Fermi Gamma-ray Space Telescope

INFN

The incremental 4FGL-DR4 Catalog

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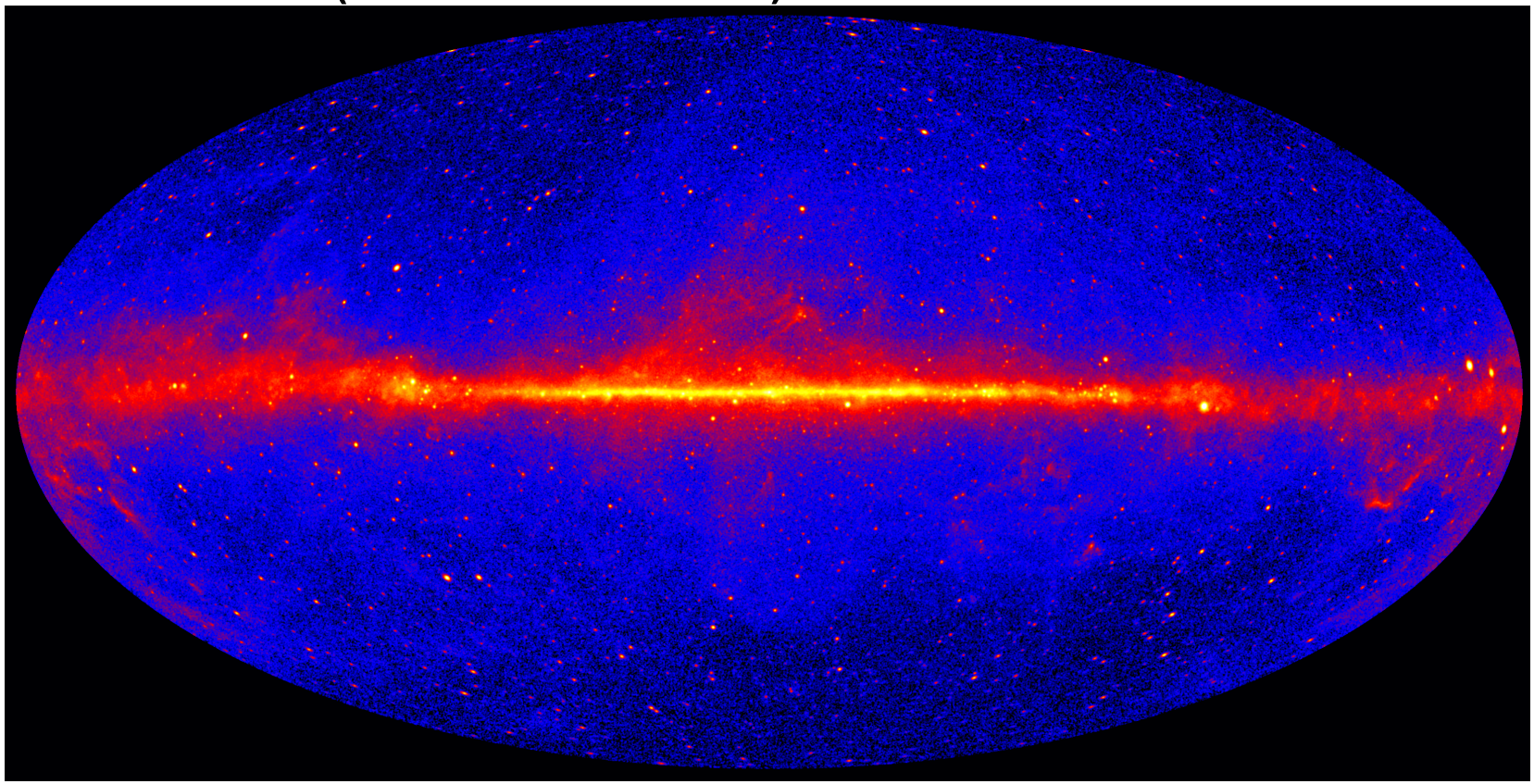
Incremental catalogue

- Same data selection (P8R3 Source) and same diffuse model (gll_iem_v07) of the first 4FGL (DR1: 2019)
- Incremental exposure (DR1: 8 years, DR2: 10 years, DR3: 12 years, DR4: 14 years)
- 4FGL sources are left in the model even if are below threshold (TS < 25)
- Add new sources (from DR2 onwards)



