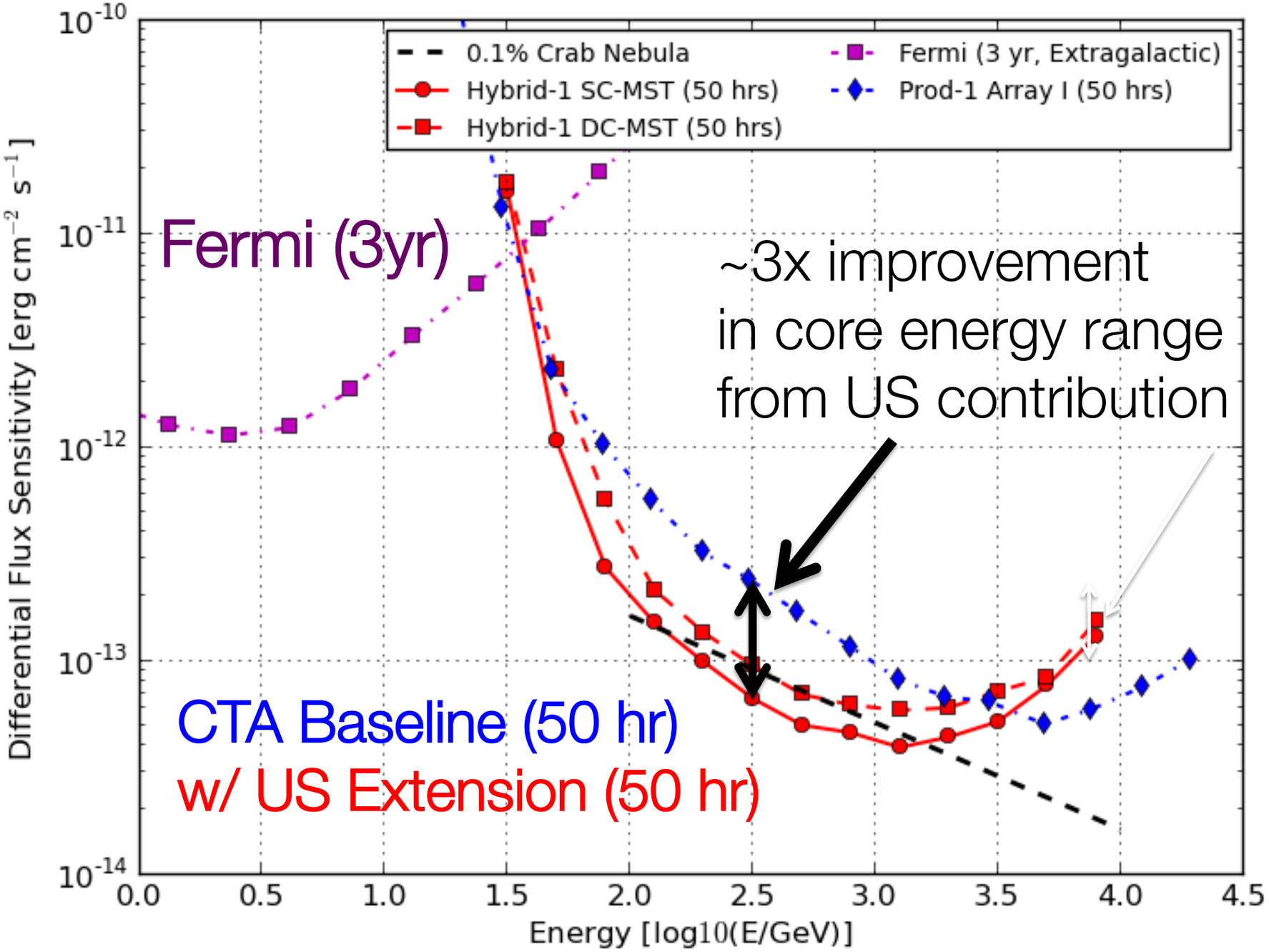
- Double the size of the southern array
- Developing novel design w/ secondary mirror & <0.07° optical psf

Schwarzschild-Couder Telescope Design

- Reduces plate scale, corrects aberrations providing higher resolution, wider field camera at similar cost to traditional, lower-resolution cameras.
- Small plate scale enables new photodetector technologies to be exploited (e.g. SiPMs)
- Deep analog memory waveform samplers to minimize dead-time, and allow more powerful/ flexible hardware array triggering.
- High level of integration into ASICs allows dramatic cost savings (<$20 per channel for waveform digitizers, <$100 per channel for total camera cost)
- Hierarchical camera design and modularity for serviceability, lower development costs



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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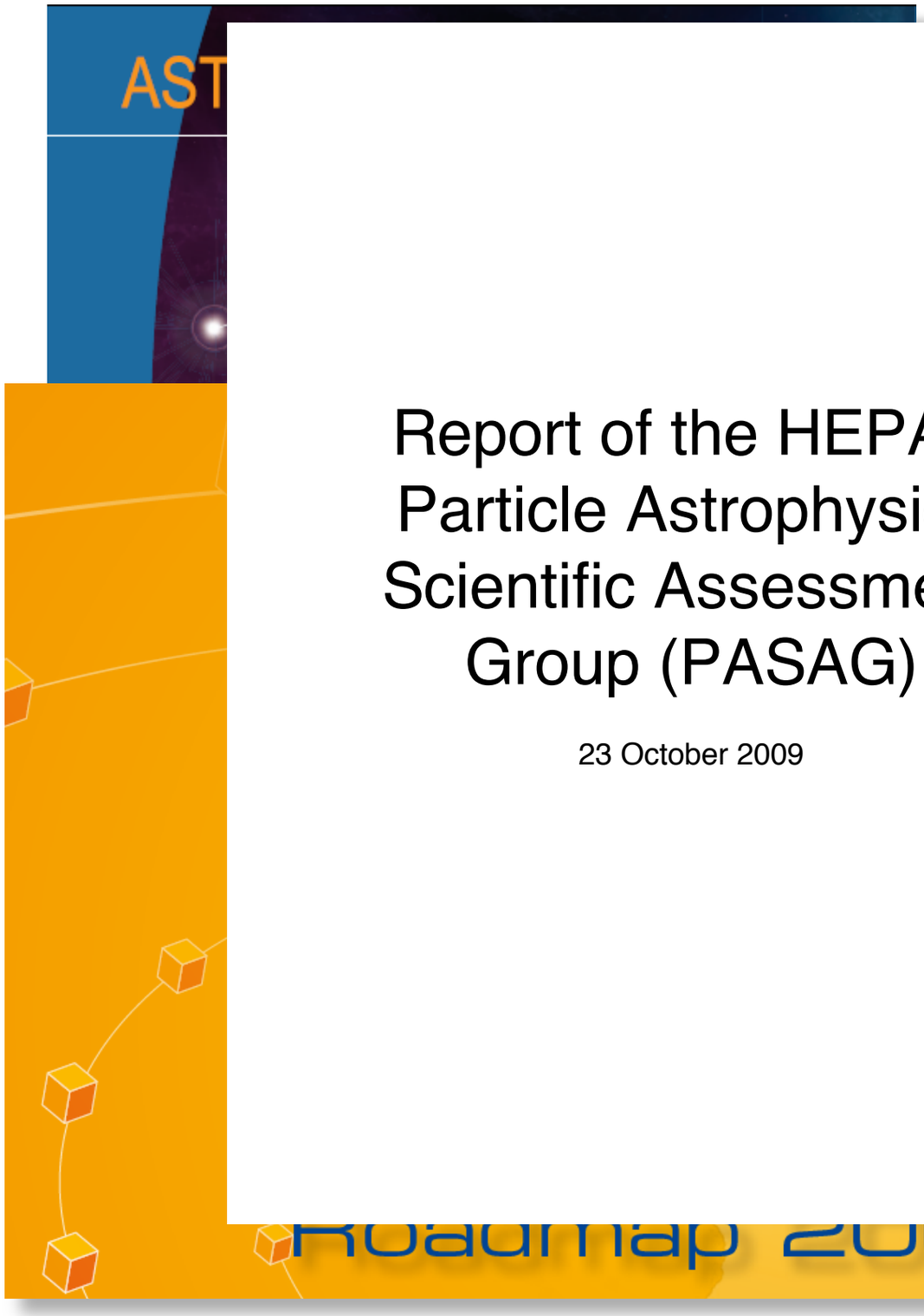
cta
cherenkov telescope array



Report of the HEPAP Particle Astrophysics Scientific Assessment Group (PASAG)

