The Pulsars and Blazars of the Fermi Unassociated Sources

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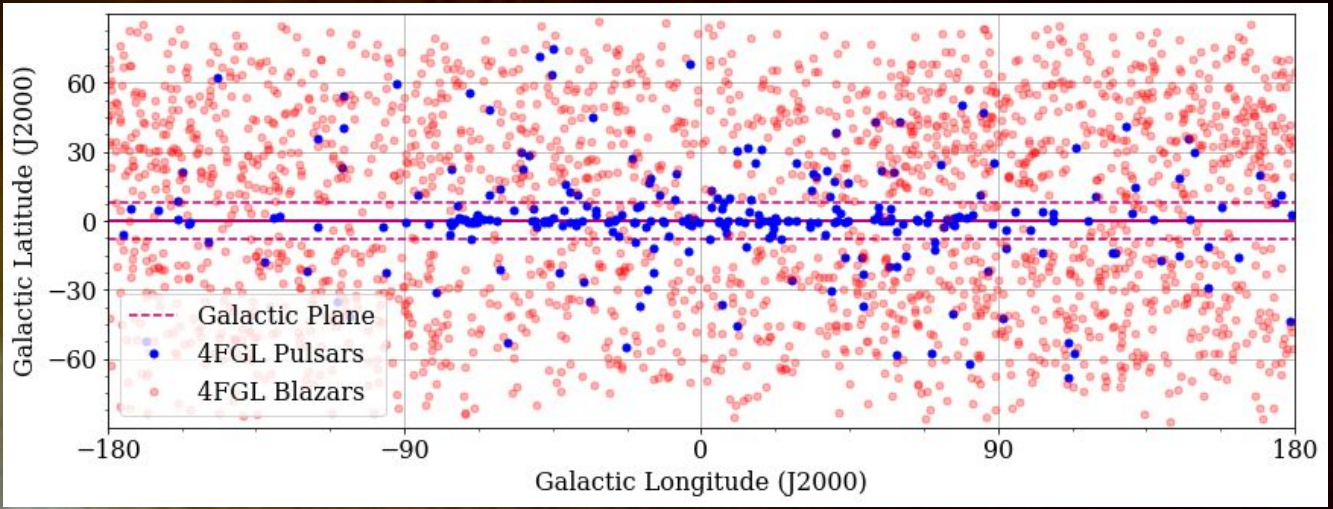
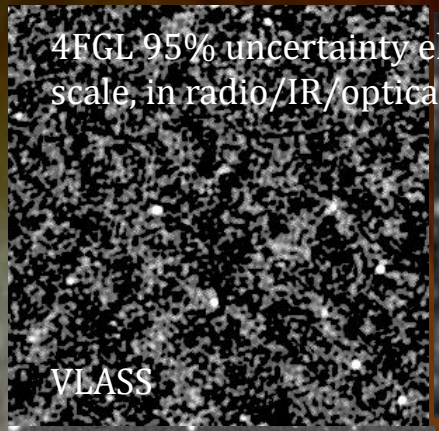
2 June 2023

