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Letter to the Editor

The new double QSO HE 1104–1805: Gravitational lens with microlensing or binary quasar?

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Abstract. We report the discovery of a bright double QSO at a redshift of 2.303, separated by 3.″0, with B magnitudes of 16.70 and 18.64, respectively. Spectrophotometry reveals distinct differences between A and B: component A has a harder continuum but, relative to the continuum, weaker emission lines than B. However, $f_\lambda(A) - 2.8 f_\lambda(B)$ yields a nearly featureless continuum, i.e. the emission line flux ratios and line profiles are identical in A and B. The observed differences are tentatively interpreted as a combination of image splitting by a macrolens with a magnification ratio $A/B = 2.8$ with additional microlensing of the quasar continuum source in the brighter image. This would cause a chromatic dependence of amplification if the size of the continuum emitting region varies with wavelength. The influence on the much larger broad emission line region is small and possibly seen only in the far Lyα wing.

No galaxy in the line of sight brighter than $R = 24$ could be detected. However, component A has a damped Lyα (plus Mg II, Fe II, C IV ...) absorption system at $z = 1.66$ which in B appears only in C IV. A further Mg II system at $z = 1.32$ is also seen only in A. The $z = 1.66$ system, possibly caused by a galactic disk in the line of sight of A, might be related to the proposed microlensing. Alternatively, the pair might be a binary QSO. The macro- plus microlensing hypothesis can be tested by long-term spectrophotometric monitoring.

Key words: quasars: individual: HE 1104−1805 – quasars: absorption lines – gravitational lensing

1. Introduction

Multiply lensed quasars have become an important tool for extragalactic astronomy and cosmology. Besides the possibility to determine the Hubble parameter by measurements of the time delay between two lensed images of a distant quasar (Refsdal 1964), microlensing by stars (compact objects) within a macrolens offers the opportunity to study the spatial structure of the lensed quasar with very high angular resolutions (micro-arcseconds), cf. Kayser (1992). Brightness variations due to microlensing have been observed in the 'Einstein cross' 2237+0305 (Irwin et al. 1989, Corrigan et al. 1991), while Racine (1992) found that the C III] emission line was much less amplified than the continuum. Line profiles possibly modified by microlensing have been observed in one component of the 'clover leaf' H1413 +117, a BAL quasar split into four images (Angonin et al. 1990). Double or multiple quasars can also be used to estimate cloud sizes of Lyα forest and metal absorbers by a detailed spectroscopic comparison of the components at high spectral resolution (Foltz et al. 1984, Smette et al. 1992). We report here the discovery of a bright double quasar where both macro- and microlensing might be present, and pronounced differences in the quasar absorption line spectra are observed.

2. Observations

2.1. Discovery

Since 1990 we conduct a wide-angle survey for bright QSOs based on objective-prism plates taken with the ESO 1 m Schmidt telescope. The plates are digitised in Hamburg and automatically searched for QSO candidates. The project is briefly described by Reimers (1990) and Wisotzki et al. (1991). We first identified HE 1104−1805 as a blue object with a non-stellar spectrum and a conspicuous but not very strong emission feature around 4000 Å. A finding chart for HE 1104−1805 is given in Fig. 1. Subsequently the object was confirmed as a QSO in March 1993 by low-resolution spectroscopy with the ESO 3.6 m telescope. However, its double QSO nature was recognised only when the data were reduced. A second, much fainter spectrum, very similar to that of the main target, was found in 3″ distance. Better observational material was thus urgently required to constrain the properties of this interesting system.

2.2. Direct imaging

Very soon after discovery, we could observe HE 1104−1805 with the ESO New Technology Telescope (NTT), in remote control operation mode. The ESO Multi-Mode Instrument EMMI in the red arm, equipped with a LORAL 2048 CCD (pixel size 15 μm, corresponding to 0.″35) was used for both direct imaging and spectroscopy. The acquired frames were directly transmitted via satellite link to Garching.

