The gravitational lens J1131–1231

How to avoid missing an opportunity

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Abstract

So far the lens J1131–1231 has been studied only at optical and X-ray wavelengths. A detection in the radio was almost missed as a result of an incorrect position and archive problems. We show how a direct analysis of NVSS *uv* data — in contrast to the catalogue or images alone — provided sufficient evidence for further radio investigations. Several projects are now in progress.

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Introduction

Gravitational lensing is a unique tool to study (a) distant sources by using the gravitational lens as a natural telescope, (b) the mass distribution of the lenses themselves using sophisticated mass-modelling methods, and (c) the geometry of the Universe as a whole, including the determination of the Hubble constant.

The lens system RXS J1131–1231 (Fig. 1) that we discuss here was serendipitously discovered in an optical survey (Sluse et al., 2003). The background source consists of a (quadruply imaged) Seyfert core in a patchy, irregular star-forming galaxy. The star-forming regions are imaged as arc-like features that form an incomplete Einstein ring of 3.″6 diameter.

J1131–1231 is unrivalled in the amount of detail and substructure in the lensed image configuration, providing a wealth of constraints for lens modelling purposes. On the other hand, many of the components are highly magnified so that a detailed study of the background source becomes possible. As noted by Sluse et al. (2003) and Claeskens et al. (2006), the flux ratios of the Seyfert cores deviate considerably from the model expectations. This can be caused by small-scale mass inhomogeneities as expected from CDM structure formation. Other effects with an influence on flux ratios are differential extinction in the lensing galaxy and microlensing effects caused by the ensemble of stars within the lens. As a matter of fact, the flux ratios show a significant wavelength dependence as expected from both effects.

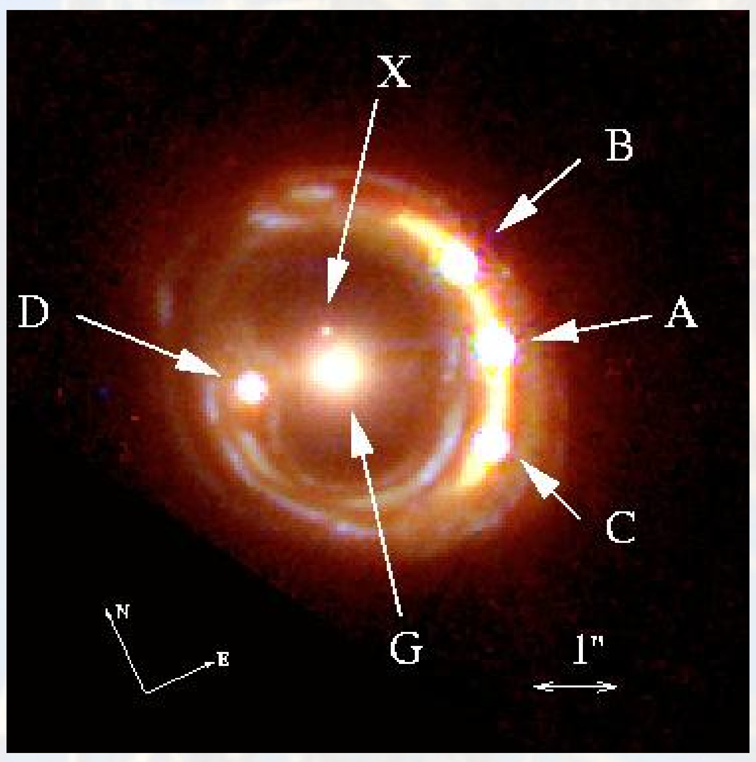

Fig. 1: HST image of the lens J1131–1231 (Claeskens et al., 2006). The star-forming galaxy with a Seyfert core (*A,B,C,D*) at $z = 0.658$ is lensed by an early-type galaxy (*G*) at $z = 0.295$.

Need for radio observations

In contrast to optical wavelengths, radio observations are not impaired by microlensing and dust extinction, and are therefore essential to resolve flux anomalies like observed in this system. In addition we can span a much wider range of resolutions (down to the sub-mas level) with the right combinations of frequencies and arrays used.

The first stop along the route to a new radio project is often the NVSS archive. Close to the position of the lens, an extended catalogue source of 29 mJy is listed that may be related to our target (Fig. 2 top). The probability for a chance alignment is small, but at the time it was unclear how our target could correspond to a very extended source that is furthermore not exactly aligned with it.

In order to extract all information from the NVSS, we analysed the visibility data directly and found that the seemingly extended source actually consists of at least three possibly pointlike subcomponents (Fig. 2 bottom). One of these components is consistent with being the radio counterpart of the lens (7″ separation, probability for chance alignment only 1:4000). The flux density of this component amounts to 6 mJy, significantly more than the flux from the star-forming regions, estimated from optical and IR-fluxes to be in the range 0.2–1.0 mJy. An obvious explanation is that the NVSS detects a combination of star-formation and AGN activity in the core.

