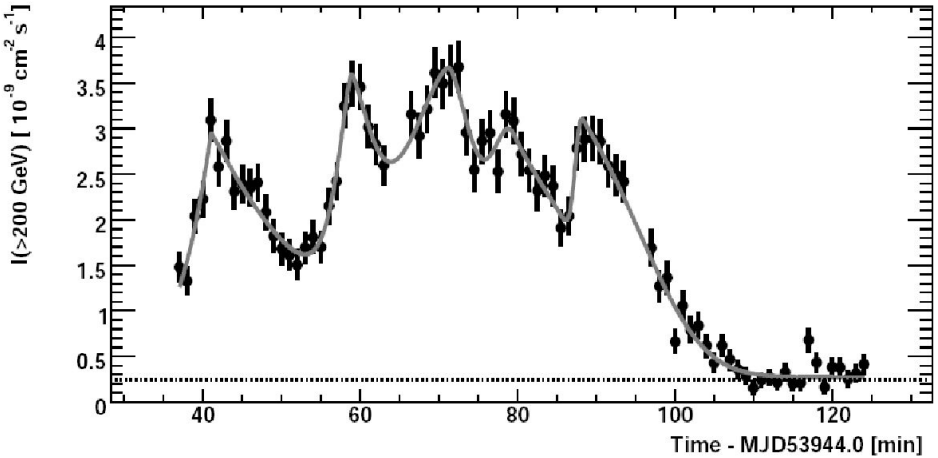
A new era for the blazar multi-wavelength studies with Rubin and CTAO

Julian Hamo, with Julien Peloton and Jonathan Biteau

Blazar variability

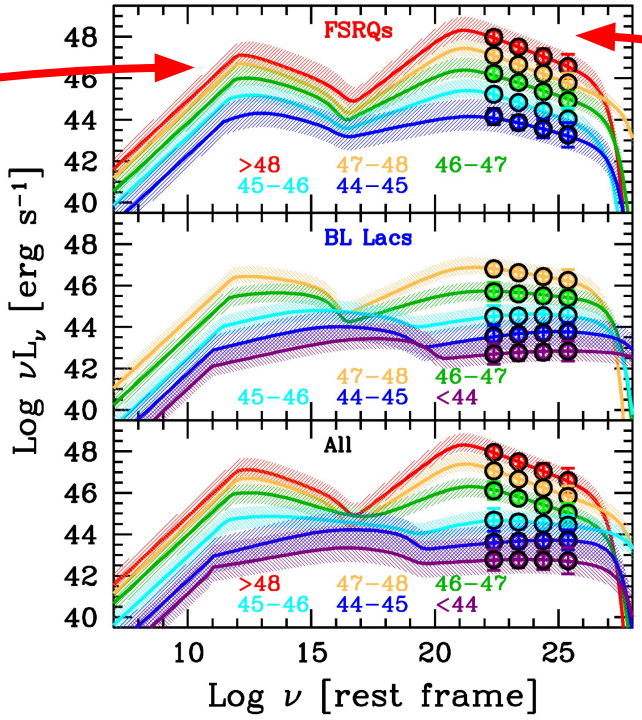


Flare from PKS 2155-304 from Aharonian et al., ApJ 2018

Stochastic process:
→ Hard-to-predict variability
(no typical timescale)

Flux variability range from up to 2 order of magnitude

Blazar SED



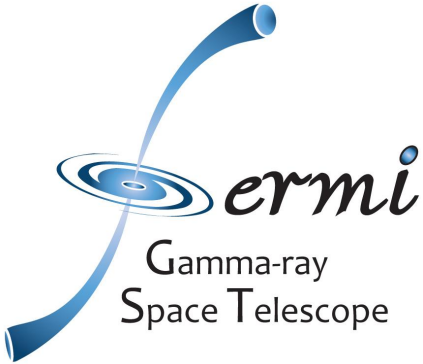
Optical to X-rays:
Synchrotron radiation