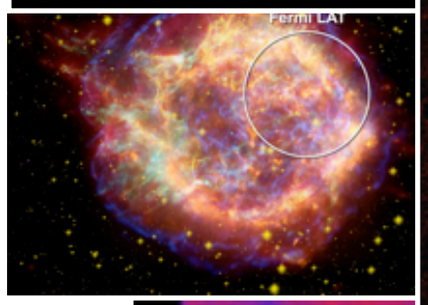
23 October 2009

Gamma-ray astrophysics

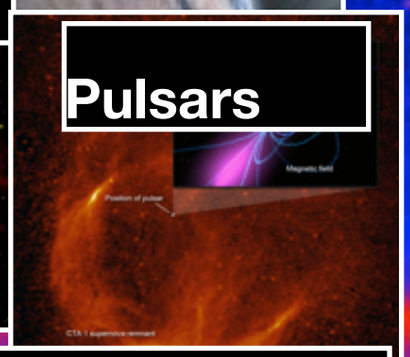
Particle Acceleration

Cosmic rays

Supernova remnants



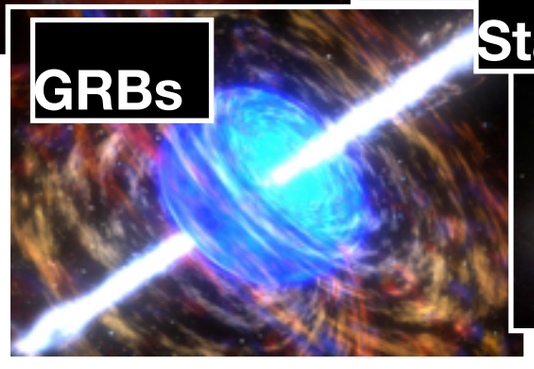
Pulsars



Binaries

AGN

GRBs



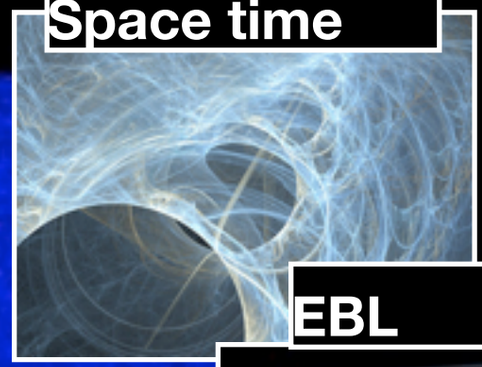
Starburst Galaxies

Dark Matter

Annihilation

Cosmology

Space time

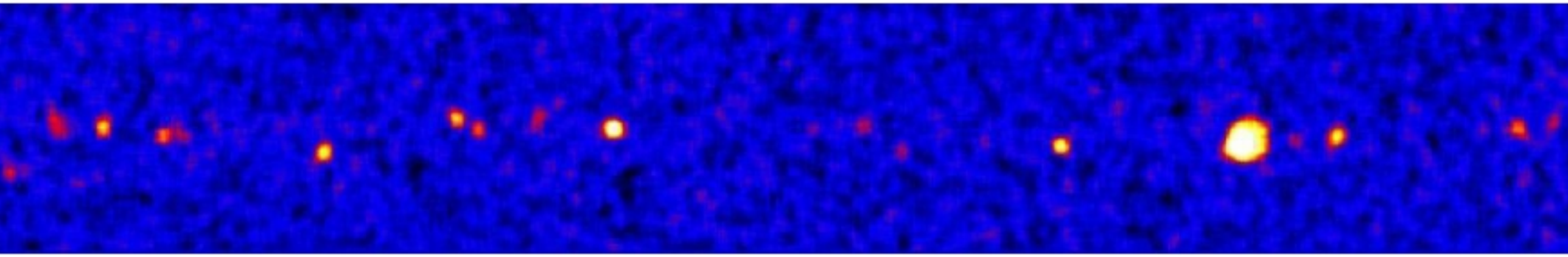


EBL

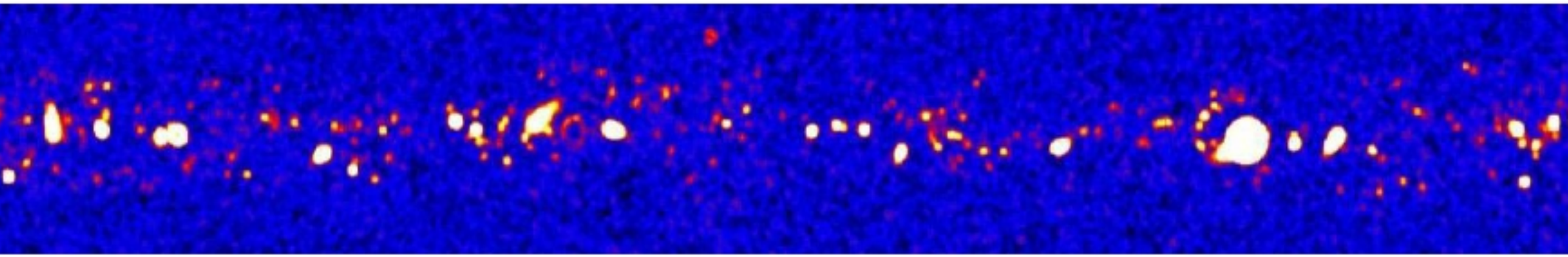
... ?

Simulated Galactic Plane surveys

H.E.S.S.



