Detection of a Radio Bubble around the Ultraluminous X-Ray Source Holmberg IX X-1

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Abstract

We present C- and X-band radio observations of the famous ultraluminous X-ray source (ULX) Holmberg IX X-1, previously discovered to be associated with an optical emission line nebula several hundred parsecs in extent. Our recent infrared study of the ULX suggested that a jet could be responsible for the infrared excess detected at the ULX position. The new radio observations, performed using the Karl G. Jansky Very Large Array (VLA) in B-configuration, reveal the presence of a radio counterpart to the nebula with a spectral slope of $-0.56$ similar to other ULXs. Importantly, we find no evidence for an unresolved radio source associated with the ULX itself, and we set an upper limit on any $5 \text{ GHz}$ radio core emission of $6.6 \mu \text{ Jy} \ (4.1 \times 10^{32} \text{ erg s}^{-1})$. This is 20 times fainter than what we expect if the bubble is energized by a jet. If a jet exists its core component is unlikely to be responsible for the infrared excess unless it is variable. Strong winds which are expected in super-Eddington sources could also play an important role in inflating the radio bubble. We discuss possible interpretations of the radio/optical bubble and we prefer the jet-winds-blown bubble scenario similar to the microquasar SS 433.

Unified Astronomy Thesaurus concepts: X-ray binary stars (1811); Emission nebulae (461); Black holes (162); Radio jets (1347); Supernova remnants (1667)

1. Introduction

Ultraluminous X-ray sources (ULXs) are unusually bright off-nuclear X-ray sources detected in nearby galaxies, with $L_X > 10^{39} \text{ erg s}^{-1}$, which is approximately the Eddington limit for a $10 M_\odot$ accretor. After ULXs were discovered roughly three decades ago, it was suggested they may harbor intermediate-mass black holes (IMBHs, e.g., Colbert & Mushotzky 1999; Miller & Colbert 2004) with $M_{\text{BH}} \gtrsim 100 M_\odot$. This interpretation was mostly based on the so-called cool accretion disk component found by modeling the X-ray spectra, as such cool disks were theoretically expected in accreting IMBHs (Miller et al. 2005). Later studies using more and better quality data have shown that this cannot be taken as evidence for IMBHs as many other explanations are possible for the soft component, which does not necessarily imply cool disks (Berghea et al. 2008; Gladstone et al. 2009). In particular in the super-Eddington accretion we also expect a soft component, which is interpreted in this case as coming from the inner photosphere of the outflowing wind (e.g., Poutanen et al. 2007).

After years of multwavelength observations, very few ULXs remain strong candidates for the IMBH scenario, such as HLX-1 in the galaxy ESO 243-49 (Farrell et al. 2009; Webb et al. 2012) and M82 X-1 (Strohmayer & Mushotzky 2003). The majority of ULXs are now thought to be super-Eddington accreting stellar-mass compact objects possibly accompanied by mild beaming (King et al. 2001). In the last few years several of the known ULXs were actually shown to contain neutron stars. For more information on ULXs see the recent review of Kaaret et al. (2017).

The ULX Holmberg IX X-1 (hereafter Ho IX X-1) has been well studied in the X-rays and optical. One of the most notable features of this ULX is a large nebula spanning a region $\sim 300 \times 400 \text{ pc}$ in extent. The ultimate power source for the nebula, like similar structures around other ULXs, has been a matter of debate (e.g., Moon et al. 2011).

The presence of these nebulæ around many ULXs and the fact that there is little evidence for IMBHs suggests that most are similar to the famous super/hyper-Eddington microquasar SS 433 as was suggested early on by many authors (Fabrika & Mescheryakov 2001; Begelman et al. 2006; Fabrika et al. 2006). Even HLX-1, which is still used as the best candidate for IMBHs could actually be such a system (King & Lasota 2014).

Most such nebulæ were found in the optical and only a handful have been detected in the radio: Ho II X-1, IC 342 X-1, and NGC 5408 X-1, S26 in NGC 7793 and MF 16 in NGC 6946. There are also a few microquasars in our Galaxy and the Local Group that have associated radio bubbles besides SS 433/W50: IC 10 X-1 (Heesen et al. 2015), and also Cygnus X-1 (Gallo et al. 2005) and Circinus X-1 (Heinz et al. 2013). A more recent discovery is S10 in NGC 300 (Urquhart et al. 2019).

