Gamma-ray blazar 1ES 0647+250: 11 years of multiwavelength data

Jorge Otero-Santos
D. Morcuende, V. Fallah Ramazani, D. Dorner & D. Paneque
on behalf of the MAGIC and *Fermi*-LAT Collaborations

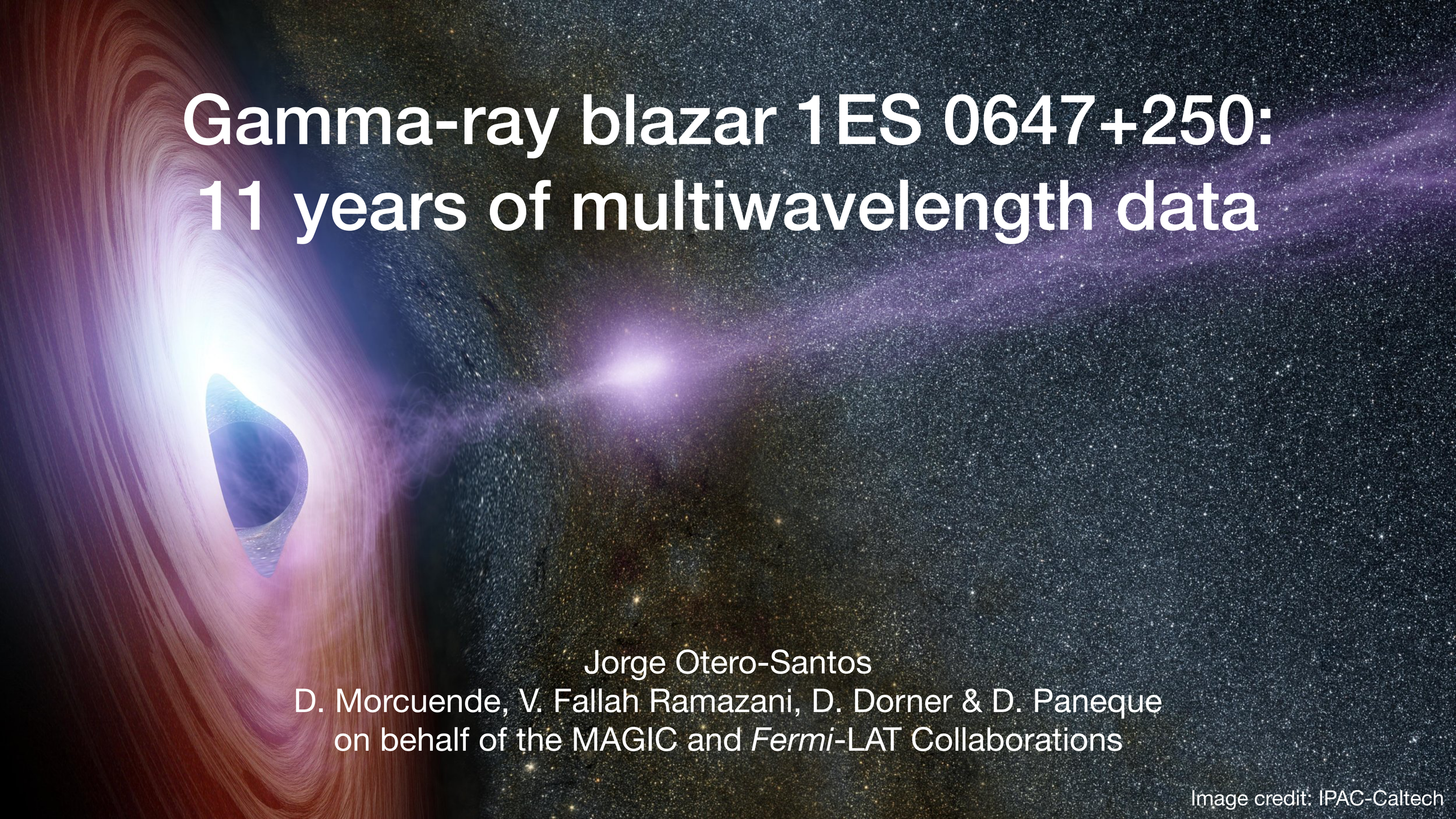
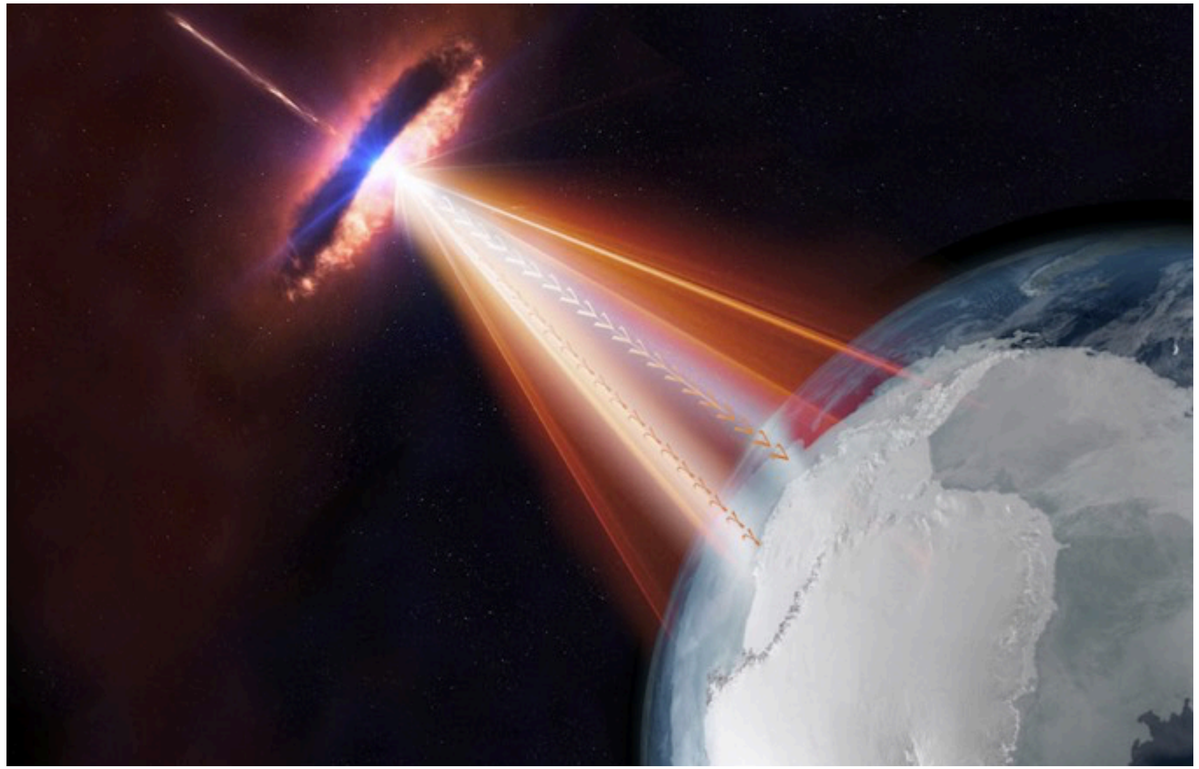
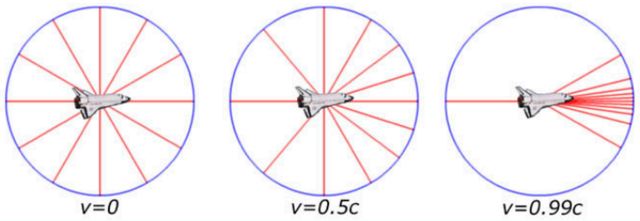


