Astron. Astrophys. 253, L13–L16 (1992)

ASTRONOMY AND ASTROPHYSICS

Letter to the Editor

Q 1208+1011: the most distant imaged quasar, or a binary?*

P. Magain[1,], J. Surdej[1,***], C. Vanderriest[2], B. Pirenne[3], and D. Hutsemékers[1]**

[1] Institut d'Astrophysique, Université de Liège, 5, avenue de Cointe, B-4000 Liège, Belgium
[2] DAEC, Observatoire de Meudon, F-92195 Meudon Principal Cedex, France
[3] ST-ECF c/o European Southern Observatory, Karl-Schwarzschild-Strasse 2, W-8046 Garching bei München, Federal Republic of Germany

Received October 22, accepted November 5, 1991

Abstract. We report the discovery of a new gravitational lens candidate: the high redshift ($z = 3.803$) and highly luminous ($V = 17.5$, $M_V = -30.3$) quasar Q 1208+1011. As derived from the analysis of direct CCD frames taken with the ESO/MPI 2.2m telescope, this multiple quasar consists of two point-like images, separated by $0\overset{''}{.}45$ and characterized by a brightness ratio of 3.5, in red light. Existing spectroscopic data support the gravitational lens interpretation for this system but cannot exclude the hypothesis of a binary quasar. In the former case, the spectrum suggests that, if the metallic absorption line system reported by Steidel (1990) at a redshift $z = 2.9157$ is associated with the deflector, the mass of the lens should be of the order of $M = 7.8\,10^{11} M_\odot$ ($q_0 = 0$, $H_0 = 50\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$). Evaluation of a recent HST PC frame obtained for Q 1208+1011 within the snapshot survey for gravitational lenses confirms the above results.

Key words: gravitational lensing – quasars – Q 1208+1011

1. Introduction

Whereas the first gravitational lens systems have been discovered by chance (cf. Walsh et al. 1979, Weymann et al. 1980, Huchra et al. 1985), systematic searches for lenses have proved to be very successful in identifying new systems (see Surdej et al. 1992 for a recent review). Taking advantage of the magnification bias, which is known to work at best for bright flux limited samples of distant sources (see Narayan 1989), we have initiated in 1986, at ESO, a survey for multiply lensed objects within a sample of highly luminous quasars (HLQs, $V \lesssim 18.5$ and $M_V \lesssim -29$; see Surdej et al. 1988a-c and also Djorgovski and Meylan 1989a,b). Several cases of multiply lensed quasars have already been reported (cf. ESO-GL-1 = UM 673, Surdej et al. 1987; ESO-GL-2 = H 1413+117, Magain et al. 1988; ESO-GL-3 = UM 425, Meylan and Djorgovski 1989), while additional good lens candidates still await a more definite confirmation (Surdej et al. 1988b,c; Magain et al. 1990, 1992).

Following the discovery of an interesting structure in the image of the very distant and luminous quasar Q 1208+1011 ($z = 3.803$, $V = 17.5$, $M_V = -30.3$; see Hazard et al. 1986 and Sargent et al. 1986) on a direct CCD frame taken with the ESO/MPI 2.2m telescope in April 1987 (see Magain et al. 1992), new data have been obtained in July 1991 with the same telescope in the context of the ESO Key Programme "Gravitational Lensing" (see Surdej et al. 1989, 1991 for a description and recent status report of this project). We confirm in this Letter that Q 1208+1011 constitutes a very good candidate for gravitational lensing.

The observations are described in the next section while the image analysis is presented in Sect. 3. Section 4 deals with a reanalysis of the spectrum published for this HLQ by Steidel (1990). General conclusions form the last section.

2. Observations

A first image of Q 1208+1011 has been obtained in April 1987 in the course of the ESO survey for gravitational lensing among HLQs. We used the direct CCD camera at the ESO/MPI 2.2m telescope with a Bessell R filter and a low resolution RCA CCD (SID 501 EX, 30 μm pixels). The exposure time amounted to 20 min and the seeing was relatively poor ($1\overset{''}{.}4$). The visual inspection of the frame revealed nothing special about the quasar image, which looked perfectly stellar.

