

Variability study of extreme Blazars with VERITAS

eXtreme 2019

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for the **VERITAS** collaboration

DESY

Jan 23, 2019



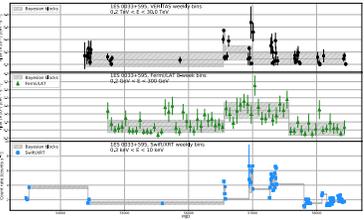


Introduction

Why variability of xHBL?

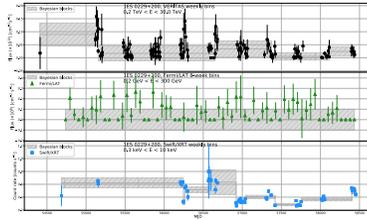
- Take advantage of the extensive VERITAS HBL dataset.

1ES 0033+595



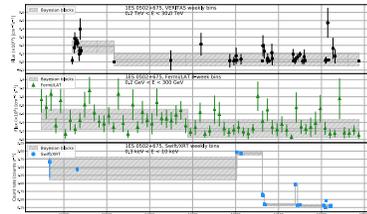
xHBL

1ES 0229+200



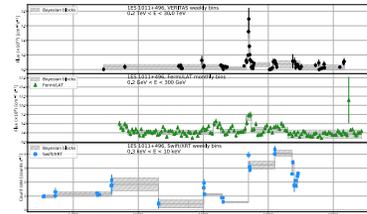
xHBL

1ES 0502+675



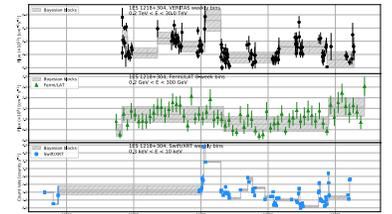
xHBL

1ES 1011+496



xHBL(?)

1ES 1218+200



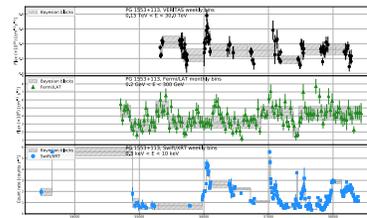
xHBL

- Could studying xHBL MWL variability help understand their nature?
- First look at lightcurves with over 10 years of data.

Secondary photons

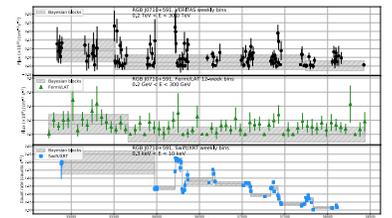
- Explore VHE short-term variability as a function of energy to probe their contribution.

PG 1553+113

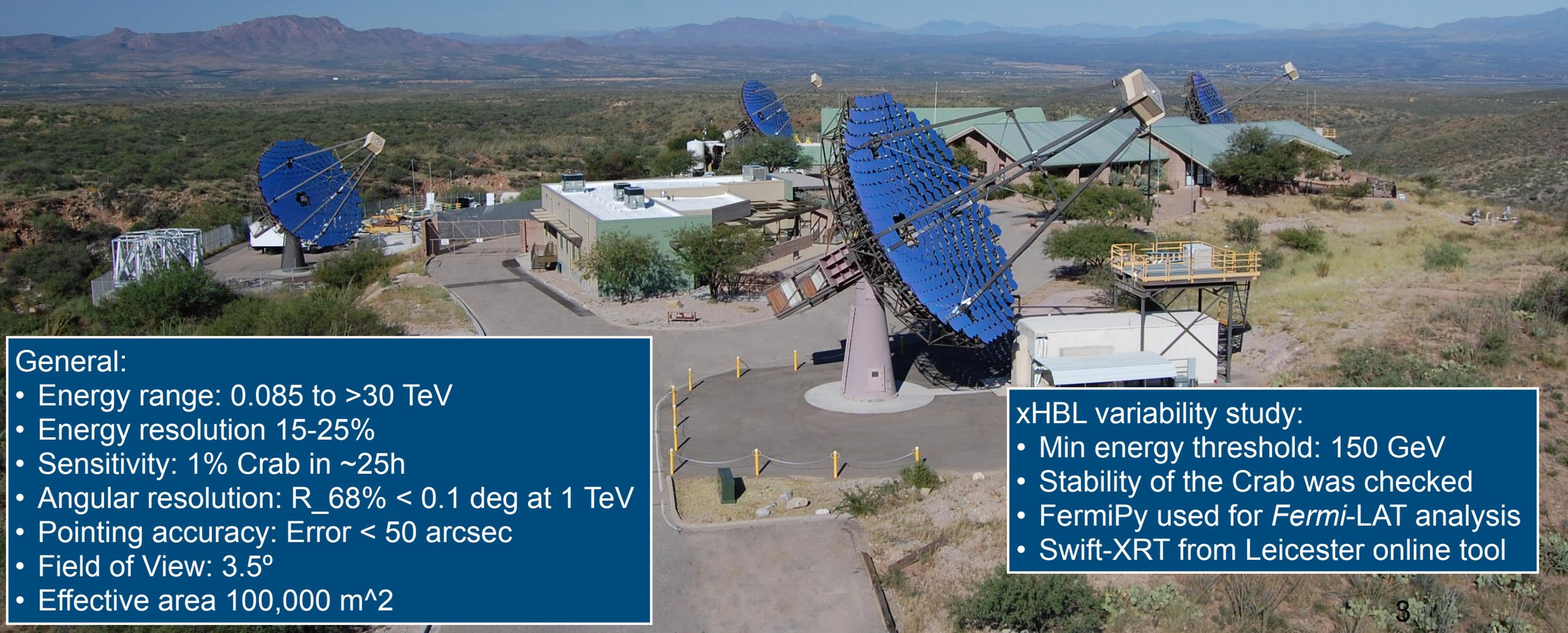


HBL

RGB J0710+591



xHBL



General:

- Energy range: 0.085 to >30 TeV
- Energy resolution 15-25%
- Sensitivity: 1% Crab in ~25h
- Angular resolution: $R_{68\%} < 0.1$ deg at 1 TeV
- Pointing accuracy: Error < 50 arcsec
- Field of View: 3.5°
- Effective area 100,000 m²

xHBL variability study:

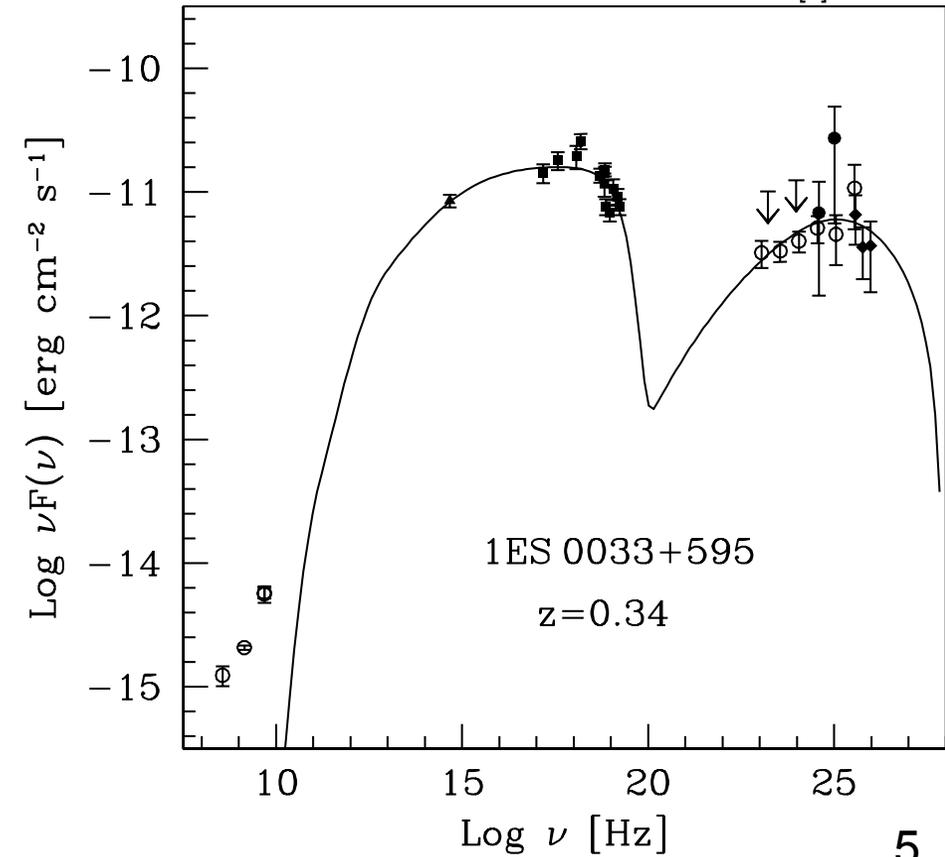
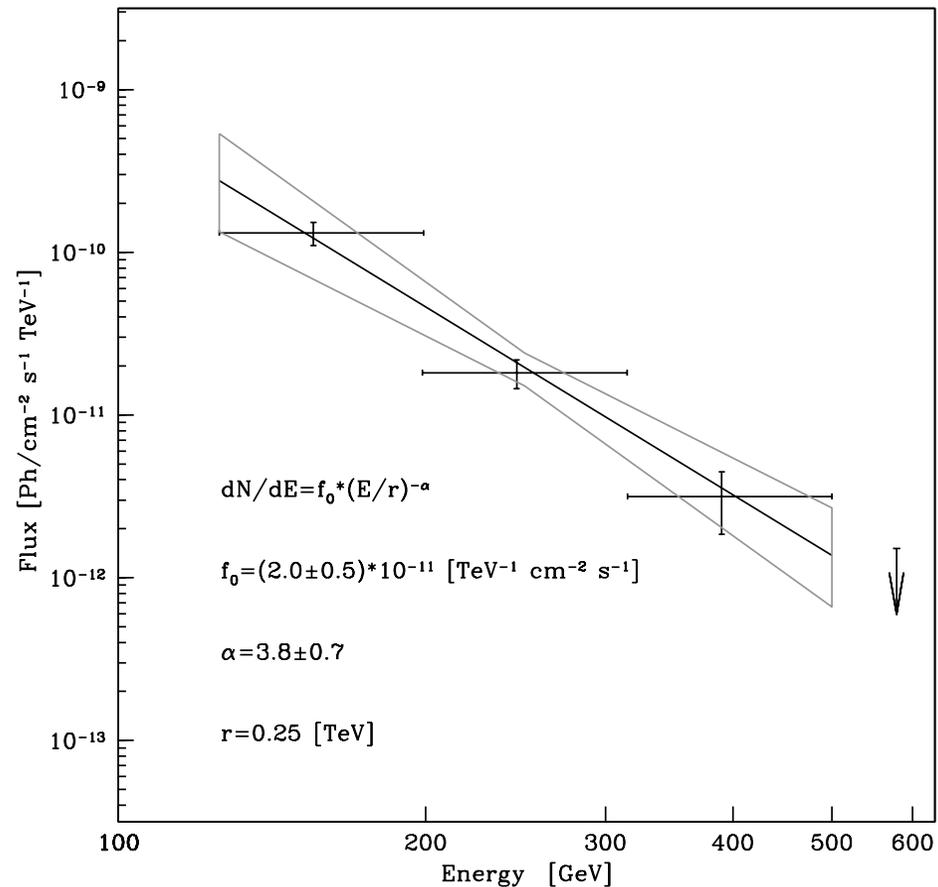
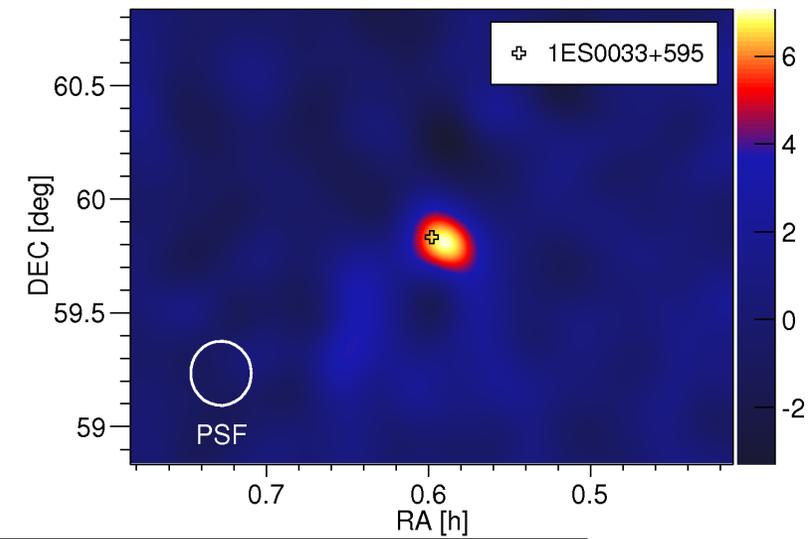
- Min energy threshold: 150 GeV
- Stability of the Crab was checked
- FermiPy used for *Fermi*-LAT analysis
- Swift-XRT from Leicester online tool

