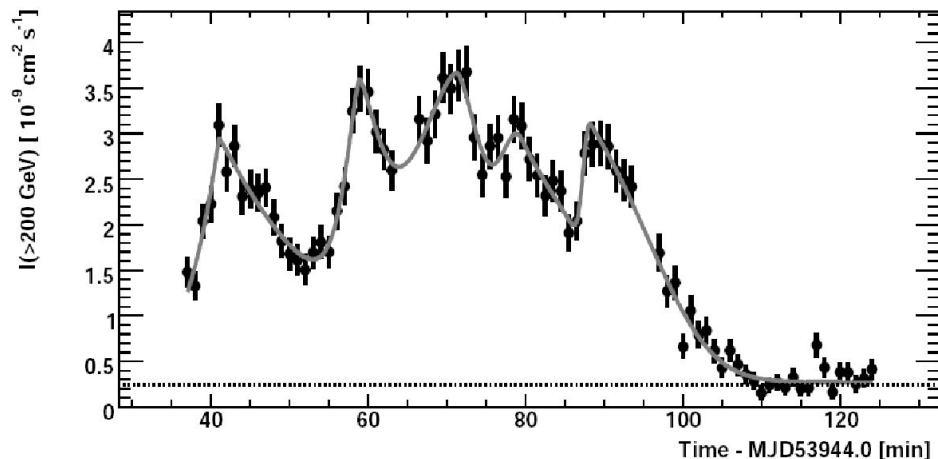


A new era for the blazar multi-wavelength studies with Rubin and CTAO

Blazar variability



Flare from PKS 2155-304 from Aharonian et al., ApJ 2018

Stochastic process:

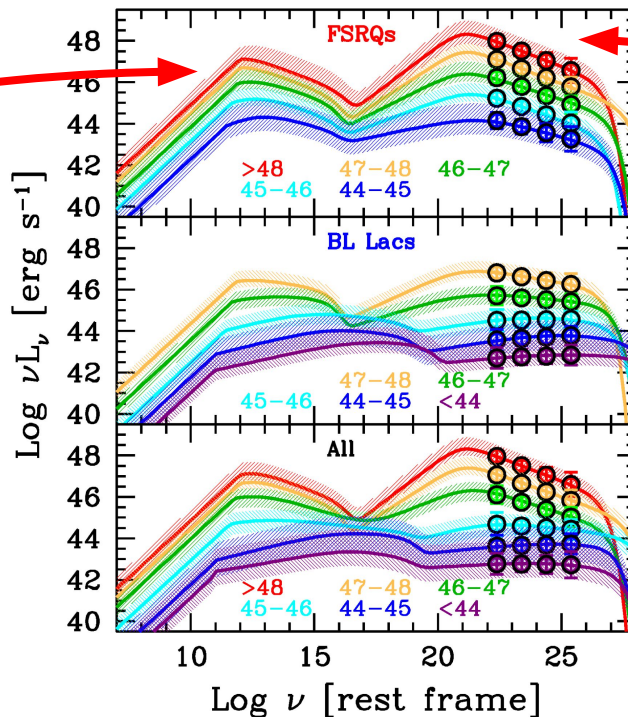
→ Hard-to-predict variability
(no typical timescale)

Flux variability range from up to 2 order
of magnitude

Blazar SED



Optical to X-rays:
Synchrotron radiation

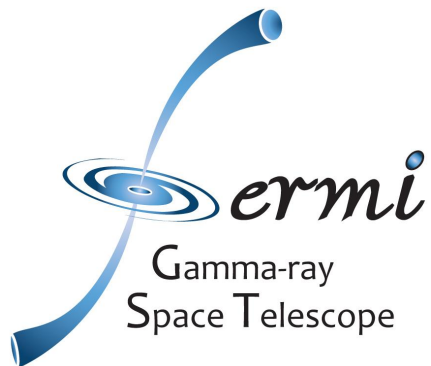


X-rays to gamma-rays:
Inverse Compton radiation

The *Fermi* blazar sequence from Ghisellini et al., MNRAS 2017

Gamma-ray observatories

Fermi-LAT satellite



- Started in 2008
- Orbits in 3 hours
- Energy range: 100 MeV-1 TeV
- Weekly sampled light curve production

Cherenkov Telescope Array Observatory

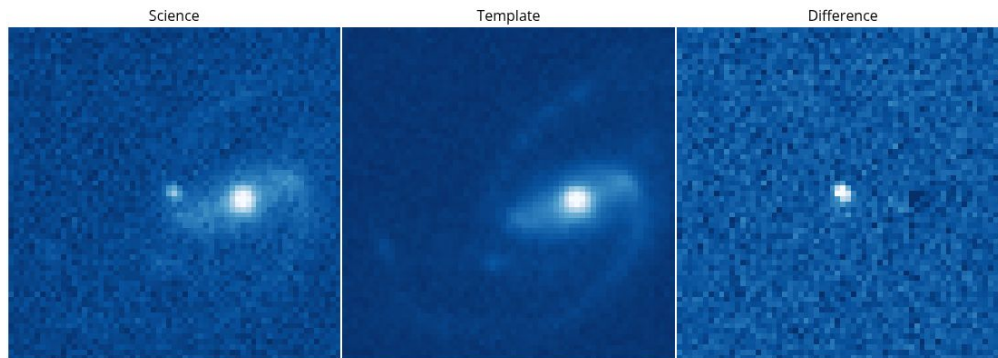


- 2 sites: Chile and La Palma
- Energy range: 20 GeV-200 TeV
- Energy resolution: <10%
- Sensitivity: x10 current gen.

