

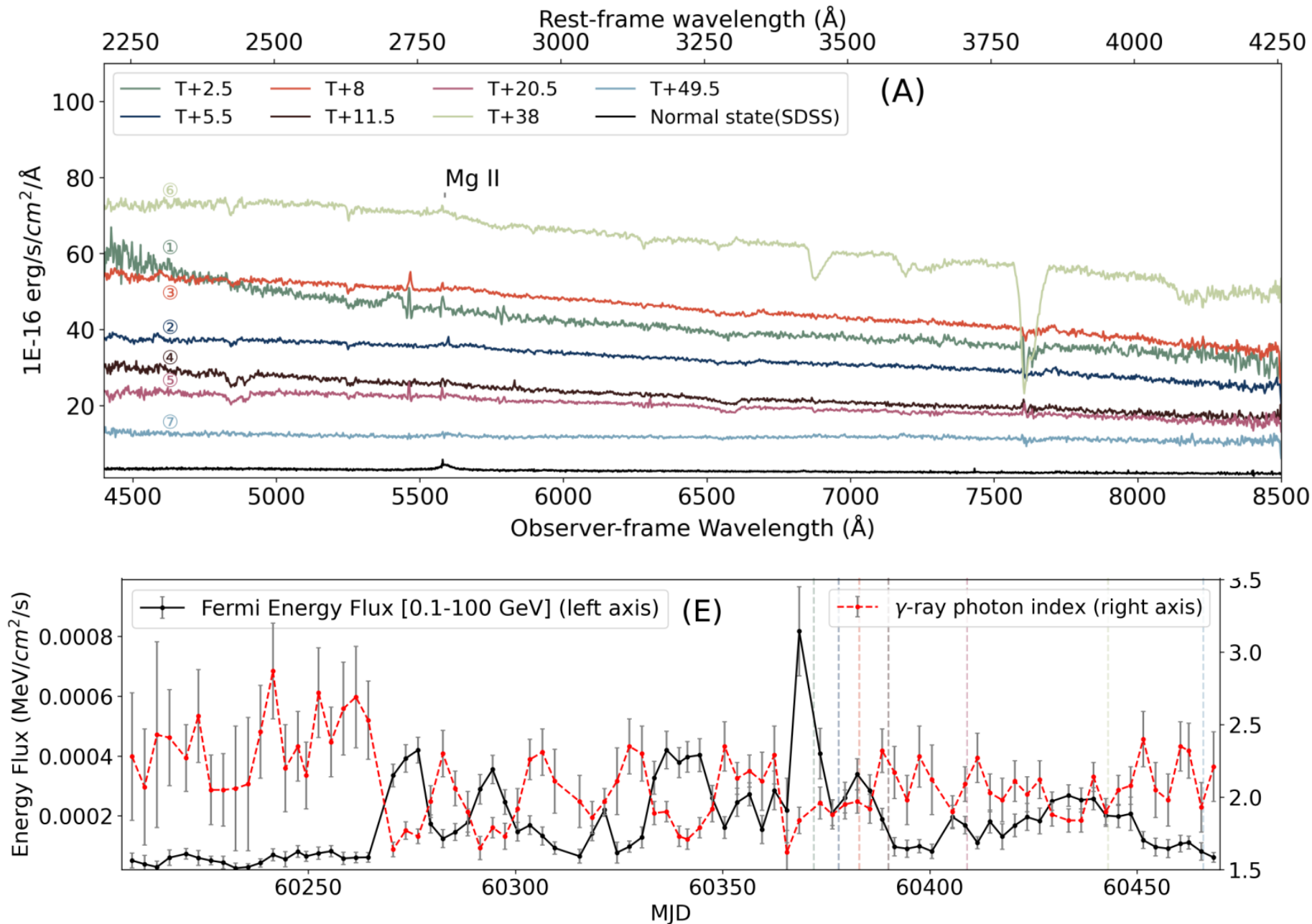
Gamma-ray Spectral Responses at Blazar Flare Peaks

A Fermi-LCR study of 130 blazars

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OP313 motivates a population study



