Twelve MAGICal years of PG1553+113

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MAGIC Major Atmospheric Gamma Imaging Cerenkov Telescopes

ABSTRACT

PG 1553+113 is a BL Lac object located at redshift z=0.433. It is one of the brightest and most observed extragalactic sources in the very-high-energy (VHE, E>100 GeV) gamma-ray band. One of its characteristics is the evidence of quasi-periodic modulation in high-energy (HE, >100 MeV) gamma-rays detected by Fermi-LAT, with with a period of about 2.2 years.
In this contribution, we present the MAGIC and multiwavelength data collected in more than a decade of observations. Intra-band correlation analysis, as well as search for periodic emission, suggest that the emission mechanisms may be described by a two-zone synchrotron-self compton (SSC) model with two distinct electron populations. While the low-energy population is responsible for the optical, UV and HE gamma-ray photons, the X-ray and VHE bands are explained by an additional high-energy population.
Very remarkably, in April 2019, PG 1553+113 reached the brightest emission ever observed at VHE. To model this emission, we tested a two-zone SSC model for this source for the first time. This model properly reproduced the data and additionally is in line with the observed correlation among bands.

PG 1553+113

PG1553+113 is a BL Lac located at redshift z=0.433 [1]. It was first discovered in 1986 in the Palomar-Green survey of UV stellar objects and in the the VHE gamma-rays it was discovered in 2005 by both MAGIC and H.E.S.S., being one of the brightest extragalactic object in this band. It is characterized by the presence of a significant quasiperiodic modulation in the HE gamma-rays [2].

DATA

We collected and analyzed data from radio up VHE gamma-ray spanning from **2007** up to **2017**, as shown in Fig. 1 [3]. The quasi periodic modulations are clearly visible simoultaneously in optical and HE gamma-ray, and delayed in the radio band.

