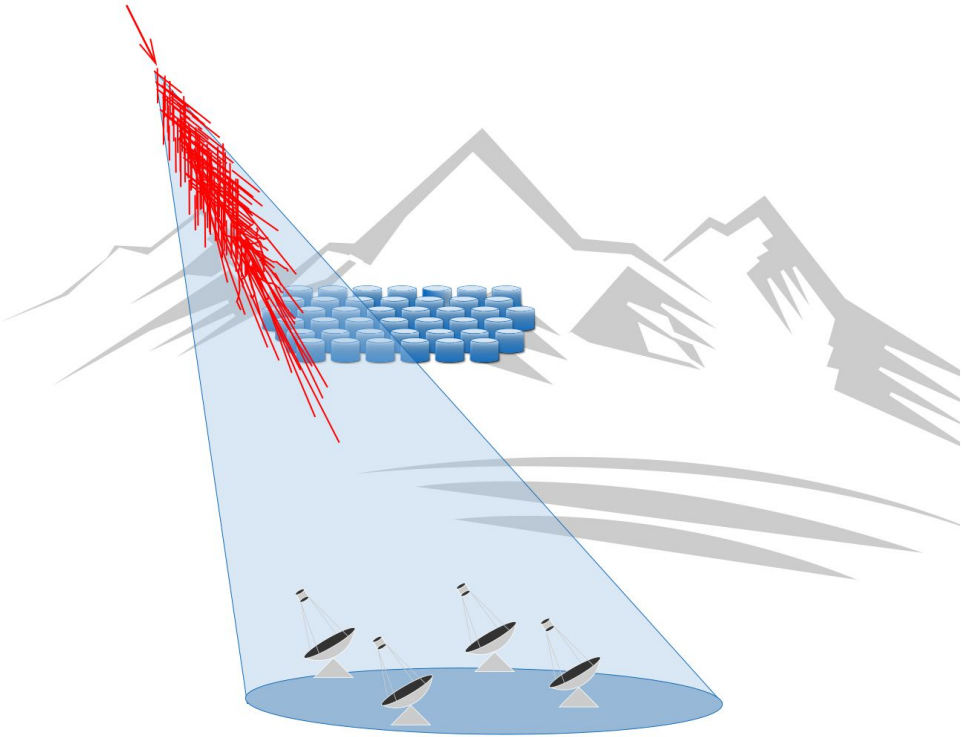
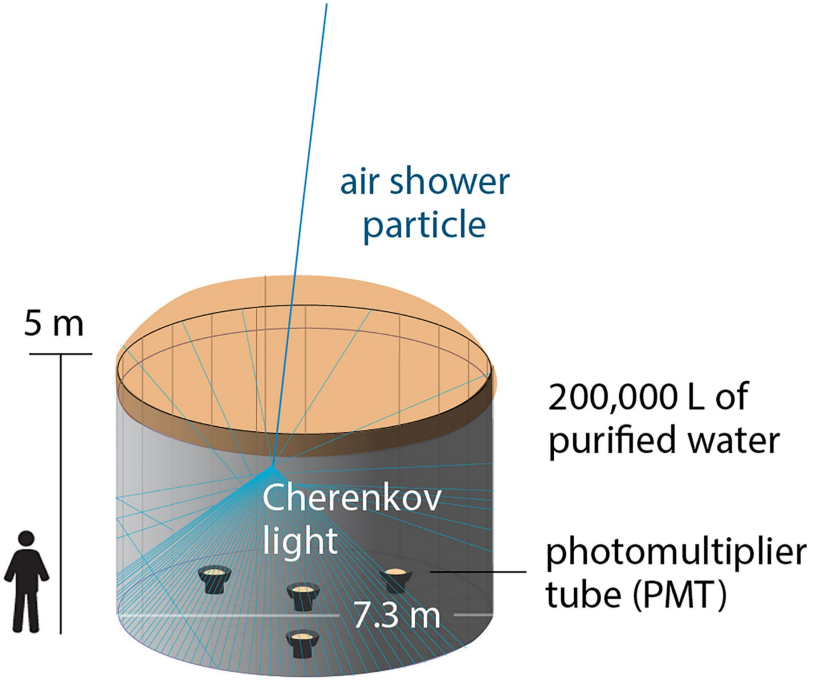
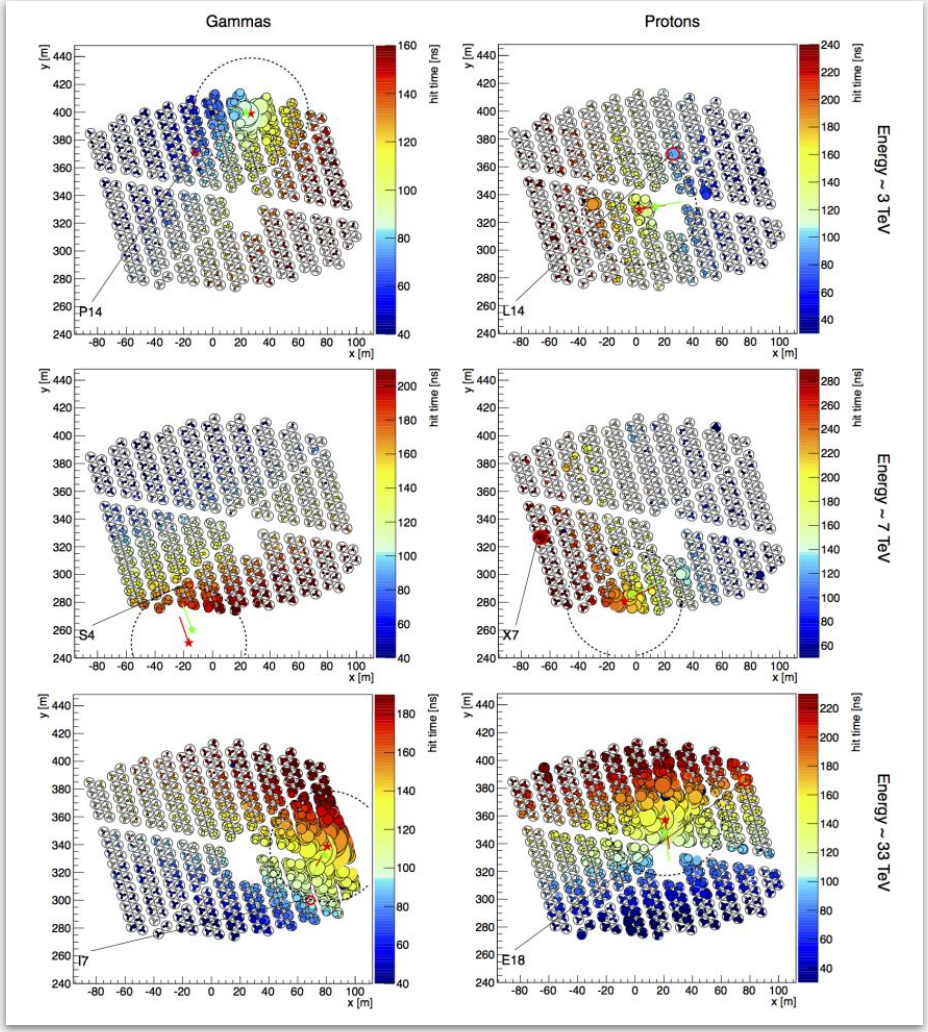
Welcome to Extragalactic & Blazar Astronomy with HAWC

