Mon. Not. R. Astron. Soc. **274**, L25–L29 (1995)

1600 + 434: a new gravitational lens system

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Accepted 1995 March 7. Received 1995 February 27

ABSTRACT

We report the discovery of a new gravitational lens system associated with the flat-spectrum radio source 1600 + 434. The system has been found in a new large survey of such radio sources. It consists of a 1.4-arcsec double radio source with an associated optical double at the same position and orientation, and with an almost identical flux density ratio to that in the radio. Spectra of the light from two optical images show broad emission lines with a redshift of 1.61. The spectral data are not of sufficient quality to show that both images have identical spectra. Nevertheless, we argue that the probability that 1600 + 434 is indeed a lensed system is very high.

Key words: galaxies: active – quasars: emission lines – gravitational lensing.

1 INTRODUCTION

The first gravitational lens system was discovered in 1979 by Walsh, Carswell & Weymann (1979). 15 more confirmed lenses have subsequently been discovered; an increasing fraction of them have been found using radio searches. Radio investigations are a particularly efficient way of finding lensed systems, both because of the consistently high dynamic range and resolution of the maps, and because of the large number of objects that can be observed in a relatively short time.

2 THE CLASS SURVEY

The Cosmic Lens All-Sky Survey (CLASS) is a survey of all northern flat-spectrum radio sources down to a limiting flux density of about 25 mJy beam^{-1} at 5 GHz. Of these, we have so far observed 3247 sources with the VLA. The NRAO 5-GHz survey of 1987 October (Condon, Broderick & Seielstad 1989) is used to define the high-frequency spectral points, and either the Westerbork Northern Sky Survey (WENSS) at 325 MHz (de Bruyn et al., in preparation) or the Texas 365-MHz catalogue (Douglas et al. 1980) is used to define the low-frequency end of the spectrum. For those sources selected by virtue of their WENSS flux densities, the spectral index cut-off has been taken as -0.5 ($S_\nu = \nu^\alpha$) and, for the remainder, -0.6 has been adopted. In the first phase of CLASS the following two groups of sources were observed:

(1) 2575 sources with 5-GHz flux densities above 50 mJy beam^{-1} selected from the Texas 365-MHz catalogue and the NRAO list;
(2) 672 sources with 5-GHz flux densities below this limit selected by use of the WENSS and NRAO catalogues.

The sources were all observed in early 1994 with the VLA in its A-configuration at 8.4 GHz, giving a resolution of 0.2 arcsec. The observations and results from the main group of 2575 sources will be described elsewhere (Myers et al., in preparation). Here we simply mention that 600 of the 672 WENSS-selected sources are unresolved and 39 of the sources were observed but not detected. Of the 33 extended sources detected, 10 are serious candidates for lensing and are described in detail elsewhere (Jackson et al., in preparation). Here we report on follow-up observations of one of these objects and show that it is very likely to be a gravitationally lensed system.

3 OPTICAL AND RADIO STRUCTURE OF 1600+434

The WENSS observations that caused the object 1600+434 to be included in the survey were taken between 1991 December and 1992 February (Fig. 1). Our VLA 8.4-GHz radio map of 1600+434, taken on 1994 April 4, is shown in Fig. 2. The observation lasted 40 s using 2×50 MHz bandwidth and reached a noise level of ~ 120 μJy. The map shows a radio double of separation 1.39 ± 0.01 arcsec. The NW component has a flux density of 73 mJy beam^{-1} and the SE component 56 mJy beam^{-1}. The two components are situated at RA $16^{h}01^{m}40\overset{s}{.}446$, Dec. $43°16'47\overset{''}{.}76$ (J2000) and RA $16^{h}01^{m}40\overset{s}{.}512$, Dec. $43°16'46\overset{''}{.}57$ (J2000), with an uncertainty of between 20 and 30 mas. The centroid is consistent with the WENSS position of RA $16^{h}01^{m}40\overset{s}{.}5$, Dec. $43°16'44''$ (J2000) to within 2σ of the WENSS error of 2 arcsec. The spectral index is not clear. The WENSS total flux of about 37 mJy, together with the NRAO 5-GHz total flux of 37 mJy, implies a roughly flat spectrum. Our 8.4-GHz total is 132 mJy, which taken at face value implies a highly inverted spectrum between 5 and 8.4 GHz. However, it seems much more likely that the source is variable and that it was in a high state during the 1994 observations. The fact that the NRAO 5-GHz flux density is less than that of the weaker of the 8.4-GHz components suggests that both of the components must be variable. The variability and the flatness of the 325 MHz–5 GHz spectrum clearly indicate that we are not dealing with a normal classical double radio source.