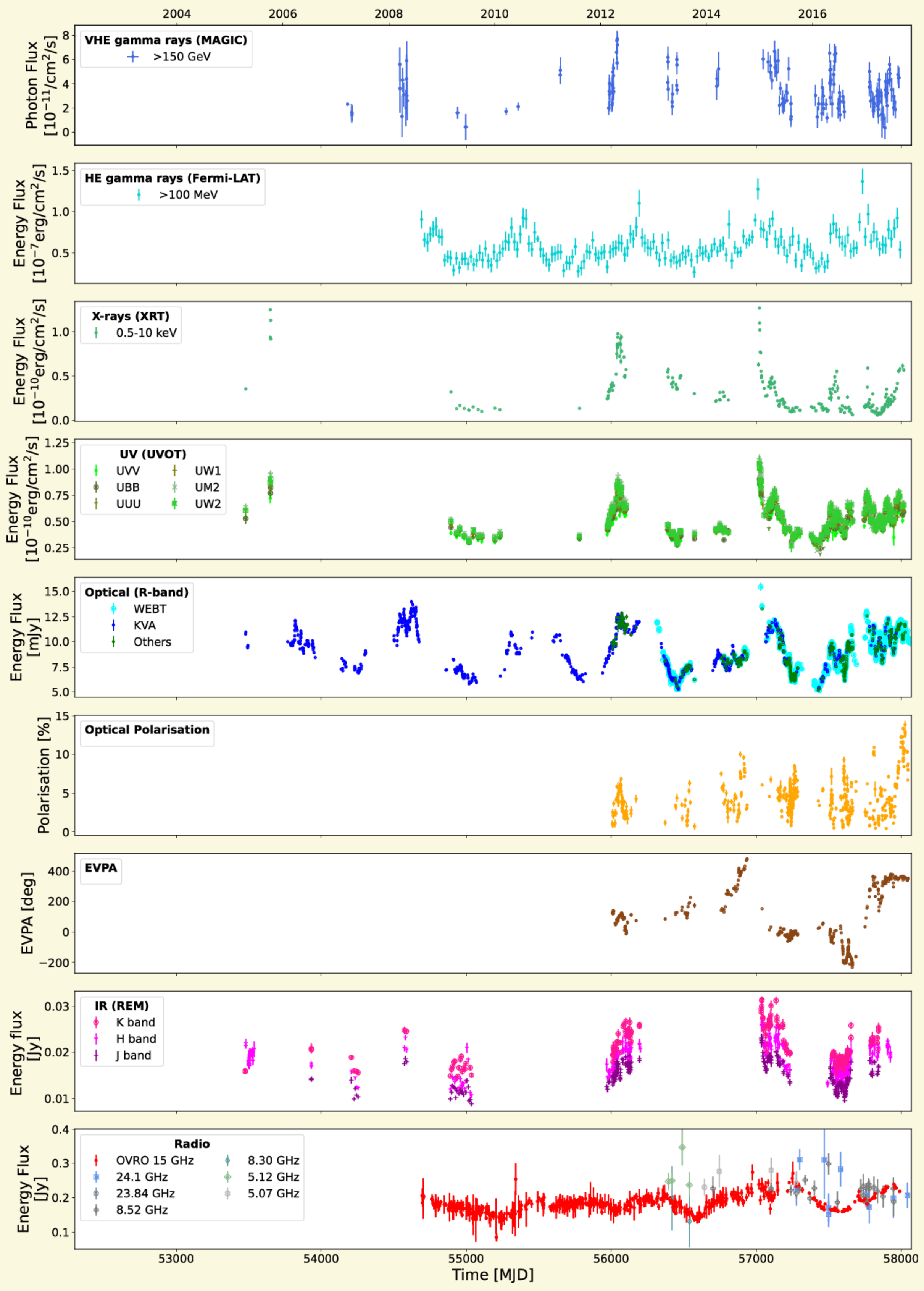

Fig. 1: Multiwavelength lightcurve of PG 1553+113 from 2003 to 2017 [3]

PERIODICITY

PG 1553+113 presents a significant quasi periodic modulation in the HE gamma-ray emission. The other frequencies show modulations with lower significances. To asses the periodicity we used the **Generalised Lomb Scargle** (GLS) periodgram as implemented in the `PyAstronomy` package. The values of the peaks and their local and global p-values are shown in Tab.1. MAGIC *and Swift*-XRT do not show a significant periodicity as suggested by the high p-value. Swift-UVOT and radio show the strongest GLS peaks, however they are also not significant.

Band	PSD index	Peak period [d]	Peak power	local p-value	global p-value	p-value (lit. period)
Radio 15 GHz	2.0 ± 0.51	865	0.40	2.3×10^{-3}	3.4×10^{-2}	2.0×10^{-2}
Optical	1.47 ± 0.08	957	0.51	9.7×10^{-2}	4.7×10^{-1}	7.8×10^{-2}
Swift-UVOT	1.41 ± 0.12	806	0.46	5.6×10^{-3}	1.0×10^{-1}	5.6×10^{-3}
Swift-XRT	1.5 ± 0.10	2521	0.47	1.4×10^{-1}	6.8×10^{-1}	8.6×10^{-1}
Fermi-LAT	1.4 ± 0.26	786	0.40	2.0×10^{-5}	1.0×10^{-3}	2.0×10^{-5}
MAGIC	1.0 ± 0.42	214	0.30	1.8×10^{-2}	3.7×10^{-1}	7.0×10^{-1}

Tab. 1: Results of search periodicity in different bands.

INTERBAND CORRELATION

Correlation between different bands can provide information on the one or more regions of the jet at which the emission occurred. We focused on the correlations between IR, optical, UV, X-ray, HE and VHE bands.
We used the `scipy` python package to compute the Spearman coefficients (Sc). We considered a time window of 1.5 days except for Fermi, for which we considered a 10 days time window due to the lightcurve binning.
The results show:

- **Strong correlation** (Sc > 0.9) for **optical** with **UV** (UW2 band) and **optical** with **IR** (H band).
- **Net correlation** (Sc > 0.6) for **optical** with **UV** and **optical** and **HE**. Similar for **X-rays** and **VHE**. This is shown in Fig. 2.
- **Hint of correlation** (Sc<0.4) for the other bands.

This suggests a common origin for the emission IR, optical, UV and HE plus the presence of another region responsible for X-rays and VHE. The SED should be described using a **two-zone model**.

