Beyond the blazar dichotomy

A study of Ap Librae

O. Hervet*, C. Boisson and H. Sol

LUTH, Observatoire de Paris, CNRS, Université Paris Diderot ; 5 Place Jules Janssen, 92190 Meudon, France

*Olivier.Hervet@obspm.fr

Abstract

It is generally accepted that BL Lacs and Flat Radio Spectrum Blazars (FSRQs) are related to two different jet radio morphologies at kpc scale FRI and FRII, and two accretion regimes "Advection-Dominated Accretion Flow" (ADAF) and Standard disk respectively. It appears that low and intermediate peaked BL Lacs (LBLs and IBLs) seen in very high energy (VHE) could challenge this dichotomy scheme.
We focus on the spectral energy distribution (SED) of the TeV LBL Ap Lib which exhibits an unusual large width of the high energy bump.
This study highlights the significant contribution of the extended jet in the whole SED and demonstrates the efficiency of the inverse-Compton effect of the blob relativistic $e^{\pm}$ interacting into the jet synchrotron radiation to reach VHE energies. By quantifying the energetics, Ap Lib appears to be a intermediate case with regard to the blazar dichotomy, suggesting a smooth transition between different regimes.

I. The strong extended jet in Ap Librae

The extended jet of Ap Lib is unusually strong for a BL Lac source:

- VLBI measurements show highly superluminal apparent velocities (~ 6c) at large distance from the core [8].
- The kpc scale jet radiates in X-rays [7].
- The SED presents a change of slope in the radio-mm range, that we associate to the signature of a transition between the emission of a strong jet and the one of a blob (see Fig. 4).

II. Blob-jet interaction model

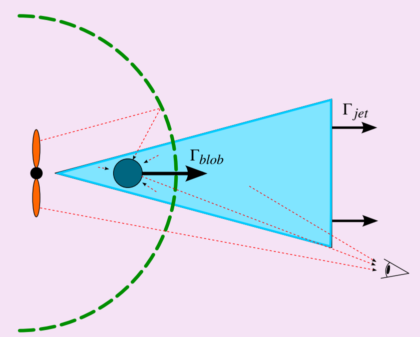

Figure 1: Scheme of the multicomponent emission zones model Bjet. Red dotted lines show differents radiation interactions taken into account in the model.

We develop a self-consistent blob-in-jet model simulating various emission zones and their interactions. Radius such as $R_{blob} \ll R_{jet}$ and densities $\rho_{blob} \gg \rho_{jet}$ are assumed. The radiation processes considered are:

- SSC emission from a blob
- SSC emission from a stratified jet
- Inverse Compton process of the blob particles onto the jet synchrotron
- Disk thermal radiation
- Inverse Compton process of the blob particles onto the disk radiation scattered by the BLR
- Absorption by pair productions from [2] on various photon fields
- EBL absorption based on the model of [3]

Acknowledgement

We thank Andreas Zech and H.E.S.S. collaboration members for helpful discussions. This research has made use of data from the MOJAVE database that is maintained by the MOJAVE team. We acknowledge the use of data and software facilities from the ASI Science Data Center (ASDC), managed by the Italian Space Agency (ASI). Part of this work is based on archival data and on bibliographic information obtained from the NASA/IPAC Extragalactic Database (NED) and from the Astrophysics Data System (ADS) of the SIMBAD database, operated at CDS, Strasbourg, France.

III. New constraints from the radio-gamma link

The model presented here has numerous free parameters, however radio observational features given by [8] can be used to constrain them.

Radio core

The radio core emission is strongly associated with the standard extended emission zone in the radio range of the SED (red dot in Fig. 4). Thus the shape and flux of the radio core are associated with the base of the simulated jet projected on the sky plane. These features are consistent with an half-opening jet angle of $\alpha = 0.4°$ and a viewing angle $\theta = 1.4°$.

Radio knots

Radio knots are seen moving along the jet with an average apparent velocity of $\beta_{app} = 6.16$ c. Knowing the viewing angle θ, an average Doppler factor value of $\delta \simeq 22$ is deduced. The size of radio knots increases with their distance to the core in accordance with a fit by linear regression. Thus, according to the viewing angle θ a knot half-opening angle $\phi = 0.1°$ can be determined (see Fig. 2).

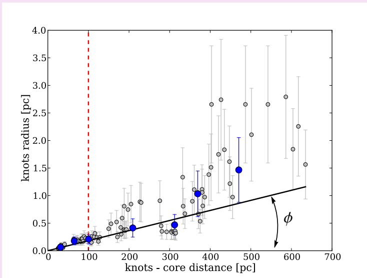

Figure 2: Core distances and radius of radio knots observed by MOJAVE for an angle with the line of sight θ of 1.38°. Grey dots show the referenced knots from August 18, 1997 to March 5, 2011. Blue dots show radio knots of December 26, 2009. The black line is a linear regression used to characterize the knots expansion angle ϕ. The red dashed line at 100 pc marks the length of the simulated jet.

In order to complete the general multi-wavelength view of the jet, the parameters of the VHE blob simulated are constrained by those of the radio knots. The radio knot parameters are in good agreement with the ones expected from the blob at this energy range which tends to confirm this association (see Fig. 4).
Fig. 3 shows the jet structure deduced from this radio analysis and the radio-gamma link. This interpretation is consistent with the observations of [9] and [8], who deduced a thin ribbon-like structure embedded within a broader conical outflow in several VLBI quasars.

