Multiwavelength observations of the extreme HBL H 1426+428

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Abstract

We present here the results of two different MWL campaigns on the BL Lac object H 1426+428 (z=0.129). The observations cover two periods. First, we describe a multi-year monitoring program with VERITAS, covering the period from 2008 - 2016, which revealed an average steady flux of approx. 2% of the Crab Nebula flux, with no variability detected on timescales of days to years. We incorporate multi-wavelength data from of optical telescopes, optical-X-ray data from the Neil Gehrels Swift Observatory and high-energy gamma-ray data from the *Fermi* Large Area Telescope (LAT). We construct and model the time-averaged spectral energy distribution, constraining the low state of this BL Lac. The second set of observations that we present are from 2021 when VERITAS detected a significantly elevated state of H 1426+428 compared to the 2008-2016 data set and conducted an extensive observational program. During this period, no cutoff is detected in the observed TeV energy spectrum up to at least 6 TeV. The results from this period are presented along with contemporaneous Swift-XRT observations.

Introduction

H 1426+428, often classified as an extreme high-frequency-peaked BL Lac object (EHBL), is located at a redshift of z = 0.129. It is a particularly bright and persistent X-ray source, first detected at X-ray energies by the Uhuru X-ray observatory (2U 1443+43 [1]). At higher energies, the detection of gamma rays from H 1426+428 was first made from the ground with the Whipple Telescope ([2]) and it was subsequently detected on a number of occasions by this previous generation of ground-based gamma-ray telescopes (Whipple, CAT and HEGRA ([2][3][4])). Its very-high-energy (E>100 GeV, VHE) flux ranged up to 80% of the Crab Nebula (Crab Units, C.U.) above a few hundred GeV. Current-generation TeV observatories (VERITAS, MAGIC) have, however, only reported low-flux detections with the flux typically ranging from 1-3% C.U. (e.g. [5]). H 1426+428 was not detected by any gamma-ray satellites until the *Fermi* Large Area Telescope (LAT [6]). It was not in any of the source catalogues, either those in the nominal energy range (e.g. [7]) or at higher energies [8], of the Energetic Gamma-ray Experiment Telescope (EGRET) on the Compton Gamma-ray Observatory. In this contribution we report the results of two observational campaigns on H 1426+428: a multi-year monitoring program with VERITAS covering the period from 2008-2016 when the source was in a relatively low state and a more concentrated campaign in 2021 covering an elevated flux state of this source. The 2008-2016 observations revealed an average steady flux of ~2% C.U. and no evidence for variability was seen on any timescales from days to years. We constrain the low state of this extreme HBL by constructing the time-averaged spectral energy distribution using multi-wavelength data from optical to gamma-ray energies. The 2021 VERITAS observations revealed a significantly elevated state of H 1426+428 and we report on the intensive observational campaign that was undertaken including contemporaneous Swift-XRT observations. During this time, the gamma-ray spectrum measured by VERITAS showed no evidence for a cutoff up to at least 6 TeV.

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References: [1] Giacconi et al. 1972, ApJS, 27, 37. [2] Horan et al. 2002, ApJ, 571, 753. [3] Aharonian et al. 2002, A&A, 384, L23. [4] Djannati-Atai et al. 2002, A&A, 391, L25. [5] Leonardo et al. 2009, 31st ICRC. [6] Atwood et al. 2009, ApJ, 697, 1071. [7] Hartman et al. 1999, ApJS 123, 79. [8] Lamb et al. 1997, ApJ, 488, 872. [9] Lien et al. 2022, in preparation, https://swift.gsfc.nasa.gov/results/bs157mon/ [10] Finke et al 2010, ApJ, 712, 238. [11] Finke et al 2008, ApJ, 686, 181.

2008-2016 Multiwavelength Light Curves

- The monthly-binned VHE Flux (E >250 GeV) shows only moderate variability, with a time averaged-flux of $(2.99 \pm 0.24) \times 10^{-12} ph\ cm^{-2} s^{-1}$ or ~2% *CU*.
- The HE flux remains approximately steady ($\chi^2/NDF = 29.5/14 = 2.1$) during the campaign and a time-averaged flux (100 MeV - 500 GeV) of $(2.33 \pm 0.36) \times 10^{-9} ph\ cm^{-2} s^{-1}$.
- The Swift-BAT 157 Monthly-binned flux [9] reveals an average (14-195 keV) of 0.84 *mC.U*.
- The daily-binned Swift-XRT observations are fit with both a power-law and log-parabola model. A log-parabola is considered when preferred by a F-test at the 95% confidence level.
- XRT spectral index varies from 1.7 - 2.1 over the 2008-2016 period, while the flux varies by a factor of ~3.5.
- The synchrotron peak is located ~2 keV through the 2008-2016 campaign.
- The variability timescale is constrained by the cadence of Swift-XRT observations to one day.

