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3CR 208.1: A RADIO-LOUD QUASAR AT $z = 1.02$ GRAVITATIONALLY AMPLIFIED BY A FOREGROUND SEYFERT GALAXY AT $z = 0.159$

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ABSTRACT

Deep high spatial resolution imaging and spectroscopy of the high-redshift radio galaxy 3CR 208.1 are presented. Our high spatial resolution imaging shows two distinct objects separated by 3″.9; the brighter has a stellar appearance and is located between the two radio lobes of 3CR 208.1, while the fainter is compact but not stellar. Individual spectra reveal that the brighter, with $z = 1.01$, has probably to be reclassified as a radio-loud QSO, while the fainter exhibits several emission lines and is an active galaxy (probably a Seyfert II) at a redshift $z = 0.159$.

Gravitational amplification due to the foreground Seyfert galaxy is found to affect the QSO by several tenths of a magnitude (for a conservative $\sigma = 200$ km s^{-1} for the foreground galaxy) and to increase its radio flux by at least a factor of 1.5. Moreover, the gravitational amplification effects on the radio source are strong enough that 3C 208.1 should be removed from the 3CR flux-limited catalog after correction from gravitational amplification. This latter point is another example corresponding to the prediction published by Hammer and colleagues in 1986 that the 3CR catalog is biased by gravitational amplification effects due to foreground matter.

Subject headings: cosmology — galaxies: photometry — gravitational lenses — radio sources: galaxies — quasars

I. INTRODUCTION

The 3CR high-redshift radio galaxies are of great importance to our understanding of galaxy evolution, since for redshift of 1–1.8 they are probes in the universe when it was only one-half to one-third of its present age. These galaxies are several magnitudes more luminous than a redshifted giant elliptical galaxy would be (Spinrad 1986), and under good seeing conditions, 75% of them exhibit multiple components (Djorgovski *et al.* 1987; Le Fèvre *et al.* 1987, 1988; Le Fèvre, Hammer, and Jones 1988; Le Fèvre and Hammer 1988; Hammer and Le Fèvre 1990).

Currently the imaging of these distant galaxies has reached a very high quality with deep images obtained under excellent seeing and has revealed the complex morphologies of almost every galaxy with $z \geq 1$ (Hammer and Le Fèvre 1990, and references therein). However, in most cases, the published spectroscopic data, although of high enough quality to prove reliable redshifts, do not contain spatial information matching the imaging data (3CR catalog of Spinrad *et al.* 1985, with references included, and subsequent updates; Djorgovski *et al.* 1988). There is therefore a possibility that some of the oberved morphologies are not internal to the galaxies but produced by the superposition of matter along the line of sight. There is indeed an increasing amount of evidence pointing toward a high contamination rate of the high-redshift 3CR galaxies by foreground matter. There are three examples among the ~ 30 3CR galaxies with $z \geq 1$ of foreground galaxies of measured redshift projected on the line of sight: 3CR 13, 3CR 194, and 3CR 225A (Hammer and Le Fèvre 1990), showing that the foreground matter can affect the observations of distant 3CR galaxies. There is a claim that 3CR 324 may be a gravitationally lensed galaxy with one of the subcomponents being at a different redshift (Le Fèvre *et al.* 1987). Moreover, at least five other sources lie close to the center of a foreground Zwicky/Abell cluster of galaxies (Hammer and Le Fèvre 1990). There are also strong theoretical arguments predicting large gravitational amplification effects on the highest redshift galaxies in flux-limited samples (Hammer, Nottale, and Le Fèvre 1986).

These arguments seems to advise some caution before interpreting observations of the distant 3CR galaxies. Indeed, if contamination is observed along the lines of sight to many distant 3CR galaxies, then this can obviously lead to reconsideration of the claim that high-redshift radio galaxies show a strong evolution of their stellar populations as compared to present-day giant elliptical galaxies. The gravitational amplification factors computed are in the range 0.5–1.6 mag for 3C 13, 3C 194, and 3C 225A (Hammer and Le Fèvre 1990, and references therein) and are to be taken out of the amount of previously suspected spectrophotometric evolution in these systems. These three systems have been easy to identify because of the brightness of the foreground galaxies due to their closeness in the redshift space, $z \sim 0.1$–0.3; however, a normal elliptical galaxy at $z \sim 0.4$–1.0 may be hard to distinguish from a background 3CR galaxy in the case of a fortuitous alignment along the line of sight but may lead to substantial gravitational amplification or lensing. Since the 3CR high-redshift galaxy sample is so far the cornerstone of most of the galaxy evolution studies at high redshifts (see, e.g., Dunlop *et al.* 1989; Lilly 1988; Djorgovski *et al.* 1988; Wyse

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and Silk 1987), it is of capital importance to carefully evaluate the contamination by foreground matter for each other galaxy in the high-redshift galaxy sample.