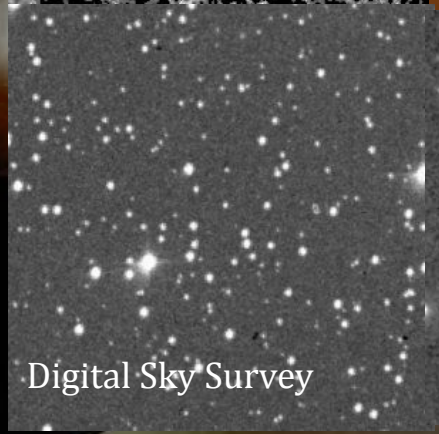


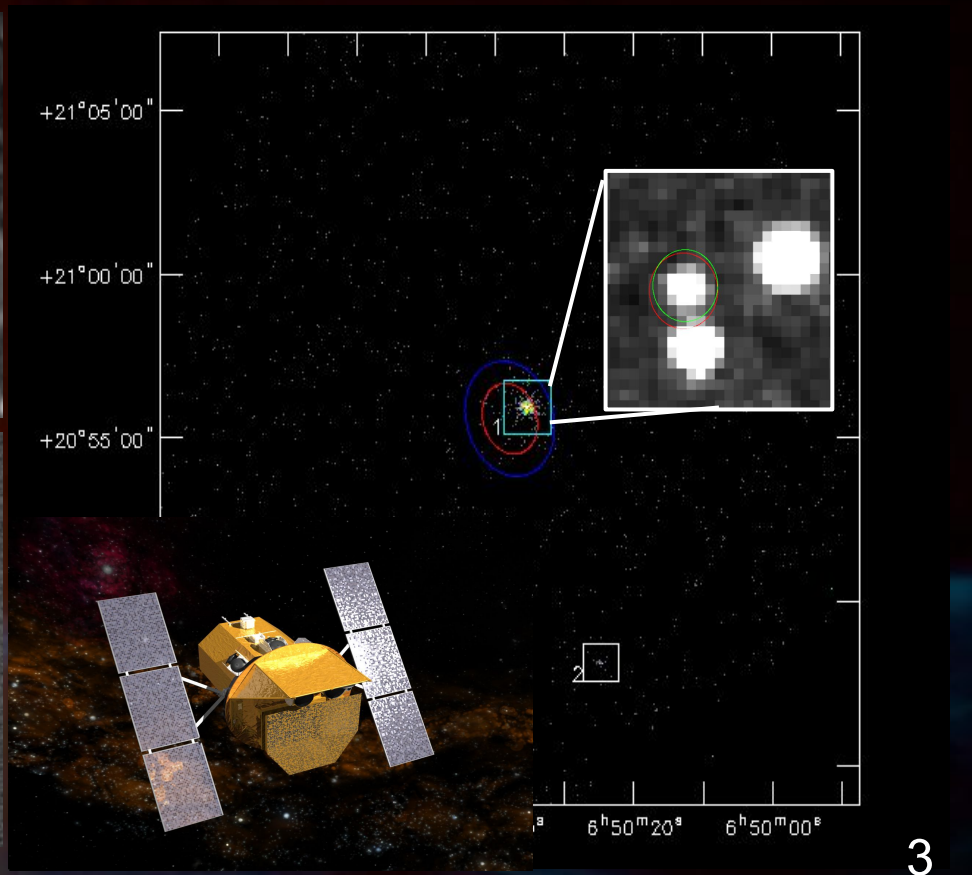
4FGL-DR3:
Abdollahi et al. 2022
4LAC-DR3:
Ajello et al. 2022

- **Fermi 4FGL-DR3:** catalog of gamma-ray point sources
  - >3500 **blazars** make up ~70% of associated sources
    - 4LAC catalog describes **BLLac** / **FSRQ** subsamples
  - ~250 **gamma-ray pulsars** via timing & radio detections
- **4FGL-DR3** also contains ~2000 **unassociated** sources
  - ***No cited astronomical counterpart at other wavelengths***
  - Naive extrapolation suggests additional blazars and pulsars?

Now that's what I call localization!