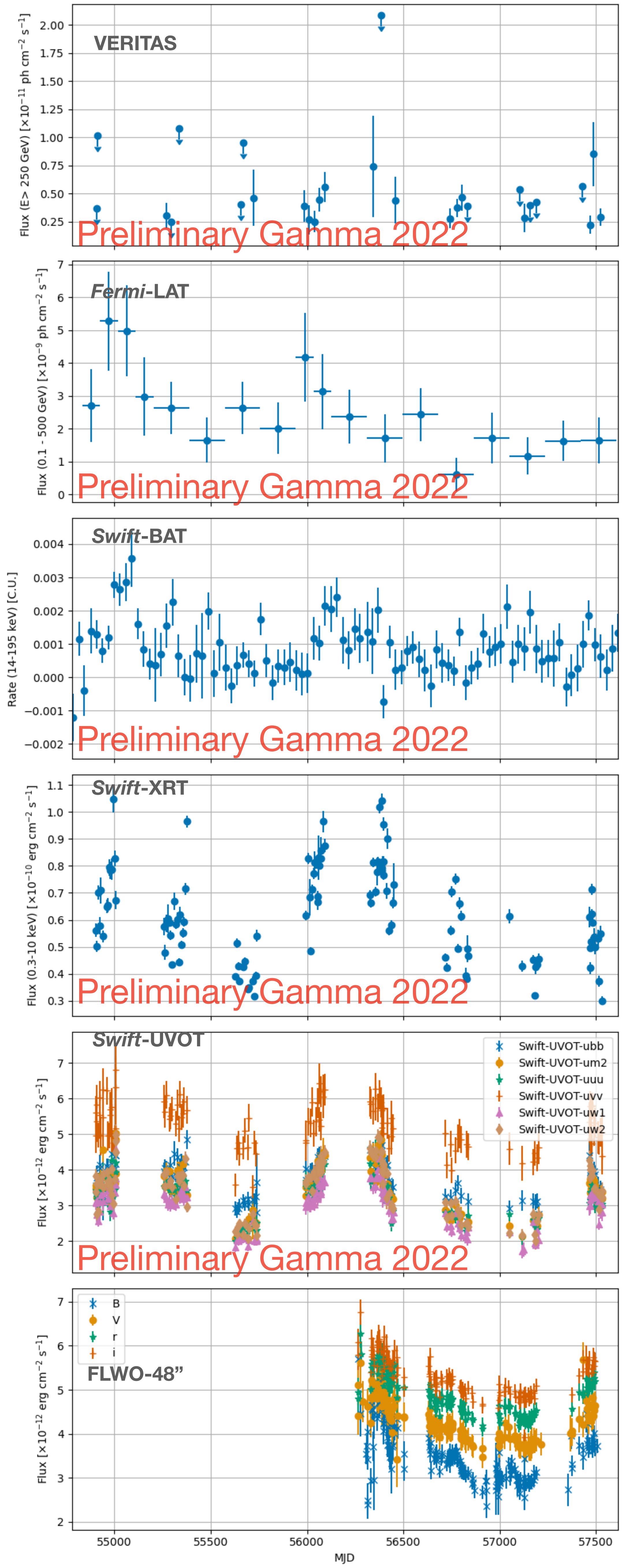

Figure 1: Multiwavelength light curve spanning 2008-2016

Spectral Energy Distribution

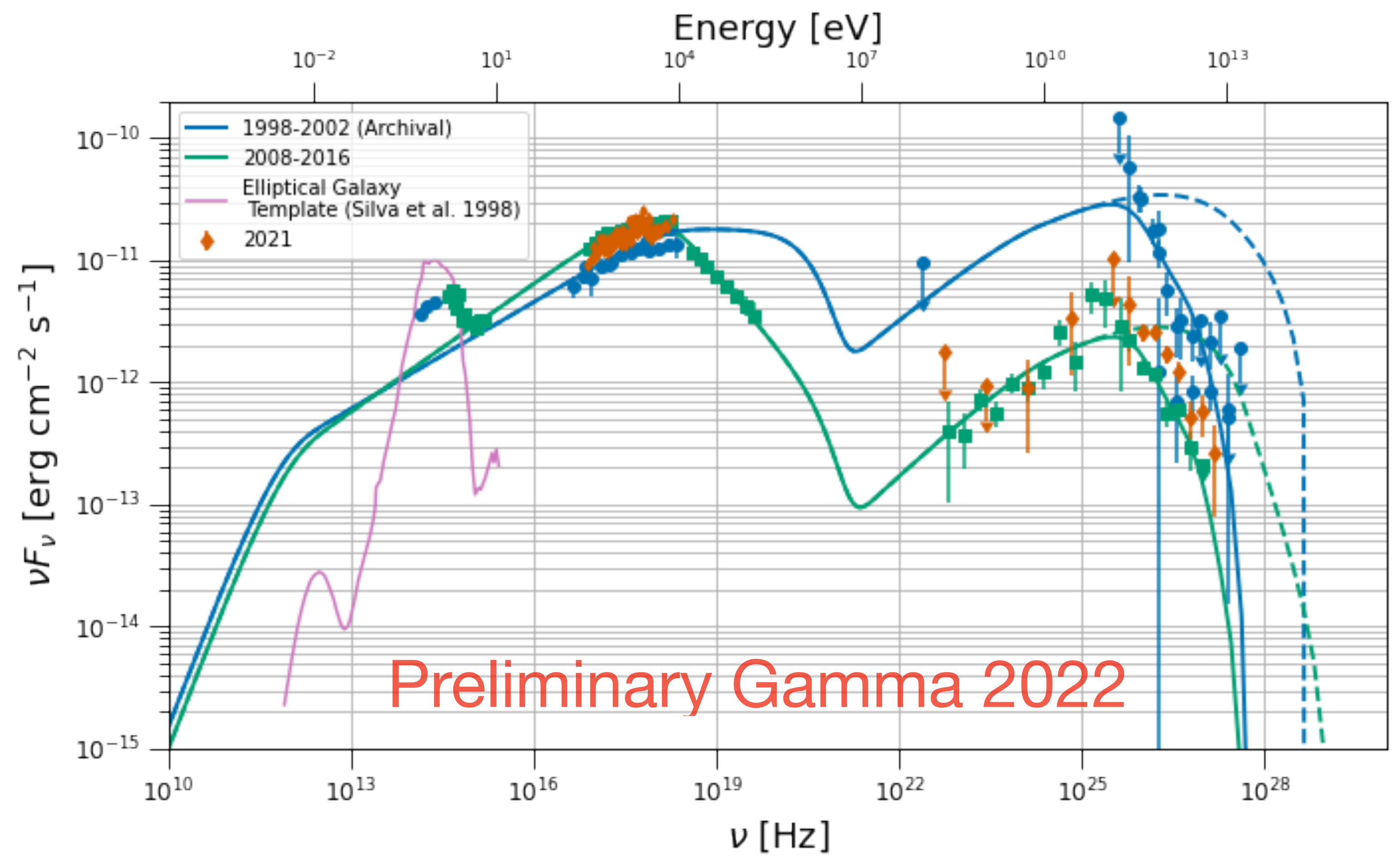

Figure 2: Broadband SED of H 1426+428. The intrinsic SEDs (dashed lines) are absorbed for EBL attenuation assuming the EBL model from [10] (solid lines).

The 1998-2002 and 2008-2016 datasets are well-fit by a single zone synchrotron self-Compton model, as described by [11]. This is shown in Figure 2. The 2008-2016 SED has a higher Doppler factor ($\delta_D = 36$), lower magnetic field ($B = 5.7mG$), and softer high-energy electron spectrum ($p_2 = 4.2$) than the archival SED from 1998-2002 ($\delta_D = 19; B = 8.7mG; p_2 = 3.0$).