With this information at hand, a VLA proposal to observe the source in L-band and C-band was submitted but rejected.

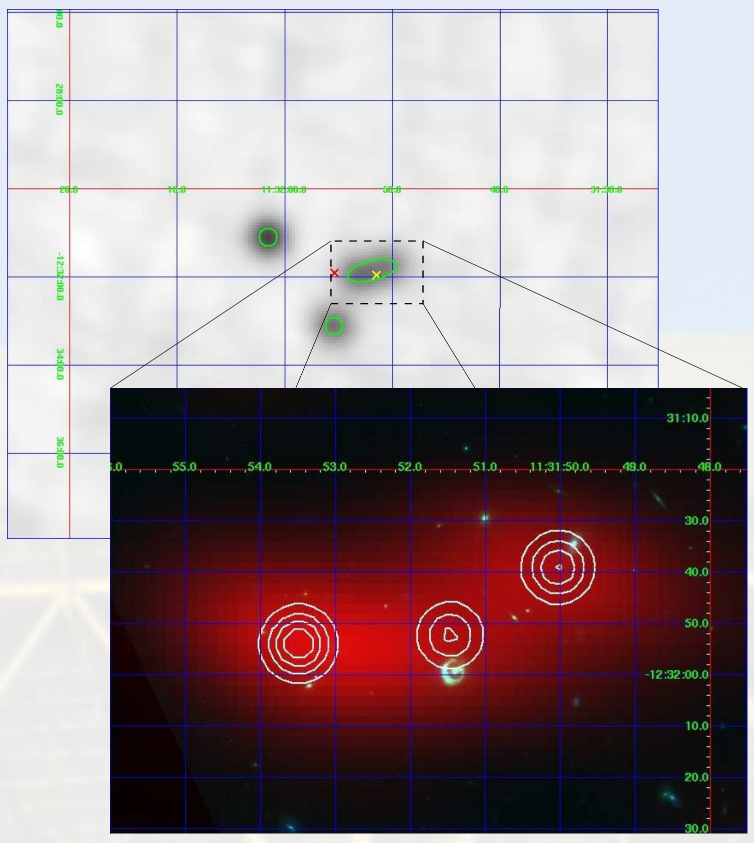

Fig. 2: Top: NVSS survey image (greyscale) overlayed with catalogue positions (green circles and ellipse) and position(s) of J1131–1231. The yellow cross identifies the true position, the red one the nominal position (1RXS J113155.4–123155). The latter is not consistent with the extended NVSS source, whilst the true position is located within its extension. Bottom: Own map made from NVSS visibility data (red) combined with optical HST data (small structures in cyan). Concentric contour lines mark the positions of compact components fitted to the visibilities. The lens can be identified with the central component.

Snapshot observations with the VLA

Independent of our effort, another group was able to obtain snapshot observations in L,C,X-bands using director's discretionary time. A non-detection was reported down to a flux level of 60 μJy. Because this low flux level was clearly inconsistent with our expectations, we tried to re-analyse the snapshot data. It turned out that these were not visible in the VLA archive because of an erroneous archive entry. Once this was fixed by the very helpful NRAO staff, the data were downloaded and mapped (see Fig. 3).

We found that — *when looking at the correct position* that did not correspond to the phase centre — the lens system is clearly detected. It is extended and consists of an AGN (0.75 mJy, flat spectrum) with jets in the lensing galaxy, and the lensed Seyfert core (0.5–1.3 mJy each, steep spectrum) and star-forming regions (1–2 mJy) in the background source. Disentangling the latter is not easy. The total flux density is about 5–6 mJy, consistent with our initial estimate from model-fitting the NVSS visibilities. In addition, we see two radio lobes connected to the AGN in the lensing galaxy.

