

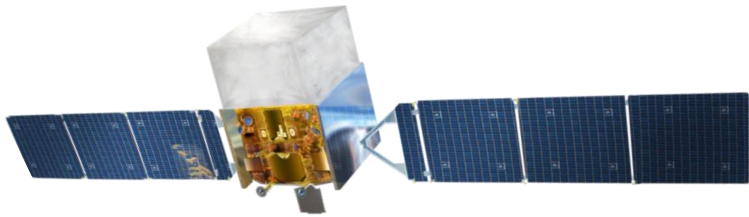
Artificial Neural Network classification of the *Fermi*-LAT 4FGL-DR4 catalog blazars of unknown type and unidentified sources

^{1,2} **Francesco Casini**, ² Sara Cutini, ^{1,2} Stefano Germani

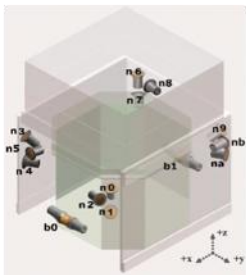
¹ University of Perugia, Department of Physics and Geology, Italy

² Istituto Nazionale di Fisica Nucleare, Perugia, Italy

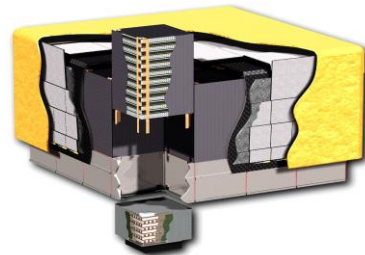
Fermi-LAT



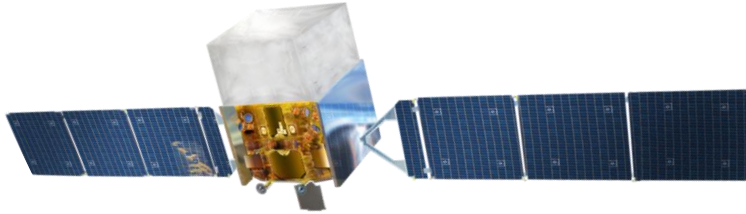
Gamma-Ray Bursts Monitor
(GBM)



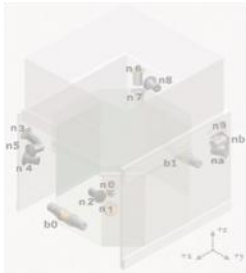
Large Area Telescope
(LAT)



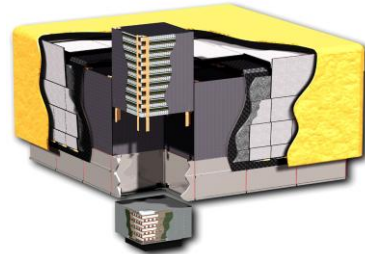
Fermi-LAT



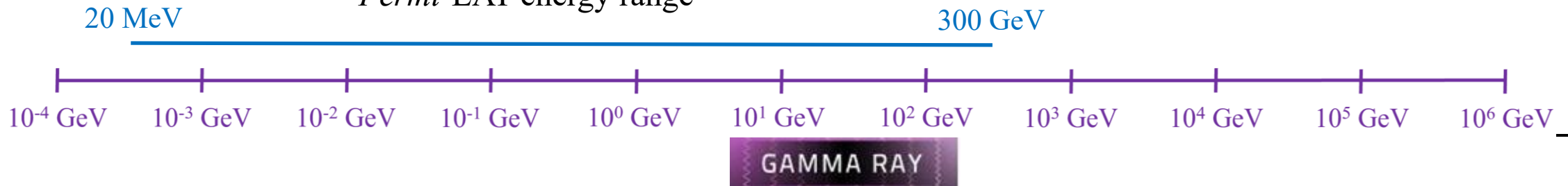
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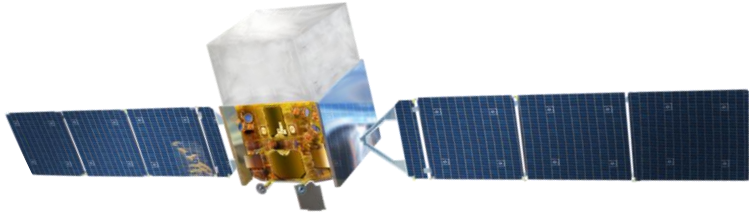
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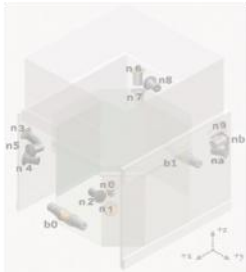
Fermi-LAT energy range



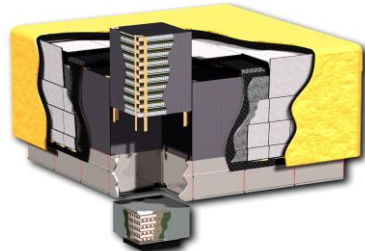
Fermi-LAT



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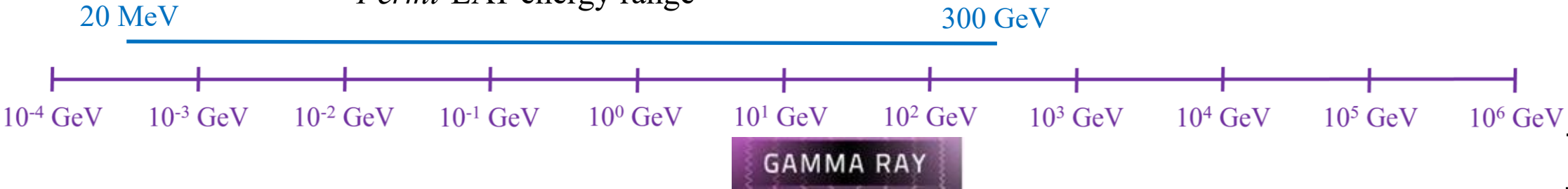
Large Area Telescope
(LAT)



NEW!

Catalog	Sources	UID (%)	BCU (%)
1FGL	1451	630 (43)	92 (6)
2FGL	1873	575 (31)	257 (14)
3FGL	3033	1010 (33)	568 (19)
4FGL-DR1	5064	1336 (26)	1310 (26)
4FGL-DR2	5788	1679 (26)	1515 (26)
4FGL-DR3	6658	2157 (32)	1492 (22)
4FGL-DR4	7195	2340 (34)	1624 (23)
FL16Y	7220	2115 (30)	1513 (21)

Fermi-LAT energy range

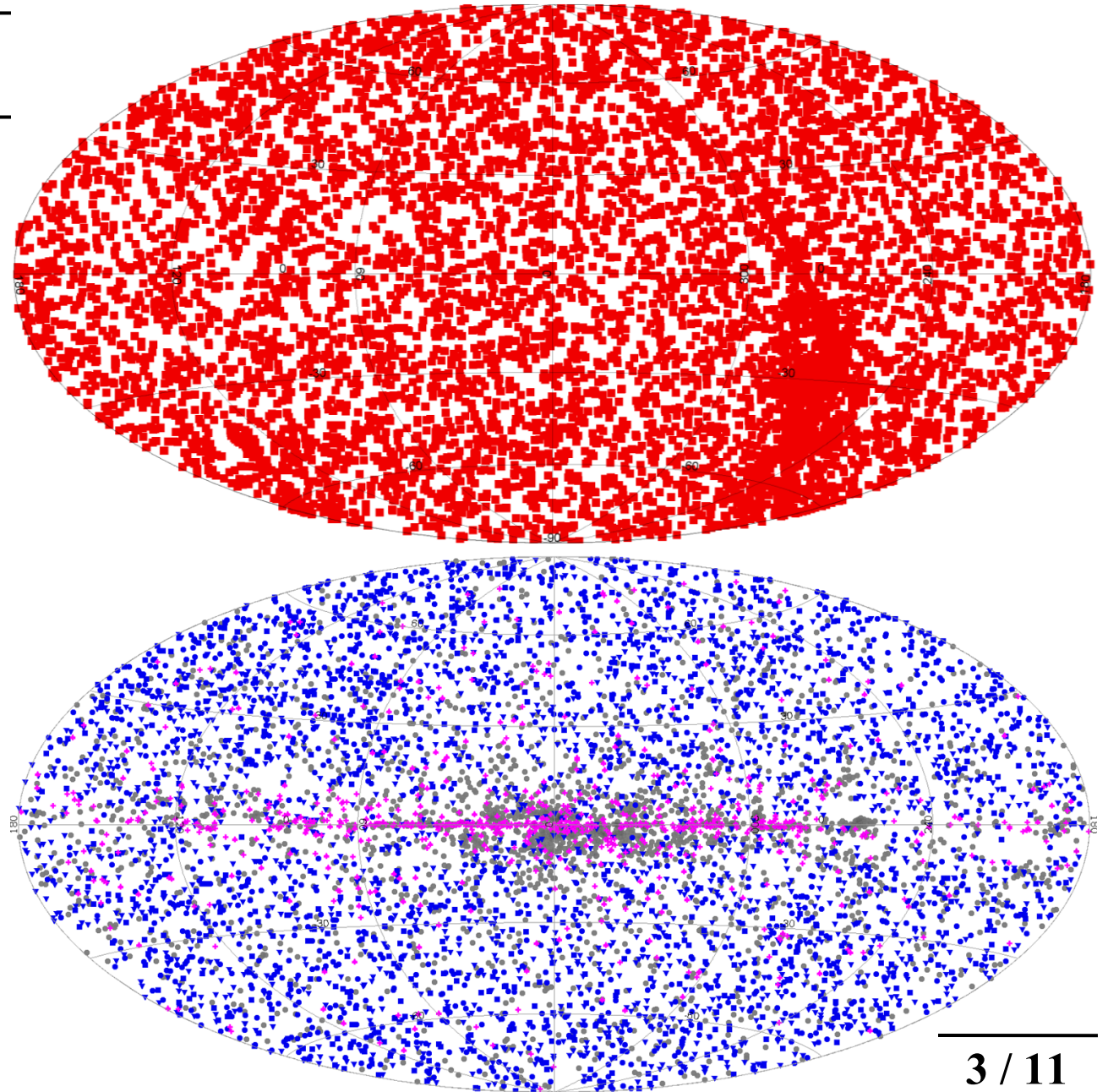
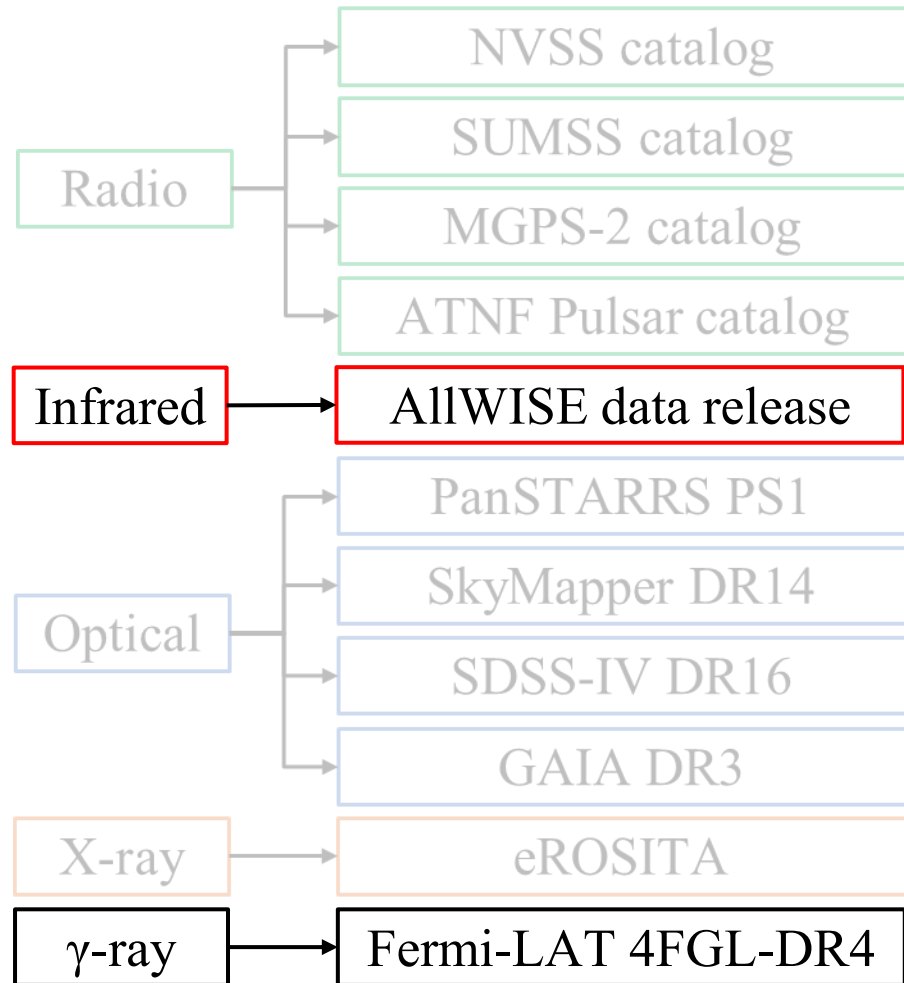


4FGL-DR4 Catalog

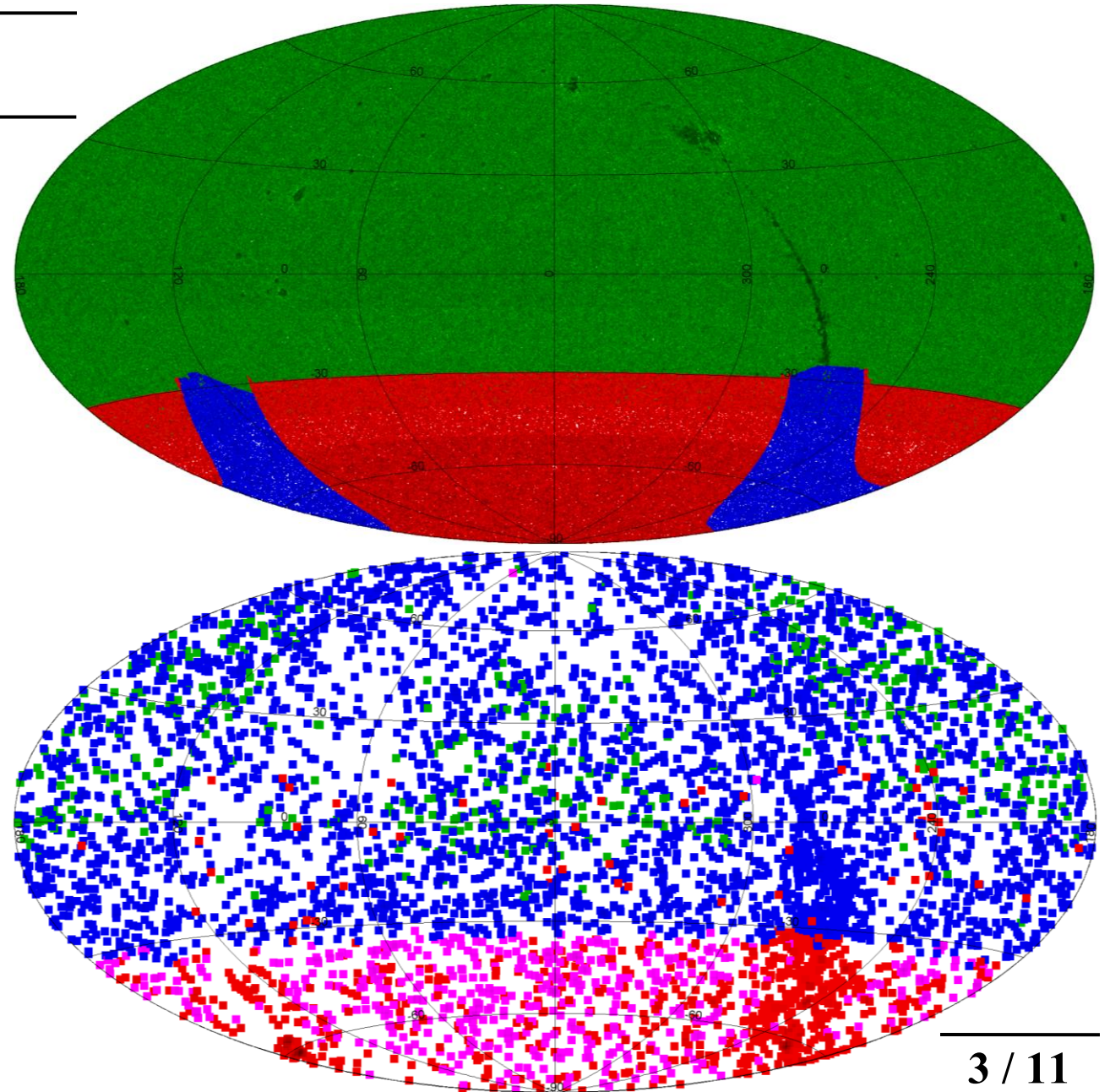
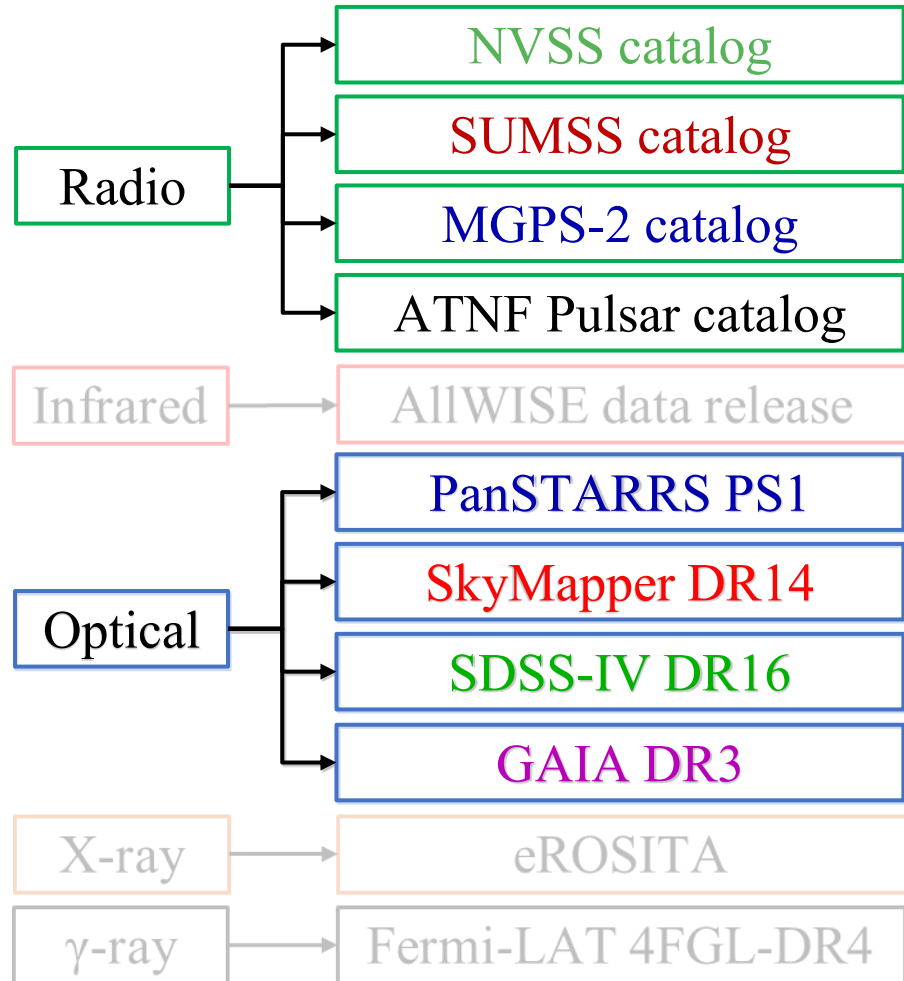
Class	Designator	Number
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Pulsar	PSR	141
Pulsar Wind Nebula	PWN	22
Radio Galaxy	RDG	54
Starburst Galaxy	SBG	8
Seyfert Galaxy	SEY	3
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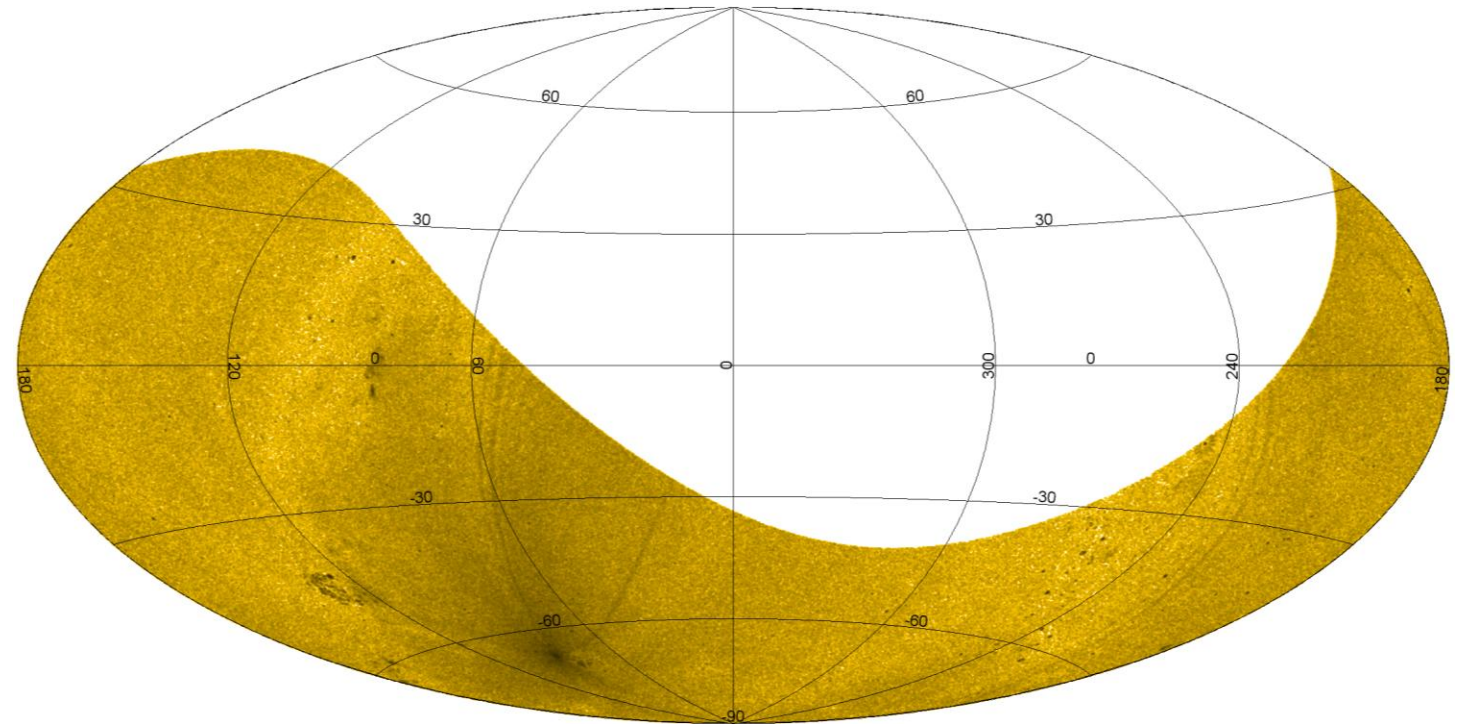
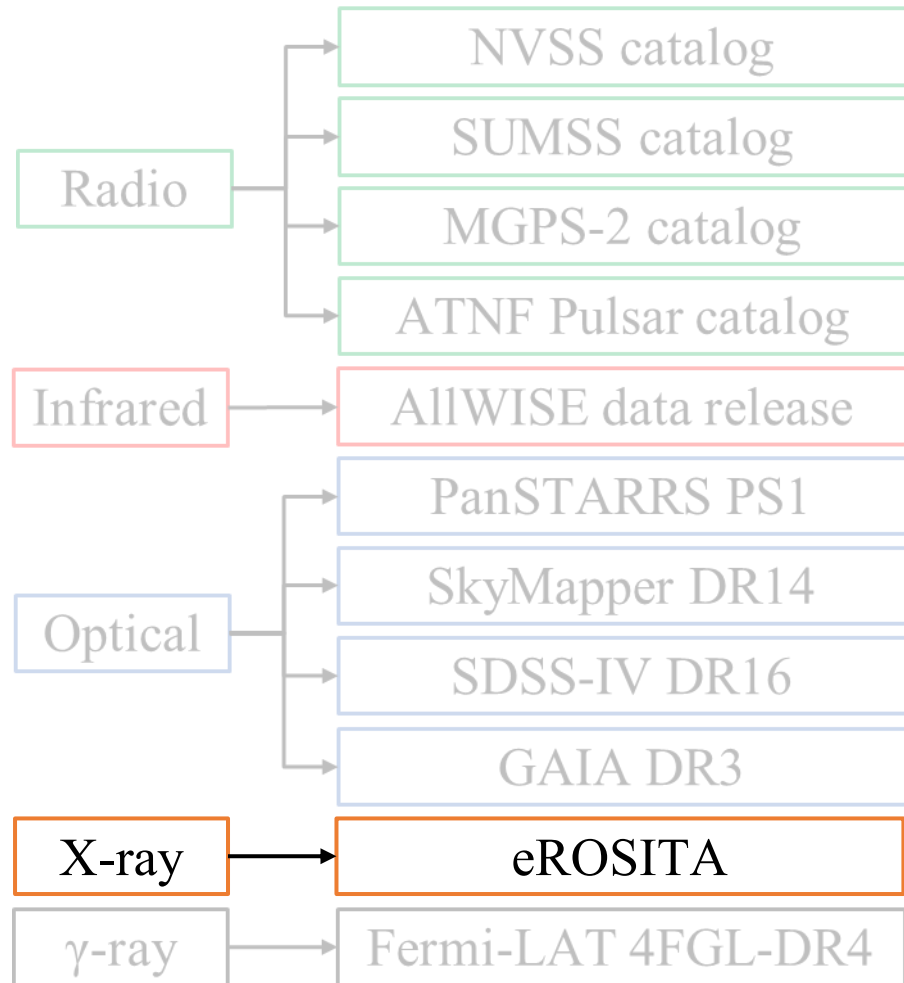
Multi-Wavelength Catalogs