2021 Very-High-Energy High State

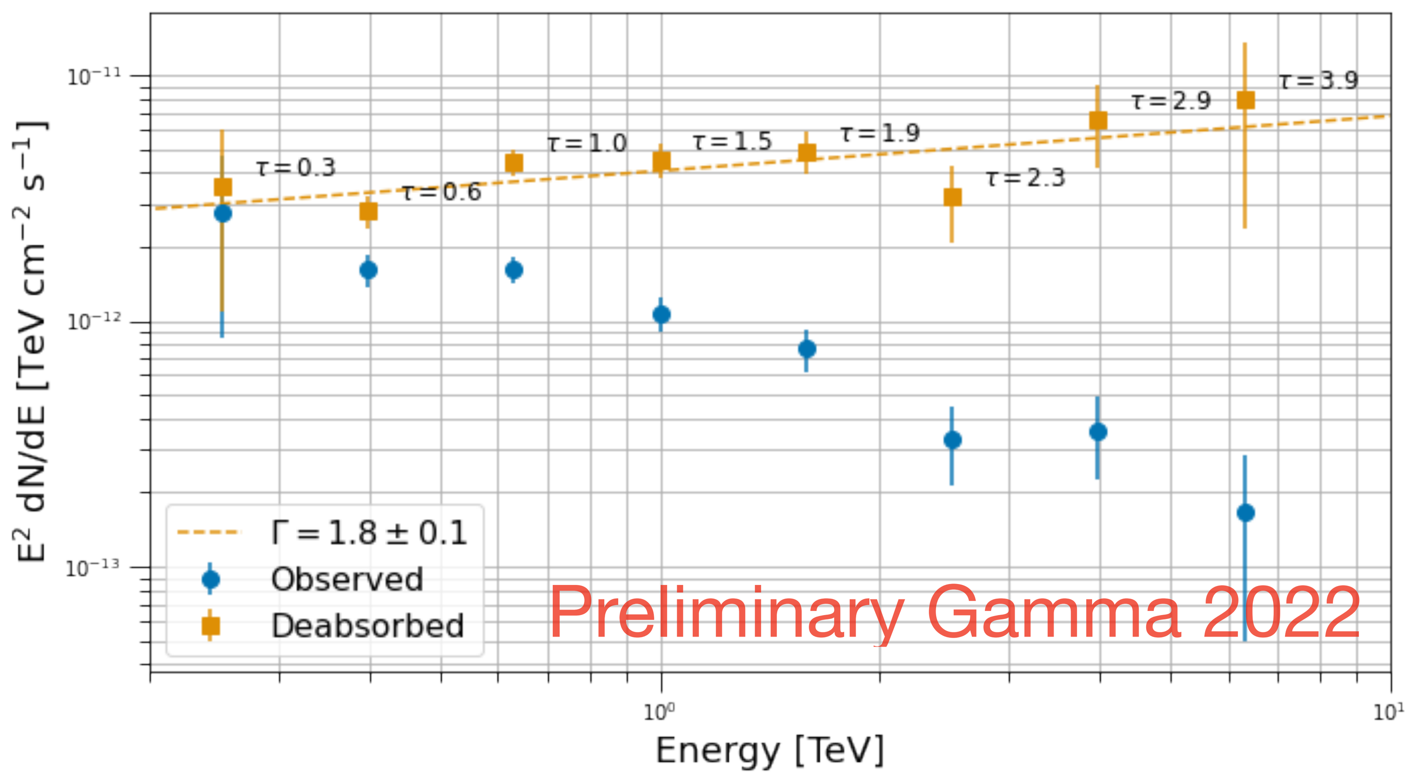

Figure 3: VHE energy spectrum during 2021. The observed spectrum is shown in blue circles, with the intrinsic spectrum (deabsorbed assuming the EBL model from [10]) is shown as orange squares. The optical depth (τ) is shown for each point.

The 2021 dataset presents a moderate increase in the broadband flux (Figure 2). During this period the intrinsic VHE spectrum is consistent ($\chi^2/NDF = 1.15$) with a power-law model of index $\Gamma = 1.8 \pm 0.1$. There is no evidence of a cut off up to 6 TeV, suggesting a IC peak beyond this range. Full SED modelling of the 2021 dataset will be presented in an upcoming publication.