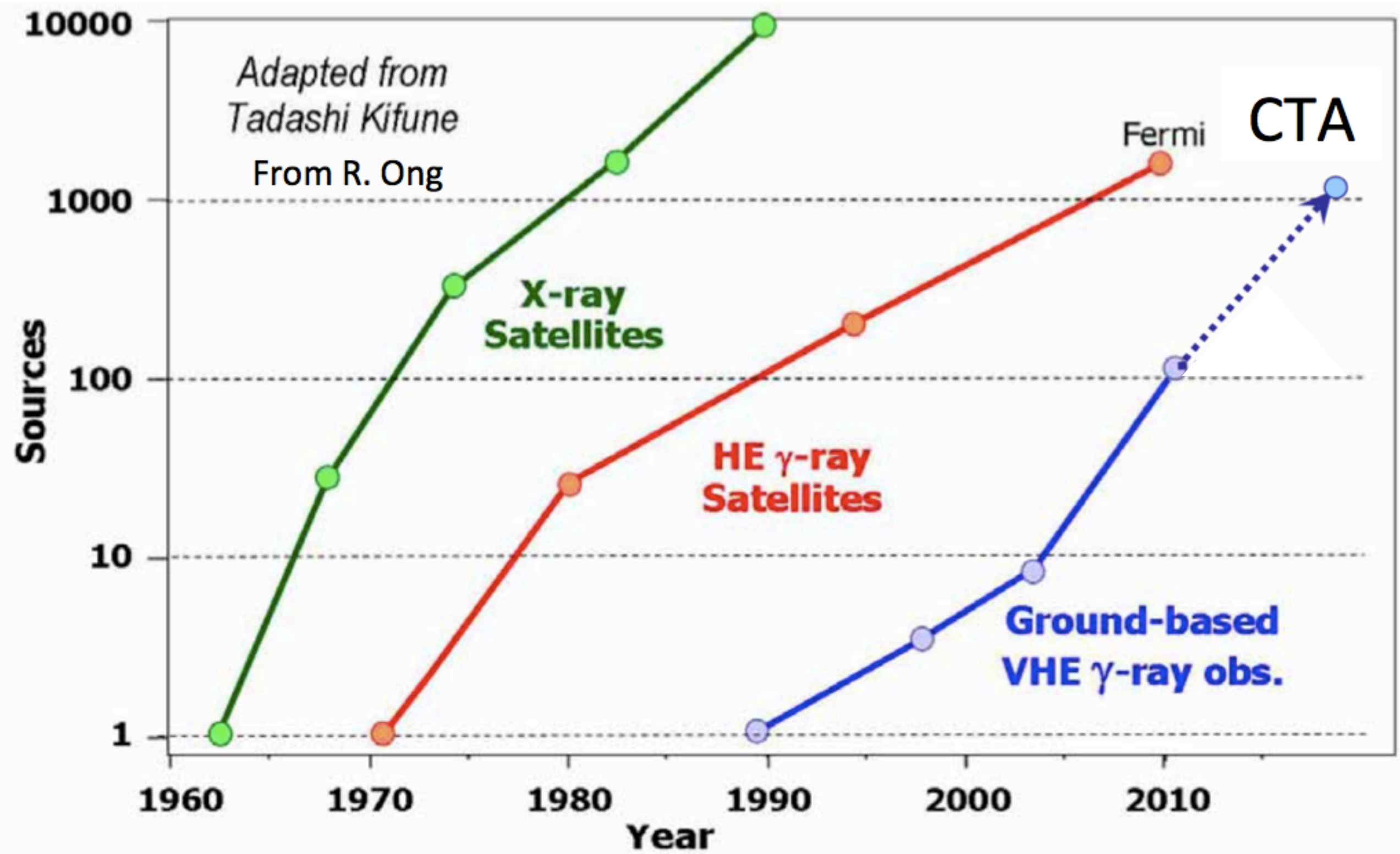
CTA, for same exposure



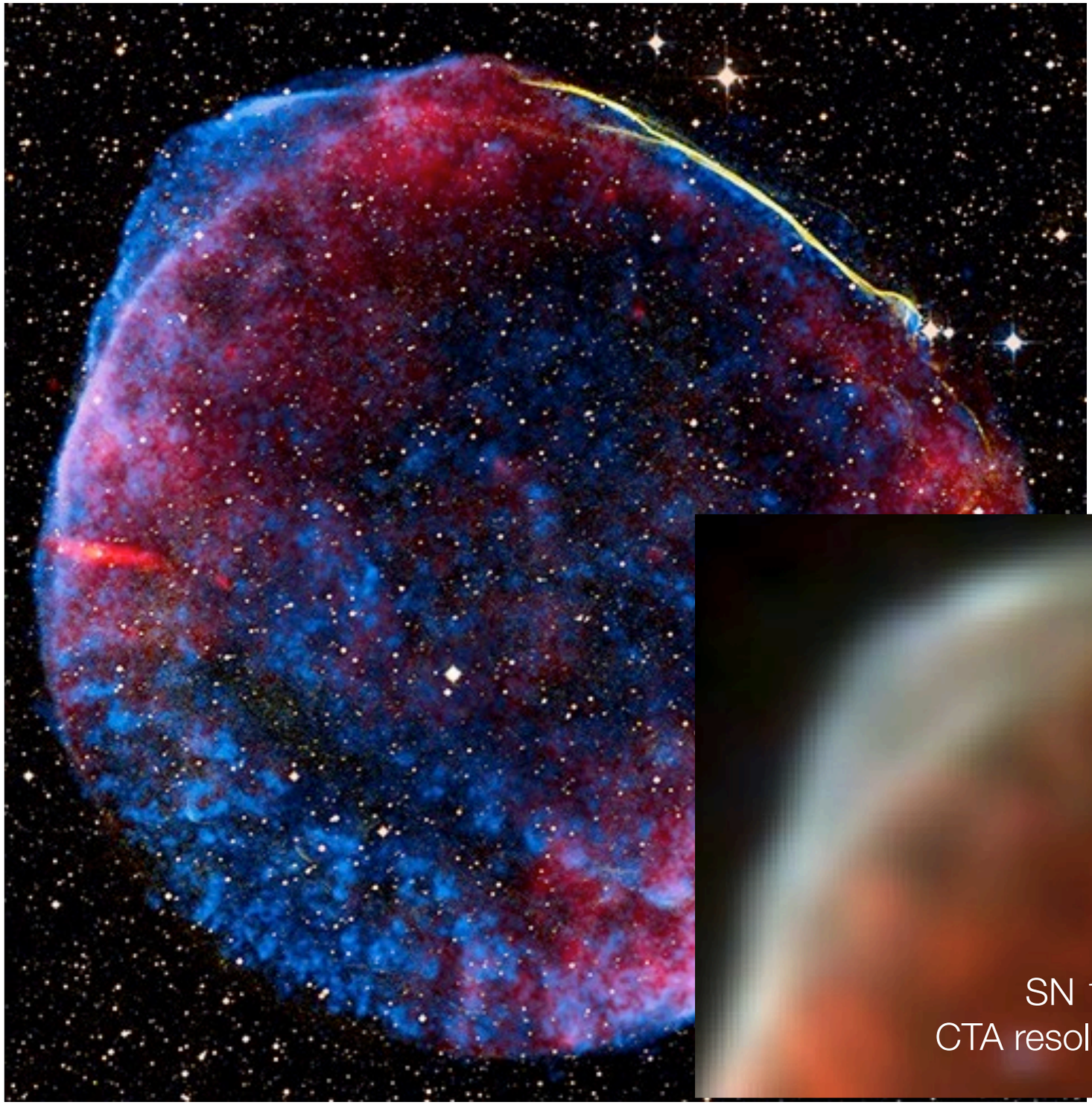
Expect ~1000 detected sources over the whole sky

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

Growth of Source Populations

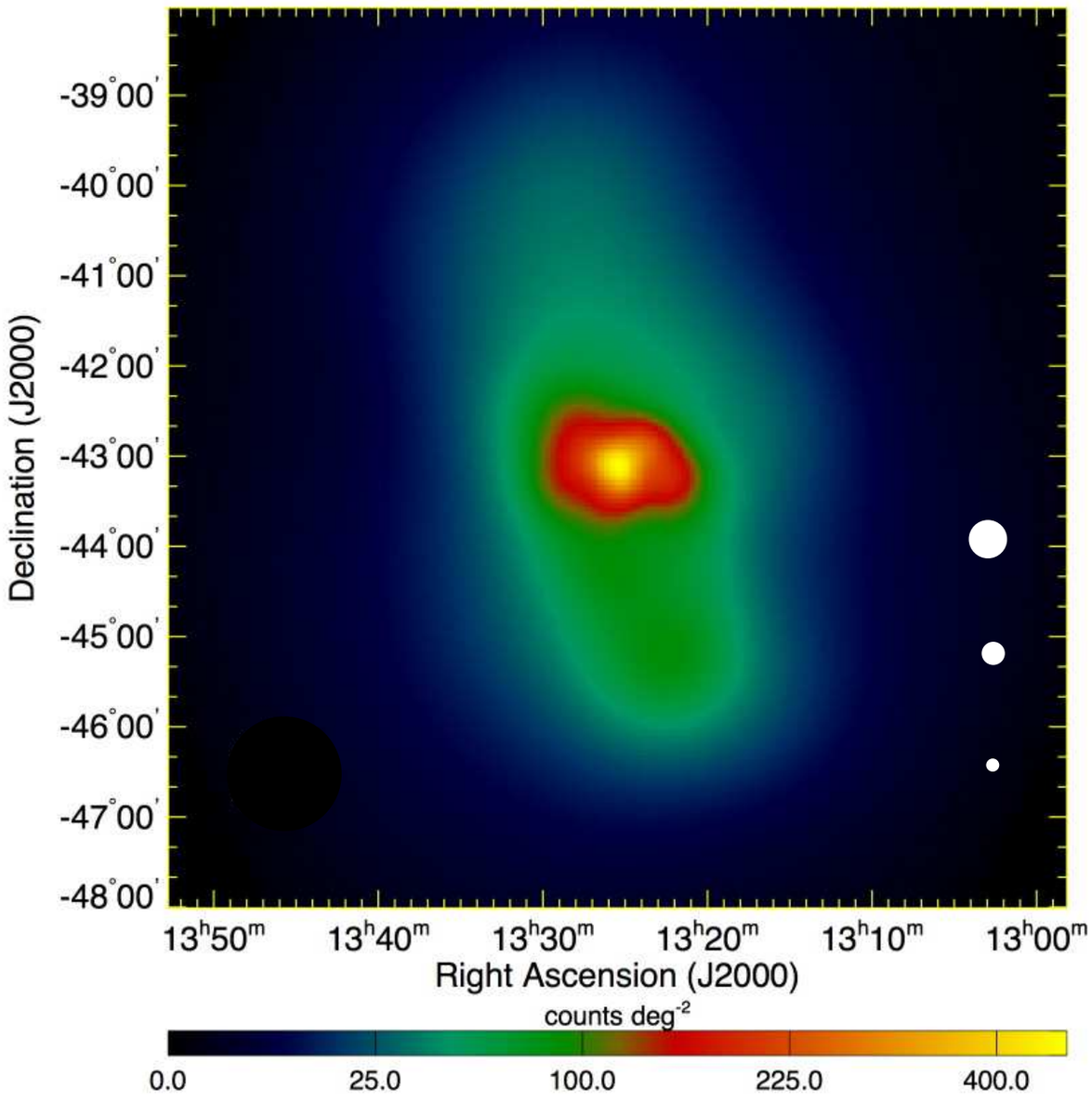


Resolving complex sources



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)

