Radio-to-Gamma Ray Monitoring of Mkn 421 and Mkn 501: Source Variability

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On behalf of the Fermi-LAT, MAGIC, VERITAS and other collaborations and groups involved in the multiwavelength campaigns

Outline

- Introduction
- 2009 MWL campaigns on Mrk 421 and Mrk 501:
  - SEDs
  - Lightcurves
  - Variability
  - Correlations
- Conclusions & Outlook

Motivation

Blazars:

- AGN with relativistic jet pointing directly towards us
- highly variable at all wavelengths
- SEDs dominated by jet emission, two non-thermal bumps at low (radio-optical-Xray) and high (X/γ-rays) energies respectively. Origin of high-energy bump not yet identified unambiguously.

➡ simultaneous observations of blazars over the whole wavelength range (Radio - TeV) over a long time period needed (mostly in low state).

Mrk 421 and Mrk 501:

- luminous gamma ray sources
- nearby blazars (z~0.03) which implies a low EBL absorption

➡ ideal candidates for multiwavelength studies

2009 MWL campaigns on Mrk421 and Mrk501

4.5 months long multiwavelength campaigns in 2009 (PI: David Paneque):

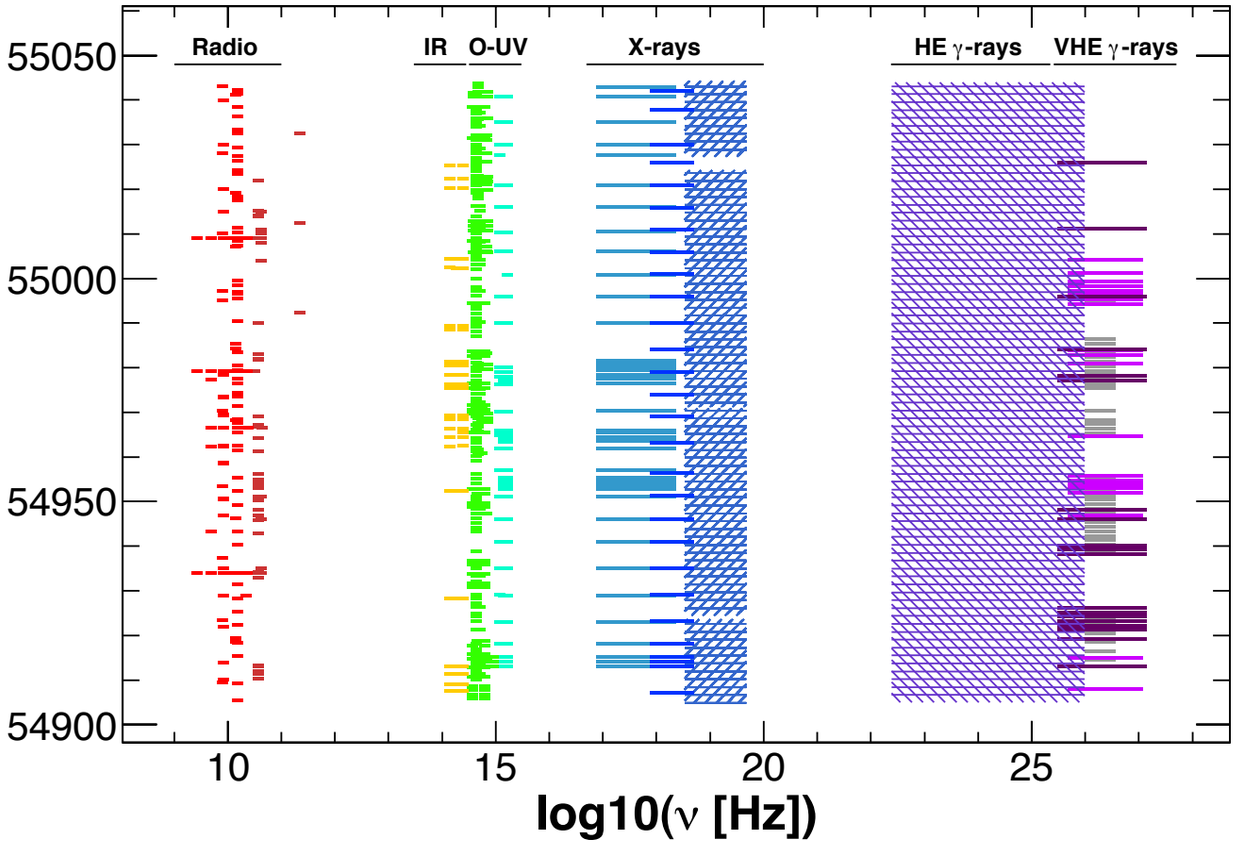
- Mrk421: Jan 19, 2009 (MJD 54850) - June 1st, 2009 (MJD 54983)
- Mrk501: Mar 15, 2009 (MJD 54905) - Aug 1st, 2009 (MJD 55044)

- monitored regardless of activity. However, both sources were in a relatively low state throughout the campaigns

- participating collaborations/telescopes/instruments:

  MAGIC, Whipple, VERITAS, *Fermi*-LAT, *Swift*/BAT, *RXTE*/PCA, *Swift*/XRT, *Swift*/UVOT, GASP-WEBT, GRT, ROVOR, New Mexico Skies, MITSuME, OAGH, WIRO, SMA, VLBA, Noto, Metsähovi, OVRO, Medicina, UMRAO, RATAN-600, Effelsberg

2009 MWL campaigns on Mrk421 and Mrk501



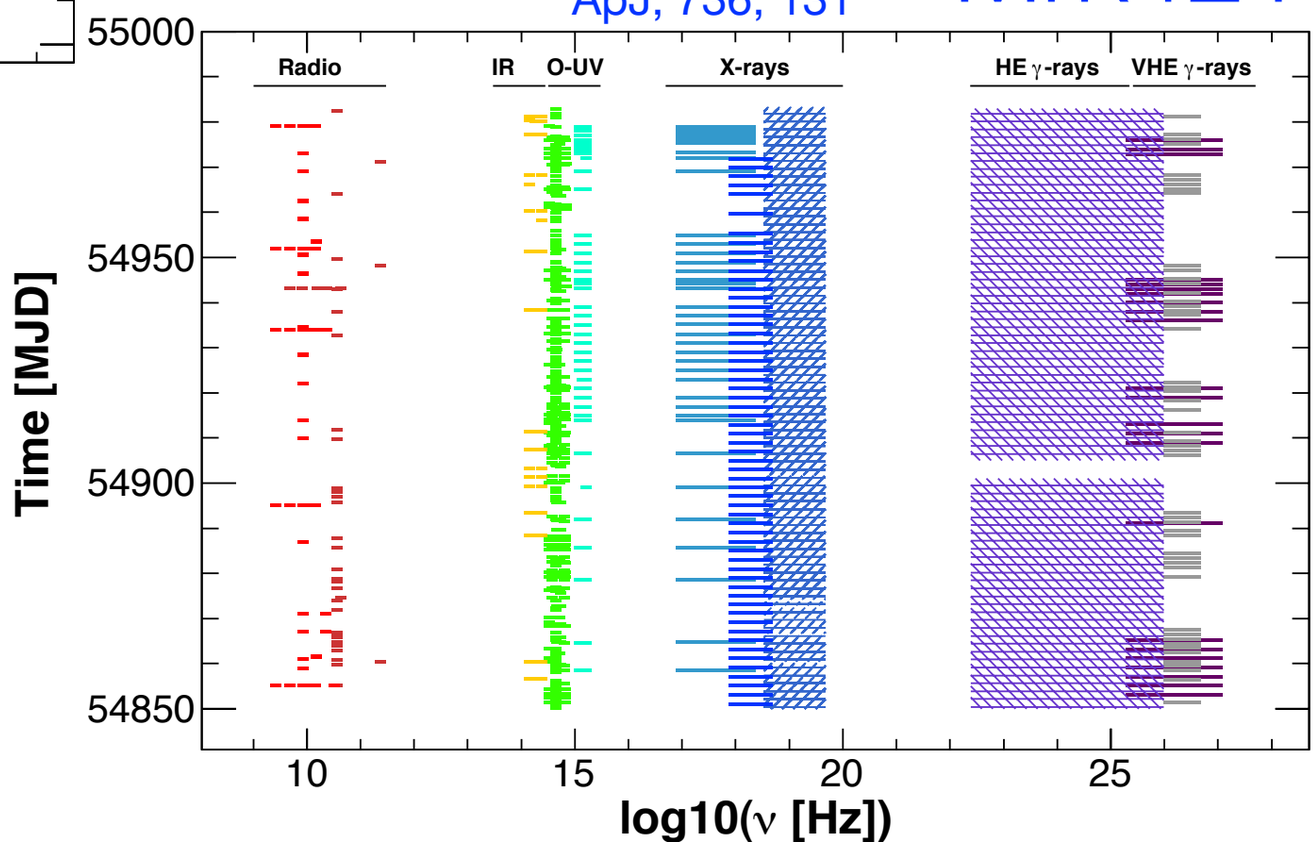
Mrk501

Abdo et al., 2011,
ApJ, 727, 129

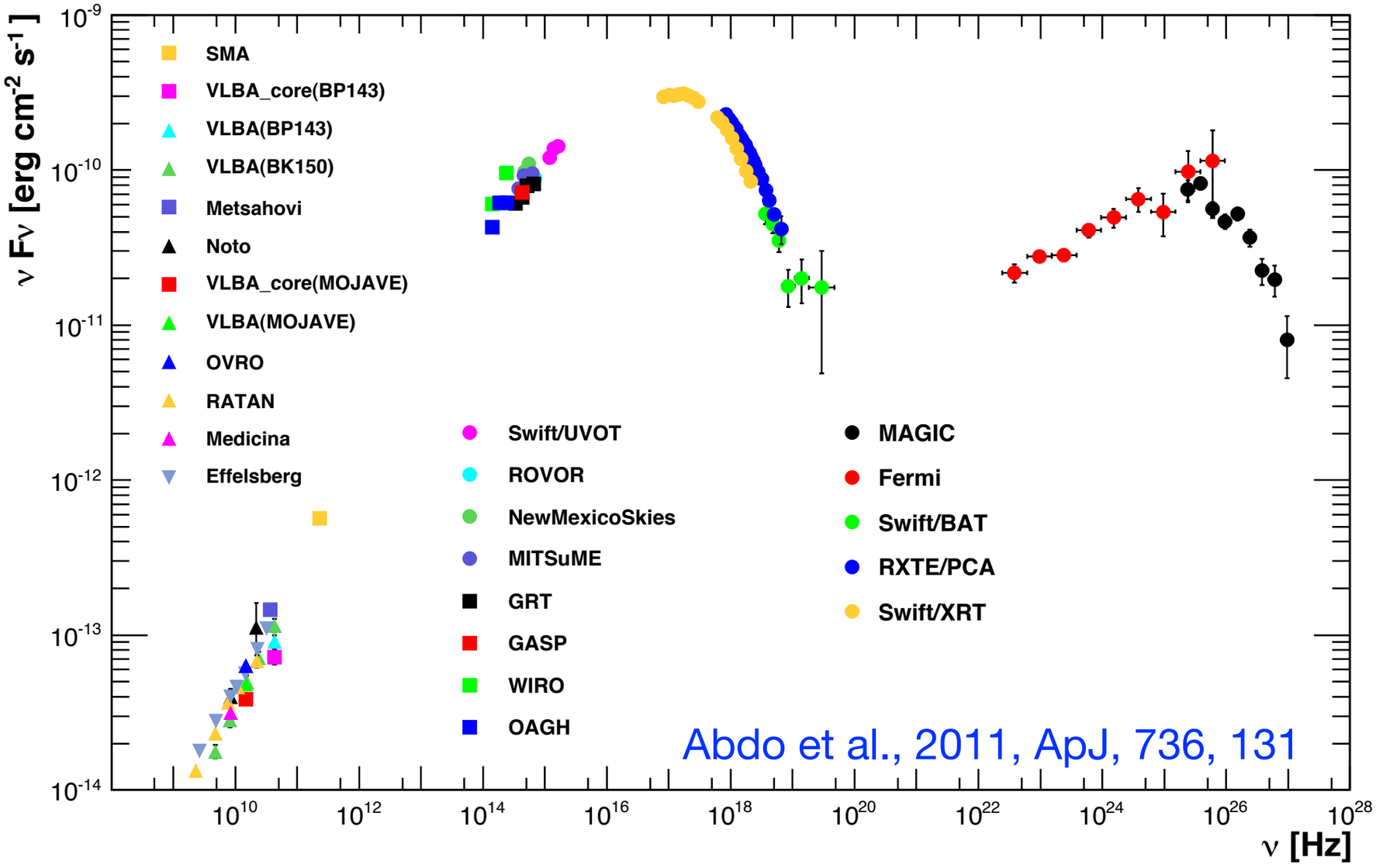
Excellent time and energy coverage for both sources

