cta pSCT

BARNARD

Cosmic Accelerators Through the Eyes of Ground-Based Gamma-Ray Telescopes

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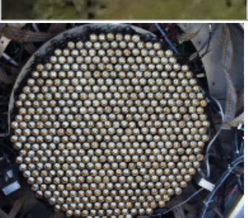
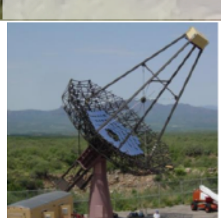
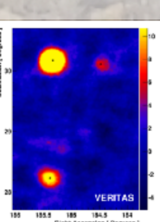
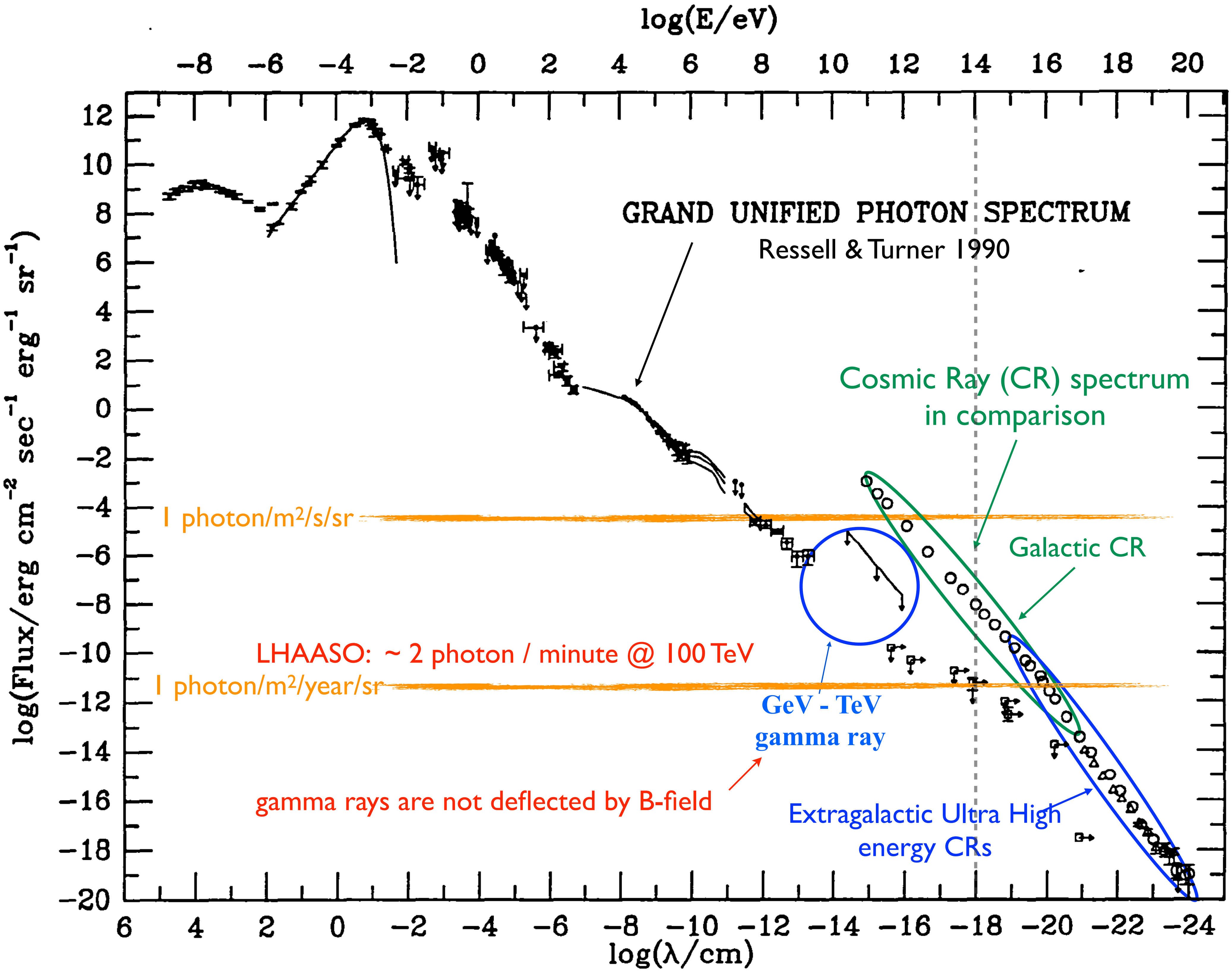
The VERITAS Collaboration, the CTA-US Collaboration

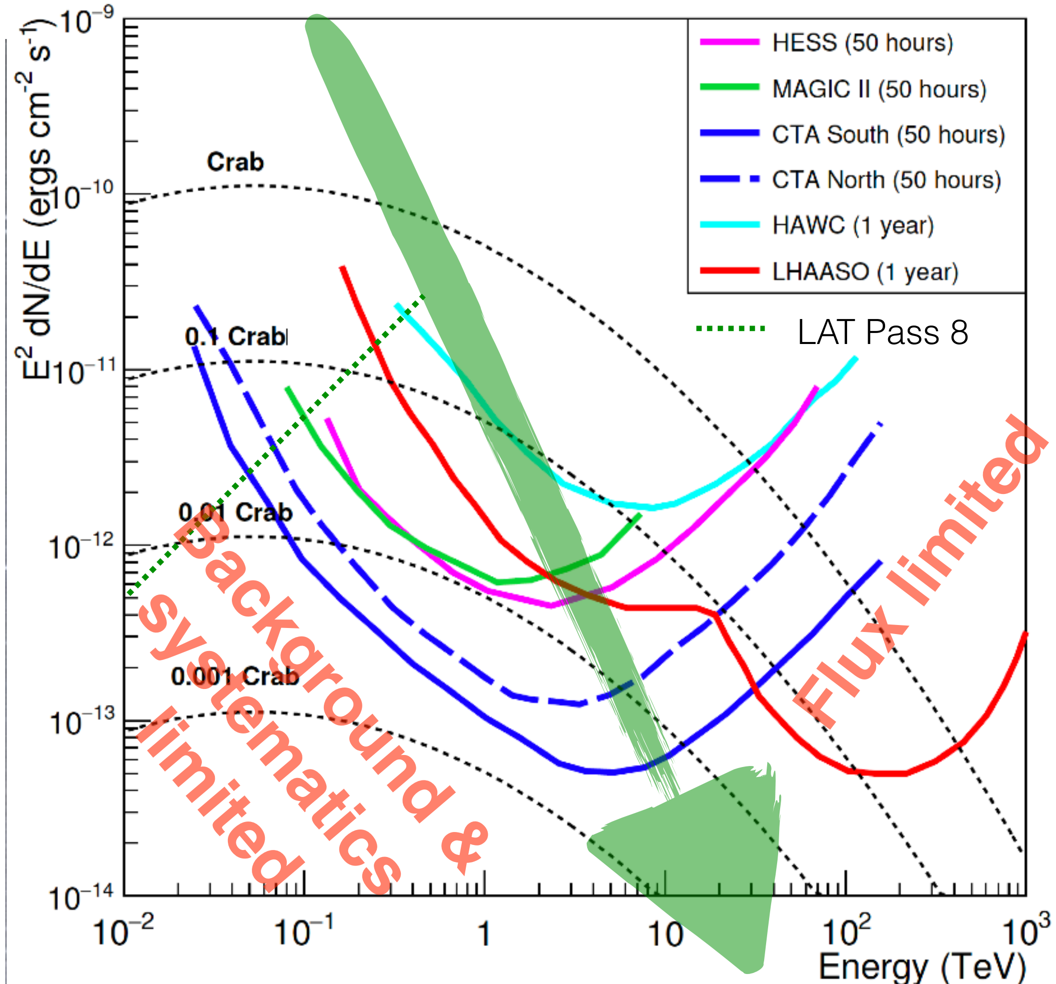




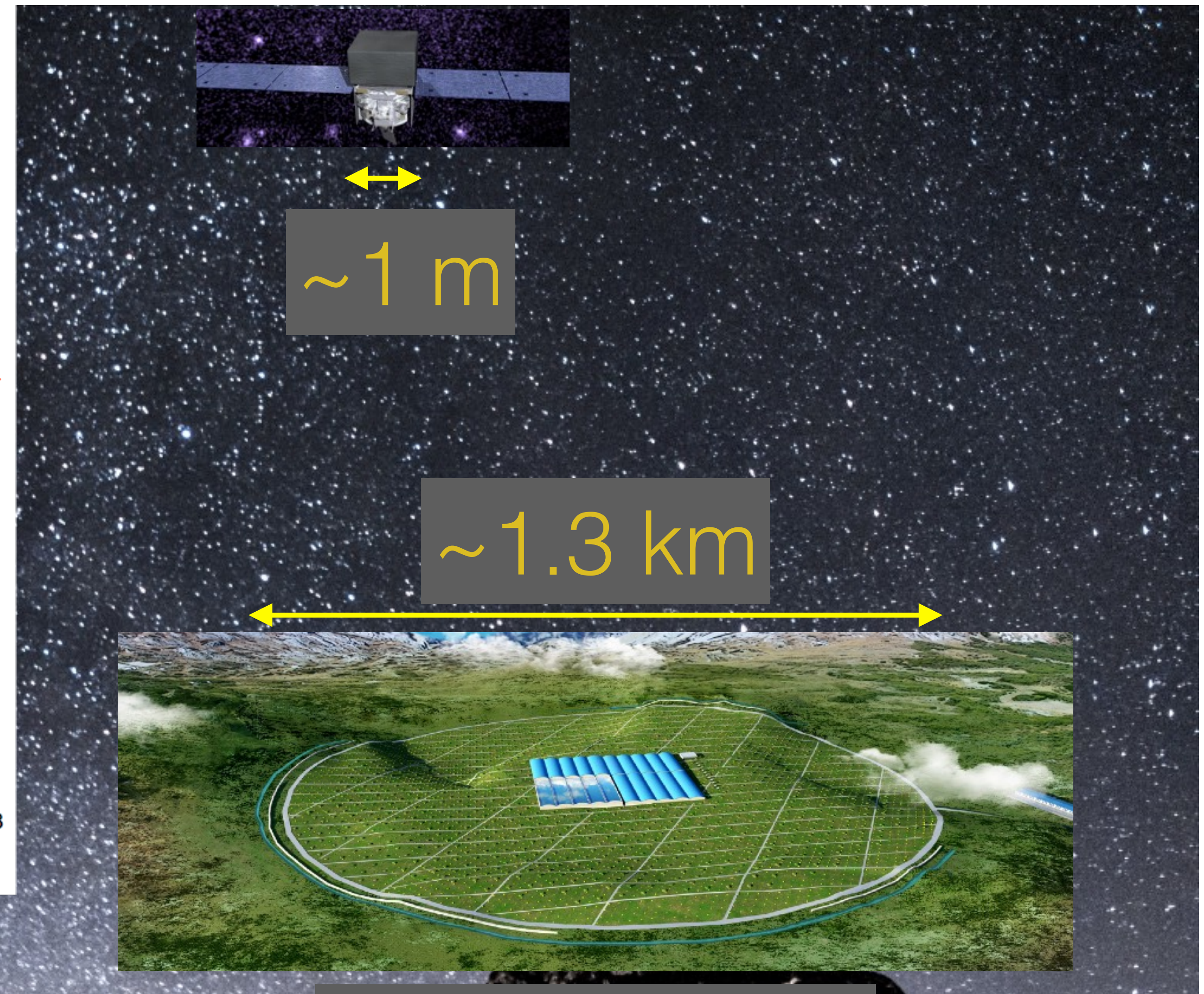

The power-law nature of diffuse photons and cosmic rays

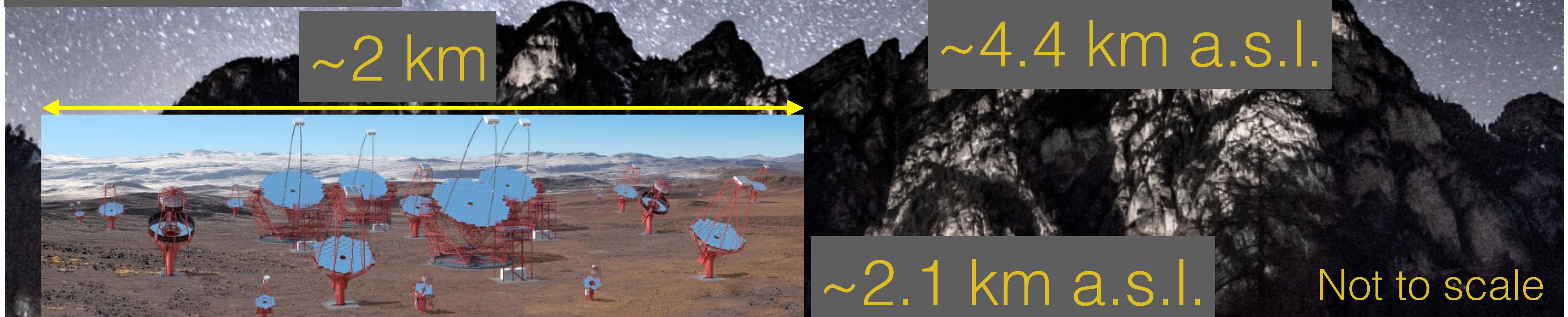


CTA & LHAASO

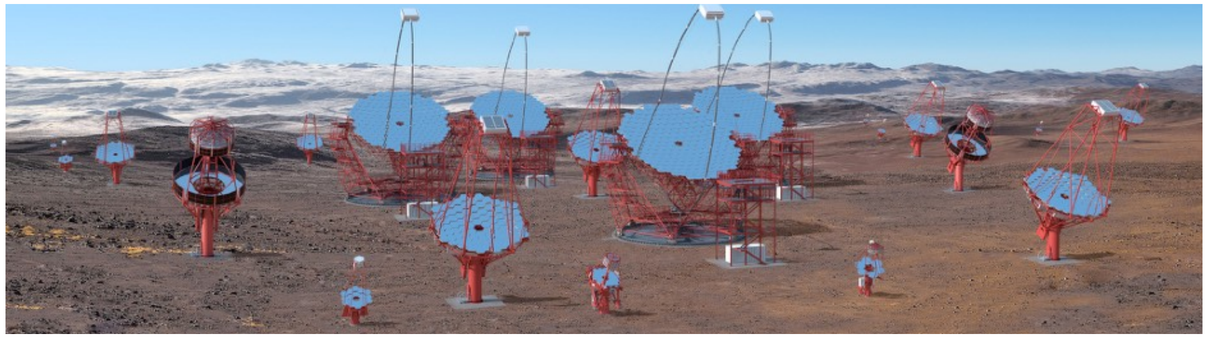


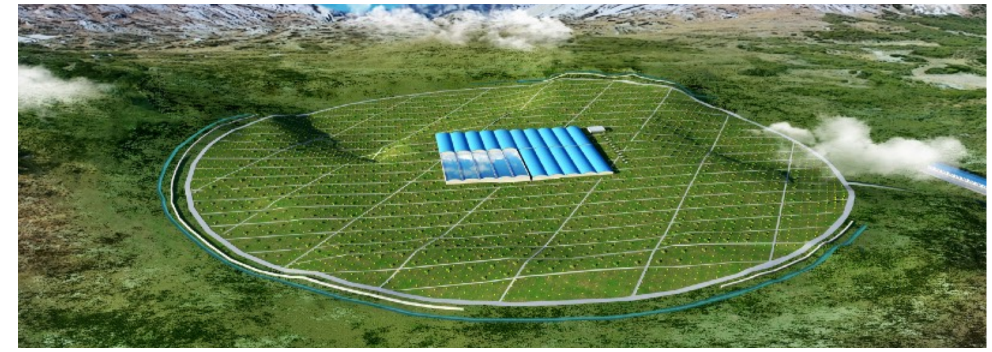
Adapted from G. Di Sciascio & the LHAASO Collaboration 2016



