1ES 0647+250: 10 years of multiwavelength observations

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on behalf of the MAGIC and *Fermi*-LAT Collaborations

7th Heidelberg International Symposium on High-Energy Gamma-Ray Astronomy
(Gamma2022)

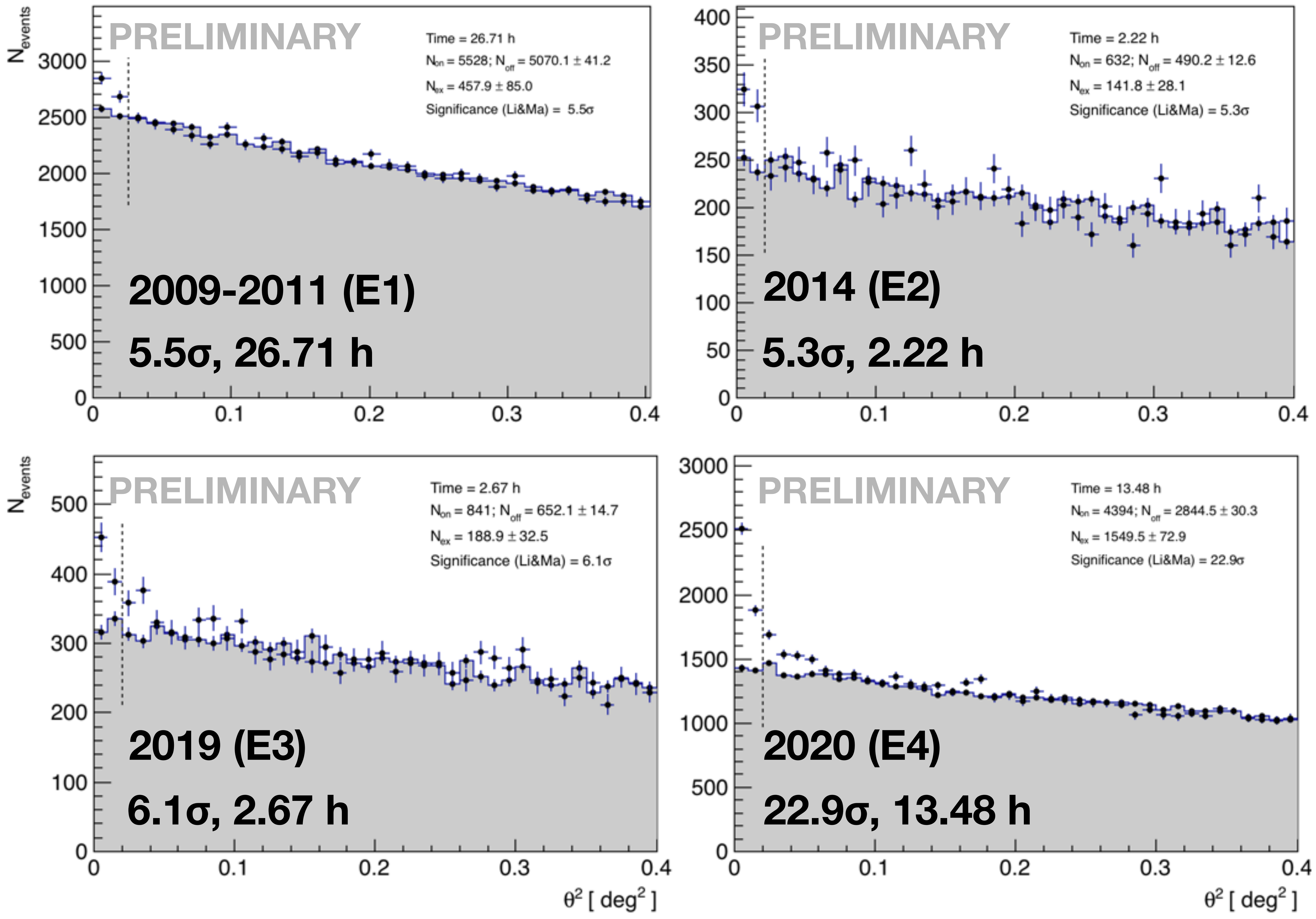
Universidad de La Laguna

MAGIC Major Atmospheric Gamma Imaging Cerenkov Telescopes

Image credit: IPAC-Caltech

BL Lac object 1ES 0647+250

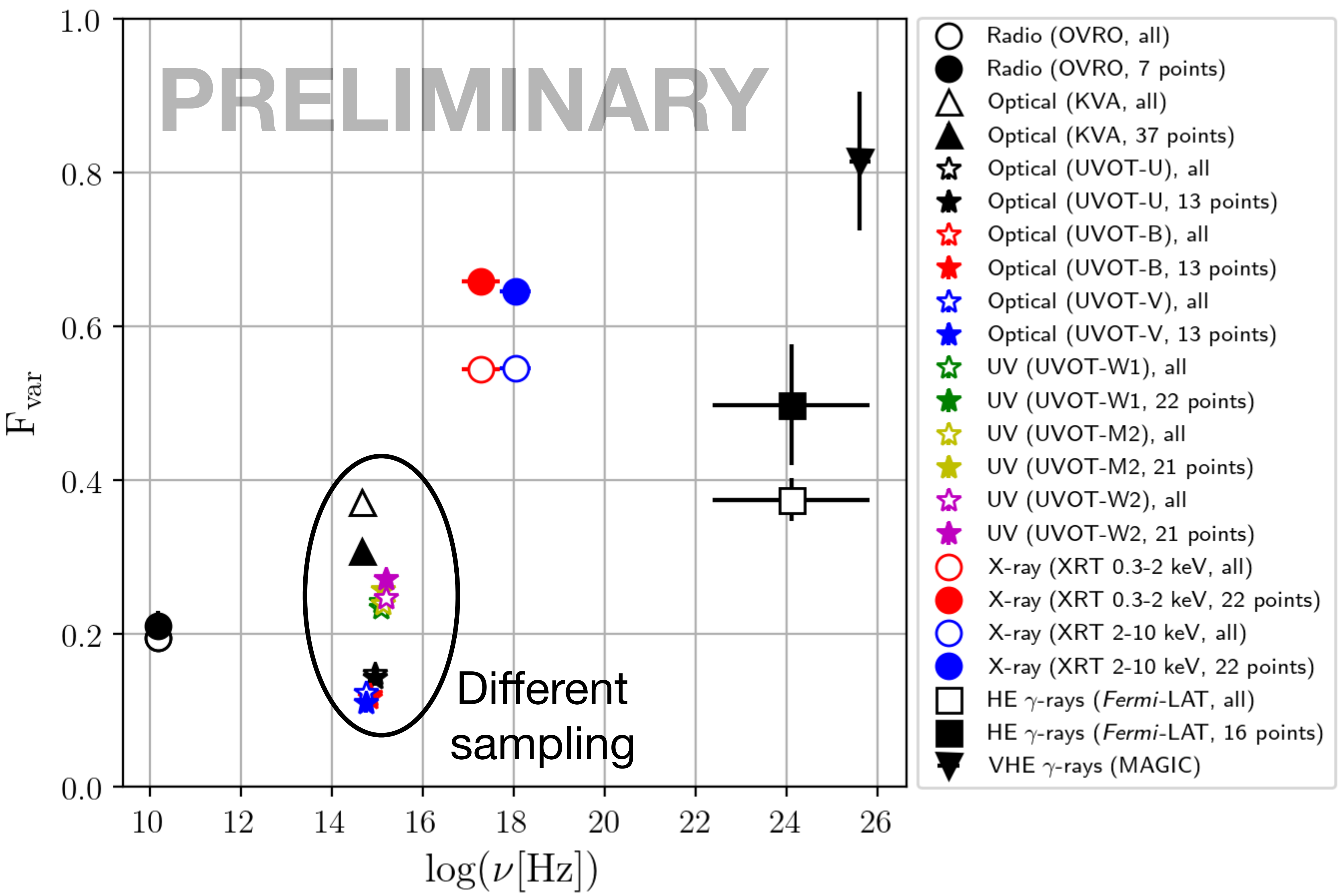
- **1ES 0647+250**: HBL (high synchrotron peaked) BL Lac object
- **Redshift unknown** (several previous measurements)
  - z = 0.41 ± 0.06 from Kotilainen et al. (2011)
  - Lower limit z > 0.29 from Paiano et al. (2017)
- Detected during **low and flaring states after high X-ray emission** with MAGIC
- Multiwavelength (MWL) data needed to understand these events → **MAGIC + MWL analysis**

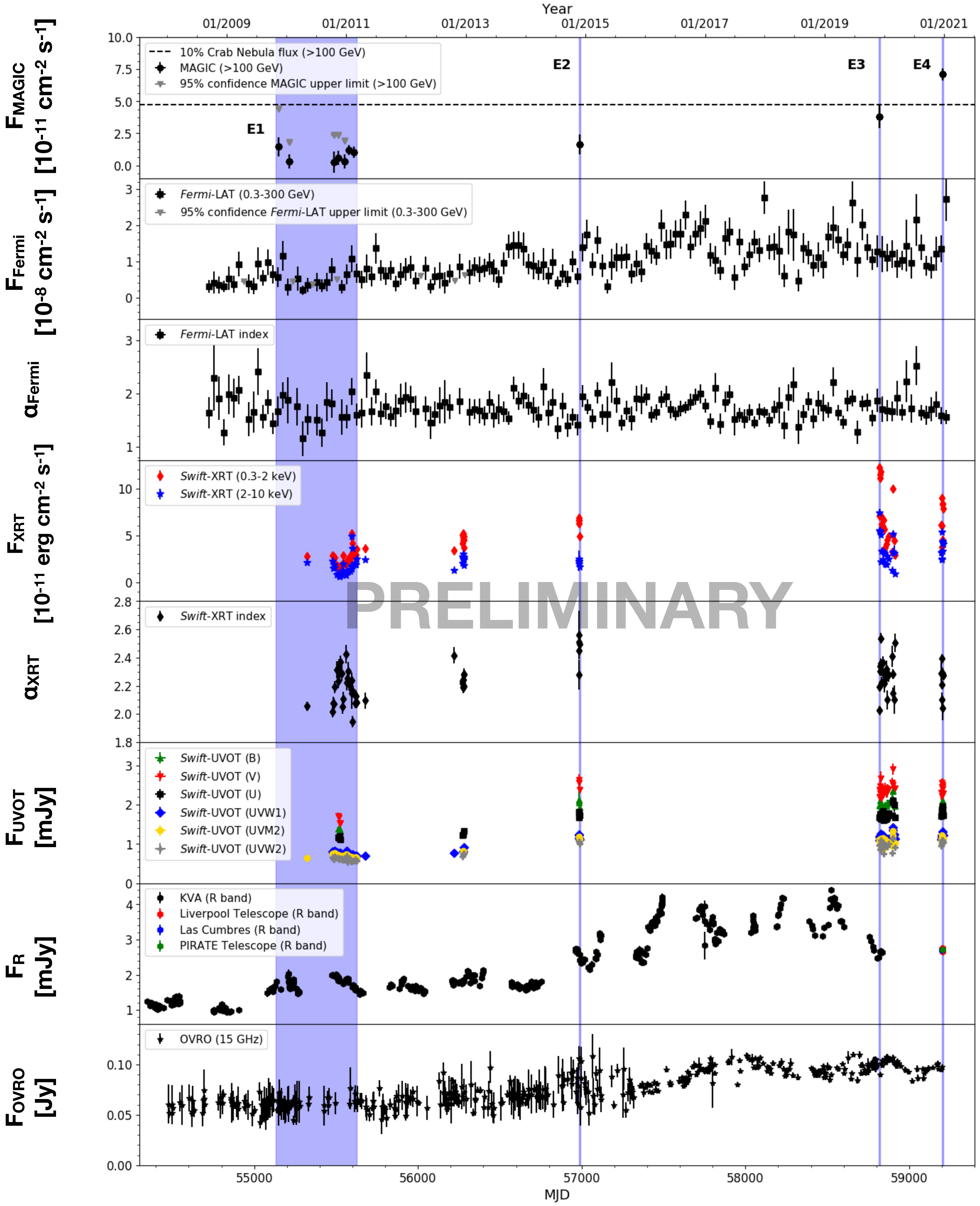


MWL data and variability

Fractional variability

- Maximum at X-rays and γ rays
- No difference between simultaneous data and full data set
- Same structure with 30-day binned data





