

# The radio-loud active nucleus in the “dark lens” galaxy J1218+2953

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## ABSTRACT

**Context.** There is a possibility that the optically unidentified radio source J1218+2953 may act as a gravitational lens, producing an optical arc  $\sim 4''$  away from the radio position. Until now, the nature of the lensing object has been uncertain since it is not detected in any waveband other than the radio. The estimated high mass-to-light ratio could even allow the total mass of this galaxy to be primarily in the form of dark matter. In this case, J1218+2953 could be the first known example of a “dark lens”.

**Aims.** We investigate the nature of J1218+2953 by means of high-resolution radio imaging observations to determine whether there is a radio-loud active galactic nucleus (AGN) in the position of the lensing object.

**Methods.** We report on Very Long Baseline Interferometry (VLBI) observations with the European VLBI Network (EVN) at 1.6 and 5 GHz.

**Results.** Our images, having angular resolutions of  $\sim 1$  to  $\sim 10$  milli-arcseconds (mas), reveal a rich and complex radio structure extending to almost  $1''$ . Based on its radio spectrum and structure, J1218+2953 can be classified as a compact steep-spectrum (CSS) source, and as a medium-size symmetric object (MSO). The object harbours an AGN. It is also found as an X-ray source in the XMM-Newton EPIC (European Photon Imaging Cameras) instrument serendipitous source catalogue.

**Conclusions.** Rather than being a dark lens, J1218+2953 is most likely a massive, heavily obscured galaxy in which the nuclear activity is currently in an early evolutionary stage.

**Key words.** radio continuum: galaxies – galaxies: active – galaxies: individual: FIRST J121839.7+295325 – techniques: interferometric – gravitational lensing: strong

## 1. Introduction

It is now widely accepted that  $\sim 95\%$  of the mass of galaxies and clusters is composed of some unknown form of dark matter. The observational evidence comes from the flat galactic rotation curves, the mass required for gravitational lensing, and the presence of hot X-ray-emitting gas in galaxy clusters (see e.g. Freese 2009, for a recent review). It is possible that empty dark matter halos may also exist. Strong gravitational lensing may in principle be a useful tool to detect massive dark matter halos that do not contain significant amounts of ordinary matter (Rusin 2002). Hawkins (1997), based on a sample of supposedly lensed double quasars without visible lensing galaxies, envisaged a large number of dark galaxies, three times more than galaxies with normal mass-to-light ratios. However, those quasars later proved to be physical binaries rather than lensed images. In fact, the extensive systematic Cosmic Lens All-Sky Survey (CLASS) that identified gravitationally lensed objects in the radio, did not find any convincing evidence for dark lens among 22 lens systems (Jackson et al. 1998; Browne et al. 2003).

Another suspected “dark galaxy”, VIRGOHI 21 has earlier been found in the Virgo Cluster, based on the broadening of its 21-cm HI emission line by the presumed rotation of the gravitationally bound neutral hydrogen gas (Davies et al. 2004; Minchin et al. 2005). In this model, the total mass of the object

could reach  $\sim 10^{11} M_{\odot}$ , with a baryonic fraction at least ten times smaller than observed in visible disk galaxies in the Universe (Minchin et al. 2007). On both observational and theoretical grounds, others claim that VIRGOHI 21 is in fact tidal debris left over from an interaction that involved the nearby bright spiral galaxy NGC 4254 (Haynes et al. 2007; Duc & Bournaud 2008). The existence of dark galaxies is therefore far from being established.

Recently Ryan et al. (2008) investigated a hypothesis that the optically unidentified radio source FIRST J121839.7+295325 (J1218+2953 hereafter) is strongly lensing a background galaxy. The arc-like lensed image is  $\sim 4''$  south-west of the radio source. Its estimated photometric redshift is  $z \approx 2.5$ . However, the suspected foreground object is so far detected only in the radio. Its integrated flux density at  $\nu = 1.4$  GHz frequency is  $S = 33.9$  mJy in the Faint Images of the Radio Sky at Twenty-centimeters<sup>1</sup> (FIRST) survey (White et al. 1997). The source is unresolved in FIRST, with a deconvolved size smaller than  $1''$ . Other total radio flux density measurements found in the literature for this object at low frequencies are: 284 mJy at 74 MHz (Cohen et al. 2004), 151 mJy at 151 MHz (Hales et al. 2007), and 129 mJy at 330 MHz (Westerbork Northern Sky Survey

<sup>1</sup> <http://sundog.stsci.edu>

Catalogue, WENSS<sup>2</sup>; de Bruyn et al. 1998). A power-law fit to the total flux density data at these four frequencies gives a radio spectral index  $\alpha = -0.7$  ( $S \propto \nu^\alpha$ ).