2024 gamma-ray flare

$$\Gamma = 2.34 \rightarrow 1.8 \pm 0.1$$

Catalog value $\rightarrow$ flare value

**Brighter optical continuum
and much weaker Mg II EW**

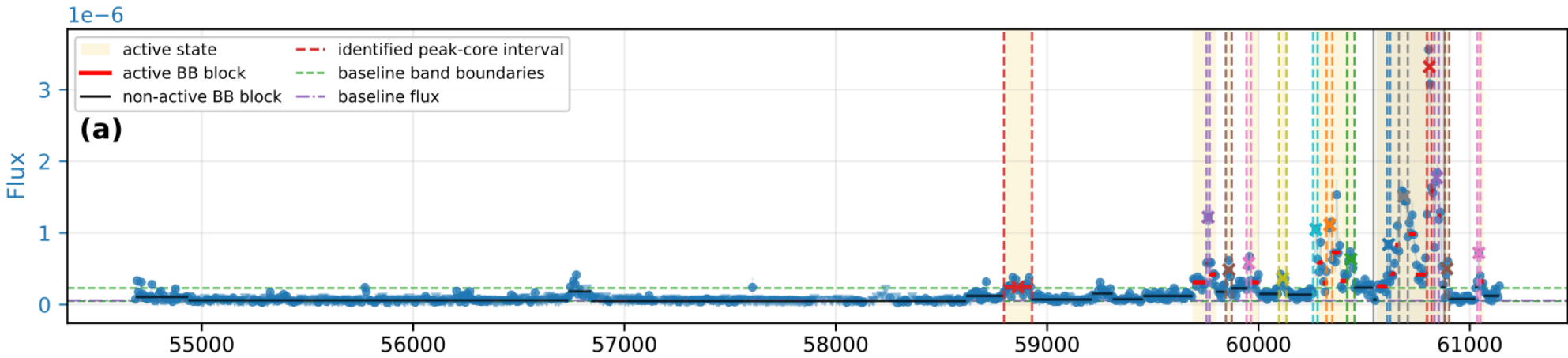
BL Lac-like optical appearance

**How common is local
hardening across blazar
flares?**

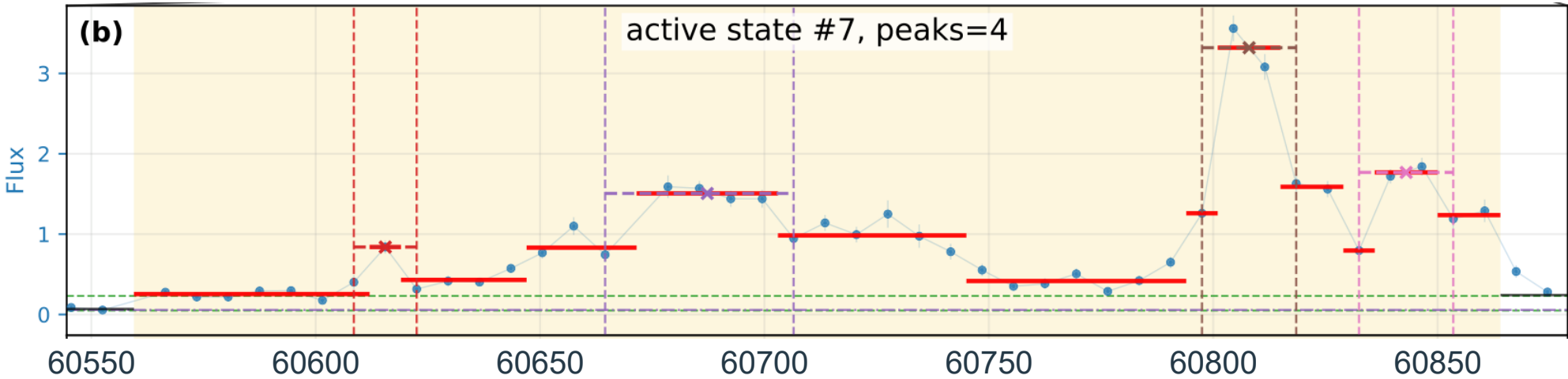
Defining flare peaks from gamma-ray flux

4LAC-DR3 + Fermi-LCR · 7-day bins · 2008–2026

OP313: long-term flux



One active state contains four local peaks



Time (MJD); flux scale: 10^{-6} ph cm $^{-2}$ s $^{-1}$

Zhang & Kokubo, manuscript (2026) · Sections 2–3 and Fig. 1

130

73 BL Lacs + 57 FSRQs

Detection fraction > 0.5

- BB segmentation
- Source-specific baseline
- Consecutive active states
- Local flux maxima