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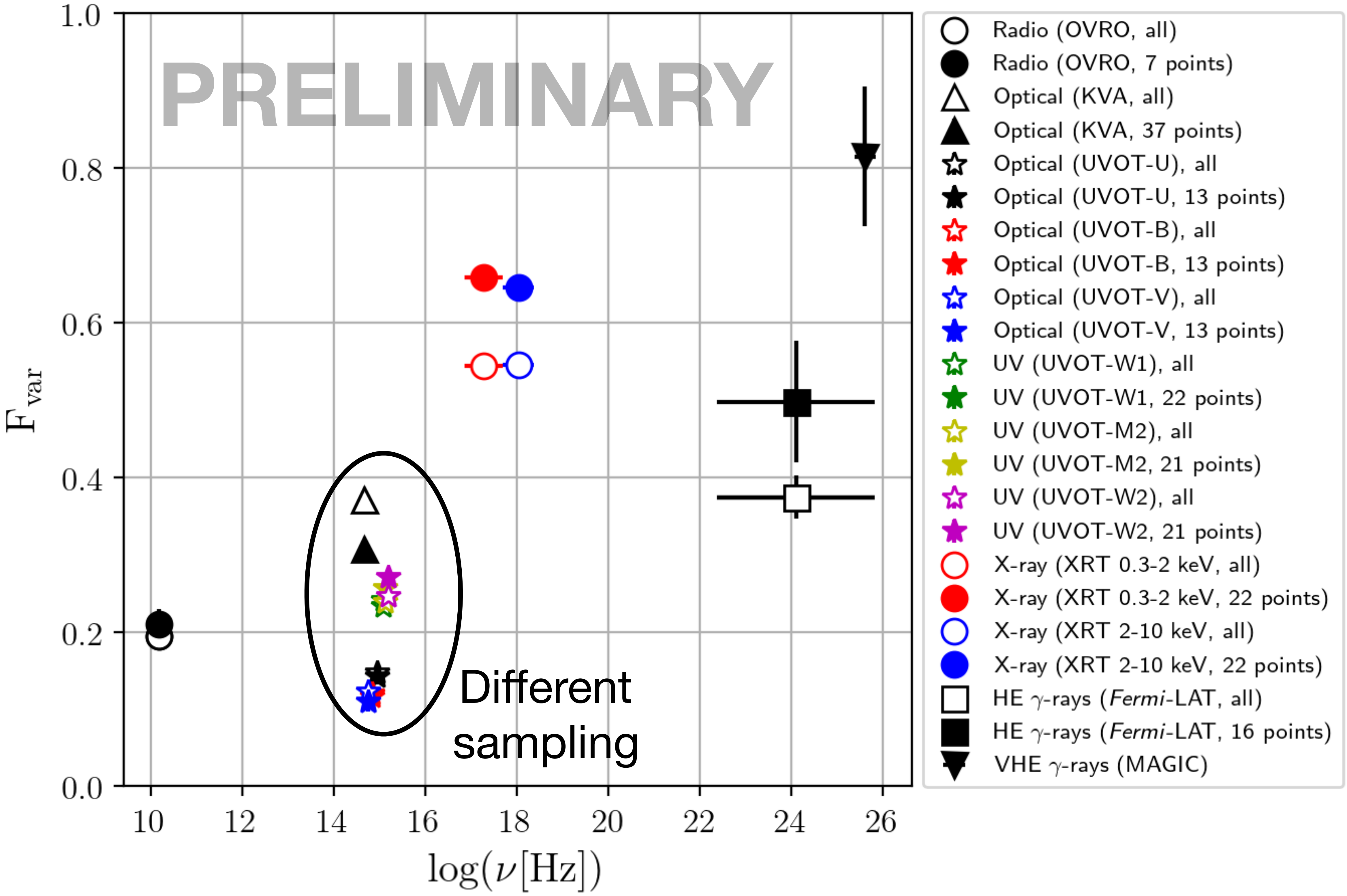
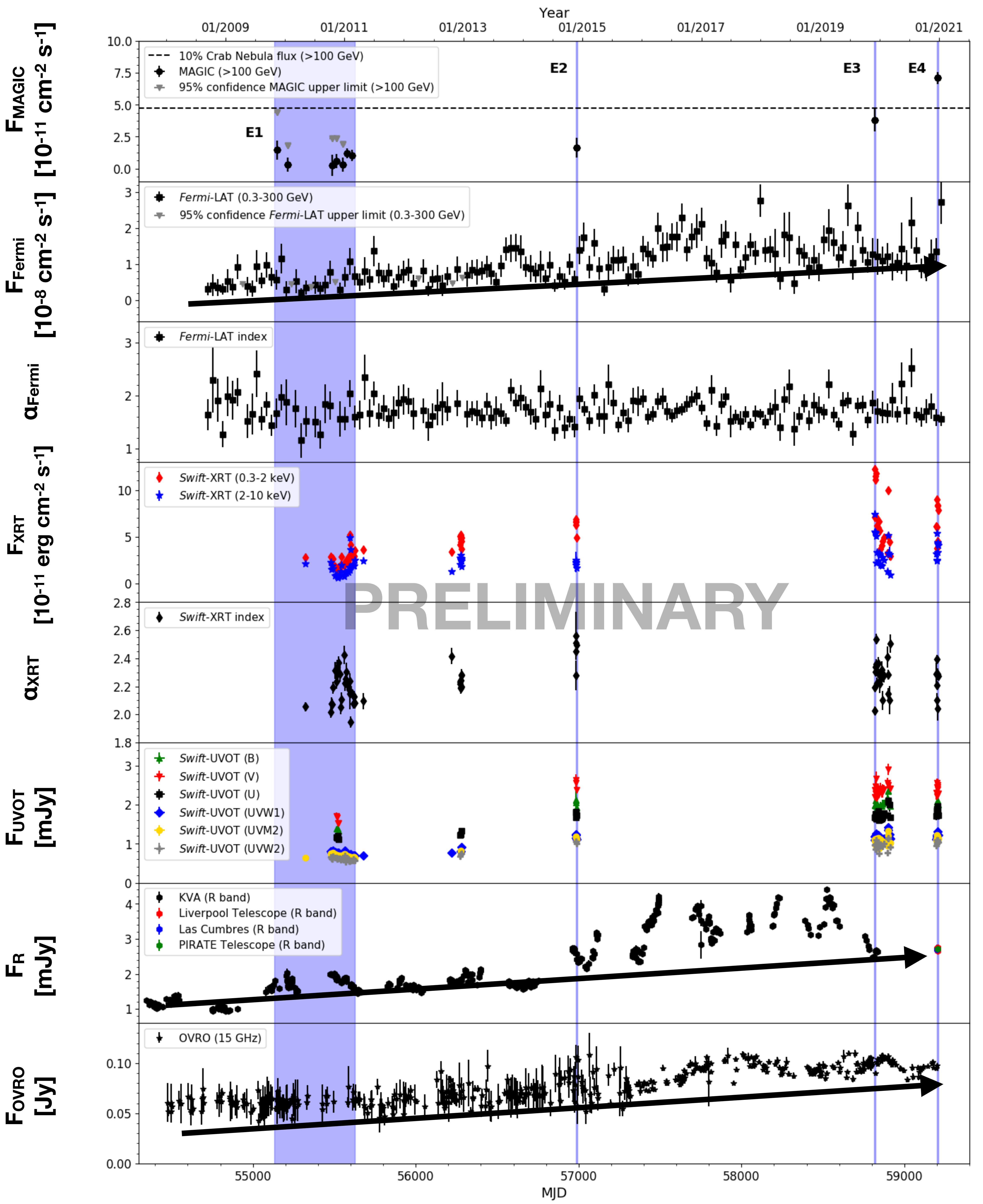
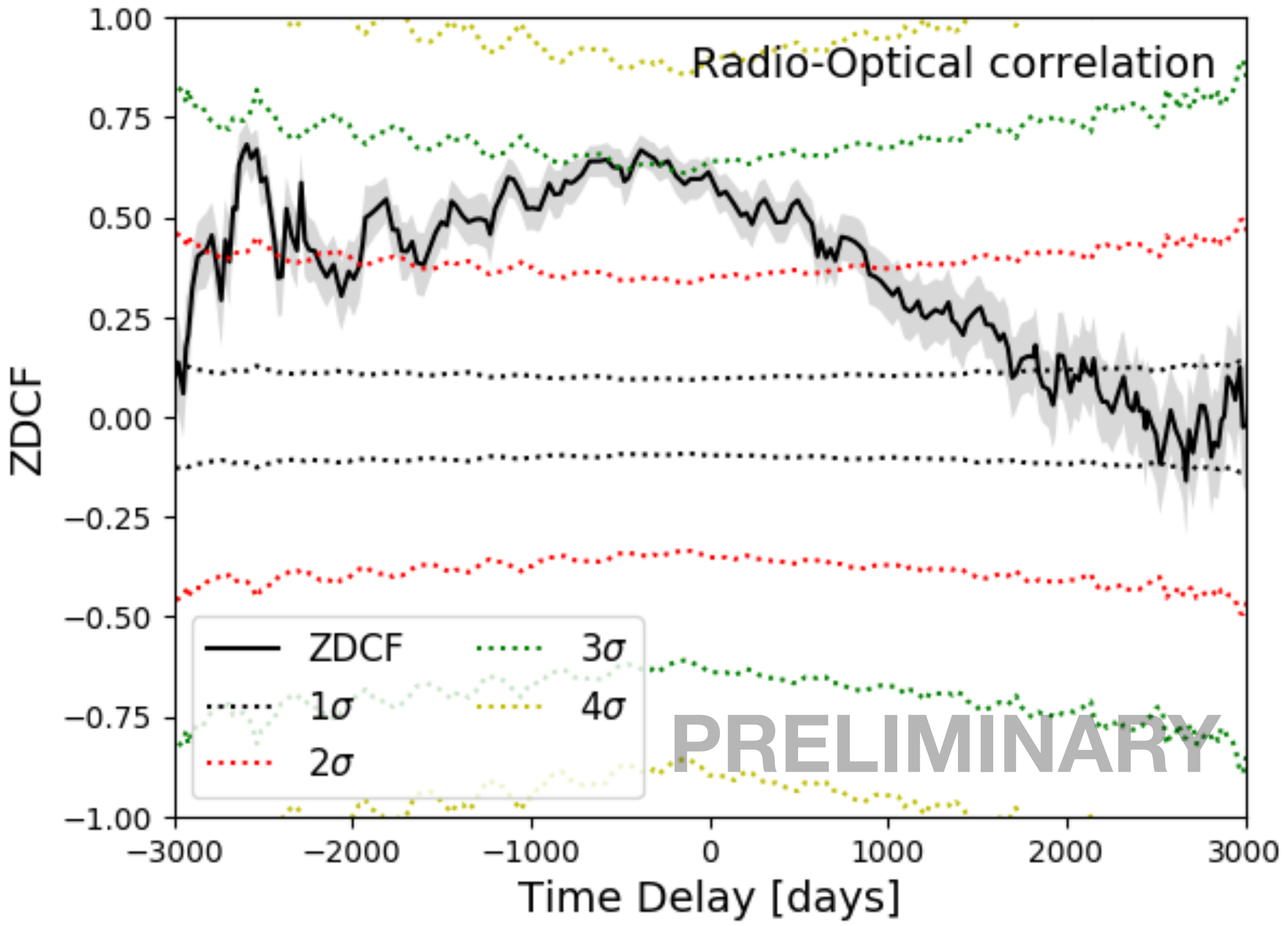
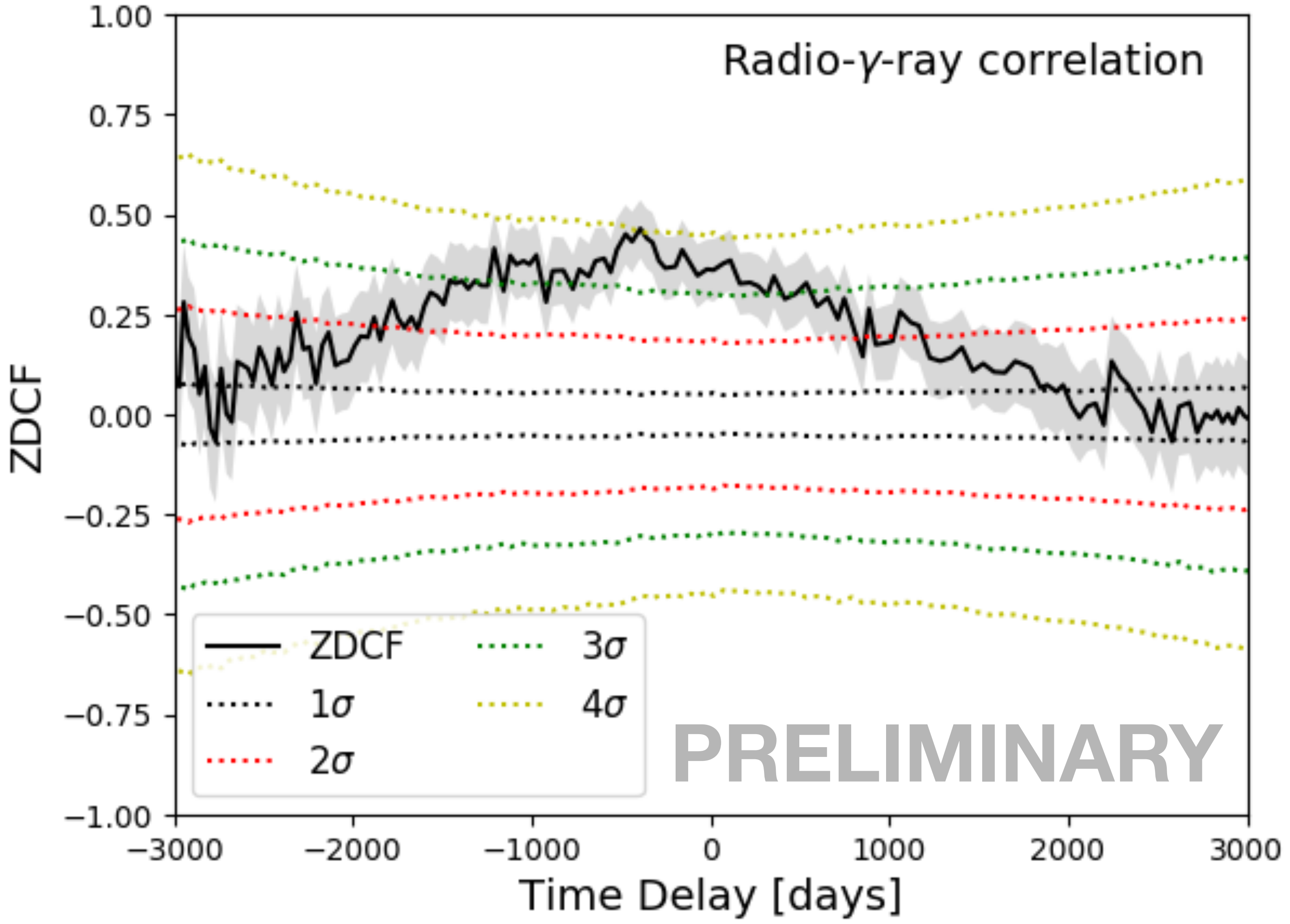