Deep optical and infrared imaging (Russell et al. 2008; Ryan et al. 2008) did not reveal any counterpart to the radio source. The limiting magnitudes are 25.5, 22.0 and 20.7 in the *V*, *J* and *H* bands, respectively. Based on the 1.4-GHz radio flux density and the optical non-detection (Russell et al. 2008), Ryan et al. (2008) place the source in an approximate redshift range of  $0.8 < z_{\text{radio}} < 1.5$ . The lower limit derives from the optical non-detection, so if the object is an unusually obscured galaxy, it could possibly be even closer. The best-fit lens model assuming an isothermal ellipsoid (Ryan et al. 2008) provides a lensing galaxy with an Einstein radius of  $1''.3$  and a dynamical mass  $10^{1.25 \pm 0.5} M_\odot$ . The apparently very large mass-to-light ratio led Ryan et al. (2008) to raise the possibility that J1218+2953 may be in fact a galaxy dominated by dark matter. Suspected dark-matter galaxies, of which this could be a very rare (or the only) example, would of course be impossible to image directly in the optical. Alternatively, the lensing radio source J1218+2953 may be a massive obscured galaxy with a central active galactic nucleus (AGN) visible in the radio. In this case, according to the optical non-detection and the lens model, the stellar mass in this galaxy would at best be only about 1% of its total dynamical mass (Ryan et al. 2008).

Firm evidence for a radio-loud AGN can be obtained with high-resolution radio interferometric observations. Here we report on our dual-frequency Very Long Baseline Interferometry (VLBI) experiments with the European VLBI Network (EVN), which have revealed a complex structure on angular scales from  $\sim 1$  to several hundred milli-arcseconds (mas) within J1218+2953. Our VLBI observations also provide an accurate astrometric position of the source. We give the details of the experiments and the data analysis, as well as our search for additional data at other wavebands in Sect. 2. We describe the observed radio structure of the source in Sect. 3 and discuss the possible implications of our results in Sect. 4.

## 2. Observations

### 2.1. Radio interferometric imaging

We observed J1218+2953 with the EVN at 1.6 GHz and 5 GHz frequencies, using the e-VLBI technique (Szomoru 2008). Unlike traditional VLBI, in which the remote radio telescopes of the network record their signals onto physical media, which are shipped to the central processor for subsequent correlation, e-VLBI streams the signals over optical fibre networks directly to the central processor for real-time correlation. This process vastly compresses the time-scale between observations and the availability of the correlated data for further analysis. On 2009 January 23 we conducted an exploratory 1.6-GHz e-VLBI experiment. This lasted only for 2 h, but allowed us to verify that the source is sufficiently compact for VLBI detection. Its radio emission was clearly detectable at  $\sim 25$  mas angular resolution, and the resulting image revealed two major components separated by  $\sim 500$  mas. Based on these exploratory observations, we conducted deeper dual-frequency observations. To make a more sensitive 1.6-GHz VLBI image, we used nine antennas of the EVN during an 8 h observation on 2009 April 21. Participating stations included Effelsberg (Germany), Jodrell Bank Lovell Telescope, Cambridge, Darnhall (UK), Medicina

(Italy), Onsala (Sweden), Toruń (Poland), Arecibo (Puerto Rico) and the phased array of the 14-element Westerbork Synthesis Radio Telescope (WSRT, the Netherlands). At most of the antennas, a data transmission rate of  $512 \text{ Mbit s}^{-1}$  was achieved in real time, which resulted in a total bandwidth of 64 MHz in both left and right circular polarizations, using 2-bit sampling. We also carried out an 8-h e-VLBI observation with EVN at 5 GHz on 2009 March 24. The maximum data rate was  $1024 \text{ Mbit s}^{-1}$ , corresponding to 128 MHz bandwidth per polarization. The successfully participating radio telescopes were Effelsberg, Jodrell Bank Mk2, Knockin (UK), Medicina, Onsala, Toruń, and the WSRT. The correlation of the VLBI data from both observations took place at the EVN MkIV Data Processor at the Joint Institute for VLBI in Europe (JIVE) in Dwingeloo, the Netherlands.