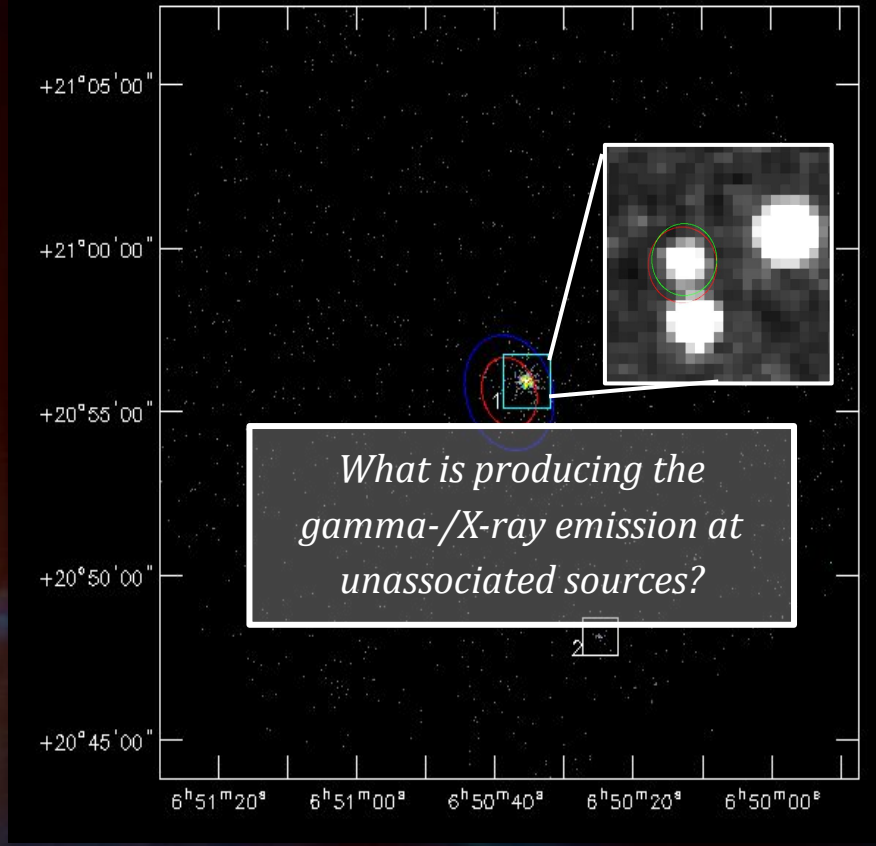




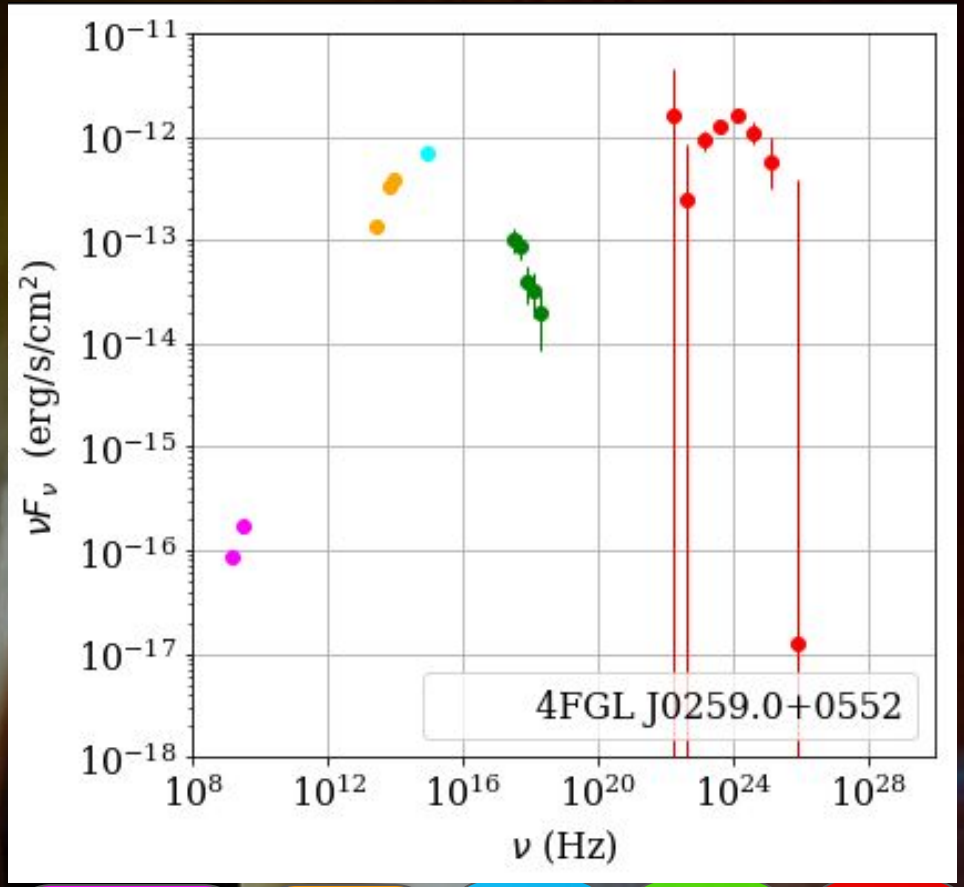


Observations: Swift-XRT/UVOT Follow-up

- Ongoing *Swift* program: observations at >1000 4FGL **unassociated** targets
  - X-ray counterparts allow for constructing wide-ranging SEDs
- **2021 catalog paper** details **205 sources** with X-ray counterparts:
  - **192** with a **solitary** X-ray excess
  - 17 with multiple
- Classification via machine learning to create entirely new samples
  - 132 likely **blazars**
  - 14 likely **pulsars**