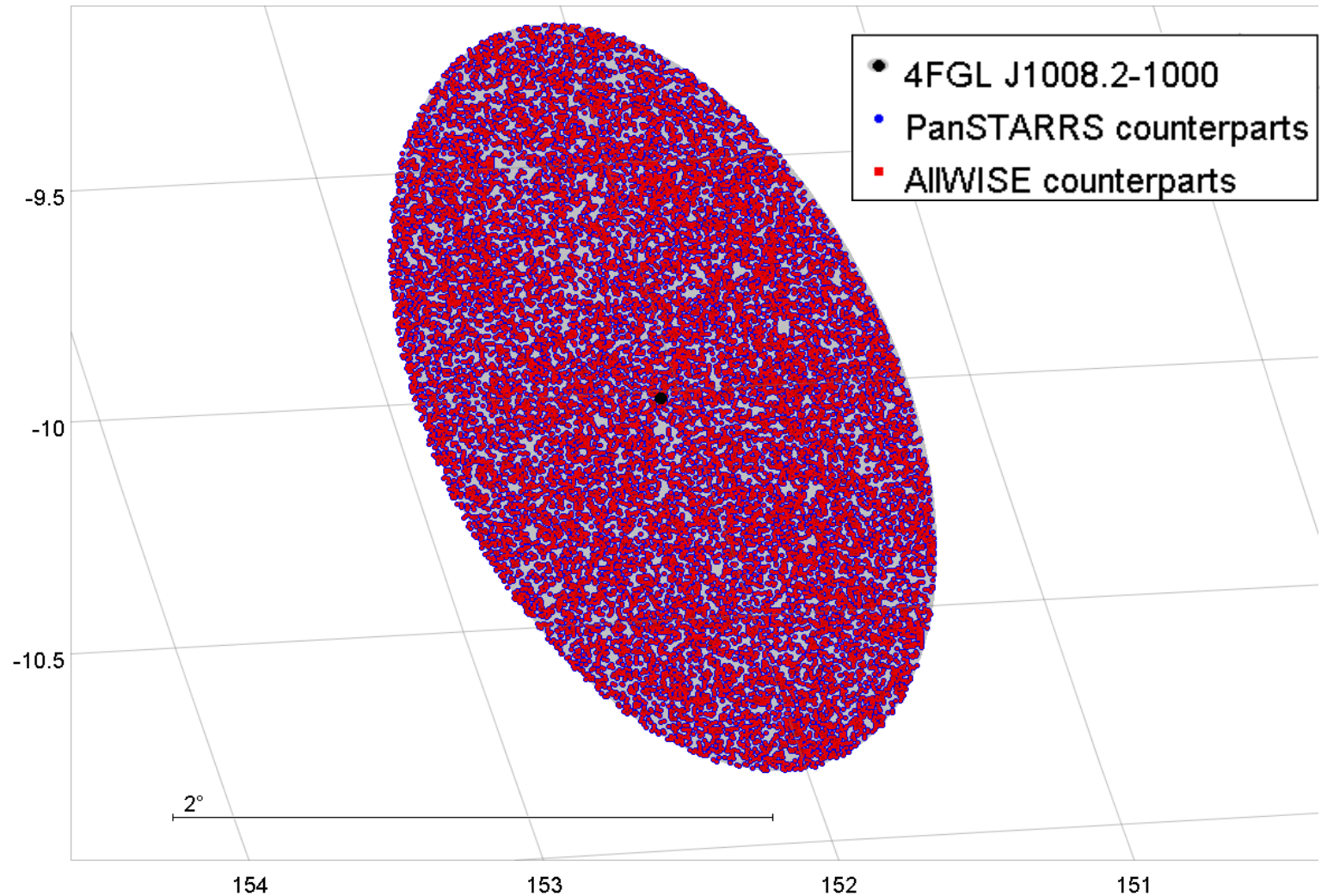
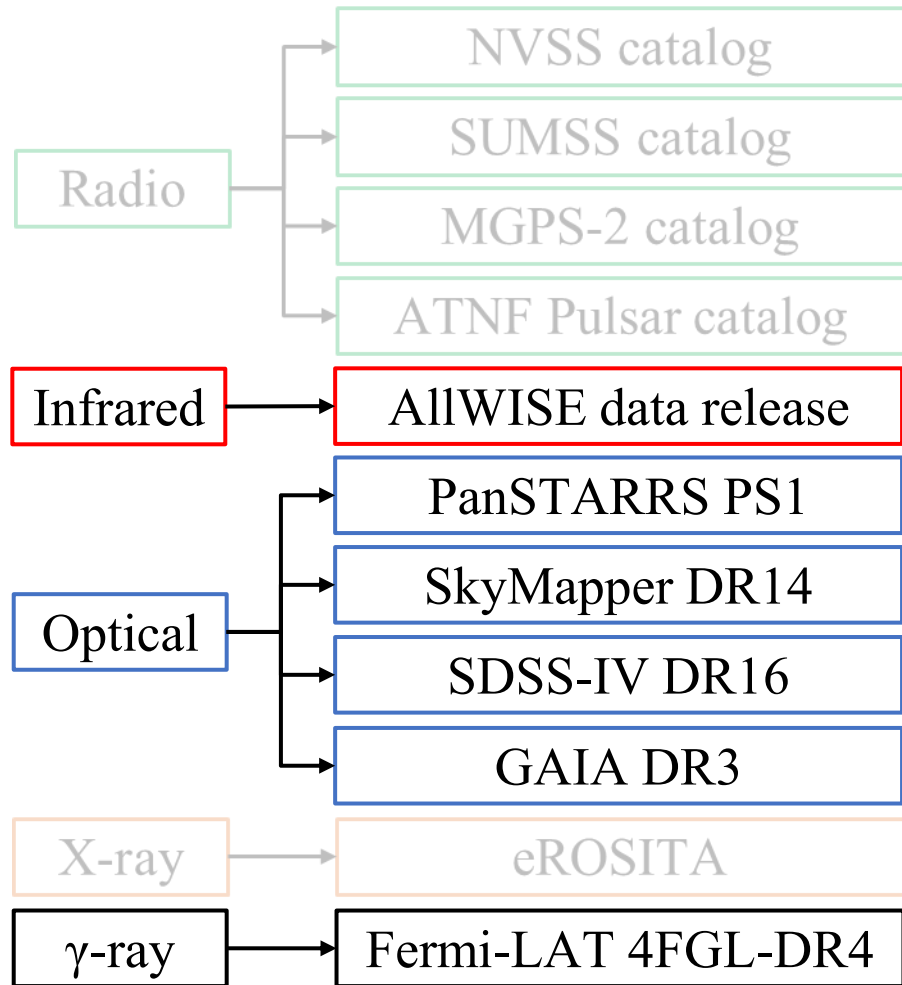
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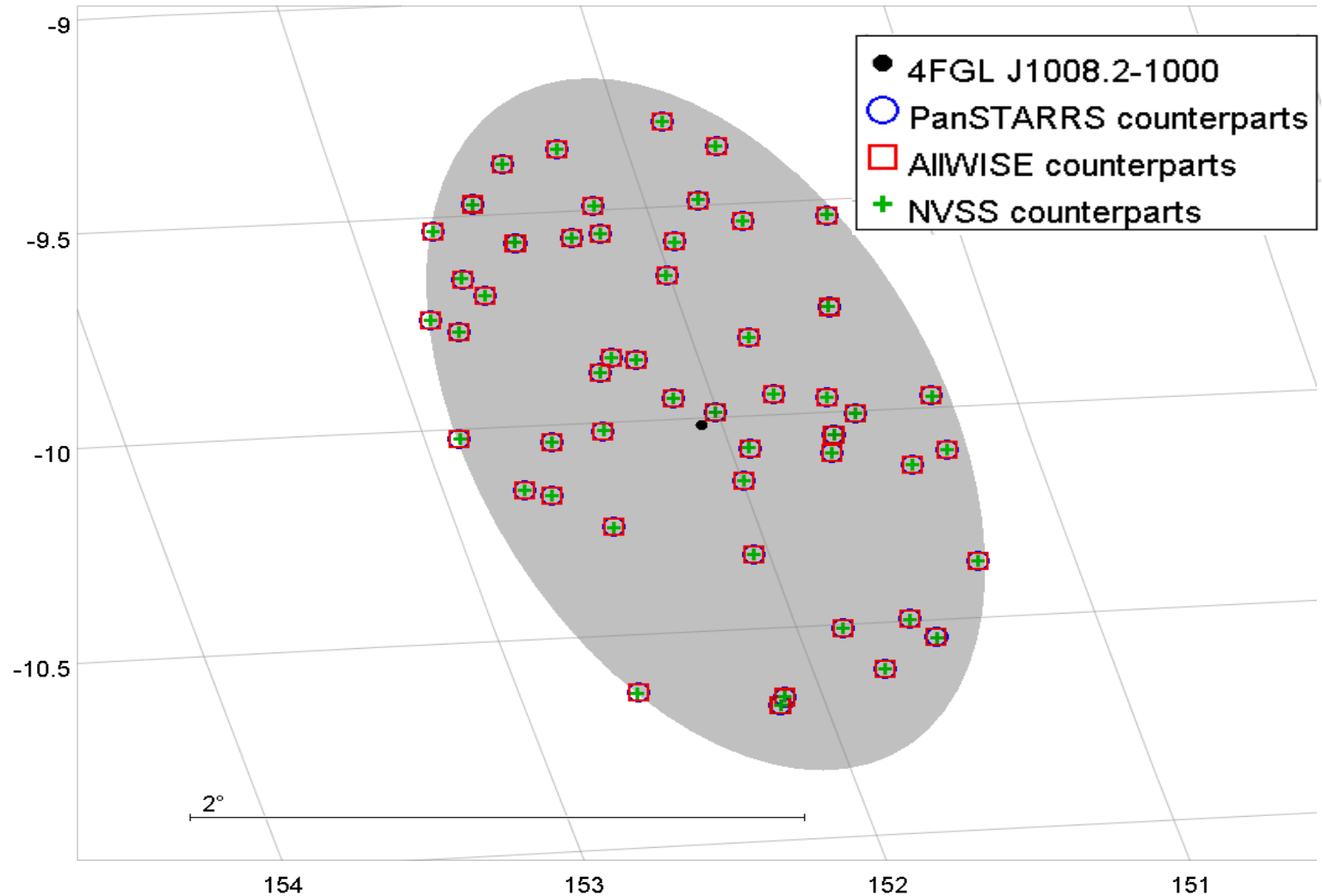
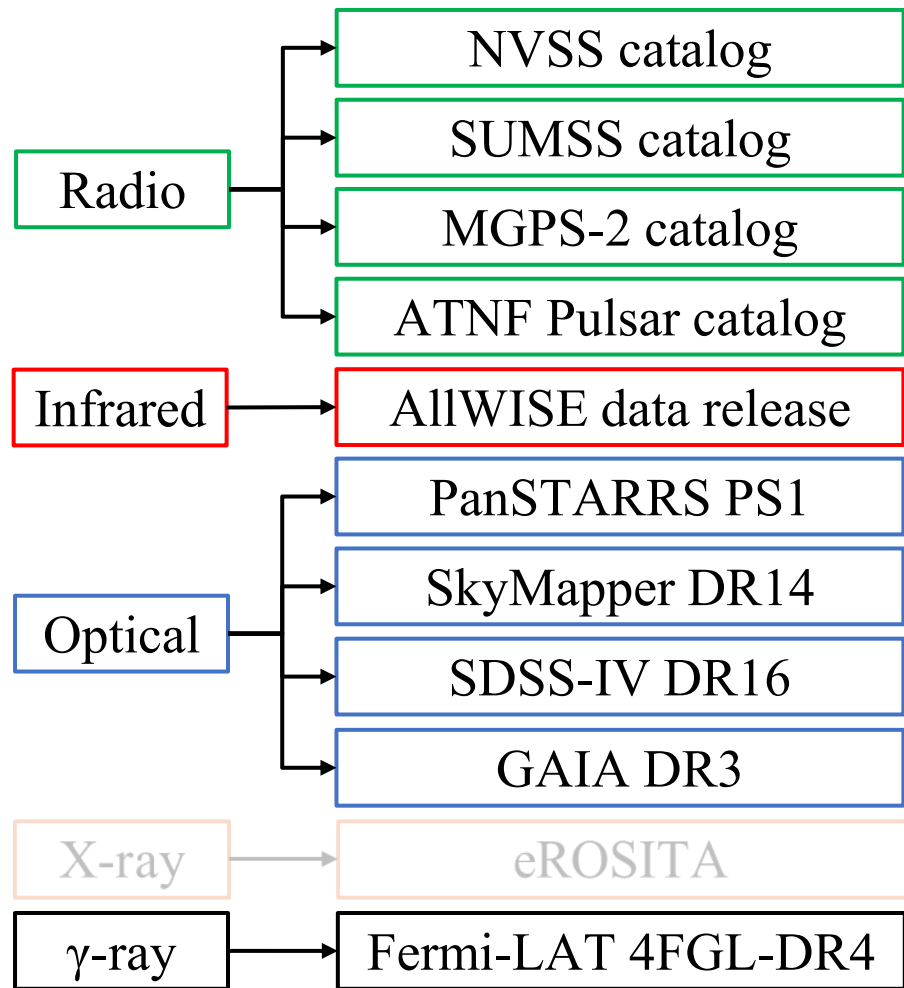
Multi-Wavelength Catalogs