Correlations

- **Long-term correlations**:
  - Correlated **optical-γ-ray** emission with **no significant time lag**
  - Correlated **radio-optical** and **radio-γ-ray** emission with **long delay (~400 days)**
- Slow long-term variability —> slow decrease of the correlation





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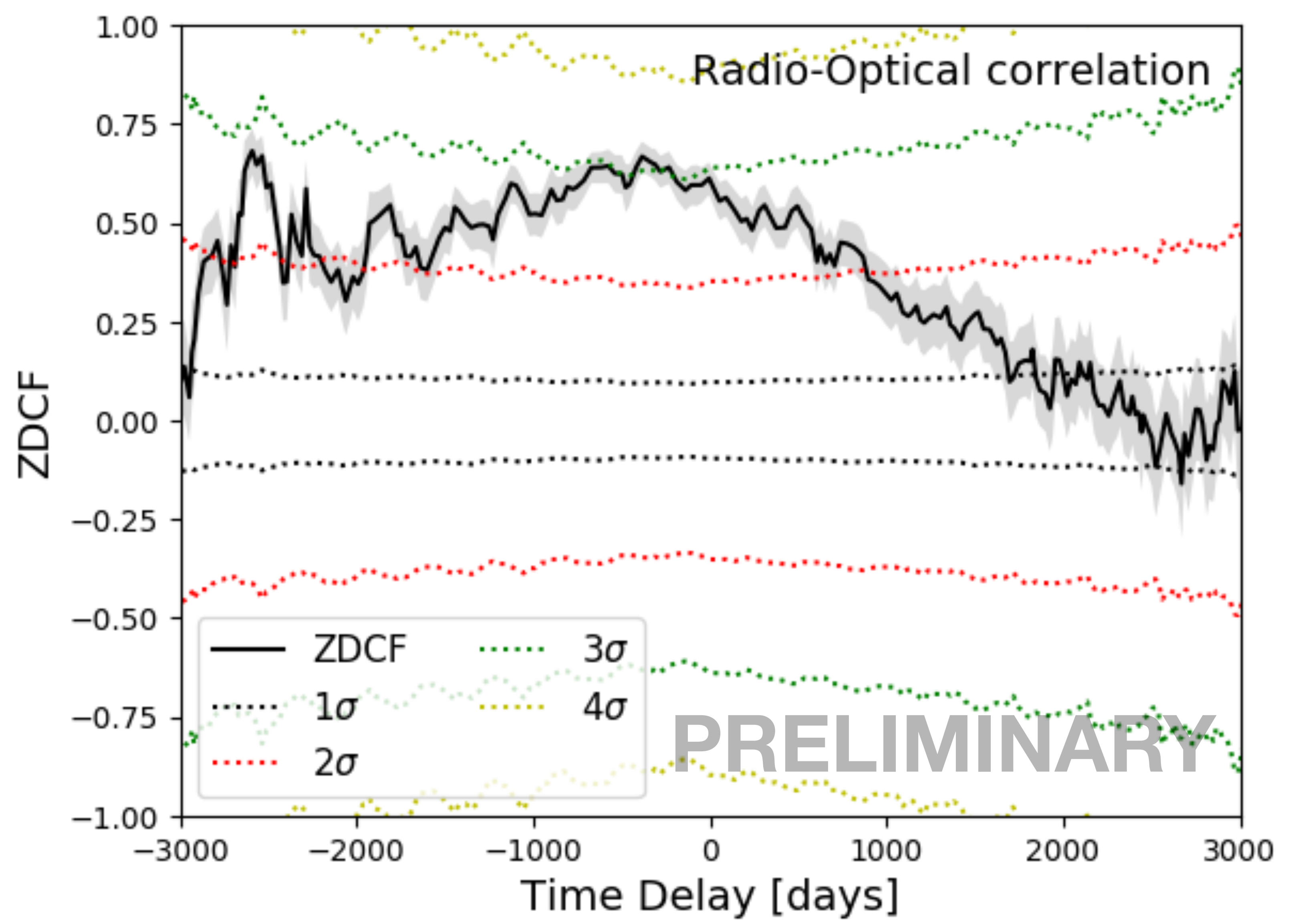
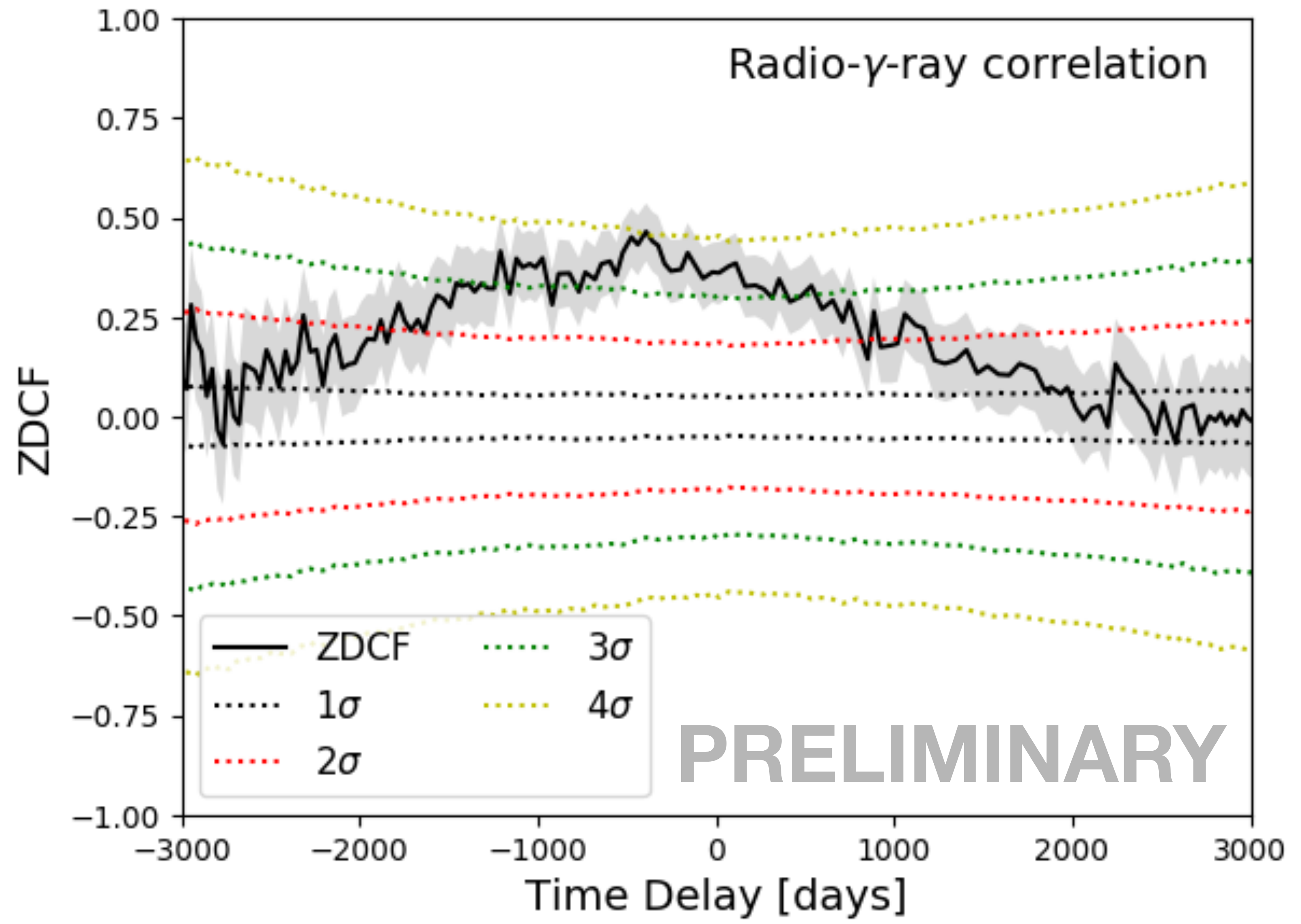
Long-term variability dominant

