A Preliminary Look at the 4HWC Catalog

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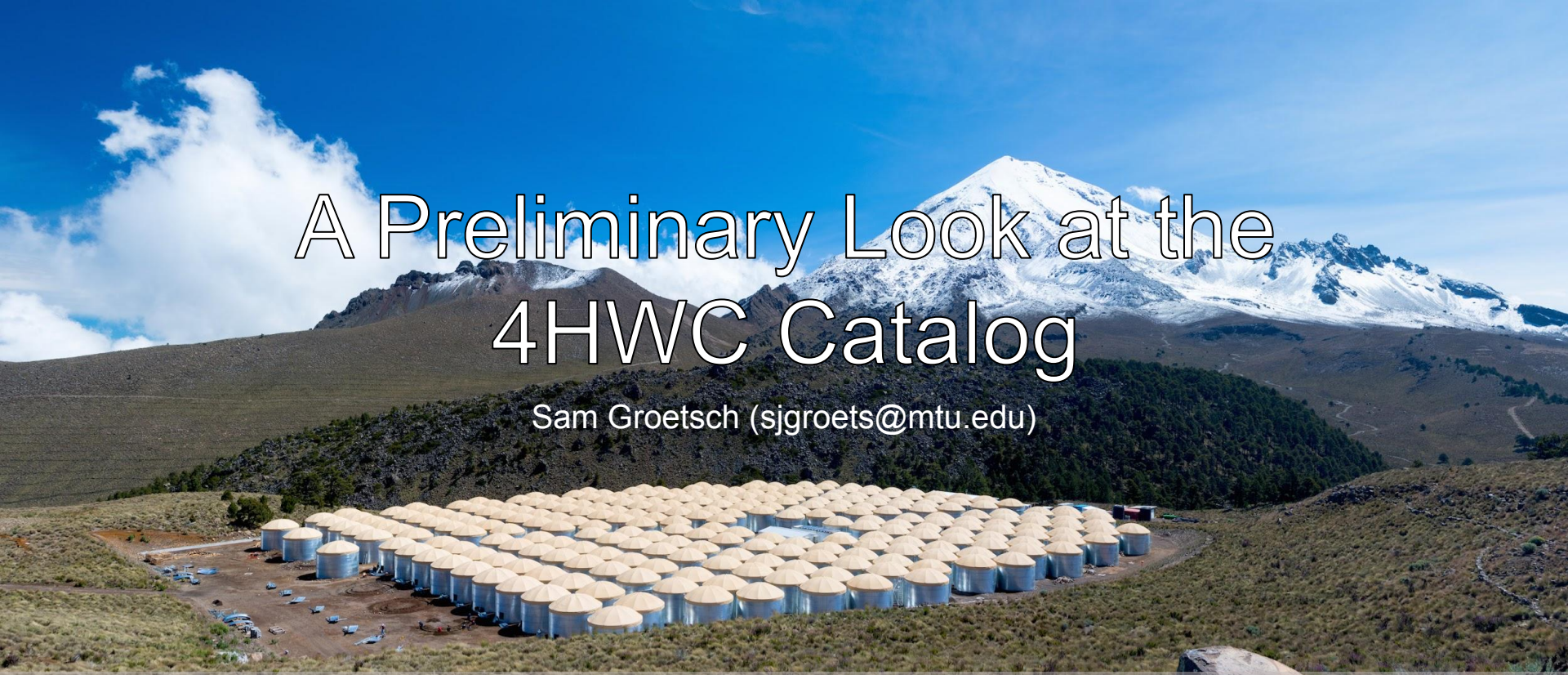


HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

NSF

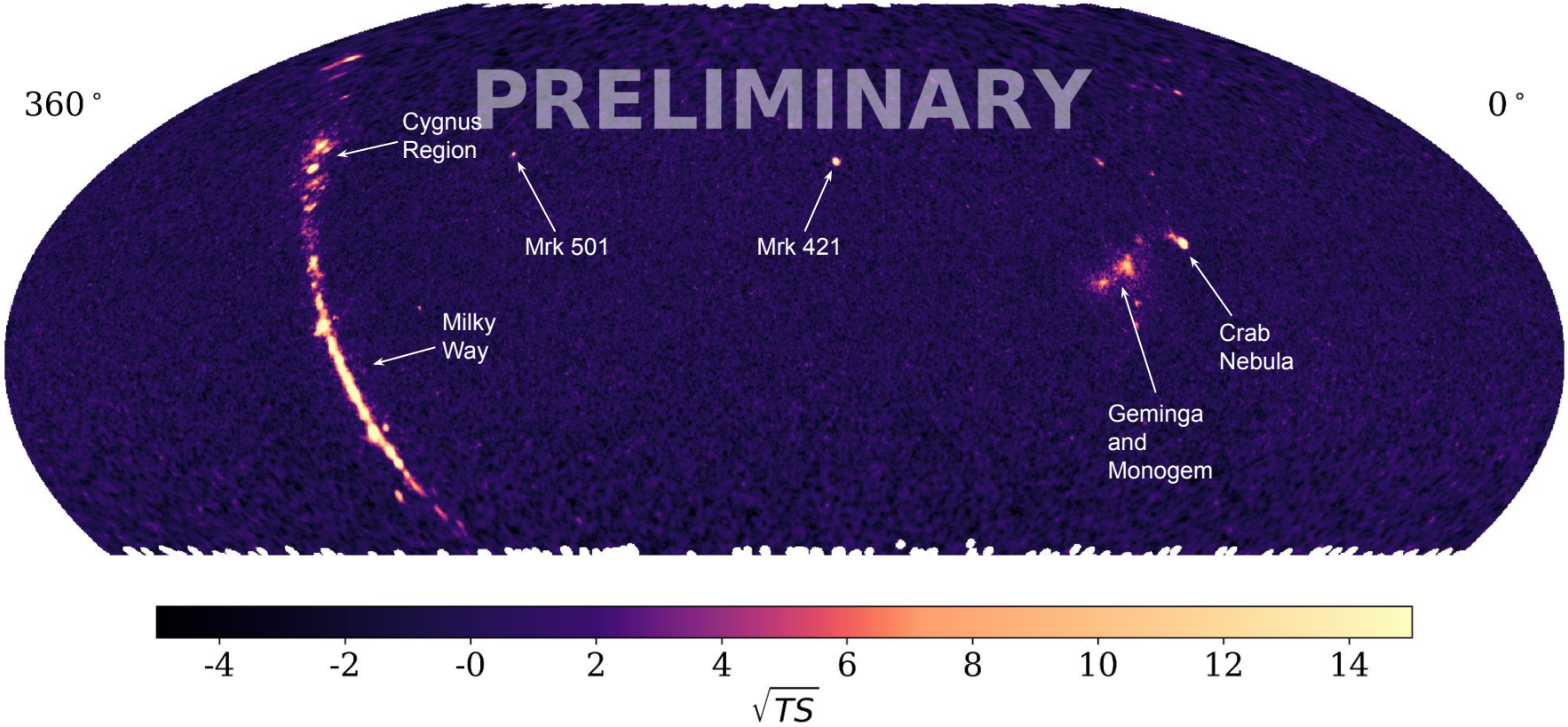
Michigan Technological University

CONACYT

Short Introduction to the HAWC Observatory

- Located near Puebla, Mexico at 4,100m
- 300 Detector tanks spread over 22,000m^2
- Sensitive to energies from 100s of GeV to 100s of TeV
- 95% Duty cycle
- 2 sr instantaneous FoV
- HAWC is a wide field observatory which makes it convenient to carry out survey and cataloging work like 4HWC

A look at HAWC data



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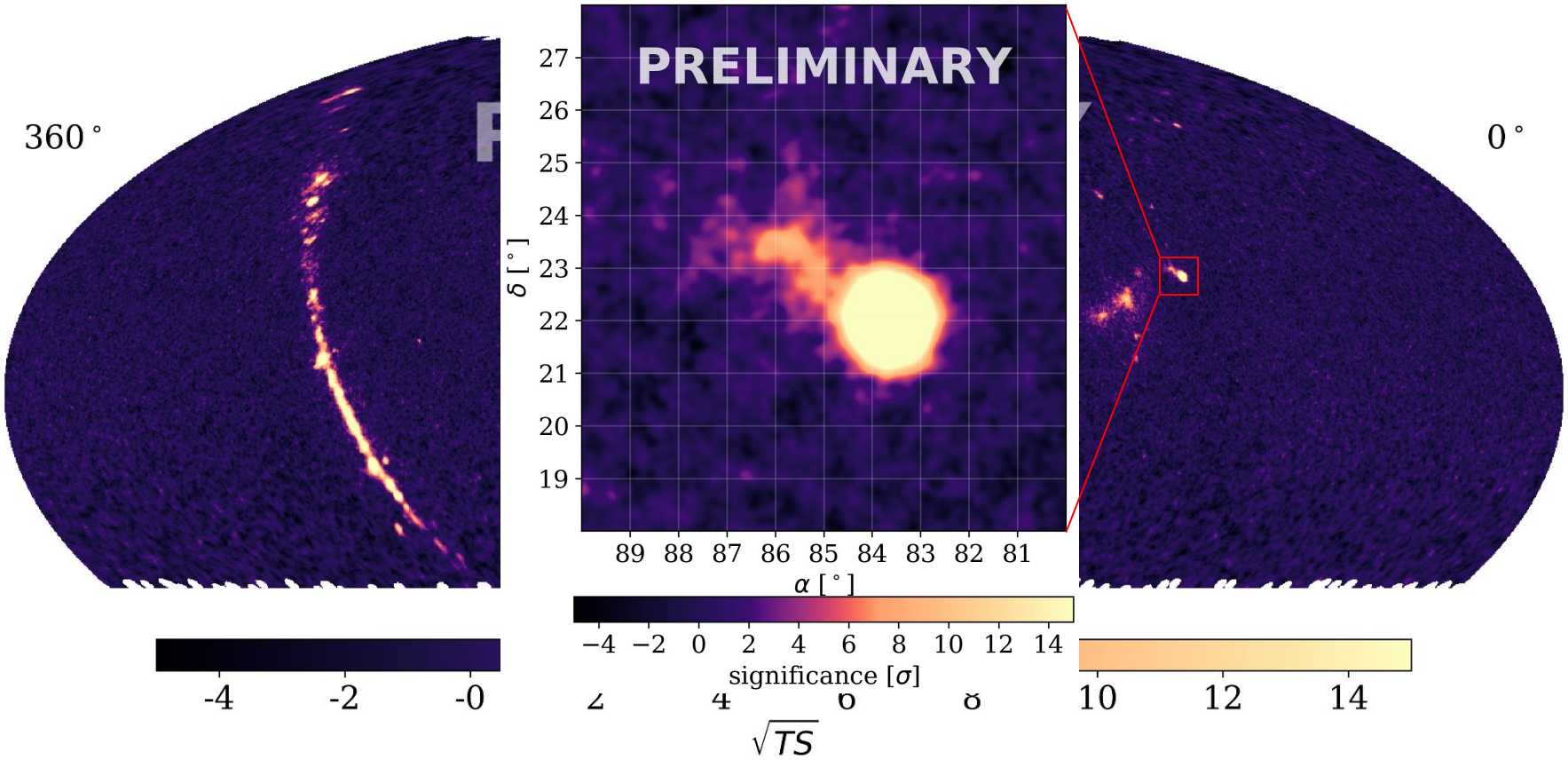
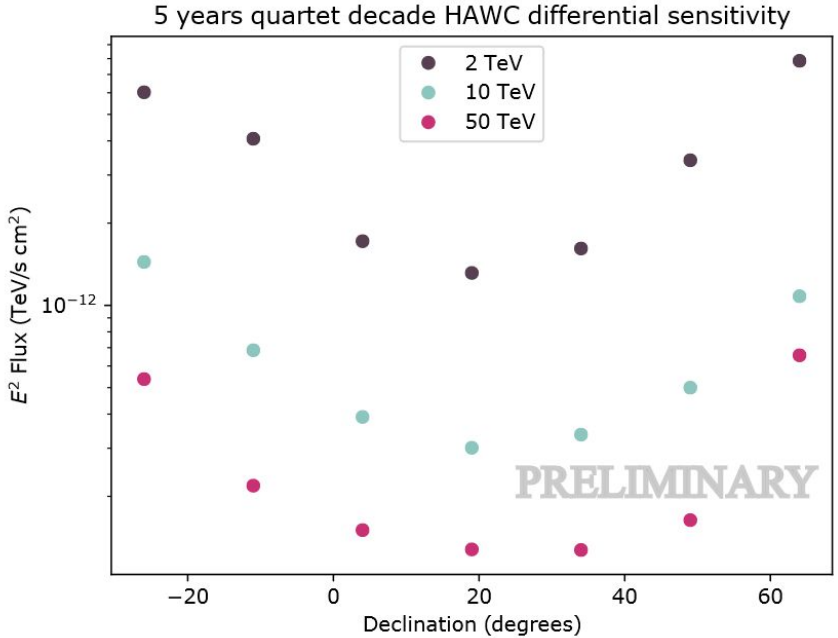