Main differences between DR1 and DR4

4FGL-DR1		4FGL-DR4
8 years, P8R3_Source_V2	Data	14 years, P8R3_Source_V3
ScienceTools v11r7p0, 50 MeV - 1 TeV	Main fit	Fermi Tools 2.2.0, 50 MeV - 1 TeV
Weights, energy dispersion	Method	Updated weights
gll_iem_v07	Interstellar model	Same with LP rescaling
Hard limits	Diffuse Parameters	Bayesian Priors
75	Extended Sources	82 (7 new + 6 updated)
Cutoff as $\exp[-aE^b]$	Pulsars	Cut off as $\exp[-d/b^2](E/E_0)^2$
TSCurv > 9 (3σ)	Curved spectra	TSCurv > 4 (2σ) and priors on curvature
7	SED bin	8
2-month & 1-year bins	Light curves	Only 1-year bins

Modulating the Diffuse Background

Problem: Fit is performed for Region of Interest (RoI), the diffuse parameters show sharp changes (even if small) at RoI boundaries

Solution: Interpolate over diffuse parameters to make them vary smoothly over the sky. Fix isotropic and apply LP modulation to the Galactic diffuse

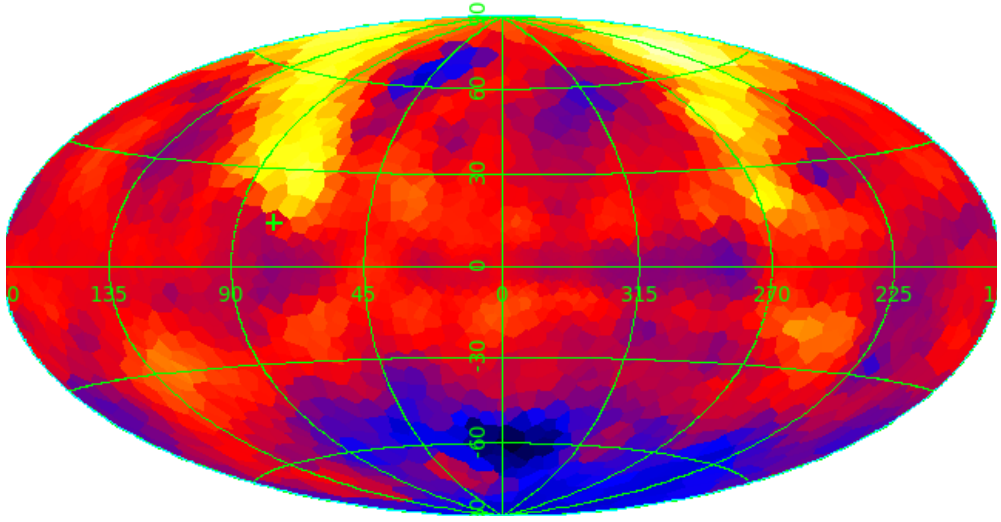
Interpolation: Weighted average of up to 15 RoIs $w_i = (\max(D_i, R_i, 2)\sigma_i)^{-2}$

- D_i: distance to RoI center
- R_i: RoI radius
- σ_i: uncertainty on parameter

Improves Loglikelihood

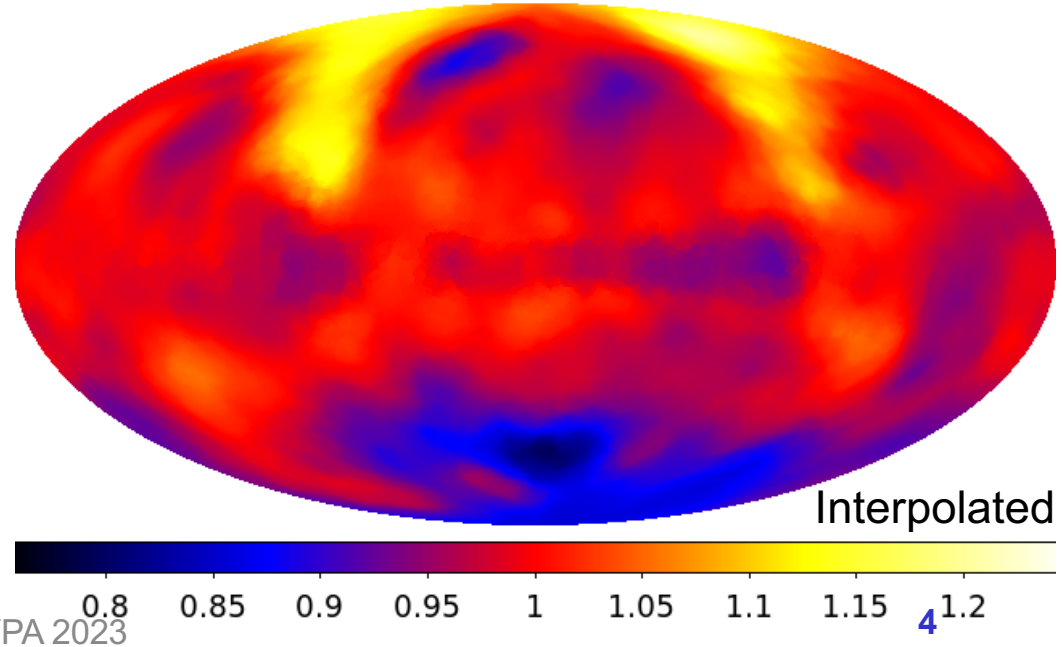
Difficulty: Still requires first run with independent parameters. Small but significant fluctuations remain