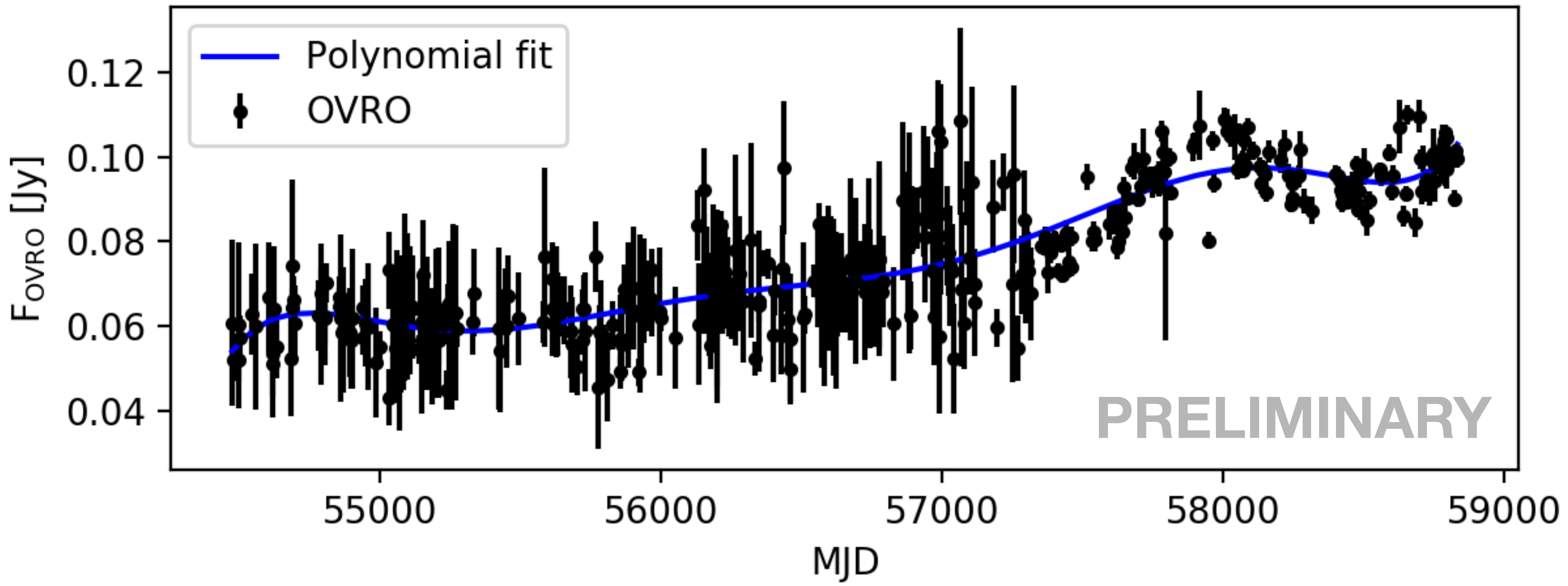
Detrending of the data to evaluate shorter time scales





Correlations

- No unique detrending method —> approach from Lindfors et al. (2016)
- Detrending by pairs of light curves with a percentage of common emission
  - Radio-optical: 51%
  - Radio-γ rays: 24%
  - Optical-γ rays: 22%



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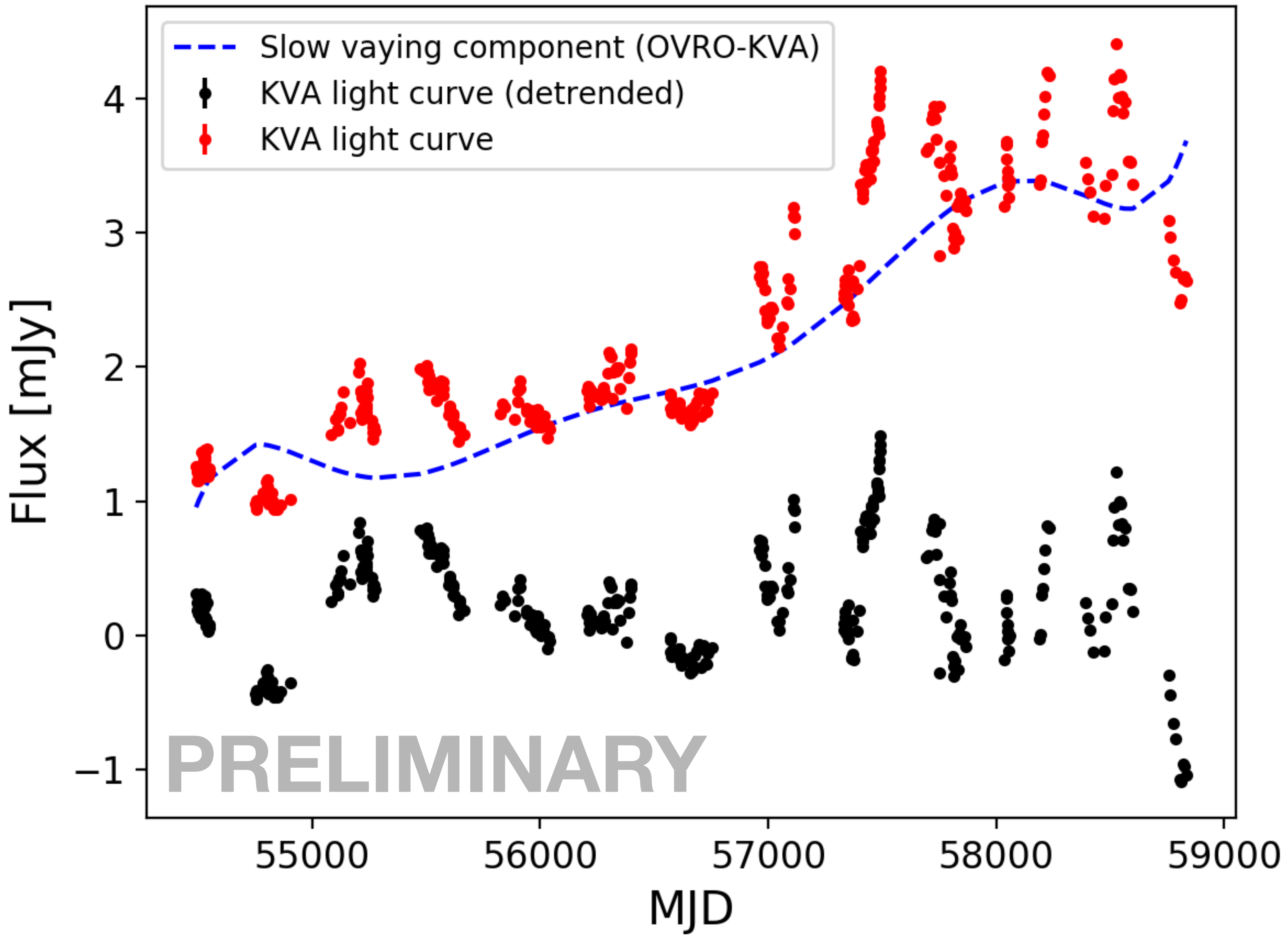
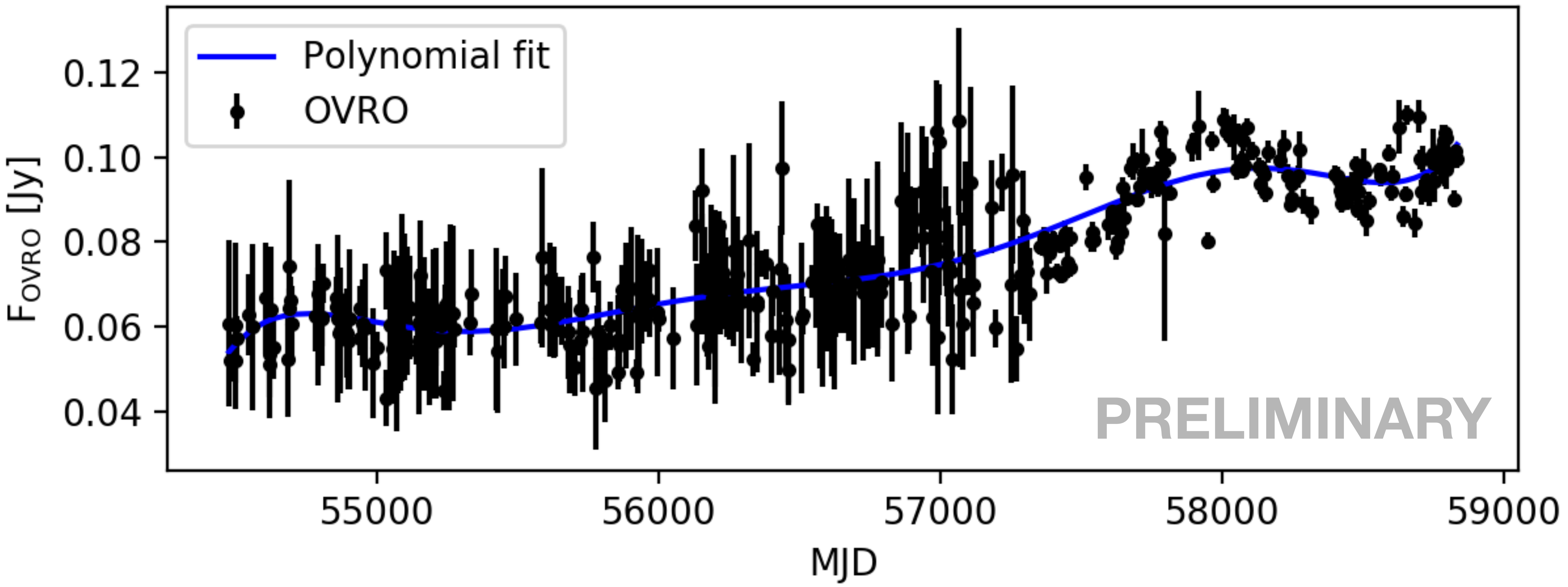
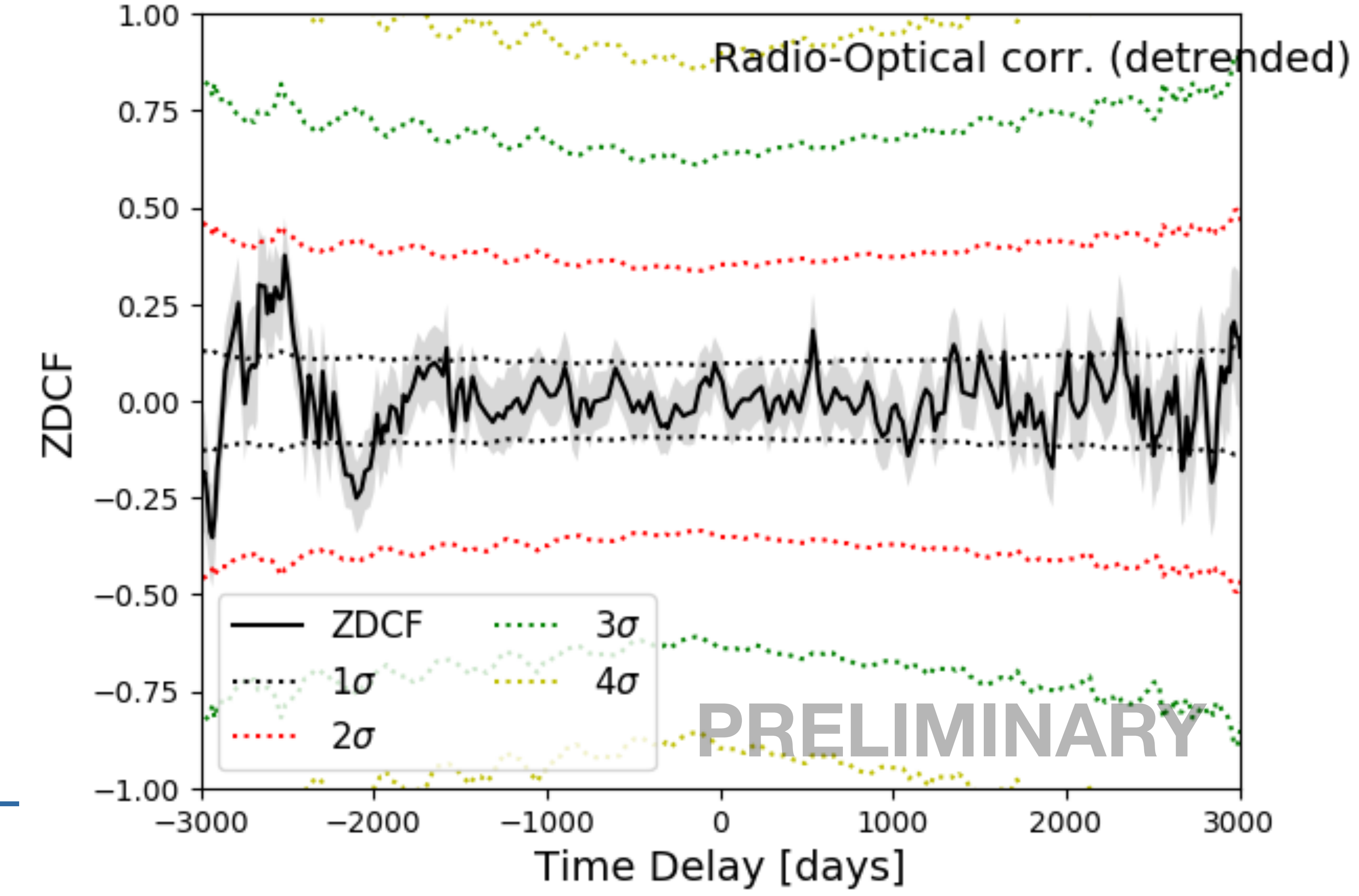


