Investigating a Binary Active Galactic Nucleus Candidate using Radio Observations from e-MERLIN

J. E. Brooks & M. K. Argo

Introduction

A sub-kpc-scale binary AGN candidate at $z \sim 0.35$ is investigated by combining several radio observations from e-MERLIN.

A dual radio source is detected which provides strong evidence for a sub-kpc-scale binary AGN; *the most distant pair discovered to date*.

The separation of the binary is approximately 1030±490pc at the epoch of the source. Further observations are required to definitively classify the target as a sub-kpc-scale AGN due to the large error on the separation. This is caused by coincident obscuration by the PSF along the position angle of the two cores.

Theory

Research shows that galaxies in the local universe have been subject to many major and minor mergers (e.g. Butcher & Oemler 1984). This would certainly involve merging black holes!

The merger occurs in a series of stages defined by Begelman, Blandford & Rees (1980):

- Dynamical Friction drives the initial stages of the merger
- At ~pc separation, the binary stalls due to a slowing of the extraction of energy from the system (see the 'final-parsec problem')
- Eventually, gravitational wave emission drives rapid coalescence

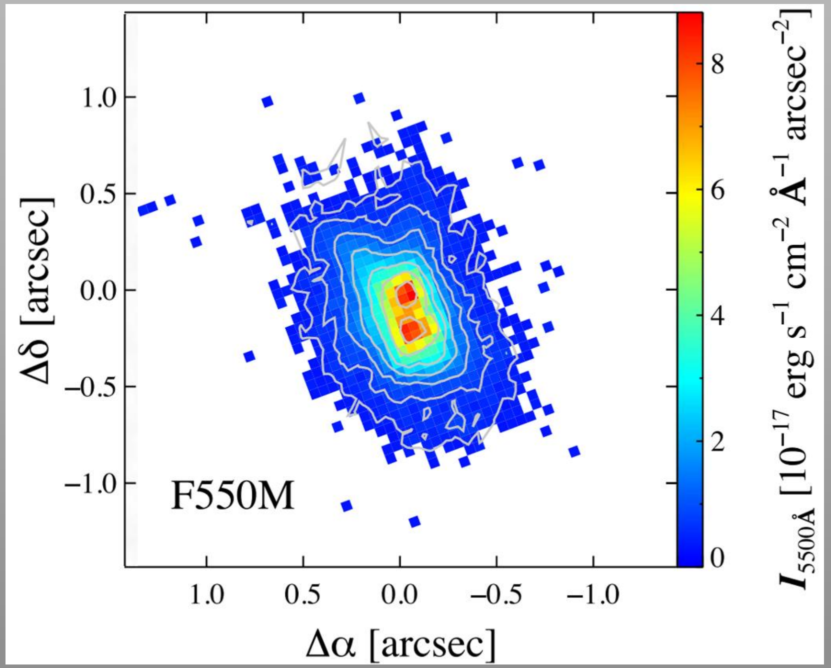
Compiling a sample of these close mergers is necessary for research into this population and the physics of the merger.

Previous Observations

The target was observed by Woo et al. (2014) using the Hubble Space Telescope. This imaging presents two optical cores of stellar emission separated by 0.20±0.01 arcsec. Additional observations in the form of VLT IFU spectra show two O[III] velocity components along the line of sight separated by 0.17±0.06 arcsec, consistent with the separation of the Hubble cores. The coincident separation of the two components in the Hubble images and the IFU spectra suggests that a binary AGN exists within double NLRs.

Other scenarios could produce the observed optical characteristics though, such as a single AGN with bipolar jets interacting with local clouds of gas. A single AGN could also illuminate the ISM of two galaxies, producing the two optical cores.

