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Letter to the Editor

J03.13 A and B: a new multiply imaged QSO candidate*

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Abstract.
Careful analysis of direct R CCD frames obtained for selected Highly Luminous Quasars in March 1993 with the MPI/ESO 2.2m telescope has revealed that the quasar J03.13 consists of at least two point-like components, constituting therefore a new gravitational lens candidate. Follow-up direct imagery of this interesting object with the New Technology Telescope (NTT) + SUSI in February 1994, using the Bessel B, R and Gunn-i filters, tends to confirm the gravitational lens hypothesis. The mean angular separation and magnitude difference between the A & B images are found to be $0.84'' \pm 0.03''$ and 2.1 ± 0.1 mag, respectively. A spatially unresolved, medium resolution spectrum of J03.13, obtained with the NTT + EMMI in February 1994, shows that the QSO has a redshift $z = 2.55$, with Lyα and CIV absorptions at $z = 2.34$ and MgII, MgI and FeII absorptions at $z = 1.085$. The latter absorptions might be associated with a $\sigma = 206$ km/s lens galaxy. B, R and Gunn-i photometric observations of J03.13 during 1994 and 1995 do not show evidence for flux variations exceeding 0.03 mag. HST direct imagery with WFPC2 and FOS spectroscopy of J03.13 A & B are planned during cycle 5.

Key words: gravitational lensing – quasars (individual): J03.13

1. Introduction

Because of their very large cosmological distances and due to the amplification bias effect (Turner et al. 1984), Highly Luminous Quasars (hereafter HLQs; typically $M_V \leq -27$) turn out to be extragalactic objects having the highest probability to be affected by gravitational lensing effects (Surdej et al. 1987, 1988; Fukugita & Turner 1991; Surdej et al. 1993a). In the remainder, we adopt a cosmological model with $H_0 = 50$ km/s/Mpc, $q_0 = 0.5$ and $\Lambda = 0$. It is then easy to estimate that the probability for a typical HLQ (cf. J03.13) to be multiply imaged is about 1% (see the above references).

The numerous possible cosmological and astrophysical applications of gravitational lensing (see Blandford & Narayan 1992 and Refsdal & Surdej 1994 for reviews on these applications) have motivated the Liège/ESO/Hamburg group to start a systematic search for gravitational lens (hereafter GL) candidates among HLQs, using high angular resolution imagery. Following several discoveries of cosmic mirages like UM673 (Surdej et al. 1987), H1413+117 (Magain et al. 1988), an ESO Key-Progamme (Surdej et al. 1989, 1992) has allowed us to directly image, between 1989 and 1993, about 250 additional HLQs selected from the Véron-Cetty & Véron catalogues of quasars (1987, 1991, 1993). Two new GL candidates have then been reported for the quasars 1208+1011 (Magain et al. 1992) and 1009-025 (Surdej et al 1993b). Further evidence for 1208+1011 being doubly imaged has been presented by Maoz et al. (1992), and by Hewett et al. (1994) for the case of 1009-025.

In this Letter, we report the discovery of a new GL candidate imaged during the 1993 campaign as well as further supporting observations obtained with the NTT in 1994. This GL candidate, listed in the Véron & Véron catalogue of quasars (1993) comes from the fifth list of the Calán-Tololo Survey (Maza et al. 1993). In the next section, we summarize the different types of observations that have been carried out for J03.13 [$\alpha(1950) = 10^h15^m01^s, \delta(1950) = -20°31'44''$] during the last two years; in section 3, we describe our method of data analysis and present the astrometric, photometric and spectroscopic results; the last section is devoted to a general discussion of these results in the context of the gravitational lensing hypothesis.