In May 1991, we started a systematic analysis of the ($\simeq$ 200) HLQ images obtained by the ESO-KP team. This analysis consisted in a visual inspection of all the images followed, whenever possible, by a subtraction of the point spread function (PSF) from the quasar images. The PSF was determined from stellar images on the same CCD frame. An analytic profile, in the form of a generalized Moffat (1969) function, was fitted to all stellar images simultaneously and subtracted. The residuals were recentered and a mean was computed. The composite PSF (analytic function + mean residual) was then fitted to all the images (quasar and stars) and subtracted. The final

Send offprint requests to: P. Magain
*Based on observations carried out at the European Southern Observatory, La Silla, Chile
**Chercheur Qualifié au Fonds National Belge de la Recherche Scientifique
***Maître de Recherches au Fonds National Belge de la Recherche Scientifique

residuals were examined, and it was then decided whether the quasar had been fitted satisfactorily or if a significant residual remained, in which case it was classified as 'interesting'. We then tried to identify the nature of the residual, either diffuse or point-like.

To our surprise, that procedure revealed a significant residual when applied to the image of Q 1208+1011. The shape of that residual indicated that the quasar image was elongated roughly in the North-South direction. A fit of two stellar images was attempted and showed that the object could be rather satisfactorily modelled with two point sources separated by 0.″65 and with an intensity ratio around 10. These results were presented at the International Conference on Gravitational Lensing in Hamburg at the beginning of September 1991 (Magain et al. 1992). In view of the mediocre seeing and of the poor sampling (pixel size = 0.″35), these results were considered as preliminary.

Of course, as soon as the PSF subtraction had revealed such a significant residual, we planned to secure additional data in order to confirm and refine our results. Several images were obtained on July 7, 1991 at the ESO/MPI 2.2m telescope equipped with the same camera, but with a high resolution RCA CCD (SID 006 EX, 15 μm pixels, corresponding to 0.″175 on the sky). The seeing was significantly better and a slight elongation of the quasar image could be detected visually (Fig. 1). The main observational data are summarized in Table 1.

Table 1. Observational data

Exp. time (s)	Filter	Seeing (″)	Exp. level (ADU)
600	R	0.90	2500
2 × 600	B	1.05	200

After having carried out these observations, we learned that Q 1208+1011 had also been observed with HST on July 22, 1991 in the framework of the snapshot survey (Bahcall et al. 1991). We obtained the image as soon as it became public, with the aim of confirming our results.

3. Image analysis

The red image obtained on July 7, 1991 was analysed in the same way as the April 1987 image. The PSF was determined using a neighbouring star having a comparable magnitude and subtracted from the quasar image. A significant residual was again observed (Fig. 1c). Then, two PSFs were fitted simultaneously to the quasar image, producing a nearly perfect fit with the following parameters: a separation of 0.″45 and intensity ratio of 3.5, the brightest image being the northern one, and the line joining the two images being at 16° from the N-S direction. A deconvolution was also attempted in order to obtain an independent confirmation of these results. The Richardson-Lucy algorithm (Richardson 1972, Lucy 1974) was first tried. The result was a more pronounced elongation of the image, but the two components could not be resolved. This is not too surprising since this algorithm is not very efficient as far as the resolution enhancement is concerned. A similar (but more efficient for resolution enhancement) algorithm was then applied (see Magain 1989) and gave the result presented in Fig. 1d, which shows two components with separation and intensity ratio similar to the ones obtained by the fitting technique. As the deconvolution algorithms are generally not photometrically accurate (they tend to enhance the brighter images relative to the fainter ones), we consider the results of the PSF fit as being superior.