Observations were conducted during the night of May 10/11, 1993. We obtained three exposures in the R band of

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*Based on observations made at the European Southern Observatory, La Silla, Chile

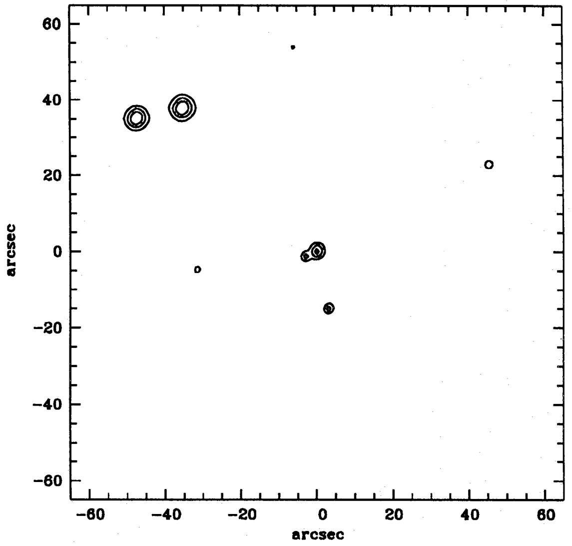

Fig. 1. Finding chart (B band) for the new double QSO HE 1104−1805. North is at the top, west is at the right. The equatorial coordinates (accuracy ~ 3″) are $11^h04^m05\overset{s}{.}1$ and −18°05′11″ (1950.0).

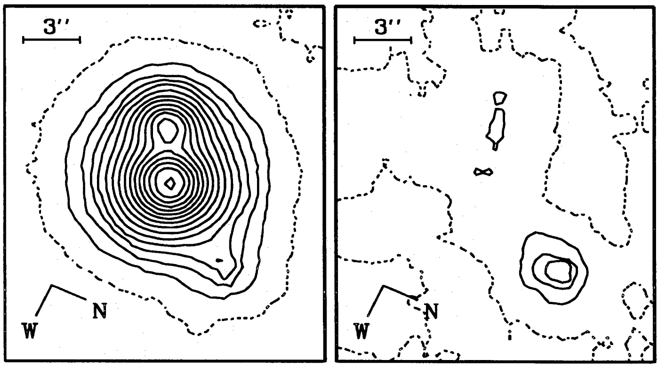

Fig. 2. Left: Composite of three 200 sec R band images of HE 1104−1805. Contour lines correspond to logarithmic surface brightness, starting at 25.5 mag/arcsec^2 (dashed) and increasing by steps of 0.5 mag inwards. The outer contour lines are slightly smoothed. Right: Same field after subtraction of the two QSO point sources. The contour lines are the same as in the left image.

200 sec each, unfortunately only under very moderate seeing conditions (1″.8). The data were reduced with MIDAS using standard procedures. Twilight exposures with the telescope pointed to the zenith were used for flatfielding. The frames were then combined with inverse variance weighing, and a formal absolute calibration was applied with observations of photometric standard stars in the E6 region (Graham 1982). The relevant section of the resulting image is shown in Fig. 2. We obtain R magnitudes of 16.2 and 18.2 for the brighter and the fainter component, respectively. Since the night was not really photometric, the absolute magnitude scale may be in error by ~ 0.2 mag. The separation of the two components is 3″.0, and the position angle is 115°, counted from north through east. The nearby star 15″ south of A has $R = 17.2$.

Using the point spread function constructed from that star (circular symmetry assumed), we have subtracted component A and B from the image. The result is also displayed in Fig. 2. Except for an extended object about 6″ NW from A with an integrated magnitude of $R = 21.3$, possibly a galaxy, there are no significant residuals near A and B. In particular, any possible galaxy close to A or between A and B must be fainter than $R = 24$.

2.3. Spectroscopy

In the same night (May 10/11, 1993) we also obtained low-resolution spectra of both components to facilitate an inter-comparison of spectral properties. Again, EMMI with its red arm and the LORAL CCD were used. A 246 Å/mm grism gave a useful spectral coverage of 4000 – 9400 Å. We used a 5″ slit oriented along the connecting line between the two QSO images, so that slit losses were negligible while both spectra could be extracted from the same frame. Spectral resolution was thus dominated by the seeing disc and gave ~ 18 Å FWHM. The exposure time was 600 sec. The data reduction followed the usual steps: bias and flatfield correction, and sky background approximation using low-order polynomial fits to the lines perpendicular to the direction of dispersion.

