Astron. Astrophys. 357, L29–L31 (2000)

ASTRONOMY AND ASTROPHYSICS

LETTER

Letter to the Editor

HS 0818+1227: discovery of a new double gravitationally lensed QSO⋆

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Received 22 March 2000 / Accepted 4 April 2000

Abstract. We announce the discovery of a new gravitationally lensed QSO within the Hamburg Quasar Survey (HQS). HS 0818+1227 is at redshift z = 3.115 ± 0.001 and consists of two components separated by 2.″1 with R-magnitudes of 18.6 and 19.8 respectively. The two components have identical redshifts ($\triangle v \leq 220$ km/s) and identical emission line spectra with a flux ratio $f_{\rm A}/f_{\rm B} = 8$. In particular, both have the same large OVI/CIV emission line ratio. Close to the fainter image B there is an extended source which cannot be separated from B and which contributes to the spectrum of B at $\lambda \geq 5500$ Å. Subtraction of a downscaled spectrum of A from B ($f_{\rm B} - f_{\rm A}/8$) reveals a residual with a spectrum similar to that of a neighbouring galaxy 5″ apart which is at redshift 0.39. The system bears similarity to UM 673 where the lensing galaxy is very close to the fainter image. Further galaxies are within roughly 20″. The suspected lensing galaxy ($R \simeq 20.6$, $M_{\rm V} \simeq -21.5$) is apparently member of a group (chain) of galaxies with several bright members within $60{\rm kpc} \cdot h_{50}^{-1}$.

Key words: galaxies: quasars: individual: HS 0818+1227 – galaxies: quasars: general – cosmology: gravitational lensing

1. Introduction

Gravitational lenses are an important tool of observational cosmology. Multiply imaged QSOs, in particular, can be used to study dark matter in an unbiased sample of galaxies (selected by mass) and to determine the Hubble constant H_0 from observed time delays between the images (Refsdal, 1964). In spite of dedicated surveys by various groups (e.g. Surdej et al. 1988, the CLASS survey (for references cf. Koopmans & Fassnacht 1999) and the Hamburg objective prism surveys), the number of confirmed lensed multiple QSOs is still small since it is often difficult to prove the gravitational lens character. While the measurements of H_0 from time delays in 4 systems seem to converge to values around 65 km/s/Mpc (Koopmans & Fassnacht, 1999), and further time delays have been measured already, more suitable systems are highly welcomed. Since ∼ 1990 we conduct an all extragalactic sky survey for bright QSOs using deep objective prism plates from both the Calar Alto Schmidt telescope – the former Hamburg Schmidt – and the ESO Schmidt telescope (Hagen et al. 1995, Reimers & Wisotzki, 1997, Wisotzki et al. 1996a). The two surveys cover roughly 22 000 deg^2 on 950 Schmidt fields. All plates have been digitized and automated search techniques are applied. Since among optically bright high-redshift QSOs the a priori probability of being lensed is enhanced (e.g. Surdej et al. 1993) one of the aims of our survey was from the beginning to discover further lensed QSOs. Indeed, in this letter we announce the sixth case of a newly identified lensed QSO from our surveys after HE 1104−1805 (Wisotzki et al. 1993), HE 2149−2745 (Wisotzki et al. 1996b), RXJ 0911.4+0551 (Bade et al. 1997), HE 0230−2130 (Wisotzki et al. 1999), HE 0512−3329 (Gregg et al. 2000). In addition, the physical pair HS 1216+5032 (Hagen et al. 1996) has been discovered.

2. Observations

HS 0818+1227 was discovered as a Lyman α quasar on a digitized objective prism plate of the northern Hamburg QSO survey (HQS) taken with the Calar Alto Schmidt due to its blue colors and its strong Lyα line visible already on the Schmidt plate. It was observed on February 18, 1998 in a regular follow-up run on the Calar Alto 2.2m telescope using CAFOS, the Calar Alto focal reducer spectrograph. CAFOS is equipped with a 2 k x 2 k CCD with a pixel size of 24 μm which corresponds to roughly 0.″5. For spectroscopy we applied a grating which provides a resolution of 9.3 Å/pixel, roughly 18 Å with a 1″ slit.