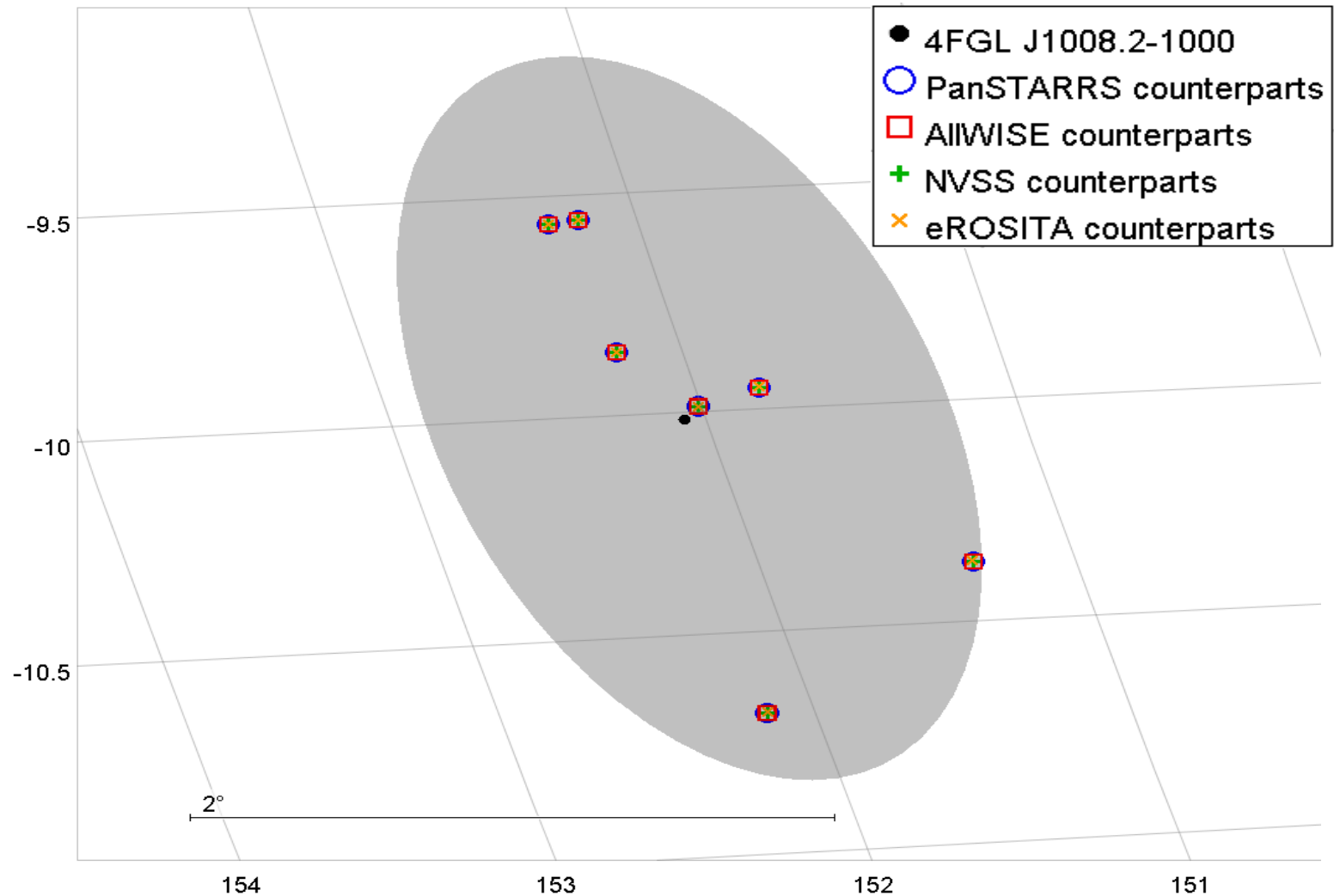
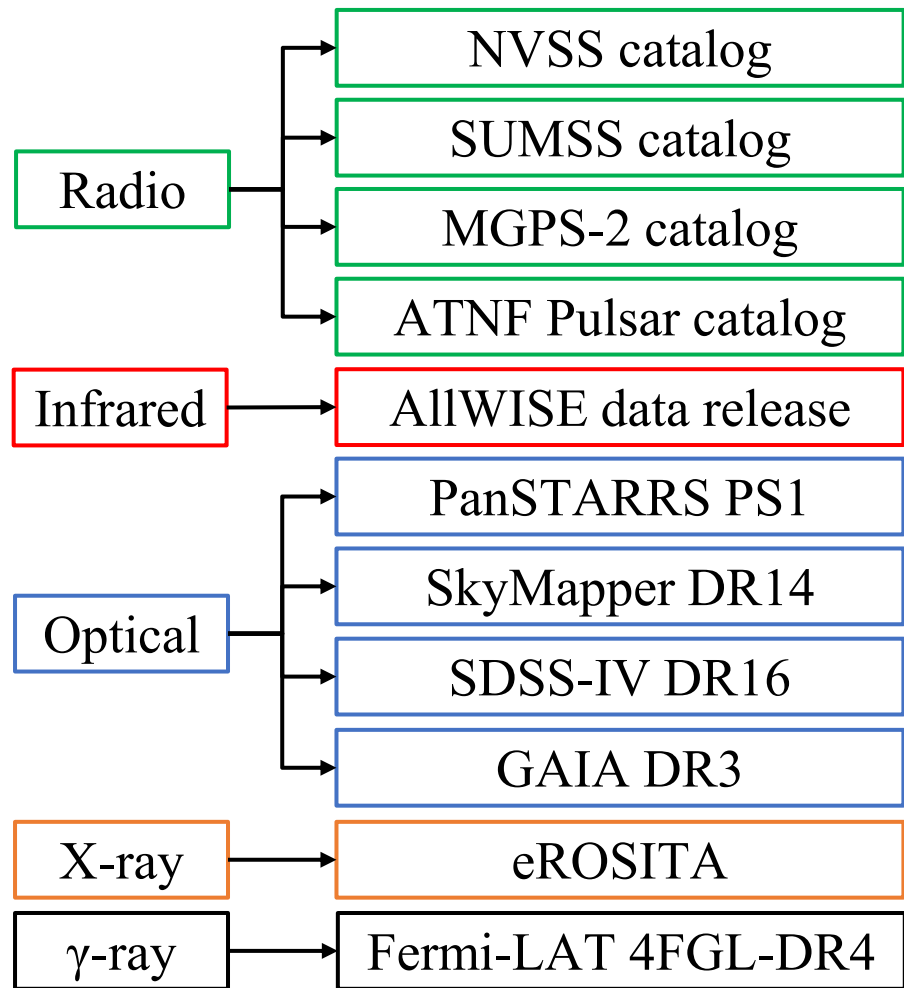
Unidentified Sources



Unidentified Sources

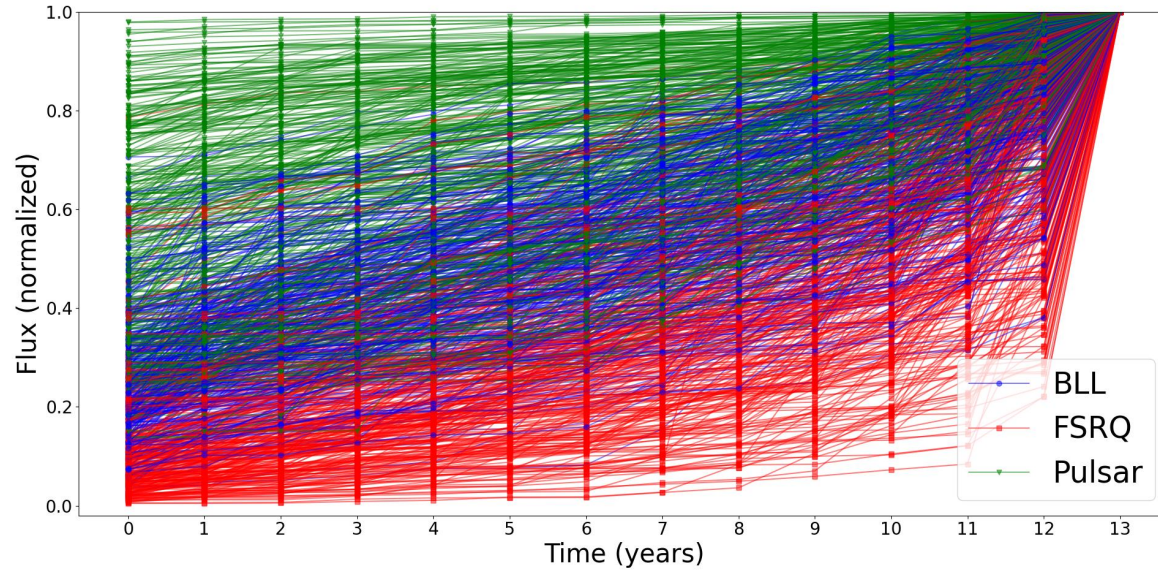


Unidentified Sources



Neural Network Input Data

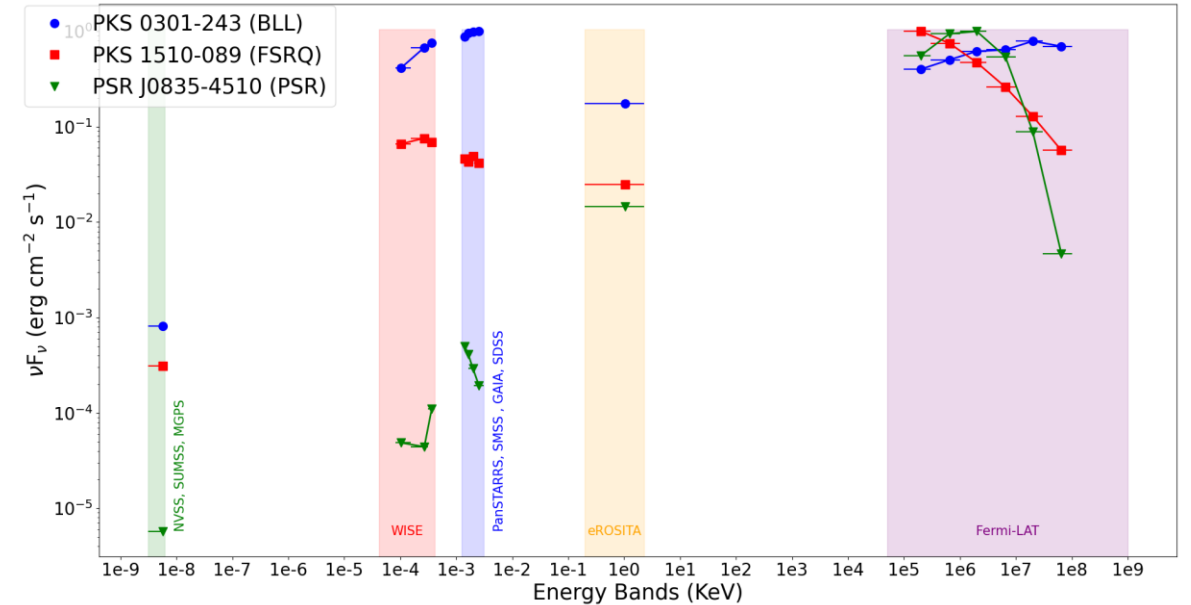
Sorted and Normalized Light Curve



Info on:

- average brightness
- maximum annual-averaged activity
- variability of sources
- flaring patterns

Normalized MW Spectral Energy Distribution

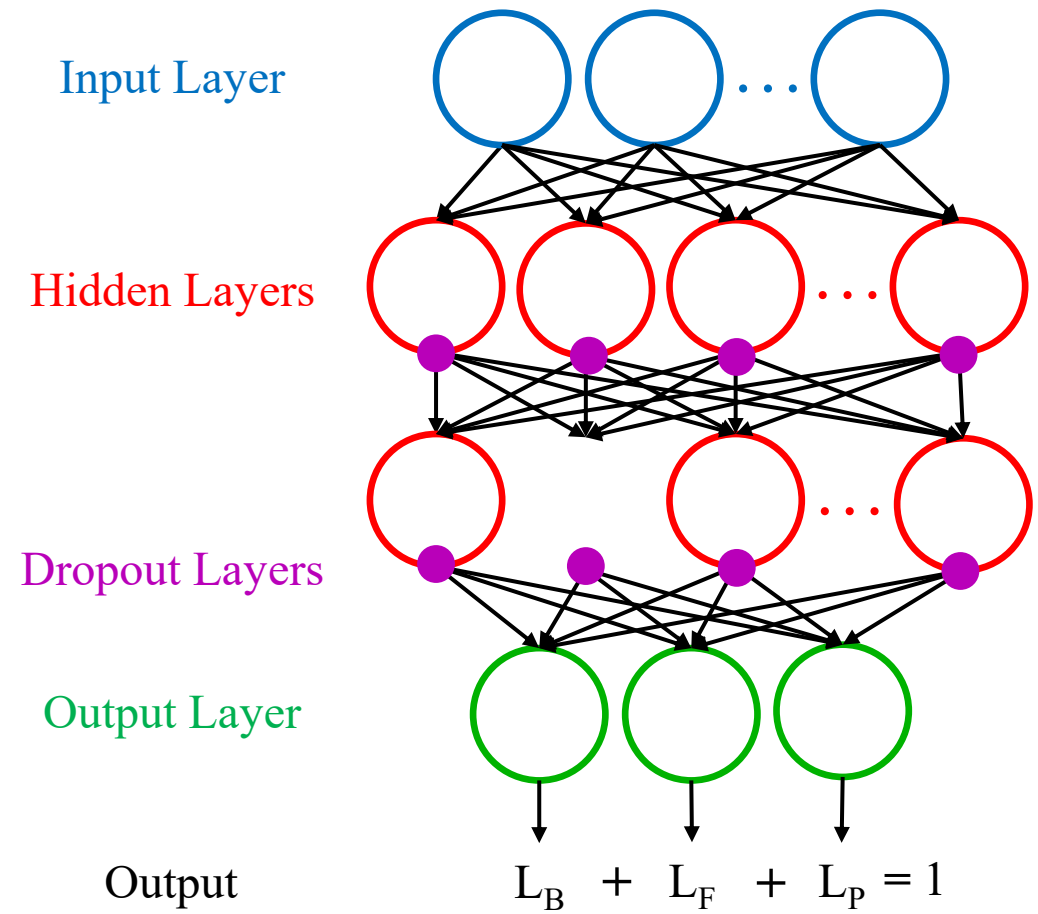
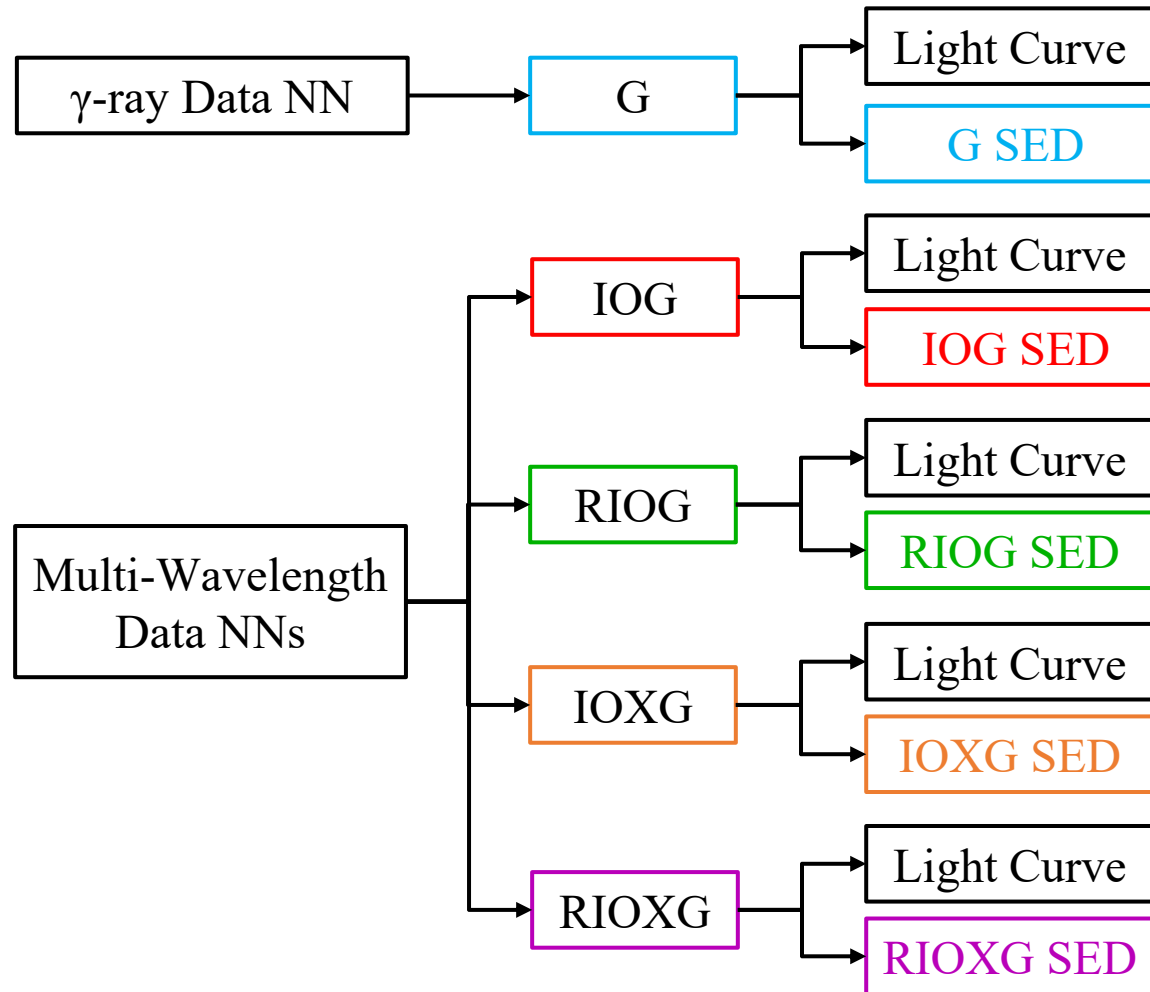


Info on:

- spectral index
- spectral curvature
- flux and harness ratio
- peak energy

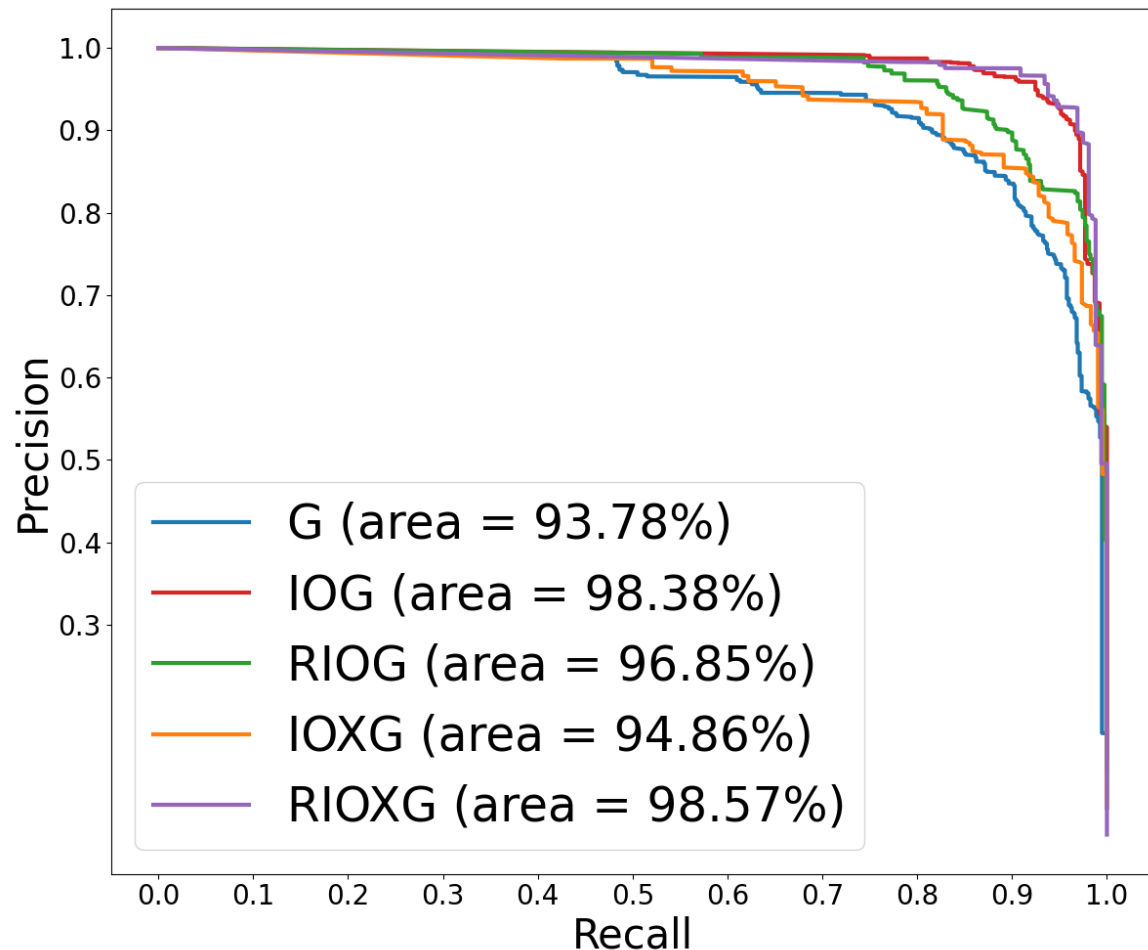
Artificial Neural Networks

Artificial Neural Networks input definition and structure

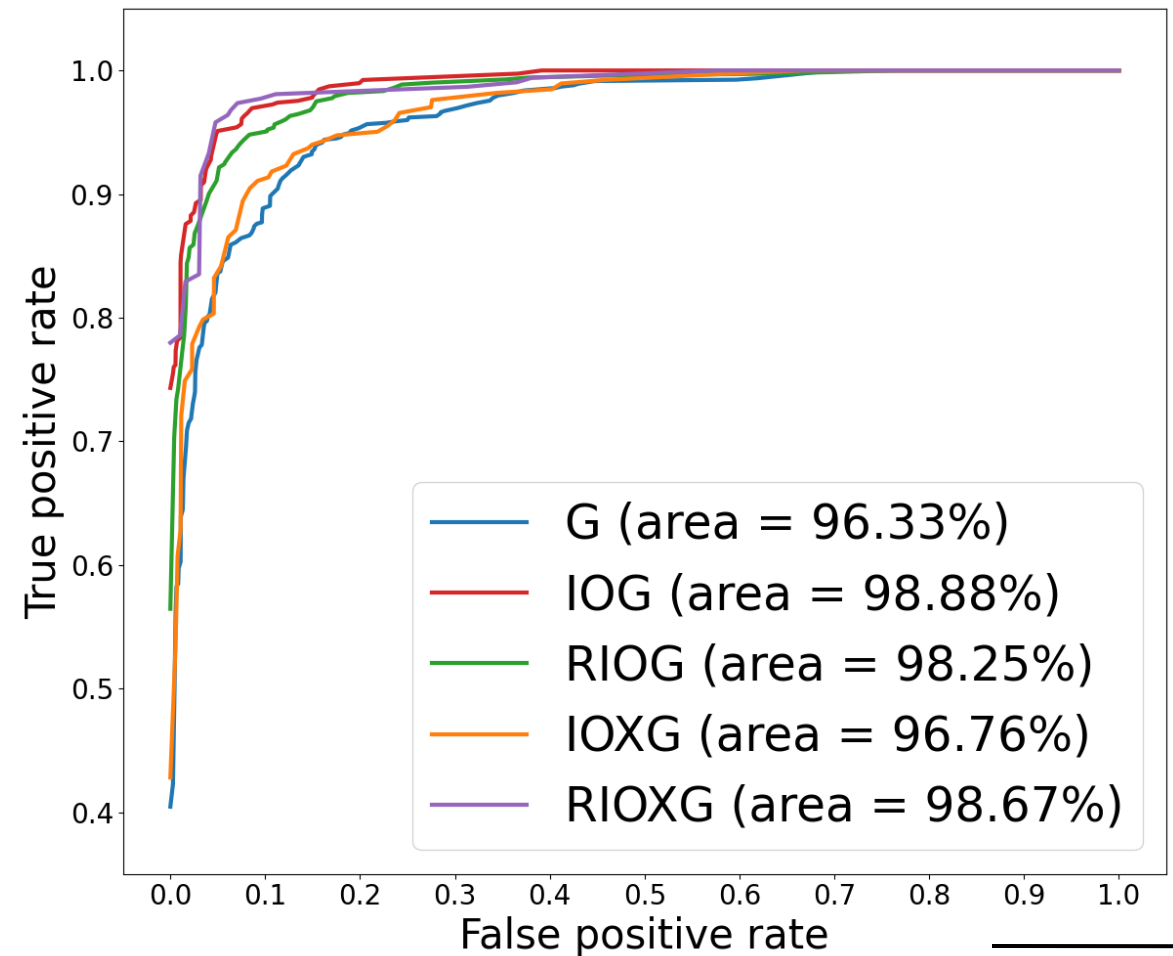


ANN Validation

Precision-Recall curve

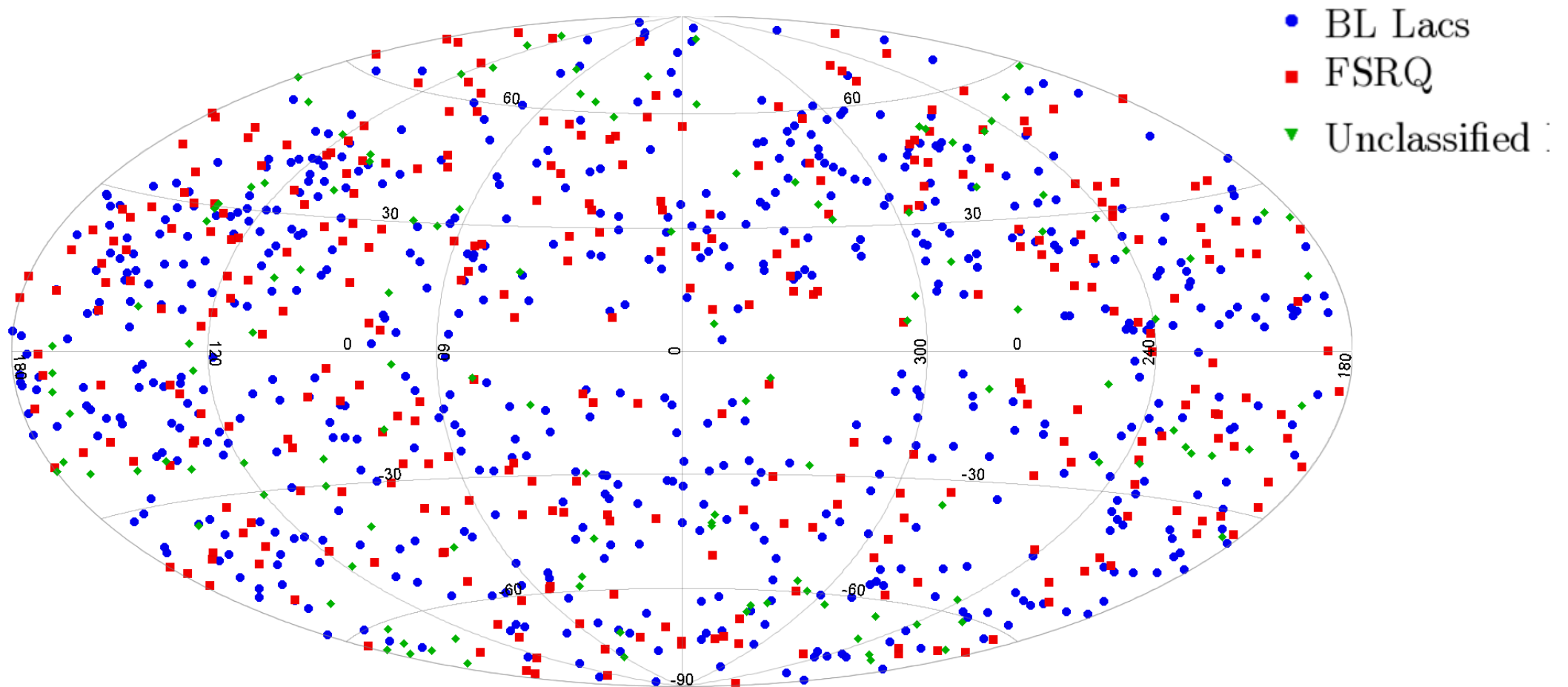


Receiver Operating Characteristic Curve



Classification Results

Blazar of Unknown Type



573 possible BL Lacs

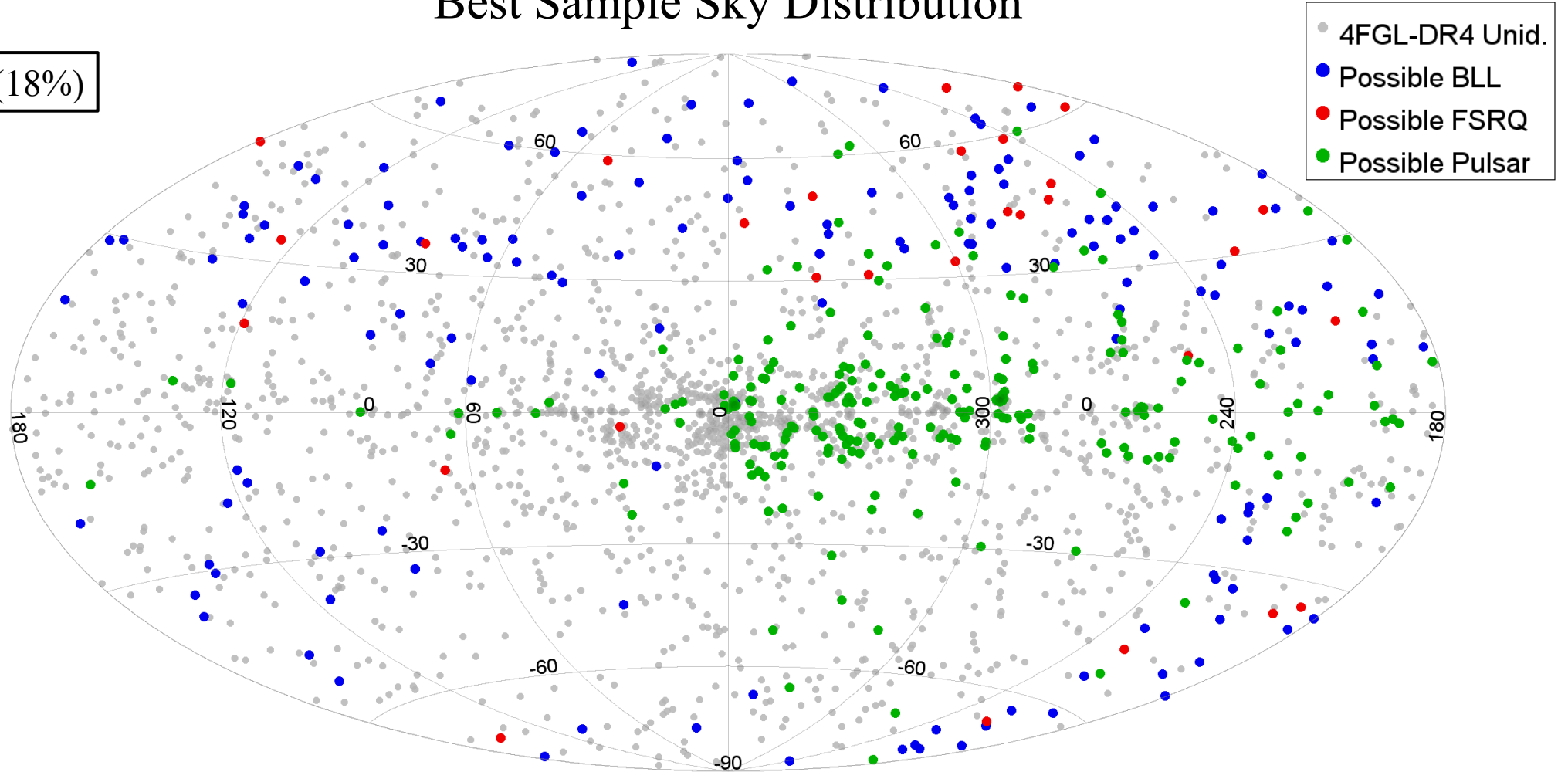
323 possible FSRQ

129 remain BCU

Classification Results

Best Sample Sky Distribution

421 sources (18%)



