Spectral analysis of S5 1803+784 in the recent flaring state

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Abstract

S5 1803+784 is a BL Lac object. Unlike most low synchrotron peaked (LSP) blazars, the spectrum of S5 1803+784 is poorly fitted with a single zone synchrotron self – Compton (SSC) leptonic jet model. This could be why recent multiwavelength studies show no clear correlation between the synchrotron emission and the gamma-ray emission in this blazar. We utilize a simple single-zone leptonic jet emission model with external Compton (EC) originating from the dusty torus (DT) to explain the emission and to produce the best-fit parameters of the emission process. We present here the spectral analysis of the recent flaring state reported in Astronomy Telegram (ATel #13633) using data from Fermi-LAT and NED archival data. The spectral energy distribution (SED) model of the flare and the quiescent states best-fit parameters produced using Jetset code are used to constrain the upper limit of the γ-ray emission region length scale, the jet energetics, and the likely acceleration mechanism of the blazar during the flare.

Brief Introduction

One possible jet emission mechanism is the leptonic model, in which ultra-relativistic electrons up-scatter soft photons produced by synchrotron emission within the jet itself or soft photons external to the jet in an inverse Compton process [1]. The single-zone SSC emission model has been successful in explaining the spectral energy distribution (SED) and variability of many blazars but there are others which require a different model to explain their unique characteristics [2].

In the previous and recent work of [3], S5 1803+784 often shows no clear cross-correlation between the radio and γ-ray emission. This lack of clear correlation and the poor fit with a single zone SSC model informed our decision to use a phenomenological fit using a single-zone SSC + EC jet leptonic model with the external photons as reflected infrared photons from the dusty torus (DT).

We adopt the definition of flare proposed in [4], in that, a flare is a continuous period, associated with a given flux peak, during which the flux exceeds the quiescent value, and the lower limit is attained twice at the beginning and the end of the flare.

Here, we use the lambda cold dark matter (ΛCDM) cosmology, H_0= 71 km s^{-1} Mpc^{-1} (2.3×10^{-18} s^{-1}), $\Omega_m = 0.27$, $\Omega_\Lambda = 0.73$.

S5 1803+784 (4FGL J1800.6+7828)

Fermi-LAT observed γ – ray flaring activity from S5 1803+784 (4FGL J1800.6+7828 in Fermi-LAT 4FGL catalog [5]), a low synchrotron peak BL Lac, with coordinates (R.A = 270.1891° and Dec. = + 78.4678 °) and redshift z = 0.684. The flaring activity is observed from MJD 58941 - MJD 58958. The highest LAT daily flux ever observed for this source was on 12 April 2020 (MJD 58951).

Data and Analysis

Fermi-LAT and NED

The reprocessed Pass 8 data sets with P8R3_SOURCE_V2 instrument response functions were used to analyze the data following the standard procedures [6][7] implemented in the Fermi ScienceTools (ver. 1.2.23) software package using Fermipy (0.20.0) [8]. The statistical significance of the HE γ-ray signal in the energy range 0.1-300 GeV is determined from the maximum likelihood ratio test statistic (TS) defined in [9]. The spectral energy distribution (SED) of the flare announced in ATel #13633, which peaked on 12 April 2020 (MJD 58951) within 10 days (MJD 58948 – MJD 58957) of the flare (as defined in Nalewajko, 2013) was extracted in the energy bins 177.83, 562.34, 1778.28, 5623.41, 17782.79, 56234.13, 177827.94 MeV. The flux densities with TS ≥ 20 (> 4σ significance) were utilized to build the SEDs. The high-energy portion of the quiescent state of the SED is obtained from the 4FGL catalog. The archival data of the blazars from radio up to X-ray was obtained from NASA/IPAC Extragalactic Database (NED) at ned.ipac.caltech.edu.

Results and Discussion

The electron injection described by a broken power-law function was used in Jetset code [10] in the framework of the jet leptonic model.

The phenomenological spectral fit in Jetset utilizes the best-fit Minuit model minimizer and the pre-fit based on the observation data to obtain the fixed parameter in Table 1. With the Monte Carlo (MCMC) sampler, we obtain the best fit of the free parameters (in Table 2) of the spectral energy distribution. The lower and upper bounds of the uncertainty are the differences to 16th and 84th percentiles in the probability density function.