For Ho IX X-1, most indications based on optical studies (He II/He I ratio) show that the nebula is produced by shocks as opposed to photoionization (e.g., Abolmasov et al. 2007; Berghea et al. 2010), suggesting jet activity similar to the W50 bubble associated with SS 433. However, more recent observations show that photoionization is also present (Abolmasov & Moiseev 2008; Moon et al. 2011) similar to other ULX nebulæ.

In our previous work on Ho IX X-1 (Dudik et al. 2016), we found an intriguing IRAC infrared excess suggesting the presence of a possible jet. We proposed for deep VLA observations, down to $5 \mu \text{ Jy}$, in the $C$ and $X$ bands to test this hypothesis. In this work, we discuss the results of this campaign. We present our radio observations. We discuss the physical properties of the bubble and possible scenarios for its origin in Section 3, and we give our conclusions in Section 4.

2. VLA Data

2.1. Observations

We obtained C- and X-band Karl G. Jansky Very Large Array (VLA) observations of Ho IX X-1 in B configuration (Project 16A-065; PI: R. Dudik) with a total time allocation of 3.3 hr. The data were calibrated using CASA version 4.7.0 and...
imaged with version 5.3.0. We began each observing session by integrating for six minutes on the primary calibrator 3C 286. We then alternated between our target source and a secondary calibrator, J1048+7143, by interweaving two minute integrations of the secondary calibrator for every 10 minutes of integration time on the target source. In this way, we were able to obtain accurate phase calibrations over the duration of our observations.

2.2. Calibration

2.2.1. C-band

The C-band data were obtained on 2016 May 26 and had significant radio frequency interference (RFI). Therefore, the data were calibrated and flagged by hand using standard CASA tasks. The methodology used in the C-band calibration was modeled after a recipe used by the Continuum HAlos in Nearby Galaxies; an EVLA Survey (CHANG-ES) collaboration (see Wiegert et al. 2015). An outline of the calibration steps is given here.

The calibration began by applying antenna position corrections followed by antenna-based delay calibrations. Next, we Hanning smoothed our data to alleviate any ringing across the band due to strong RFI. The data were then

2.2.2. X-band

The X-band data were obtained on 2016 June 5 and had little RFI. The data were again calibrated by hand using the same procedure as used for the C-band. The absolute flux density scale was again determined using the primary flux calibrator, 3C 286 and applying the Perley & Butler (2013) flux density scale.

Figure 1. C-band continuum with Subaru Hα contours overlaid. The position of the ULX is marked with a red “x.” The faint source just north of the ULX is not significant at the 3σ level and has an upper limit of 6.6 μJy, which corresponds to a luminosity of \(4.1 \times 10^{35}\) erg s⁻¹.

2.3. Imaging

Once the C- and X-band data were successfully calibrated, we used the CASA version 5.3.0 task CLEAN to produce images. The imaging process was a time consuming step as multiple iterations were required to produce high-fidelity maps.

We began with the calibrated C-band data and produced a “dirty” image of the FWHM of the primary beam to determine if there were strong continuum sources in the field. There were no continuum sources that appeared to cause any obvious artifacts that would impede the imaging process; however, the dirty image showed hints of low surface brightness extended, possibly diffuse emission at the phase center coincident with the ULX. Nonetheless, we began our imaging with a “standard” clean using a robust = 0.0 weighting and the “clarkstokes” point-spread function (psf) mode and cleaned down to an rms threshold of 3σ where we used a theoretical rms noise of \(\sigma = 2.2 \mu\text{Jy beam}^{-1}\) based on the integration time. Due to the high decl. of the source and the relatively short on-source integration time of ~75 minutes for the C-band, the synthesized beam of the robust = 0.0 weighting used in the initial standard clean was extremely elongated and produced an FWHM beam of \(2″ \times 0″.8\) at a position angle of 19°8. This initial image (see Figure 1) showed no emission at the phase center and therefore, we began exploring more complex imaging methods.