1,079 peaks

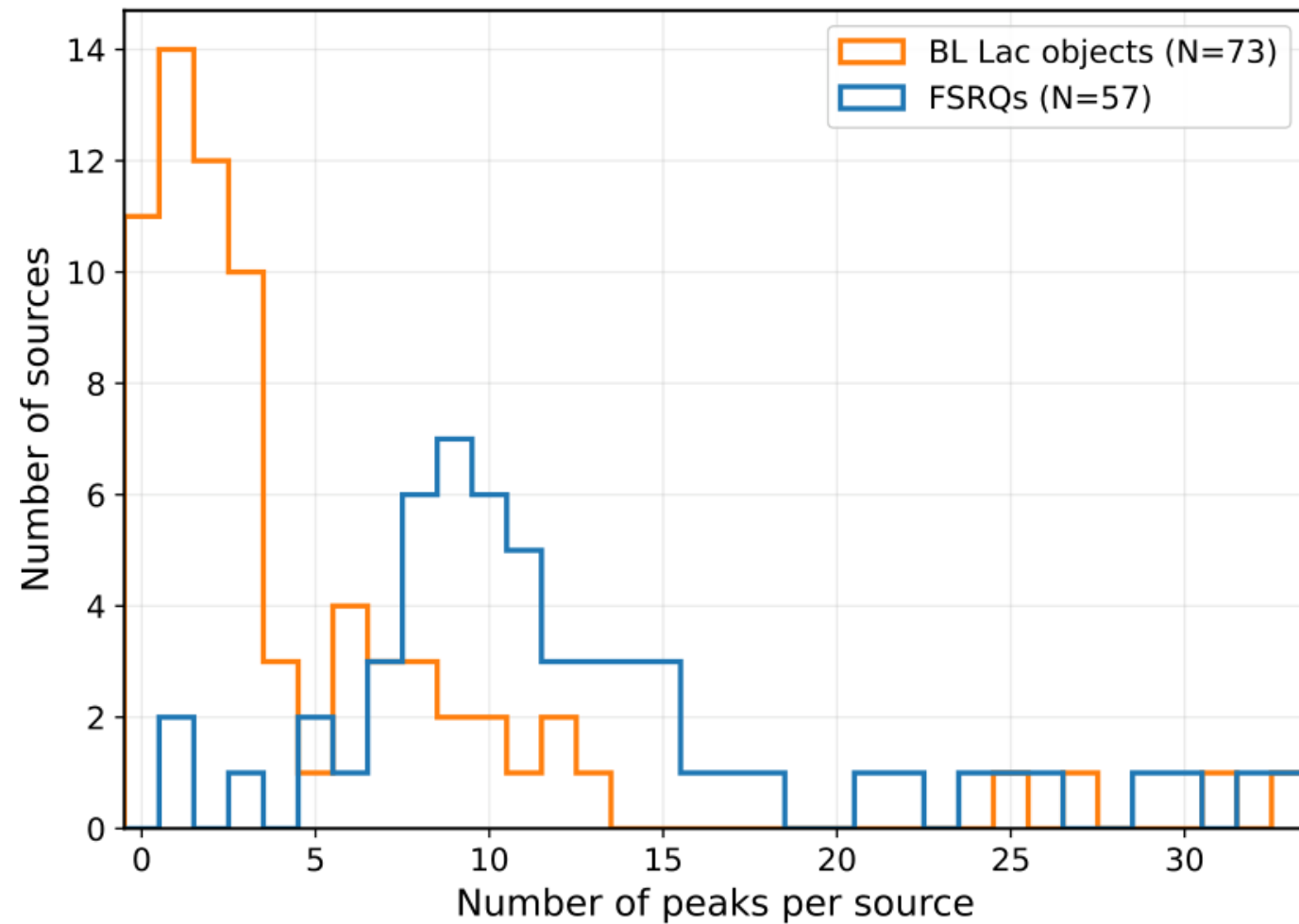
Γ enters after peak selection.

