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HST confirmation of the lensed quasar J03.13*

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Abstract. In order to definitely prove the claim by Claeskens et al. (1996) that J03.13 is a doubly imaged quasar, WFPC2 direct imaging and FOS spectroscopy of this compact system have been obtained with HST. These *textbook case* observations clearly show that J03.13 consists of two point-like images separated by $0.849'' \pm 0.001''$ with a magnitude difference of 2.14 ± 0.03 in V and I. We see no trace of a lensing galaxy. From the FOS observations, we find that J03.13 A and B have identical spectra within the measurement uncertainties. The data also show that spectroscopic contamination of B by A is negligible. We do confirm the redshift $z = 2.545$ for J03.13 A and B (emission-lines due to Ly$-\beta$ λ1025 and O VI $\lambda\lambda$1031, 1037 are also detected), first derived from an unresolved ground-based spectrum of the two components by Claeskens et al. We also find that the absorption line system at $z = 2.344$ (C IV and Ly$-\alpha$) is present in the spectra of A and B. On the contrary, the absorption line system at $z = 1.085$ (Mg II) is only present in the spectrum of J03.13 A. If this latter system is associated with the lens, we may expect that image A consists of two radially merging images with a very small angular separation. From the WFPC2 imagery, we can rule out the presence of a third component fainter than A by up to 5.2 mag. with an angular separation $\geq 0.13''$.

Key words: – gravitational lensing – quasars: individual: J03.13 – Techniques: image processing

1. Introduction

In a search for gravitational lensing within a sample of highly luminous quasars (hereafter HLQs, Surdej et al. 1993), Claeskens et al. (1996, Paper I) have reported the identification of a new candidate for the quasar J03.13. On the basis of direct images obtained with the MPI/ESO 2.2m and NTT telescopes, they found that this high redshift and bright (B = 17.4) quasar consists of two point-like images with magnitude differences ΔB = 2.15, ΔR = 2.14 and Δi = 2.05 ± 0.05, and angular separations of $0.88''$, $0.84''$ and $0.81'' \pm 0.02''$, in the B, R and Gunn-i passbands, respectively. Because of the too small angular separation, they could only obtain a spatially unresolved low resolution spectrum of J03.13 A and B with the NTT + EMMI in February 1994. They measured a redshift z = 2.55 for the quasar and identified two narrow absorption line systems at $z = 2.344$ (Ly$-\alpha$, C IV) and $z = 1.085$ (Fe II, Mg I, Mg II). They concluded that it was mandatory to obtain spectra of the two resolved point-like images in order to definitely prove the gravitational lens hypothesis for this system.

Multiple direct CCD frames of J03.13 were obtained on November 28, 1995 through the F555W and F814W filters with the WFPC2 camera onboard HST. Analysis of these observations is described in section 2. From these direct images, it was possible to measure very accurate astrometric positions and brightnesses of the two components. It then became feasible to properly center these targets within the standard 0.5 circular aperture of the Faint Object Spectrograph (FOS). As a result, good S/N low resolution FOS spectra of J03.13 A and B could be obtained on October 28, 1996. These data and their interpretation are presented in section 3.

Finally, a discussion and conclusions form the last section.

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2. WFPC2 direct imaging of J03.13

Following the ground-based identification of two resolved point-like images for the quasar J03.13 (see Paper I), we proposed to image this interesting system with the WFPC2 planetary camera (PC1) through two wideband filters in order to search for possible structure of the QSO images at $\simeq 0.1''$ angular scales and also to possibly set additional constraints on the lensing model. The good dynamic range of the WFPC2 was essential to achieve these goals. Based on the photometry reported for this system in Paper I, we chose the ADC channel with 14 e/ADU gain and integration times of 160 (resp. 400 and once 300) sec., to avoid the saturation of the brightest QSO image through the F555W (resp. F814W) broadband filters. Given the two orbits allocated to this HST direct imagery program (ID 5958), our strategy has been to obtain 5 (resp. 6) such PC1 exposures with the F555W (resp. F814W) filters. Each of these exposures has been offset by $\simeq 1.6''$ in order to optimally dither the QSO images and possibly detect faint structures at small angular scales. In the usual nomenclature for WFPC2 data, the dataset names obtained on November 28, 1995 (18h32m - 20h34m UT) with the F555W (resp. F814W) filters range from U2YK0101T to U2YK0105T (resp. from U2YK0106T to U2YK010BT). Please note that the integration time for dataset U2YK0107T is 300 sec., instead of 400 sec. for all remaining F814W CCD frames.

Composite F555W and F814W images of J03.13 made after proper recentering and coaddition of the single PC1 frames are shown on the left panels of Figure 1.