We implemented the multiscale, multifrequency synthesis (ms-mfs) algorithm (Rau & Cornwell 2011) with the number of Taylor series expansion terms (nterms) set to two with a natural weighting and four spatial scales equal to 0 (“standard clean”), \(2 \times \text{beam}, 4 \times \text{beam},\) and \(10 \times \text{beam}\). In this manner, we aimed to fit for the in-band spectral index, \(\alpha\), assuming

\[ I_\nu \propto \nu^{-\alpha}, \]  

where \(I_\nu\) is the intensity at frequency \(\nu\). This image produced two point-like detections near the phase center; however, the
signal-to-noise was below 3σ (see Figure 3). Therefore, we reimaged using the ms-mfs algorithm with “Briggs” robust = 2.0 weighting and a uv-taper of 120,000λ. With these parameters set, the resulting image began to show a diffuse, extended structure coincident with the location of the ULX. The uv-tapering was reduced systematically until the final image shown in the left panel of Figure 2 was produced. This image has a uv-taper of 50,000λ and a uniform rms noise of 5.3 μJy beam⁻¹. We corrected the image for the drop-off in the primary beam and integrated the emission for a flux density measurement of 0.24 ± 0.025 mJy. The FWHM of the beam is 5″2 × 2″4 at a position angle of 19°5.

We applied a similar approach to imaging the X-band data. However, the resulting source structure appears dramatically different. The total integrated flux density for the primary beam corrected X-band emission is 0.18 ± 0.018 mJy and the uncorrected primary beam image with uniform noise has an rms noise of 4.2 μJy beam⁻¹. The FWHM of the beam is 3″7 × 2″4 at a position angle of 20°3.

To assess the validity of the X-band structure, we used a point source that lies to the south of the ULX and is visible in both bands as show in Figure 3. This image also shows that there is no evidence in either band of residual RFI or other spurious bad data. If there were problems with the calibration or imaging of the data at X-band, then, the point source would show a deviation in its point-like structure. We compare the peak to the integrated flux for the point source as a measure and test of the compactness of the source using the primary beam corrected intensity map for each band. The C-band and X-band peak-to-integrated flux density ratios are 0.92 ± 0.12 and 1.01 ± 0.076, respectively, both of which are consistent with and indicative of a perfect point source. The peak-to-rms ratios for the C- and X-bands are 17 and 27, respectively, with the X-band having nearly a factor of 1.5 better signal-to-noise. Due to the lack of any visual artifacts in the maps and the ratios of peak-to-integrated and peak-to-rms values being comparable between the bands, we conclude that the C- and X-band images are of similar quality both in calibration and image fidelity.

It is interesting that the structures between the two bands are so strikingly different. We note that the intensity distribution between the bands near the center of the Hα bubble is more prevalent in the X-band and more diffuse in the C-band. The C-band radio emission appears most intense at the edge of the Hα shell while the X-band emission appears to drop off. The largest angular scale at X-band for the B-array configuration is ∼17″, which is roughly the major axis of the Hα outer green contour. Likewise, the largest angular scale for C-band at B-array is ∼29″. Thus, it is probable that we have recovered most, if not all, of the emission interior to the green contours shown in Figure 2 at both frequencies. However, we note that our experimental design was maximized for detection of a point source and not a diffuse extended “bubble-like” structure so longer uv-tracks across larger parallactic angles might aide in recovery of the extended emission especially if these observations occur at a more compact configuration. However, by applying a uniform uv-taper across both frequency bands, we aimed to find a balance between matching resolution and maintaining sensitivity so that we could feasibly compare the integrated fluxes and draw a few first-order conclusions.

As Figure 2 shows, the radio bubble is slightly smaller in size than the optical counterpart, approximately 200 by 300 pc. We assume the same distance of 3.6 Mpc to Holmberg IX as we used in Dudik et al. (2016), at this distance 1″ = 17.5 pc. We also note the large differences between the C and X band images. While the emission is in general located in a similar area around the ULX position, the X-band emission is less extended and shows a very different structure compared to the C-band.

Unfortunately, due to the diffuse, extended nature of the source and low signal-to-noise, an in-band spectral index was not possible to produce in either band for these observations.
3. Discussion

The main motivation for our VLA observation was to search for a possible jet in Ho IX X-1, based on our previous paper (Dudik et al. 2016), where we found an IR excess and we suggested it could be caused by a jet. While there is a faint source very close to the ULX position in the first C-band image (see note in Figure 3 caption), it is below the 3σ upper limit of 6.6 μJy. The upper limit on any ULX counterpart source in the X-band image is 21 μJy, given the rms depth of the image. We show these upper limits in Figure 4 on the spectral energy distribution (SED) plot from Dudik et al. (2016). The C- and X-band upper limits are both below the level expected based on extrapolation from the Spitzer IRAC data. This does not rule out a jet because it may well be variable as seen for example in Ho II X-1 (Cseh et al. 2015) and SS 433 (Broderick et al. 2018).

