Emission lines properties of the radio-loud quasar LAMOST J1131+3114
(Research Note)

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ABSTRACT

The radio-loud quasar LAMOST J1131+3114 (Ton 580, B2 1128+315), showing asymmetrical profile in Hβ and [OIII] lines, has been selected from the LAMOST Pilot Survey for further study. We present an analysis of its emission lines by means of multiple Gaussian fitting, performed on LAMOST, Apache Point Observatory, and archival spectra. The broad line region, with an Hβ line of FWHM ∼ 4000 km s⁻¹ has been fit with a double Gaussian, one of which is very broad and redshifted from the reference frame. The object is a likely Population B quasar. The [OIII]λλ4959, 5007 lines profiles of the source have been formally fit with two Gaussian components, one of which is as broad as ∼700 km s⁻¹. This broader component, if physically meaningful, appears to be subject to moderate velocity shock excitation. The forbidden line ratios correspond to a poorly populated area in standard diagnostic diagrams of AGN narrow line regions.

Key words. quasars: individual: LAMOST J1131+3114 – quasars: emission lines – galaxies: jets – galaxies: interactions – galaxies: kinematics and dynamics

1. Introduction

The geometry and kinematics of the broad line region (BLR) in active galactic nuclei (AGNs) have been studied for a long time, but still remain unexplained. Zamfir et al. (2010) explores the properties of the Hβ emission line profile in a large, homogeneous, and bright sample of N ∼ 470 low redshift quasars extracted from Sloan Digital Sky Survey (DR5). Their results give further support to the concept of two populations A and B (with line FWHM, respectively, narrower and broader than 4000 km s⁻¹; Sulentic et al. 2007). Hu et al. (2008) report on a systematic investigation of the Hβ and FeII emission lines in a sample of 568 quasars within z < 0.8 selected from the SDSS and suggest the existence of an intermediate FWHM region.

Some sources have asymmetric and shifted Hβ profiles, suggesting that the BLR has a structure more complex than a single virialized component (Marziani et al. 1996, 2003). We have visually inspected all quasar spectra, which produced by the Pilot Sky Survey of LAMOST. An object exhibiting asymmetric [OIII] line profiles and an extended red wing of Hβ has been selected for further study: LAMOST J113109.5+311405.4 (hereafter LAMOST J1131+3114), a radio-loud quasar already known as Ton 580 or B2 1128+315.

We report on the analysis of several spectra of this source, including archival data. In Sect. 2, we briefly review the literature on this object, present our LAMOST and Apache Point Observatory (hereafter APO) spectra and summarize the archival data. In Sect. 3, we present the multicomponent spectral line fitting and its results. In Sect. 4, we discuss the characterization of BLR and narrow line region (NLR).

2. Literature, new spectra and archival data

2.1. Summary of previous work

The radio-loud quasar LAMOST J1131+3114, an UV excess source in the Tonantzintla survey (Ton 580; Irrarte & Chavira 1957), was first detected at 408 MHz in Colla et al. (1970) and listed in the Second Bologna Catalog (B2). Its redshift is z = 0.289 (Hewitt & Burbidge 1980). Classified as a single component radio source with a flat spectrum by Fanti et al. (1975), it has been mapped at 1.4 GHz in the FIRST survey, where it exhibits a curved extended jet/lobe protruding out of the dominating compact radio core towards the east. Kimball et al. (2011) classify it as a J (core + jet) quasar and Snellen et al. (2002) as a flat spectrum radio quasar (FSRQ). Assuming isotropic emission, the radio luminosity at 1.4 GHz is log L_{1.4GHz} = 32.9 for an optical (V band) luminosity of log L_{5500 A} = 30.6 (L in erg s⁻¹ Hz⁻¹). Unlike most FSRQ, optical variability and optical polarization remain undetected (see, e.g., Stalin et al. 2004a,b; Stockman et al. 1984) and the 1.4 GHz polarized flux fraction is very low. From a 5 GHz VLBA map (Helmold et al. 2007), FIRST, and NVSS maps, a Fanaroff-Riley type II seems unlikely. The radio loudness (Kellermann et al. 1989) is R ∼ 80 for the core alone and R ≥ 105 for the whole source (Helmold et al. 2007). The spectral index is −0.63 between 74 MHz and 8.4 GHz. This quasar should be a young, core dominated source using the classification of Zamfir et al. (2008).

Stockton (1978) measured redshifts of two faint galaxies at 7° SE and 35° SW from the quasar (30 kpc and 150 kpc in projected distance) and found values very close to the quasar

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redshift, showing evidence for its belonging to a physical group of objects.