On these composite and on each single CCD frames, J03.13 appears to be clearly resolved as two point-like components. No trace of a third compact image or of a faint intervening galaxy is visible. The somewhat extended core and knotty-like structure seen for each single image component are essentially due to the complex shape of the combined "HST + WFPC2 + filters" point spread function (PSF).

Due to a very slight error in the typing of its equatorial coordinates, our target has not been properly centered on the PC1 detector; it fell very near to one of its edges. For this location, we were not able to identify an adequately observed PSF using the WFPC2 PSF library search tool available at STScI. We therefore decided to proceed as follows. A set of approximately 100 simulated PSFs has been computed by means of TinyTim (Krist 1997) for different values of the focus (Zernicke parameter Z4) and of the jitter of the telescope. These numerical PSFs have then been fitted to the images of J03.13 with an automatic procedure fully described in Østensen et al. (1997). For each CCD frame, optimal values for the Z4 and jitter parameters have been selected on the basis of the minimum χ^2 for the residuals. Note that due to the orbital breathing of the telescope, excursions of up to 7 microns have been found for the focus (Z4) during the F814W ob-

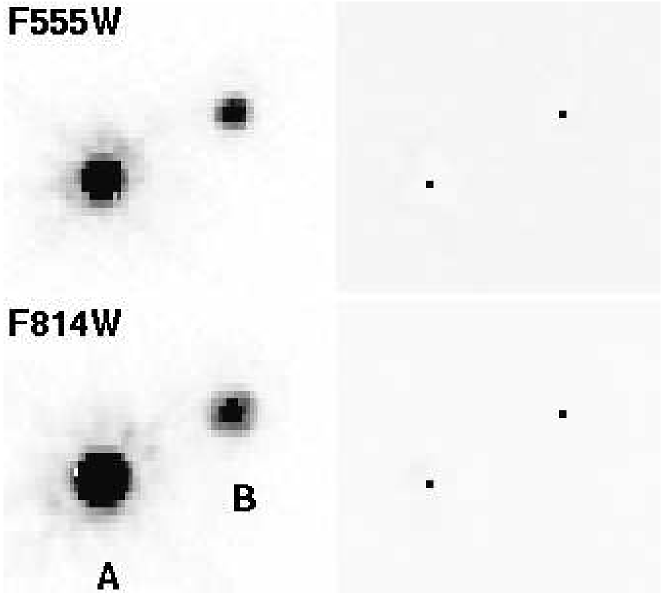

Fig. 1. Composite F555W (upper left panel) and F814W (lower left panel) CCD frames of J03.13 A and B. The right panels correspond to the results of PLUCY deconvolutions using appropriate simulated TinyTim PSFs (see text). All four subimages have been normalized to the peak maximum of the A component. The faint residuals seen on the deconvolved images are well below 0.3%. North is at position angle 334.7° and east at 244.7°. The angular separation between J03.13 A and B is $0.849'' \pm 0.001''$

servations of J03.13. A PSF was subsequently constructed with a pixel replication factor of 10 using TinyTim. An iterative procedure has then been applied to this 10x10 oversampled TinyTim PSF to address the problem of fitting the undersampled HST PSF peaks after proper recentering, rebinning and application of an appropriate pixel response function (Kernel). A more detailed description of this method is to be found in Remy et al. 1997 (in preparation). PSFs were constructed for the two resolved image components. Finally, these PSFs were used with the PLUCY application program (Hook and Lucy 1994) to deconvolve each single CCD frame of J03.13. The combined results of those deconvolutions are presented for the F555W (resp. F814W) filters in the upper (resp. lower) right panels of Figure 1. From these results, we can rule out the presence of a third component fainter than A by up to 5.2 mag. at angular separations $\geq 0.13''$. Given that TinyTim PSFs are not more accurate than a few tenths of a percent, the very faint residuals seen near J03.13 A and B on the deconvolved images turn out to be non significant. Using the PLUCY deconvolution algorithm, the magnitude difference between the two unresolved components is found to be 2.14 ± 0.03 and 2.16 ± 0.03 for the F555W and F814W filters, respectively. We also used the optimal TinyTim PSFs selected above and the automatic photometric fitting technique described in Østensen et al.

(1997) to decompose all images of J03.13 with two point-like components, their relative positions and brightnesses being the only free parameters. After subtraction of the best fitted double PSFs, no significant residuals are seen. Adopting a scale of $0.04553''$/pixel for the PC1 detector, we derive an average angular separation of $0.849'' \pm 0.001''$ between J03.13 A and B, and magnitude differences of 2.14 $\pm$ 0.01 and 2.13 $\pm$ 0.01 for the F555W and F814W observations, respectively. These values compare rather well with those inferred from the PLUCY deconvolutions and with those reported in Paper I. We can also certify that the derived angular separation between J03.13 A and B does not vary with wavelength, contrary to a possible trend that was suggestive from Table 3 in Paper I.