The Dataset summarized

- >2500 days of data collection
- -35 to 75 degrees declination
- Crab seen at 281.8 sigma vs 189 in 3HWC dataset
- Using reduced subset of data
  - fHit bins 2-10 (minimum of 7% PMTs triggered)
  - On array only events (shower core reconstructed within area of main array)



The Multi Source Fit Method for 4HWC

- Compared to previous catalogs (2HWC and 3HWC) a Multi Source Fit (MSF) method is being used instead of the local maxima finding algorithm (A. Albert et al 2020)
- Adapted from the method used by Fermi LAT for their extended source catalog (M. Ackermann et al 2017)
- MSF method additionally includes an URM (Unresolved Radiation Model) which takes into account numerous factors such as diffuse emission and any unresolved or subthreshold sources

Overview of MSF method

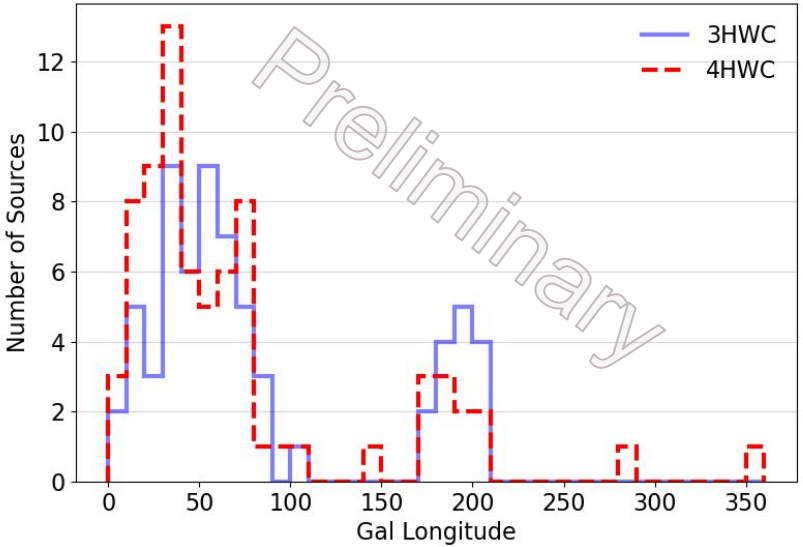
- Begin with a Region of Interest (ROI)
  - If near galactic plane add URM and fit
  - Otherwise move directly to point source adding
- Find pixel with highest significance and add point source model with simple power law assumption
  - Fit with location and spectral parameters free
  - Fix location parameters and repeat process with new point source until significance threshold reached
- After threshold reached loop over all sources and test for extension (symmetric gaussian model) and spectral curvature (log parabola model)
  - Free location parameters for source being tested
  - Remove any source which drops below significance threshold after fit
  - Refit parameters of any source which is near a removed source if any
- After all alternate model assumptions tested perform one final refit of all parameters to ensure proper minimum found