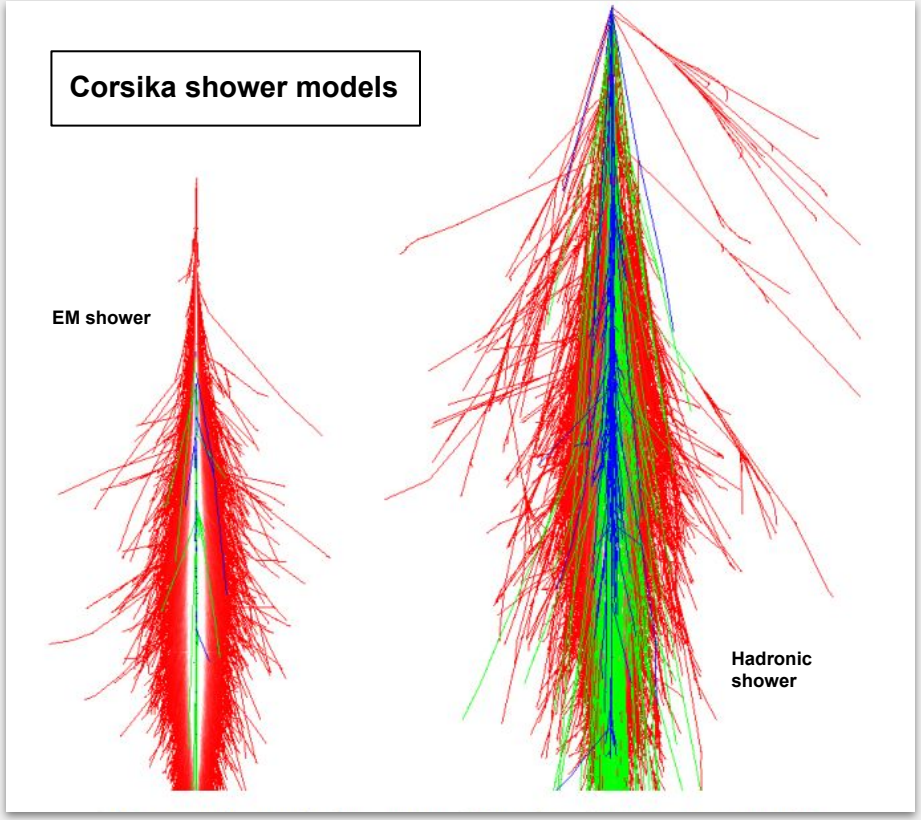
Kara Whitaker, Fermi Summer School 2023

HAWC Observatory Run-down







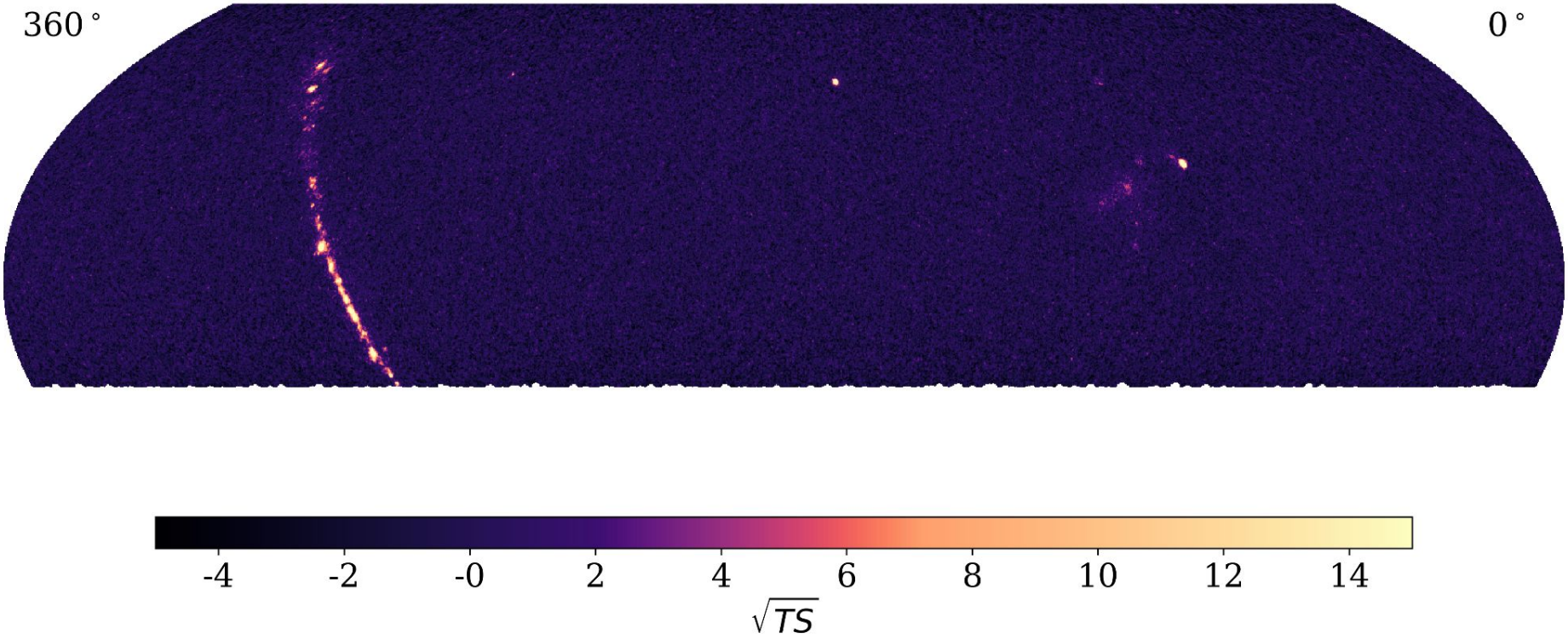


Red: gamma, Green: muon, Blue: hadron

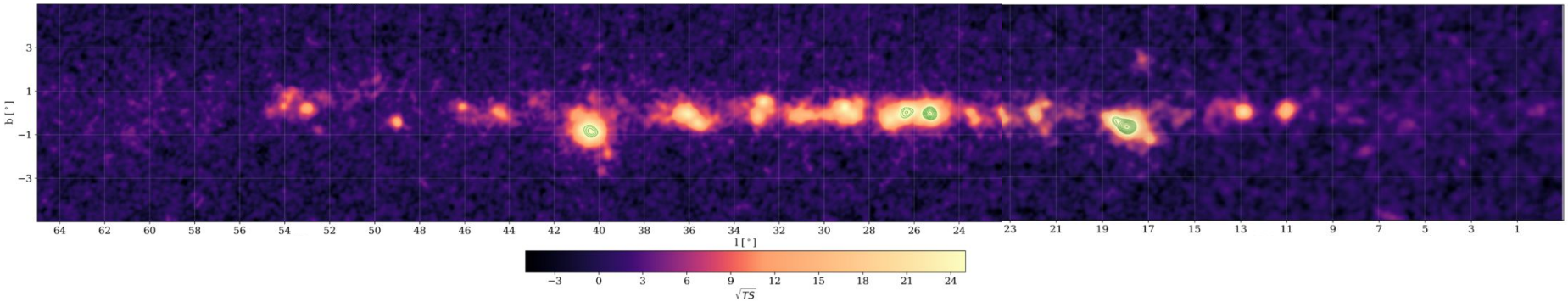
Left: K. Sparks Woodle 2015 Thesis
Right: H. Ayala 2017 Thesis

HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

Field of View



Blind vs A Priori Source Searches