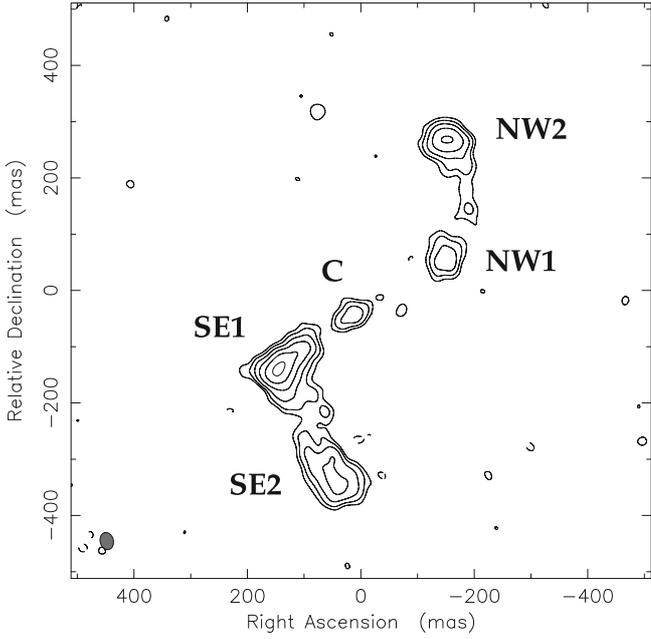
We also analysed the synthesis array data recorded at the WSRT during the e-VLBI observations. Here, the source J1218+2953 appeared unresolved on arcsecond scales at both 1.6 and 5 GHz, allowing us to obtain simultaneous total flux density measurements.

Because our target radio source is relatively weak, we observed in phase-reference mode. This method is usually applied to increase the total coherent integration time spent on the source and consequently to improve the sensitivity of the observations. Phase-referencing is done by regularly changing between the target source and a bright, compact reference source lying nearby on the plane of the sky (e.g. Beasley & Conway 1995). We chose J1217+3007, a BL Lac object with compact VLBI structure (Bondi et al. 2004) having an angular separation of  $0''.28$  from J1218+2953, as the phase-reference calibrator. We took the position of J1217+3007 from the US National Radio Astronomy Observatory (NRAO) Very Long Baseline Array (VLBA) Calibrator Survey<sup>3</sup>, which quoted right ascension and declination uncertainties of 0.21 mas and 0.41 mas, respectively. The delay, delay rate and phase solutions derived for the phase-reference calibrator were interpolated and applied to J1218+2953 within the target-reference cycle time of  $\sim 5$  min. The target source was observed for 3.5-min intervals in each cycle. The total observing time on J1218+2953 was nearly 5 h and 4 h at 1.6 GHz and 5 GHz, respectively.

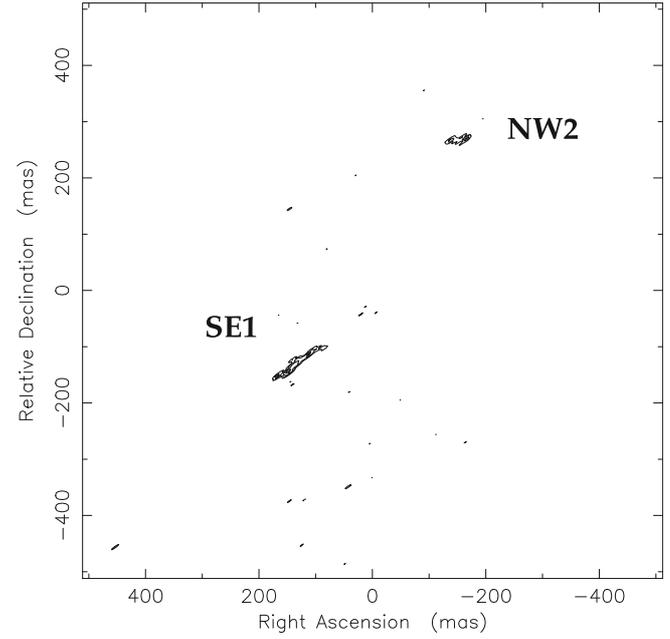
We used the NRAO Astronomical Image Processing System (AIPS; e.g. Diamond 1995) for the data calibration. The visibility amplitudes were calibrated using system temperatures and antenna gains measured at the antennas. Fringe-fitting was performed for the calibrator (J1217+3007) and fringe-finder sources (J0927+3902, J1159+2914, J1407+2827) using 3-min solution intervals. We exported the data to the Caltech Difmap package (Shepherd et al. 1994) for imaging. The conventional hybrid mapping procedure involving several iterations of CLEANing and phase (then amplitude) self-calibration resulted in the images and brightness distribution models for the calibrators. Overall antenna gain correction factors ( $\sim 10\%$  or less) were determined and applied to the visibility amplitudes in AIPS. We then repeated fringe-fitting for the phase-reference calibrator in AIPS, now taking its CLEAN component model into account in order to compensate for residual phase corrections resulting from its non-pointlike structure. The solutions obtained were interpolated and applied to the target source data. The calibrated and phase-referenced visibility data of J1218+2953, unaveraged in time, were also exported to Difmap for imaging. The total intensity images at 1.6 GHz (Figs. 1, 2) and 5 GHz (Fig. 3) were made after several cycles of CLEANing in Difmap. The lowest contours are drawn at  $\sim 3\sigma$  image noise levels. The coordinates