Caveat: Do not use blindly instead of gll_iem_v07 (LP extrapolation > 10 GeV)



Gal norm at 1 GeV

ROI-based



Interpolated

Adding priors to spectral curvature

Problem: LogParabola β ~ 0.1 (low curvature) in bright AGN but unrealistic large β (very peaked spectra) in faint sources

Hard cut at 1 disrupts the covariance matrix.

Solution: Enter priors on curvature parameters to stabilize the model.

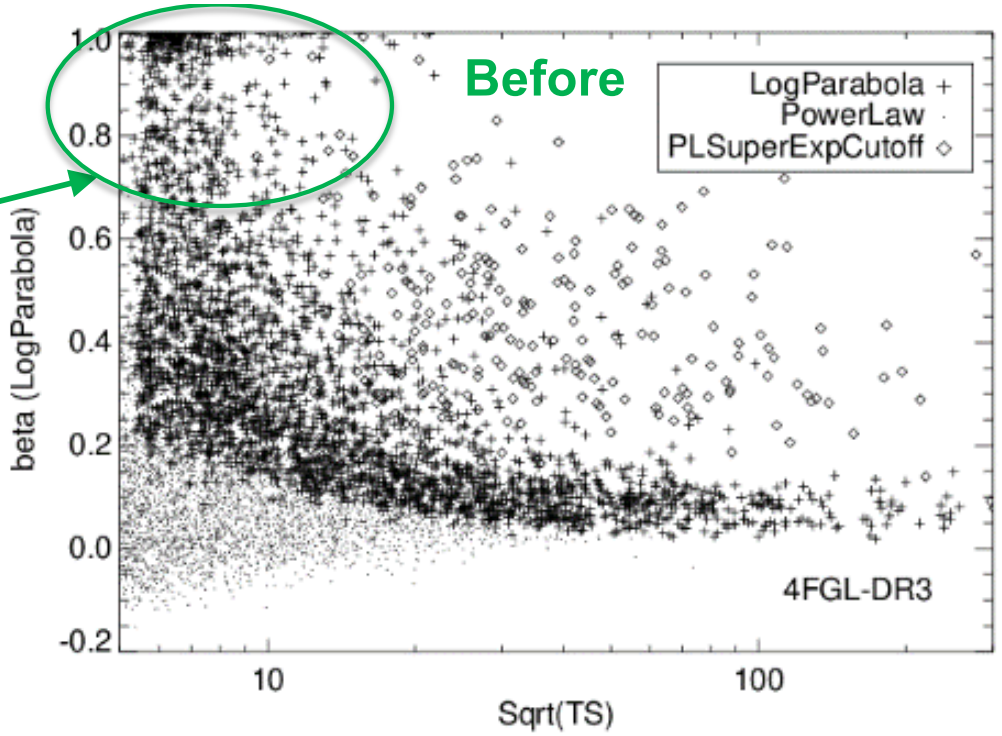
Difficulty: SNRs and pulsars are more curved than AGN and binaries.