1ES 0033+595

1ES 0033+595

Previous publications

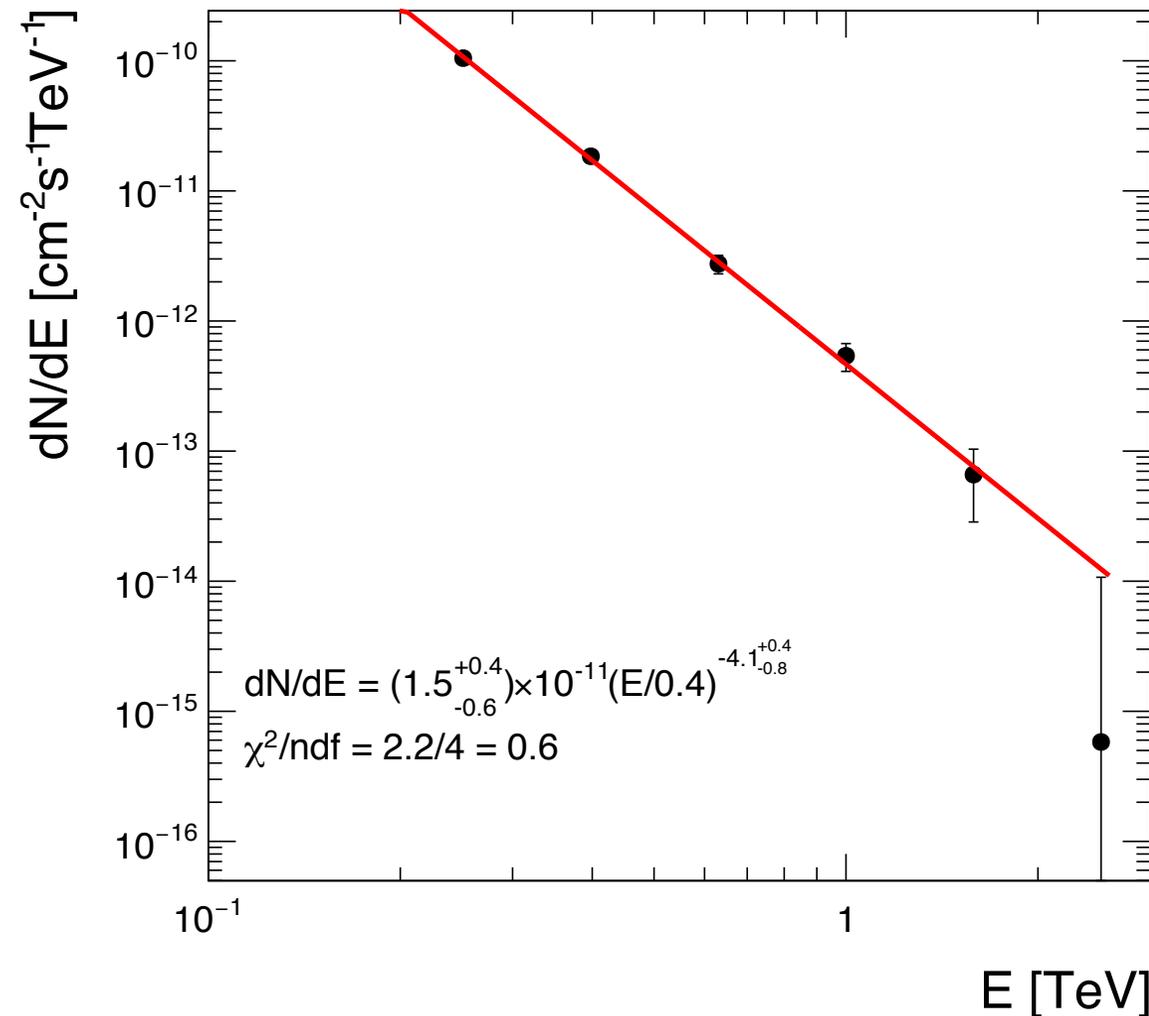
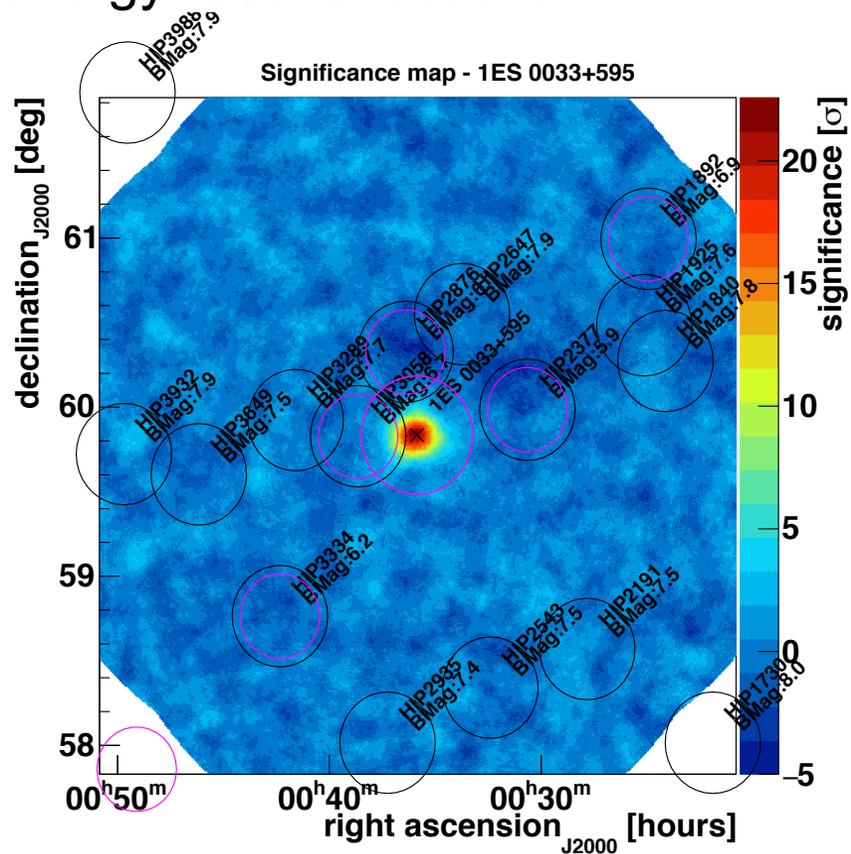
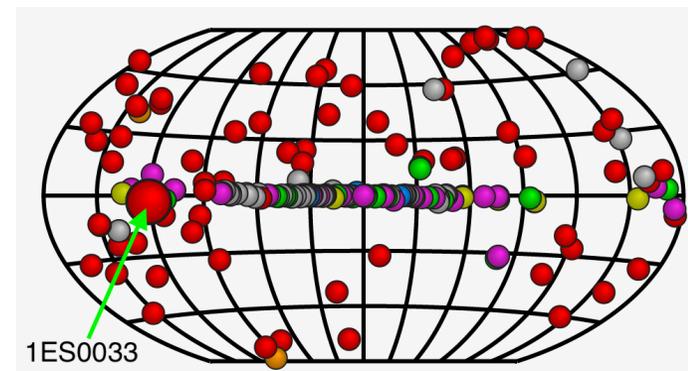
- Classified as an extreme HBL ([Nieppola E. et al.](#)).
- [MAGIC detected in 2009](#), estimate $z = 0.34 \pm 0.08 \pm 0.05$.
- [Paiano et al. 2017](#) (tentatively) set $z = 0.467$.



VERITAS analysis 1ES 0033+595

Analyse full 1ES 0033+595 dataset

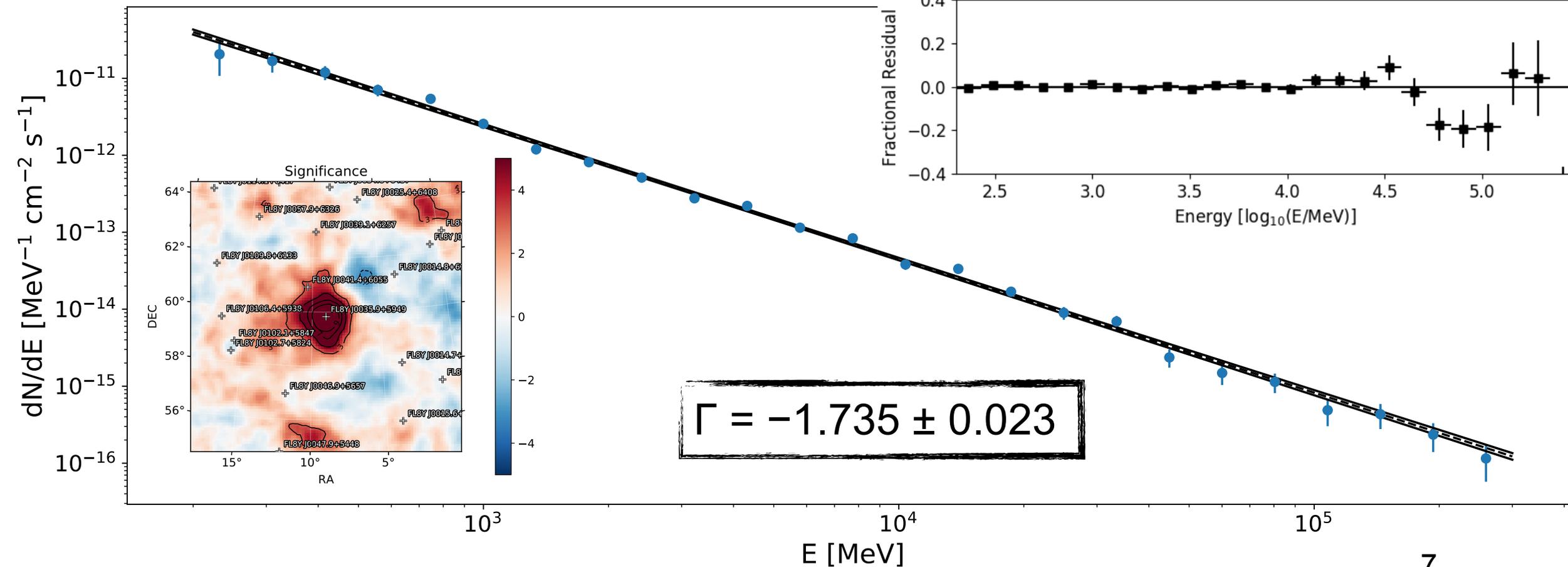
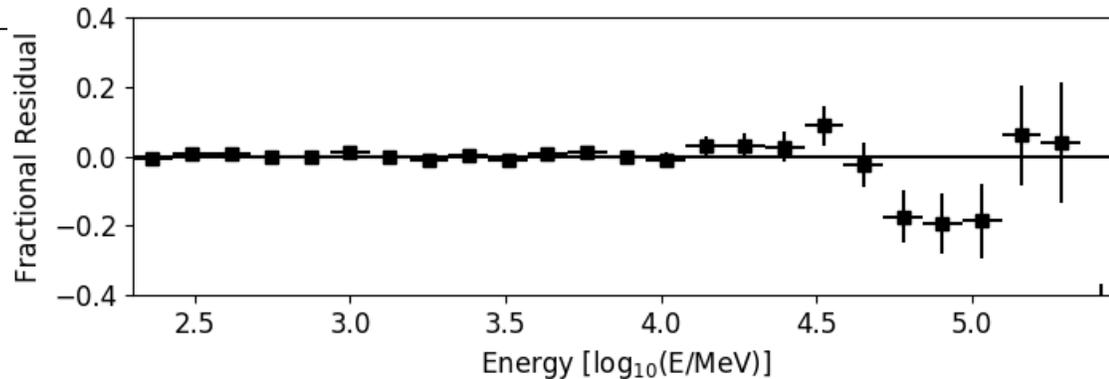
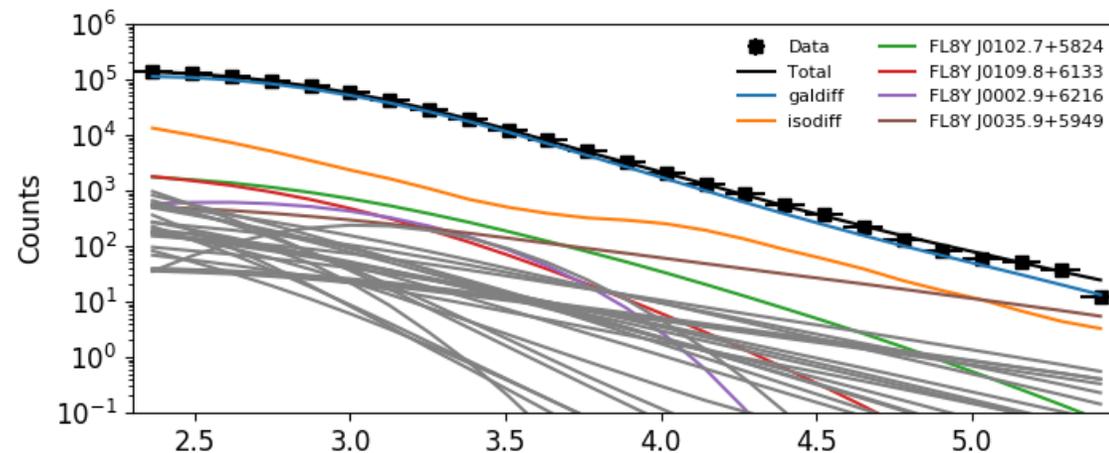
- ~63 hours of data, 0.27 +/- 0.01 gammas/min
- Cumulated significance 21.9 σ .
- Soft BDT cuts, $E > 200$ GeV.
- Incorporate systematic uncertainties on flux due to energy reconstruction.



Fermi-LAT analysis 1ES 0033+595

11 years of data

- Use preliminary 8-year catalogue (FL8Y).
- Include all available Fermi data (up to Dec 18').



