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On the redshift of the blazar PKS 0447-439[⋆,⋆⋆] *(Research Note)*

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ABSTRACT

PKS 0447-439 is one of the BL Lacertae objects that have been detected at very high energy. There has been a recent report of a lower limit of $z \geq 1.246$ for the redshift of this blazar, challenging the current paradigm in which very high-energy γ-rays cannot freely propagate in the $z \gtrsim 1$ universe. In this research note, we present a new MagE/Magellan spectrum of PKS 0447-439 with exquisite signal-to-noise ($S/N > 150$ at 6500 Å). Our analysis confirms the presence of the previously-reported absorption line at 6280 Å, which we identify, however, with a known telluric absorption, invalidating the claim that this blazar lies at $z > 1$. Since no other extragalactic spectral features are detected, we cannot establish a redshift based on our spectrum.

Key words. galaxies: active – BL Lacertae objects: individual: PKS0447-439 – galaxies: distances and redshifts

1. Introduction

Blazars are among the most powerful astrophysical objects so are excellent laboratories for studying a variety of phenomena, ranging from the origin of relativistic particles in jets to the properties of the extragalactic background light (EBL) and intergalactic magnetic field (IGMF). Since very high-energy (VHE; $E > 100$ GeV) γ-rays are absorbed as they propagate through the photon field of the extragalactic background, blazars that emit at VHE are particularly useful probes for the EBL and IGMF. Unfortunately, blazars and, in particular, BL Lacertae (BL Lac) objects, often exhibit a featureless power-law spectrum, making the task of establishing redshifts with optical spectroscopy particularly challenging. This nagging problem has favored the development of independent techniques that are now being used to constrain the distance to blazars, including the near-IR and optical imaging of the host galaxies (e.g. Sbarufatti et al. 2005; Nilsson et al. 2008; Meisner & Romani 2010; Kotilainen et al. 2011), the minimum equivalent-width method to set redshift limits in featureless spectra (e.g. Sbarufatti et al. 2006), the simultaneous analysis of GeV and TeV emission (e.g. Prandini et al. 2012), or UV and molecular spectroscopy (e.g. Danforth et al. 2010; Fumagalli et al. 2012).

This research note focuses on the redshift of PKS 0447-439, a BL Lac object that is detected at VHE (Zech et al. 2011). Based on weak Ca II absorption lines, Perlman et al. (1998) report a spectroscopic redshift of $z = 0.205$ for this source. This redshift is consistent with the lower limit $z > 0.176$ reported by Landt & Bignall (2008) using photometric techniques, and it also agrees with the redshift constraints inferred from the analysis of GeV and TeV emission by Prandini et al. (2012) of $z = 0.2 \pm 0.05$ and by Zech et al. (2011) of $z < 0.53$. However, Landt (2012) has recently announced a much higher spectroscopic redshift of $z > 1.246$ based on detection of Mg II lines in two high signal-to-noise (S/N) optical spectra. Because the mean free path of VHE γ-ray photons steeply decreases for increasing redshift owing to electron-positron pair production against the lower frequency EBL photons, a redshift $z > 1$ for a VHE-detected blazar is quite surprising, and it directly challenges the current paradigm for the propagation of VHE photons in the universe (see e.g. Aharonian et al. 2012). The important implications of this redshift for studies of the EBL and IGMF have led us to scrutinize the optical spectrum of PKS 0447-439 further, presenting conclusive evidence that the previously reported redshift of $z > 1.246$ is incorrect.

2. Observations and data reduction

We observed the blazar PKS 0447-439 with the Magellan Echellette Spectrograph (MagE; Marshall et al. 2008) mounted at the Clay Magellan II telescope on UT 2012 July 12. Weather conditions were fair, with mostly clear skies and moderate seeing (∼1.5″). Two exposures of 900 s were acquired through a 0.7″ slit. The source was observed at airmass 1.7 because PKS 0447-439 was transiting after the morning twilight at the time of the observations. Spectra for different spectrophotometric standard stars were also acquired before and after the science observations. The spectra were reduced using the MASE pipeline (Bochanski et al. 2009), which coadds the

⋆ This paper includes data gathered with the 6.5 m Magellan Telescopes located at Las Campanas Observatory, Chile.