Blazars: In Focus



Archival Radio | WISE | UVOT | XRT | LAT

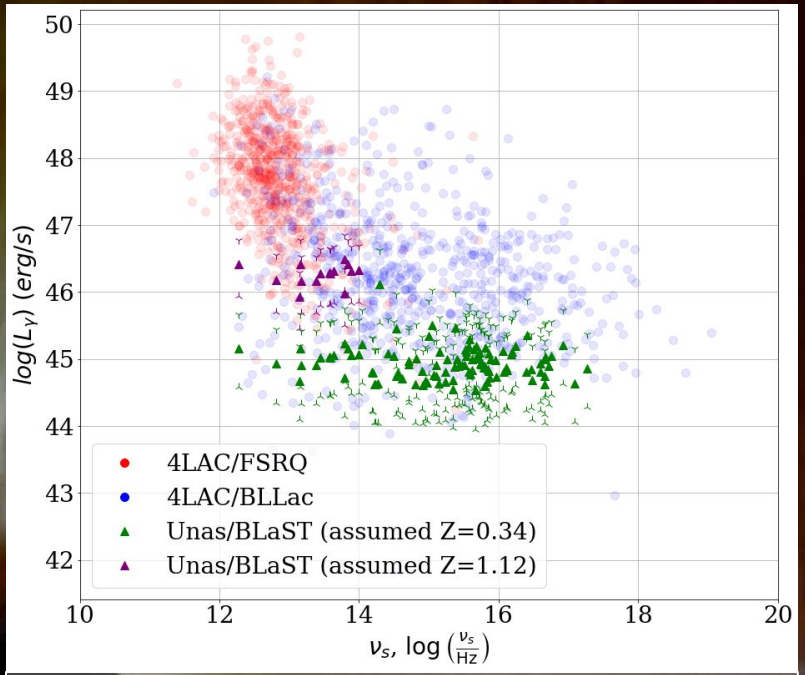
Are the new blazars similar or different to known blazar samples?

(besides being dimmer)

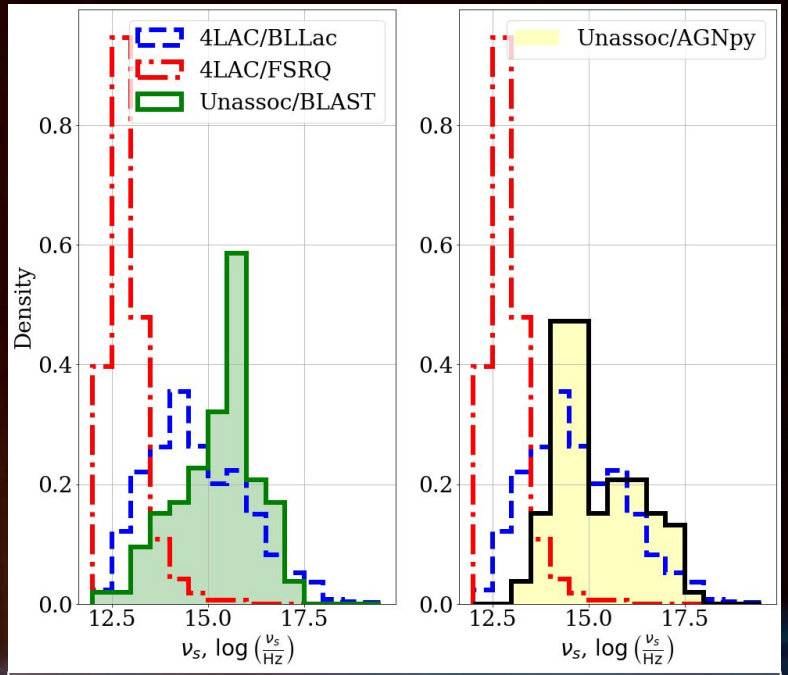
Swift-XRT detection allows for…

+ Adding WISE magnitudes, radio fluxes creates broadband SEDs with two-hump shape
+ Extracting features like peak frequencies, Compton dominance ratio
+ Conducting physical jet fitting