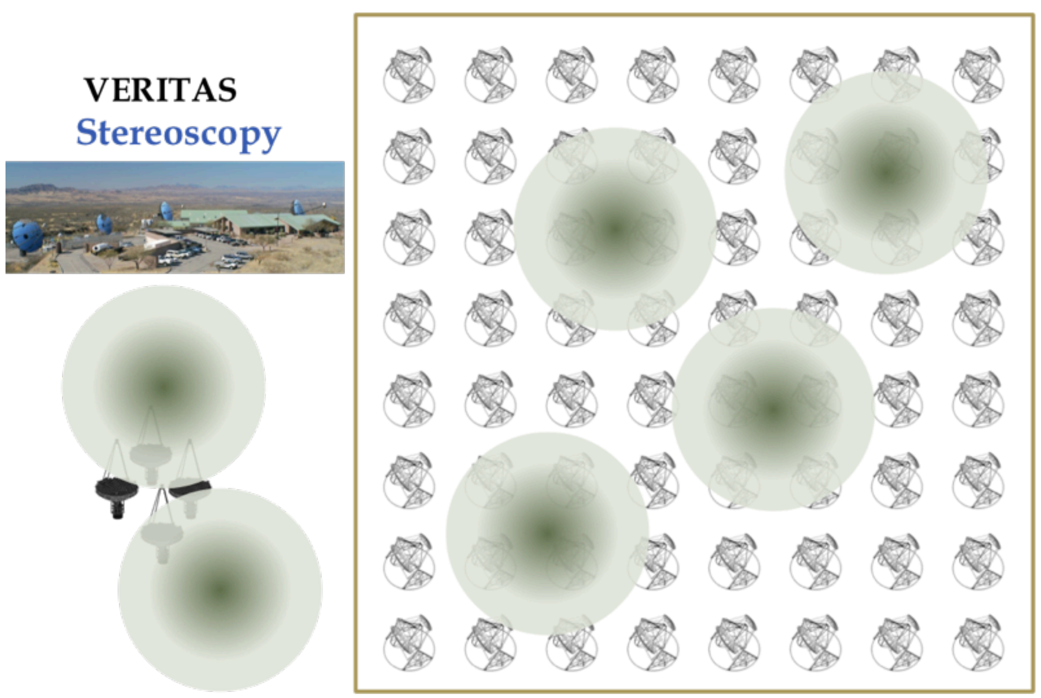


CTA & LHAASO

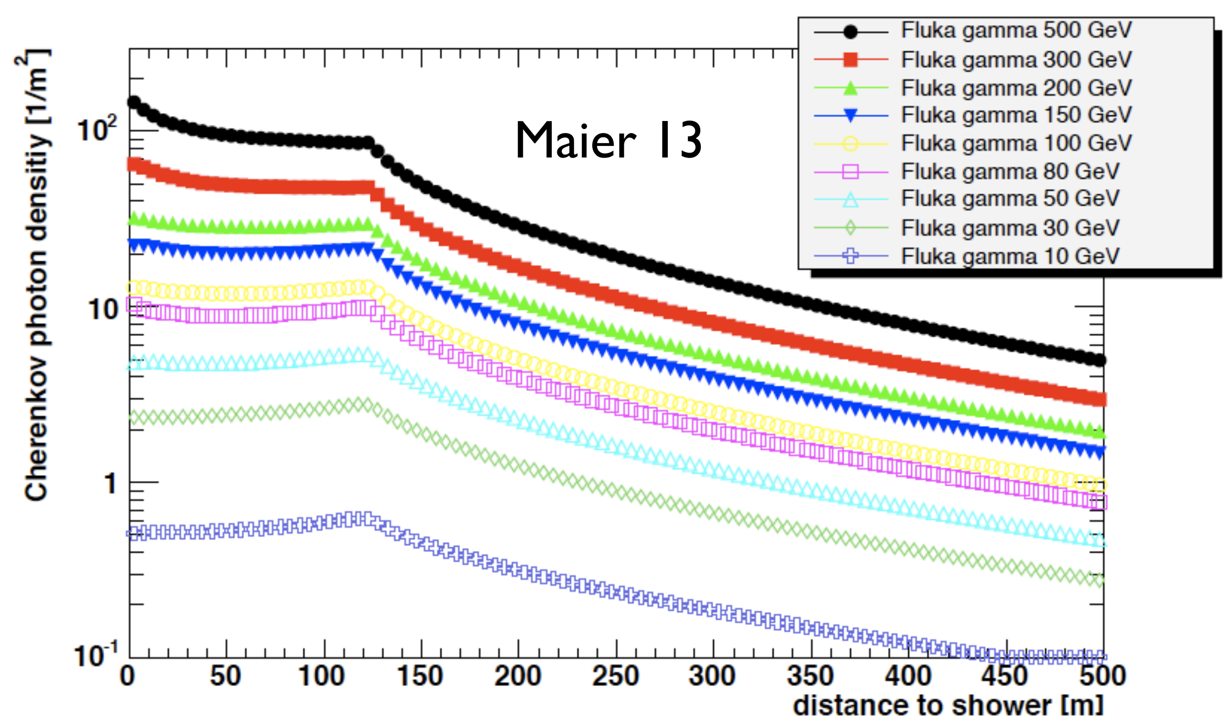




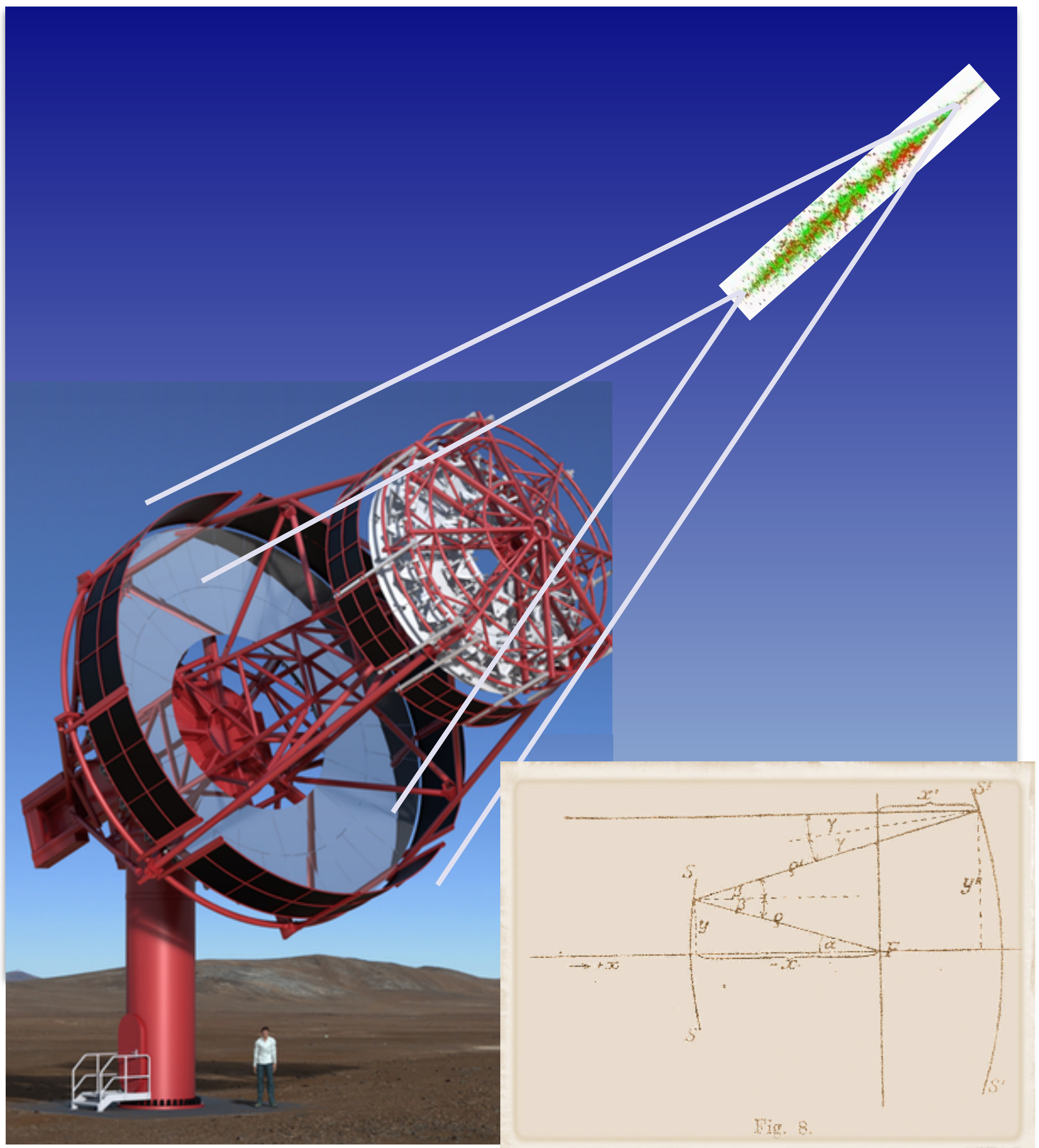
To improve	CTA	LHAASO
High energy coverage	Footprint / Effective area	Footprint / Effective area
Low energy coverage	Collecting area (reflector size)	WCDA (larger PMT?)
Angular resolution	**Imaging capability (optical PSF)** / Large FoV	Timing?
Energy resolution	Event containment	Dense detectors? WFCTA?
Field of view (FoV)	Large camera / Optical design	Northern sky (zenith>?)

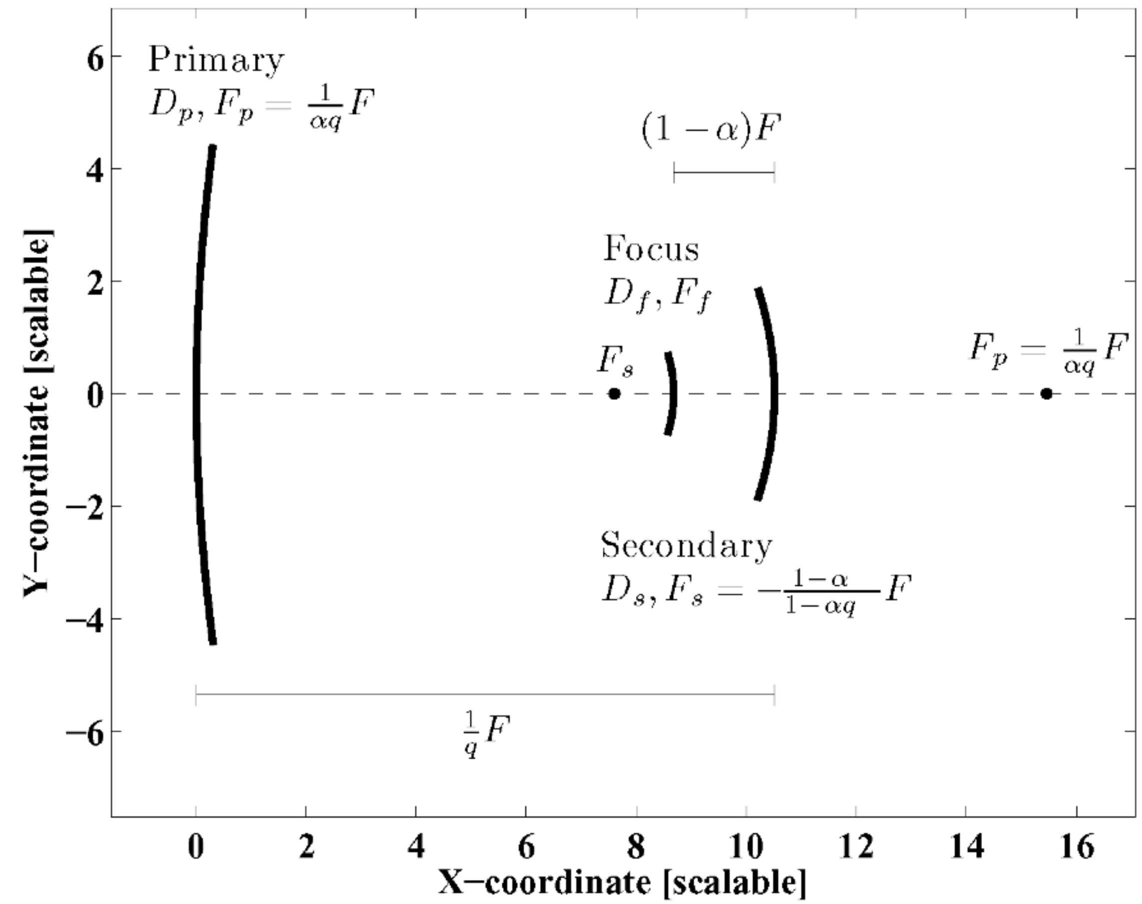


Adapted from Vassiliev



Schwarzschild-Couder Telescope (SCT)

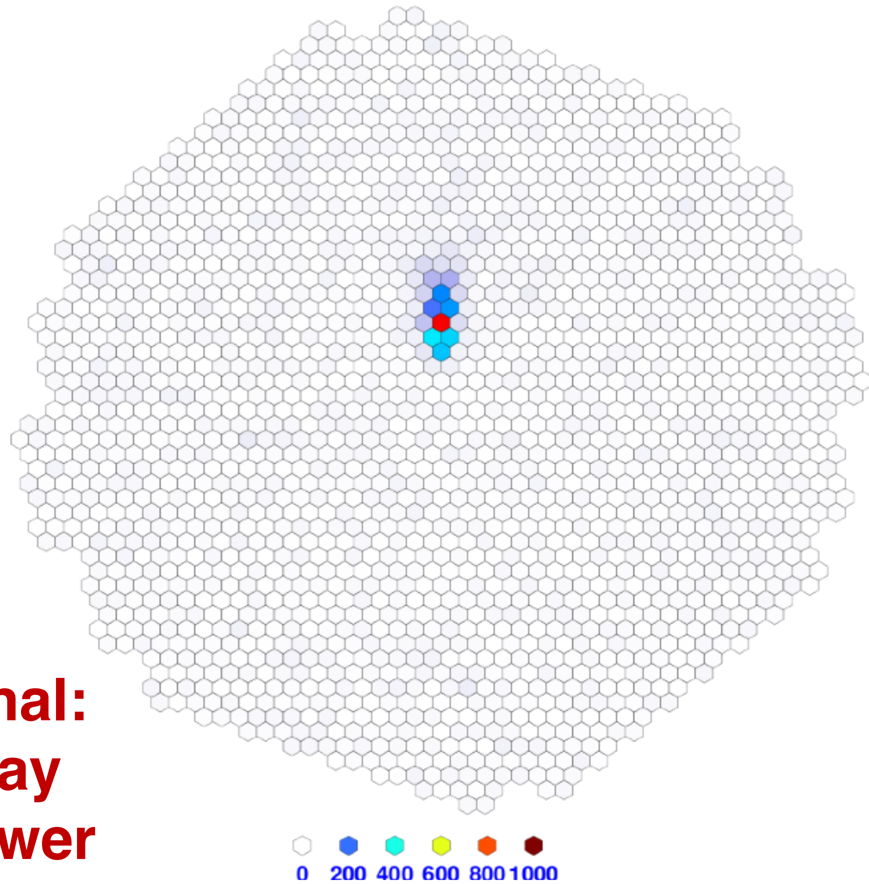




Vassiliev, Fegan, & Brousseau Astropart.Phys.28:10-27,2007

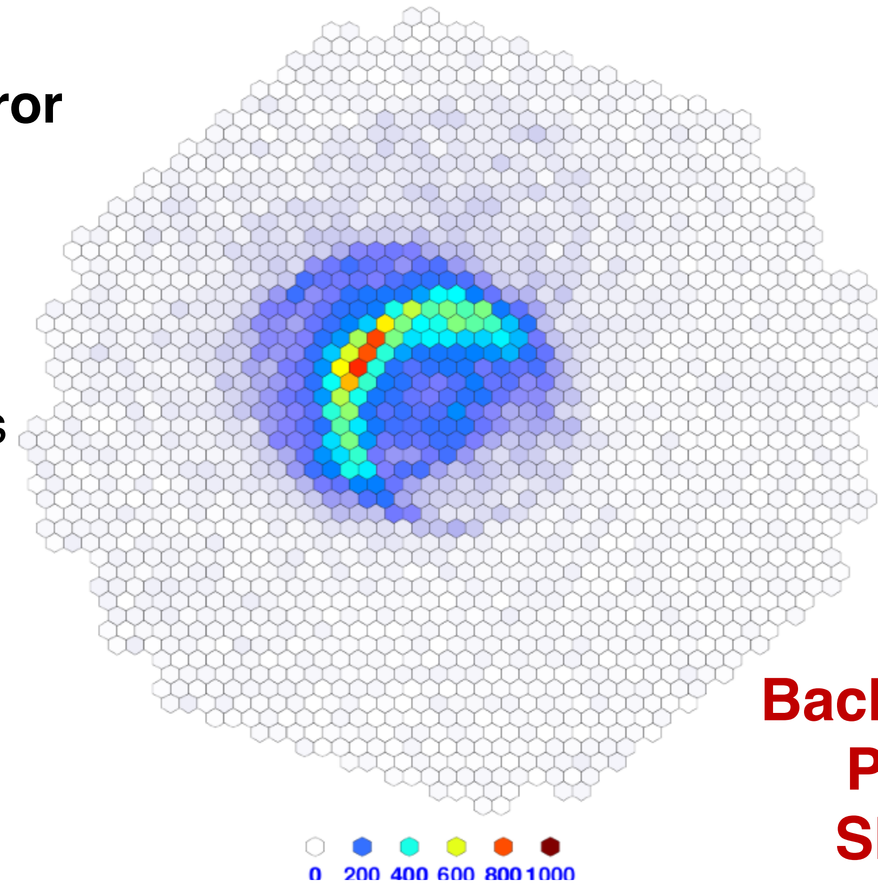
- Aplanatic - correct for spherical aberration and coma - good optical PSF on and off axis
- Design requires: large collection area & large FoV (étendue), small plate scale.
- Schwarzschild 1905

SCT Design Advantage



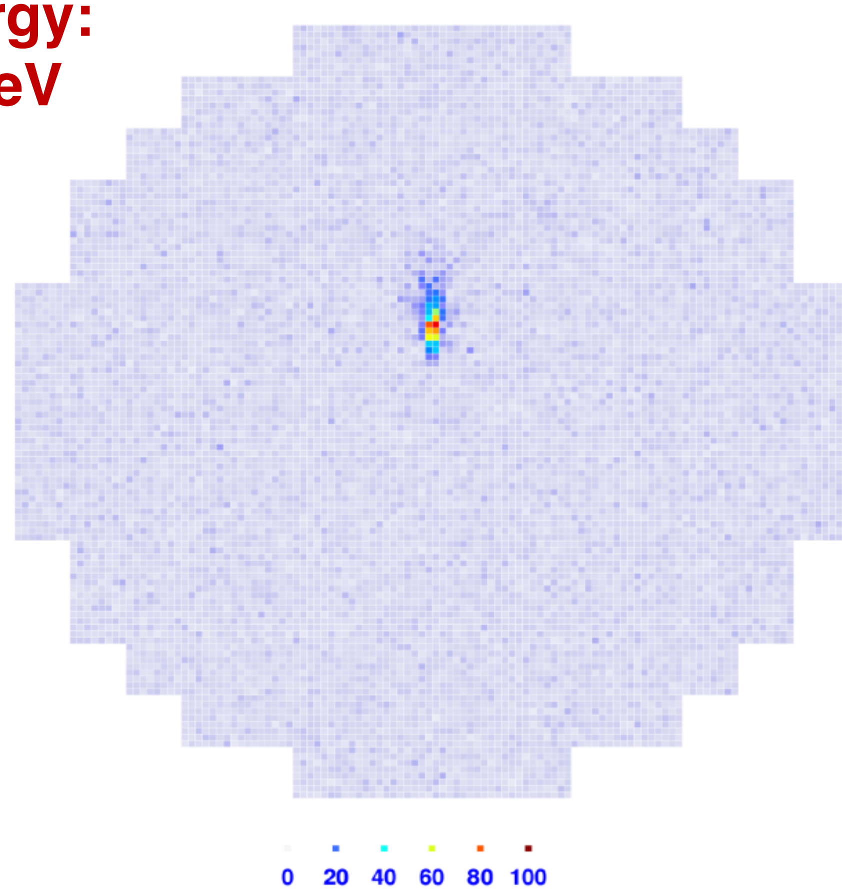
Single-Mirror MST

8° FoV
1,570
0.18° pixels



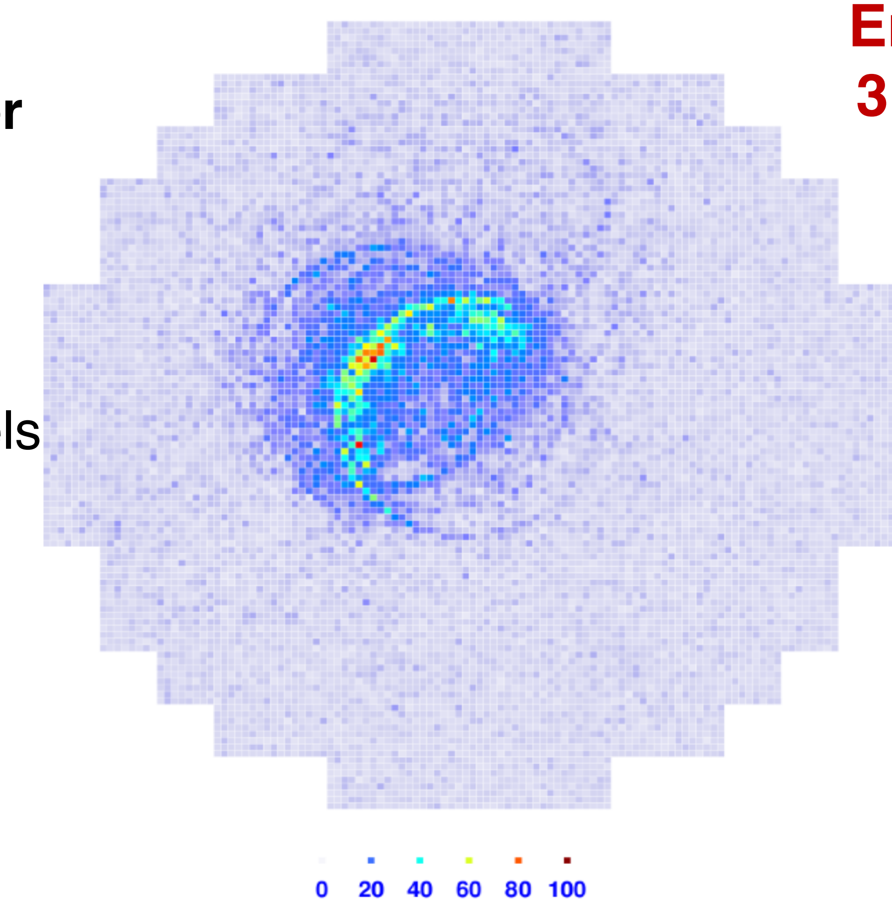
Signal: γ-ray Shower Energy: 1 TeV

Background: Proton Shower Energy: 3.2 TeV



Dual-Mirror SCT

8° FoV
11,328
0.067° pixels



Prototype SCT (pSCT) inauguration (Jan 17, 2019)

