The relevance of a blazar kinematical classification

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Abstract

Blazar jets seen in radio very long baseline interferometry (VLBI), very close to the core, show various and intriguing behaviours. Some of them present multiple quasi-stationary knots, others have ultra relativistic ones. Also some of them present multiple behaviours depending of the jet zone and/or depending of the epoch. The wealth of the radio VLBI data, accumulated during many years, allows us to begin a global approach of a blazar classification following their kinematical features.
After a selection of 161 blazars on the MOJAVE sample [7], we identify three main classes of VLBI jets: class I with quasi-stationary knots, class II with knots in relativistic motion from the radio core, and class I/II, intermediate, showing quasi-stationary knots at the jet base and relativistic motions downstream.
It appears that these three classes can be associated with the multi-wavelength spectral properties of blazars and also with their large-scale structures. The interpretation by a global scenario of multiple recollimation shocks in an embedded jet structure is found to be the most appropriate to chart these tree classes properties.

I. Method

From the original sample of 200 AGN presented in [7], we select blazars with known redshift and sufficiently monitored to allow an estimation of apparent velocities. This leads to a sample of 161 sources, which can be classified by distinct kinematic structures of jets. Distinguished by minimal and maximal apparent velocities, three classes are identified:

- Class I: Blazars with quasi-stationary knots or with "low" apparent velocities ($\max(\beta_{app}) < 2$ c): 25 sources.
- Class II: Blazars with knots in relativistic motion from the jet base ($\max(\beta_{app}) \geq 2$ c): 99 sources.
- Class I/II: Blazars with quasi-stationary knots close to the jet base ($\min(\beta_{app}) \leq$ c) and in relativistic motion downstream ($\max(\beta_{app}) \geq 2$ c): 37 sources.

II. Link with the spectral classification

A notable result is the good overlap of this kinematic classification with the usual spectral classification; class I corresponds to HBLs, class II to FSRQs, and class I/II to IBLs/LBLs. The HBL sources, which are less luminous in radio, are unfortunately under-represented in the MOJAVE database.

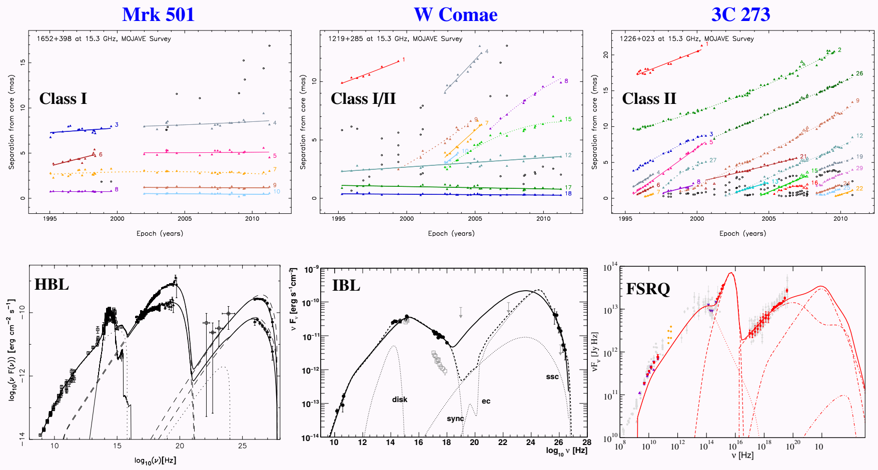

Figure 1: Example of three blazars representative of the link between this kinematical classification and the usual spectral classification. SEDs from [4],[1], and [2].

Spectral class	number	Class I	Class I/II	Class II
HBLs	5	100%	0%	0%
IBLs/LBLs	23	32%	56%	12%
FSRQs	125	8%	16.5%	75.5%

Table 1: Blazar percentage overlap of the kinematic classification with spectral classification in our sample.

III. Overlap with large-scale radio jets

Following the radio features of numerous blazars described in [6], we can check the overlap between VLBI kinematic classes and the large-scale morphologies. Classes I/II and II are mostly in the FR II domain, contrary to class I, which present a median extended luminosity that is almost two orders of magnitude lower than the other classes. This suggests that large-scale radio jet properties are more affected by the VLBI kinematic difference between class I and the other classes than between classes I/II and II.

