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On the Nature of BL Lac Objects

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Abstract. The BL Lacertae objects, or BL Lacs, have multi-wavelength continua dominated by non-thermal emission from a relativistic jet, and are characterised by a lack of optical emission lines. We find, through observations and modelling that the dominant factor in a source being called a BL Lac is the intrinsic lack of flux from the broad-line region – likely connected with a weak accretion disc – rather than an overwhelmingly powerful jet. This has important implications for the nature of the accretion flow in these objects.

Key words. BL Lacertae objects: general – quasars: general – accretion

1. Introduction

BL Lacertæ objects, or BL Lacs, are a class of AGN that are defined on the basis of their optical spectra. A BL Lac exhibits no emission line with a rest frame equivalent width $W_\lambda > 5$Å (Stocke et al., 1991) (although this criterion is sometimes weakened in the case of low-luminosity objects where the host galaxy is important in the optical spectrum (Marchã & Browne, 1995)). BL Lacs are generally found via surveys at radio or X-ray wavelengths and confirmed as BL Lacs through follow-up optical spectroscopy.

In this paper, we discuss the reason for the lack of prominent emission lines in BL Lacs. Most theories (Blandford & Rees, 1978; Urry & Padovani, 1995) invoked to explain this lack involve the presence of an extra continuum component that masks emission lines. From the shape of the radio–IR–optical spectral energy distribution (SED) (e.g. Impey & Neugebauer, 1988), as well as high optical and radio polarisation, this extra component is understood to be synchrotron emission, which comes from the relativistic jet. In this picture, the Doppler boosting from the jet, which is viewed at a small angle to the direction of its propagation, strongly increases the flux of this synchrotron component, swamping the emission line flux.

2. Modelling the PHFS

We are able to examine this model for BL Lacs by modelling the optical emission from sources in the Parkes Half-Jansky Flat-spectrum Sample (PHFS, Drinkwater et al., 1997). This is a sample of 323 radio-bright flat spectrum radio sources, consisting mostly of flat-spectrum radio quasars, FSRQs, with some BL Lacs and radio galaxies.

Optical–near-infrared spectral energy distributions (SEDs), covering the filters $BVRIJHK$, were obtained through quasi-simultaneous observations by Francis et al. (2000) for a subset of the PHFS. In Whiting et al. (2001), we fit models to this broad-band data for approximately a third of the PHFS, concentrating on the unresolved “stellar”

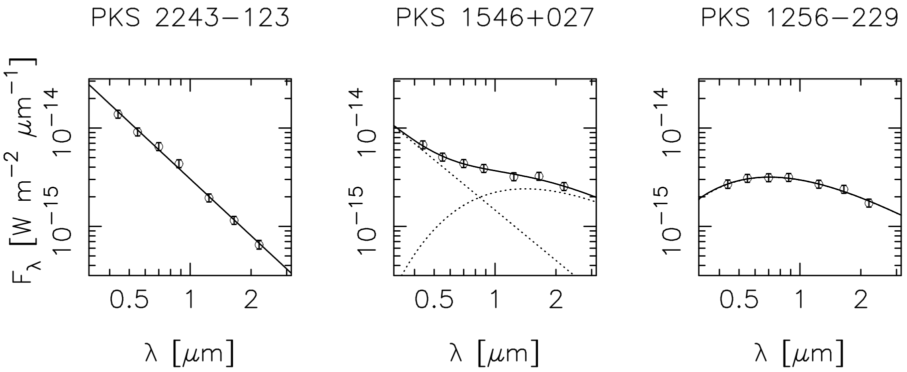

Fig. 1. Example fits from Whiting et al. (2001). From left to right: accretion disc dominated; equal amounts of accretion disc and synchrotron; synchrotron dominated.

sources where the host galaxy is not an important contributor to the optical emission. The two models are: a blue power law representing accretion disc emission, with a slope $f_\lambda \propto \lambda^{-1.7}$ (the median slope of optically-selected LBQS quasars (Francis, 1996)); a synchrotron component comprising a power law at long wavelengths with an exponential cutoff parametrised by some "peak" wavelength λ_p, representing emission from the jet. Some examples of the fits are shown in Fig. 1.

Approximately a third of these sources are dominated by the accretion disc component with no sign of optical synchrotron. These sources do have synchrotron emission from the jet present (as it is responsible for the flat-spectrum radio emission), but that component most likely turns over at longer wavelengths than those probed by our optical/NIR data. A similar number of sources, however, do show good evidence for optical synchrotron emission. In many cases, this emission dominates the continuum, and there is no evidence for any accretion disc component.

All the BL Lac objects in this sample fall in the latter group, as they all have SEDs dominated by the synchrotron component. However, their properties are indistinguishable from the rest of the optical synchrotron sources. Their distributions of λ_p and ratio of synchrotron to accretion disc flux are statistically indistinguishable (although all the BL Lacs have a high ratio). The main difference lies in the emission line equivalent widths, with all the BL Lacs at the low end of the distribution.

BL Lacs, then, seem to have similar broadband spectral properties to quasars with optical synchrotron emission. The defining difference appears to be with the strength of the emission lines, where BL Lacs have intrinsically weaker lines. This is in accord with previous studies of BL Lacs and quasars, such as Scarpa & Falomo (1997).