2. Observations

Observations of J03.13 have been made at the European Southern Observatory (La Silla, Chile), using various instruments and telescopes. They include a direct CCD camera at the Cassegrain focus of the ESO/MPI 2.2m telescope, EMMI and SUSI at the Nasmyth foci of the 3.5m NTT, and direct CCD cameras with the Danish 1.54m and Dutch 0.92m telescopes. Table 1 summarizes technical data relevant to each type of instrumentation that has been used and Table 2 displays the observational characteristics pertaining to each individual recorded CCD frame. Direct imaging has been carried out during photometric nights, and Johnson UBVRI standard fields

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have also been imaged (Landolt 1992), allowing an absolute flux calibration of the frames of J03.13.

Table 1. Technical data for the different instrumentations. Columns: 1) Telescope; 2) Instrument; 3) ESO CCD#; 4) Readout Noise (ADU); 5) Conversion Factor (e^-/ADU); 6) Non linearities (%); 7) Pixel Size (″)

1	2	3	4	5	6	7
2.2m	Dir Cam	8	6.34	4.10	< 2	0.175
NTT	SUSI	25	2.60	3.38	< 2	0.128
NTT	EMMI	34	4.37	1.38	< 2	0.34
1.54m	Dir Cam	28	3.80	3.60	< 1.5	0.38
0.92m	Dir Cam	33	2.34	4.10	< 0.1	0.44

Table 2. Observational data for direct imagery & spectroscopy of J03.13

Date (UT)	Tel. Inst.	Filter/ Grating	Exp. sec	Airmass	Sky ADU	FWHM (″)
1993.21	2.2m	R	300	1.030	159	1.12
1994.12	SUSI	R	180	1.062	103	0.70
″	″	″	″	1.031	105	0.81
″	″	i	300	1.036	188	1.00
″	″	″	″	1.054	149	0.80
″	″	B	″	1.044	18	1.00
″	″	″	″	1.036	18	0.85
1994.11	EMMI	Gr 13	1200 (3X)	∼ 1.05		∼0.60
1994.23	1.54m	R	300	1.023	6920	1.11
″	″	B	″	1.012	2177	1.18
″	″	″	″	1.013	2313	1.25
1994.94	0.92m	R	180	1.163	83	1.27
″	″	i	240	1.130	157	1.40
″	″	B	420	1.146	41	1.42
1995.18	1.54m	R	180	1.056	184	1.25
″	″	i	900 (3X)	∼ 1.1	1490	0.9
1995.19	″	i	900	1.016	1650	0.8

Moreover, three spectra of J03.13 with 20 min exposure have been obtained during the night of 11-12 February 1994, using EMMI in the REMD mode with grating #13. Combined with ESO CCD #34, this mode leads to a spectral dispersion of 3.5 Å per pixel. The angular scale of these spectra along the slit is 0.34″per pixel.

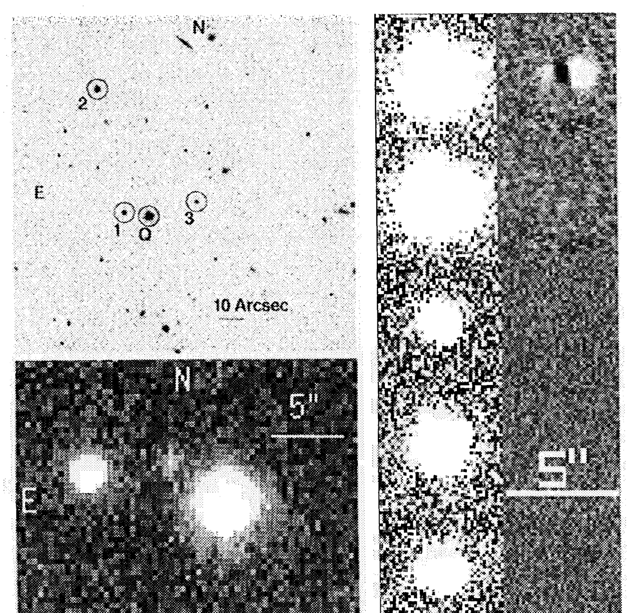
3. Data Reduction and Results

Data reduction and image analysis have been performed using standard MIDAS commands as well as personal procedures and programs (Remy 1995). Besides the usual bias and sky-flat calibration frames, pairs of dome-flats have also been obtained for the 2.2m, the NTT + SUSI and EMMI and the 1.54m telescopes, at different flux levels, in order to test the linearity of the relevant CCDs. This is simply done by expressing the variance of the ratio of two equally exposed flats as a function of their common flux level. The value of the conversion factor can then also be derived; it is reported in Table 1. Note that for the 0.92m Dutch telescope (CCD #33), we have only quoted the values listed in the instrumentation manual.