Image credit: IPAC-Caltech

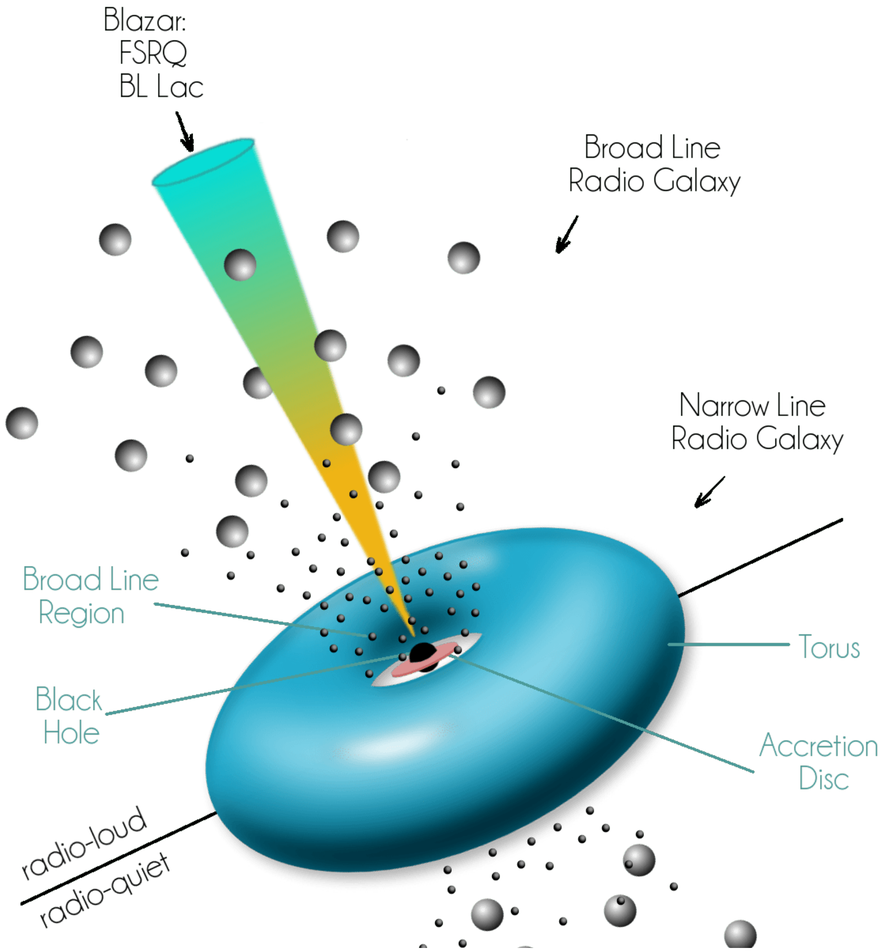
Blazars



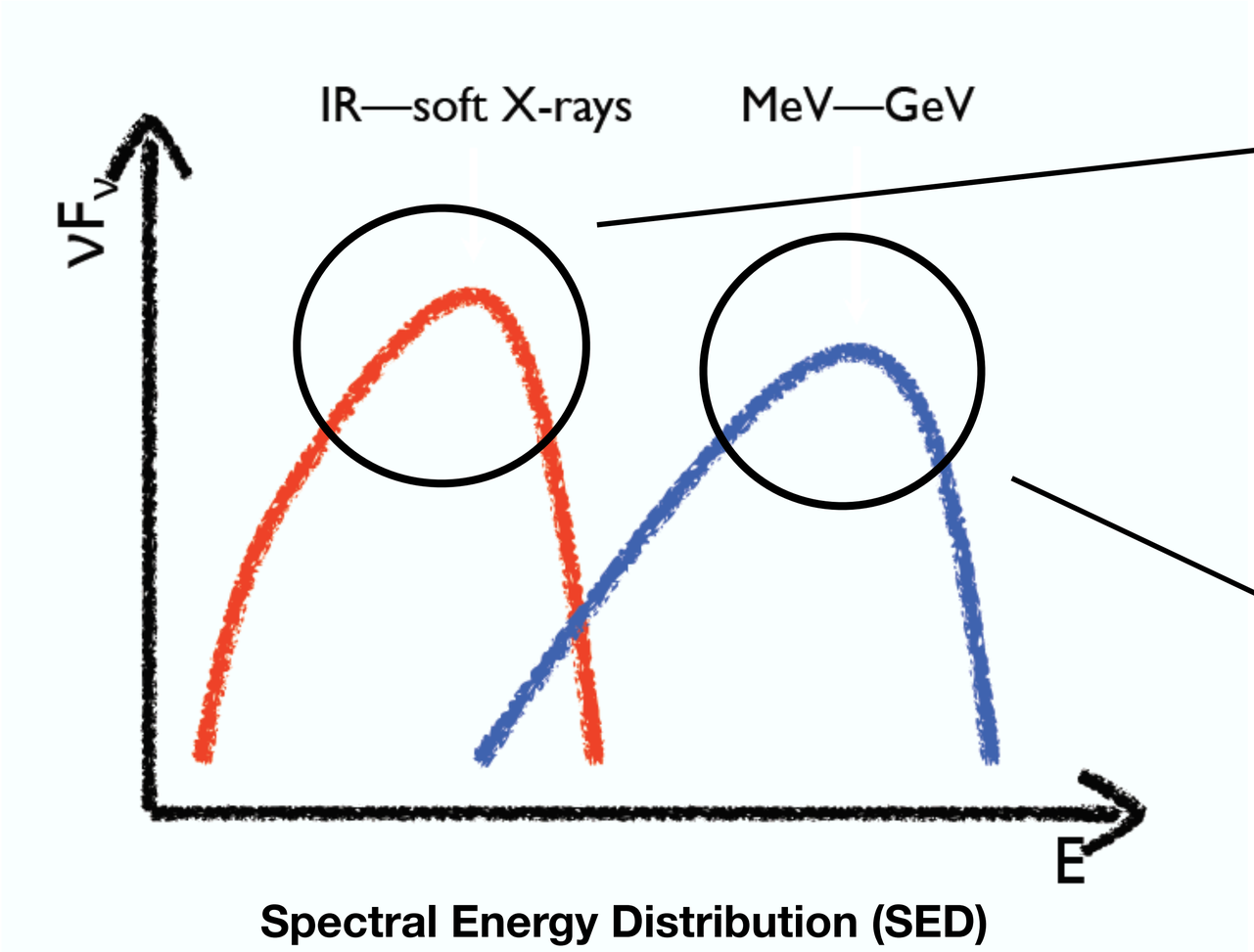
Doppler beaming



Amplification $L_{\rm obs} = L' \delta^4$

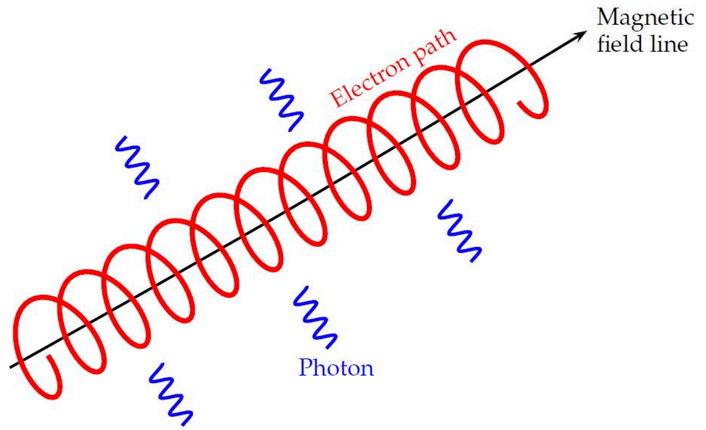


Broadband emission of blazars

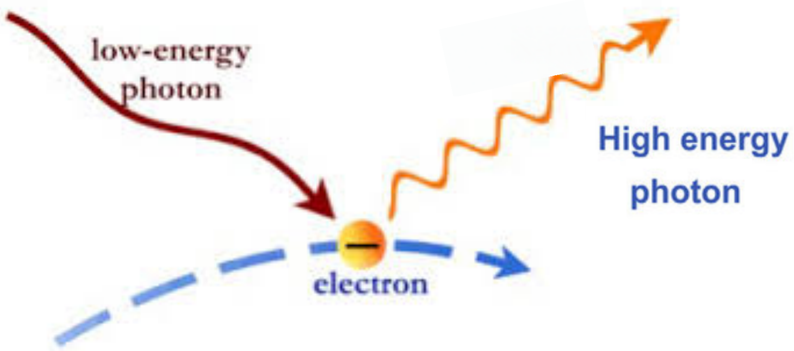


Spectral Energy Distribution (SED)

Synchrotron emission



Inverse Compton



BL Lac object: 1ES 0647+250

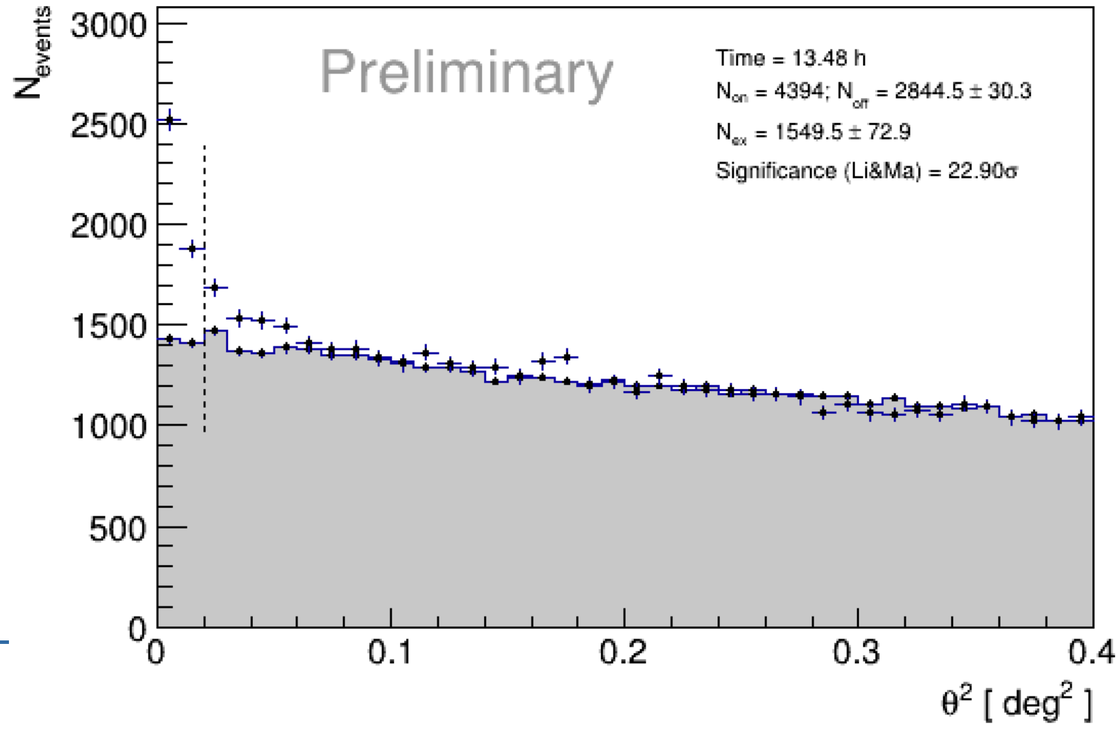
- **1ES 0647+250**: HBL (high synchrotron peaked) BL Lac object
- Redshift unknown (several previous measurements)
  - z = 0.41 ± 0.06 from Kotilainen et al. (2011)
  - Lower limit z > 0.29 from Paiano et al. (2017)
- Detected during **low and flaring states after high X-ray emission** with MAGIC
- Multiwavelength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

The Higherst Historical 0.3-10 keV State of the TeV Source 1ES 0647+250

ATel #13324; *bidzina Kapanadze (Ilia State University, Abastumani Astrophysical Observatory, Georgia)*
*on **2 Dec 2019; 06:35 UT***
Credential Certification: Bidzina Kapanadze (bidzina_kapanadze@iliauni.edu.ge)

MAGIC detection of increased flux from 1ES 0647+250 at very-high-energy gamma rays

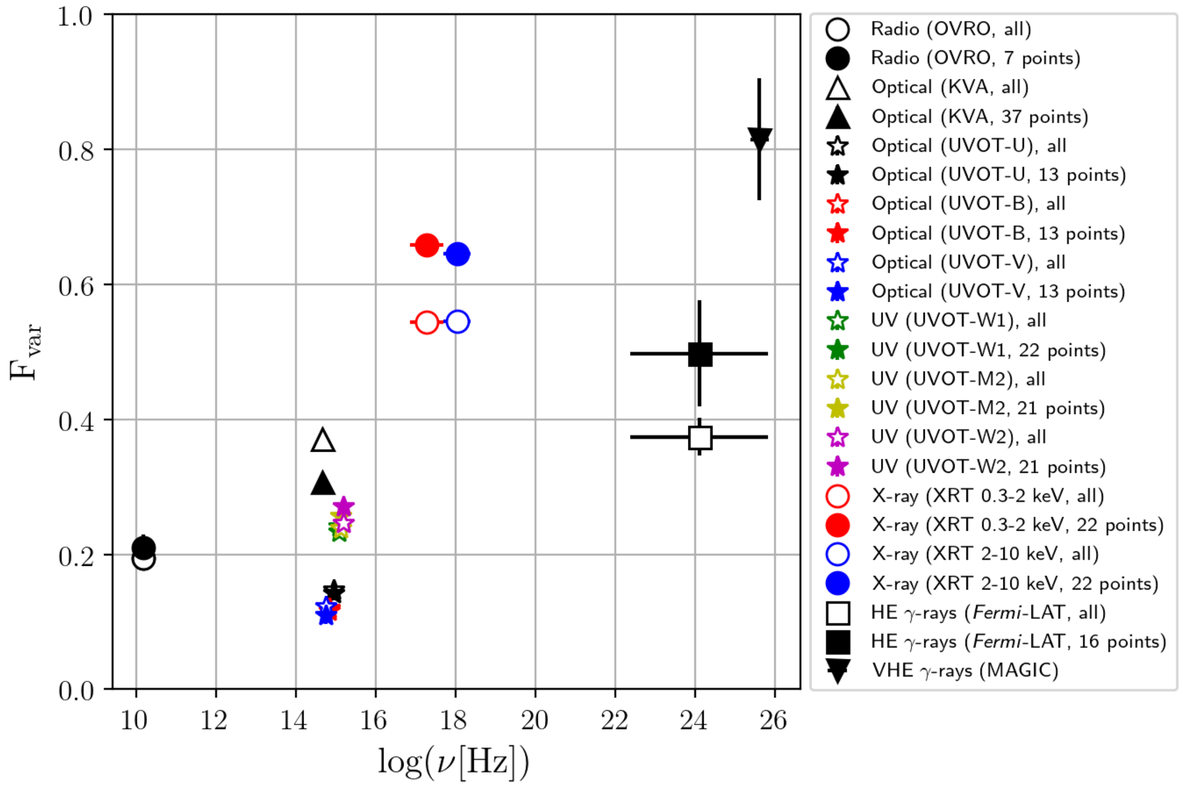
ATel #13331; *Razmik Mirzoyan (Max-Planck-Institute for Physics, Munich), on behalf of the MAGIC collaboration*
*on **5 Dec 2019; 15:05 UT***
Distributed as an Instant Email Notice Transients
Credential Certification: Daniela Dorner (dorner@astro.uni-wuerzburg.de)

