The incremental 4FGL catalog

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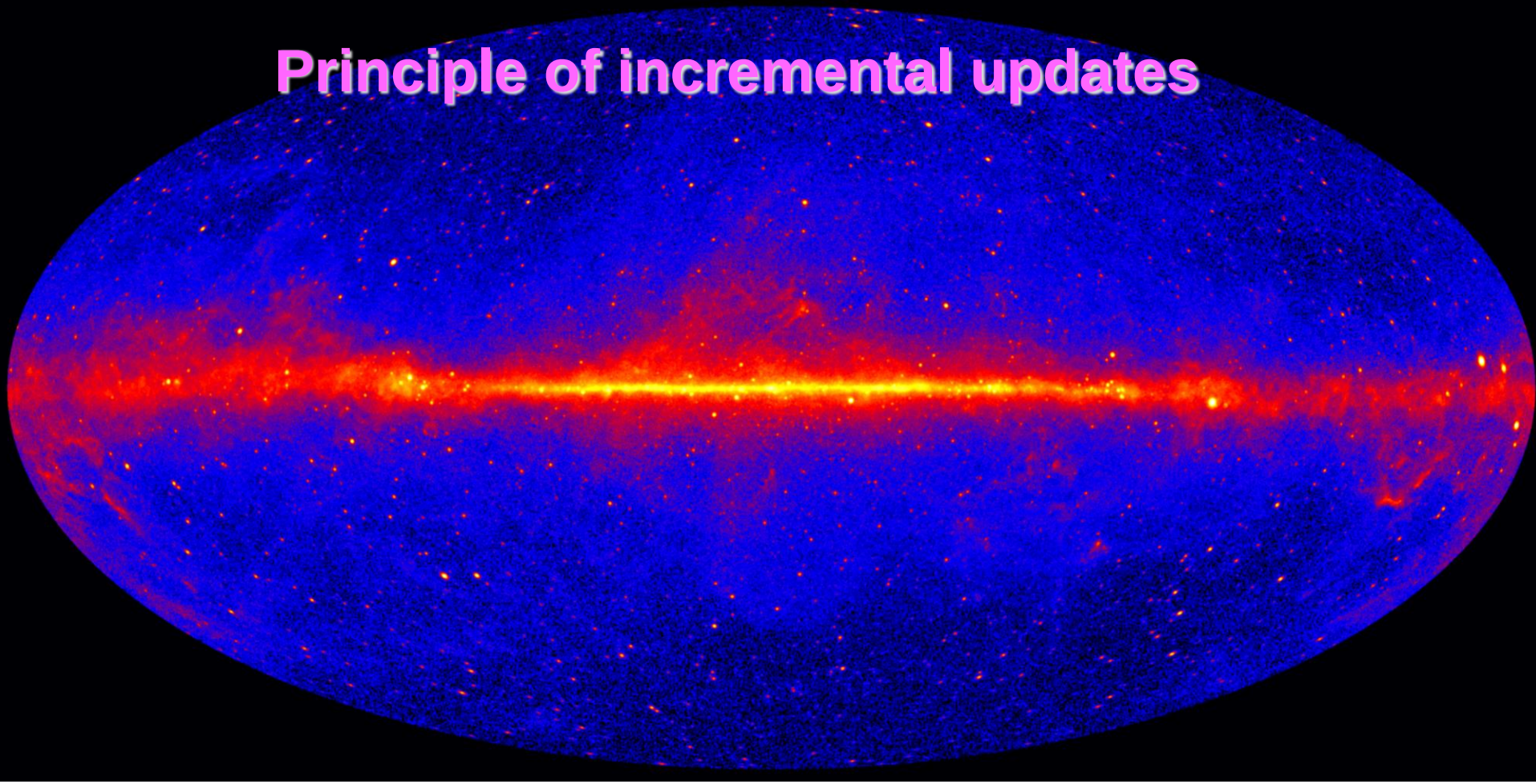
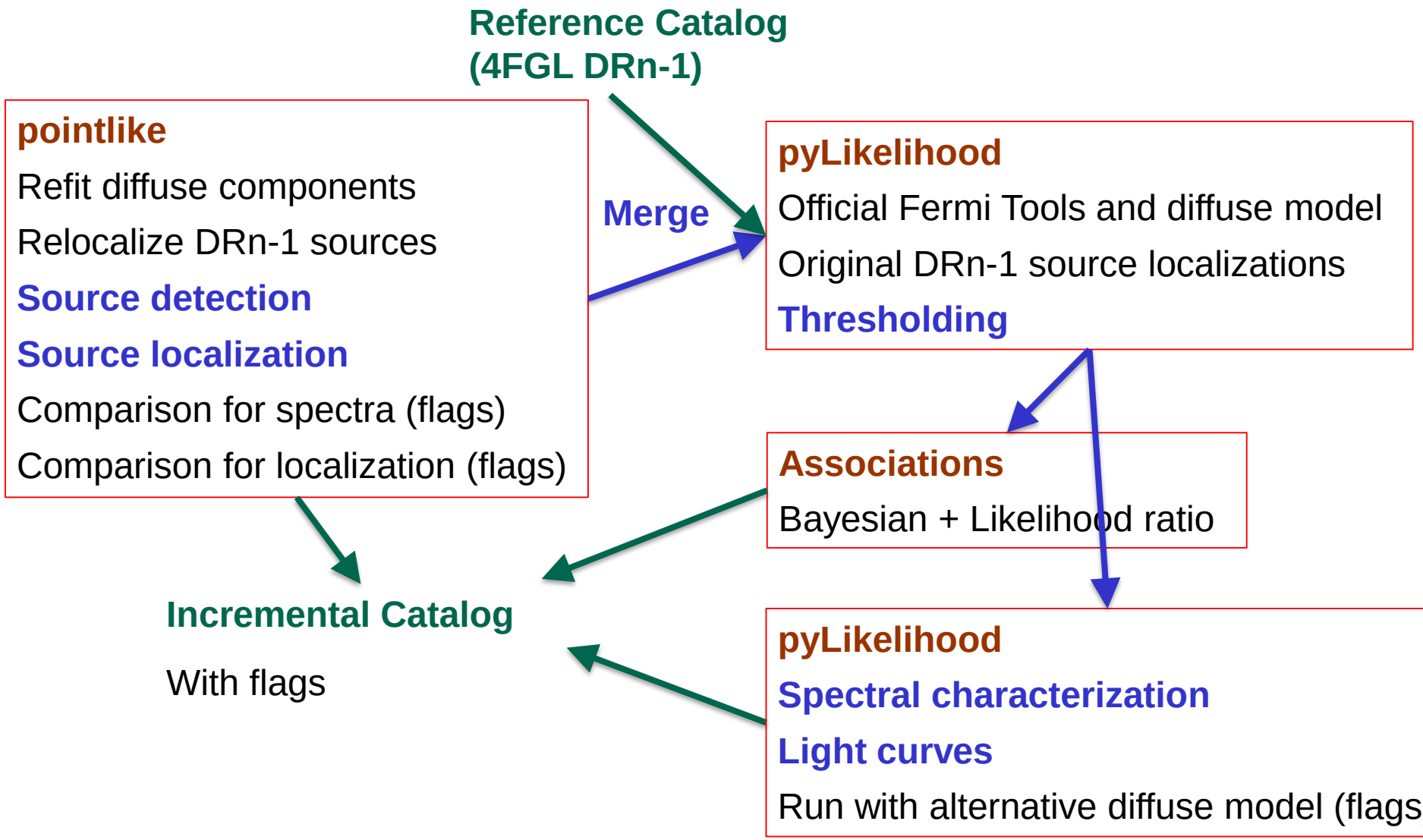
Principle of incremental updates