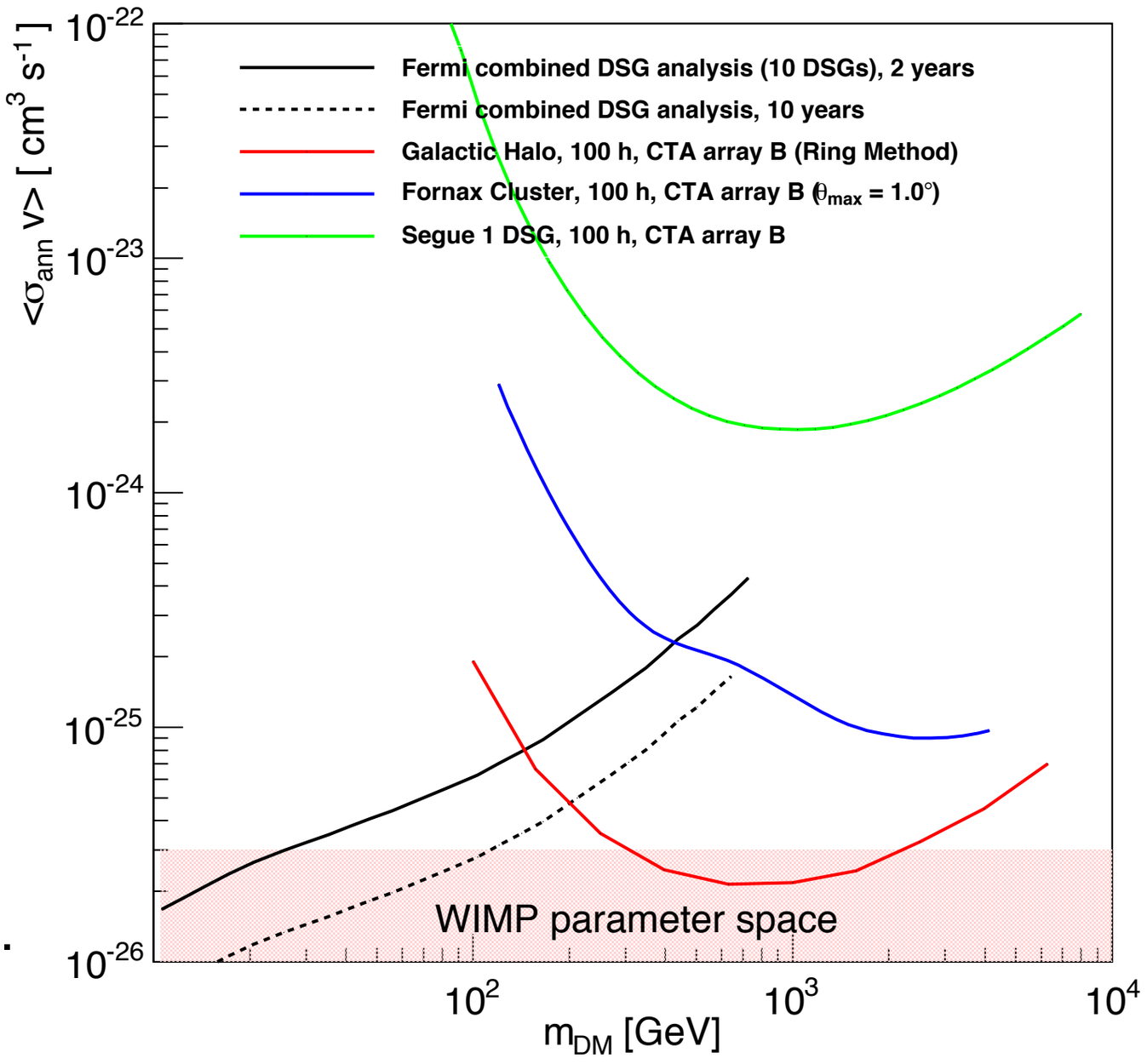
Expect to detect hundreds of AGN

Dark matter searches with CTA

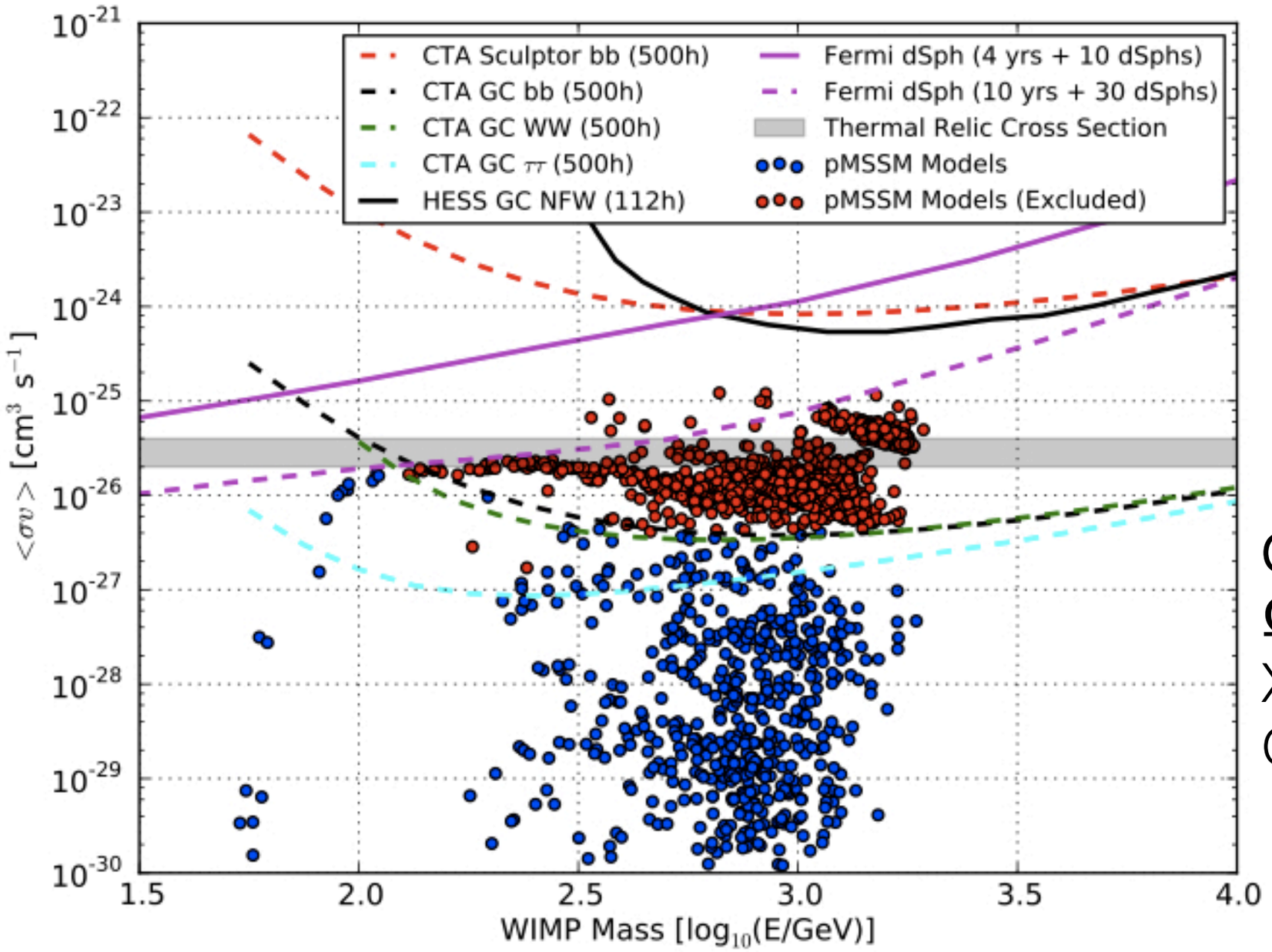
Fermi dwarf spheroidal and CTA Galactic Center searches are complementary

Assuming b b-bar decay channel

LAT 2-year result from Ackermann et al. 2011, *Phys. Rev. Lett.* **107**, 241302.



Dark matter searches with CTA



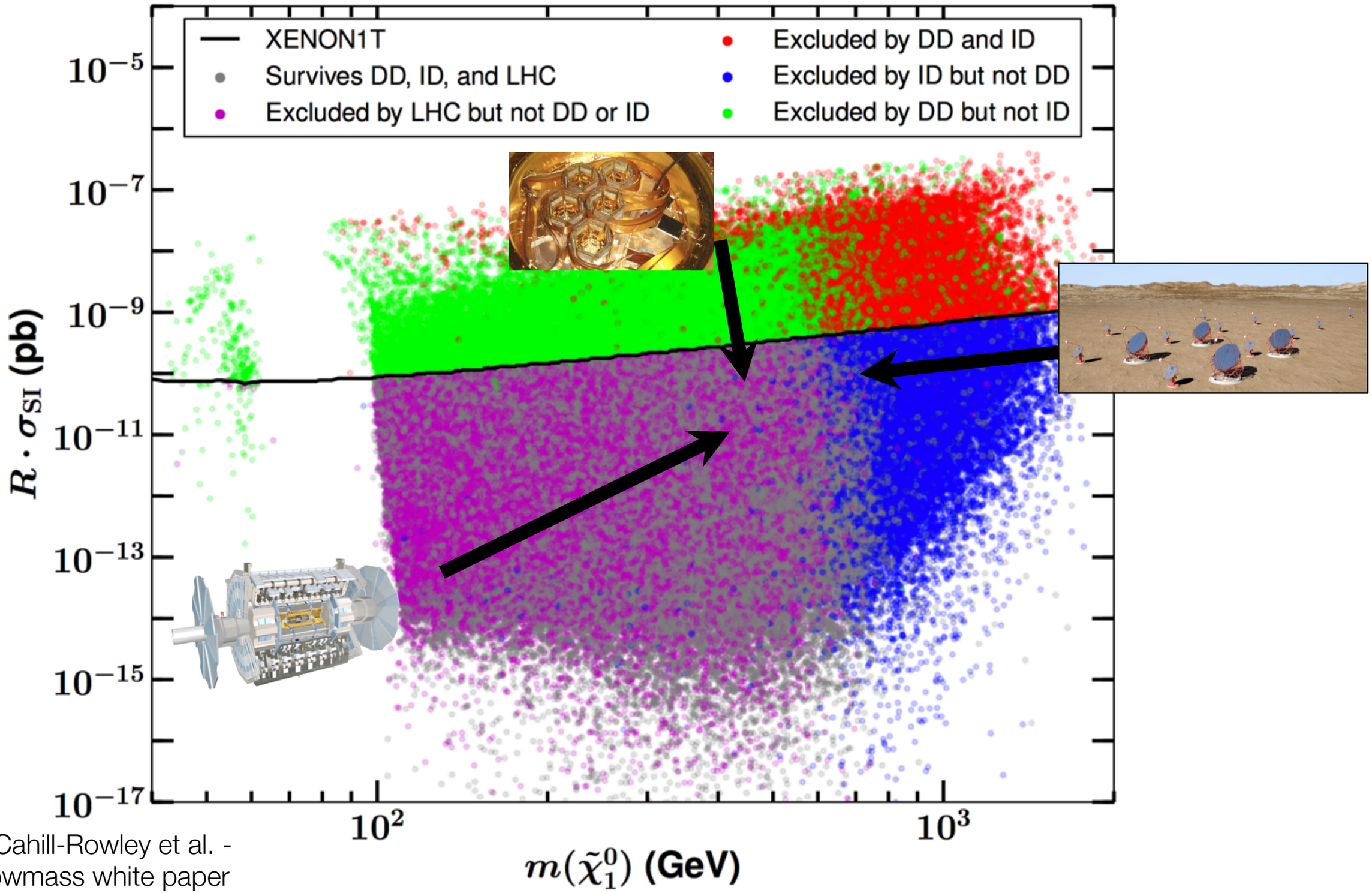
Constraints

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

XENON100 (2011)