Upper limit on 1ES 0033+595 redshift

Spectrum + EBL + *Fermi-LAT* $\rightarrow z \leq z_{\max}$

- De-absorb the measured VERITAS spectra using Franceschini 2008, incrementally increasing z , until

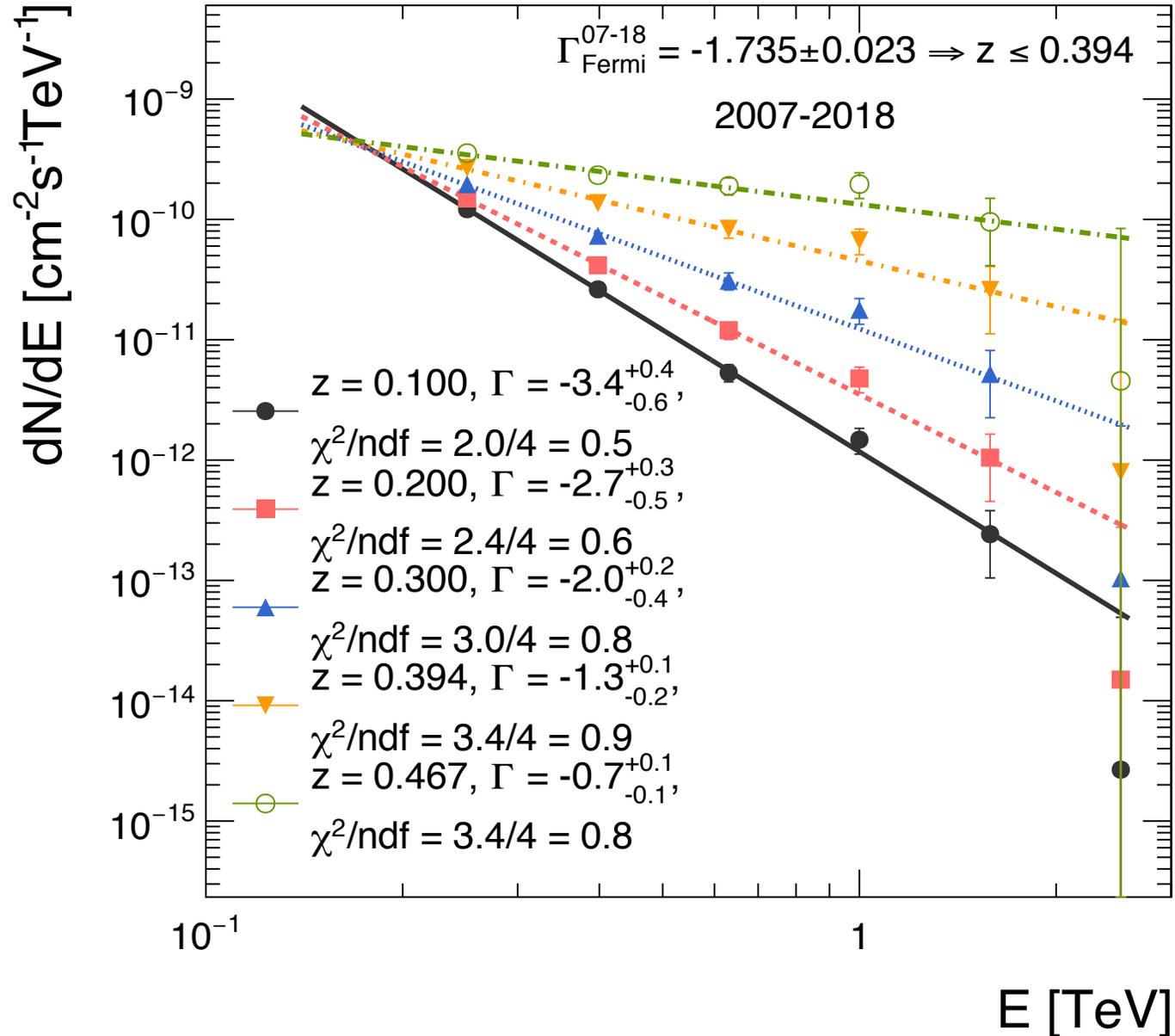
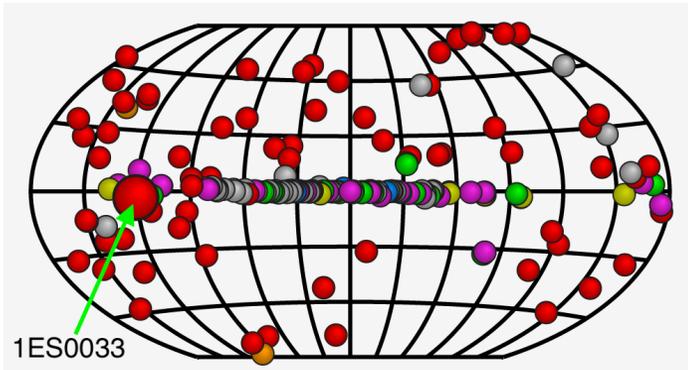
$$(\Gamma_{\text{deabs}} \pm \Delta\Gamma_{\text{deabs}}) - (\Gamma_{\text{Fermi}} \pm \Delta\Gamma_{\text{Fermi}}) > 2\sigma \text{ (95 \% conf.)}$$

- Resulting upper limit

$$z \leq 0.394$$

- Reminder, [Paiano et al. 2017](#) (tentatively) set

$$z = 0.467$$



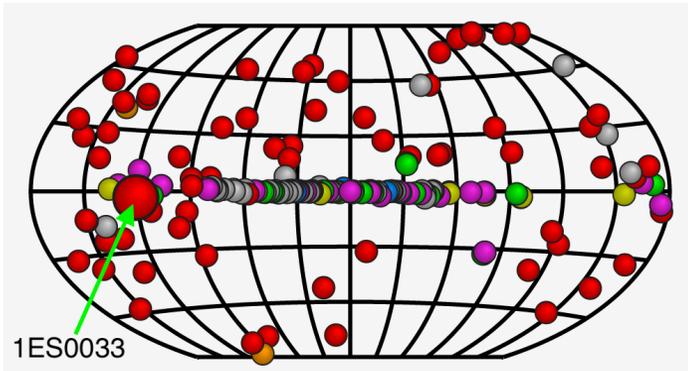
1ES 0033+595 SED

SED at estimated redshift

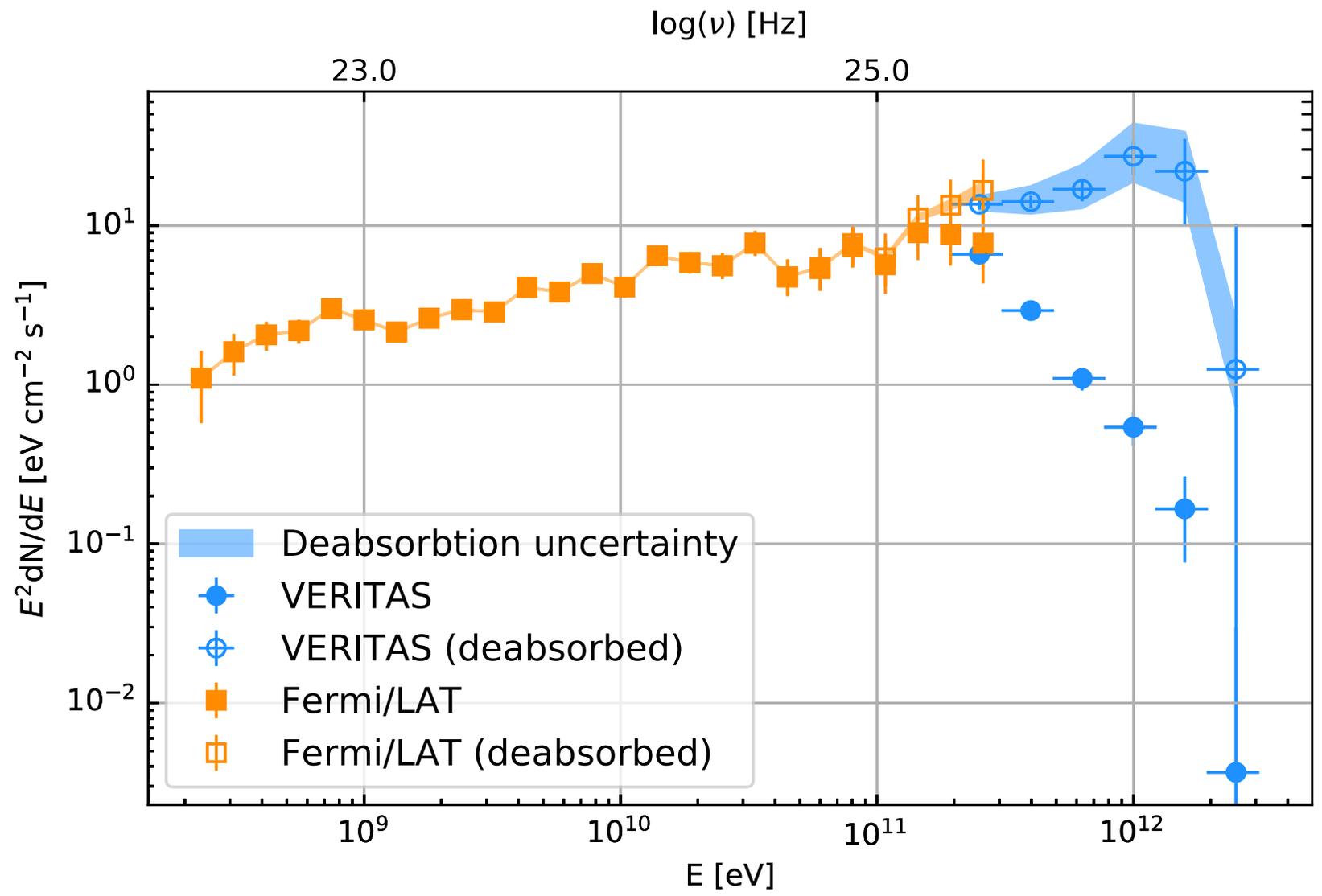
- Redshift estimated by searching for best fit between VHE and *Fermi*-Lat spectra.

$$z = 0.331^{+0.035}_{-0.029}$$

- MAGIC estimated $z = 0.34 \pm 0.08 \pm 0.05$
- Does not include EBL model uncertainty.
- Add more MWL data.

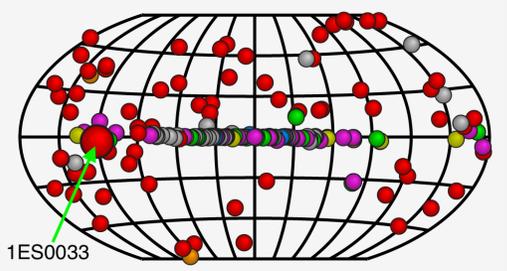
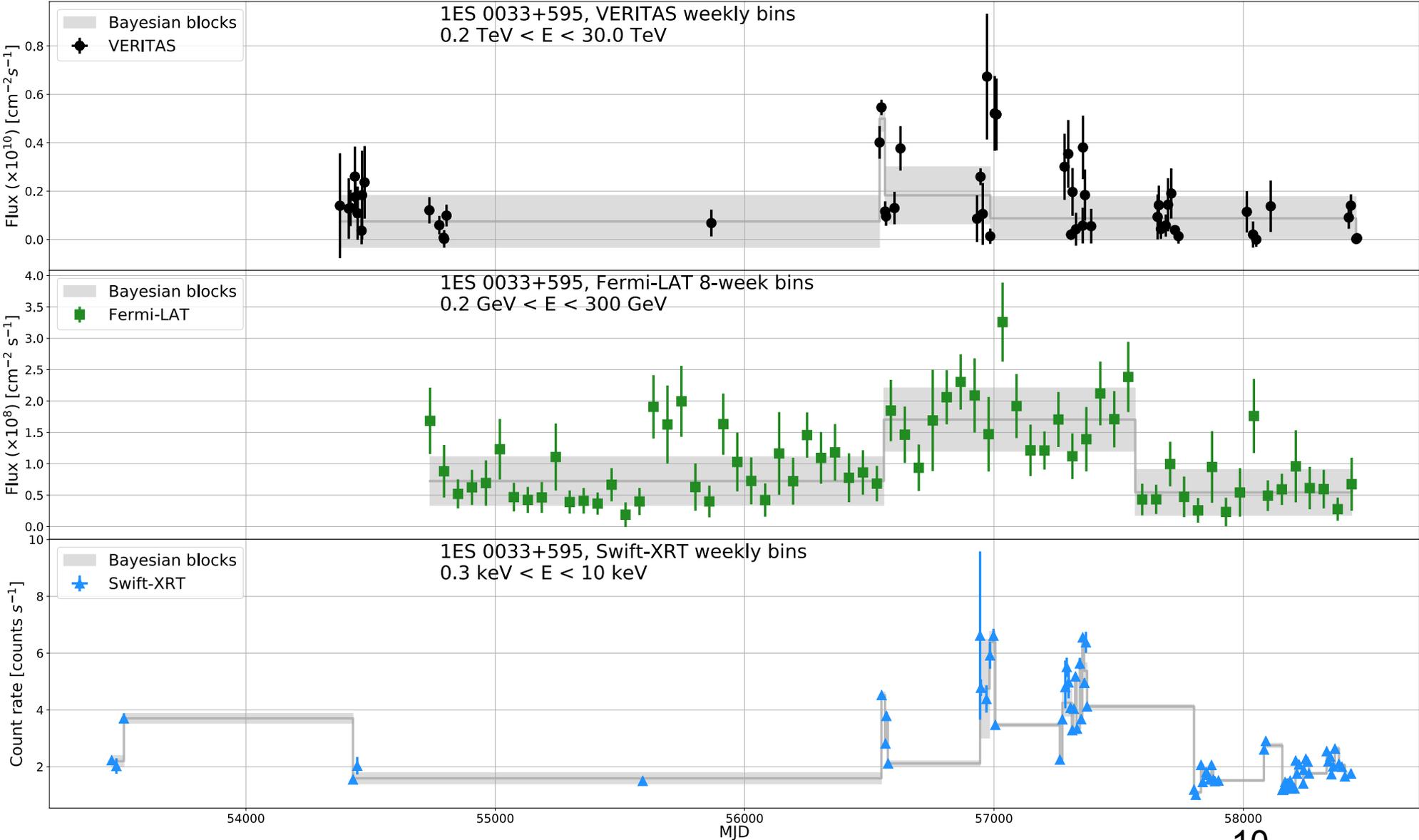


1ES 0033+595, $z=0.331$



MWL long-term lightcurves 1ES 0033+595

- Weak in HE (8-week bins).
- Not enough data points to claim correlation.
- Focused study of flare period?