We present here the imaging and spectroscopic observations of 3C 208.1, first identified by Wlérick, Lelièvre, and Véron (1971) and with a redshift $z = 1.02$ measured by Spinrad and collaborators (see Spinrad *et al.* 1985). In the high-quality images, we observed two distinct components separated by 3″.9. Subsequent spectroscopy allows us to show that these two components are not at the same redshift and that therefore gravitational amplification is occurring.

II. HIGH SPATIAL RESOLUTION IMAGING AND SPECTROSCOPY

We first observed this galaxy in V and R bands on 1987 October 23 at the prime focus of the CFHT 3.6 m telescope using a double-density RCA CCD (640 × 1024 pixels of 15 μm, i.e., 0″.207). The seeing was 1″ FWHM for both frames. In 1988 January we obtained two other frames of 600 s, each in R in the same configuration, and the seeing measured on the CCD frames was 0″.7 and 0″.85, respectively.

Two images a and b are observed at 3″.9 from each other close to the radio position, while a faint object c is detected at 6″.2 from a as seen on a composite frame made up from the sum of the three 600 s R frames (Fig. 1 [Pl. L1]). The photometry was calibrated with the cluster fields from Christian *et al.* (1985), and corrections from Galactic absorption have been applied from the Galactic absorption maps of Burstein and Heiles (1982) and the extinction coefficients of Rieke and Lebofsky (1985). This yields a magnitude $R_{26.5} = 19.26 \pm 0.04$ and $V - R_{26.5} = 0.70 \pm 0.08$ for a and $R_{26.5} = 20.85 \pm 0.08$ and $V - R_{26.5} = 0.79 \pm 0.15$ for b; c was only detected in the R frames with a magnitude $R_{26.5} = 24.2 \pm 0.25$. The object a is to be considered as stellar with a profile indistinguishable from a star in the frame with the 0″.7 seeing, except for a slight E-W elongation observed at low intensities. On the other hand, b is compact but not stellar with a deconvolved FWHM = 1″.3 ± 0″.1.

The astronometry of the field was performed using the calibration stars of Wlérick *et al.* (1971; G. Lelièvre 1987, private communication), with an internal accuracy better than 1″. Positioning of the two radio hot spots from the VLA radio map kindly communicated by H. Spinrad and P. J. McCarthy is indicated on Figure 1: component a lies on the radio axis joining the two radio lobes, 1″.6 from the western lobe, and is therefore the likely counterpart to the radio source. Note that b is only 2″.5 from the western radio lobe.

In order to establish whether a and b are at the same redshift or not, we observed these two components in a long-slit spectroscopic mode with the focal reducer at the Cassegrain focus of the CFHT. This instrument provides imaging and spectroscopic capabilities, depending on whether a slit and a grism are inserted in the beam or not (Le Fèvre 1989). The detector was a Thomson CCD 384 × 576 pixels^2 with $12e^-$ readout noise and a pixel size of 23 μm, providing a scale of 0″.64 pixel^{-1} at the output focus of the focal reducer. The slit was 2″.5 wide and the grism used gave a dispersion of ~10 Å pixel^{-1} on the CCD binned by 2 in the dispersion direction with a spectral coverage from 4300 to 7200 Å and an instrumental resolution of 20 Å. The slit position was at P.A. −40° to include the two components on the slit and is indicated on Figure 1. Three spectra of 2700, 1800, and 1500 s exposure time, respectively, were obtained in this configuration on 1988 December 8 with a seeing measured at 0″.9 FWHM on an image taken just before the spectroscopic exposures. The three CCD images containing the spectra were then processed in a standard way with the IRAF package to remove the bias level, flat-field the images, and subtract the sky emission. Then the three sky-corrected images were normalized to a common exposure time and combined using a median filter which discarded most of the cosmic-ray events. A spectrum was then extracted for each component, calibrated in wavelength and with a relative flux scale set up with the star G191B2B (Oke 1974). The resulting spectrum for a is shown in Figure 2. The signature of Mg II ($\lambda_0 = 2799$ Å) at $\lambda = 5628 \pm 10$ Å is the most obvious, although close to the 5577 Å oxygen sky line, and gives a redshift of 1.011 ± 0.003; Ne IV ($\lambda_0 = 2424$ Å) is also marginally detected at $\lambda = 4875 \pm 10$ Å, yielding $z = 1.011 \pm 0.003$; and we therefore confirm the measurement of Spinrad *et al.* (1985). The Mg II line has a redshift-corrected FWHM of 65 ± 5 Å, i.e., 7000 ± 500 km s^{-1}, and an equivalent width of 26.3 Å. The final spectrum for b is shown in Figure 3. The emission line spectrum is easy to identify with the [O III] doublet, Hβ, Hγ, and possibly He I, and it is characteristic of an