<sup>2</sup> <http://cdsarc.u-strasbg.fr/viz-bin/Cat?VIII/62>

<sup>3</sup> <http://www.vlba.nrao.edu/astro/calib/index.shtml>



**Fig. 1.** The naturally weighted 1.6-GHz VLBI image of J1218+2953. The positive contour levels increase by a factor of 2. A Gaussian taper with the value of 0.5 at the projected baseline length of 10 million wavelengths ( $M\lambda$ ) was applied to reduce the relative weight of the longest baselines (i.e., mainly the baselines from the European antennas to Arecibo). This provided better imaging of the extended emission. The lowest contours are drawn at  $\pm 70 \mu\text{Jy}/\text{beam}$  (negative contours are dashed). The peak brightness is  $2.67 \text{ mJy}/\text{beam}$ . The Gaussian restoring beam is  $30.9 \text{ mas} \times 23.3 \text{ mas}$  at a major-axis position angle of  $13^\circ$ .



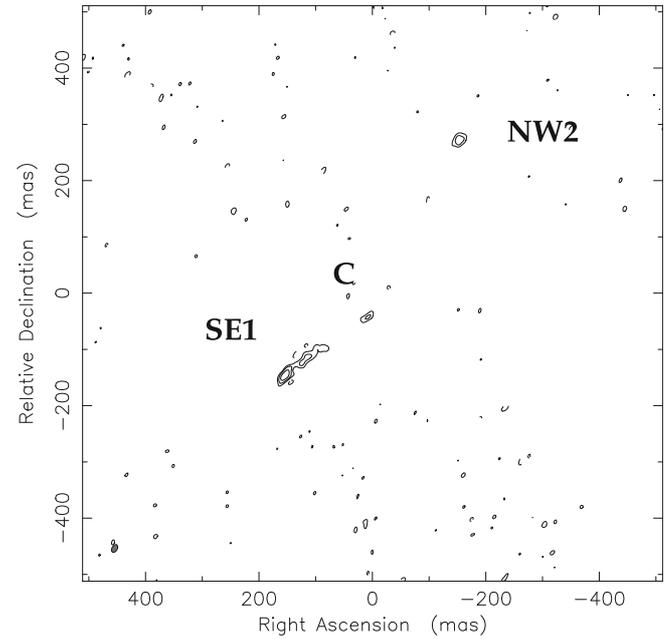
**Fig. 2.** The uniformly weighted 1.6-GHz VLBI image of J1218+2953. The positive contour levels increase by a factor of 2. The first contours are drawn at  $-60$  and  $60 \mu\text{Jy}/\text{beam}$ . The peak brightness is  $0.62 \text{ mJy}/\text{beam}$ . The Gaussian restoring beam is  $15 \text{ mas} \times 2.2 \text{ mas}$  at  $\text{PA} = -54^\circ$ .

in all images are relative to the a priori position taken from the FIRST catalogue ( $\alpha_0 = 12^{\text{h}}18^{\text{m}}39^{\text{s}}.718$ ,  $\delta_0 = +29^\circ53'25''.58$ ). This position was used as the correlation phase center for both e-EVN experiments.

## 2.2. Infrared and X-ray data

At the position of J1218+2953, the archive of the Submillimetre Common-User Bolometer Array (SCUBA) at the James Clerk Maxwell Telescope (JCMT) does not contain data. To look for archival observations at shorter wavelengths, we searched the Spitzer Space Telescope archive for possible measurements at our target position. This resulted in two Infrared Array Camera (IRAC) images at  $3.6$  and  $5.8 \mu\text{m}$ , which belong to the same observation (AOR key 12451840) targeting the nearby Seyfert galaxy Markarian 766 (NGC 4253). We started the data processing of these images with the BCD files (Basic Calibrated Data) and then performed additional corrections as described by Hora et al. (2008). Since J1218+2953 was not detected in the final images, we derived upper limits at the position of our radio source of  $0.030 \text{ mJy}$  ( $17^{\text{m}}4$ ) and  $0.28 \text{ mJy}$  ( $14^{\text{m}}4$ ) at  $3.6$  and  $5.8 \mu\text{m}$ , respectively. However, these limits are not very deep.