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2008-2016 Multiwavelength Light Curves

- The monthly-binned VHE Flux (E >250 GeV) shows only moderate variability, with a time averaged-flux of $(2.99 \pm 0.24) \times 10^{-12} ph\ cm^{-2} s^{-1}$ or ~2% CU. 95% confidence level upper limits are shown for points with $< 2\sigma$ significance

- The high-energy (HE, 0.1-500 GeV) light curve is obtained using 185-day and 92.5-day binning. A TS > 5 is required for each bin.

- The HE flux remains approximately steady ($\chi^2/NDF = 29.5/14 = 2.1$) during the campaign and a time-averaged flux (100 MeV - 500 GeV) of $(2.33 \pm 0.36) \times 10^{-9} ph\ cm^{-2} s^{-1}$.

- The Swift-BAT 157 Monthly-binned flux[9] reveals an average (14-195 keV) of 0.84 $mC.U.$

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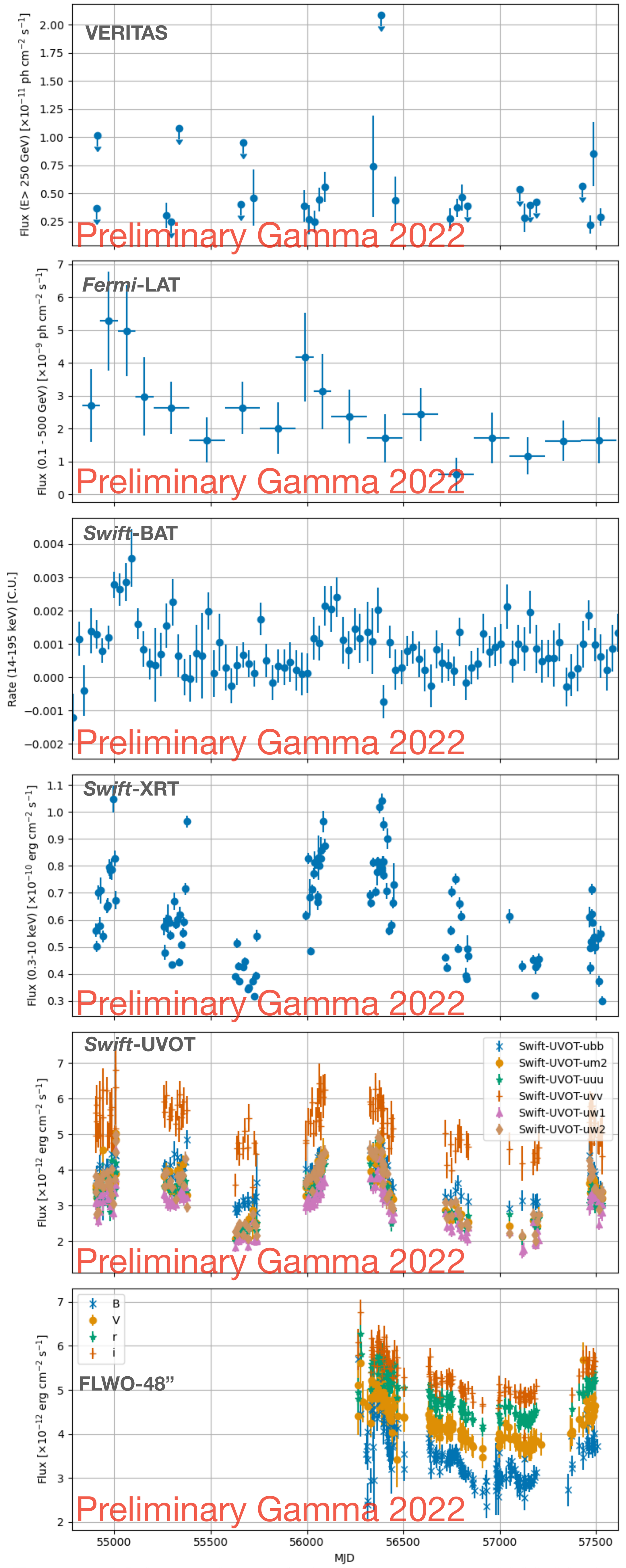

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Spectral Energy Distribution