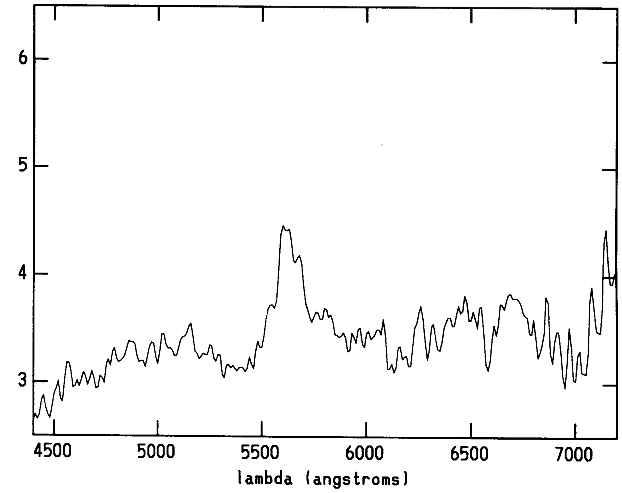

FIG. 2.—Spectrum of component a of 3C 208.1. The prominent line at $\lambda = 5628$ Å is Mg II[2799 Å] redshifted to $z = 1.011$.

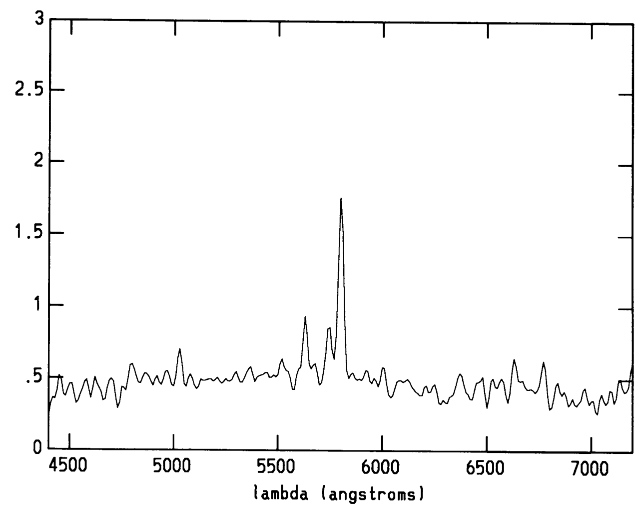

FIG. 3.—Spectrum of component b of 3C 208.1. The lines at 5030 Å, 5641 Å, 5745 Å, and 5802 Å are identified with the Hγ, Hβ, and the [O III] doublet redshifted to $z = 0.159$.

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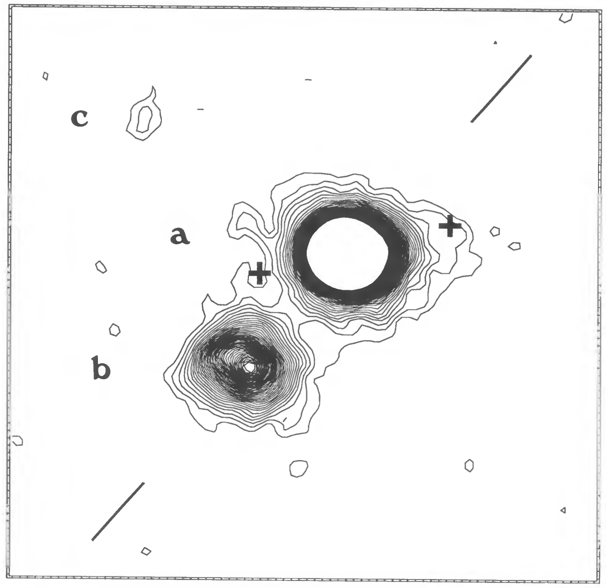