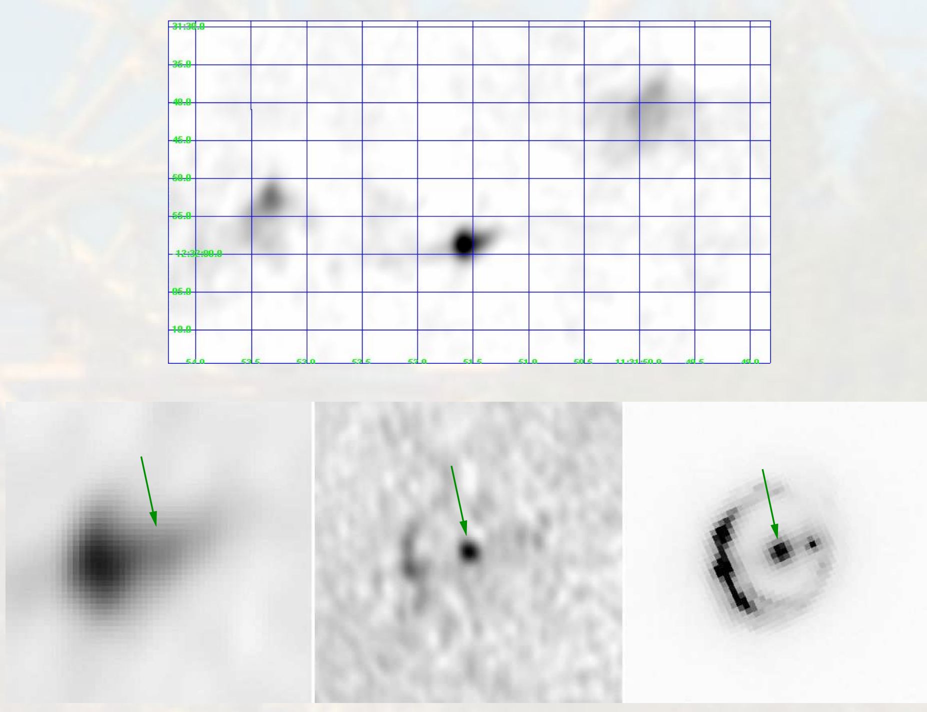

Fig. 3: VLA snapshot results. Top: L-band overview showing the lens system in the centre and two radio lobes probably belonging to the lensing galaxy. These three emission regions correspond to the NVSS source shown in Fig. 2. Bottom: The inner region around the lens system in L-band and C-band, with an HST image for comparison. The arrows mark the position of the lensing galaxy which seems to harbour an AGN.

MERLIN observations

In May 2008 this system was observed with MERLIN including the Lovell telescope (2 full tracks at 1420 and 3 at 1658 MHz, respectively). Fig. 4 shows a preliminary map produced after subtracting interfering sources with an own peeling algorithm and combining the two frequencies. We are inclined not to trust all the components before our exploration of the reliability is completed.

Most of the emission detected seems to originate from the star-forming regions. The compact Seyfert core is weaker than expected from the VLA observations.

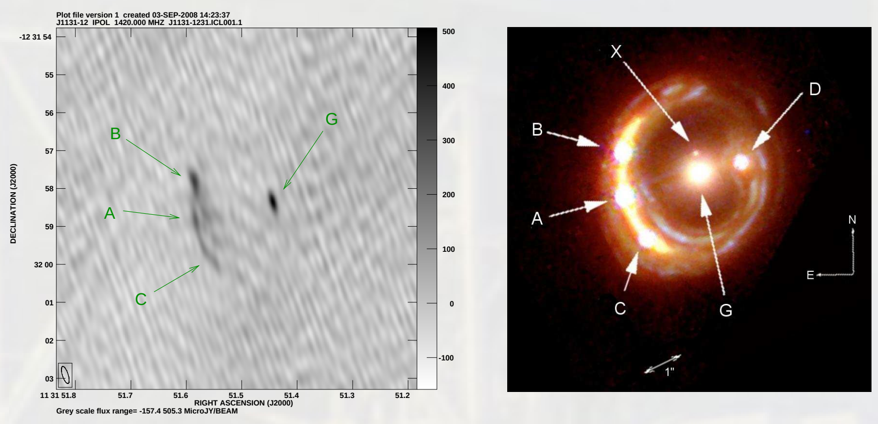

Fig. 4: Preliminary L-band MERLIN map, 40 h at frequencies 1420 and 1658 MHz, compared to the HST image at the same orientation and scale. The lensing galaxy's core *G* and the arc connecting *A,B,C* are clearly visible.

An e-VLBI experiment

In order to explore the feasibility of detailed VLBI studies, we recently (June 2008) carried out a short (1 h on source) e-VLBI experiment at 18 cm, using six telescopes (Cm, Mc, Ef, JB1, Tr, Wb) with a data-rate of 512 Mb/s. We clearly detected the core of the lensing galaxy at a flux level of ~ 0.5–0.7 mJy but see no hints of the lensed Seyfert core images down to $< 100\,\mu$Jy. This supports the evidence that most of the lensed radio flux is due to star formation in the background source.

Future projects

Further observing time at the VLA has now been granted to observe this system at C-band in A-configuration to produce a much deeper version of Fig. 3 (bottom centre) and allow more accurate spectral index measurements.

In addition to studying the lensed source and the mass distribution of the lens, this system offers the rare opportunity to see a background source *through* the jet emanating from the AGN core of the lensing galaxy. This can potentially be used to study the physical conditions in the jet.

This lensed star-forming galaxy is a prototype of the population of lensed objects that will be discovered by e-LOFAR (Wucknitz & Garrett, 2007) and sub-mm surveys. We have to study it *now* to prepare for these future projects.

Lessons learned

- Archives are not always complete.
- Original visibility data of radio surveys are an invaluable source of information being superior to maps alone. *If you are conducting a radio survey — and can afford it — please store the visibilities!*
- Do not trust non-detections or any other results reported by others. Taking into account a modified Copernican Principle, this implies that one should not trust own results either.

J1131–1231 has been detected at radio wavelengths and shows structures of the lensed star-forming galaxy. It offers the opportunity to study physical conditions in an AGN jet via propagation effects acting on radiation from the lensed background source.

References

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