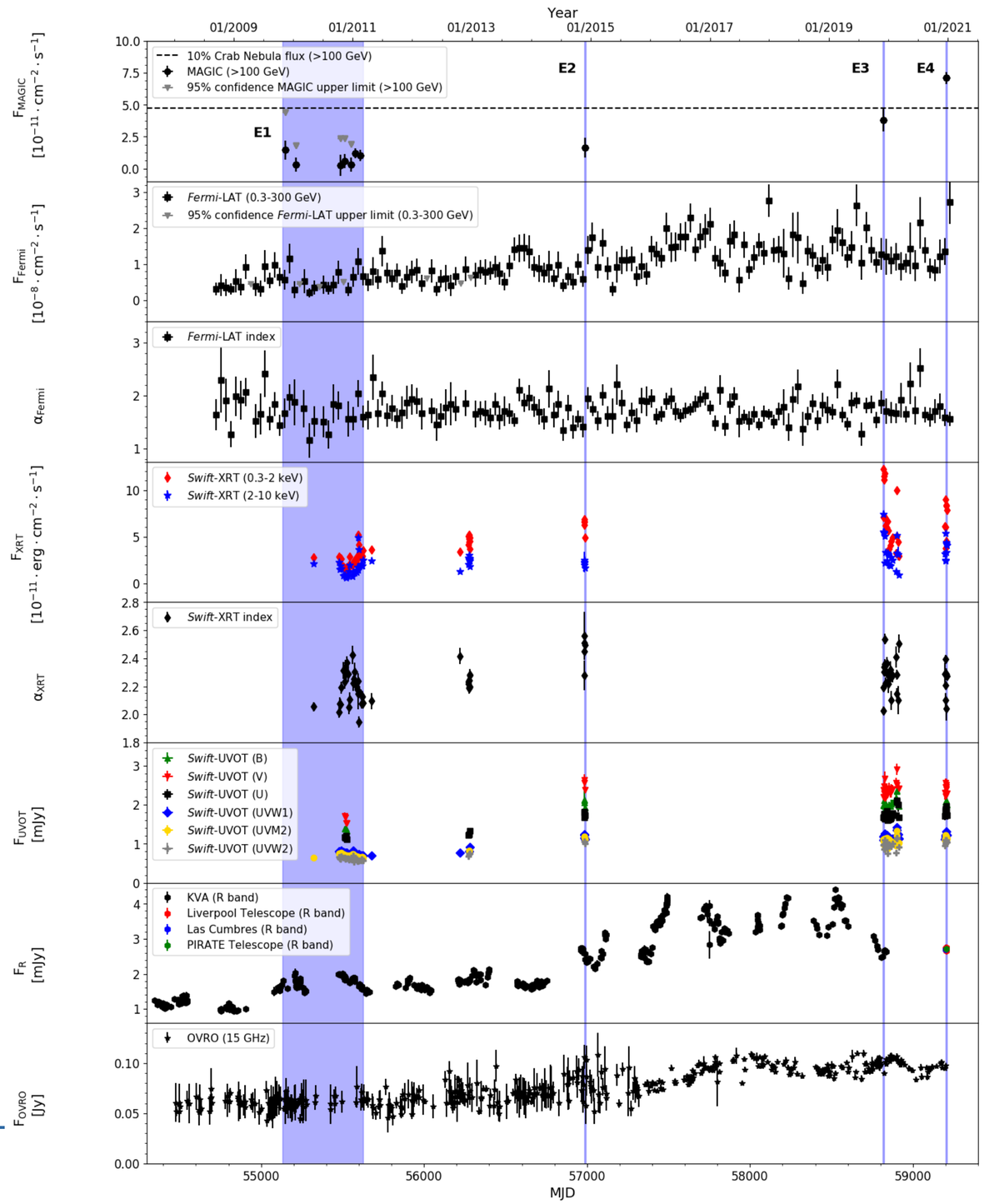


MWL data and variability

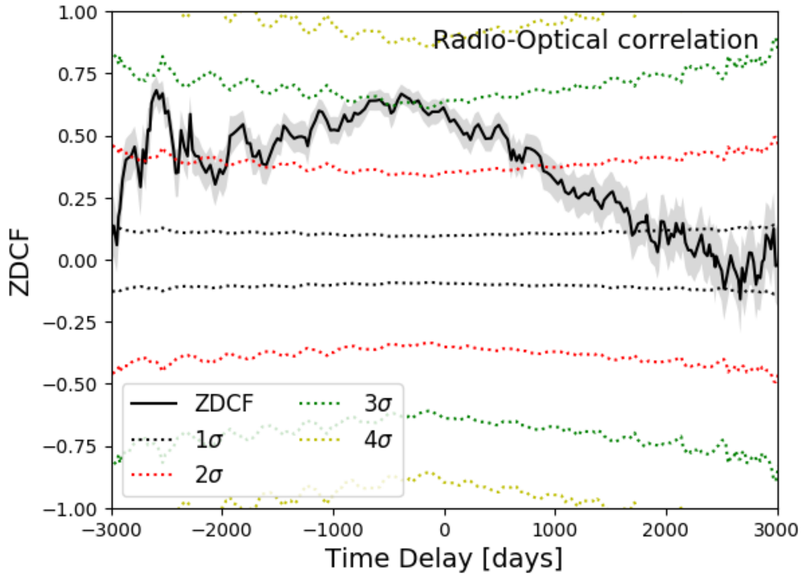
Fractional variability

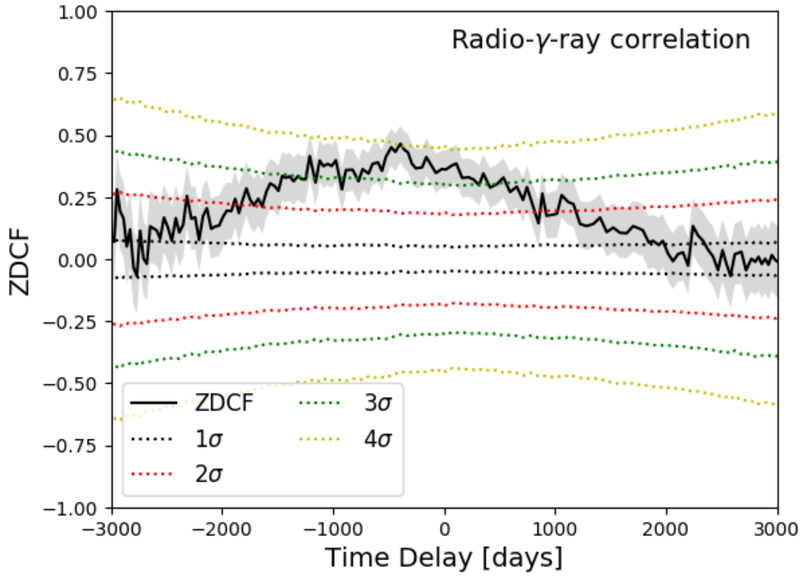
$$F_{\rm var} = \sqrt{\frac{S^2 - \langle \sigma_{err}^2 \rangle}{\langle x \rangle^2}}$$





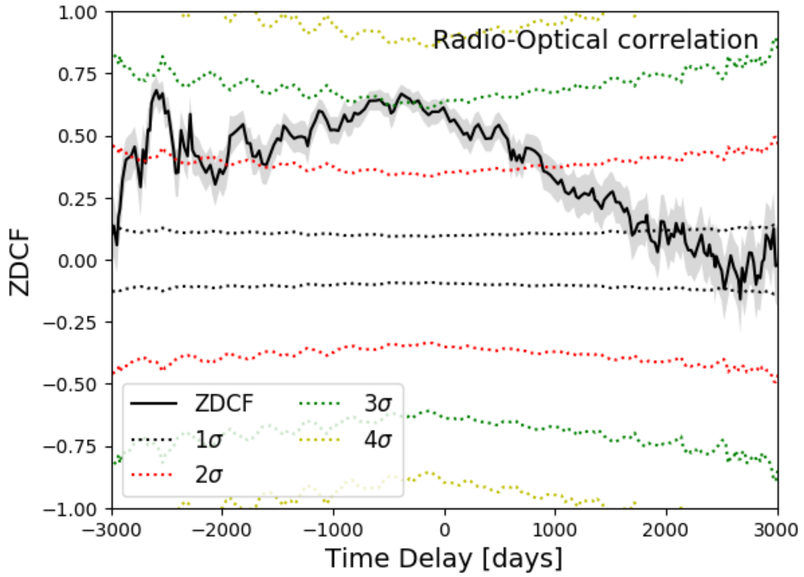
Correlations

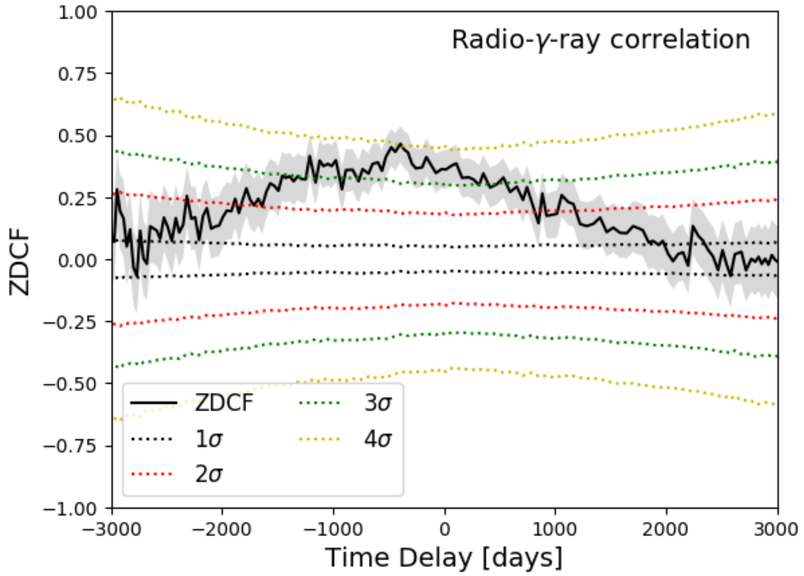




- Long-term correlations:
  - Correlated optical-gamma-ray emission with no significant time lag
  - Correlated radio-optical and radio-gamma-ray emission with long delay (~400 days)
- Slow long-term variability —> slow decrease of the correlation

Correlations





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Long-term variability dominant