The Third HAWC Catalog: 1523 days, 4 source morphologies tested (point source, 0.5°, 1.0°, and 2.0° extension), resulted in 65 sources detected at ≥ 5 sigma significance

Blind vs *A Priori* Source Searches

3FHL Catalog:

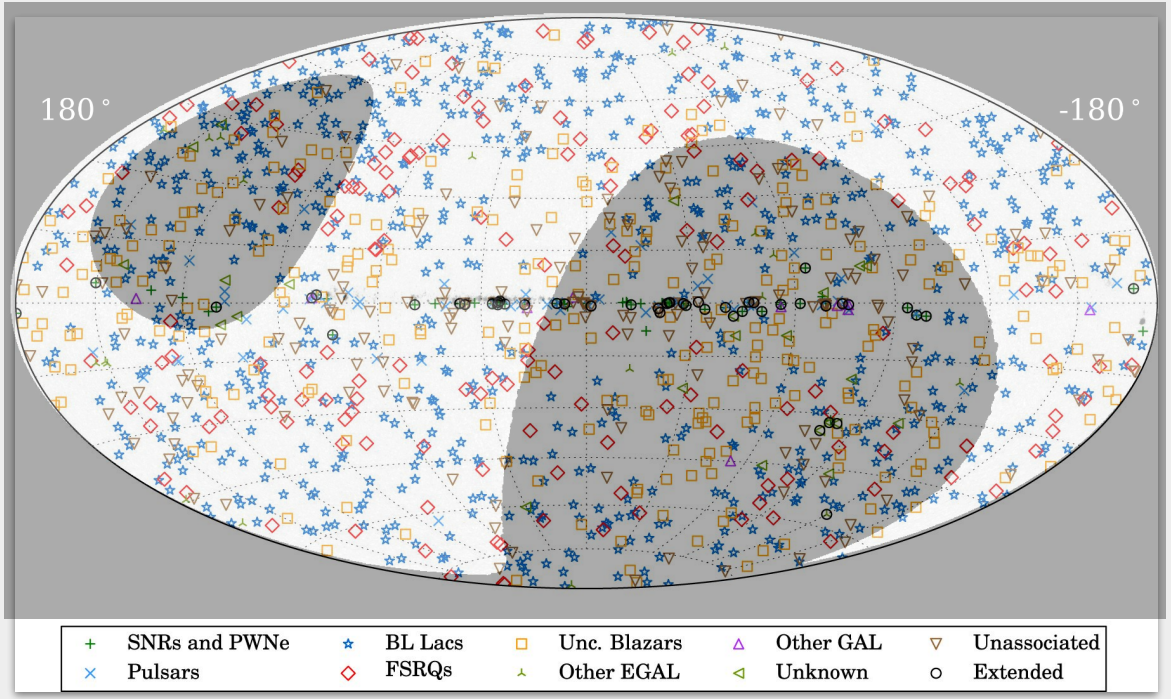
- 1556 sources, 79% extragalactic
- 9% identified, 78% associated, 13% unassociated

Source types:

- BL Lacertae objects
- Flat Spectrum Radio Quasars
- Radiogalaxies
- Blazars Candidates of Uncertain type
- Starburst galaxies