- Same data (P8_P305) and diffuse model (gll_iem_v07) as 4FGL
- More exposure (8 years for DR1, 10 years for DR2, 12 years for DR3)
- 4FGL sources are normally left in the model (even when TS < 25)
- Add new sources (**DataRelease** > 1)

Methodology

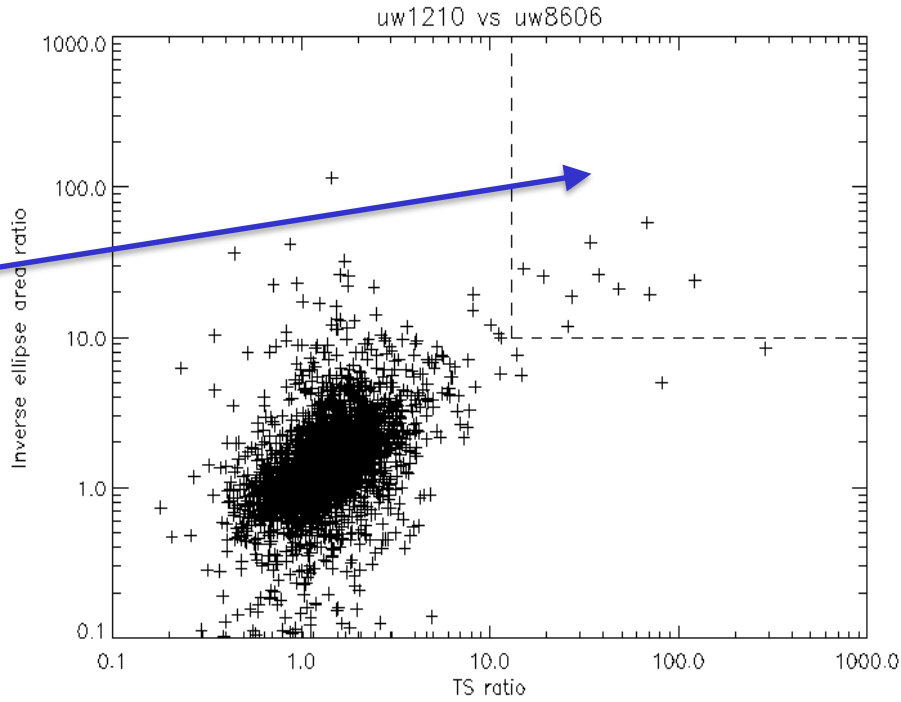


4FGL (and DR2) vs DR3

4FGL (and DR2)		DR3
8 years P8R3_Source_V2	**Data**	12 years P8R3_Source_V3
PSF types, zmax depend on energy	**Selection**	Idem
ST v11r7p0, 50 MeV – 1 TeV	**Main fit**	FT 1.4.7, 50 MeV – 1 TeV
Weights, energy dispersion	**Method**	Updated weights, edisp_bins = – 2
gll_iem_v07	**Interstellar**	Idem
Hard limits	**Diffuse parameters**	**Bayesian priors**
75	**Extended sources**	78 (3 new + 4 updated)
Cutoff as $\exp[-aE^b]$	**Pulsars**	Cutoff as $\exp[-d/b^2(E/E_0)^b]$
TSCurv > 9 (3 σ)	**Curved spectra**	**TSCurv > 4** (2 σ)
7	**SED bins**	8
2-month + 1-year bins	**Light curves**	1-year bins (**not 2-month**)

Merging with 4FGL-DRn-1

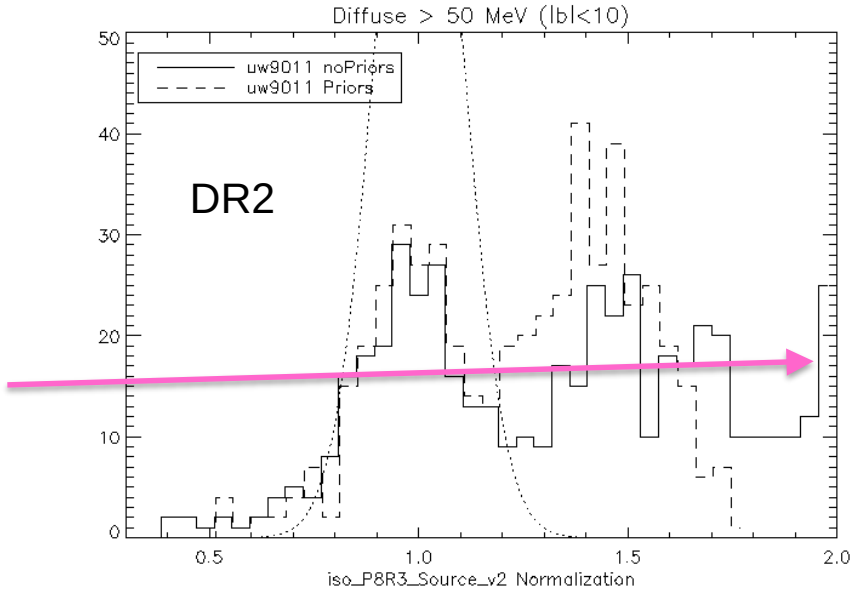
- 11,000+ detections, **correlate** with DR2
- Adopt **12-year position and error ellipse** instead of 4FGL (DR2) for
  - ✓ 9 sources with TSx10, error ellipse/10
  - ✓ 2 pulsars too far from true position
  - ✓ 3 sources with $R_{95} > 1°$
  - ✓ 5 split sources (new detection inside R_{95})
  - ✓ 1 source in cluster (catXcheck)
- **Deleted** 12 inside new/modified extended sources and 7 faint (TS < 25) too soft/hard/close-to-extended sources
- **Added** 11 LAT pulsars (only one survives)



Results in **5,000+ new seeds** on top of 4960 4FGL, 713 DR2, 78 extended and 20 modified entries

Diffuse priors

- Stabilize the diffuse model parameters
- Diffuse parameters should be close to 1 (norms) or 0 (spectral bias)
- Isotropic normalization can get stuck at 2 (maximum) in Galactic Ridge
- **Gaussian priors** based on DR2