The object 2XMM J121839.6+295327 found in the XMM-Newton EPIC (European Photon Imaging Cameras) instrument serendipitous source catalogue (Watson et al. 2009) is  $2''.08$  away from the center of the radio source, to the north. This difference is comparable to the formal X-ray positional error ( $1''.99$ ). Therefore we identify our radio source with the X-ray object. It is detected in the three highest-energy bands out of the five bands, with flux values of  $(11.3 \pm 4.2) \times 10^{-19} \text{ W m}^{-2}$  ( $1\text{--}2 \text{ keV}$  band),  $(17.3 \pm 9.7) \times 10^{-19} \text{ W m}^{-2}$  ( $2\text{--}4.5 \text{ keV}$  band), and



**Fig. 3.** The naturally weighted 5-GHz VLBI image of J1218+2953. The positive contour levels increase by a factor of 2. The first contours are drawn at  $-50$  and  $50 \mu\text{Jy}/\text{beam}$ . The peak brightness is  $0.34 \text{ mJy}/\text{beam}$ . The Gaussian restoring beam is  $14.9 \text{ mas} \times 9.2 \text{ mas}$  at  $\text{PA} = -29^\circ$ .

$(222.3 \pm 82.5) \times 10^{-19} \text{ W m}^{-2}$  ( $4.5\text{--}12 \text{ keV}$  band). The total-band ( $0.2\text{--}12 \text{ keV}$ ) X-ray flux is  $(258.8 \pm 83.3) \times 10^{-19} \text{ W m}^{-2}$ . Although the uncertainties are large, we can estimate the absorbing neutral hydrogen column density based on the detections in the 3 hardest EPIC bands, assuming a typical power-law spectral slope of 1.8. The value of  $N_{\text{H}} \sim 10^{22} \text{ cm}^{-2}$  is about two orders of magnitude higher than the Galactic one.

### 3. The radio structure of J1218+2953

Our tapered 1.6-GHz VLBI image (Fig. 1) reveals a rich and complex structure in an “inverted S” shape, spanning almost  $0''.7$ . This corresponds to a projected linear size of 5–6 kpc, if the source is indeed in the  $0.8 < z_{\text{radio}} < 1.5$  redshift range. (We assume a flat cosmological model with  $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$ ,  $\Omega_m = 0.3$  and  $\Omega_\Lambda = 0.7$ .) The major components of the brightness distribution are labeled in the images. The two brightest ones (SE1 and NW2) seen also in the highest-resolution image (Fig. 2) are on opposite sides of the approximate center of symmetry (component C). The 1.6-GHz data measured on the longest baselines to Arecibo indicate that there isn’t any compact unresolved component visible with the sensitivity of those baselines (Fig. 2). Therefore SE1 itself is in fact not a “core-jet” structure: the linear  $\sim 100$ -mas long jet-like feature in the southeast ends in a “hot spot”. Here the shape of the radio structure abruptly changes at right angles, ending up in component SE2. On the northwestern side of C, a similar but somewhat smoother directional change occurs between NW1 and NW2.

The sum of flux densities in the CLEAN components is 20.8 mJy. Our WSRT data give 27 mJy total flux density, closer to the FIRST value (33.9 mJy). The correlated flux density measured on only the shortest e-VLBI baseline in our experiment (Jodrell Bank Lovell Telescope-Darnhall, 17.6 km) is also consistent with this higher value. Therefore we believe that there is still some extended emission in the  $\sim 1''$  angular scale which our e-VLBI observations resolved out.

The 5-GHz image (Fig. 3) shows only those components that have somewhat flatter spectra and compact structures not resolved out at this higher observing frequency. The sum of CLEANed flux densities is 1.6 mJy, while the WSRT data give 9 mJy total flux density. The difference is attributed to extended radio emission. The total flux density is consistent with the steep overall radio spectrum of the source.

The astrometric position of component C ( $\alpha_C = 12^{\text{h}}18^{\text{m}}39^{\text{s}}.7186$ ,  $\delta_C = +29^\circ53'25''.537$ ) was determined with the AIPS task MAXFIT using the 5-GHz image, and is accurate to 1 mas. We suggest that this coincides with the center of the galaxy.