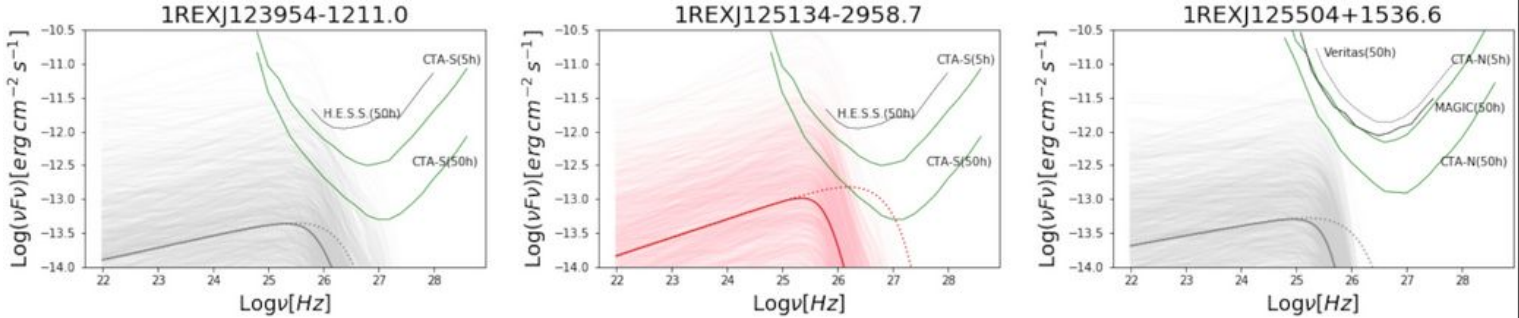
HAWC source selection:

- 138 sources identified or associated and within 40° of zenith and z ≤ 0.3



M. Ajello et al 2017 ApJS 232 18

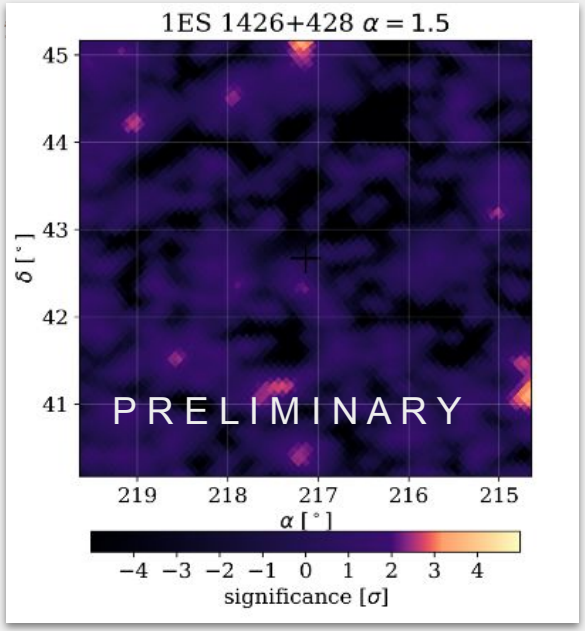
Blind vs *A Priori* Source Searches

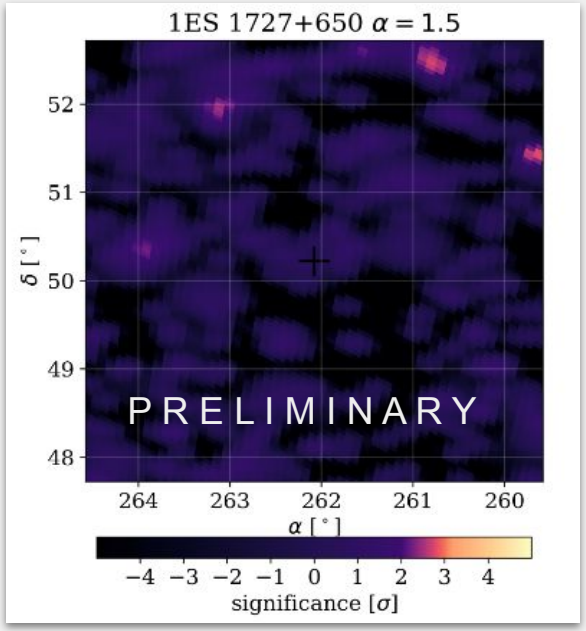


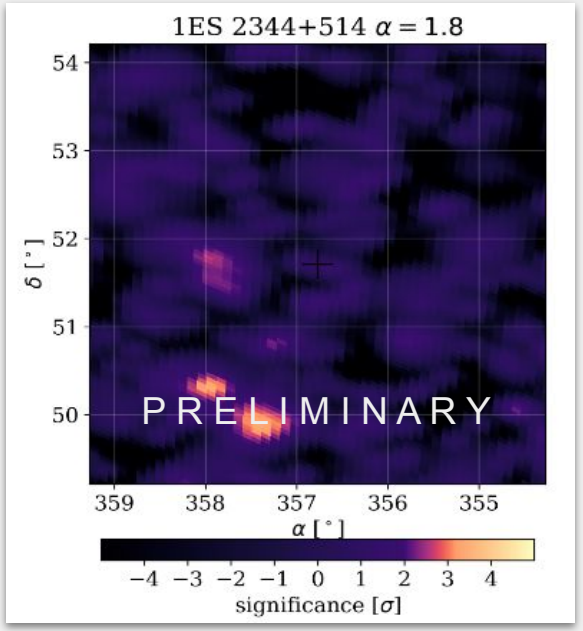
REX catalog: Catalogue of ~1600 Radio-Emitting X-Ray Sources identified by cross-matching X-Ray and Radio Data

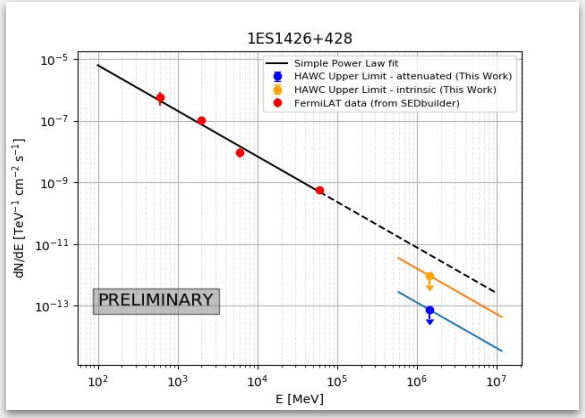
Te-REX catalog: REX sub-catalog. Selection criteria include CTA FoV, X-Ray to Radio emission ratio, counterpart's optical magnitude, source extension, and spectral classification. 46 sources pass all cuts, 14 of those have a 5% detection probability.