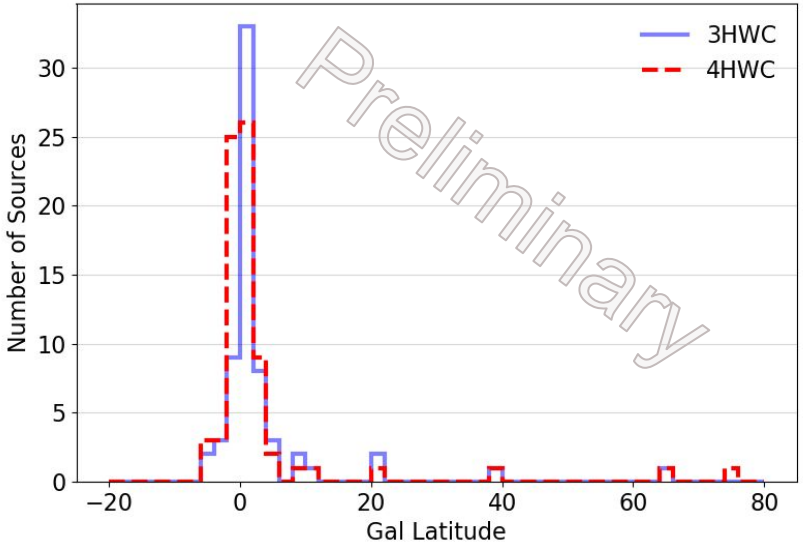
Sliding ROIs and Off-plane ROIs

- The ROIs for the fits are in two categories
  - Sliding ROIs on the plane
    - 6 degrees in longitude and 20 in latitude that “slide” across the plane
    - Each ROI is offset from its neighbors by 3 degrees resulting in all regions of the plane being in 2 neighboring ROIs
  - Off-plane ROIs
    - Centered on pixels with TS > 16 more than 10 degrees off the plane
    - 10 x 10 degree squares
    - Special ROI for Geminga/Monogem due to size

Looking at the Distribution of Sources

Total number of sources in 4HWC so far - 74
Total number of sources in 3HWC - 65





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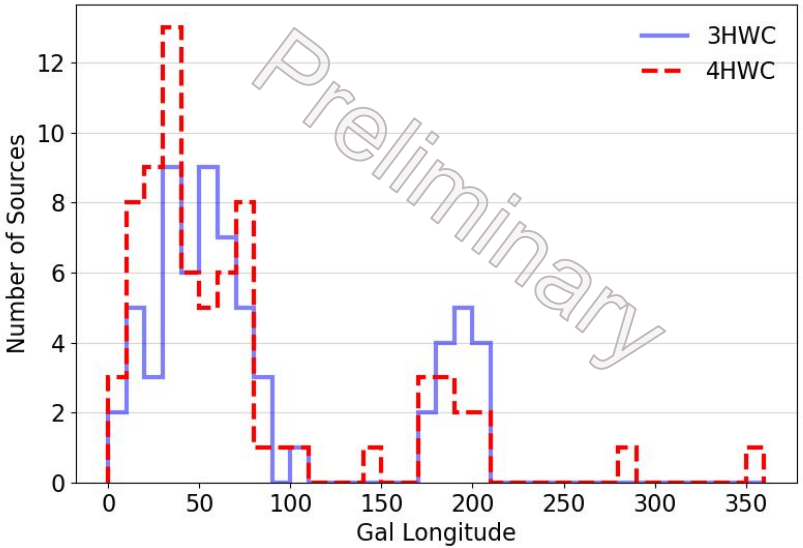
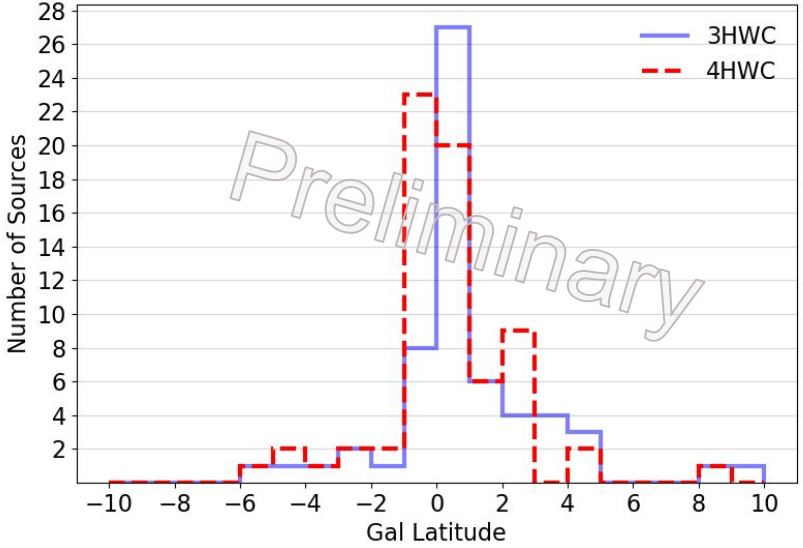