Abdo et al., 2011,
ApJ, 736, 131

Mrk421

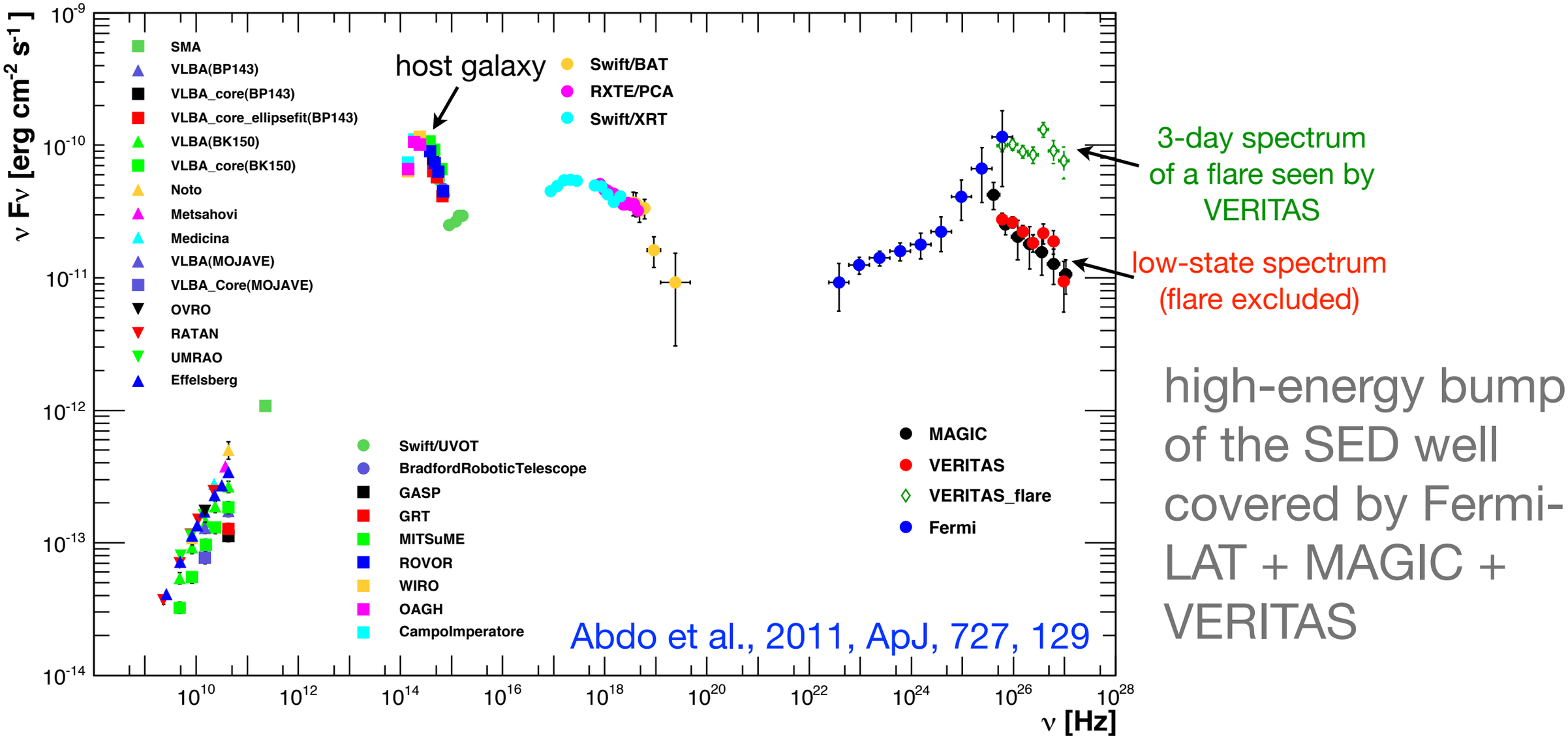


Spectral Energy Distribution of Mrk 421



high-energy bump of the SED well covered by Fermi-LAT + MAGIC

Spectral Energy Distribution of Mrk 501

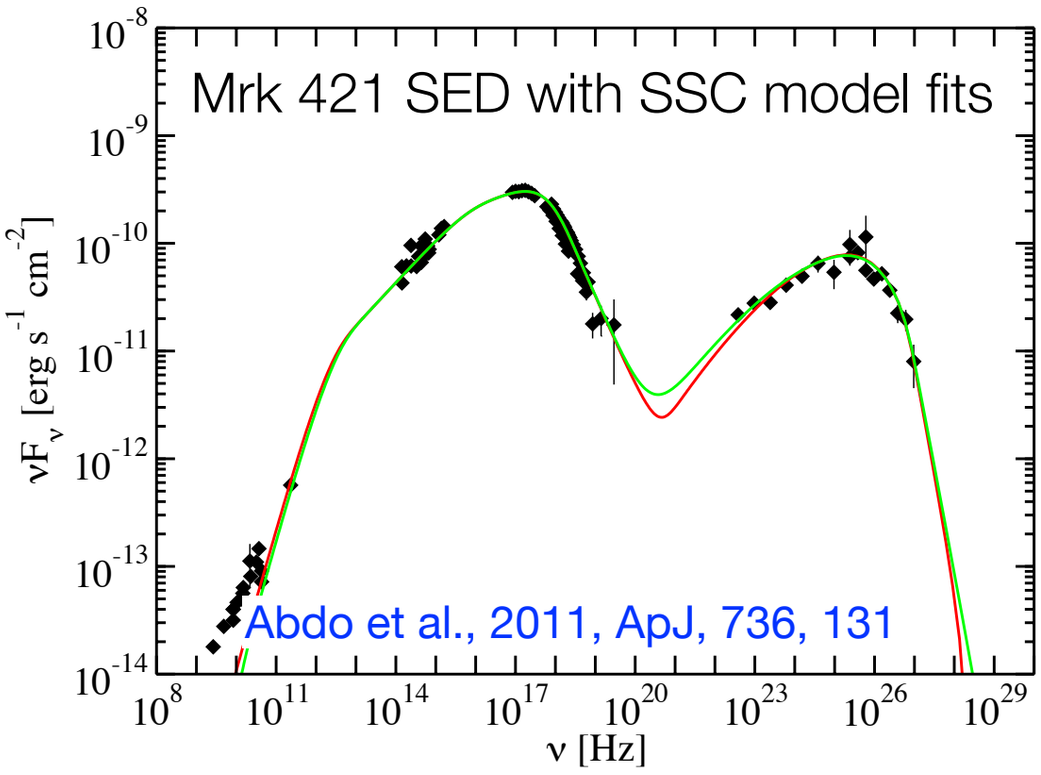


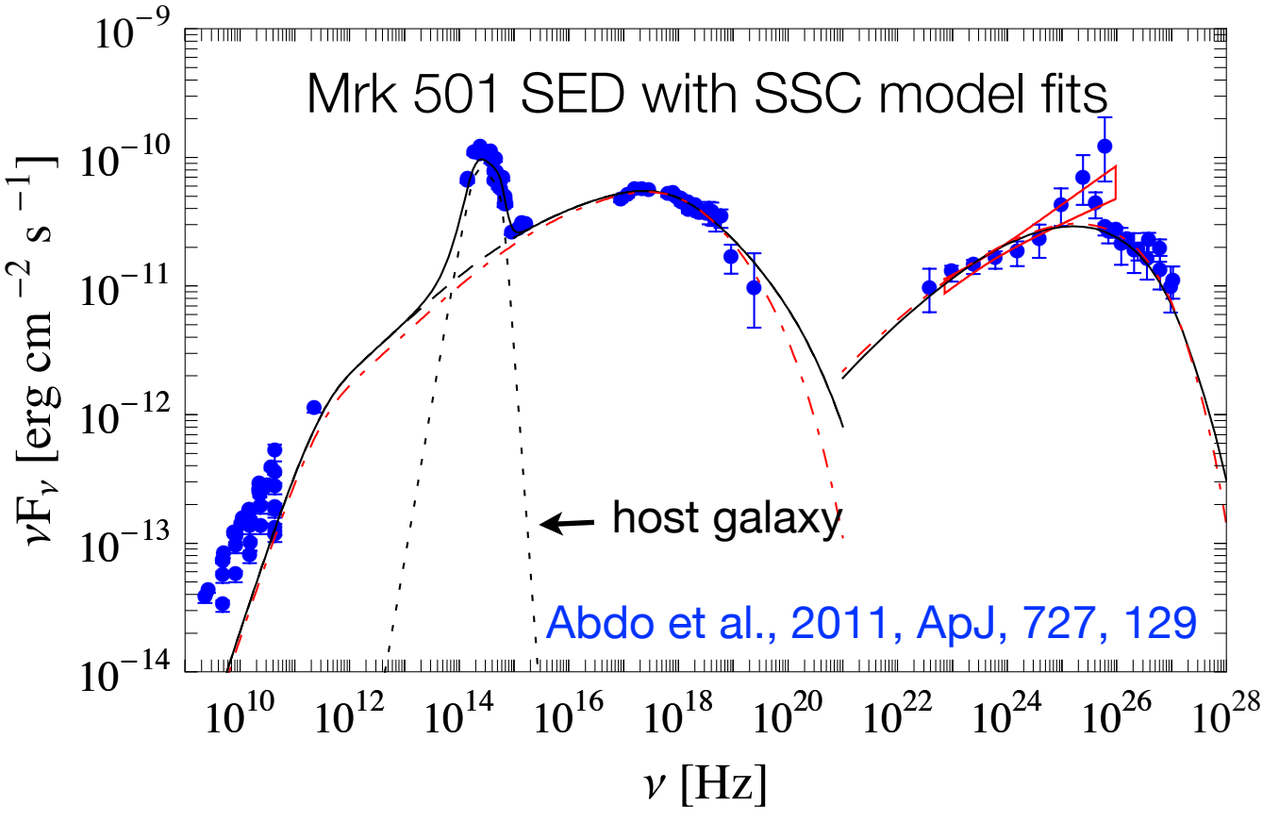
high-energy bump of the SED well covered by Fermi-LAT + MAGIC + VERITAS

Modelling the Mrk 421 and Mrk 501 SEDs

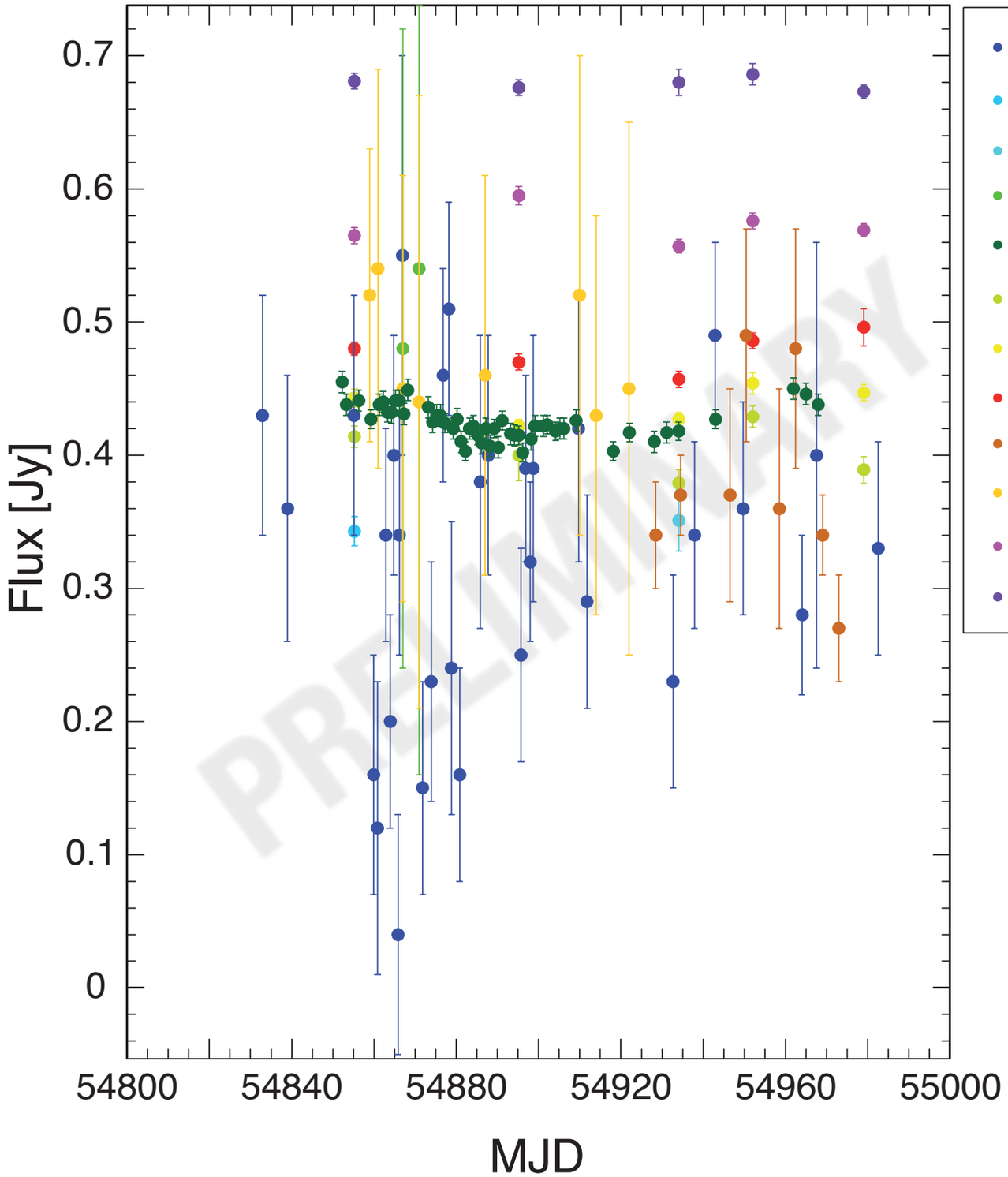
- can be well described by standard one-zone synchrotron self-Compton model with 2 breaks in the electron spectrum
- model parameters (e.g. Doppler factor, size of emitting blob, magnetic field, properties of the electron population, ...) are very similar for both objects

➡ common properties of jets and acceleration mechanisms in blazars





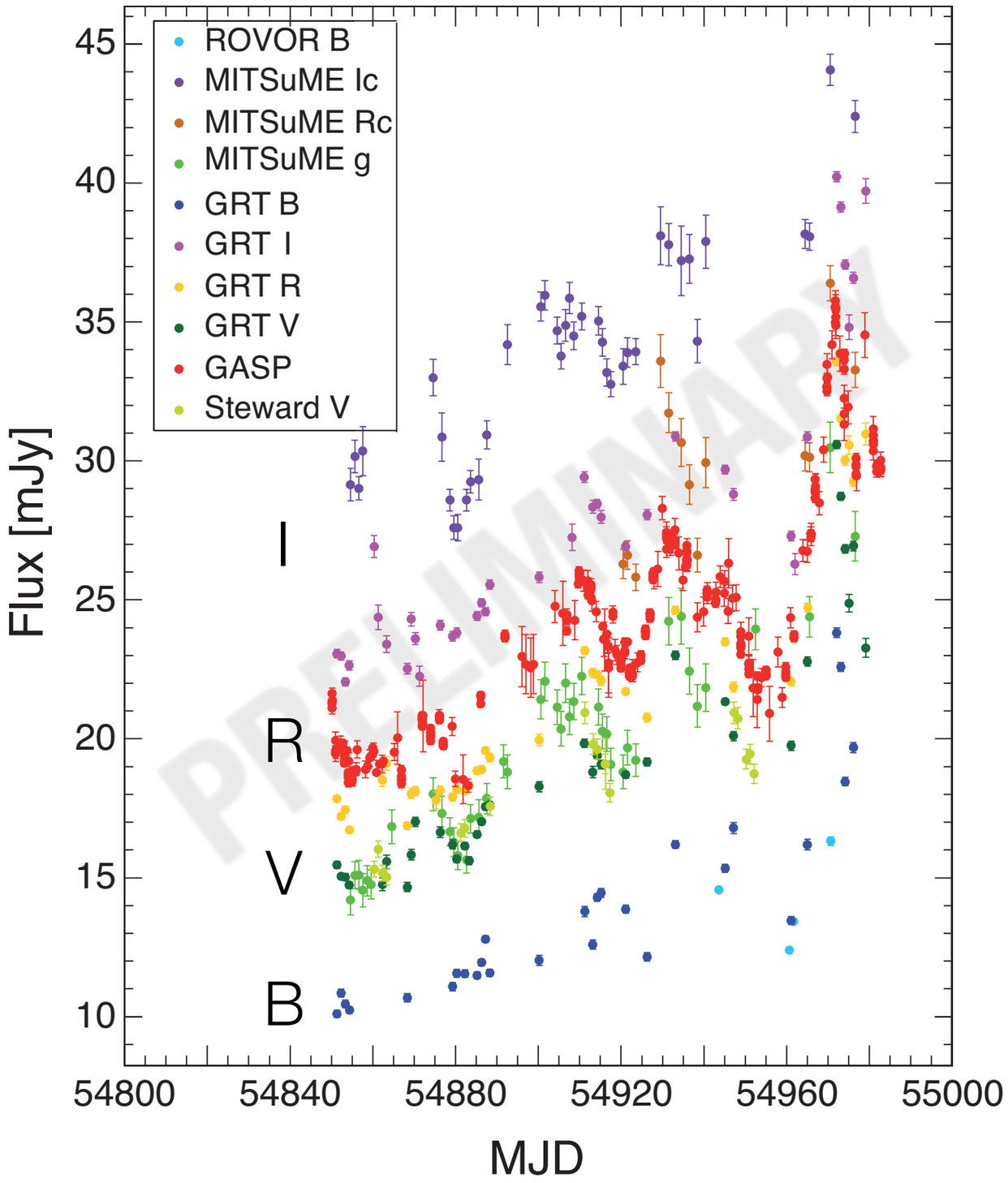
Lightcurves for Mrk 421 – Radio

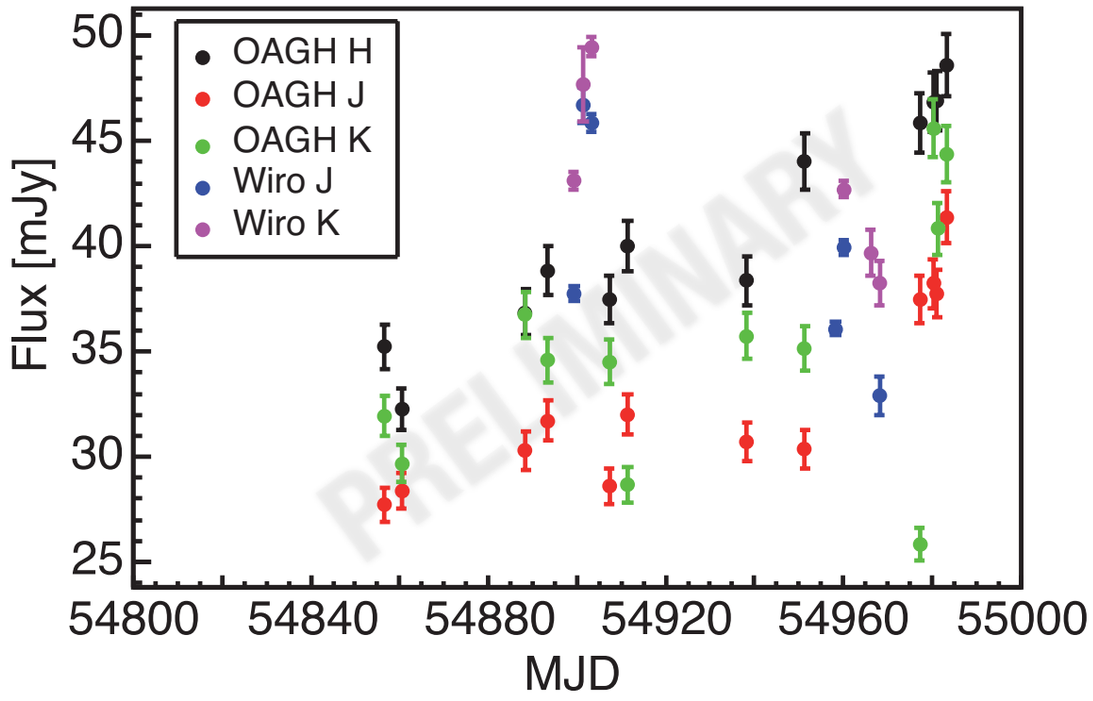


- Metsähovi 37GHz
- Effelsberg 9mm
- Effelsberg 13mm
- Noto 22GHz
- OVRO 15GHz
- Effelsberg 20mm
- Effelsberg 28mm
- Effelsberg 36mm
- Medicina 8GHz
- Noto 8GHz
- Effelsberg 60mm
- Effelsberg 110mm