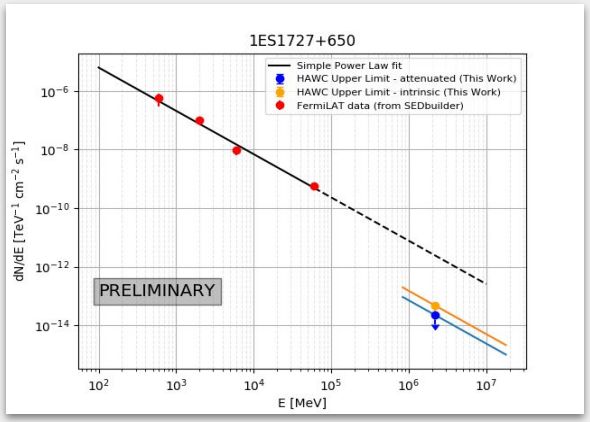
HAWC Source Selection: HAWC's sensitivity curve & FoV applied in place of CTA to produce a source list akin to Te-REX. Resulted in 16 potentially observable extragalactic TeV sources.


1ES 1426+428 $\alpha = 1.5$
PRELIMINARY
δ [°]
α [°]
significance [σ]


1ES 1727+650 $\alpha = 1.5$
PRELIMINARY
δ [°]
α [°]
significance [σ]


1ES 2344+514 $\alpha = 1.8$
PRELIMINARY
δ [°]
α [°]
significance [σ]


1ES1426+428
Simple Power Law fit
HAWC Upper Limit - attenuated (This Work)
HAWC Upper Limit - intrinsic (This Work)
FermiLAT data (from SEDbuilder)
PRELIMINARY
dN/dE [TeV^{-1} cm^{-2} s^{-1}]
E [MeV]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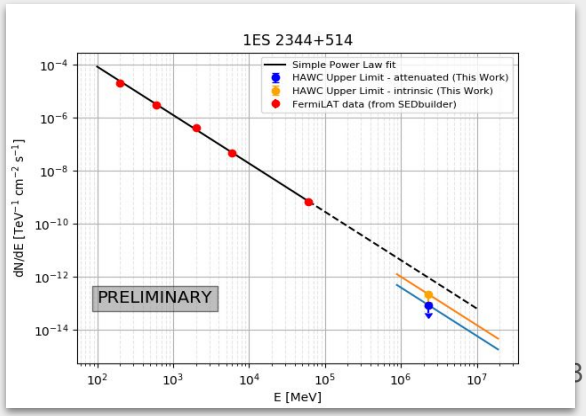
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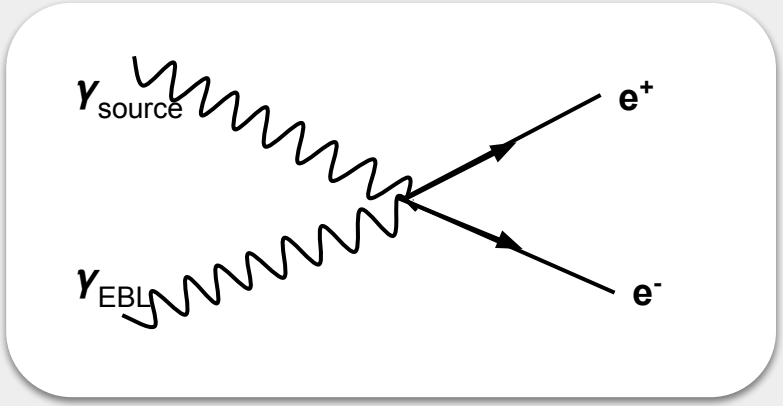
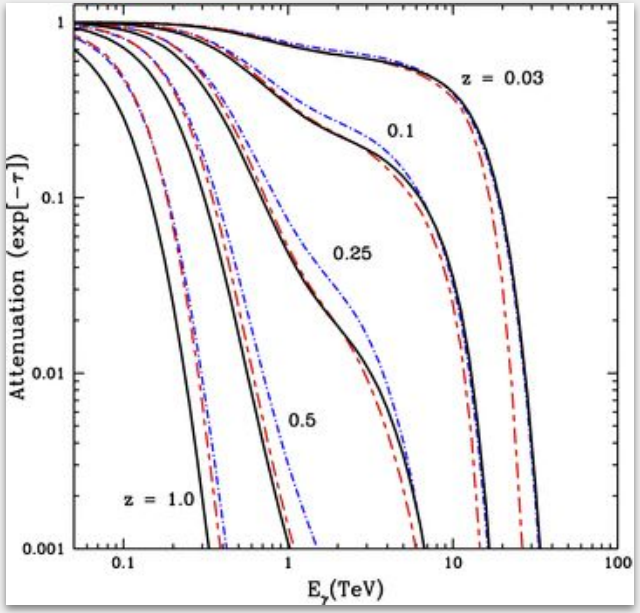
E [MeV]

Impact of Extragalactic Background Light



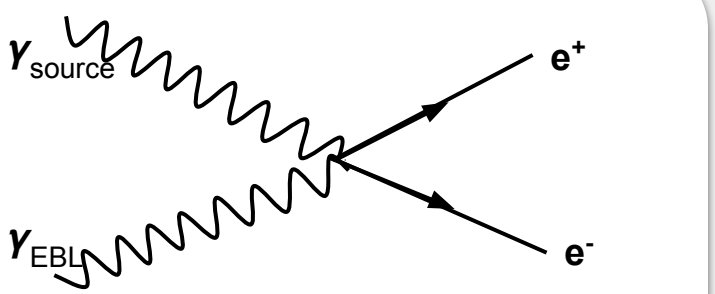
$$\frac{dN}{dE}_{obs} = \frac{dN}{dE}_{int} \times e^{-\tau(E,z)}$$



The attenuation $e^{-\tau}$ of gamma-rays versus gamma-ray energy, for sources at z= 0.03, 0.1, 0.25, 0.5 and 1. Results are compared for our fiducial *WMAP*5 (solid) and *WMAP*5+fixed (dash–dotted violet) models, as well as the model of D11 (red dash–dotted). Increasing distance causes absorption features to increase in magnitude and appear at lower energies. The plateau seen between 1 and 10 TeV at low redshift is a product of the mid-IR valley in the EBL spectrum.