FSRQs show more frequent and stronger peaks

Median peaks per source

BL Lacs: 2

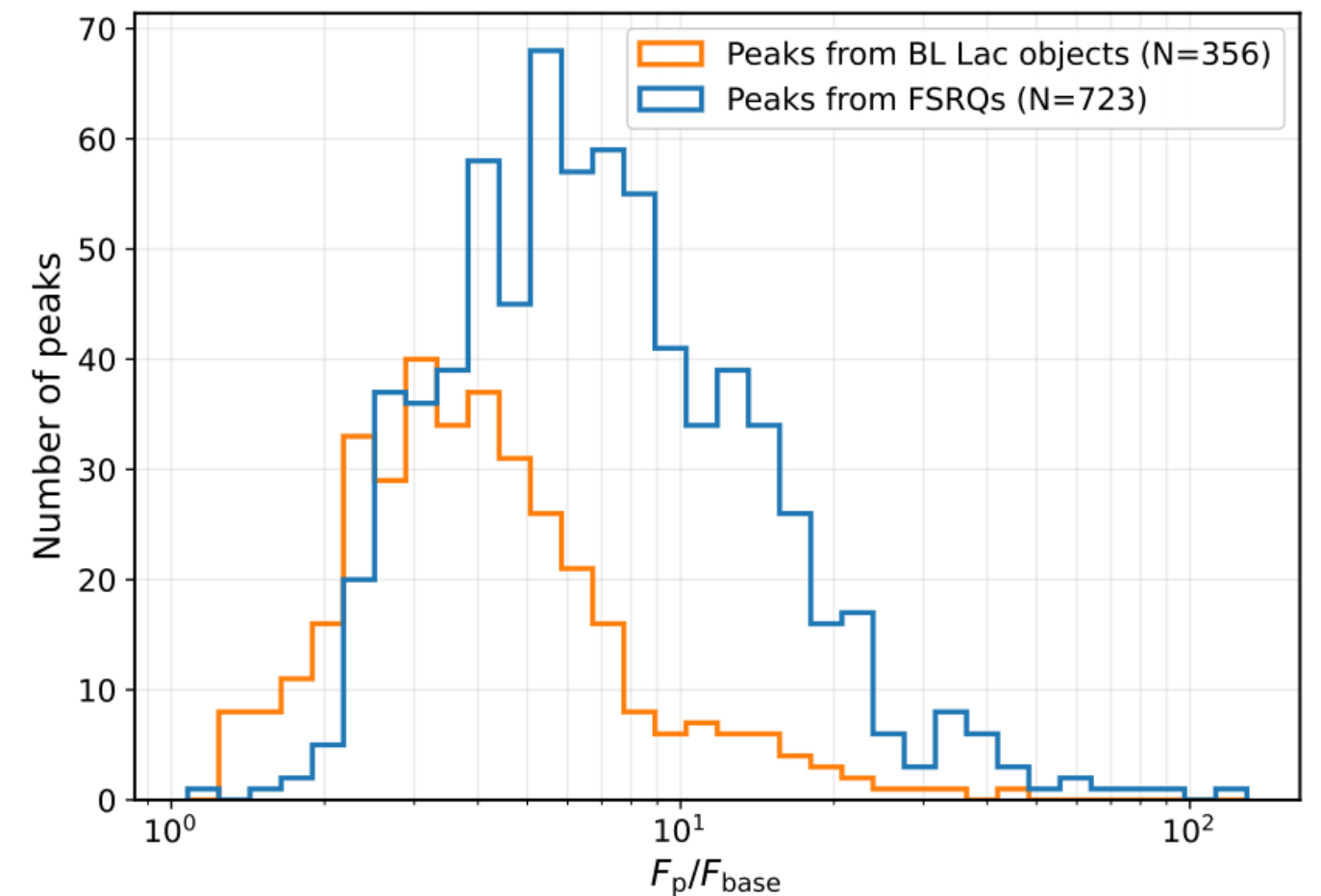
FSRQs: 11



Median peak / baseline

BL Lacs: 3.81

FSRQs: 6.61



Measuring spectral changes around each peak

Local reference

Nearby bins outside the peak core;
neighboring peaks are screened.

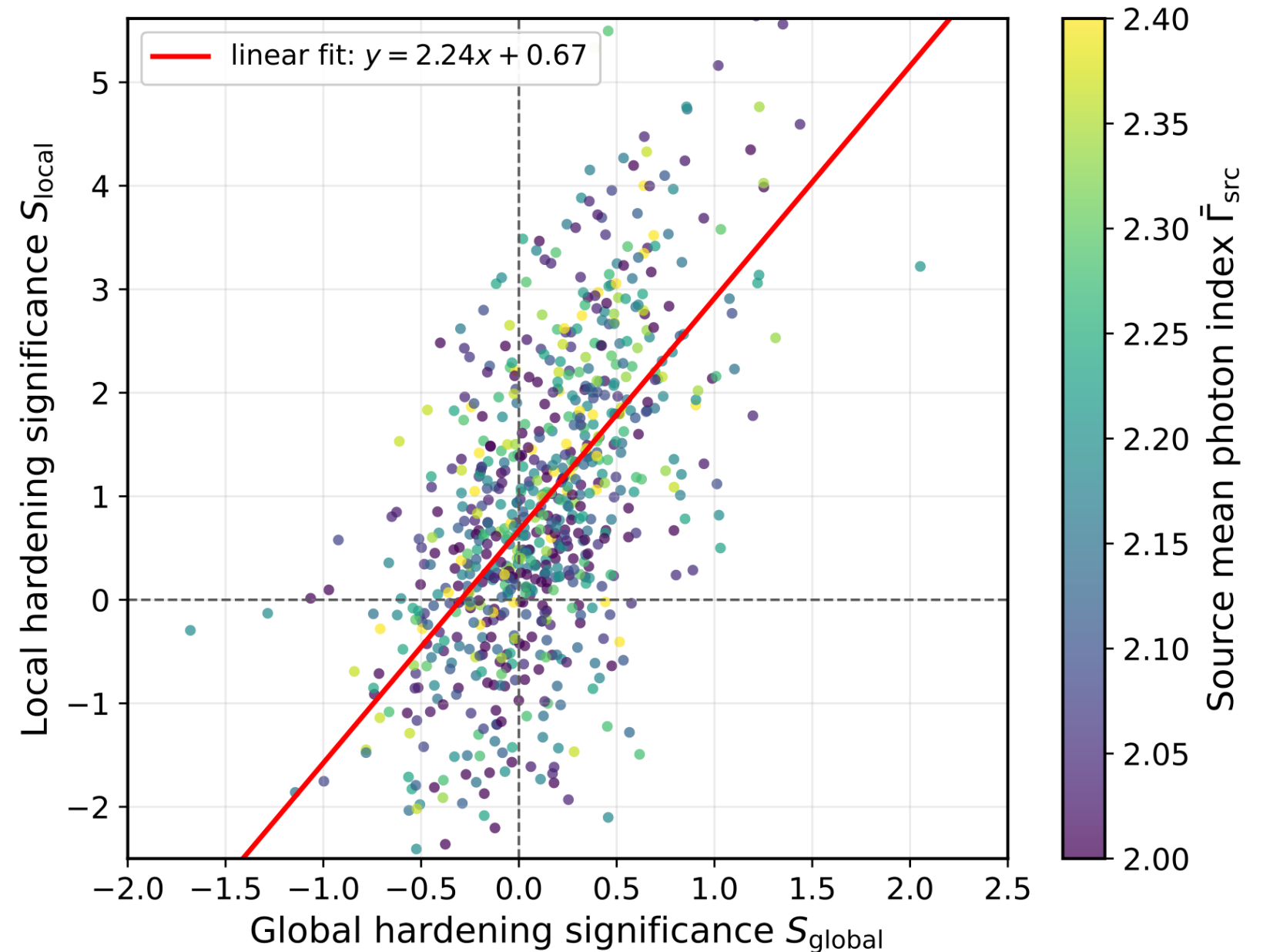
Global reference

Long-term mean index, with
long-term scatter in the uncertainty.

