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The extreme high frequency peaked BL Lac 1517+656*

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Abstract. We present optical spectroscopy data that allowed a measurement of the redshift for the X-ray selected BL Lacertae object 1517+656. With a redshift of $z = 0.702$ this object has an absolute magnitude of $M_B = -26.4$ and is also an extremely powerful radio and X-ray source. Although being a high frequency peaked BL Lac, this object is one of the most luminous BL Lac objects known so far. Being also a candidate for gravitational lensing, this object is of high interest for the BL Lac research. Assuming several cosmological models and a realistic redshift for the lensed object, we find that 1517+656 has a mass $> 2 \cdot 10^{12} M_\odot$ and a high velocity dispersion > 350 km sec^{-1}.

Key words: galaxies: BL Lacertae objects: general – galaxies: BL Lacertae objects: individual: 1517+656 – galaxies: distances and redshifts – cosmology: gravitational lensing

1. Introduction

The physical nature of BL Lacertae objects is not well understood yet. The most common view about BL Lac objects is that we are looking into a highly relativistic jet (Blandford & Rees 1978). This model can explain several observational parameters, but there are still unsolved problems like the nature of the mechanisms that generate and collimate the jet or the physical nature and evolution along the jet. An important question is also, if there is a fundamental difference between BL Lac objects that are found because of their emission in the radio or in the X-ray range respectively. In order to study the nature of this class of BL Lac, extreme objects help to give constraints on the physics which is involved. One of the greatest problems while studying BL Lac is the difficulty in determining their redshifts because of the absence of strong emission and absorption lines. Usually large telescopes and long exposure times are needed to detect the absorption lines in the surrounding host galaxy.

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2. History of 1517+656

Even though 1517+656 is an X-ray selected BL Lac, this object was detected in the radio band before being known as an X-ray source. It was first noted in the *NRAO Green Bank* 4.85 GHz catalog with a radio flux density of 39 ± 6 mJy (Becker et al. 1991) and was also included in the *87 Green Bank Catalog of Radio Sources* with a similar flux density of 35 mJy (Gregory & Condon 1991) but in both cases without identification of the source. The NRAO Very Large Array at 1.4 GHz confirmed 1517+656 as having an unresolved core with no evidence of extended emission although a very low surface brightness halo could not be ruled out (Kollgaard et al. 1996). The source was first included as an X-ray source in the HEAO-1 A-3 Catalog and was also detected in the *Einstein* Slew Survey (Elvis et al. 1992) in the soft X-ray band (~ 0.2–3.5 keV) the Imaging Proportional Counter (IPC, Gorenstein et al. 1981). The IPC count rate was 0.91 cts sec^{-1}, but the total Slew Survey exposure time was only 13.7 sec. Even though 1517+656 by then was a confirmed BL Lac object (Elvis et al. 1992) with an apparent magnitude of $B = 15.5$ mag, no redshift data were available. Known as a bright BL Lac, 1517+656 has been studied several times in different wavelengths in the recent years. Brinkmann & Siebert (1994) presented ROSAT PSPC (0.07–2.4 keV) data and determined the flux to $f_X = 2.89 \cdot 10^{-11}$ erg cm^{-2} sec^{-1} and the spectral index to $\Gamma = 2.01 \pm 0.08$[1]. Observations of 1517+656 with *BeppoSAX* in the $2 - 10$ keV band in March 1997 gave an X-ray flux of $f_X = 1.03 \cdot 10^{-11}$ erg cm^{-2} sec^{-1} and a steeper spectral slope of $\Gamma = 2.44 \pm 0.09$ (Wolter et al. 1998). The Energetic Gamma Ray Experiment Telescope (EGRET, Kanbach et al. 1988) on the *Compton Gamma Ray Observatory* did not detect 1517+656 but gave an upper flux limit of $8 \cdot 10^{-8}$ photons cm^{-2} sec^{-1} for $E > 100$ MeV (Fichtel et al. 1994). In the hard X-rays 1517+656 was first detected with OSSE with $3.6 \pm 1.2 \cdot 10^{-3}$ photons cm^{-2} sec^{-1} at 0.05–10 MeV (McNaron-Brown et al. 1995). The BL Lac was then detected in the EUVE-All-Sky Survey with a gaussian significance of 2.6σ during a 1362 sec exposure, giving a lower and upper count rate limit of 0.0062 cps and 0.0189 cps respectively (Marshall et al. 1995). For a plot of the spectral energy distribution see Wolter et al. 1998.