Gamma – ray emission and Acceleration processes

S5 1803+784 spectrum is a LSP which is supposed to produce a good fit to single zone SSC leptonic jet model, but the phenomenological spectral best fit for this blazar requires external photons from the dusty torus for the γ – ray emission (Figures 2 and 3). The ratio of the magnetic energy density and particle energy density in the emitting region (Figure 1) is $\left(\frac{U_B}{U_e}\right)$ = 6.29e-04/4.45e-03 = 0.14 during the flare and 5.15e-03/ 1.39e-03 = 3.70 in the quiescent state of the blazar, implying a particle-dominated emitting region during the flare which is evidence of magnetic dissipation in the emitting region (blob). Also, the ratio of the photon's radiation density and the magnetic energy density $\left(\frac{U_{rad}}{U_B}\right)$ (Figure 1) shows Compton dominance. The jet is magnetically dominated in the quiescent state, but particle dominated during the flaring state. This scenario favors an enhanced particle acceleration through magnetic reconnection during

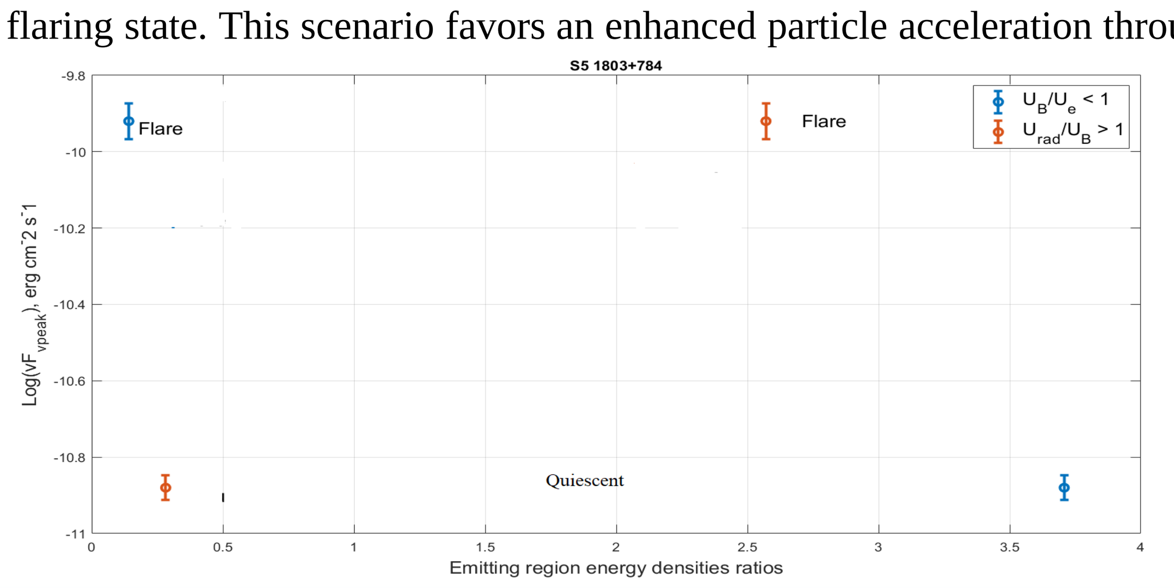

Figure 1: The observed peak flux density during the flare and the quiescent state vs the ratios of the energy densities.

Table 1: Fixed parameters in the spectral fit

Symbol (unit)	Description	Quiescent	Flare
$R_H \times 10^{18}$cm	Emitting region distance from the black hole	1.00	1.00
$L_{Disk} \times 10^{44}$erg / s	Disk luminosity	2.12	2.30
$R_{DT} \times 10^{18}$ cm	Size of the dusty torus	1.15	1.20
$R_{BLR-in} \times 10^{16}$cm	The inner radius of the BLR	4.60	4.80
$R_{BLR-out} \times 10^{16}$cm	The outer radius of the BLR	9.20	9.60
$T_{Disk} \times 10^4$ K	Disk temperature	3.02	3.02
tau_{BLR}	% of external photons reflected from the BLR	0.1	0.1
tau_{DT}	% of external photons reflected from the DT	0.1	0.1
T_{DT} (K)	The temperature of the dusty torus	655	655