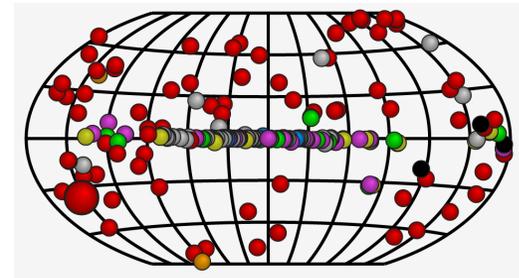
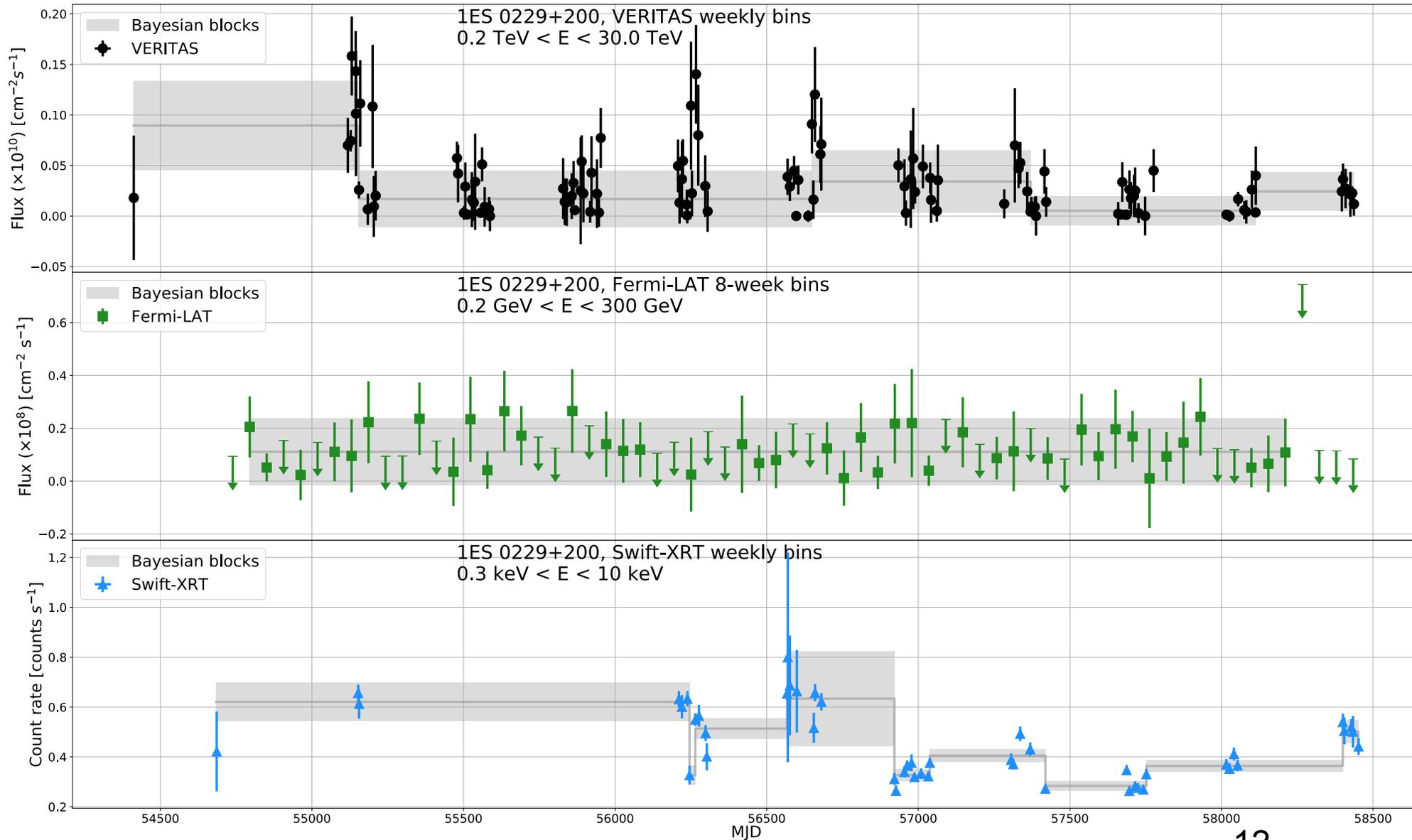


1ES 0229+200

MWL long-term lightcurves 1ES 0229+200

z=0.14

- Very weak in HE, most bins undetected.
- Some variability observed in Swift, a little less in VHE.
- Not enough data points to claim correlation.

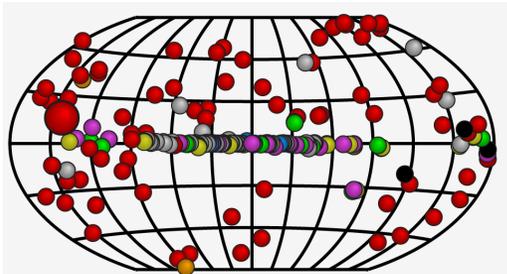
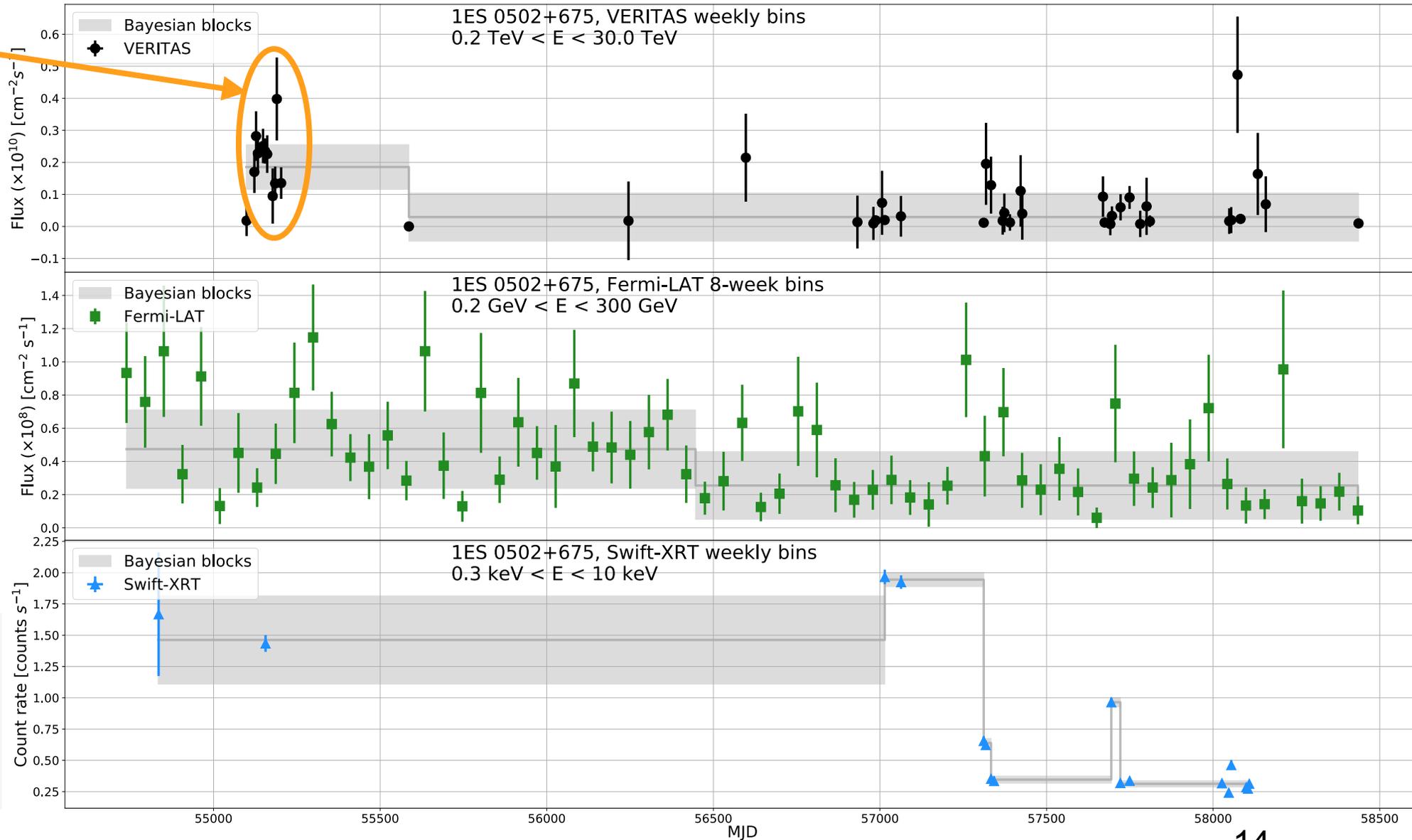


1ES 0502+675

MWL long-term lightcurves 1ES 0502+675

$z=0.341$

- High state in VHE when discovered.
- Weak and stable since then.
- Few X-Ray data available.
- No apparent correlation between Swift and HE/VHE.

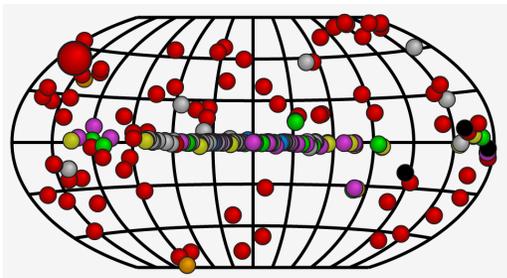
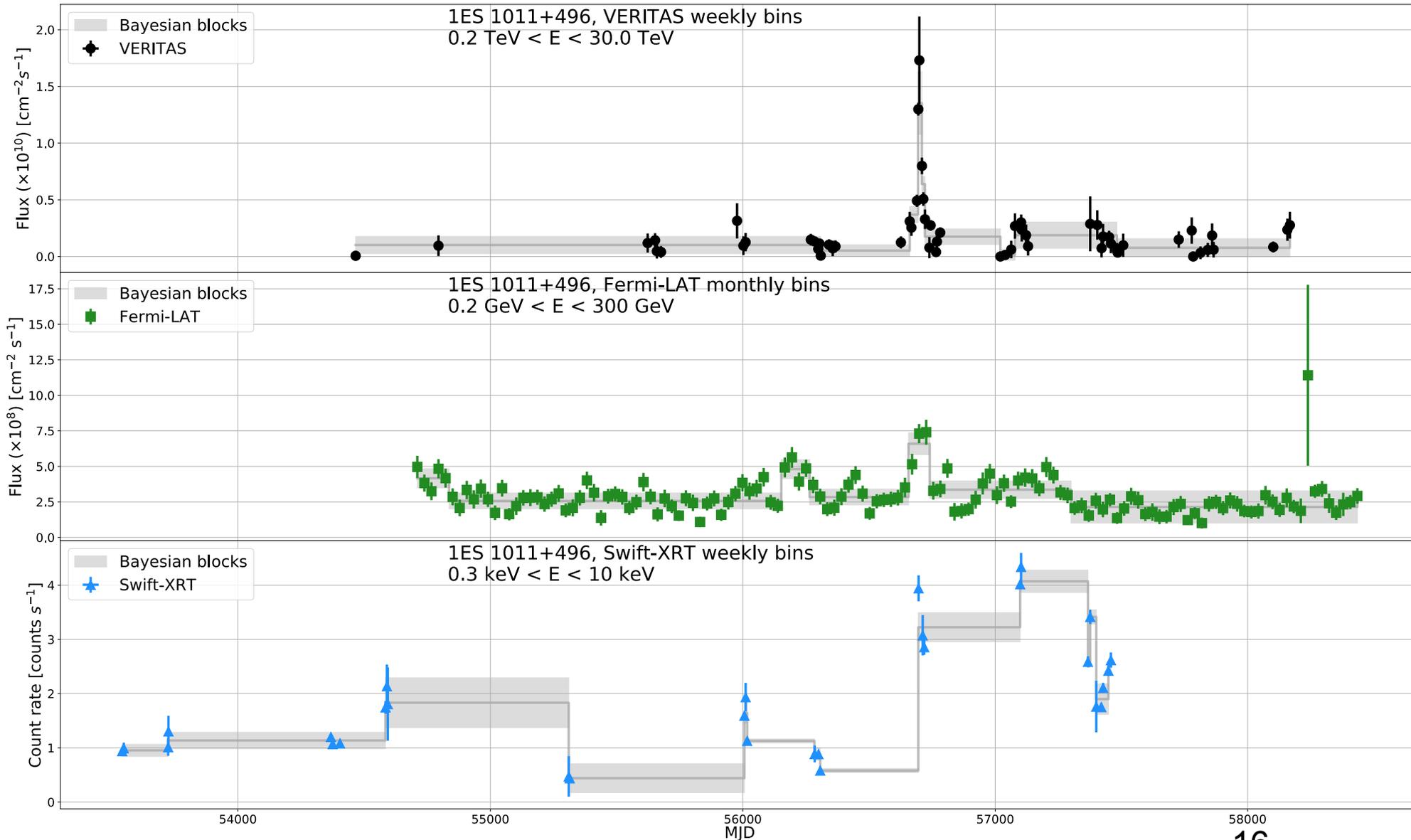