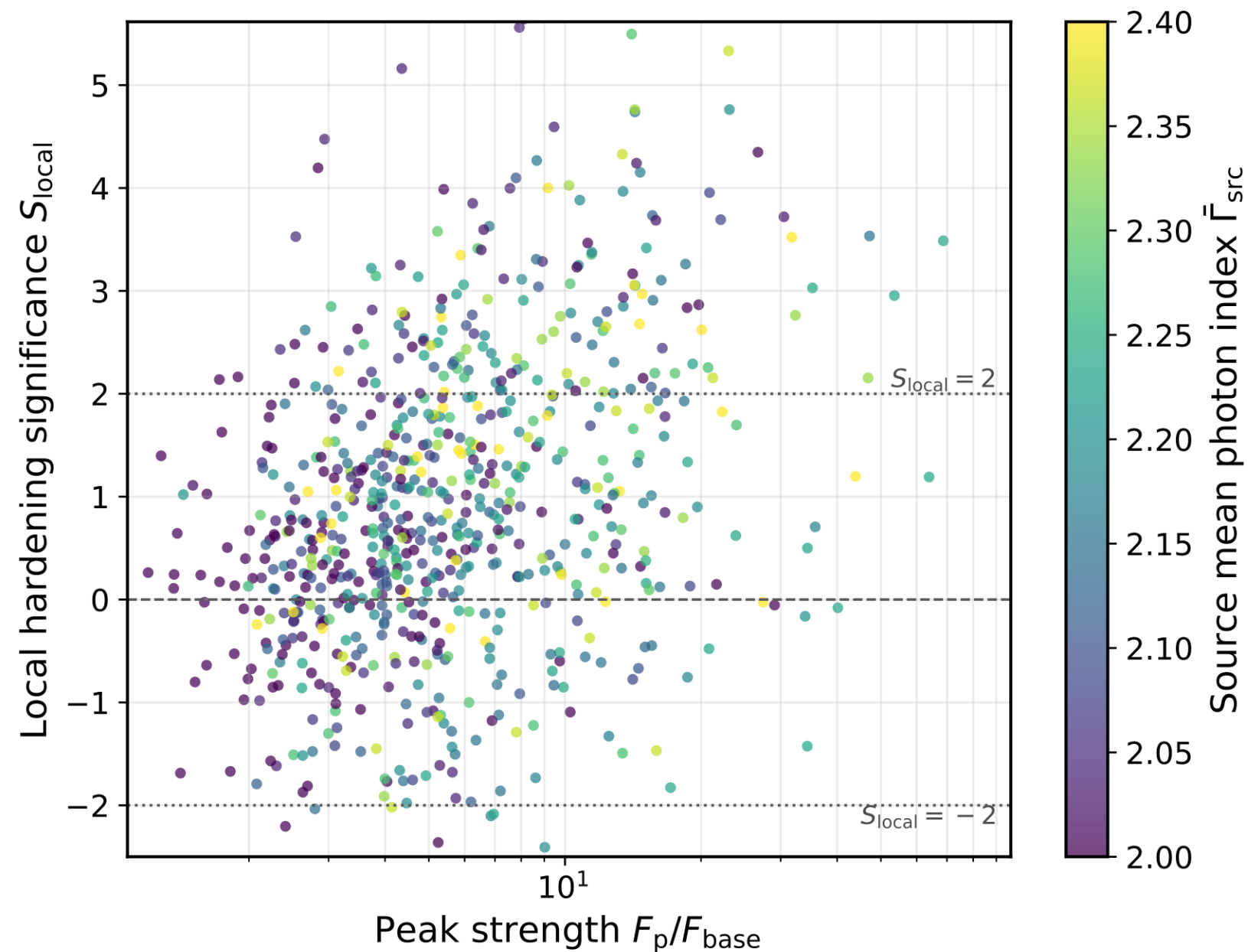
$$S_{\text{local}} = \frac{\Gamma_{\text{ref}} - \Gamma_{\text{peak}}}{\sqrt{\sigma_{\Gamma_{\text{ref}}}^2 + \sigma_{\Gamma_{\text{peak}}}^2}}$$

Positive = hardening; negative = softening.

781 peaks pass Γ coverage > 80%.
733 have valid local references.



