The Spectral Energy Distribution of Galaxies
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The challenging SED of AP Librae

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on behalf of the H.E.S.S and *Fermi*-LAT collaborations

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Abstract. Matching the broad-band emission of active galaxies with the predictions of theoretical models can be used to derive constraints on the properties of the emitting region and to probe the physical processes involved. AP Librae is the third low frequency peaked BL Lac (LBL) detected at very high energy (VHE, E>100GeV) by an Atmospheric Cherenkov Telescope; most VHE BL Lacs (34 out of 39) belong to the high-frequency and intermediate-frequency BL Lac classes (HBL and IBL). LBL objects tend to have a higher luminosity with lower peak frequencies than HBLs or IBLs. The characterization of their time-averaged spectral energy distribution is challenging for emission models such as synchrotron self-Compton (SSC) models.

Keywords. gamma rays: observations, galaxies: active, BL Lacertae objects: individual

1. Introduction

Of the 125 sources detected at TeV energies, 41 are blazers. The vast majority (34) are HBLs. Only four are LBLs: S5 0716+714, 1ES 1215+303, BL Lacertae, and AP Librae.

LBLs tend to have a lower synchrotron emission peak than HBLs, but a higher synchrotron peak luminosity. Synchrotron Self-Compton (SSC) models successfully reproduce the time-average Spectral Energy Distribution (SED) of HBLs but have difficulties for LBLs. The characterization of the SED of LBLs from radio to TeV energy is of primary importance to constrain emission models.

AP Librae ($z = 0.049$) was recently detected by the Fermi Large Area Telescope (LAT) Atwood *et al.* (2009) as a bright source (0FGL J1517.9-2423) Abdo *et al.* (2009) and subsequently detected at VHE by the High Energetic Stereoscopic System (H.E.S.S.).

2. Observations and Analysis

AP Librae has been observed by H.E.S.S. during 10.9 hours of live time after the detection. Data were analyzed with the *Model* analysis method (de Naurois *et al.* 2009) leading to a detection with a significance of 7σ for an excess of 81 γ-rays. The spectrum is compatible with a power law of index $\Gamma = 2.45 \pm 0.20$ with a differential flux at the decorrelation energy $E_0 = 0.664$TeV of $I = (1.63 \pm 0.23) \times 10^{-12}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{TeV}^{-1}$.

The analysis includes 3 years of data (from August 4, 2008 to August 4, 2001) taken in the normal all sky survey mode. A binned likelihood method implemented in the `gtlike` tool, part of the *Fermi* analysis software (ScienceTools v9r24p0), was used to derive the spectral parameters of the source. Events from the P7 SOURCE class with an energy between 300 MeV and 300 GeV were considered. The instrument was described by the Instrumental Response Functions (IRFs) P7SOURCE_V6.

The source spectrum is well described by a simple power law of index $\Gamma = 2.09 \pm 0.04$ for a total flux above 300 MeV of $(1.98 \pm 0.10) \times 10^{-8}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. A fit with a log-parabola function does not improve the fit significantly.

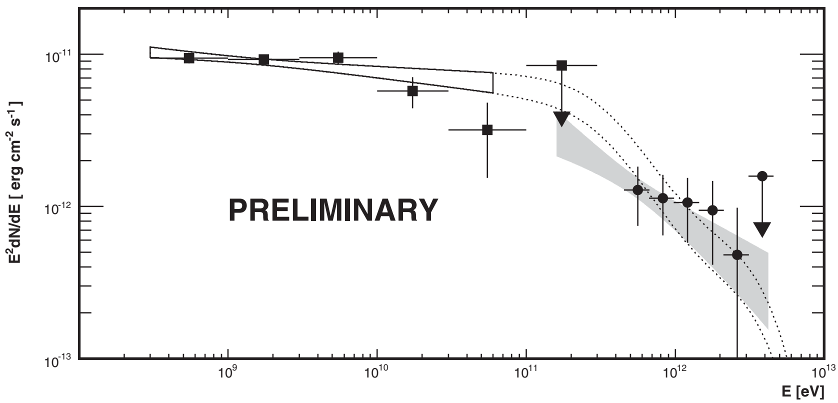

Figure 1. *Fermi*-LAT (square/black) and H.E.S.S. (circle/grey) SEDs. The contours correspond to the 1σ error. The dotted line is the *Fermi* error extrapolated and corrected for EBL using Franceschini *et al.* (2008).

