The Second Fermi All-Sky Variability (FAVA) Catalog

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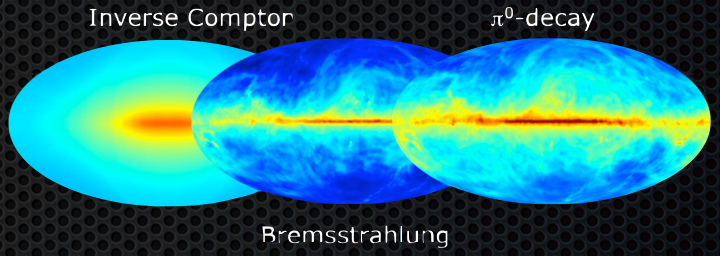
Traditional Likelihood Analysis

- The likelihood approach calculates the probability of obtaining the observed counts given an assumed model
  - Model components include: Galactic diffuse, Isotropic diffuse, and known point sources
- Vary model parameters to maximize this probability (best fit)
- Pros:
  - Very sensitive to the low count regime
  - Can naturally be made Bayesian by applying priors
  - Source significance easily assessed via likelihood ratio tests
- Cons:
  - Can be very computationally intensive to search for new sources
  - Only as good as the assumed model
  - Uncertainties in the diffuse models can mask emission from weak sources in high background environments

Galactic diffuse emission

(CR interactions with the interstellar medium)



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Isotopic extragalactic diffuse emission

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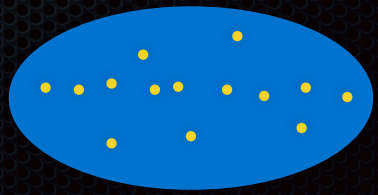
Resolved Point Sources

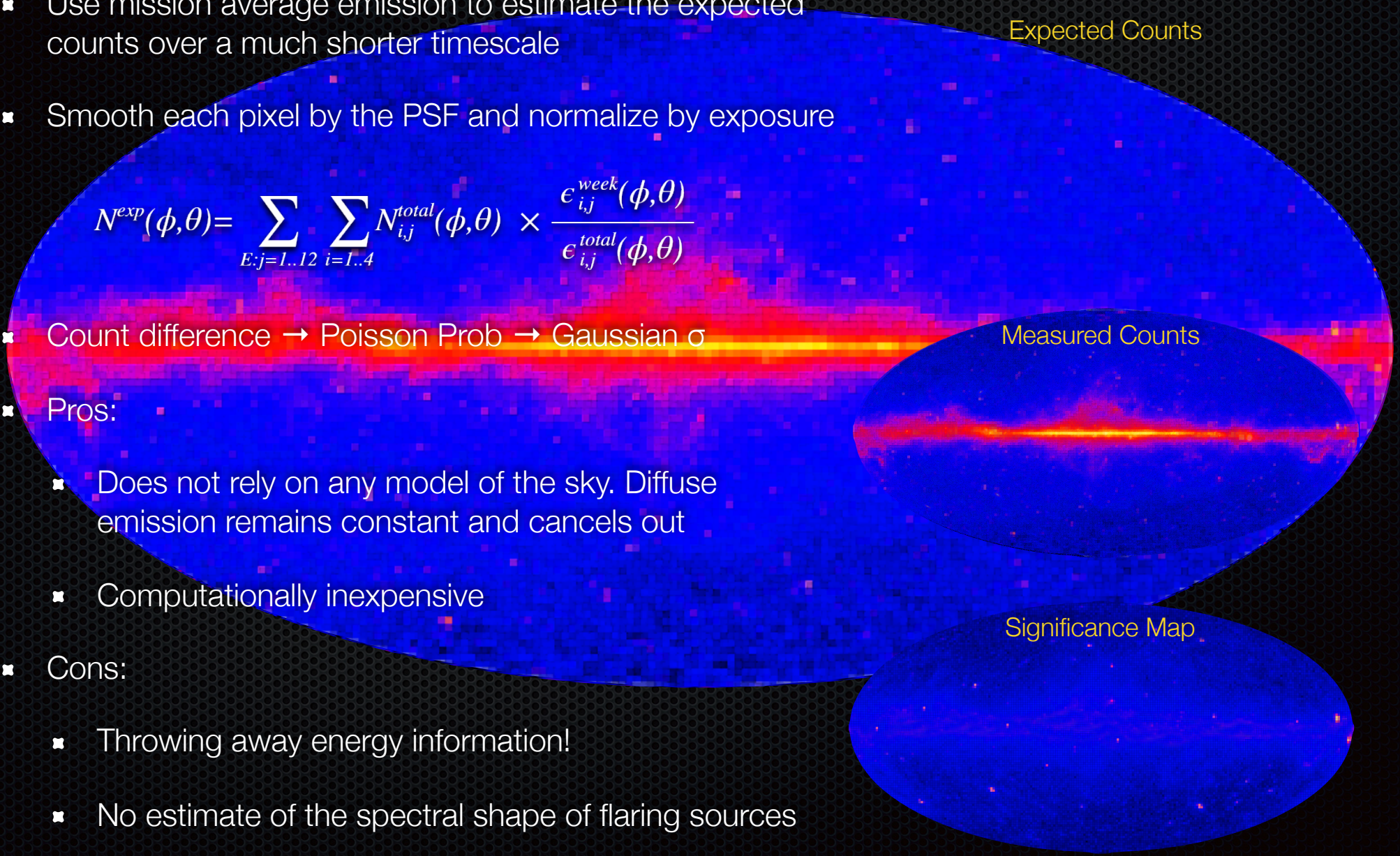


Fermi All-Sky Variability Analysis

- Use mission average emission to estimate the expected counts over a much shorter timescale
- Smooth each pixel by the PSF and normalize by exposure

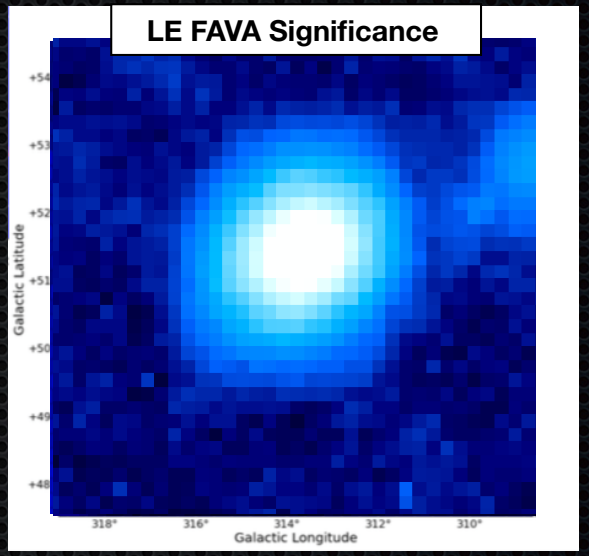
$$N^{exp}(\phi,\theta) = \sum_{E:j=1..12} \sum_{i=1..4} N_{i,j}^{total}(\phi,\theta) \times \frac{\epsilon_{i,j}^{week}(\phi,\theta)}{\epsilon_{i,j}^{total}(\phi,\theta)}$$