3. Clues from other surveys

What support is there from the literature for such a picture of BL Lacs? Firstly, we can look at ultraviolet spectroscopy of BL Lacs and FSRQs, such as that of Kinney et al. (1991). If there was an accretion disc and broad-line region (BLR) present but swamped by a synchrotron component, their emission would be relatively more prominent in the UV, since the disc flux increases for shorter wavelengths and stronger lines are seen at shorter wavelengths, while the synchrotron components tend to decrease (due to the cutoffs seen in the PHFS sources). However, the BL Lac objects in Kinney et al. (1991) show either very weak lines or an absence of lines, suggesting an intrinsically weak BLR flux in these objects.

In the objects we have looked at thus far, the synchrotron component has only extended to optical (or UV) energies. However, there are high-frequency-peaking BL Lacs (HBLs) where this component dominates all frequencies up to X-rays. In analogy with the low-frequency peaking objects, we should expect sources that have an HBL-like SED but with quasar-like emission lines in the optical. Recent deep X-ray and radio surveys, such as DXRBS and RGB, have found sources that fit this description (Padovani et al., 2003, also Landt et al. in these proceedings). These sources have a jet-dominated continuum, but with a strong enough accretion disc and BLR to have significant emission lines present in their optical spectrum.

Finally, there exists one *optically*-selected sample of BL Lacs, the 2dF BL Lac sample (2BL) of Londish et al. (2002). These are objects selected on the basis of their optical colour as targets for the 2dF Quasar Redshift Survey (Croom et al., 2001), and which were subsequently found to have featureless spectra. These objects are generally radio-quiet (most have $S_{8.4\mathrm{GHz}} < 0.2$mJy) and weak at X-rays. A likely interpretation for such objects (discussed in Londish et al., 2004) is that they are otherwise normal radio-quiet AGN that have a weak/absent BLR, and so the optical continuum is dominated by just the accretion disc. These objects are then at the extreme end of the distribution of BLR strengths in radio-quiet quasars.

4. How do you make a BL Lac?

It is clear, then, that the disc, the emission lines and the jet can span a wide range of relative strengths. Simply having a dominant jet component does not necessarily mean that there will be no emission line or accretion disc flux seen. In this picture of BL Lacs, the lack of emission lines is due to an intrinsically weak BLR flux. Either there is little or no gas in the BLR, or the gas that is there is not sufficiently ionised. The continuum from the relativistic jet then dominates by default, and is not necessarily very strongly boosted.

There are (at least) two scenarios in which this could be the case. First, the BLR could be relatively depleted in gas, with a relatively normal accretion disc present. This is likely to be the case for the 2BL sources. The second alternative is that the gas is there, but there are insufficient ionising photons to produce the required emission line flux.

The best candidate for the source of ionising photons is the accretion disc. The jet could provide some ionising photons, but it is unlikely to be the major source: Corbett et al. (2000) found that the response of the weak Hα line in BL Lac to continuum variations was best explained by the presence of a hot accretion disc, weak enough not to be detected in optical spectra. Thus, we expect that in BL Lacs the flux from the accretion disc is weaker than that seen in quasars. This implies that the accretion process is somewhat different in the BL Lacs.

5. Accretion processes in BL Lacs

A possible accretion scenario for BL Lacs is that the accretion onto the black hole (BH) is not progressing via a standard quasar-style thin disc but via a low-radiative-efficiency process, such as an advection-dominated accretion flow (ADAF). Wang et al. (2002) found that both LBLs and HBLs have highly sub-Eddington accretion rates, which could be explained by the presence of an ADAF.

An alternative scenario is that the accretion in BL Lacs does proceed via a “normal” thin disc, but that the inner, hotter regions of the disc closest to the BH are disrupted or absent. For an accretion disc around a typical supermassive BH, the bulk of the ionising radiation will come from the innermost parts, and so a depletion of this region would reduce the ionisation of the BLR markedly. A hybrid model might be possible, where a thin disc dominates at large disc radii, but an ADAF is present in the inner regions, reducing the disc output (see e.g. Cao, 2003).

An instructive comparison may be made by looking at Galactic black hole X-ray binary systems, in particular the system GRS 1915+105, which has a similar structure to AGNs with both an accretion disc and jets. This system shows evidence of coupling between the disc and the jet, where disturbances in the inner disc, seen as spikes and dips in X-rays, coincide with ejections of matter into the jet, as observed in the radio. A comprehensive review of this source can be found in Fender & Belloni (2004).

This situation is qualitatively similar to our description of BL Lacs, where the jet is dominating, and the disc emission is suppressed. Note that there is no equivalent of the BLR in X-ray binaries, so we can only compare the relative strengths of the emission from the inner disc. This explanation would mean that we are seeing BL Lacs during an ejection event, where the disc is relatively depleted, with matter falling into the BH and a small amount being injected into the jet.

Such a comparison raises the intriguing possibility that BL Lacs represent a transient phase of AGNs, where the jet is dominating during the suppression of the inner accretion disc. Inevitably the disc will fill up again, with the AGN reverting back to a quasar-like state. If one scales the timescales of XRBs (of the order of 100 s) by the BH mass, the lifetime of the BL Lac phase is $\sim 30 - 300$ yr. The lower end of this range is becoming observable for some sources, and we encourage more spectral monitoring of BL Lacs to search for spectral variations.

An important caveat on this is that scaling by mass is probably too simplistic, as the cooling time and dynamical time do not scale the same way, so the response of an AGN disc to disruption will differ from that of an XRB disc.

6. Summary

We find that BL Lacs do not have substantially different SEDs from quasars with dominant optical synchrotron components. The primary difference lies in the strength of the emission line flux. This, in turn, is caused by a reduced ionising flux from a less radiatively-efficient accretion flow than those found in quasars.

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