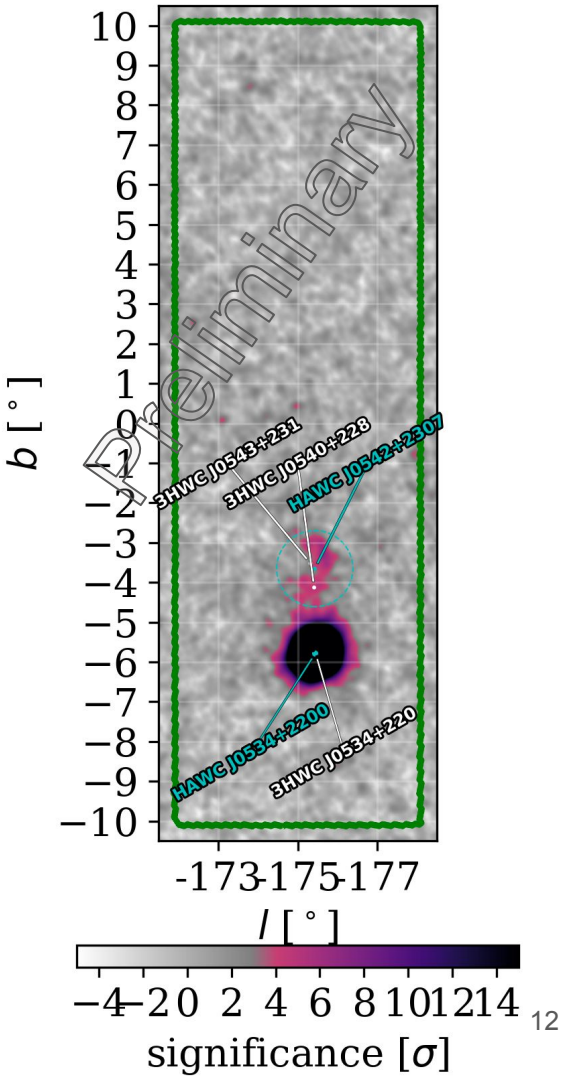
Comparing to Other Catalogs

- We compare the source locations of 4HWC sources to three catalogs (ATNF, SNRCat, and TeVCat) and note the number that are within 0.2, 0.5, and 1.0 degrees of sources in each catalog

Catalog	<1.0 deg	<0.5 deg	<0.2 deg
ATNF	67	57	35
SNRCat	57	47	21
TeVCat	65	57	35
Any Above	72	69	53

Comparing The Crab Nebula Modeling

- As expected great agreement on Crab position
- Major difference is that “Crab on Fire” region of emission is identified as a single extended source as opposed to two point sources



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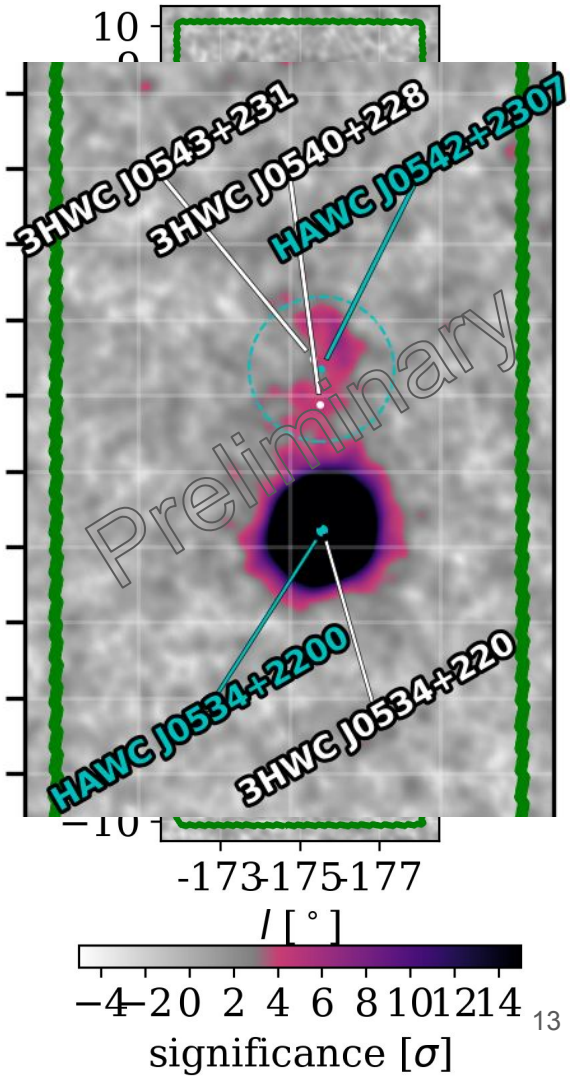