Following standard HST photometric procedures (Whitmore 1997) and relying upon the values of the PHOTFLAM keyword appearing in the header of the WFPC2 frames, we have derived the integrated magnitudes of J03.13 in the STMAG system to be 16.5 and 17.3 $\pm$ 0.1 through the F555W and F814W filters, respectively. Because the images of J03.13 are located at approximately $4''$ from the X CCD axis of the PC1, no CTE correction has been applied. Making use of the general relations between the STMAG F555W and F814W magnitudes and the Johnson V and Kron-Cousins I ones (Holtzman et al. 1995), the standard magnitudes of J03.13 are derived to be V = 17.3 and I = 16.8 $\pm$ 0.1. We conclude that within the observational uncertainties, J03.13 A and B have not varied photometrically between March 1993 (see Paper I) and November 1995.

As previously mentioned, the pointing of HST towards J03.13 has been erroneously made using the approximate J2000 equatorial coordinates originally published by Maza et al. (1993): RA = 10h17m23.735s, Decl. = $-20°46'45.09''$. The quasar was found to be at approximately $13''$ from the center of the PC1 frames. Using the "metric" task in IRAF and from these slightly offset WFPC2 observations, we have derived the J2000 coordinates of J03.13 A and B to be 10h17m23.84s, $-20°46'58.4''$ and 10h17m23.78s, $-20°46'58.4''$, respectively. These more accurate coordinates were mandatory in order to properly center the individual components of J03.13 within the standard 0.5 circular FOS aperture.

3. FOS observations of J03.13

To definitely prove the spectral similarity between the J03.13 A and B images ("to be or not to be lensed"), we have taken on October 28, 1996 (17h31m - 25h06m UT) FOS spectra at the positions of these two components, and at a third position C, symmetric from B with respect to A. These FOS/RD spectra were obtained with the grating G650L (central wavelength of 4400 Å, FWHM $\simeq$ 30.5 Å, COSTAR deployed) and the small 0.5 (actually $0.43''$) circular aperture. A four stage ACQ/PEAK acquisition of the bright A component has first been successfully achieved through the standard 4.3, 1.0, 0.5 and 0.3 FOS apertures. With the goal of reaching a signal-to-noise ratio of $\simeq$ 20 per resolution element, integration times of 840 and 4860 sec. have been aimed for the spectra of J03.13 A (HST dataset Y2YK0406T) and B (datasets Y2YK0407T - Y2YK040AT). Since a total of 3 HST orbits was allocated for these FOS observations, there remained 1200 sec. for the integration of the spectrum of C (dataset Y2YK040BT). Two reference wavelength spectra (datasets Y2YK0405T and Y2YK040CT) were also obtained right before and after the target observations. No significant shift between the reference spectral lines is detectable. The spectra of J03.13 A and B are shown in figure 2.

We find that, apart from a multiplicative constant of 7.5 $\pm$ 0.7 (corresponding to a magnitude difference Δm = 2.2 $\pm$ 0.1), the spectra of J03.13 A and B are identical. We have also reproduced in Fig. 2 the residual spectrum $A - B * 7.5$ showing that apart from a few datapoints near the emission line peaks -which are undersampled by the FOS- and the MgII absorption lines at $z = 1.085$, the spectra of J03.13 A and B do indeed look quite similar. Spectrum of C probes for the possible contamination of component B by A, which turns out to be absolutely negligible. We confirm the emission-line redshift $z_{\rm em} = 2.545$ reported in Paper I as well as the two absorption line systems at $z_{\rm abs} = 2.344$ and $z_{\rm abs} = 1.085$ (the latter one being only detected from its MgII resonance lines in the spectrum of image A). Note that due to the somewhat larger spectral coverage of the present FOS data, we do also detect the Ly$-\beta$ λ 1025 and OVI $\lambda\lambda$ 1031, 1037 emission lines at $z_{\rm em}$ = 2.545.

4. Discussion and conclusions

Direct imagery of J03.13 with the PC1 camera clearly reveals that this bright and distant quasar consists of just two point-like components having an angular separation of $0.849'' \pm 0.001''$ and magnitude difference Δm = 2.14 $\pm$ 0.03 in V and I.

Low resolution FOS spectra of J03.13 A and B show that these two components are lensed images of a same quasar at redshift $z_{\rm em} = 2.545$, with a common absorption line system at $z_{\rm abs} = 2.344$ and MgII at $z_{\rm abs} = 1.085$ being only detected in the spectrum of the A component. Assuming that the deflector is associated with the latter system, one could expect that the quasar is located very close to the radial caustic in the source plane (cf. Fig. 6c in Surdej et al. 1988). One would then expect the bright lensed QSO component (A) to be a radially merging double image, with very small angular separation (typically $\simeq 0.1''$).