Since the CAFOS acquisition image and the first spectrum both confirmed its QSO spectra and revealed its multiple character as well as faint galaxies close to it, additional observations were performed subsequently with the immediate aim to investigate the properties of this serendipitously discovered gravitational lens system. We took two R images (400 sec each) (Fig. 1). Two spectra were taken with the slit oriented at the two QSO images with 1800 sec exposure each. A further spectrum was taken (1800 sec) of the galaxy C (Fig. 1). The seeing was

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⋆ Based on observations at the German - Spanish Astronomical Center (DSAZ) on Calar Alto, Spain

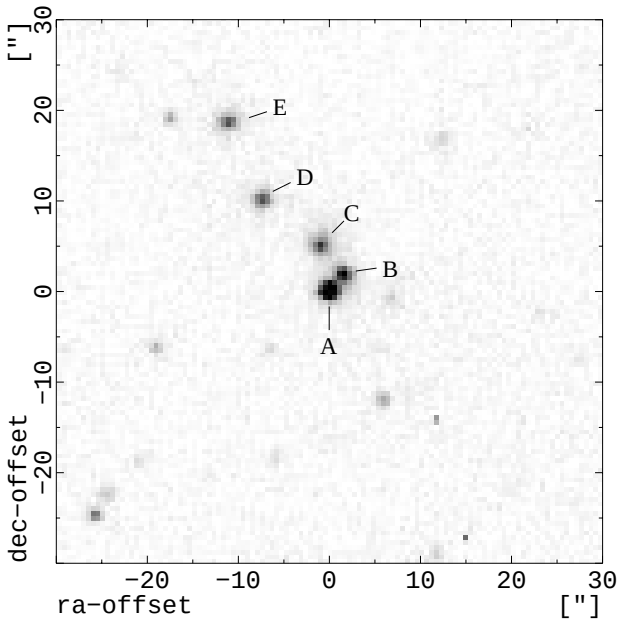

Fig. 1. R image of the double QSO HS 0818+1227 AB. North is top, west is right. Coordinates of A are α = $8^h21^m39\overset{s}{.}1$, δ = $+12^\circ17^m29''$(2000).

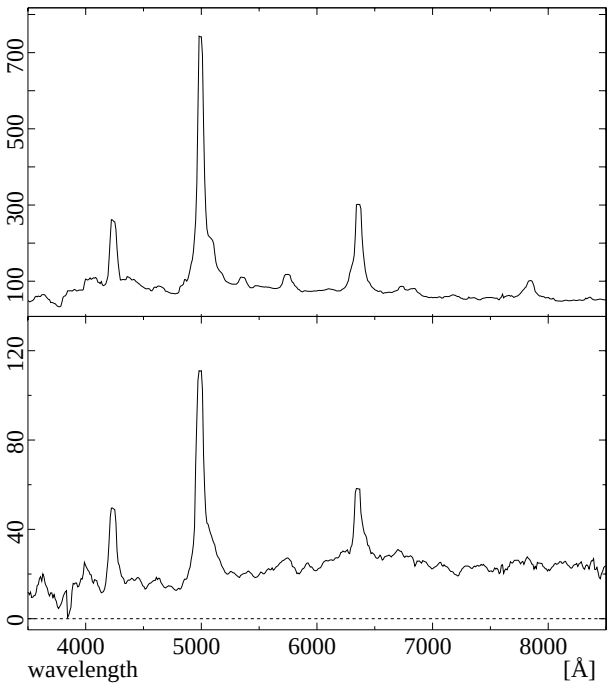

Fig. 2. Spectra of HS 0818+1227, upper/lower panel show components A and B respectively, flux units are 10^{-18} erg cm^{-2}s^{-1} Å^{-1}

$\sim 1''$ (as measured from the images and the individual spectra). The reduction of images and calibration of spectra followed standard procedures. For the R-image no absolute calibration is available, while for spectroscopy, absolute spectrophotometry was performed relative to standard stars.