As stated in Section 2.3, an in-band spectral index was not feasible due to the diffuse nature of the source. Furthermore, it was not possible to create a spectral index map of the source using the C- and X-bands as the source structure between the bands is so different. However, because of the uniform uv-taper that we applied to both the C- and X-bands, which provides comparable resolution between the bands, we found it appropriate to compare the integrated flux densities of the source between these bands and applied a standard power law using the commonly used spectral index definition provided in

![Figure 3. C- (left) and X-band (right) continuum images showing a point source south of the ULX. This source has been used in Section 2.3 to assess the validity of the X-band structure. This image also shows that there is no evidence in either band of residual RFI or other spurious bad data.](image1)

![Figure 4. SED from Dudik et al. (2016) with upper limits for a radio point source measured from our VLA observations. We show the infrared excess we detected in that paper with extrapolated power law into radio. Accretion disk models shown (DISKR) are based on X-ray, UV, and optical data. The optical/UV data alone can also be well fit by a companion B0 Ib star.](image2)
Equation (1). In this way, we aim to assess if first order what the overarching emission mechanism is, i.e., thermal versus nonthermal, that is responsible for the continuum bubble that we observe.

The band-to-band spectral index of $-0.56$, is very similar to other radio ULX bubbles (Ho II X-1, IC 342 X-1, S26, MF 16, and IC 10) and suggests synchrotron emission. If we assume the radio emission is synchrotron we can calculate the minimum total energy contained in the nebula for equipartition following Longair (1994). We use the radio luminosity density at 6 GHz, $L_{\nu} = 3.8 \times 10^{17}$ W Hz$^{-1}$, the volume of the nebula $5.6 \times 10^{26}$ m$^3$, and the fraction of the energy in protons to electrons $\eta$ = 1. We assume no protons as in Fender et al. (1999), but this could be as high as 1000 and the minimum energy could then increase by a factor of 50 (e.g., Cseh et al. 2015). On the other hand, the filling factor of the radio emitting material could be small and therefore decrease the energy requirement, for example, a filling factor of 0.1 will change the minimum energy by a factor of 0.37. Given these assumptions we obtain $E_{\text{min}} = 4.3 \times 10^{50}$ erg. This value is similar to other ULX radio nebulae and much higher than SS 433 ($5 \times 10^{45}$ erg). We can also calculate the corresponding magnetic field and the lifetime of the electrons, $B_{\text{min}} = 2.9 \mu G$, $\tau = 70.4$ Myr.

Next we discuss two possible scenarios for the radio/optical bubble.

### 3.1. Scenario 1: Super/Hypernova Remnant (SNR)

If the nebula is a supernova remnant, its high energy content suggests a hypernova. The structure appears to be more plerionic than shell-like. We can use the (1 GHz) surface brightness diameter relation $(S \propto D)$ from Asvarov (2006) to compare with known Galactic and some extragalactic SNRs. We use our band-to-band spectral index of $-0.56$ to extrapolate to 1 GHz and obtain a surface brightness $9.0 \times 10^{-22}$ W m$^{-2}$ Hz$^{-1}$ sr$^{-1}$. In Figure 5 we show the evolutionary models and SNRs from Asvarov (2006). We overplot Ho IX X-1 and other known ULX radio bubbles plus bubbles similar to W50/SS 433. Two of our objects (W50/SS 433 and S26 NGC 7793) were already plotted in Asvarov (2006) but we used more recent published data as shown in Table 1. While many of the ULX bubbles are known to have energies in excess of the higher model plotted here ($5 \times 10^{52}$ erg), even some of the lower energy cases such as W50/SS 433 do not fit these SNR models well.

We can estimate the initial expansion energy of the supernova following Gioffi et al. (1988) using the expansion velocity > 20 km s$^{-1}$ and an electron preshock density $n = 5$ cm$^{-3}$, based on the $H_{\beta}$ line (Abolmasov & Moiseev 2008). We obtain $E > 4.7 \times 10^{53}$ erg, a very powerful hypernova. Ramsey et al. (2006) estimated that an energy of only about $6 \times 10^{51}$ erg could have been released if multiple supernovae exploded in the OB association located within the bubble so this scenario is not very likely.