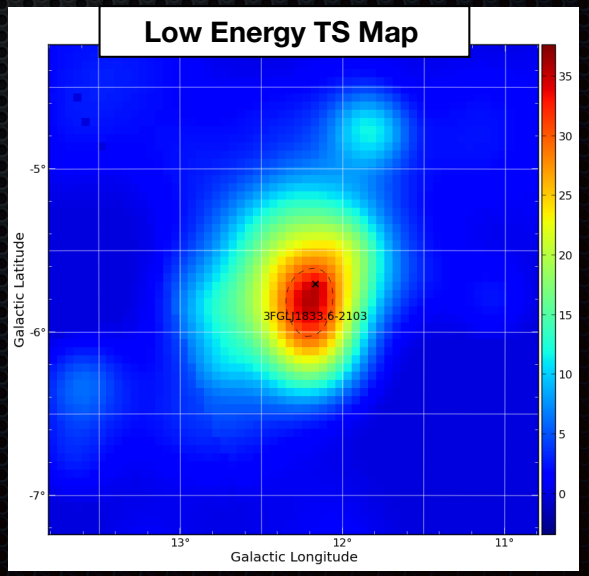
- Count difference → Poisson Prob → Gaussian σ
- Pros:
  - Does not rely on any model of the sky. Diffuse emission remains constant and cancels out
  - Computationally inexpensive
- Cons:
  - Throwing away energy information!
  - No estimate of the spectral shape of flaring sources



FAVA Flare Search

- FAVA detections as seed positions for likelihood analysis
- Mission averaged emission: 4 years
  - Selected to match 3FGL interval
- Analysis duration: 339 weeks (6.5 years)
- Analysis time bins: 1 week
- Sky bins: 0.5 deg
- Energy bins: 100 - 800 MeV & 800 - 3e5 MeV
- Data/IRFs: P8_SOURCE, P8R2_SOURCE_V6
- If FAVA sigma > 4σ (either at LE or HE) → do both TS maps
  - Low energy: Binned likelihood, 7 * 7 deg^2 , 0.15 deg
  - High energy: Unbinned likelihood, 3 * 3 deg^2, 0.05 deg



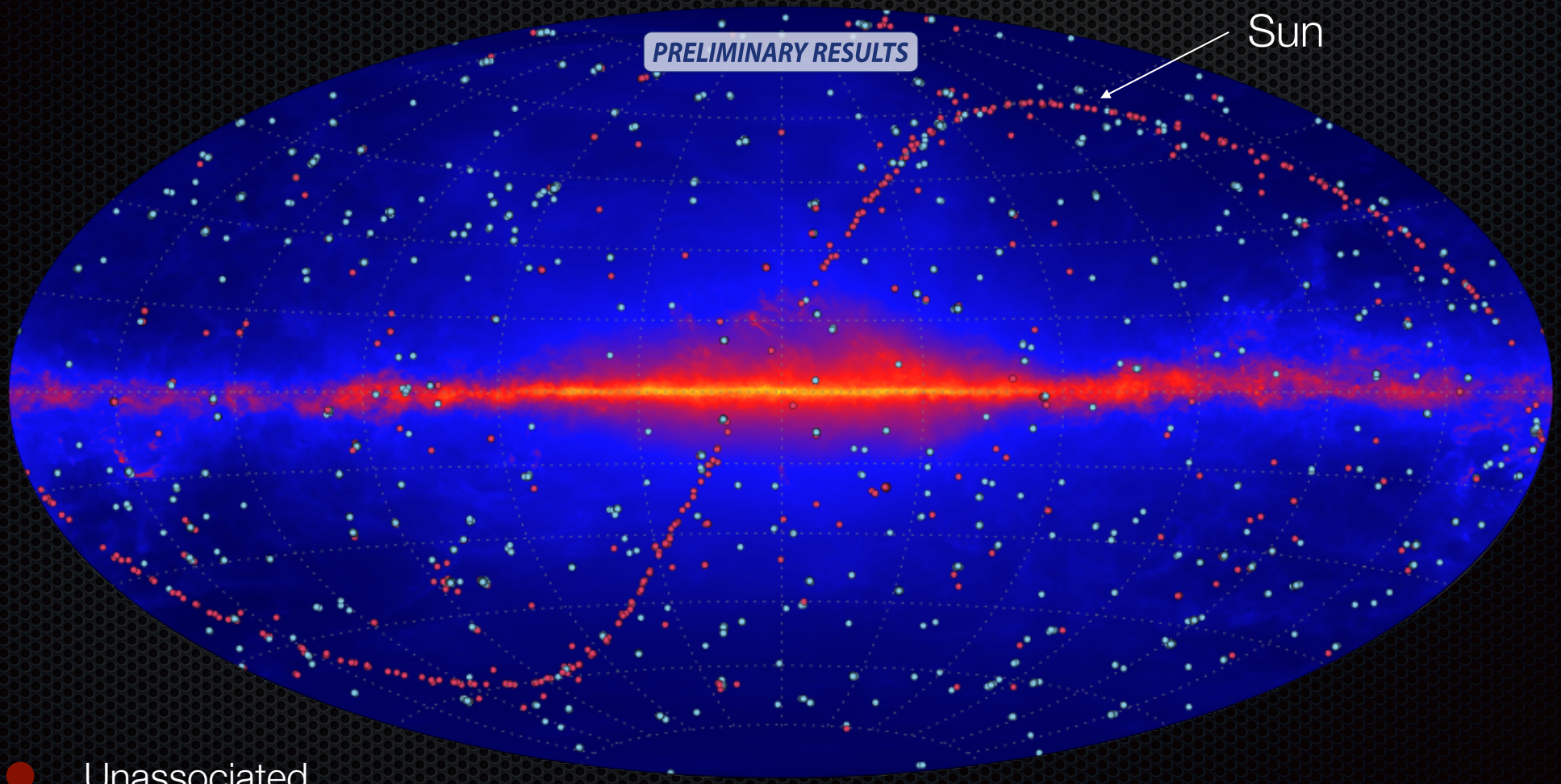


2FAV Flare Selection

- Duration: 339 weeks (2008-08-04 to 2015-02-02)
- FAVA Seeds: 5422 flares > 4σ in either energy range (~16 flares per week)
- Catalog Selection: 2938 flares detected with 6σ in either energy range or 4σ in both
- Efficiency: 53.16% of the seeds are included in the catalog