Qi Feng, Andriy Petrashyk, Deivid Ribeiro, Ari Brills, Colin Adams, Brian Humensky, Reshmi Mukherjee, Brandon Stevenson, Ruo-Yu Shang, Vladimir Vassiliev, Patrick Wilcox, Phil Kaaret, Dave Kieda, Leslie Taylor, Thomas Meures, Justin Vandenbroucke, Manel Errando, Jim Buckley, Scott Wakely, Marcos Santander, Nepomuk Otte, Olivier Hervet, David Williams, …

Prototype SCT (pSCT) inauguration (Jan 17, 2019)

Mirror Panel Modules (MPMs) Overview

48 Primary Mirror Panels

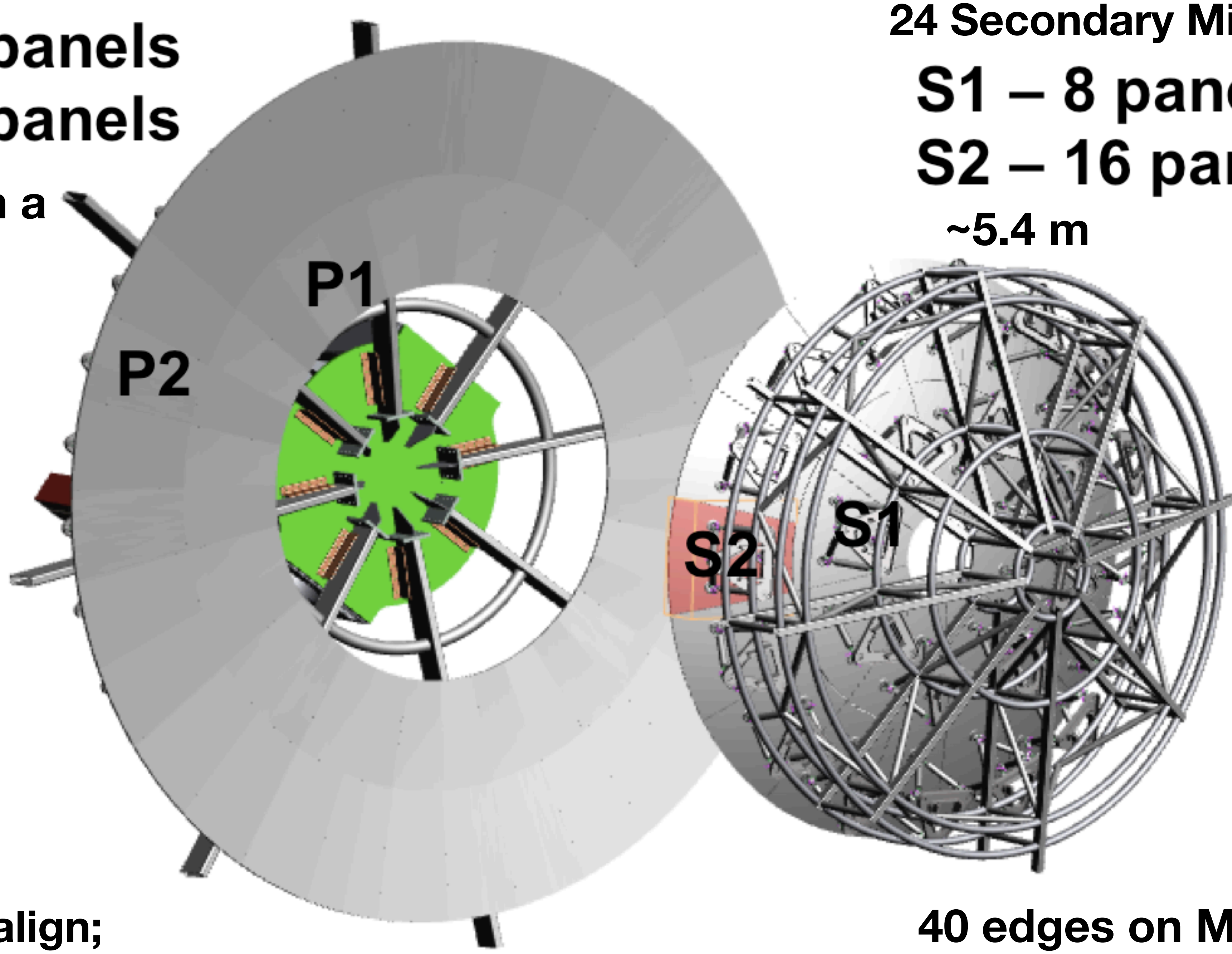
P1 – 16 panels
P2 – 32 panels

~9.6 m with a 4.3 m hole

24 Secondary Mirror Panels

S1 – 8 panels
S2 – 16 panels

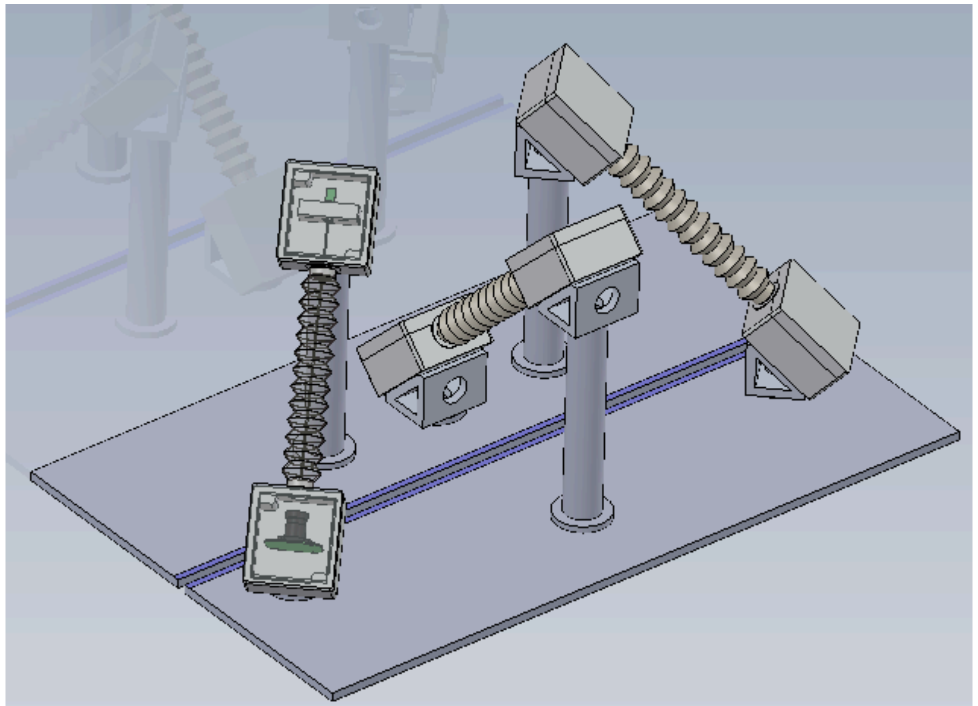
~5.4 m

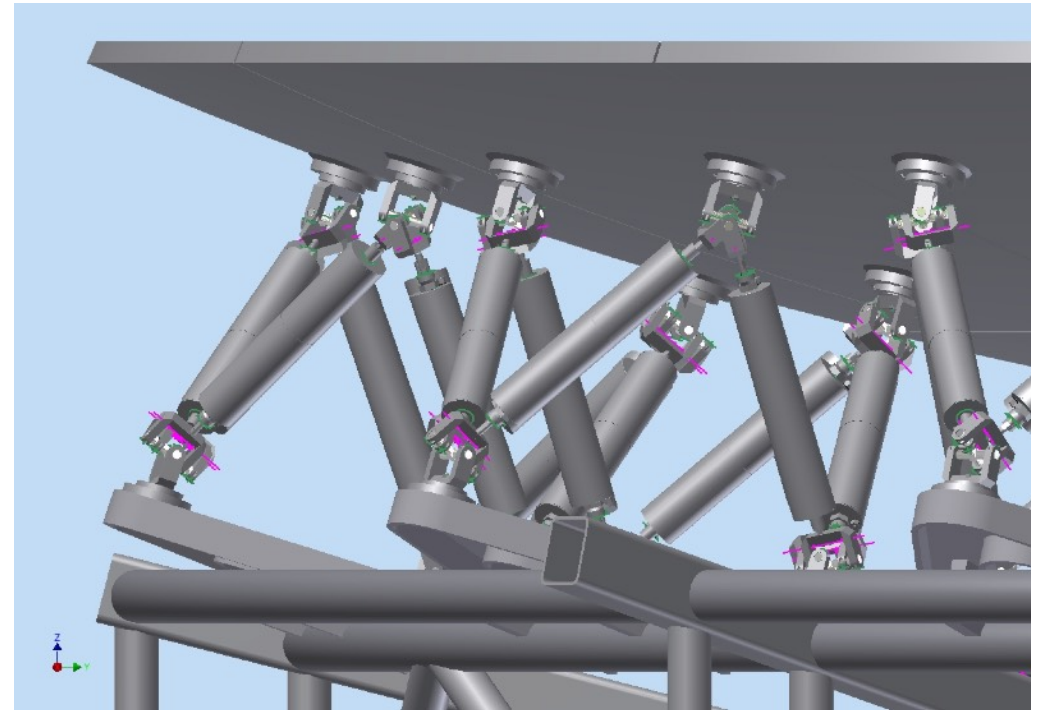


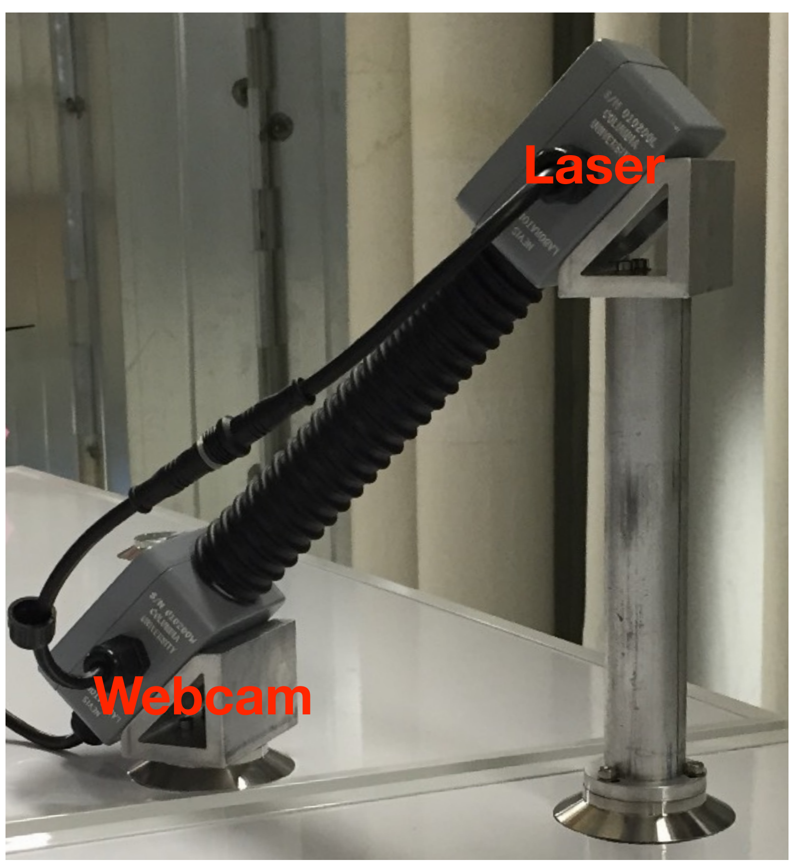
80 edges on M1 to align;
48 Steward platforms (SPs);
288 Actuators;
208 Mirror panel edge sensors (MPESes).

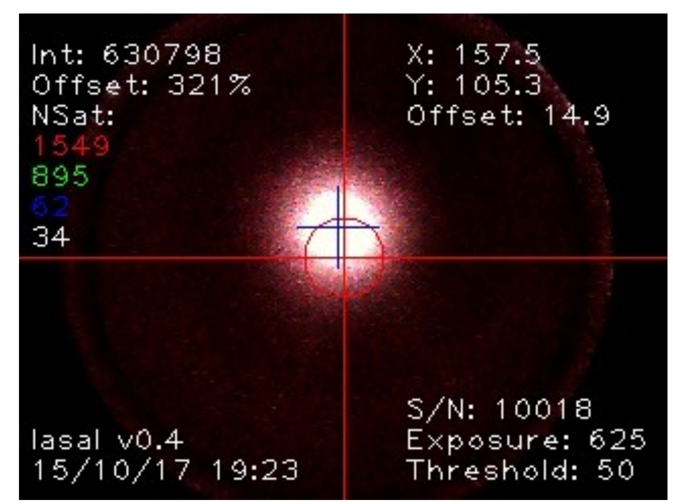
40 edges on M2 to align;
24 SPs;
144 Actuators;
104 MPESes.

Panel-to-Panel Alignment System



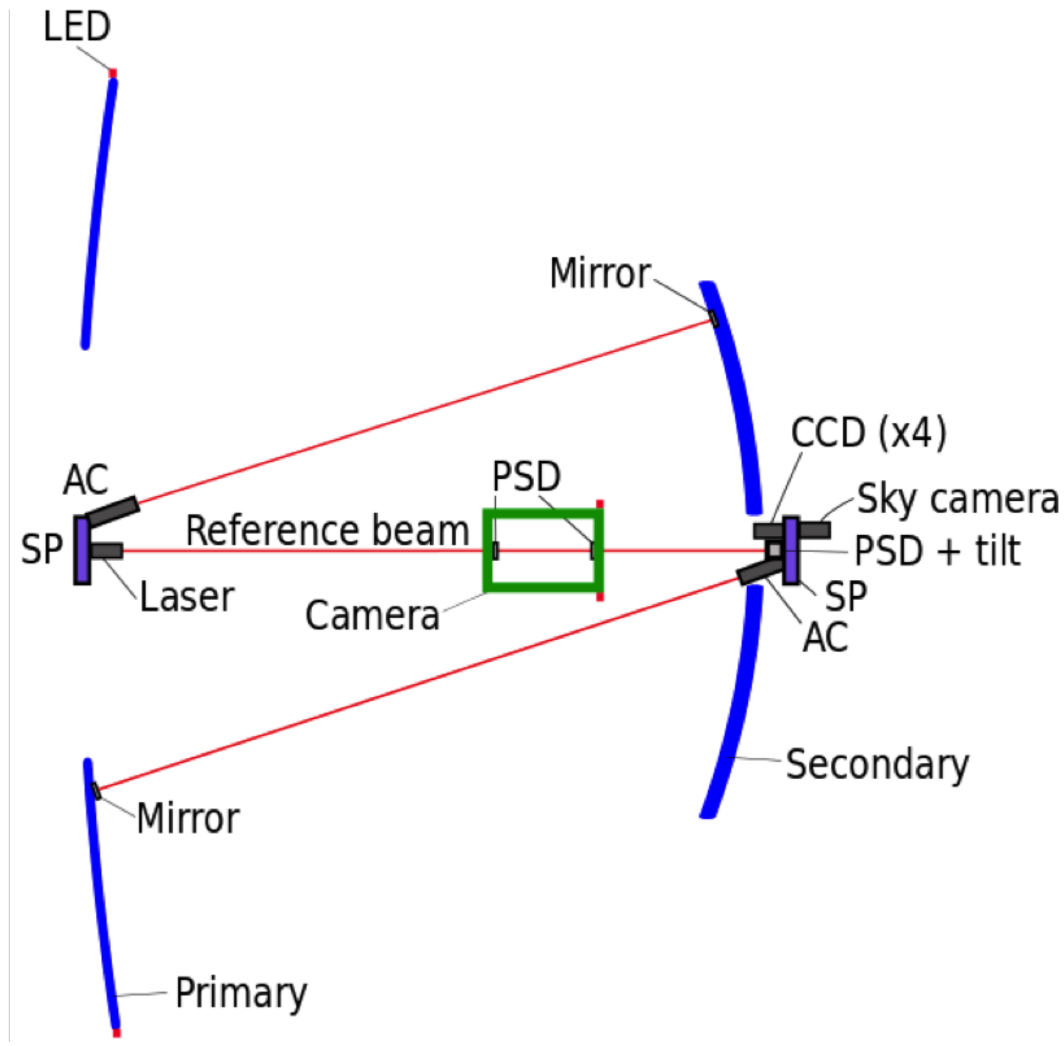




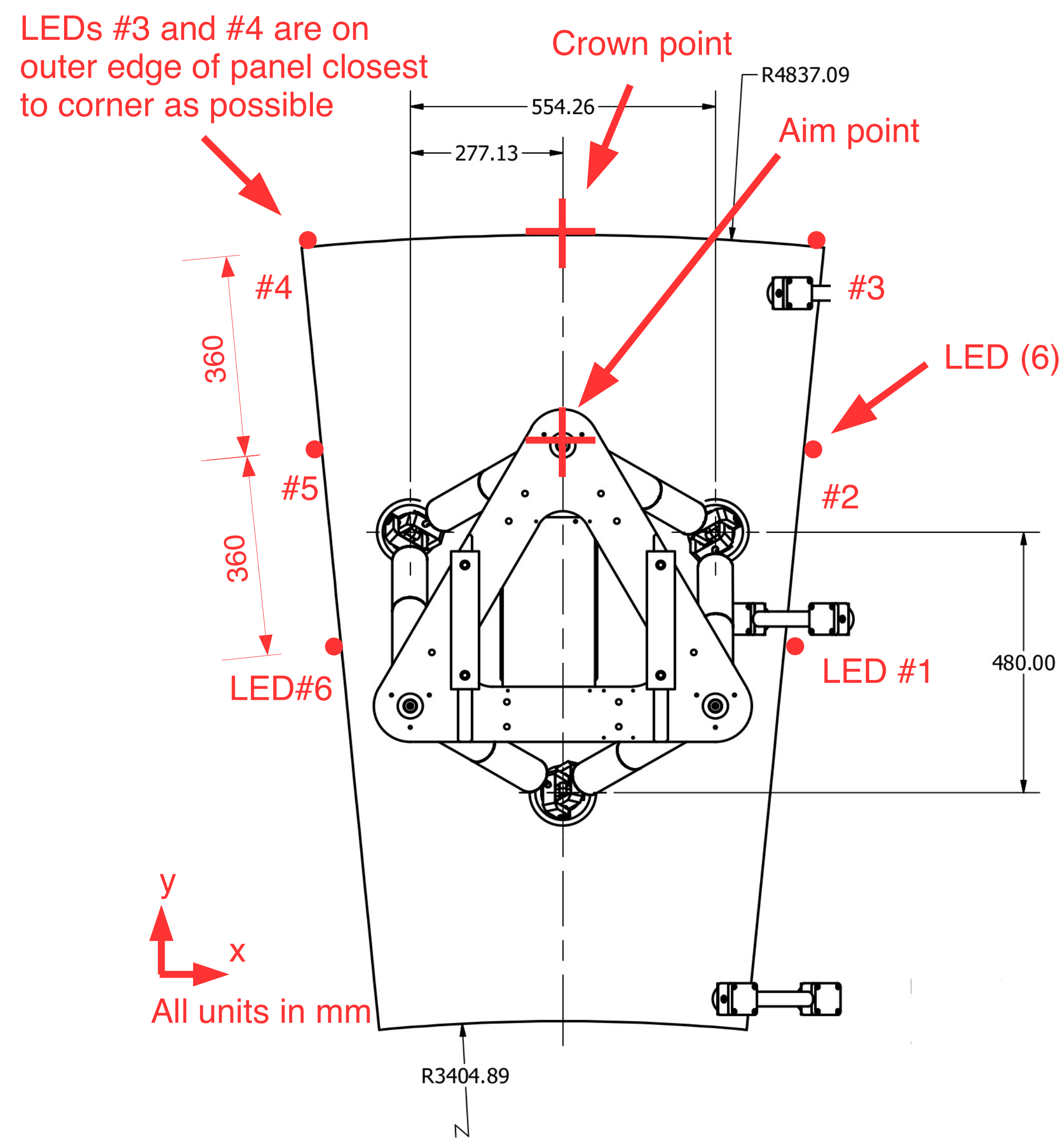


Global Alignment System

Global alignment system (GAS)