Gilmore et al (2012). https://doi.org/10.1111/j.1365-2966.2012.20841.x

Impact of Extragalactic Background Light



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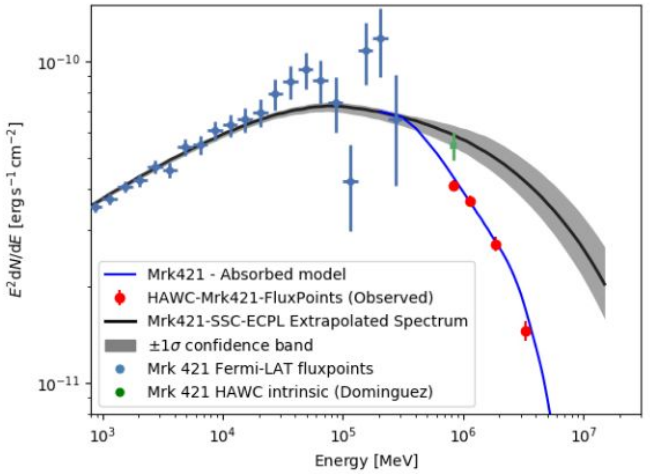
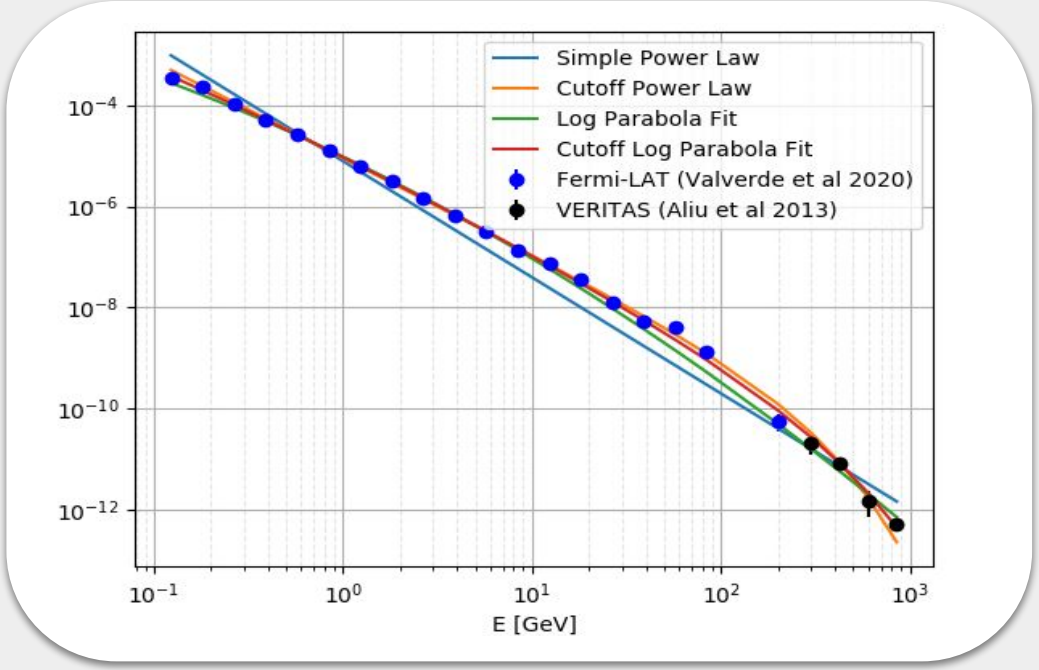
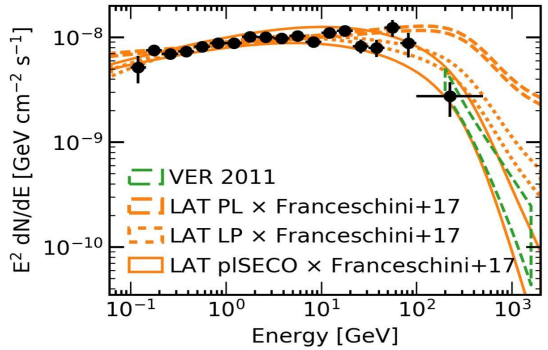


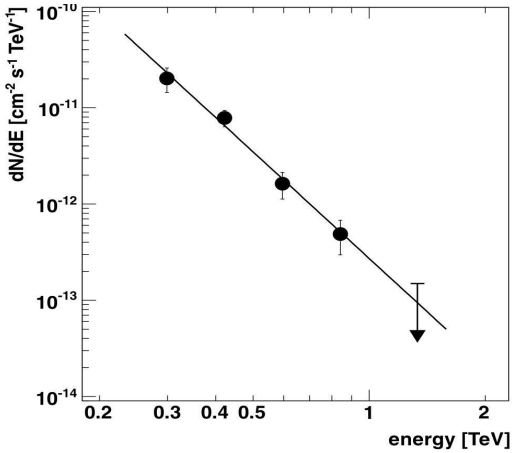
Figure 2. Extrapolated intrinsic emission spectrum for Mrk 421 (black line) along with the $\pm 1\sigma$ confidence band (statistical uncertainty only). Also shown, the resulting absorbed spectrum (blue line) according to a random EBL model along with HAWC data, the fluxpoints resulting from the $Fermi - LAT$ analysis (light-blue points) and the deabsorbed HAWC fluxpoint (green) according to Franceschini et al. (2008) EBL model.