153 possible BLL

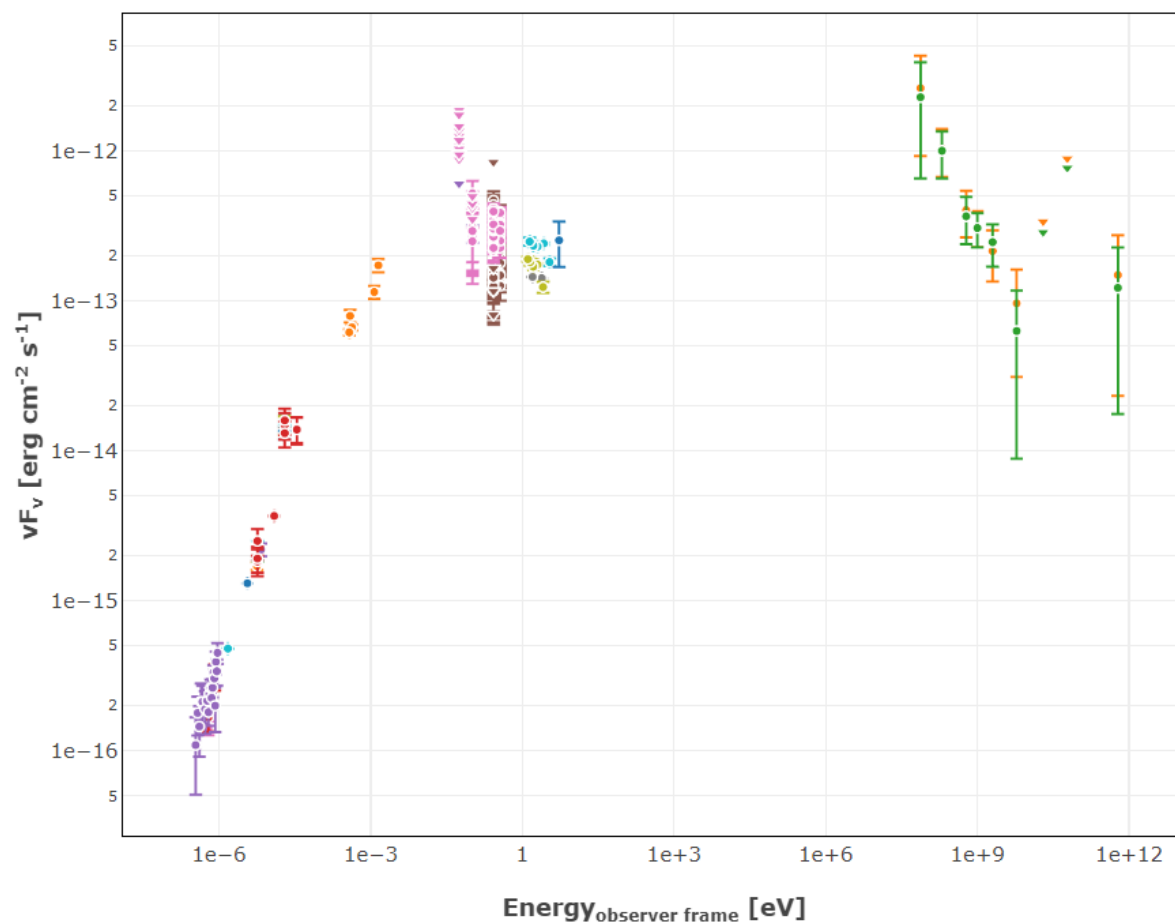
33 possible FSRQ

235 Possible Pulsar

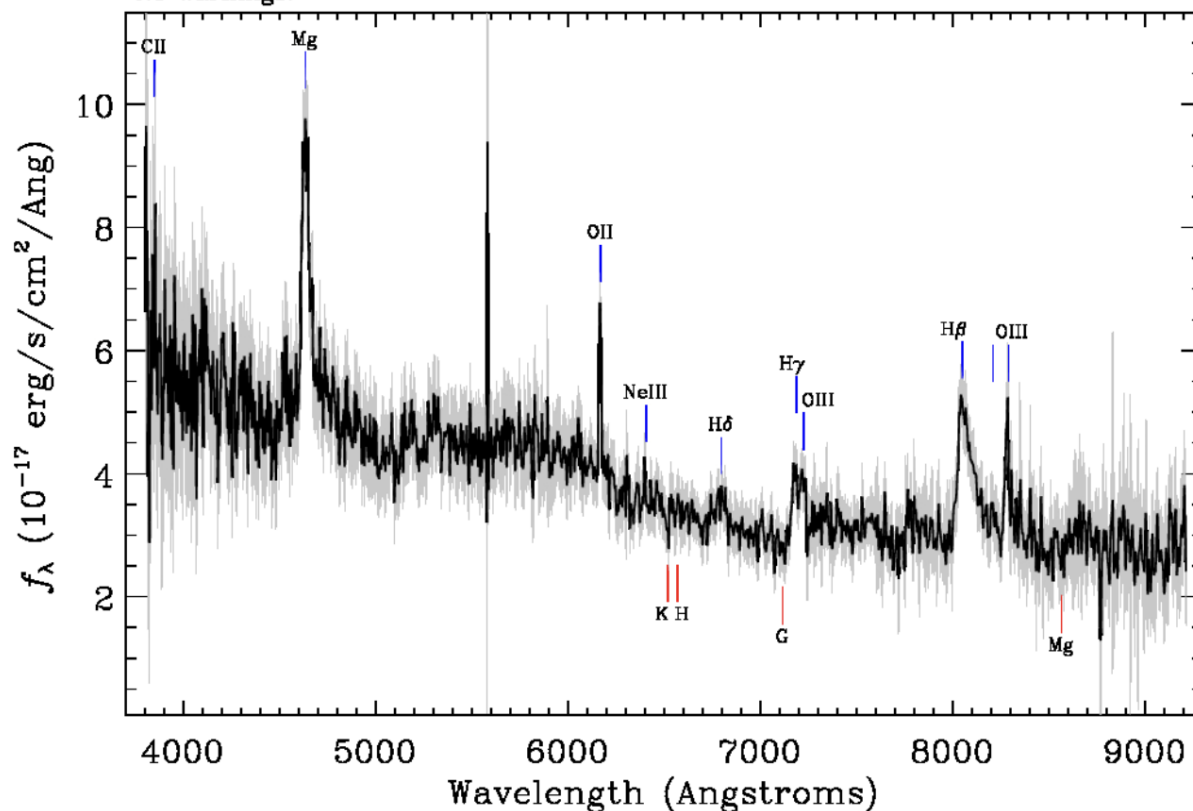
Classification Results

33 possible FSRQ

Example of one UID classified as possible FSRQ



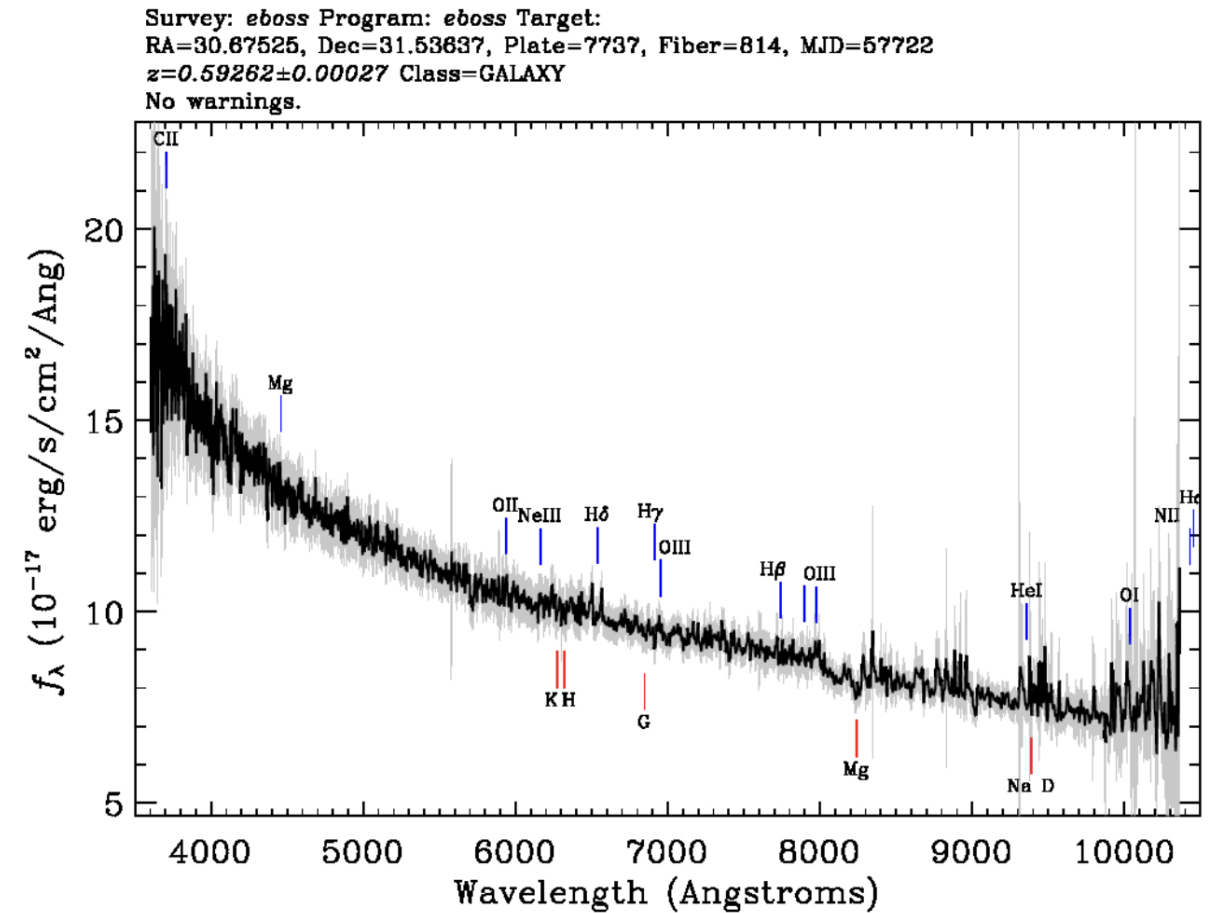
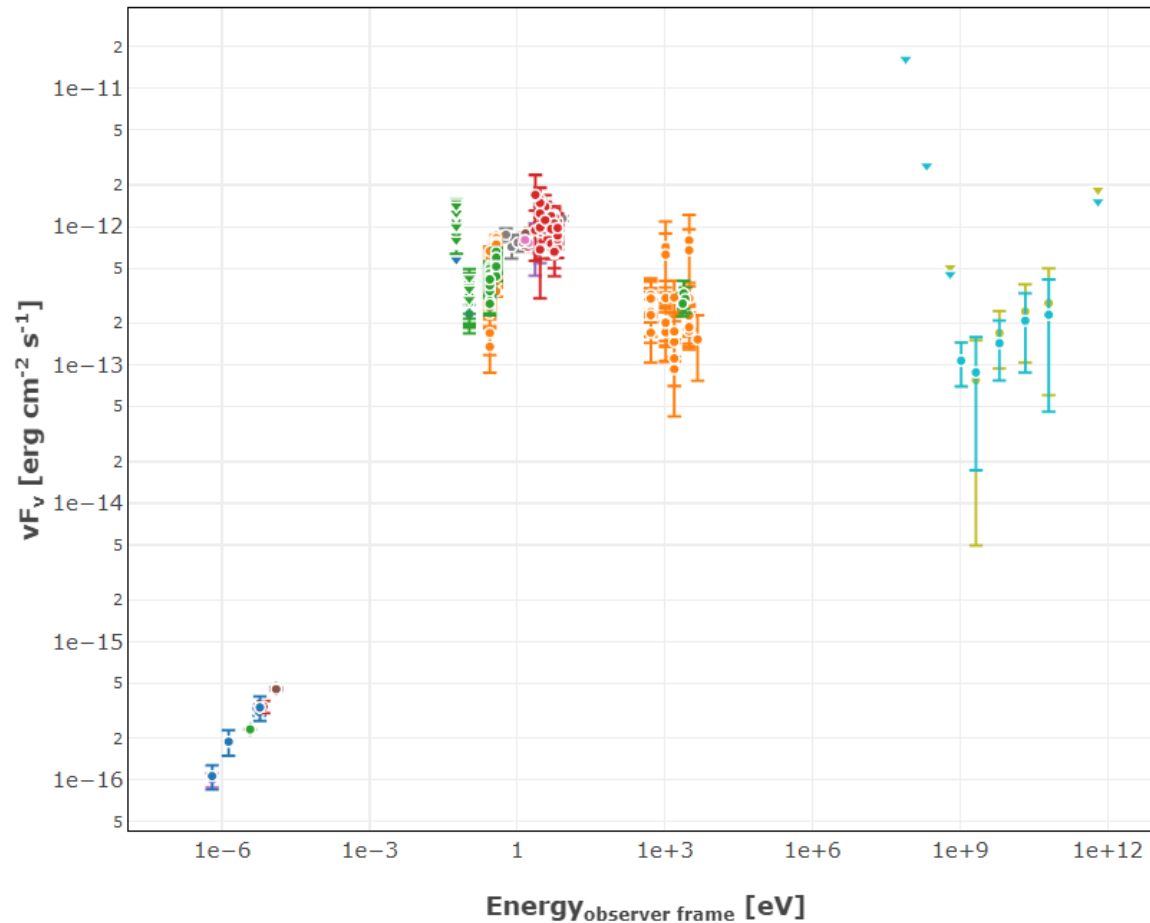
Survey: *sdss* Program: *legacy* Target: *SERENDIP_FIRST QSO_MAG_OUTLIER*
RA=133.64598, Dec=7.34006, Plate=1299, Fiber=91, MJD=52972
 $z=0.65507 \pm 0.00019$ Class=QSO BROADLINE
No warnings.



Classification Results

153 possible BLL

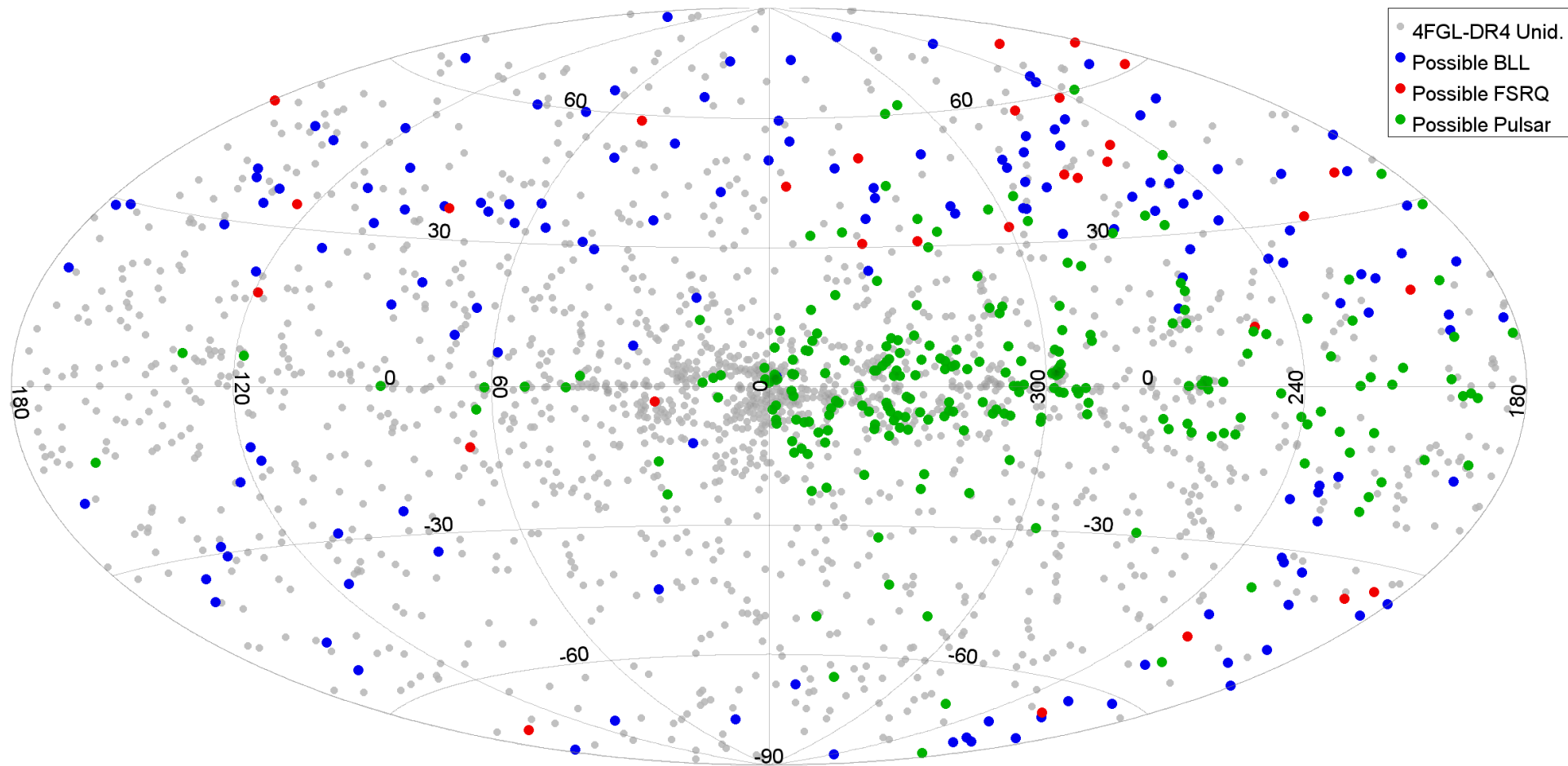
Example of one UID classified as possible BLL



Classification Results

235 possible Pulsar

Possible Pulsar population



Conclusions

Unidentified Sources classification and possible counterparts

Major points:

Multi-Wavelength data usefulness

Classification of 90% UID and possible multi-wavelength association of 84% UID

Possible UID counterparts distribution reflects blazar-pulsar positional differences

Things to check

Imbalance → fewer pulsar-like sources than blazar like sources

Classes → address presence of other sources classes (SPP, PWN ecc.)

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Blazar of unknown type classification

Major points:

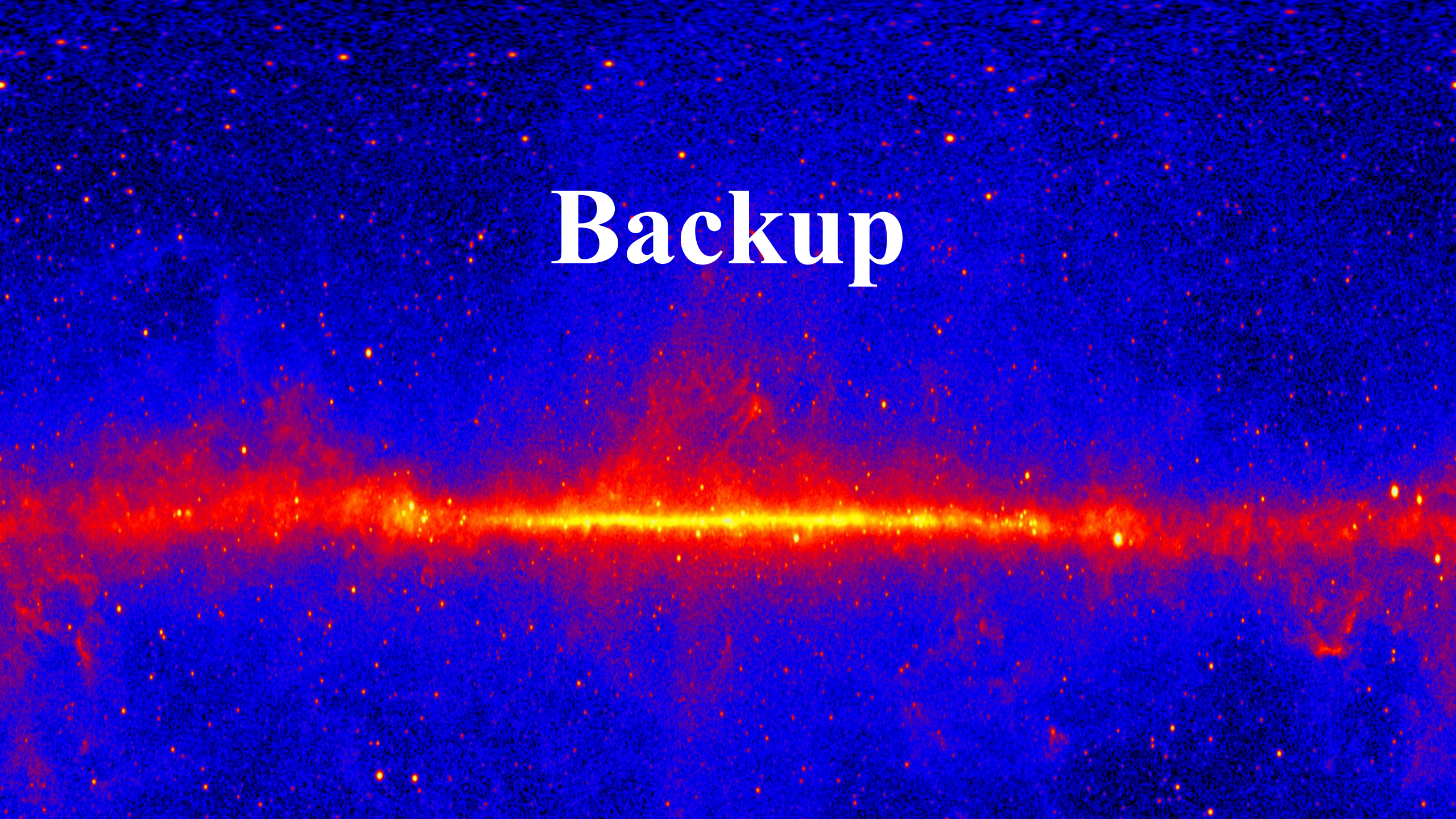
- Multi-Wavelength data usefulness
- Classification of 88% BCU

Things to check

- Compare results with previous works
- Dedicated search to study the optical energy range