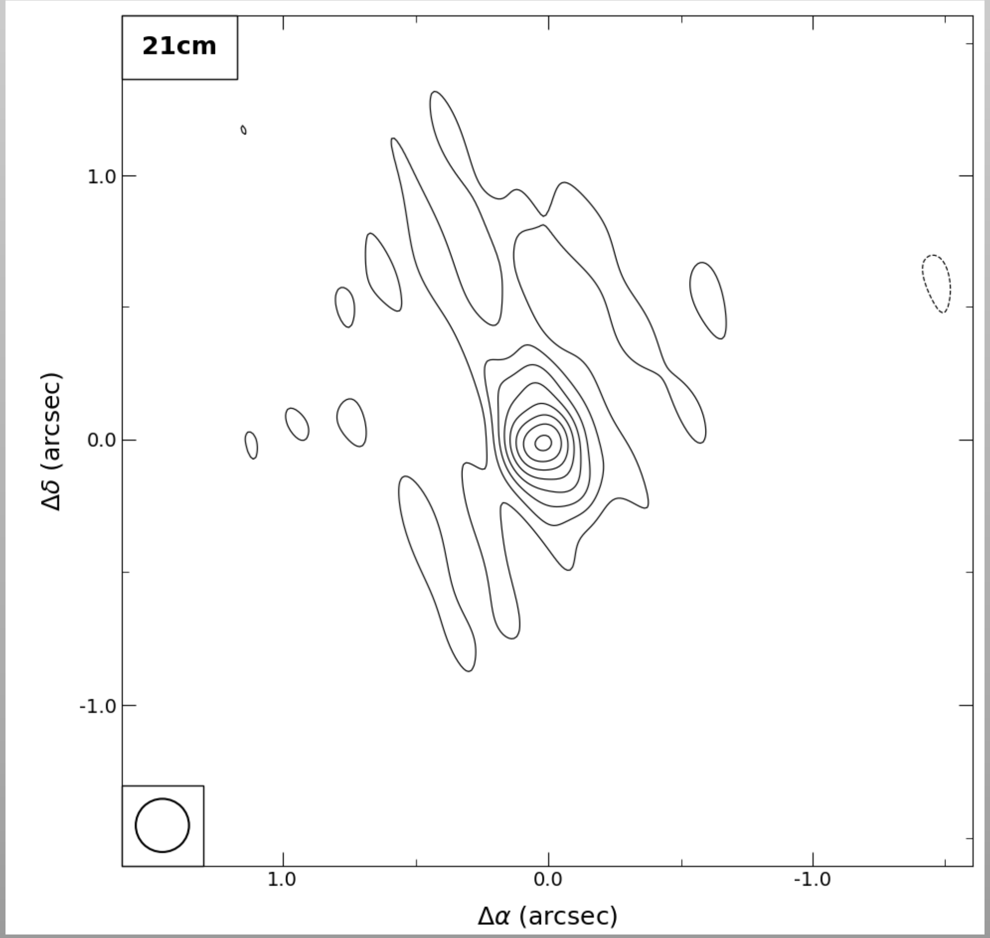
In the case of a binary AGN, follow-up radio observations should show dual unresolved cores of emission, produced by the jets of two AGN.



Hubble F550M image of the target presented in Woo et al. (2014)