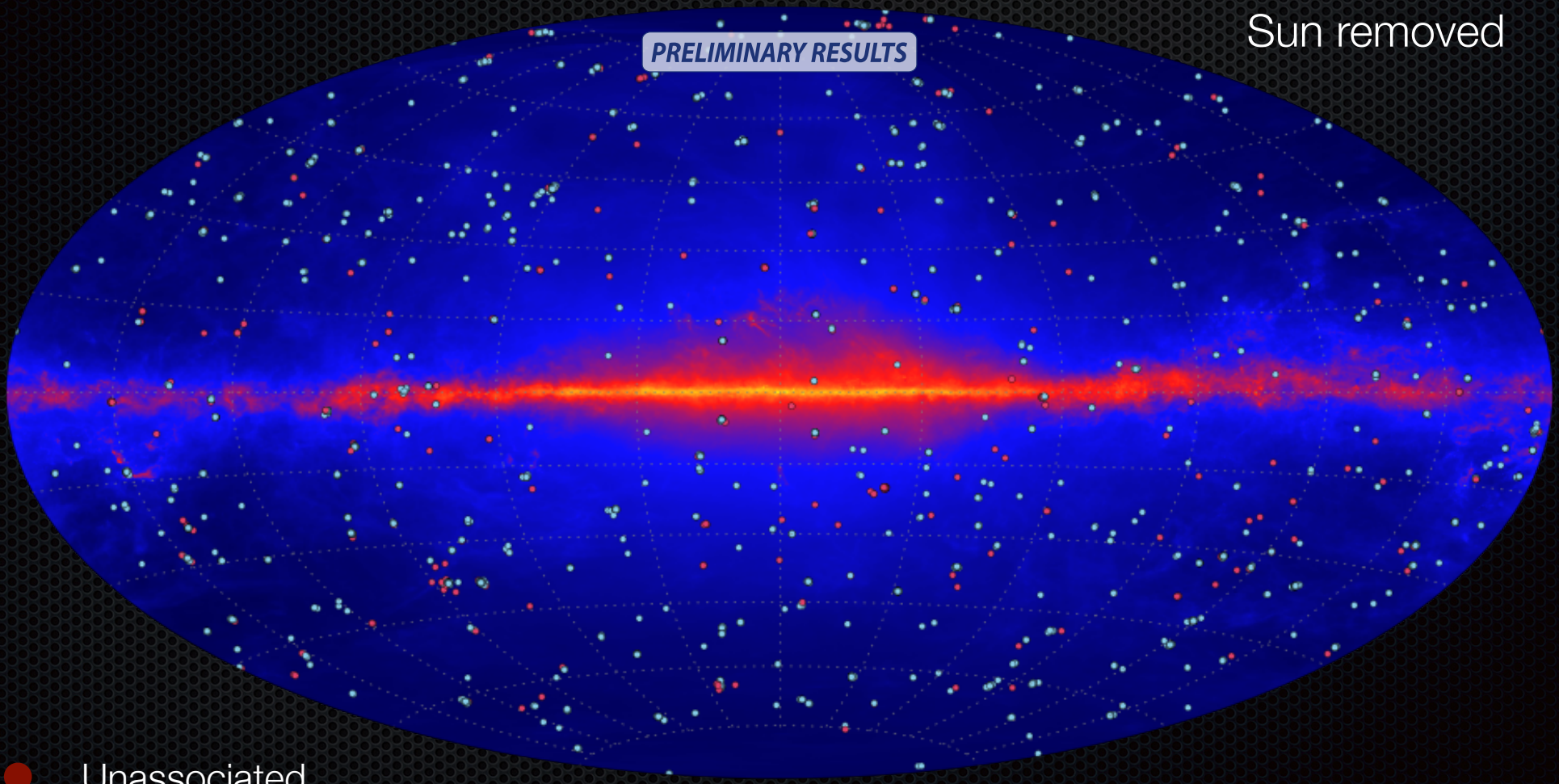
Energy Bin	FAVA Analysis	Likelihood Analysis
Low energy [100-800] MeV	(sigma>6 && sundist>10)	(le_ts>39 && le_sundist>10)
High energy [800-3e5] MeV	(he_sigma>6 && sundist>10)	(he_ts>39 && he_sundist>10)
Coincidence	((sigma>4 && he_sigma>4 && sundist>10) && !(sigma>6 || he_sigma>6))	(le_ts>18 && he_ts>18) && (le_sundist>10 && he_sundist>10) && (he_le_dist<1.5) && !(he_ts>39 || le_ts>39))