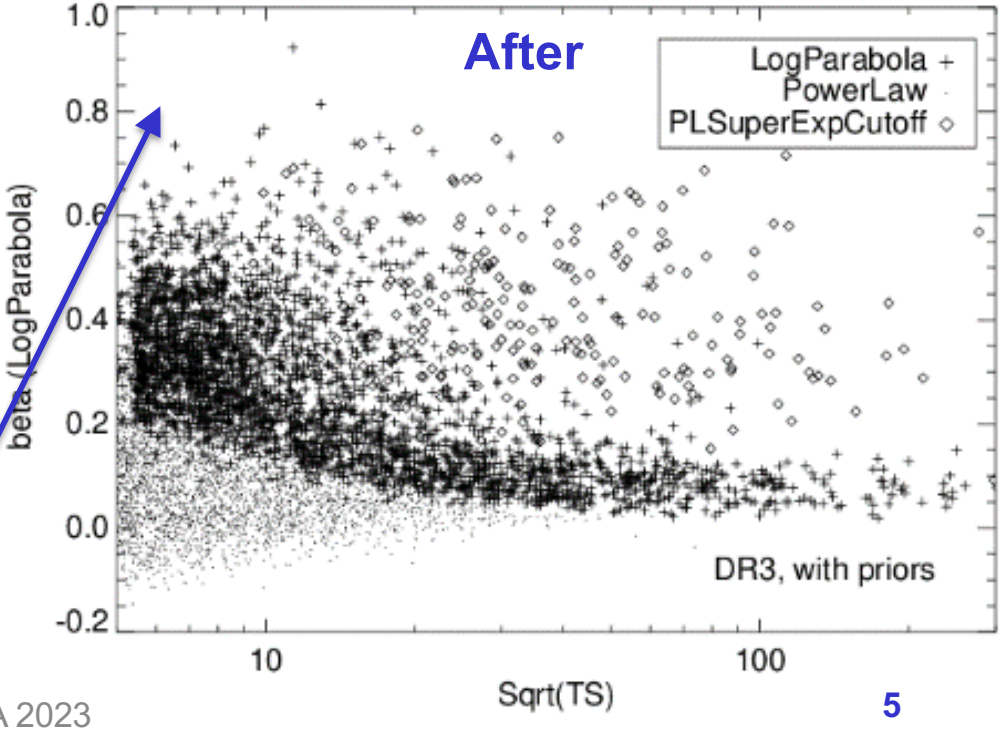
Soft priors to accommodate all:

- on LogParabola β: mean = 0.1, stdev = 0.3
- on PLEC4 ExpfactorS (~ 2β): mean=0.6, stdev=0.6

As expected, gets rid of the tail at large β

No impact on β error (< 0.3 at TS > 25)





Including transient sources

- **Problem:** Transient sources are diluted over many years and can be too faint to appear in the general catalog
- They can however be significant over 1 year and affect the light curves of nearby sources
- **Solution:** Include transients that reach TS > 25 over 1 year
- Too faint to fit spectral index over 14 years. Fit over best year
- They are found by dedicated means:
  - **4 novae** (V407 Cyg, V339 Del, V856 Sgr, YZ Ret) besides the 4 brighter ones that are detected over 14 years (V1369 Cen, V5668 Sgr, V906 Car, RS Oph)
    Positions fixed to the optical
  - **10 monthly transients** (1FLT, iFLT, ASV) besides 9 that naturally appeared in DR4
    Positions taken from the dedicated search

4FGL DR4: 14 years

- Adopt much better DR4 localization for 9 DR1 and 1 DR2 sources
- Delete 14 sources in new extended sources or too faint/soft/hard
- Replace 2 extended sources (Cygnus Loop and Puppis A) with MWL templates
- Add 4 new extended sources (3 around pulsars)

546 new sources (median energy flux = 0.9 eV/cm²/s). 7194 in all

119 DR1, 82 DR2 and 106 DR3 sources end up in DR4 with 6 < TS < 25

Average TS increase by 11% with respect to DR3 at high latitude (17% exposure increase).

TS increase by only 7% at low latitude, limited by weights and confusion

Median log(energy flux ratio) is – 2 % (DR3 larger): selection bias

Spectral Shapes

Fewer curved sources due to the priors on curvature

277 pulsars (255 in DR3)

Spectral shape	4FGL	DR3	DR4
PowerLaw	70%	49%	53%
LogParabola	26%	47%	43%
PLSuperExpCutoff	4%	4%	4%

105 of the 199 DR4 sources at TS > 25 above 100 GeV are **not known TeV sources yet**

84 are BL Lacs.