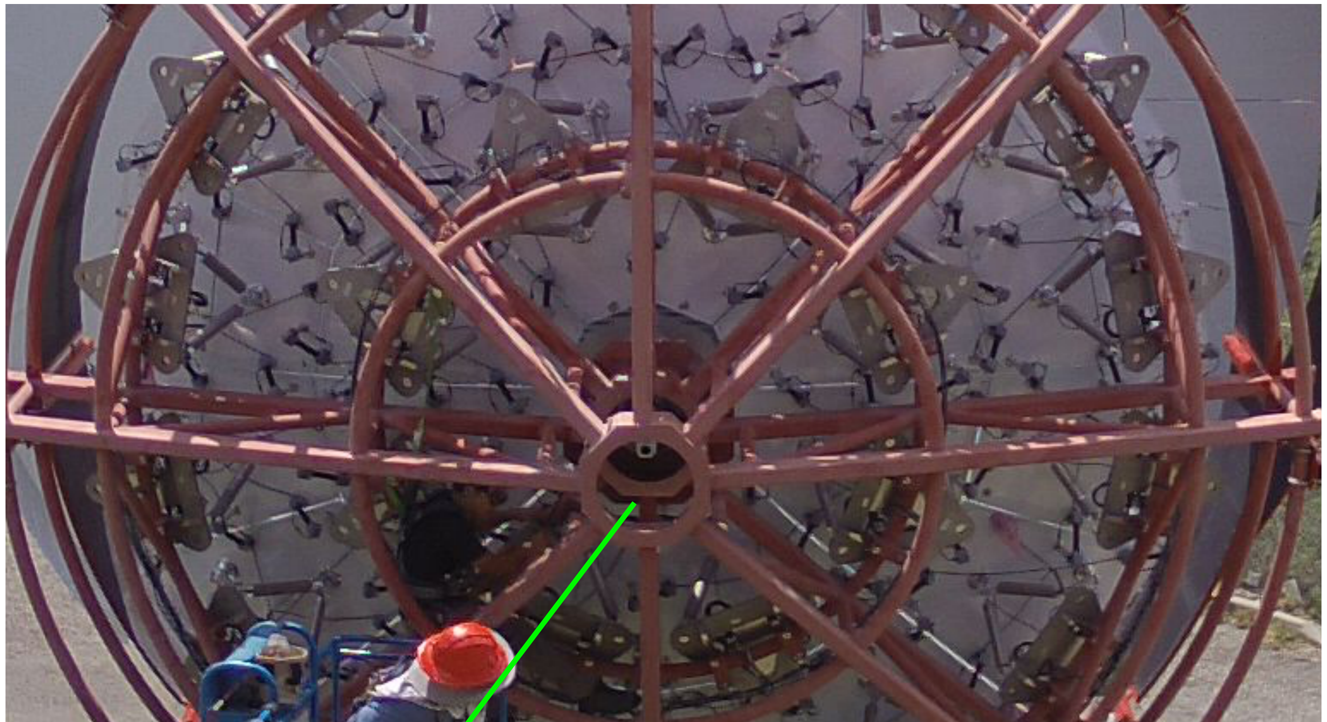


Primary GAS panel

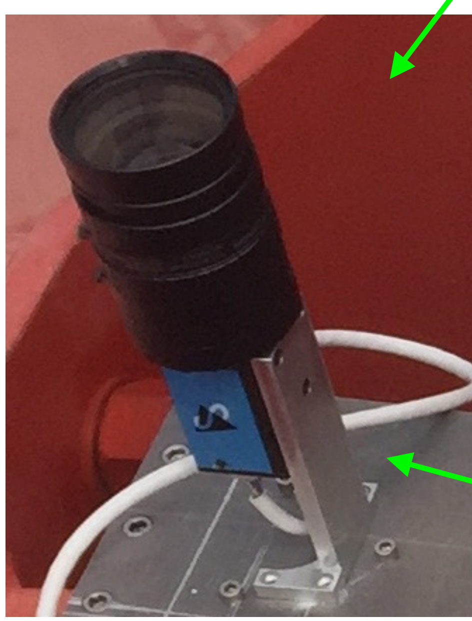


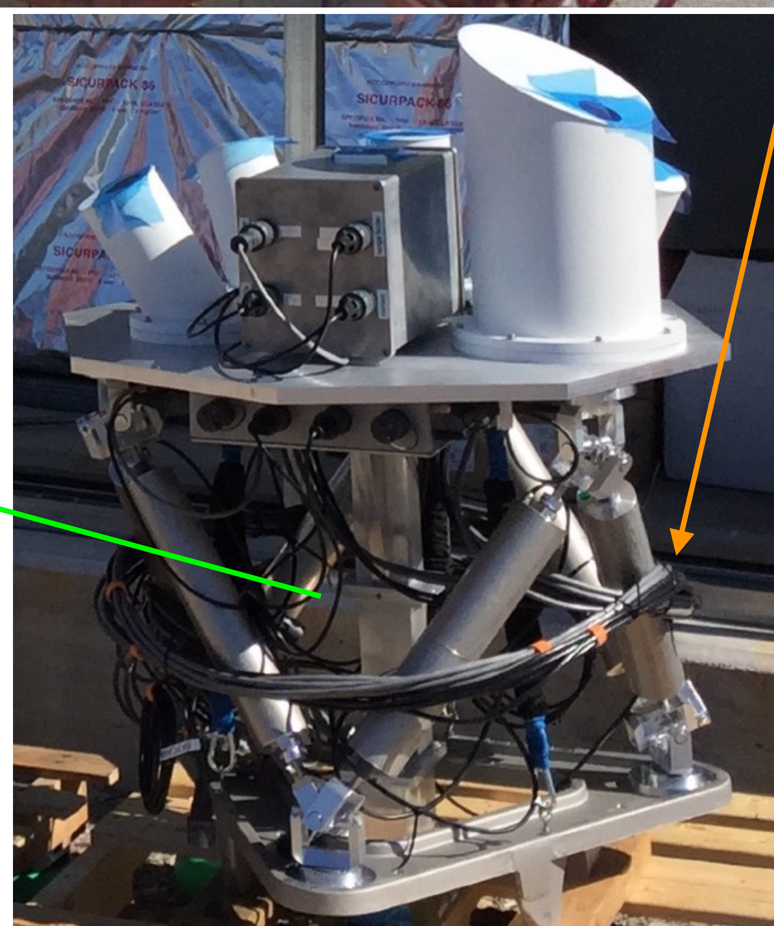
3 Primary + 3 Secondary GAS panels with LEDs imaged by CCD cams;
1 Primary + 1 Secondary GAS panel with a mirror for the autocollimator.

Pointing Correction with a CCD Sky Camera

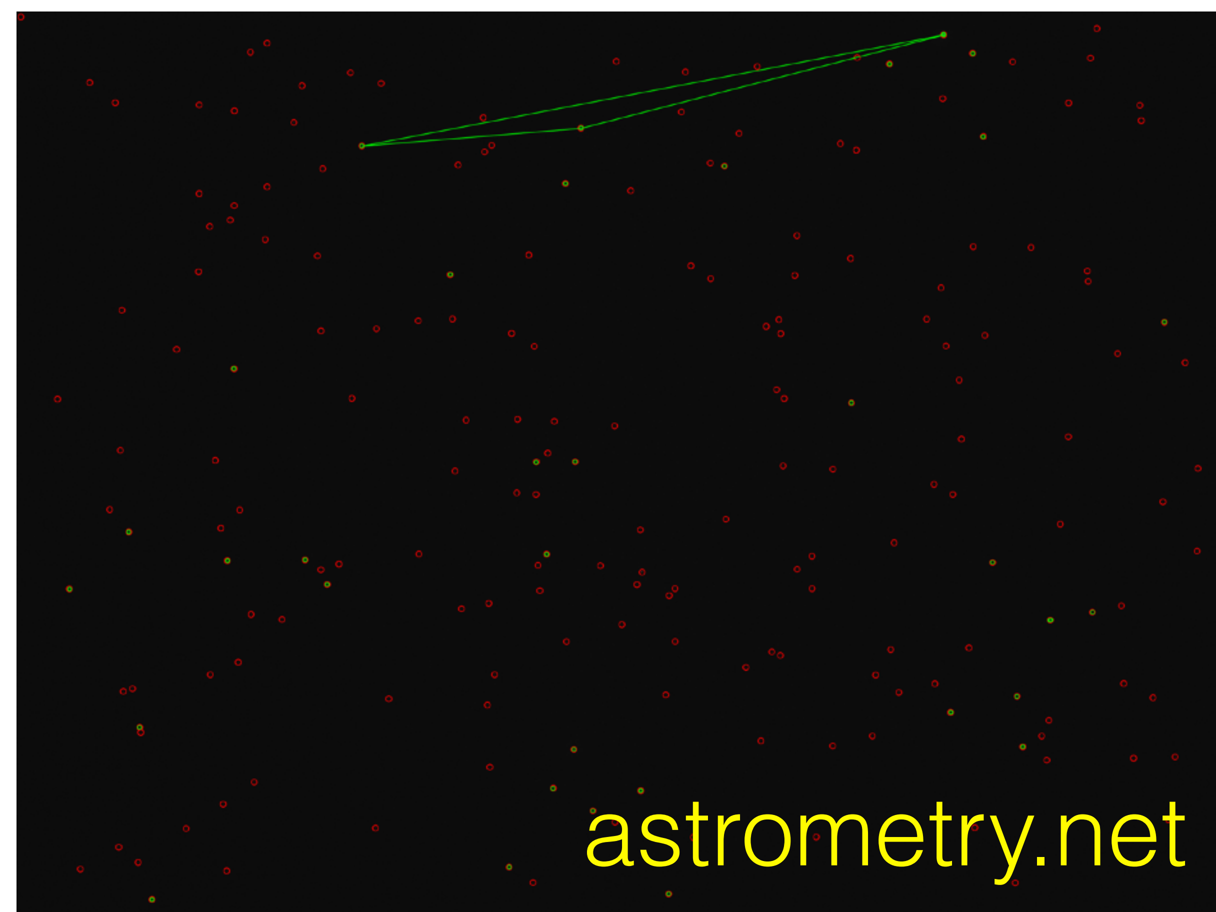


Steward Platform:
6 actuators controlling the
6 degree of freedom of the
motion of any panel.

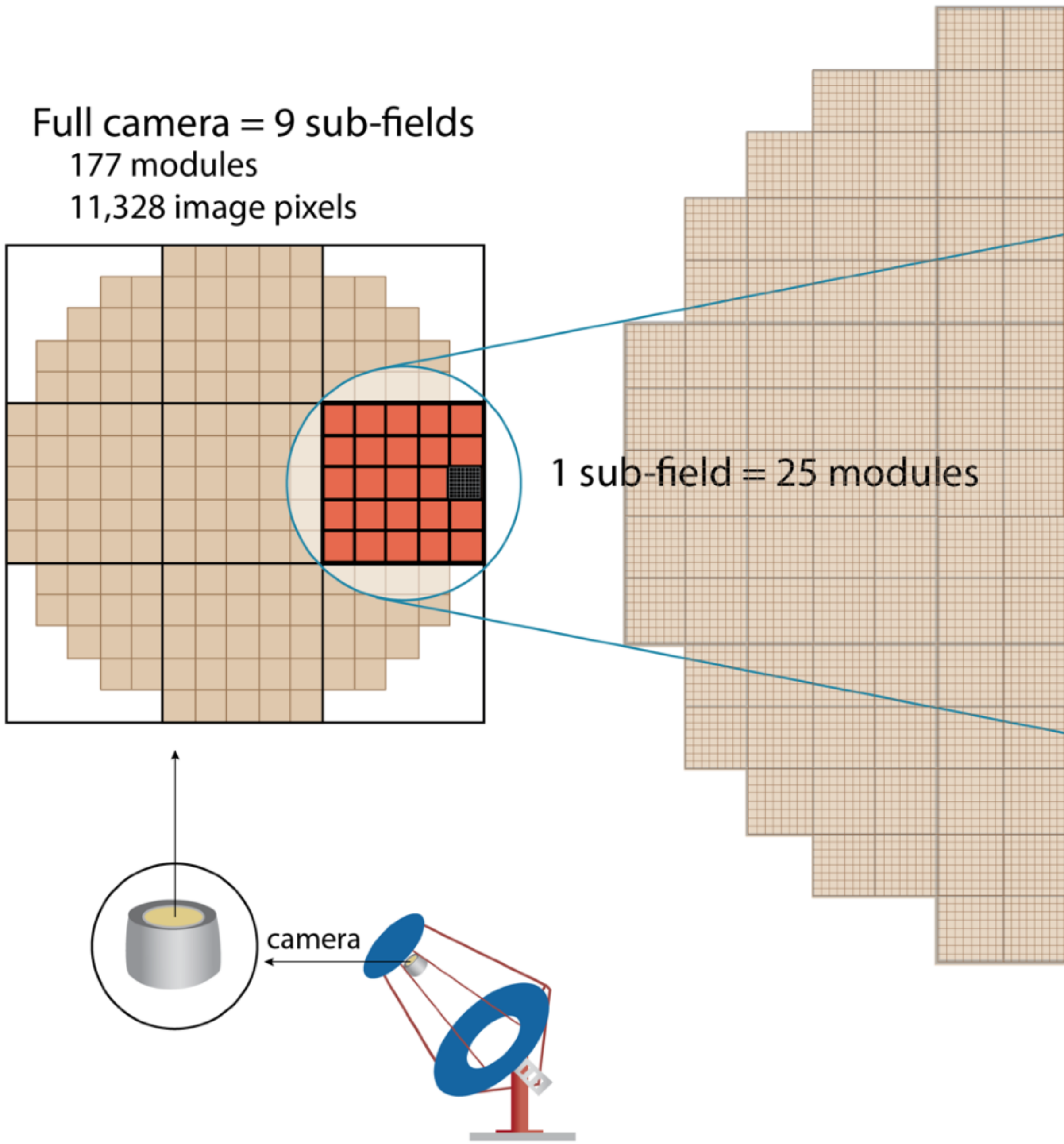


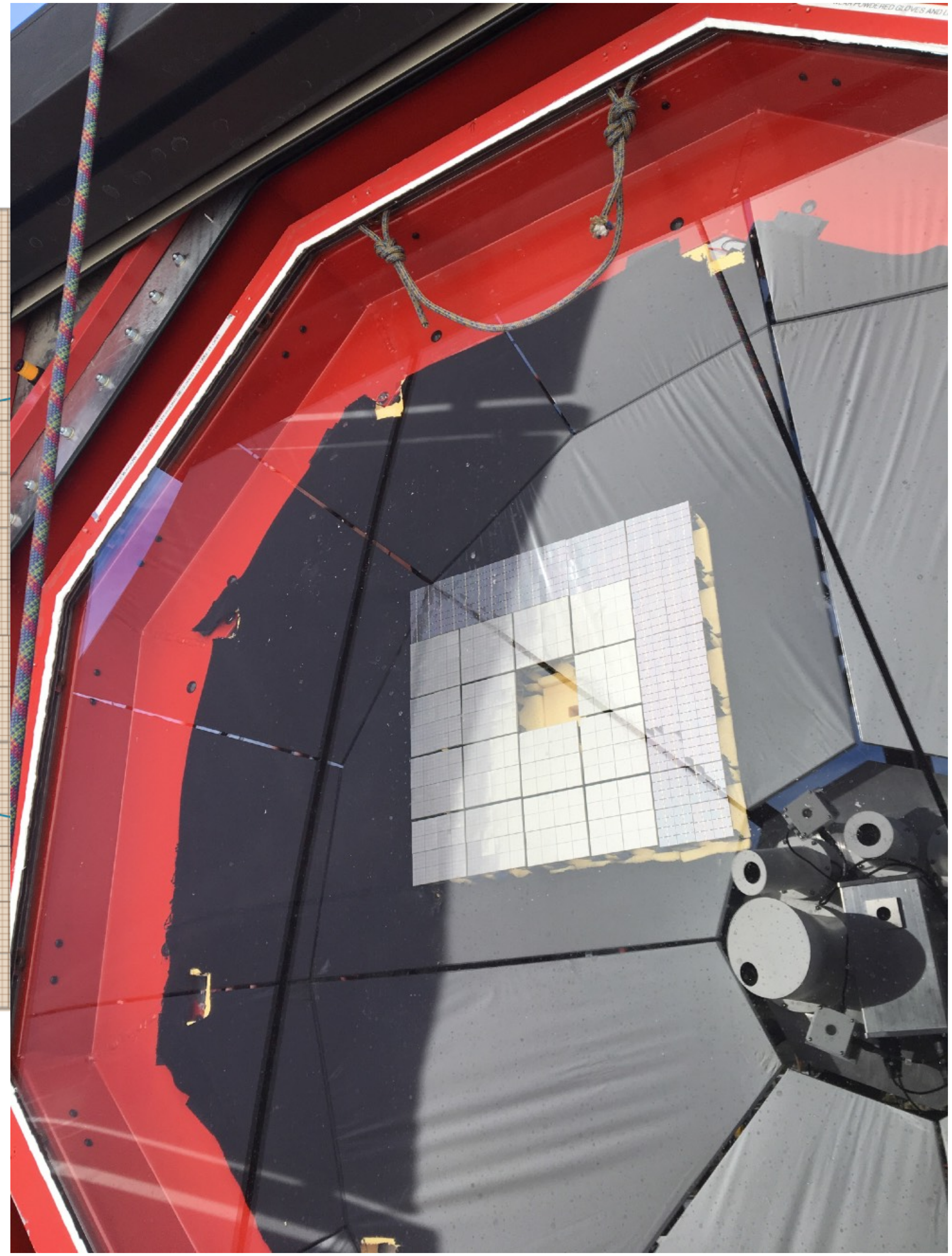


Solving starfield gives the actual pointing of the telescope.