### 3.2. Scenario 2: Jet/Wind-blown Type SS 433 Bubble

We did not detect a jet in our observations but it is possible that it exists, it could be fainter than we expected or it could be variable. Miller et al. (2005) found a radio nebula associated with Ho II X-1 and later Cseh et al. (2012) detected jets with a deeper VLA observation. The best example of a jet-blown bubble is the microquasar SS 433, with its associated bubble W50 (Dubner et al. 1998). Another good example is S 26 in NGC 7793 (Soria et al. 2010), which has a similar size and energy with Ho IX X-1 and also Ho II X-1 Cseh et al. (2014, 2015). Additional evidence for a variable jet in Ho IX X-1 was recently reported by Lau et al. (2019). The authors analyzed Spitzer data taken before and after the data used in Dudik et al. (2016) and found no other detection. They suggest that Dudik et al. (2016) observed an outburst and ruled out a circumbinary disk as the source of IR, therefore strengthening the variable jet interpretation. We intend to perform deeper or repeated VLA monitoring to look for a jet in Ho IX X-1.

In addition to a jet, bubble nebulae can also be inflated by winds, which are expected to be powerful in super-Eddington sources such as SS 433 (Begelman et al. 2006). In fact there is evidence for a radio outflow near the equatorial plane of SS 433, possibly driven by a disk wind (Paragi et al. 1999; Blundell et al. 2001). It is therefore likely that both jets and winds are inflating the Ho IX X-1 bubble and we are now considering both mechanisms.

We can estimate the radiative power following Cseh et al. (2012) based on the $H_{\beta}$ line in Abolmasov & Moiseev (2008) who found shock velocities in the range 20–100 km s$^{-1}$. We obtain $P_{\text{rad}} = (1.6-4.2) \times 10^{39}$ erg s$^{-1}$. The total power $P_{\text{tot}} = 77/27 P_{\text{rad}} = (0.5-1.2) \times 10^{40}$ erg s$^{-1}$. This is consistent with similar estimates in Abolmasov et al. (2007), Abolmasov & Moiseev (2008).

To get the total energy we multiply by the characteristic age (Sedov age) of the bubble. This can be estimated using the shock velocities above and the bubble radius (200 pc). We obtain $r = 1.2-5.9$ Myr and the total energy $E_{\text{tot}} = (4.4-8.6) \times 10^{53}$ erg.

Following Cseh et al. (2012) and Körding et al. (2008) we can estimate the radio jet power from the total power estimated above. For a typical jet we obtain a jet power greater than $1.1 \times 10^{34}$ erg s$^{-1}$, which is a factor of at least 20 times higher than the upper limit of our radio observations. This luminosity is consistent with what we expected from the extrapolation of the infrared excess we found (Dudik et al. 2016), suggesting once more that if there is a radio jet responsible for inflating the bubble, it is probably variable.

Let us now consider if the winds alone could produce the radio bubble in Ho IX X-1 ULX. Using a long Chandra observation of Ho IX X-1 to look for X-ray outflows Walton et al. (2013) did not detect any strong winds but they could still be present. Siwek et al. (2017) simulated wind inflated ULX bubbles assuming typical physical properties for the ULX and the surrounding medium and estimated the emission at different wavelengths, including radio and X-ray. In their fiducial model the radiative phase happens after 0.5 Myr at a radius of 100 pc. At 5 GHz the luminosity starts at about $10^{34}$ erg s$^{-1}$ and increases to $10^{35}$ after about 0.3 Myr. Our estimated 5 GHz luminosity is $1.4 \times 10^{34}$ erg s$^{-1}$. Given the Sedov age of a few megayears, the above measured luminosity is slightly lower than the model of Siwek et al. (2017). Recently, Sathyaprakash et al. (2019) attempted to detect the Ho IX X-1 bubble in X-rays using the Chandra X-ray Observatory. By stacking multiple X-ray images they were not able to detect the bubble to a limiting luminosity of $2 \times 10^{36}$ erg s$^{-1}$. This is also consistent with Siwek et al. (2017), as their fiducial model predicts X-ray luminosities peaking at $2 \times 10^{35}$ erg s$^{-1}$ but dropping by a factor of 10 after 0.3 Myr.
It is finally probable that both jet and winds play a role just as in SS 433 and therefore the estimates of Siwek et al. (2017) are a lower limit to the expected radio emission. In a similar way the estimated jet power in the only-jet scenario would be overestimated. A combination jet/winds as in SS 433 would actually better explain the data because the upper limit for a jet is still 20 times lower than our estimates required to inflate the bubble. If the jet is variable as the current data suggest, this represents the average flux needed, so actual variations are expected to be even higher. In SS 433 variations are only of the order of a factor of a few above base level (see Broderick et al. 2018, and references therein). Same with Ho II X-1, measured variations so far are less than a factor of 10 (Cseh et al. 2015).