Local hardening is common, but not universal



73.9%

show a local hardening trend

542 of 733 valid local responses

170

significantly
harder

23.2%

Local significance > 2 or < -2

12

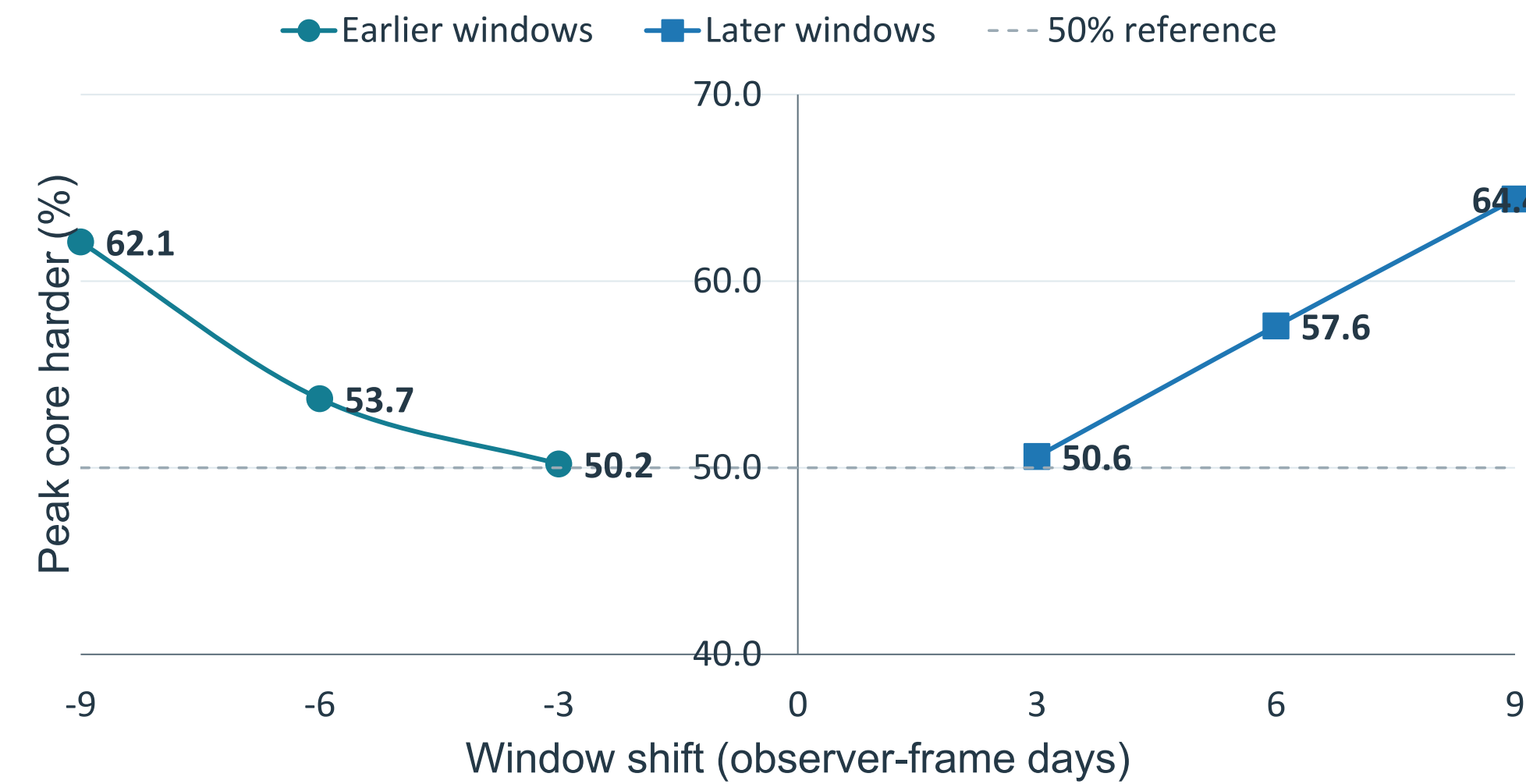
significantly
softer

1.6%

Greater flux does not guarantee hardening.

Hardening remains comparable in nearby windows

Shift the spectral window; keep the flux peak and local reference fixed.



