The Redshift of BL Lacertae Objects from High Signal-to-Noise VLT Spectra

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BL Lacertae objects are active galactic nuclei dominated by non-thermal continuum emission and characterised by absence or extreme weakness of emission lines. These properties in several cases hinder the determination of their distance and thus the assessment of the properties of the class. High signal-to-noise optical spectra of these sources obtained with the VLT help to overcome these difficulties and allow one to obtain new redshifts and set stringent limits on the distance for pure lineless objects.

The class of BL Lac objects

The absence or weakness of emission lines in the optical spectra is one of the defining characteristics of BL Lac objects, together with the high polarisation, large amplitude and rapid flux variability. The standard interpretation of these properties, originating from Blandford and Rees back in 1968, is that BL Lacs are radio loud active galactic nuclei (AGN) where the relativistic jet is pointing close to the observer direction, so that the continuum emission is significantly enhanced and the line equivalent width is depressed. BL Lacs therefore offer one of the best opportunities to study relativistic jets, which are manifest from the radio-band to 100 MeV gamma-rays. The atmospheric Cherenkov technique has given only a lower limit to the redshift of the object, while the third

Observations and data analysis

Optical spectra were collected in service mode with FORS1 on the VLT. The observations were obtained in service mode from April 2003 to March 2004 with UT1 and from April to October 2004 with UT2. We used the 300 V + l grism combined with a 2" slit, yielding a dispersion of 110 Å/mm (corresponding to 2.64 Å/pixel) and a spectral resolution of 15–20 Å covering the 3 800–8 000 Å interval. The seeing during observations was in the range 0.5–2.5", with an average of 1".

The procedure for calculating $EW_{\text{min}}$ was applied to all featureless or quasi-featureless spectra to find faint spectral lines. All features above the $EW_{\text{min}}$ threshold, ranging from 1 Å to 0.1 Å, were considered as line candidates and were carefully visually inspected and measured. Based on the detected lines and the shape of the continuum it is possible to characterise the spectroscopic properties of the objects, confirm or dispute the BL Lac classification and derive new redshifts.

Examples of high S/N spectra of BL Lacs at the VLT

As a direct consequence of the improved signal-to-noise of the optical spectra collected at the VLT, we are able to detect a number of spectral features, either emission from the gas surrounding the nuclear region or absorption lines of the host galaxy. Examples of high S/N VLT spectra are shown in Figures 1 and 2. In the first case (PKS 0808-019) the high S/N spectrum shows clearly two weak emission lines ($EW = 3–5$ Å) of a moderately
high \((z = 1.148)\) redshift object. In the second case (EXO 00556.4-3838) the spectrum allows us to detect the faint absorption features of the host galaxy.

In a third case we show the spectrum of the BL Lac object PG 1553+11. This is a bright \((V = 14)\) object, which, although studied with the most advanced instrumentation, remains line-less (e.g. Falomo and Treves 1990). No signature of its host galaxy is apparent from the high-resolution HST image (Urry et al. 2000 and Scarpa et al. 2000). In this case the spectrum (see Figure 2) obtained with the VLT, in spite of the high \((S/N \sim 300)\), does not allow to detect either faint emission from the nucleus or absorption from the host galaxy.

**Analysis of the BL Lac spectra**

The observed spectrum of a BL Lac object is given by the contribution of two main components: (1) a non-thermal emission from the nucleus that can be described by a power law; (2) a thermal component due to the host galaxy. In some cases weak emission lines from the nucleus can be also present. Depending on the relative contribution of the two components, the optical spectrum will be dominated by the non-thermal (featureless) emission or by the spectral signature of the host galaxy. In Figure 3 the combination of the two components is compared with the observed spectra for six objects. The host galaxy magnitude deduced from this decomposition is in good agreement with that deduced directly from the image (Sbarufatti et al. 2005b).

Under the assumption that the host galaxy luminosity is confined in a narrow range (e.g. Sbarufatti et al. 2005b) from the EW limits of spectral features, it is possible to constrain the position of the source on the nucleus-to-host flux ratio \((p)\) vs redshift plane. This is illustrated in Figure 4. Using this approach it becomes possible therefore to obtain a lower limit to the redshift for objects with featureless spectra (Sbarufatti et al. 2006). For example in the case of PG 1553+11 (Figure 2) the redshift must be \(z > 0.1\).
The optical spectra of BL Lacs obtained at the VLT have been made available to the astronomical community through a spectroscopic library at the web page: [http://www.oapd.inaf.it/zbllac/index.html](http://www.oapd.inaf.it/zbllac/index.html). This includes most of the objects observed at the VLT and others with good quality spectra. For each object in the database we give basic data (coordinates, V-band magnitude, the redshift or a lower limit to it), the optical spectrum (in PDF and ASCII table format) and details on the references to the target. In general the best available optical spectrum is linked in the main page of the database, while additional spectra are appended and linked in separate pages. These web pages are also open to external contributions (see [http://www.oapd.inaf.it/zbllac/intro.html](http://www.oapd.inaf.it/zbllac/intro.html) for details).

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