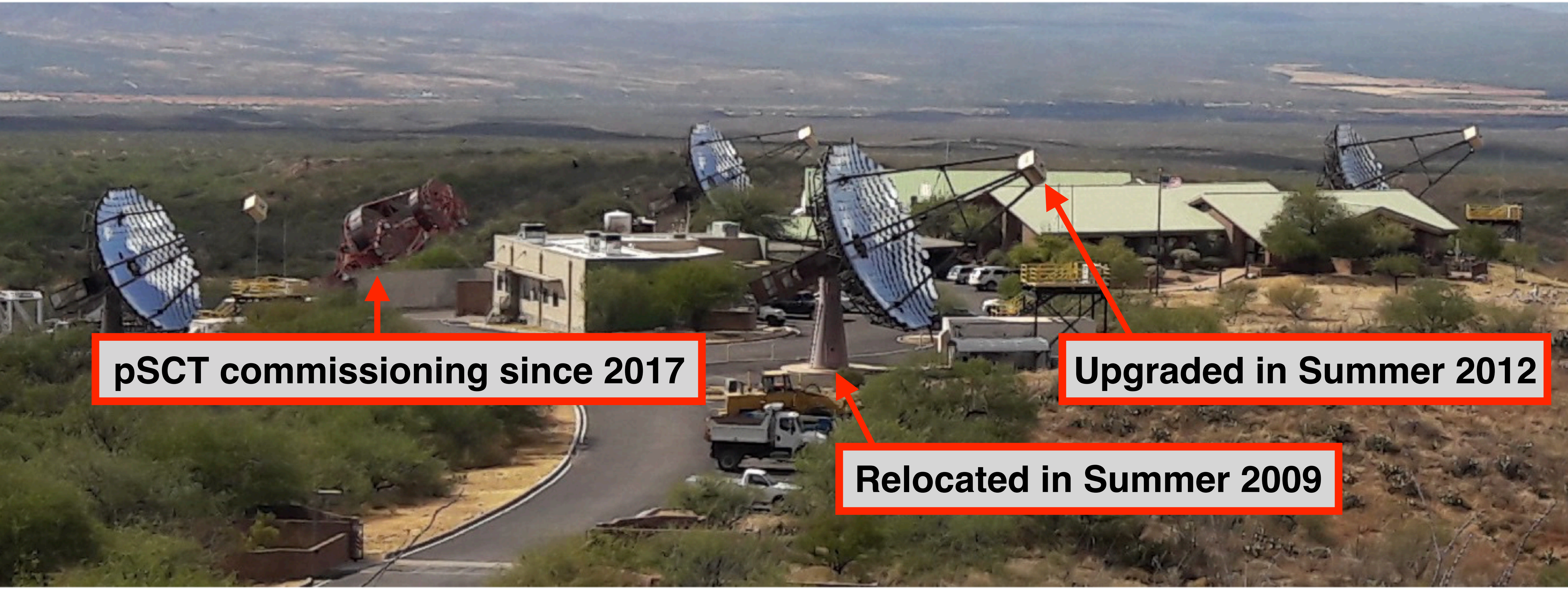


Gamma-Ray Camera





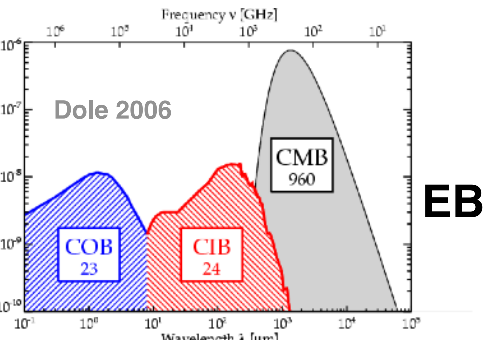
VERITAS Observatory Overview

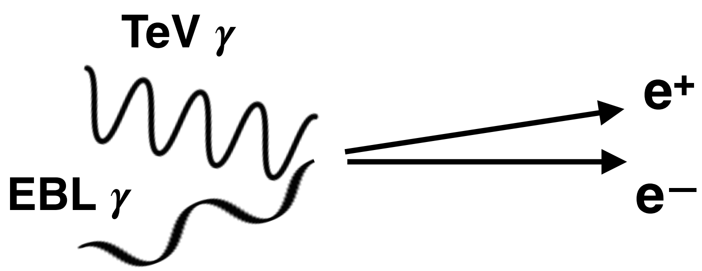


- Study very-high-energy (~85 GeV to ~30 TeV) γ-rays from astrophysical sources
- Full-scale operations since 2007; Major upgrade completed in 2012
- Good-weather data / yr: ~950 h in "dark time" + ~250 h in "bright moon" (illum. >30%)

- Sensitivity: 1% Crab in <25 h
- Angular resolution: $r_{68\%}$ ~ 0.08°@ 1 TeV
- Energy resolution: ~17%
- Energy Threshold: ~85 GeV
- Spectral reconstruction > 100 GeV
- Systematic errors: Flux ~20%; Γ ~ 0.1

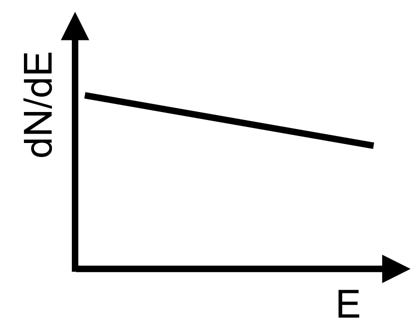
Extragalactic Sensitivity & Extragalactic Background Light (EBL)





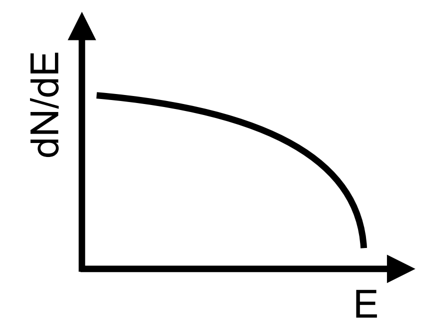
Intrinsic spectrum:

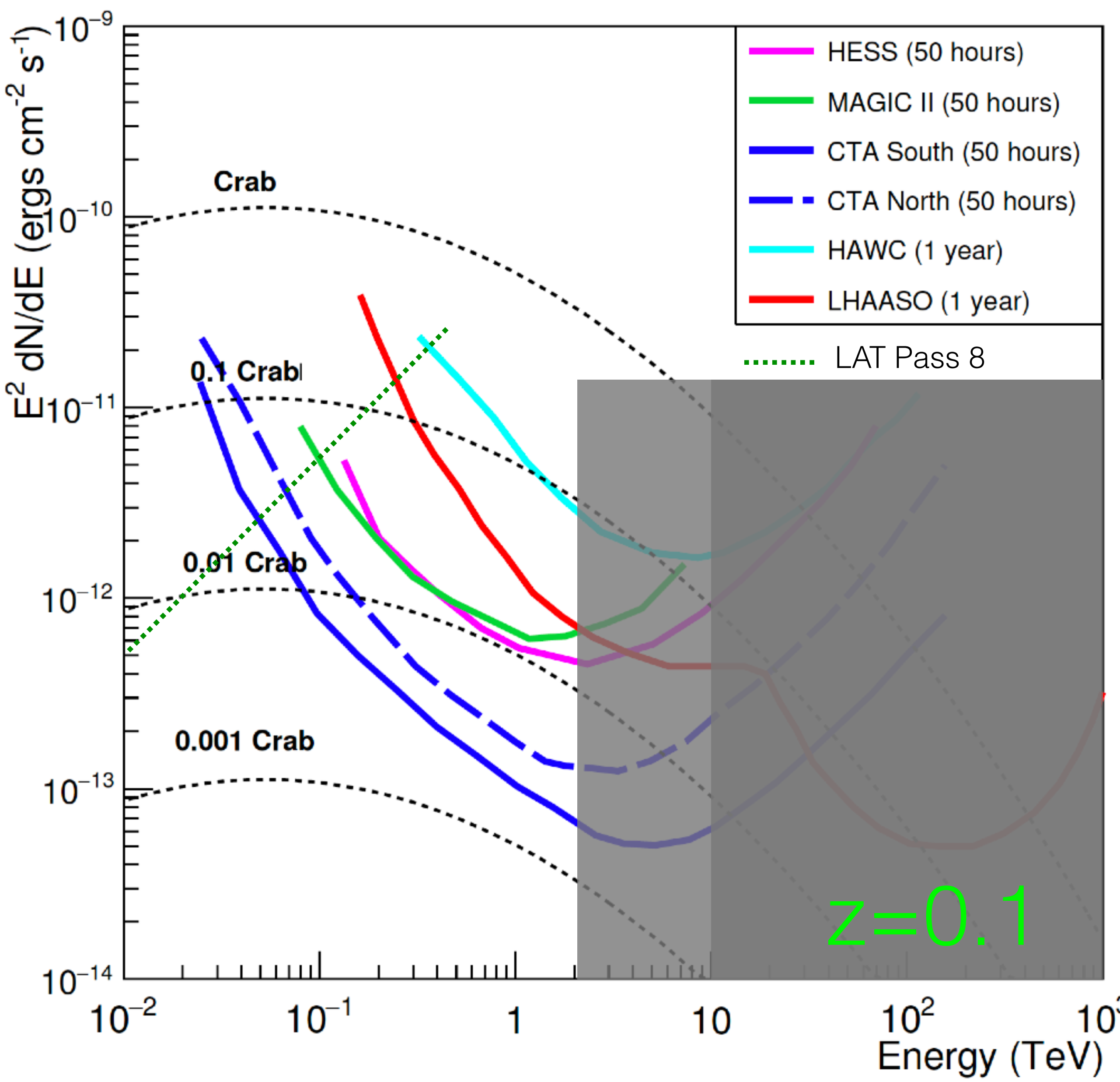
$$\frac{dN}{dE} \propto E^{-\Gamma}, \frac{dN}{dE} \propto E^{-\Gamma} \exp\left(-\frac{E}{E_C}\right), \ldots ?$$



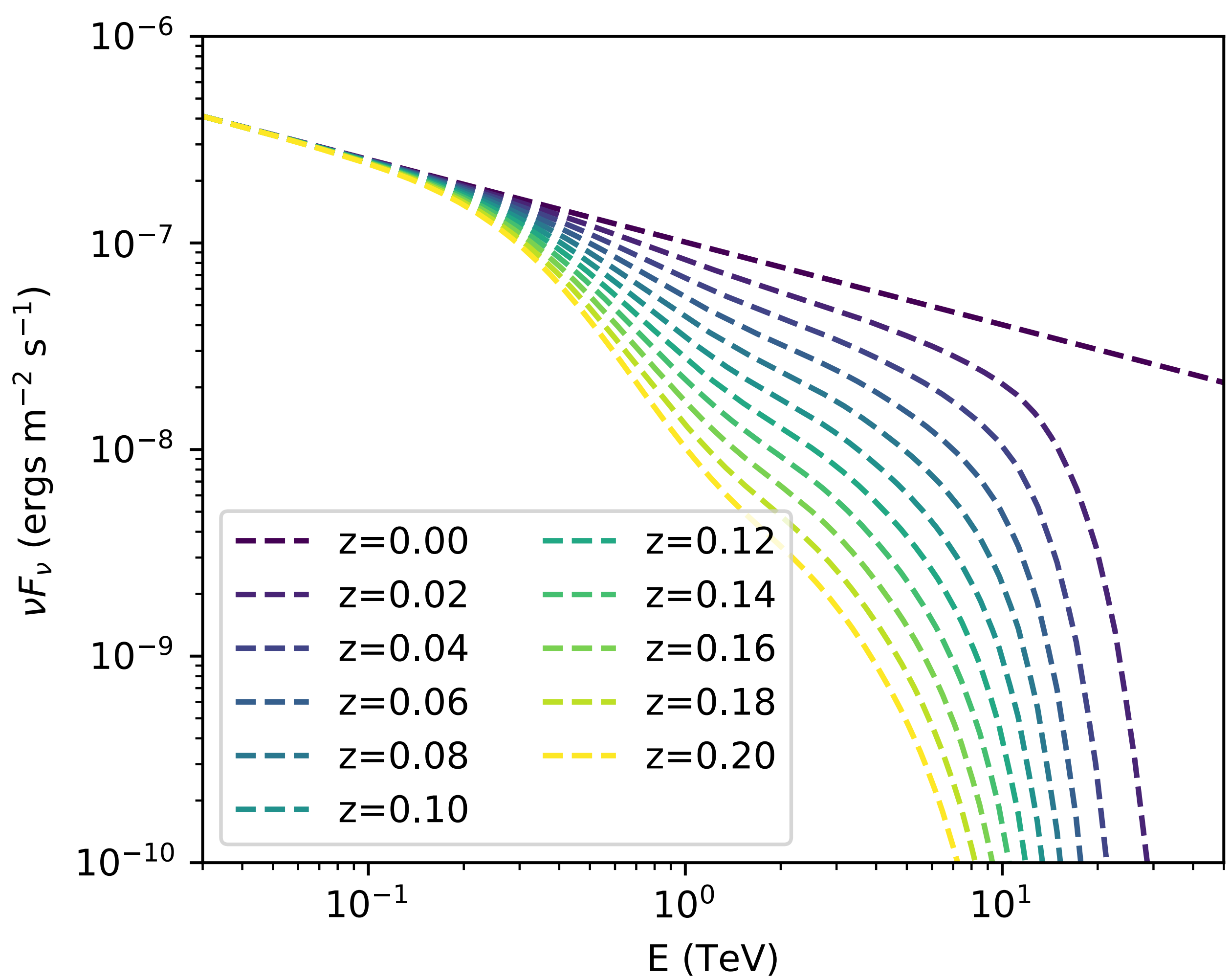
Observed spectrum:

$$\frac{dN}{dE} \propto \left(\frac{dN}{dE}_{int}\right) \exp(-\tau_{\gamma\gamma})$$



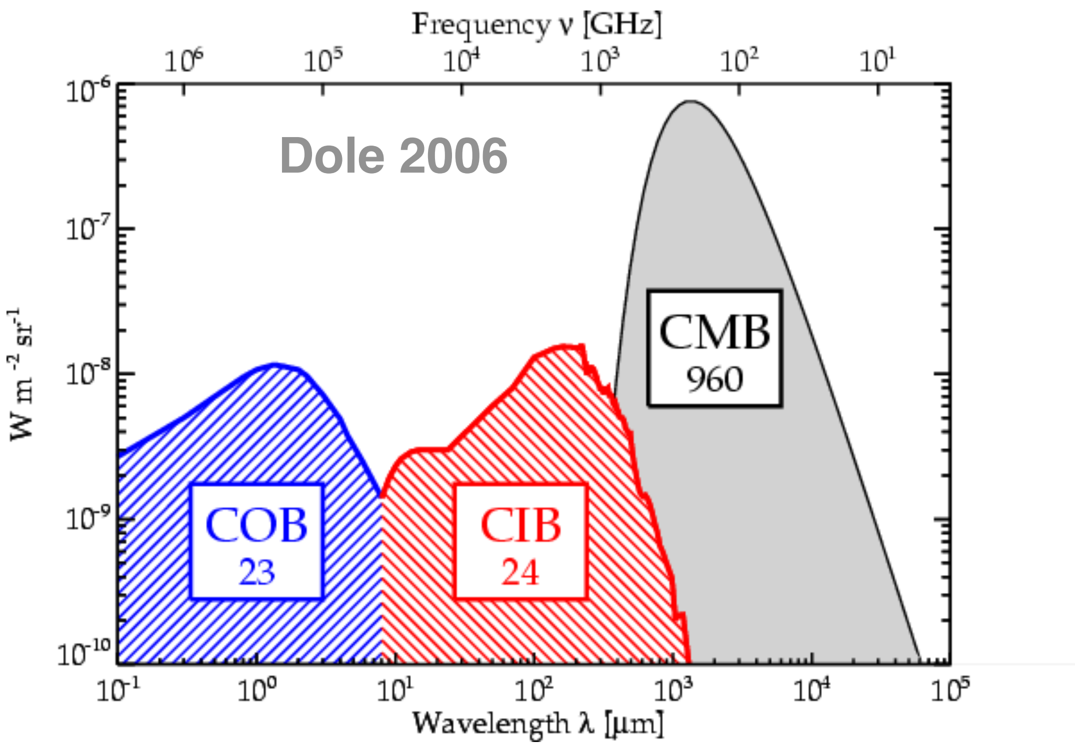


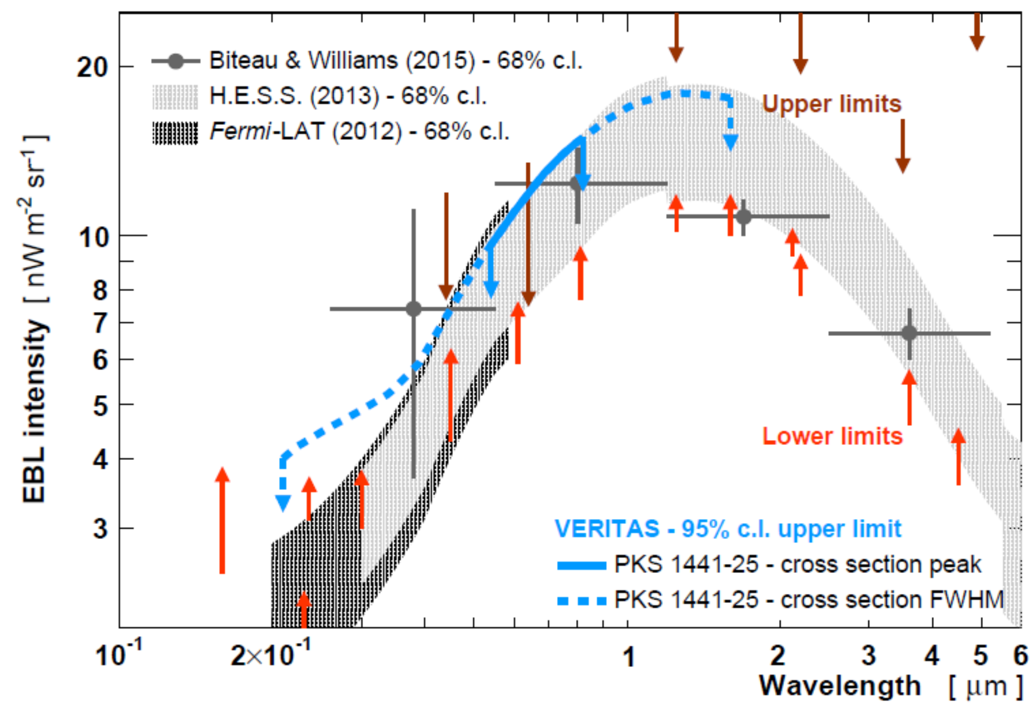
Adapted from G. Di Sciascio
& the LHAASO Collaboration 2016