3.1. High Angular Resolution Imagery

The very good sampling of the point spread function (PSF) recorded with the 2.2m + direct CCD camera or NTT + SUSI allows us to make use of a very performing numerical profile fitting program in order to decompose the image of the QSO into several point-like components (Remy 1995). First, a 2-dimension numerical PSF is constructed from selected nearby stars (see the finding chart in Fig. 1a; three PSF stars have been selected in the present case). Then, this PSF profile is fitted to the object itself, its X and Y positions and the intensity of the peak being the only adjustable free parameters. The simultaneous fit of multiple PSFs is also possible. In this way, one can determine the relative astrometric and photometric quantities of each individual point-like component. Since the same PSF profile is used for each component, the ratio of the peak intensities provides a very precise measurement of their flux ratio. The adequation of the fit to the object, determined by the minimisation of a χ^2 between the observation and the model, is also checked afterwards by visual inspection of the residuals. For the B frames, the fit of a pure analytical Moffat profile for the PSF led to better results, because of the presence of higher noise in the numerical PSF.

Fig. 1. (a; left): R CCD frame of J03.13 recorded with SUSI (FWHM = 0.7″). The three stars used to construct the PSF are labelled 1, 2 and 3. **(b; right):** Enlargments of the direct (left column) and residual (right column) images of J03.13 after subtracting a single scaled PSF (first row) and a double PSF (second row); the three PSF stars and their residuals after subtraction of the scaled PSF (rows 3-5; see text). **(c;bottom left):** Enlargment of J03.13 and the nearby galaxy at 4.5″ from J03.13, in the i filter (see text)



The magnitude differences between the A and B components, as derived from the numerical fits, are listed in Table 3. for various filters. The angular separations between the A and B components are also reported there.

The residual images shown in Fig. 1b have been normalized to units of 1σ uncertainties due to the CCD readout, to the object plus sky photon noises and to the noise in the PSF (however the latest is not taken into account in the minimisation of the χ^2). Note the very significant image residual left over for J03.13 (first row). In the second row, is also shown the residual image of J03.13, after subtraction of a double PSF on the R frame with the best seeing. The faint ($\sim 3\sigma$) but systematic residuals seen on the frames taken under the best seeing conditions tend to show that image A probably consists of a bright image of the QSO and of a very faint and close ($< 0.2''$) companion. In spite of many attempts, we could not find a systematic way to eliminate those residuals. Indeed, their low significance, together with a rather low S/N ratio in the PSF preclude any realistic modelization of this hypothetical third component, and thus, no quantitative estimation of its shape, brightness, relative position and colors could be made.

Moreover, a faint galaxy (i $\sim$ 21.5) is detected on a deep frame (equivalent integration time: 1h) taken with the i filter at the Danish 1.54m telescope. Its location is only 4.5″away from J03.13, at a position angle of 35° (see Figure 1c).

Table 3. Average photometry and relative astrometry: results from multiple PSF fittings

Object	B$\pm\sigma_B$	R$\pm\sigma_R$	i$\pm\sigma_i$
J03.13 A	17.6±0.1	17.2±0.1	16.9±0.1
J03.13 B	19.7±0.1	19.3±0.1	18.9±0.1
J03.13 A-B	-2.15±0.05	-2.14±0.05	-2.05±0.05
$\Delta\theta_{AB} \pm \sigma$ ($''$)	0.88±0.02	0.84±0.02	0.81±0.03

3.2. Photometric Data

In addition to the high angular resolution direct imagery presented above, we have also obtained unresolved CCD images of J03.13, under photometric conditions, in 1994 and at the beginning of 1995 (see Table 2). We find that the dispersion of the recorded photometric values [R = 17.01 (1994.23), 17.02 (1994.94) and 17.01 (1995.18)] is fully compatible with the measurement uncertainties (0.03 magnitude), indicating that we may set firm upper limits of 3 % and 23 %, respectively, on possible flux variations of the A and B components between March 1993 and March 1995.