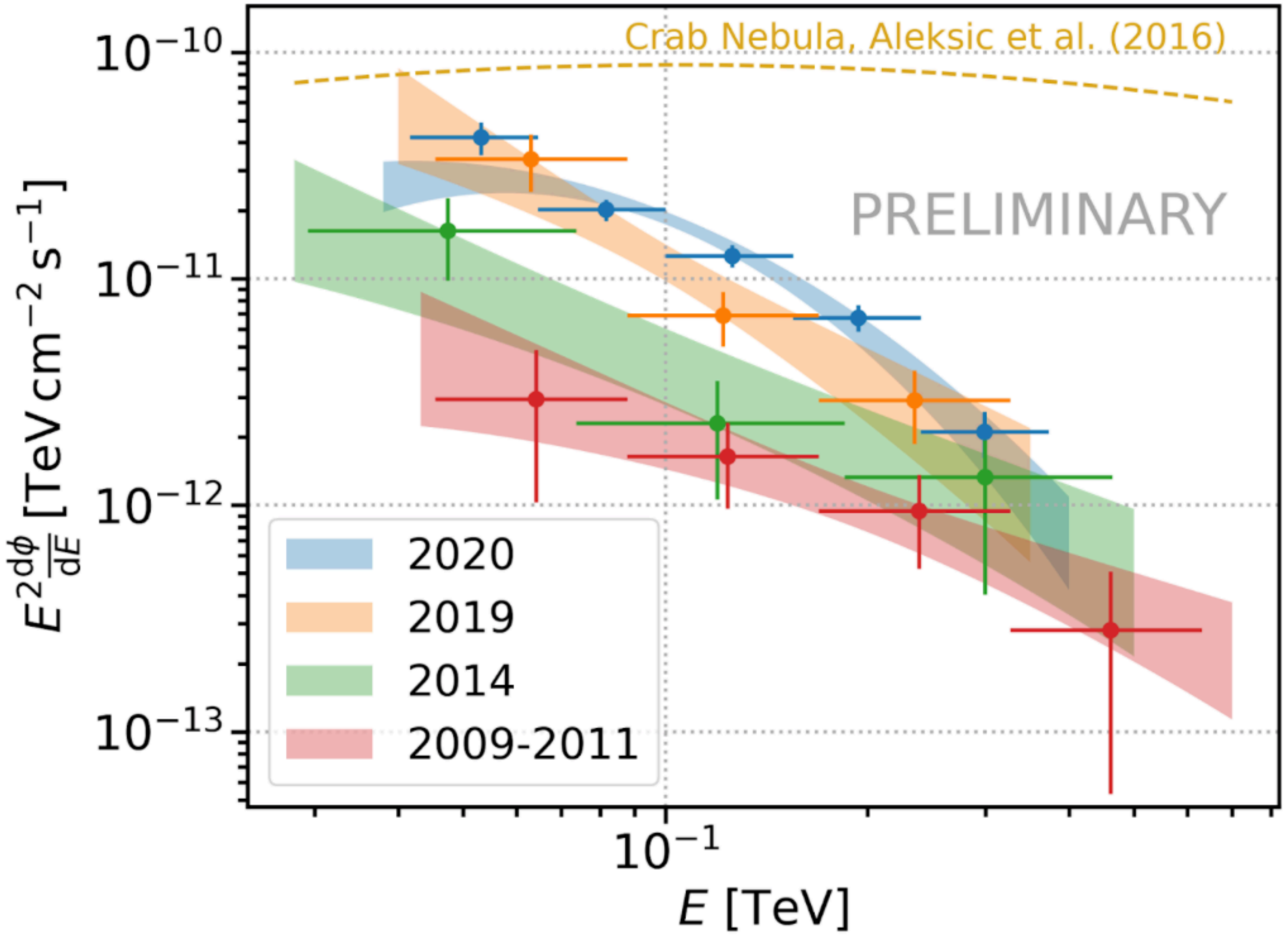
No correlation in shorter time scales





Spectral analysis and redshift estimation

VHE γ-ray spectra

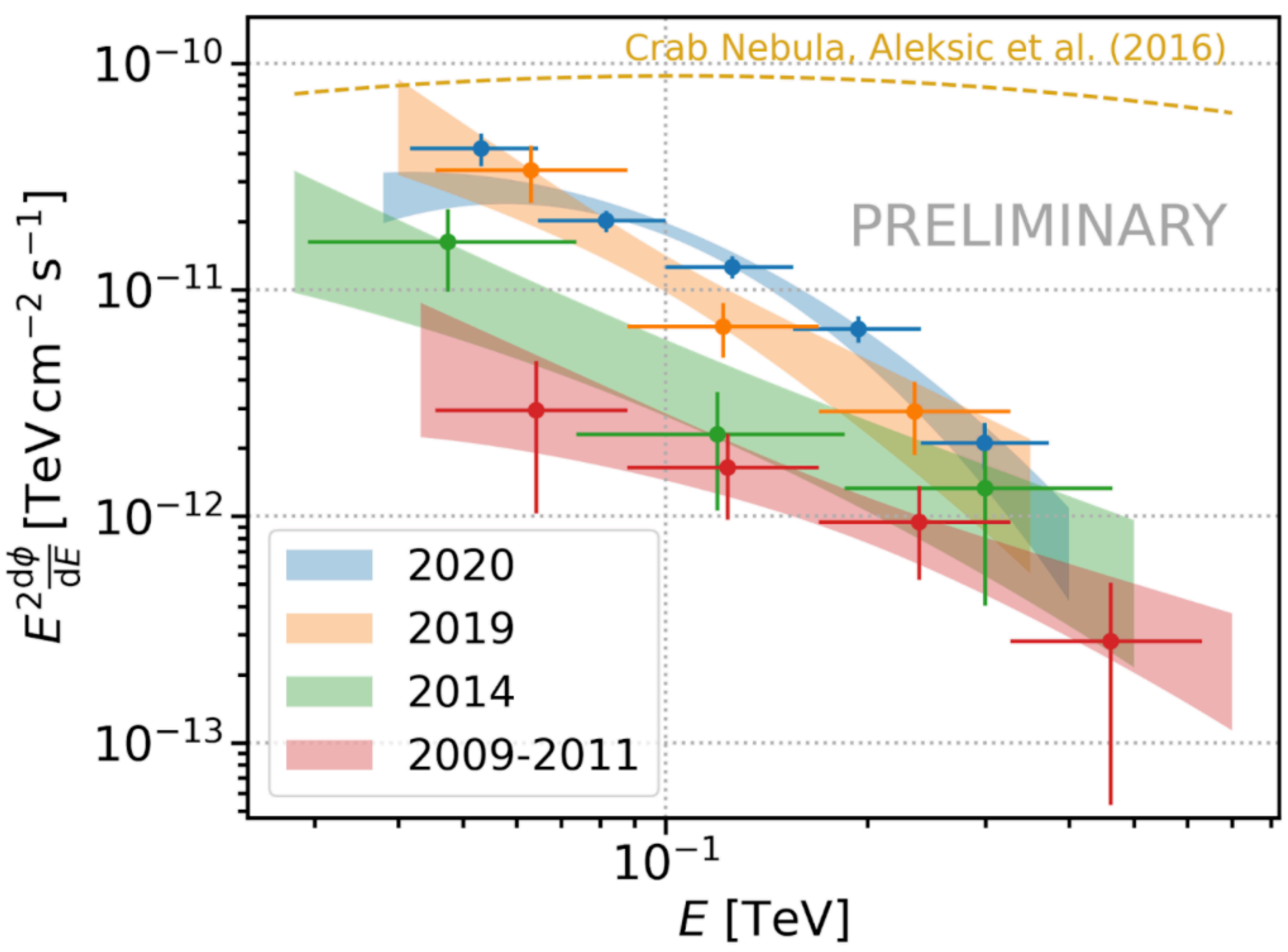


Epoch	Fit Model*	f_0 [10^{-10}· TeV^{-1} · cm^{-2} · s^{-1}]	E_0 [GeV]	Spectral index α	Curvature β	χ^2/d.o.f.
E1	PL	0.29 ± 0.07	190	3.12 ± 0.37	–	1.2/3
E2	PL	4.40 ± 1.63	100	3.25 ± 0.74	–	2.1/2
E3	PL	12.0 ± 2.2	100	3.73 ± 0.58	–	2.2/2
E4	PL	16.9 ± 1.0	100	3.70 ± 0.10	–	18.1/5
E4	LogP	18.9 ± 1.6	100	3.16 ± 0.21	1.91 ± 0.68	5.3/6