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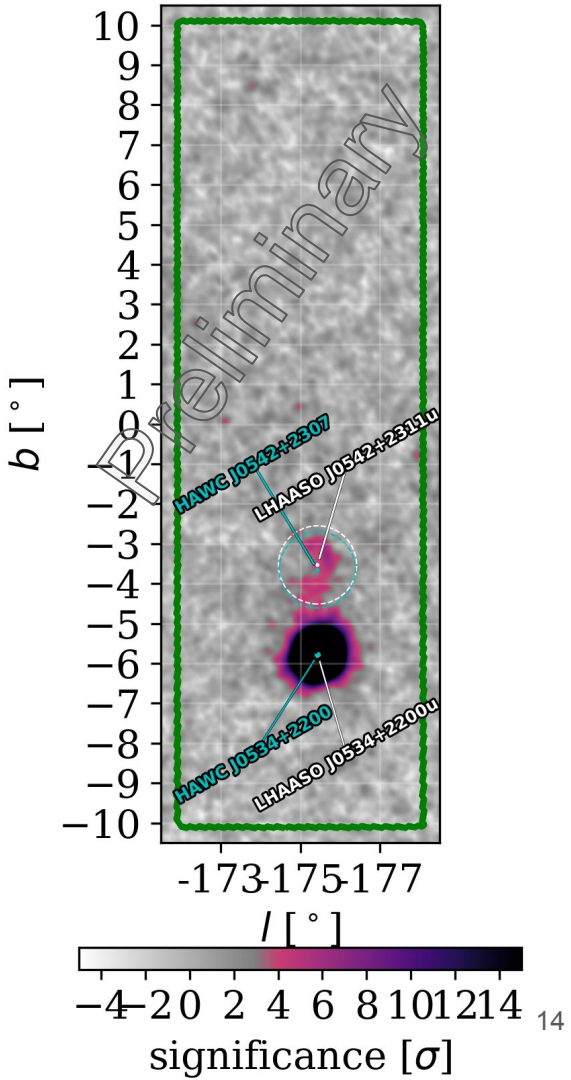
- Much better agreement between 1LHAASO and 4HWC than 3HWC and 4HWC
- A very nice cross check that LHAASO catalog MSF method and HAWC MSF method agree on the Crab and surrounding region



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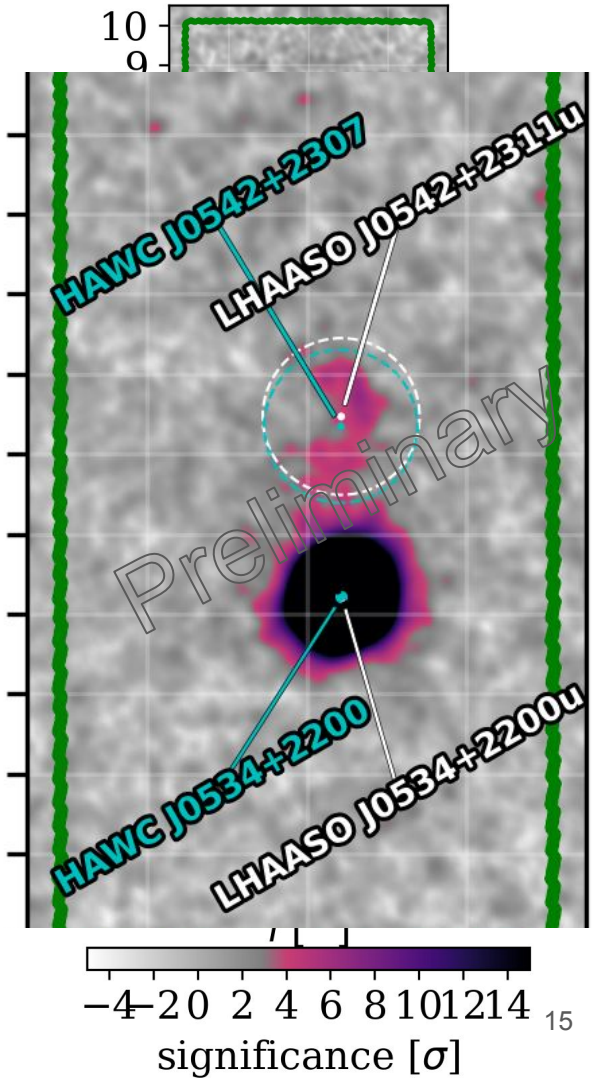


Rough Comparison to LHAASO

HAWC

- So far 74 sources identified at 5σ in a reduced dataset with more expected
- Begin with point source assumption and test for extension
- Use the URM to model non-source originated emission
- Energy Range 100s GeV to 100s TeV
- ~58% extended morphology at 4σ
- ~34% curved spectrum at 4σ