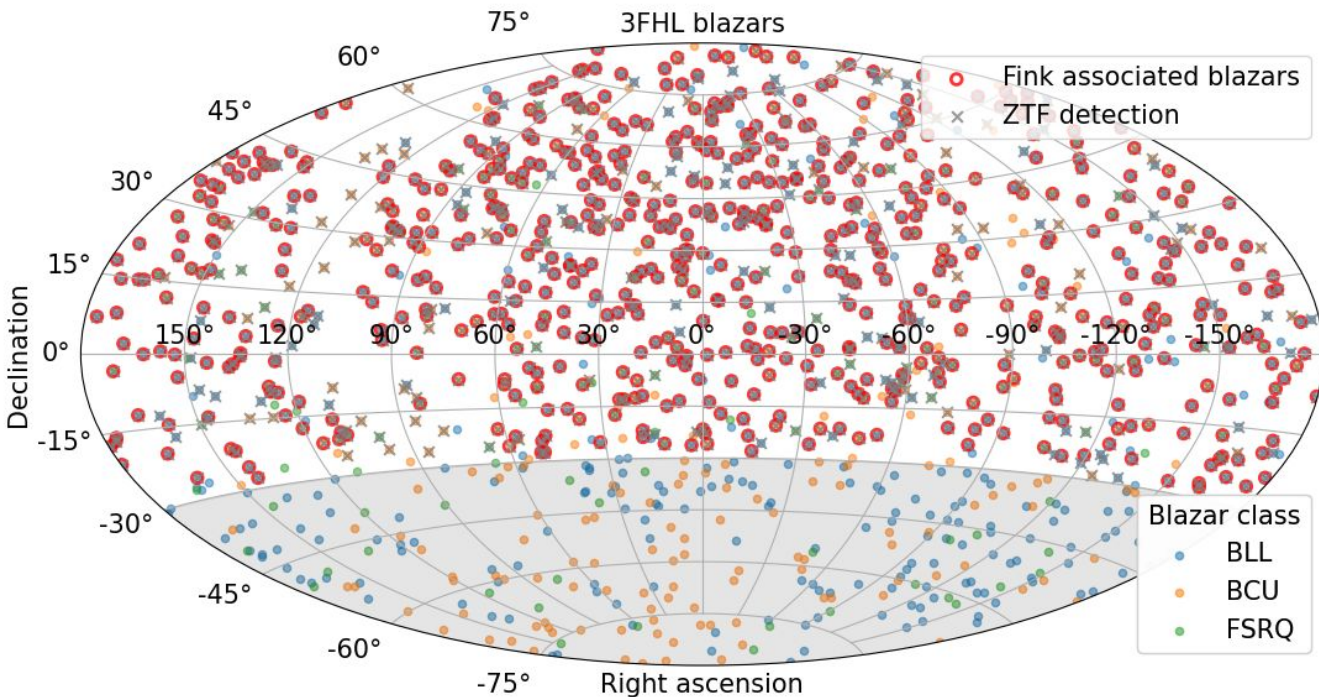
Alert broker: Fink



- ZTF stream real-time analysis
- Event database: 1B entries
- Community-based science modules
- KAKFA CGN-based
- Multi messenger inputs:
 - Optical spectrum
 - Gravitational waves...
- Personalizable output