3.3. Spectroscopic Data

The medium dispersion (3.5 Å per pixel) spectra obtained for J03.13 with the NTT+EMMI have been calibrated in wavelength using He+Ar calibration frames, and a relative response curve has been deduced from the observation of the Oke-HST Standard HZ21. Note that CCD #34 suffers from charge traps for about 20 columns. Therefore, the information lost in these traps could not be properly restored.

In order to achieve the best spectral extraction, we have used the Horne algorithm (Horne 1986), as implemented in the MIDAS package. The reduced spectra have then been added together to yield the final spectrum, characterized by a signal to noise ratio of about 90 in the continuum at 6000 Å. The charge traps have been identified by correlating the spectrum of the quasar with that of the standard star. The data affected by these traps have been replaced, using a linear interpolation between non affected neighbour pixels. Unfortunately, the moderate angular resolution along the slit did not allow us to extract separately the spectra of the two A & B point-like components. The resulting spectrum is reproduced in Figure 2 and the main spectral features are identified in Table 4. From the observed wavelengths of the SiIV, OIV], CIV and CIII] emission lines, we derive a redshift $z = 2.545 \pm 0.003$ for the QSO, significantly different from the value $z = 2.80$ originally proposed by Maza et al. (1993). Two intervening absorption systems may be identified: Lyα and the CIV doublet at $z = 2.344$ and the MgII doublet, MgI and FeII lines at $z = 1.085$. The spectral feature detected at 7616 Å is mainly caused by a telluric absorption due to O_2.

Table 4. Identified emission and absorption features in the spectrum of J03.13

Ion	λ_{lab} (Å)	λ_{obs} (Å)	EM/ABS	z
Lyα	1215	4066	ABS	2.344
Lyα?	1215?	4187	ABS	2.446?
Lyα	1215	4320	EM	2.553
NV	1240	4377	EM	2.530
?	?	4756	ABS	?
FeII	2344	4887	ABS	1.085
SiIV	1394	4937	EM	2.542
FeII	2382	4967	ABS	1.085
OIV	1406	4985	EM	2.546
CIV	1549	5182	ABS	2.343
FeII	2586	5391	ABS	1.085
FeII	2600	5421	ABS	1.085
CIV	1549	5494	EM	2.547
MgII	2796	5830	ABS	1.085
MgII	2803	5845	ABS	1.085
MgI	2853	5948	ABS	1.085
CIII]	1909	6770	EM	2.546