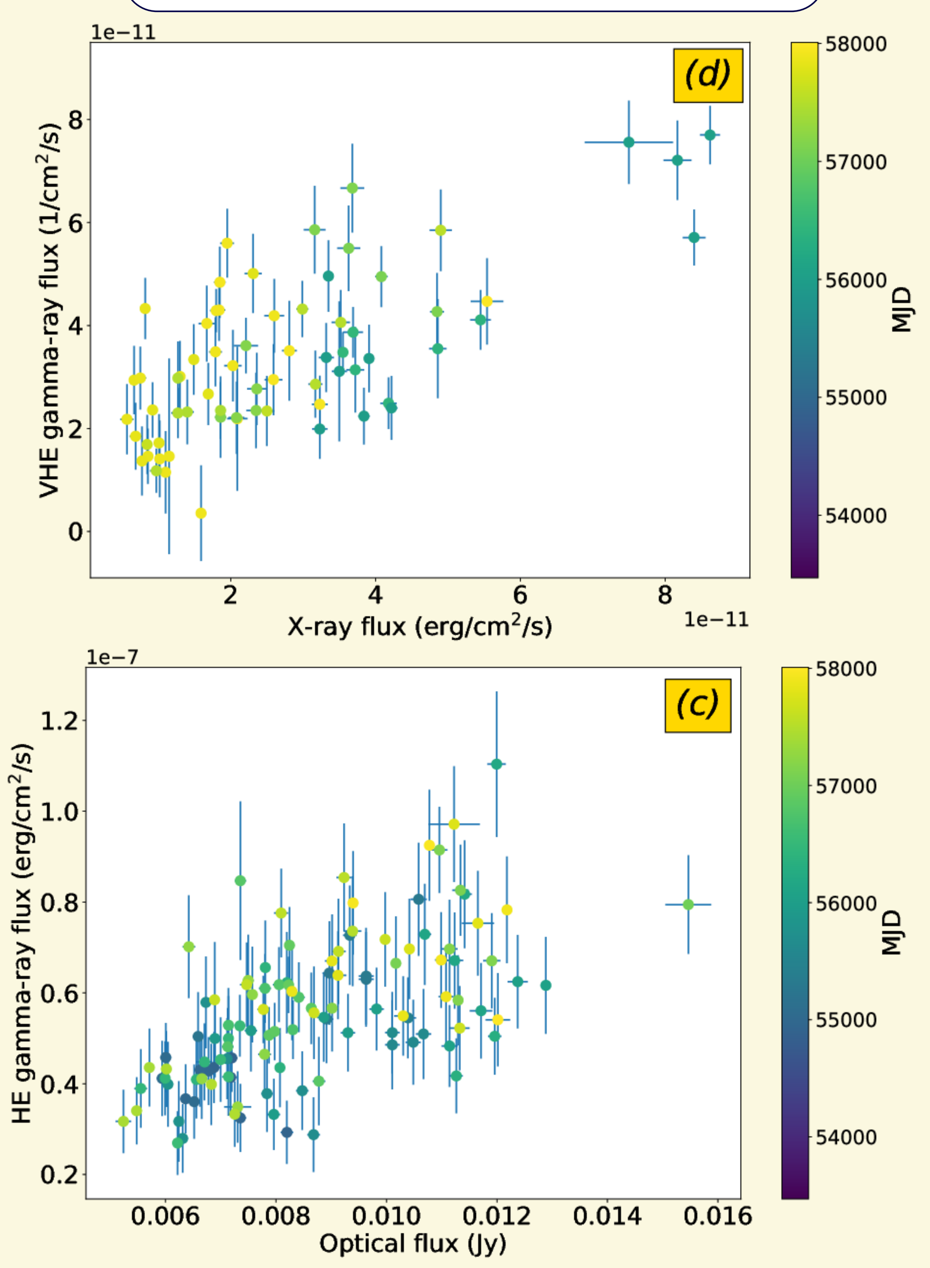

Fig. 2: Interband correlations: MAGIC vs XRT (upper), Fermi vs KVA (lower) [3]

TWO-ZONE SSC MODEL OF 2019 FLARE

The source, as expected from the 2.2 year modulation, entered a flaring episode in April of 2019 (Fig. 3). It was the highest flux ever recorded in VHE. We applied, for the first time for this source, a two-zone SSC model. We divided our data into two groups: **April** and **June-August**. We used the `jetset [4]` tool to perform the fit using two broken power laws, one fitting the low energy and HE zone (zone 1) and the other fitting the zone emitting X-ray and VHE (zone 2), as shown in Fig. 4.
The change from June-August to April is mostly on the **spectral indices** of zone 2 and **B** and **N** for both zones, as shown in Tab. 2.
The physical interpretation of the models is still ongoing.