±3 days

50.2% / 50.6%

core harder

±9 days

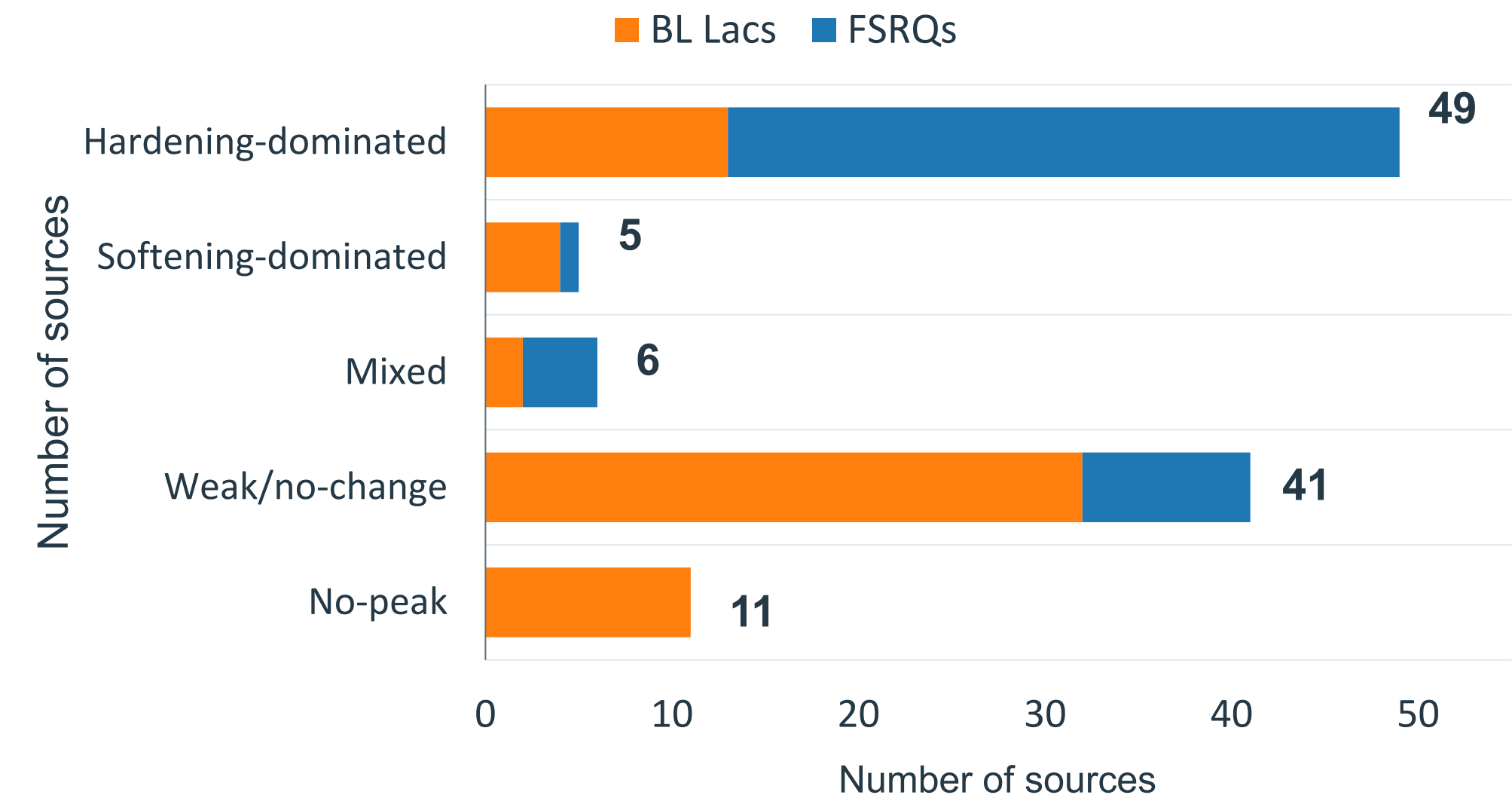
62.1% / 64.4%

core harder

3-day bins; overlapping windows. A robustness test, not a precise lag measurement.

Sources show different flare spectral responses

Classes reflect the presence of significant hardening and/or softening events.



49

hardening-dominated sources

36 FSRQs + 13 BL Lacs

6 mixed sources

Opposite responses occur in the same source.

112 classifiable sources; 18 with flux peaks have no valid local response.

Using spectral responses to guide CLB searches

A harder LAT component can reflect several processes.

Particle injection / acceleration · IC-peak shifts · Changes in seed fields

Optical follow-up

Observational test

Rubin/LSST

Compare long-term optical activity across response classes.

Tomo-e Gozen

Test the timing of rapid optical and gamma-ray changes.

Seimei/KOOLS-IFU

Measure changes in emission-line EW and continuum.

Priorities: hardening-dominated and mixed sources; weak/no-change as a comparison.

Optical spectroscopy remains essential for CLB confirmation.

A local view of blazar flare spectra

1,079 peaks

A uniform sample from 130 blazars,
with peaks selected using flux alone.

73.9%

show a local hardening trend.
Significant events: 170 harder versus 12 softer.

Follow-up

Source response classes guide optical monitoring
and spectroscopic tests of CLB-like behavior.

Hardening is favored, while individual flares remain diverse.