"Probing the extragalactic mid-infrared background with HAWC" (2022) https://doi.org/10.48550/arXiv.2204.12166

Possible TeV Blazar Analysis - In Progress







Upper Right: A decade of multi-wavelength observations of the TeV blazar 1ES 1215+303, Abeysekara et al (2020). Fermi-LAT data.

Lower Right: Long Term Observations of B2 1215+30 with VERITAS, Aliu et al (2013)

Possible TeV Blazar Analysis - In Progress

Simple Power Law Parameters

VERITAS index (α): 3.6 ± 0.4stat ± 0.3syst

HAWC index (α): 3.45 ± 0.16stat

$$N\left(\frac{E}{E_0}\right)^{-\alpha}$$

Cutoff Log Parabola Parameters

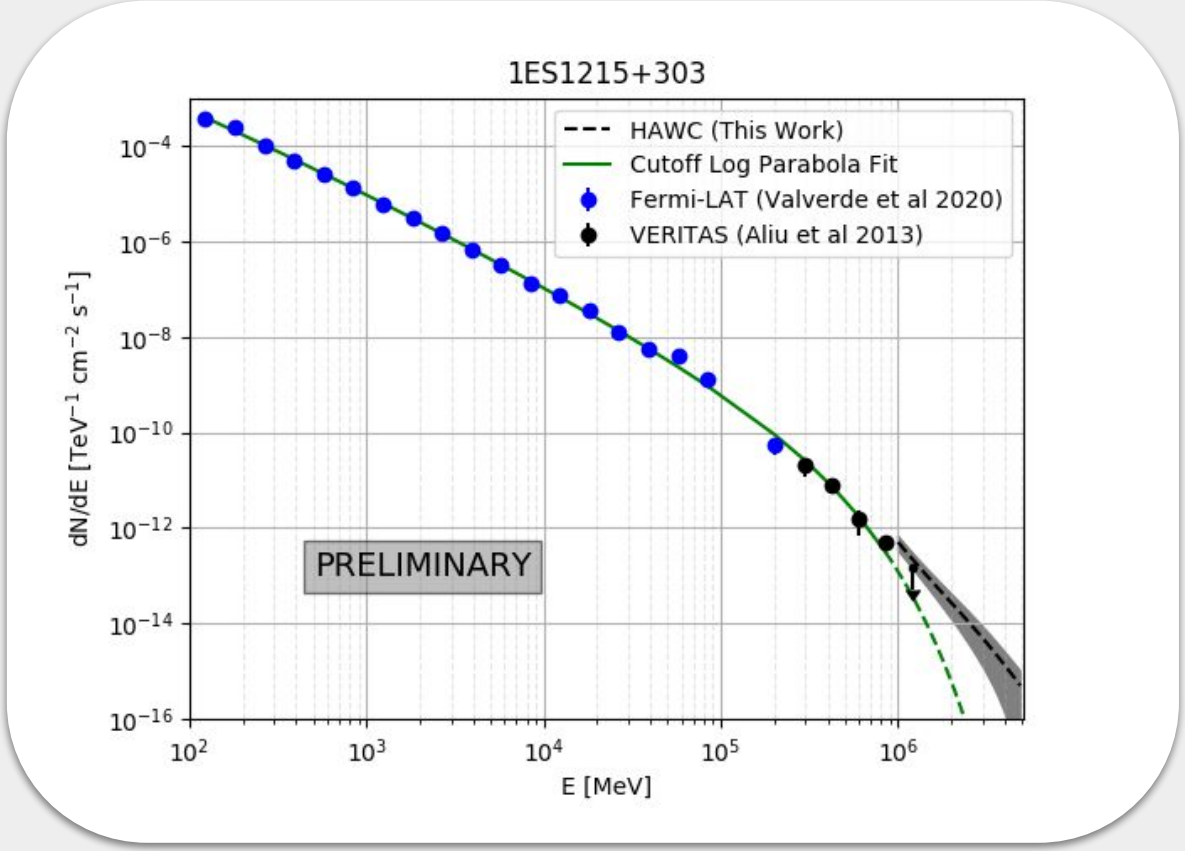
Index (α): 0.5

Beta (β): 4e-02

Cutoff Energy (EC): 330 GeV

** Pivot Energy (E0) set to 1 TeV – not parameter of fit

$$N\left(\frac{E}{E_0}\right)^{-\alpha-\beta ln\frac{E}{E_0}} e^{-\frac{E}{E_c}}$$



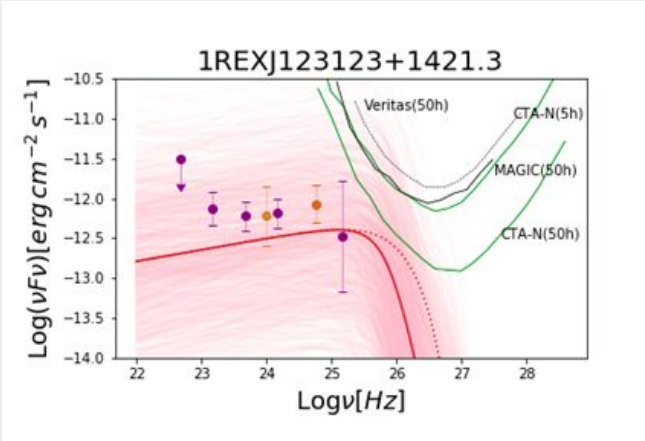
Fermi
Gamma-ray
Space Telescope

Backup slides following

Part 1: Te-REX Catalogue

Te-REX: “Te-REX: a sample of extragalactic TeV-emitting candidates,” Balmaverde et al, Monthly Notices of the Royal Astronomical Society, Volume 492, Issue 3, March 2020, Pages 3728-3741, https://doi.org/10.1093/mnras/stz3532