Detrending of the data to evaluate shorter time scales

Correlations

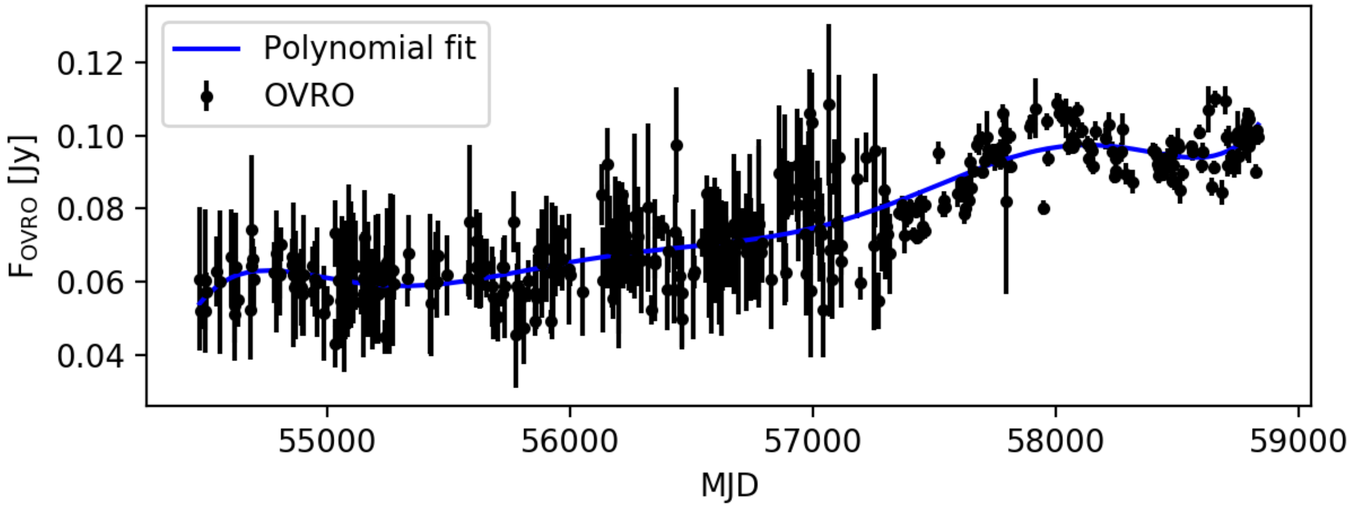
- No unique detrending method —> approach from Lindfors+16

- Detrending by pairs of light curves with a percentage of common emission

  - Radio-optical: 51%

  - Radio-gamma rays: 24%

  - Optical-gamma rays: 22%



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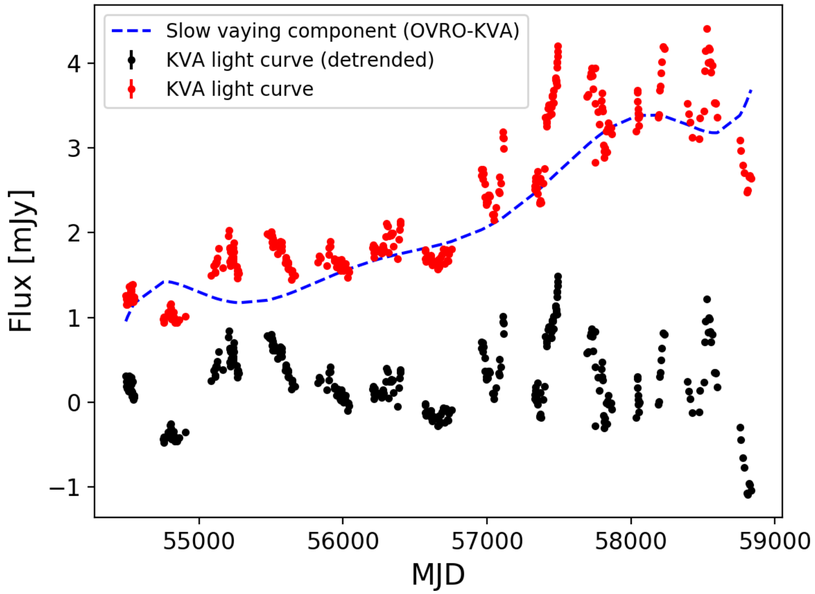
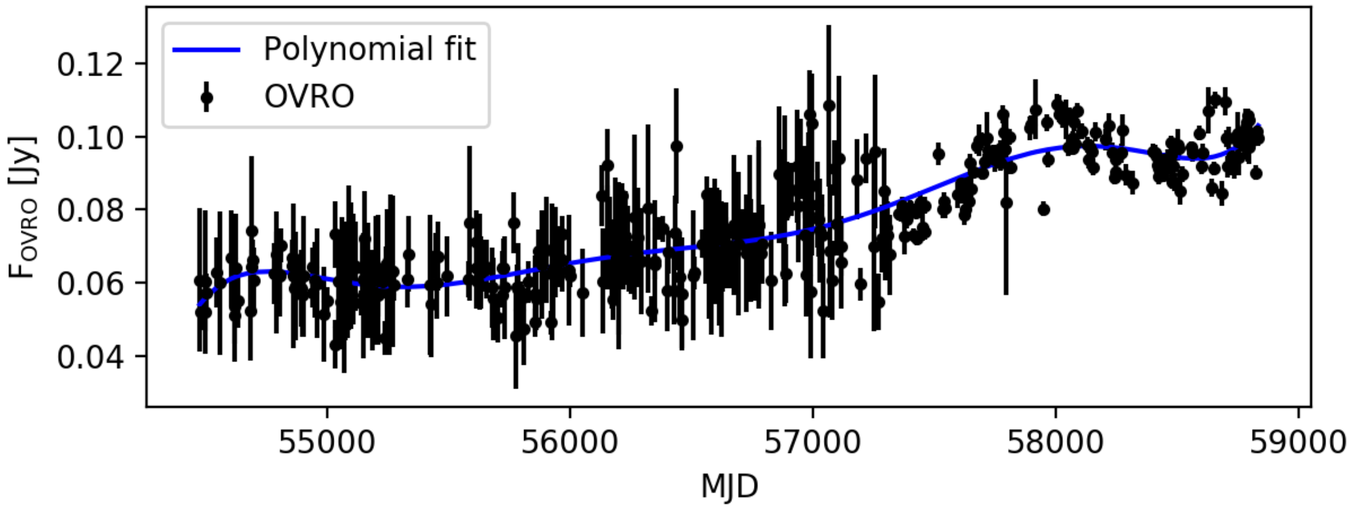
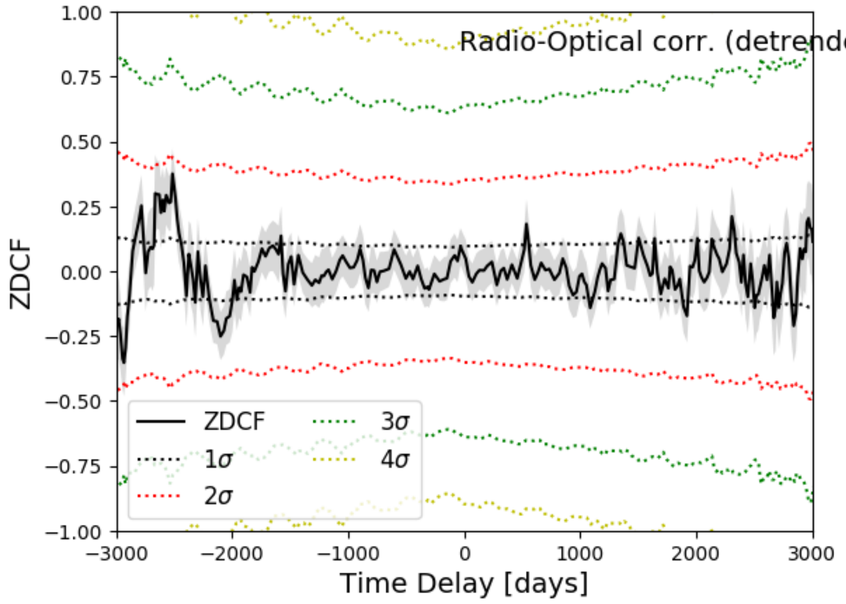


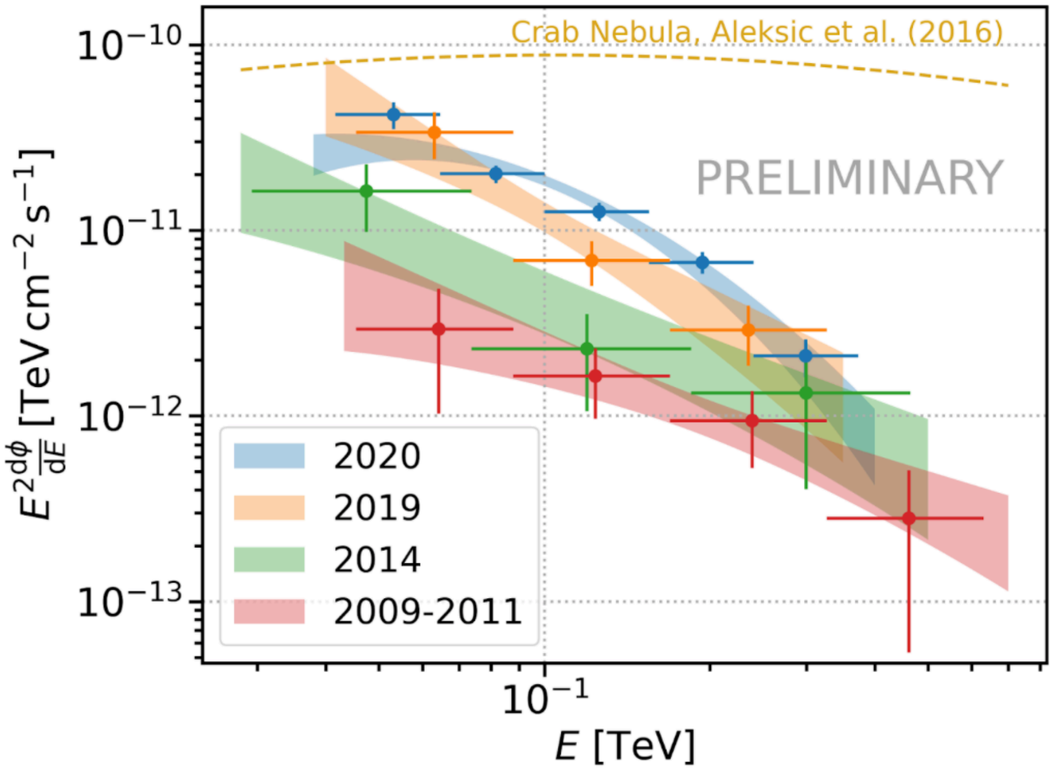
No correlation in shorter time scales





Spectral analysis and redshift estimation

VHE gamma-ray spectra

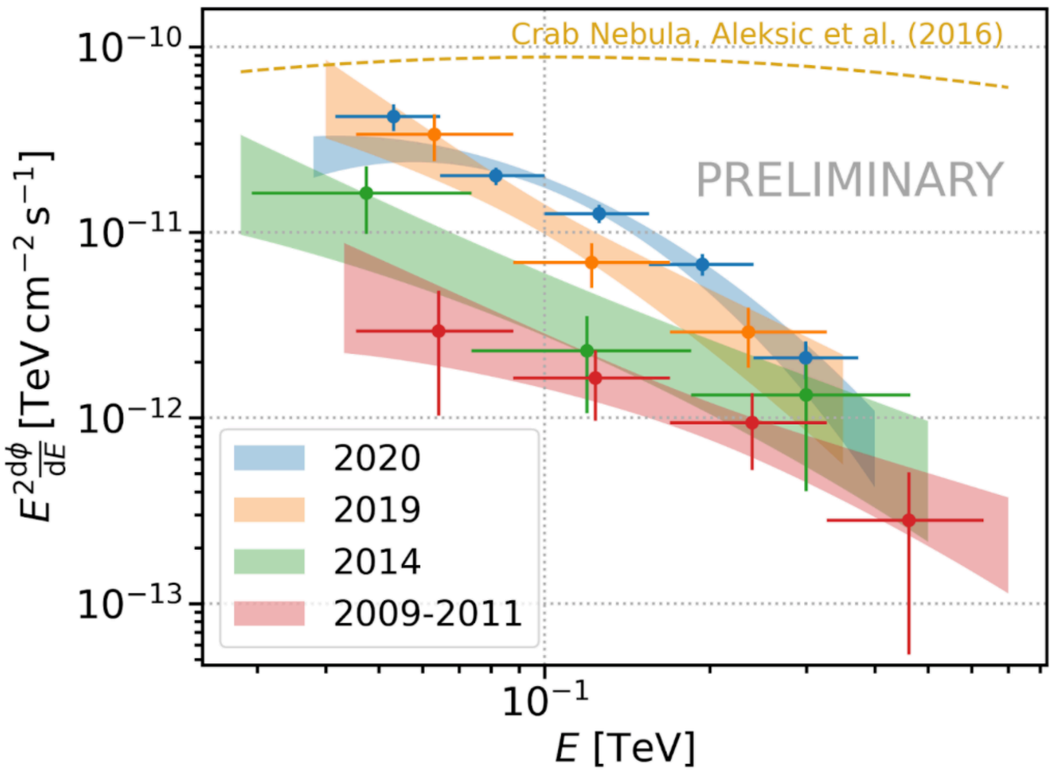


Epoch	Fit Model*	f_0 [$10^{-10}\cdot$ TeV$^{-1}\cdot$ cm$^{-2}\cdot$ s^{-1}]	E_0 [GeV]	Spectral index α	Curvature β	χ^2/d.o.f.
E1	PL	0.29 ± 0.07	190	3.12 ± 0.37	–	1.2/3
E2	PL	4.40 ± 1.63	100	3.25 ± 0.74	–	2.1/2
E3	PL	12.0 ± 2.2	100	3.73 ± 0.58	–	2.2/2
E4	PL	16.9 ± 1.0	100	3.70 ± 0.10	–	18.1/5
E4	LogP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