LHAASO

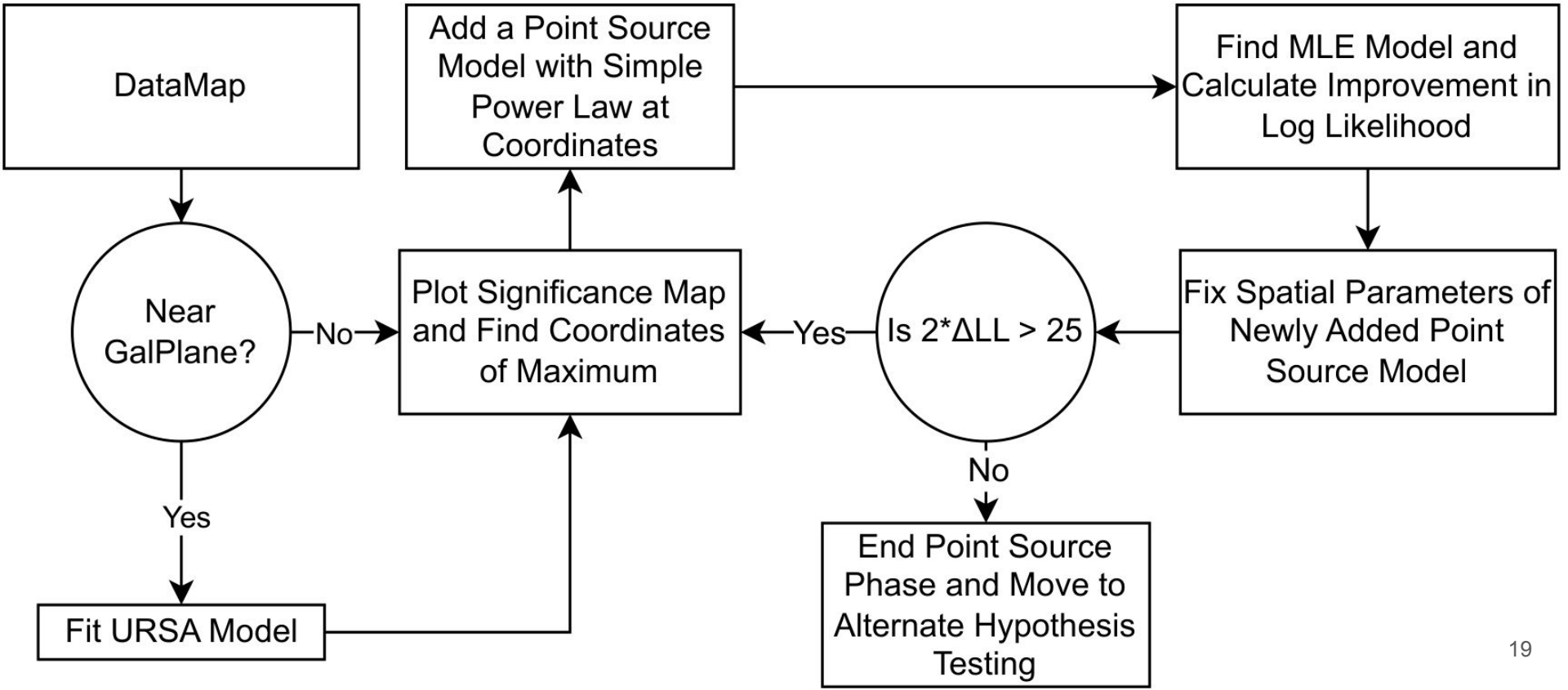
- 90 sources at 5σ combining WCDA and KM2A
  - 75 in WCDA
  - 69 in KM2A
- Energy Range 1 TeV to >1PeV
  - WCDA 1-25 TeV
  - KM2A 25 TeV to >1 PeV
- Begin with extended source assumption and test for point source-ness
- Use Plank gas map morphology to model diffuse emission
- ~72% Extended at 3σ
- No spectral curvature test performed

Outlook

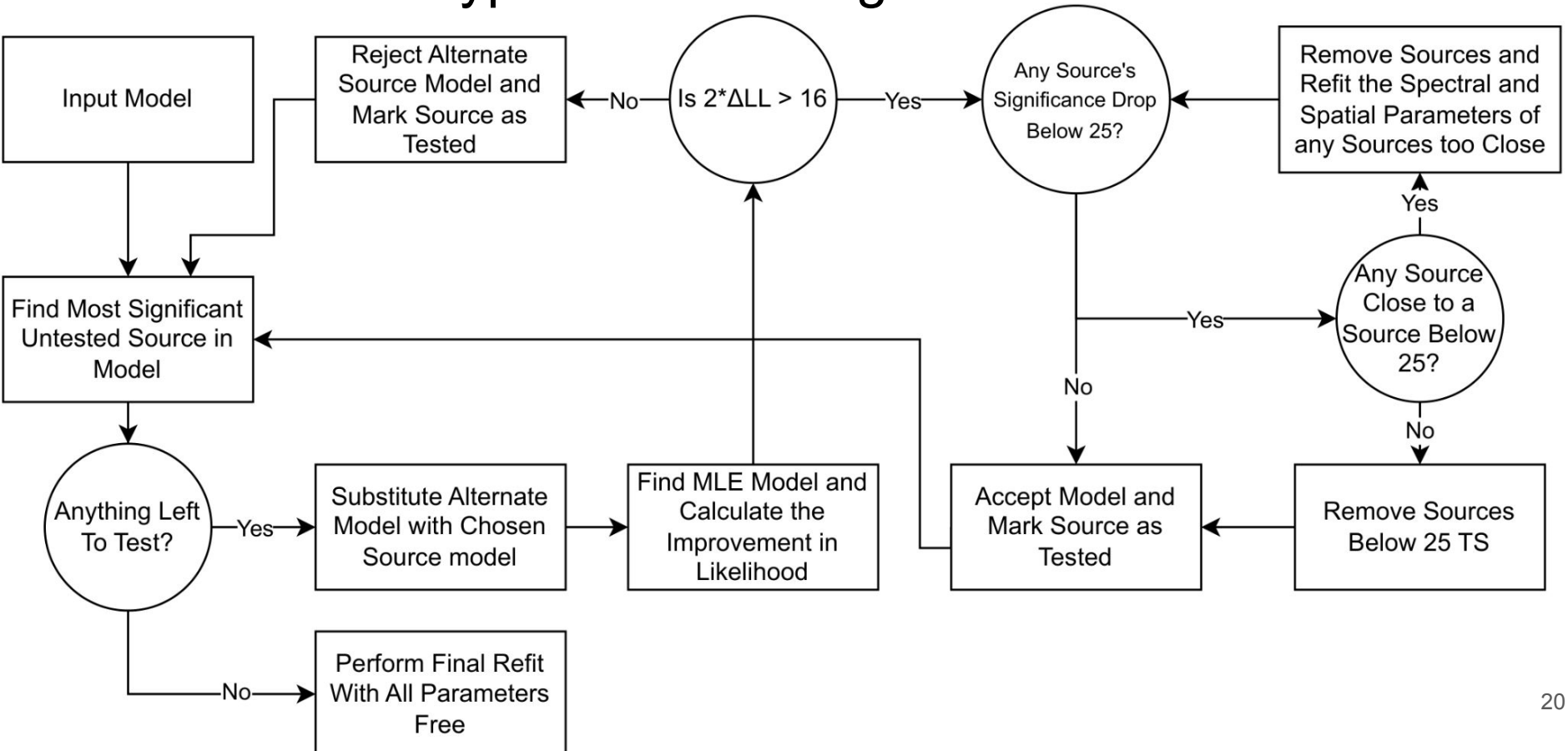
- So far 74 sources identified in a reduced dataset with more expected
- Detailed Association of sources forthcoming especially with larger dataset results