Blazars: Testing the Blazar Sequence

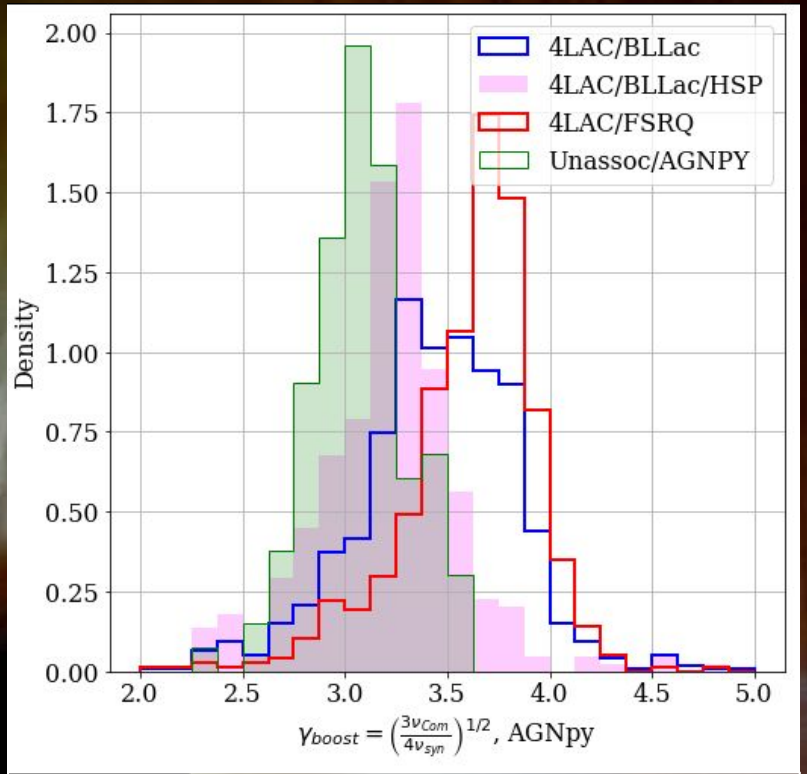


The blazars of the unassociated sources **extend** and **confirm** the blazar sequence out to lower luminosity & higher ν_{syn}

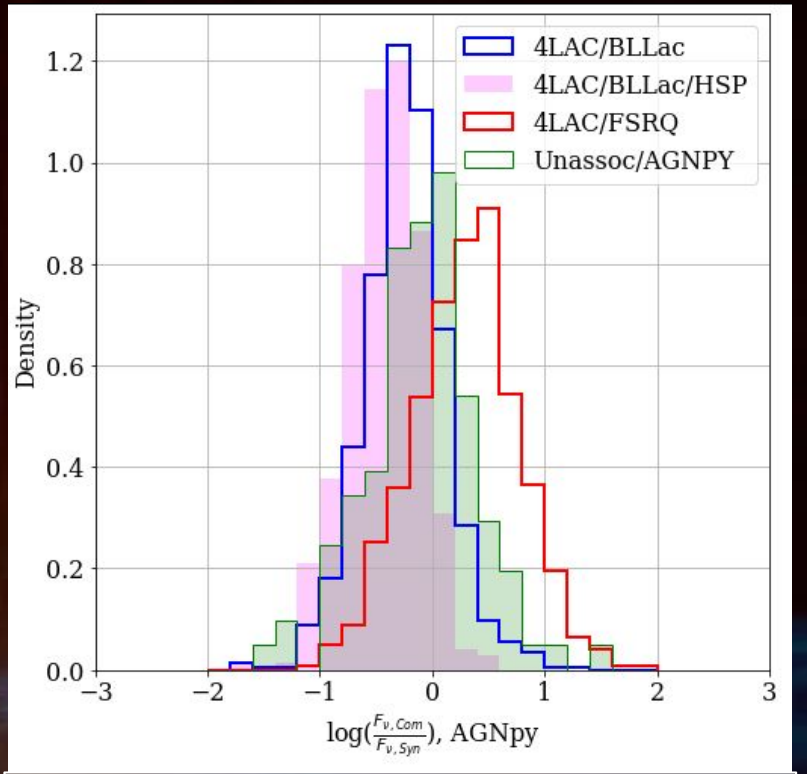


This new sample probes extreme gamma-ray blazars and constrains leptonic and hadronic emission models

Blazars: Towards Physical Comparisons



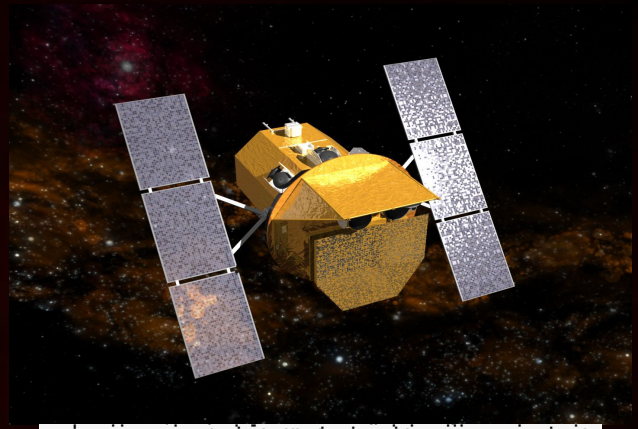
Distance between peaks: **As predicted by the blazar sequence**