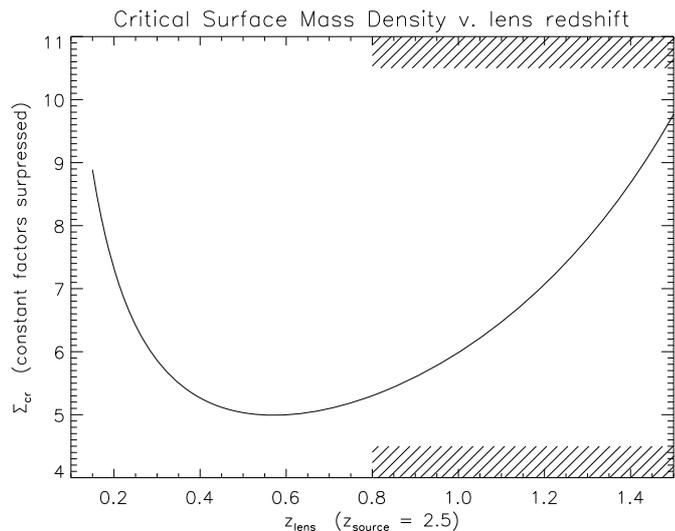
### 4. Discussion

Here we follow the assumption of Ryan et al. (2008) that the optical arc seen  $\sim 4''$  away from the radio position of J1218+2953 is a result of gravitational lensing. However, we cannot provide any further proof for this scenario based on our own observations. We stress nevertheless that our interpretation of the compact radio source itself is independent of the lensing hypothesis.

#### 4.1. The nature of the radio source: lensed or lens?

Are J1218+2953 and the optical arc all gravitationally lensed images of the same background object, or does the compact radio source reside in the lens forming the optical arc?

A static gravitational lens would be achromatic and conserve surface brightness in its images; these characteristics form the basis for the principal objection to the former interpretation. The radio flux density of the images should scale with their size, and since the arc is elongated, its radio flux density should be much higher than we observe in the compact J1218+2953 components. However, the optical arc does not show sufficient radio emission. At 1.6 GHz, both our VLBI radio source and the optical arc are located within the same WSRT restoring beam. Yet the measured



**Fig. 4.** The critical surface mass density as a function of the lens redshift for the case of a background source at  $z = 2.5$ . The constant factor ( $cH_0/4\pi G$ ) in  $\Sigma_{\text{cr}}$  is suppressed. The hatched region along the abscissa is the range of  $z_{\text{lens}}$  considered by Ryan et al. (2008).

WSRT flux density is only  $\sim 25\%$  greater. In principle it might be possible that we see a gravitational lens system in which one of the ray paths suffers high obscuration in the optical, while the other one does in the radio, for example due to free-free absorption (e.g. Mittal et al. 2007). However, we find this configuration very unlikely, because of the extended area of the arc that would require free-free absorption in order to mask a radio detection.

The structure seen in Fig. 1 may suggest the appearance of two close images of a single bent structure in a background source. While the configuration of an extended arc plus two more compact images is quite feasible (e.g. B0128+437; Biggs et al. 2004, Biggs 2004), conservation of surface brightness would imply that the relative flux densities of the two components in each “image” should be similar. However, it is clear that NW1 is rather fainter than NW2, and the opposite case holds for SE1 and SE2.

It thus seems very unlikely that the radio structure of J1218+2953 and the optical arc arise from gravitational lensing of the same background source. Therefore we interpret the host galaxy of J1218+2953 as (part of) the gravitational lens forming the optical arc.

Assuming a background object at  $z = 2.5$ , even if the lensing galaxy is much closer than estimated by Ryan et al. (2008), i.e. at  $0.15 < z < 0.8$ , the total lensing mass required to produce the same image-plane geometry would not change dramatically, only within a factor of  $\sim 2$ . Figure 4 plots the critical surface mass density,

$$\frac{c^2}{4\pi G} \frac{D_s}{D_d D_{ds}}, \quad (1)$$

suppressing the explicit constants and the net factor of  $H_0/c$  arising from the ratio of the usual lensing angular diameter distances. Therefore the interpretation of the VLBI radio source as belonging to the lensing object is not terribly sensitive to the redshift of the lens, even if the lensing galaxy moves significantly closer, reflecting higher obscuration in the optical.

Note that the center of the lens model (Fig. 2 of Ryan et al. 2008) is offset from our radio position by  $\sim 2''.2$ , beyond the  $1\sigma$  positional uncertainty of the HST-WFPC2 observations ( $\sim 1''$ ; Russell et al. 2008). In their model, Ryan et al. (2008) treated

the position of the lensing galaxy, an isothermal ellipsoid, as a free parameter. The accurate coordinates derived from our VLBI observations could provide further constraints to refine the lens modeling, leading to somewhat different values for other parameters. On the other hand, similar radio sources are often associated with merging or disturbed-morphology hosts. Thus it is also possible that the VLBI structure does not coincide with the mass center of the galaxy.