[1] The energy index α_E is related to the photon index $\Gamma = \alpha_E + 1$

Table 1. Observed wavelengths and equivalent widths for absorption lines in the February 1998 spectrum

λ_{obs}[Å]	W_λ[Å]	λ_0 [Å]	Ion	Redshift
4194	0.03	2463.4	FeI	0.7025
-	-	2484.0	FeI	not detected
4404	0.15	2586.7	FeII	0.7026
4429	0.17	2600.2	FeII	0.7033
4761	0.48	2796.4	MgII	0.7025
4774	0.52	2803.5	MgII	0.7028
4855	0.15	2853.0	MgI	0.7017
4999	0.09	2937.8	FeI	0.7016

3. Optical data

The BL Lac 1517+656 was also included in the Hamburg BL Lac sample selected from the ROSAT All-Sky Survey. This complete sample consists of 35 objects forming a flux limited sample down to $f_{\rm X}(0.5–2.0\ {\rm keV}) = 8 \cdot 10^{-13}\ {\rm erg\ cm^{-2}\ sec^{-1}}$ (Bade et al. 1998, Beckmann 1999). Studying evolutionary effects, we had to determine the redshifts of the objects in our sample. In February 1998 we took a half hour exposure of 1517+656 with the 3.5m telescope on Calar Alto, Spain, equipped with MOSCA. Using a grism sensitive in the 4200–6600 Å range with a resolution of $\sim$ 3 Å it was possible to detect several absorption lines. The spectrum was sky subtracted and flux calibrated by using the standard star HZ44. Identifying the lines with iron and magnesium absorption we determined the redshift of 1517+656 to $z \geq 0.7024 \pm 0.0006$ (see Fig. 1). The part of the spectrum with the FeII and MgII doublet is shown in Fig. 3. The BL Lac has also been a target for follow-up observation for the Hamburg Quasar Survey (HQS; Hagen et al. 1995) in 1993, because it had no published identification then and was independently found by the Quasar selection of the HQS. The $2700\ {\rm sec}$ exposure, taken with the 2.2m telescope on Calar Alto and Boller & Chivens spectrograph, showed a power-law like continuum; the significance of the absorption lines in the spectrum was not clear due to the moderate resolution of $\simeq 10$ Å (Fig. 2). Nevertheless the MgII doublet at 4761 and 4774Å is also detected in the 1993 spectrum, though only marginally resolved (see Table 2). The equivalent width of the doublet is comparable in both images ($W_{\rm Å} = 0.8/0.9$ for the 1993/1998 spectrum respectively). Also the Fe II absorption doublet at $4403/4228$ Å ($\lambda_{\rm rest} = 2586.6/2600.2$ Å) and Mg I at 4859 Å ($\lambda_{\rm rest} = 2853.0$ Å) is detectable. For a list of the detected lines, see Table 1. Comparison with equivalent widths of absorption lines in known elliptical galaxies is difficult because of the underlying non-thermal continuum of the BL Lac jet. But the relative line strengths in the FeII and MgII dublet are comparable to those measured in other absorption systems detected in BL Lac objects (e.g. 0215+015, Blades et al. 1985).

Because no emission lines are present and the redshift is measured using absorption lines, the redshift could belong to an absorbing system in the line of sight, as e.g. detected in the absorption line systems in the spectrum of 0215+015 (Bergeron & D'Odorico 1986). A higher redshift would make 1517+656

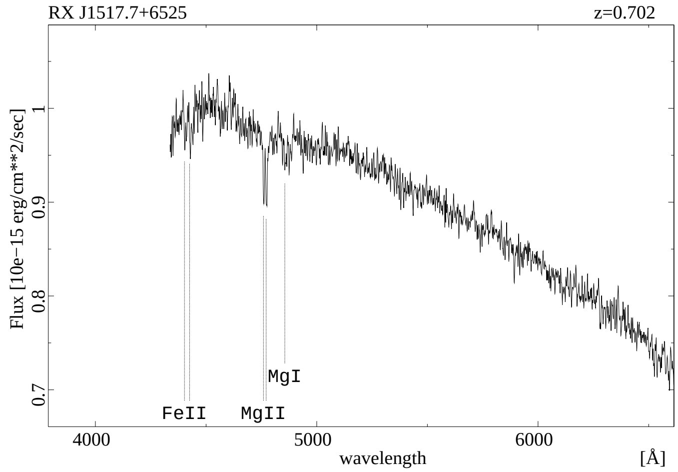

Fig. 1. The spectrum of 1517+656, taken in February 1998 with the 3.5m telescope on Calar Alto, Spain using the MOSCA spectrograph. The conditions during the exposure where not photometric, so the flux values can only give a hint to the real flux. The curvature at the blue end below ~ 4500Å is due to calibration problems. For the doublets see also Fig. 3