FIG. 1*a*

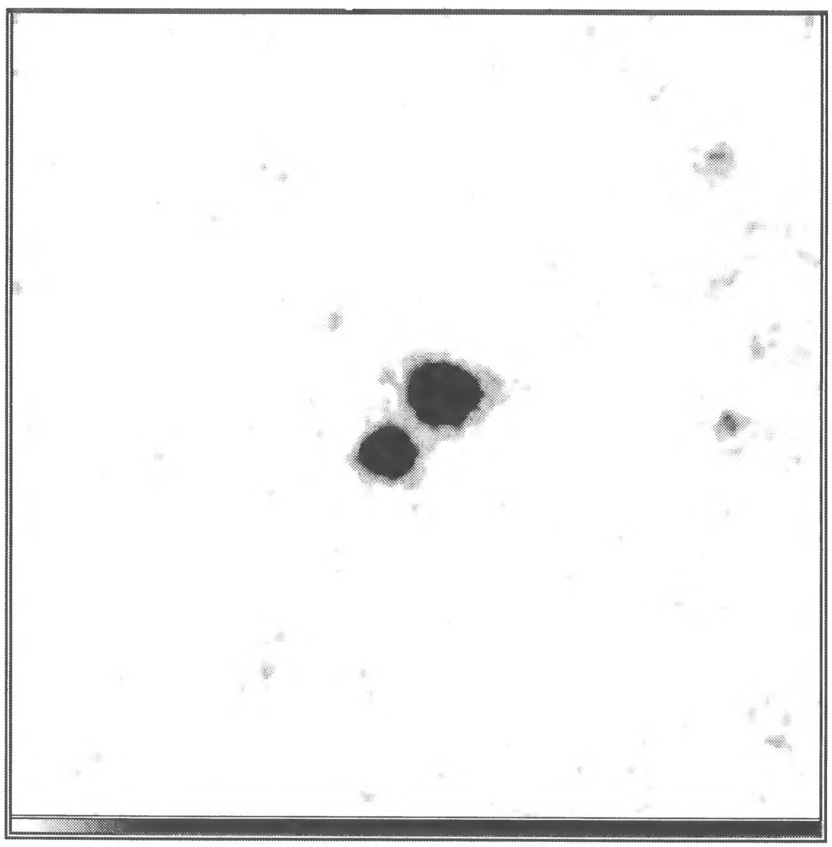

FIG. 1*b*

FIG. 1.—Sum of 3 *R* images of 3C 208.1, 30 minute exposure time total, seeing 1″. (*a*) Isophotal representation of components a and b. The field is 15.5 × 15.5 arcsec^2 with north up and east left. The lowest isophote is at 3 σ above the sky background. The positions of the radio lobes are indicated by crosses, and the slit position for the spectroscopic observations is indicated by the two bars. (*b*) Gray-level representation. The field is 41 × 41 arcsec^2. Notice the faint extended feature under a and galaxy c.

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TABLE 1

IDENTIFICATION OF LINES IN THE SPECTRUM OF COMPONENT b

Line	λ_{obs} (Å)	$\lambda_{emis.}$ (Å)	Redshift	I (relative to O III[5007])	FWHM (km s^{-1}) (Rest Frame)
Hγ	5029.5	4340	0.1589	0.20 ± 0.07	659 ± 120
Hβ	5630.9	4861	0.1584	0.30 ± 0.06	Not resolved
O III	5745.0	4959	0.1585	0.33 ± 0.06	707 ± 155
	5801.7	5007	0.1587	1 ± 0.02	656 ± 102

active galaxy at a redshift $z = 0.1586 \pm 0.0002$. Subsequent measurements show that [O III$_{5007}$]/[O III$_{4959}$] $= 3.00 \pm 0.17$, compatible with the canonical ratio of 3 between these two oxygen lines. Table 1 summarizes the spectroscopic data on the observed emission lines.

III. DISCUSSION

a) *Nature of 3CR 208.1*

Our high spatial resolution imaging and spectroscopy definitely prove that the optical appearance of 3CR 208.1 is due to the close projection of the optical counterpart to the radio source at $z = 1.01$ (component a) and a foreground galaxy at $z = 0.159$ (component b).