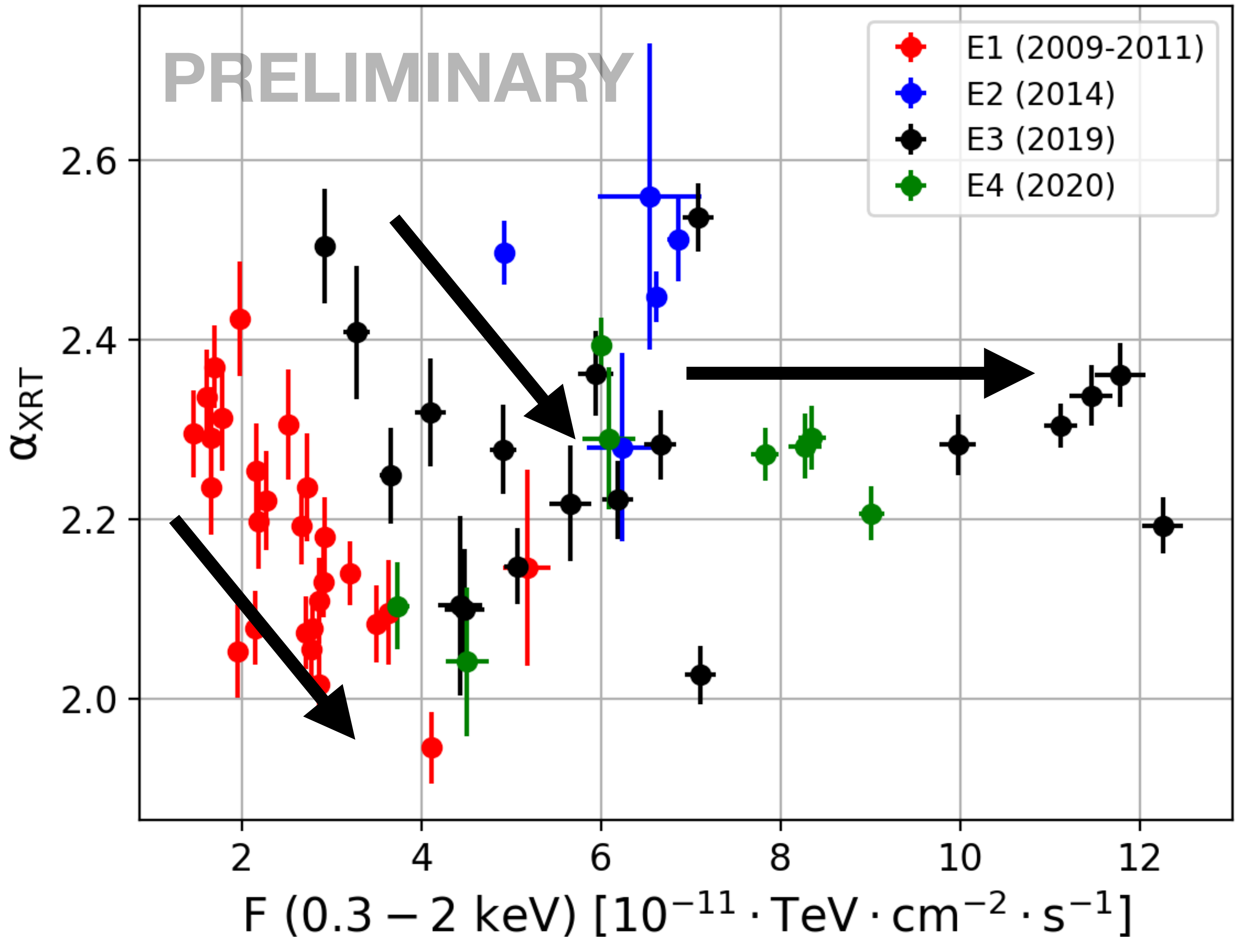
- **No harder-(softer)-when-brighter** trend (large errors)
- **Power law** functions for **E1, E2 and E3**
- Log-parabola tested for **E4** —> **3σ preference** of **log-parabola** over power law

Spectral analysis and redshift estimation

VHE γ-ray spectra



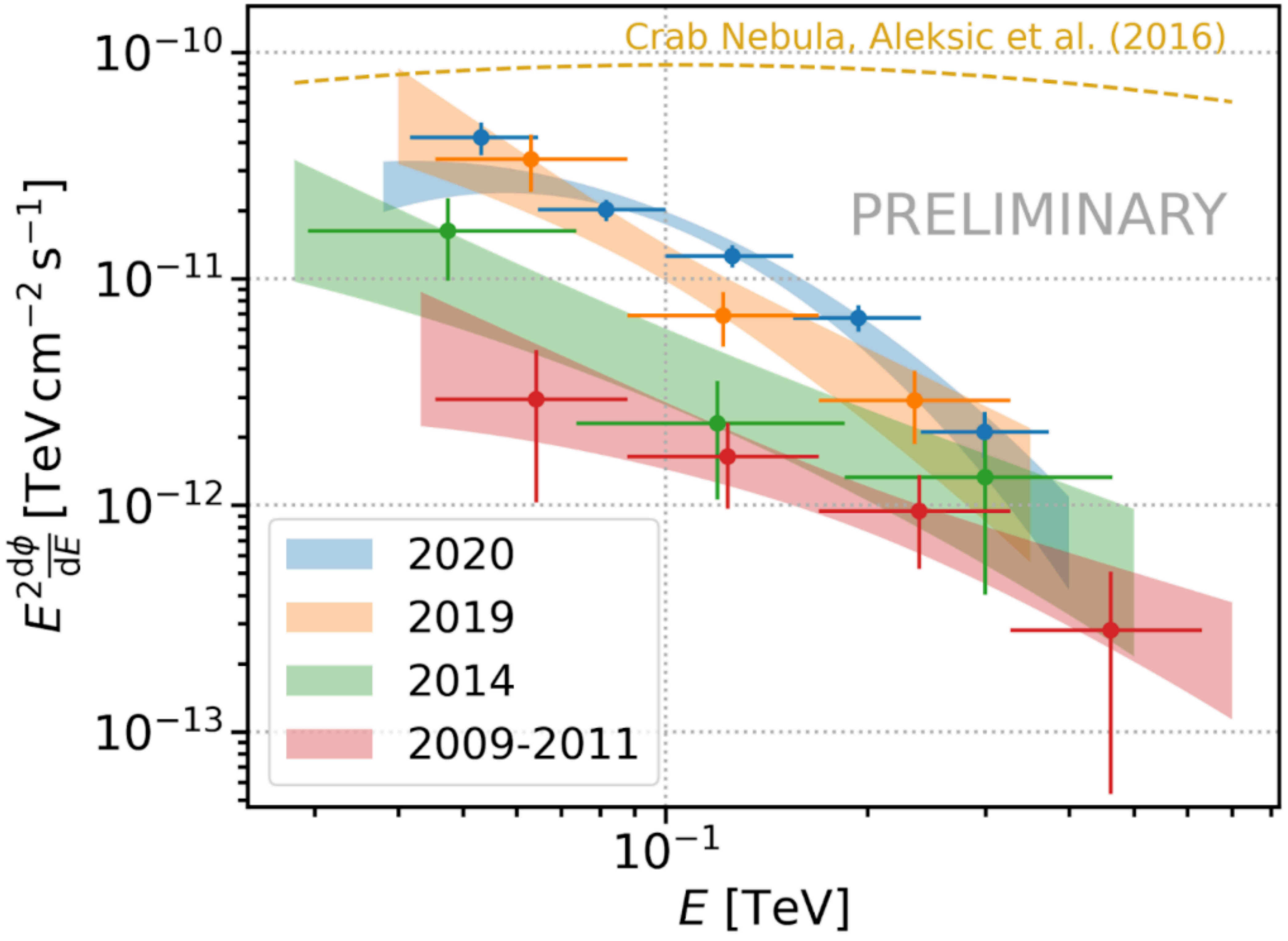
X-ray and HE gamma-ray spectral variability



Harder-when-brighter
Saturation during the brightest flare?

Spectral analysis and redshift estimation

VHE γ-ray spectra



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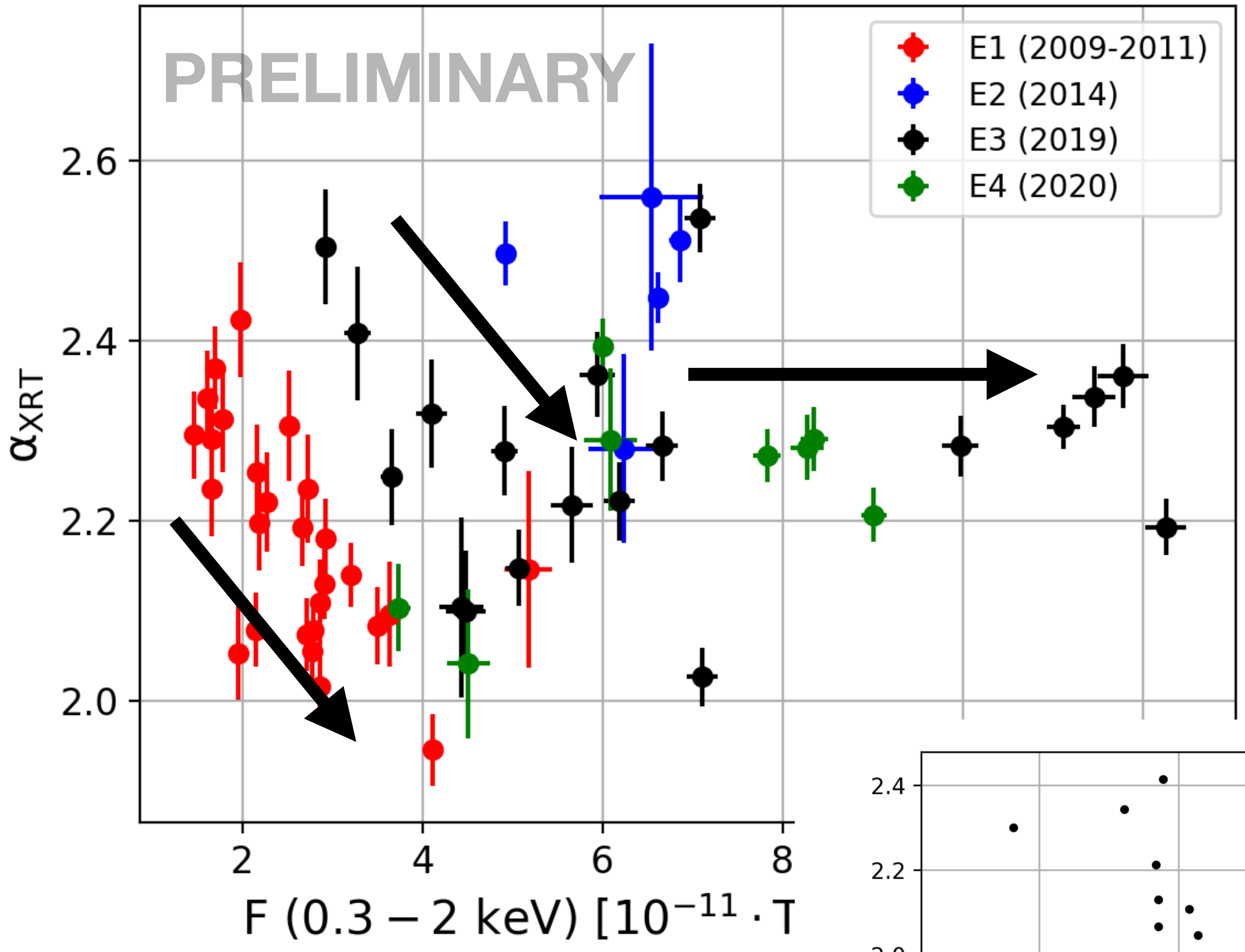
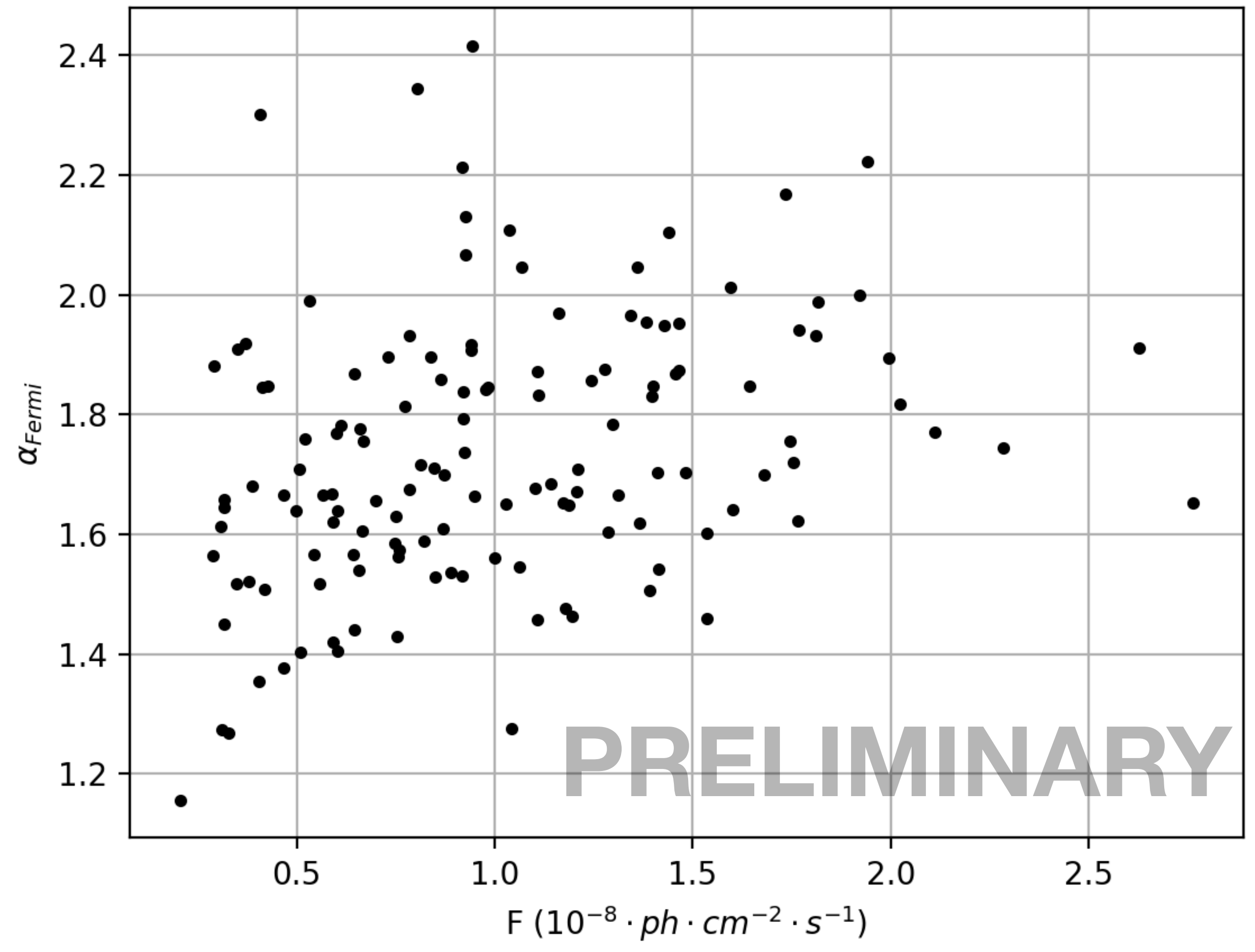