Table 2: Free parameters and best fit results

Symbol (unit)	Description	Quiescent	Flare
γ_b	Turn-over-energy Lorentz factor	$514.56^{+50.25}_{-49.48}$	$628.31^{+73.37}_{-55.60}$
p	Low energy spectral slope	$-0.83^{+0.11}_{-0.12}$	$-0.56^{+0.12}_{-0.12}$
p_1	High energy spectral slope	$3.53^{+0.11}_{-0.12}$	$3.53^{+0.11}_{-0.11}$
γ_{min}	Low-energy-cut-off Lorentz factor	$5.92^{+0.71}_{-1.08}$	$14.11^{+0.73}_{-1.70}$
γ_{max}	High-energy-cut-off Lorentz factor	$102027.74^{+19849.84}_{-13859.63}$	$110210.23^{+27454.78}_{-27922.57}$
R (cm)	Emitting region size	19.88×10^{16}	9.66×10^{16}
δ	Beaming Lorentz factor	$12.25^{+1.35}_{-1.12}$	$25.79^{+2.24}_{-2.41}$
B (G)	Magnetic field	$0.36^{+0.03}_{-0.03}$	$0.13^{+0.01}_{-0.01}$
N (cm^{-3})	Emitter density	$3.08^{+0.40}_{-0.50}$	$8.71^{+1.34}_{-1.11}$

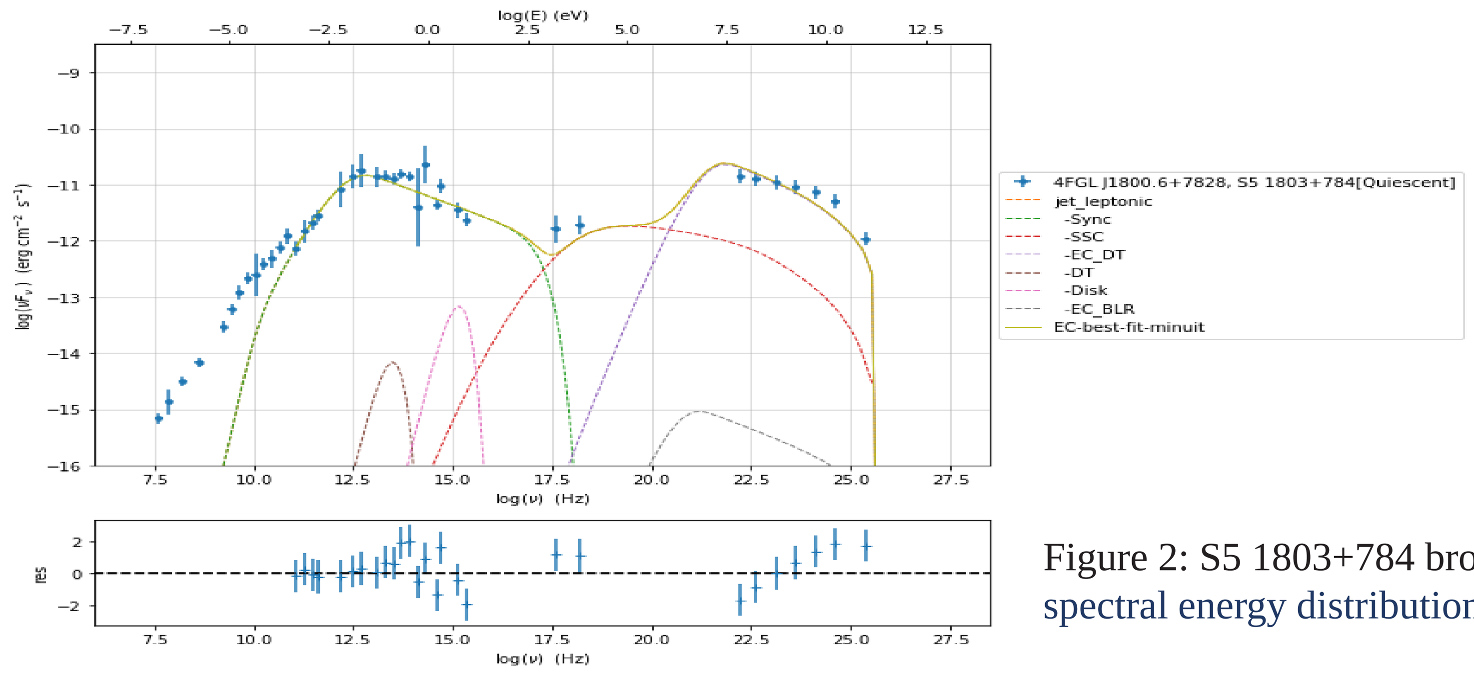

Figure 2: S5 1803+784 broad band best fit spectral energy distribution quiescent state