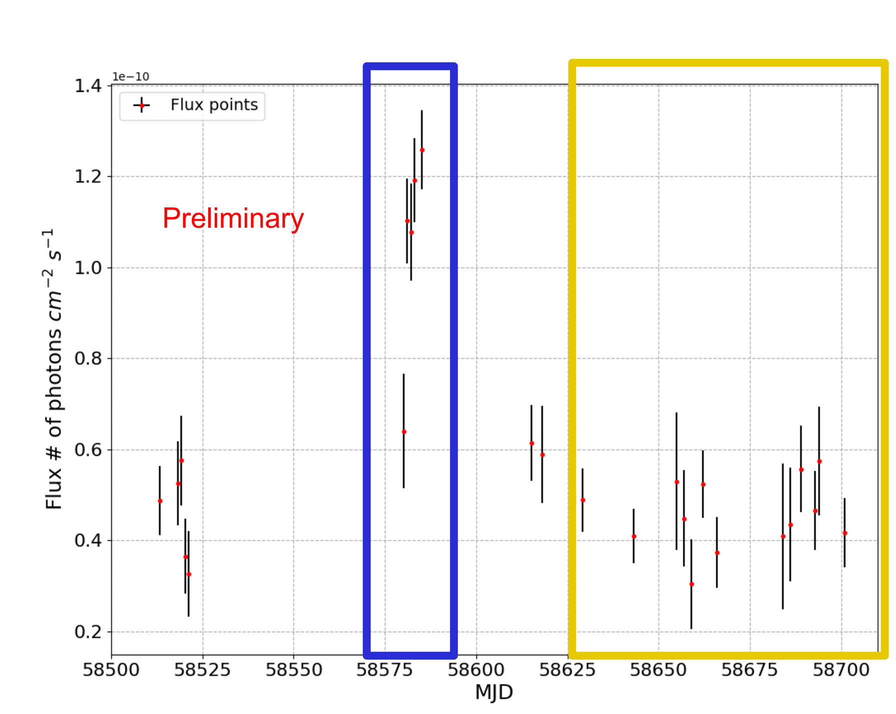

Fig. 3: VHE gamma-rays lightcurve of 2019 of PG1553+113. The energy threshold is set to 150 GeV. The flaring episode is clearly visible inside the blue rectangle.

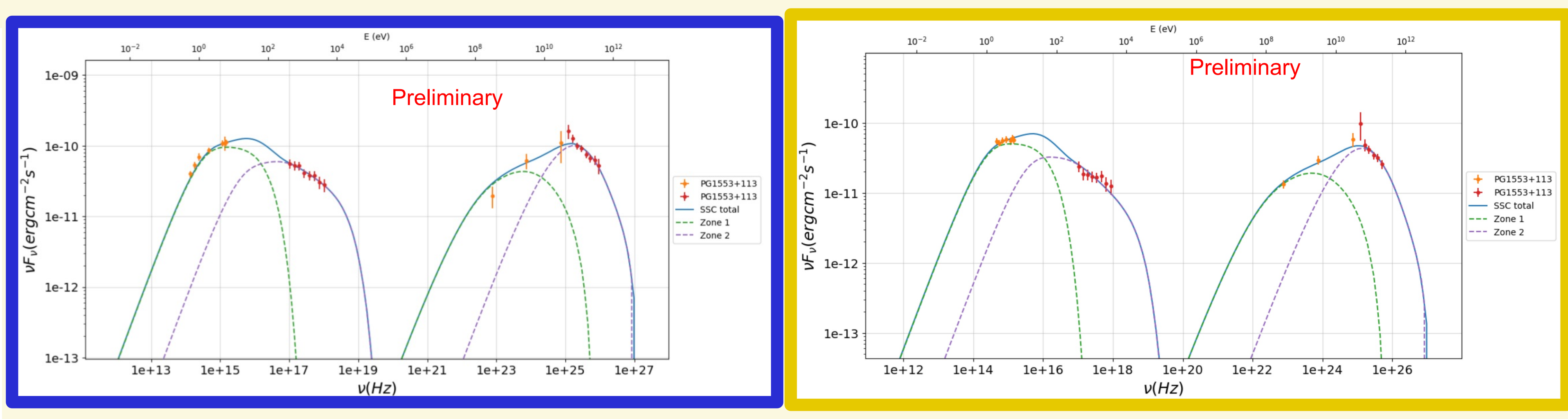

Fig. 4: April SED with two zone SSC model (left panel). June-August SED with two-zone SSC model (right panel)

	April		June-August	
	zone 1	**zone 2**	**zone 1**	**zone 2**
δ_D	2×10^1	2×10^1	2×10^1	2×10^1
γ_{min}	5×10^3	2×10^4	5×10^3	2×10^4
γ_{max}	5×10^4	8×10^5	5×10^4	8×10^5
γ_b	3×10^4	9.5×10^4	3×10^4	9.5×10^4
p	2.9	2.6	2.9	2.9
p1	2.9	3.6	3.9	3.9
$t_{var}(days)$	3	1	3	1
$N\ (cm^{-3})$	0.061(8)	0.099(5)	0.051(5)	0.075(4)
$B(G)$	0.16	0.114(5)	0.125	0.108(5)

Tab. 2: Parameters of the models of the SEDs

This work is currently under internal review and is soon to be published.

[1] Dorigo Jones, J. et al. (2022). Improving blazar redshift constraints with the edge of the Ly α forest: 1ES 1553+113 and implications for observations of the WHIM. , 509(3):4330–4343
[2] Ackerman M. et al. (2015). Multivalength evidence for quasi periodic modulation in the gamma-ray blazar PG 1553+113
[3] MAGIC collaboration et al. (2024). The variability patterns of the TeV blazar PG1553+113 from a decade of MAGIC and multi-band observations
[4] Tramacere A., (2020) JetSeT: Numerical and SED fitting tool for relativistic jets