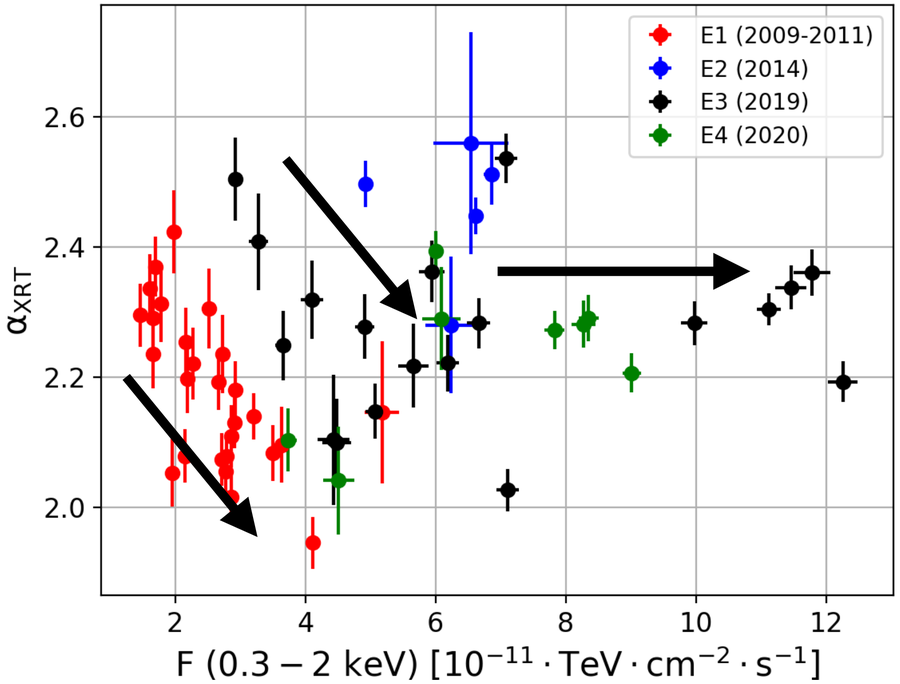
- No harder-(softer)-when-brighter trend (large errors)
- Power law functions for E1, E2 and E3
- Log-parabola tested for E4 —> 3σ preference of log-parabola over power law

Spectral analysis and redshift estimation

VHE gamma-ray spectra



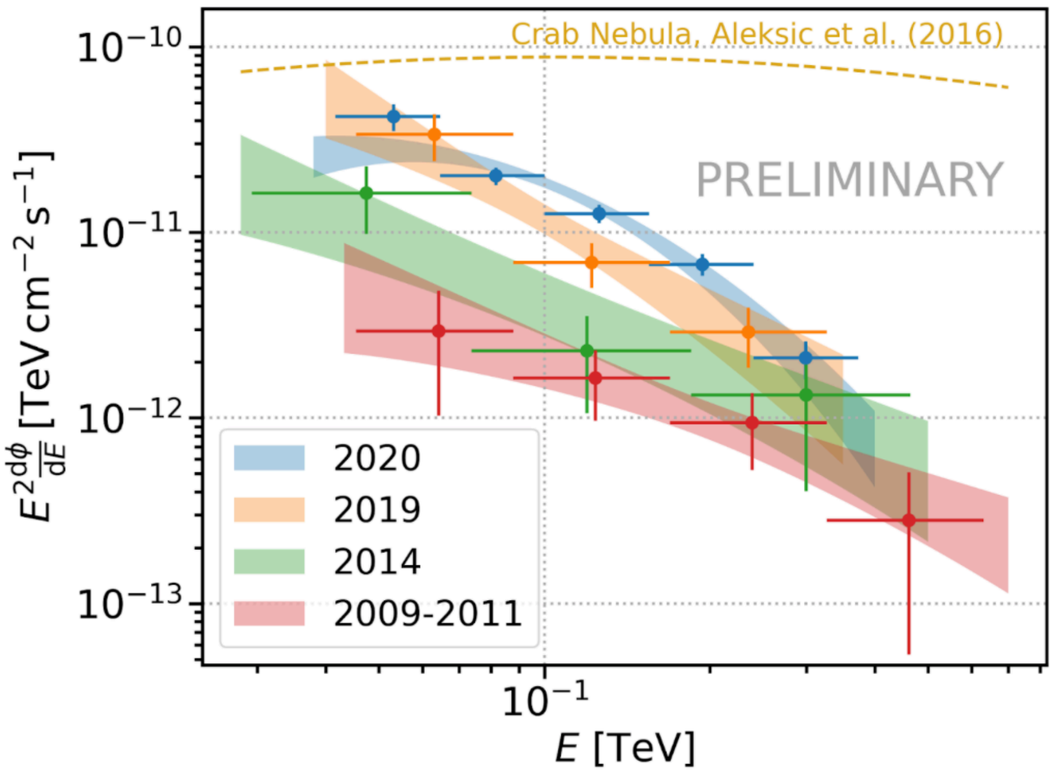
X-ray spectral variability



Harder-when-brighter
Saturation during the brightest flare?

Spectral analysis and redshift estimation

VHE gamma-ray spectra



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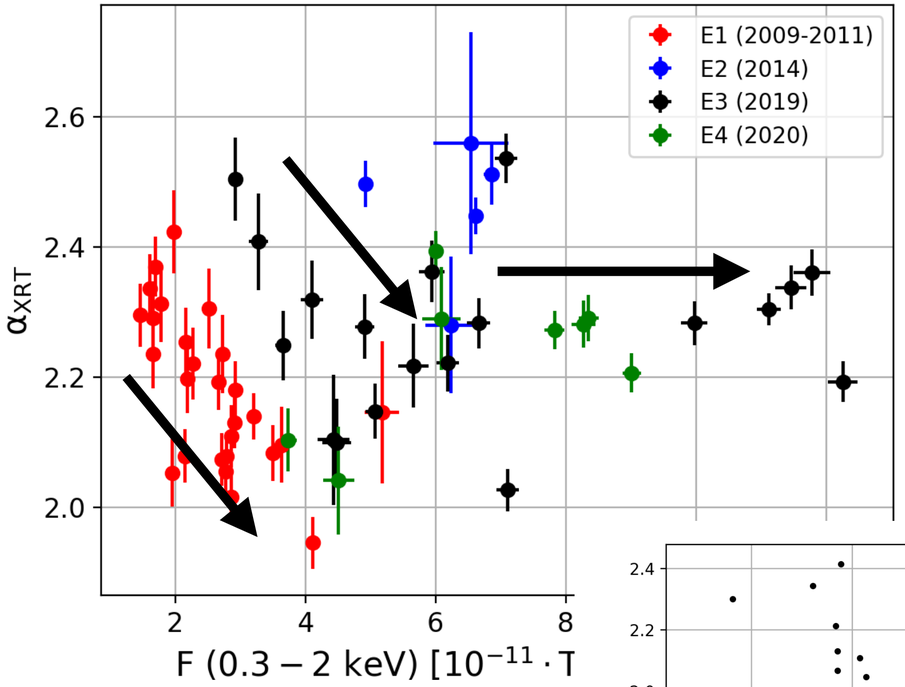
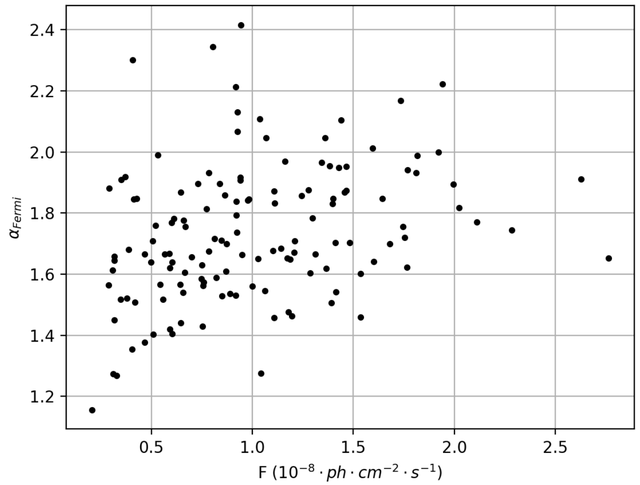
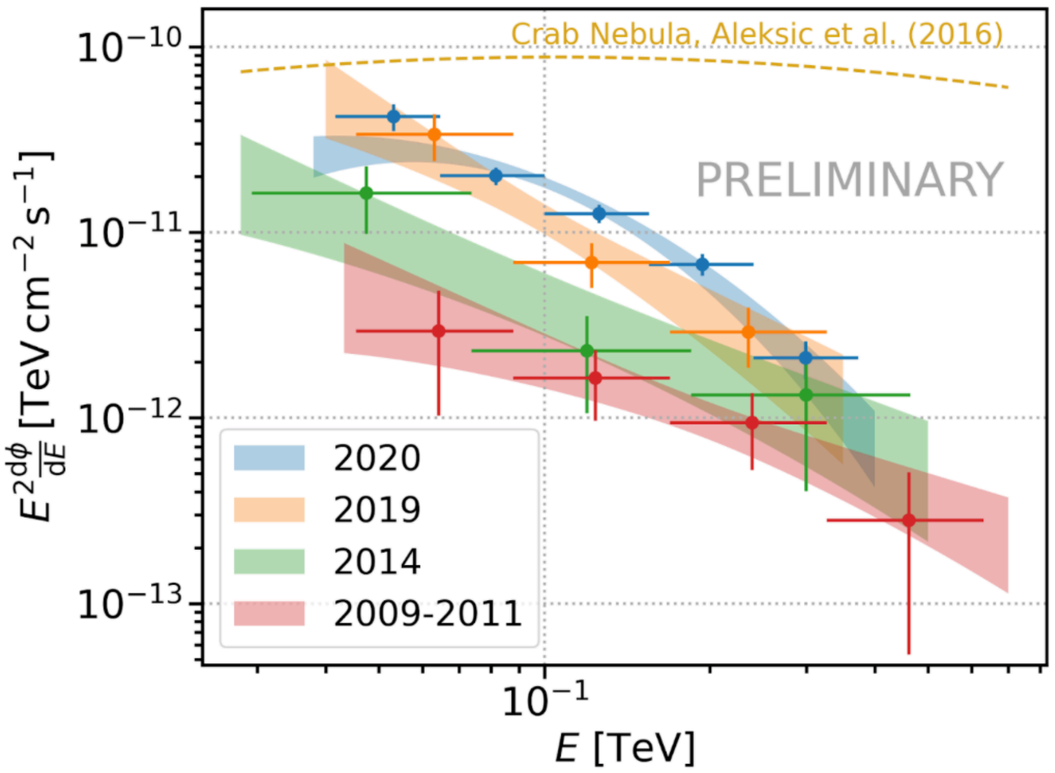