The optical spectrum of LAMOST J1131+3114 has been studied by several authors. Eracleous & Halpern (1994) from a 6 Å resolution spectrum covering Hα found a broad line with a full width at zero intensity of 22 000 km s\(^{-1}\) and a FWHM of 4000 km s\(^{-1}\). Corbin (1997) shows a spectrum where what he calls the “blue bump” (yielding the UV excess in imagery) is obvious, with very weak Fe\(\text{II}\) broad lines. Marziani et al. (2003) studied the H\(\beta\) line range and confirmed a low value of Fe\(\text{II}\) blends for our object. They found an asymmetric H\(\beta\) line profile with a weak, redshifted barycenter, very broad component extending beyond 5000 Å in rest frame. Grupe et al. (2004) also gave low values of Fe\(\text{II}\) equivalent width and Fe\(\text{II}\)/H\(\beta\) ratios.

Finally, the X-ray properties of this source were studied using the Einstein Observatory (Shastri et al. 1993; and Wilkes et al. 1994), ROSAT (Brinkmann et al. 1995), XMM-Newton (Page et al. 2004), and Swift (Grupe et al. 2010). Page et al. (2004) showed evidence of a soft X-ray excess in the spectrum. Giommi et al. (2012) did not detect LAMOST J1131+3114 in γ-ray or submillimeter ranges using Fermi and Planck.

2.2. New observations

The LAMOST instrument is a multi-object spectroscopic facility able to take 4000 spectra of objects distributed across a field of 25 square degrees simultaneously in a single exposure (Cui et al. 2012). The spectral range extends from 3700 repeat unit to 9000 Å with a resolution of \(R = 1800\). Prefiguring the large LAMOST survey of 10 million objects, a Pilot Survey was initiated on 2011 Oct. 24 for extensive performance evaluation. LAMOST J1131+3114, was observed on 2011 December 24, targeted by fiber 51 of spectrograph number 15. The raw data have been reduced using the LAMOST data reduction pipeline and only a coarse relative flux calibration was applied (Luo et al. 2004, 2012).

Follow-up observations of LAMOST J1131+3114 were made with the Double Imaging Spectrograph on the ARC 3.5 m telescope at APO on 2012 June 15. The spectrograph was used in high-resolution mode (2 Å/pixel) with a 1.5" slit (6 kpc) oriented east-west. The gratings were centered at 6800 Å (red) and 4400 Å (blue), yielding wavelength coverages of 6200–7600 Å and 3800–5000 Å, unfortunately slightly too red to cover completely the H\(\beta\) line profile of the source shotward of 4815 Å (in rest frame).

The data were reduced with IRAF reduction procedures, following the usual path (bias, flats, HeNe arc, flux standard) with calibration data taken on the same night. The source HZ44 was used as the spectrophotometric flux standard star. Since the APO spectrum flux calibration is very consistent with the Marziani et al. spectrum, we extrapolated the missing region 4815–4700 Å from the latter.

2.3. Archival data

Except for the new LAMOST and APO data, we have used available archival spectra from Eracleous & Halpern (1994), Marziani et al. (2003), and Grupe et al. (2004). The SDSS catalogue provided a spectrum (Plate 1974, MJD 53 430, Fiber 174), but unfortunately in the range H\(\beta\) - [O\(\text{III}\)] lines are missing. We note that the flux calibration of the Marziani et al. spectrum agrees closely with the SDSS spectrum for the flux densities of H\(y\) and [O\(\text{II}\)] \(\lambda\)4363. After proper normalization on the peak flux density of [O\(\text{III}\)] \(\lambda\)5007, the five spectra are very consistent, implying overall temporal stability in the emission lines fluxes across 15 years.

3. Data analysis

3.1. Multicomponent fitting of H\(\beta\) and [O\(\text{III}\)] lines

The H\(\beta\) line of LAMOST J1131+3114 shows a sharp peak superimposed over a much broader and asymmetric profile, with a very broad and weak wing extending even beyond [O\(\text{III}\)] \(\lambda\)5007. Owing to the Fe\(\text{II}\) emission weakness, we have assumed that the principal contributor to the local background below the [O\(\text{III}\)] lines is the H\(\beta\) red broad tail.

In Fig. 1, the profiles of both [O\(\text{II}\)] lines appear asymmetric with an extended wing on the blue side. A check of the PSF of LAMOST and APO spectrographs did not show any skewness in their PSFs, whose FWHM were locally measured at 3.96 ± 0.02 Å and 1.74 ± 0.07 Å at \(\lambda = 6400\) Å. We chose the reference frame for the systemic redshift of the object as that defined by the central wavelength of the observed principal peak of the [O\(\text{II}\)] \(\lambda\)5007 line. All spectra were first shifted back to this rest frame after conversion to the vacuum wavelength system when necessary. We measured \(z = 0.28946 ± 0.00025\) (using a weighted average based on the spectral resolutions).