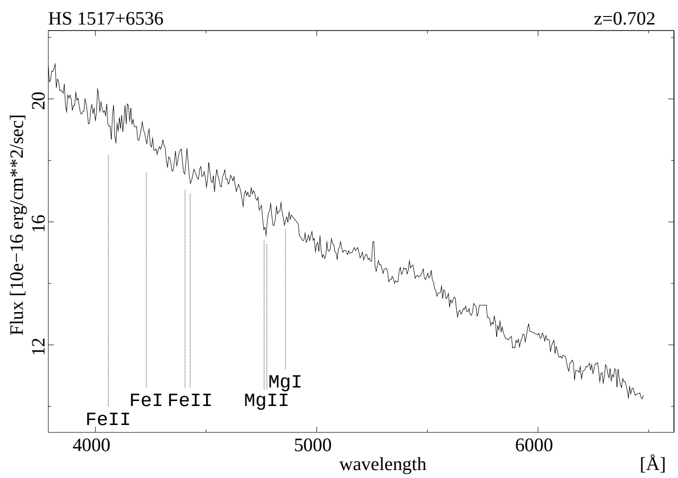

Fig. 2. The spectrum of 1517+656, taken with the 2.2m telescope on Calar Alto in August 1993. Observation conditions were not photometric.

even more luminous; we will consider this case in the further discussion, though we assume that the absorption is caused by the host galaxy of the BL Lac. Assuming a single power law spectrum with $f_\nu \propto \nu^{\alpha_o}$ the spectral slope in the $4700–6600$ Å band can be described by $\alpha_o = 0.86 \pm 0.07$. The high redshift of this object is even highly plausible, because it was not possible to resolve its host galaxy on HST snap shot exposures (Scarpa et al. 1999). The apparent magnitude varies slightly through the different epochs, having reached the faintest value of $R = 15.9$ mag and $B = 16.6$ mag in February 1999 (direct imaging with Calar Alto 3.5m and MOSCA). These values were derived by comparison with photometric standard stars in the field of view (Villata et al. 1998). $H_0 = 50\ {\rm km\ sec^{-1}\ Mpc^{-1}}$ and $q_0 = 0.5$ leads to an absolute optical magnitude of at least $M_R = -27.2\ {\rm mag}$ and $M_B \leq -26.4$ (including K-correction).

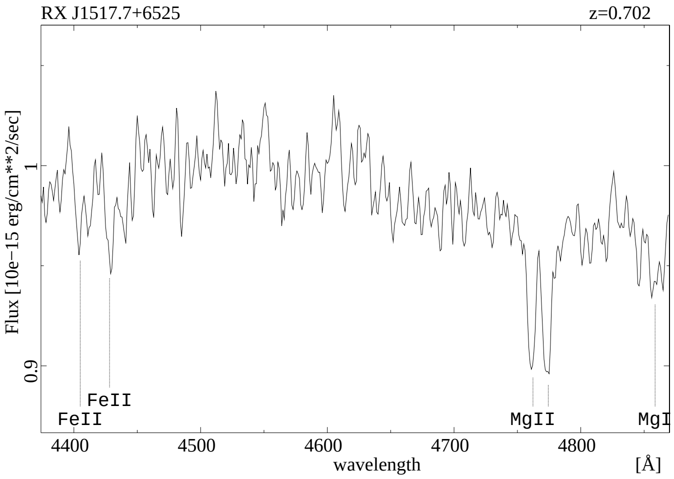

Fig. 3. Detail of the February 1998 spectrum with the FeII and MgII doublets.