No significant HE gamma-ray spectral variability

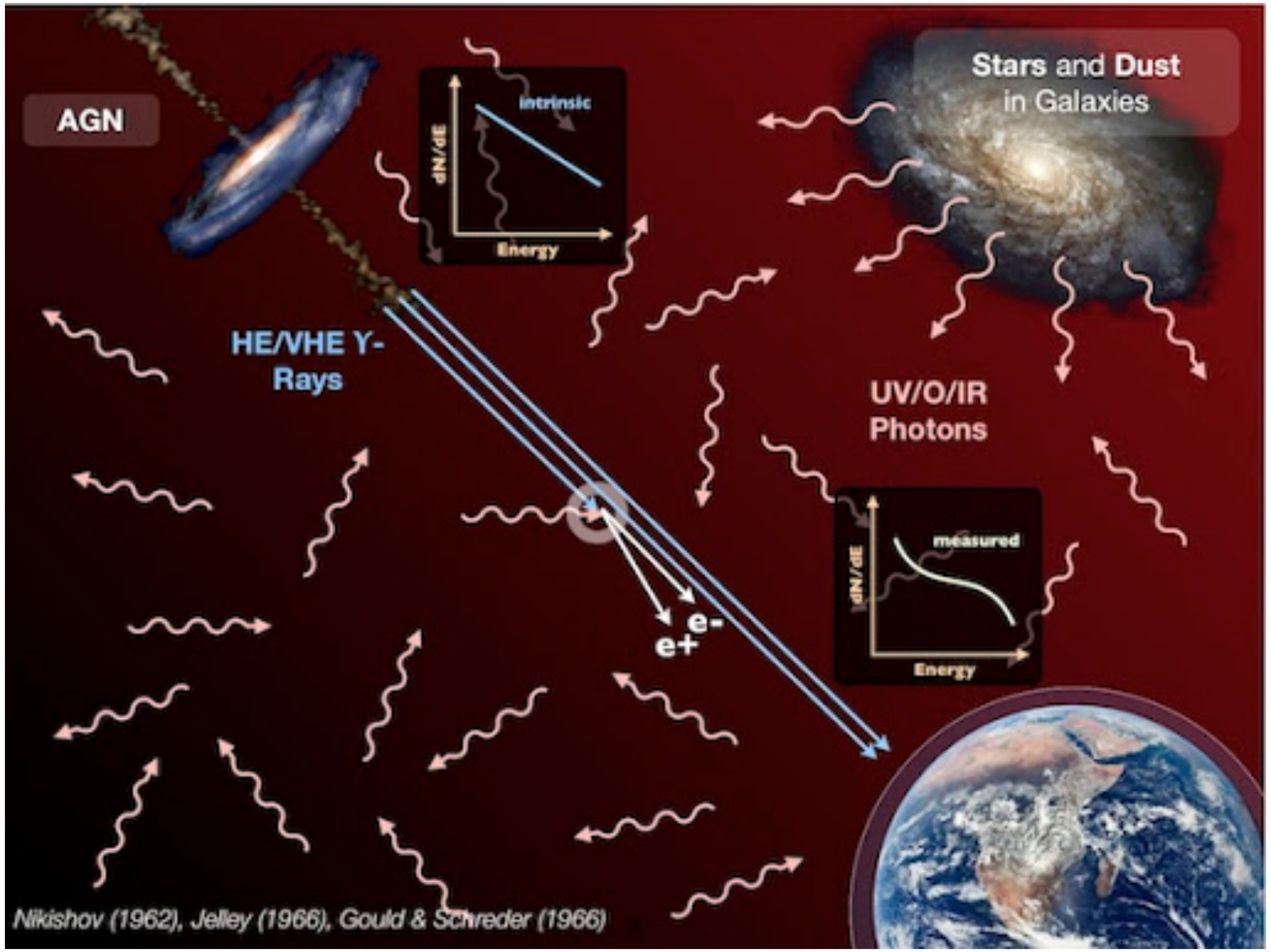
Spectral analysis and redshift estimation

Joint HE+VHE γ-ray spectrum

Empirical redshift determination method from Prandini et al. (2011)

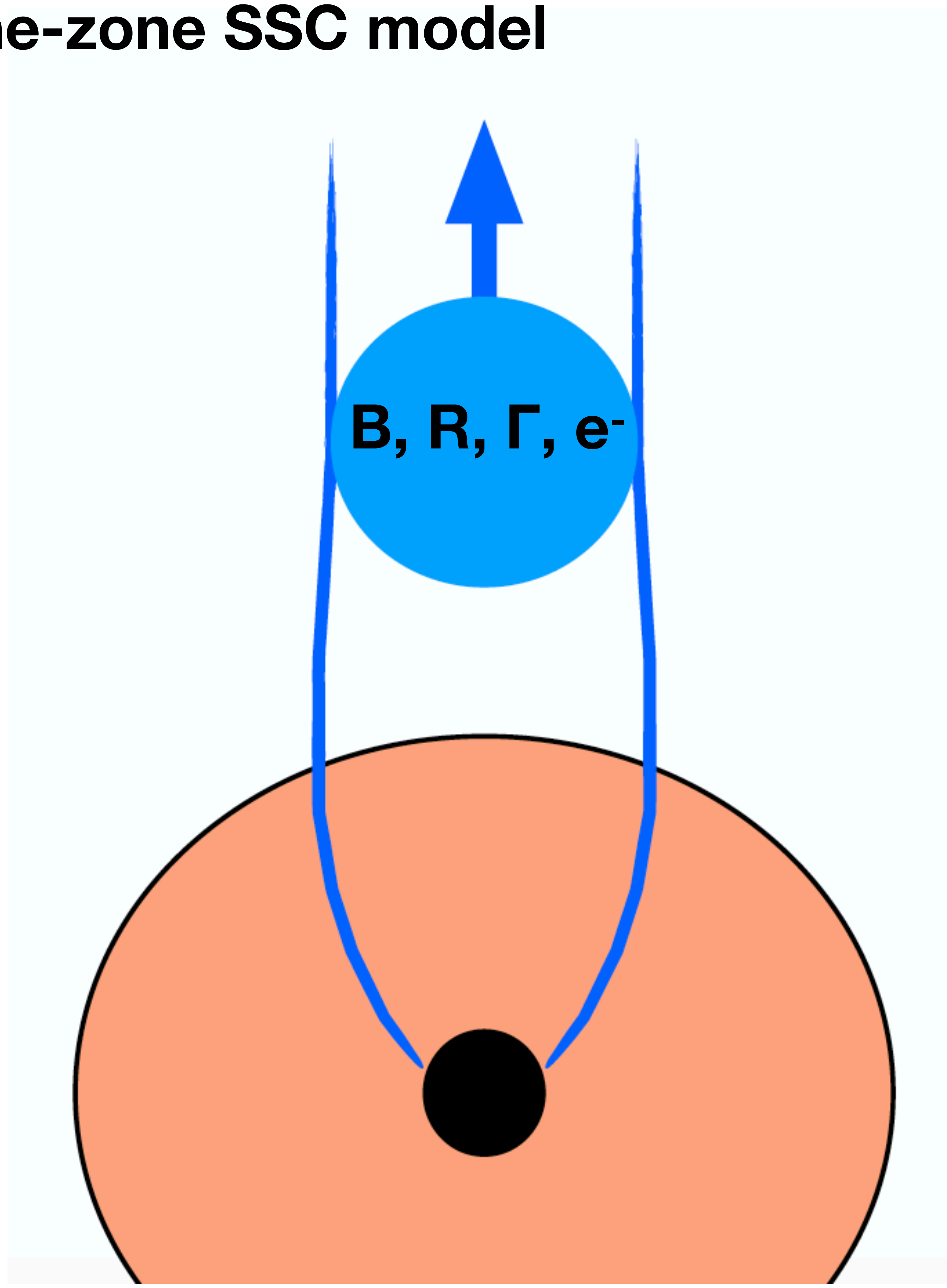
- Difference between **HE and VHE** spectrum —> **EBL**
- **Deabsorbed specrtum —> Upper limit z***
- **z*** related to **true z** through **empirical relation**