2FAV Flare Selection

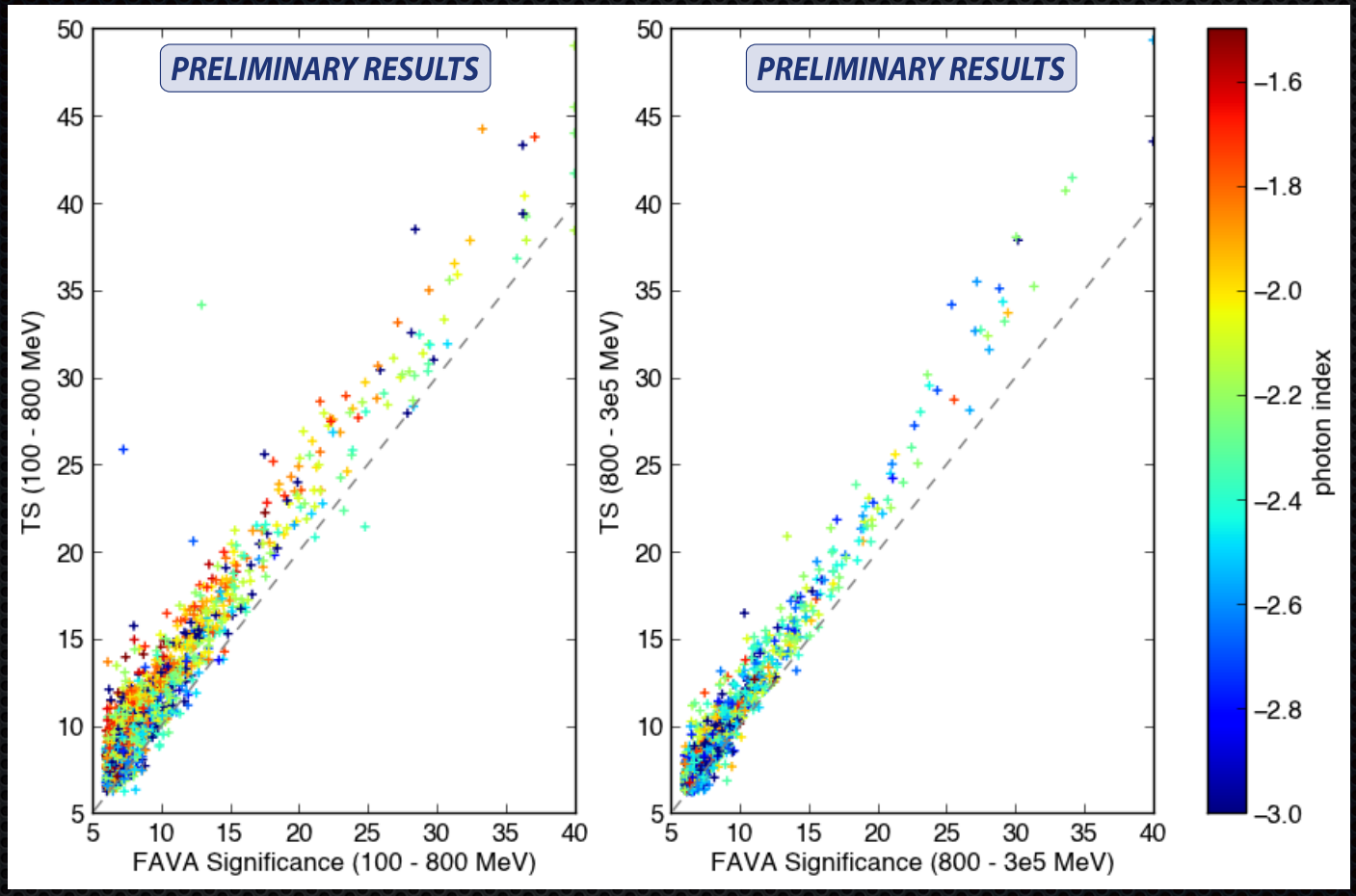


- Unassociated
- Associated

2FAV Flare Selection

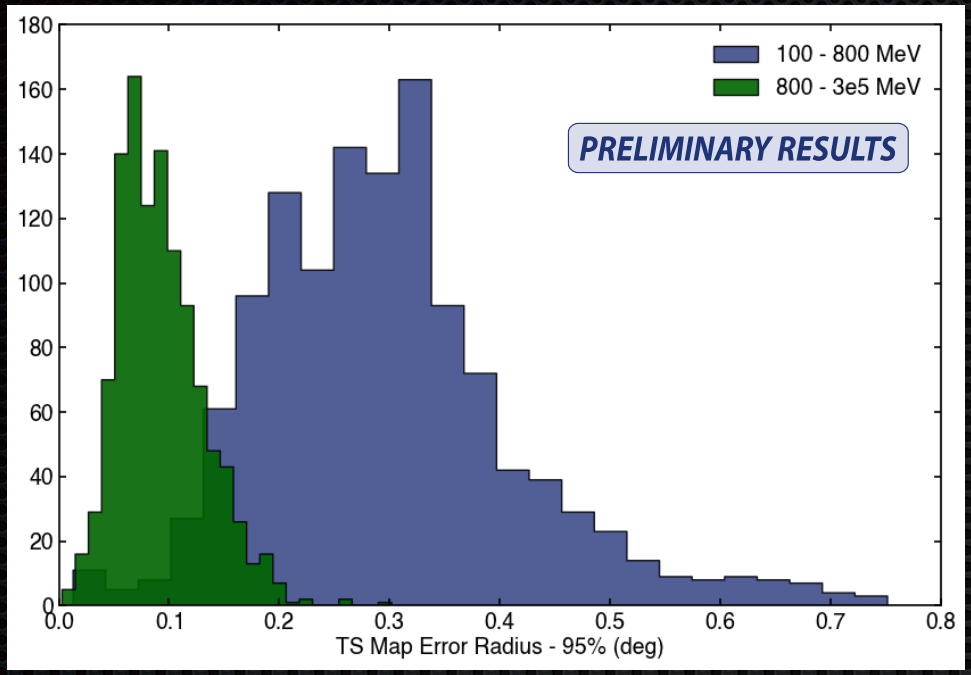


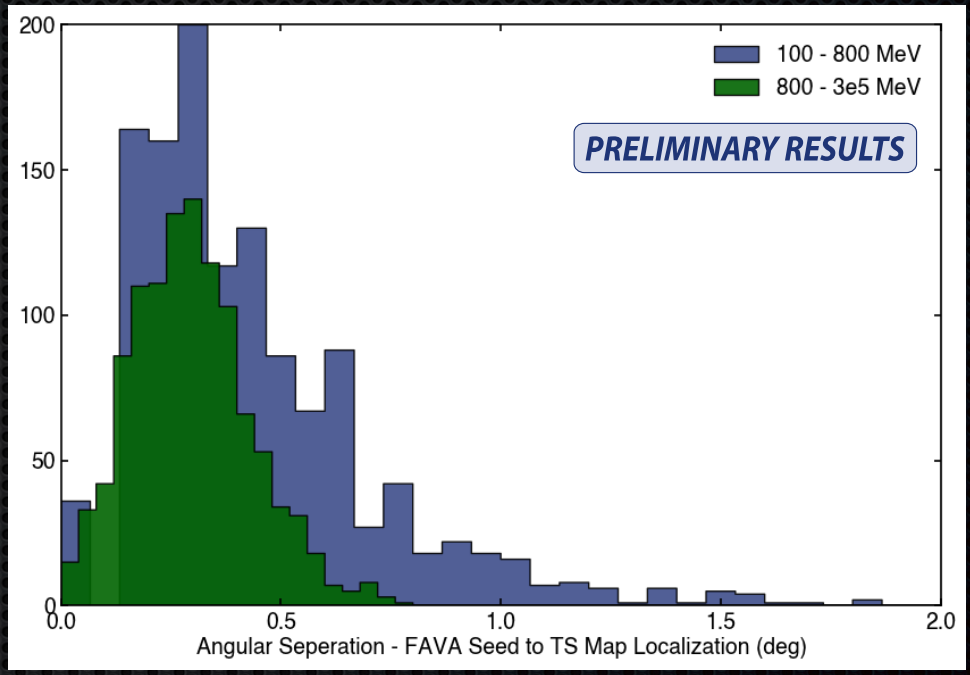
Significance Comparisons



- Standard likelihood is more sensitive that the FAVA approach
- Harder flares are detected more significantly by likelihood than FAVA (at least at low energies)