#### 4.2. The classification of the radio source

Based on its radio spectrum and structure, J1218+2953 can be classified as a compact steep-spectrum (CSS; e.g. O’Dea 1998) source, and a medium-size symmetric object (MSO; Fanti et al. 1995). These objects are believed to be young radio sources, recently (about  $10^5$ – $10^6$  years ago) triggered AGNs. Their host galaxies are the most easily identified in the nearby Universe. Beyond redshift  $\sim 1$ , the hosts have typical  $R$ -band magnitudes around 24. These galaxies often have very red colors ( $R-K > 5$ ). (See e.g. de Vries 2003; Holt 2009, for reviews.)

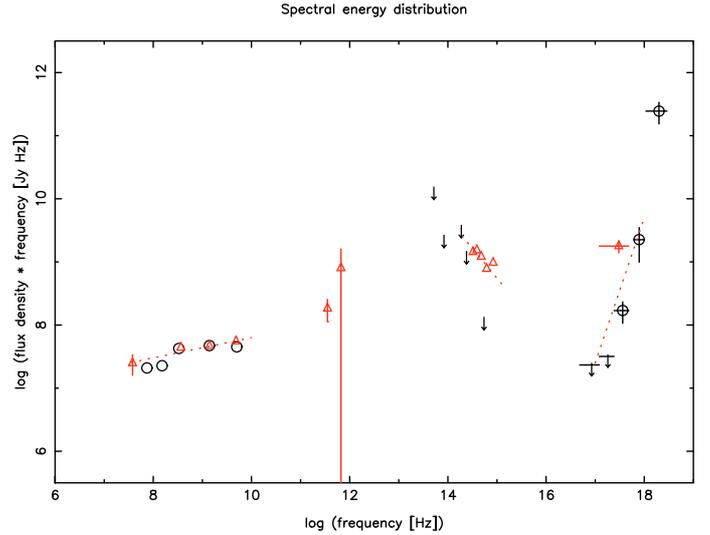
The radio source J1218+2953 is probably entirely contained within its host galaxy. A plausible assumption is that the mass center of the host coincides with component C. The interaction of the outflowing plasma in the jets with the dense interstellar medium could result in the observed two-sided bent radio structure. This qualitative picture is consistent with the supposed presence of a large mass of gas and dust in this “dark” galaxy. Notably, the position angle of the practically linear inner part of the radio source (SE1–NW1) is coincident with the minor axis of the gravitational lens model (Fig. 2 of Ryan et al. 2008). This is to be expected if we assume that the inner jets mark the spin axis of the central black hole, which itself coincides with the rotation axis of the entire galaxy.

#### 4.3. Is J1218+2953 a highly obscured galaxy?

According to our VLBI imaging results, J1218+2953 can most naturally be identified with the lensing galaxy, if the optical arc is indeed due to gravitational lensing as we assume. The lens is therefore not completely dark matter, but rather not (yet) detected in the optical and near-infrared wavebands. According to Ryan et al. (2008), this galaxy has an extremely high (over  $\sim 100$ ) dynamical-to-stellar mass ratio. However, due to the suspected high obscuration, the stellar mass could take more of the total mass in this galaxy. It is feasible to expect mid- and far-infrared emission from the dust, and (hard) X-rays from the high-energy photons originating from the accretion disk around the central black hole that can penetrate the dense material in the galaxy.

The early evolutionary stages of the growth of massive black holes are highly obscured. The model of Fabian (1999) accounts for the observed hard X-ray background and states that the growth of the central black hole continues until the obscuring gas is ejected from the galaxy. Before that, the absorbed radiation from the obscured AGN is re-emitted mostly in the far-infrared and sub-millimeter bands. Direct X-ray radiation from around the accreting black hole may be observed above 30 keV. According to theoretical models, CSS sources should generally be strong X-ray emitters. However, at  $z \approx 1$  and beyond, the angular resolution of current X-ray telescopes is not sufficient to resolve the expected kpc-scale structure spatially (Siemiginowska 2009, and references therein).

The flux density upper limit in the 3.6- $\mu\text{m}$  Spitzer band and the measured XMM-Newton EPIC flux allow us to compare our



**Fig. 5.** The SED of J1218+2953. Measured values are indicated with open circles, upper limits with arrows. The values for RX J1011.2+5545 (Barcons et al. 1998) divided by 5 are plotted with triangles. The data are taken from the NASA/IPAC Extragalactic Database (NED). Dashed lines characterise the radio (left) and optical (middle) part of the comparison SED. The dashed line at the X-rays (right) is the approximation of the spectrum of RX J1011.2+5545 from Fig. 6 of Barcons et al. (1998).

source with a sample of obscured AGNs selected by Eckart et al. (2010) from moderately deep fields observed by both the Spitzer Space Telescope and the Chandra X-ray Observatory. While our source fits in the general X-ray-infrared dependence, our upper limit indicates that J1218+2953 could be relatively faint in the mid-infrared compared to other obscured AGNs.