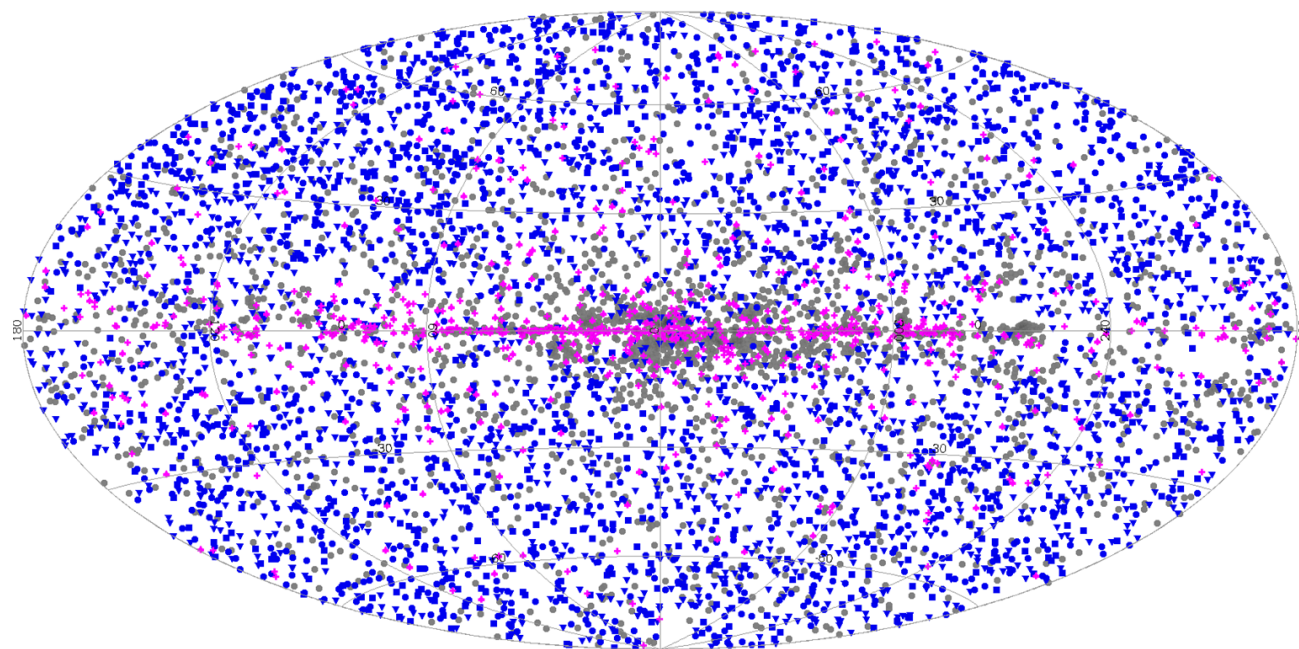
Thank you



Backup

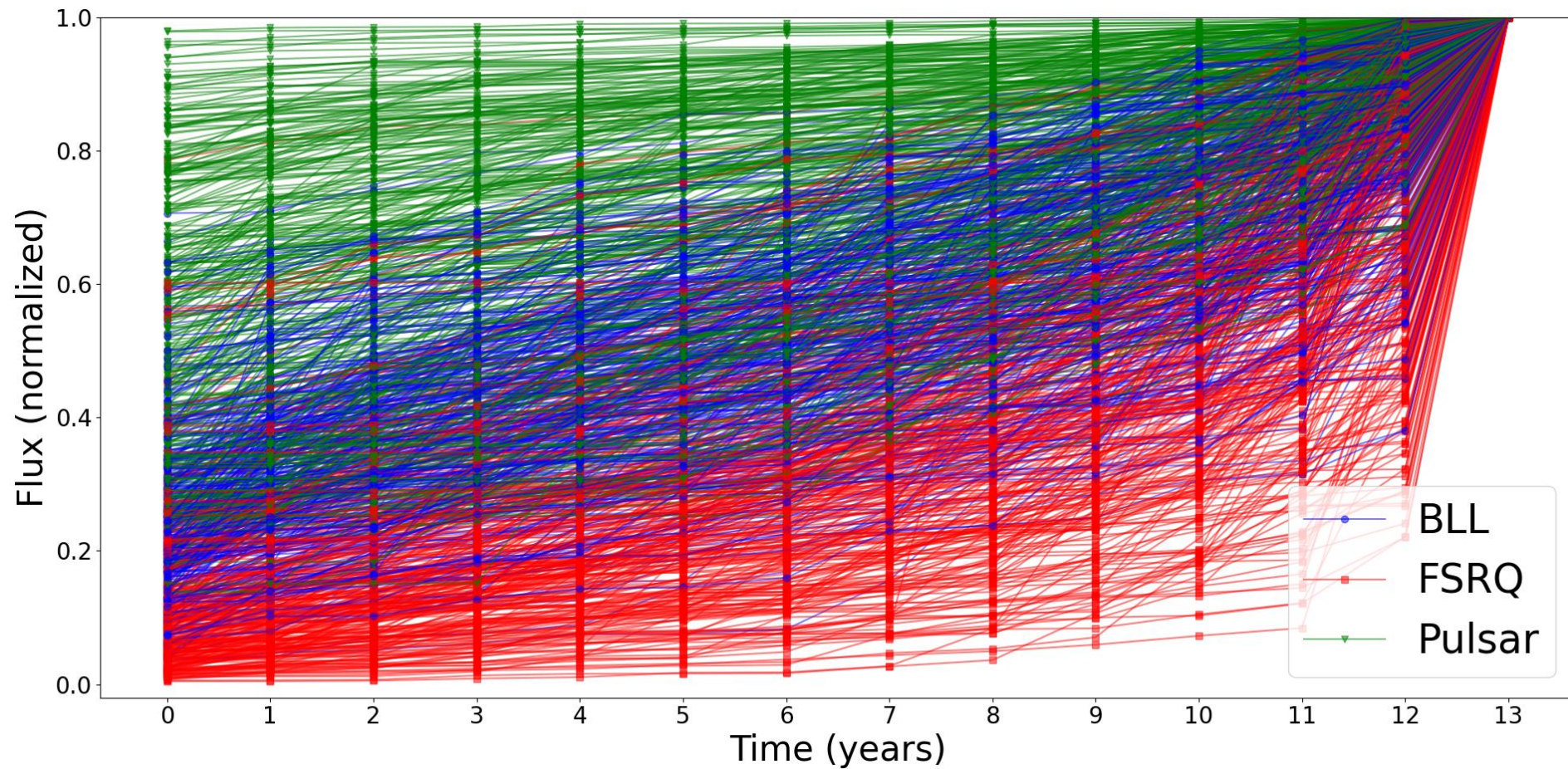
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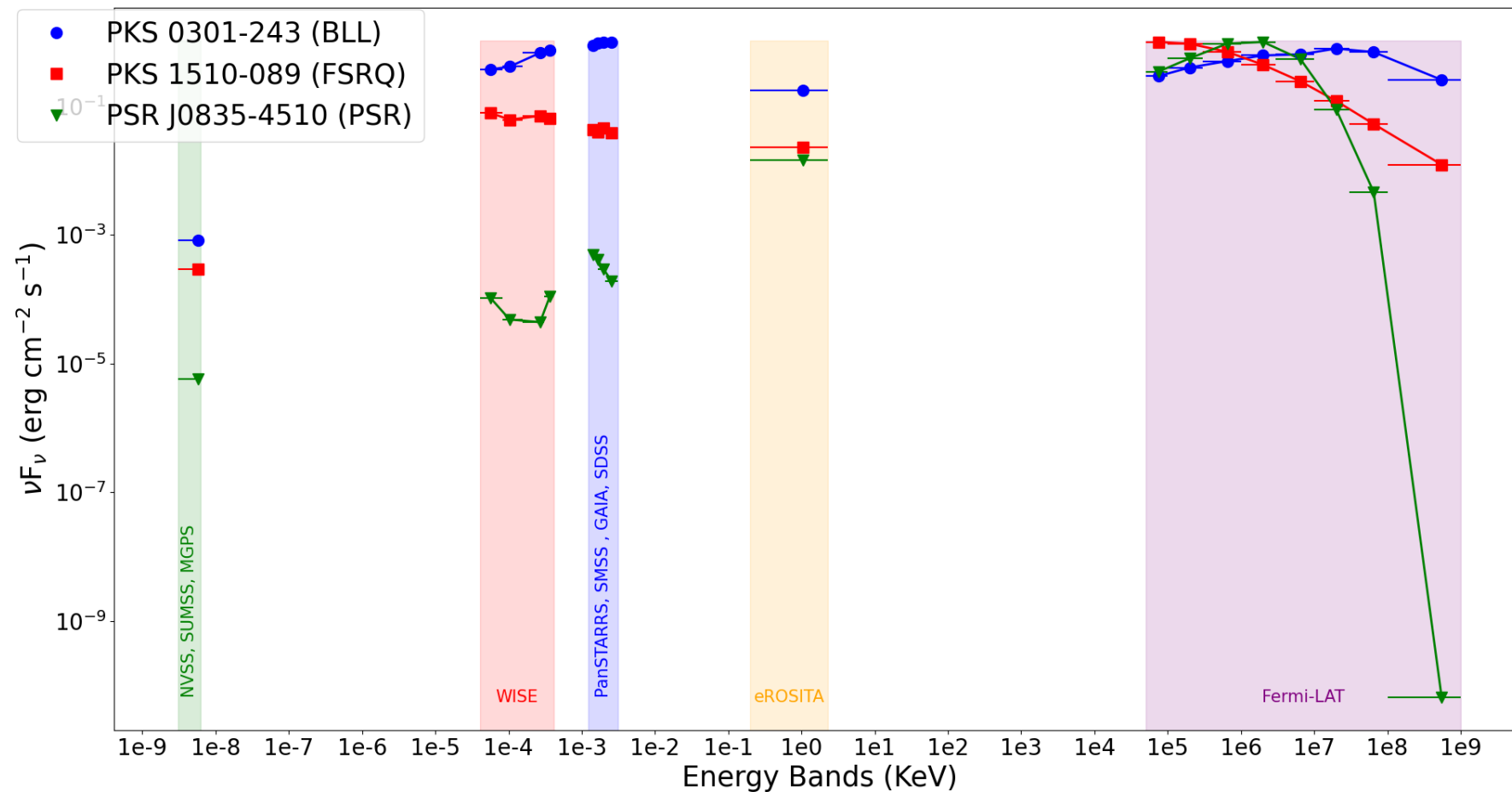
Neural Network Input Data

Sorted and Normalized Light Curve



Neural Network Input Data

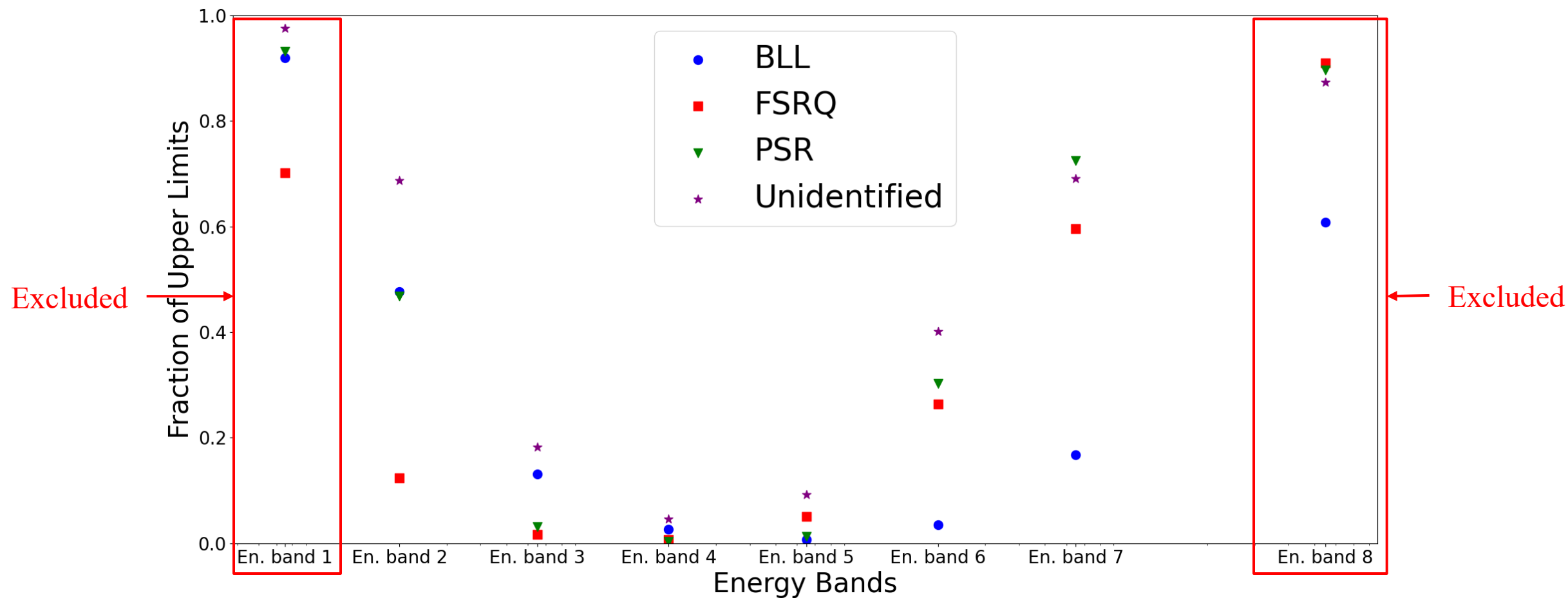
Normalized Multi-Wavelength Spectral Energy Distribution



Example of SED for **BL Lac**, **FSRQ** and **Pulsar** type source

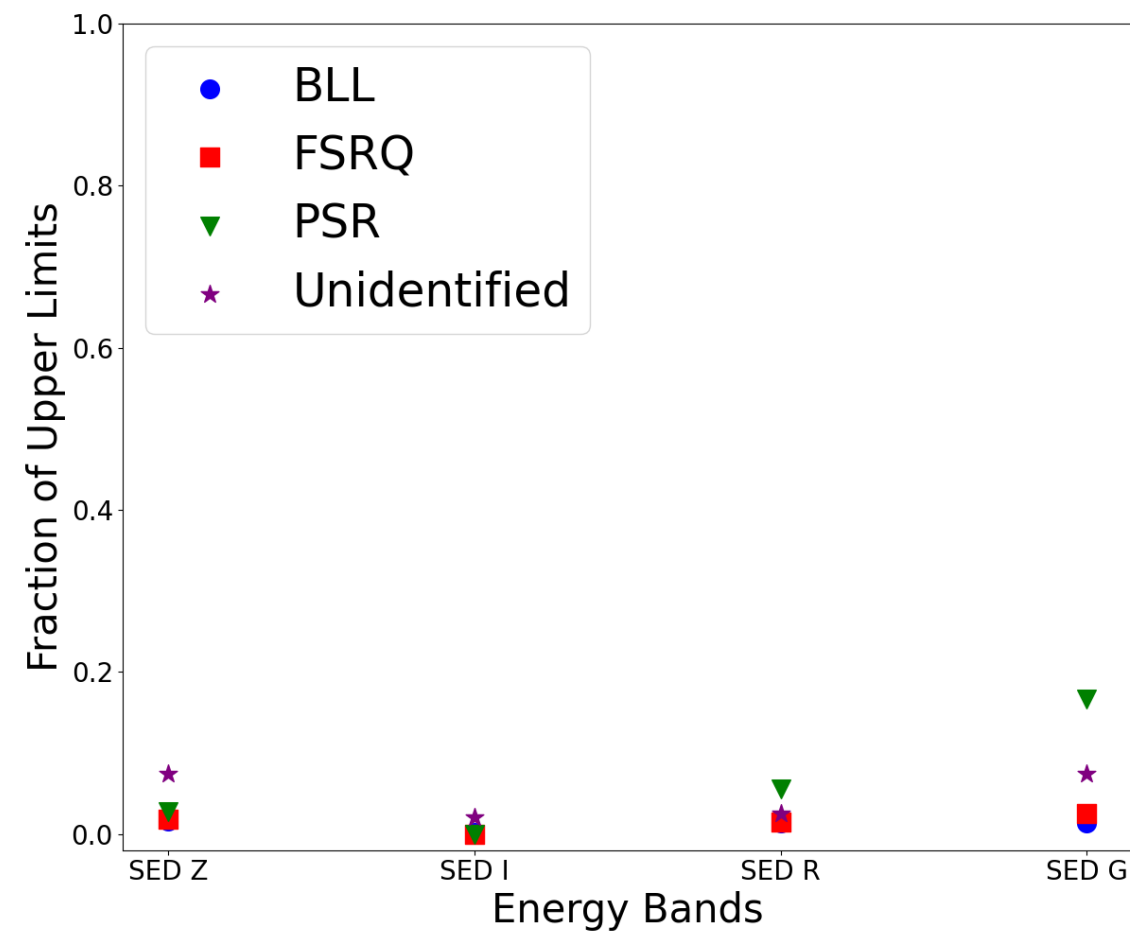
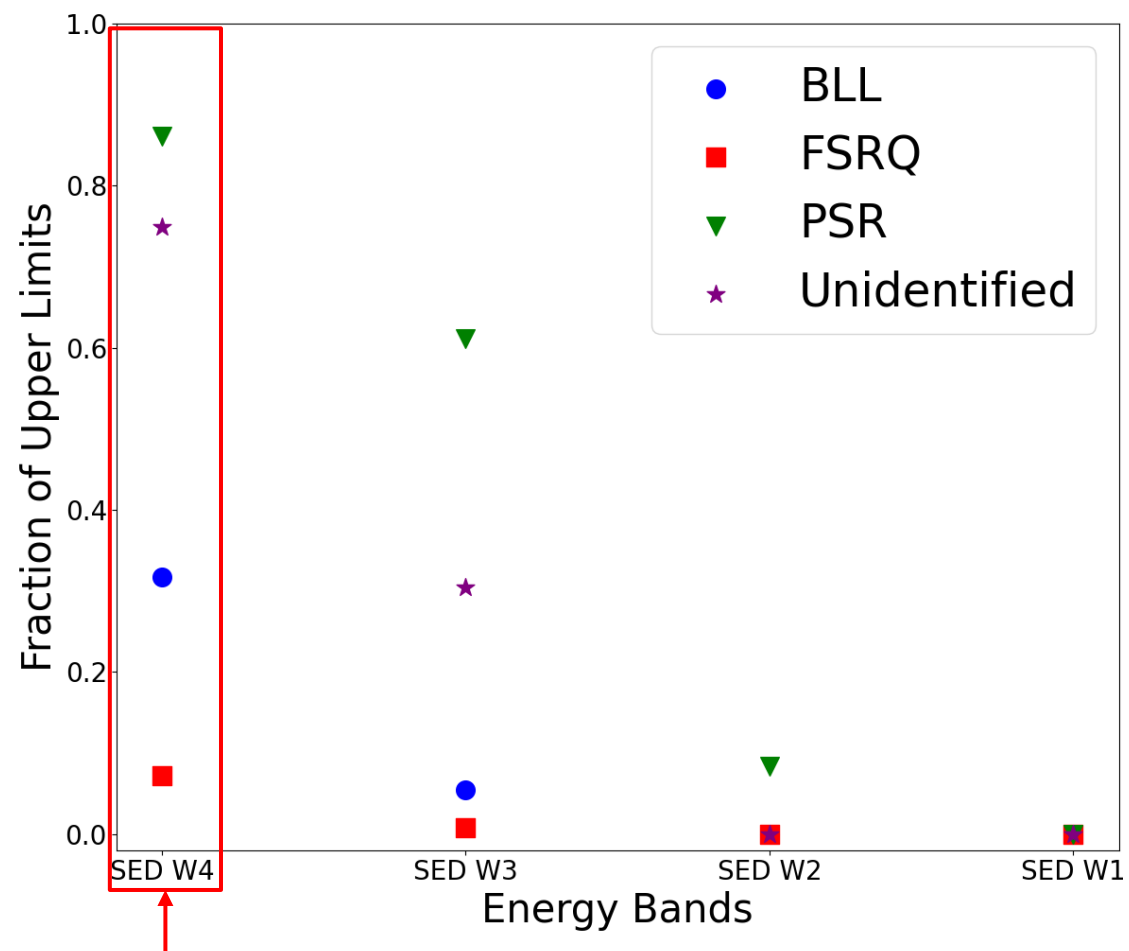
Neural Network Input Data

Upper Limits in the Fermi-LAT energy bands



Neural Network Input Data

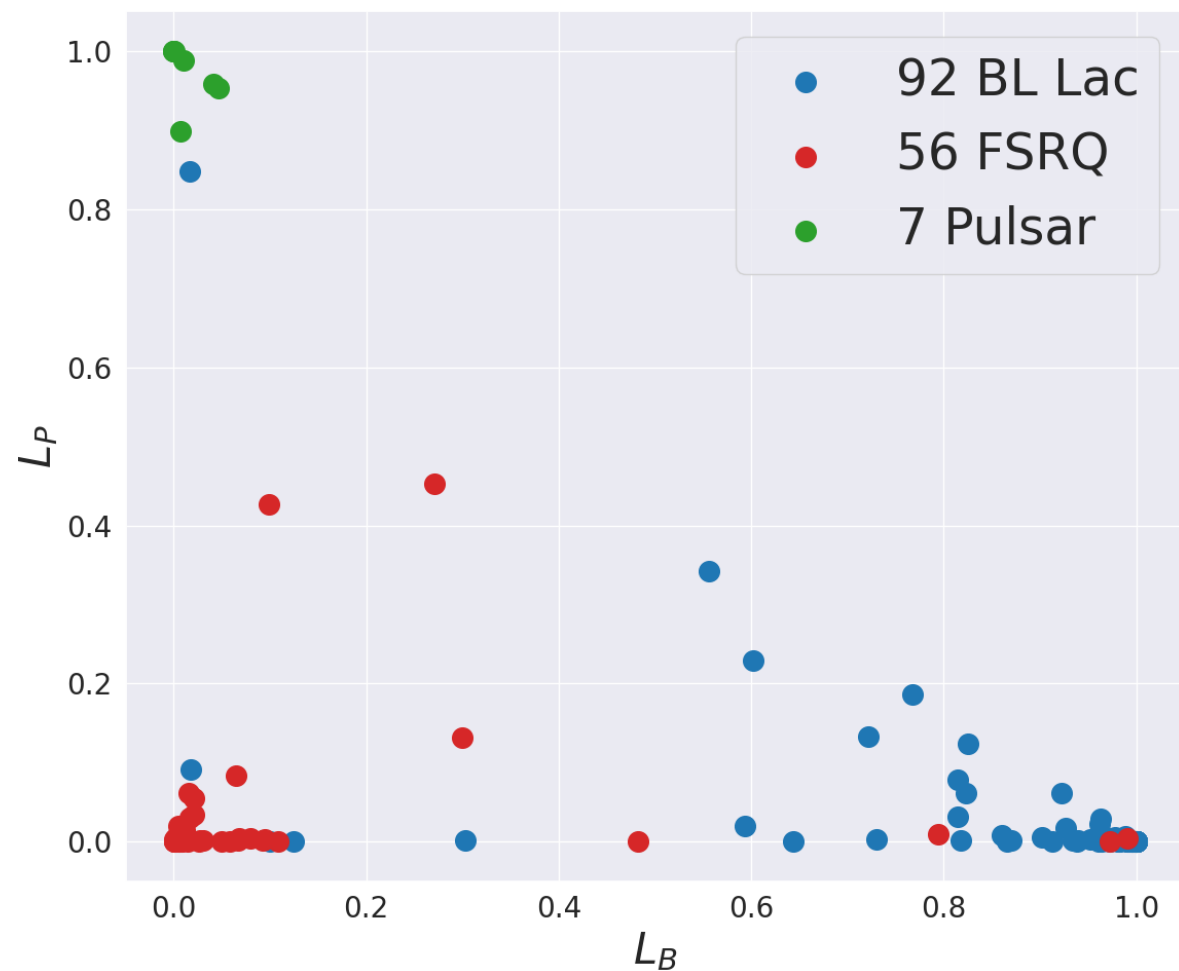
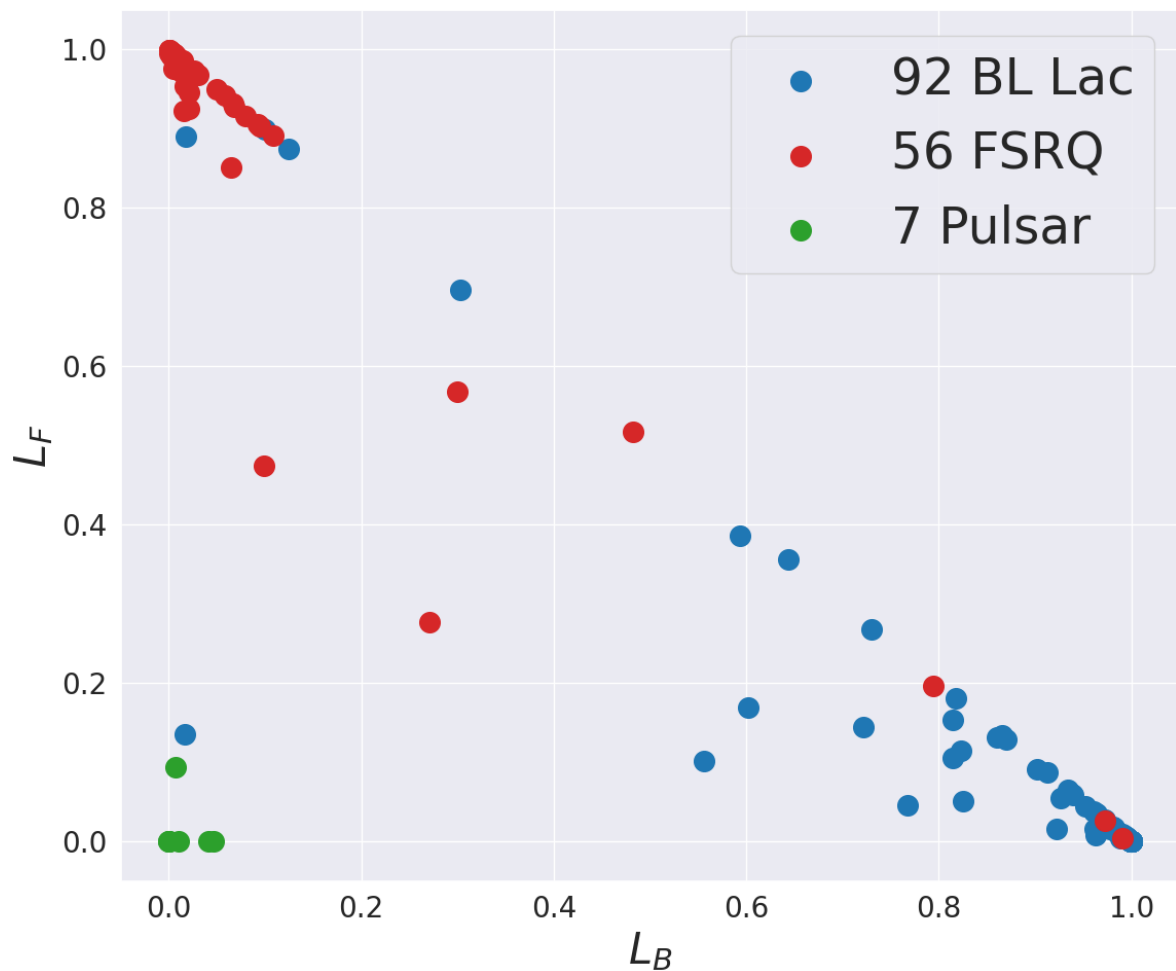
Upper Limits in other energy bands