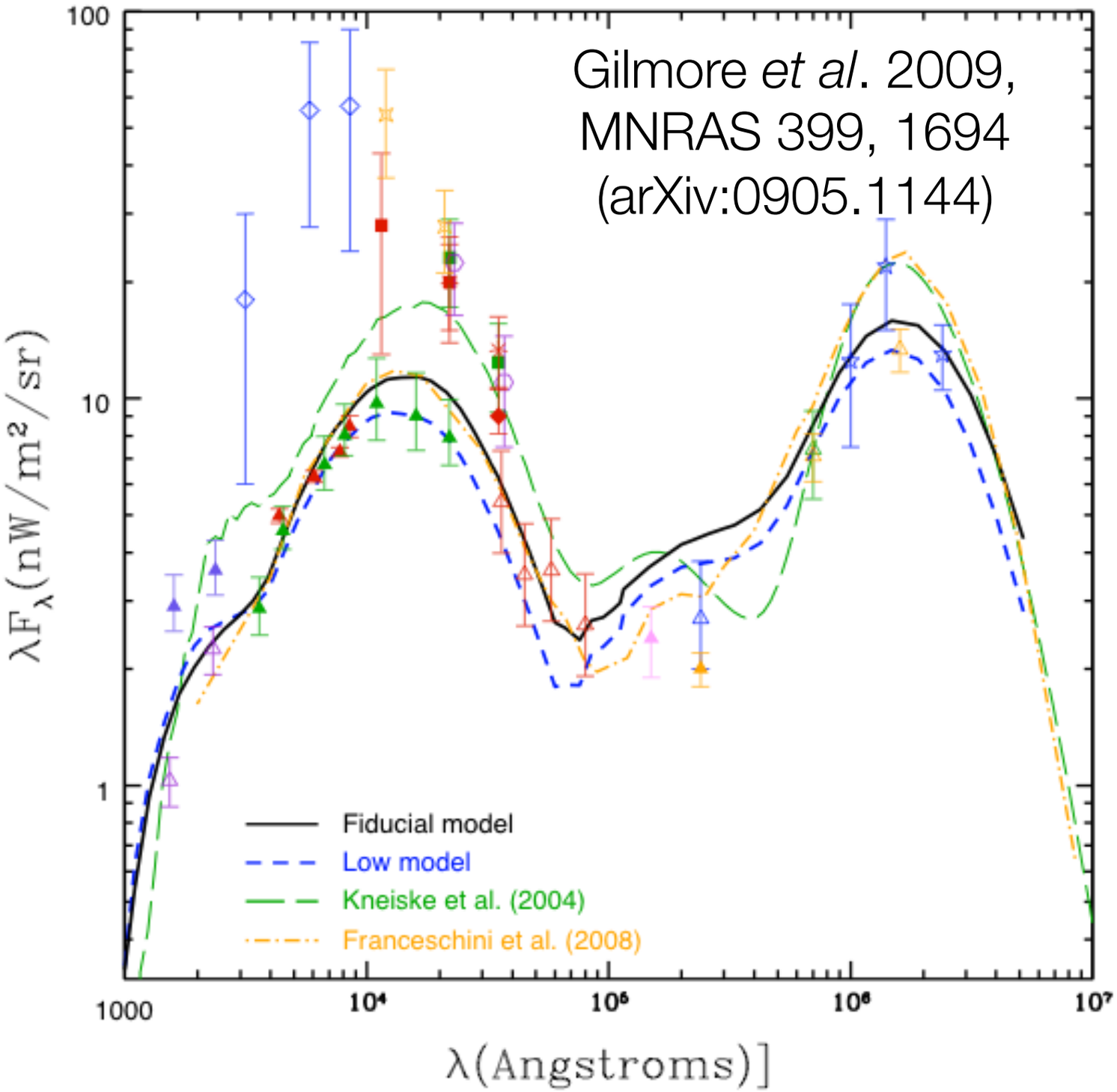
CMS+ATLAS (2012)

Complementarity -SUSY scan (pMSSM)



M. Cahill-Rowley et al. - Snowmass white paper

Extragalactic Background Light



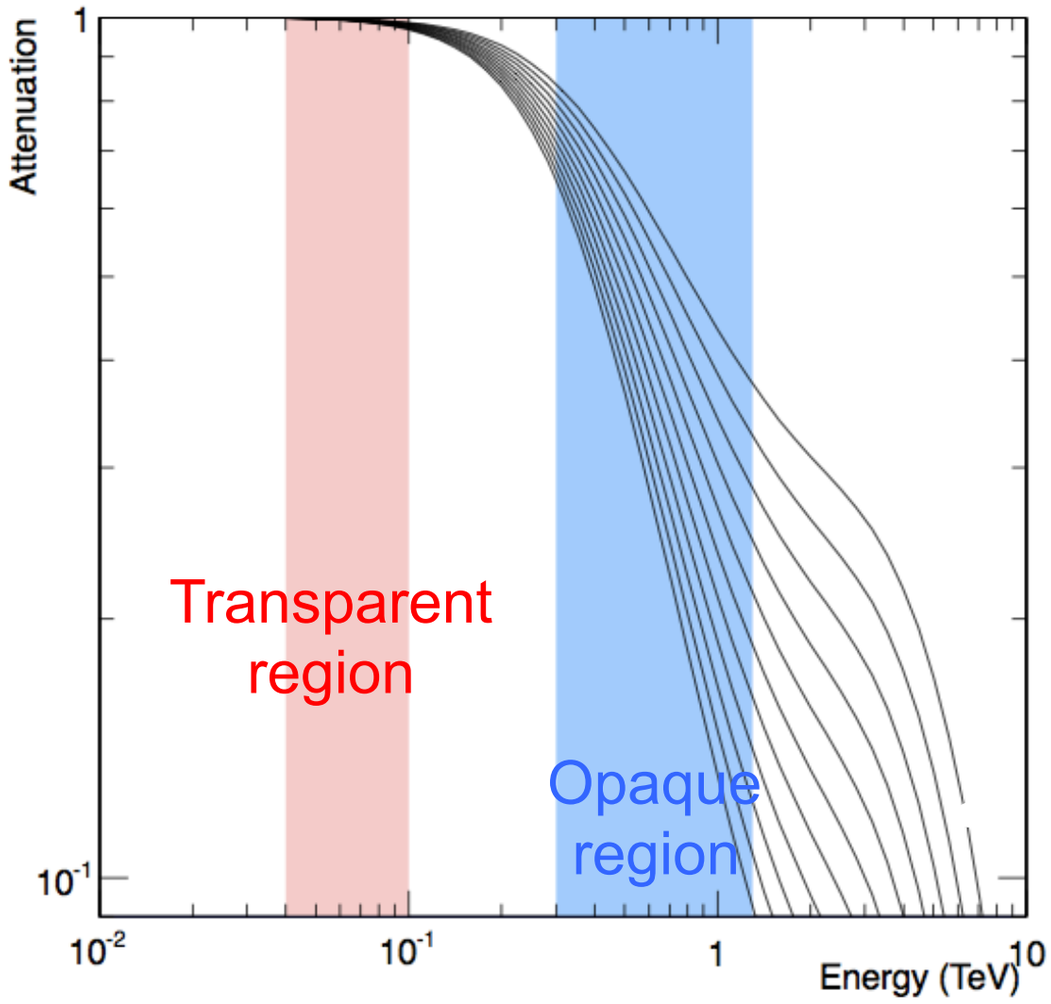
$\gamma_{\text{High Energy}} + \gamma_{\text{EBL}} \rightarrow e^+ e^-$

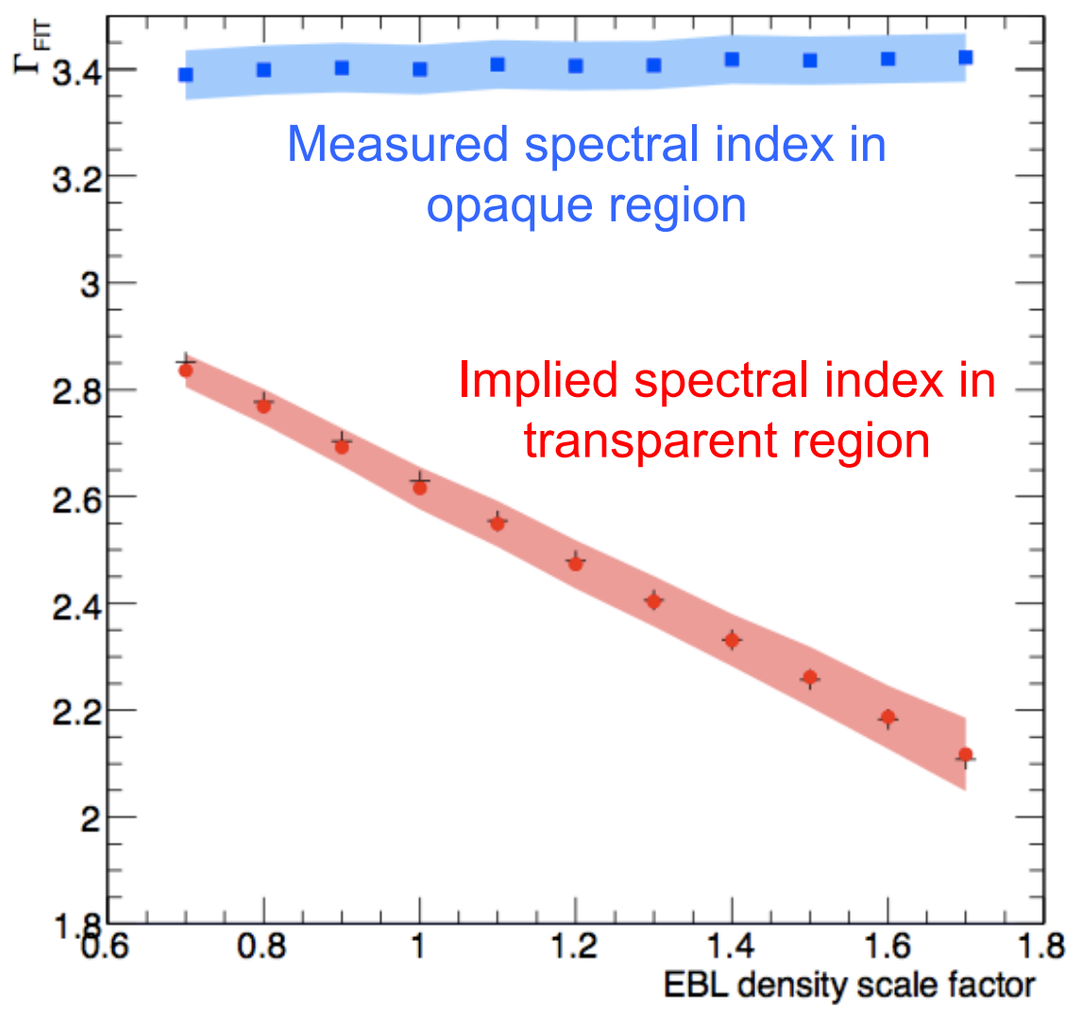
Difficult to measure EBL because of foreground sources