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

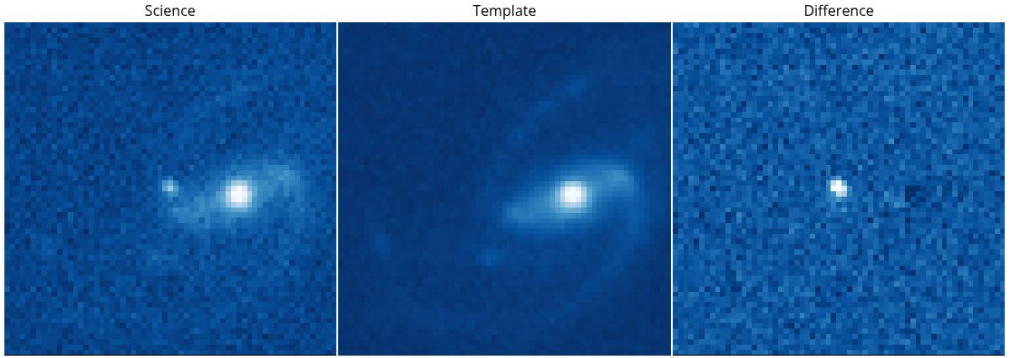
CTAO

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

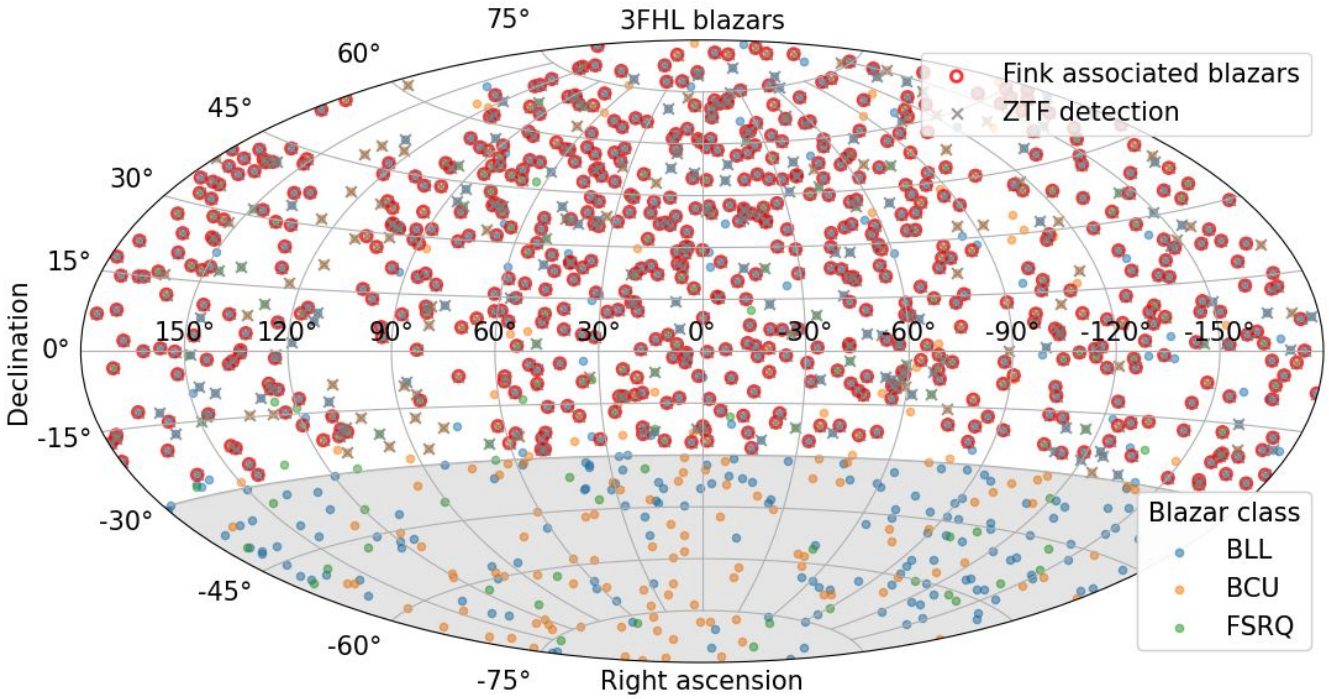
Alert broker: Fink

- 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