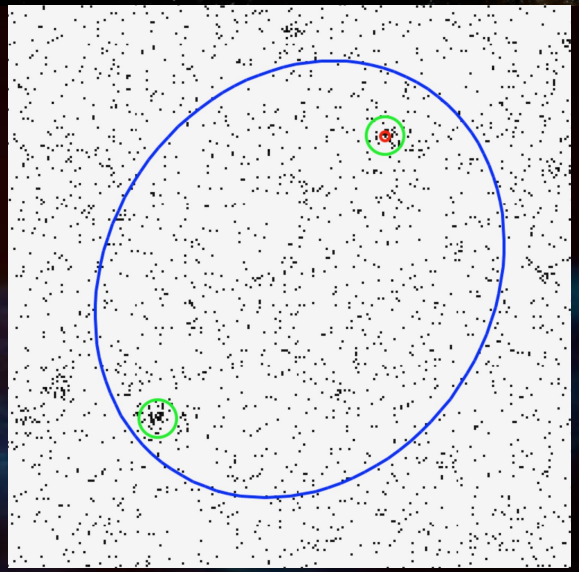


Compton dominance: **Unexpectedly bright high-energy peaks?**

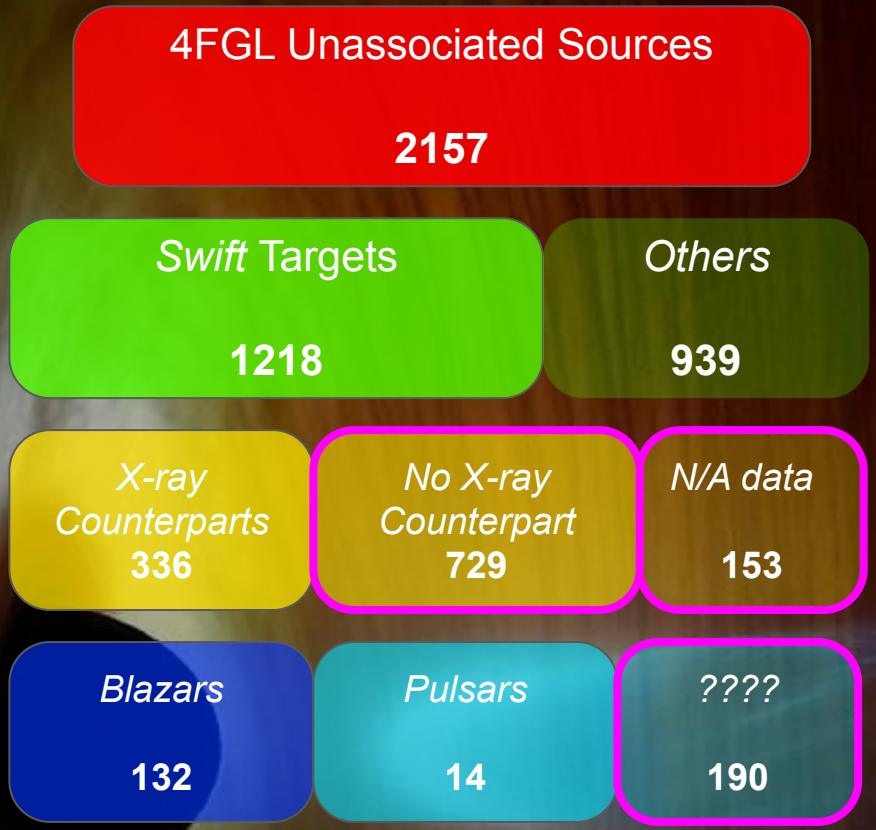
Pulsars: In Pursuit with *Swift*

- TRAPUM consortium + MeerKAT telescope discovers redback/BW pulsars at *Fermi* unassociated sources
- With ToO *Swift*-XRT observations, we detect X-ray counterparts and confirm radio discoveries
- Some *Fermi* sources w/ radio pulsars have seperate/alternative X-ray counterparts
  - M dwarfs, galactic systems, **or background blazars linked to *Fermi* emission?**





Summary: Unassociated Target Breakdown



+ *Swift* observations at *Fermi* unassociated sources can **pinpoint low-energy counterparts** with ~5" source localization
+ ML classification sorts creates a new sample of **dim blazars** and identifies **pulsar candidates**
+ The likely blazars are mostly **dimmer, bluer BL Lacs**
+ *Multiwavelength followup can unravel the mysteries of the unassociated sources*

Special thanks to the High-Energy Astro Analysis + Instrumentation groups at PSU Astro!