A double radio structure is of course not proof of gravitational lensing by itself. To confirm lensing, a matching optical morphology is required, or, alternatively, radio structure such as rings or arcs which are characteristics of lensing. The object has been identified with a magnitude 20 stellar object using the digitization of the Palomar Sky Survey plates carried out at the Institute of Astronomy in Cambridge (Irwin, Maddox & McMahon 1994). We therefore followed up the initial radio observation with an optical image taken with the William Herschel Telescope (WHT), La Palma, on the night of 1994 July 7. The auxiliary port CCD was used for the observation. This system has an extremely fine pixel scale (0.1 arcsec), which is suitable for very good seeing conditions such as those in which we observed 1600+434. During the observations the seeing averaged between 0.5 and 0.6 arcsec, with occasional excursions just above 0.6 arcsec. The spatial resolution is thus adequate to resolve any double structure in the object.

The result of the optical imaging is shown in Fig. 3. Our image shows an optical double, and the separation of the images is 1.38 ± 0.05 arcsec, consistent to within the errors with the separation of the radio double. The optical and radio flux density ratios are about the same (1.38 ± 0.05 as opposed to 1.30 ± 0.04).

4 SPECTRA OF 1600+434

Spectra of both images were taken using the ISIS spectrograph on the WHT. The slit was positioned across both images by a blind offset from a nearby star: this was necessary as the target itself could not be seen on the acquisition TV due to dust in the atmosphere. A relatively wide (1.7 arcsec) slit was used for these observations due to uncertain-

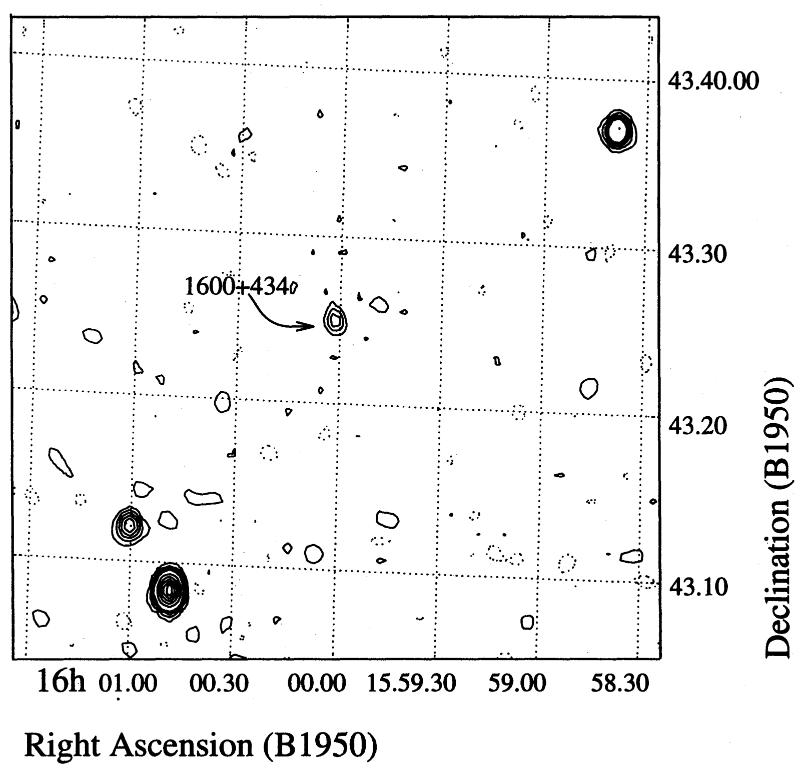

Figure 1. The Westerbork Northern Sky Survey image of the 1600+434 region, taken at 325 MHz. Contours are given at 1 mJy beam^{-1} × [−2 (dotted), 2, 4, 6, 8, 10, 20, 30, 40, 50, 60].