⋆⋆ Reduced spectrum is only available at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/545/A68

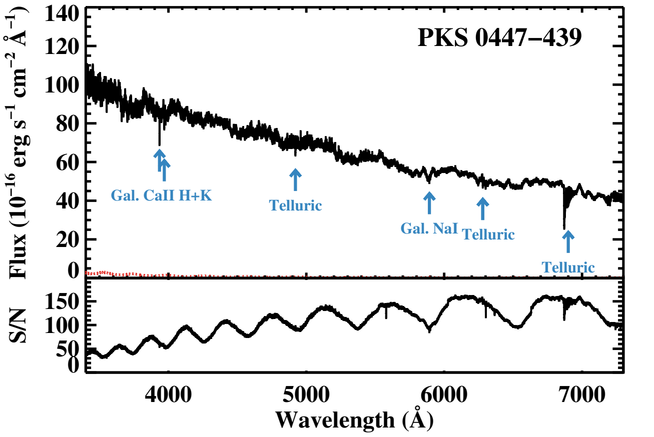

Fig. 1. MagE spectrum (*top*) and wavelength dependent S/N per pixel (*bottom*) for the BL Lac PKS 0447-439. The 1σ error is represented by the red dotted line. All the visible absorption lines are of either Galactic or terrestrial origin, resulting in an unknown spectroscopic redshift for this source.

1D spectra extracted from the flat-fielded and sky-subtracted 2D spectral images. The final spectrum covers the wavelength interval 3000−10 000 Å with $S/N \sim 50$−150 per pixel of 0.4 Å. This spectrum was flux calibrated using the standard star Feige110. Due to varying seeing conditions during the observations, the absolute flux scale is affected by a ~20−30% uncertainty. We also note that the wiggles superimposed on the blazar power-law are not intrinsic, since caused by small irregularities in the sensitivity function and in the flat-field correction.

3. Discussion

3.1. Analysis of visible spectral features

A visual inspection of the spectrum reveals multiple absorption lines (see Fig. 1). The most prominent absorption features are telluric lines in the wavelength range ~6800−6950 Å, ~7200−7300 Å, and ~7600−7700 Å. Also, Galactic Ca II H+K absorption lines at 3934.79 Å and 3969.61 Å are clearly detected. We further identify weak absorption features associated with Galactic Na I lines at 5891.61 Å, 5894.13 Å, and 5897.57 Å. The Ca II H+K lines found at $z = 0.205$ by Perlman et al. (1998) are not detected in our spectrum. Finally, two remaining absorption features are visible at 4921.1 Å and 6280.0 Å. The line at 4921.1 Å is also detected in the spectra of multiple standard stars, proving that this is not an extragalactic feature.

Intriguingly, the line at 6280.0 Å coincides with the absorption reported by Landt (2012). If associated to Mg II at a rest-frame wavelength 2796.82 Å, this line would place PKS 0447-439 at $z > 1.245$, as claimed by Landt (2012). Neither the associated Fe II absorption features (e.g. the strong 2382.76 Å line) nor the Mg I line at 2852 Å are visible. However, the same absorption line at 6280.0 Å is also clearly detected in the spectra of multiple standard stars that have been observed at different airmasses throughout the observing run, confirming that this absorption is not associated with an intervening Mg II systems, but originates in the Earth's atmosphere. The independent analysis of an earlier X-shooter spectrum by Pita et al. (2012) also shows that the observed absorption is indeed atmospheric.