Positional Accuracy



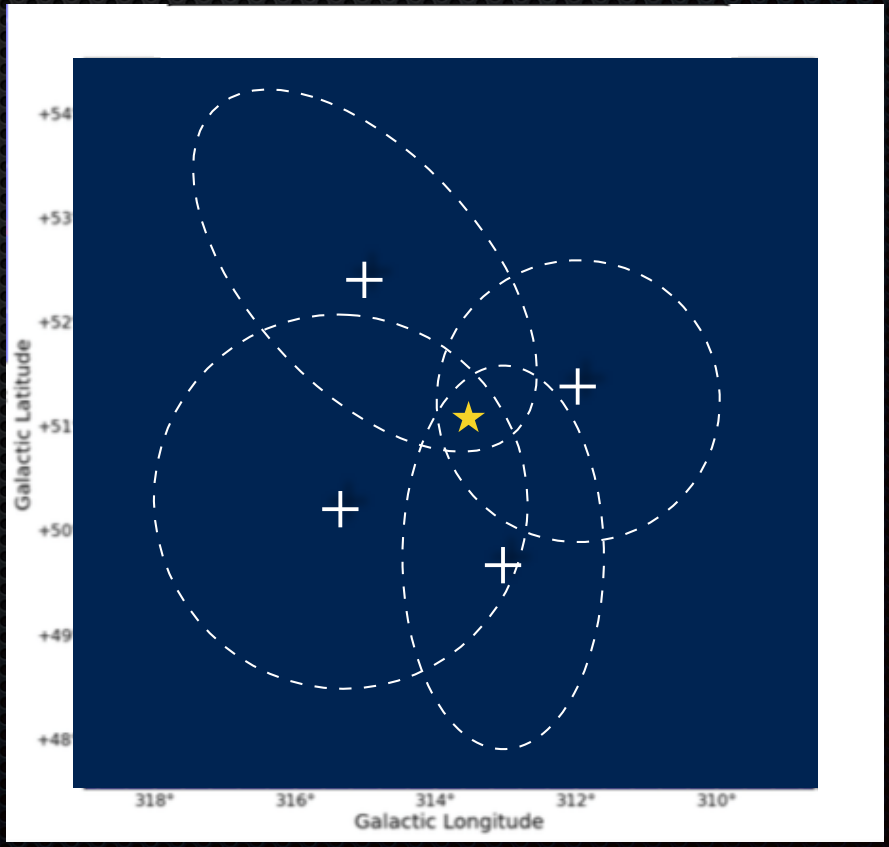


- The average localization error is ~ 0.3 & 0.075 for the low and high energy TS maps respectively
- The average separation from the TS map and FAVA localizations is roughly ~0.35 deg