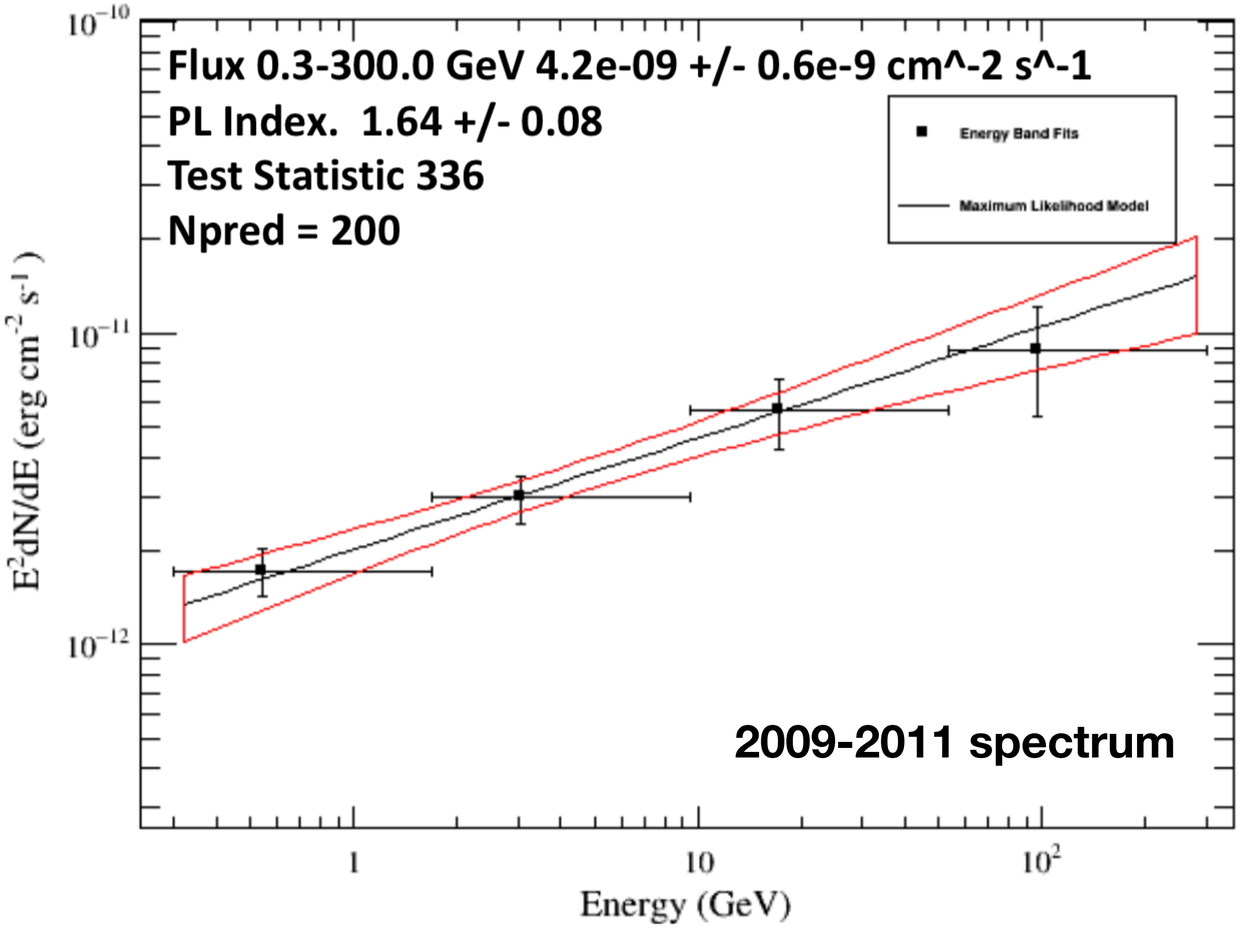
No HE gamma-ray spectral variability

Spectral analysis and redshift estimation

VHE gamma-ray spectra



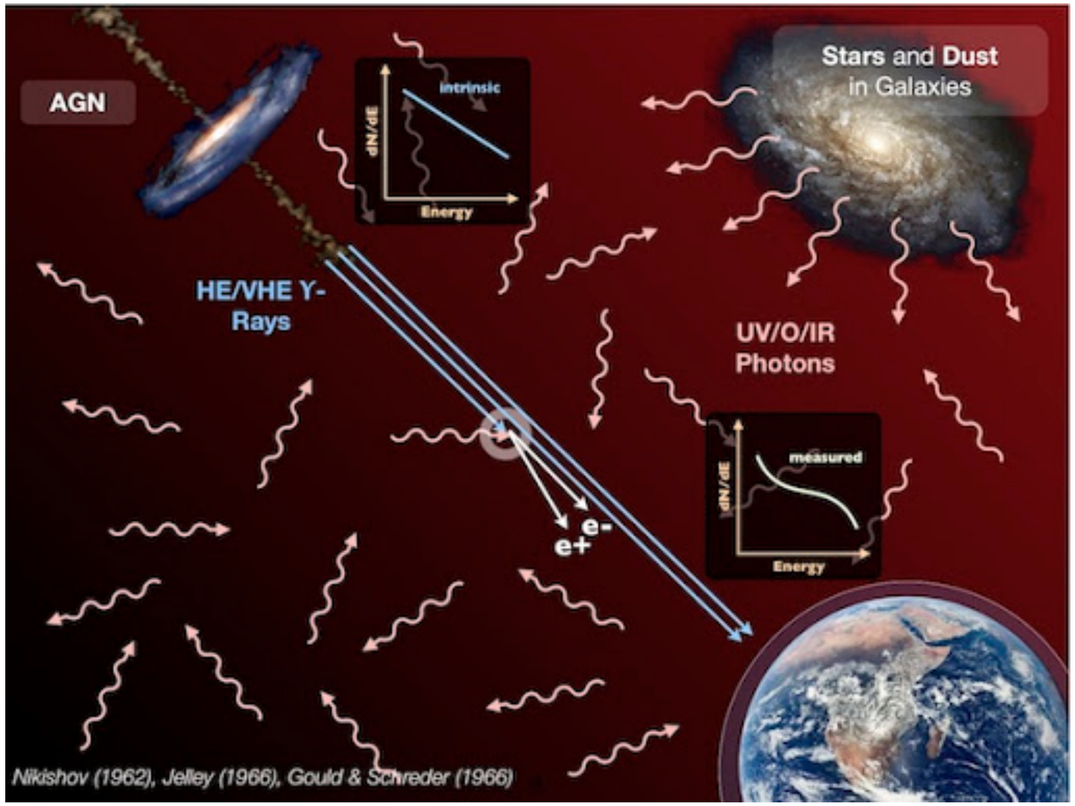
HE gamma-ray spectra

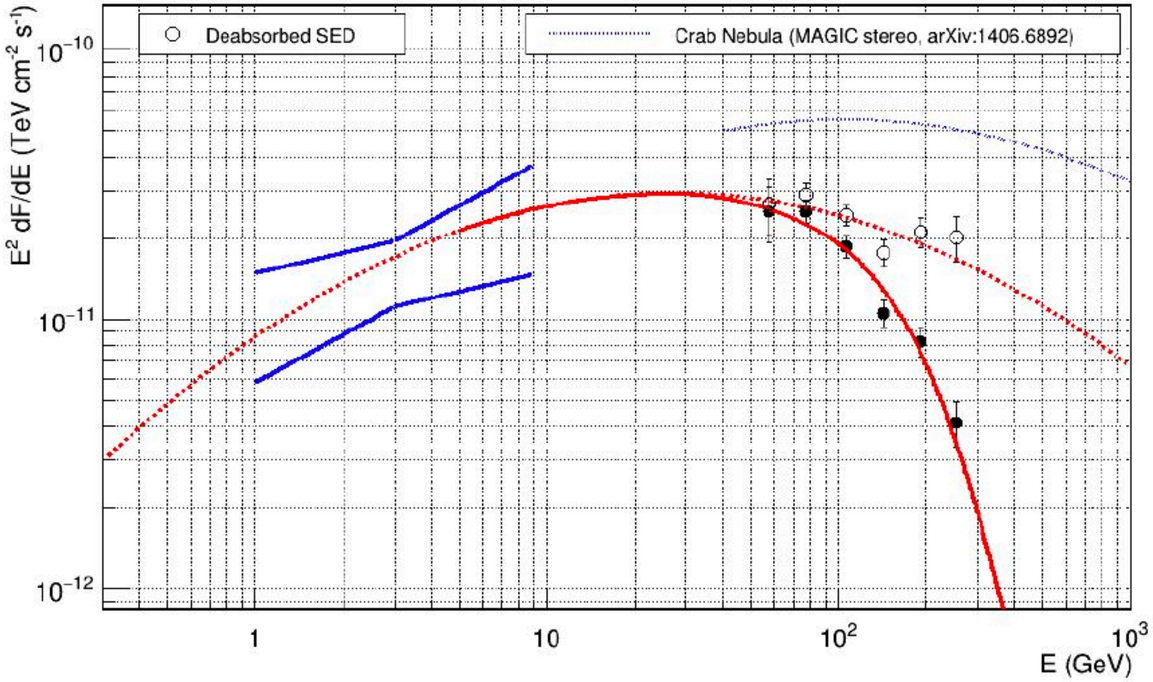


Spectral analysis and redshift estimation

Joint HE+VHE gamma-ray spectrum

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

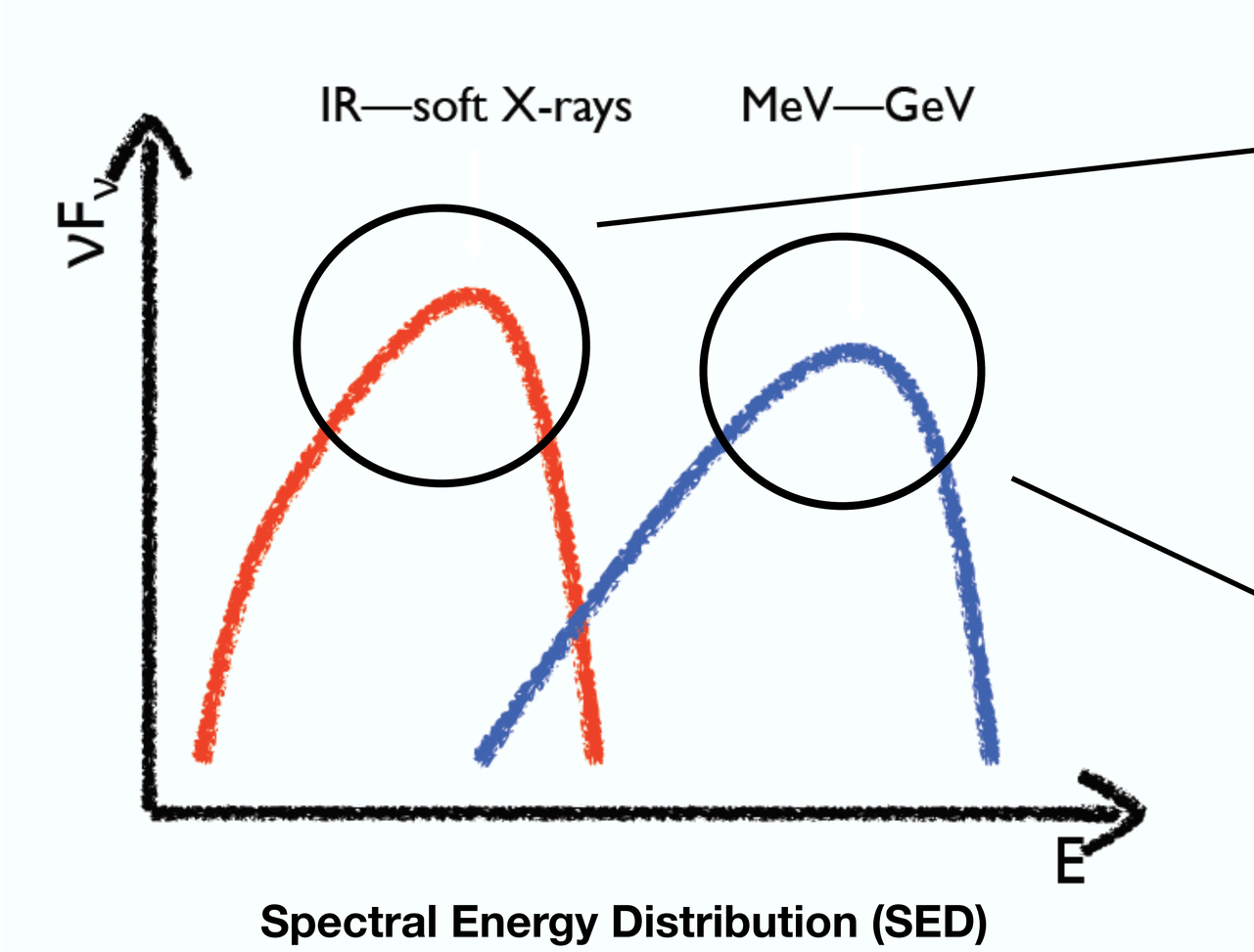




Estimated redshift z_{est}	z^*
0.45 ± 0.05	0.75 ± 0.11