TS > 25	4FGL	DR3	DR4
Above 30 GeV	618	907	1028
Above 100 GeV		172	199

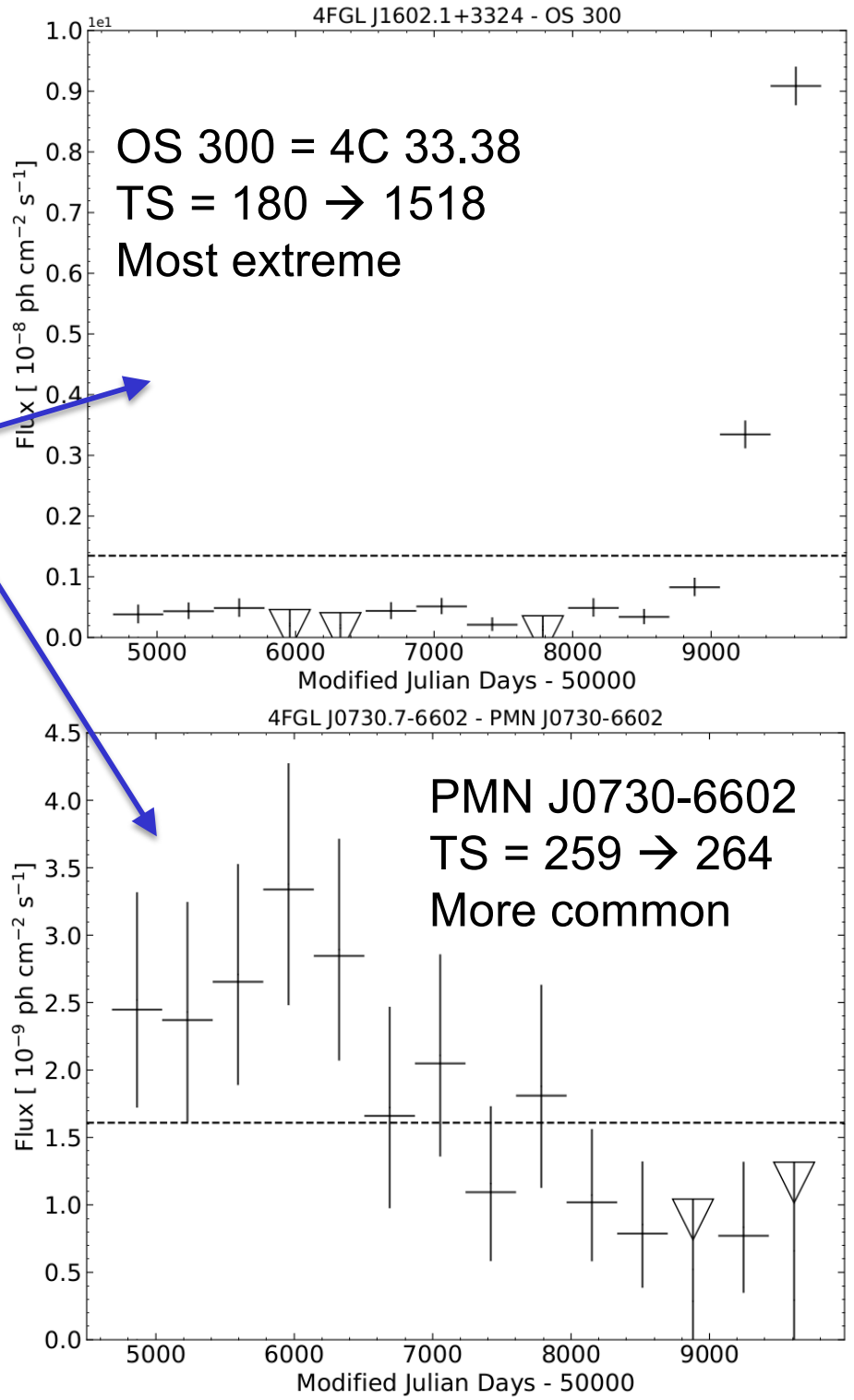
Light curves

1825 significantly variable sources in DR4

179 DR3 sources newly variable
103 not variable any longer

Fraction of variable sources (from 1-year light curves) remains around 1/4 (1/3 at high latitude).