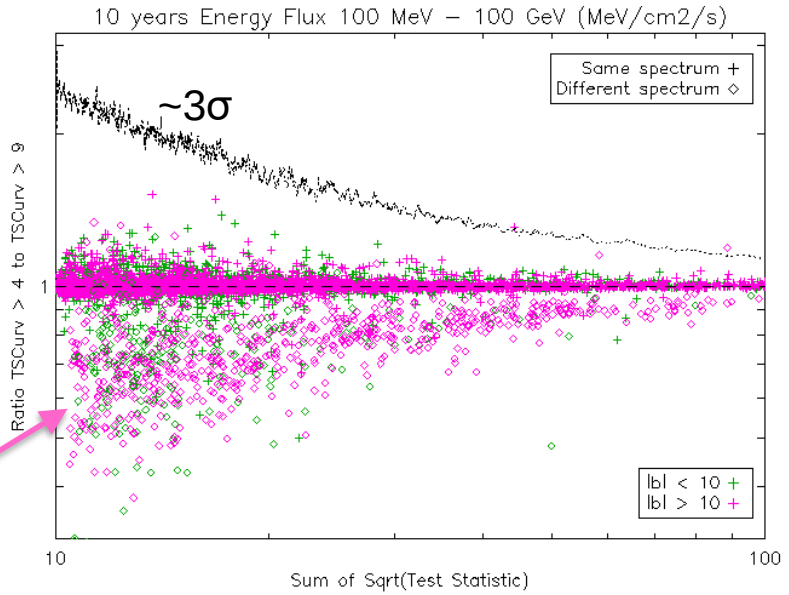


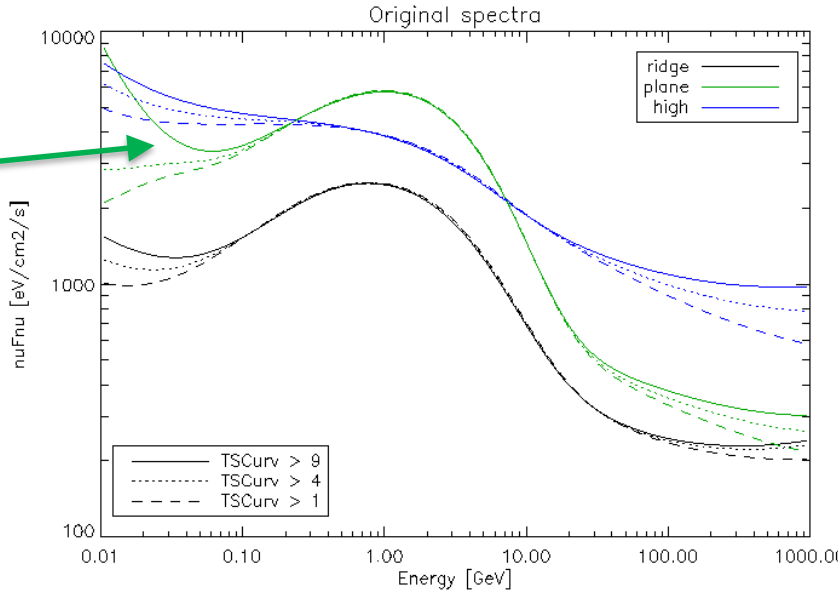
Parameter	Mean	Scatter
Galactic norm at 1 GeV	0.97	0.03
Galactic spectral bias	0.01 (harder)	0.02
Isotropic norm	1.00	0.10

Isotropic never gets stuck at 2 any more

TSCurv threshold

- Most source spectra are curved
- Adopt **TSCurv > 4** (was 9 in DR2)
- TS gain for sources that switch from PLaw to LogP, indirect effect on close neighbors
- Large decrease in photon flux > 100 MeV for sources that switch from PLaw to LogP, smaller **energy flux decrease** (but > 1 σ)
- Neighbors tend to become a little softer (Γ += 0.02)
- **Global source spectrum** better behaved (no upturn) at low and high energy

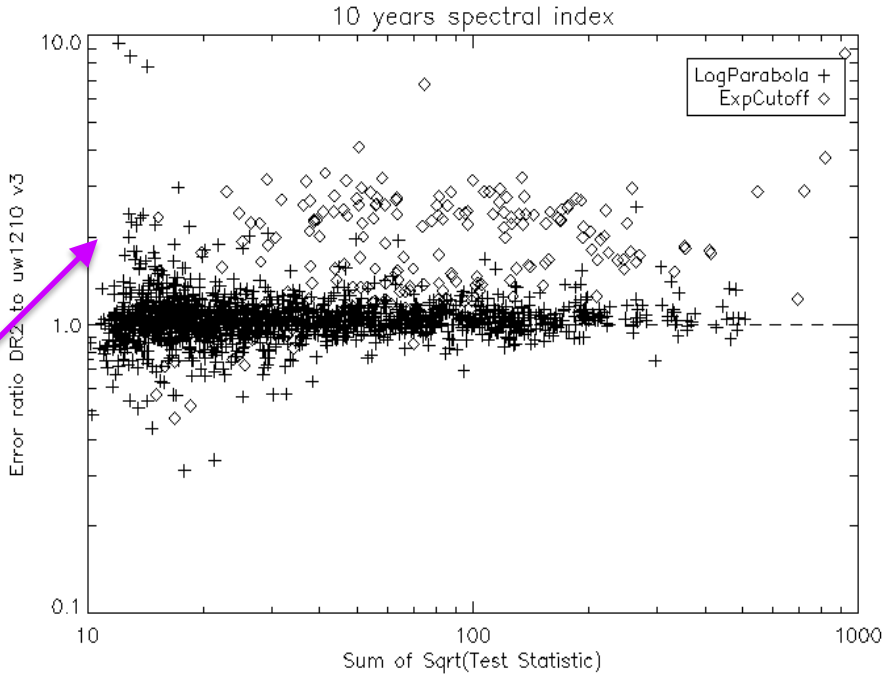




New spectral columns

- PLEC_EPeak and LP_EPeak (+ errors) report **νF_ν peak** when it is meaningful (exists and not too far from GeV range)