To model the H\(\beta\) profile, we built a three-Gaussian fit: a narrow component, a broad component (BC), and a very broad component (VBC), the center of the third being redshifted with respect to the BC by around 2000 km s\(^{-1}\). The BC itself has...
Average parameters of emission lines components derived on the spectrum published by Eracleous & Halpern (1994), Grupe et al. (2004); (2): the same plus Eracleous & Halpern (1994); (3) LAMOST and SDSS.

3.2. Other lines of LAMOST J1131+3114

The very broad component of the Hβ emission is expected to be visible in all permitted lines of H and HeI. In Hα it is clearly visible on the spectrum published by Eracleous & Halpern (1994) and also on the SDSS spectrum, extending largely beyond the position of the [S II] lines. The Hα complex is expected to contain a narrow component, BC and VBC of Hα, the two [N II] lines, and BC and VBC of the HeI line at 6678 Å. We did not attempt to fit the spectrum with multiple Gaussian across this range because of numerical stability problems.

The Hγ−[O III] λ4363 emission complex is only covered by LAMOST and SDSS spectra. We have made a tentative multicomponent fit of this complex, using 4 Gaussians, after a 5 Gaussians trial showed that the NC was not confidently detectable in [O III] line. The result is given in Table 1. From the residuals of the fit, we can derive upper limits of the total fluxes of a NC in Hβ as 12.5×10^{-17} erg s^{-1} cm^{-2} and in [O III] λ4363 as 10×10^{-17} erg s^{-1} cm^{-2}.

From the SDSS spectrum, we also tentatively derive upper limits estimates for the unusually weak [O I] λ6300 and [S II] λ6717, 6731 fluxes, after removing the Hα + [N II] background represented by a smooth function, and assuming that the FWHM of these lines was consistent with that of the “base” component. They are given in Table 3.

The very broad component of the Hβ has a slight blueshift. The blue wing asymmetry of [O III] λ4363, 5007 lines prevented correct single-Gaussian modeling. We first tried two Gaussians of more or less similar FWHM, but the APO spectrum did not attempt to fit the spectrum with multiple Gaussian across this range because of numerical stability problems.

The Hβ−[O III] λ4363 emission complex is only covered by LAMOST and SDSS spectra. We have made a tentative multicomponent fit of this complex, using 4 Gaussians, after a 5 Gaussians trial showed that the NC was not confidently detectable in [O III] line. The result is given in Table 1. From the residuals of the fit, we can derive upper limits of the total fluxes of a NC in Hβ as 12.5×10^{-17} erg s^{-1} cm^{-2} and in [O III] λ4363 as 10×10^{-17} erg s^{-1} cm^{-2}.

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3. About the NLR

The question of the physical existence of two separate components, NC and a base in the NLR is open: they are used to form a single, global plasma entity for the NLR. We thus assume a value of \( L_{\text{bol}}/L_{\text{Edd}} \) of 0.3 ± 0.1 (with a \( L_{5100}^A \) assumed uncertainty of 20%). We note that alternate derivations (Kaspi et al. 2000, 2005; Wu et al. 2004; Bian et al. 2008) of \( M_{\text{BH}} \) based on the total (BC + VBC) \( H/β \) luminosity of \( 8.9 \times 10^9 \) erg s\(^{-1}\) (assuming no internal reddening in the BLR and no flux losses in the spectrographs) lead to \( 1.4 \times 10^9 M_\odot \leq M_{\text{BH}} \leq 2.6 \times 10^9 M_\odot \) and an even higher Eddington ratio in the range 0.6 to 1.2.

Instead, these figures place our quasar as a member of Population B defined by Sulentic et al. (2007) and also characterized by Zamfir et al. (2010), this being supported by the radio loudness and weak Fe\(\text{II} \) emission. The Eddington ratio, tracing the accretion rate of the central BH, is high for Population B sources, which could explain the soft X-ray excess (Page et al. 2004), but uncertainty on this parameter is high because of possible continuum boosting and \( M_{\text{BH}} \) underestimation.

4.2. About the NLR

As usual in AGN spectra, the \([\text{O\textsc{III}}]\) \( \lambda 4363 \) is much brighter than in classical low-density HII regions. Current explanations are based on the combination of normal photoionization with shock excitation, the latter providing specific contributions to some emission line ratios, especially the low ionization ratios. In diagnostic diagrams built from shock models, for example those by Dopita & Sutherland (1995), or composite shock + photoionization models (see, e.g., Moy & Rocca-Volmerange 2002) the base component is that which moderate velocity (~100–150 km s\(^{-1}\)) shock excitation plays a major role, while the NC is largely dominated by photoionization by the hard UV flux from the central source. If NC and the base do not represent physically separated entities, these line ratios remain similar, and the contribution of moderate velocity shocks remains likely.

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