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

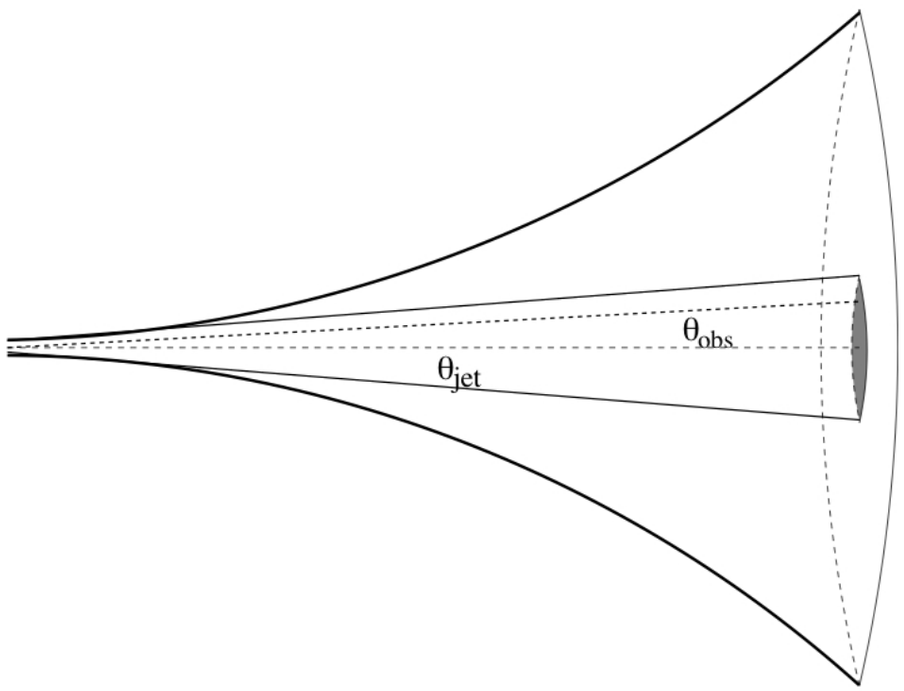




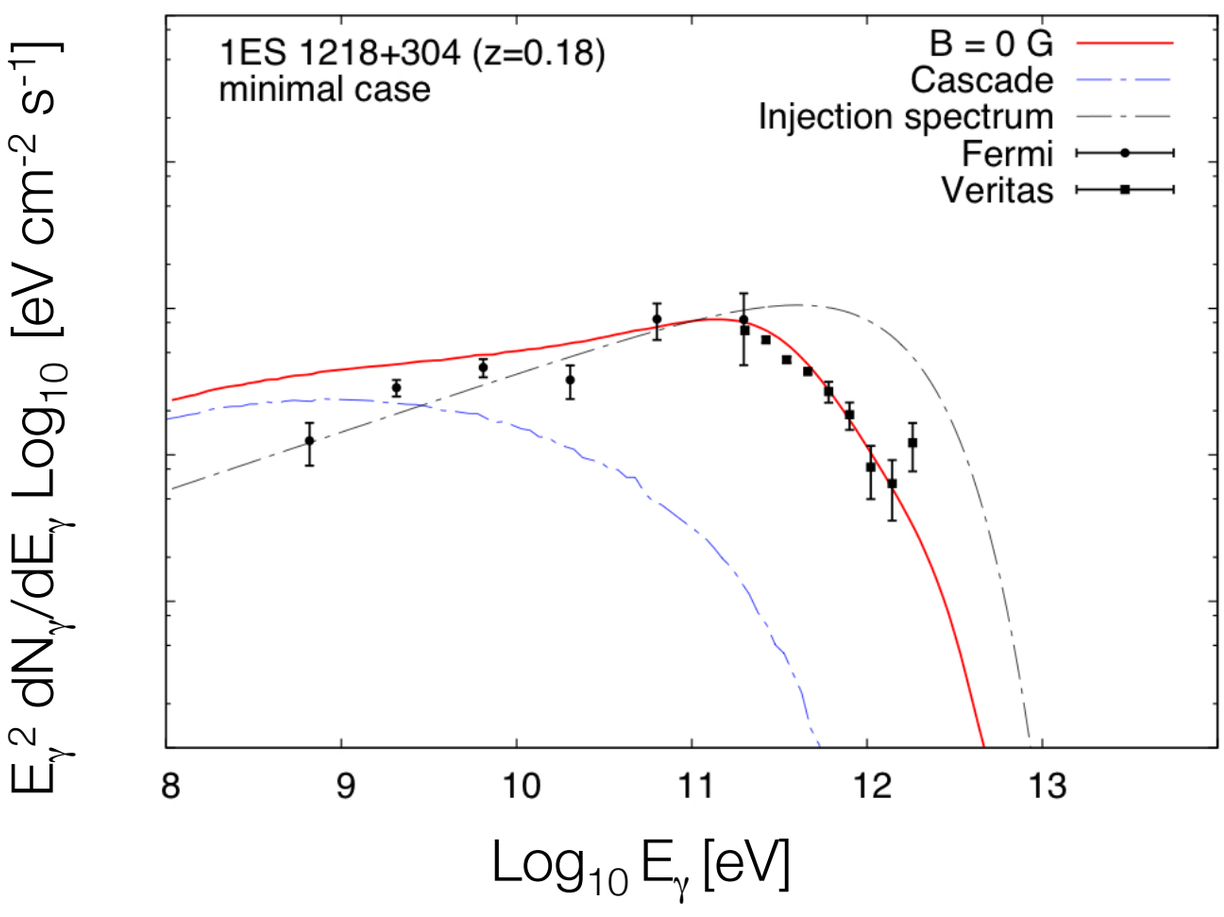
Spectral index Γ from fit to $dN/dE \sim E^{-\Gamma}$
EBL model of Franceschini et al. 2008

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

The EBL and Intergalactic B Fields

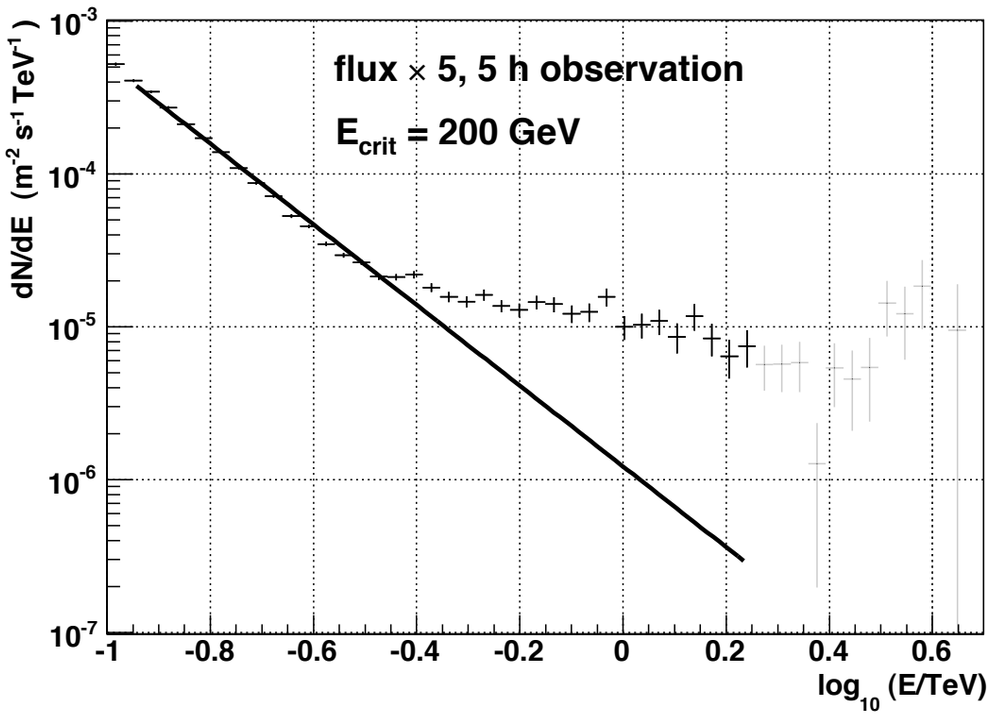


- Electrons produced by
  $\gamma_{\text{High Energy}} + \gamma_{EBL} \rightarrow e^+ e^-$
  Compton scatter off EBL to produce more photons
- Amount that the cascade fans out depends on intergalactic magnetic field (IGMF) strength
- Observable effects:
  - Pair halo
  - Spectral distortion
  - Large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