- **PLSuperExpCutoff4** parameters are index Γ_s (PLEC_IndexS) and curvature *d* (PLEC_ExpfactorS) at the reference energy E_0
- Reduces considerably the correlation between parameters and error on index



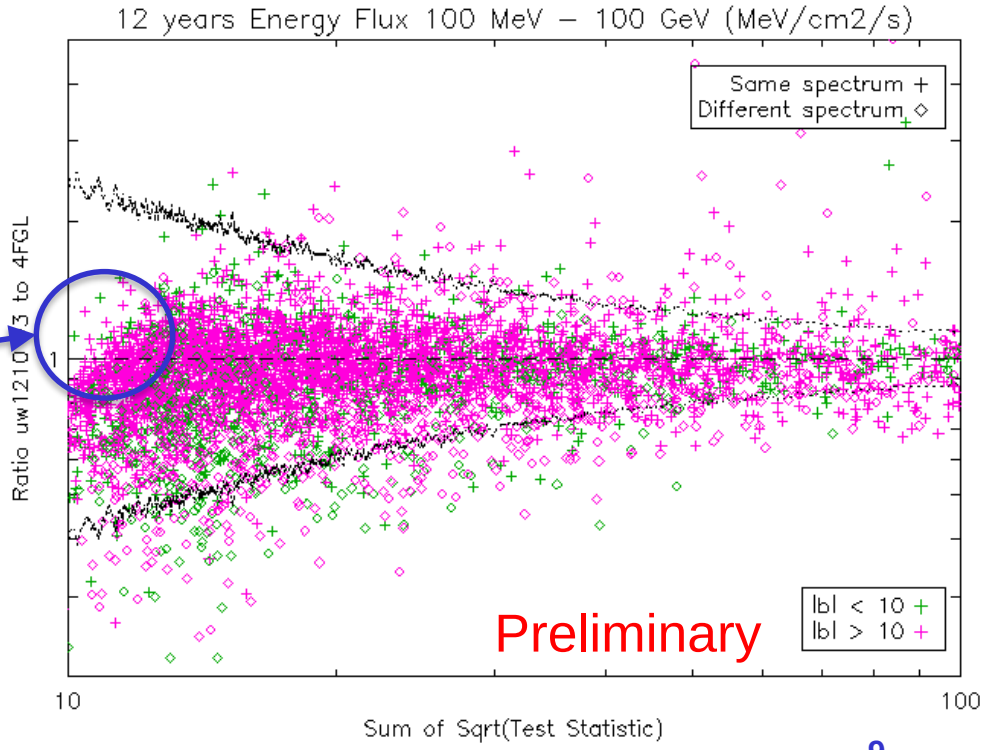
$$K_3 \left(\frac{E}{E_0}\right)^{\left(\Gamma_s+\frac{d}{b}\right)} \exp\left[\frac{d}{b^2} - \frac{d}{b^2}\left(\frac{E}{E_0}\right)^b\right]$$

4FGL DR1 sources at 12 years

- Average **TS increase by 39%** with respect to DR1 at high latitude (50% exposure increase). Deficit due to **selection bias** (variable sources brighter in interval in which they were first defined) and **signal-splitting** with new sources
- TS increase by only 27% at low latitude, limited by weights and confusion
- 114 4FGL DR1 and 70 DR2 **sources with 10 < TS < 25** in DR3

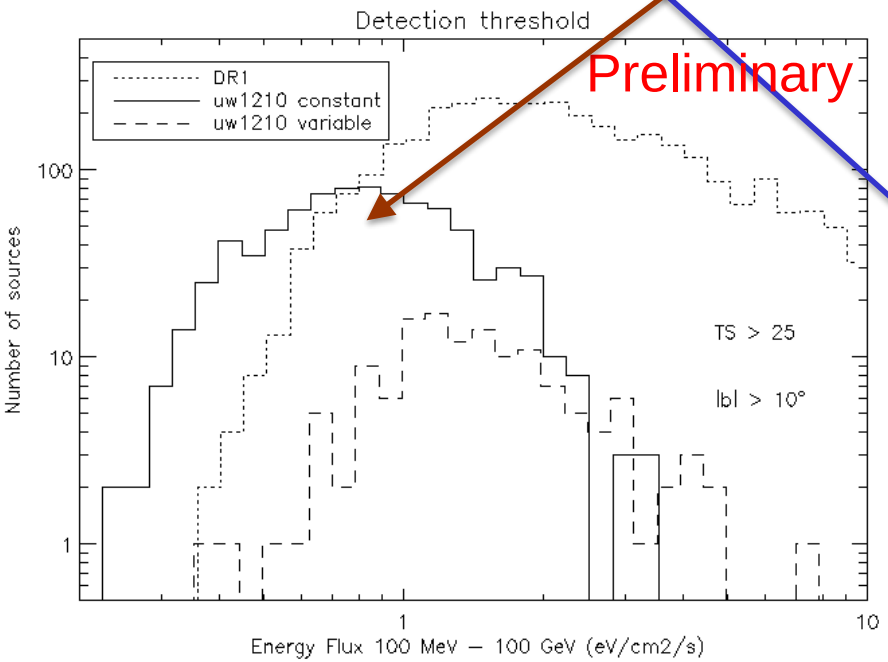
Median log(energy flux ratio) is about – 5 % (4FGL larger)