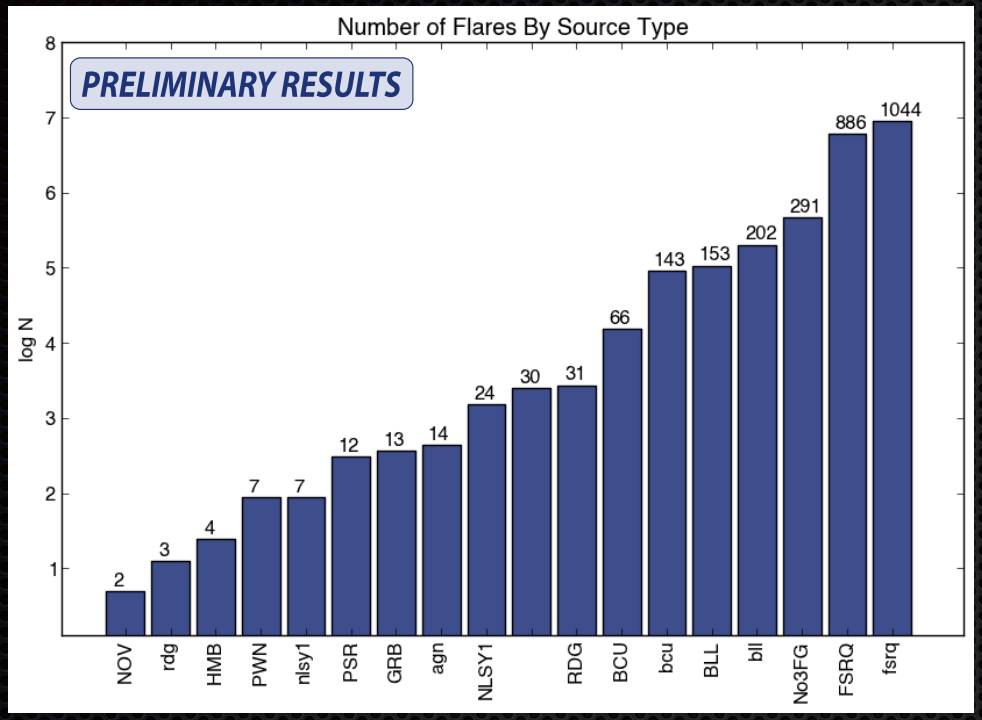
Associations & Clustering

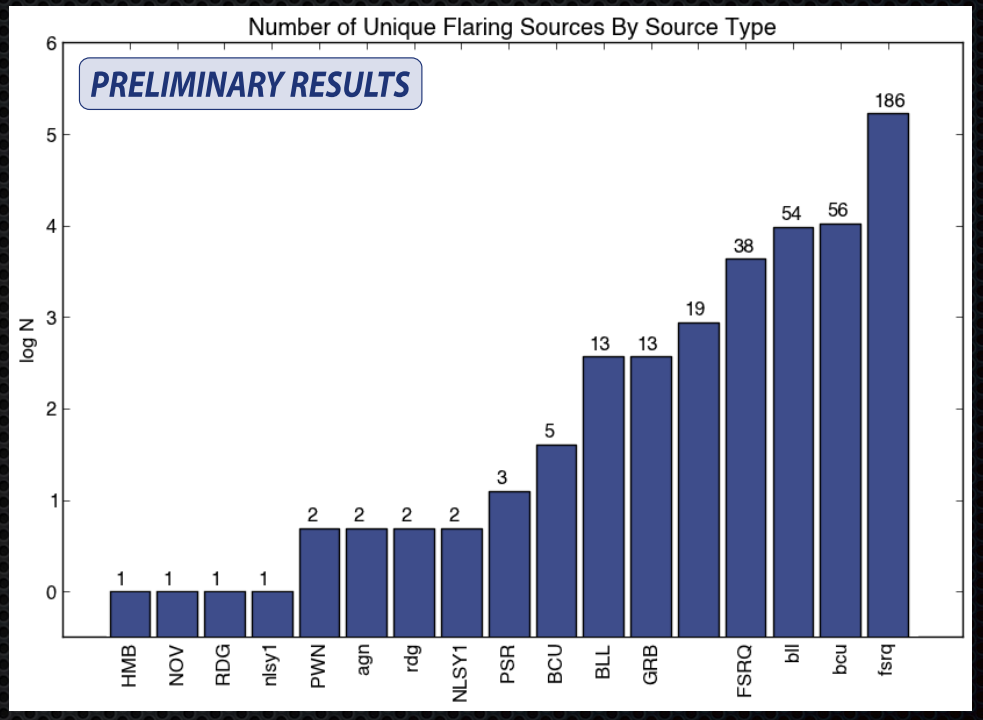
- Associations made to 3FGL, GRB, and ATel catalogs
  - Simply select the closest source within the 3σ localization error
- Cluster sources based on common associations

2FAV Selected Flares	2932
Catalog Associated Flares	2641 (90%)
Unassociated Flares	291 (10%)
Flares With 2 Possible Associations	44
Flares With 3 Possible Associations	22
Flares With 4 Possible Associations	3
Number of Unique Catalog Sources	399



