# *An extended X-ray jet and TeV emission in a low frequency peaked BL Lac object*

S. Kaufmann*[1], S. Wagner[1] , O. Tibolla[2]

1) Landessternwarte, ZAH, Universität Heidelberg, Germany
2) ITPA, Universität Würzburg, Germany

**Abstract**

BL Lac objects are known to have very energetic jets pointing under small viewing angle towards the observer. Many of these show high luminosity over the whole energy range up to TeV, mostly classified as high-energy peaked BL Lac objects. Recently, TeV gamma-ray emission was detected from the low-energy peaked BL Lac object (LBL) AP Lib. Interestingly, this source has also a clear detection of an X-ray jet. The X-ray jet, measured by Chandra, show the same morphology than the detected radio jet. The X-ray spectra of the core and jet component are dominated by inverse Compton emission and their flux differ by one order of magnitude. A narrow synchrotron and a very broad inverse Compton peak up to TeV gamma-rays is visible in the spectral energy distribution.

## AP Lib - extended X-ray jet

The low-energy peaked BL Lac object AP Librae is well known as one of the most active blazars in the optical band. It has a redshift of z=0.049 [2] and is located at $\alpha$(J2000) = 15h 17m 41.8s, $\delta$(J2000)= -24° 22' 19". It has been classified as a BL Lac object by [3] and [4]. AP Lib is the first LBL with detected TeV $\gamma$-ray emission and a clearly visible extended non-thermal X-ray jet. We detected the X-ray jet in our analysis of the 14ks Chandra observation of 4. July 2003 (see Fig. 1). The jet is located in the south-east direction of the source. The jet is dominated by non-thermal emission. Unfortunately only a small frame (subarray) of the CCD was used, so that the real extension of the jet can only be traced out to ~14".

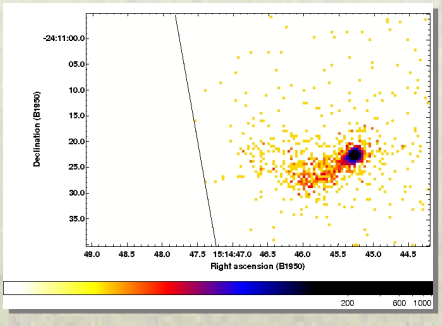
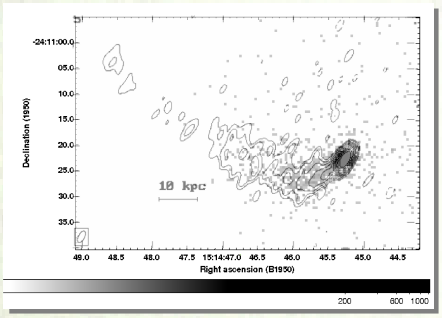



Figure 1:
X-ray count map (0.2 - 8keV) extracted from Chandra observations (14ks) on 4. July 2003. The non-thermal jet is clearly visible. Due to the used subarray, the observed frame is cut (indicated by the line).

Figure 2:
Radio contours of the VLA observation of AP Lib in A+B configuration at 1.36 GHz are plotted on top of the Chandra count map. The restoring beam is 3.0 x 2.0 arcsec in PA 28°. The peak flux density is 1625 mJy/beam and the r.m.s. noise on the image is 0.15 mJy/beam [1].




The spectrum of the core can be well ($\chi^2$/dof=165/147) described by a power law with $\Gamma$ = 1.58 ± 0.04 taking into account the Galactic absorption of $N_H$ = 8.36 *$10^{20}$ cm$^{-2}$ (LAB survey,[5]). The spectrum of the jet can be described by a power law with $\Gamma$ = 1.76 ± 0.14 ($\chi^2$/dof = 9/19), but the statistics is low due to low exposure. The resulting fluxes are F(core,2-10keV) = (2.9 ± 0.1)*$10^{-12}$ erg cm$^{-2}$ s$^{-1}$ and F(jet,2-10keV) = (2.6 ± 0.3)*$10^{-13}$ erg cm$^{-2}$ s$^{-1}$. No significant spectral change between the jet and the core spectrum could be determined, but the hardness ratio indicates a slight change between the core and the jet. Due to limited statistics, the radial trend of the hardness ratio cannot be determined in detail. The spectra determined by Swift/XRT observations from 2007 to 2011 can be described by a power law with photon index of $\Gamma$ = 1.61 ± 0.11.

Observations with the Very Large Array (VLA) on AP Lib show clear detection of the radio jet (see Fig. 2). The radio jet at 1.36GHz emerges along the SE direction and bends towards NE after ~10", for a total extend of ~55". The observations with the D array at 1.4 GHz show a diffuse emission on arcmin scale on the same side of the jet [1]. The comparison of the kpc jet in radio and X-rays reveil the same location of the emission along the SE direction.