1ES 1011+496

MWL long-term lightcurves 1ES 1011+496

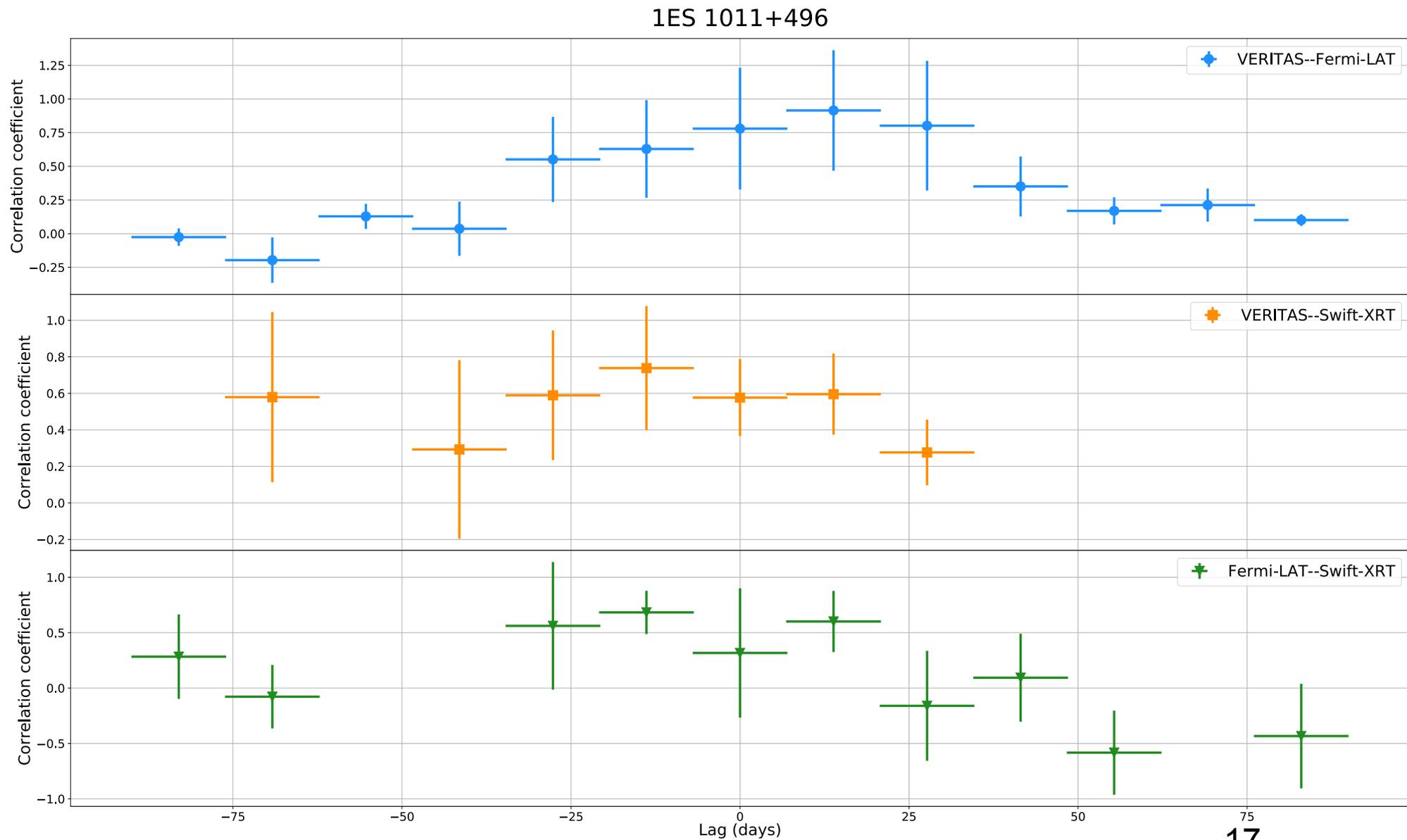
$z=0.212$

- unclear xHBL classification (peak exactly at 10^{17} Hz).
- Strong VHE flare, observed also in HE (X-Ray?).
- A dedicated study of the flare is necessary.



Correlations between lightcurves 1ES 1011+496

- Apply DCF to study correlations
- VHE/HE correlated with possible HE lag of ~3 weeks.
- Correlations with X-Ray fail due to sparse data.
- A dedicated correlation study during the flare is planned.

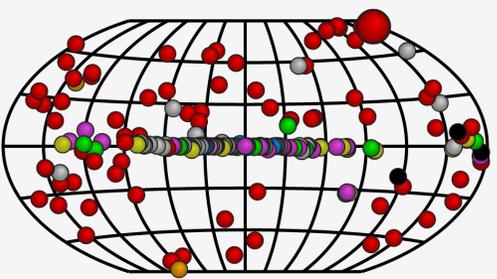
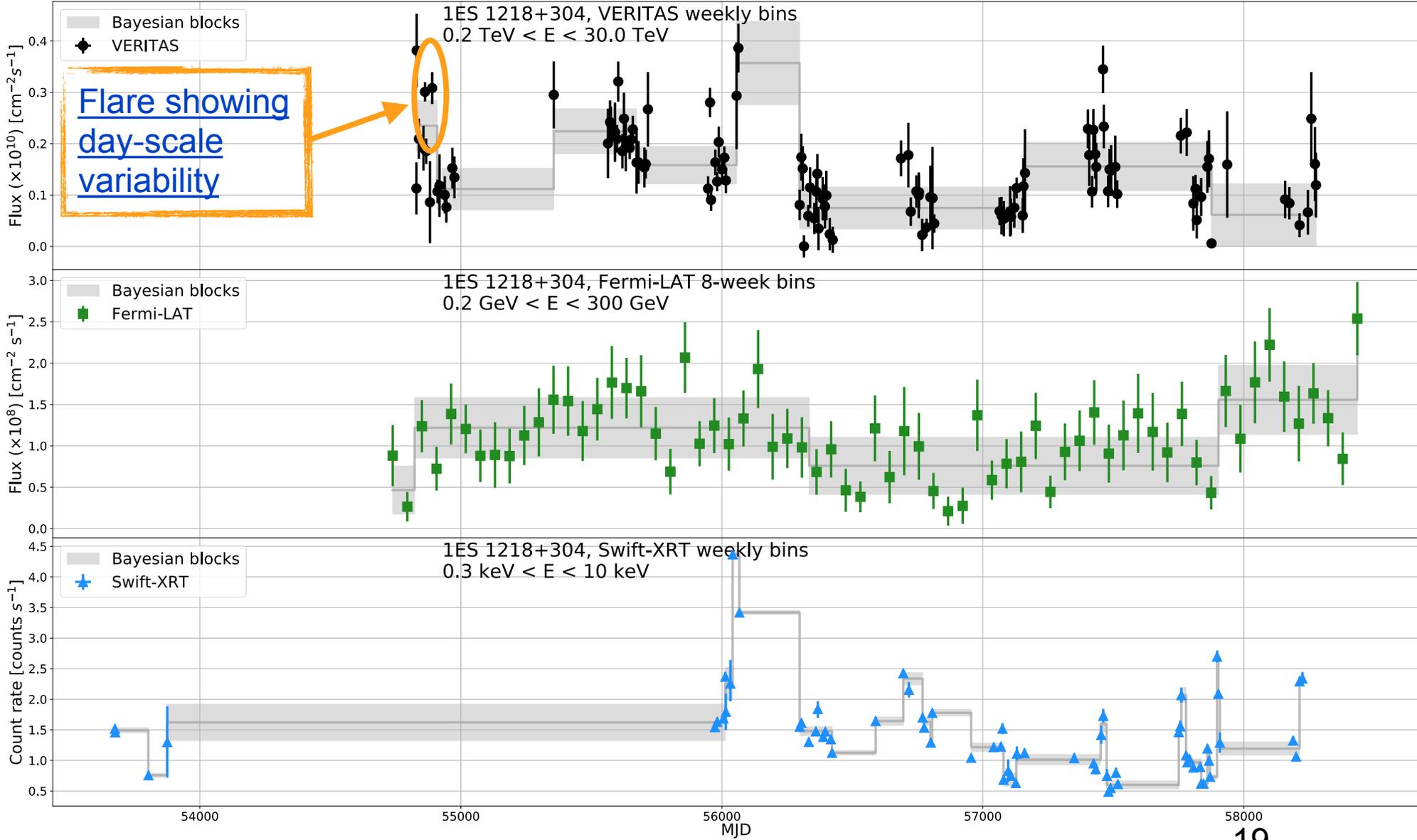


1ES 1218+304

MWL long-term lightcurves 1ES 1218+304

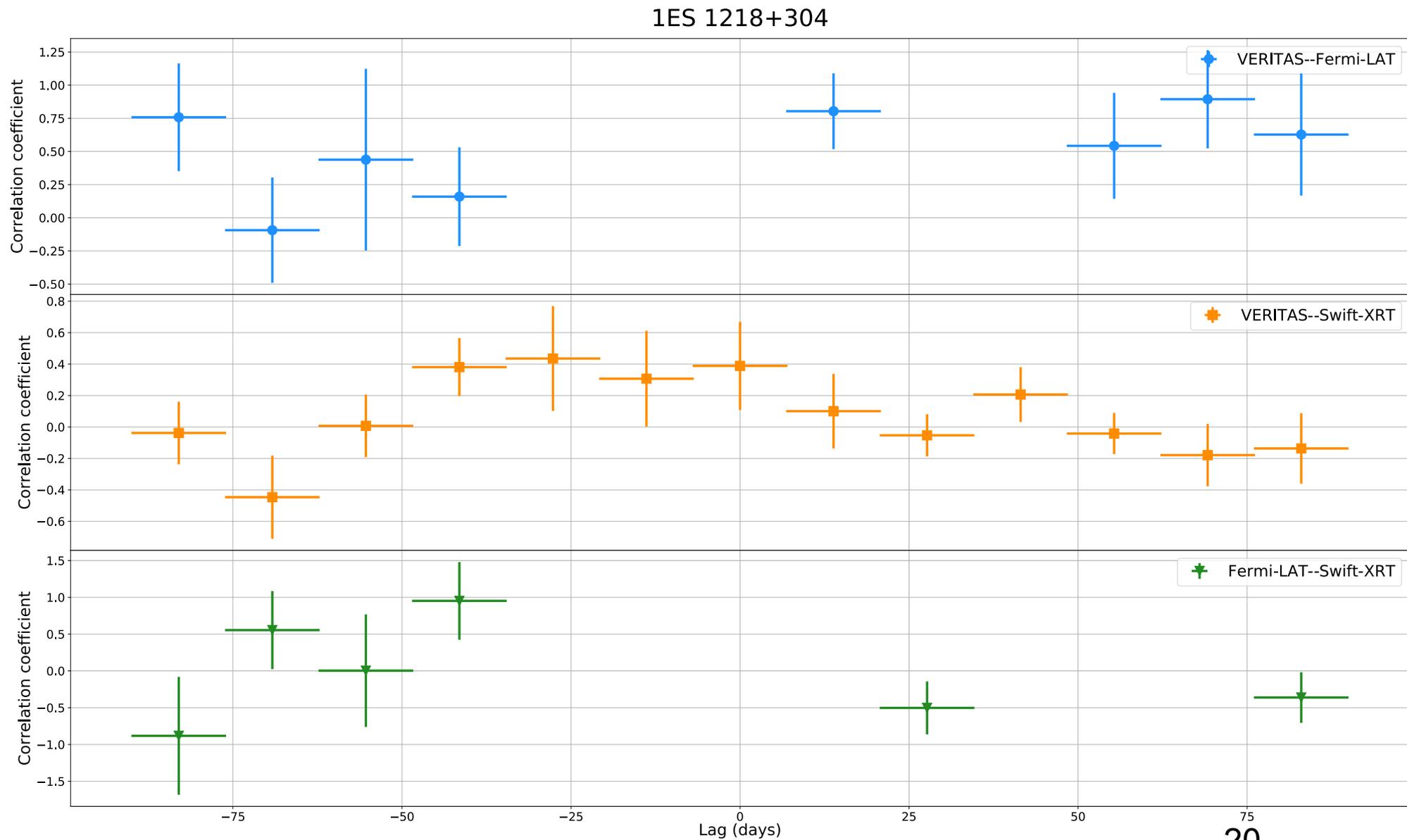
z=0.182

- Plenty of data available
- VHE and X-Ray are variable, HE more stable.
- X-Ray variable on short-time scales, VHE less so.



Correlations between lightcurves 1ES 1218+304

- Apply DCF to study correlations
- VHE/X-Ray show some correlation.
- Correlations with HE fail (not enough points).
- Additional studies required.