21cm Radio Observations

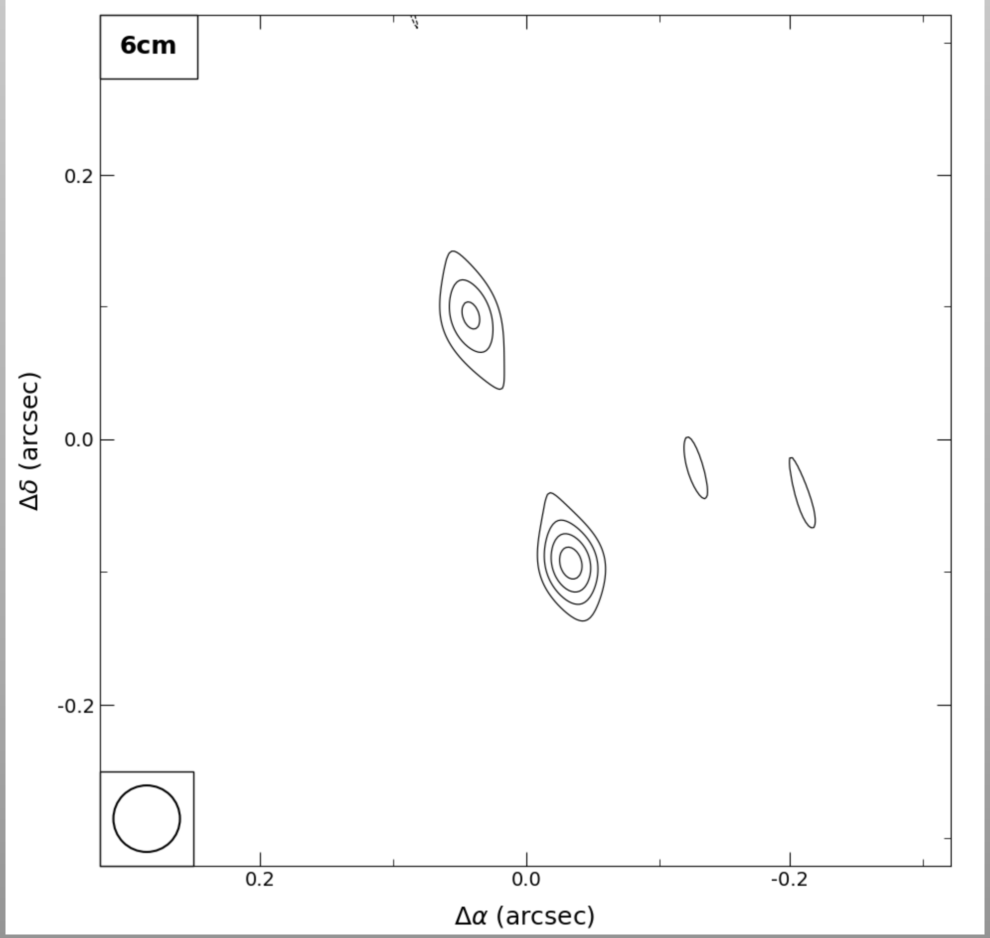
Four L-band observations of the target (amounting to ~22 hours on-source time) have been conducted by e-MERLIN in 2016 and 2020. The imaging shows a single unresolved source with a peak flux of 0.4mJy. Observations at L-band cannot adequately resolve the target to reveal a dual core; C-band observations are necessary for this.



Contours showing the combined 21cm radio emission. The noise in the map is σ = 22.6μJy/beam and the contours are given at -3σ, 3σ, 5σ, 7σ and so on. A circular restoring beam is applied, shown to-scale in the bottom left. A single unresolved radio core is detected as e-MERLIN cannot resolve the target at L-band. This is surrounded by patchy noise structures due to missing medium length baselines.

6cm Radio Observations

Several observations of the target have been made at C-band by e-MERLIN, producing ~59 hours of on-source data. The target cannot be detected in any one observation, so they are combined together to improve the SNR sufficiently for a detection (shown below). The resulting combined image shows the presence of two radio cores within the target, separated by 0.21±0.11''. This is remarkably consistent with the separation of the optical cores measured by Woo et al. (2014).



Contours showing the combined 6cm radio emission. The noise in the map is σ = 8.7μJy/beam and the contours are given at -3σ, 3σ, 5σ, 7σ and so on. A circular restoring beam is applied, shown to-scale in the bottom left. A dual source is detected, presumably originating from two AGN.