4. Conclusions

We performed C- and X-band VLA observations to look for a jet in Ho IX X-1 ULX. We did not detect a jet with an upper limit of 6.6 μJy in the C band, which is lower than the expected flux extrapolated from the infrared excess detected in our previous paper. However, the infrared flux is variable and therefore the jet could be also variable as in Ho II X-1, for example.

However, we discovered extended radio emission slightly smaller in size than the optical bubble in both radio bands, increasing the small sample of known ULX radio bubbles. We calculate the minimum energy assuming synchrotron emission

![Figure 5. Surface brightness–diameter relation (Σ = D) from Asvarov (2006). The models are for typical SNRs of energy 10^{50} erg (blue) and 10^{51} erg (black) for decreasing gas densities, and 5 × 10^{52} erg (red).](image)

| Object Name       | Spectral Index | Log Σ_{C1} (W m^{-2} Hz^{-1} sr^{-1}) | Log Diameter (pc) | Reference          |
|-------------------|----------------|--------------------------------------|-------------------|--------------------|
| Ho IX X-1         | −0.56          | −21.0                                | 2.5               | This work          |
| S26 NGC 7793      | −0.70          | −19.5                                | 2.4               | Soria et al. (2010) |
| W50 SS433         | −0.48          | −20.7                                | 2.3               | Dubner et al. (1998) |
| IC 342 X-1        | −0.50          | −20.7                                | 2.5               | Cseh et al. (2012)  |
| Ho II X-1         | −0.53          | −19.3                                | 1.9               | Cseh et al. (2012)  |
| NGC 5408 X-1      | −0.80          | −20.0                                | 1.8               | Cseh et al. (2012)  |
| MF16 NGC 6946     | −0.50          | −17.9                                | 1.4               | van Dyk et al. (1994) |
| S10 NGC 300       | −0.40          | −20.3                                | 2.2               | Urquhart et al. (2019) |
| IC 10 X-1         | −0.41          | −19.1                                | 2.3               | Lozinskaya & Moiseev (2007) |
| Circinus X-1      | −0.50          | −20.9                                | 1.0               | Tudose et al. (2006) |
| Cygnus X-1        | −0.50          | −20.3                                | 0.7               | Gallo et al. (2005)  |

Note. We use −0.5 as a substitute for missing spectral indexes.
(4.4 × 10^{50} \text{erg}) and the lifetime of electrons (70.4 \text{Myr}). We proposed two scenarios for the radio nebula based on our radio observations and previous optical studies. For an SNR interpretation we find that it requires a very high explosion energy, greater than 4.7 × 10^{53} \text{erg} and therefore suggests a hypernova. We compare the \( \Sigma - D \) relation with known Galactic and other ULX bubbles and find that Ho IX bubble is similar to other ULX radio bubbles but not described well by SNR models. This is also true for radio bubbles associated to other microquasars similar to W50 (SS 433).

Although we did not directly detect a jet in our VLA observations and winds were not yet observed in Ho IX X-1, given the above considerations we prefer the jet/wind-blown bubble interpretation similar to the microquasar SS 433. We estimate that the total energy is greater than 4.4 × 10^{52} \text{erg}, with a characteristic timescale of a few million years. These are much larger than SS 433 but similar to other ULX bubbles. We measure a 5 GHz luminosity of 1.4 × 10^{34} \text{erg s}^{-1}, while wind models suggest 10^{35} \text{erg s}^{-1}. On the other hand a jet power greater than 1.1 × 10^{34} \text{erg s}^{-1} is required to inflate the bubble, which is a factor of at least 20 times higher than the upper limit of our radio observations. Therefore a combination jet/winds as in SS 433 could better explain the data.

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Facility: VLA.

Software: Astropy (Astropy Collaboration et al. 2013, 2018), CASA (McMullin et al. 2007).

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