EBL absorption using Dominguez et al., 2011, MNRAS, 410, 2556

Constraints on Extragalactic Background Light with VERITAS Blazar Observations



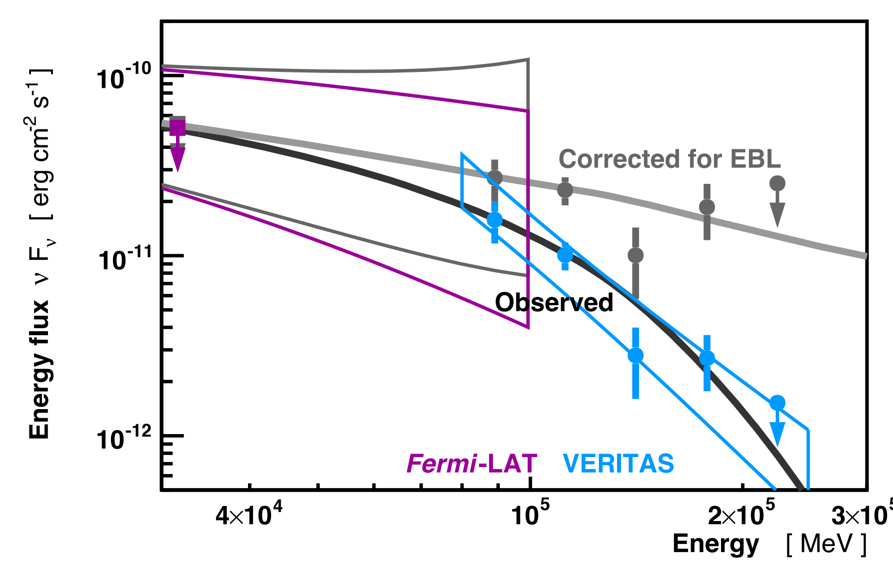


- Interaction of EBL-VHE photons results in attenuation above 100 GeV

  Minimal assumptions on intrinsic spectral properties

  1. No convex spectral shapes
  2. Extrapolate *Fermi*-LAT spectra to > 100 GeV

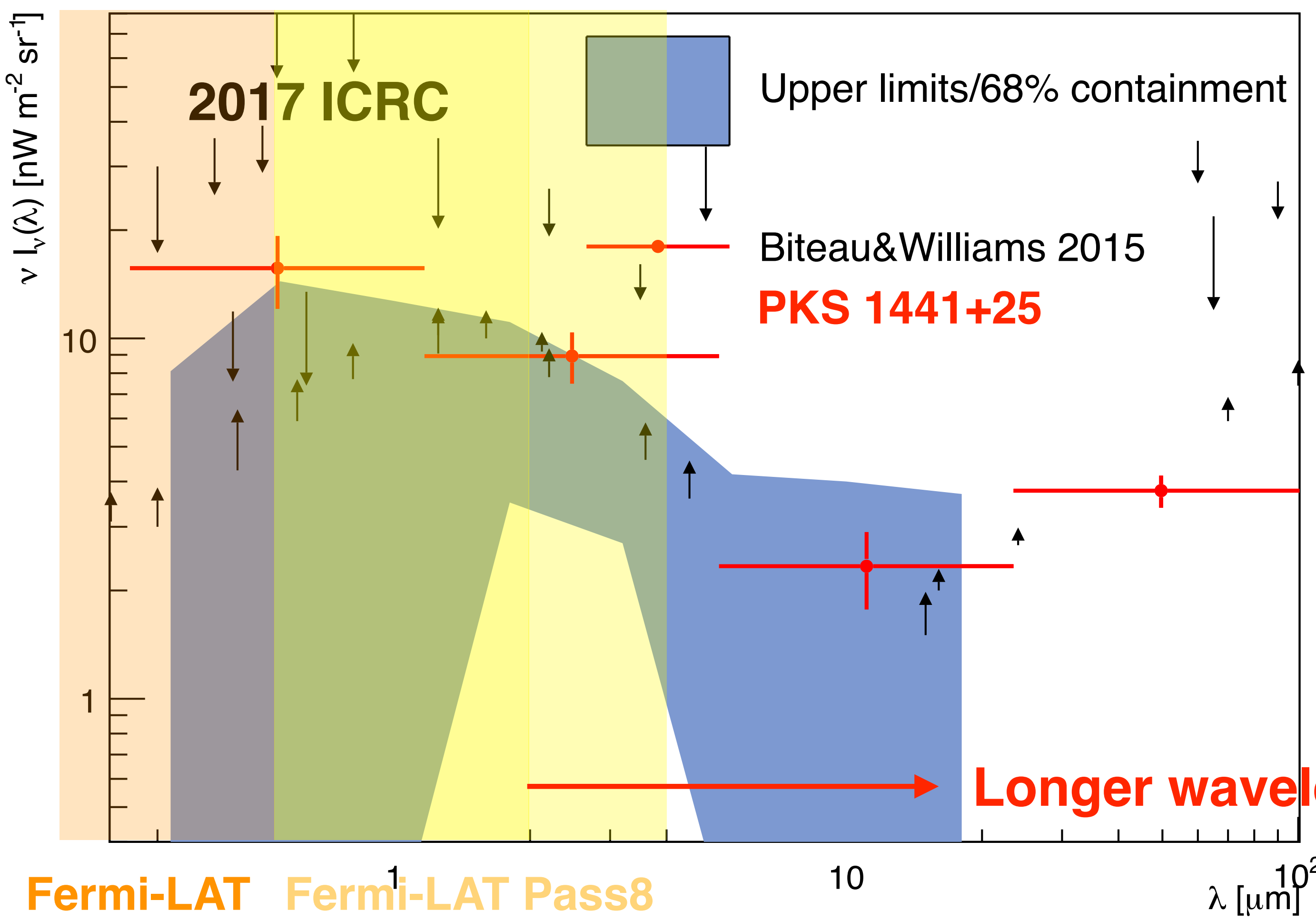
- Single source constraints:
  A quasar half a Universe away:
  PKS 1441+25 @ **z = 0.939** !

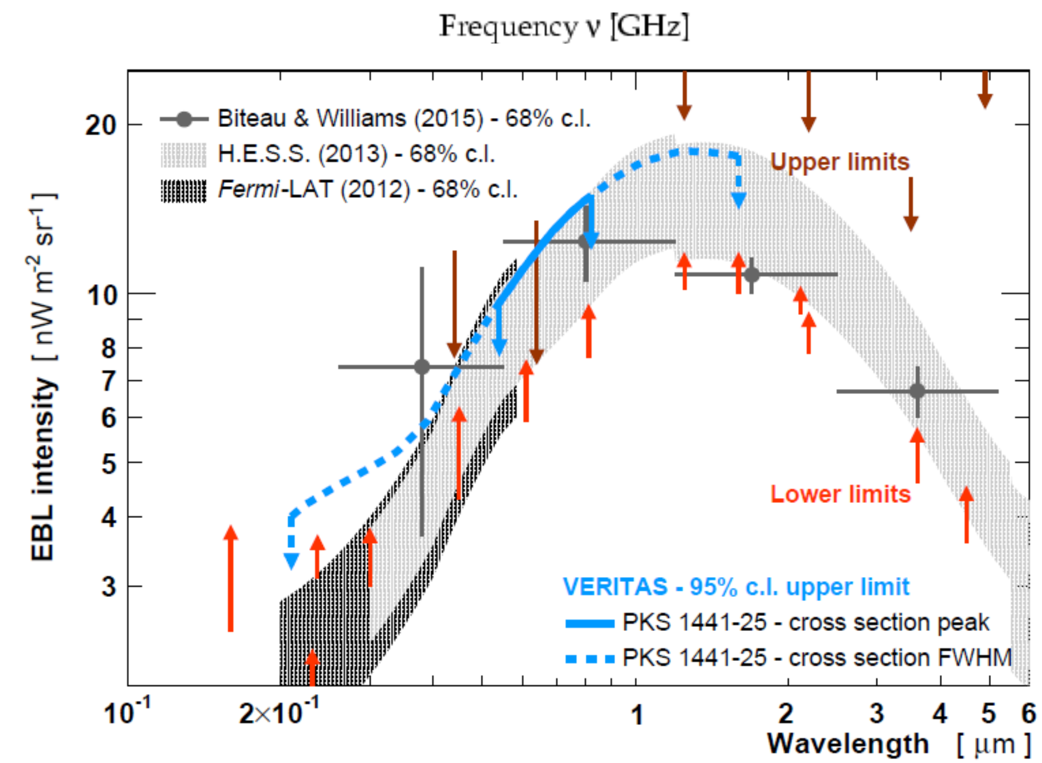


Abeysekara+ 2015, arXiv: 1512.04434

Constraints on Extragalactic Background Light with VERITAS Blazar Observations

Puschel 2017 ICRC POS 1107

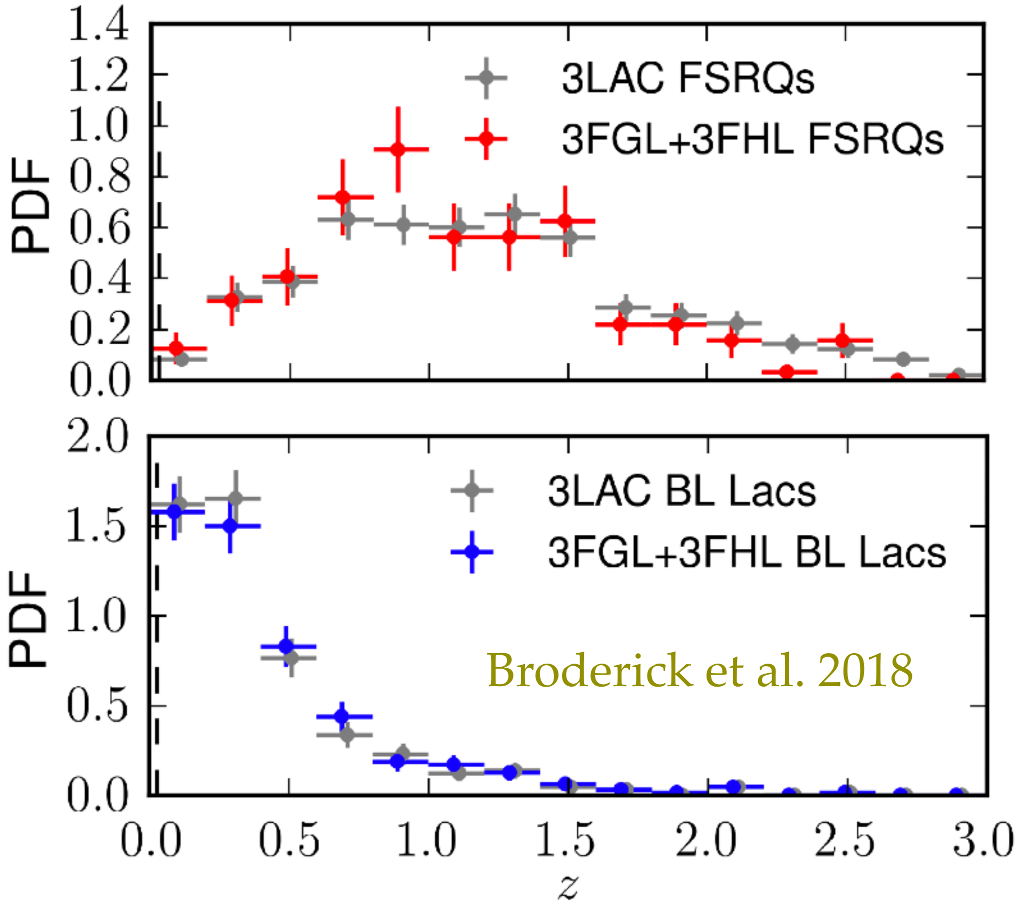


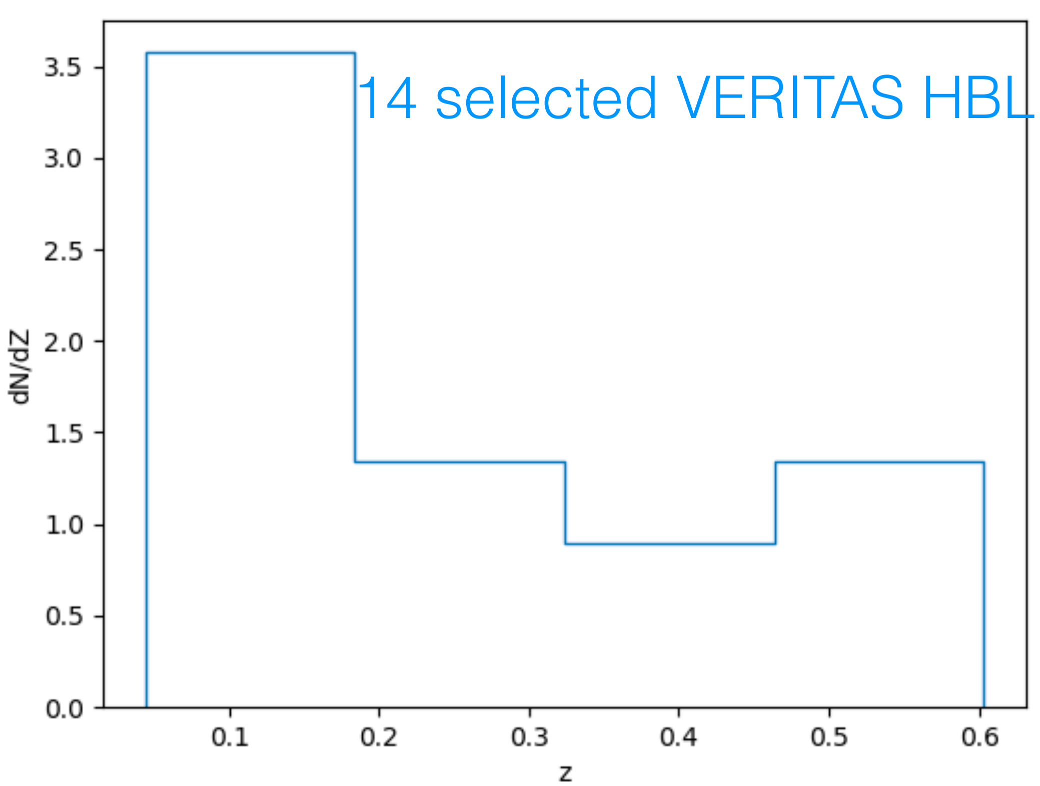


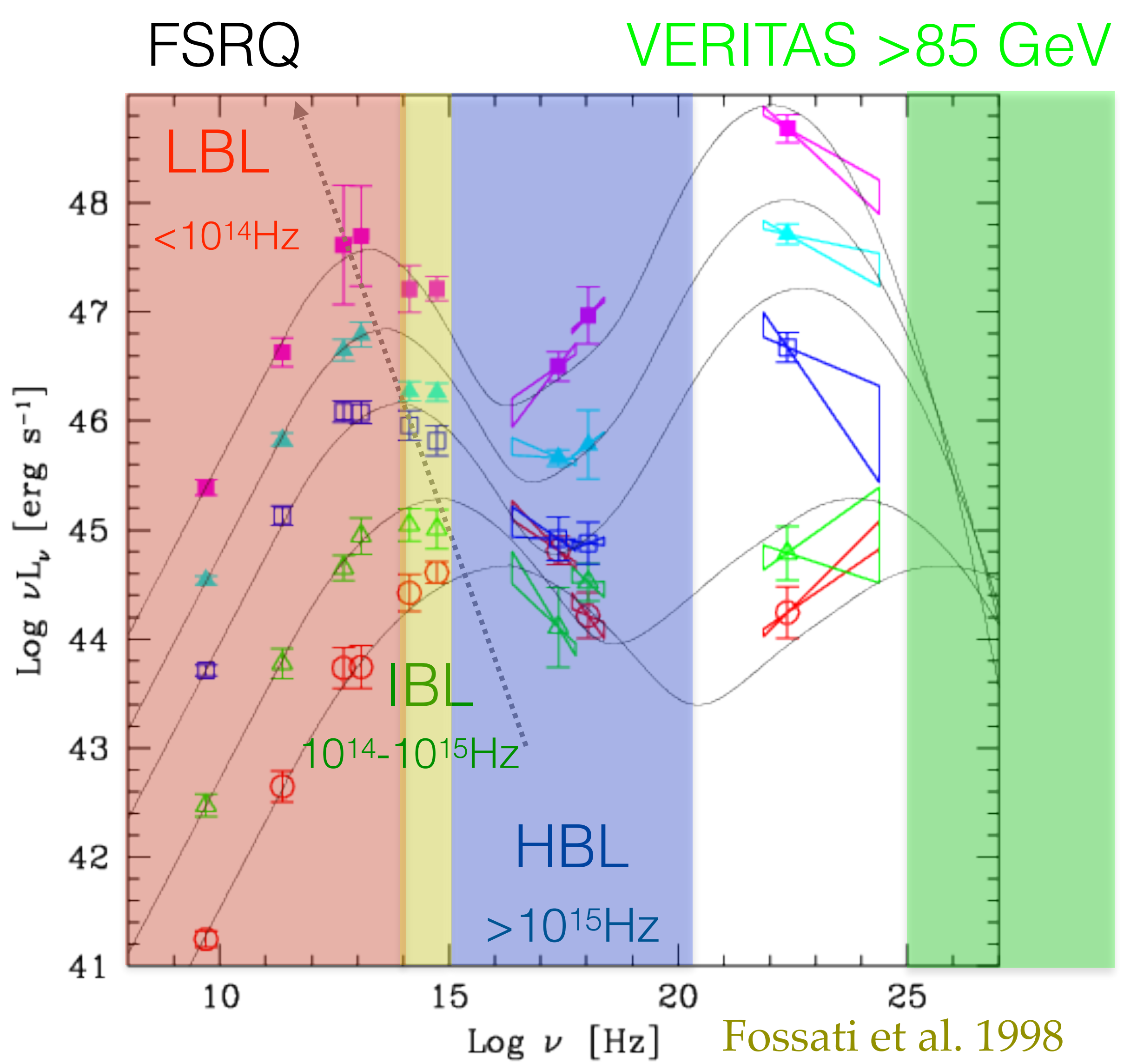
Longer wavelengths absorb higher energies

- Interaction of EBL-VHE photons results in attenuation above 100 GeV
- VERITAS long term program on extreme blazars exhibiting high-energy spectrum with no evidence of a cutoff up to a few TeV
- **Model-independent upper limits on EBL spectrum from 8 VERITAS blazars => galaxy surveys have resolved most of the sources of the EBL at these wavelengths**
- VERITAS fills a unique niche with observations of extreme blazars at nearby to moderate redshift ($0 < z < 0.3$), great for probing the longer wavelength EBL, complimentary to Fermi-LAT, with better sensitivity than HAWC