Source classes in index–luminosity space

100 / 112

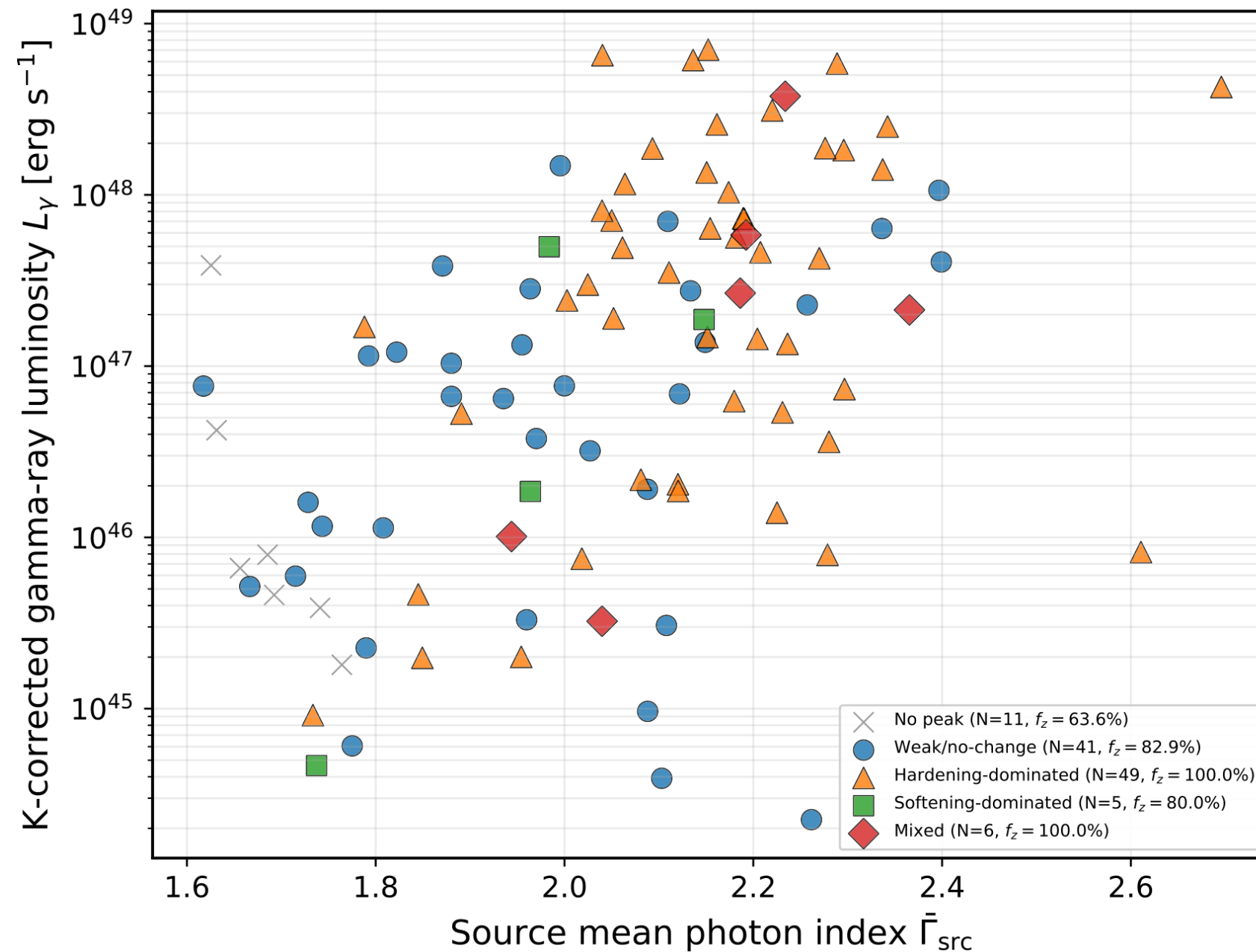
classifiable sources have redshifts for this plot.

$$L_\gamma = 4\pi d_L^2 F_\gamma (1+z)^{\Gamma_{4\text{LAC}} - 2}$$

Horizontal axis:
source-averaged LCR index

K-correction:
4LAC catalog index

The classes overlap in this plane.



Operational definitions and sample selection

Flux-defined peaks

BB: $p_0 = 0.001$; flux $S/N \geq 1.5$.

Baseline: duration-weighted
15th–85th percentile band.

$$F_{\text{block}} - \sigma_{\text{block}} > F_{\text{base, high}}$$

Peak core: last sample in the preceding block
to first sample in the following block.

Index measurements

Free-index fits: $1 \leq \Gamma \leq 5$; $0 < \sigma\Gamma < 1$.

Power law: Γ ; log parabola: α ; cutoff: γ_1 .

Curvature fixed; peak-core coverage > 80%.

Local reference

Weekly bin offsets: $-3, -2, +2, +3$.

Exclude the core; screen each side for
other peak cores within 30 days.

Use both clean sides, or one clean side.

Global vs local significance

$$S_{\text{global}} = \frac{\bar{\Gamma}_{\text{src}} - \Gamma_{\text{peak}}}{\sqrt{\sigma_{\Gamma_{\text{peak}}}^2 + \sigma_{\bar{\Gamma}_{\text{src}}}^2 + \sigma_{\Gamma, \text{src}}^2}}$$

Global includes robust long-term index scatter.

$$S_{\text{local}} = \frac{\Gamma_{\text{ref}} - \Gamma_{\text{peak}}}{\sqrt{\sigma_{\Gamma_{\text{ref}}}^2 + \sigma_{\Gamma_{\text{peak}}}^2}}$$

Full shifted-window comparison

Hardening-selected: N = 514

Shift (days)	Core harder (%)	Shifted harder (%)	Equal (%)
−9	62.1	37.9	0.0
−6	53.7	46.1	0.2
−3	50.2	47.5	2.3
+3	50.6	48.1	1.4
+6	57.6	42.4	0.0
+9	64.4	35.6	0.0

Softening-selected: N = 149

Shift (days)	Core softer (%)	Shifted softer (%)	Equal (%)
−9	66.4	33.6	0.0
−6	60.4	39.6	0.0
−3	53.7	45.0	1.3
+3	45.6	51.7	2.7
+6	53.7	45.6	0.7
+9	53.0	47.0	0.0

Selected by the sign of the unshifted local response; not restricted to significant events.

Weekly core coverage $\geq 90\%$; unshifted 3-day-product coverage $\geq 80\%$.

Overlapping windows and shared LAT photons prevent a precise lag interpretation.