- Catalogue of Radio-Emitting X-Ray Sources identified by cross-matching X-Ray and Radio Data
- Specifically focuses on 46 high-energy peaked BL Lac (HBL) that are thought to be TeV-emitting sources with a greater than 5% chance
- Predicts that ~30% of the HBL could be detected by CTA in 50 hours and ~15% could be detected by current Cherenkov facilities



1ES1215+303

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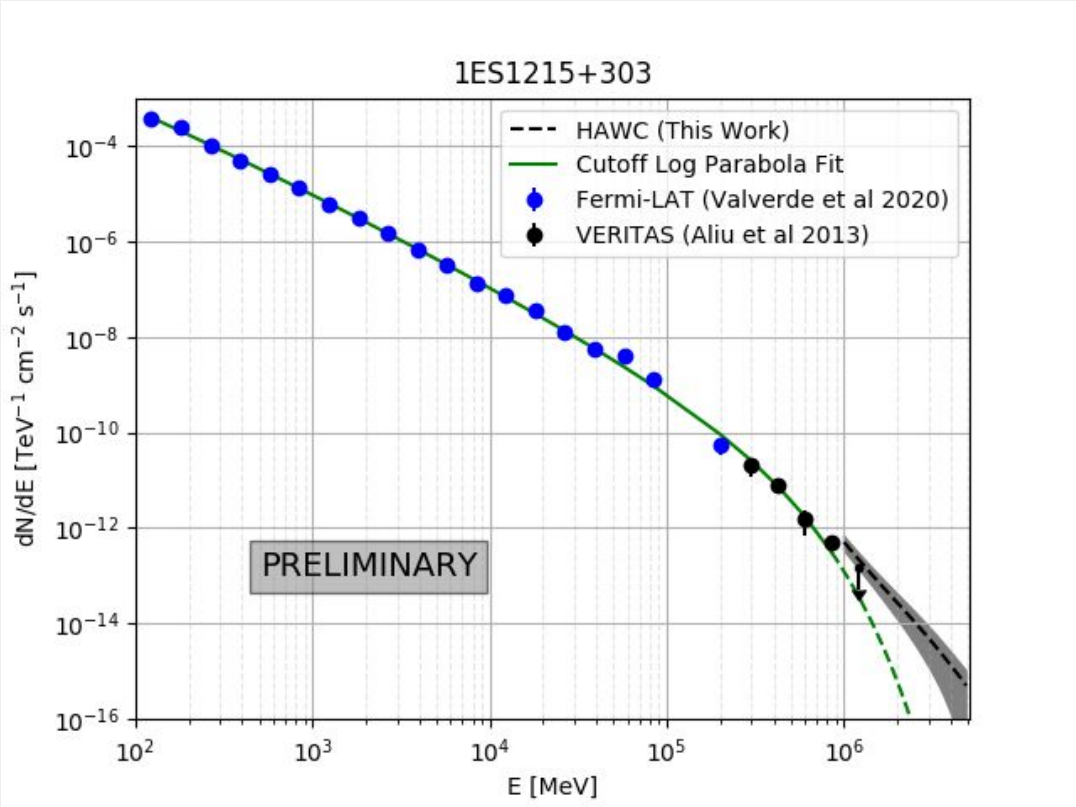
$$N\left(\frac{E}{E_0}\right)^{-\alpha-\beta ln(E/E_0)} e^{-E/E_c}$$

Pivot Energy (E0) set to 1 TeV – not parameter of fit



Possible TeV Blazar Analysis - In Progress

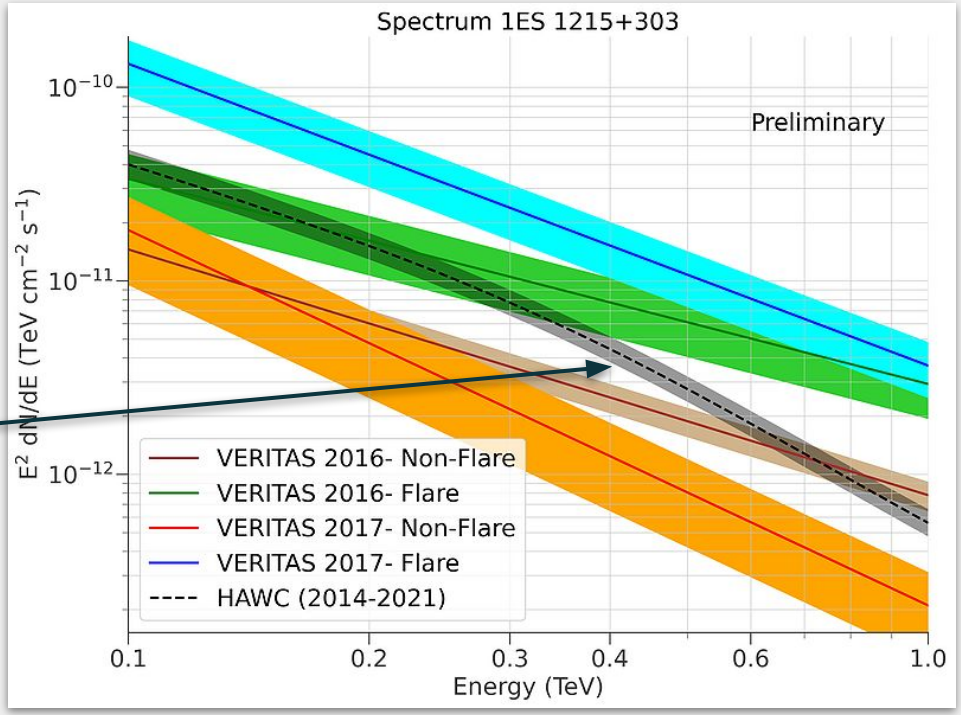
Flaring & Source Variability:

Notable flares: Feb 7 2013, Feb 8 2014, Jan 17 2015, April 9 2016, March 5 2017, April 1 2017
*no evidence in the corresponding HAWC data

HAWC Simple Power Law:
α = 3.56 ± 0.19

VERITAS fits a “high” and “low” state corresponding to 2 flare periods

- 2016 high low
- 2017 high low



F. Urena (2022)