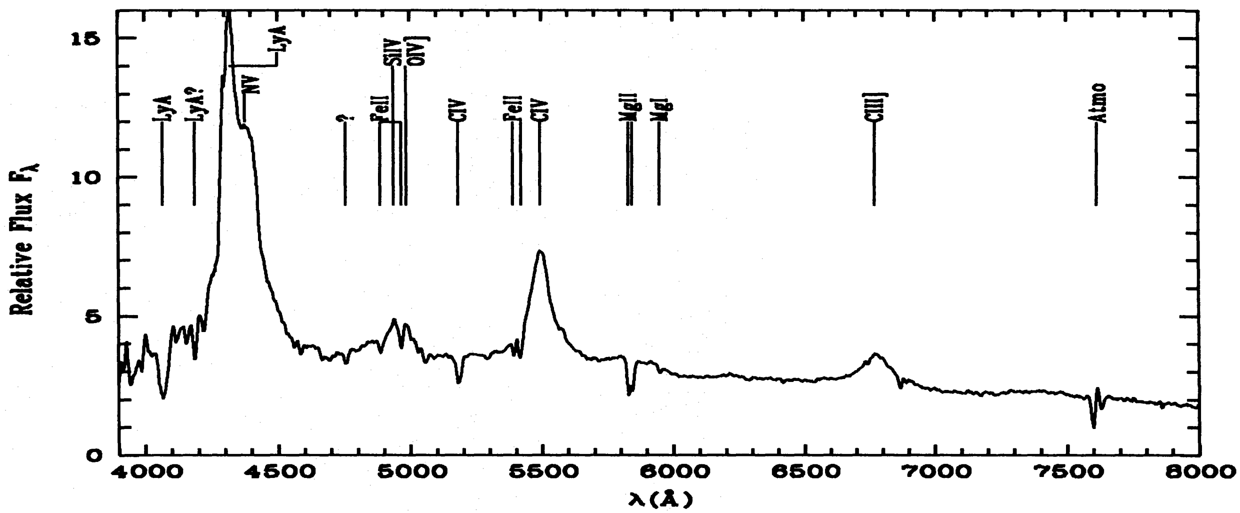
4. Discussion

The observational data presented in the previous section tend to support the GL hypothesis for the J03.13 system. The high angular resolution direct CCD frames provide us with very strong evidence that both the A & B components have approximately the same colors. The photometric data in Table 3 indicate that the B component is slightly brighter and closer to A in the i band. Such a trend may easily be accounted for by the contamination of a foreground lens galaxy at high redshift, expected to be located closer to the faintest lensed (i.e. B) image, on the plane of the sky. The faint residuals seen on the best seeing SUSI frames near image A of J03.13 could be due to a foreground galaxy (the line of sight seems indeed very rich), but no firm conclusion can be drawn from our data.

HST observations of J03.13 to be obtained with the WFPC2 planetary camera in the I band during cycle 5 will enable us to check the morphology of this interesting object, and especially the presence of nearby foreground galaxies.

The NTT spectroscopic data acquired for J03.13 point towards a possible "natural" lens at $z = 1.085$. By computing the differential probability for J03.13 to be lensed, we find that the most likely position for the lens should be at $z = 0.52$, but that the probability for it to be at $z = 1.085$ is only twice smaller. In order to produce the observed angular separation between the two lensed images (0.84″), a galaxy located at such a redshift should have, for the case of a Singular Isothermal Sphere

Fig. 2. Medium resolution spectrum of J03.13



(SIS) lens model, a velocity dispersion $\sigma = 206$ km/s. Choosing the velocity dispersion parameter of the Schechter's luminosity function for elliptical galaxies $\sigma^* = 225$ km/s (Fukugita & Turner 1991), and applying the Tully-Fisher relation between the velocity dispersion and the luminosity of these galaxies (Tully & Fisher 1977, de Vaucouleurs & Olson 1982), we find in this case that the lens should be a $0.7L^*$ elliptical galaxy. The apparent brightness of such a galaxy at $z = 1.08$, including or not a mild evolution, the K correction as well as the effects of nebular emission and internal extinction as calculated by Guiderdoni and Rocca-Volmerange (1988) and Dickinson (1995, private communication) should be in the range $R = 22.2 - 23.2$. This is too faint to be detected on our R CCD frames, near the much brighter A & B components.

Note that the identification of GLs with such small angular separations is now possible due to the higher angular resolution provided by the PSF subtraction technique, and is fully compatible with normal expectations. Indeed, Fukugita & Turner (1991) estimate that $\sim 43\%$ of multiply imaged QSOs should show angular separations less than $1''$, while the present observed fraction of such multiply imaged QSOs is $\simeq 35\%$. So, if confirmed to be a new GL system, J03.13 will strengthen the agreement of GL statistics with the dynamical measurement of σ^*, without the necessity of any dark matter correcting factor (Kochanek 1993, Claeskens et al. 1995).

Finally, spectra of the individual point-like components A and B are mandatory in order to definitely prove the gravitational lens hypothesis of J03.13.

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