These data also allow us to discuss the nature of both components in spite of their faintness. Component a lies just between the two radio lobes, and almost all of its large luminosity $L_V = 5 \times 10^{45} h_{50}^2$ ergs s^{-1} comes from a region smaller than 3 $(50/H_0)$ kpc, including also the very luminous Mg II emission line with $L = 1.3 \times 10^{44} h_{50}^2$ ergs s^{-1} ($W_\lambda = 26.3$ Å at rest). The FWHM of the Mg II line in its rest frame is larger than 7000 km s^{-1}, which is typical of a broad emission line. Combining these arguments with the stellar profile and the strong continuum, we therefore infer that a is a radio-loud QSO. The faint extended feature observed underlying a may be the QSO host galaxy as has been observed in a sample of 3CR QSOs with redshifts up to $z = 0.5$ by Hutchings (1987) and Hutchings, Johnson, and Pyke (1988). Component b is only 3".9 from a and is an AGN from its emission-line spectrum. Its observed luminosity is $L_V = 7.6 \times 10^{42} h_{50}^2$ ergs s^{-1} and is coming from a region of about 3 $(50/H_0)$ kpc. The [O III] lines at 5007 Å and 4959 Å and the Hγ line are just resolved, and we can deduce an internal velocity around 650 ± 120 km s^{-1} which is consistent with a Seyfert II or a LINER but excludes a starburst galaxy (Feldman *et al.* 1982). The ratio [O III$_{5007\,\text{Å}}$]/Hβ is 3.3 ± 0.5, which is close to the limit set by Shuder and Osterbrock (1981) to discriminate a Seyfert II galaxy from a LINER. The emission lines are rather strong, e.g., the [O III] equivalent width of 62 Å at rest corresponds to $L = 5 \times 10^{41} h_{50}^2$ ergs s^{-1}. We therefore suggest that component b is a Seyfert II galaxy.

b) *Gravitational Amplification Effects on the Radio-loud QSO from the Foreground Seyfert*

Since the line of sight of the optical counterpart of 3CR 208.1 ($z = 1.011$) is less than 4" from a Seyfert II galaxy at $z = 0.159$ and since one of the radio source lobes is less than 2".5, we have to consider the possibility of gravitational lensing effects. We can compute the gravitational amplification from the following (derived from Hammer and Nottale 1986):

$$\mathrm{Amp}^{-1} = \left(1 - 3\,\frac{\pi\sigma_v^2 D_d D_{ds}}{c^2 D_s l}\right)^2 - \left(\frac{4GMD_d D_{ds}}{c^2 l^2 D_s}\right)^2 \quad (1)$$

which assumes that the density profile of the deflecting object follows a Hubble-Reynolds law with a cutoff at a radius $R \gg l$. Since the shear term is negligible for a reasonable range of the Seyfert mass ($M \leq 10^{11}\,M_\odot$), the gravitational amplification as expressed in equation (1) depends on the velocity dispersion of component b only. If we consider the reasonable hypothesis that the galaxy underlying the Seyfert activity is a spiral galaxy with a minimum velocity dispersion $\sigma = 200$ km s^{-1}, then component a is gravitationally magnified by ~ 0.5 mag, while the brightest radio lobe, only 2".5 from b, is found to be amplified by a factor ~ 2. Higher values of σ would lead to a substantial increase in the amplification factor as computed in Table 1. No gravitational multiplication is expected since a M/L ratio as high as 100 to multiply the close radio lobe, or 230 for the optical counterpart, would be needed for the Seyfert galaxy. After correction for gravitational amplification, the radio flux of 3CR 208.1 becomes less than 5.4 Jy instead of 8.4 Jy, and therefore it is probable that 3CR 208.1 would never have been included in the 3CR catalog if its flux had not been boosted by the gravitational amplification.

IV. CONCLUSION

The optical counterpart of 3CR 208.1 was previously classified as an "N galaxy" at $z = 1.02$ (Spinrad *et al.* 1985). New imaging data show that this galaxy is in fact made of two distinct components separated by 3".9. High spatial resolution spectroscopy then indicates that the two components are at different redshifts. The first one is the optical counterpart of the radio source and seems to be a radio-loud QSO with a redshift $z = 1.011$, while the other one is a foreground Seyfert II galaxy with $z = 0.159$. Gravitational amplification calculations show that the foreground Seyfert gravitationally magnifies the QSO in the optical wavelengths by more than 0.5 mag. Moreover, the radio lobe closest to the Seyfert is amplified by more than a factor of 2 which after correction leads to a real radio flux well below the 3CR catalog flux limit. Therefore, 3CR 208.1 has been included in the 3CR catalog *only because its radio flux has been gravitationally amplified* by the foreground Seyfert galaxy. It should also be reclassified as a QSO and not be used in a radio galaxy sample. This is a case verifying the prediction of Hammer, Nottale, and Le Fèvre (1986): selection effects due to gravitational amplification are at work on the 3CR sample for the highly redshifted sources with radio fluxes close to the catalog flux limit. We finally emphasize as in previous papers (Hammer and Le Fèvre 1990, and references therein) that before interpreting the properties of the distant 3CR radio galaxies in terms of internal phenomena, it is of crucial importance to know as accurately as possible the real location of their multiple components in the redshift space.

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