3FHL/ZTF candidate association



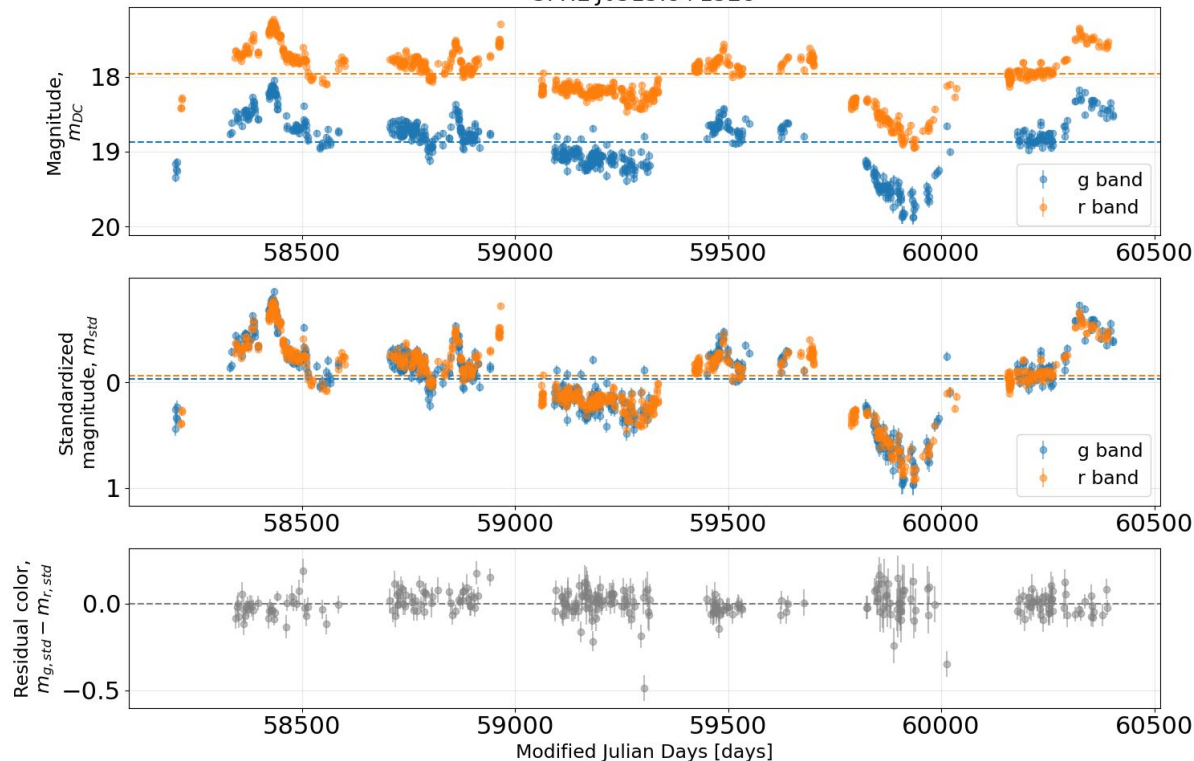
3FHL catalog:

1212 blazars

- No ZTF coverage: 282 (~23%)
- ZTF candidate: 815 (~67%)
 - Fink blazar: 621 (~76%)
- Remainder: ~10%
Not variable enough,
high magnitude

Standardization method

3FHL J0515.8+1528



Concomitant r & g band measurements:

$$\Delta t < 12\text{h}$$

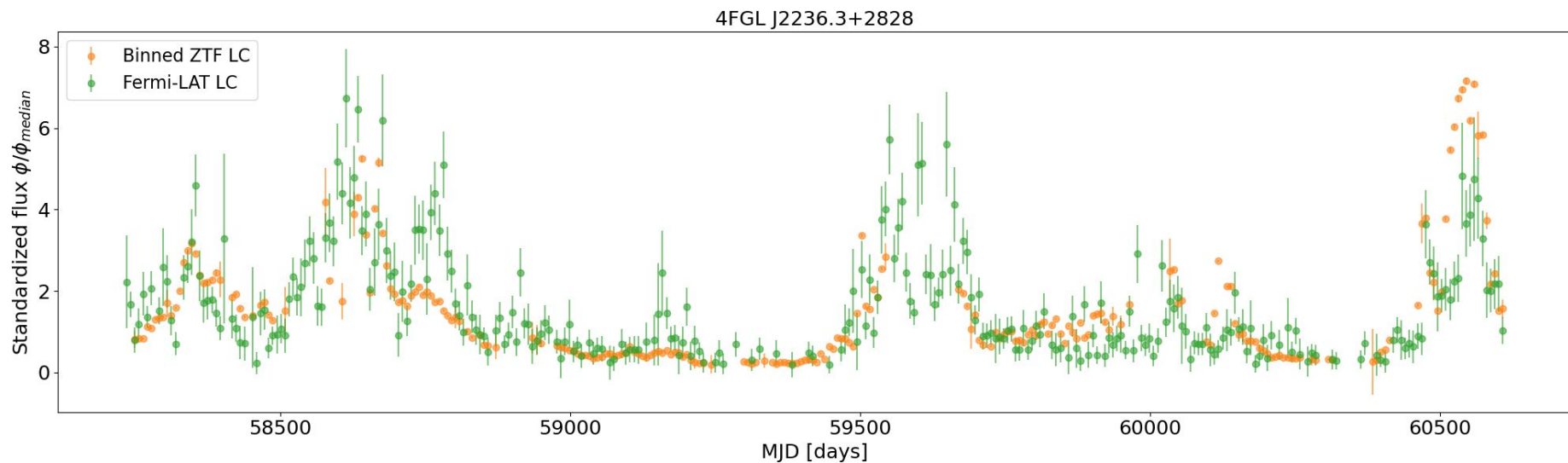
Standardization:

$$\text{mag} - \text{med}_{\text{con}}(\text{mag})$$

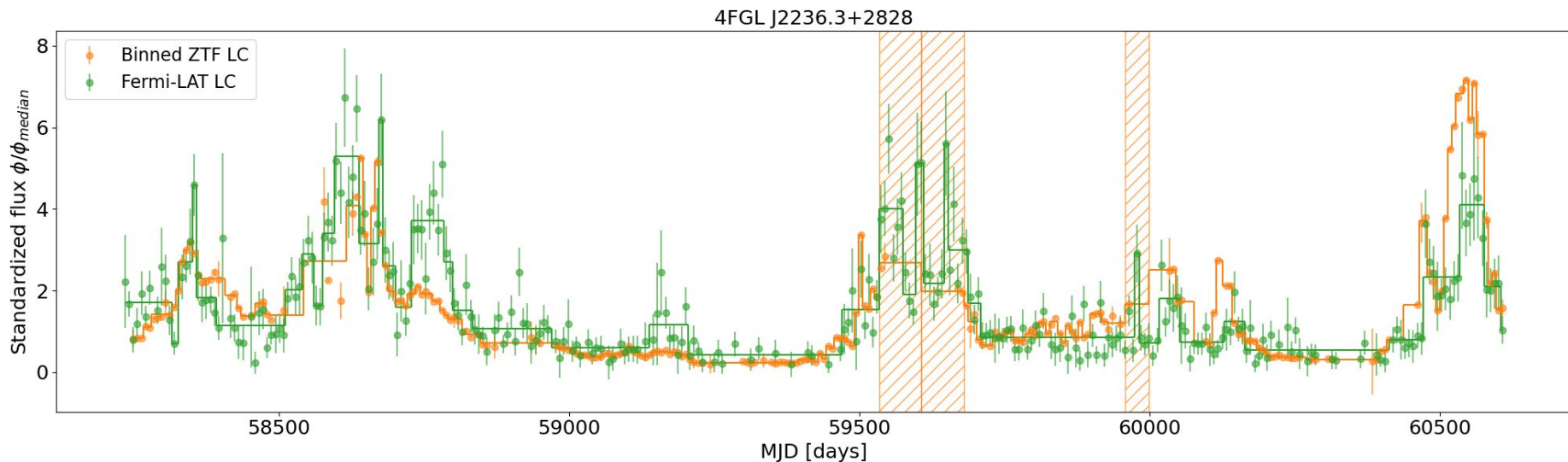
Residual color:

- Different emission processes in r- and g-band
- Intra-night time scale phenomena

Flare detection



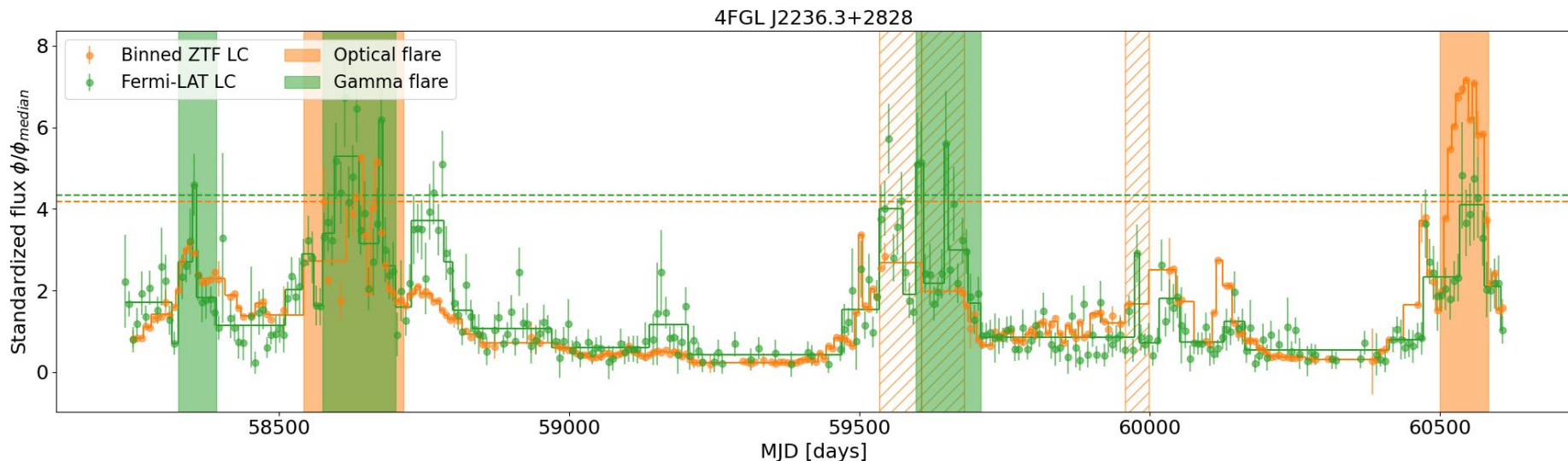
Flare detection



Independent detection of flare states:

- Bayesian block for flux state
- Only significant number of points

Flare detection



Independent detection of flare states:

- Bayesian block for flux state
- Only significant number of points
- Threshold from 95% quantile

Multi wavelength behaviour:

- Only gamma flare
- Only optical flare
- Cross bands flare

Fink: standardized flux panel

Search Data Transfer Gravitational Waves

Statistics

ZTF18aboksgd

BLLAC RADIO STAR UNKNOWN NAN
VSX: NAN ZTF: 0.0" PS1: 0.1" GAIA: 0.1"

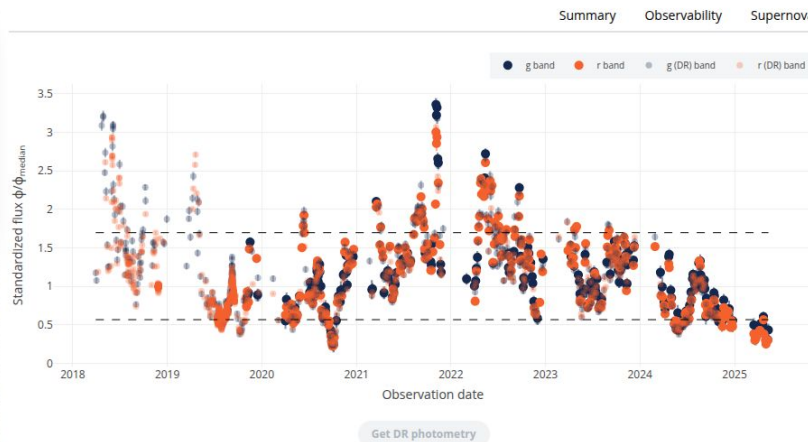
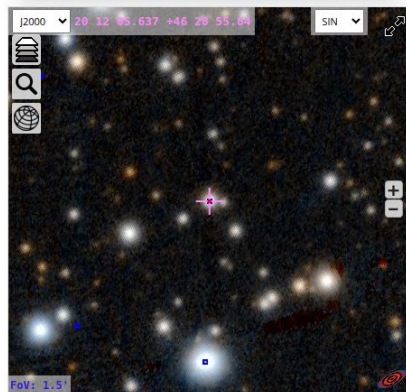
Discovery date: 2019-11-03 03:10:33

Last detection: 2025-05-11 10:53:14

Duration: 2016.32 / 2702.32 days

Detections: 539 good, 119 bad, 303 upper

RA/Dec: 20 12 05.64 +46 28 55.8



How to use this panel?

This light curve is obtained by dividing each band by a meaningful calculation of its median. Each median is calculated by selecting measurements in one band if and only if there is at least one other measurement in the other band less than 12 hours after the first. The sub-selections of measurements are then used to calculate the respective medians.

Once these medians have been calculated, the entire light curve is divided by its overall median to make it equal to 1.

The slider allows you to drag the lowest and highest percentile of your choice. When you are happy with the value for that percentile, click Update Plot.

You can also add measurements from the Data Release by loading them using the Get DR Photometry button.

Summary Observability Supernovae Variable stars Solar System Tracklets **Blazars** GRB

