The variety of extreme blazars in the AstroSat view

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Abstract

In this contribution, we present a spectral study of extreme blazars (also eHBL) which are known to exhibit hard intrinsic X-ray/TeV spectra and extreme SED peak energies. We study four eHBLs 1ES 0120+340, RGB J0710+591, 1ES 1101-232, 1ES 1741+196 and one HBL 1ES 2322-409 using new X-ray data from AstroSat, together with quasi-simultaneous Fermi-LAT and other archival multi-frequency data. Three of the eHBLs are non-variable, as is typically attributed. On the contrary, RGB J0710+591 shows spectral softening in both X-ray and GeV bands indicating a significant change in the synchrotron cut-off. Typically, a standard one-zone synchrotron self-Compton (SSC) model reproduces well eHBL SEDs, but often requires a large value of the Doppler factor and minimum electron energy. We have thus conducted a detailed investigation of the broadband SEDs under both leptonic and (lepto-)hadronic scenarios. We employ 1) a steady-state one-zone synchrotron-self-Compton (SSC) code and 2) a one-zone hadro-leptonic (OneHaLe) code. The latter is solved for two cases of the high energy emission – a pure hadronic case (proton synchrotron) and a lepto-hadronic case (synchrotron emission of secondary electrons from pion decay and Bethe-Heitler pair production). By fixing the Doppler factor at δ=30, we find that all models can reproduce the SEDs of eHBLs. For the normal HBL, SSC and proton synchrotron models are superior to the lepto-hadronic model. As no model is superior explaining the eHBLs, we discuss in detail the pros and cons of each model.

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Objective

- The extreme blazars, also known as extreme HBLs (eHBLs) have shown ambiguous spectral properties in high energy emission. Their X-ray and VHE emission is characterized by hard intrinsic spectrum.
- Challenge case for leptonic models to explain the hard VHE spectrum.
- Non-variable? - non detection of variability or flaring activities in all wave bands.
- In this contribution, we studied X-ray spectra of four eHBLs, model their broadband SED and provided plausible interpretations.

Observations

We selected 5 HBL sources observed by *AstroSat*. Sources are not well studied in X-ray energies, and hence, their spectral/variability properties are poorly understood. Except for the HBL source, all other sources are known to exhibit extreme nature in the VHE energies.

- Four eHBLs: 1ES0120+340, RGBJ0710+591, 1ES1101-232, 1ES1741+196
- HBL: 1ES2322-409

Data:

- X-ray: AstroSat (SXT + LAXPC) observed during 2018-2020 and quasi-simultaneous XRT
- GeV: Fermi-LAT (averaging of 4-6 years, centered at AstroSat observation)
- MWL: archival TeV and optical/IR, UVOT

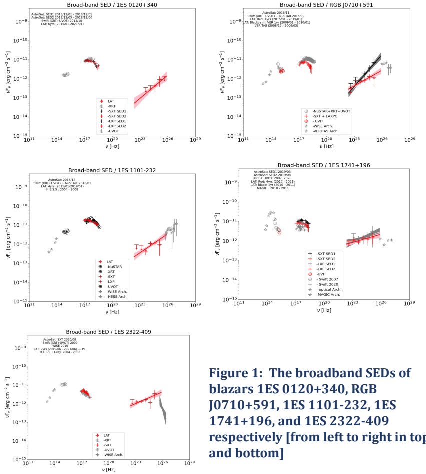

Figure 1: The broadband SEDs of blazars 1ES 0120+340, RGB J0710+591, 1ES 1101-232, 1ES 1741+196, and 1ES 2322-409 respectively [from left to right in top and bottom]

Modeling:

Models used:

One-Zone Leptonic Model:

One-zone steady state leptonic model developed by **Böttcher et al. (2013)**

- Considered ultrarelativistic e- (or e+) population with power-law injection
- Cooling is due to synchrotron and IC (synchrotron self compton, no contribution from external photon fields are considered here)
- Resultant particle distribution is a broken power-law.

One-Zone Hadro-Leptonic (*OneHaLe*) Jet model:

One-zone hadro-leptonic time dependent model developed by - **Zacharias (2021), Zacharias et al. (2022)**

Description:

- Primary injection of protons and electrons in simple power-law form and particles evolved self-consistently
- Cooling is due to : synchrotron (e-, p, pion, muon), inverse Compton, adiabatic, secondary emissions via Bethe Heitler and Pion production

Two different solutions are considered to explain the high energy component,

- Proton synchrotron (shown by the orange dot-dashed line in Fig.2)
- Synchrotron emission from secondary pairs from Bethe-Heitler and pion production (shown by blue dashed line in Fig.2)

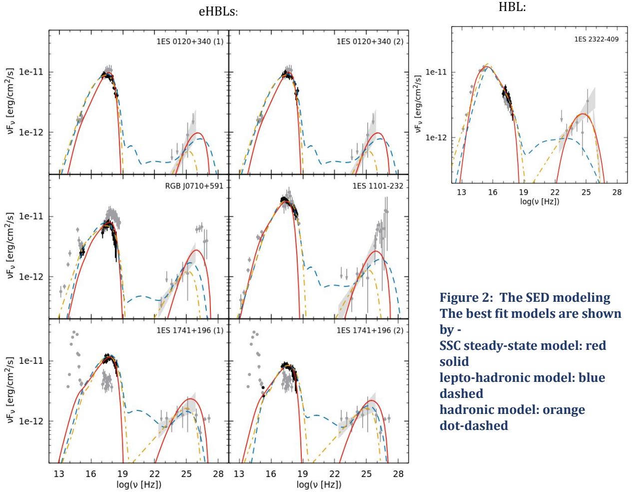

Figure 2: The SED modeling
The best fit models are shown by -
SSC steady-state model: red solid
lepto-hadronic model: blue dashed
hadronic model: orange dot-dashed

Key results and conclusion:

We perform spectral analysis of X-ray in the range 0.3 -15 keV and LAT in 0.3-300 GeV. The main results are as follows:

Results from X-ray and GeV spectral analysis:

Model used: TBabs*log-parabola for X-rays and power-law for LAT spectrum

- All eHBL sources show hard X-ray spectrum ($\alpha \leq 2$), mild to significant curvature ($\beta \sim 0.16$ - 0.45) and their synchrotron peaks are extending up to ~ 1.2 keV.
- PL index for LAT spectra varies between 1.3 - 1.8
- X-ray and GeV spectra of three of the sources (1ES0120, 1ES1101, 1ES2322) are consistent with the previous XRT and LAT results, however,
  - RGBJ0710 shows long term flux variability and spectral softening both in X-rays and γ-rays
  - 1ES1741 indicates long term flux and spectral variability in X-rays (refer to fig. 1)

Results from SED modeling:

Model used: One-zone SSC, OneHaLe - (Lepto-)hadronic and hadronic scenarios

- One zone SSC and (lepto-)hadronic models provide equally good fit to all the SEDs - while hadronic models require extreme values of jet power.
- However, none of the models could explain the VHE data for RGBJ0710 and 1ES1101 - could be associated with the long-term variability in GeV and the VHE band.
- An important caveat is the non-simultaneity of data and the complete interpretation would require simultaneous data in the VHE.

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