We constructed the spectral energy distribution (SED) of J1218+2953 from the measured data in the radio and X-rays, and from the upper limits available in the optical and near-infrared (Fig. 5). For comparison, we plotted the SED of an X-ray-selected moderately obscured radio-loud AGN at  $z = 1.25$ , RX J1011.2+5545 (Barcons et al. 1998). The flux densities of the comparison object were scaled down by a factor of 5 throughout the whole electromagnetic spectrum, such that the 1.4-GHz flux densities of the two sources were aligned. While the two resulting SEDs are remarkably similar in the radio and X-ray bands, J1218+2953 appears at least an order of magnitude fainter in the optical, suggesting an additional extinction  $\Delta A_V > 2^m$ .

Without dust obscuration, Ryan et al. (2008) place the dynamical mass-to-light ratio in the range of  $\sim 30$  to  $150 M_\odot L_\odot^{-1}$  for J1218+2953. A strong extinction of  $\sim 3^m$  would imply higher luminosity and consequently a mass-to-light ratio consistent with the typical values for other galaxies. The  $A_V/N_H$  ratio in our case ( $\sim 10^{-22}$  mag  $\text{cm}^2$ ) is less than the standard Galactic value of  $5.3 \times 10^{-22}$  mag  $\text{cm}^2$ , but there is observational evidence that this ratio is nearly always lower in other AGNs, typically by factors of  $\sim 3$  to 100 (Maiolino et al. 2001). Thus for J1218+2953, there is a rough agreement between the likely amount of extinction and the column density of the absorbing neutral hydrogen inferred from the X-ray data.

## 5. Conclusion

Our EVN observations have revealed that the optically unidentified radio source J1218+2953 has a radio-loud AGN in its center.

The tapered 1.6-GHz e-VLBI image (Fig. 1) shows a complex, two-sided radio structure. The angular size of the radio source is less than  $1''$ . Although the redshift of the object is unknown, we used the range  $0.8 < z_{\text{radio}} < 1.5$  estimated by Ryan et al. (2008) to conclude that the source is confined to a sub-galactic projected linear size, 5–6 kpc. Our higher-resolution images at 1.6 GHz (Fig. 2) and 5 GHz (Fig. 3) indicate two “hot spots” and a possible weak central component. The latter may mark the location of the massive black hole in the center of this galaxy. We determined the position of this radio component to an accuracy of 1 mas.

The suspected lensing object thus coincides with a compact radio source associated with an AGN. According to well-established models, its radio jet activity is driven by accretion onto a supermassive (typically  $\sim 10^8 M_{\odot}$ ) black hole (see e.g. Urry & Padovani 1995 for a review). Moreover, we found that the object also emits X-rays. It is therefore detected in two different electromagnetic wavebands, which indicates that its total mass could not be exclusively in the form of dark matter.

Based on its radio spectrum and morphology, J1218+2953 can be classified as a compact steep-spectrum (CSS) source, and as a medium-size symmetric object (MSO). Our object is unique in a sense that the CSS samples studied to date contain radio sources at least twice as bright. The faintest CSS sample of Tschager et al. (2003) was compiled from unresolved WENSS sources with at least 250 mJy flux density at 330 MHz. However, even those sources usually lack high-resolution VLBI data, therefore their pc-scale properties are unknown.

A few relatively weak MSOs have been observed by Kunert-Bajraszewska et al. (2005) with the NRAO Very Large Array (VLA) and the UK Multi-element Radio Linked Interferometer Network (MERLIN), with an eventual goal of establishing a more complete evolutionary scheme for radio sources. In our case, J1218+2953 has attracted much attention as an potential “dark” gravitational lens, not because it was a faint CSS. The complex structure we observe draws attention to the importance of in-depth high-resolution studies of faint CSS sources, and obscured radio-loud X-ray-selected AGNs. These would help provide a better understanding of the early evolution of radio AGNs, the interaction between the host galaxies and the expanding radio sources, and AGN feedback processes.

Our results render the “dark lens” interpretation of Ryan et al. (2008) unlikely. Supported by the X-ray detection of J1218+2953, we suspect that it is a heavily obscured galaxy in which the nuclear activity is in an early evolutionary stage. Deeper observations in the future in the mid-infrared, far-infrared, and sub-millimeter bands might be able to detect the source and put more constraints on its spectral energy distribution.

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