The H.E.S.S. and *Fermi* spectra are shown in Figure 1. The *Fermi* spectrum has been extrapolated towards the H.E.S.S energy range and corrected for Extragalactic Background Light (EBL) absorption using the model of Franceschini *et al.* (2008). This extrapolation is in good agreement with the data points with a χ^2 of 5.7 for 5 degrees of freedom. The corresponding χ^2 probability is 34%.

3. Spectral Energy Distribution

The Spectral Energy Distribution of AP Librae is presented on Figure 2. Contemporaneous data are from UVOT, *Swift*-XRT, *RXTE*, *Fermi* and H.E.S.S. Archival data from NED have also been added. The most important feature of this SED is the broadness of the high energy component, usually assumed to come from inverse Compton (IC) scattering. The low energy cutoff (≈ 0.1 keV) of the synchrotron emission and the spectral index ($\Gamma = 1.60 \pm 0.06$) of the *Swift/RXTE* spectrum clearly show that the X-rays are produced by IC emission. This is quite remarkable since for the HBLs, the X-ray emission is synchrotron emission. This makes AP Librae an interesting source, with a fairly narrow synchrotron component but a broad high-energy component.

The energy of the photons produced by synchrotron is $E_s \propto \gamma^2$. In a SSC framework, assuming IC scattering in the Thomson regime, the photon energy is $E_c \propto \gamma^4$. A ratio between the IC width divided by the synchrotron width of 2, in logarithmic scale, can then easily be explained by SSC models. This is somehow optimistic while Klein-Nishina effects tend to narrow the IC component since the photon energy in this regime is $E_c \propto \gamma^2$. Then, one can expect to find a ratio between 1 and 2.

A fair estimation of the width of the components is obtained by fitting with a 3rd order polynomial and computing the size at half maximum. Following this procedure, the IC component is found to have a FWHM more than a factor of 4 greater than the synchrotron component, larger than a ratio of 2 found in SSC framework.

The result of a simple one zone SSC calculation is also shown in Fig. 2 as well as the model from Tavecchio *et al.* (2010). The electron distribution is described by a broken power law of index $S_1 = 2$ below an energy break $\gamma_b = 1.4 \times 10^4$ and $S_2 = 4.9$ above. A magnetic field B of 0.1G and $\delta = 29$ were chosen for the model, so as to reproduce the low energy and X-ray components, but the model cannot reproduce the *Fermi* and H.E.S.S. data. Adding another spectral component to reproduce the H.E.S.S data does not help

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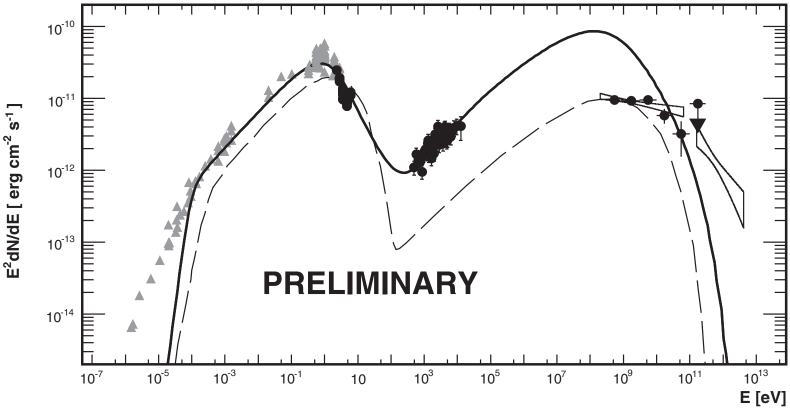

Figure 2. The time-averaged SED of AP Librae. The solid line is our SSC model; dashed line is the model from Tavecchio *et al.* (2010).

since the *Fermi* spectrum is already overestimated by over a factor of 10. For other LBLs, similar difficulties arose - the SED can only be reproduced by adding a component or using multiple emission zones (Abdo *et al.* 2011, Anderhub *et al.* 2009). Thus, TeV LBLs are a challenging and constraining class of objects for the emission models.

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