3. Analysis

3.1. Imaging and astrometry

The combined 800 sec exposure is shown in Fig. 1. The double QSO is located at the end of a chain of 3 galaxies of roughly the same brightness (C,D,E.). The angular separation between the QSO images A and B is $2\overset{''}{.}1$ as measured in R. The coordinates of the brighter component A are: α = $8^h21^m39\overset{s}{.}1$ δ = $+12^\circ17^m29''$(2000). The coordinates of B relative to A are $\triangle\alpha$ = $-1\overset{''}{.}3$, $\triangle\delta$ = $1\overset{''}{.}6$ (position angle 321°). However, as shown below, image B is contaminated by a galaxy G, which at our angular resolution cannot be separated from B, and which has about the same brightness in R as image B. This means that in R the center of gravity of the B image might be shifted and the true separation A-B could be slightly larger. Due to the comparable brightness of G and B, our attempts to separate the expected point source B from the extended source G using a PSF from point sources in the field have been rather unsatisfactory. While after subtraction of a point source an extended image (G) becomes visible, it is difficult to quantify its contribution from the R image alone.

3.2. Spectroscopy

Although the spectra of A and B, taken simultaneously with both components on the slit, are rather well separated due to the excellent seeing conditions, we applied the following procedure to correct for the overlap: The position and the full width half maximum (FWHM) of a Gaussian profile perpendicular to the dispersion of spectrum A were determined in a spectral region with high S/N (Lyα). With fixed numbers for position and FWHM the spectrum of component A was extracted from the image with the amplitude f_λ (A) as a free parameter determined by the condition of vanishing residuals from A. The remaining spectrum is that of B corrected for overlap from A. The resulting wavelength and flux calibrated spectra are shown in Fig. 2. The identical emission line ratios, in particular the large OVI/CIV ratio provide already strong evidence for A and B being images of the same object. It would be rather contrived to assume a physical pair with both components having the same (rare) strong OVI emission lines. The redshifts are identical: within the accuracy of measurements: z = 3.115 $\pm$ 0.001; the mean velocity difference between A and B is $\leq$ 220 km/s. From spectrophotometry of A and B, we find $R_{\rm A}$ = 18.6 and $R_{\rm B}$ = 19.8 respectively. Comparing the continuum of B with a spectrum of A downscaled by a factor of 8 shows that B contains a contribution from a red galaxy G (Fig. 3). While, as discussed above, a separation is difficult in the R image, the two components can be separated spectroscopically. Assuming that B has an identical spectrum to that of A downscaled by a factor of 8, i.e. f_λ(B) = f_λ (A) / 8, we simply subtract the assumed intrinsic spectrum of B from the observed one f_λ(B)$-f_\lambda$ (A) / 8 = f_λ(G). The resulting spectrum of the underlying galaxy f_λ (G) is shown in Fig. 3 in comparison with the spectrum of the neighbouring galaxy C. Due to a small misalignment of the spectrograph slit with the AB position angle, atmospheric refraction caused loss of a fraction of the bluest part of spectrum A. Therefore the pu-