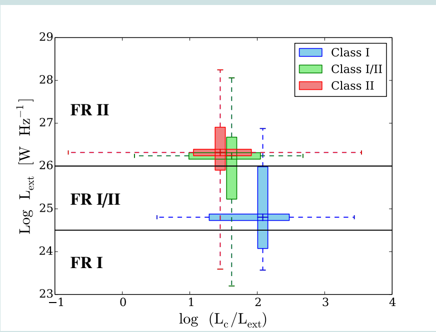

Figure 2: Box plots of extended jets radio luminosities vs. core-extended jet luminosities ratio for the three kinematic classes. Boxes are delimited by the first and last quartiles, middle lines are medians, and dashed lines account for the distributions size. Black lines delimit regions where the luminosities of extended jets are typical of FR I or FR II.

IV. Radio knot evolution

It is also possible to study the knot evolution for the three classes with the radio knot features given in [7], such as their radio flux and sizes. We determine the flux and size median evolutions, dF_k/dt and dD_k/dt, for each source, respectively.
There is a clear distinction between the three kinematic classes. The median values of class I sources show an almost non-evolution of their knots, regarding their flux or size. The other classes show a clear expansion and cooling with values increasing continuously between class I/II and II.

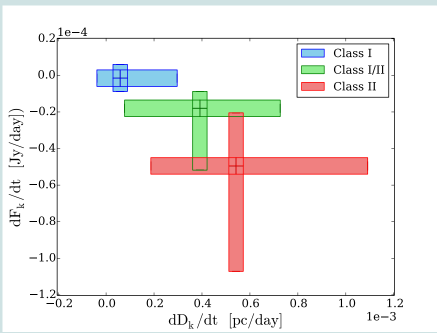

Figure 3: Box plots of knot diameter evolution vs. knot flux evolution for sources of the three kinematic classes. Boxes are delimited by the first and last quartiles; middle lines are medians.

V. Discussion & interpretation

The radio knot structure can be associated to multiple recollimation shocks in jets. This is supported by the measurements of jet magnetic topologies [5, 3], which is consistent with the jets MHD simulations showing that longitudinal magnetic fields, as seen in HBLs, induce more powerful recollimation shocks than the other magnetic topologies, as seen in LBLs and FSRQs [11]. Moreover, multiple stationary shocks, as in class I sources, can further increase the particle acceleration [9]. Thus, the synchrotron peak frequency appears to be linked to the shock efficiency, depending on the jet magnetic topologies.
Regarding the various kinematic behaviour between the classes, the huge domination of the kinetic power of IBLs, LBLs and FSRQs and the instabilities provoked by their imbricated jet structure could break the magnetic recollimation shock strings, but maintain a good general collimation due to the strong kinetical power [10].

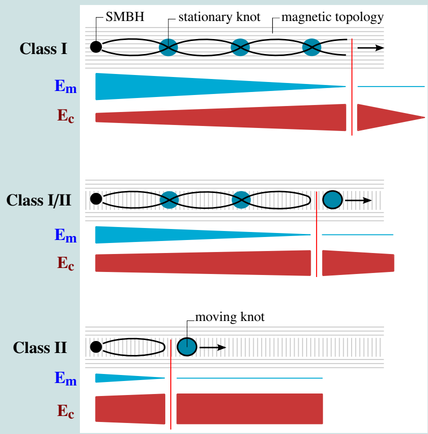

Figure 4: Scheme of the three kinematic classes. We link the kinematics with the various balances between jet magnetic energy E_m, and the kinetic energy E_c. Their width is representative to their relative strength along the jets.

Conclusion

The link between spectral and kinematic classifications (class I corresponding to HBLs, class I/II corresponding to IBLs and LBLs, and class II corresponding to FSRQs) gives valuable clues to the area and mechanisms responsible for the particle acceleration. A scenario of multiple recollimation shocks is favoured to interpret this link and also to describe the various behaviours of VLBI jets.
In any case this scenario with multiple recollimation shocks in blazars will be tested along several paths, via MHD simulations and variability studies.
For a more detailed study, see O. Hervet, C. Boisson, and H. Sol. *ArXiv: 1605.02272*, 2016

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