- Radio observations at different frequencies
- single-dish instruments
- flux ~const., no strong variability

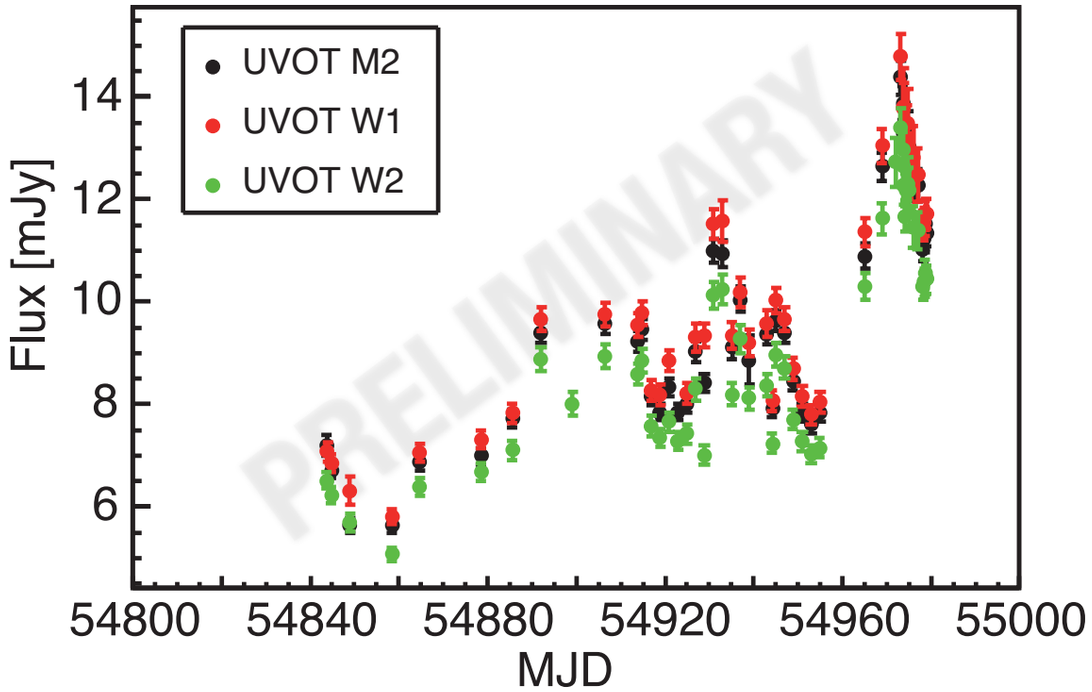
Lightcurves for Mrk 421 – NIR and Optical

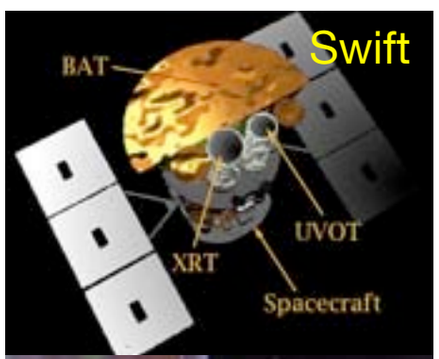


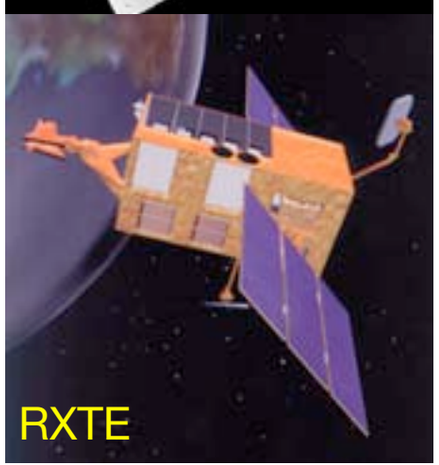


- good coverage of optical-NIR wavelengths provided by many telescopes around the world
- flux increases with time
- significant variability

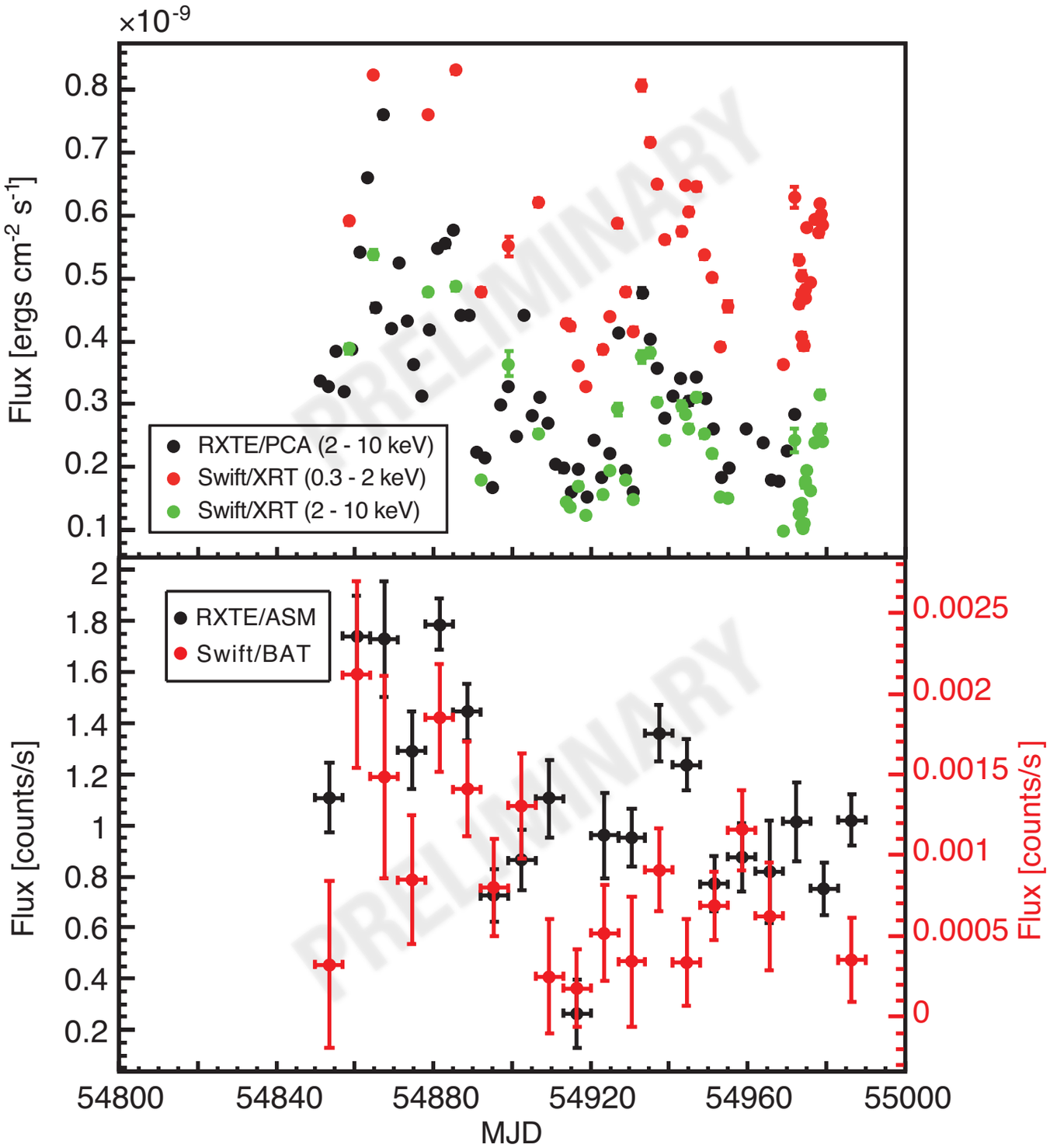
Lightcurves for Mrk 421 – UV and X-rays



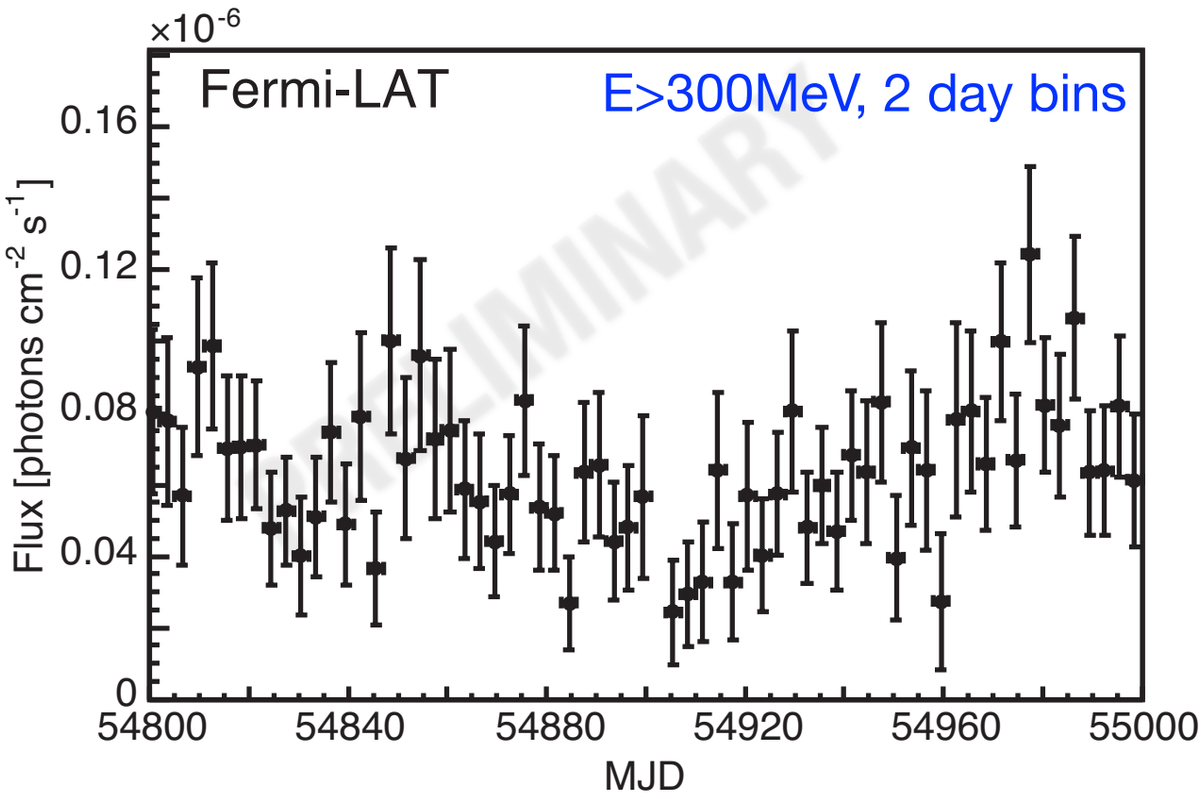




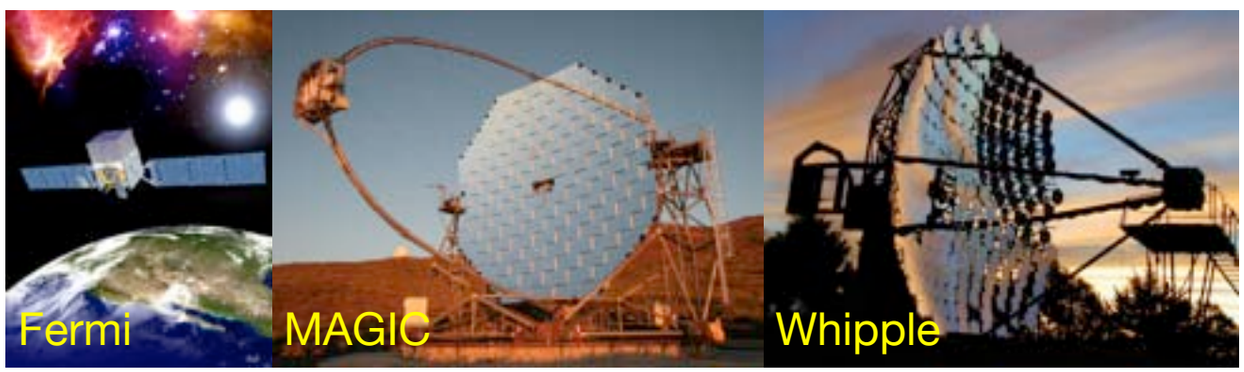
- UV: flux increases with time, significant variability
- X-rays: large variability amplitudes of ~factor 2

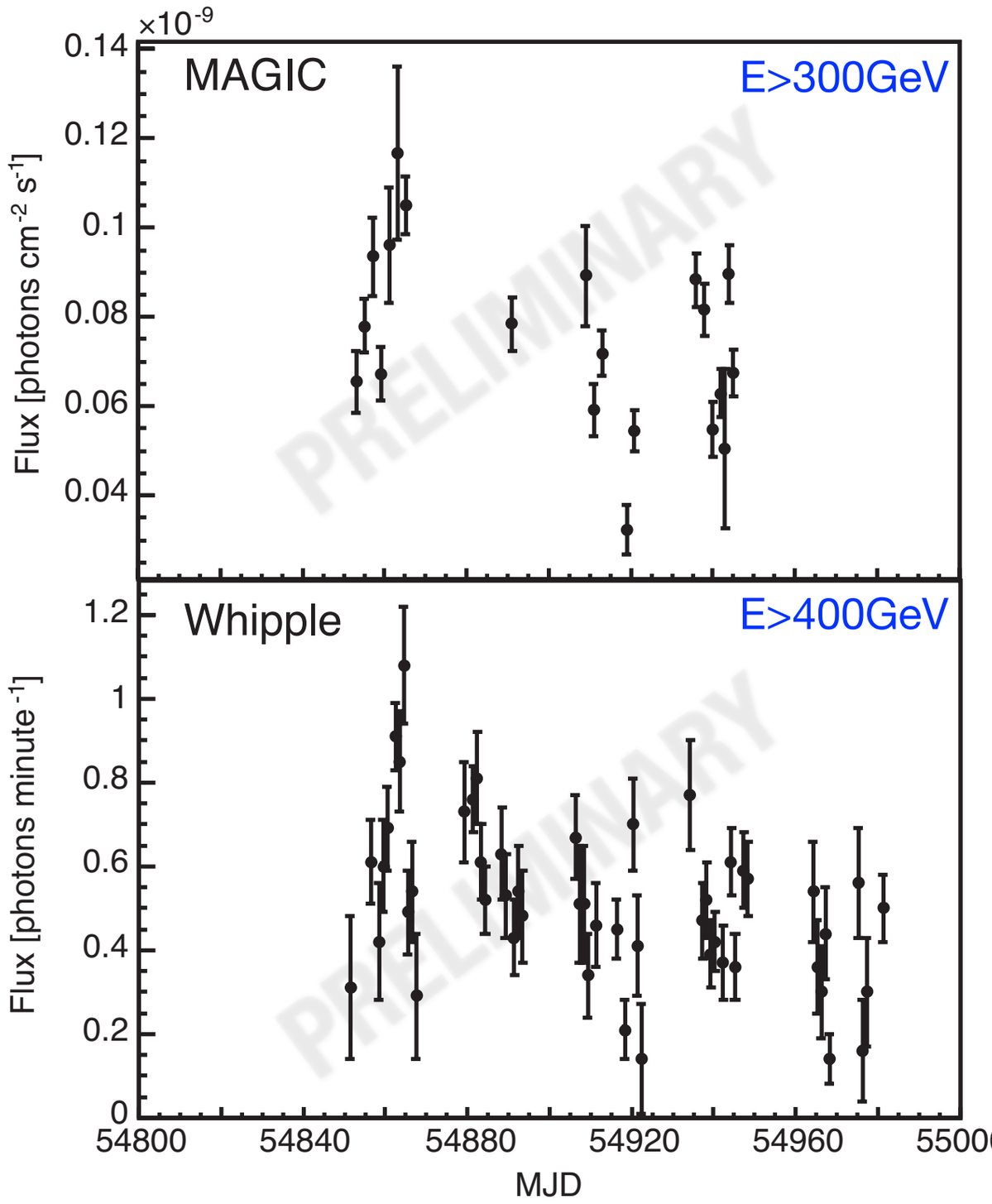


Lightcurves for Mrk 421 – γ-rays and VHE

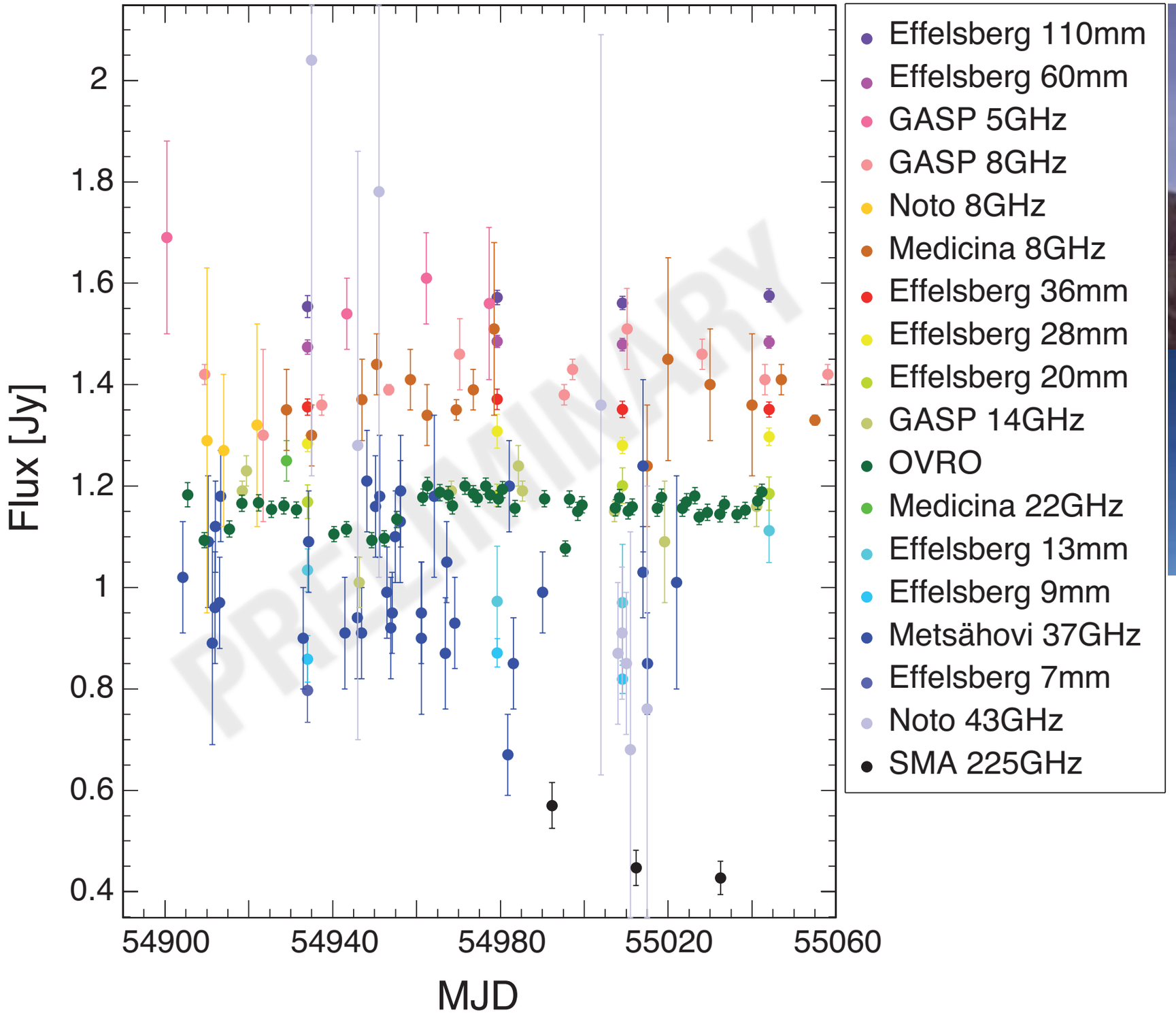


- γ-rays and VHE: some level of variability
- no significant flaring activity



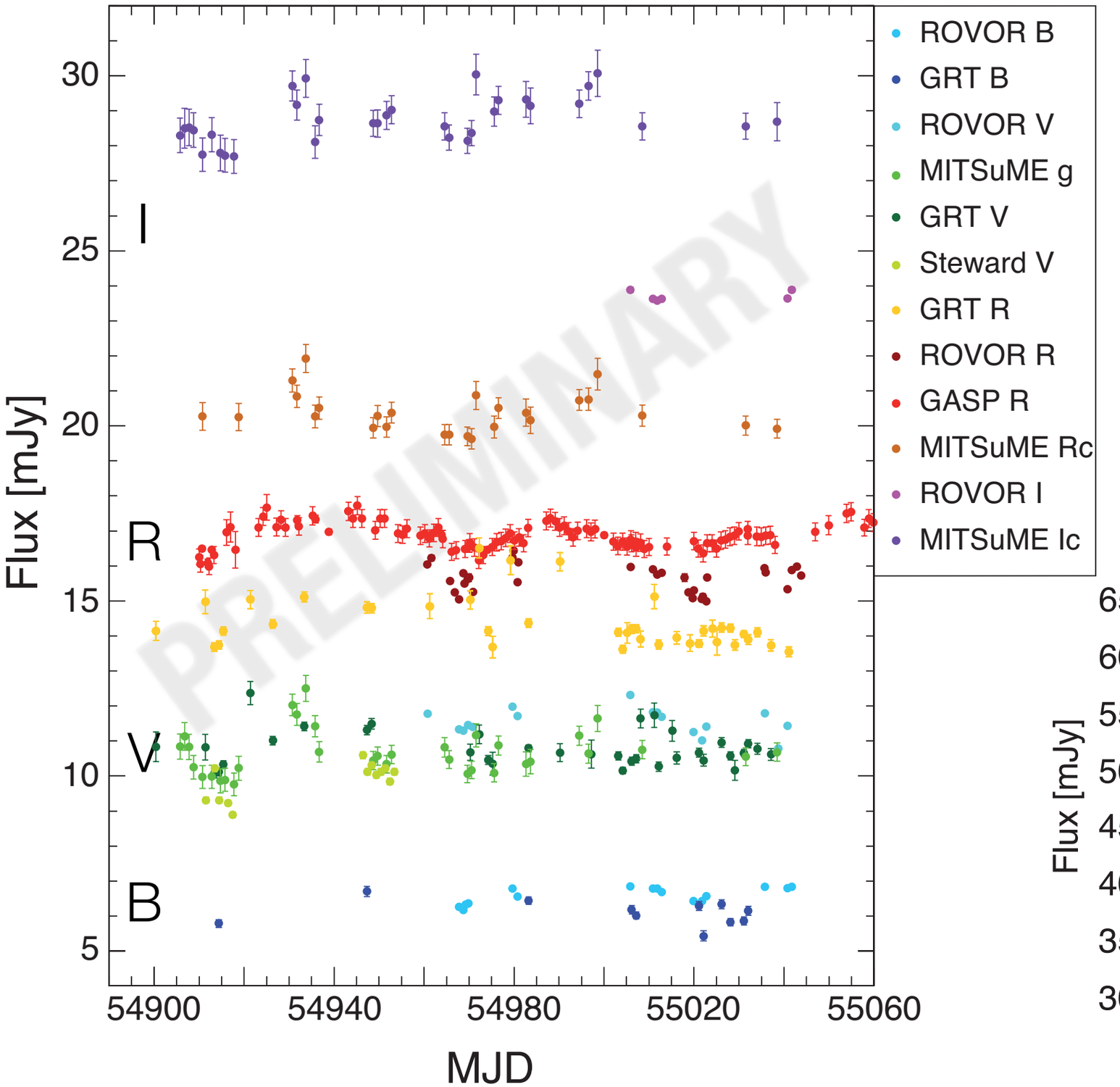


Lightcurves for Mrk 501 – Radio

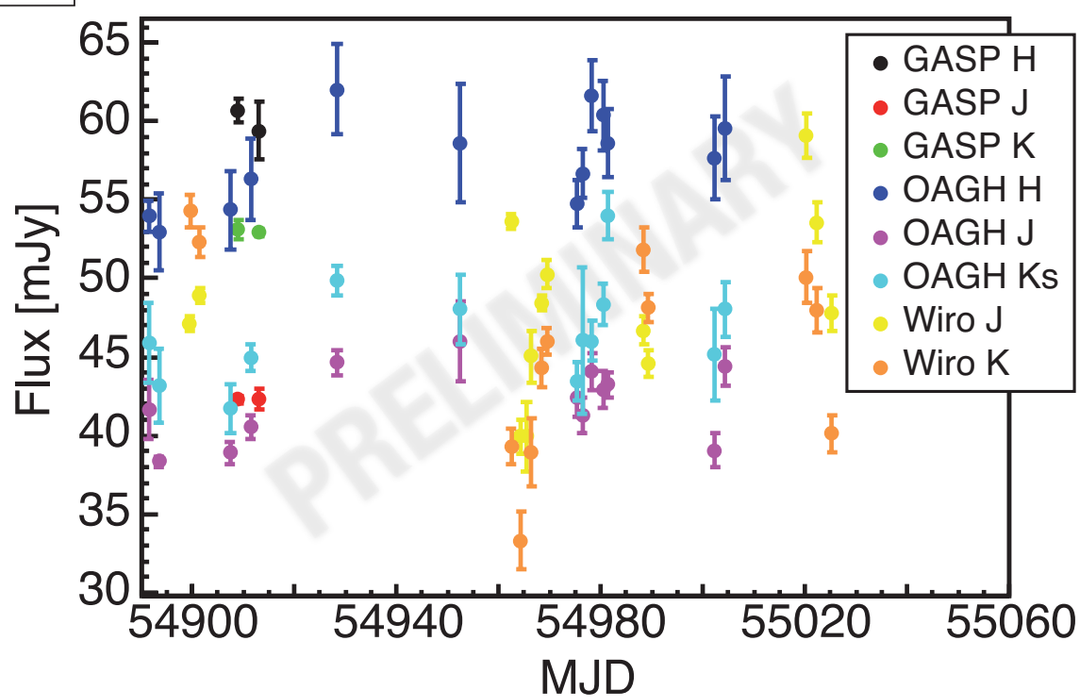


- Radio observations at many different frequencies
- no strong variability

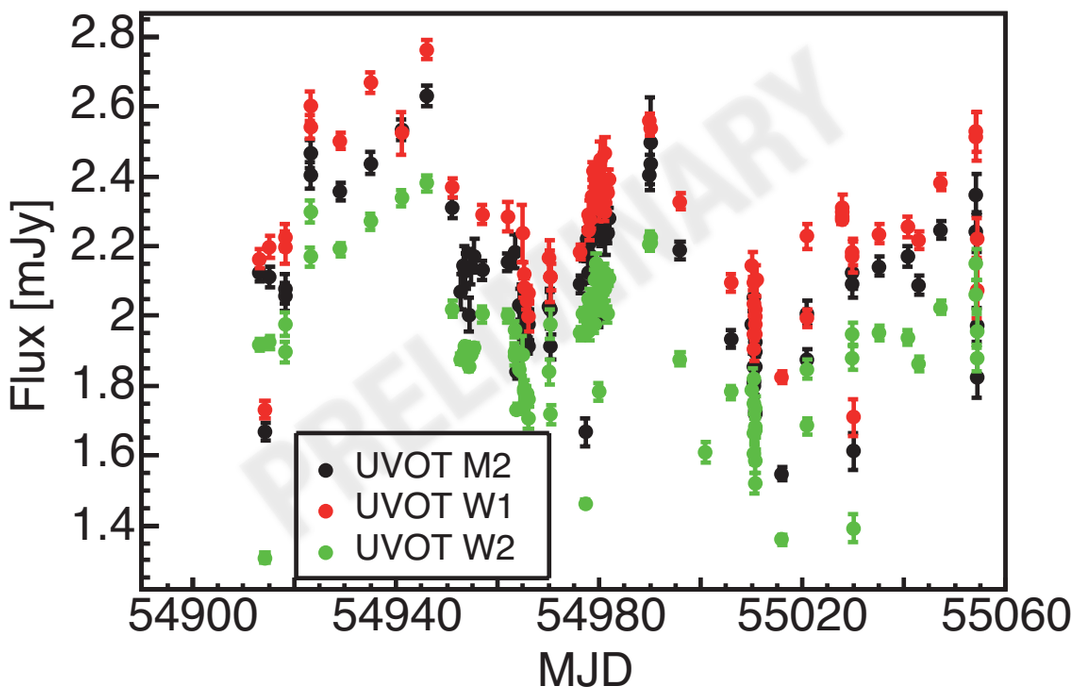
Lightcurves for Mrk 501 – NIR and Optical

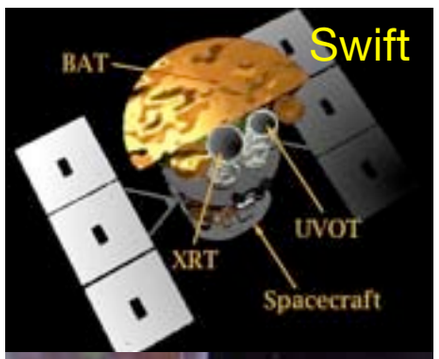


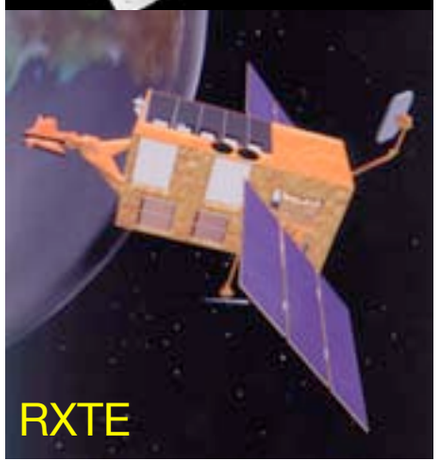
- good coverage of optical-NIR wavelengths provided by many telescopes around the world
- flux ~const. with time
- little variability



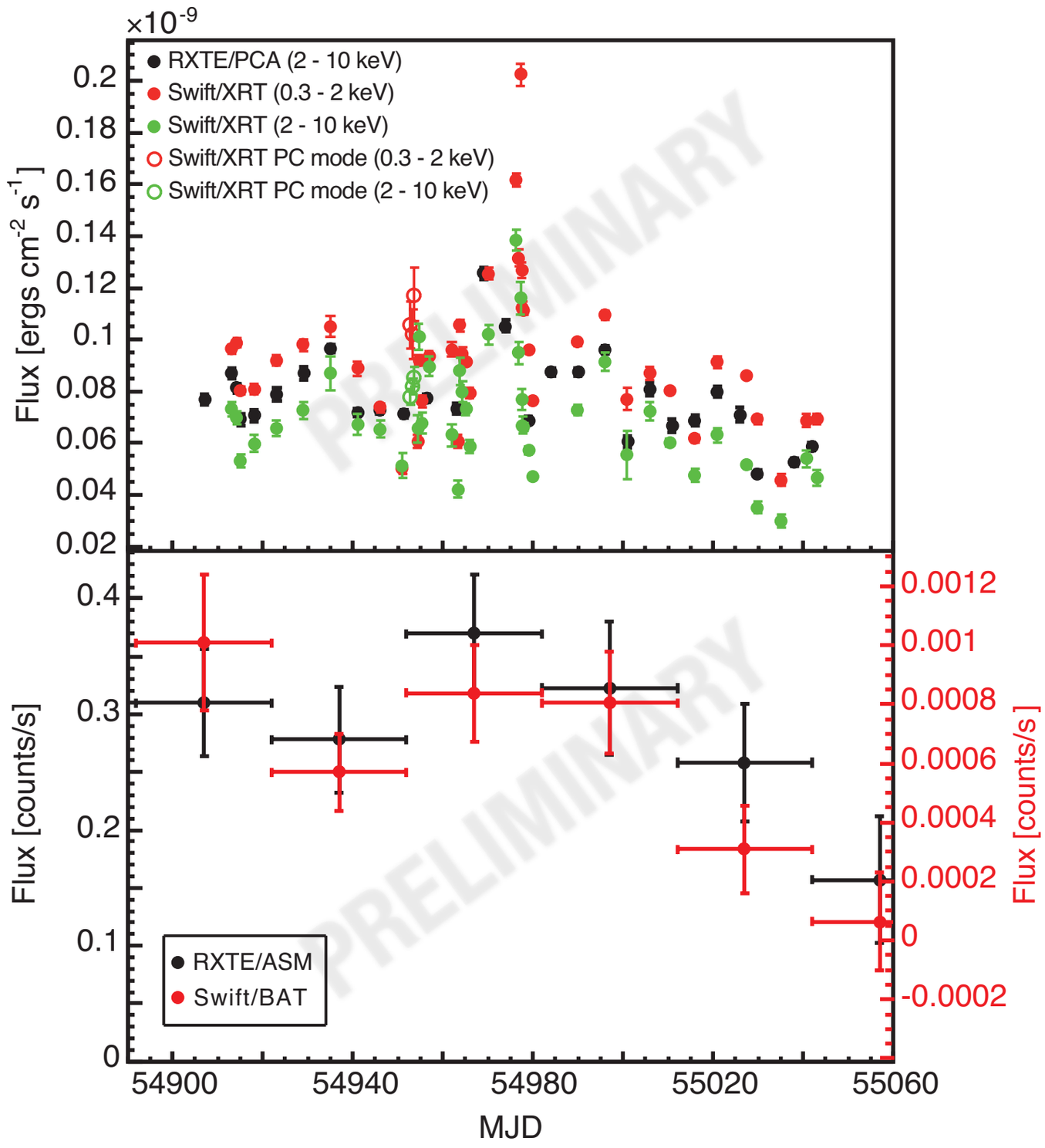
Lightcurves for Mrk 501 – UV and X-rays







- UV and X-rays: significant variability



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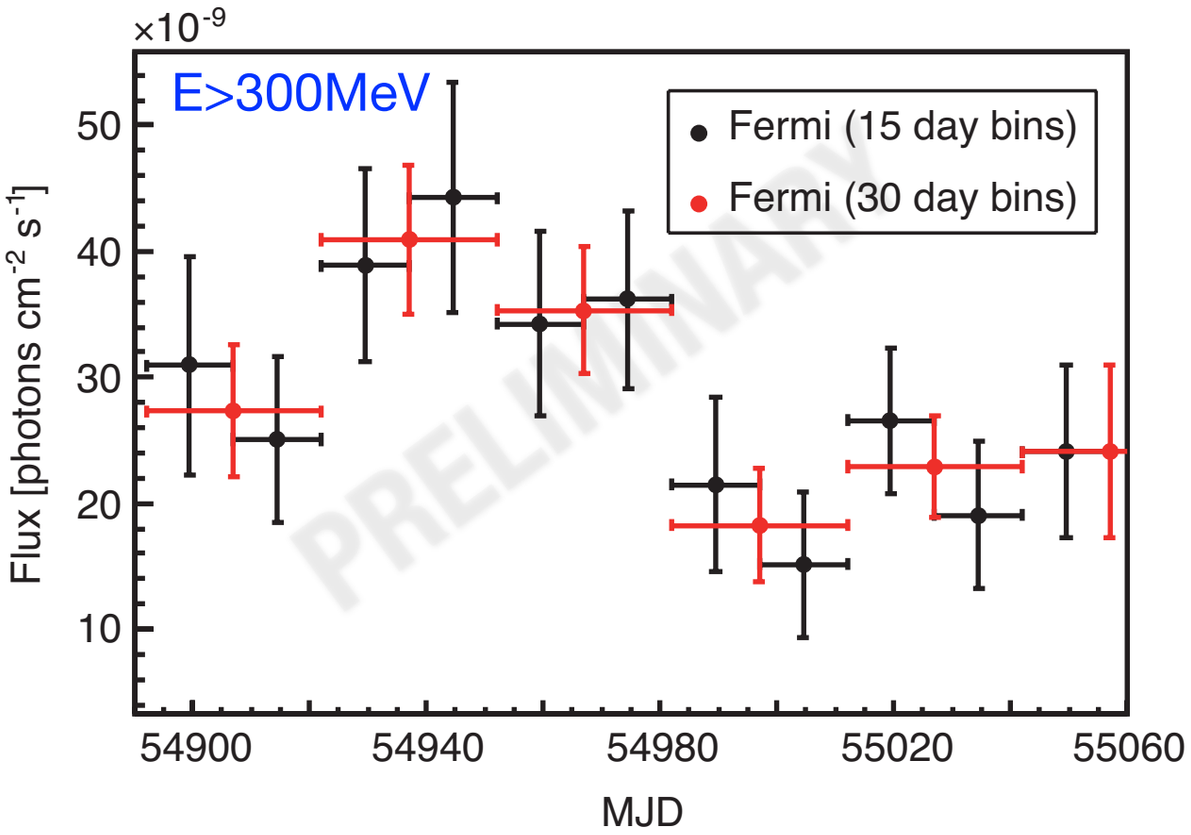
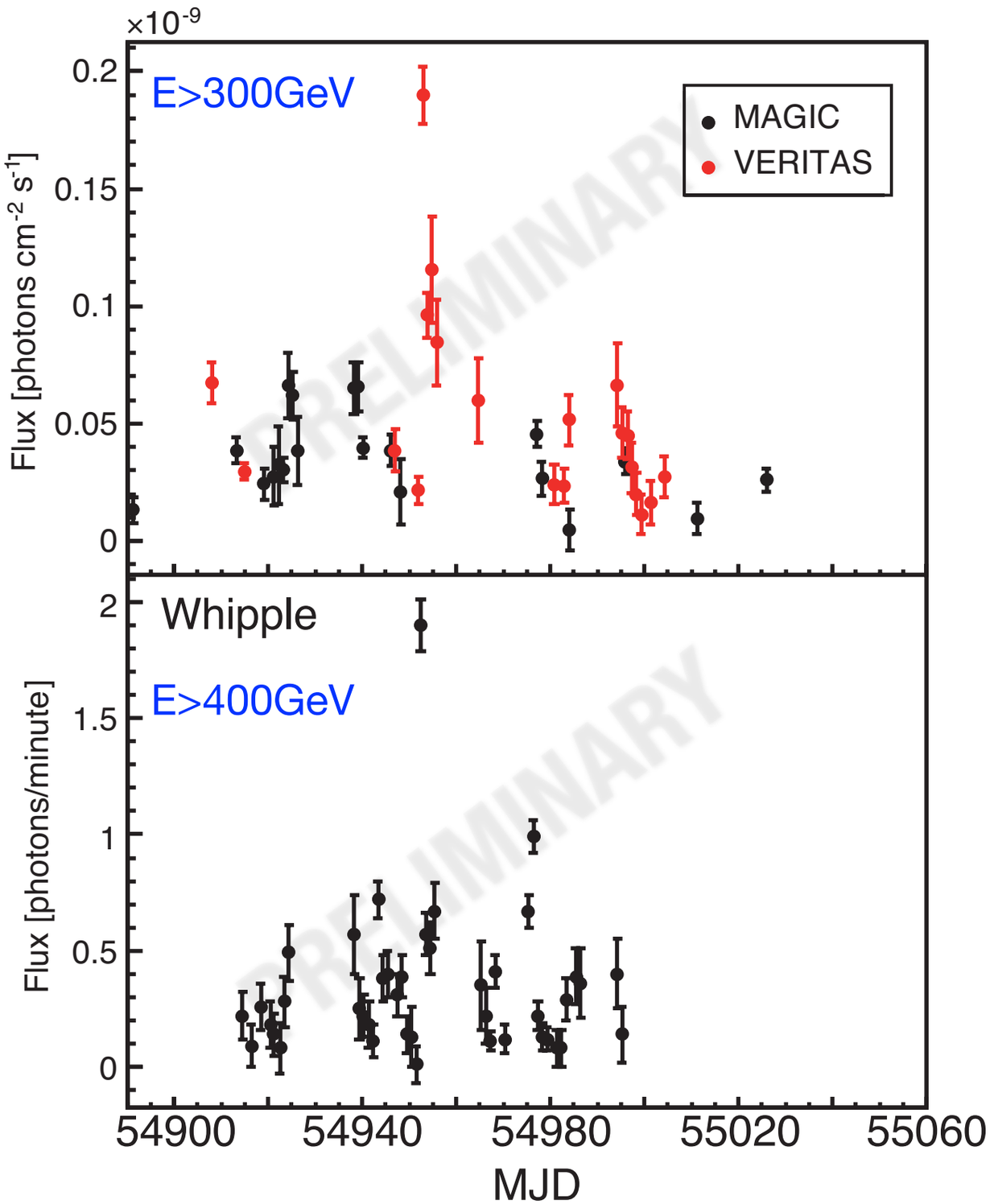


Large flare in VHE around MJD 54952 (May 1st, 2009). No obvious correlation with other wavelengths.



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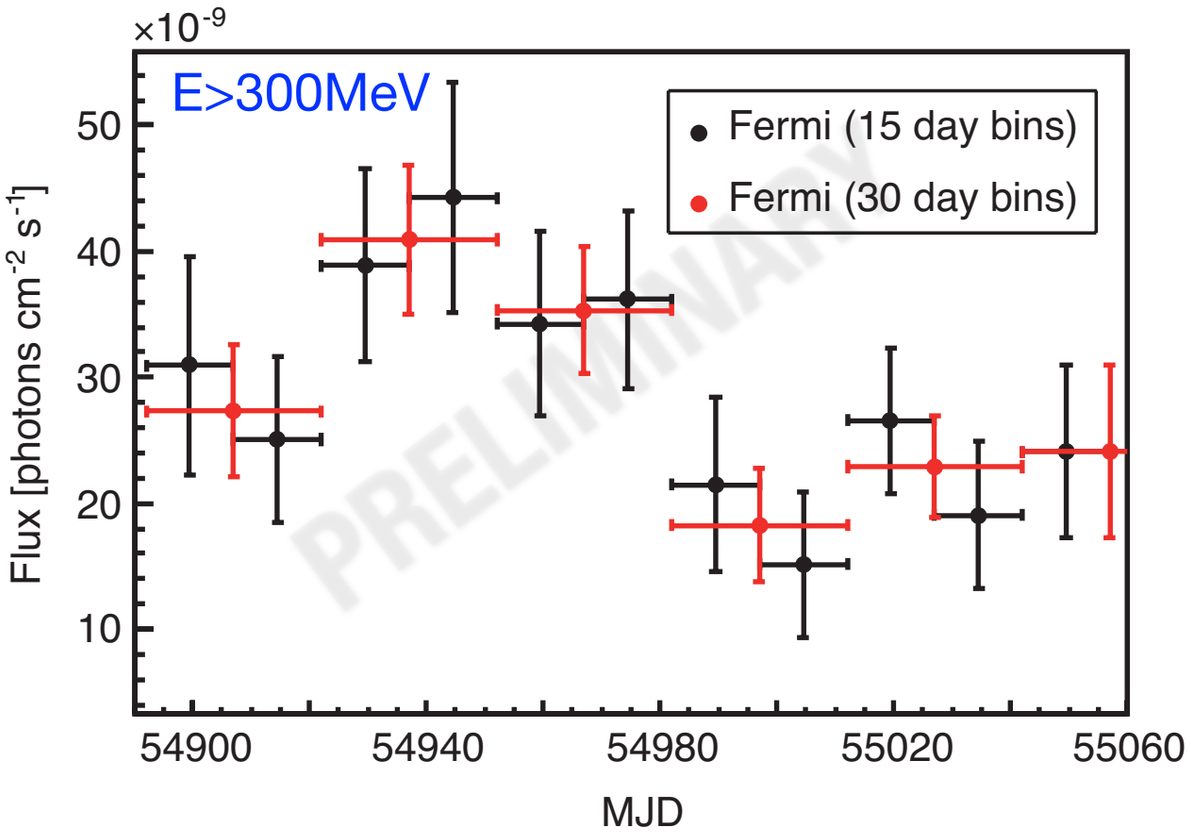

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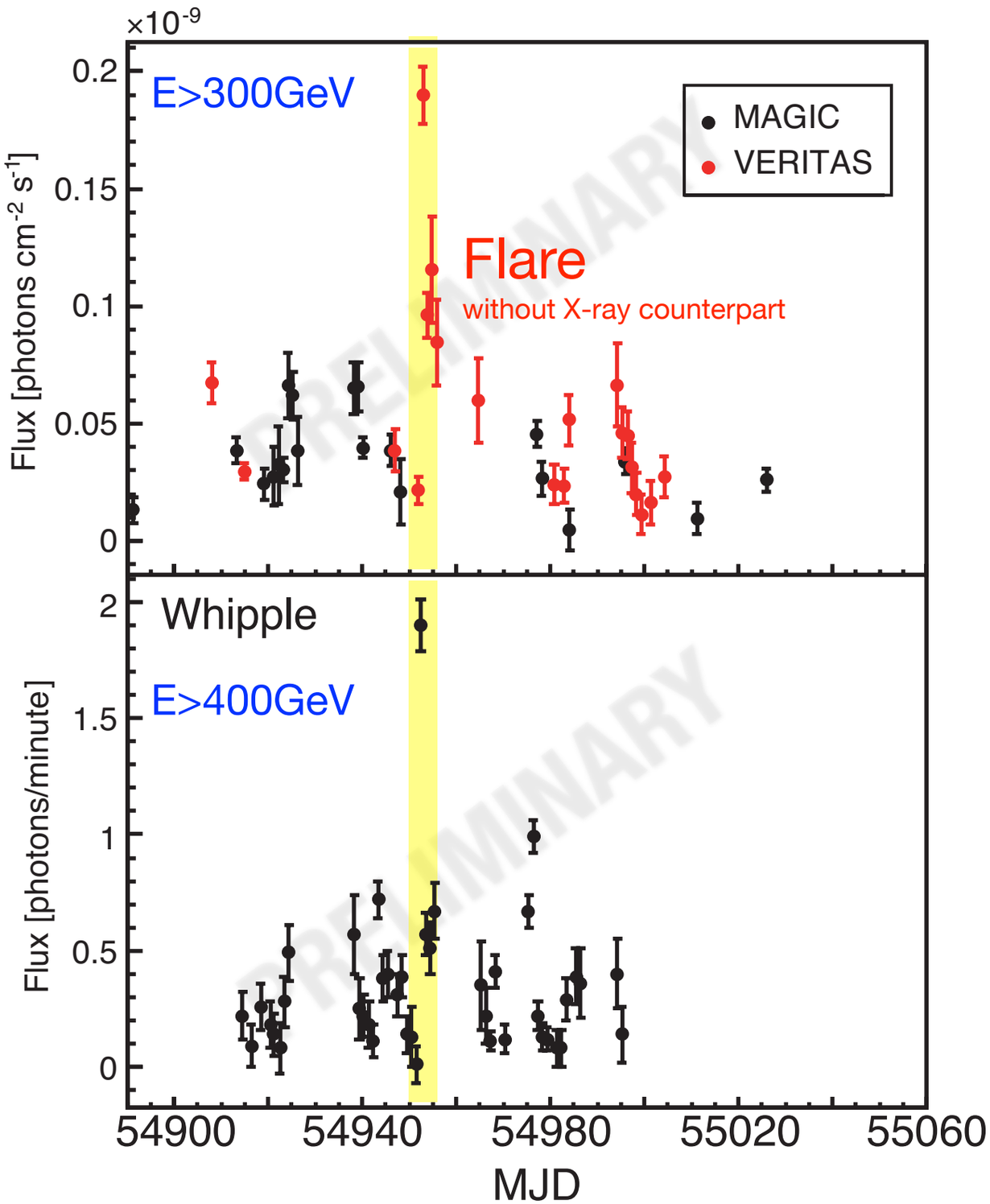

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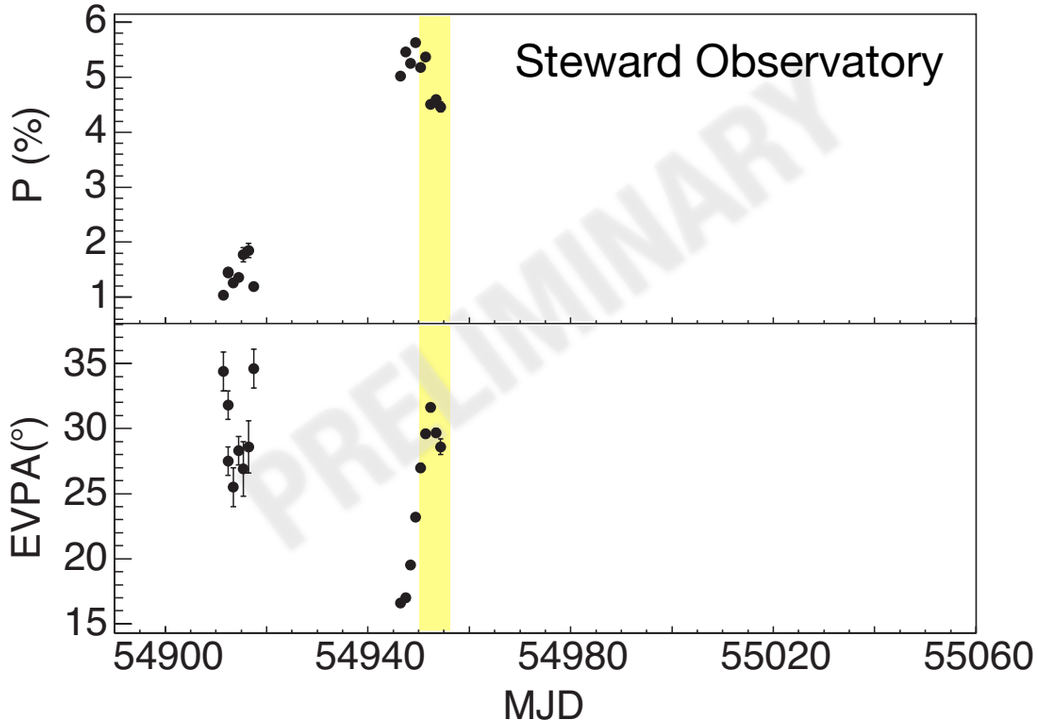
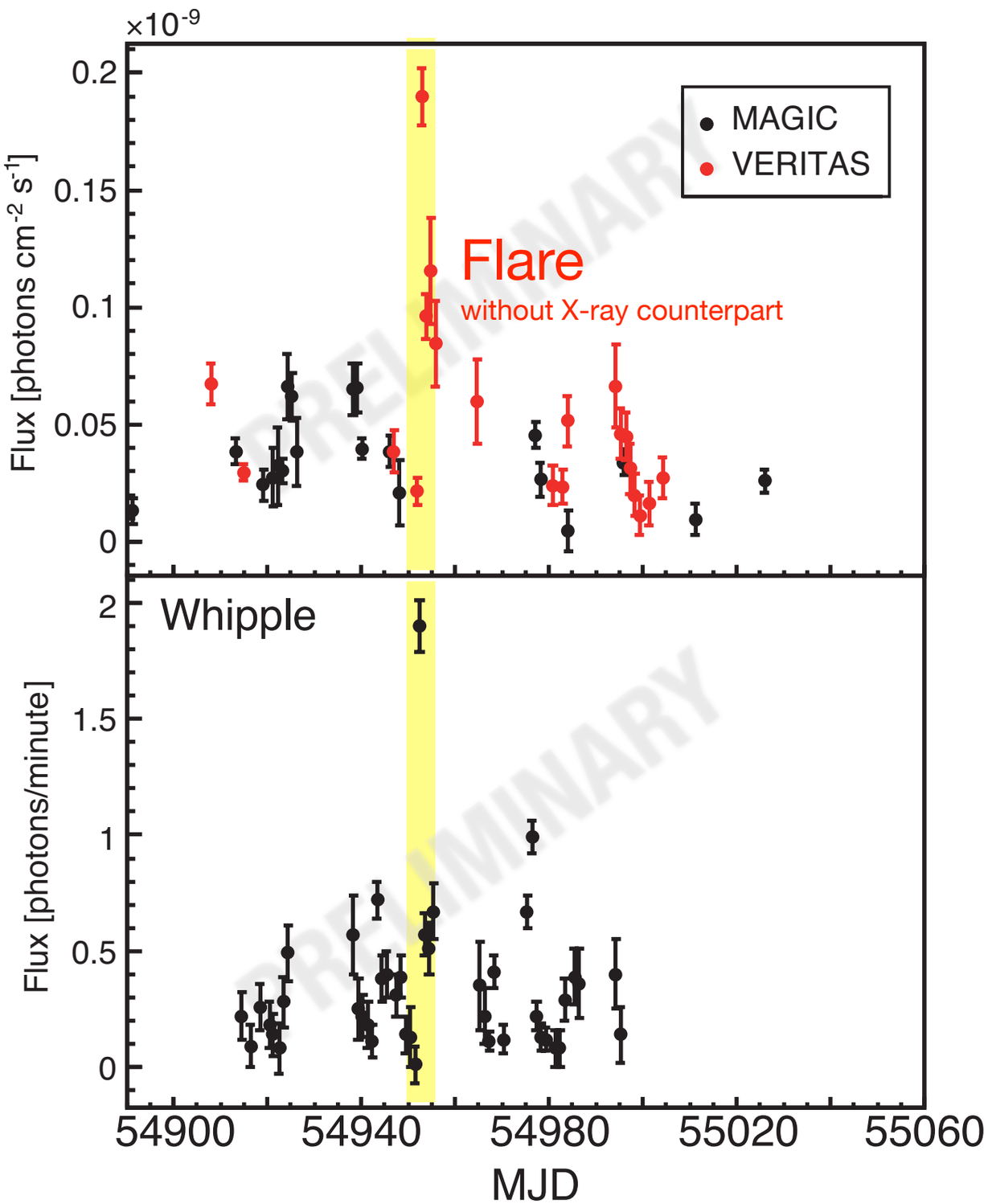


optical linear polarisation:
- steady and then drops by ~15% after flare
- much larger than in March 2009

EVPA:
- continuous increase from ~15° to ~30° in 3 days before flare
- rotation stops when flare occurs

➡ indicates common origin for optical and γ-ray emission (e.g., Marscher et al. 2010)



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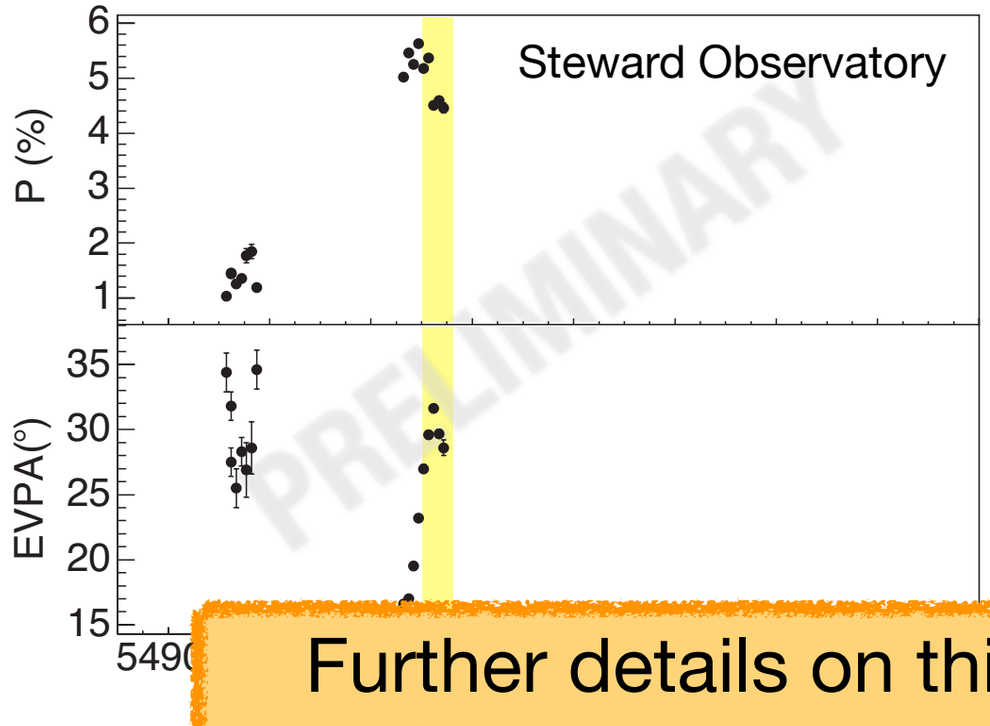

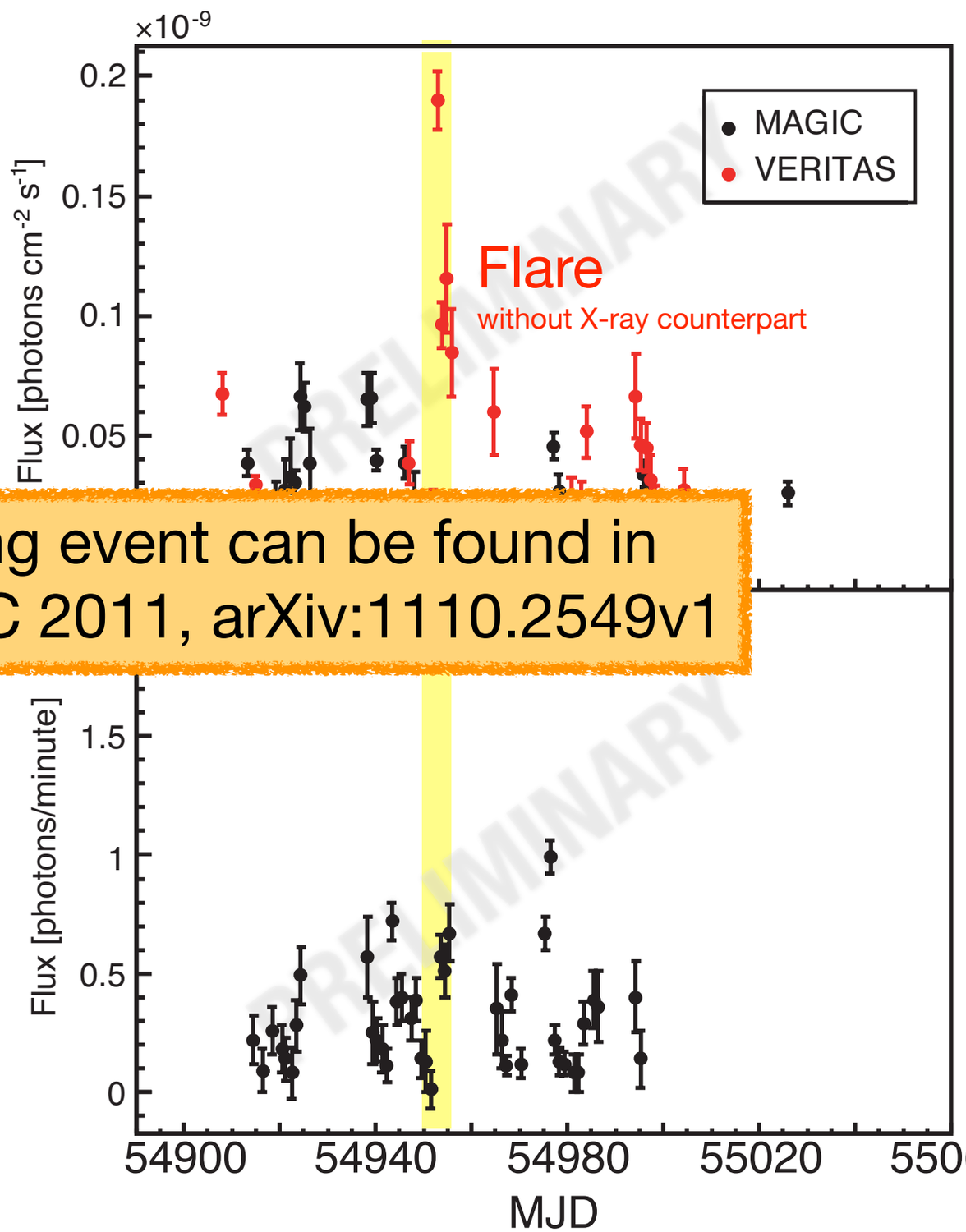

Further details on this flaring event can be found in Pichel & Paneque, Proc. ICRC 2011, arXiv:1110.2549v1

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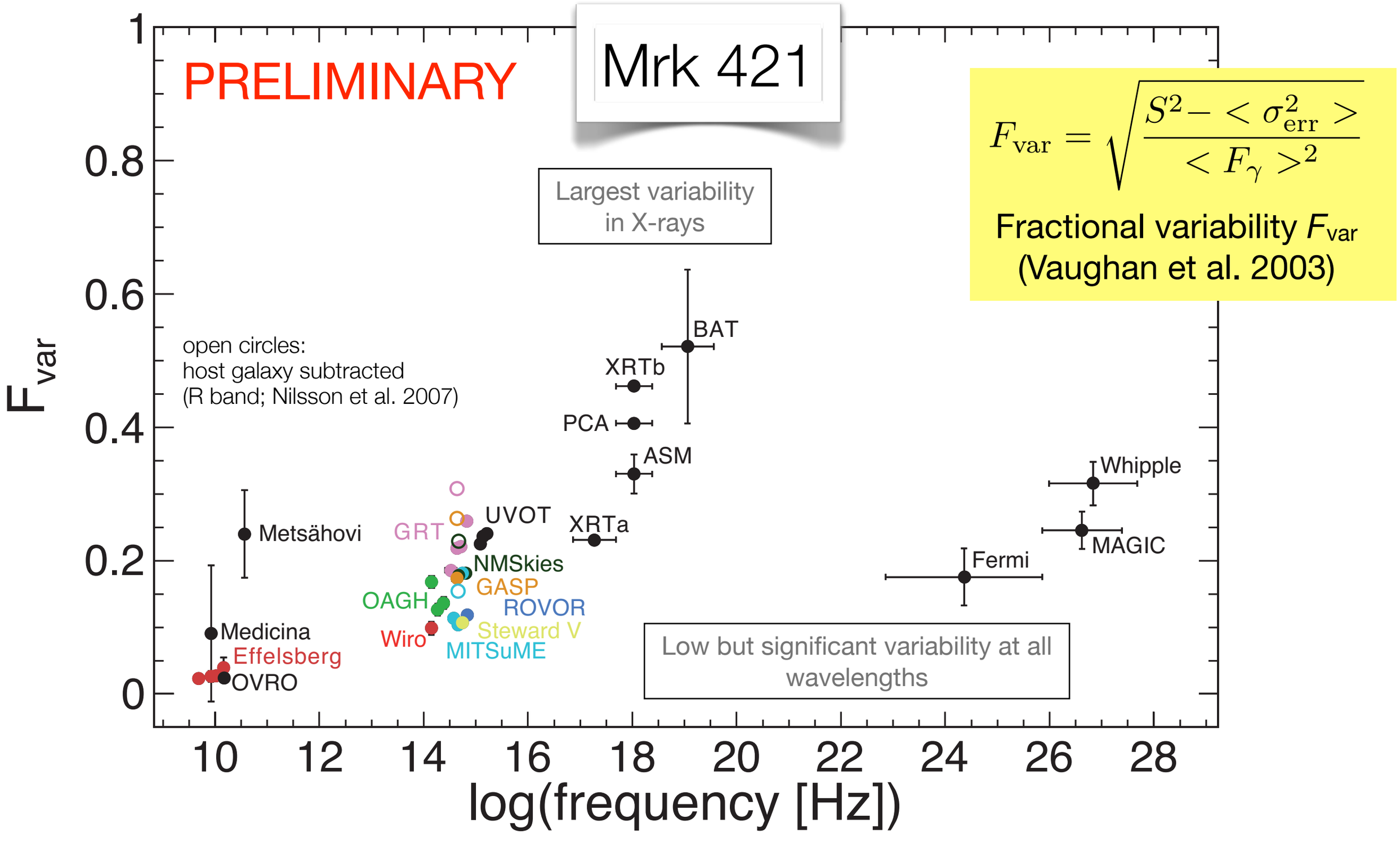
Variability of Mrk 421 and Mrk 501