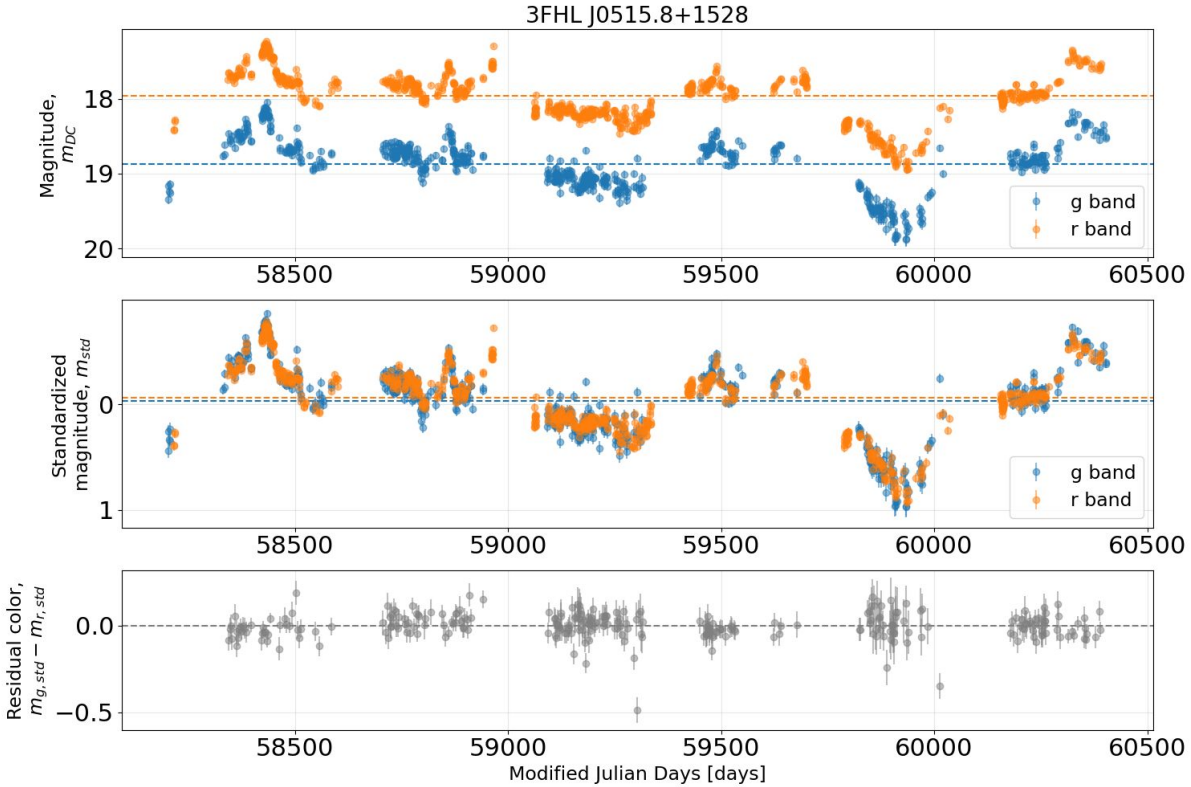
3FHL/ZTF candidate association



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



Concomitant r & g band measurements:

$\Delta t < 12h$

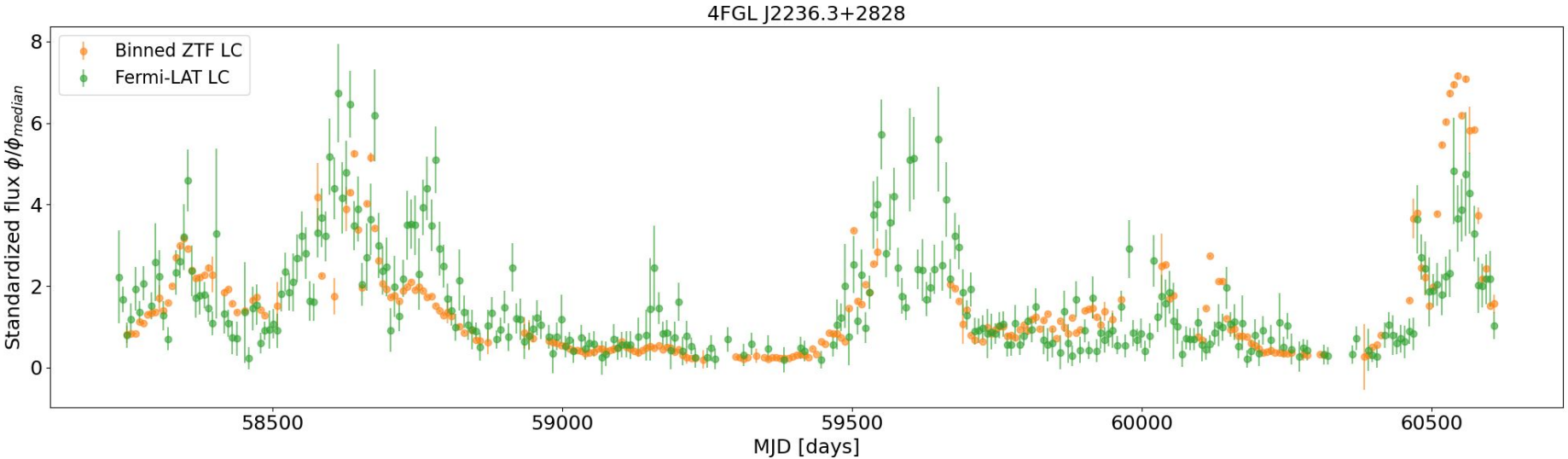
Standardization:

$mag - med_{con}(mag)$

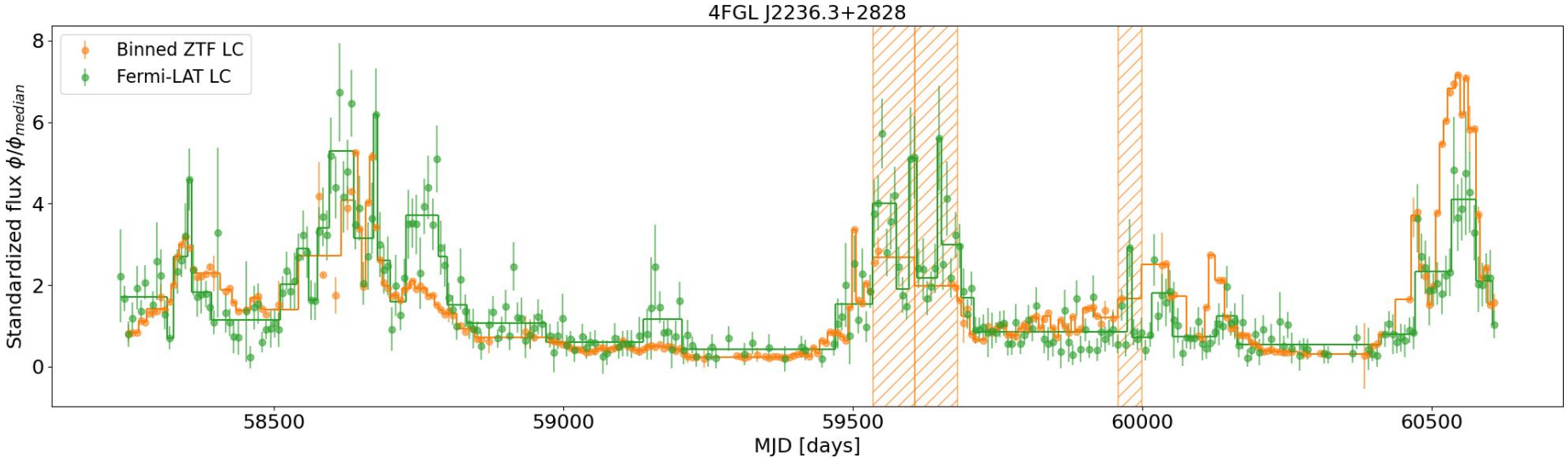
Residual color:

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

Flare detection



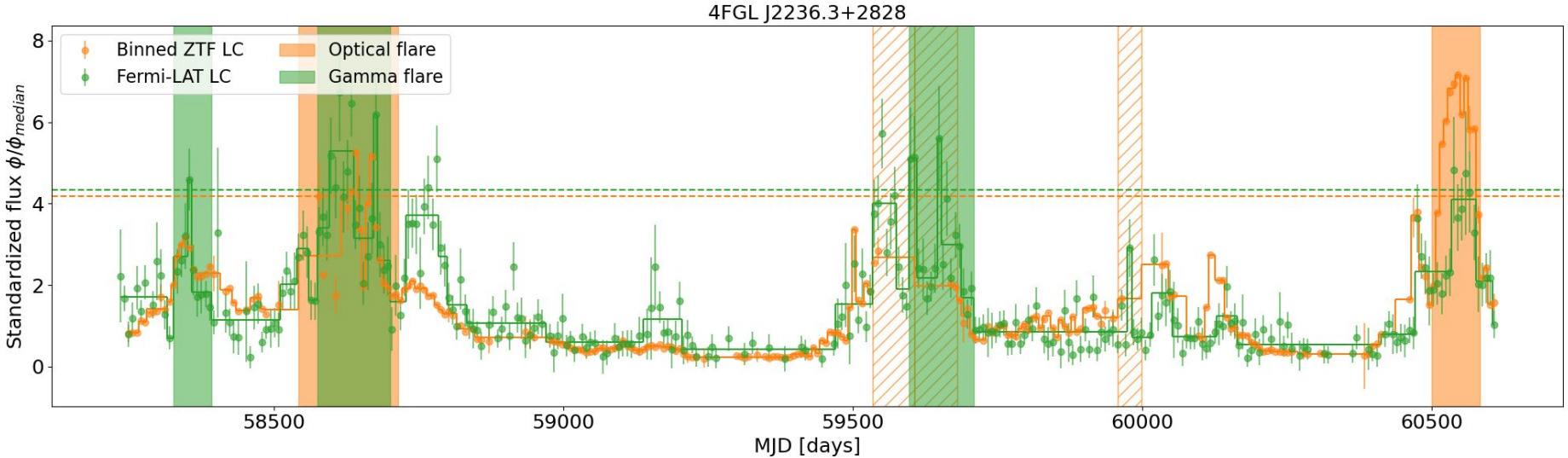
Flare detection



Independent detection of flare states:

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

Flare detection



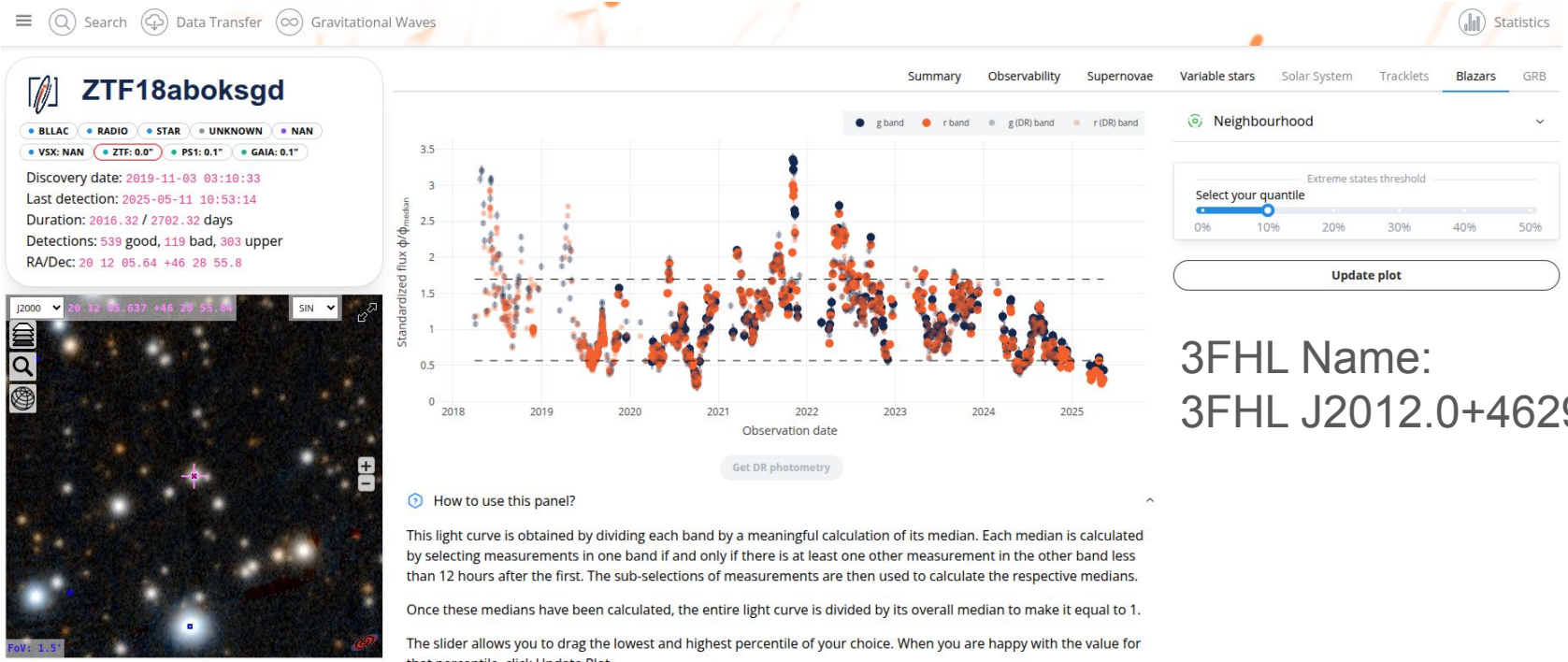
Independent detection of flare states:

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

Multi wavelength behaviour:

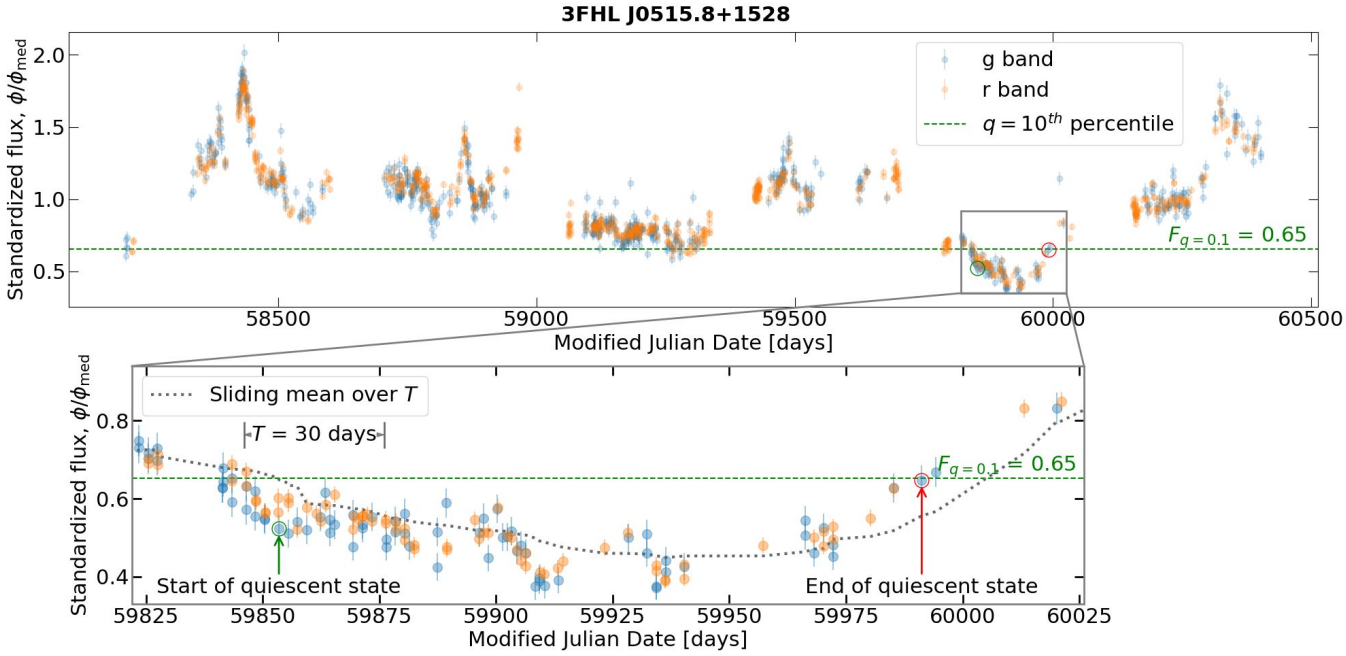
- Only gamma flare
- Only optical flare
- Cross bands flare

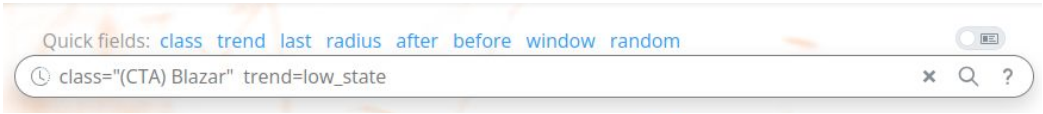
Fink: standardized flux panel



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)

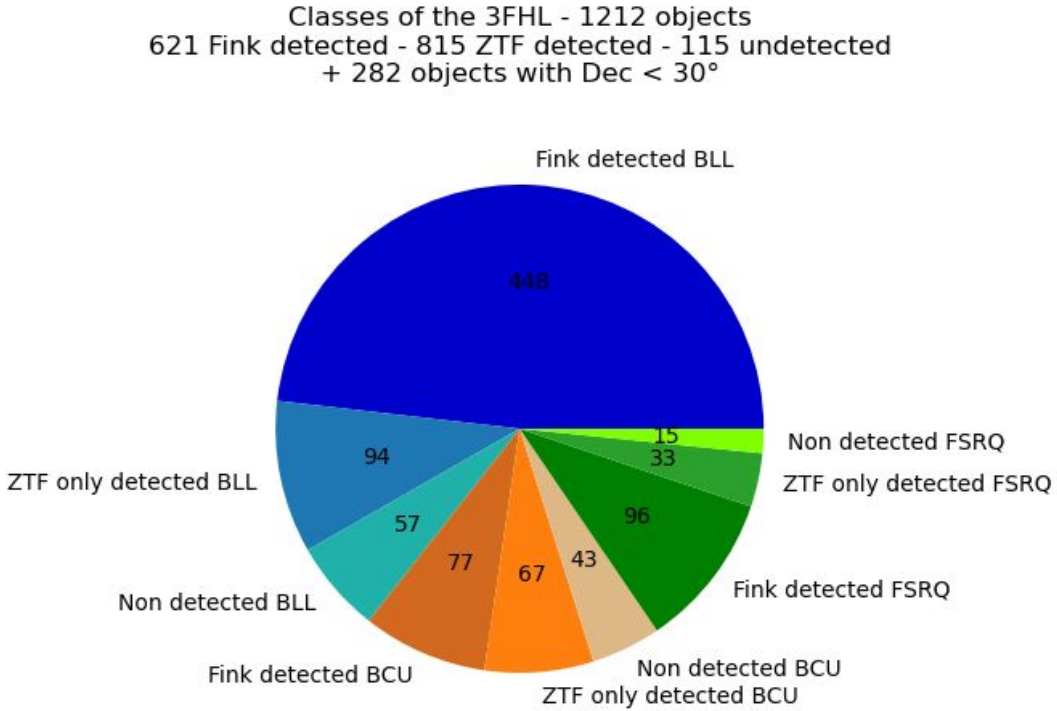
Next steps:

- 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

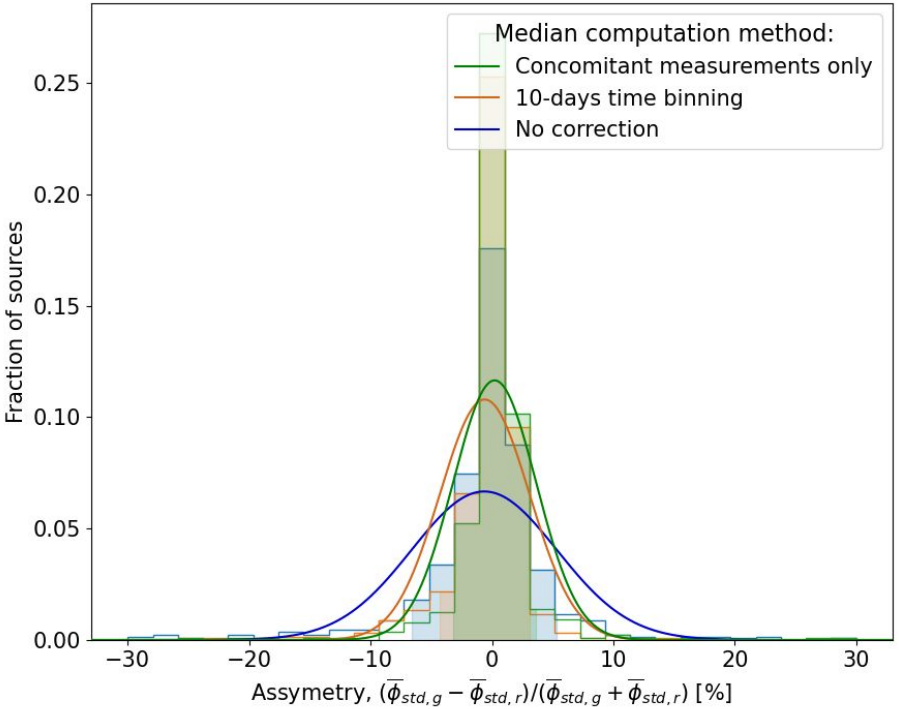
Dataset



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

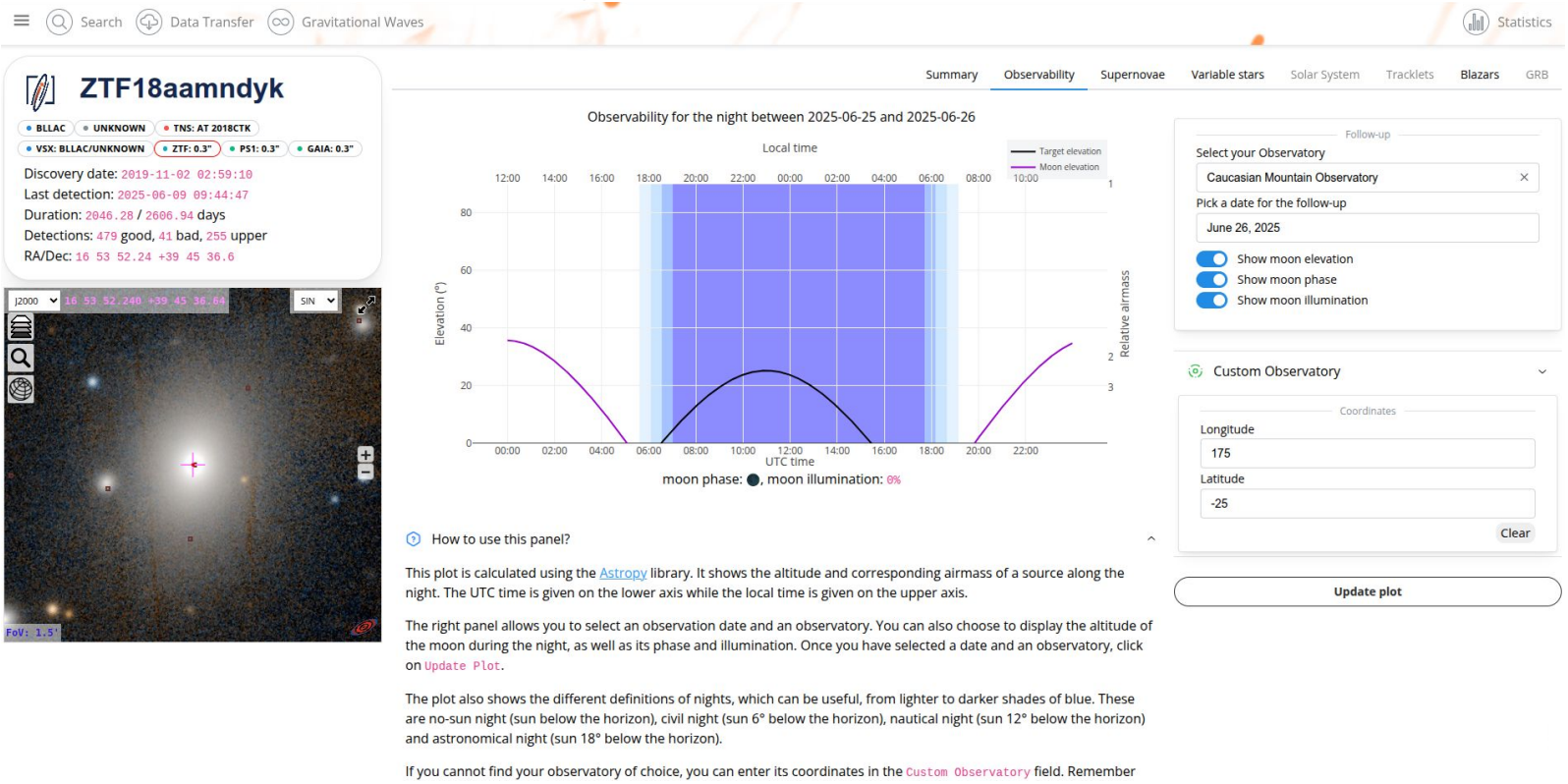


- No correction method:
  - Mean: -6x10^{-3} %
  - Std: 6.0x10^{-2} %
- 10-days time binning method:
  - Mean: -6x10^{-3} %
  - Std: 3.7x10^{-2} %
- Concomitant measurement method:
  - Mean: 2x10^{-3} %
  - Std: 3.4x10^{-2} %

⇒ Smaller std: Less residual color

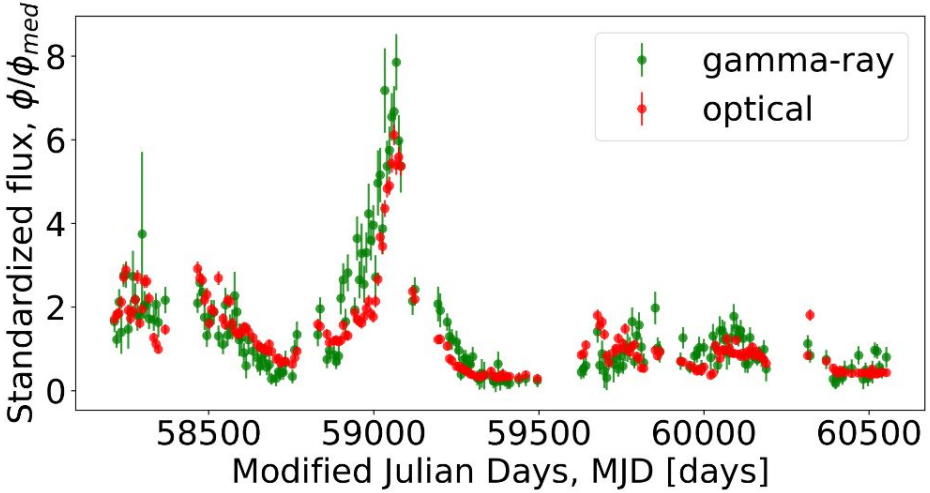
⇒ Smaller mean: weaker systematic offset

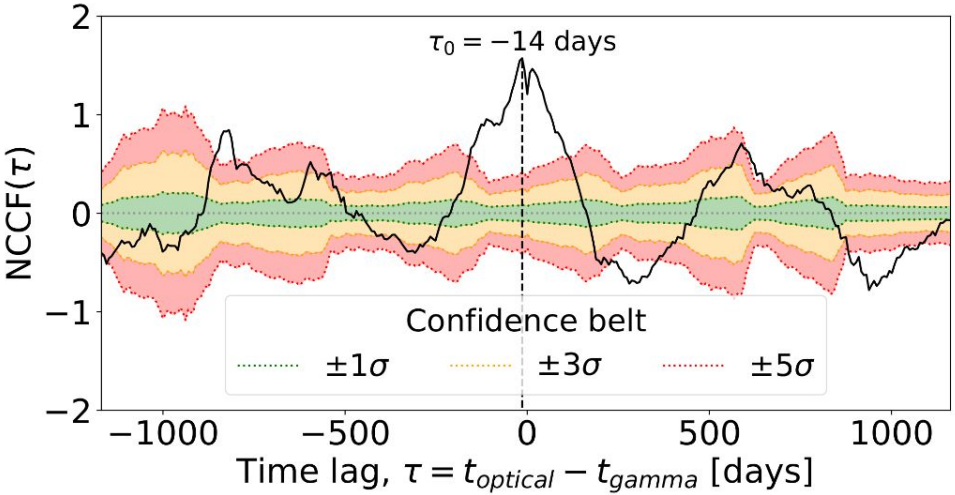
Fink: observability panel



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

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

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