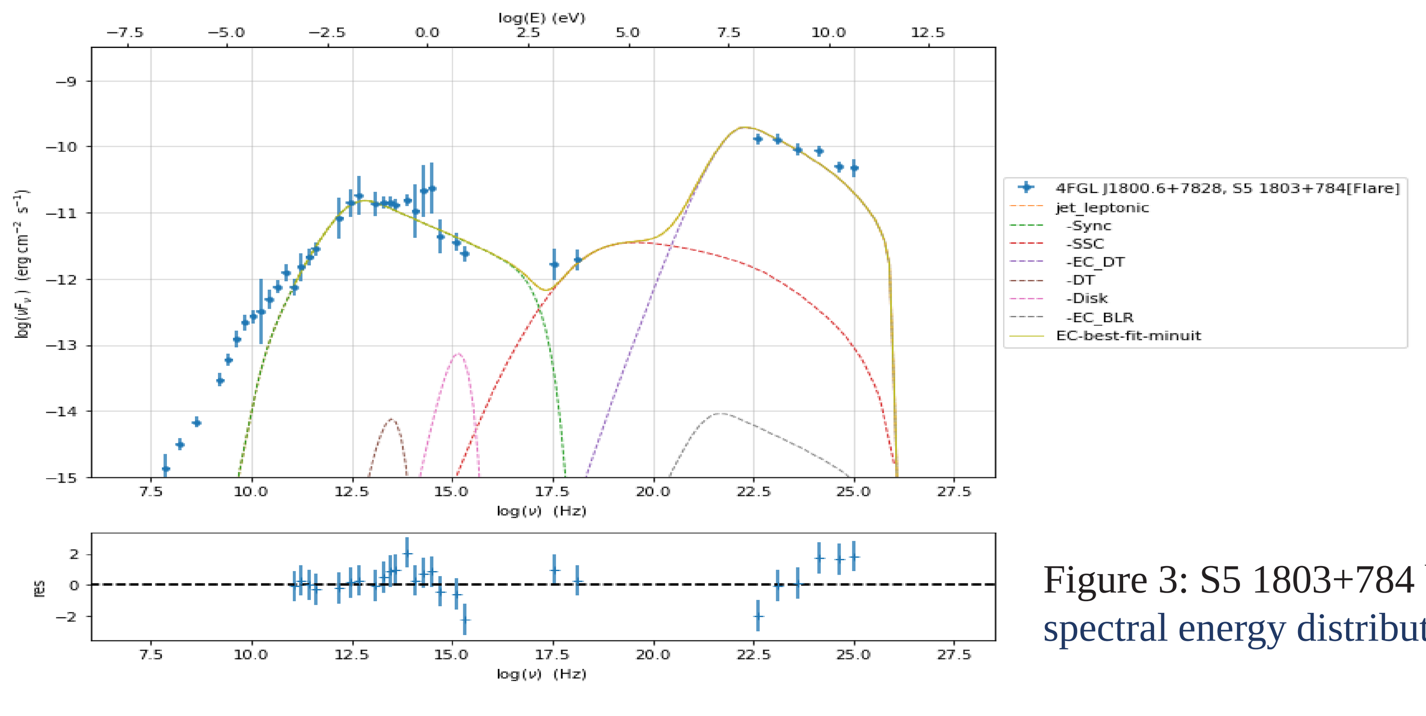

Figure 3: S5 1803+784 broad band best fit spectral energy distribution flaring state

Conclusion

The jet energetics and the phenomenological spectral best fits for both the quiescent and flaring state of the blazar are reported in Figures 2-3. The lack of clear cross-correlation between the radio band and the γ-ray energy in this source could be explained by the fact that the γ-rays are up-scattered soft infrared photons originating from the dusty torus. This blazar may be a masquerading BL Lac [12] since the broadband spectral energy distribution produces a poor fit with the single-zone SSC leptonic model expected of BL Lacs.

The flare which peaks on MJD 58951 from this source presents signatures and features that are consistent with magnetic dissipation through magnetic reconnection as a process enhancing particle acceleration

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