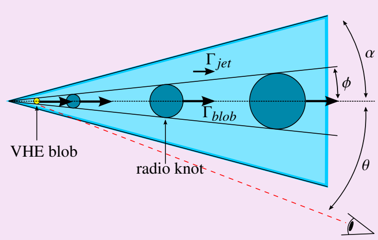

Figure 3: Sketch of the Ap Lib structured jet showing the knot expansion angle ϕ, the opening jet angle α, and the angle with the line of sight θ. Not to scale.

References

[1] A. Celotti and G. Ghisellini. MNRAS, 385, 2008.
[2] P. S. Coppi and R. D. Blandford. MNRAS, 245, 1990.
[3] A. Franceschini, G. Rodighiero, et al. A&A, 487, 2008.
[4] G. Ghisellini and F. Tavecchio. MNRAS, 387, 2008.
[5] O. Hervet, C. Boisson, et al. *ArXiv: 1503.01377*, 2015.
[6] H.E.S.S. Collaboration. A&A, 573:A31, 2015.
[7] S. Kaufmann, S. J. Wagner, et al. ApJ, 776, 2013.
[8] M. L. Lister, M. F. Aller, et al. AJ, 146, 2013.
[9] M. Perucho, Y. Y. Kovalev, et al. ApJ, 749, 2012.
[10] Q. Wu and X. Cao. ApJ, 687, 2008.

V. Modelling and discussion

From the SED modelling presented in Fig. 4, it is possible to test the consistency of the emission and propagation scenario, and evaluate the energy budget of the source.

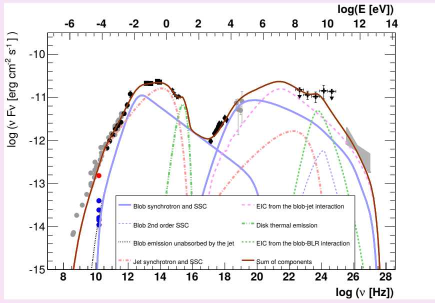

Figure 4: Multi-component SSC modelling. Black data: simultaneous or quasi-simultaneous observations from Planck, Wise, UVOT and Fermi. Grey data: non-simultaneous observations from 2MASS, BAT, H.E.S.S. and archivals data. The blue dots are the VLBI radio knots and the red dot is the VLBI radio core. The EBL absorption based on the model of [3] is taken into account in this modelling. Recently the H.E.S.S. collaboration redefined the VHE spectrum of Ap Lib with more observation time [6], remaining compatible with the modelling presented here.

The blob synchrotron cooling time is 12.8 h for the VHE emission and 9.7 years for the lowest radio frequencies. Considering the low VHE variability and the large distance of radio knots to the core, a very stable and efficient particle acceleration mechanism over long periods is needed.
Assuming that the high-energy emerging blob follows the same expansion as the observed radio knots, we can approximate its expansion velocity with the Alfven velocity and deduce the mass density. Making the same calculation for the pc-scale jet, it appears that the cold particle density dominates widely the density of non-thermal particles.

Following the description of [1], we can determine the power of various components as follows.

Table 1: Powers of the different components of the Ap Lib total jet expressed in log(P [erg.s^{-1}])

Power	Blob	Jet	Total
Radiation	42.7	41.7	42.7
Magnetic	40.9	41.2	41.4
Cold electrons	43.5	42.6	43.5
Non-thermal electrons	43.9	42.0	43.9
Protons	46.8	45.5	46.8

The source is dominated by the kinetic power of particles, mainly in the cold protons of the blob, which represent 99.8% of the total power (see Table 1). The non-thermal electrons slightly dominate the cold electron population in the blob, while it is the opposite in the jet, but the two cases show almost an equipartition between cold and non-thermal electrons. The magnetic field appears far below the equipartition with the non-thermal electrons and the radiation in the blob, while this equipartition is almost achieved in the longer lifetime jet.

VI. A smooth transition in the dichotomy scheme

The energetics allows us to evaluate the accretion regime. Considering the mass inflow and outflow rates $\dot{M}_{out} \simeq \dot{M}_{in}$, we have an accretion efficiency of $\eta \simeq 9.3 \times 10^{-3}$ at the limit between ADAF and standard disk regime of $\eta \simeq 0.01$ proposed by [10]. Following the description of [4], we obtain $\eta_{crit} \simeq 3.1 \times 10^{-3}$, very close to the limit value of 3×10^{-3} between BL Lac and FSRQ.
Ap librae has a FRI morphology but the low aperture angle, the radio superluminal apparent speeds and the jet energetics strongly matter dominated are specific to FRII sources. In all criterions given by the blazar dichotomy scheme, Ap Librae seems to be an intermediate source.
The existence of this kind of intermediate blazar tends to prove the presence of a continuity between different jet and accretion regimes. They are an essential key to understand the mechanisms of radio-loud AGN.

A more detailed study on this subject can be found in Hervet et al. (2015) [5].

Relativistic Jets: Creation, Dynamics, and Internal Physics, Krakow, Poland, 2015