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 arc data — in contrast to the catalogue or images alone — provided sufficient evidence for further radio investigations. Several projects are now in progress.

GRS 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.

Need for radio observations

In contrast to optical wavelengths, radio observations are not impeded 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 step 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 1.400%). 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 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′. The background source is unambiguously the lensing galaxy. 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.

Radio surveys are not indicated 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 micro.lensing 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.

The lens 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.

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 = 0.659 is lensed by an early-type galaxy (G) at z = 0.295.

Fig. 2: Top: NVSS survey image (grayscale) overlayed with catalogue positions (green circles and ellipses) and positions (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 ellipse. Bottom: Own map made from NVSS visibility data (red) combined with optical HST data (small structures in cyan). Centric contour lines mark the positions of compact components fitted to the visibilities. The lens can be identified with the central component.

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.

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, El, JB1, Tr, Wb) with a data-rate of 512 Ms. 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 µJy. 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.

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References


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