AP Librae is known to be one of the most active blazars in the optical band. In 1973, intra-day varibility was detected with a very high rate of 0.5 mag on timescales of 20min [6]. In 1993, [7] found that the host galaxy of Ap Lib appears asymmetric and elongated towards a nearby galaxy (≈ 65" to the north east). Therefore they suggested that Ap Lib is an interacting system. Further observations reveal that both galaxies are at the same redshift indicating a real association [8].

## Ap Lib - Spectral Energy Distribution

The first VHE $\gamma$-ray emission was detected from AP Lib by the H.E.S.S. Cherenkov telescope array in June/July 2010 [9], [10]. It was detected with a significance of 6$\sigma$ above 300GeV, which corresponds to ~2% of the flux of the Crab nebula. No significant flux variations were observed during the ~8 hours of observation. The TeV spectrum can be described by a power law with $\Gamma$ = 2.5 ± 0.2 [10]. Due to this VHE detection, AP Lib is the third LBL after BL Lac and S5 0716+716 detected at VHE $\gamma$-rays. AP Lib is one of few BL Lac objects in which the width of the inverse Compton emission in the SED is $\Delta\nu^2$ and $\Delta\nu$ for the synchrotron emission peak.
A GeV source, 1FGL J1517.8-2423 was detected by the Fermi Gamma-ray space telecope and can be associated with AP Lib. The GeV spectrum can be fit by a power law with a photon index of $\Gamma$ = 2.1 ± 0.1 and result in a flux of F(100MeV-100GeV)=(5.5 ± 0.6)*$10^{-12}$ erg cm$^{-2}$ s$^{-1}$ [11]. No significant flux variation was detected over 11 months of observations.

In Fig. 3, a collection of data from radio to TeV $\gamma$-rays are shown to characterize the spectral energy distribution (SED) of AP Lib. In the radio, observations in several bands from [12] as well as new results from PLANCK [13] are shown. In the optical bands, observations by ATOM are shown, but since the optical emission of the source is very variable, this represents only one flux state of the source comparable to the shown Swift/UVOT observations.

The host galaxy was studied with deep NOT observations by [14] resulting in $m_{host}$ = 14.29 ± 0.01 mag and an effective radius of $r_e$ = 6.72 ± 0.04" in the R-band. In the UV, optical and X-ray regime, the simultaneous observations by Swift are shown. The presented flux values are corrected by the influence of the host galaxy using the template for elliptical galaxies at z=0 by [15]. Since the influence by the host galaxy in the UV is unknown, the fluxes are shown as upper limits for the SED characterizing the blazar. The UV and optical fluxes are also corrected for dust absorption using E(B-V) = 0.138 [16]. The X-ray spectra have been corrected for the Galactic absorption. In near and far UV, results from the GALEX [17] satellite, corrected for extinction, are shown. They are marked as upper limits as well, since they were not taken simultaneous to the UV observations by Swift and the influence of the host galaxy is unknown.

Together with the Swift spectrum, also the core and jet spectra taken from the Chandra observations are shown here. Clearly a lower flux level than with Swift is detected. A slight change in spectral shape is visible between the core and the jet spectrum, but both spectra are dominated by inverse Compton emission. A narrow synchrotron and a very broad inverse Compton peak is visible and the X-ray domain is clearly dominated by the IC emission. Therefore AP Lib is classified as LBL.

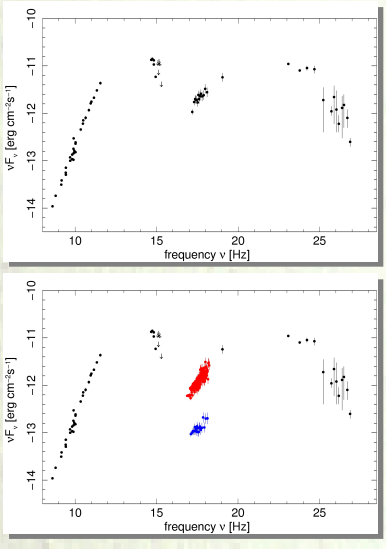



Figure 3: *top*: Spectral energy distribution of AP Lib showing historical radio data from [12], radio data from PLANCK, optical data from ATOM, UV and X-ray results from the Swift observation in 2011, the hard X-ray flux mentioned in the Swift/BAT catalog [18] and the GeV and TeV flux points from [10].
*bottom:* In addition the core (red) and jet (blue) spectrum measured by Chandra in 2003 are shown. Both spectra are dominated by the inverse Compton emission of AP Lib.

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ARI ITA LSW
bmb+f - Förderschwerpunkt Astro-Teilchenphysik Großgeräte der physikalischen Grundlagenforschung

*email: S.Kaufmann@lsw.uni-heidelberg.de

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