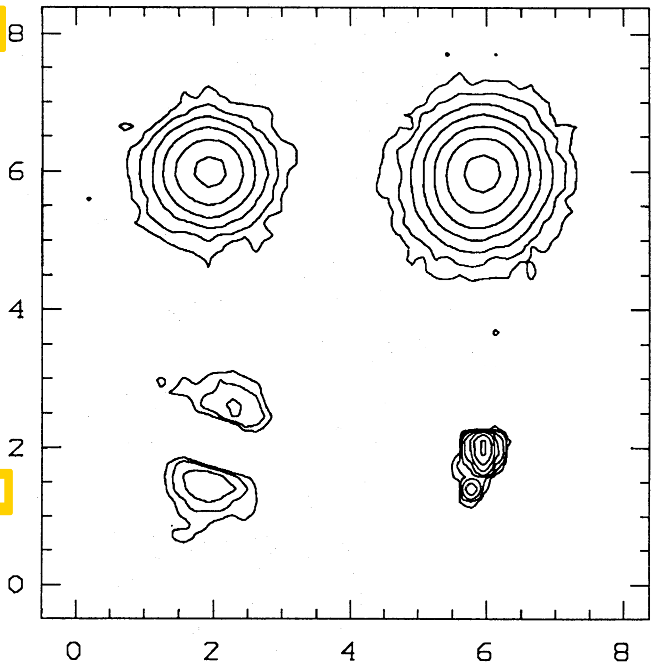

Fig. 1. Contour plots obtained from the R image of Q 1208+1011. Successive contour levels differ by a factor two in intensity and the first one starts at 30 ADU. (a) Top left: star used for PSF determination; (b) top right: Q 1208+1011; (c) bottom left: residual after subtraction of the PSF from the quasar image; (d) bottom right: deconvolution of the quasar image (intensity is scaled down by a factor 10 in this case). Scale in arcseconds. North is to the top and East to the left

Due to the lower quality seeing and the much lower signal-to-noise ratio, the blue image could not be analysed as accurately as the red one. In fact, the data are too poor to constrain the model and many solutions may be found. All we can say is that the blue image is not incompatible with the red one, although it seems to indicate a larger intensity ratio between the two components, the fainter one being thus possibly redder than the brighter one.

The HST image has been obtained using the Planetary Camera with a V filter and an exposure time of 260 s. Due to the procedure adopted in the snapshot survey (no fine locking) the images are generally trailed, and this one is no exception. Fortunately, the direction of the trail was roughly E-W so that there is no danger that the two images would be superimposed. The HST image indeed confirms that Q 1208+1011 is double, as first indicated by the ground-based observations. Due to the spherical aberration, the PSF varies strongly in the PC field. It was thus not possible to attempt any more detailed analysis of that image. However, the separation and intensity ratio were determined approximately from the N brightest pixels in each of the two components. The best results were obtained for $N = 10$, which gave a separation of 0.″46, an angle of 12° from the N-S direction and an intensity ratio of 3.4. After correction for the contamination of the faintest image by the wings of the PSF of the brightest one, the intensity ratio seems to be closer to 4.0. The results from the HST are thus in very good agreement with those from the ground-based image.

4. Re-analysis of the spectrum of Q 1208+1011

An analysis of a moderate resolution spectrum (5340-7300 Å, FWHM $\simeq$ 1.7 Å) obtained for Q 1208+1011 in 1988 at the Palomar 5m telescope, through a 1″ slit, has been reported by Steidel (1990).

The high redshift spectrum of Q 1208+1011 displays a prominent Ly α forest (more than 68 lines detected) shortward of 5850 Å and several (14) narrow absorption lines at longer wavelengths. Among the four metallic absorption line systems proposed by Steidel, we confirm that the system at $z = 2.9157$ (resonance doublets of Si IV, C IV and possibly Si II 1526) is very likely, the ones at $z = 2.9137$ and $z = 2.8573$ (C IV) are only possible and his proposed system at $z = 3.1918$ is improbable (the match in wavelength between the C IV resonance doublet lines is very poor). On the other hand, we have identified 16 additional possible systems: $z = 3.0823$ (Si IV), $z = 3.0750$ (Si IV), $z = 2.9495$ (Si IV), $z = 2.8640$ (C IV), $z = 2.8478$ (Si IV), $z = 2.7613$ (C IV), $z = 2.7263$ (C IV + Si II 1526), $z = 2.7649$ (C IV), $z = 2.6534$ (C IV + Si II 1526), $z = 2.6034$ (C IV), $z = 2.5191$ (C IV), $z = 2.1289$ (resonance doublets of Al III), $z = 1.1355$ (resonance doublets of Mg II + Fe II 2600), $z = 0.9281$ (Mg II), $z = 0.3850$ (resonance doublets of Ca II) and $z = 0.3741$ (Ca II); 11 of the systems being in the range $2.5 < z < 3.1$. Of course, most of these possible systems may turn out to be spurious and additional data as well as interpretation efforts will be necessary in the future to progress further on this matter.