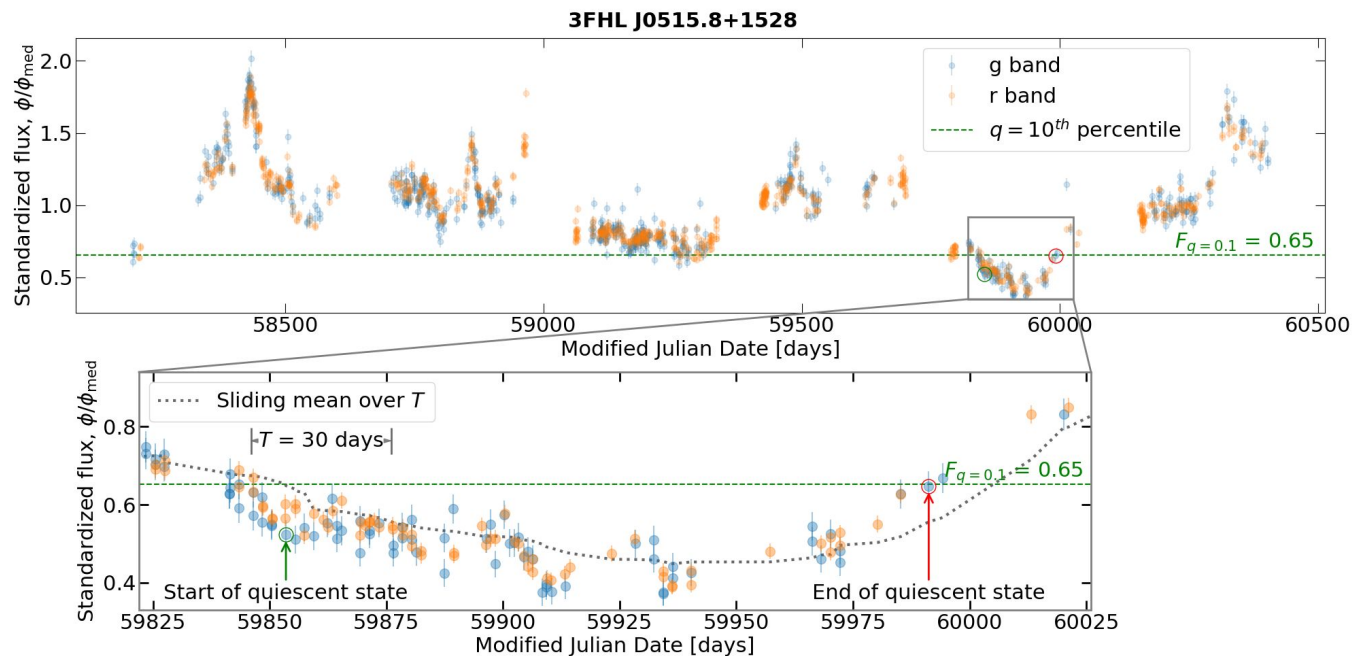
Neighbourhood



Update plot

3FHL Name:
3FHL J2012.0+4629

Fink: low state detection



- 1st criterion:
Measurement
< threshold
- 2nd criterion:
Mean flux of the
last 30 days
< threshold



+ Monthly/Weekly
newsletter

Conclusion

Correlation between optical and gamma-ray bands

⇒ Possible **common origin population** for Synchrotron and Inverse Compton radiation

- Correlation study in extreme states

Current results:

- High state correlation in optical and gamma-ray bands: **multiple mechanisms?**
- Modules and panels added in Fink broker (+ possible extension to sources outside of blazars)

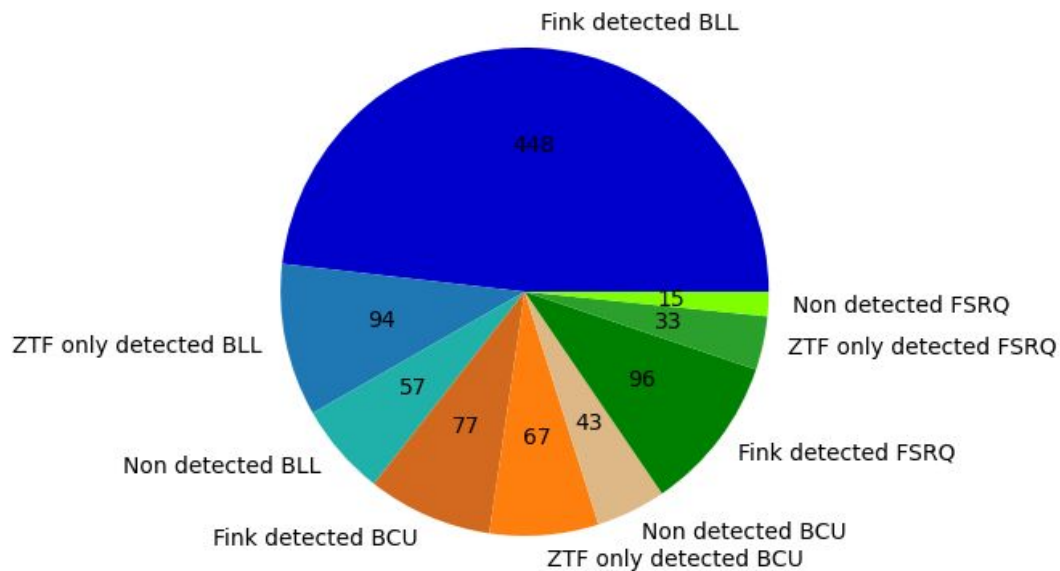
Next steps:

- Characterization of optical and gamma-ray flares to differentiate multi- and mono-wavelength flares
- Characterization of blazar light curves in multiple bands → new blazar detection possible from ZTF and LSST