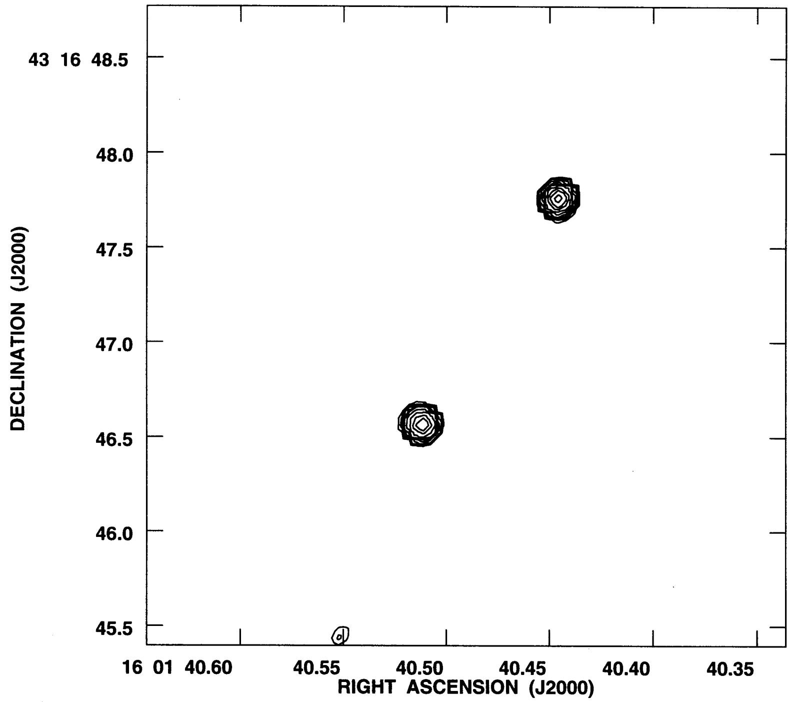

Figure 2. The radio map of 1600 + 434 at 8.4 GHz. Contours are given at 1 mJy $\mathrm{beam}^{-1} \times [0.5, 0.8, 1.3, 2, 3, 5, 10, 20, 30, 50]$.

ties in the astrometry of the offset star. Blue and red spectra (3×900 s) were obtained from 3500 to 8900 Å using a dichroic cutting at about 6200 Å and the results are shown in Fig. 4. A clear separation of the two images was detected in the red spectrum. The object contains obvious quasar features – namely broad lines at 4016, 4922 and 7253 Å – which we identify with C IV at a redshift of 1.61, C III] at a redshift of 1.58 and Mg II at a redshift of 1.59, respectively. There is also a weak feature at 4250 Å which is consistent with He II at a similar redshift. We adopt a redshift of 1.61 since the C III] and Mg II lines are both weak and, in addition, Mg II lies on skylines. Ly α at this redshift is unfortunately just below the atmospheric cut-off at 3200 Å and is therefore inaccessible to us.

A more conclusive proof of the lensed nature of this system would be the demonstration that both images had identical redshifts. Unfortunately, different factors meant that this was difficult given our spectra and the position of the two strong lines. Mg II is redshifted into a bad area of skylines and is in any case weak, leading to a low signal-to-noise ratio in the individual spectra. C IV, although strong enough, is in a region where the spectra are blended into each other because the seeing in the blue is generally worse than in the red.

5 DISCUSSION AND CONCLUSION

We have presented evidence that the 1600 + 434 system is a radio and optical double at the same separation and the same position angle. Although the flux density ratio is not identical in the optical and the radio, we suggest that 1600 + 434 is highly likely to be a gravitationally lensed system. The splitting of 1.4 arcsec could be caused, for example, by a single galaxy of mass $\sim 10^{12}\,\mathrm{M}_{\odot}$.

We regard the similarity of the optical and radio images as very strong evidence that we are seeing two images of the same object. The slight difference in the optical and radio flux density ratios is to be expected as the radio emission is highly variable. If the variability time-scale is less than or comparable to the image time delay, this will be reflected in changes in the radio flux density ratio. The optical flux density ratio can similarly be affected by variability, by microlensing or by contamination of the light of one of the images by emission from the lensing object itself.

