Extragalactic jets from every angle
Proceedings IAU Symposium No. 313, 2014
F. Massaro, C. C. Cheung, E. Lopez, A. Siemiginowska, eds.

doi:10.1017/S1743921315001842

The link between broad emission line fluctuations and non-thermal emission from the inner AGN jet

J. León Tavares[1], V. Chavushyan[1] A. Lobanov[2,3] E. Valtaoja[4] and T. G. Arshakian[5]

[1]Instituto Nacional de Astrofísica Óptica y Electrónica (INAOE), Apartado Postal 51 y 216, 72000, Puebla, México
email: leon.tavares@inaoep.mx
[2]Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany
[3]Institut für Experimentalphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany
[4]Tuorla Observatory, Department of Physics and Astronomy, University of Turku, 20100 Turku, Finland
[5]I. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Germany

Abstract. AGN reverberate when the broad emission lines respond to changes of the ionizing thermal continuum emission. Reverberation measurements have been commonly used to estimate the size of the broad-line region (BLR) and the mass of the central black hole. However, reverberation mapping studies have been mostly performed on radio-quiet sources where the contribution of the jet can be neglected. In radio-loud AGN, jets and outflows may affect substantially the relation observed between the ionizing continuum and the line emission. To investigate this relation, we have conducted a series of multi-wavelength studies of radio-loud AGN, combining optical spectral line monitoring with regular VLBI observations. Our results suggest that at least a fraction of the broad-line emitting material can be located in a sub-relativistic outflow ionized by non-thermal continuum emission generated in the jet at large distances (> 1 pc) from the central engine of AGN. This finding may have a strong impact on black hole mass estimates based on measured widths of the broad emission lines and on the gamma-ray emission mechanisms.

Keywords. galaxies: nuclei, galaxies: jets, quasars: emission lines, galaxies: individual (3C 120, 3C 454.3, 3C 390.3), gamma rays: observations

1. Introduction

The correlated variability of the optical-UV continuum emission and the strength of the broad emission lines in AGN has been known and characterised with monitoring campaigns over the last decades (e.g. Blandford & McKee 1982, Peterson 1993, Shapovalova et al. 2001, Shapovalova et al. 2013). The delay between increases in the continuum optical-UV emission and the onset of the increase in the intensity of the broad emission lines allows to obtain a direct estimation about the distance of the broad-emission line region to the ionizing source. Then, assuming that the BLR clouds follow a virialized motion, the mass of the central black hole can be estimated. The so-called reverberation mapping technique has been used to determine structure and dynamics of the BLR and to provide scaling relations to estimate black hole masses by characterizing single-epoch spectra (e.g. Vestergaard & Peterson 2006).

However, reverberation mapping studies have been traditionally performed mostly on radio-quiet AGN where the dominant source of continuum emission has a thermal origin