Fractional variability did not increase significantly going from 8 to 14 years, still peaking between 50 and 90%



DR4 associations

26 new associations among former sources (23 pulsars, 3 binaries)

2 changes (glc → MSP and nova → blazar)

14 class changes among AGN (mostly to BL Lac)

236 associations among new DR4 sources:

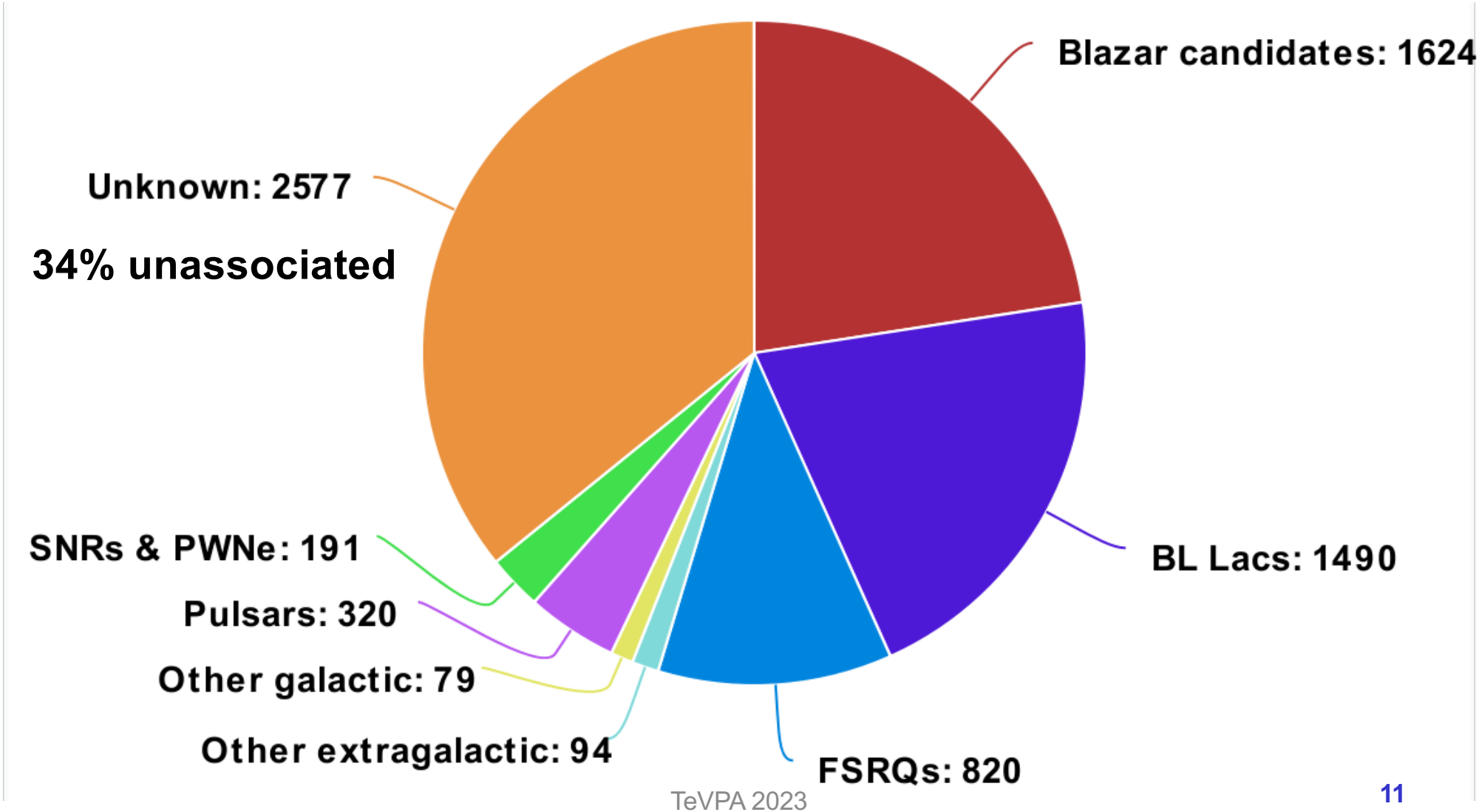
- **83% blazars (mostly uncertain type)**
- **11% unclear (several options or unknown counterpart)**
- **6% Galactic**

- **57% of new DR4 sources are unassociated**

DR4 associations

Since DR3 we distinguish MSPs (recycled) and PSRs (young) pulsars

Still 17% Soft Galactic Unassociated sources



Conclusions and outlook

- Incremental 4FGL versions every 2 years
- DR4 adds about 550 more sources
- Smooth adjustment of interstellar emission model
- Prevents strongly curved spectra in faint sources
- Includes bright transients
- Fraction of unassociated remains about 1/3

4FGL-DR4 is available at the FSSC

https://fermi.gsfc.nasa.gov/ssc/data/access/lat/14yr_catalog/

Expect soon also the AGN companion catalog 4LAC-DR4 with redshift and synchrotron peak of the counterparts

Next may be full reanalysis with new interstellar emission model