Excluded

Thresholds

Test data distribution

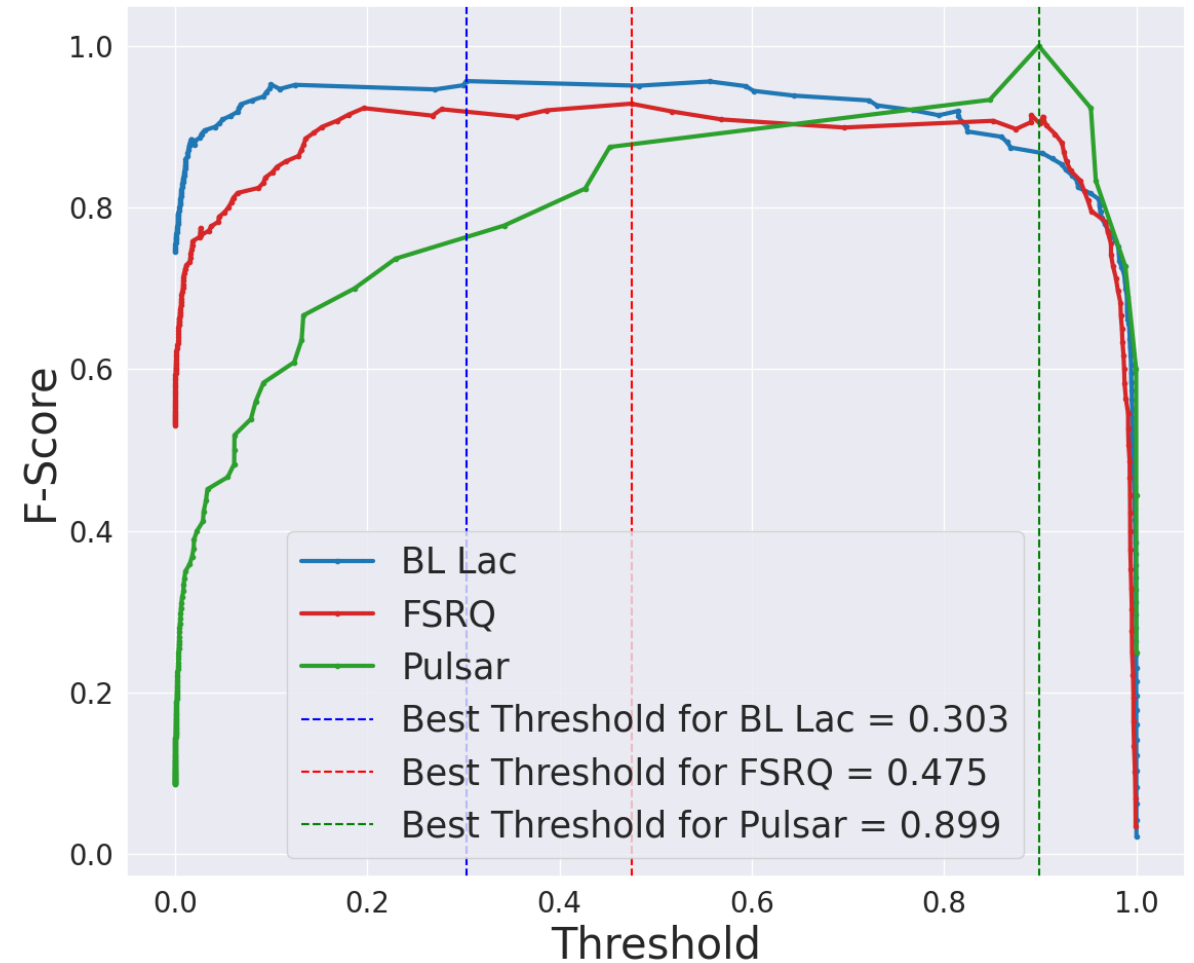


Thresholds

$$F_{\beta} = \frac{\beta^2 + 1}{\frac{\beta^2}{recall} + \frac{1}{precision}} = \frac{(\beta^2 + 1) \cdot TP}{(TP + FN) \cdot \beta^2 + (TP + FP)}$$

is the harmonic mean of precision and recall if $\beta = 1$

F_{β} -Score



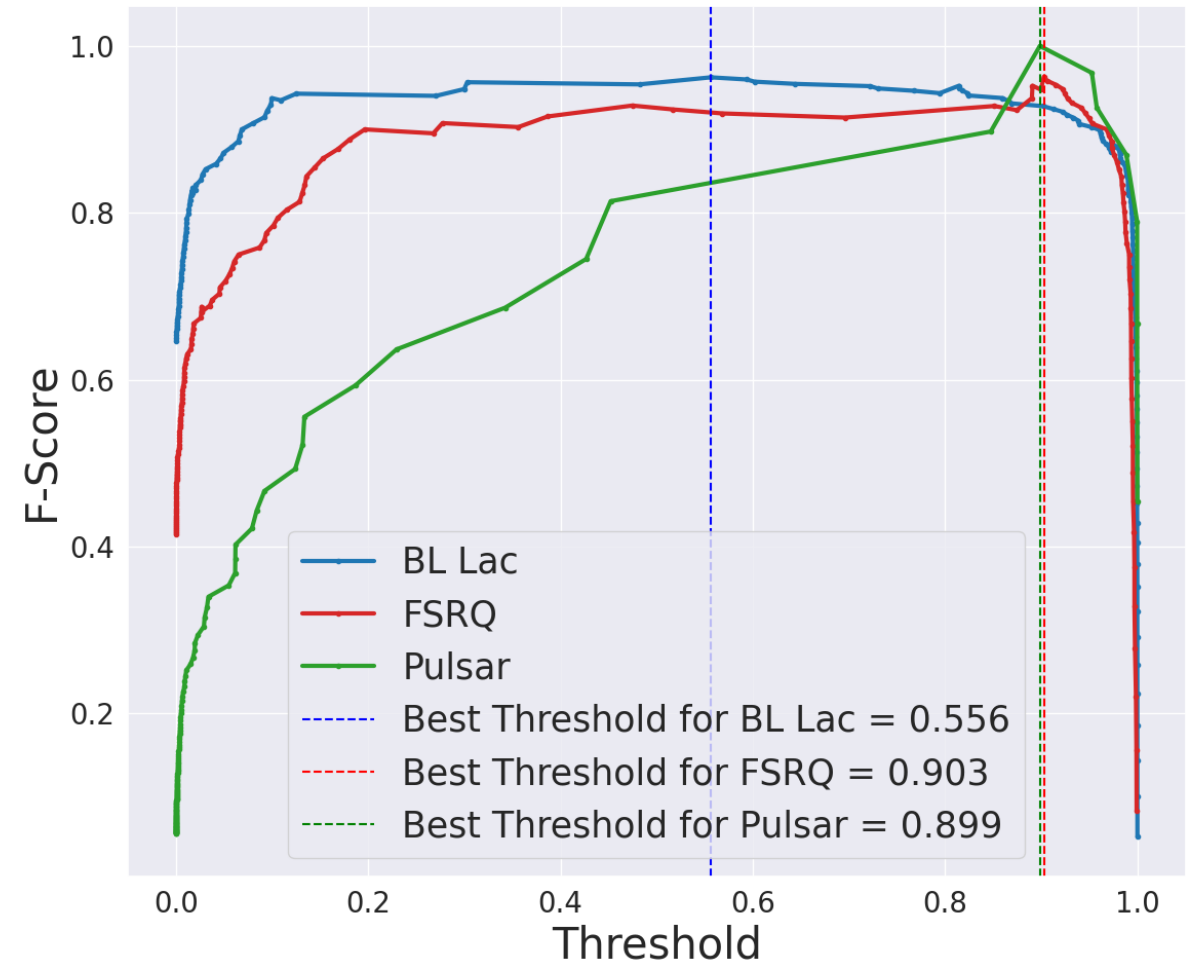
Thresholds

F_β -Score

$$F_\beta = \frac{\beta^2 + 1}{\frac{\beta^2}{recall} + \frac{1}{precision}} = \frac{(\beta^2 + 1) \cdot TP}{(TP + FN) \cdot \beta^2 + (TP + FP)}$$

changing β to improve the threshold: $\beta = 0.50$

Precision is 2 times more important than *Recall*



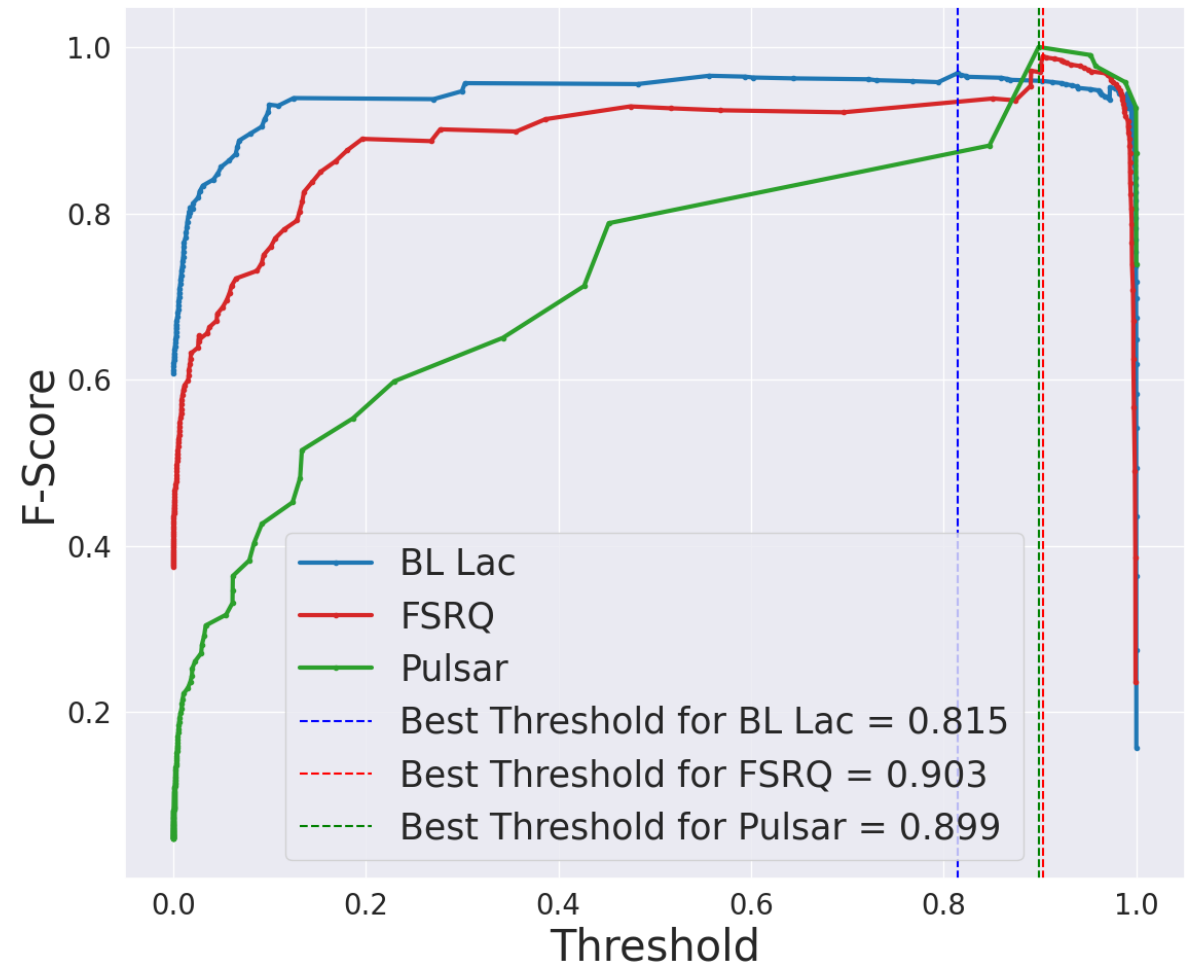
Thresholds

$$F_{\beta} = \frac{\frac{\beta^2}{recall} + \frac{1}{precision}}{\beta^2 + 1} = \frac{(\beta^2 + 1) \cdot TP}{(TP + FN) \cdot \beta^2 + (TP + FN)}$$

changing β to improve the threshold: $\beta = 0.25$

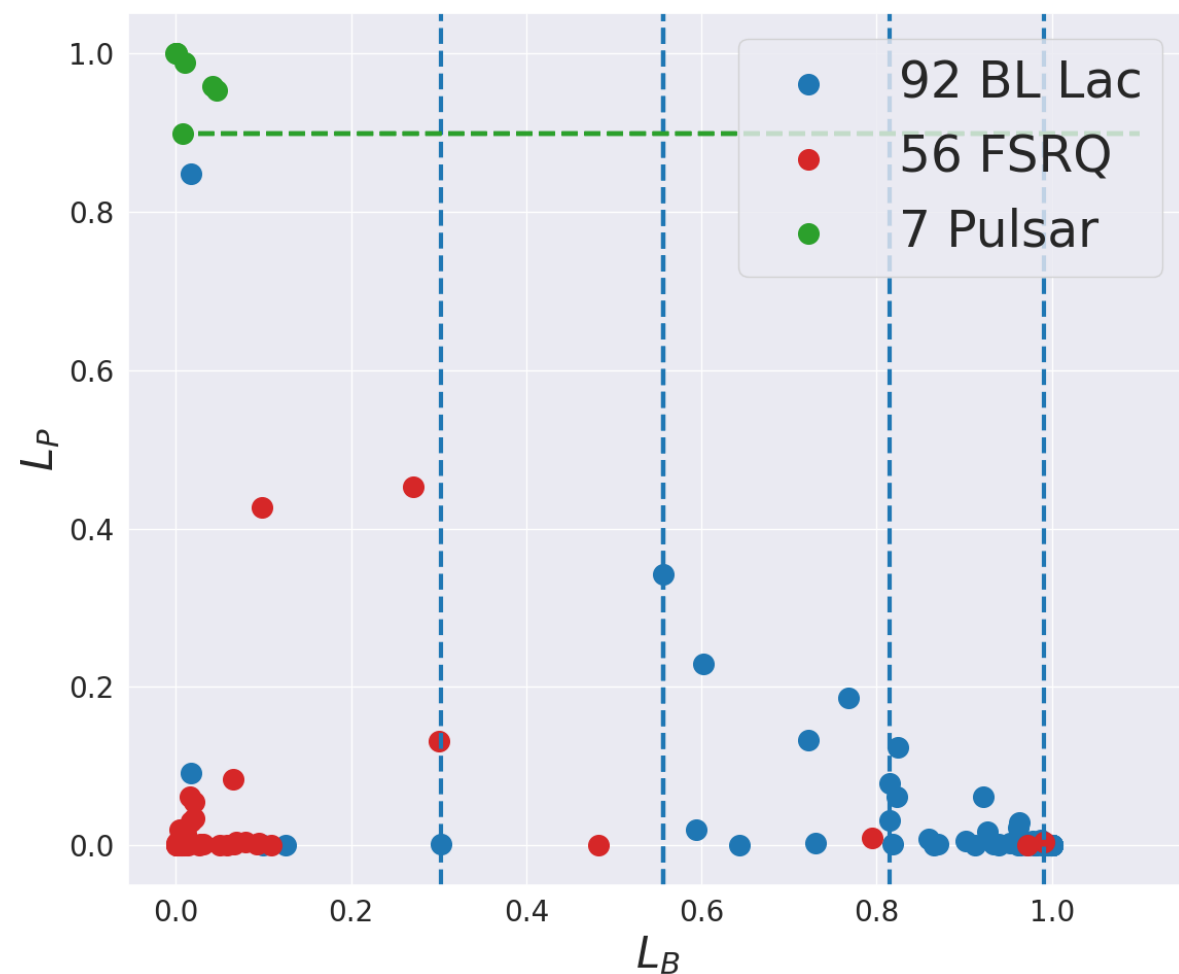
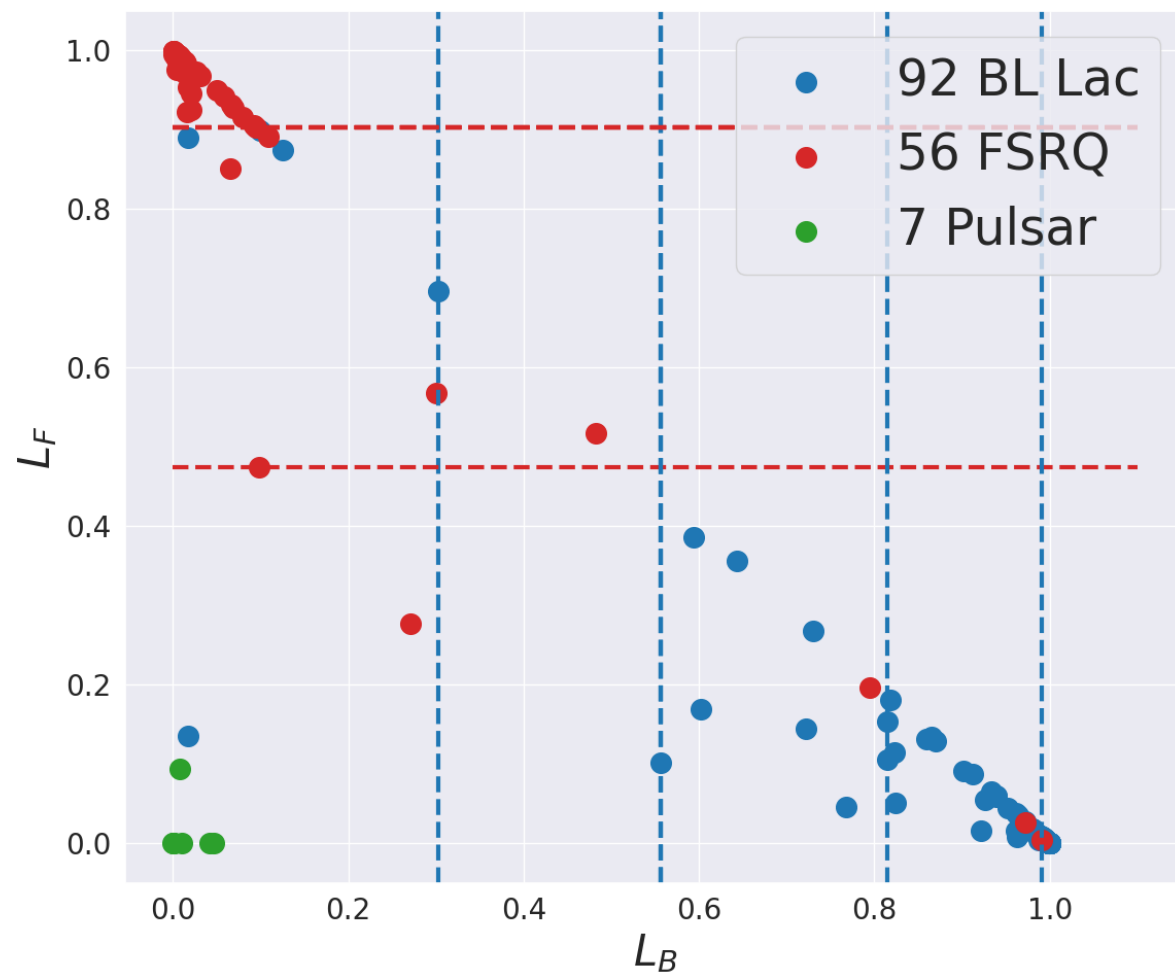
Precision is 4 times more important than *Recall*