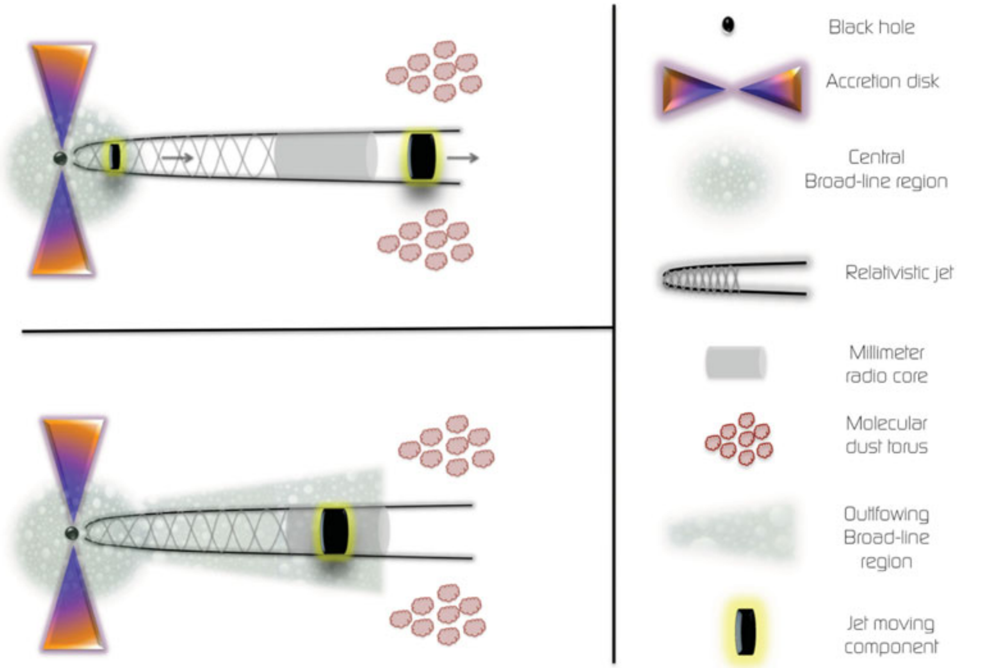

Figure 1. *Top-left panel*: Sketch of the inner regions of a radio loud AGN. *Right panel:* Identification of each of the inner AGN components. *Bottom-left panel:* Sketch of the inner regions of the γ-ray blazar 3C 454.3 (León-Tavares *et al.* 2013). The dimensions in the sketch are not to scale.

(e.g. accretion disk). Nevertheless, in radio-loud sources, the non-thermal emission produced in the inner regions of relativistic jets (see Figure 1) can dominate at all energies and could become an important source of ionizing continuum. So the question arises: Can the non-thermal continuum emission from the inner jet ionize clouds of the BLR?

2. 3C 454.3

We have explored the variability of the broad emission lines in 3C 454.3 (so far, the brightest blazar seen by the *Fermi* gamma-ray space telescope) in order to use it as an auxiliary piece of information to probe the geometry and physics of its innermost regions and to discriminate between scenarios of the gamma-ray production. The optical spectra of 3C 454.3 have been acquired, as part of the Ground-based Observational Support of the Fermi Gamma-ray Space Telescope at the University of Arizona monitoring program (Smith *et al.* 2009), over a period of three years (2008-2011) and due to its redshift ($z = 0.859$) we have had access to the middle-UV region of the spectrum, allowing us to monitor its Mg IIλ2800Å broad-emission line and adjacent UV-continuum λ3000Å.

https://doi.org/10.1017/S1743921315001842 Published online by Cambridge University Press