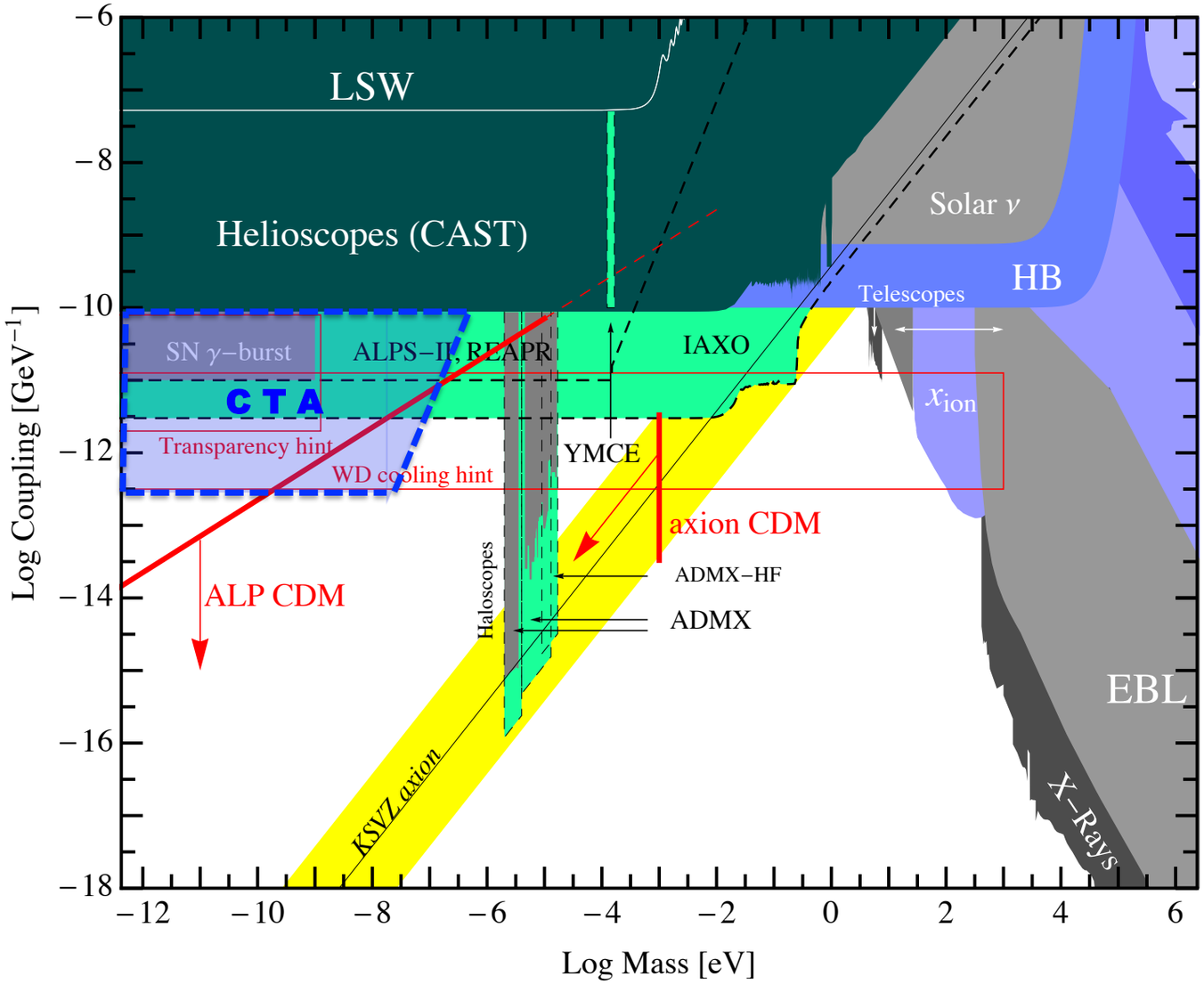


Figures from Taylor *et al*. 2011, arXiv: 1101.0932

Axion-like Particles (ALPs)



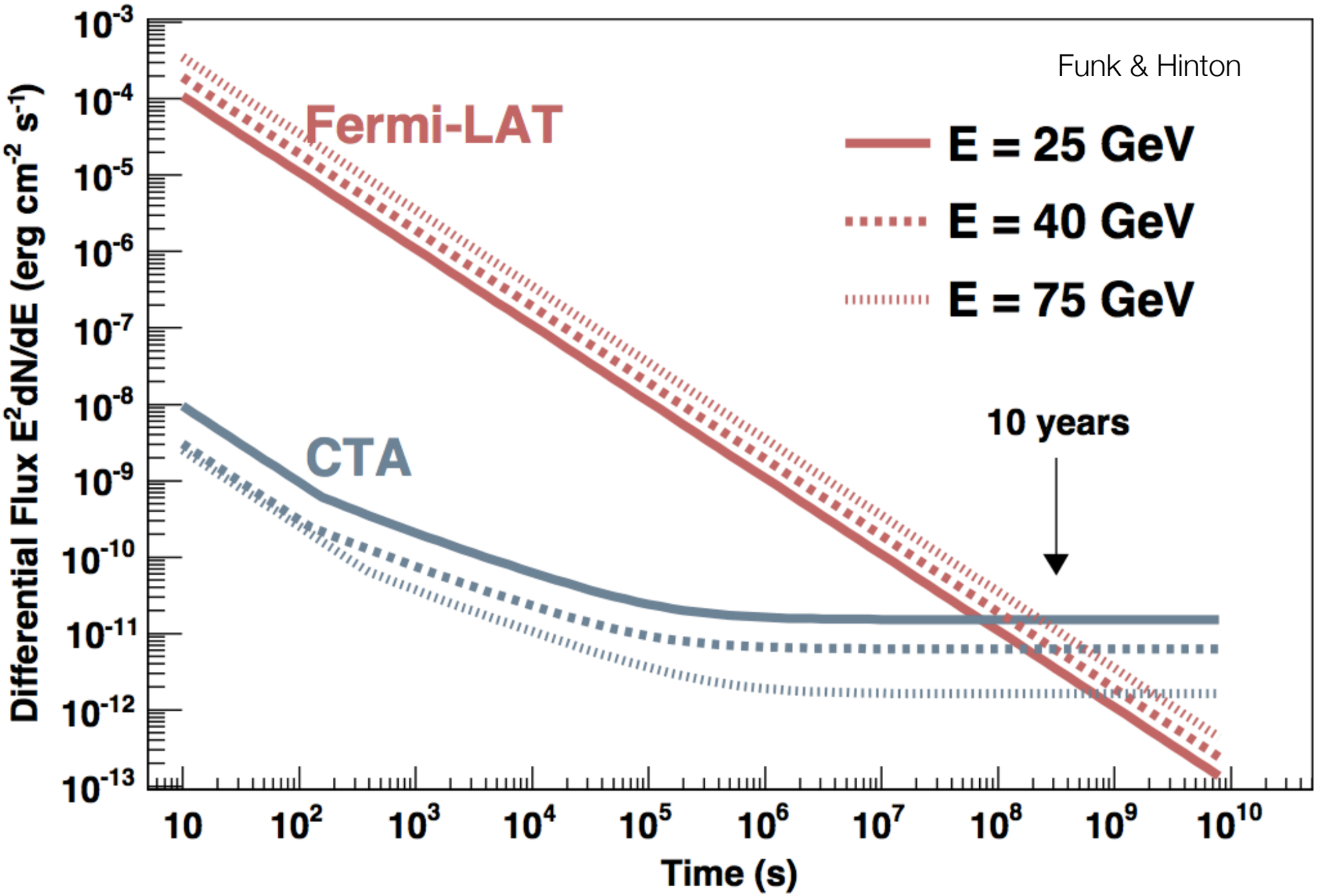
Simulated CTA observation
Bright flare from 4C 21.35
0.1 nG IGMF
EBL of Dominguez et al. 2011



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

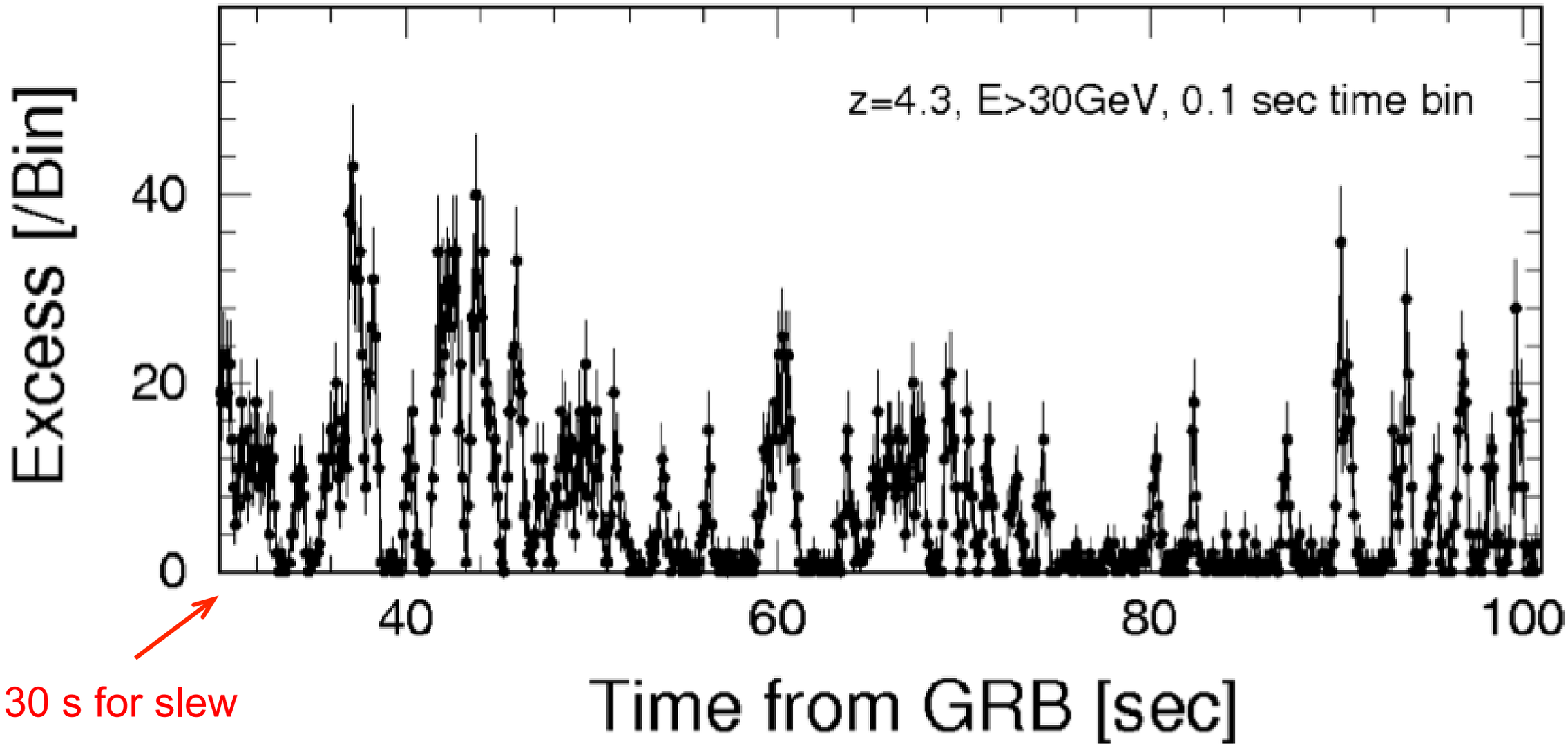
Opening up the Transient Domain



Field of view, duty cycle also matter

A simulated GRB (E > 30 GeV)