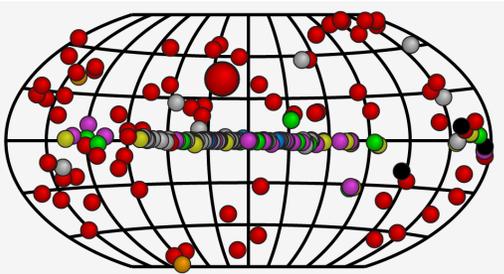
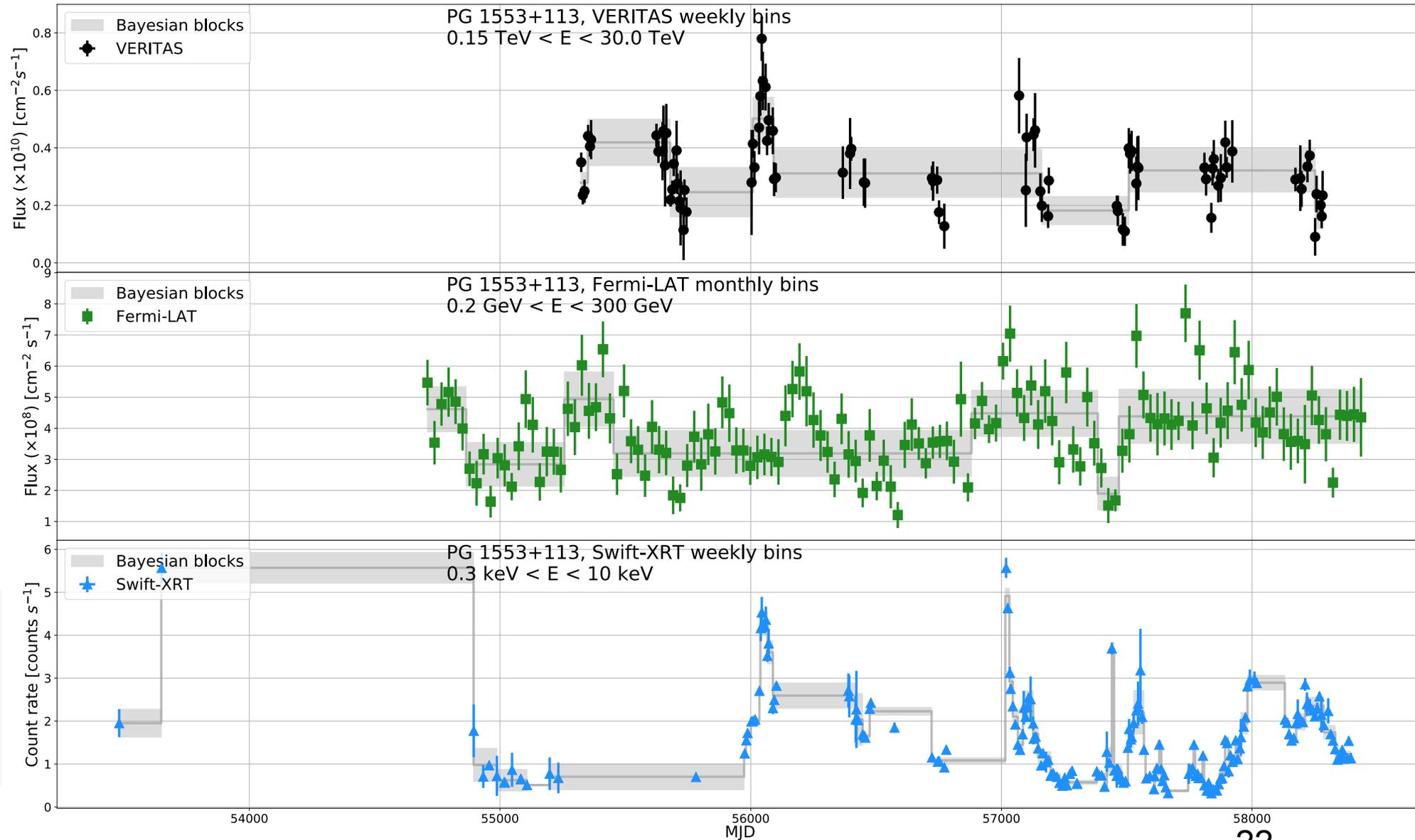


PG 1553+113

MWL long-term lightcurves PG 1553+113

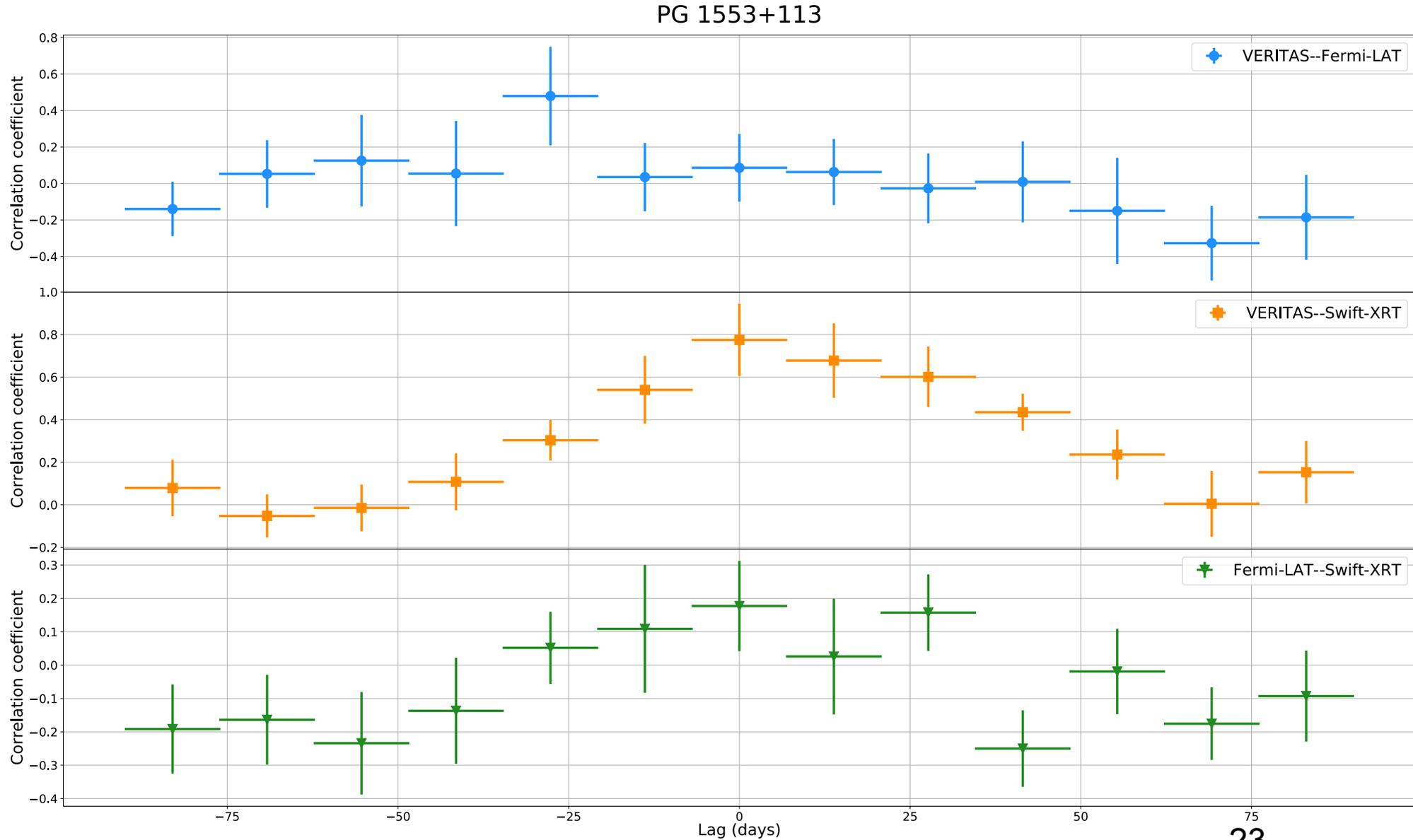
$z=0.43 - 0.58$

- Classified as an HBL.
- Variable in all energy bands.
- Flare in VHE and X-Ray.
- Enough data to study correlations



Correlations between lightcurves PG 1553+113

- Apply DCF to study correlations
- potential VHE/HE correlation with HE lagging behind.
- Correlation with 0 ± 14 days lag observed in VHE/ X-Ray.
- No correlation observed for HE/X-Ray

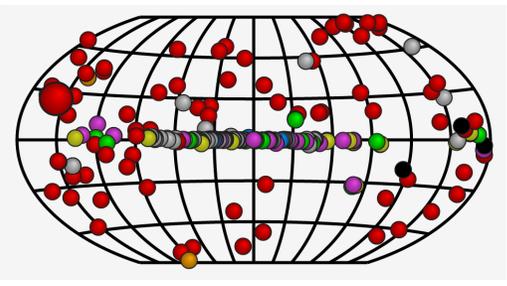
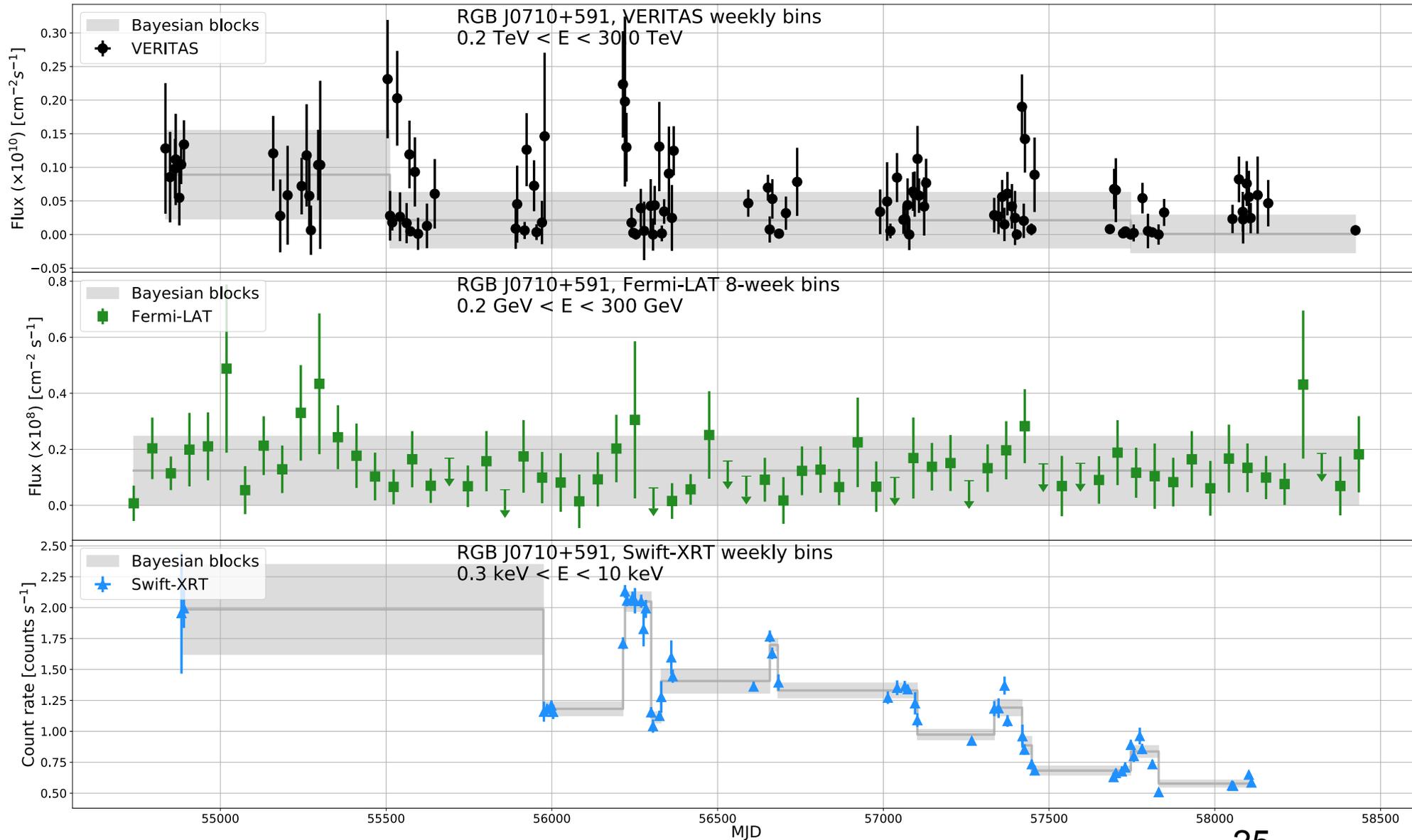


RGB J0710+591

MWL long-term lightcurves RGB J0710+591

z=0.125

- Weak and stable at VHE/HE.
- Short-term variability seen in X-Ray.
- Decreasing Long-term trend?
- No apparent correlation.



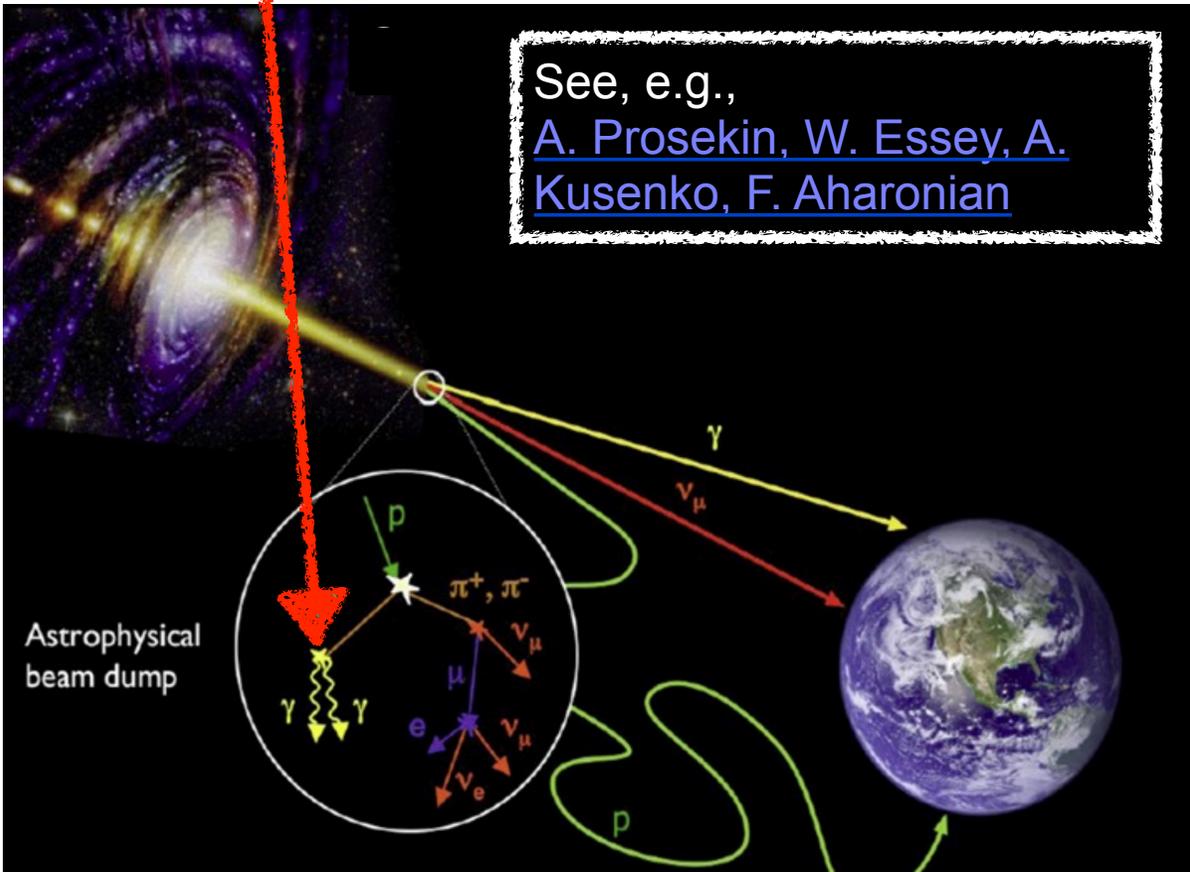
Contribution from secondary photons

Search for short-term correlations in VHE

High energy photons come from secondary photons.