As the seeing was more than half the image separation, the two seeing disks displayed some non-negligible overlap, and the two spectra had to be decomposed from the two-dimensional frame in order to leave as little mutual interference as possible. This proceeded as follows: We assumed that the true spatial profile on the detector remained constant with wavelength, and that the only variation was a slow shift of the profile centroid relative to the detector columns, basically caused by atmospheric dispersion. We first determined the amplitude of this displacement as a function of wavelength by cross-correlating each data row with the combined spatial profile and fitting a polynomial to the individual offsets. We next reconstructed the actual seeing profile of a single point source by reflecting the undisturbed wing of the brighter component about its centre. Both components were then extracted separately by matching the properly shifted and normalised point source profile template to the data in each wavelength bin (such template matching is formally equivalent to the profile-weighted summation employed in optimum extraction routines for isolated point sources).

Due to a malfunction of the argon lamp for the comparison arc spectrum, no lines shortward of 5000 Å could be used for wavelength calibration, and the wavelength scale for $\lambda < 4500$ Å must be considered rather inaccurate. The instrumental response was obtained by observing the spectrophotometric standard star GD 108 (Oke 1990). Again, the absolute flux scale may be in error by up to ~ 20 per cent. The two spectra are shown in Fig. 3. The redshift, determined by fitting a Gaussian to the broad C IV emission lines, is identical in both components within the measurement error: $z = 2.303 \pm 0.001$.

3. Analysis and discussion

3.1. Continuum and emission lines

If the two components of HE 1104−1805 are multiple images of one and the same object due to gravitational lensing, they should have similar spectra. Since the redshifts are identical to within ±90 km/s in the QSO rest frame, the pair would have to be a physical binary if not lensed. At least one such object is

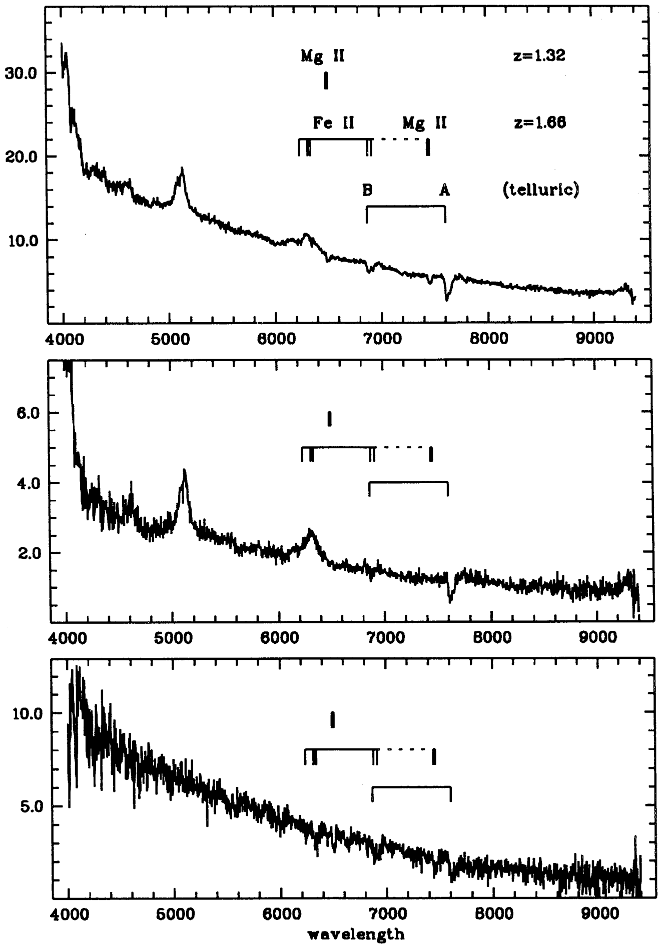

Fig. 3. Upper and middle panel: Spectra of HE 1104−1805 A and B at ~ 18 Å resolution. Flux units are 10^{-16} erg s^{-1} cm^{-2} $Å^{-1}$. Lower panel: Difference spectrum $f_\lambda(A) - 2.8 f_\lambda(B)$. The metal absorption line systems at $z = 1.32$ and $z = 1.66$ as well as the atmospheric O_2 features are marked in all three panels.