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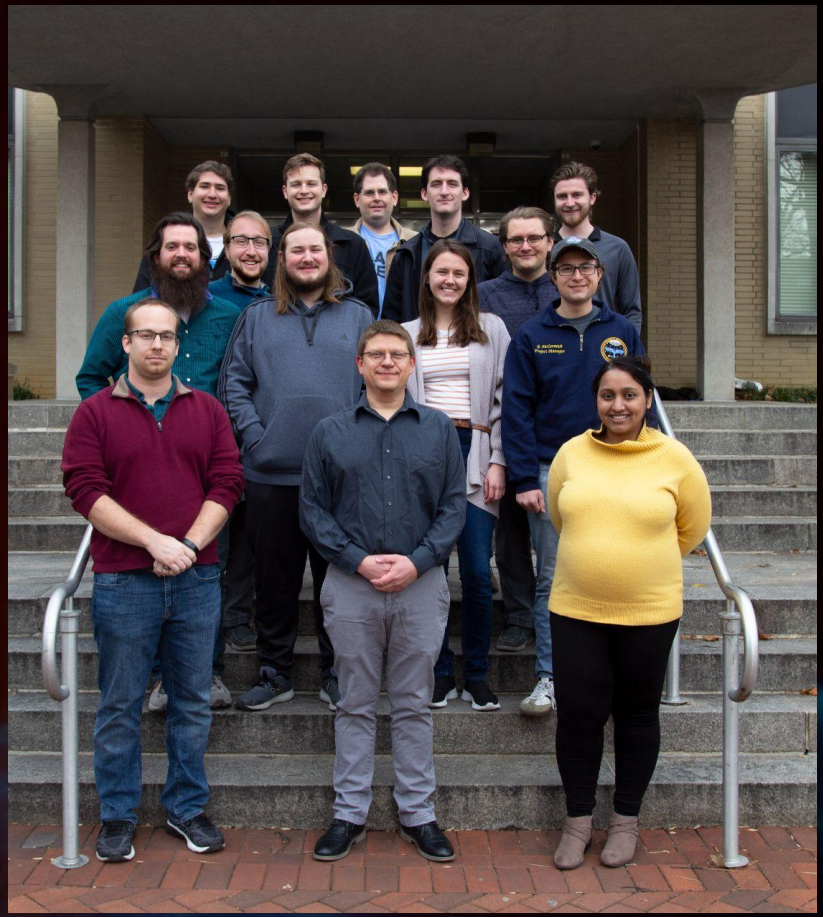


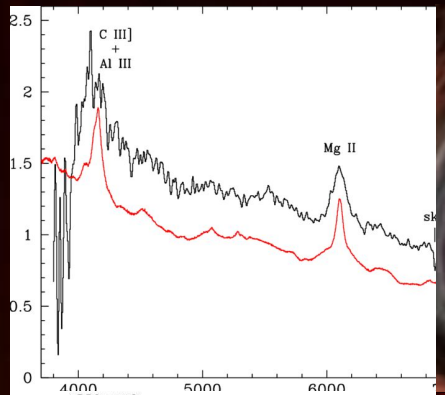
A Brief Summary of Gamma-Ray Pulsars/Blazars

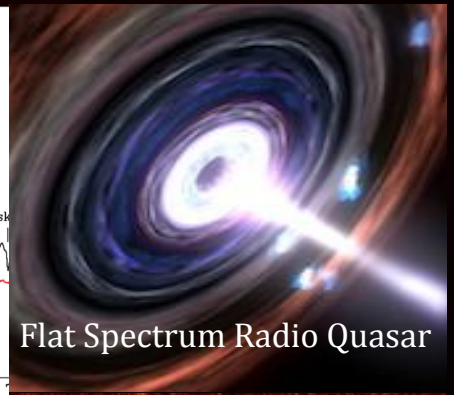
Blazars:

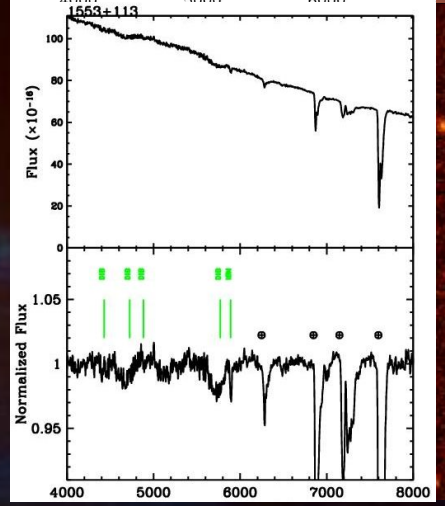
- Radio-loud jetted AGN, viewed down the jet
- Characteristic 2-humped spectrum (synchrotron + high-E components)
- Major subtypes include…
  - **BLLac**: small optical line EW, blue/dim/low-Z
  - **FSRQ**: significant optical lines, red/bright/high-Z