Very interestingly, several narrow absorption lines in the Ly α forest appear to be almost saturated (cf. the line #56 at 5787.2 Å and additional ones as seen in Fig. 1 of Steidel 1990). Given the brightness ratio (3.5 - 4) between the A and B images of Q 1208+1011, we conclude that no such saturated absorption line could have been observed in the combined spectrum of A + B, would this multiple image object not be a gravitational lens system or a binary quasar. Given that, in the latter case, some Ly α clouds should remain totally opaque over distances much greater than typically 6 kpc, we conclude that the binary quasar interpretation is less probable and that it is likely that Q 1208+1011 constitutes a new example of gravitational lensing. Of course, individual spectra of the two components are required to prove definitely the true nature of this system.

5. Conclusions

We have shown in this Letter that the quasar Q 1208+1011, discovered by Hazard et al. (1986) on UK objective prism plates and which held for some time the world record with a redshift of 3.803 (Sargent et al. 1986), constitutes either a new example of multiply lensed quasar - with the smallest angular separation known up to date - or an even more interesting case of binary quasar. Because we know that both the magnification bias (Narayan, 1989) and the redshift dependence of the optical depth for lensing (Turner et al. 1984) conspire to boost multiply lensed quasars in bright flux limited samples, it is not surprising that such a high redshift and highly luminous quasar as Q 1208+1011 (= ESO-GL-4?) has been found to be multiply lensed. If this is the case (we tend to believe so) and because 14 among the 19 suggested metallic absorption line systems are located in the redshift range 2.5-3.1, it would also not be surprising that the deflector responsible for the small observed splitting of the quasar images is located in that redshift interval. Considering for instance the most likely absorption line system at $z = 2.9157$, it is straightforward to derive that the mass of the lens should be of the order of $M = 7.8\,10^{11} M_{\odot}$ ($q_0 = 0$, $H_0 = 50\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$). If, on the other hand, Q 1208+1011 is a binary "highly luminous" quasar, this finding would have profound consequences because of the information it would provide on the early history and evolution of the Universe. Furthermore, the detection of saturated narrow absorption lines in the Ly α forest of the quasars Q 1208+1011 A and B, separated by a proper distance of the order of 6 kpc, would have great implications on the size ($\gg$ 6 kpc) of nearly opaque Ly α clouds. Of course, spectra of the two images A and B of Q 1208+1011 are mandatory in order to definitely settle the true nature of this system.

The finding of these multiple quasar images with a separation of 0.″45 from the ground, under medium seeing conditions, also illustrates very clearly the power of a clean image processing and analysis, when carried out carefully and on high quality data (good sampling, suitable comparison stars, instrument well functioning). We plan to obtain further good quality data (images and spectra) from the ground with either the SILFID integral field spectrograph (cf. Vanderriest and Lemonnier, 1987) or with the Bonn-MPI speckle camera (Weigelt 1988) combined with the wideband projection speckle spectroscopy technique (Grieger et al. 1988).

Acknowledgements. We thank Jean-Pierre Swings for a careful reading of the manuscript. This research was partly supported by contract ARC 90/94-140 "Action de recherche concertée de la Communauté Française de Belgique". DH acknowledges support from a Grant FNRS.