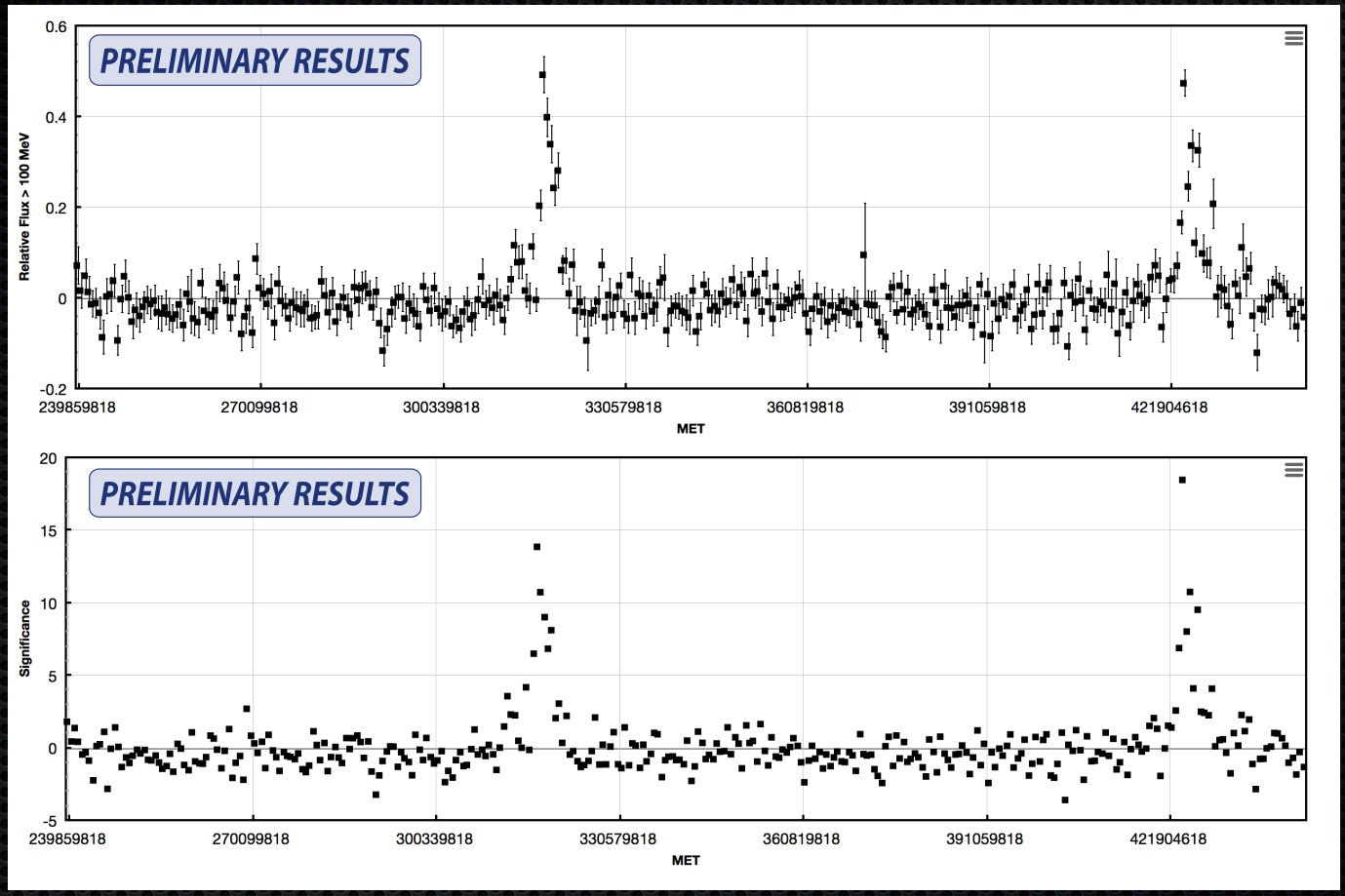
Flares By Source Type





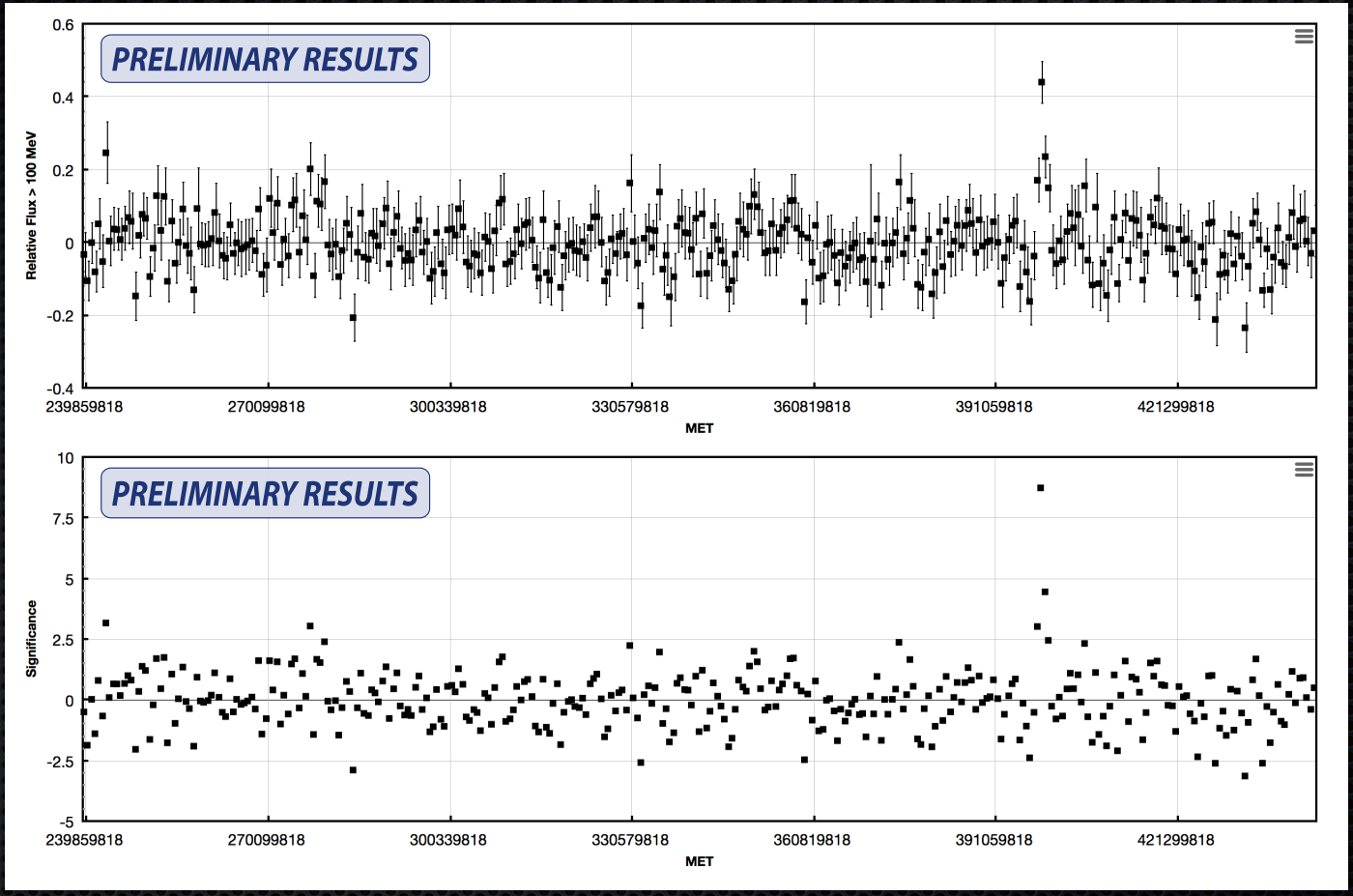
- Most catalog associated flares come from FSRQs and BLLs
- A large number of flares are not associated with any known catalog source
- The unassociated 3FGL sources make up ~33% of the 3FGL catalog, but represent a small fraction (4.7%) of FAVA detected sources

PSR B1259-63/LS 2883



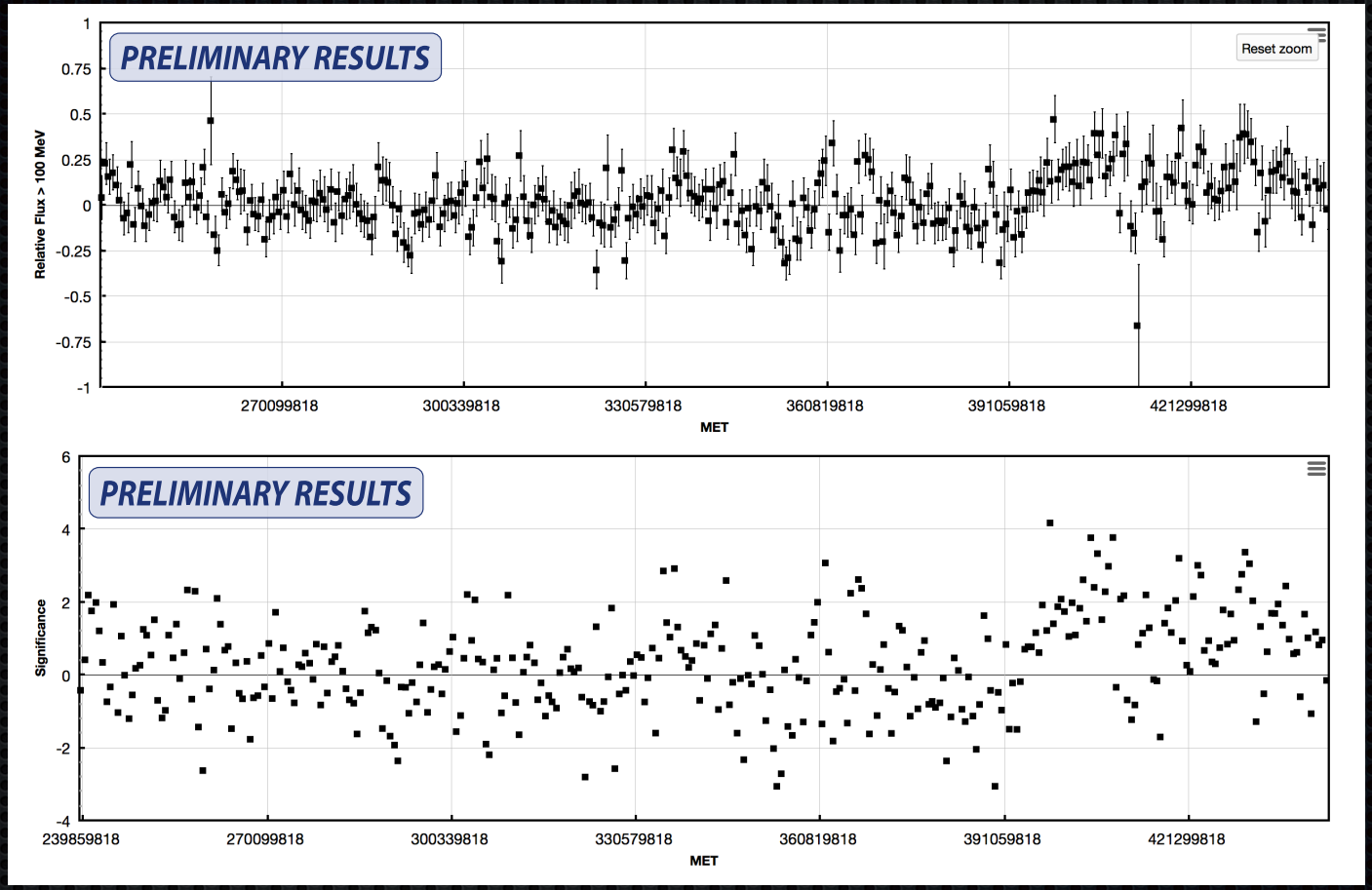
- Emission associated with periastron passage of HMXB through the stellar wind of a massive companion star. Period of 3.4 years easily detected by FAVA
- FAVA easily detected the rise of the emission in both instances