The only other alternative to gravitational lensing is that 1600 + 434 is a pair of independent quasars. These quasars would both have to be radio-loud and variable, and both would have to have flat radio spectra. The space density of such objects is very low. Interpolating between the 5-GHz surveys listed by Kellermann & Wall (1986) we expect about 3200 flat-spectrum sources of 60 mJy or brighter per steradian. The probability of finding such a source within 1.4 arcsec of any given point is therefore of the order of 10^{-7}. Furthermore, one would have to attribute to coincidence the similarity of optical and radio morphologies and the existence of only one redshift system in the combined spectrum. This seems to be an overly contrived hypothesis, particularly since the quasars are only just over 1 arcsec apart.

Further confirmation of the lensing hypothesis is being sought in two ways. First, higher-resolution radio maps of greater sensitivity will be made using MERLIN to attempt to detect rings, arcs and other structures which are indicative of a lensed system. Secondly, we intend to search for the lensing galaxy by high-resolution imaging with the *HST* to detect the lensing galaxy directly, and by obtaining a high-quality optical spectrum in which we may see absorption features arising in the lensing galaxy.

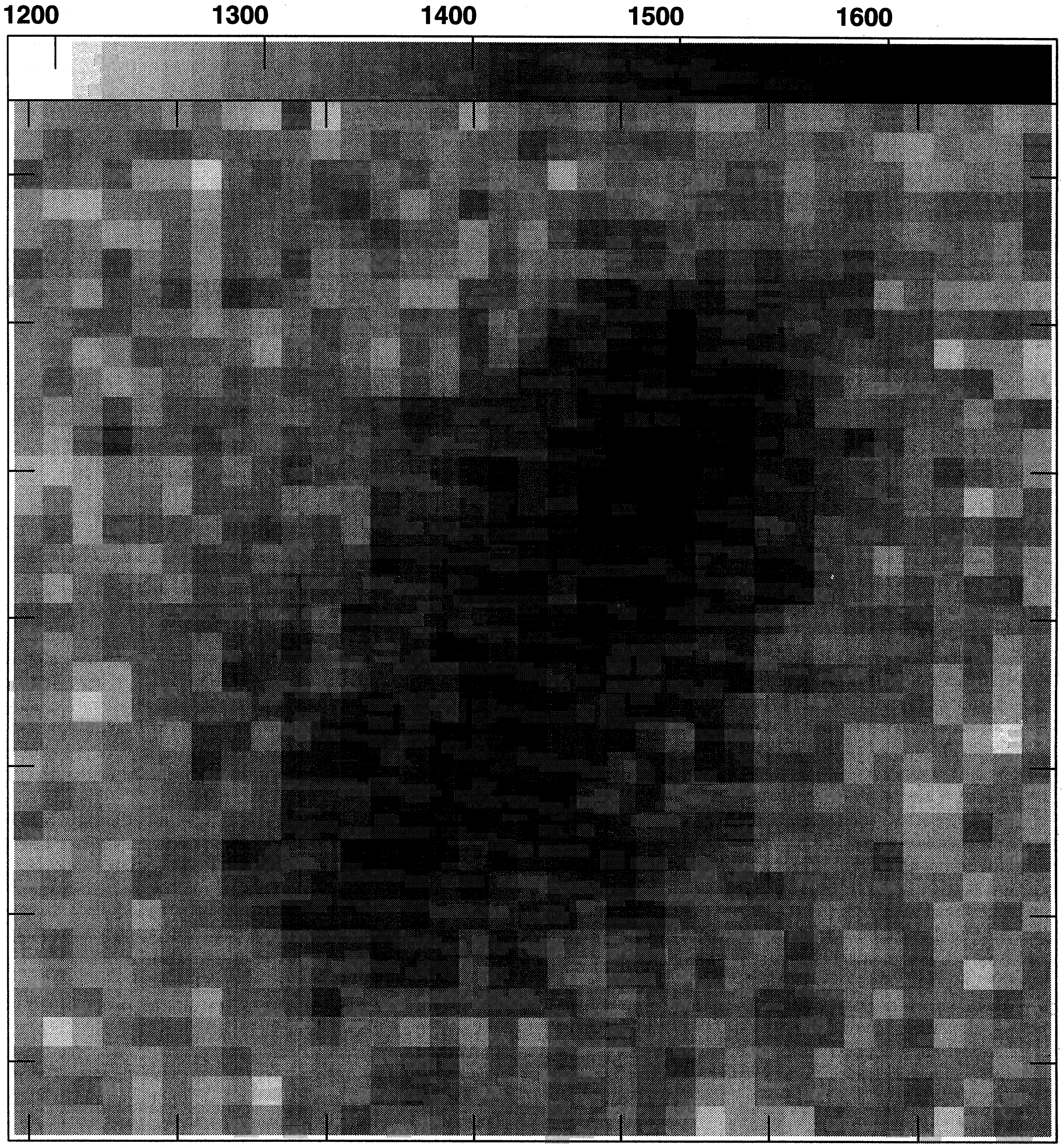