Estimated redshift z_{est}	z*
0.45 ± 0.05	0.75 ± 0.11



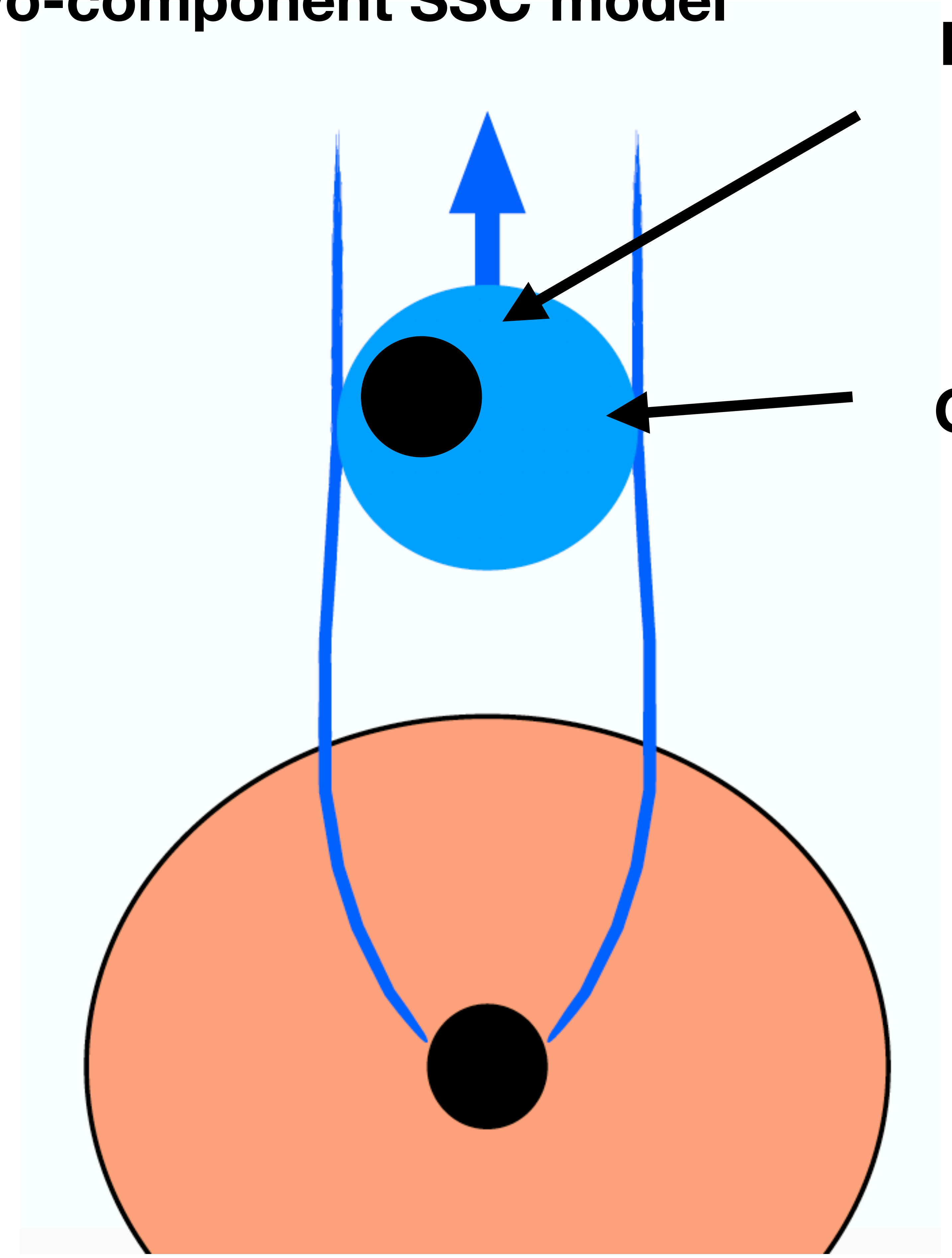
SED modeling

One-zone SSC model



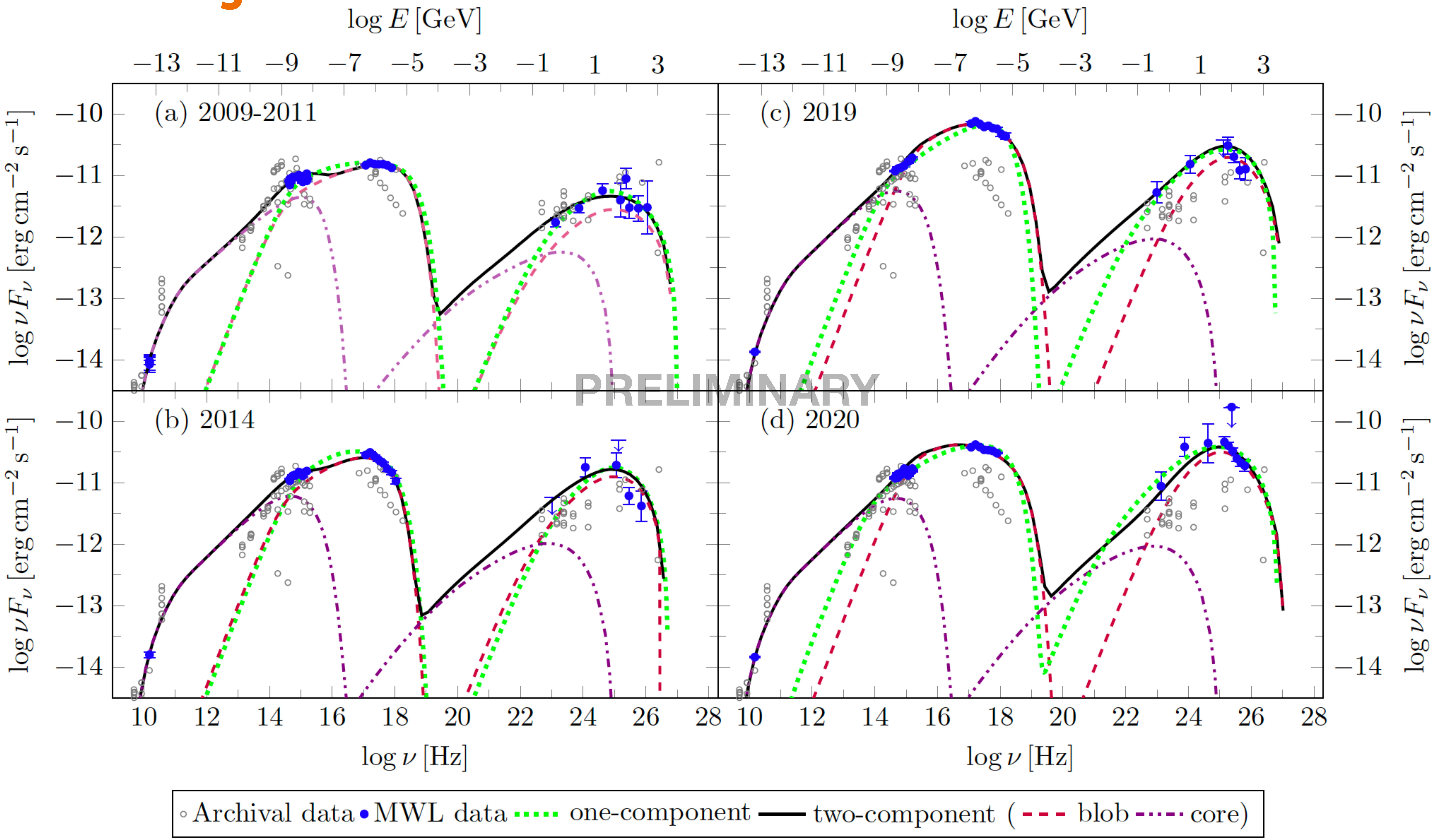
Tavecchio+98

Two-component SSC model



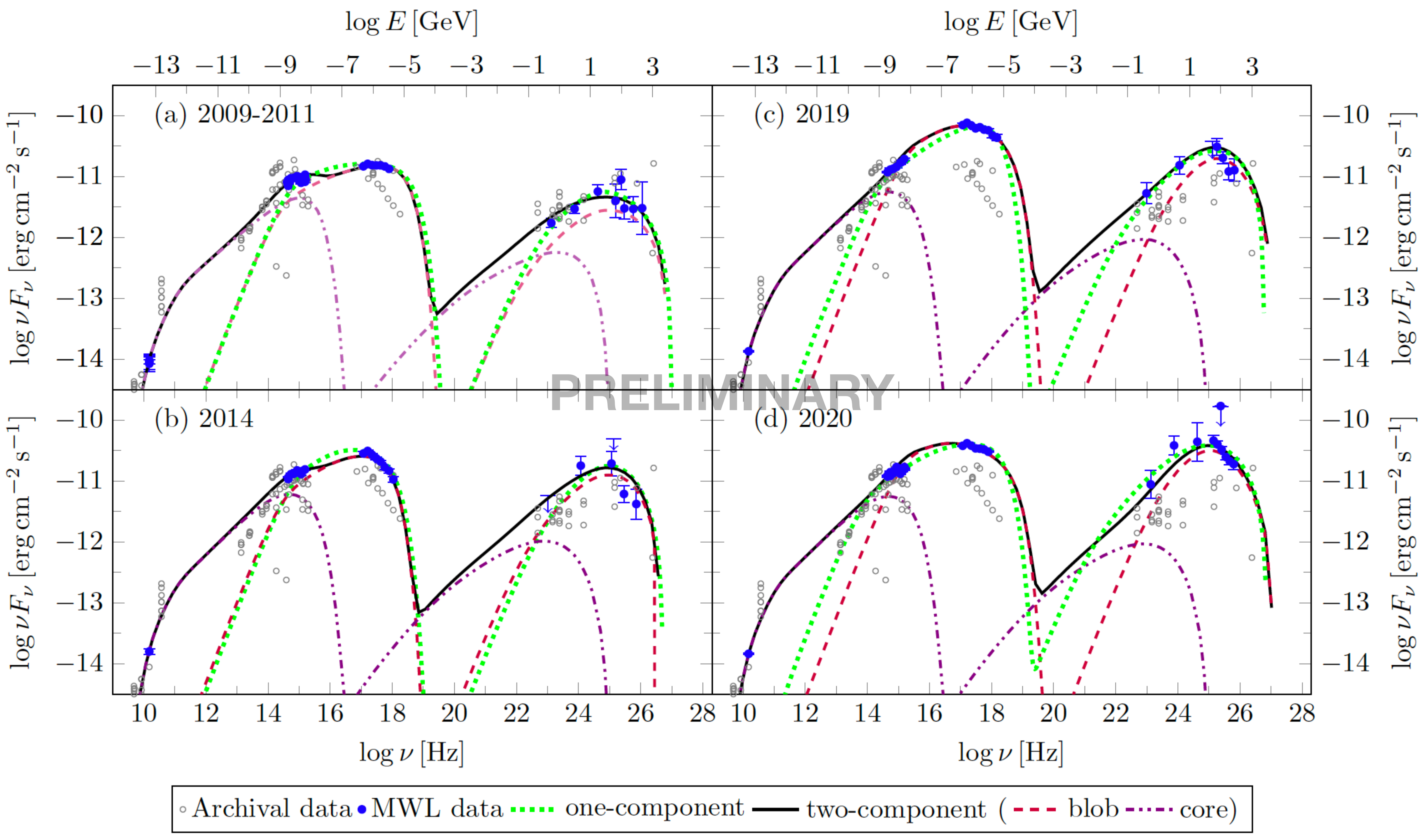
Tavecchio+11

SED modeling



SED modeling

- **One-zone:** electron distribution and population changes and B for 2019, close to equipartition (except for 2020)
- **Two-zone:** electron population and distribution, and blob's Lorentz factor changes
  - **Core:** dominated by magnetic energy density
  - **Blob:** close to equipartition



(1) Epoch	(2) Model (region)	(3) γ_{min} ($\times10^3$)	(4) γ_b ($\times10^4$)	(5) γ_{max} ($\times10^5$)	(6) n_1	(7) n_2	(8) B (G)	(9) K ($\times10^3$ cm^{-3})	(10) R ($\times10^{15}$ cm)	(11) Γ	(12) U'_B/U'_e
E1	one-comp	5.8	2.1	6.5	2.0	3.1	0.16	2.0	34	18	0.39
	2-comp (blob)	4.5	1.9	5.5	2.0	2.9	0.16	1.0	38	18	0.82
	2-comp (core)	0.2	2.2	0.4	2.0	2.4	0.16	0.04	720	4	12.09
E2	one-comp	7.0	6.3	3.4	2.02	3.6	0.16	2.5	34	18	0.23
	2-comp (blob)	5.0	6.5	3.1	2.04	3.25	0.16	2.5	35	17	0.27
	2-comp (core)	0.18	2.2	0.4	2.0	4.6	0.16	0.04	790	4	5.96
E3	one-comp	4.0	9.4	3.9	2.07	2.9	0.18	3.9	34	18	0.30
	2-comp (blob)	9.5	9.5	5.7	2.08	3.7	0.16	2.1	37	23	0.49
	2-comp (core)	0.21	2.2	0.4	2.0	4.6	0.16	0.04	770	4	6.14
E4	one-comp	2.5	4.7	5.0	2.0	3.12	0.16	4.5	30	17	0.09
	2-comp (blob)	9.5	5.5	6.7	2.08	3.6	0.16	7.5	29	20	0.16
	2-comp (core)	0.19	2.2	0.4	2.0	4.6	0.16	0.04	770	4	6.02

Conclusions

- **Distant BL Lac** detected in both **low and flaring states**
- **Variable**, specially in **long time scales**, increasing trend observed in the MWL emission
- **Correlation** in the long-term emission
  - Optical-γ rays: no delay
  - Radio-optical and radio-γ rays: several hundred days.
    Distance of the radio emitting region: d = 3.5 +/- 0.4 pc
- **Harder-when-brighter** in X-rays
- **Redshift estimation** yields z = 0.45 +/- 0.05
- **Broadband SED** well-modeled with **one-zone** and **two-component** models

Thank you for your attention

Questions?

Image credit: IPAC-Caltech