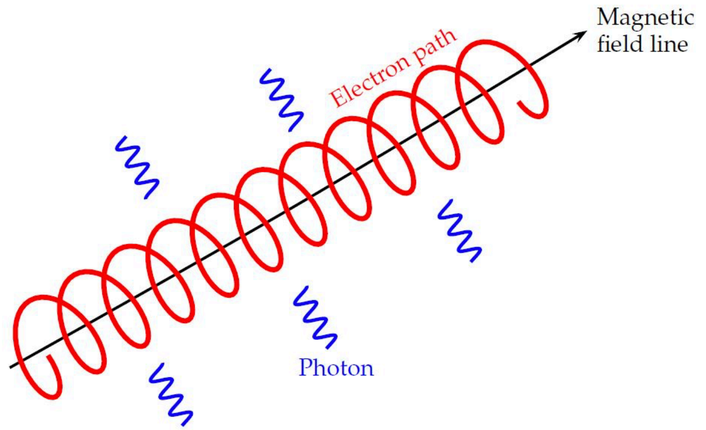
MAGIC Major Atmospheric Gamma Imaging Cerenkov Telescopes

SED modeling



Spectral Energy Distribution (SED)

Synchrotron emission



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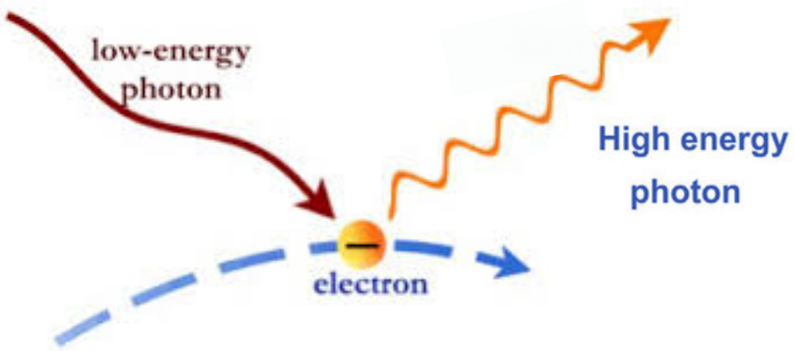
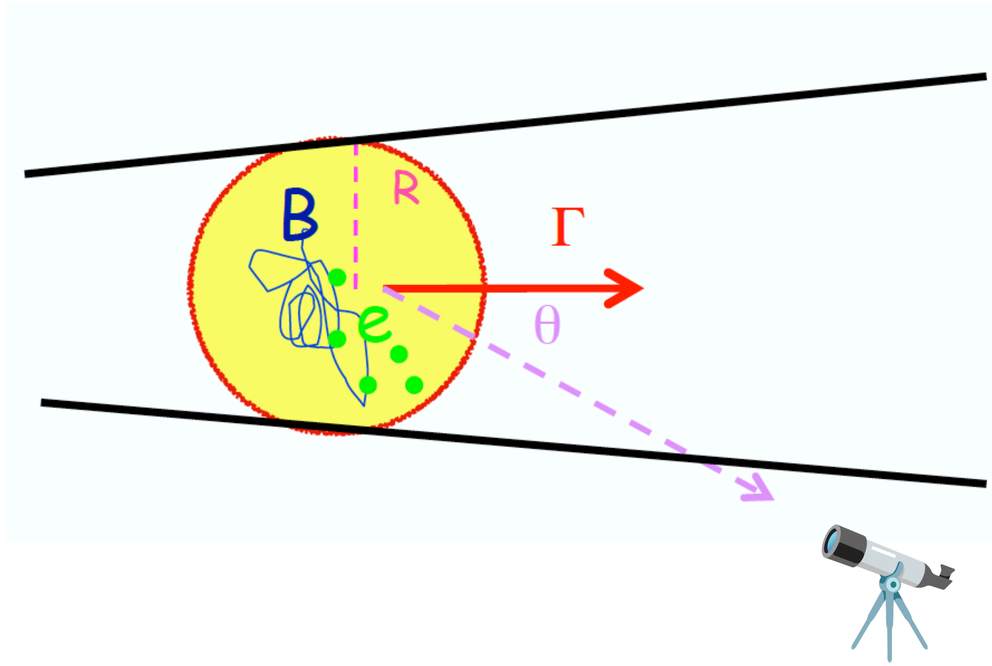
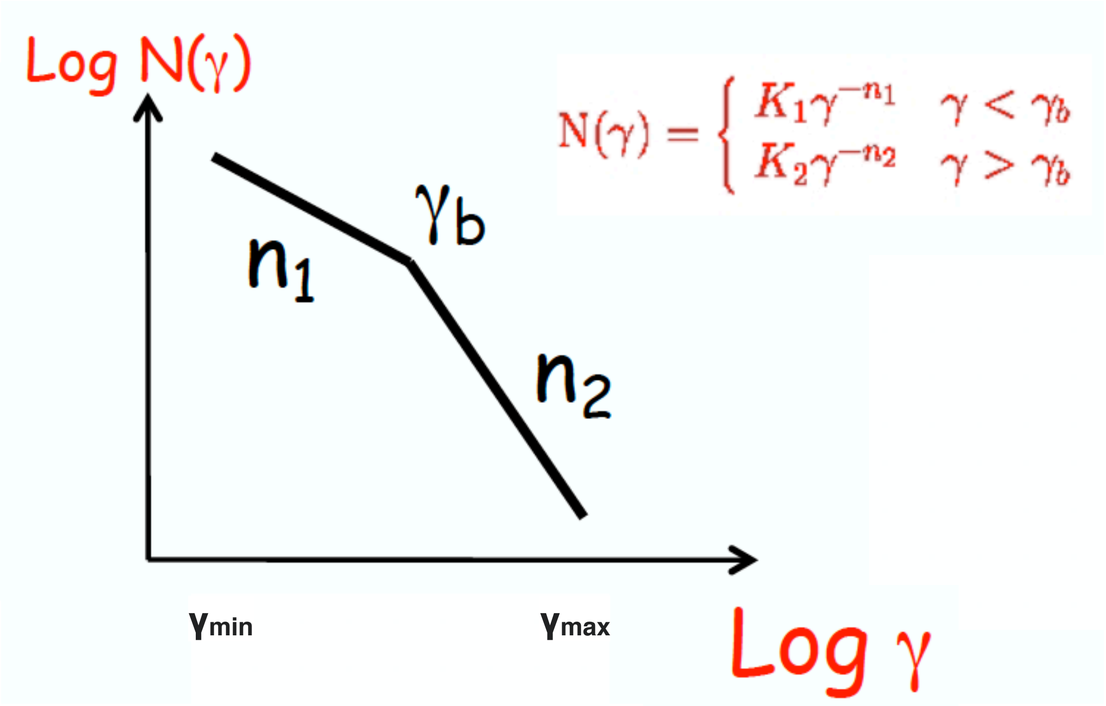


SED modeling

One-zone SSC model





9 parameter fit:

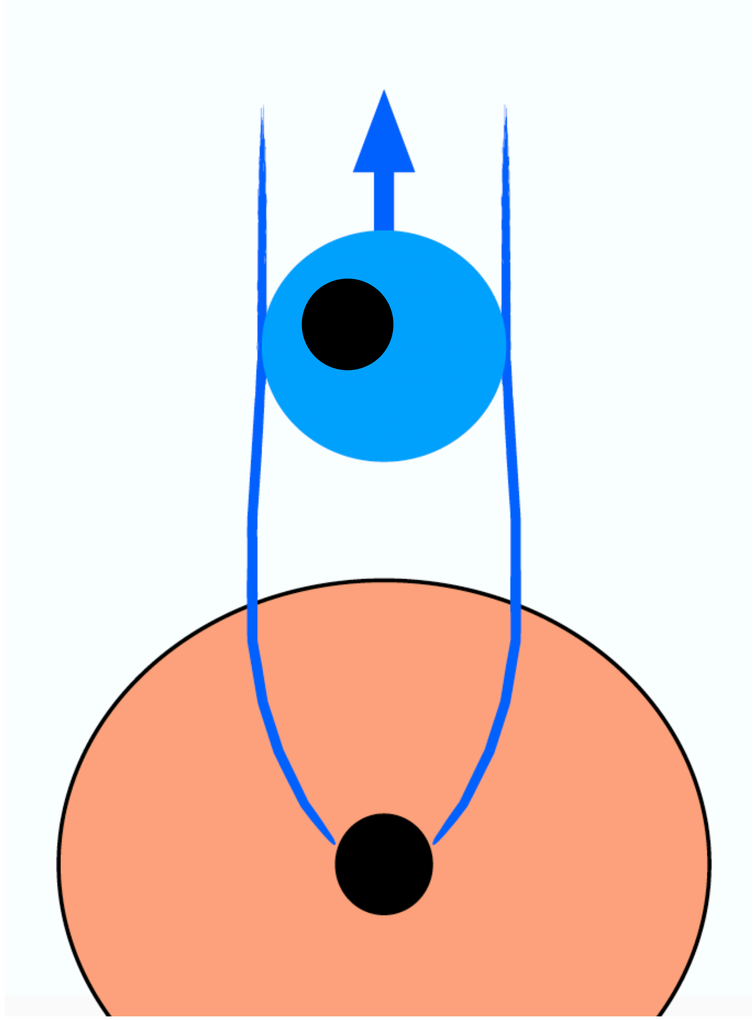
γ_{min}, γ_b, γ_{max}, n1, n2, B, n_e, R_b, Γ