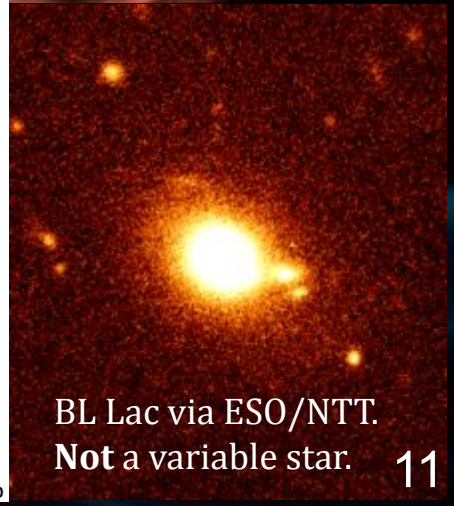
Gamma-ray pulsars:

- Gamma/X-ray emission from energetic processes in strong EM environment

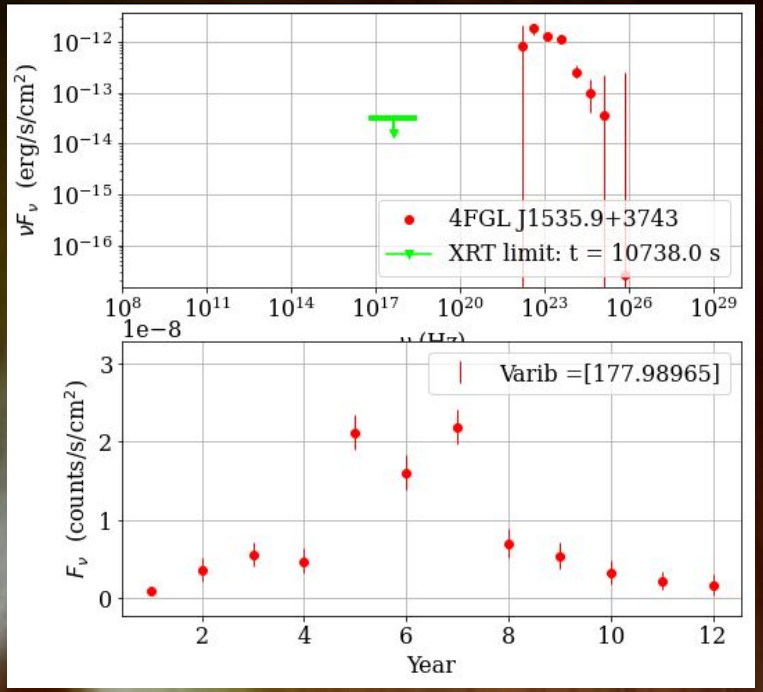



Flat Spectrum Radio Quasar

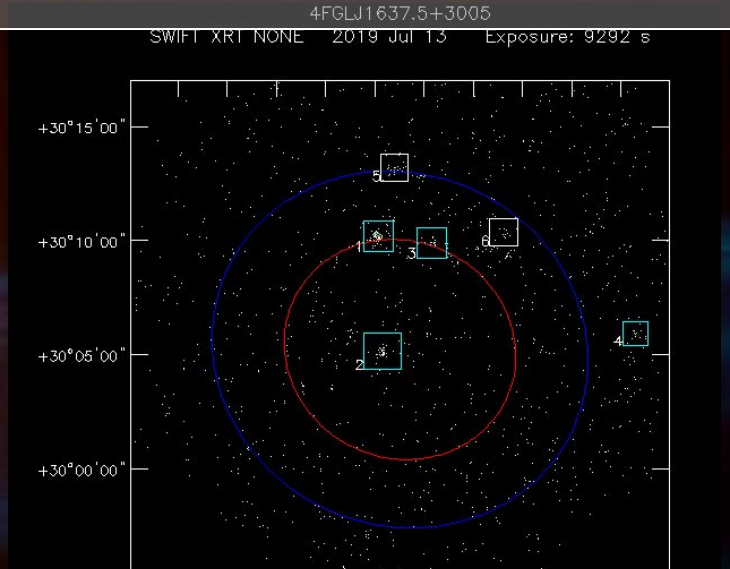



BL Lac via ESO/NTT.
Not a variable star.

Oddballs and Outliers



- Many gamma-/X-ray sources defy pulsar/blazar classification
  - X-ray binaries, extreme sources, etc…
- *Swift* observations also reveal dozens of new X-ray active stars



- Hundreds of unassociated targets with **no X-ray counterpart** or **more than one possible counterpart** still require further investigation