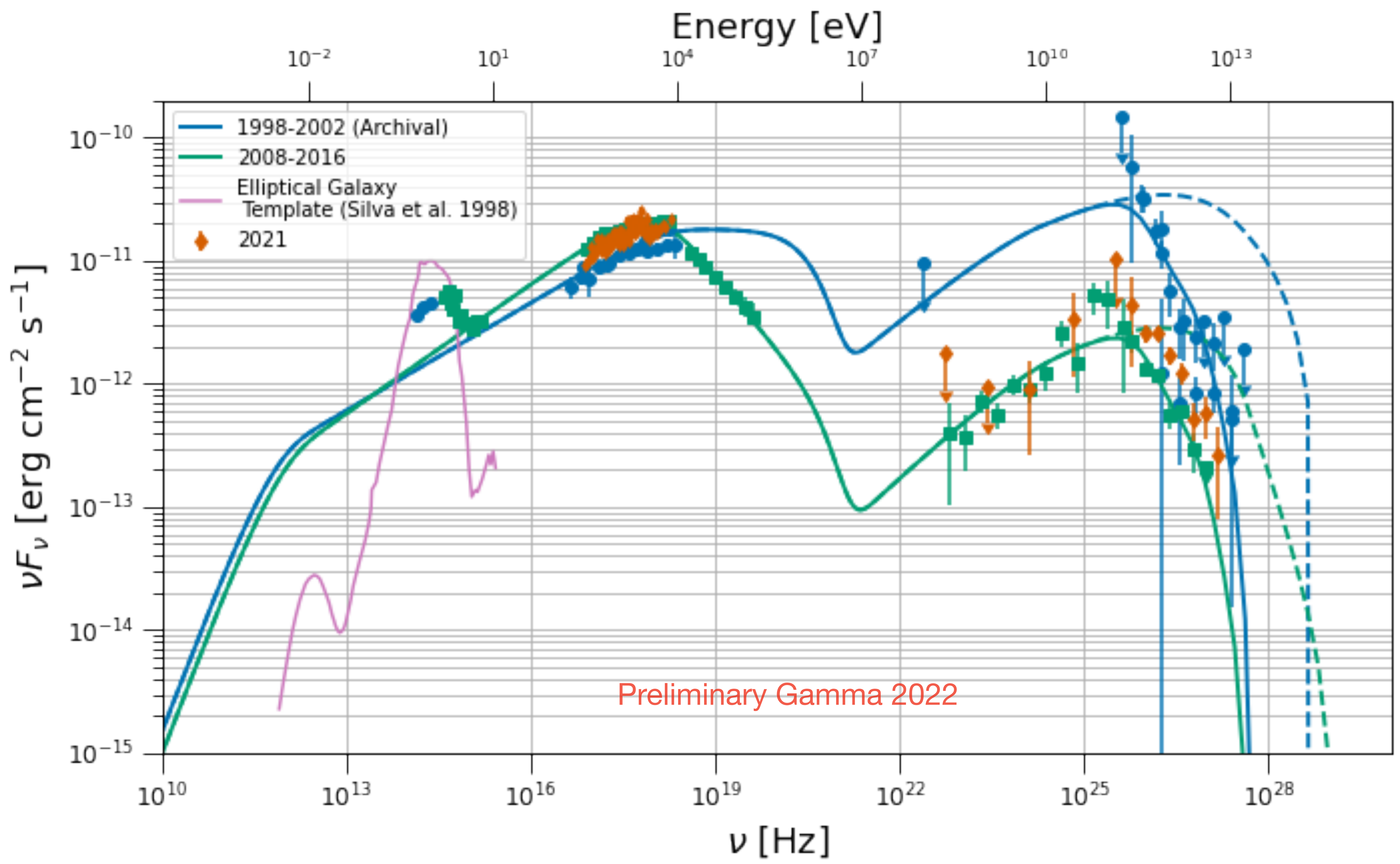

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Table 1. H1426+428 Model Fit Parameters

Parameter	Symbol	1998-2002	2008-2016
Bulk Lorentz Factor	Γ	19	36
Doppler Factor	δ_D	19	36
Magnetic Field [mG]	B	8.7	5.7
Variability Timescale [s]	t_v	10^5	10^5
Comoving Blob Radius [cm]	R'_b	5.0×10^{16}	9.7×10^{16}
Low-Energy Electron Spectral Index	p_1	2.4	2.3
High-Energy Electron Spectral Index	p_2	3.0	4.2
Minimum Electron Lorentz Factor	γ'_{min}	10^3	10^3
Break Electron Lorentz Factor	γ'_{brk}	1.7×10^6	1.2×10^6
Maximum Electron Lorentz Factor	γ'_{max}	3.0×10^7	3.0×10^7
Jet Power in Magnetic Field [erg s^{-1}]	$P_{j,B}$	5.2×10^{41}	3.0×10^{42}
Jet Power in Electrons [erg s^{-1}]	$P_{j,e}$	1.2×10^{45}	4.3×10^{44}