Should smear out short-term variability of the source (0.1 year).

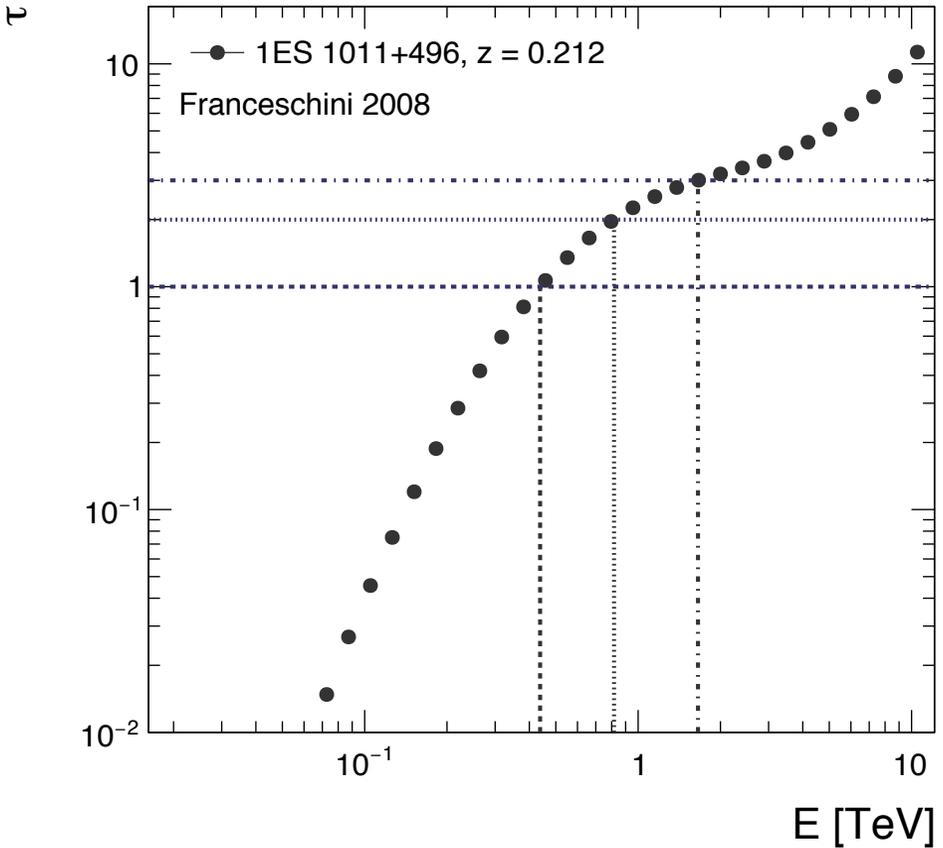
See, e.g.,
[A. Prosekin, W. Essey, A. Kusenko, F. Aharonian](#)



Photon survival probability

- $\tau = 1 \rightarrow \sim 37\%$
- $\tau = 2 \rightarrow \sim 13\%$
- $\tau = 3 \rightarrow \sim 5\%$

Derive energy thresholds based on photon survival probability for each source.