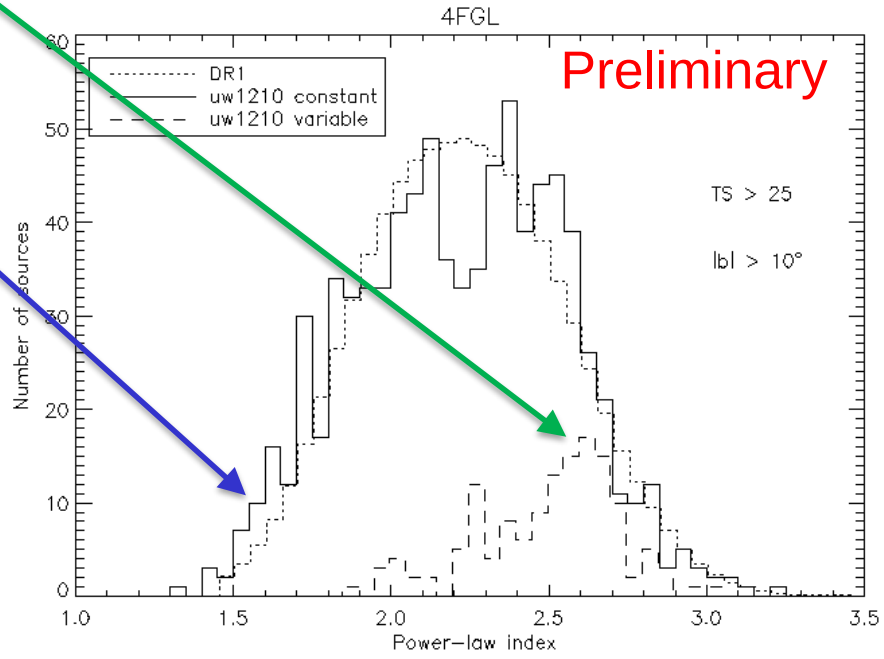
Selection bias



New 4FGL-DR2+3 sources

- About 1500 new sources
- Comparison of DR2+3 sources to original 4FGL outside Gal plane
- Lower detection threshold (**median energy flux** = 0.9 eV/cm²/s)
- More **soft variable sources** (similar to FSRQs)
- More **hard sources** (photon limited)