Backup Slides

Dataset

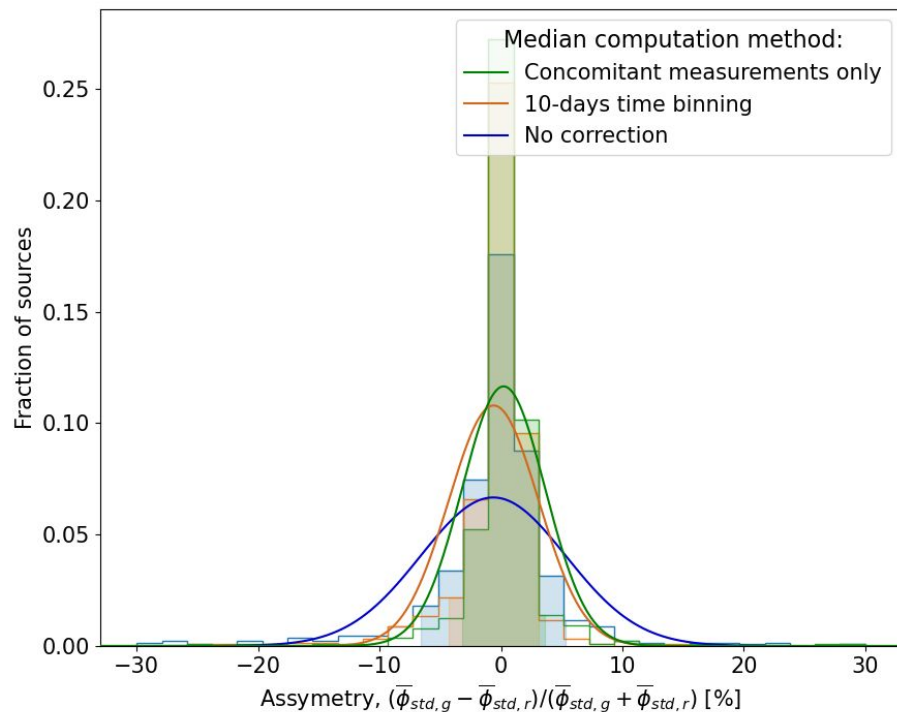
Classes of the 3FHL - 1212 objects
621 Fink detected - 815 ZTF detected - 115 undetected
+ 282 objects with Dec < 30°



1212 objects:

- 23% < 30° Dec
- 88% detected by ZTF
- 67% classified as blazars
- 12% not detected
 - Multiples sources
 - Not enough variation
 - Too high magnitude