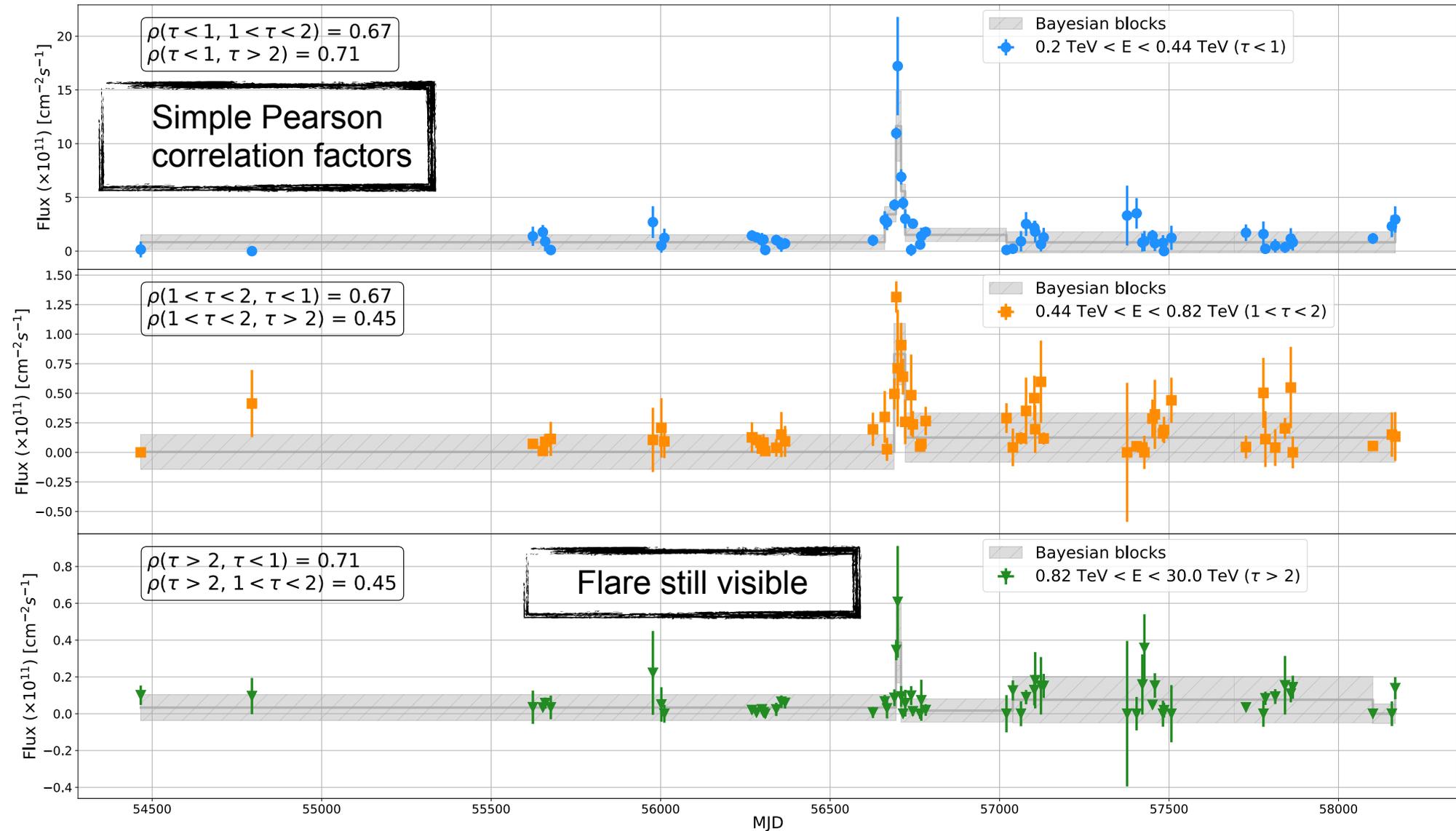


1ES 1011+496

VHE lightcurves, 1ES 1011+496

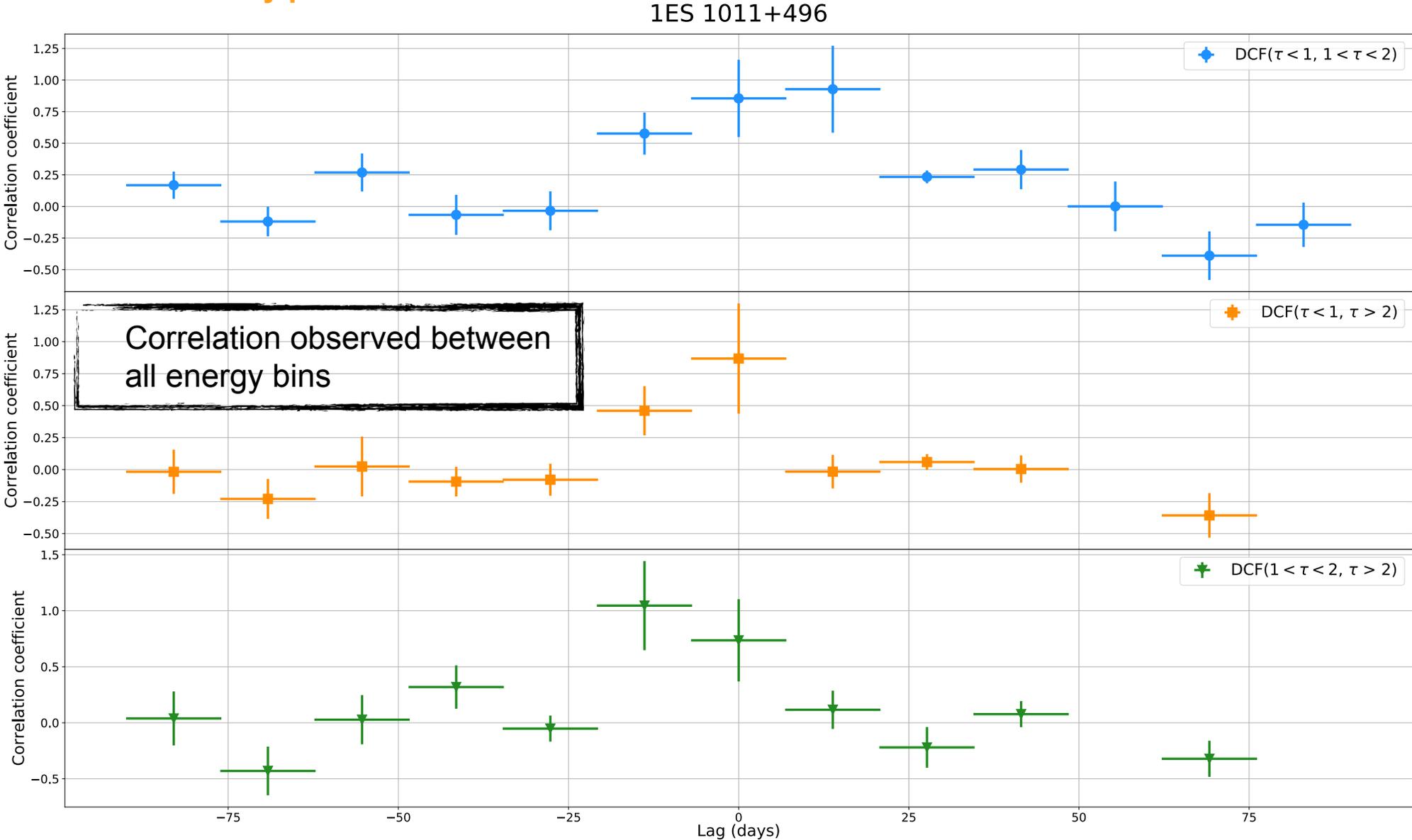
Contribution from secondary photons

1ES 1011+496, weekly bins



DCF for VHE lightcurves, 1ES 1011+496

Contribution from secondary photons

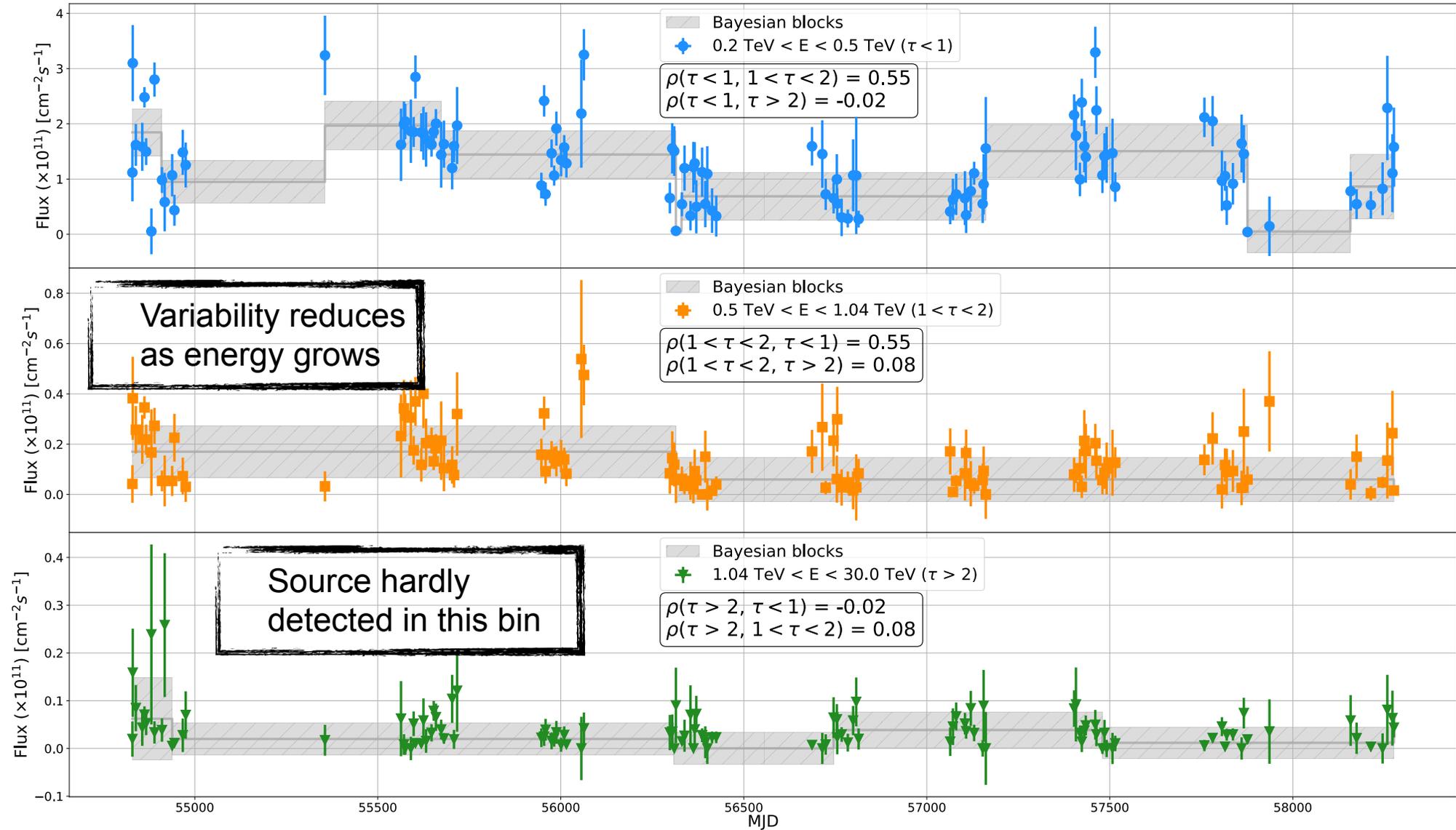


1ES 1218+304

VHE lightcurves, 1ES 1218+304

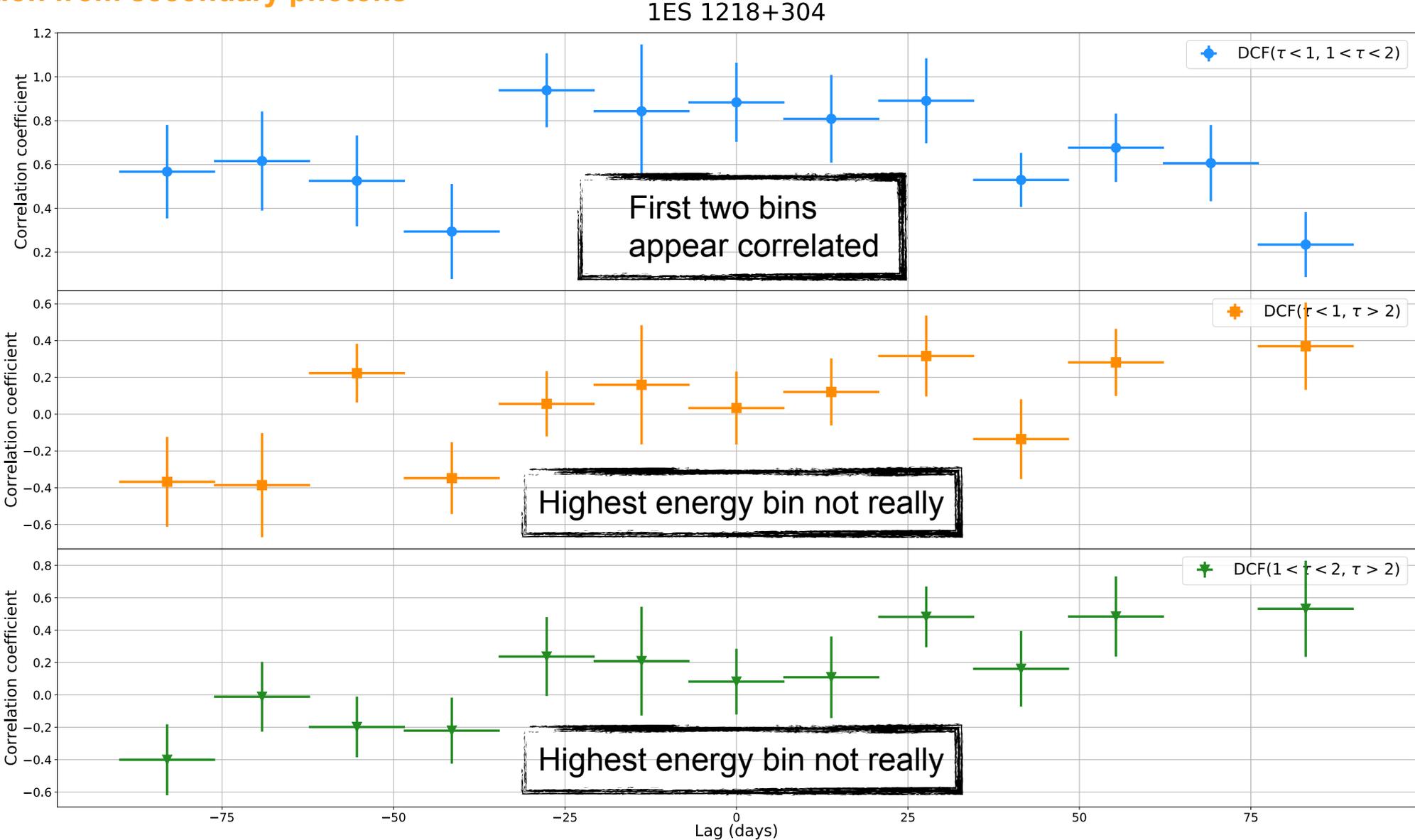
Contribution from secondary photons

1ES 1218+304, weekly bins



DCF for VHE lightcurves, 1ES 1218+304

Contribution from secondary photons

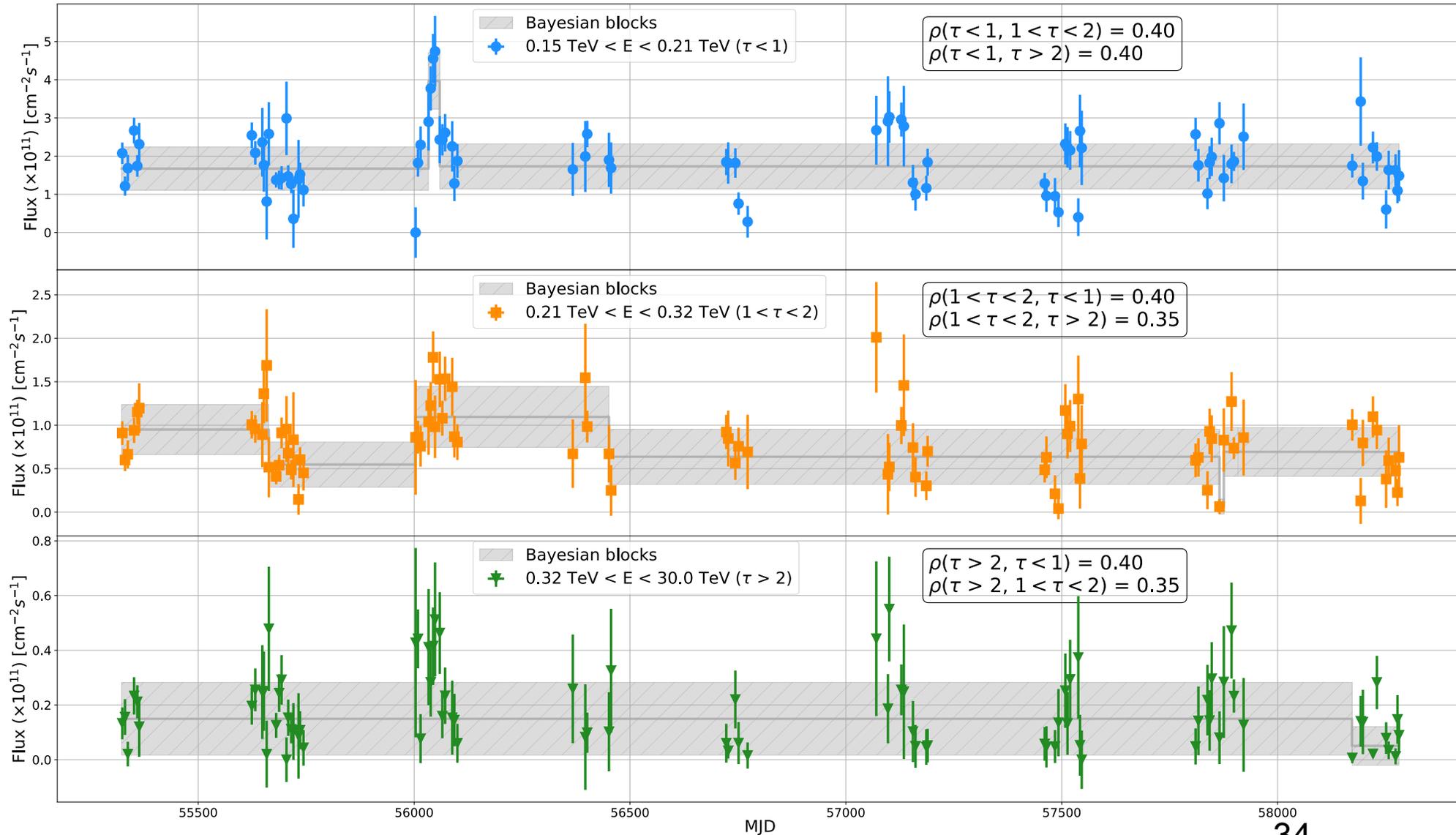


PG 1553+113

VHE lightcurves, PG 1553+113

Contribution from secondary photons

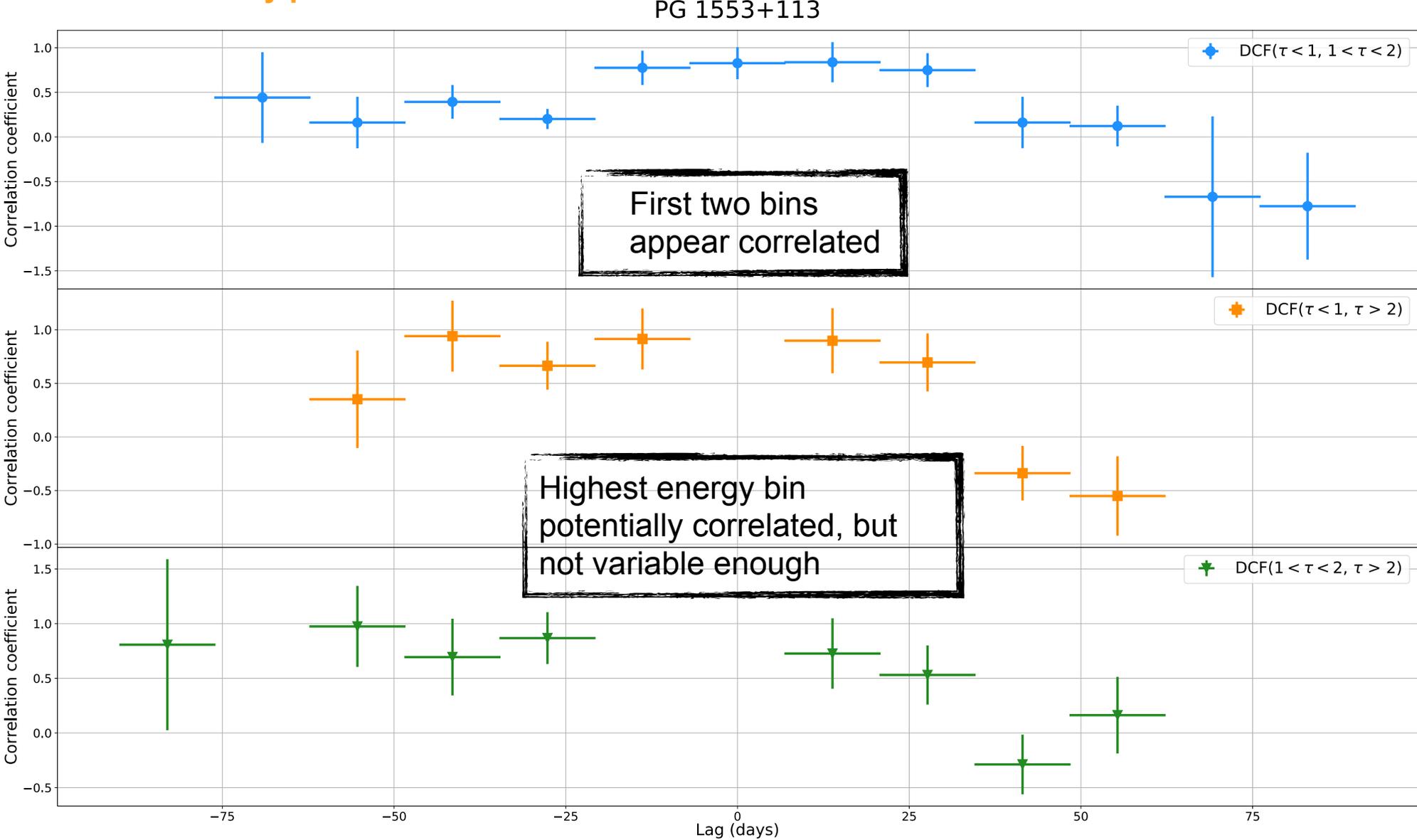
PG 1553+113, weekly bins



Flare becomes less significant as energy grows

DCF for VHE lightcurves, PG 1553+113

Contribution from secondary photons



Summary and outlook

Summary

- Studied long-term lightcurves of various HBLs/xHBLs, spanning a decade of VERITAS data.
- Long-term variability observed in all energy bands.
- Some sources present short-term variability, where
 - VHE/HE/X-Ray show potential correlation (1ES 1011+496 flare).
 - VHE/X-Ray vary, HE does not (e.g., 1ES 1218+304).
 - VHE/HE are stable, strong X-Ray variations.

xHBLs are not all the same?

- Intra-VHE correlation observed, implications for secondary photons contribution?

Outlook

- Estimate additional systematic uncertainty on 1ES 0033+595 redshift.
- Model the 1ES 0033+595 MWL SED.
- Test different lightcurve binning, coarser and finer.
- Expand correlation study and repeat for flares with finer binning.
- Explore SED variations (long-term).

Backup slides