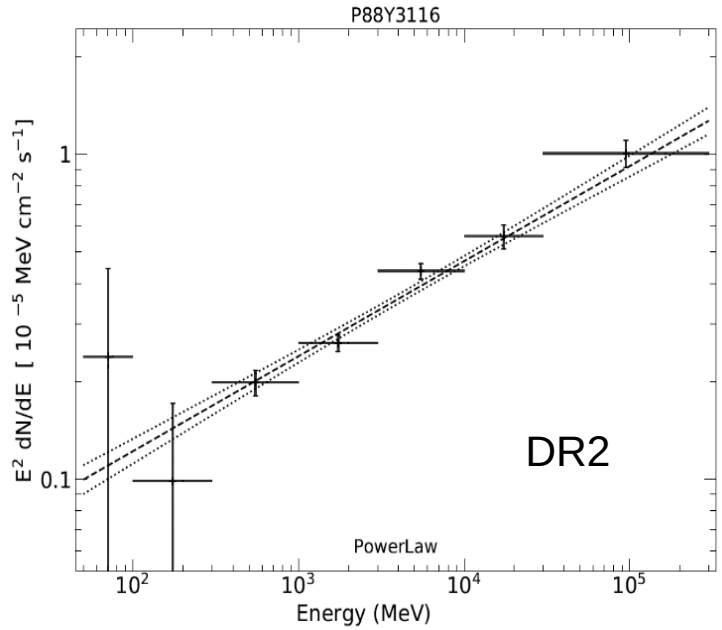


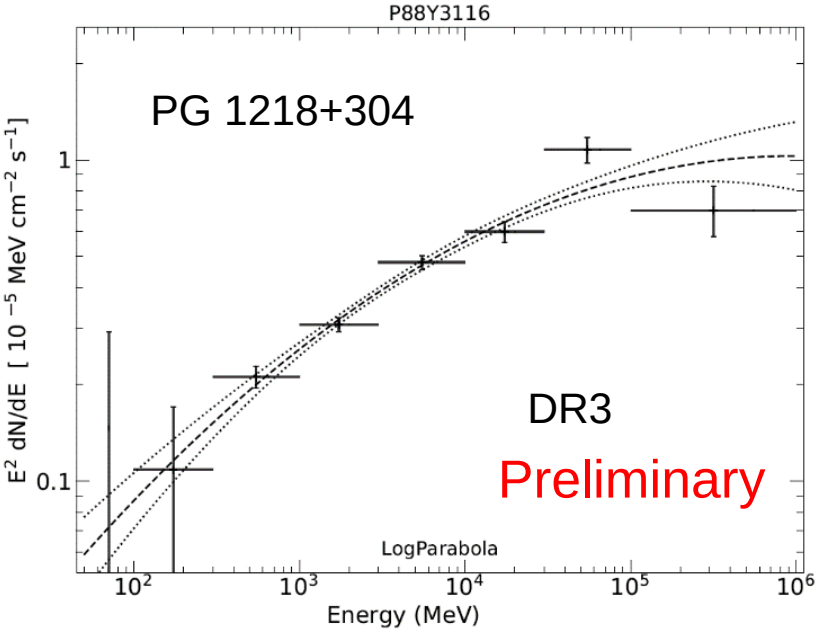
Spectral Energy Distributions

- DR3 has an additional high-energy band
- **More curved sources** thanks to lower TSCurv threshold and improved statistics
- 52% of new curved sources are at |b| < 10°

Spectral shape	4FGL	in DR3	DR2+3
PowerLaw	70%	46%	61%
LogParabola	26%	49%	39%
PLSuperExpCutoff	4%	5%	0%

30% ➔ 51% curved sources overall

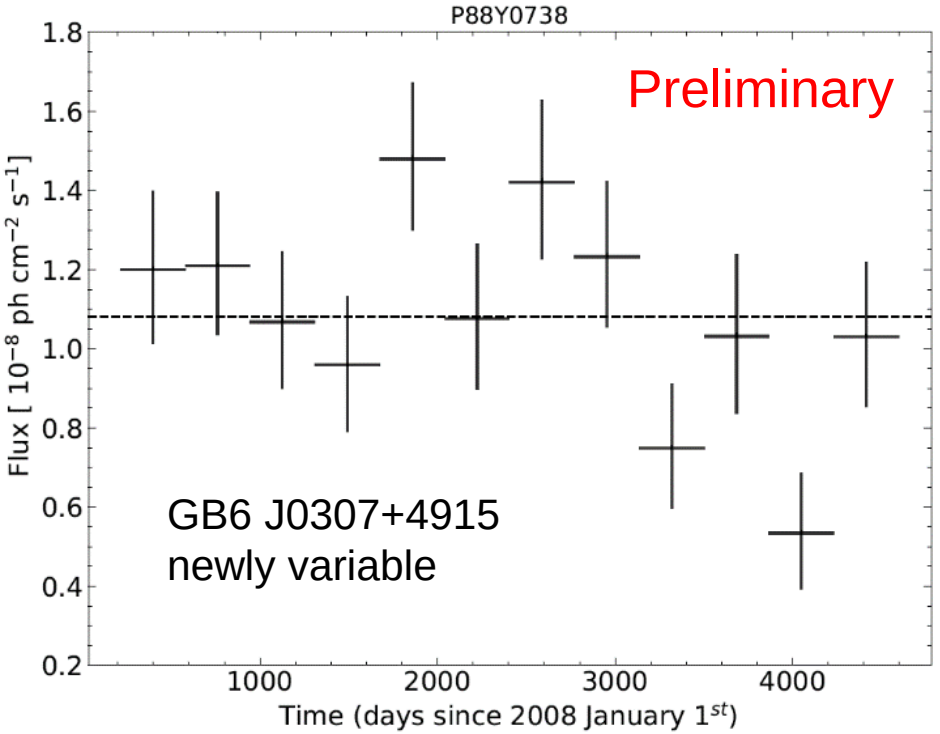




Light curves

Total number of variable sources in 4FGL (including 2-month) was 1443, 1327 considering only 1-year bins

Fractional variability did not increase significantly going from 8 to 12 years, still peaking between 50 and 90%



Variable (1-year)	4FGL	in DR3	DR2+3
Fraction (%)	26%	30%	11%
At |b| > 10°	33%	37%	14%

Associations

- In DR3 we now distinguish **MSP**s and **PSR**s (young)

More than 50 new associations among DR1 sources:

- 60% pulsars, 20% other Galactic, 20% blazars

Preliminary numbers

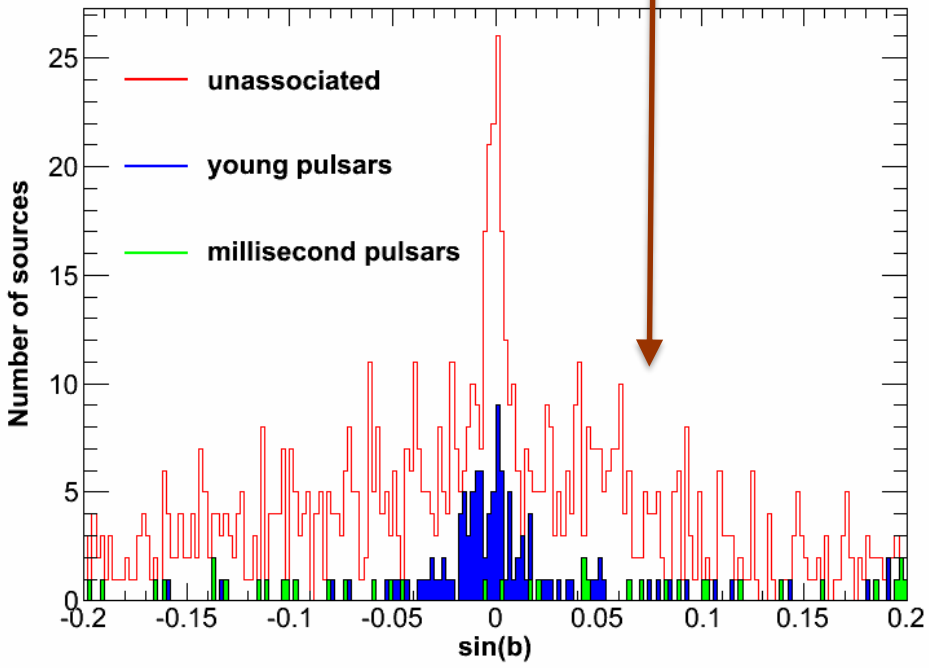
About 700 new associations among DR2 or DR3 sources:

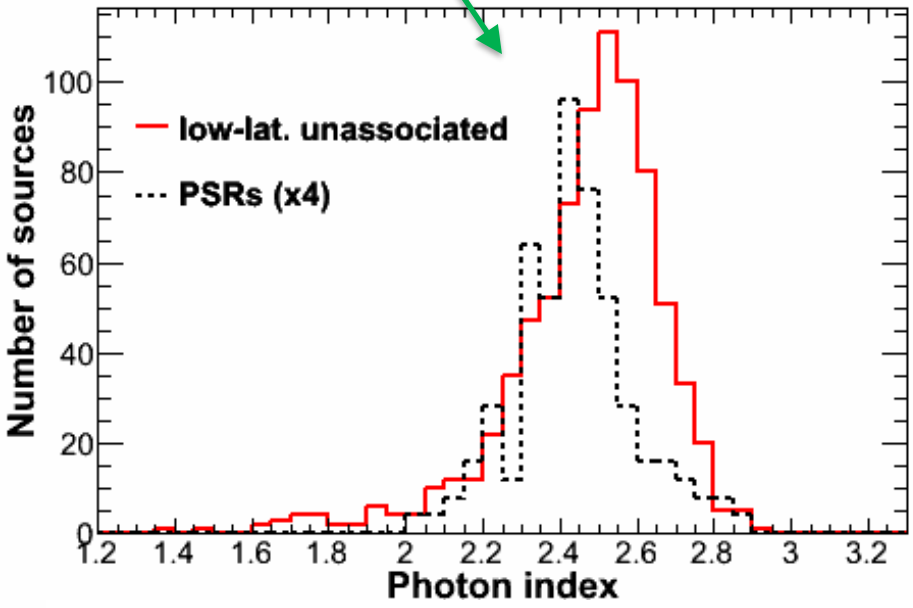
- 83% blazars (mostly uncertain type)
- 12% unclear (several option or unknown counterpart)
- 5% Galactic

- 32% unassociated sources (54% of DR2 or DR3 sources)

Low-latitude unassociated sources

- Half the unassociated sources are within 10° of the Galactic plane
- Curved spectra, like those of pulsars, but **softer**
- Relatively **broad latitude distribution**, unlike that of pulsars
- Notable degree of clustering; diffuse emission?
- Most of those are flagged





Conclusions and outlook

- Incremental 4FGL versions every 2 years until a new interstellar emission model is available
- Each one adds about 700 more sources
- Better spectral characterization for DR3
- Fraction of unassociated remains below 1/3

4FGL-DR3 will be posted at FSSC before July

Extended sources

- 75 extended sources in 4FGL and DR2
- 4 **modified**, 2 **new** , 1 **point → extended**
- **Deleted** 12 4FGL-DR2 sources inside those

Source name	TS	Reference	Comment
HESS J1825-137	498	Grondin+ 2011	Correction
HB 21	2360	Ambrogi+ 2019	One more point source
SNR G106.3+2.7	43	Xin+ 2019	VER J2227+608 next to PSR J2229+6114
SNR G150.3+4.5	518	Devin+ 2020	Gaussian model
Vela X	499	Tibaldo+ 2018	Radio template
SNR G279.0+1.1	237	Araya 2020	Cluster of DR2 sources
HESS J1640-465	326	Marès+ 2021	HESS template