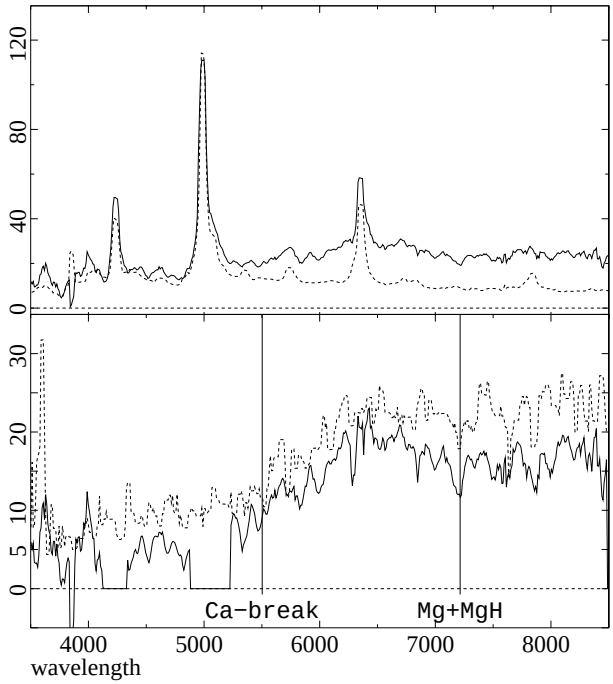

Fig. 3. Upper panel: Flux spectra f_λ (B) (solid line) and f_λ (A) / 8 (dotted line). Lower panel: f_λ (B) - f_λ (A)/8 = spectrum of galaxy G hidden in the spectrum of B (solid line) compared with spectrum of galaxy C (dotted line, plotted with an offset of 6 10^{-18} erg cm^{-2}s^{-1} Å^{-1})

tative magnification factor 8 was determined from the CIV flux ratio only. On the other hand, the high line-to-continuum ratio would cause large residuals in f_λ(B) = f_λ (A) / 8 at the positions of the emission lines in the blue even for small slit losses in A. Therefore in Fig. 3 we have cut out the spectral regions around OVI and Lyα. Nevertheless the similarity is striking. We conclude that indeed a galaxy at the same redshift 0.39 as galaxy C with a similar brightness is hidden in the spectrum of B. We conclude that while the lens galaxy G cannot be isolated directly from the image, there is strong evidence that we have discovered the lens galaxy spectroscopically. The lens galaxy G hidden in B is probably the fourth member of a chain of 4 luminous galaxies at redshift 0.39. R(G) = 20.6 leads to $M_{\rm V}$ = $-$21.5 taking into account the K correction from Fig. 3. This is roughly an L* galaxy ($M_{\rm V}$ = $-$ 21.7). The luminosity (mass) is consistent with what is necessary to cause the observed image splitting of 2.″1. If galaxies D and E are also at the same redshift 0.39 as C and G, we have 4 luminous galaxies – and further fainter ones (Fig. 1) – within a radius of 20″($\hat{=}60\,{\rm kpc}\,h_{50}^{-1}$ at z = 0.39), apparently a small cluster or group of galaxies.

4. Conclusions and discussion

We believe that we have presented strong evidence for HS 0818+1227 being a double QSO gravitationally lensed by a foreground galaxy. The evidence rests on the – besides identical redshifts – striking similarity of the spectra of the two components, in particular the strong OVI emission line relative to CIV and Lyα and the identical flux line ratios of all emission lines. The gravitational lensed nature is further supported by a contribution to the fainter image B of an extended source with a galaxy type spectrum at redshift 0.39. The lens galaxy is apparently member of a group or small cluster of galaxies. The configuration of HS 0818+1227 reminds us of UM 673 ($\equiv$ Q0142 $-$ 100, Surdej et al. 1988, z = 2.719, A-B $\simeq$ 2.″2, z (lens) = 0.49). According to the CASTLE survey (http://cfa-www.harvard.edu/castles) using HST the lens is between A and B close to image B at 0.″383. A comparable configuration for HS 0818+1227 would ask for HST imaging in order to map the geometry of the system. The galaxy group might also be detectable in X-rays. HS 0818+1227 is not known to be a radio source according to available sources like that of Becker et al. (1991).

Acknowledgements. The Hamburg Quasar Survey has been supported by the Deutsche Forschungsgemeinschaft under Re 353/14 and Re 353/22.

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