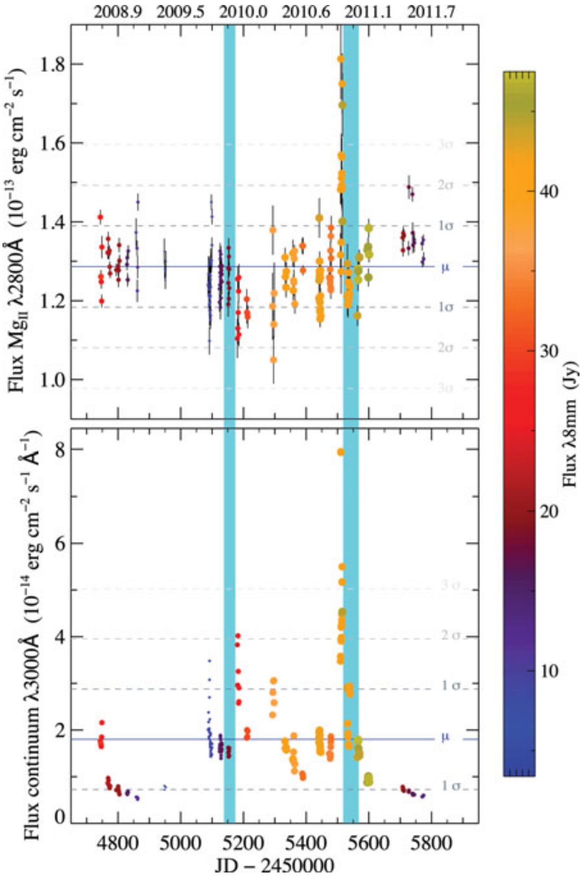

Figure 2. Flux evolution of Mg IIλ2800Å emission line (*top panel*) and UV-continuum λ3000Å emission (*bottom panel*). For each panel, the solid (blue) horizontal line denotes the mean flux (μ) observed during the monitoring period, whereas dashed (gray) horizontal lines show multiples of σ, where σ is the standard deviation of the flux. In this work, we consider a significant flare if the levels of emission exceed 2σ. Symbol size and color are coded according to the color bar displayed, where the larger and lighter the symbols, the higher the level of λ8mm emission observed. The vertical stripes show the time when new blobs were ejected from the radio core and their widths represent the associated uncertainties.

In León-Tavares *et al.* (2013), we found for the first time a statistically significant flare-like event in the Mg IIλ2800Å light curve of 3C 454.3. As shown in Figure 2, the highest levels of Mg IIλ2800Å line flux ($\geqslant 2\sigma$) occurred after λ8mm flare onset, during an increase in the optical polarization percentage, before the emergence of a new superluminal component from the radio core and within the largest gamma-ray flare ever seen. This finding crucially links the broad-emission line fluctuations to the non-thermal continuum emission produced by relativistically moving material in the jet and hence to the presence of broad-line region clouds surrounding the radio core (see bottom-left panel of Figure 1). The variability of other broad-emission lines in 3C 454.3 has been reported in Isler *et al.* (2013).

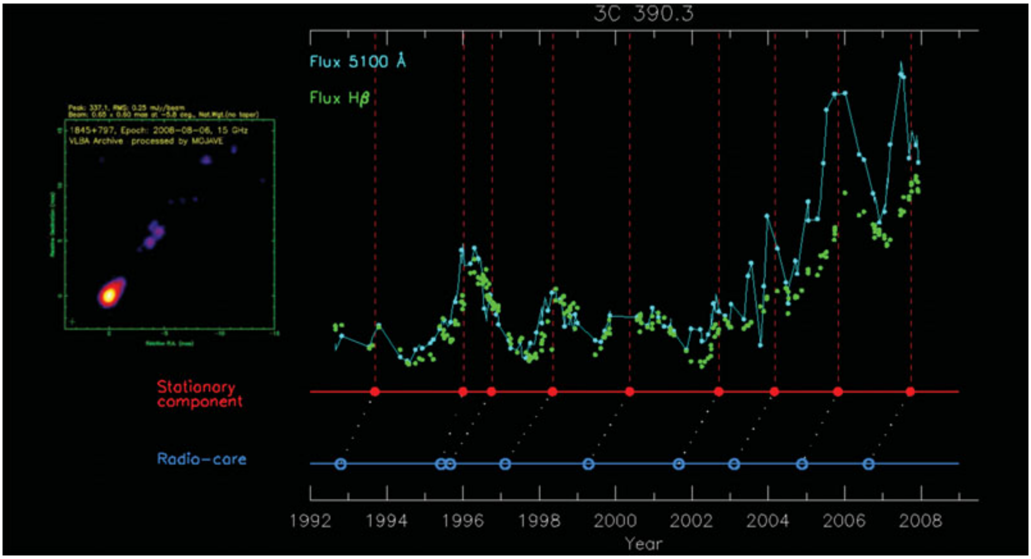

Figure 3. Variability of the optical continuum (5100 Å), Hβ broad-line emission and jet kinematics in the radio galaxy 3C 390.3 (Arshakian *et al.* 2010). All optical flares (both continuum and Hβ broad emission line) are associated with component jet ejection events: the flare rises after the epoch of ejection of a new jet component from the radio-core and it reaches the maximum around the epoch at which the ejected radio knot passes through a stationary component downstream the jet. The maximum of Hβ broad-line emission occurs when a component passes through a stationary component in the inner jet located at a distance of $\sim$ 0.5 pc from the radio-core (the radio core might be located at several parsecs from the black hole). This result strongly suggests: (i) that the jet can power a significant amount of broad-line emission and, (ii) the presence of broad-line region material at distances well beyond the canonical BLR (< 1 pc).