F_{β} -Score



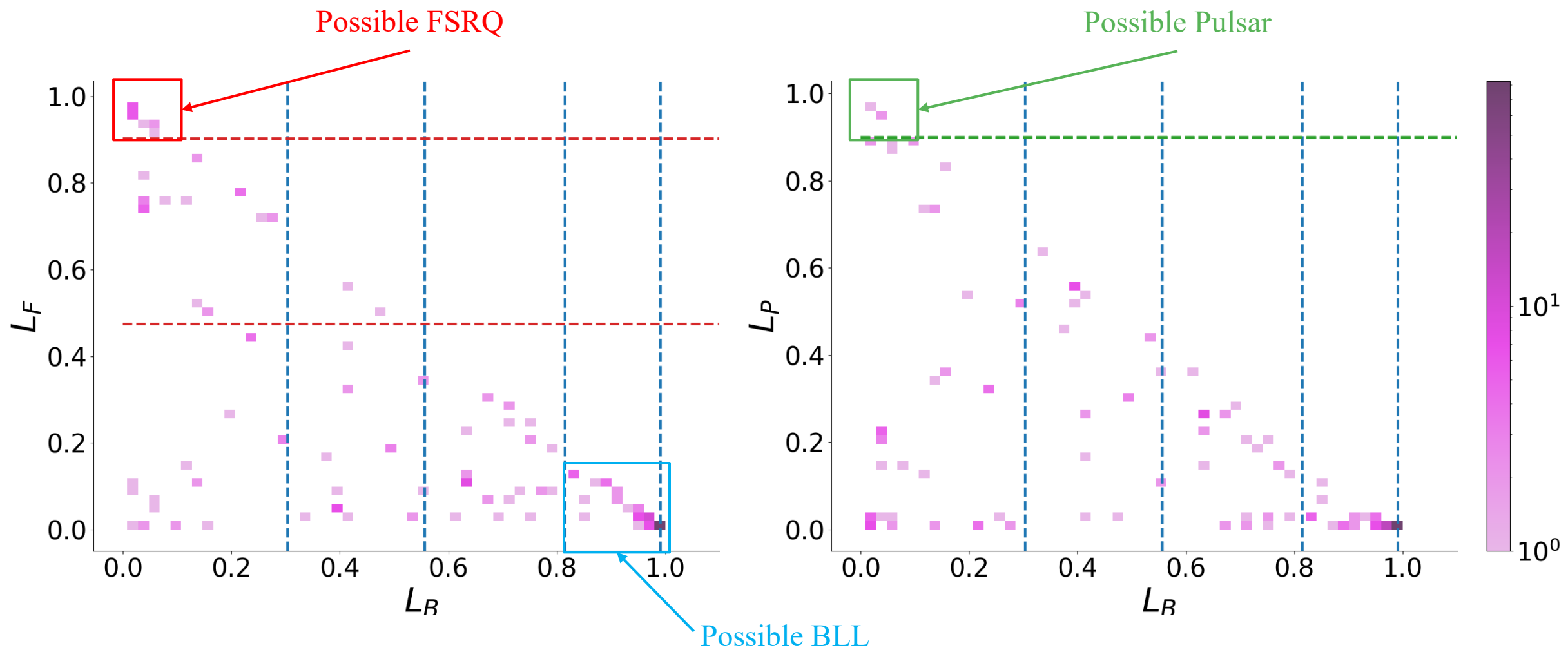
Thresholds

Test data distribution



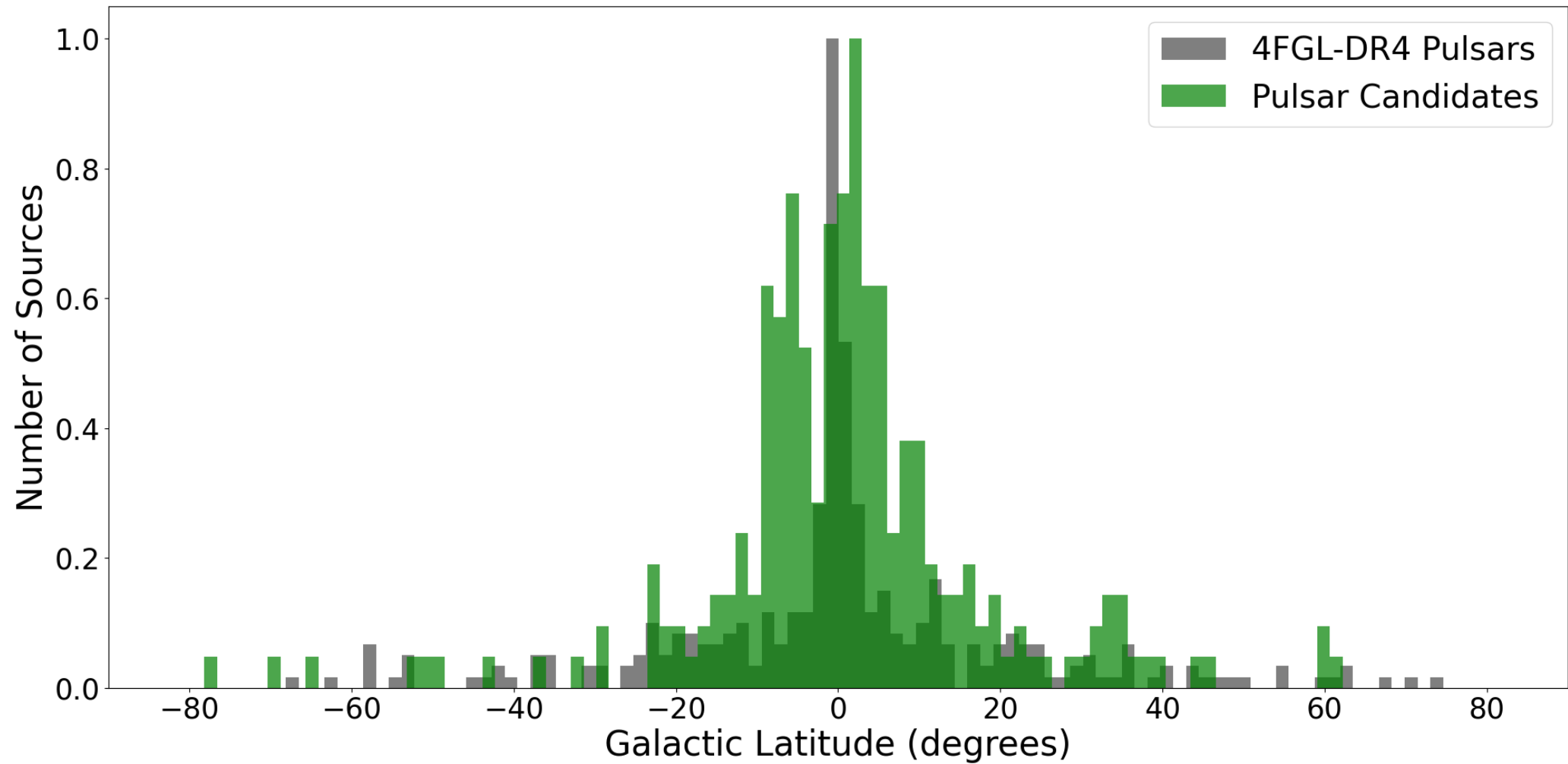
Thresholds

Results distribution



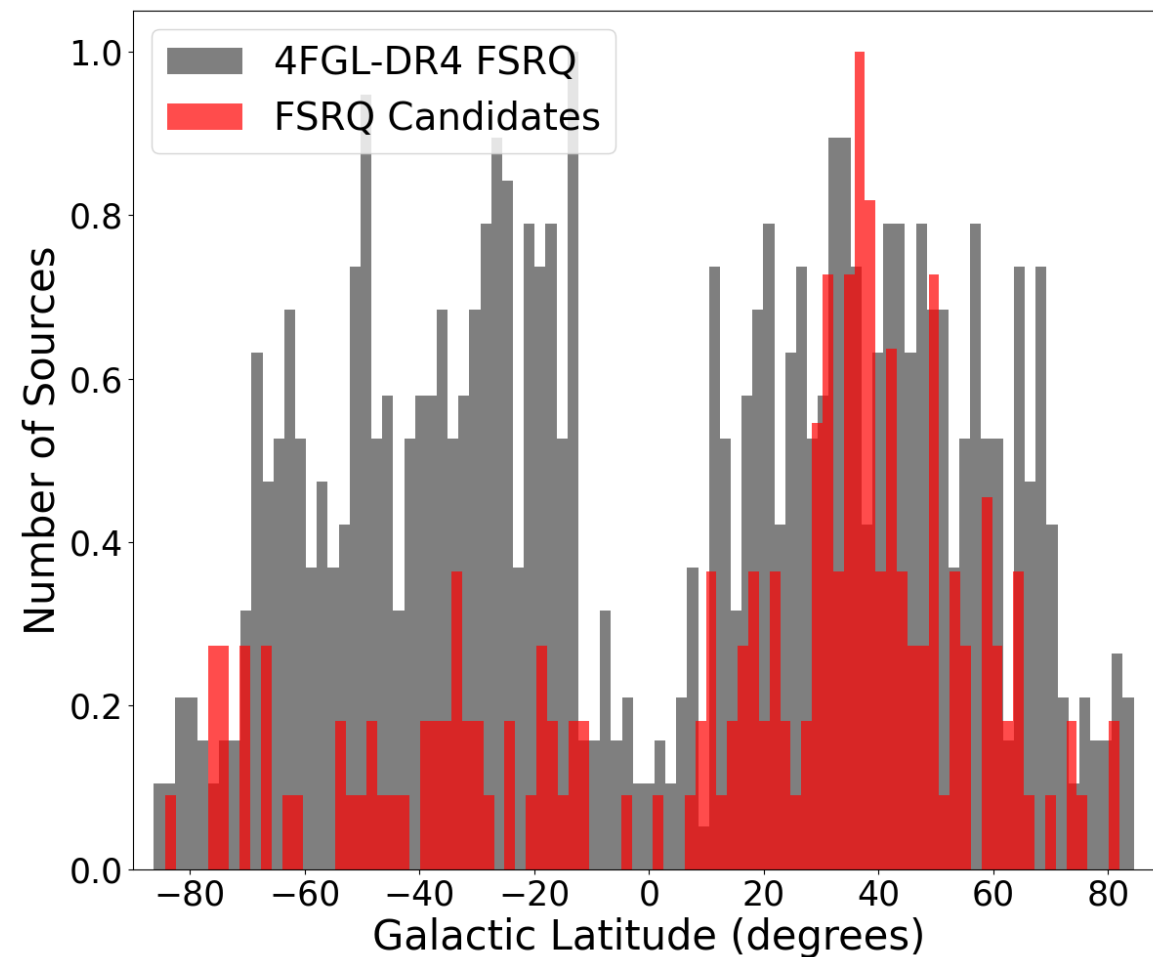
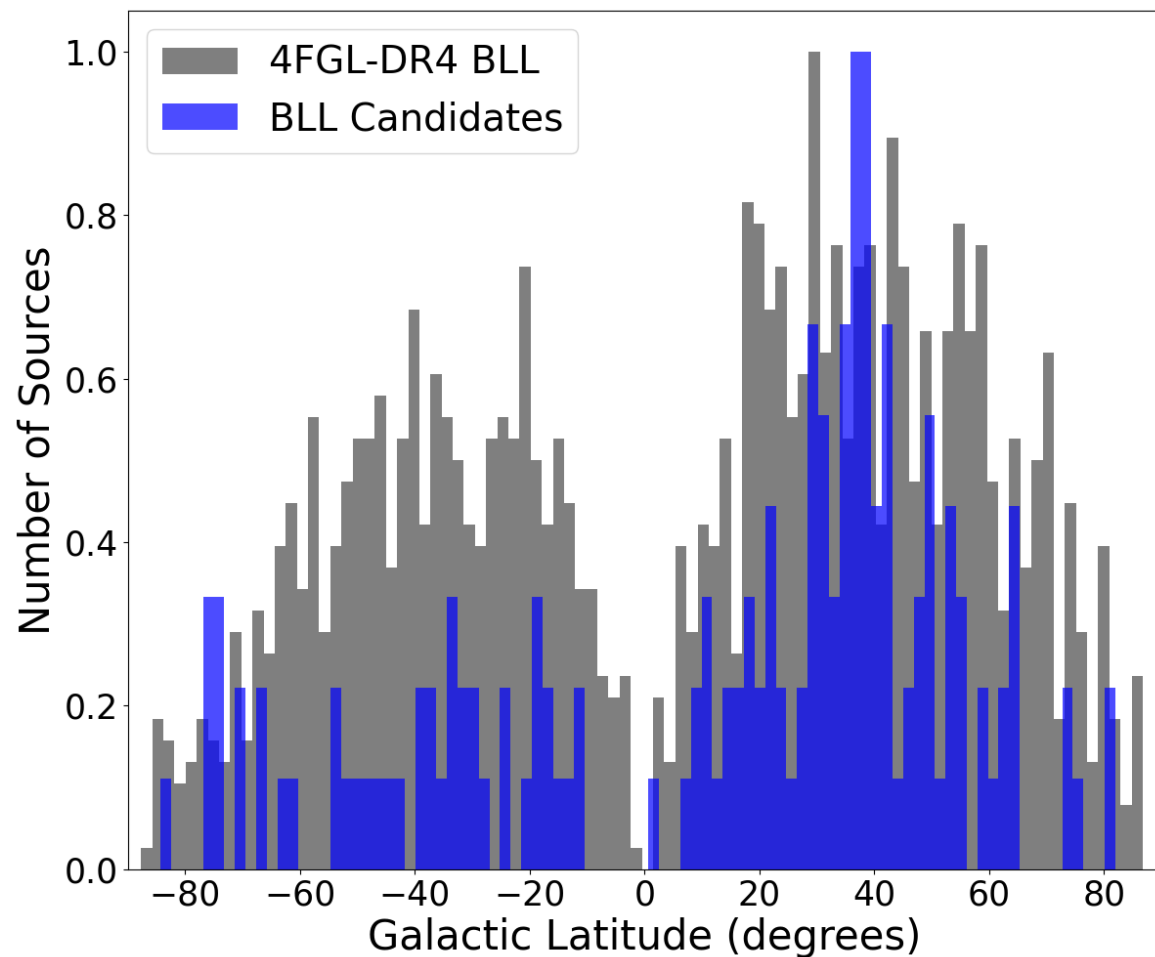
Classification Results

Best Sample possible Pulsar



Classification Results

Best Sample possible BLL and FSRQ

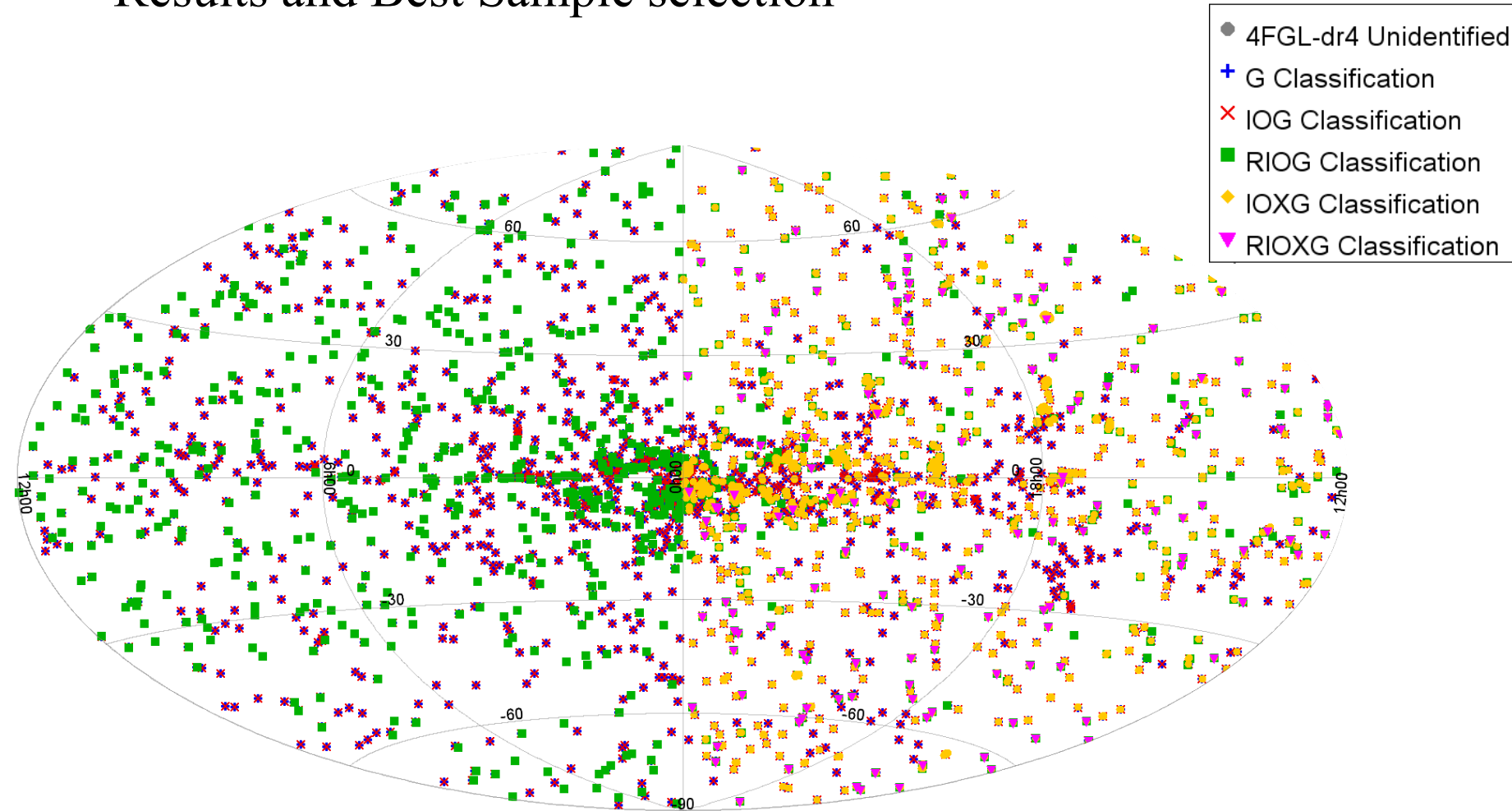


Classification Results

Results and Best Sample selection

RIOXG	121 (5%)
RIOG	449 (19%)
IOXG	458 (19%)
IOG	957 (41%)
	1985 (84%)
G	145 (6%)

84% UID are classified with a possible association
6% UID are classified without a possible association
10% UID remain unassociated and unclassified



Classification Results

Results and Best Sample selection

RIOXG

121 (5%)

RIOG

449 (19%)

IOXG

458 (19%)

Best Sample

At least R or X data

$L_S > F_{\beta=0.25}$

$L_B > 94, L_F > 99,$
 $L_P > 98$

$L_B > 85, L_F > 92,$
 $L_P > 95$

$L_B > 81, L_F > 90,$
 $L_P > 89$