Conclusions

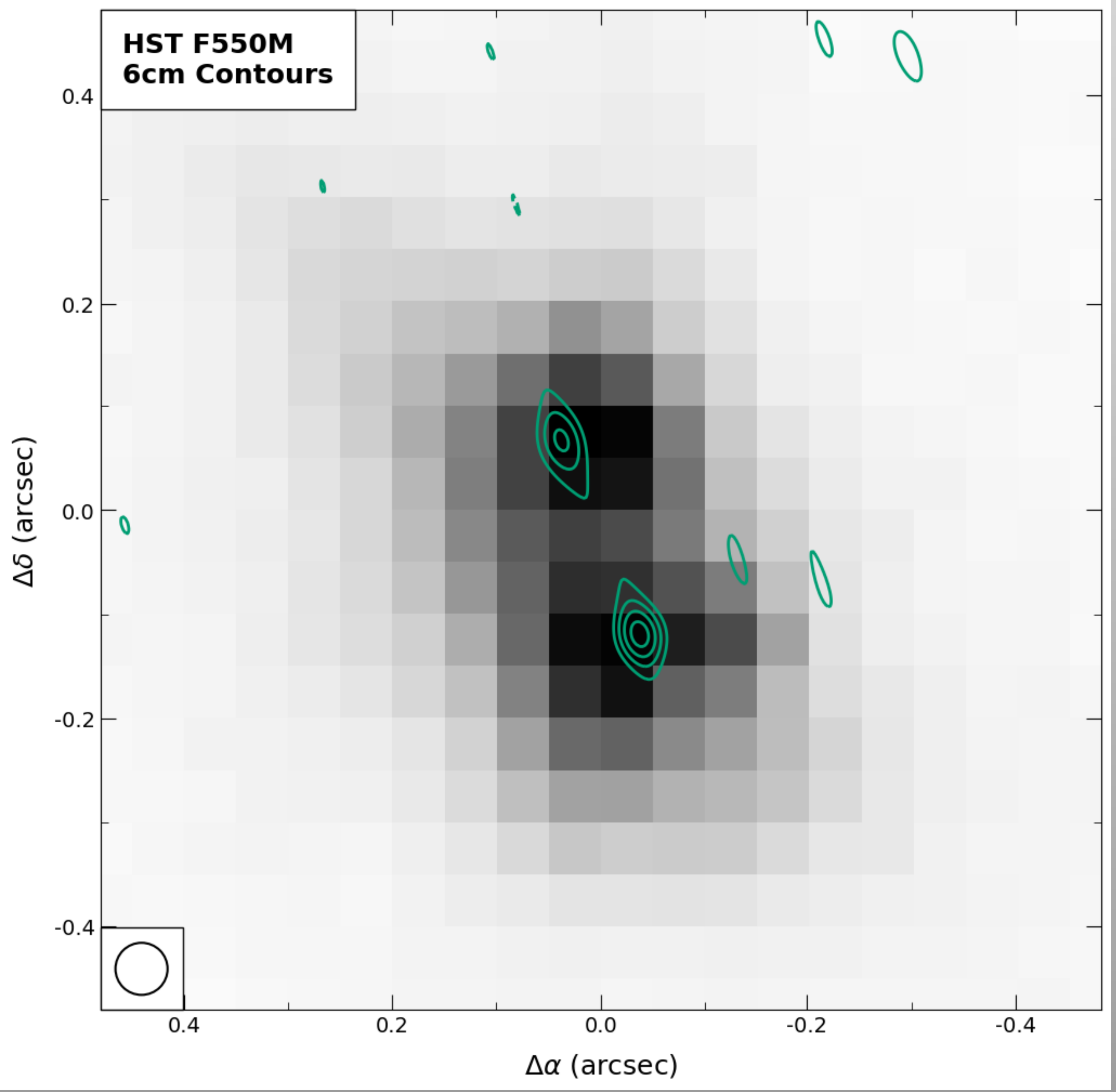
The discovery of two unresolved radio sources in the target is strong evidence of a binary black hole, especially considering the coincident overlap with the optical cores and their similar positional measurements (shown across).

A possible scenario remains though: a single AGN with bipolar jets catalysing star formation in local concentrations of mass to produce the two radio cores. This is very unlikely as the two radio cores are unresolved and there is no evidence of extended jet emission in any observation. Additional higher resolution observations have been scheduled by the European VLBI Network which will give further evidence of the true nature of this rare source.

Nevertheless, the current evidence, both optical and radio, presents a convincing case for a sub-kpc-scale binary AGN. A brief survey of the literature shows only a handful (~10) of such close separation binary AGN, so adding to this small sample is a critical objective for future work on the mechanics and frequency of mergers and their signature in the gravitational wave background.

Jeremiah Horrocks Institute
University of Central Lancashire

A student research project supervised by Dr M. Argo
Contact: jebrooks@uclan.ac.uk



A plot of the C-band (6cm) contours (in colour) overlaid on the F550M image (in grayscale) from the HST. A very small shift of ~pixel (corresponding to ~0.05 arcsec) has been applied to the Hubble data to correct for astrometric errors, and bring the radio cores into alignment over the brightest pixel in the optical cores. Note the similarity in separation and position angle.