Blazar sequence & population study





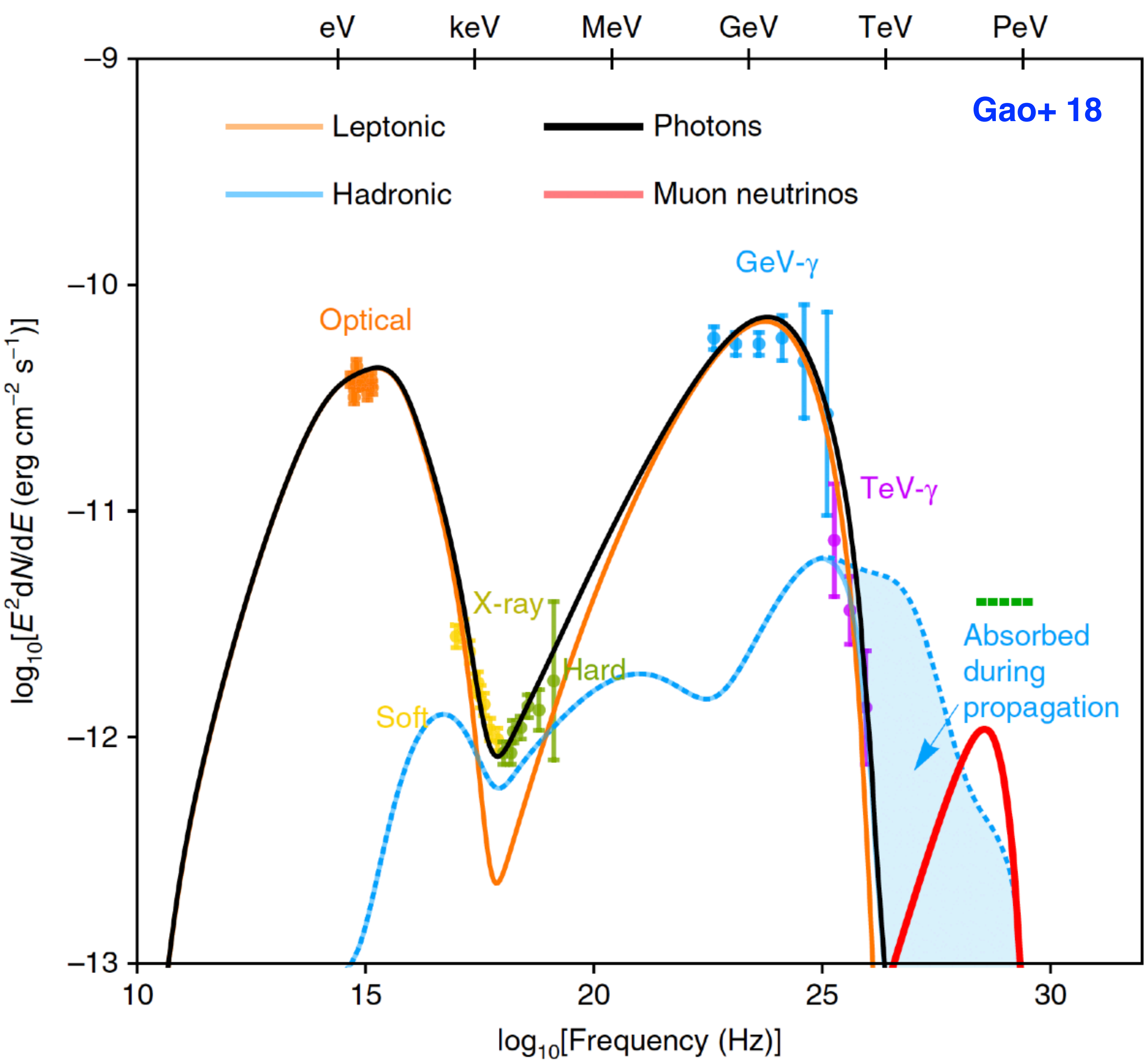


LHAASO ~>200 GeV

- Complete sample of local (z~<0.1) TeV emitting AGN (new, extreme HBLs?).
- Luminosity function, diffuse gamma-ray background, baseline for testing for evolution.
- Spectral curvature, EBL constraint

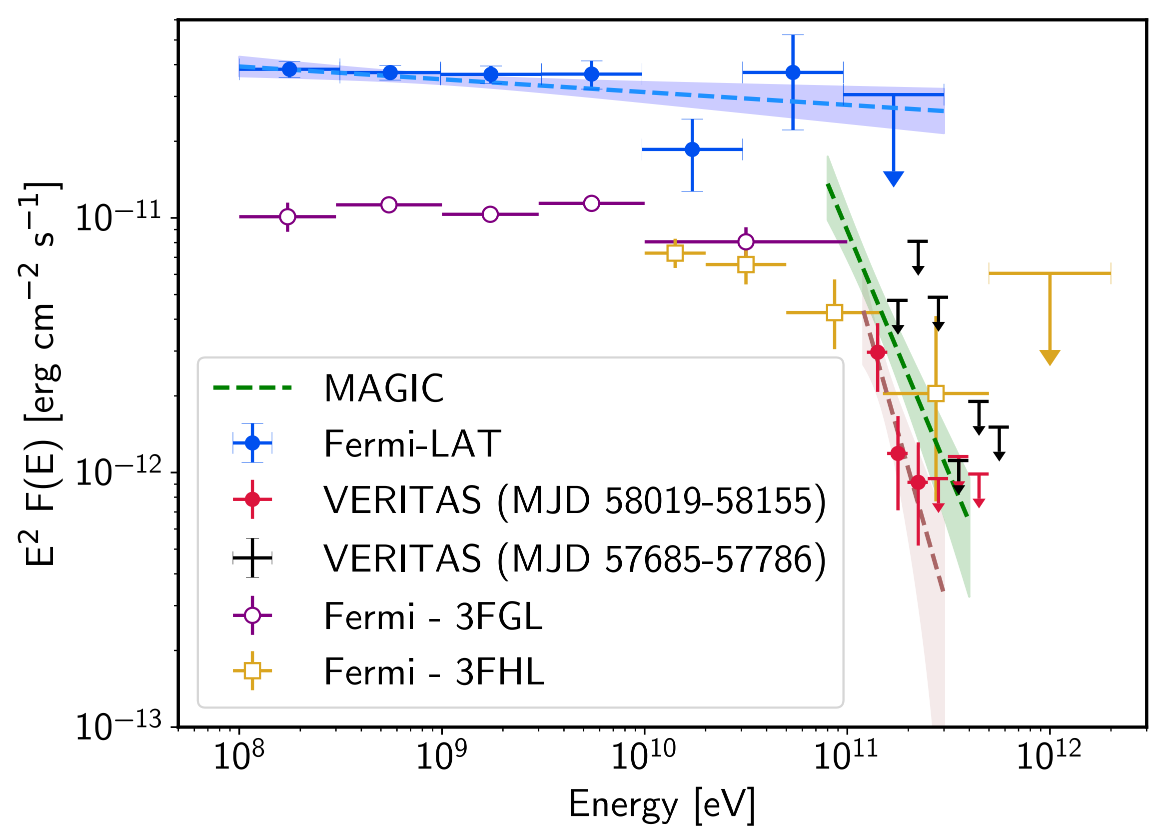
TXS 0506+056: The "Neutrino Blazar"

SED Modelling examples

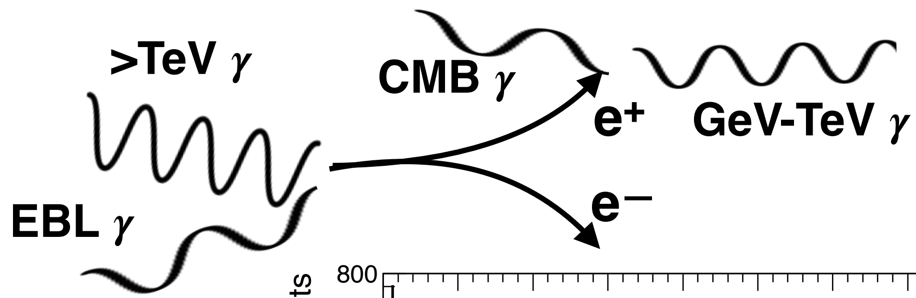


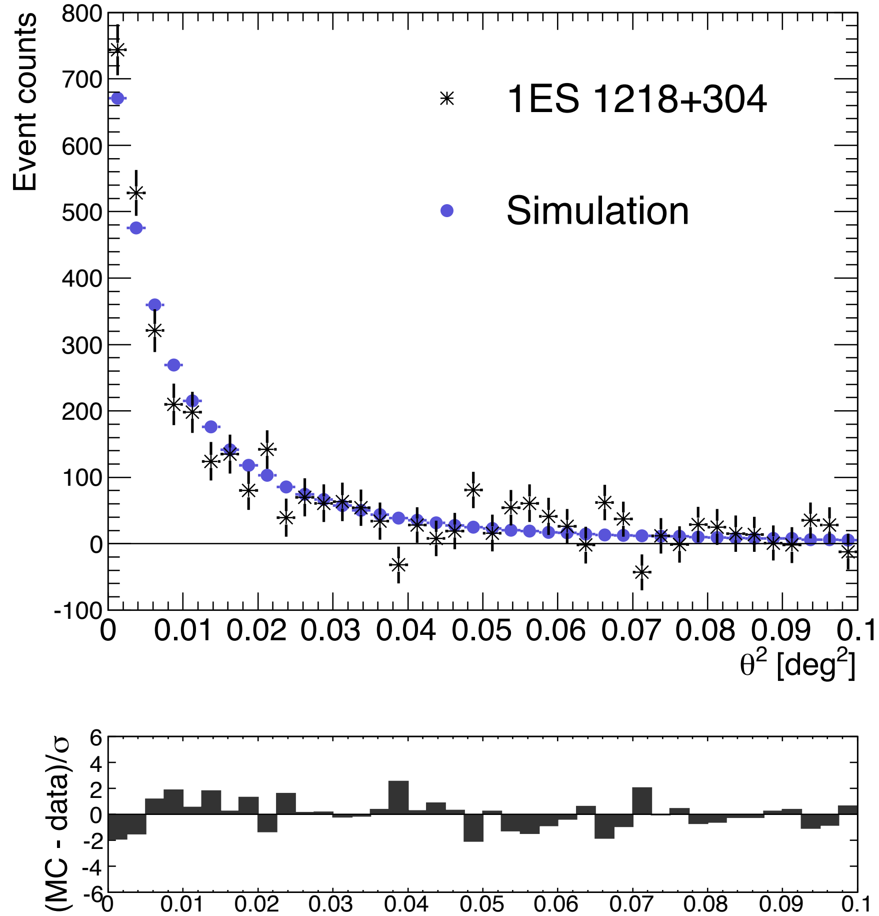
- z = 0.34

- Hard X-ray is VERY constraining (Emission from Bethe-Heitler pairs cannot exceed the observed flux)
- EBL absorbs ALL emission > TeV

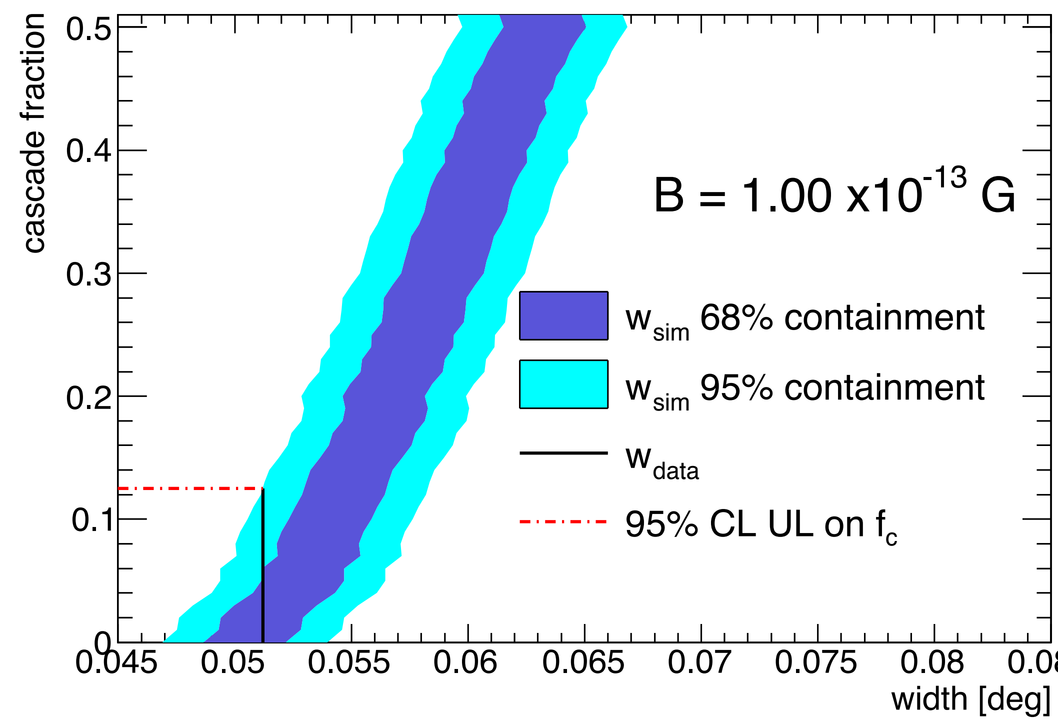


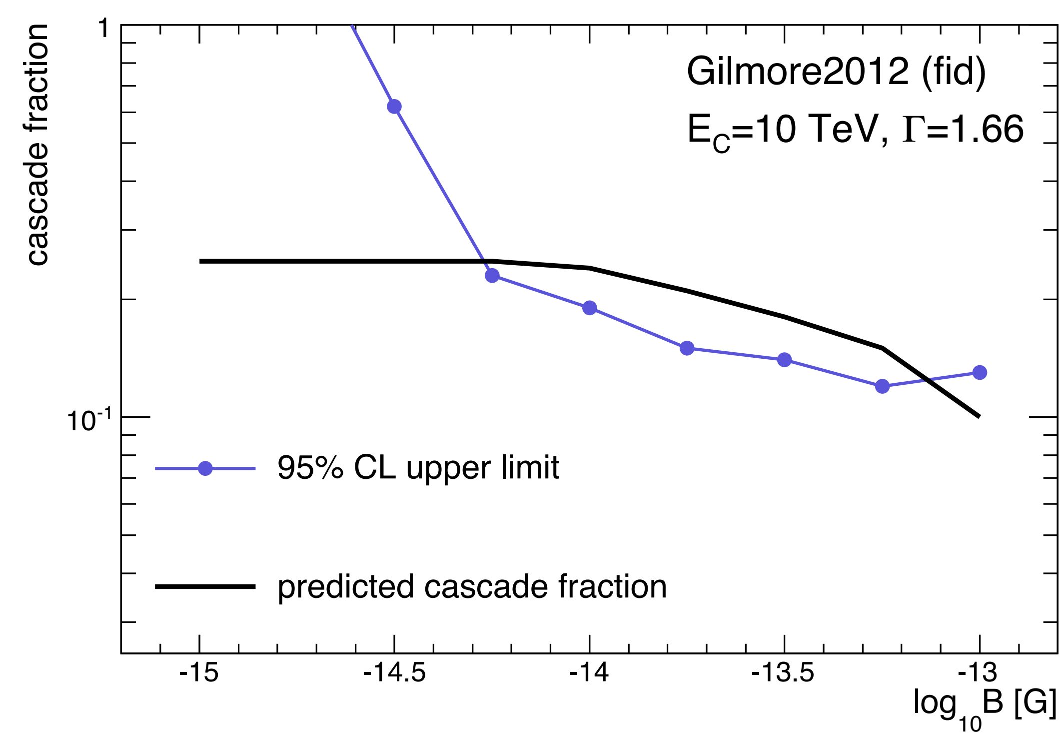
Constraints on Intergalactic Magnetic Field with VERITAS Blazar Observations





VERITAS Collaboration 2017 ApJ: arXiv:1701.00372

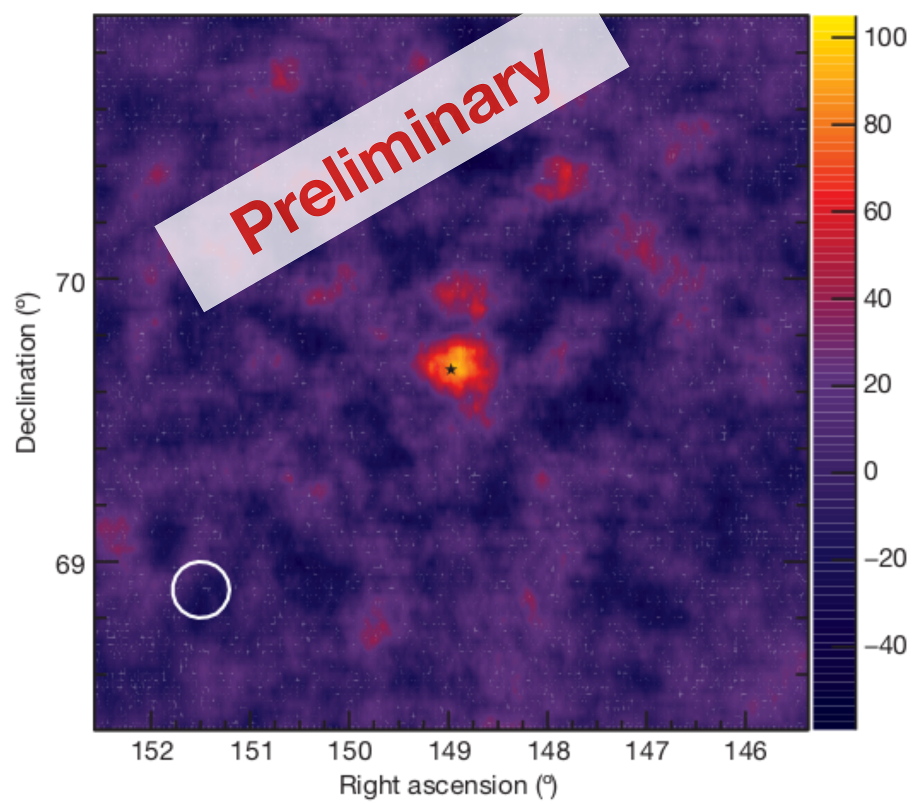


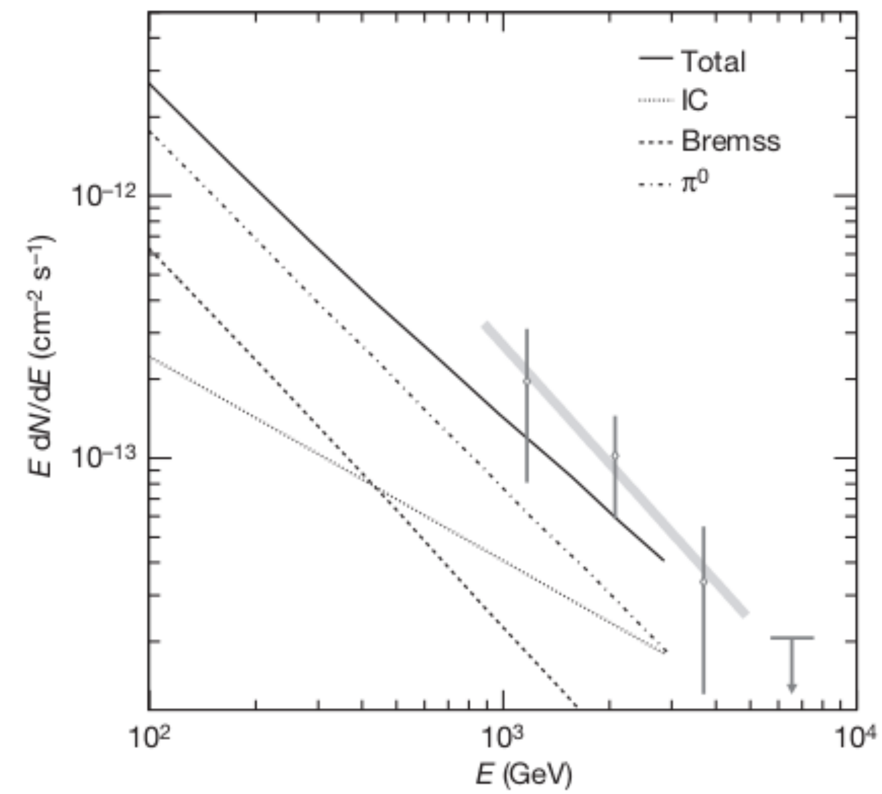


- For IGMF 10^{-16} G — 10^{-12} G, pair halos for blazars (z: 0.1 – 0.2) are detectable by current IACTs
- Tested for extended emission around 7 hard-spectrum blazars
- No deviation from simulated instrument PSF
- **Exclude IGMF strengths around ~10^{-14} G at 95% confidence level**