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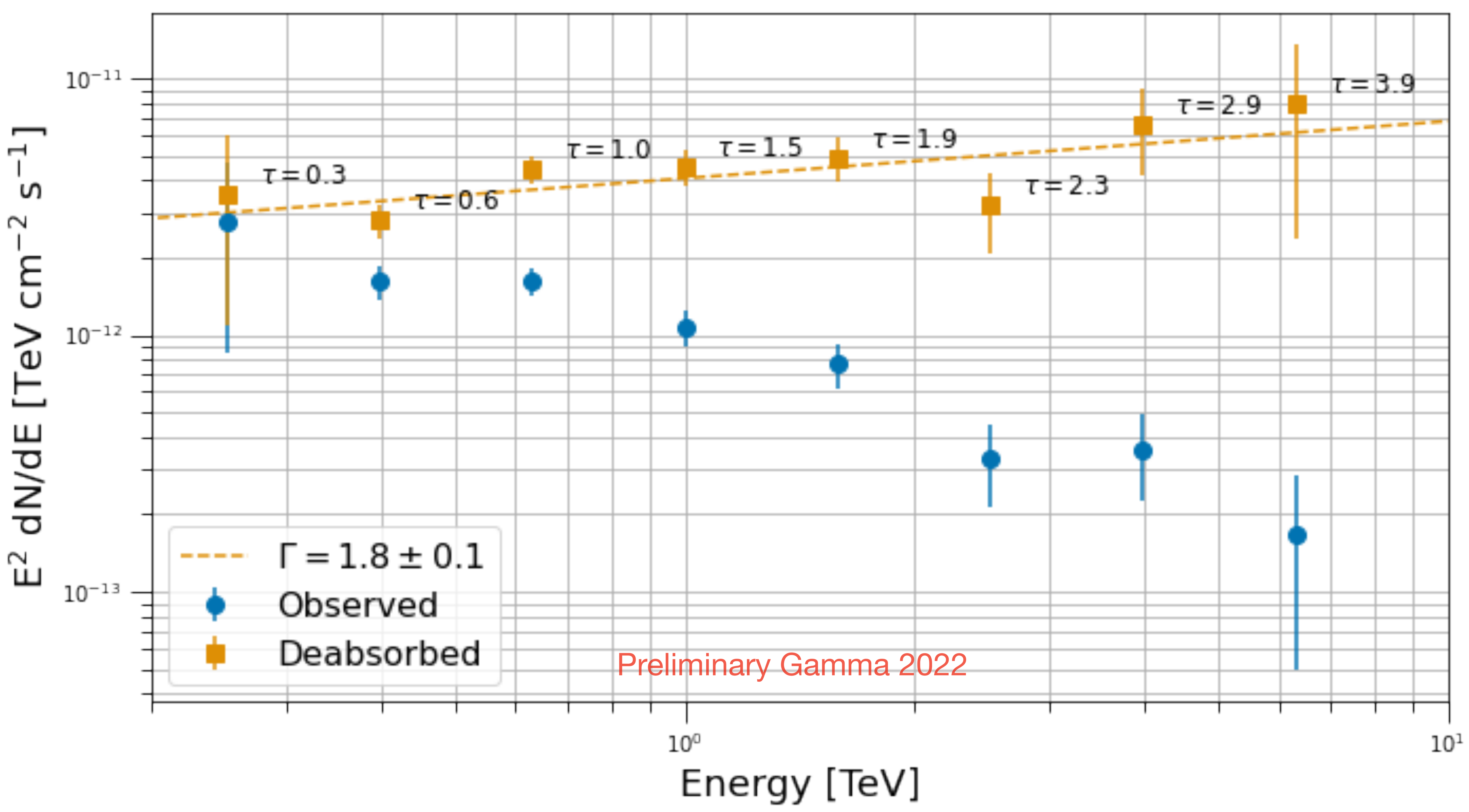

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