Nova V339 Delphini



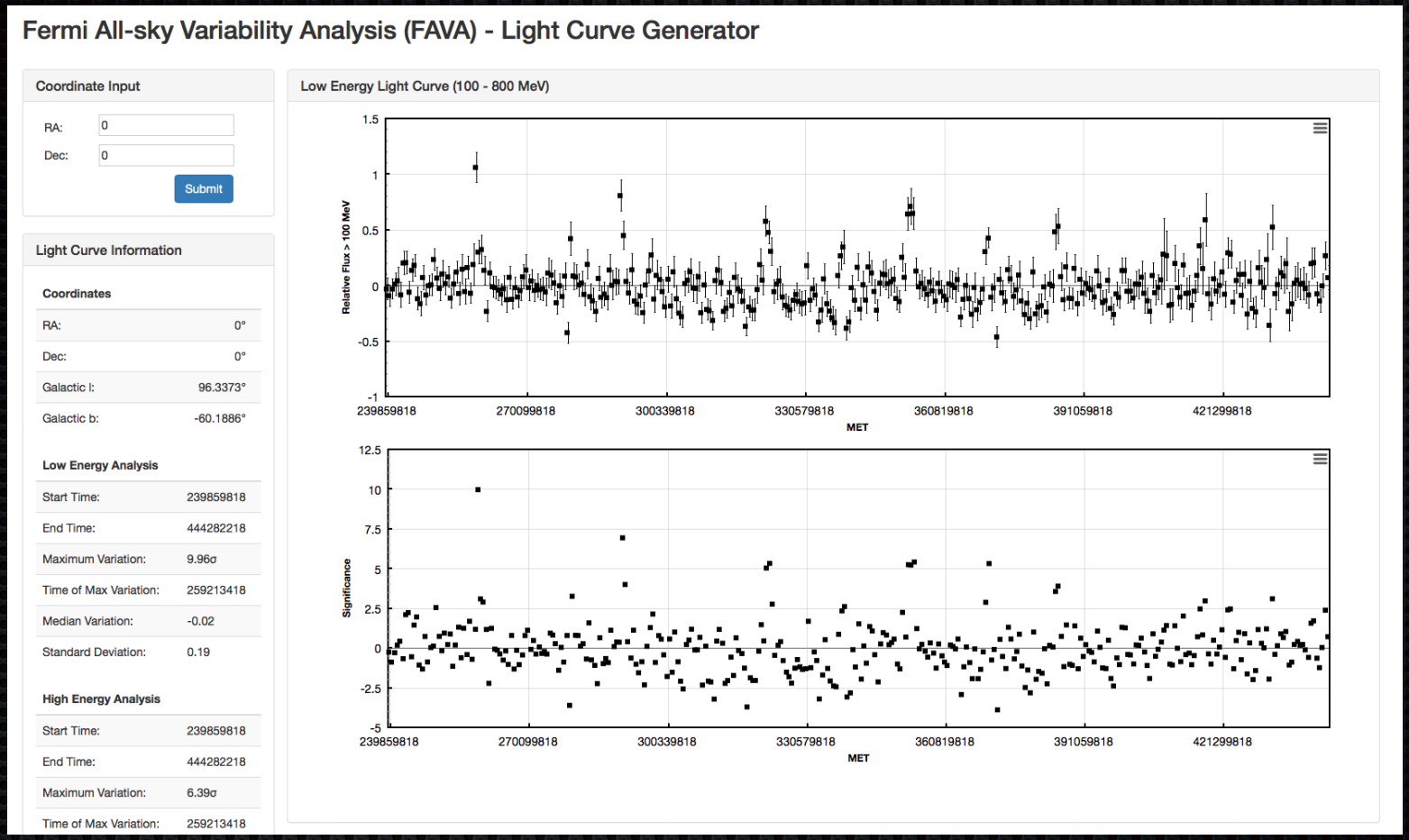
- Naked eye nova detected by amateur astronomers on 2013
- One of the few nova with observed gamma-ray emission. Well detected by FAVA

PSR J1023+0038 (LMXB)



- This system harbored a bright millisecond radio pulsar (300-5000 MHz) prior to mid-2013
- Radio pulsation has become undetectable, coinciding with an increase in observed X-ray and gamma-ray flux. Pulsar possibly went through a state transition that facilitated gamma-ray emission

FAVA Online



- Public FAVA data repository will be released as part of the 2FAV catalog
- Instant access to FAVA light curves, new weekly analysis, and 1FAV/2FAV results
- URL: http://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA/

Conclusions

- FAVA has proven to be very efficient at detecting variability in the gamma-ray sky
  - Capable of quickly searching the entire sky on a variety of timescales and provide seeds to more sensitive likelihood analysis
  - Not as dependent on uncertainties in the Galactic diffuse model
- The 2FAV catalog, with almost 3000 flares, is currently being prepared for release
- FAVA will also continue to be run on weekly and eventually 3-day timescales
  - We have set up dedicated multi-wavelength (Swift, Chandra, GROND) followup of any new sources detected in the Galactic plane
- Results of the weekly and 3-day analysis will be made public in real-time
- Light curve generator and FAVA database will also be accessible for data mining
  - Watch this space: http://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA/