Variability of Blazar Light Curves

Bernd Schleicher, Sergej Grischagin

for the FACT Collaboration

Fractional Variability

- Variance of a lightcurve (effect of measuring errors included) $\sigma_{xs}^2 = S^2 - < \sigma_{err}^2 >$
- With the mean square error

$$< \sigma_{err}^2 >= \frac{1}{N} \sum_{i=1}^{N} \sigma_{err,i}^2$$

- Normalized excess variance

$$\sigma_{NXS}^2 = \frac{\sigma_{XS}^2}{< x >^2}$$

- Fractional root mean square (rms) variability amplitude

$$F_{var} = \sqrt{\frac{S^2 - < \sigma_{err}^2 >}{< x^2 >}}$$

Vaughan, S., Edelson, R., Warwick, R. S., & Uttley, P. 2003, MNRAS, 345, 1271

Fractional Variability Error

- Uncertainty of Fvar

$$\Delta F_{Var} = \sqrt{F_{Var}^2 + err(\sigma_{NXS}^2)} - F_{var}$$

- Uncertainty of normalized excess varianz

$$err(\sigma_{NXS}^2) = \sqrt{\left(\sqrt{\frac{2}{N}}\frac{\overline{\sigma_{err}^2}}{\overline{x}^2}\right)^2 + \left(\sqrt{\frac{\sigma_{err}^2}{N}}\frac{2F_{Var}}{\overline{x}}\right)^2}$$

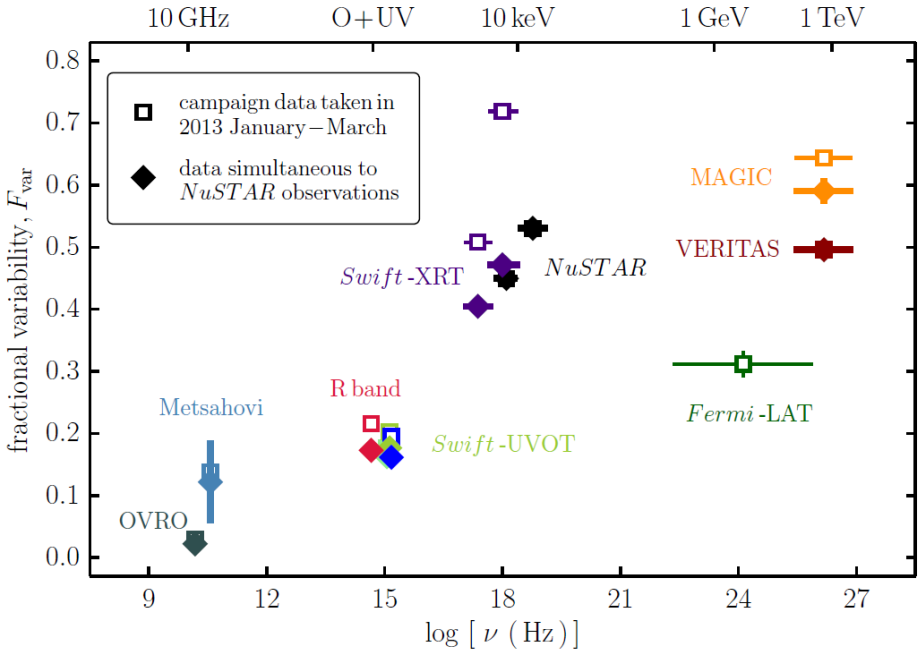
Poutanen, Zdziarski, & Ibragimov, MNRAS, 389, 1427 (2008)

Historical Results

- Fvar often used to study variability
- Small datasamples in most studies (in the order of few weeks)

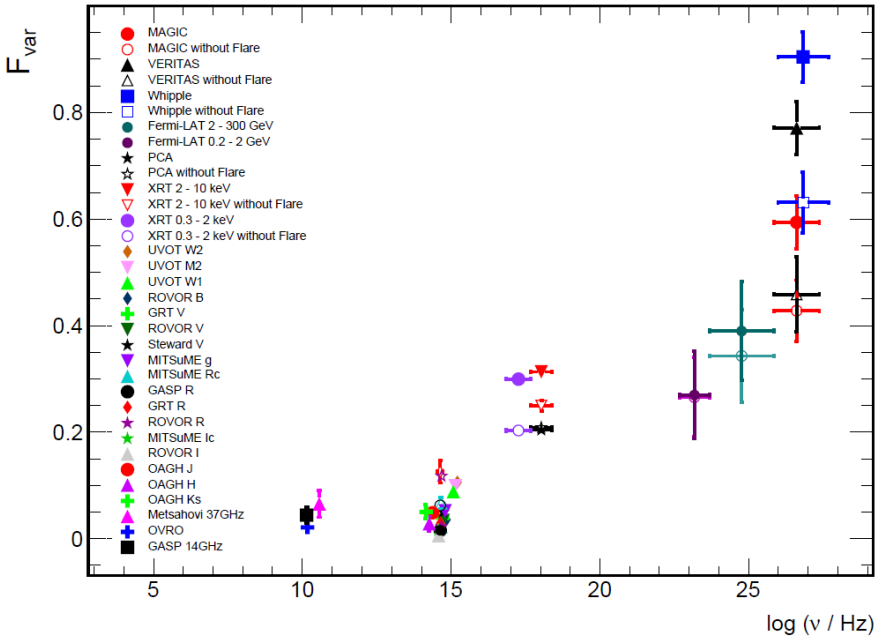
Historical Results

Mrk 421



Baloković et al., ApJ, 819, 156 (2016)

Mrk 501



Ahnen et al., A&A 603, A31 (2017)

Historical Results

- Fvar often used to study variability
- Small datasamples in most studies (in the order of few weeks)
- Fvar vs Energy:
  - Increase with energy
  - Double peak structure for Mrk 421
  - No double peak for Mrk 501
- Limitations due to datasamples
  - Simultaneous observations?
  - Binning , gaps …

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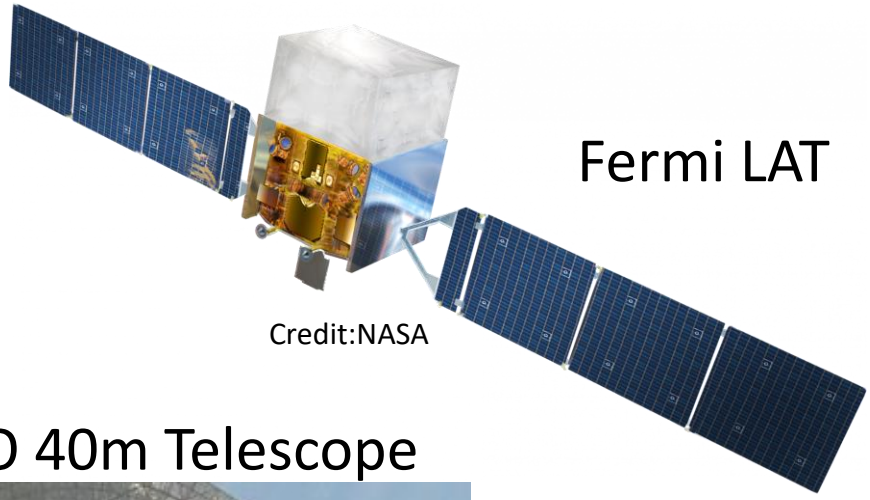
-> Study Effect of Datasample

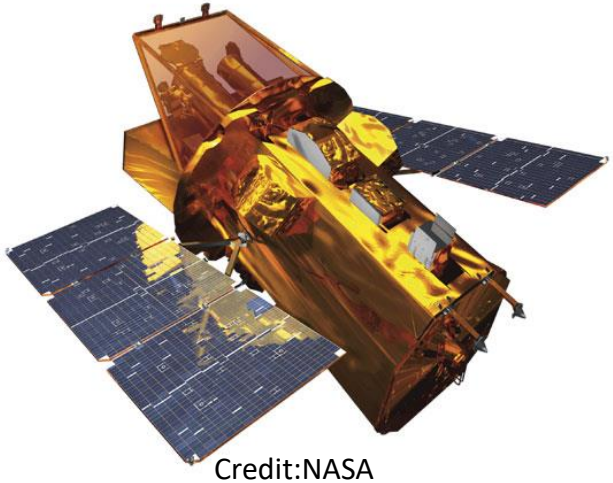
Instruments

Fermi LAT



Credit:NASA

Swift BAT/XRT



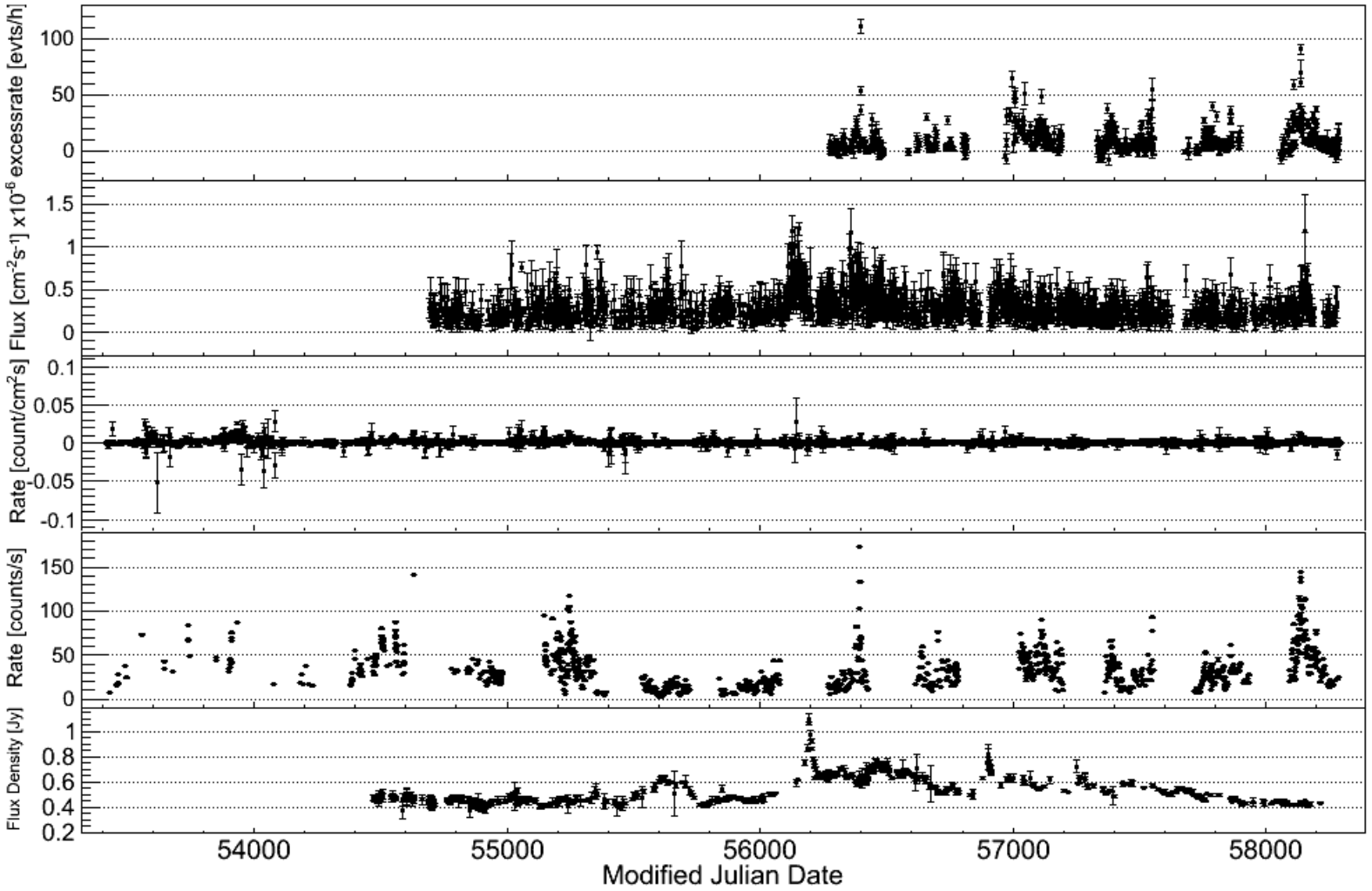
Credit:NASA

OVRO 40m Telescope

FACT

Data available on:
https://fermi.gsfc.nasa.gov/ssc/data/access/
https://swift.gsfc.nasa.gov/results/transients/bat_team/index.html
https://www.swift.psu.edu/monitoring/
http://www.astro.caltech.edu/ovroblazars/data.php?page=data_query
https://fact-project.org/monitoring/

Light Curve Mrk 421 (daily binning)



FACT (TeV)

Fermi (GeV)

BAT (keV)

XRT (keV)

OVRO (radio)

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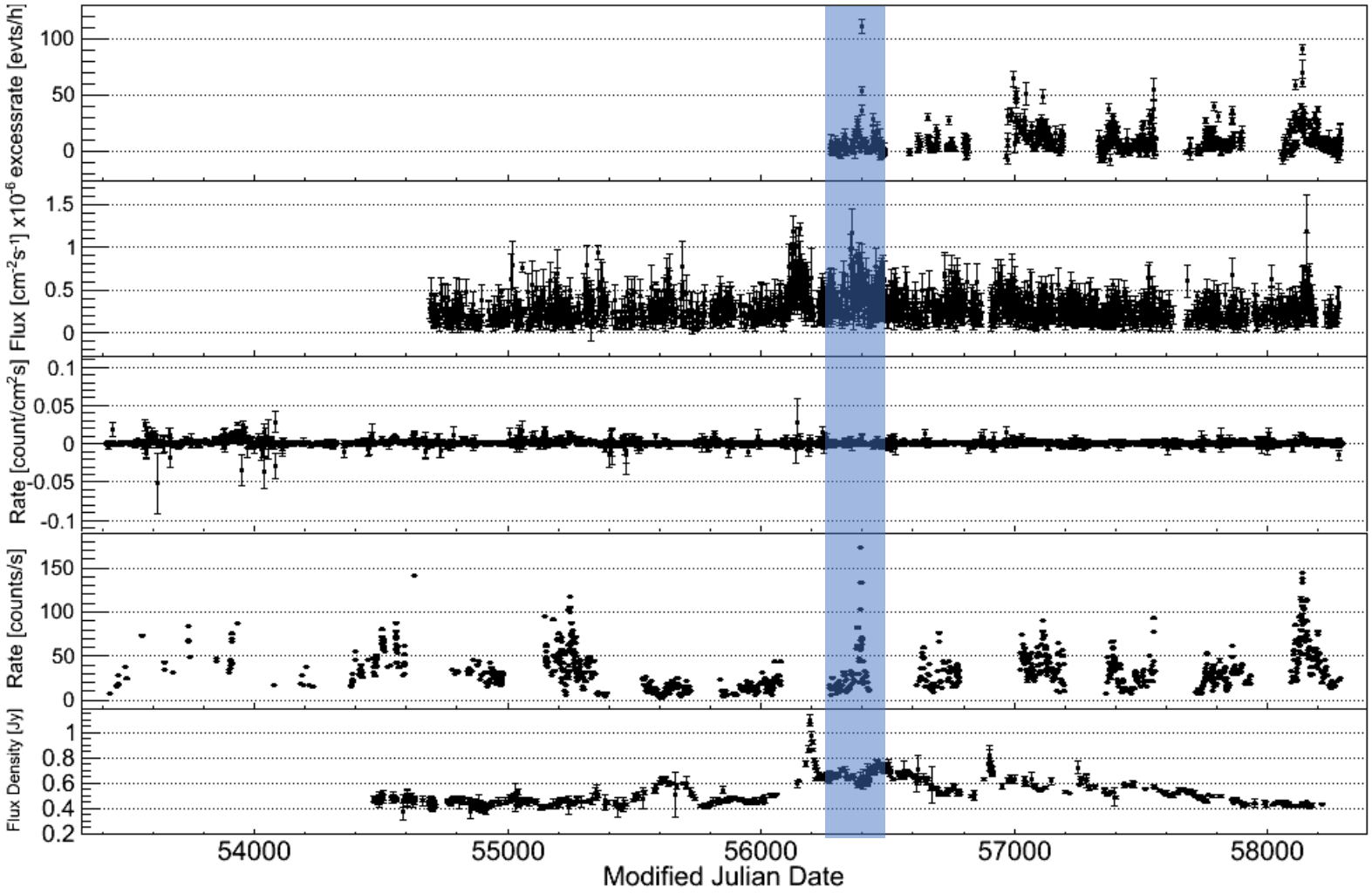

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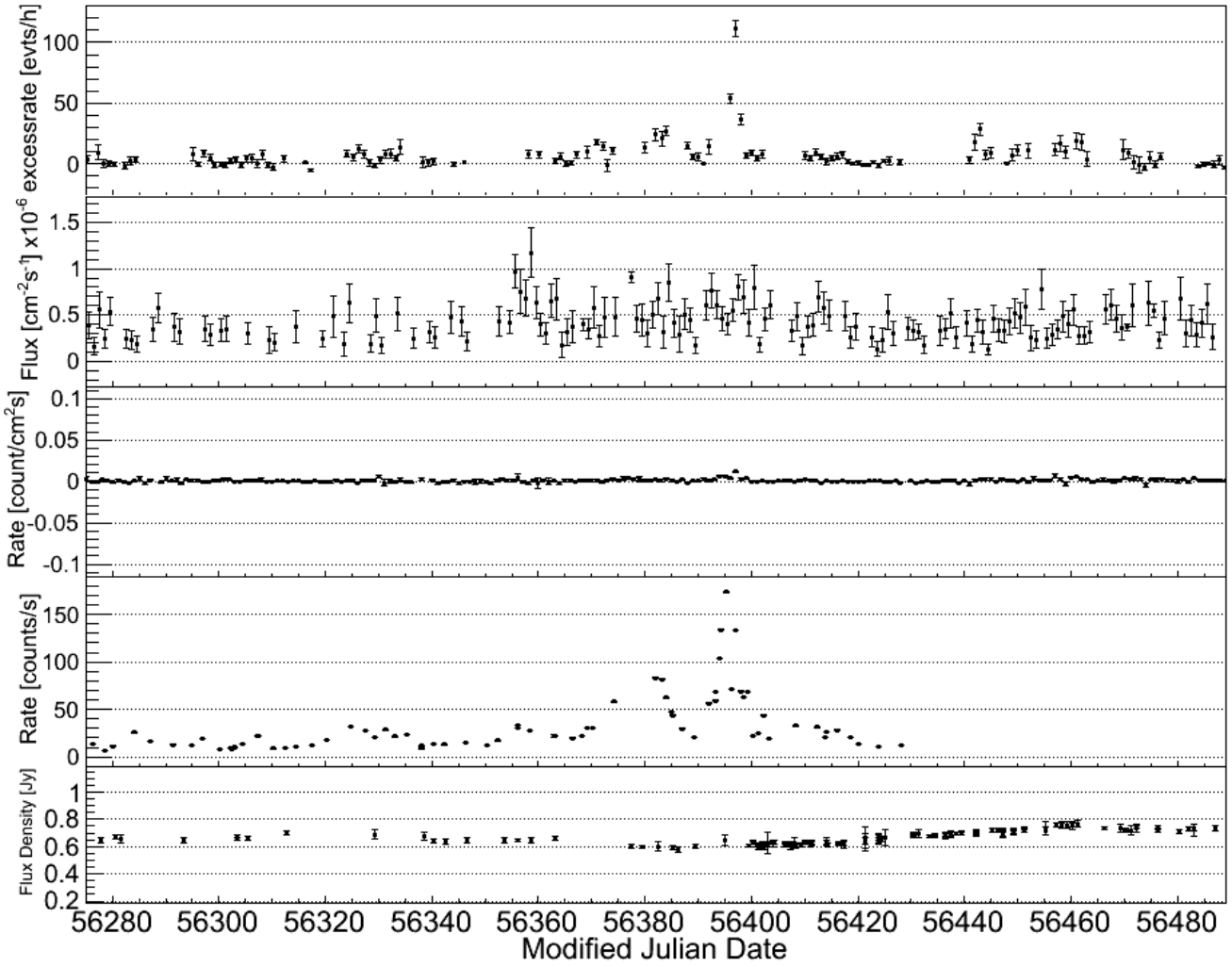
Lightcurve Mrk 421 (2013 season)



FACT
Daily 1-6 h

Fermi
“continuous“

BAT
“continuous“

XRT
every few days

OVRO
every few days

Limitations on Fvar from Datasample

Observational constraints

- Sensitivity of instrument
- Observational technique
  - Weather
  - limitation due to method
- Observing strategy
- Technical issues

Influence on datasample

- Bin size/exposure per bin
- Gaps
- Cadence
- Completeness of datasample

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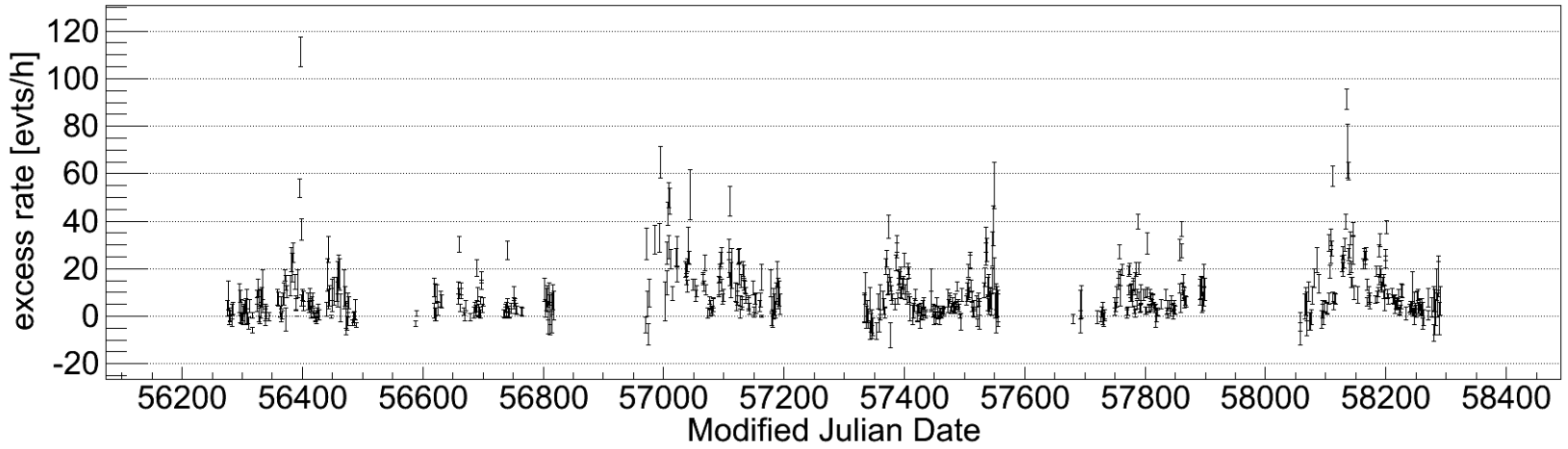
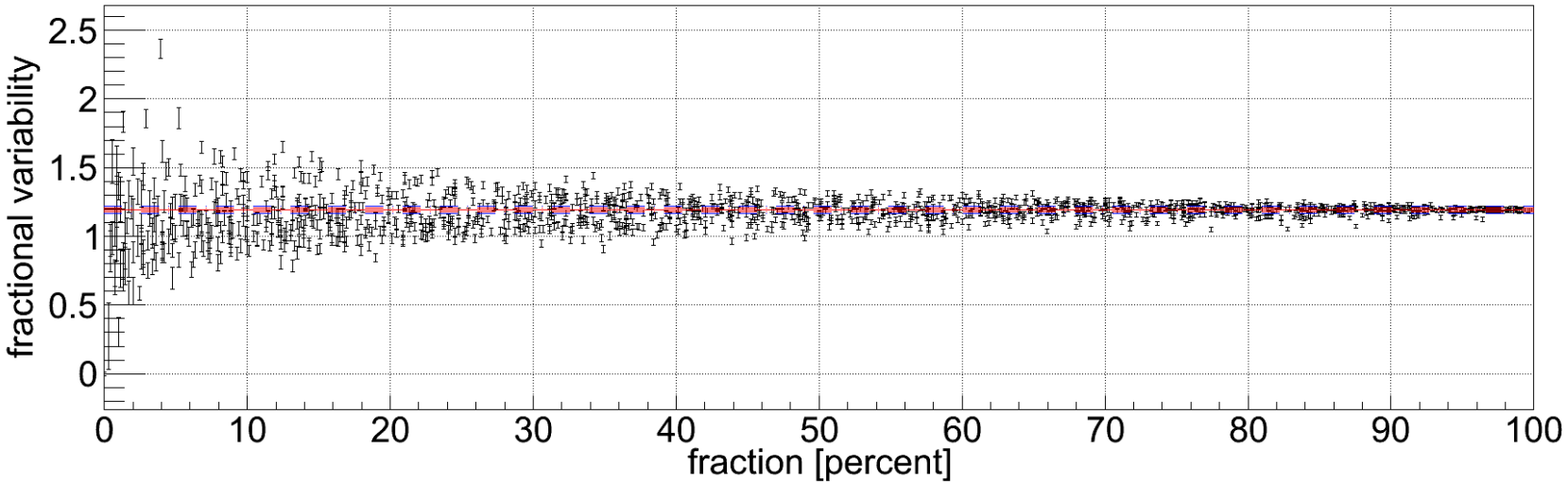
Effect of Incomplete Datasample





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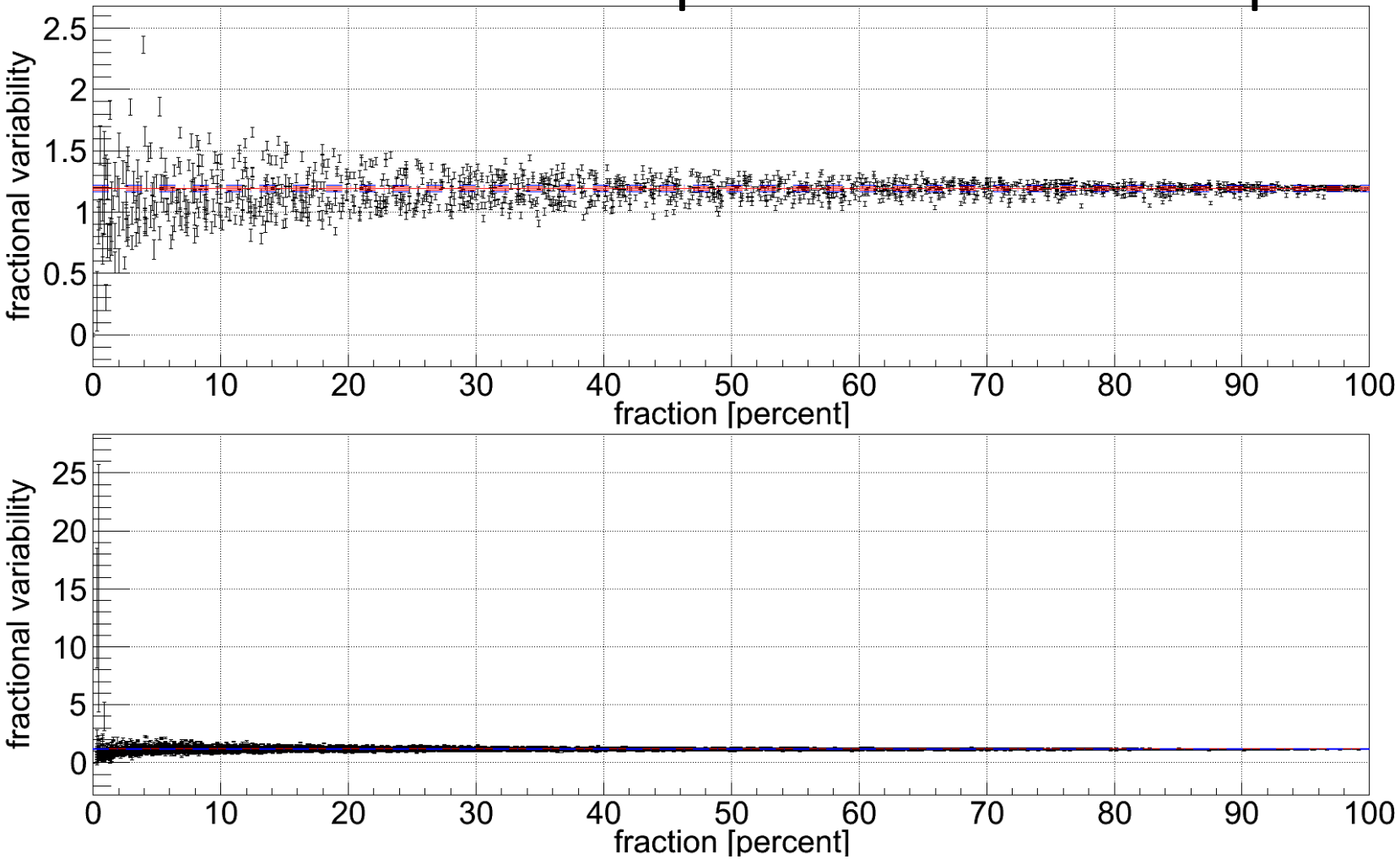

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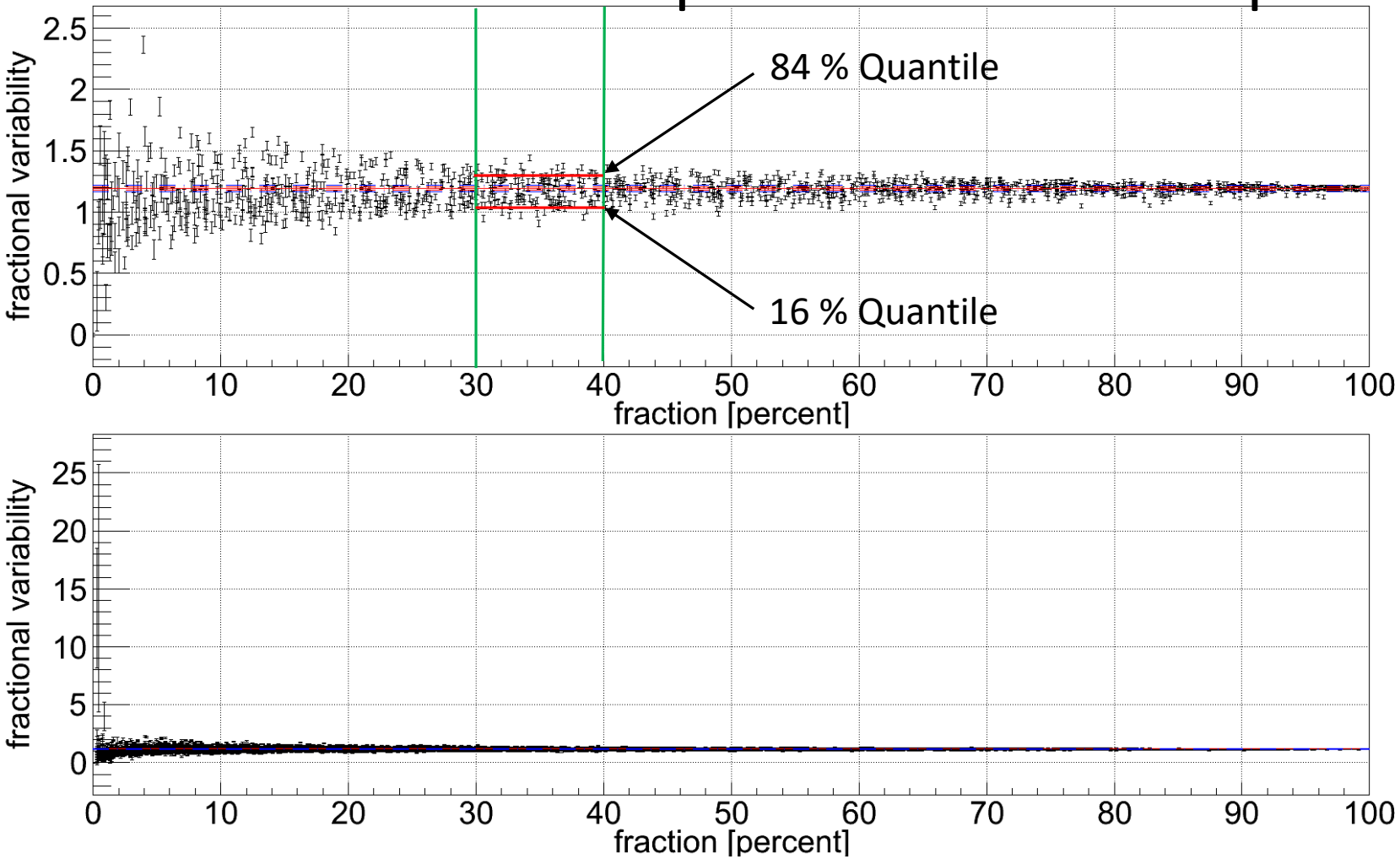

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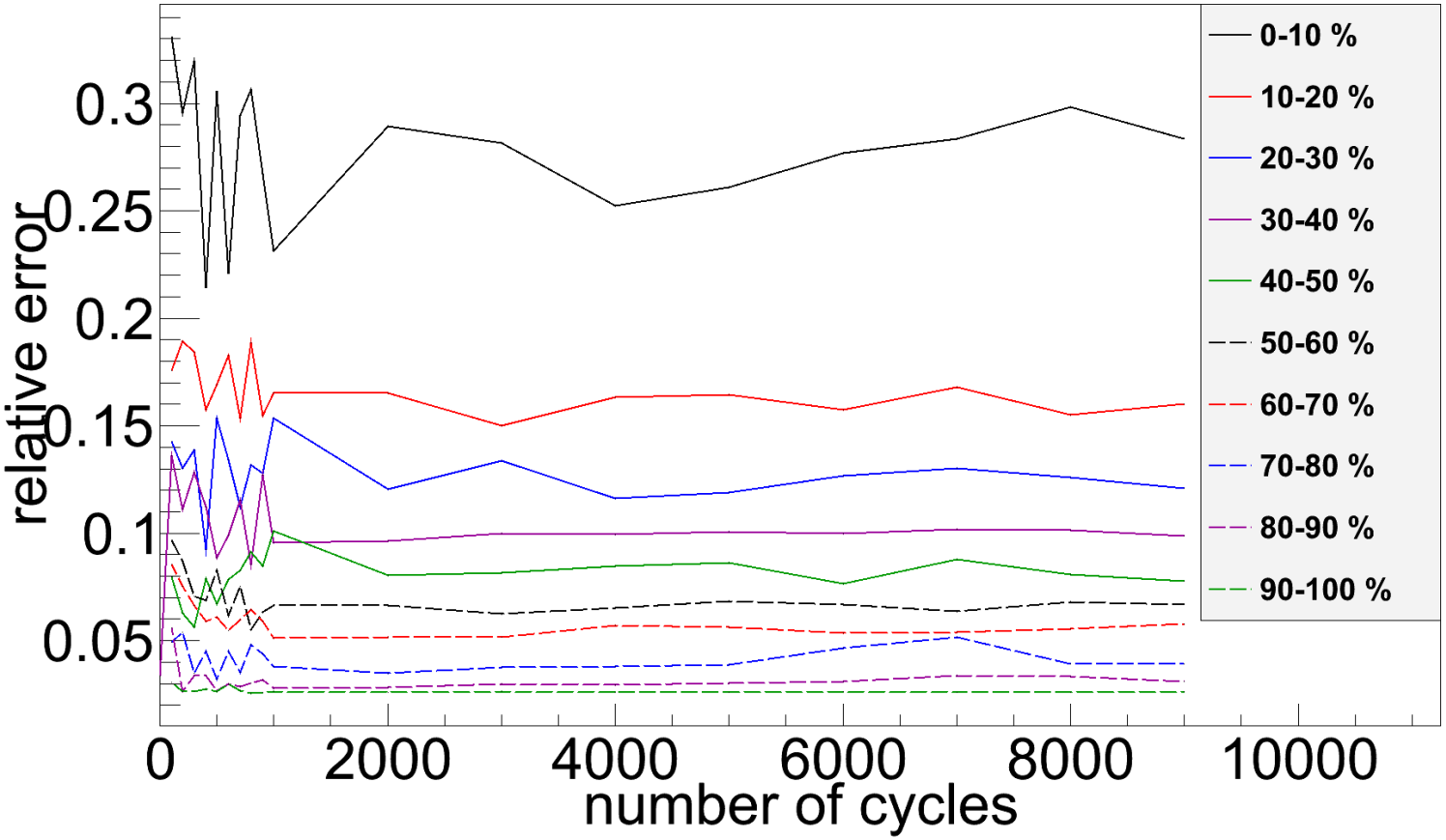
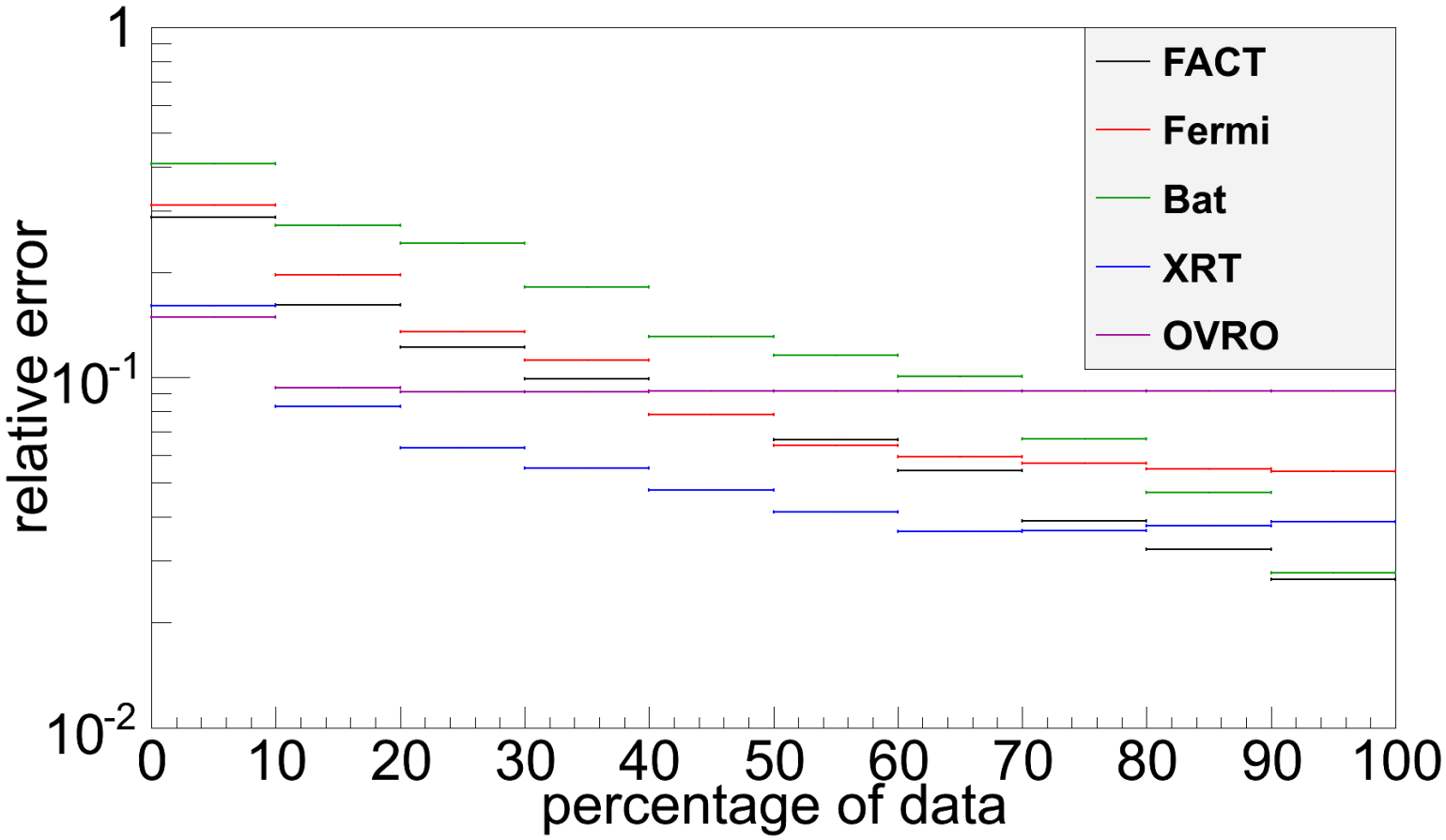
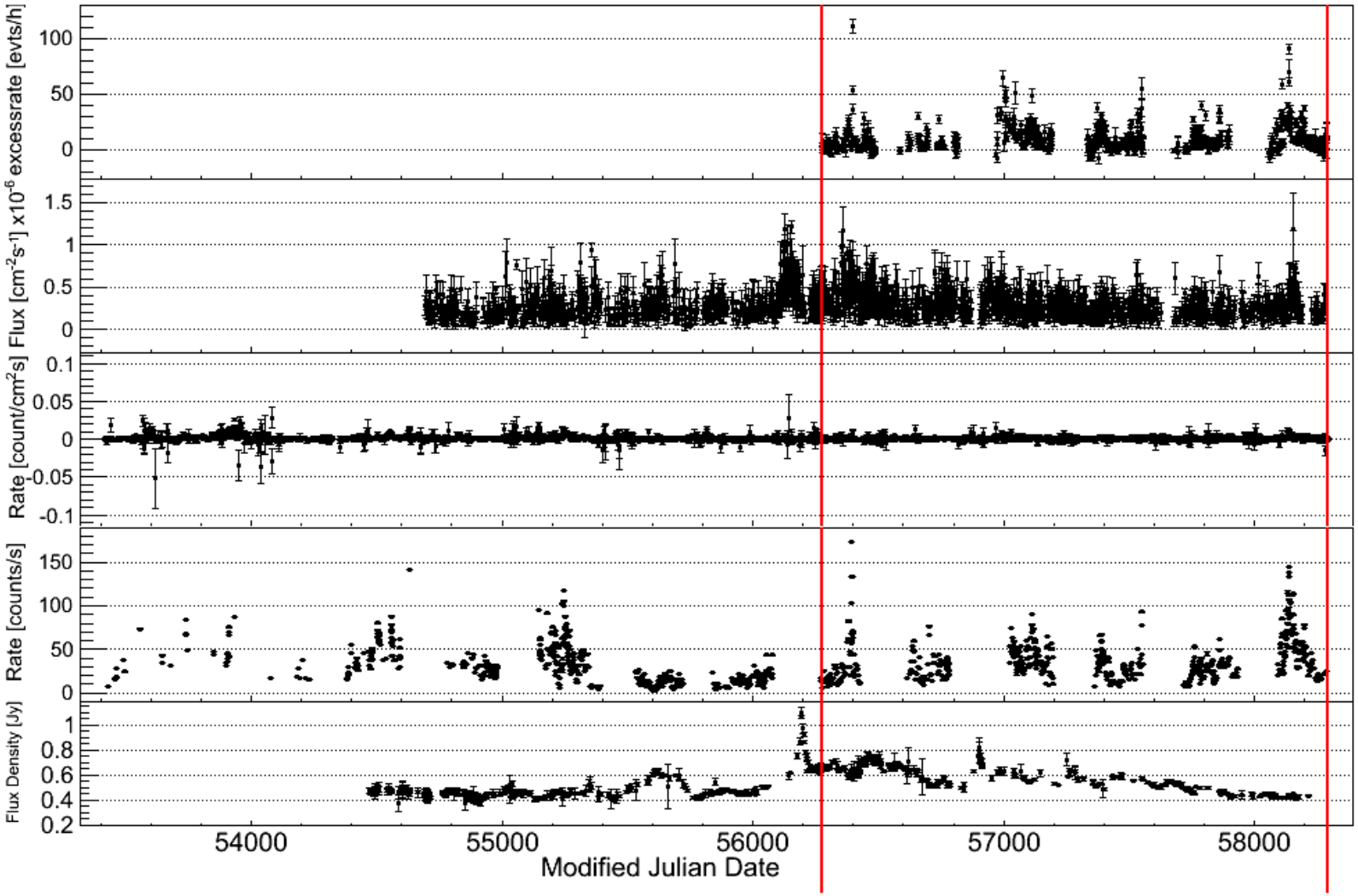


Relative Error (Instruments)



Light Curve Mrk 421



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Fermi (GeV)

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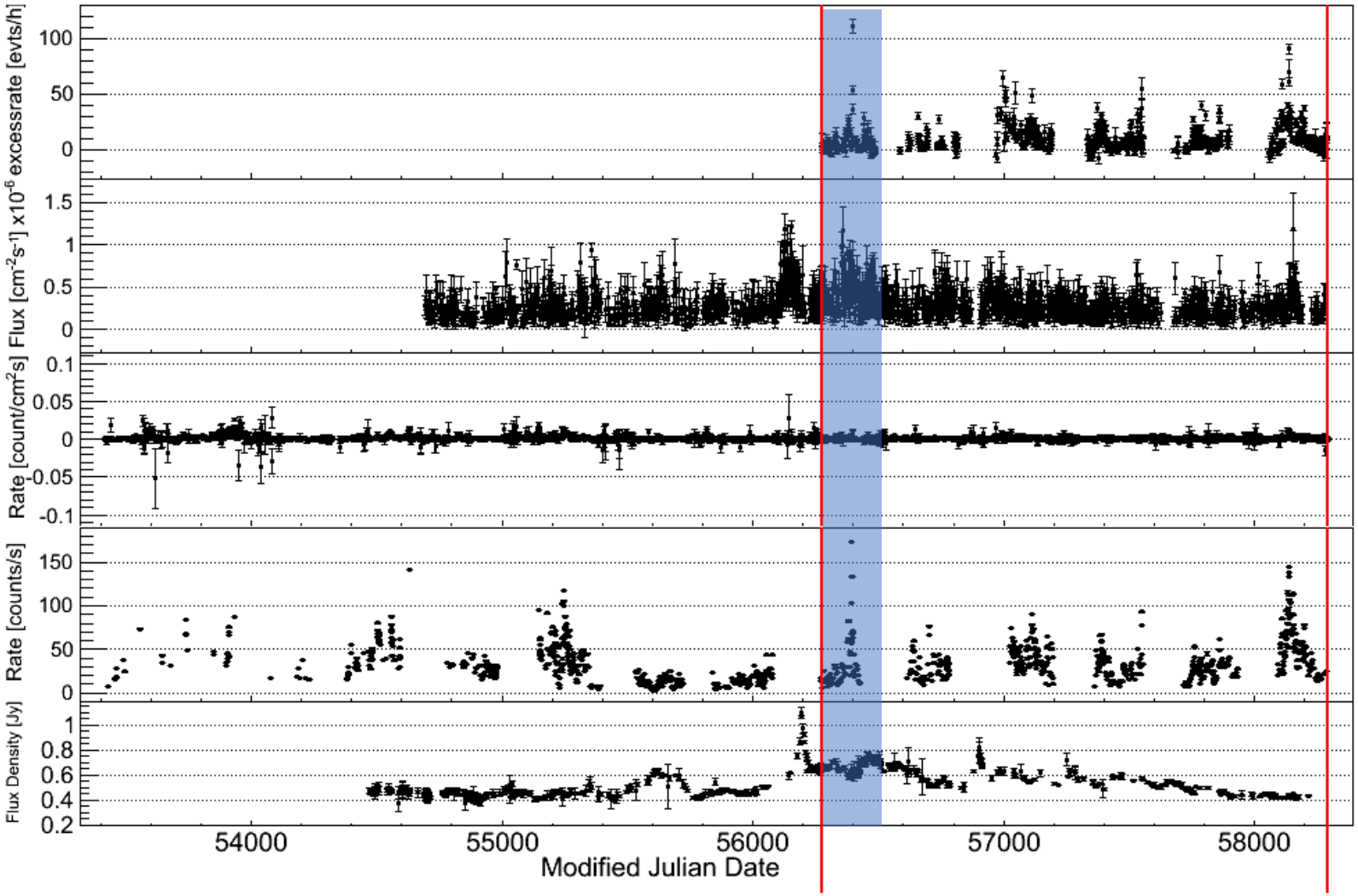

FACT (TeV)

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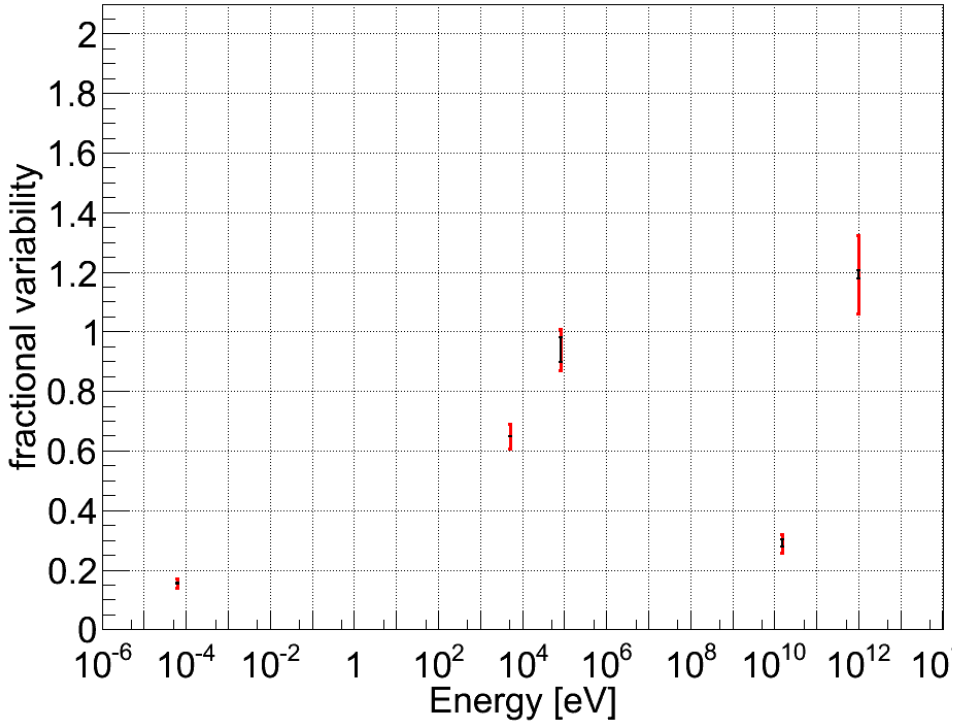
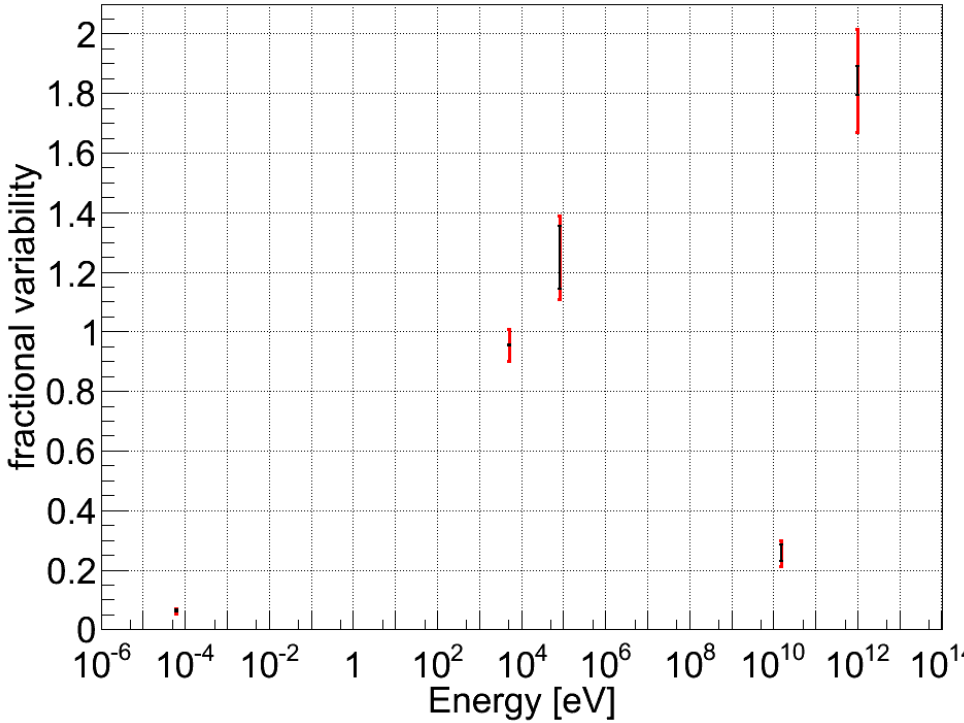
Fvar vs Energy (Mrk 421)

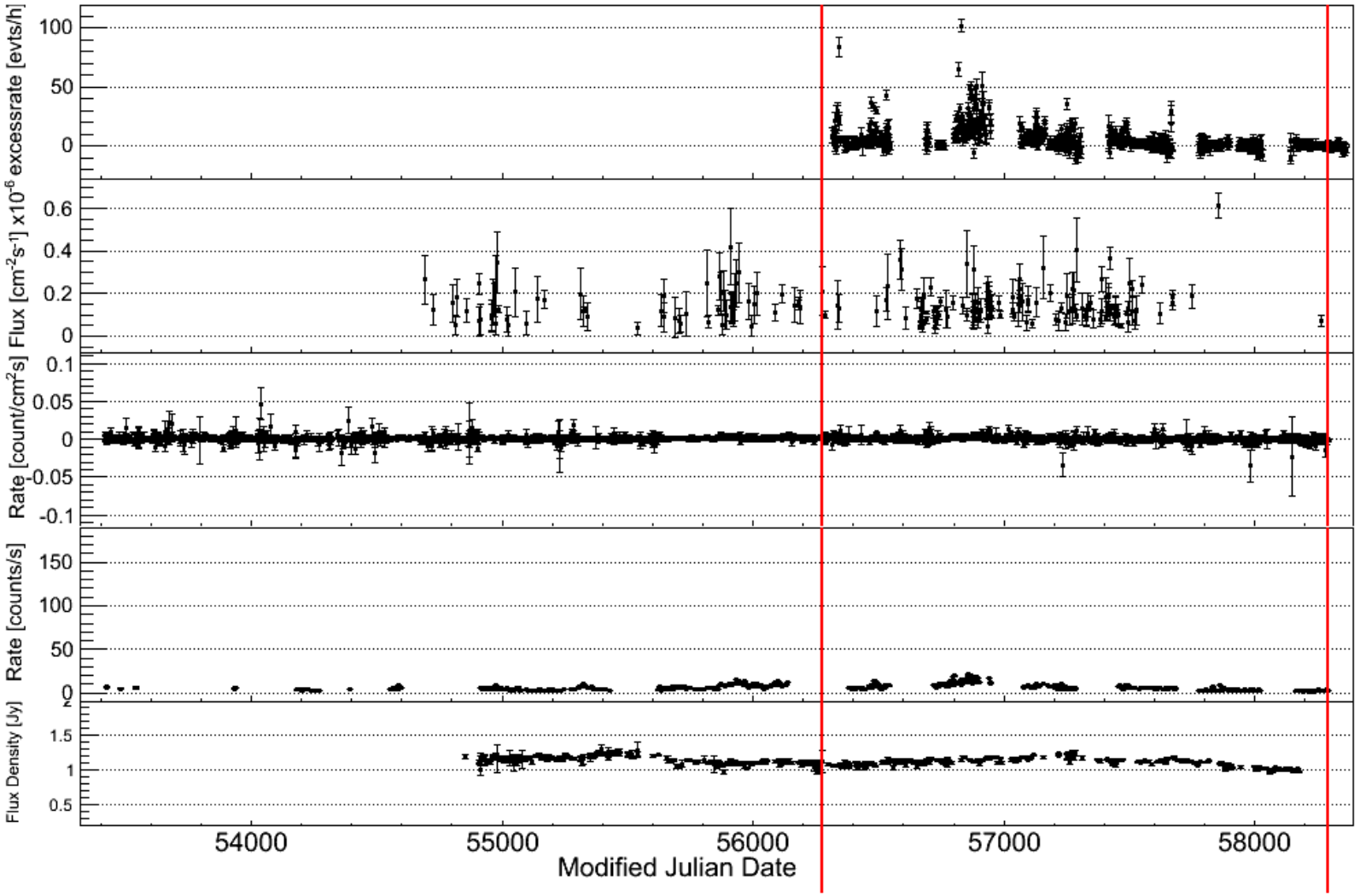
complete datasample



2013 season



Light Curve Mrk 501



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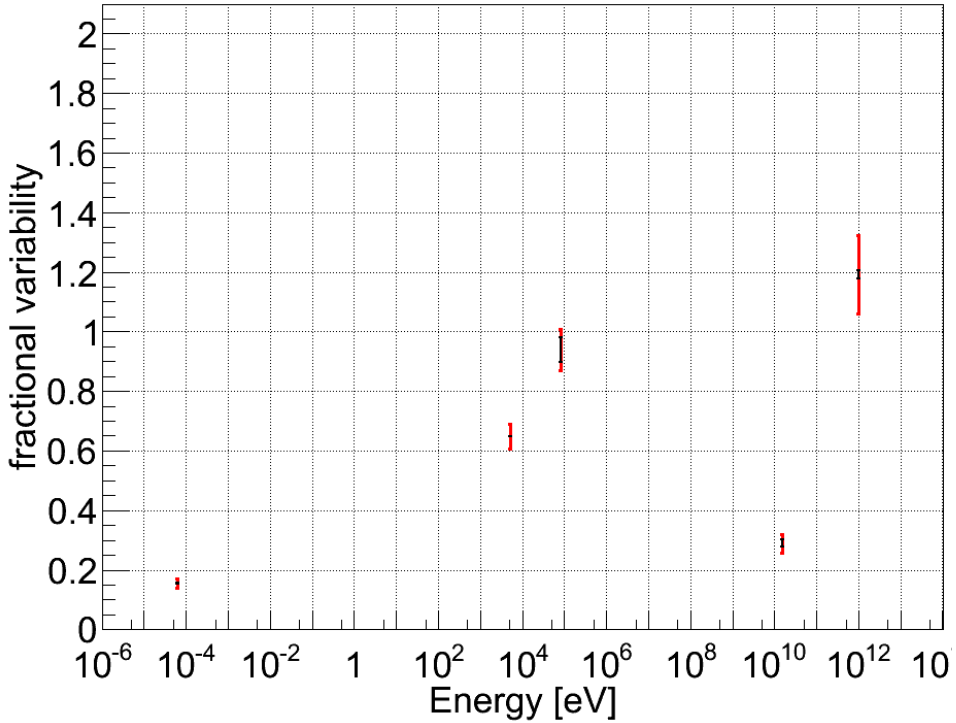
Fvar vs Energy

Complete datasample Mrk421



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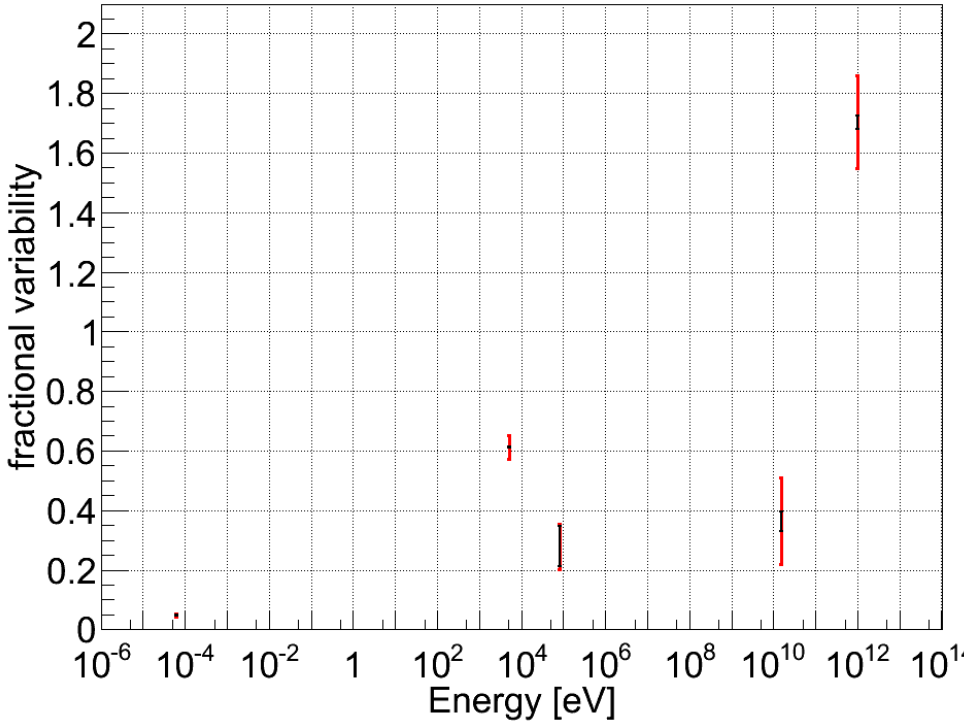

Fvar vs Energy

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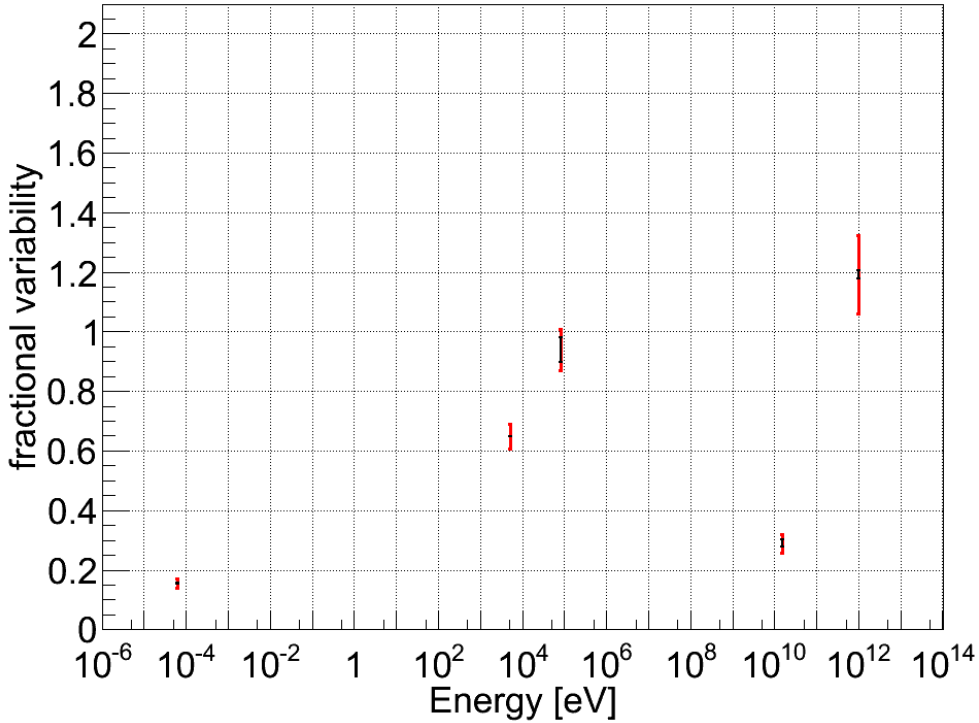
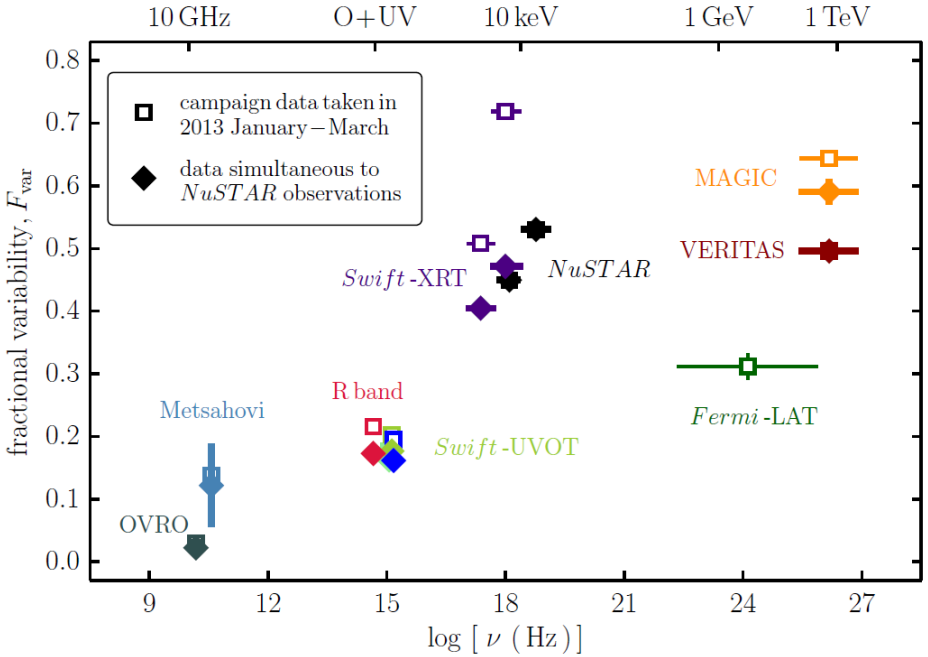


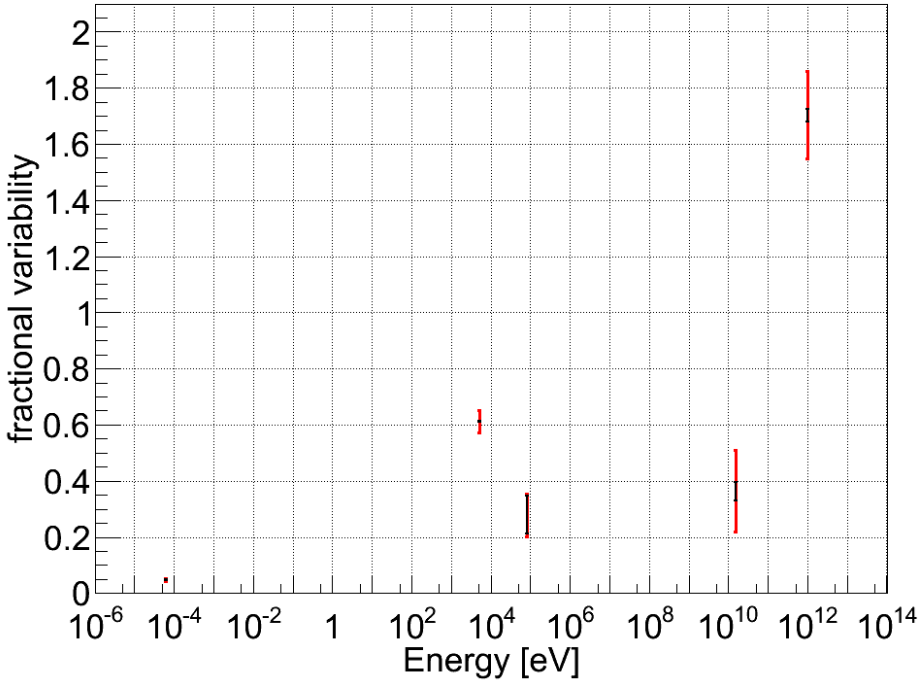
Historic results Mrk421



->Higher variability on longer time range, but similar behaviour vs energy

Fvar vs Energy

Complete datasample Mrk501



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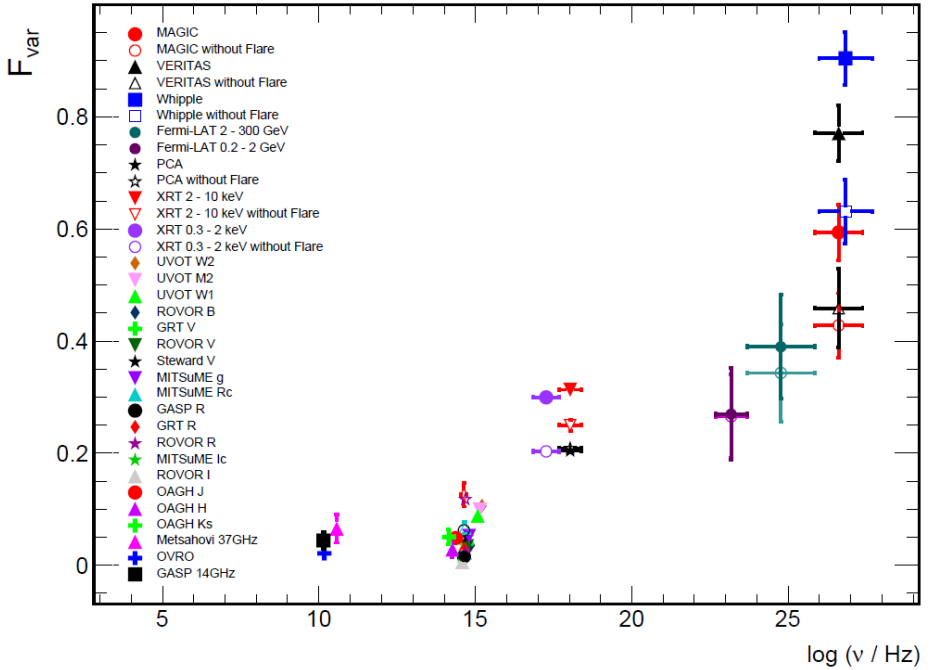
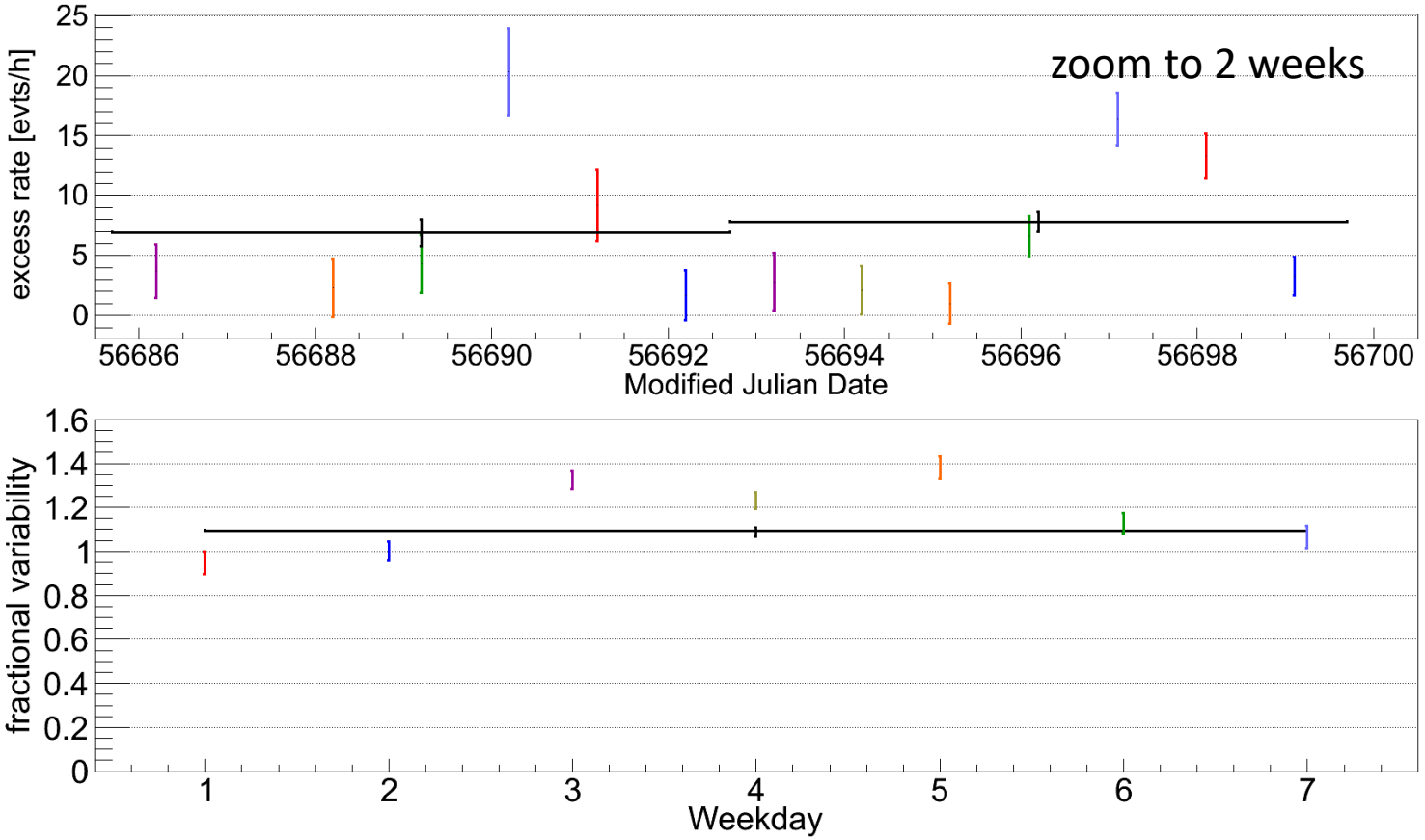


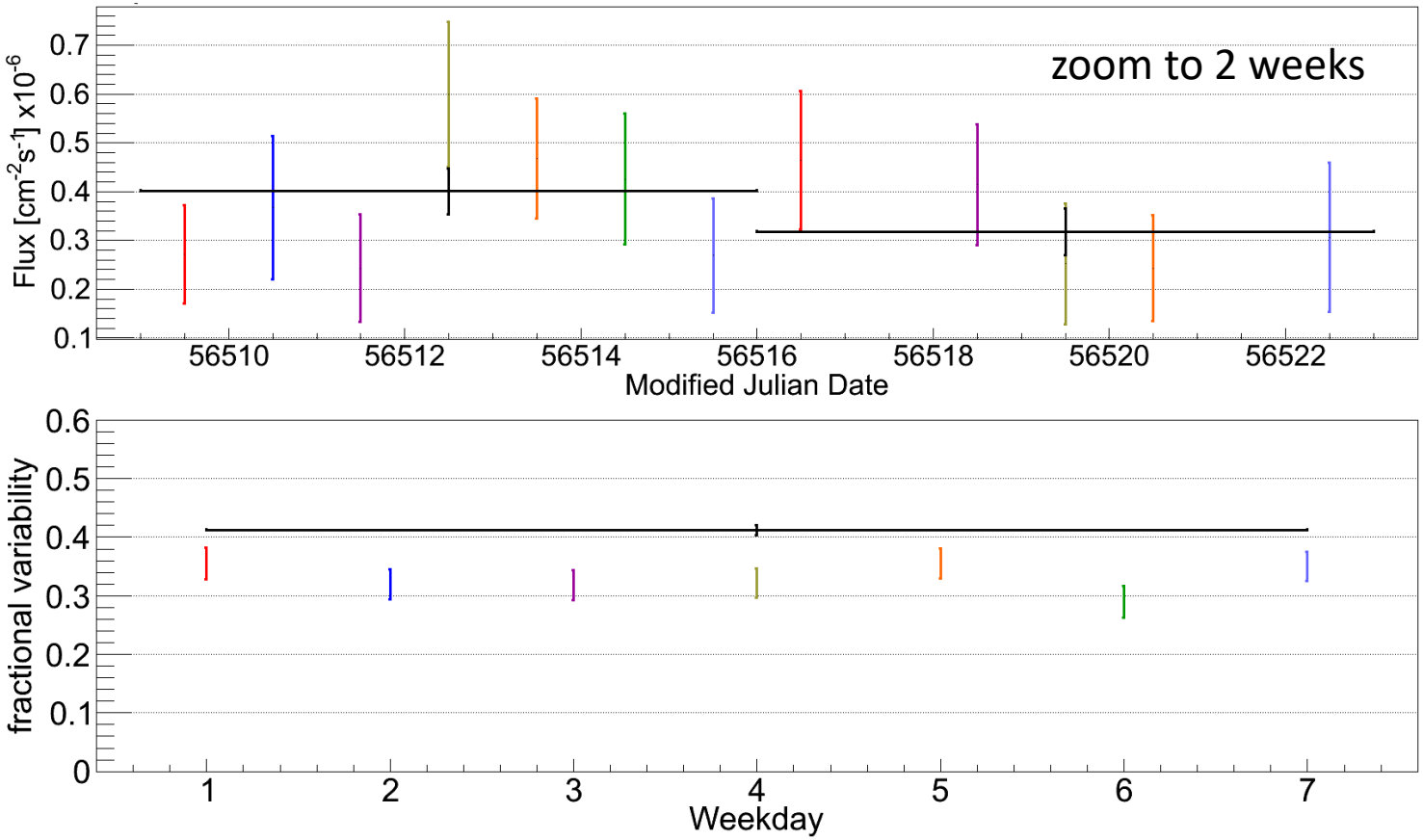
->shape of Fvar vs energy biased by length of data sample

Effect of binning data (FACT)



FACT complete datasample (Mrk 421), weekly binning and weekday binning

Effect of binning data (Fermi)



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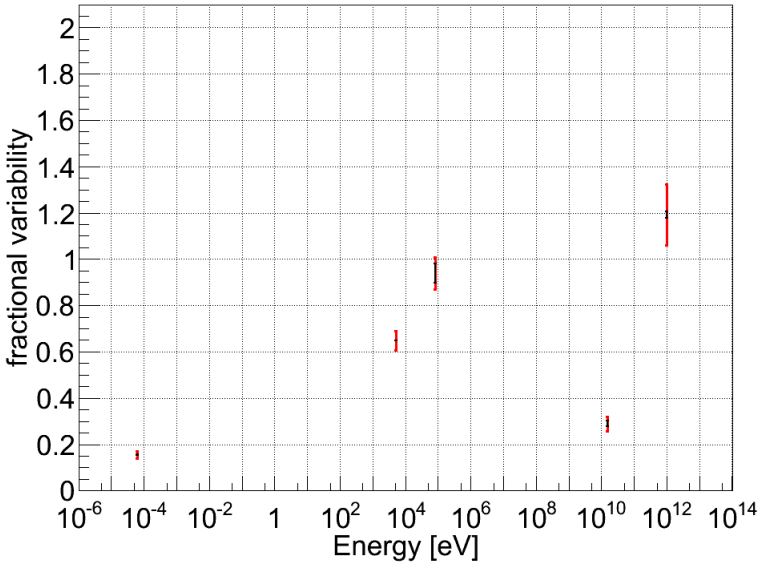
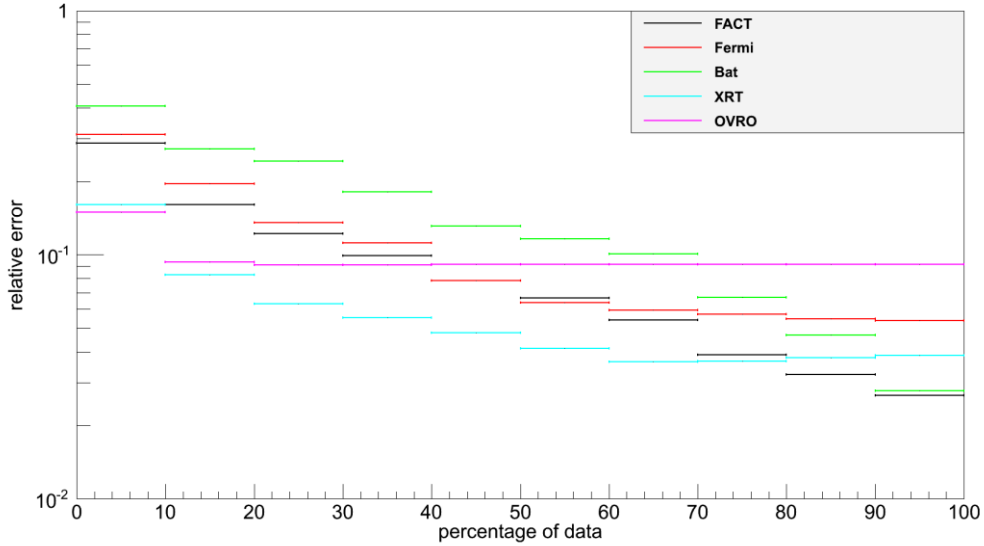
Conclusions and Outlook

Systematic effects of data sample on Fvar studied





Can we draw conclusions on the physics?

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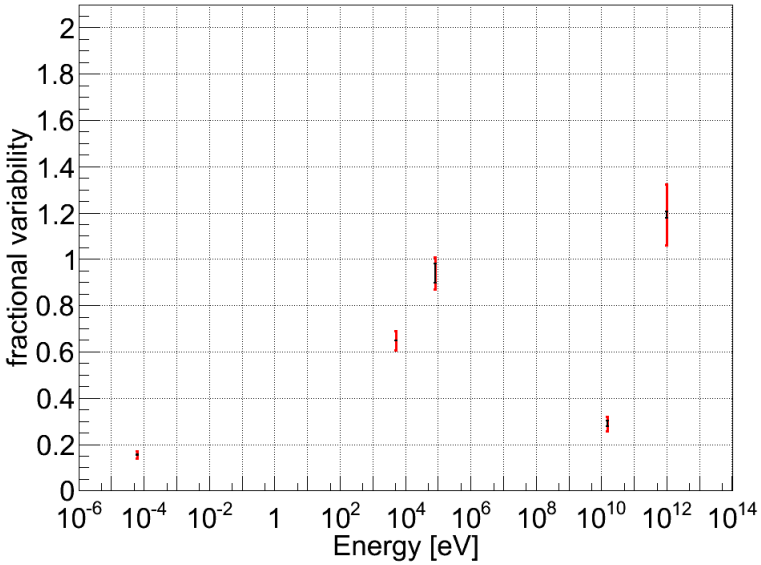

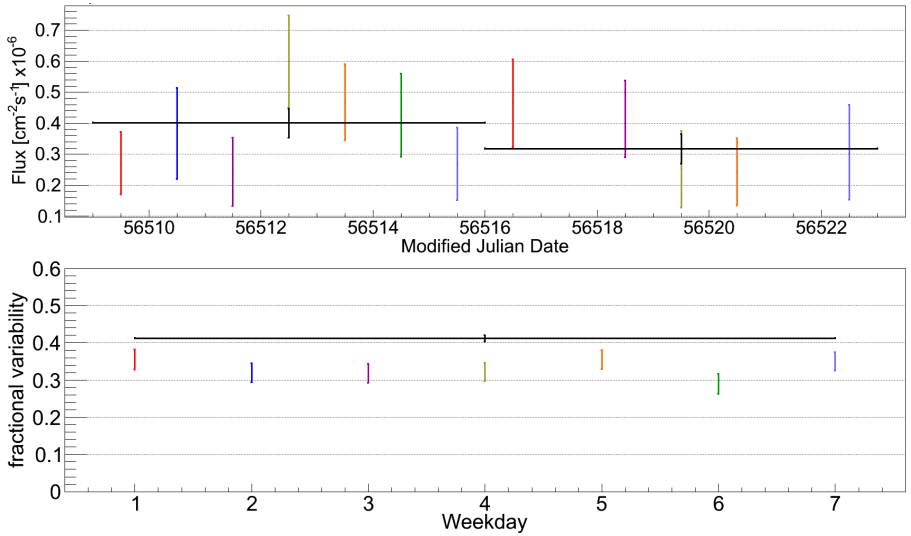

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