From a detailed analysis of our composite PC1 CCD frames, there is no evidence for the presence of additional objects brighter than V = 22.6 (resp. I = 22.1) at angular separations $\geq 0.13''$ from either component A or B.

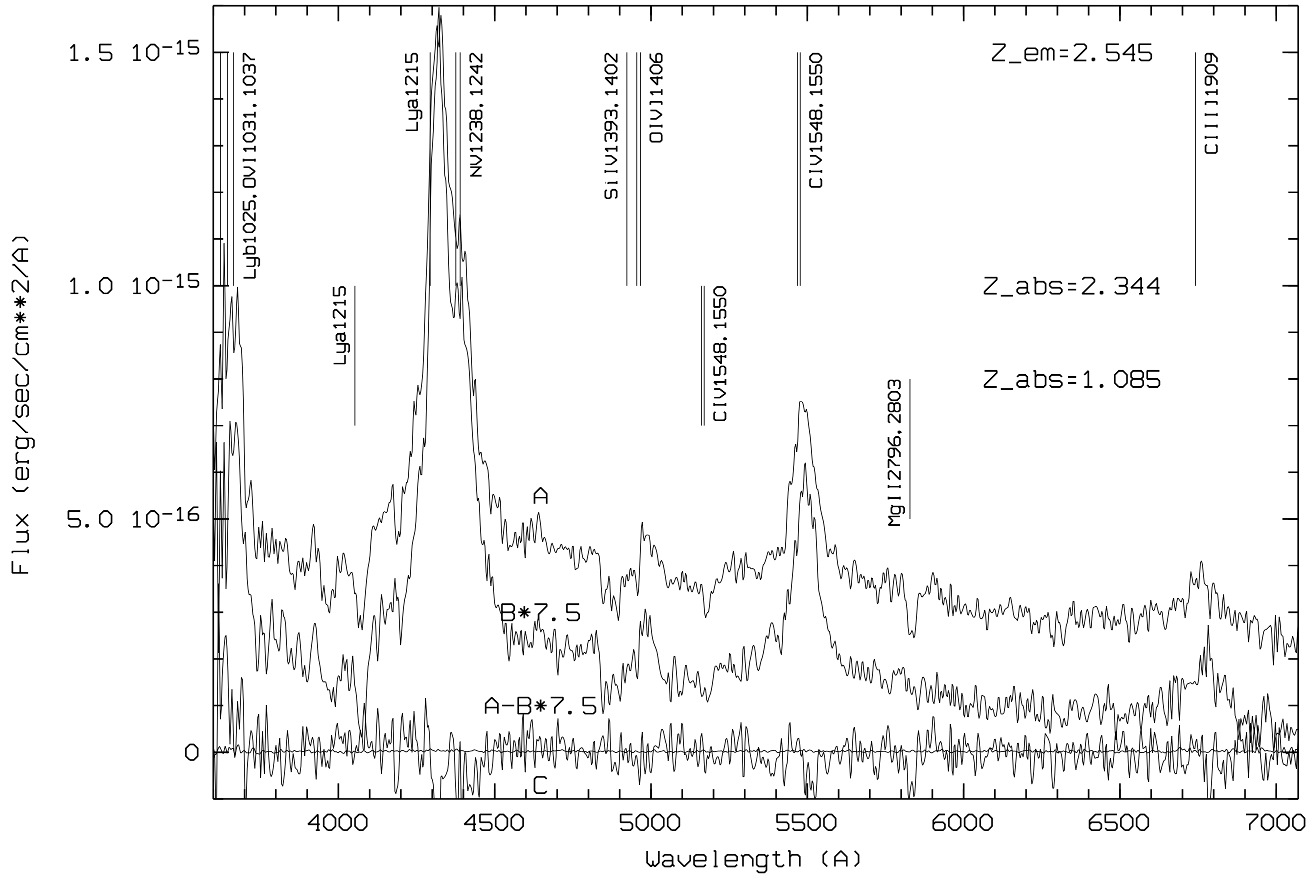

Fig. 2. FOS spectra of (A) J03.13 A, (B) J03.13 B after multiplication of its flux by 7.5 and a vertical offset by -2.010^{-16} erg/sec/cm^2/Å, (C) a fiducial target at the symmetric position of B with respect to A for probing light contamination from the latter component and (D) the residual spectrum of $A - B * 7.5$. The QSO emission and two intervening absorption line systems are identified with vertical lines and labels at different redshifts (see text).

In Paper I, we have inferred that the apparent magnitude of a galaxy located at $z = 1.085$ capable of producing a doubly imaged quasar with an angular separation of $0.85''$ ought to be fainter than R = 22.7 ± 0.5. Our present observations do not preclude the presence of such a galaxy. NICMOS observations of this system in the near IR ought to be very valuable for the detection of such a putative lens.

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