Standardization methods

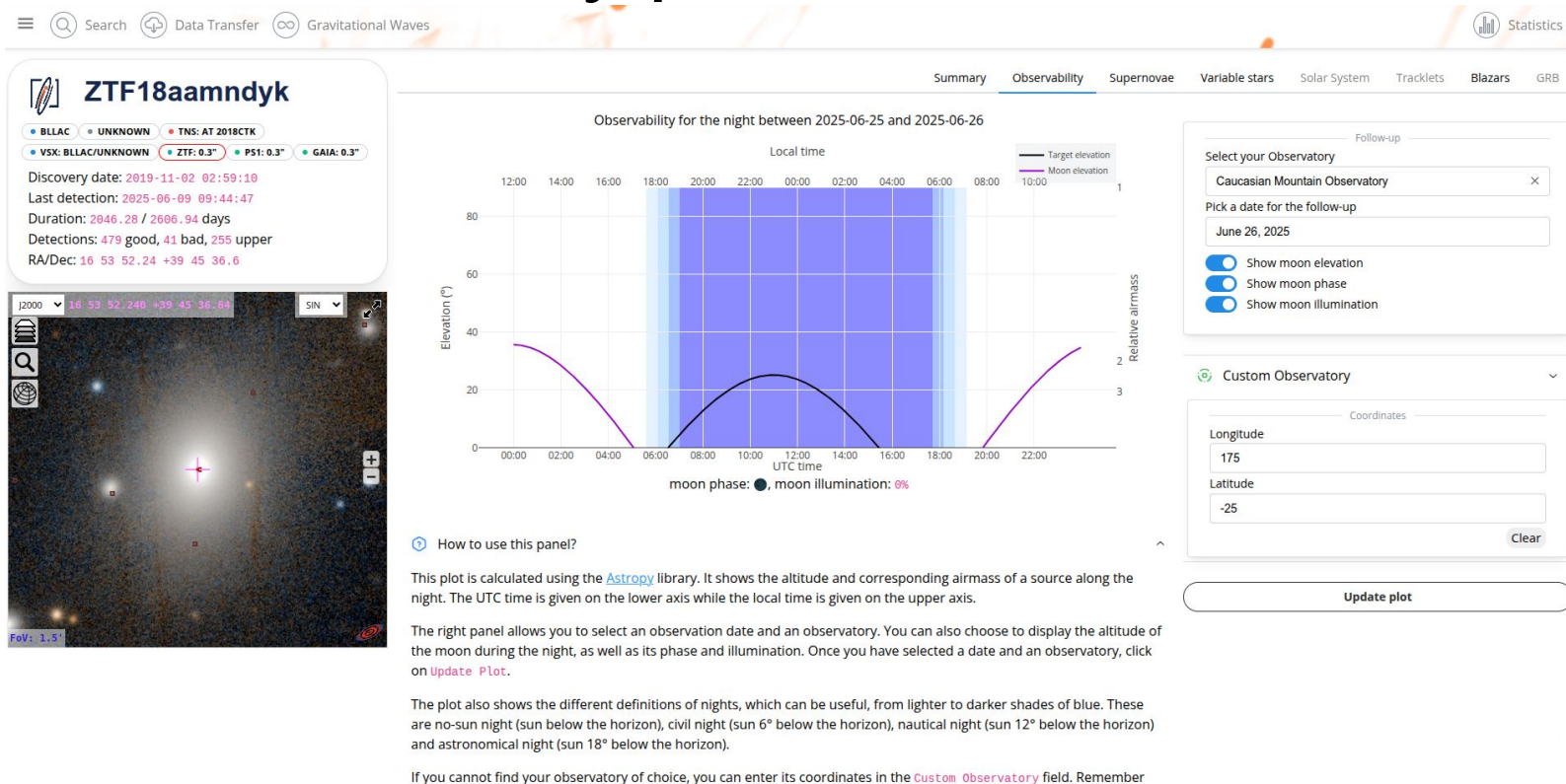


- No correction method:
 - Mean: $-6 \times 10^{-3} \%$
 - Std: $6.0 \times 10^{-2} \%$
- 10-days time binning method:
 - Mean: $-6 \times 10^{-3} \%$
 - Std: $3.7 \times 10^{-2} \%$
- Concomitant measurement method:
 - Mean: $2 \times 10^{-3} \%$
 - Std: $3.4 \times 10^{-2} \%$

⇒ Smaller std: Less residual color

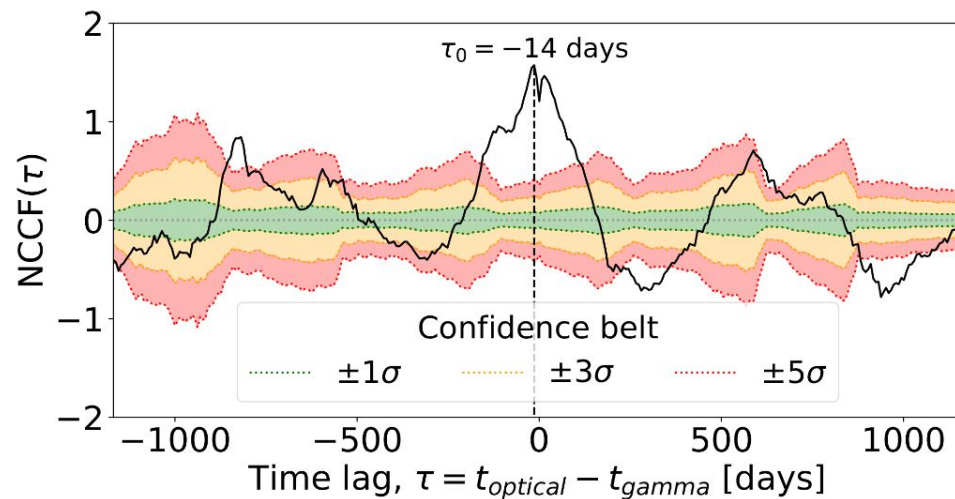
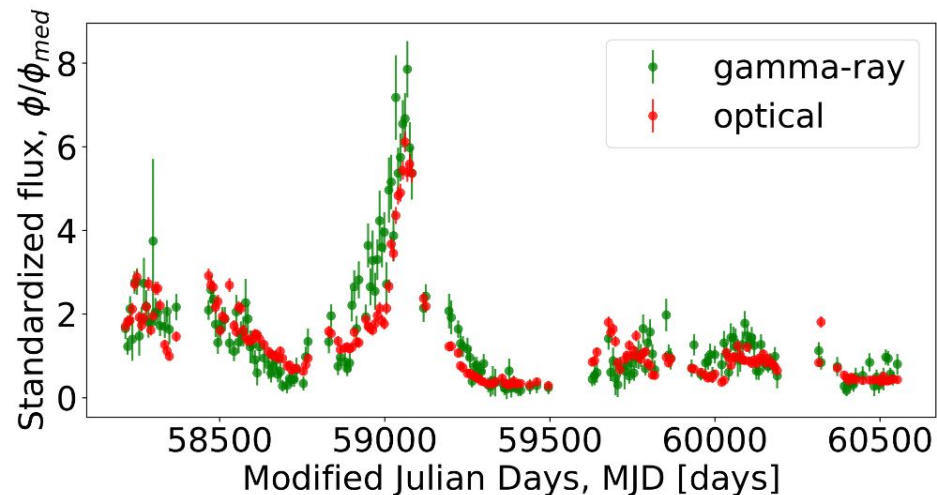
⇒ Smaller mean: weaker systematic offset

Fink: observability panel



Cross correlation result

4FGL J1504.4+1029 / QSO B1502+1041



Standardization process applicable to other wavelength: *Fermi*-LAT

→ Significance of the cross-correlation to a non correlated multiband signal

Normalized Cross-Correlation Function

$$\text{NCCF}(\tau) = \frac{1}{N - n_\tau + 1} \frac{1}{\sqrt{(\sigma_x^2 - \bar{e}_x^2)(\sigma_y^2 - \bar{e}_y^2)}} \sum_i (x_{i+n_\tau} - \bar{x})(y_i - \bar{y})$$

$$\sigma_{\text{NCCF}}(\tau) = \frac{1}{N - n_\tau + 1} \frac{1}{\sigma_x} \sqrt{\left(1 + \frac{1}{N}\right) \sum_{i=0}^N x_{i+n}^2 - \frac{1}{N} \left(\sum_{i=0}^N x_{i+n}\right)^2}$$