Information through observable quantities:

ν_{sync}, ν_{IC}, L, α_1, α_2, t_{var}

SED modeling

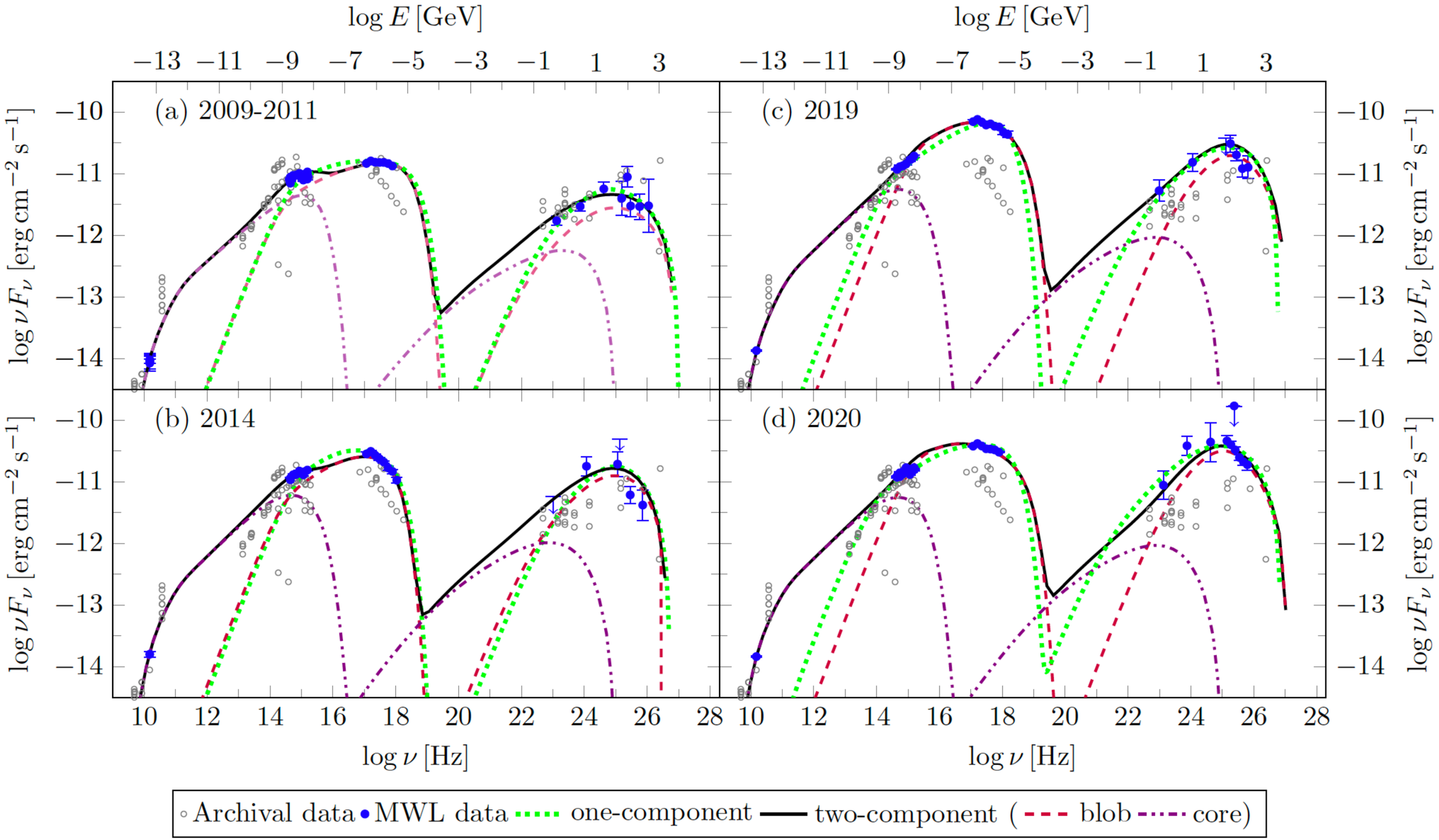
Two-component SSC model



- Two interacting regions: core and blob
  - Core: dominates the radio+optical emission
  - Blob: main contribution to the X-ray and VHE gamma-ray emission
- 9 parameters —> 18 parameters

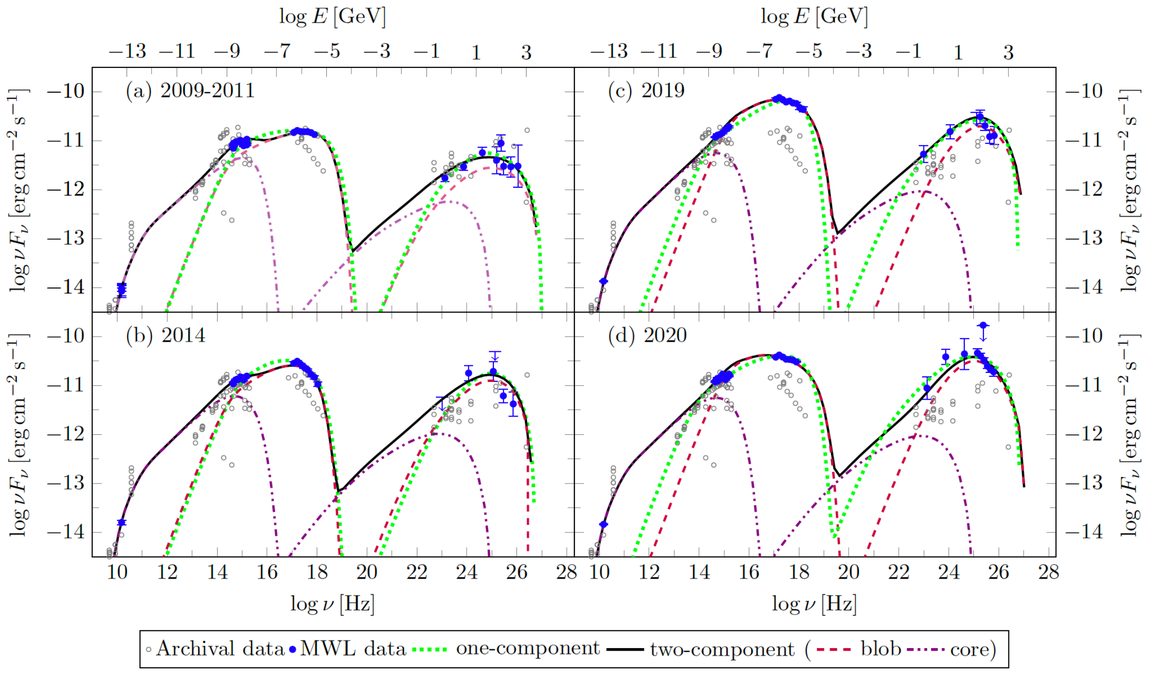
Able to reproduce the radio emission

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



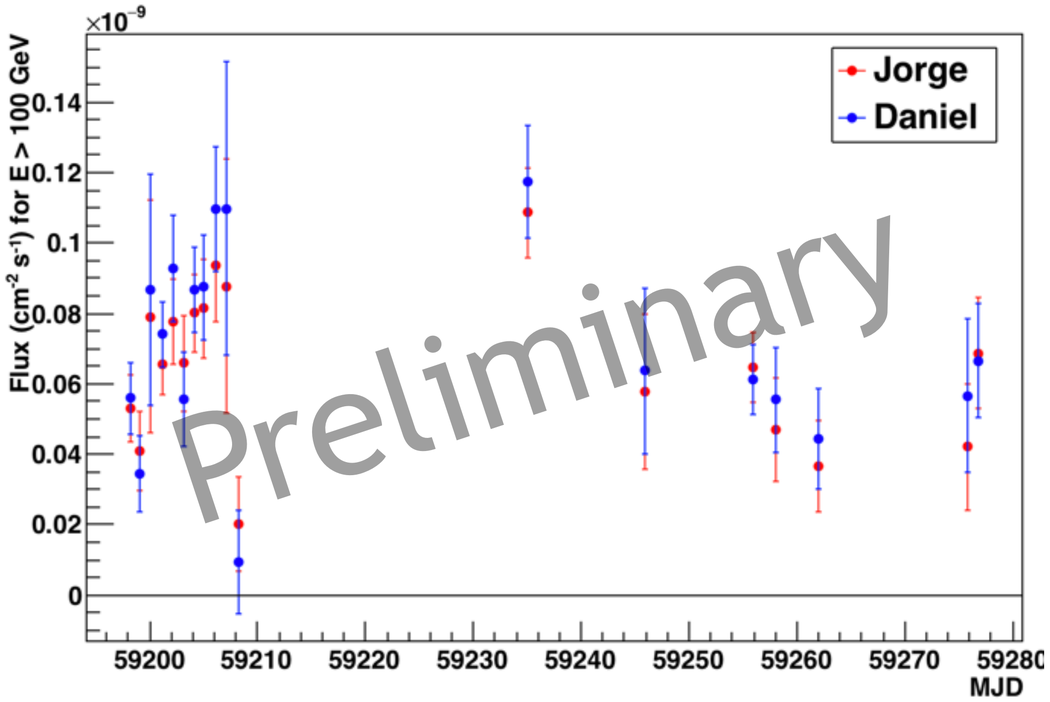
(1) Epoch	(2) Model (region)	(3) γ_{min} ($\times 10^3$)	(4) γ_b ($\times 10^4$)	(5) γ_{max} ($\times 10^5$)	(6) n_1	(7) n_2	(8) B (G)	(9) K ($\times 10^3$ cm^{-3})	(10) R ($\times 10^{15}$ cm)	(11) Γ	(12) U'_B/U'_e
2009-2011											
E1	one-comp	5.8	2.1	6.5	2.0	3.1	0.16	2.0	34	18	0.39
	2-comp (blob)	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
2014											
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
2019											
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

Future work

MAGIC measures high flux state from the blazar 1ES0647+250

ATel #14268; *Oscar Blanch(IFAE-BIST), on behalf of the MAGIC Collaboration*
on 15 Dec 2020; 19:33 UT
Credential Certification: Daniela Dorner (dorner@astro.uni-wuerzburg.de)

Observed from Dec. 2020 to Apr. 2021



Cherenkov Telescope Array
4 de febrero a las 10:01 ·

The prototype Large-Sized Telescope, the LST-1, has successfully detected the blazar 1ES 0647+250 with a redshift of at least 0.45 or an estimated 5.4 billion light years from Earth! The source was observed during the commissioning of the telescope as it was performing engineering runs for seven hours over three nights starting on 15 December 2020, after prompted by an ATel from our MAGIC neighbors. Early analysis shows detection of gamma rays with an energy range of 50-400 GeV, further proving LST-1's low-energy performance and ability to detect distant Active Galactic Nuclei. The analysis was performed by Chaitanya Priyadarshi (PREBIST Fellow, IFAE-BIST, Barcelona) and confirmed by Seiya Nozaki (Kyoto University). IAC - Instituto de Astrofísica de Canarias Cabildo de La PalmaAyuntamiento de la Villa de Garafia

Major Atmospheric Gamma Imaging Cerenkov Telescopes


Thank you for your attention
Questions?