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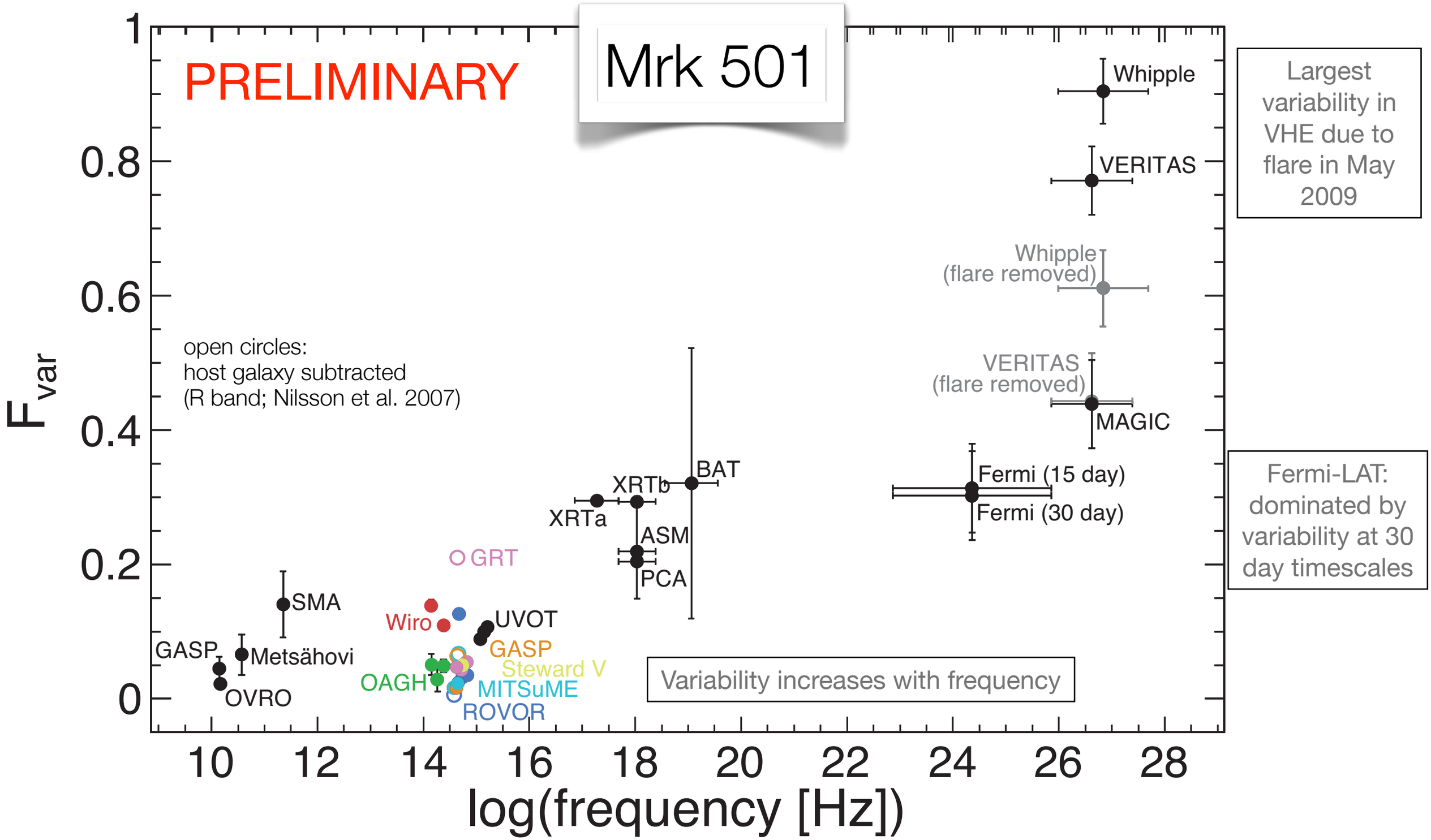

Unequally & unevenly sampled lightcurves

- unevenly sampled lightcurves, gaps
- each lightcurve has a different sampling, different number of data points

What is the error in $F_{\rm var}$ introduced by this? How many flux measurements are needed to obtain a reliable $F_{\rm var}$ estimate?

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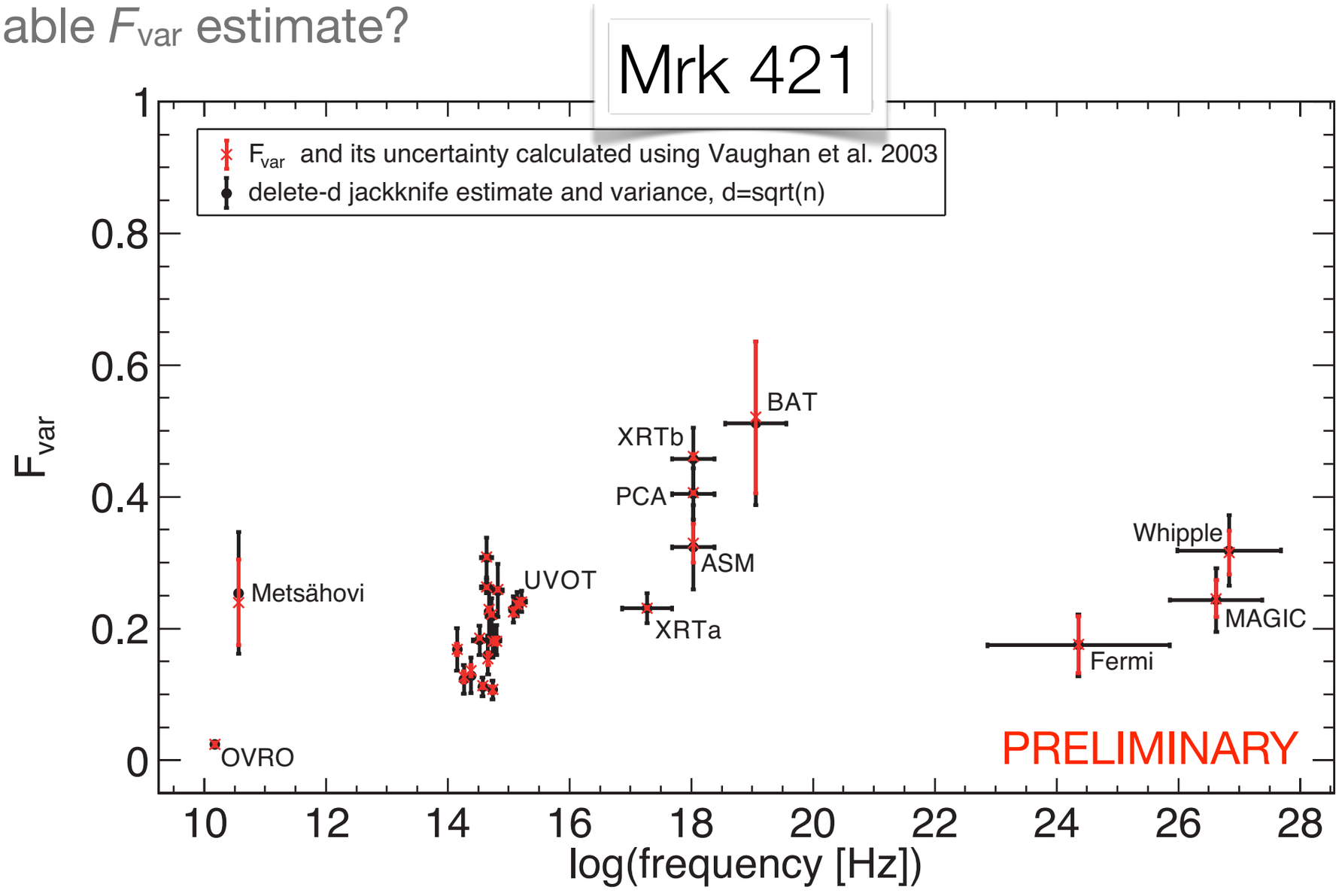
d randomly selected flux measurements removed from each lightcurve without replacement (Jackknife)



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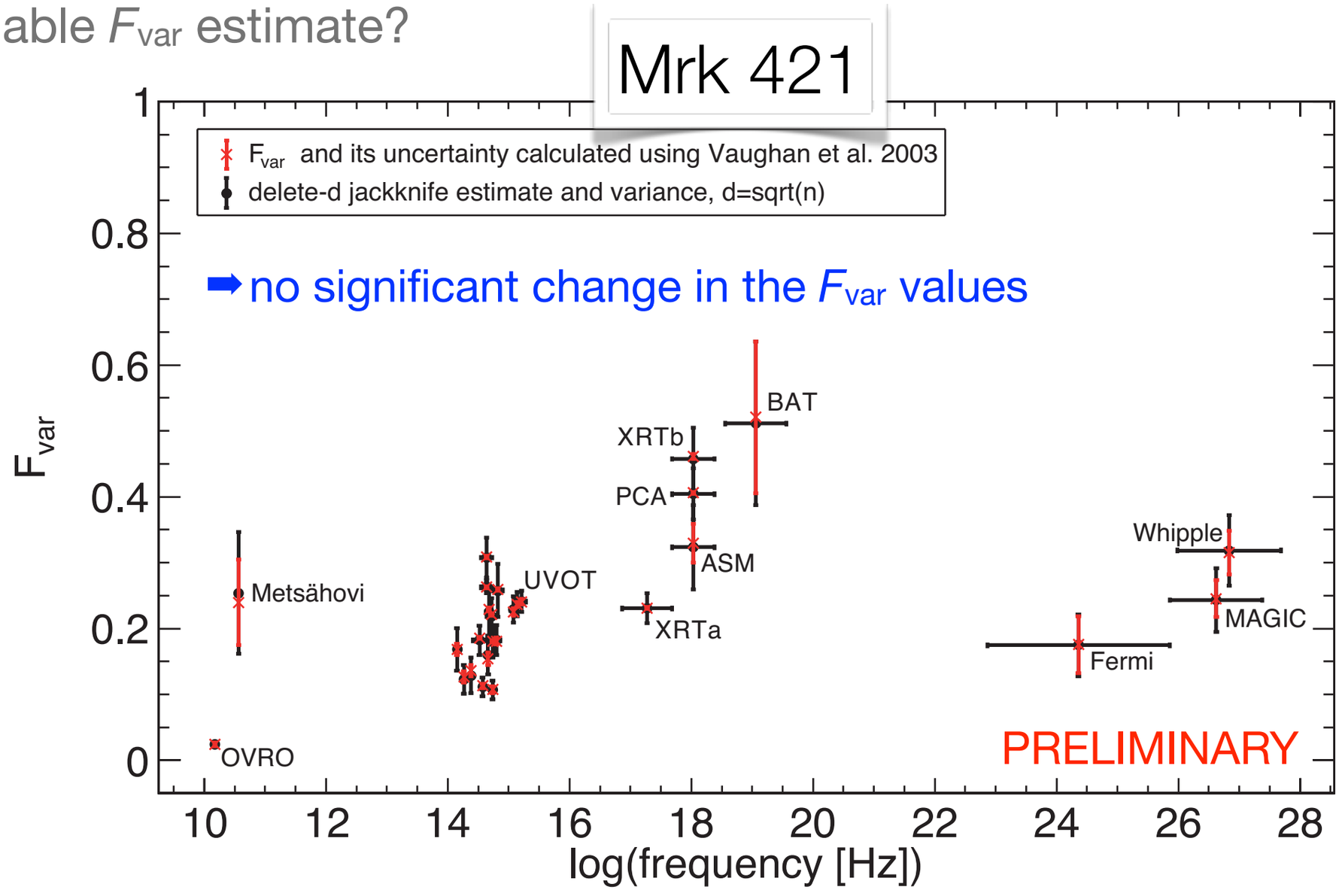

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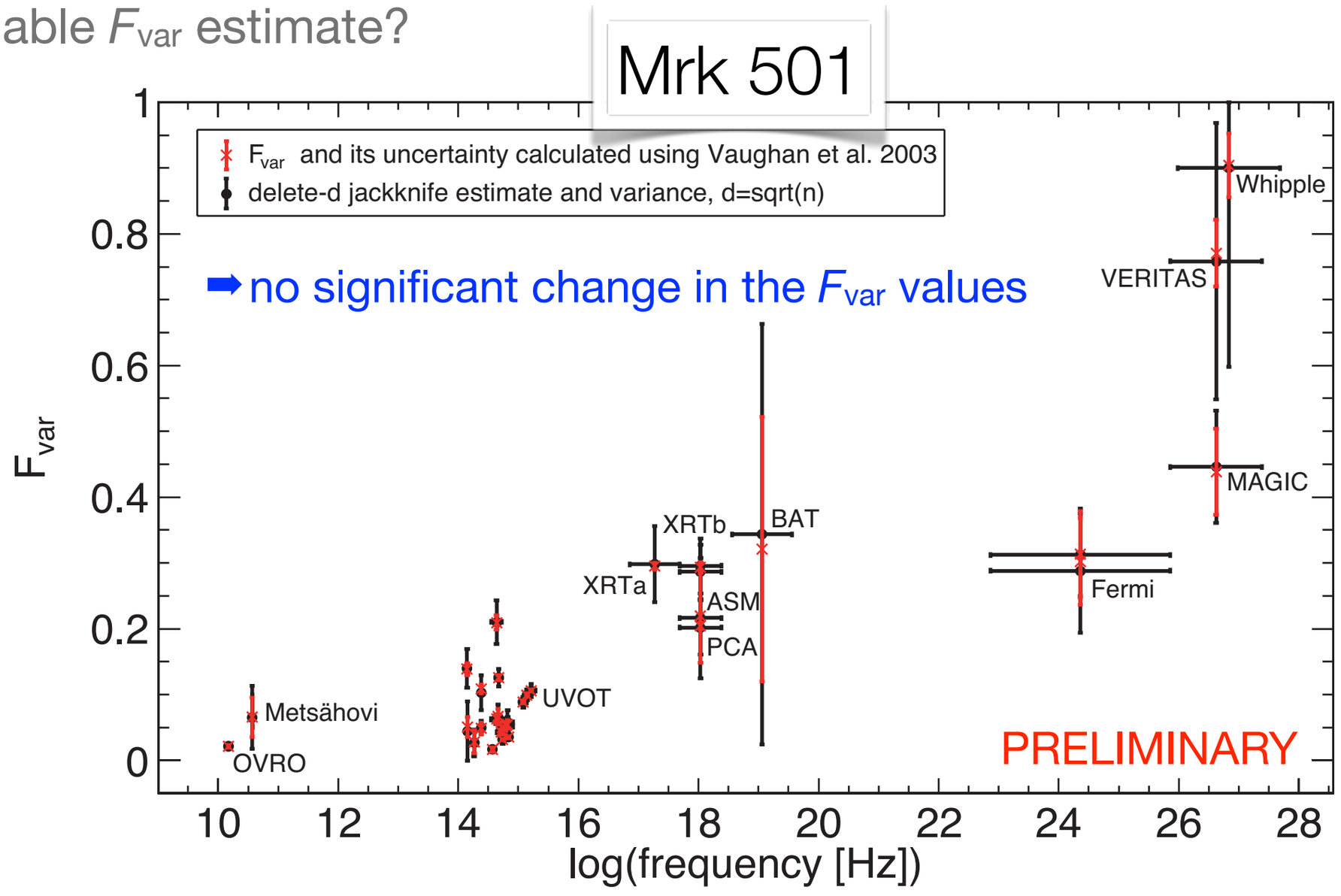
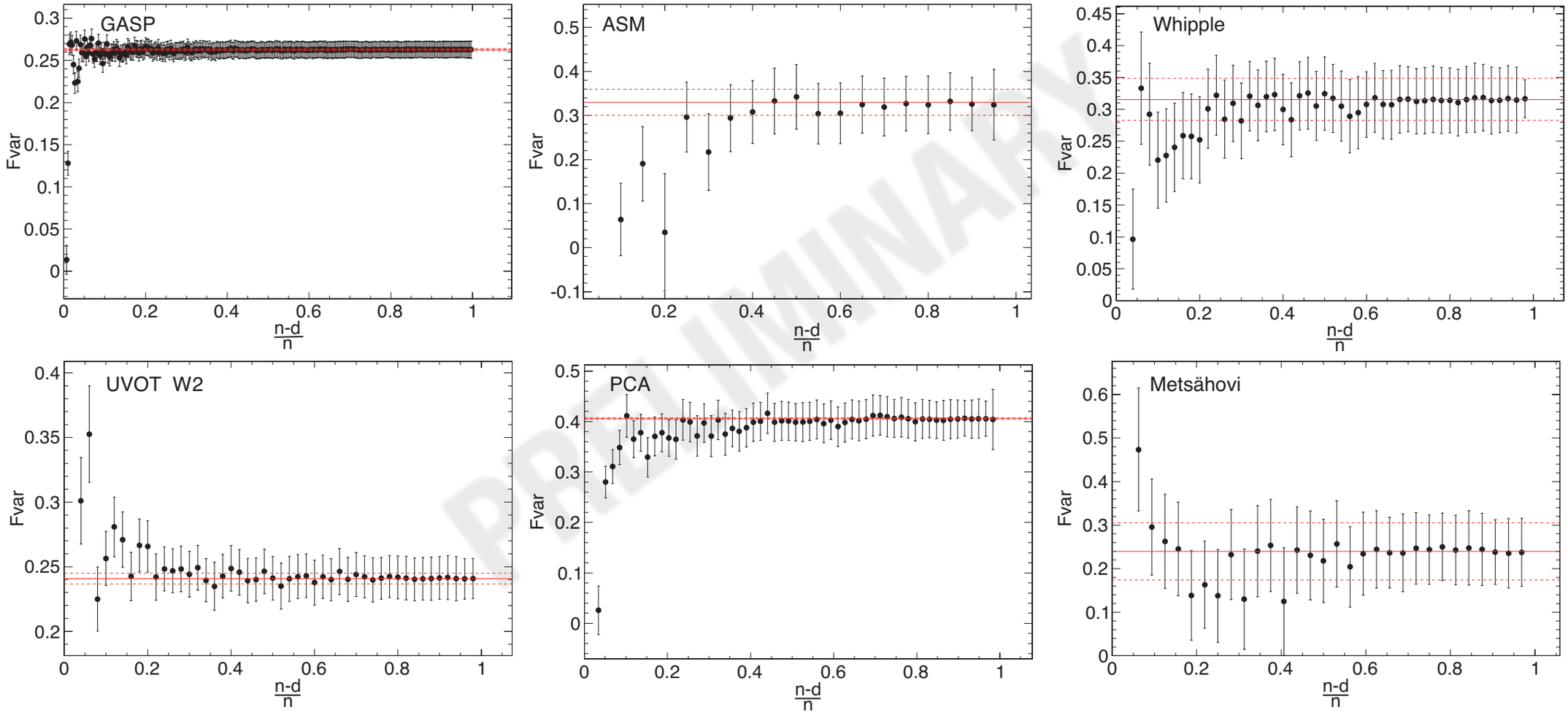