known (Q 1145−071, Djorgovski et al. 1987), and Q 2345+007 may be another case (Steidel & Sargent 1990, but see Steidel & Sargent 1991). From inspection of Fig. 3 it is obvious that the spectra are not identical. Component A has a much steeper spectral slope than component B. If expressed in terms of a power-law index α ($f_\nu \propto \nu^\alpha$), the values are $\alpha(A) = +0.15$ and $\alpha(B) = -0.25$. In addition, all emission lines in A are weaker relative to the continuum than in B. However, the equivalent width ratios $W_\lambda(A)/W_\lambda(B)$ of all the lines in Tab. 1 decrease with wavelength from 0.69 (Mg II) to 0.44 (Si IV) by precisely the same factor the continuum flux ratio $f(A)/f(B)$ increases at the corresponding wavelengths. This is demonstrated in Fig. 3, where we show that $f_\lambda(A) - 2.8 f_\lambda(B)$ gives a featureless continuum (except for the QSO absorption lines), i.e. the emission line ratios and line profiles appear to be identical in both spectra. In other words, the differences between the spectra of A and B can be fully explained by 'diluting' the spectrum of A and adding a 'hard' continuum component. In Lyα (+N V), which is not completely covered by our spectrum, there is marginal evidence for an enhancement of the far red wing in A relative to B.

Table 1. Rest frame equivalent widths of emission lines in the spectra of HE 1104−1805 A and B, measured in Å.

Ion	Si IV	C IV	C III] + Al III	Mg II
A	3.6	10.4	15.7	8.2
B	8.1	21.0	25.6	12.7

3.2. Evidence for microlensing?

Such spectral differences are consistent with what has been predicted by calculations of gravitational microlensing from stars in a macrolensing galaxy (Kayser et al. 1986). Since the quasar is not a point source, and the size of the continuum source depends in most models on wavelength, the amplification factor may vary considerably over the source. This results in a chromatic effect, similar to what we observe between the continua of A and B, if A is amplified by microlensing in addition to macrolensing. The same theoretical calculations also predict that the emission line strengths will not be affected by microlensing since the emission line region is much larger (by at least one order of magnitude) than the continuum source, i.e. the equivalent widths of the emission lines will vary along with the microlensing induced variations of the continuum. We conclude that there is strong evidence – but no proof – for microlensing in component A of HE 1104−1805. The observed microlensing amplification is plausible for source sizes $> 10^{-3}$ pc.

Model calculations of the macrolensing using singular isothermal spheres for the lens galaxy (assuming standard Friedmann cosmology with $\Omega_0 = 1$ and $\Lambda_0 = 0$), and adopting the absorption system redshift of 1.66 (or 1.32, respectively) as $z_{\rm lens}$, demand a velocity dispersion of 600 km/s (500 km/s), which for $H_0 = 50$ corresponds to a deflector mass of 3.7×10^{12} (2.5×10^{12})$M_\odot$, large but not unrealistic values. The maximum time delays obtained from the models are 9 (7) years. However, the time delay depends sensitively on the lens position and can be as short as months.

How can the macro- plus microlens hypothesis be confirmed? The lens galaxy has to be fainter than $R = 24$, which almost excludes a low-redshift lens but is consistent with the existence of a galaxy at $z > 1$, as suggested by the strong absorption line systems (see next section). In particular, the $z = 1.66$ damped Lyα system could be caused by the line of sight passing through a galactic disk with a considerable optical depth for microlensing due to stars. In that case, time variability of both the microlensing amplification *and* the chromatic effect must be expected.