References

Bahcall, J.N., Maoz, D., Doxsey, R. et al. 1991, preprint
Djorgovski, S., Meylan, G. 1989a, in "Active Galactic Nuclei": Proceedings of the IAU Symposium Nr. 134, eds. D. Osterbrock and J. Miller, (Dordrecht: Kluwer), p. 269
Djorgovski, S., Meylan, G. 1989b, in "Gravitational Lenses", eds. J.M. Moran et al. (New York: Springer-Verlag), p. 173
Grieger, F., Fleischmann, F., Weigelt, G. 1988, in Proceedings of the ESO Conference "High-Resolution Imaging by Interferometry", ed. F. Merkle, p. 225
Hazard, C., McMahon, R.G., Sargent, W.L.W. 1986, Nat, 322, 38
Huchra, J.P., Gorenstein, M., Kent, S. et al. 1985, AJ, 90, 691
Lucy, L. 1974, AJ, 79, 6
Magain, P. 1989, in Proceedings of the First ESO/ST-ECF Data Analysis Workshop, eds. P.J. Grosbol, F. Murtagh and R.H. Warmels, p. 205
Magain, P., Surdej, J., Swings, J.-P. et al. 1988, Nat, 334, 325
Magain, P., Remy, M., Surdej, J., Swings, J.-P., Smette, A. 1990, in Proceedings of the Toulouse workshop on "Gravitational Lenses", September 1989, eds. Y. Mellier, B. Fort, G. Soucail, Springer-Verlag, Lecture Notes in Physics, vol. 360, 88-92.
Magain, P., Hutsemékers, D., Surdej, J., Van Drom, E. 1992, paper presented at the Hamburg International Conference

on Gravitational Lenses, Hamburg (9-13 september 1991), to appear in the proceedings of the conference, Springer, Lecture Notes in Physics series
Meylan, G., Djorgovski, S. 1989, ApJ, 338, L1
Moffat, A.F.J. 1969, A&A, 3, 455
Narayan, R. 1989, ApJ, 339, L53
Richardson, W.H. 1972, J. Opt. Soc. America, 62, 55
Sargent, W.L.W., Fillipenko, A.V., Steidel, C.C., Hazard, C., McMahon, R.G. 1986, Nat, 322, 40
Steidel, C.C. 1990, ApJS, 72, 1
Surdej, J., Magain, P., Swings, J.-P. et al. 1987, Nat, 329, 695
Surdej, J., Magain, P., Swings, J.-P. et al. 1988a, A&A, 198, 49
Surdej, J., Magain, P., Swings, J.-P. et al. 1988b, in "Large Scale Structures: Observations and Instrumentation", Proceedings of the First DAEC Workshop (Paris-Meudon), eds. C. Balkowski and S. Gordon, p. 95
Surdej, J., Swings, J.-P., Magain, P. et al. 1988c, in Proceedings of a workshop on optical surveys for quasars, eds. P. Osmer, A.C. Porter, R.F. Green and C.B. Foltz, Astr. Soc. Pac. Conf. Ser. 2, 183
Surdej, J., Arnaud, J., Borgeest, U. et al. 1989, The Messenger, 55, 8
Surdej, J., Angonin, M.-C., Arnaud, J. et al. 1991, invited paper to the Second DAEC Workshop on "Large Scale Structures in the Universe", proceedings in press
Surdej, J., Claeskens, J.-F., Hutsemékers, D., Magain, P., Pirenne, B., 1992, review article presented at the Hamburg International Conference on Gravitational Lenses, Hamburg (9-13 september 1991), to appear in the proceedings of the conference, Springer, Lecture Notes in Physics series
Turner, E.L., Ostriker, J.P., Gott, J.R. 1984, ApJ, 284, 1
Vanderriest, C., Lemonnier, J.-P. 1987, in "Instrumentation in Astronomy", Proceedings of the 1987 Santa Cruz Workshop, p. 304
Walsh, D., Carswell, R.F., Weymann, R.J. 1979, Nat, 279, 381
Weigelt, G. 1988, in Proceedings of the Summer School Astrophysics I, Les Houches, France, September 1988, Lecture Notes in Physics, Springer-Verlag
Weymann, R.J., Latham, D., Angel, J.R.P. et al. 1980, Nat, 285, 641

This article was processed by the author using Springer-Verlag LaTeX A&A style file 1990.