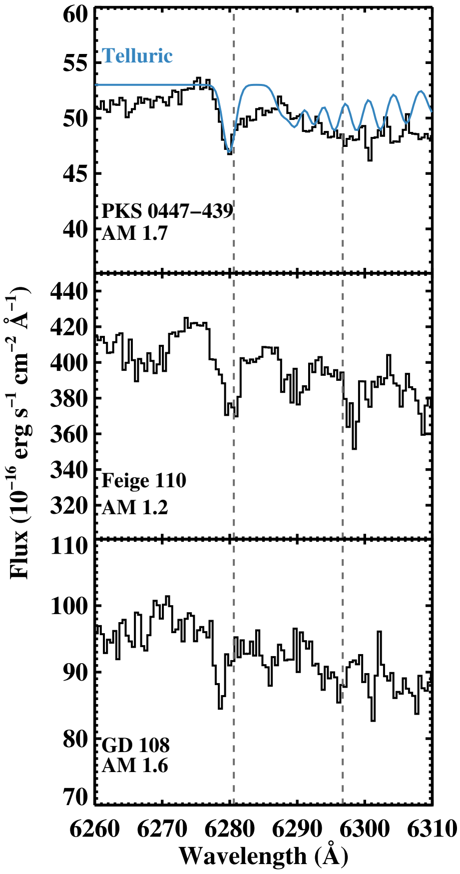

Fig. 2. Zoom-in spectra for PKS 0447-439 and the two standard stars Feige 110 and GD 108 in the wavelength interval corresponding to the claimed Mg II absorption lines (Landt 2012). In the top panel we superimpose on the spectrum of PKS 0447-439 a model of the Earth atmospheric absorption (in blue), derived from the position and relative strength of known telluric lines (see text). The two vertical dashed lines mark the frequency of the previously claimed Mg II absorption at $z = 1.246$, which corresponds instead to atmospheric features.

Figure 2 shows a comparison of the spectral region between 6260 Å and 6310 Å in PKS 0447-439, Feige 110, and GD 108. Absorption lines are consistently found around ~6280.0 Å and lie at slightly different wavelengths, as expected from the motion of the Earth. Furthermore, as typically found for telluric lines, the absorption strength varies as a function of the airmass. In Fig. 2, we show a model spectrum based on the position and relative strength of known O_2 telluric lines[1] (see also Fig. 1 in Stevenson 1994). This spectrum has been shifted by −1.8 Å and arbitrarily rescaled to match the observed absorption. The satisfactory agreement, including the evident absorption between 6290−6310 Å, strengthens our interpretation.

3.2. Redshift lower limit

Following the procedure described in Sbarufatti et al. (2005, 2006), we set a redshift lower limit for PKS 0447-439 under the hypothesis that (i) the blazar host galaxy is a standard candle and (ii) spectral features cannot be detected when the ratio of the nonthermal nuclear component to the thermal emission from the host galaxy exceeds a maximum value set by the S/N of the spectrum. Throughout this analysis, all the values have been

[1] http://www2.keck.hawaii.edu/inst/hires/makeewww/Atmosphere/

homogenized to modern cosmological parameters (WMAP7; Komatsu et al. 2011).

As in Sbarufatti et al. (2006), we computed the redshift-dependent nucleus-to-host ratio $\rho_0(z)$ for a host galaxy with absolute magnitude $M_R = -22.9 \pm 0.5$ in the R-band. For the nuclear component, we used $m_n = 13.58 \pm 0.15$ mag as measured from our spectrum after accounting for slit-loss corrections, Galactic extinction, and the host galaxy contribution. Next, we computed the maximum nucleus-to-host ratio $\rho_{0,max}(z)$ for which a Ca II ($\lambda = 3934.79$ Å) absorption line with rest-frame equivalent width $W_0 = 16$ Å can be detected at a given redshift. For the mean S/N of our spectrum, the minimum detectable equivalent width is $W_{min} = 0.68$ Å (see Sbarufatti et al. 2005). When $\rho_0 > \rho_{0,max}$, the host galaxy spectral features are outshined by the nonthermal continuum, providing a redshift lower limit of $z > 0.012$ for PKS 0447-439. If we assume a fainter nuclear component of $m_n = 14.4$ from previously reported magnitudes we instead find $z > 0.025$. Despite the high S/N of this spectrum, the brightness of this blazar and the fact that the spectrum was acquired in moderate seeing conditions meant we were prevented from establishing a more stringent limit on the redshift.

In summary, from the analysis of this new optical spectrum of PKS 0447-439, we conclude that there is no evidence of a redshift $z > 1.24$ and that the spectroscopic distance to this blazar is only constrained by the tentative detection of the Ca II lines reported by Perlman et al. (1998).

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