Table 2. Observed wavelengths and equivalent widths for absorption lines in the 1993 spectrum

λ_{obs}[Å]	W_λ[Å]	λ_0 [Å]	Ion	Redshift
4194	0.2	2463.4	FeI	0.7025
4231	0.1	2484.0	FeI	0.7033
4401	0.3	2586.7	FeII	0.7014
4429	0.4	2600.2	FeII	0.7033
4761	0.4	2796.4	MgII	0.7025
4771	0.4	2803.5	MgII	0.7018
4855	0.15	2853.0	MgI	0.7017
-	-	2937.8	FeI	not detected

4. Mass of 1517+656

Scarpa et al. (1999) report the discovery of three arclike structures around 1517+656 in their HST snapshot survey of BL Lac objects. The radius of this possible fragmented Einstein ring is 2.4 arcsec. If this feature indeed represents an Einstein ring, the mass of the host galaxy of 1517+656 can easily be estimated. As the redshift of these background objects is not known, we can only derive a lower limit for the mass of the lens.

For a spherically symmetric mass distribution (with θ being the radius of the Einstein ring, $D_{\rm d}$ the angular size distance from the observer to the lens, $D_{\rm s}$ from observer to the source, and $D_{\rm ds}$ the distance from the lens to the source) we get (cf. Schneider et al. 1993):

$$M = \theta^2 \frac{D_{\rm d}\, D_{\rm s}}{D_{\rm ds}} \frac{c^2}{4G} \qquad (1)$$

Thus the lower limit for the mass inside the Einstein ring is $M = 1.5 \cdot 10^{12}\, M_\odot$ for Einstein-de Sitter cosmology and $H_0 = 50\,{\rm km\,sec^{-1}\,Mpc^{-1}}$. For other realistic world models (also including a positive cosmological constant), this limit is even higher.

Assuming an isothermal sphere for the lens, the velocity dispersion in the restframe can be calculated by

$$\sigma_v^2 = \frac{\theta}{4\pi} \frac{D_{\rm s}}{D_{\rm ds}} c^2 \qquad (2)$$

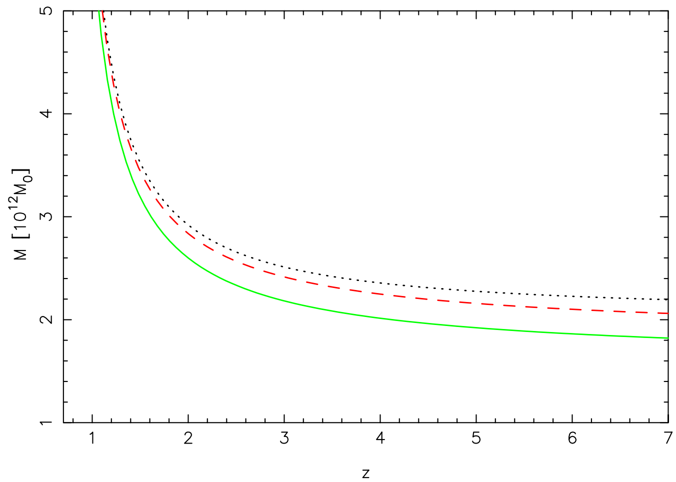

Fig. 4. Mass of the host galaxy of 1517+656 for different redshift of the background source. The dotted line is for a low-density universe without cosmological constant ($\Omega_{\rm M} = 0.3$, $\Omega_\Lambda = 0$), the dashed one for a flat low-density universe ($\Omega_{\rm M} = 0.3$, $\Omega_\Lambda = 0.7$), and the solid for Einstein-de Sitter cosmology ($\Omega_{\rm M} = 1$, $\Omega_\Lambda = 0$). We assumed $H_0 = 50\,{\rm km\,sec^{-1}\,Mpc^{-1}}$.

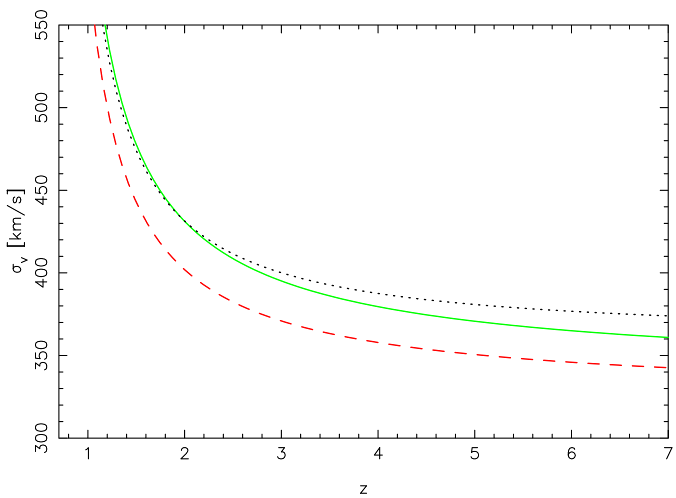

Fig. 5. Velocity dispersion of the host galaxy of 1517+656 for the same cosmological models as in Fig. 4.