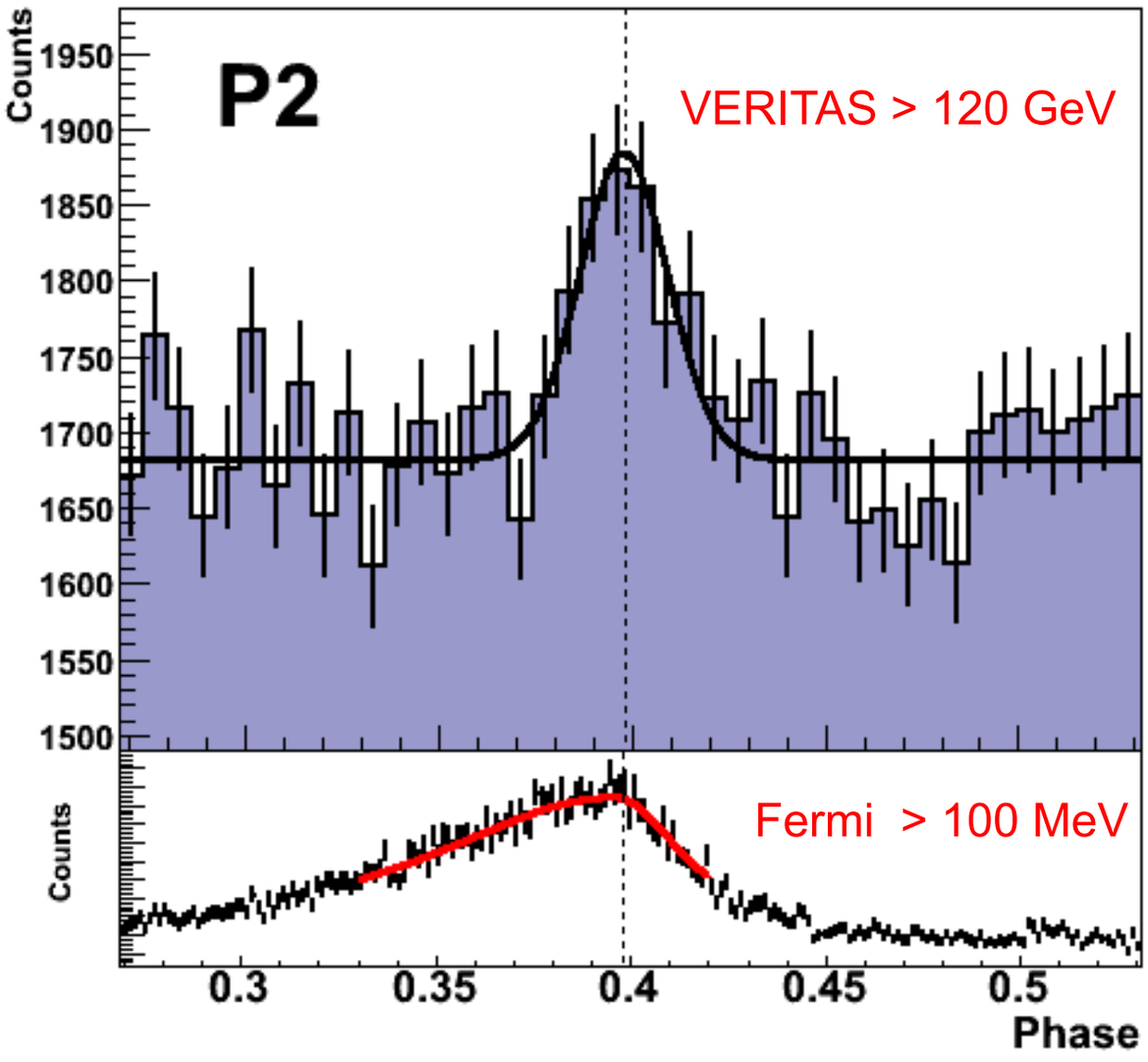
CTA Simulation of GRB 080916C seen by GBM + LAT

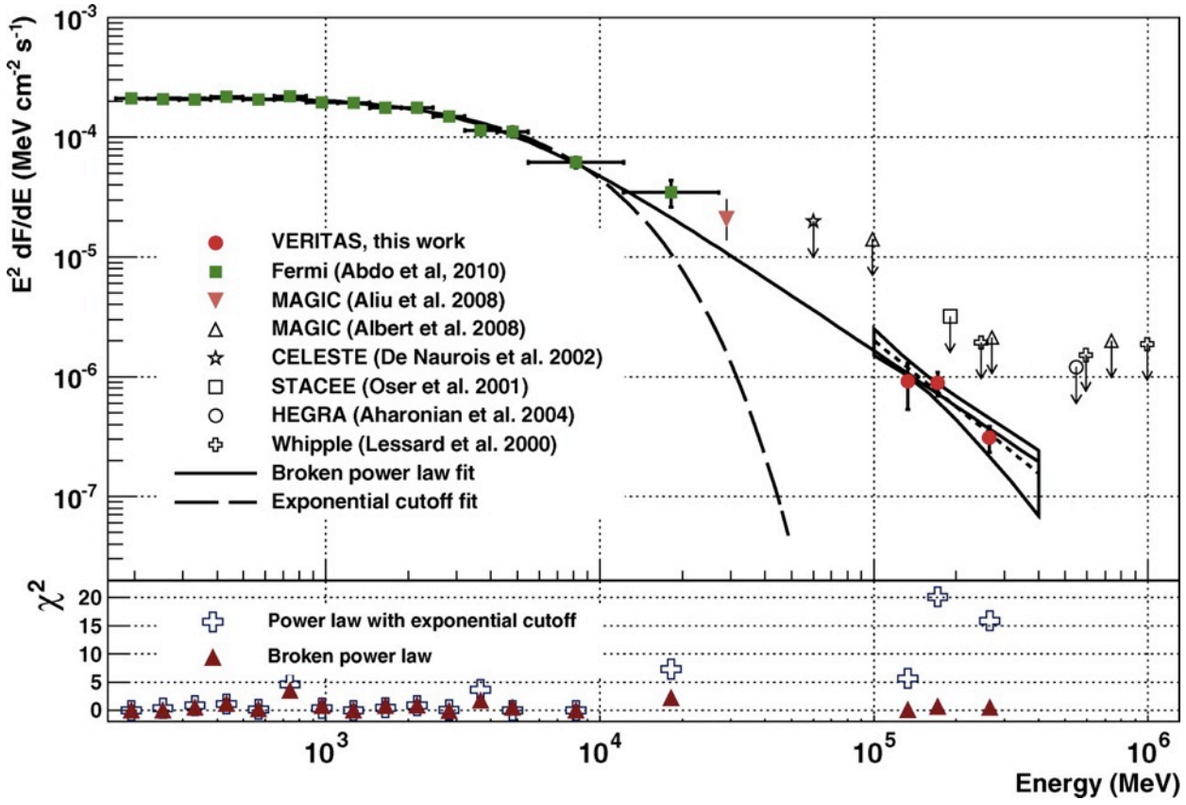


from
Gamma-Ray Burst Science in the Era of Cherenkov Telescope Array
(Astroparticle Physics special issue article)
Susumu Inoue et al.

More about GRBs with CTA in
Yoshiyuki Inoue's talk on Wednesday

Lorentz Invariance with Pulsars





100 MeV and 120 GeV peaks line up

Linear: $E_{LIV} > 3 \times 10^{17}$ GeV

Quadratic: $E_{LIV} > 7 \times 10^{9}$ GeV

Higher statistics, larger energy reach, more pulsars with CTA

E. Aliu et al. (The VERITAS Collaboration), *Science* 334, 69–72 (2011)

A. N. Otte 2011, arXiv:1208.2033

A New Understanding of the TeV Universe

- 10-fold improved sensitivity for TeV studies of the cosmos
  - ✓ Analogous to the advance from EGRET to Fermi-LAT
- Detailed studies of Galactic cosmic-ray acceleration
- New sensitivity to the high-energy processes in blazar jets
- Astrophysics foundation and sensitivity for recognizing new fundamental physics
  - ✓ Sensitive searches for dark matter in its cosmic home
  - ✓ Tests of cosmology — EBL, IGMF
  - ✓ γ-ray propagation over cosmic distances — LIV, ALPs