The corresponding time scale depends on the motions of the observer, the microlens, and the quasar perpendicular to the line of sight as well as on the source size and the lens properties. We notice that according to the dipole anisotropy of the 3 K background radiation our own velocity vector points nearly into the direction of HE 1104−1805. For a single star microlens, an effective transverse velocity of 1000 km/s, and a source size of 3×10^{14} cm, the minimum variability time scale is ≈ 1 year (Schneider et al. 1992). For an ensemble of lenses, which is likely to be encountered on a light path through a galactic disk,, the time scale on which the observed moderate microlensing amplification disappears may be much longer. In the case of HE 1104−1805, the time scale is probably fairly long since between spectra of component A taken in March 20 and May 10, 1993, no change is visible. Also, photometry in the B band between March 13/14 (ESO) and May 21/22 (1.23 m Calar Alto) 1993 shows that the brightness ratio A/B has been constant within 0.07 mag.

3.3. QSO absorption lines in A and B

Double quasars offer the possibility to study the size of absorbing clouds from differences in their absorption line spectra. Already at low resolution (Fig. 3) it is evident that most strong absorption features in the red are only seen in component A. Higher resolved spectra of A taken in March 93 with the B&C spectrograph of the ESO 1.52 m telescope with a resolution of ∼ 4 Å allow identifications and redshift measurements. Details will be presented in a future paper, where both higher resolved spectra and IUE observations will be analysed. We mention here only that A contains a strong absorption system at $z = 1.66$ which shows prominent Mg II and Fe II lines as well as an optically thick Lyman limit system at 2450 Å and a damped Lyα line at 3240 Å. While both A and B show C IV belonging to this system, the low-ionization metal lines are essentially absent in B. A further Mg II system at $z = 1.32$ is also seen only in A, while the C IV absorption at $z = 2.29$ (thus an 'associated' system) occurs in both QSO components.

The pair HE 1104−1805 A, B shows that damped Lyα clouds with strong singly ionized metal lines (Mg II, Fe II, Al II, Si II) are geometrically smaller than C IV absorbing regions. This is consistent with the concept that damped Lyα lines are produced by galactic disks (Wolfe 1987) while high-ionization systems are formed in galactic halos (Steidel 1990, Reimers et al. 1992).

The separation of the light beams between A and B as a function of redshift z depends on the unknown lens redshift. Our model calculations for a homogeneous universe with $H_0 = 50$, $\Omega_0 = 1$, and $\Lambda_0 = 0$ yield for $z_{\rm lens} = 1.66$ (1.32) proper separations at $z = 1.66$ and 1.32 of 25.4 (13.3) kpc and 25.8 (25.8) kpc, respectively. This would imply cloud diameters less than 13 or 25 kpc for the damped Lyα system at $z = 1.66$, and less than 25 kpc for the $z = 1.32$ Mg II system.

4. Conclusions

The bright double QSO HE 1104−1805 has compelling properties of a gravitationally lensed object if microlensing is taken into account. Although no galaxy image could be detected with $R \lesssim 24$, strong metal line absorption systems at $z = 1.32$ and $z = 1.66$ indicate the presence of galaxies in the line of sight that could act as lenses. Direct observations of these galaxies will be essential to model the (macro-) lensing configuration in detail.

The emission line ratios and profiles are so similar in both components that a chance resemblance is not very probable, considering the diversity of the quasar zoo seen elsewhere. By invoking the combined effects of macro- and microlensing, where the latter affects only the compact continuum source, the two spectra can be brought to an almost perfect match. The microlensing hypothesis predicts characteristic spectral variability on time scales of up to many years. Accurate simultaneous spectrophotometric monitoring of both components over a long time may be necessary to confirm the gravitational lens nature of HE 1104−1805.

To enable the proposed lensing mechanism to work, a dependence of microlensing amplification on wavelength is required. This argument can be reversed: Accepting the lens hypothesis for HE 1104−1805, the observed chromatic effect provides a remarkable probe of the temperature structure in the continuum emitting region. If indeed variability due to microlensing should be detected in the future, even a two-dimensional scan over the active nucleus might be possible.

The absorption line spectra of A and B are distinctly different. Both components are bright enough to obtain very good signal-to-noise spectra at high spectral resolution. Independent of its yet open gravitational lens nature, the system offers therefore exceptional opportunities to study the spatial extent of both the Lyman forest clouds in the range $1.6 < z < 2.3$, and of metal line absorbing regions with the Hubble Space Telescope.

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