Independent of H_0 we get a value of at least $330\,{\rm km\,sec^{-1}}$ for Einstein-de Sitter cosmology, and slightly less ($320\,{\rm km\,sec^{-1}}$) for a flat low-density universe ($\Omega_{\rm M} = 0.3$, $\Omega_\Lambda = 0.7$). Other models again lead to even higher values. The true values of the mass and velocity dispersion might be much higher if the redshift of the source is significantly below $z \approx 2$. Figs. 4 and 5 show the mass and velocity dispersion as a function of the source redshift.

If the observed absorption is caused by a foreground object and the redshift of 1517 is higher than 0.7, the mass and velocity dispersion of the host galaxy have to be even higher.

More detailled modelling of this system will be possible when the redshift of the background object is measured. If the arcs are caused by galaxies at different redshift, the mass distribution in the outer parts of the host galaxy of 1517+656 can be determined which will provide very important data for the understanding of galaxy halos. High resolution and high S/N direct images may allow to use more realistic models than symmetrical mass distributions by providing further constraints.

5. Discussion

The BL Lac 1517+656 with $M_R \leq -27.2$ mag and $M_B \leq -26.4$ is the most luminous BL Lac object in the optical band. Padovani & Giommi (1995) presented in their catalogue of 233 known BL Lacertae objects an even brighter candidate than 1ES1517+656: PKS 0215+015 (redshift $z = 1.715$, $V = 15.4$ mag, Véron-Cetty & Veron 1993). This radio source has been identified by Bolton & Wall (1969) as an 18.5 mag QSO. The object has been mainly in a bright phase starting from 1978, and became faint again since mid-1983 (Blades et al. 1985). Its brightness is now $V = 18.8$ mag ($M_V = -26.2$ mag; Kirhakos et al. 1994, Véron-Cetty & Veron 1998).

Also the X-ray properties of 1517+656 are extreme: with an X-ray flux of $f_{\rm X}(0.07\text{–}2.4\ \rm keV) = 2.89 \cdot 10^{-11}$ erg cm^{-2} sec^{-1} in the ROSAT PSPC band we have a luminosity of $L_X = 7.9 \cdot 10^{46}$ erg sec^{-1} which is a monochromatic luminosity at 2 keV of $L_X = 4.6 \cdot 10^{21}$ W Hz^{-1}. The radio flux of 37.7mJy at 1.4 GHz leads to $L_R = 1.02 \cdot 10^{26}$ W Hz^{-1}. Thus 1517+656 is up to now one of the most luminous known BL Lac in X-rays, radio and optical band, also compared to newest results from HST observations (Falomo et al. 1999). They give detailed analysis for more than 50 BL Lac objects with redshift $z < 0.5$, showing none of them having an absolute magnitude $M_R < -26$. Compared to the 22 BL Lac in the complete EMSS sample (Morris et al. 1991), 1517+656 is even more luminous in the radio, optical and X-ray band than all of those high frequency peaked BL Lac objects (HBL). Finding an HBL, like 1517+656 with $\nu_{\rm peak} = 4.0 \cdot 10^{16}$ Hz (Wolter et al. 1998), of such brightness is even more surprising, because the HBL are usually thought to be less luminous than the low frequency peaked ones (e.g. Fossati et al. 1998, Perlman & Stocke 1993, Januzzi et al. 1994). In comparison to the SED for different types of Blazars, as shown in Fossati et al. (1998), 1517+656 shows a remarkable behaviour. The radio-properties are similar to an HBL ($\log(\nu L_{4.85\ \rm GHz}) = 42.7$), in the V-Band ($\log(\nu L_{5500\ \AA}) = 46.1$) and in the X-rays ($\log(\nu L_{1\ \rm keV}) = 46.4$) between bright LBL and faint FSRQ objects.

On the other hand it is not surprising to find one of the most luminous BL Lac objects in a very massive galaxy with $M > 2 \cdot 10^{12} M_\odot$. This mass is a lower limit, as long as the redshift of 1517+656 could be larger than $z = 0.702$, and is depending on the cosmological model and on the redshift of the lensed object (see Fig. 4).

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