- Analysis of continuity of URM across galactic plane to ensure no drastic differences between ROIs
- Strong overall agreement between 4HWC and 1LHAASO provides great cross check of many sources in addition to sources in non-overlapping FoVs

The Point Source Adding Phase

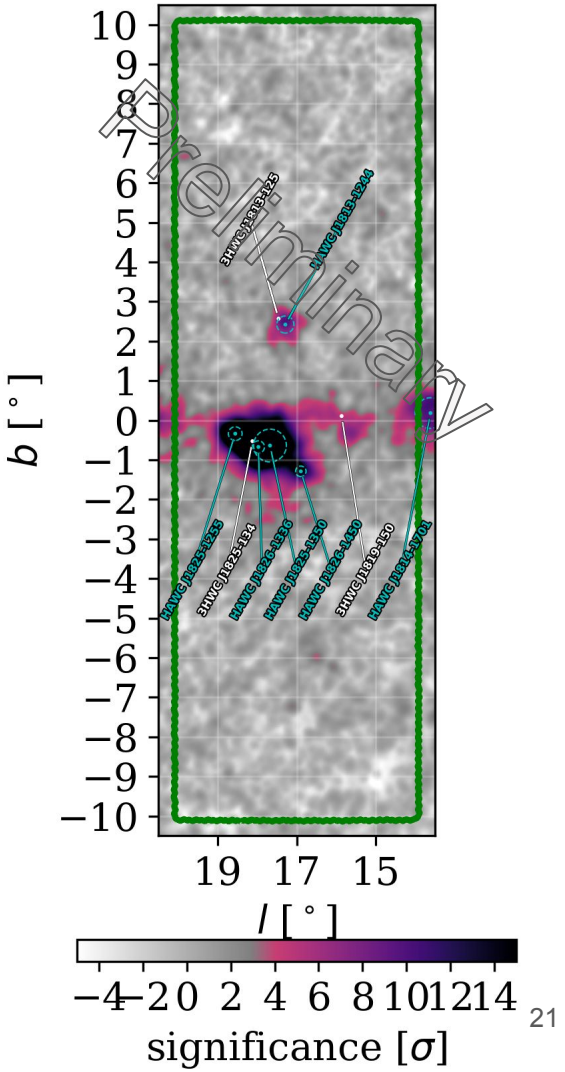


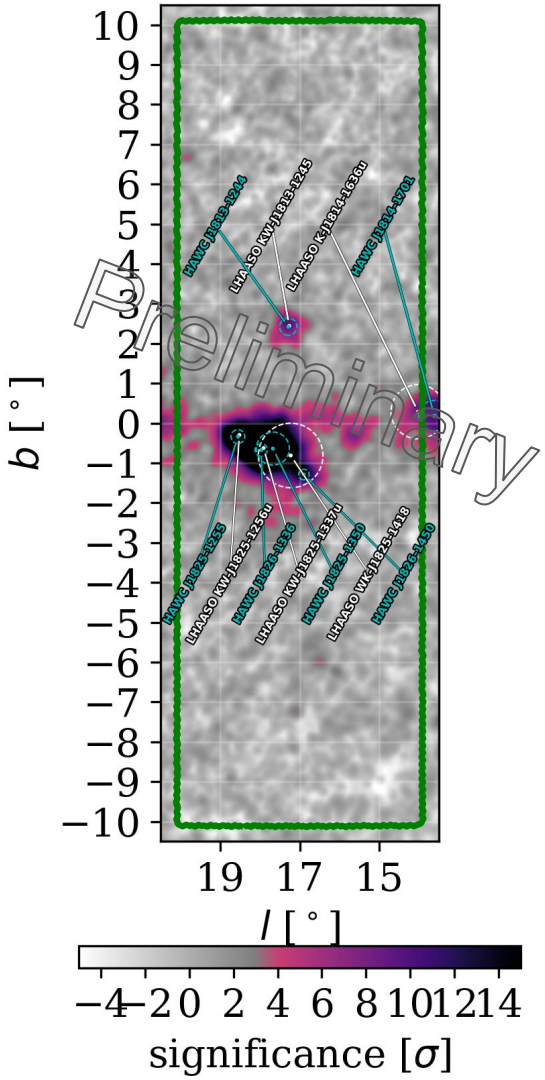
The Alternate Hypothesis Testing Phase



Comparing a Sample ROI to 3HWC

- Some significant differences in modeling between 3HWC and 4HWC
- Strengths of MSF method become apparent in regions that have multiple sources nearby
- Results from less restricted binlist include source near ~(16,0.1)



Comparing to LHAASO

- Overall Good agreement on the region except for one large LHAASO source vs two smaller HAWC sources
- Region is at high zenith for both LHAASO and HAWC but more favorable for HAWC