

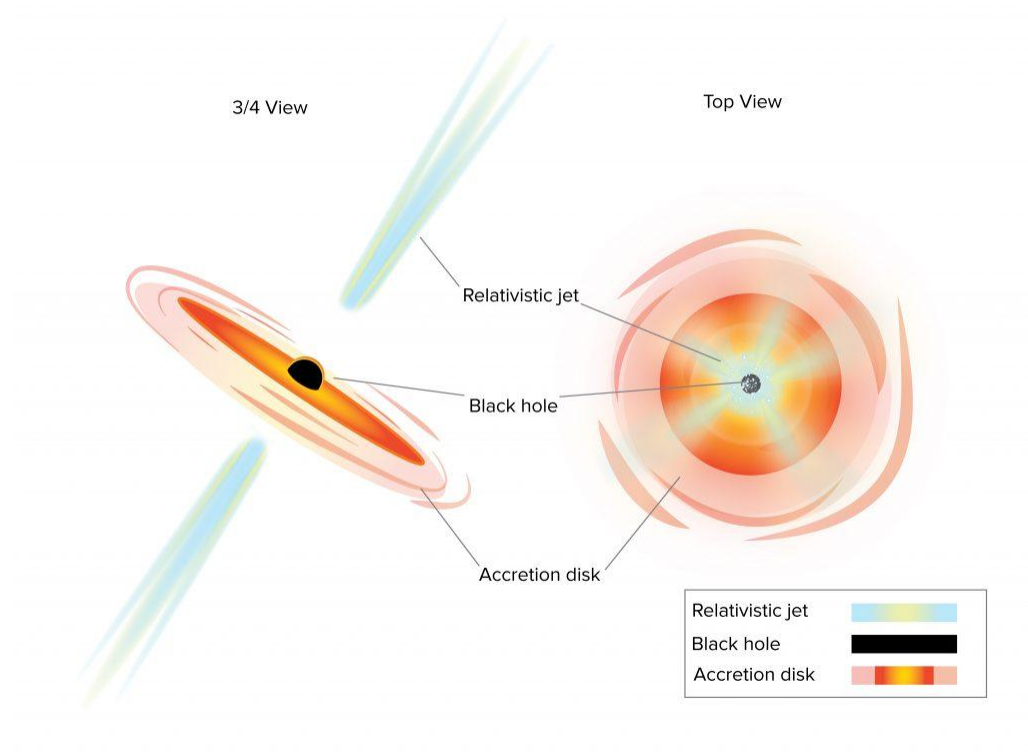
A new era for the blazar multi-wavelength studies with Rubin and the CTAO

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

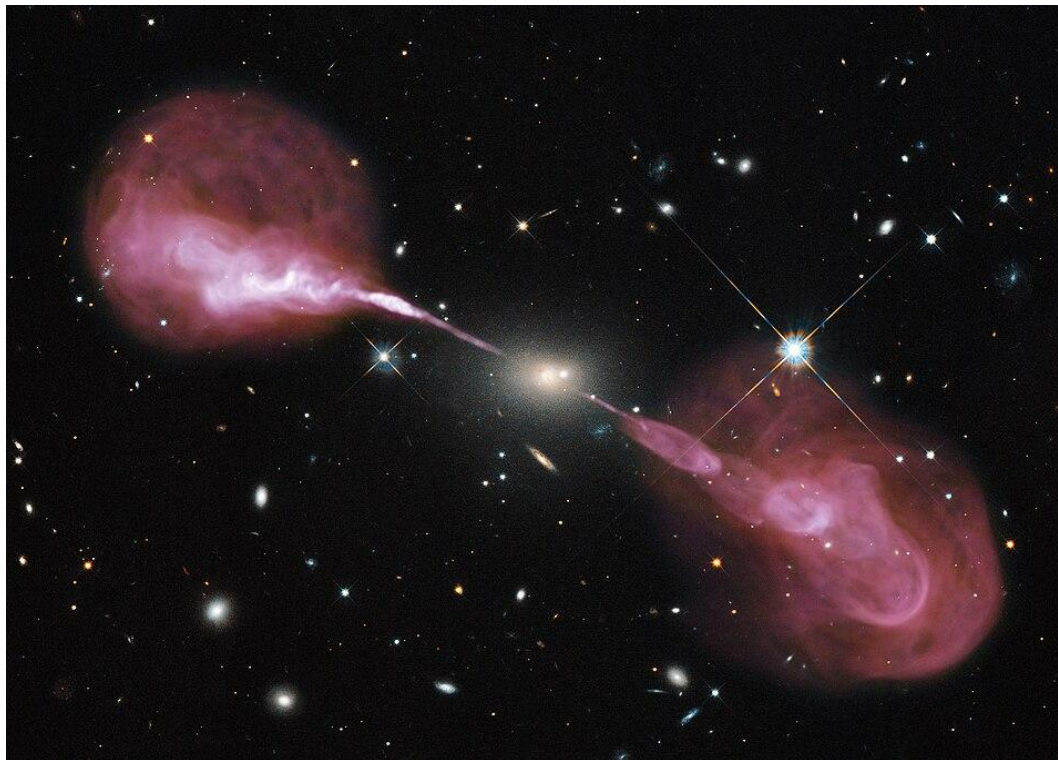
What is a blazar?

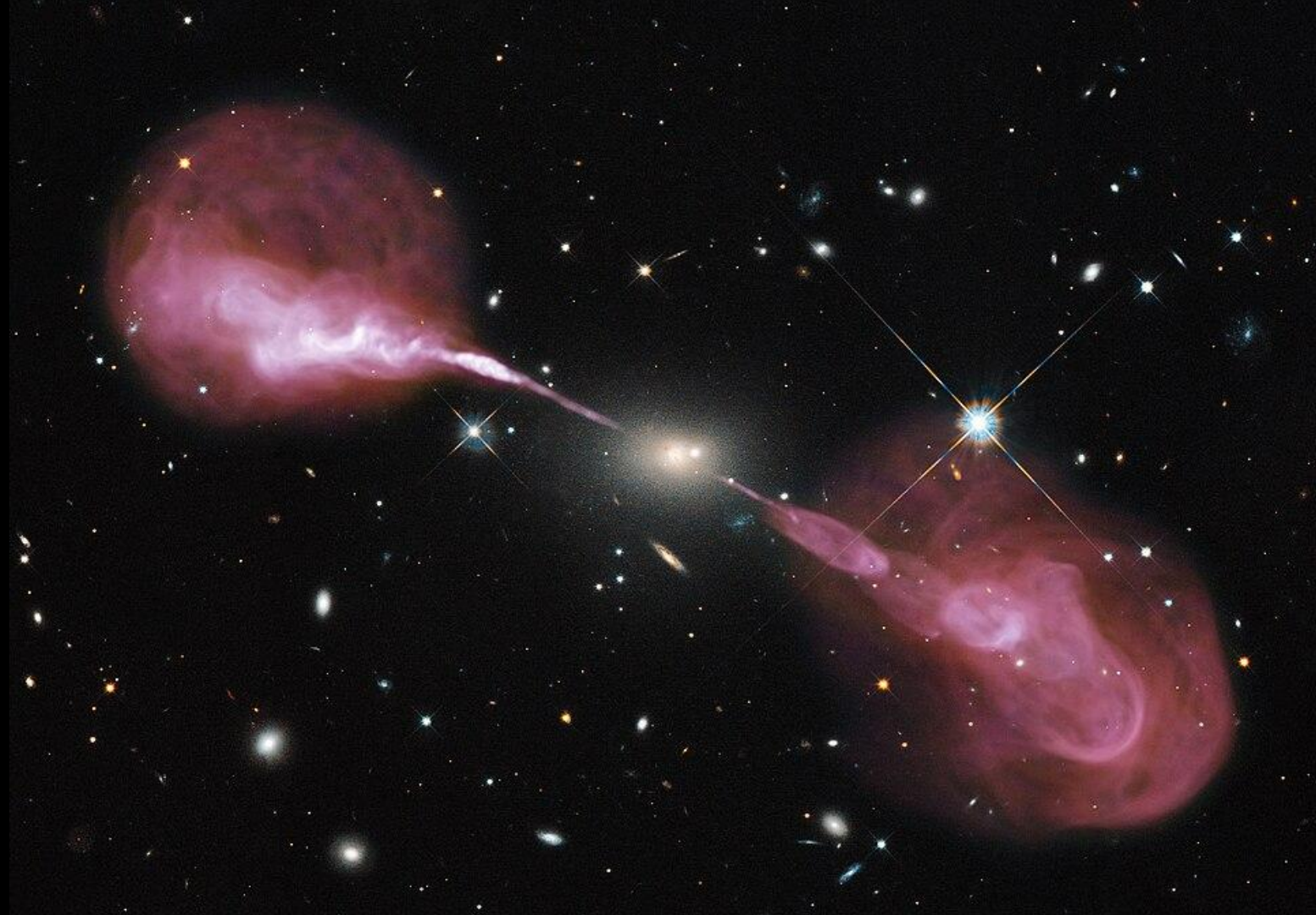
From AGNs to blazars

- Radio-loud jetted AGN
- Jet pointing the line of sight
- Extremely bright compared to the host galaxy (up to 10-100 times)
- Extremely variable (~min to years)

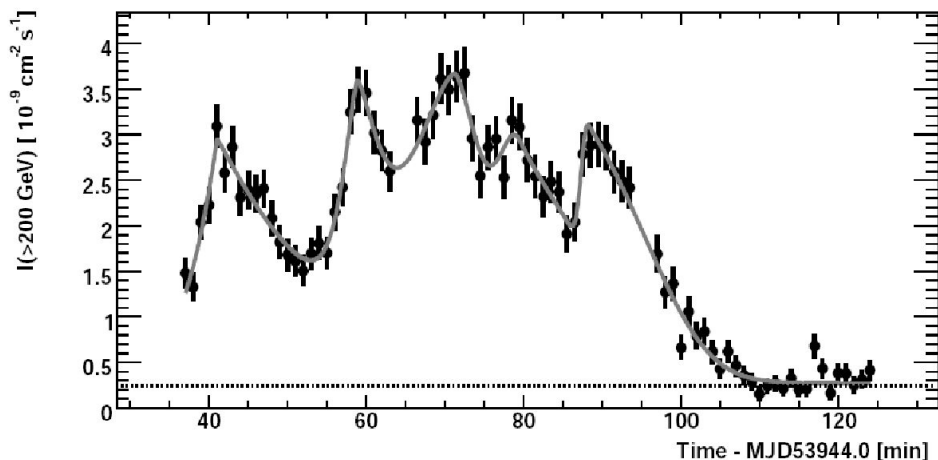


From AGNs to blazars





Blazar variability



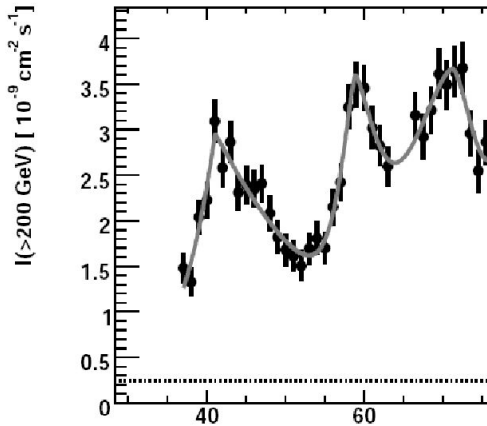
Flare from PKS 2155-304 from Aharonian et al., ApJ 2018

Stochastic process:

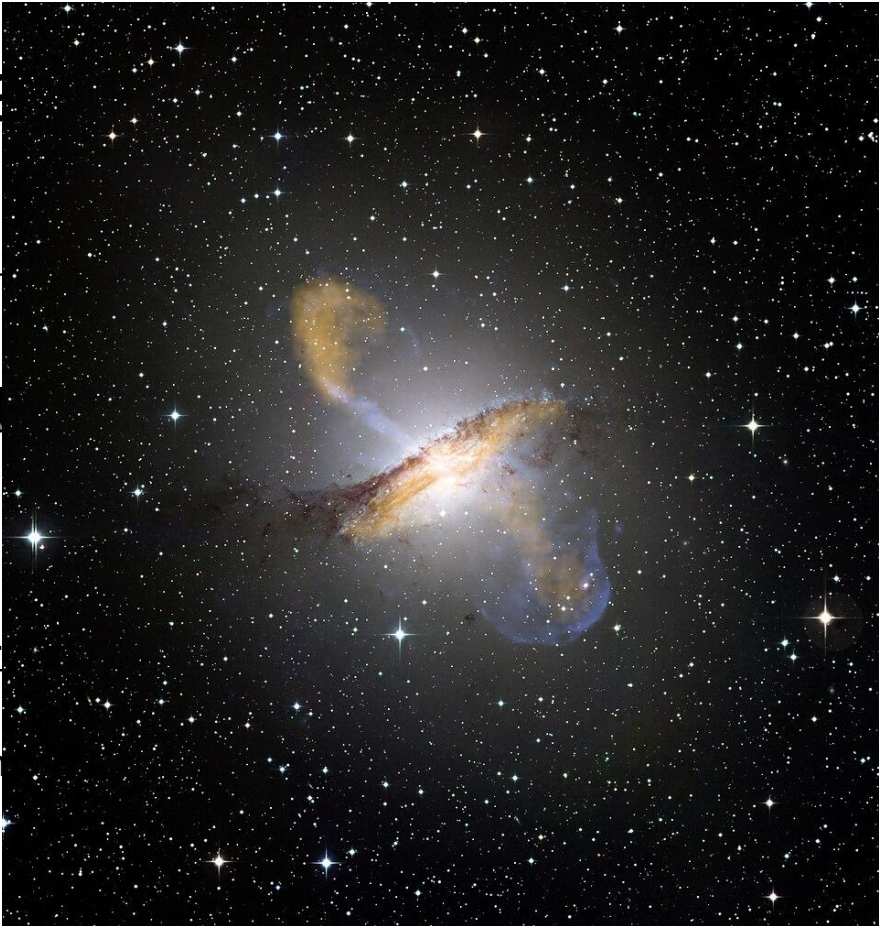
→ Hard-to-predict variability
(no typical timescale)

Flux variability range from up to 2 order
of magnitude

Blazar variability



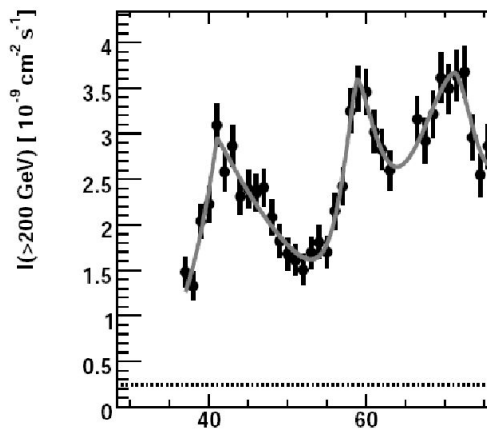
Flare from PKS 2155-304 from



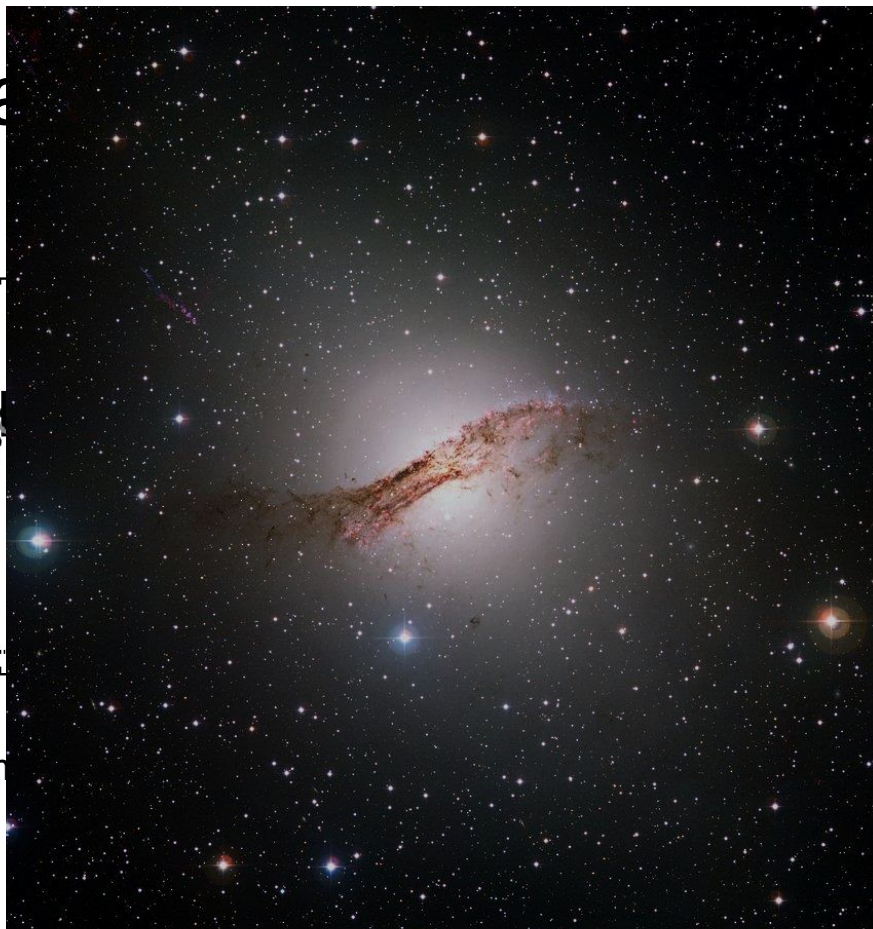
...ss:
...t variability
...mescale)

...ange from up to 2 order

Blazar variability



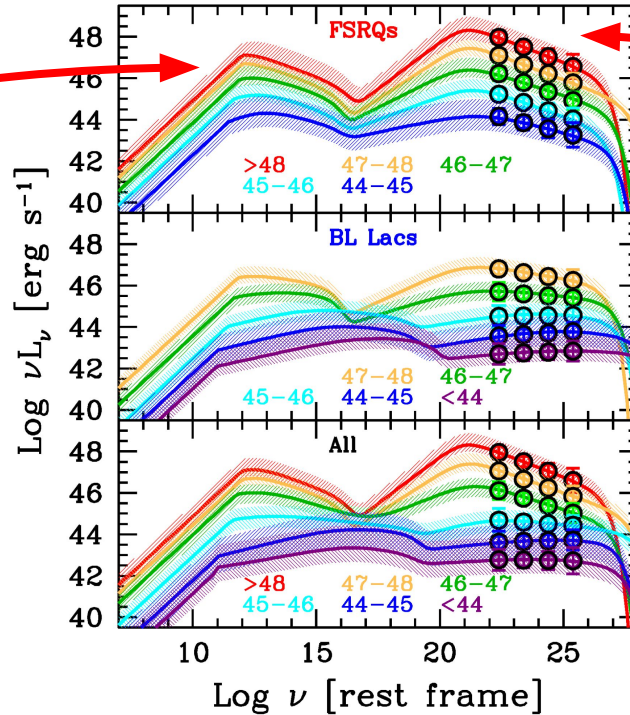
Flare from PKS 2155-304 from



ss:
t variability
(mescale)

ange from up to 2 order

Blazar SED



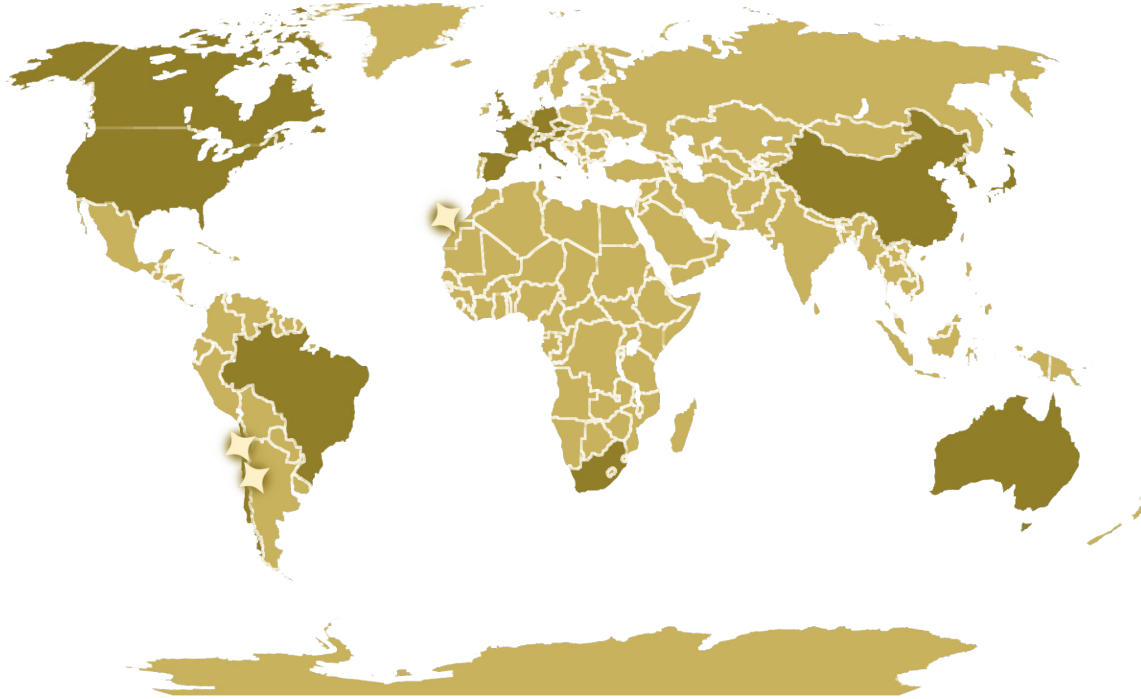
X-rays to gamma-rays:
Inverse Compton radiation

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



How to observe them?

The new generation observatories



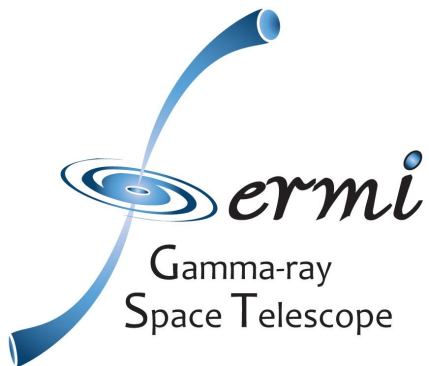
Credits: Gabriel Pérez Diaz



Credits: NOIRLab/NSF/AURA

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



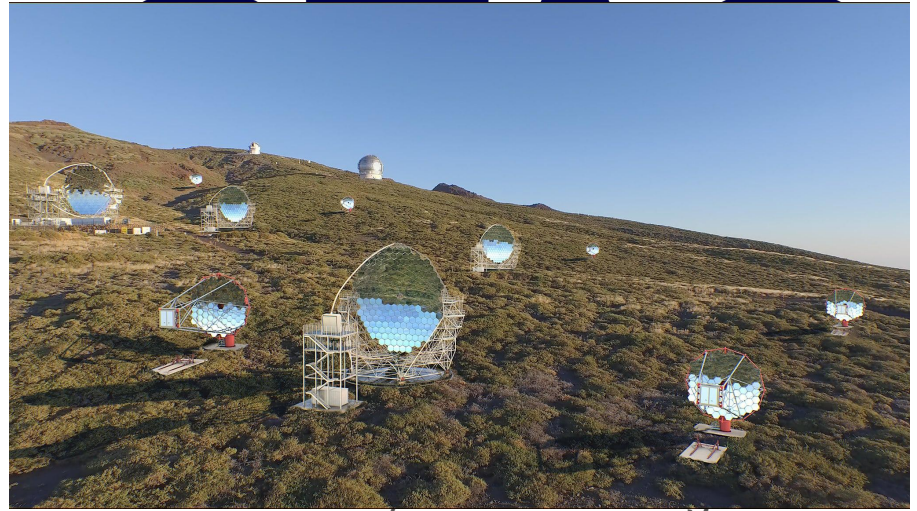
- 2 sites: Chile and La Palma
- Energy range: 20 GeV-200 TeV
- Energy resolution: <10%
- Sensitivity: x10 current gen.

Gamma ray observatories



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

Cherenkov Telescope Array Observatory



Large Scale optical Surveys

ZTF with the Palomar Observatory



- 3 filters (g, r, i)
- Up to -30 declination
- 100k alerts/night
- ~20.5 max magnitude

LSST with the Vera Rubin Observatory



- 6 filters (u, g, r, i, z, y)
- Up to +30 declination
- 10M alerts/night
- ~23 max magnitude



veys

LSST with the Vera Rubin Observatory



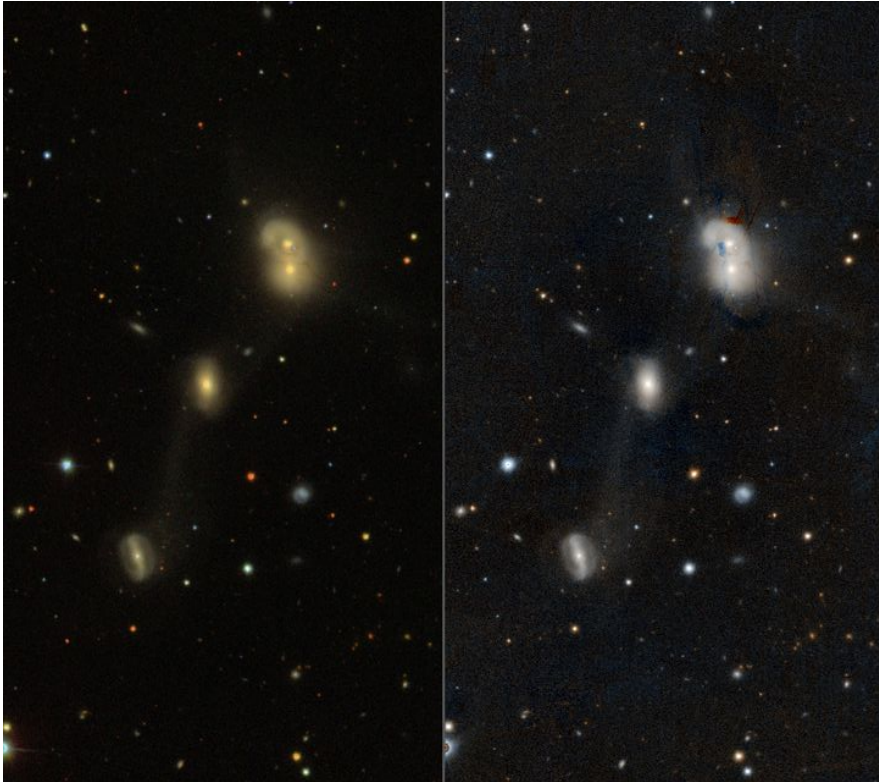
- 3 filters (g, r, i)
- Up to -30 declination
- 100k alerts/night
- ~20.5 max magnitude



Rubin observatory: a comparison



Rubin observatory: a comparison



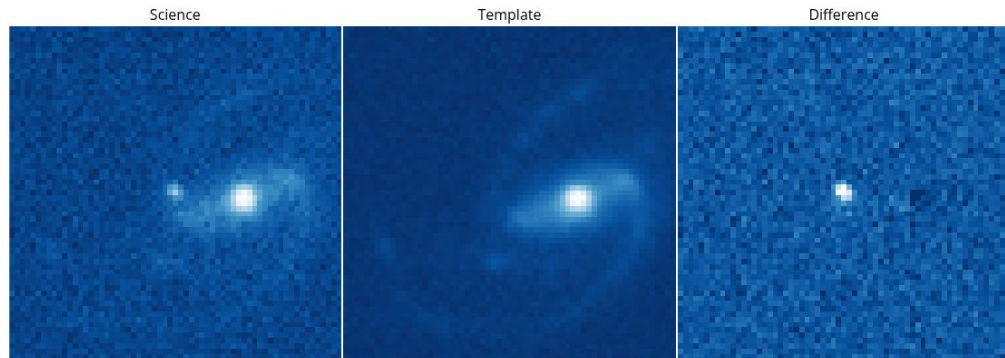
Julian Hamo

Rubin observatory: a comparison



Julian Hamo

Alert broker: Fink

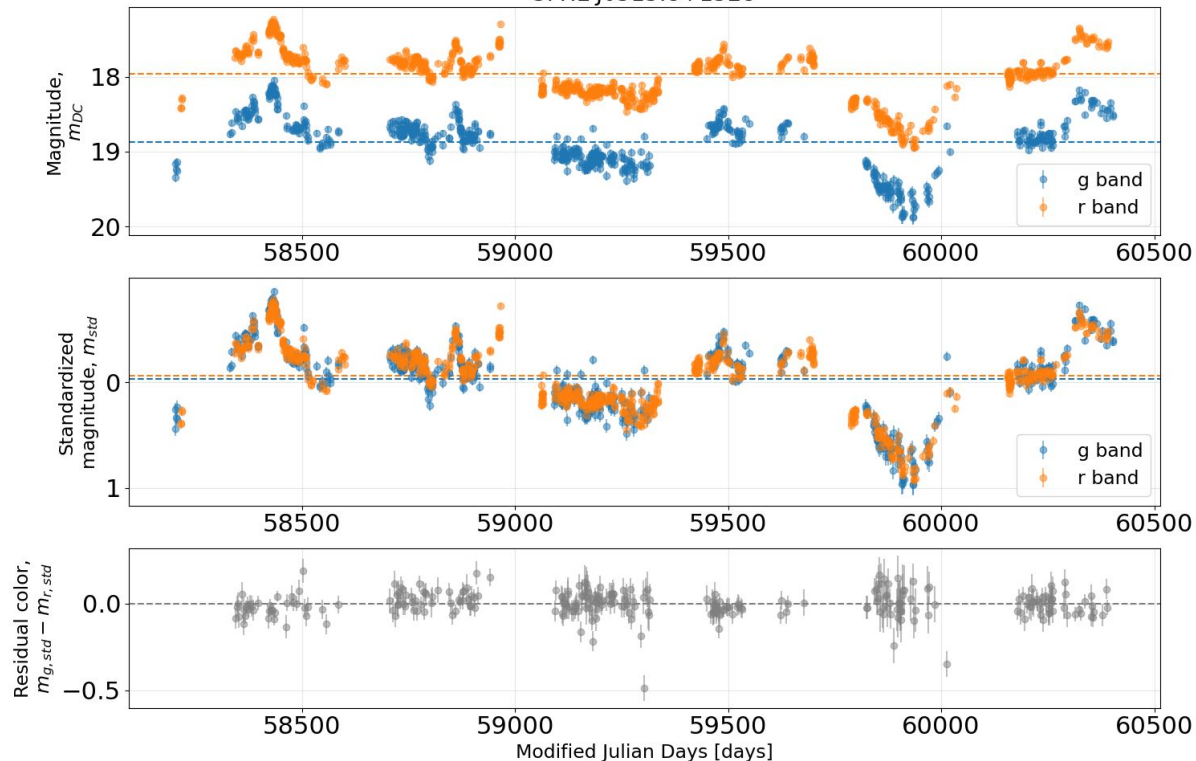


- ZTF/LSST stream real-time analysis
- Multi-messenger input (GW, neutrinos, MWL spectrum - through GCN)
- Community-based science modules with personalizable output - we do what you want!
- 10^7 alerts in a night, less than 60s seconds before the closing of the shutter and the data delivered at home

What is my work in there?

Standardization method

3FHL J0515.8+1528



Concomitant r & g band measurements:

$$\Delta t < 1\text{h}$$

Standardization:

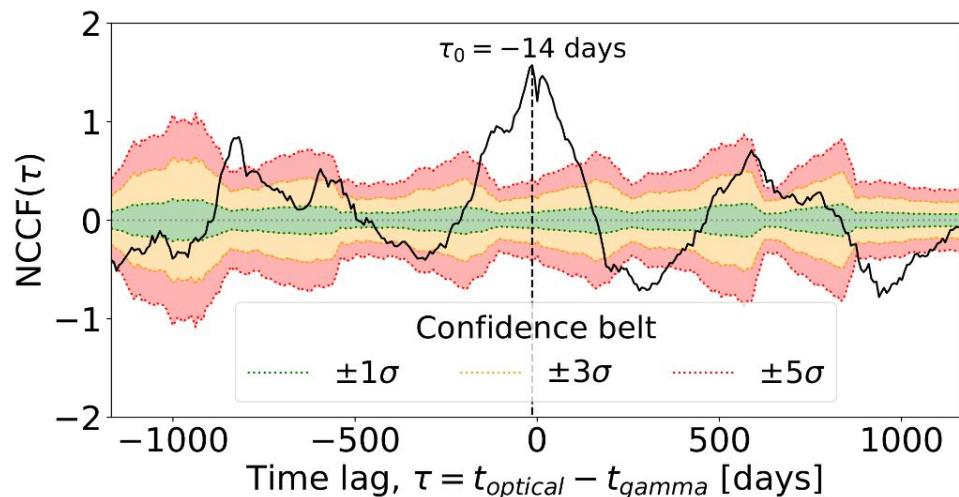
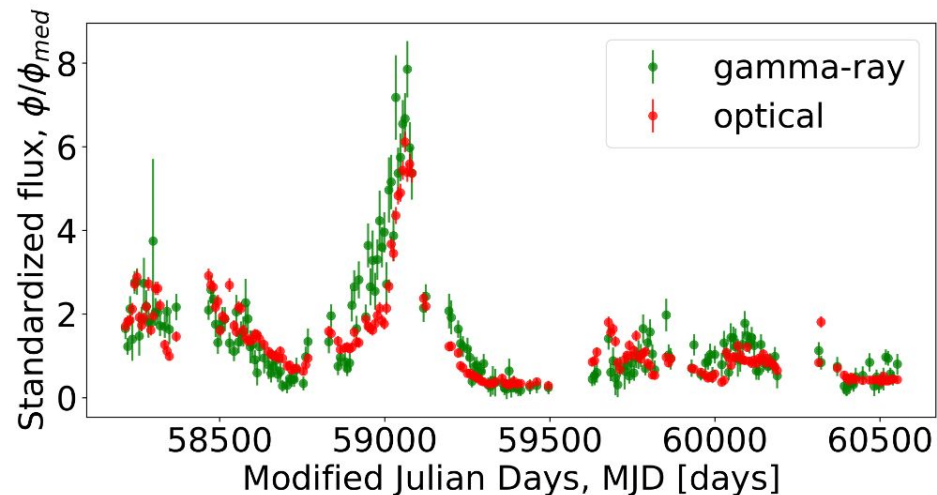
$$\text{mag} - \text{med}_{\text{con}}(\text{mag})$$

Residual color:

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

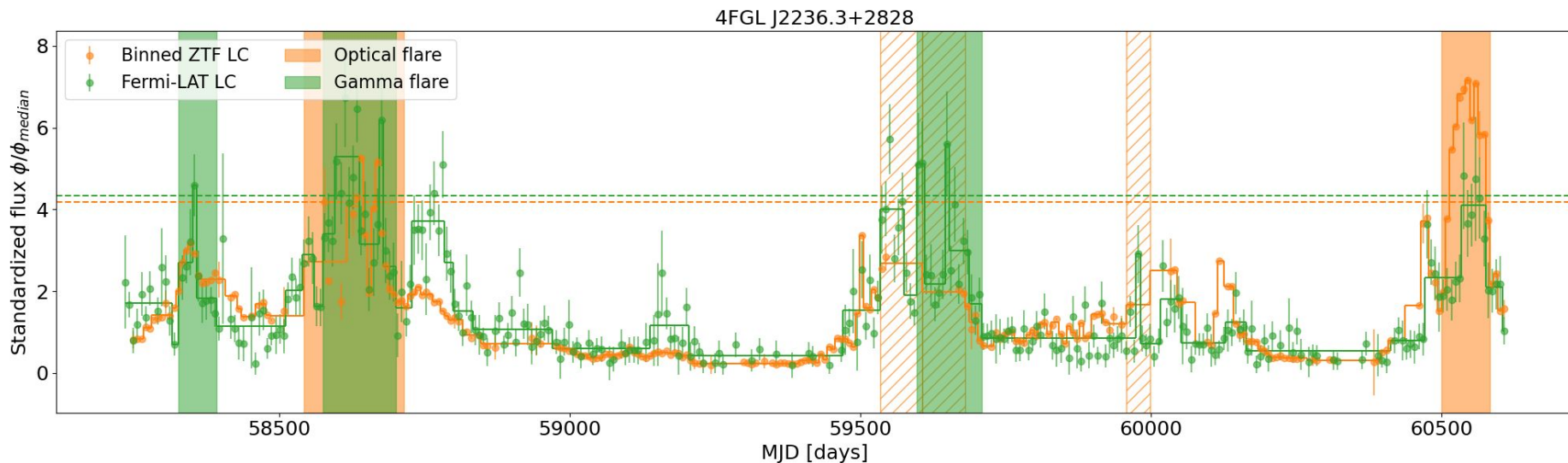
Multi wavelength time-lag evaluation

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



- Analytical formula to assess (possibly time shifted) similarity between two light curves with its significance
- Normalization to allow for physical significance and multi source comparison

Flare detection



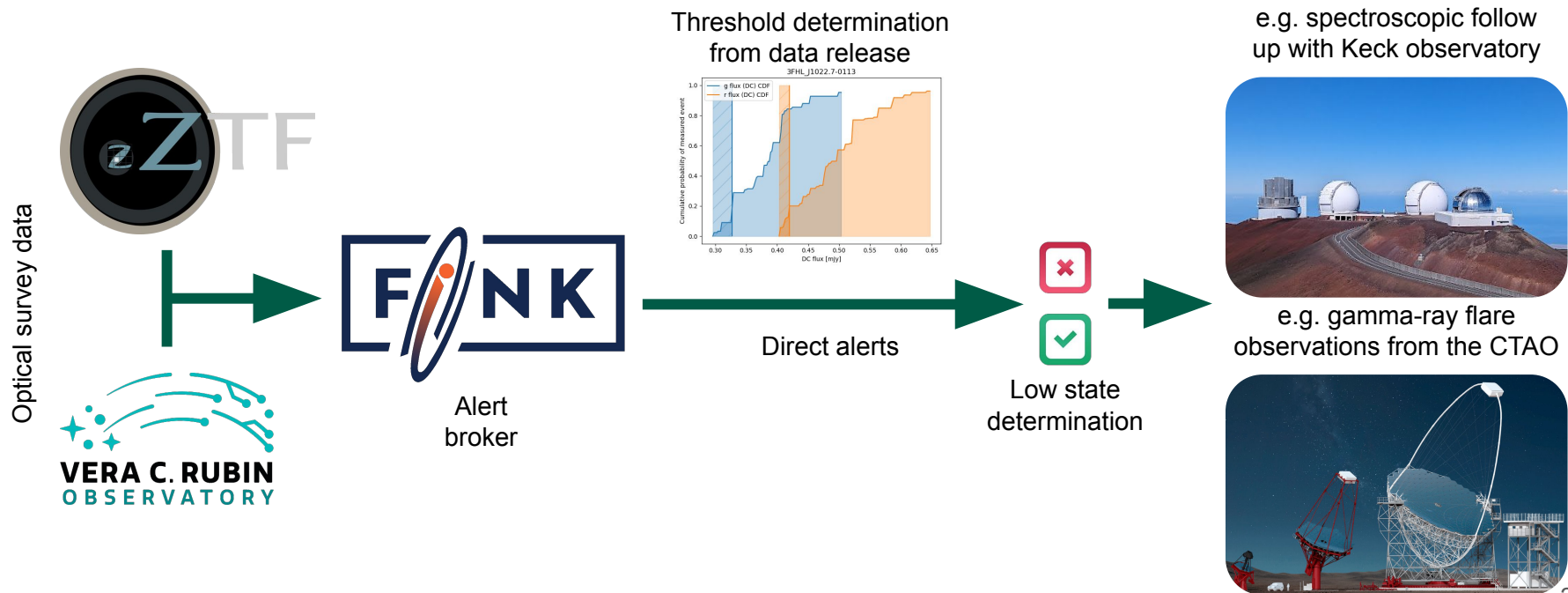
Independent detection of flare states:

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

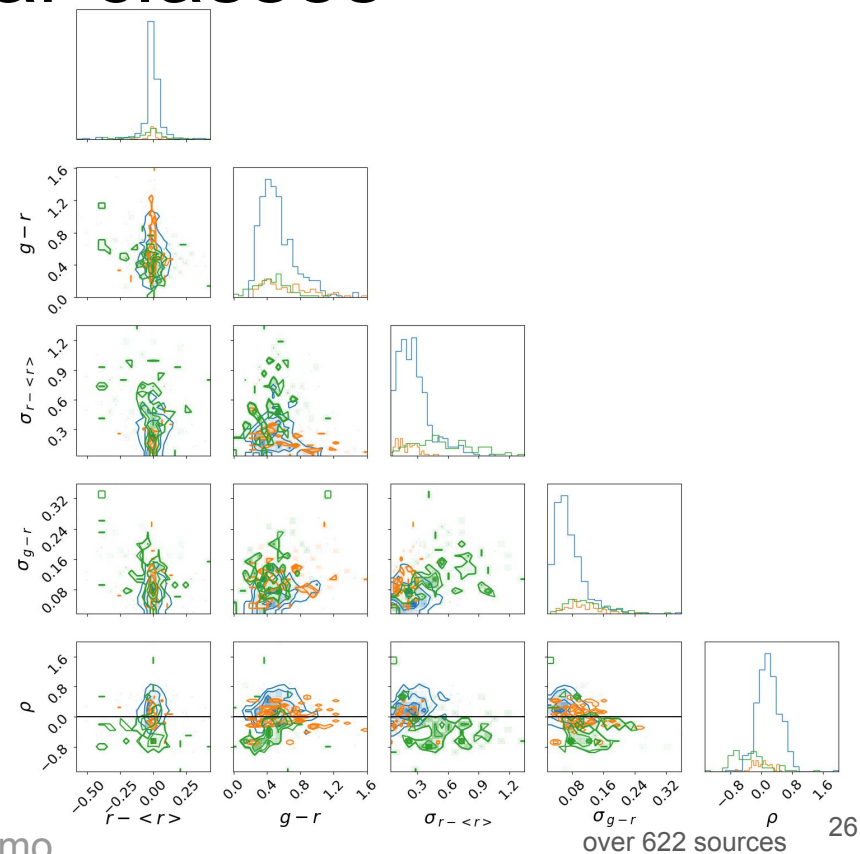
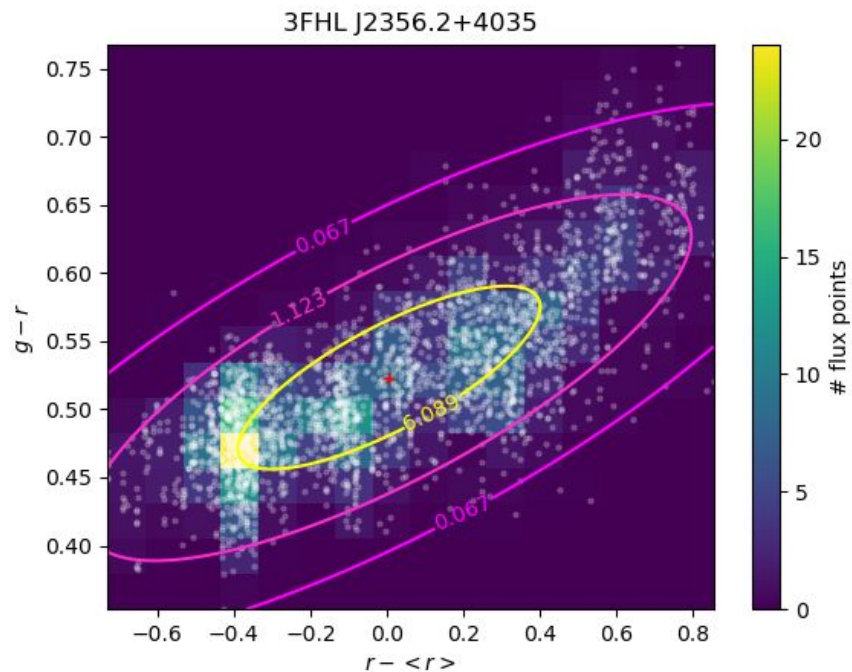
Multi wavelength behaviour:

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

Triggering blazar's host galaxy observations



Characterisation of blazar classes





Why is it interesting?

Key questions for blazars

- Study of the extreme astrophysics environment
 - Relativistic jets and black holes through GRMHD
 - Origin of high energy emission and variability
 - gamma-ray background
- Extreme probes of the Universe fields
 - Evolution of the EBL with redshift
 - Constraints on the IGMF
- UHECR and the limits of fundamental physics
 - Origin and propagation of cosmic UHECR
 - Signature of axion-like particles
 - Lorentz invariance violation



Extended work

- Possible **optical-to- γ -ray** synergy for blazars - for various states
 - Fink has been chosen as the privileged communication channel to listen by the CTAO!
- Multi wavelength can get broader: **Radio-to-optical-to- γ -ray** analysis with ASKAP VAST and the CTAO
- Who is already collaborating with us?
 - Comparison of 1ES 0229+200 optical data with Swift **X-ray** data with Padova team
 - **Multi-wavelength** flare characterization with DESY/Bochum team
 - **Spectroscopic** campaign for redshift determination with Paris team
 - Database from Santiago Pita for CTAO blazar watchlist
 - Follow-up alerts with Astro-Colibri team
 - +NectarCAM Real Time Analysis with LAPP for the preparation of the CTAO start

Conclusions

- Blazars: jetted aligned AGN → main gamma-ray contributors in the sky
- New cutting edges observatories: Rubin and the CTAO
→ Perfect synergy for blazar MWL study
- My work:
 - Determination and characterization of MWL behaviour of blazar
 - Characterization of blazars and their defining properties through using the best features of the new eyes of the Universe
- Why it is cool:
 - Understanding the backgrounds of the Universe (EBL, IGMF, ...) and cosmological parameters
 - Probing what is happening inside the most violent galaxies of the Universe, around the biggest black holes
 - Exploring the frontiers of fundamental physics through the biggest particle accelerators in the Universe



Thank you!

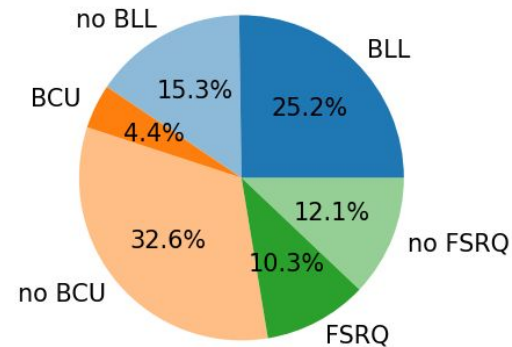
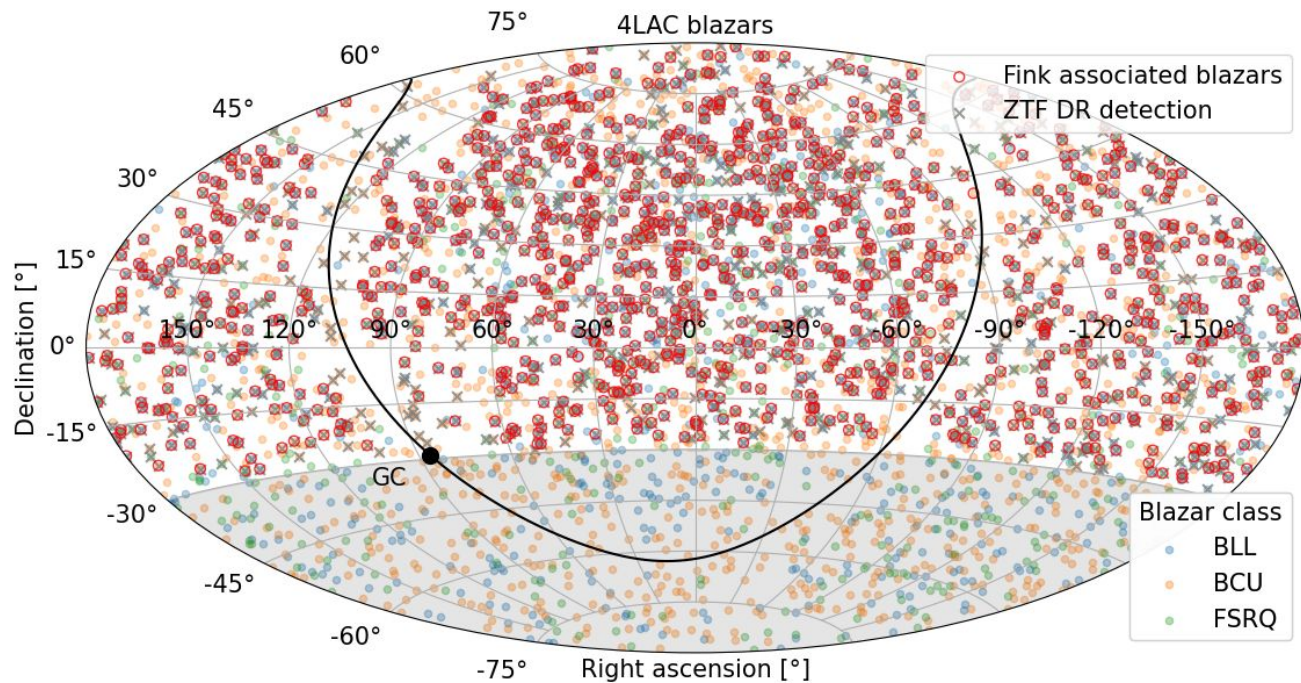


Julian Hamo



Backup slides

Dataset selection

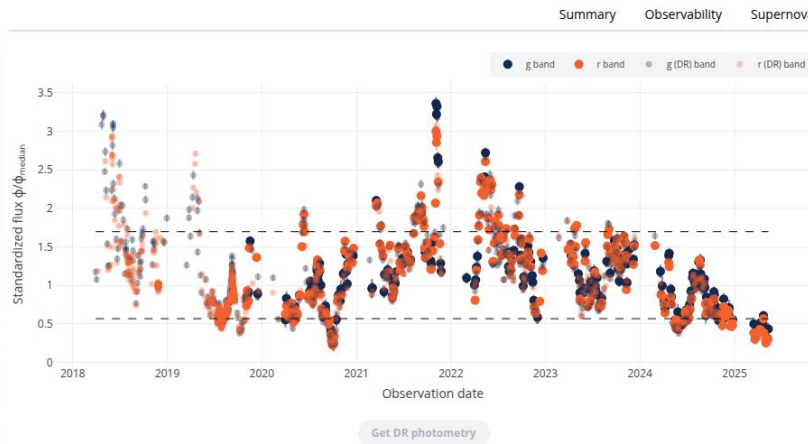
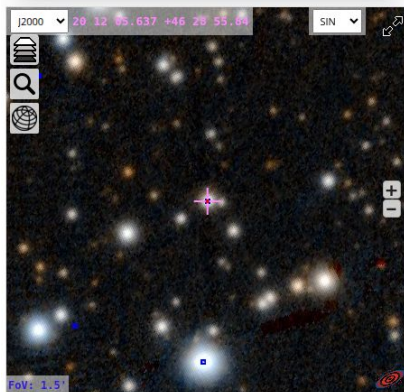


Fink: standardized flux panel

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



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

Neighbourhood

Extreme states threshold

Select your quantile

0% 10% 20% 30% 40% 50%

Update plot

How to use this panel?

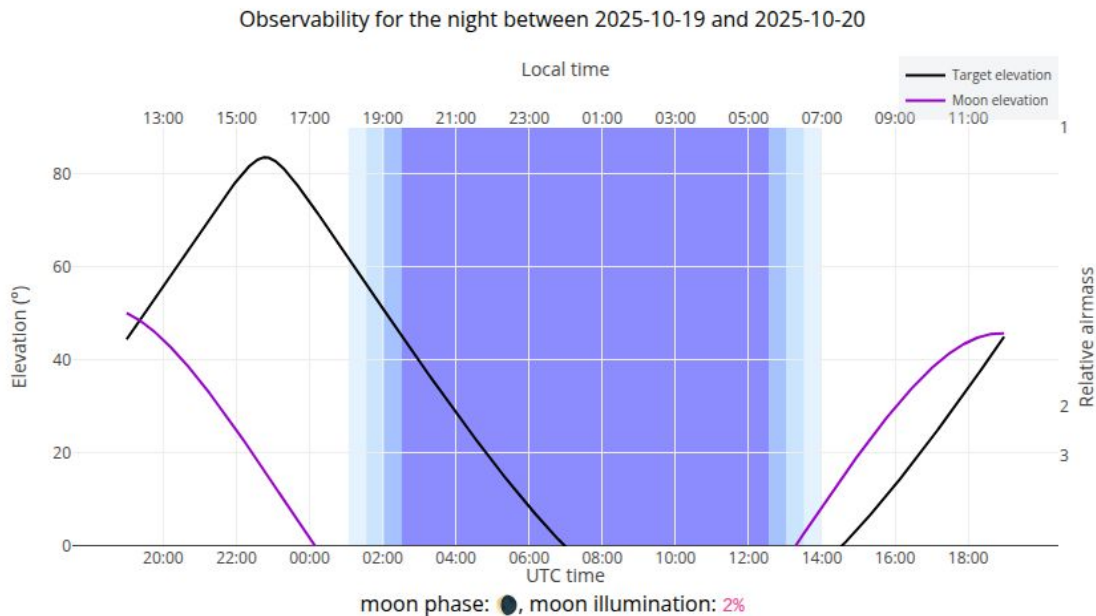
This light curve is obtained by dividing each band by a meaningful calculation of its median. Each median is calculated by selecting measurements in one band if and only if there is at least one other measurement in the other band less than 12 hours after the first. The sub-selections of measurements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

Observability panel



Follow-up

Select your Observatory

Palomar

Pick a date for the follow-up

October 20, 2025

Show moon elevation

Show moon phase

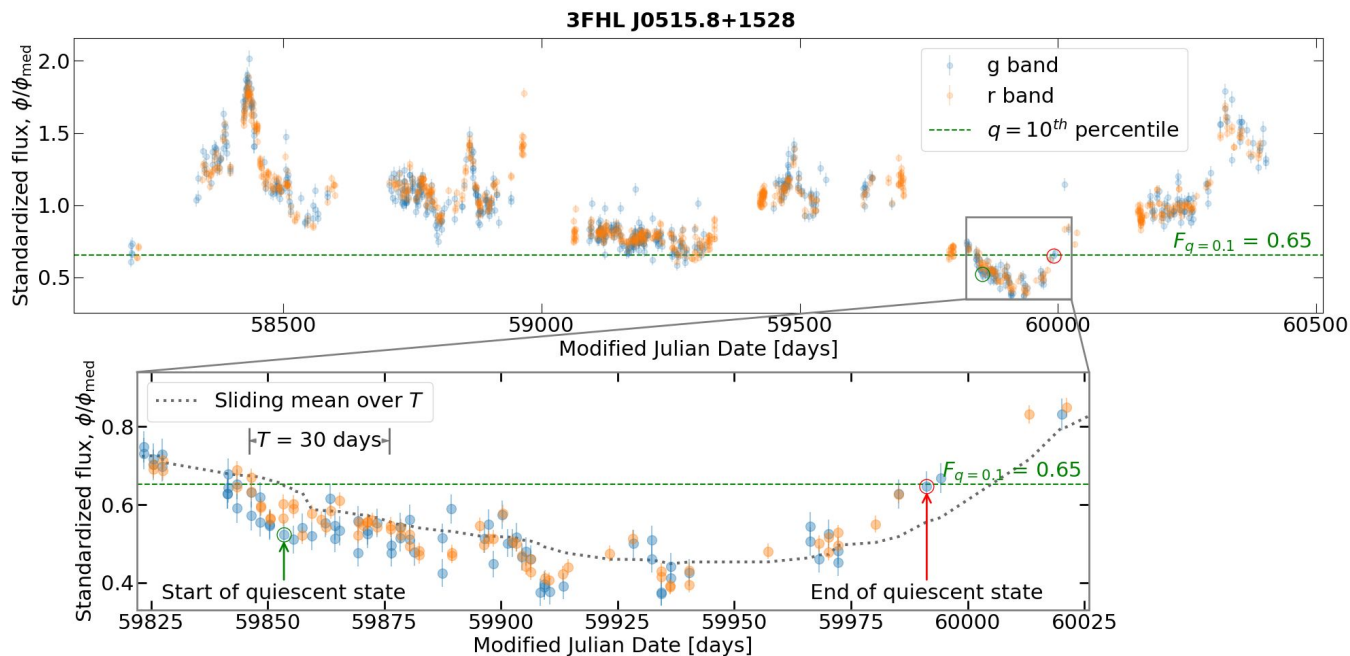
Show moon illumination

Custom Observatory

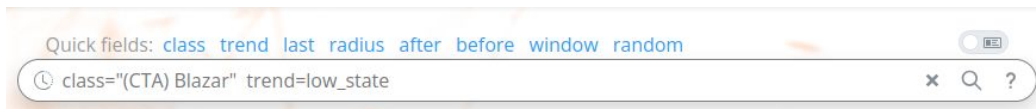
Update plot

Dynamical observability of the source for any date at any location
+ status of the Moon

Fink: low state detection



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



+ Monthly/Weekly
newsletter

Normalized Cross-Correlation Function

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

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

Caveat: Assume white noise for PSD → overestimation of the significance

NectaRTA (real time analysis of NectarCAM)