3. 3C 390.3 and 3C 120

Arshakian *et al.* (2010) and León-Tavares *et al.* (2010) found that for the radio galaxies 3C 390.3† and 3C 120‡, the variable optical continuum starts to rise when a new superluminal component leaves the radio core seen at 15 GHz and its maximum occurs when the component passes through a stationary feature located downstream of the radio core. Since these two radio galaxies are known to reverberate (Shapovalova *et al.* 2010; Grier *et al.* 2012), in the sense that the Hβ broad emission line responds to changes in the optical continuum, the authors conclude that the jet can power a significant amount of broad-line emission particularly during strong non-thermal continuum flares from the jet (see also Belokon' 1987 and Perez *et al.* 1989).

4. Summary

The above results suggest the presence of an additional component of the BLR, dubbed as *outflowing BLR* (see bottom-left panel of Figure 1), which in effect might be filled with BLR material dragged by the relativistic jet as it propagates downstream of the black hole or perhaps could be a sub-relativistic outflow arising from an accretion-disk wind. The presence of broad-line region material surrounding and being ionized by the radio core (at distances beyond the inner parsec) have far reaching implications for the current AGN energy release models (León-Tavares et al. 2011b) as well as for black hole mass

† `http://www.metsahovi.fi/~leon/movies/3c3903.gif`
‡ `http://www.metsahovi.fi/~leon/movies/3c120.gif`

https://doi.org/10.1017/S1743921315001842 Published online by Cambridge University Press

estimates made in AGN using the technique of reverberation mapping and its scaling relations.

The fact that broad emission lines in radio-loud AGN might respond to changes of the non-thermal continuum prevents us from using the single epoch virial black hole mass estimates because the latter assumes: (1) a single localized ionization source (i.e., accretion disk) and (2) virial equilibrium of the BLR clouds. The latter assumptions cannot be fulfilled during episodes of strong flaring activity, hence the ionization of BLR clouds by non-thermal emission from the jet might introduce uncertainties to the black hole mass estimates derived by assuming virial equilibrium of the BLR. Alternative scaling relations to weigh the black holes in strongly beamed sources are discussed and implemented in León-Tavares *et al.* (2011a, 2014).

References

Arshakian, T. G., León-Tavares, J., Lobanov, A. P., *et al.* 2010, *MNRAS*, 401, 1231
Belokon', E. T. 1987, *Astrophysics*, 27, 588
Blandford, R. D. & McKee, C. F. 1982, *ApJ*, 255, 419
Grier, C. J., Peterson, B. M., Pogge, R. W., *et al.* 2012, *ApJ*, 755, 60
Isler, J. C., Urry, C. M., Coppi, P., *et al.* 2013, *ApJ*, 779, 100
León-Tavares, J., Lobanov, A. P., Chavushyan, V. H., *et al.* 2010, *ApJ*, 715, 355
León-Tavares, J., Valtaoja, E., Chavushyan, V. H., *et al.* 2011a, *MNRAS*, 411, 1127
León-Tavares, J., Valtaoja, E., Tornikoski, M., *et al.* 2011b, *A&A*, 532, A146
León-Tavares, J., Chavushyan, V., Patiño-Álvarez, V., *et al.* 2013, *ApJ* (Letters), 763, L36
León Tavares, J., Kotilainen, J., Chavushyan, V., *et al.* 2014, *ApJ*, 795, 58
Perez, E., Penston, M. V., & Moles, M. 1989, *MNRAS*, 239, 75
Peterson, B. M. 1993, *PASP*, 105, 247
Shapovalova, A. I., Burenkov, A. N., Carrasco, L., *et al.* 2001, *A&A*, 376, 775
Shapovalova, A. I., Popović, L. Č., Burenkov, A. N., *et al.* 2013, *A&A*, 559, A10
Smith, P. S., Montiel, E., Rightley, S., *et al.* 2009, eConf Proceedings C091122, arXiv:0912.3621
Vestergaard, M. & Peterson, B. M. 2006, *ApJ*, 641, 689

https://doi.org/10.1017/S1743921315001842 Published online by Cambridge University Press