Figure 3. The optical image of 1600+434. The image was taken in the *R* band during very good (≤0.6 arcsec) seeing. The pixel scale is 0.1 arcsec pixel^{-1} – note the double separation of about 14 pixel, agreeing well with the radio separation. The corners of the image have been aligned with those of Fig. 1, assuming the above pixel scale and offsetting from a star visible on the chip at RA $15^h59^m58\overset{s}{.}32$, Dec. $43°25'15\overset{''}{.}2$ (B1950). The grey-scale bar indicates the number of counts in each pixel.

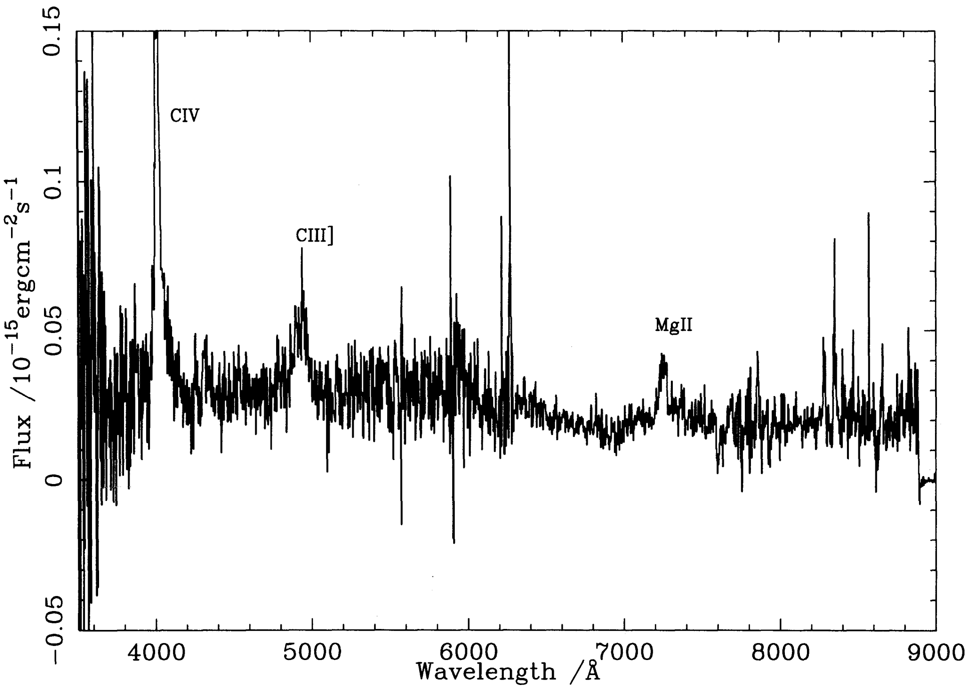

Figure 4. The integrated spectrum of 1600+434 (both components). C IV, C III] and Mg II are visible. The line at 6300 Å is a combination of a cosmic ray and a badly subtracted skyline around the point of the dichroic cut.

ACKNOWLEDGMENTS

We acknowledge the communication of unpublished Texas Survey material which was used in the sample selection for the CLASS observations. The William Herschel Telescope is operated on the island of La Palma by the Royal Greenwich Observatory at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias. The Very Large Array is operated by the US National Radio Astronomy Observatory on behalf of the US National Science Foundation. The WSRT is operated by the NFRA with the financial support of the Netherlands Organization for Scientific Research (NWO).

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