M 82: A TeV Starburst Galaxy

- VERITAS detected M82 in 2009 (~3.7 Mpc).
- Among weakest-ever VHE sources, 0.9% Crab
- No clear determination of the origin of the VHE emission

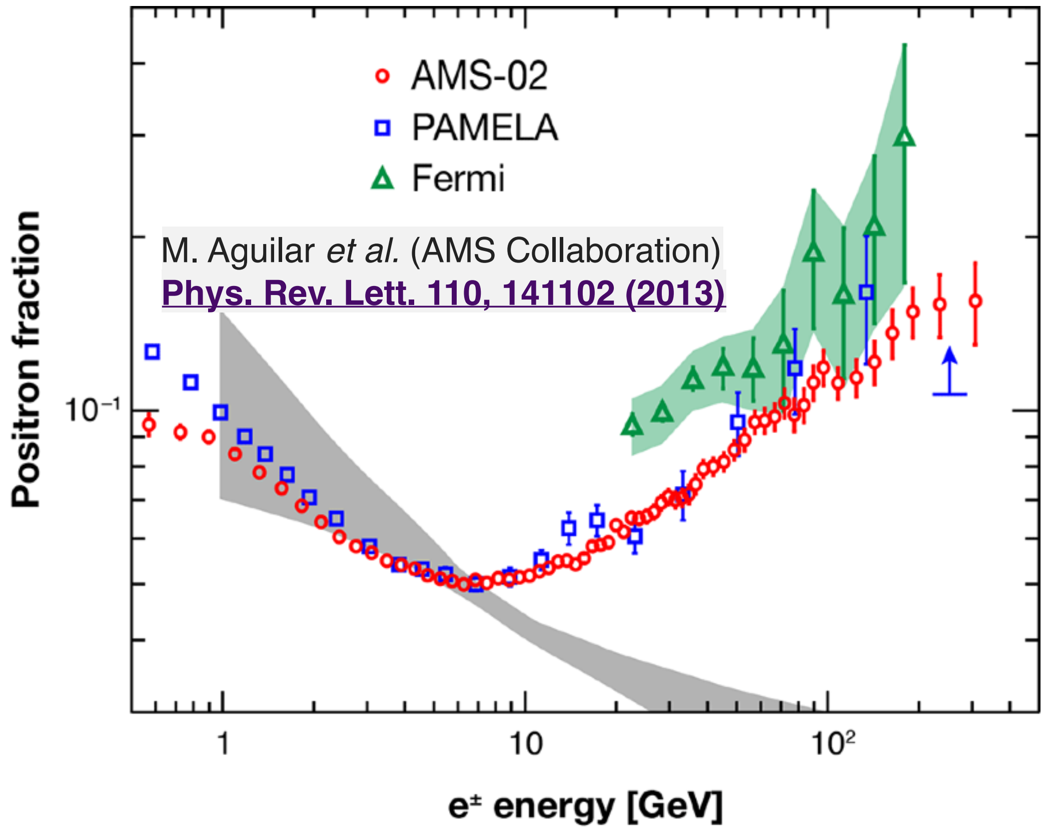




=>
Better sensitivity + energy resolution will help!

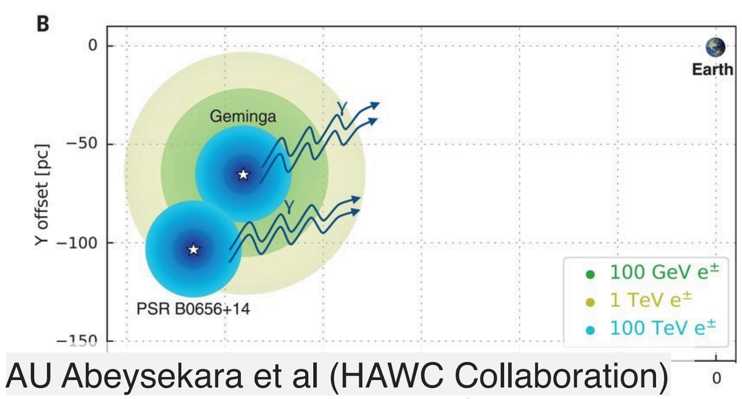
- VERITAS has since undergone two upgrades
- The exposure on M82 has increased: ~137 hours → ~240 hours
- We have deployed new analysis methods => improved low energy reconstruction

Local Cosmic-Ray Sources



M. Aguilar *et al.* (AMS Collaboration)
[Phys. Rev. Lett. 110, 141102 (2013)](https://doi.org/10.1103/PhysRevLett.110.141102)

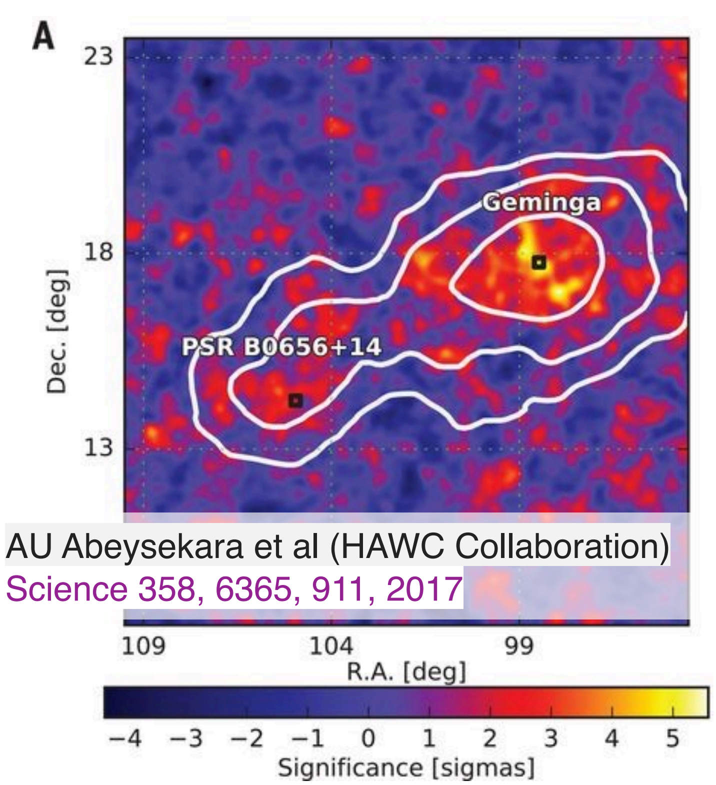
Can local PWN explain the positron excess?
HAWC says no (PSF limited),
VERITAS is trying at lower energy (FoV limited),
CTA/LHAASO will improve both.



AU Abeysekara et al (HAWC Collaboration)
Science 358, 6365, 911, 2017

=>

Better angular resolution + larger FoV will help!



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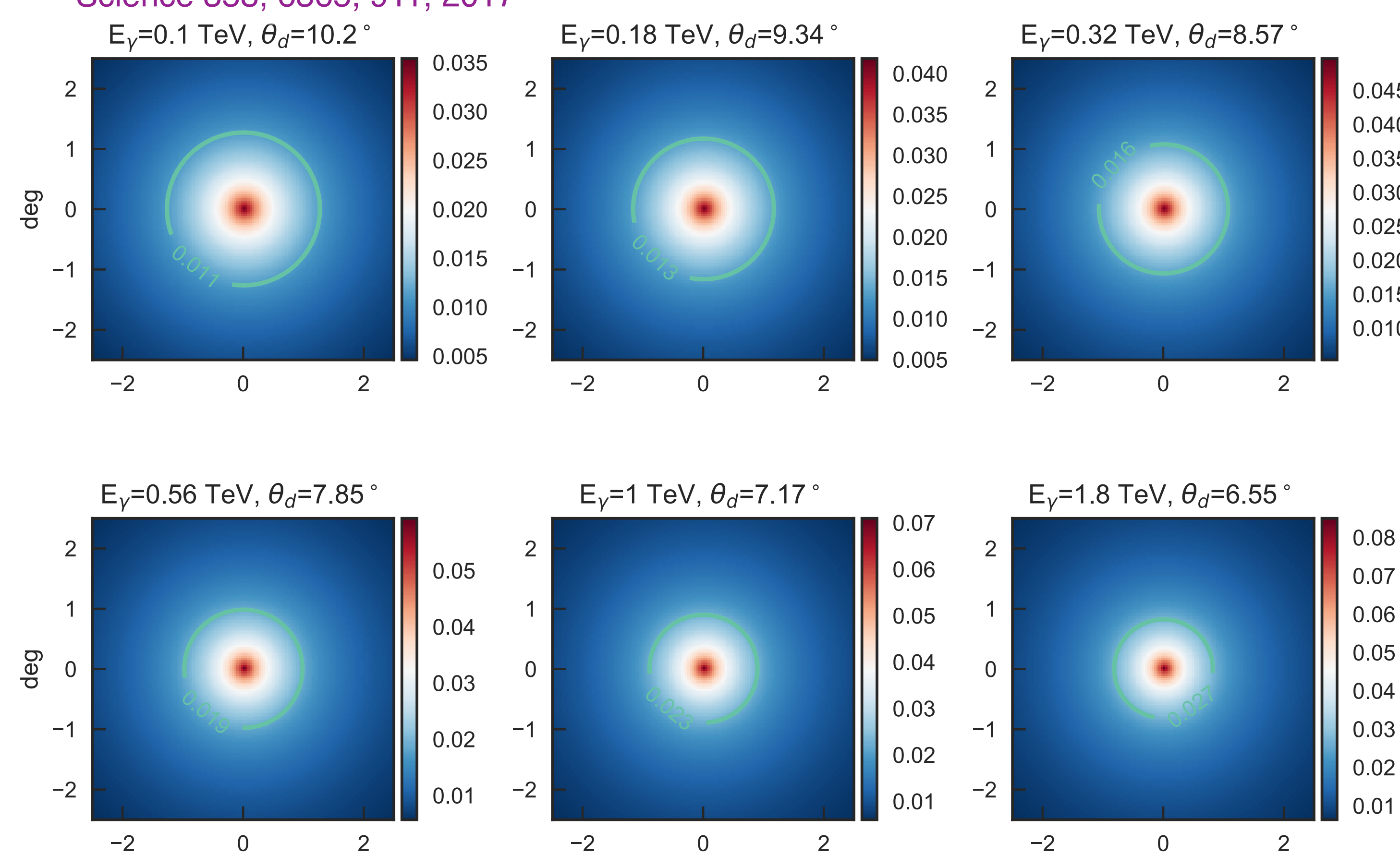


Supernova remnants

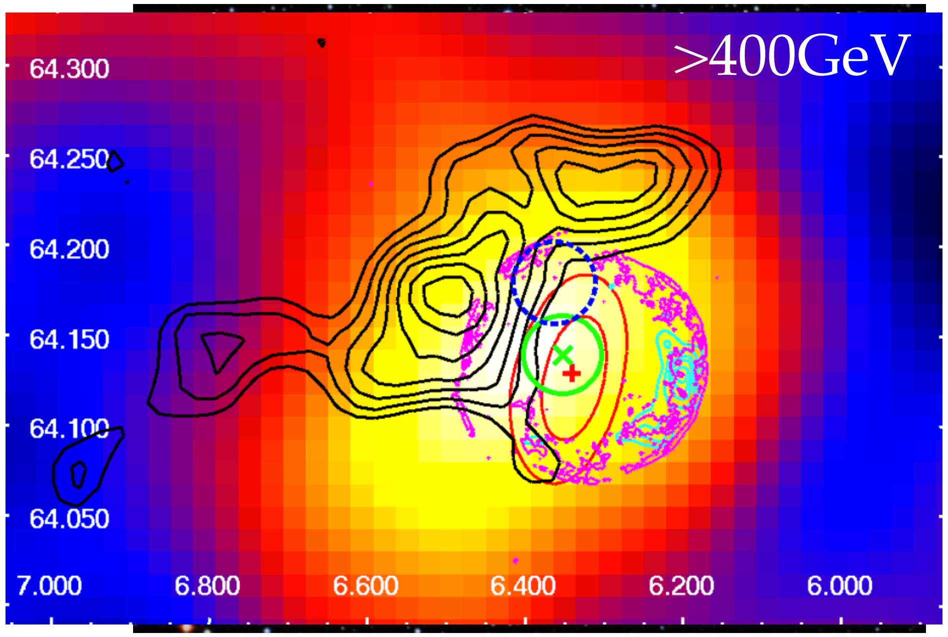
- Potential accelerators of Galactic cosmic ray particles
- Shock structure (e.g. X-ray)
- Young SNRs

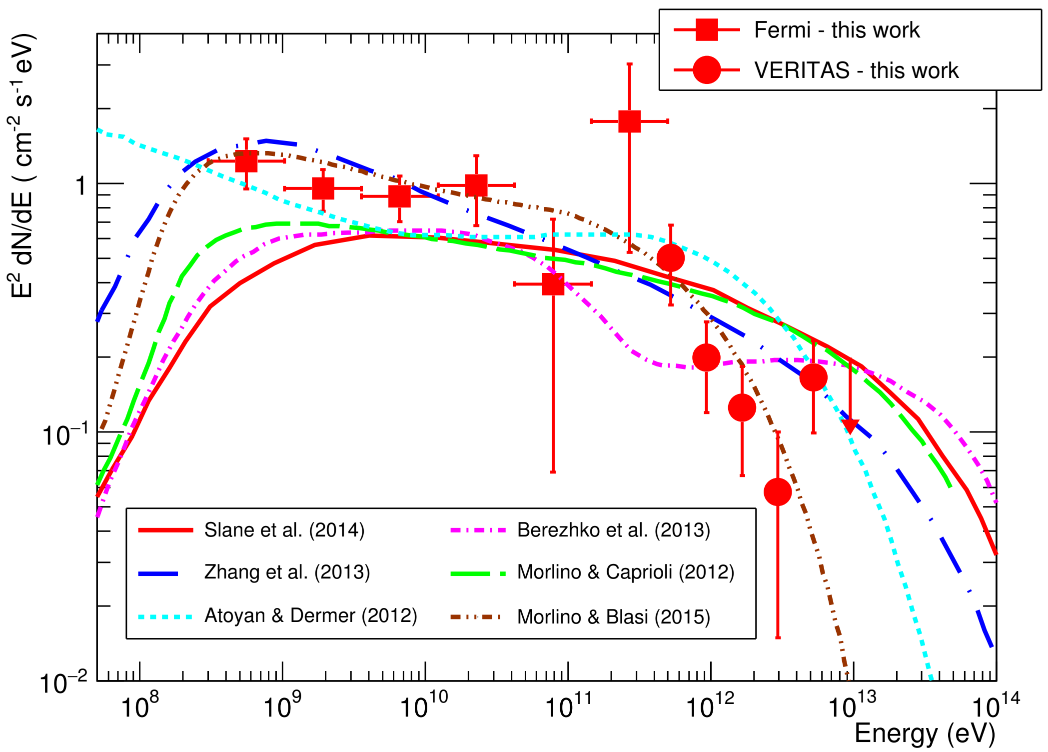
  e.g. Tycho (~444 yr)

- Both leptonic and hadronic models can describe the gamma-ray SED

=>

Higher energy will help





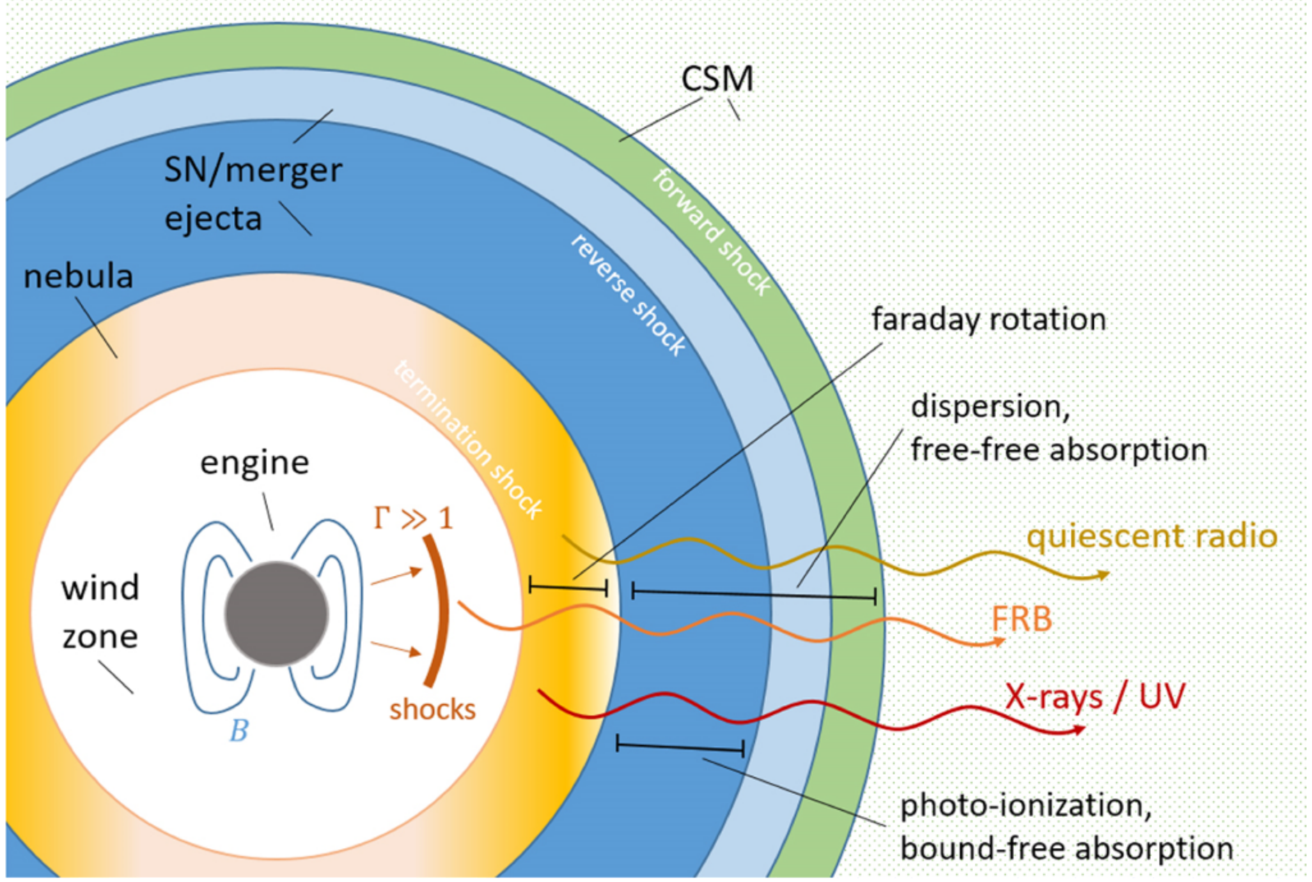
VERITAS Collaboration 2017 ApJ: arXiv:1701.06740

Gamma-Ray Transients

- Gamma-ray bursts
- Gravitational wave transients, e.g., Neutron star (NS-NS) mergers (kilonova)
- Astrophysical neutrino transients

- Fast radio bursts (FRBs)
- Galactic transients
  - PWN flares
  - Microquasars
  - Classic novae
  - Stellar bow shocks
- AGN flares
- Other magnetar powered transients e.g., Superluminous supernovae

Margalit, Metzger + 2018 MNRAS 481(2):2407-2426



More

~~Yet~~ To Be Detected!

=>

Larger FoV,
larger collecting area, +
wider energy coverage
will help!

Congratulations LHAASO!