Unequally & unevenly sampled lightcurves

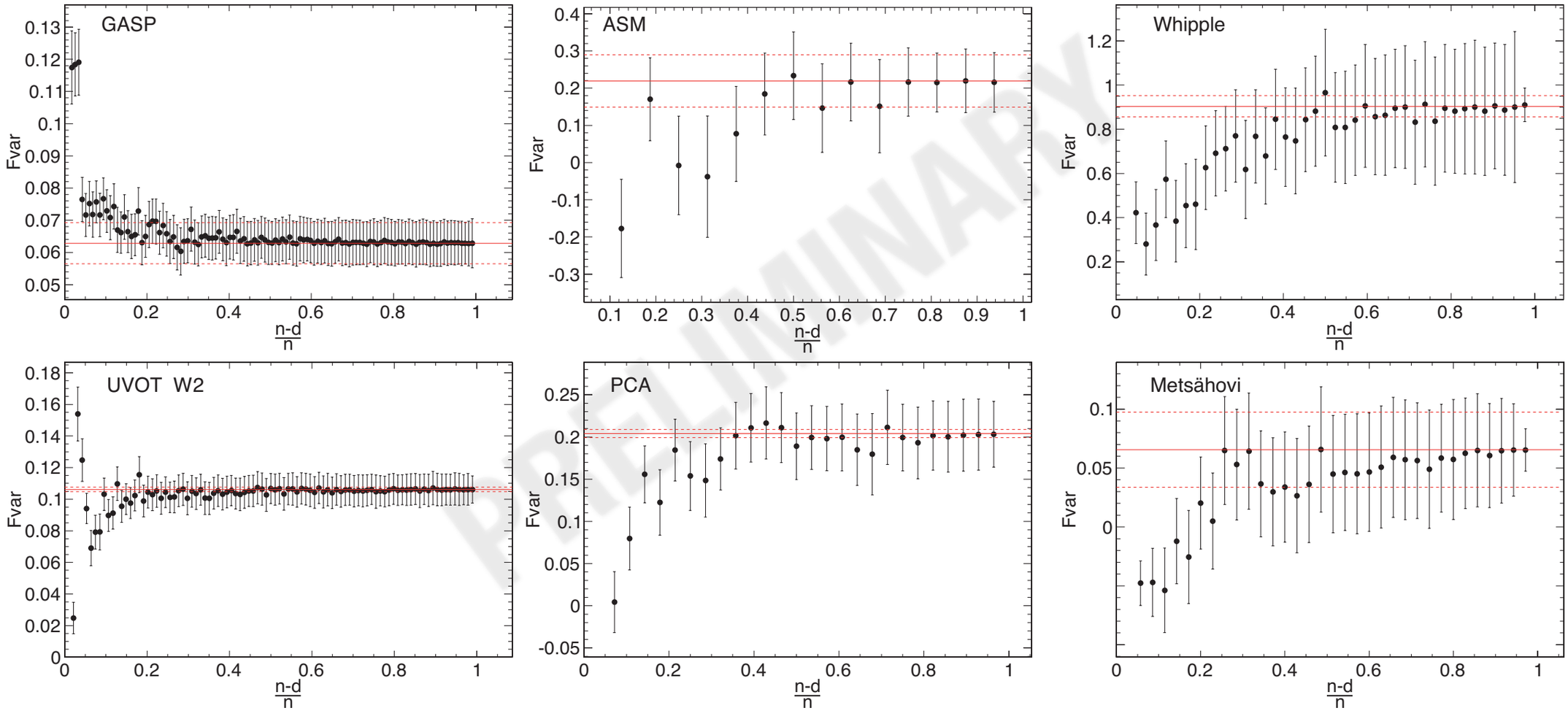
Mrk 421



- $d = 1 \ldots n\text{-}2$ flux values removed from each lightcurve
- F_{var} measurements reliable for all but the smallest ($n \gtrsim 10$) samples

Unequally & unevenly sampled lightcurves

Mrk 501



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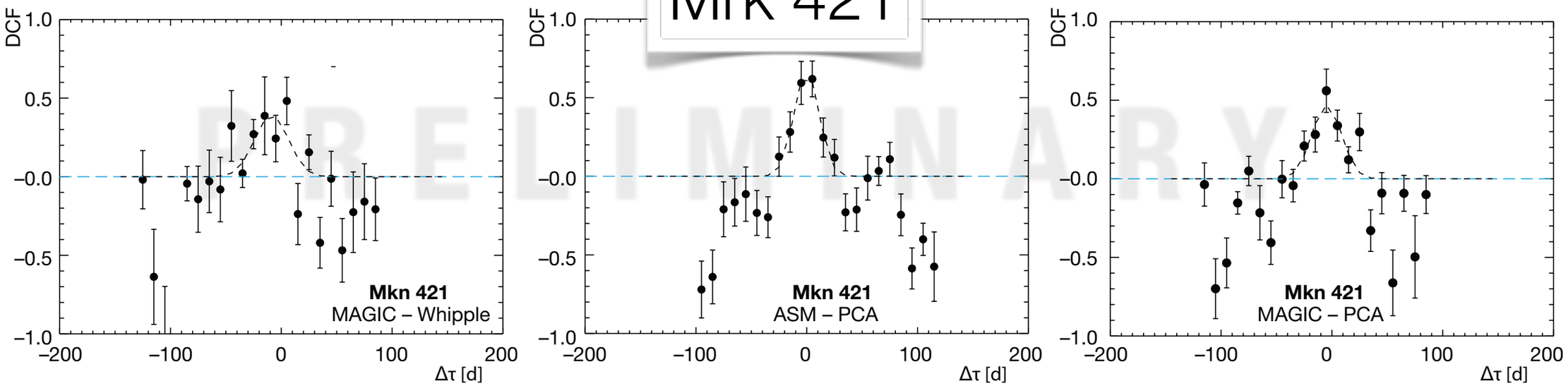
- $F_{\rm var}$ measurements reliable for all but the smallest ($n \lesssim 10$) samples

Correlations

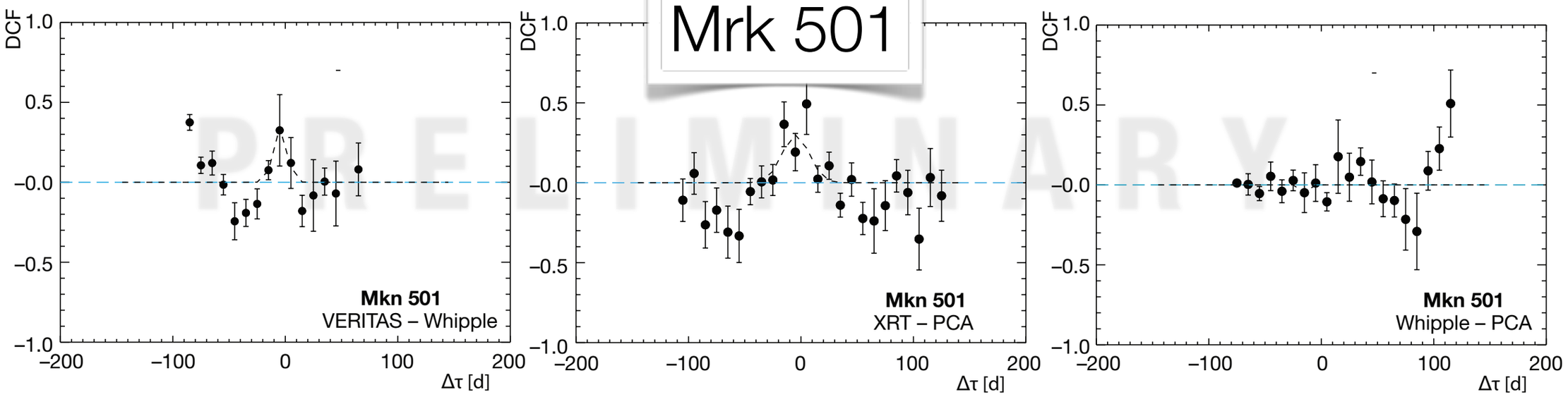
Mrk 421



Discrete correlation function (Edelson & Krolik 1988)

Mrk 421: clear correlation between VHE and X-rays

Mrk 501



Mrk 501: no correlation between VHE and X-rays

Conclusions & Outlook

- 2009 MWL campaings on Mrk 421 and Mrk 501
- preliminary results on variability:
  - both sources in low activity state
  - Mrk 421:
    - Fractional variability F_{var} low but significant at all frequencies, largest in X-rays
  - Mrk 501:
    - flare in VHE in May 2009, accompanied by changes in optical polarisation and EVPA
    - Mrk 501: Fractional variability F_{var} increases with frequency, largest in VHE due to flare
- Problem of unevenly and unequally sampled lightcurves: first quick test shows that F_{var} is not significantly affected by sampling, gaps and different number of flux measurements
- more detailed analysis of the variability and correlation studies (discrete correlation functions) under way

SED fitting parameters

Mrk 501: Stawarz's code

Abdo et al., 2011, ApJ, 727, 129

R [cm]	1.3e17
B [G]	1.5e-2
delta	12.0
η_e	56
γmin	600
s1	2.2
γbrk_1	4.e4
s2	2.7
γbrk_2	9.e5
s3	3.7
γmax	1.5e7

Mrk 421: Finke's code

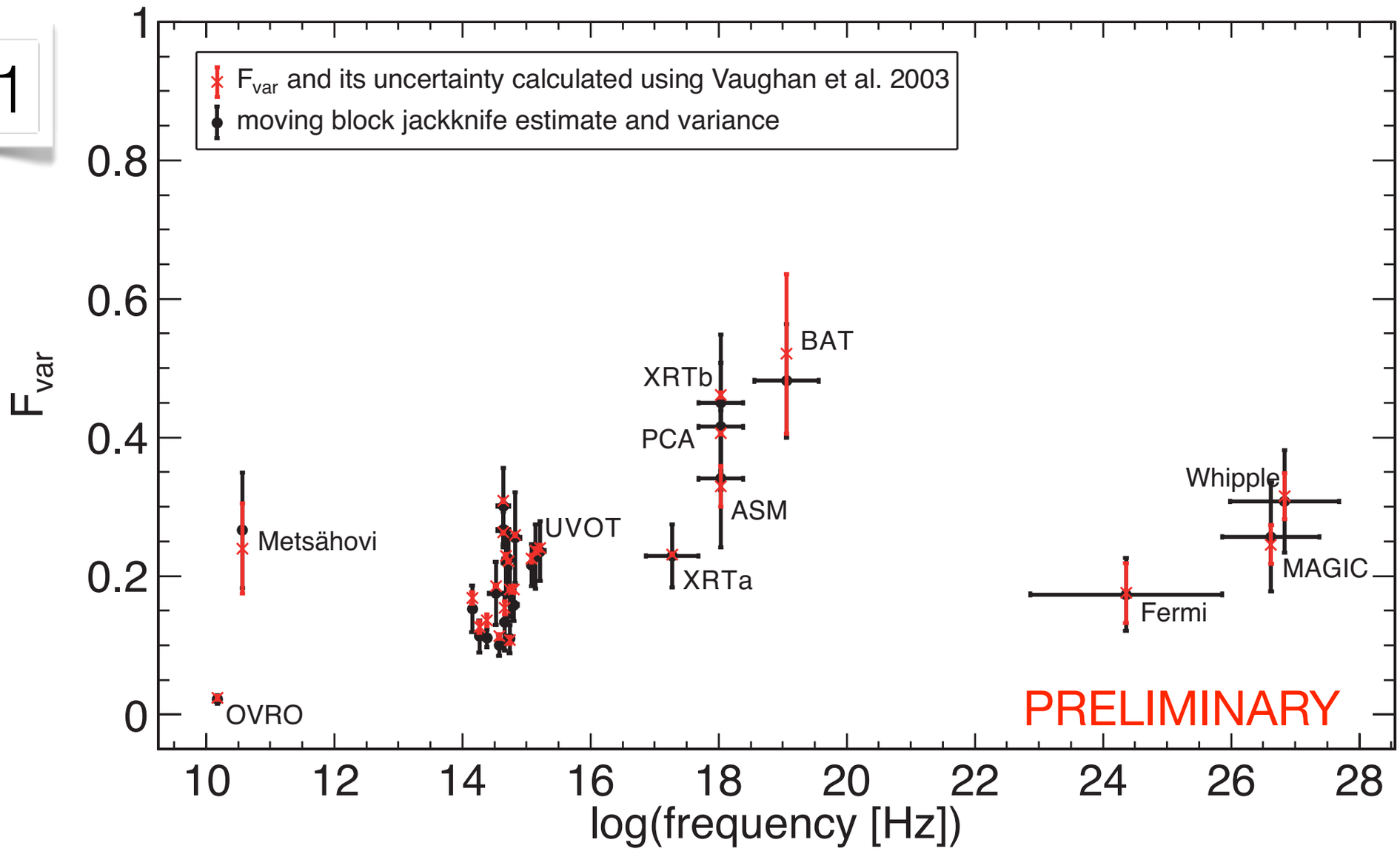
Abdo et al., 2011, ApJ, 736, 131

R [cm]	5.2e16
B [G]	3.8e-2
delta	21.0
η_e	10
γmin	800
s1	2.2
γbrk_1	5.e4
s2	2.7
γbrk_2	3.9e5
s3	4.7
γmax	1.0e8

Unequally & unevenly sampled lightcurves

- removed block of m consecutive flux measurements, $m=n^{1/3}$
- somewhat larger errors

Mrk 421



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