Petrov

No code

Follow-up of candidates to small separation gravitational lenses

Abstract

We propose to observe 8 candidate gravitational lenses with separations below eMERLIN resolution. The objects selected all have two-three compact components seen in vlbi maps. They will also be observed with the EVN at 5 and 22GHz to check if the two components have surface brightnesses and spectral indices consistent with lensing. Complimentary e-MERLIN observations at 1.4GHz will provide information about jets on kiloparsec scales and/or evidence for core/hotspot morphology, both of which would rule out a lensing explanation.

Total requested time

59.00 hours

Applicants

Name	Affiliation	Email	Country		Potential observer
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Anthony Readhead	Caltech	acr@astro.caltech.edu	USA		
Peter Wilkinson	University of Manchester at Jodrell Bank Centre for Astrophysics	peter.wilkinson@manchester.ac.uk	UK		

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1 Science case

The dark matter is one of the most prominent open questions in physics. While existing searches are restricting conventional models, there is increasing interest in alternative models and lensing is a way to test such models.

The proposed eMERLIN observations are a part of the larger project with the overall goal to search for rare lensing events in the lens mass range of $10^6 \mathrm{M}_\odot$ to $10^{10} \mathrm{M}_\odot$. Such lensing effects will results in separations 3–300 mas. The abundance of lensing events depends on the model of the dark matter contribution to the gravitational field. Therefore, detecting gravitational lenses at such separations will allow us to constrains models of dark models.

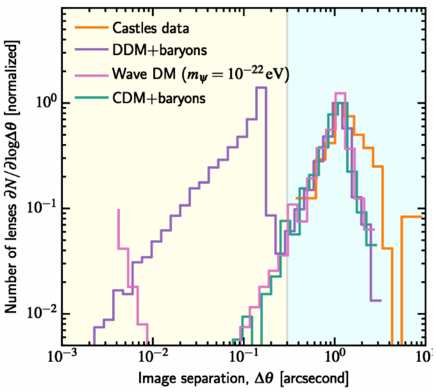

Fig. 1: Image separation distribution for various dark matter models. The right hand part (cyan background) shows the resolution range of existing large-scale lens surveys that probe halos with mass $10^{11} M_\odot$. Currently, viable dark matter models agree on such large scale and high halo masses. The left hand region (yellow background) is the VLBI regime where the models may be distinguished.

Dissipative dark matter (DDM) models posit that DM is composed of dark-sector particles that follow dissipative dynamics similar to baryons. While the supernova feedback from the postulated kinetic coupling of DM to photons is sufficient to maintain extended halos in galaxies more massive than 10^{11} $\mathrm{M}_\odot$, at lower masses DM is expected to collapse into an exponential disk much in the same way baryons form galaxies (Foot and Vagnozzi, 2016). We simulated this collapse, maintaining mass and angular momentum conservation (see e.g. Mo et al., 1998, sec 2.3), and find that if 10% of matter is dissipative 100 mas scale lenses will be found by this survey with rates comparable to existing arcsecond-scale surveys (see Fig. 1).

The previous searches of gravitation lenses were based on surveys with VLA and MERLIN. Such searches could not help finding lenses with separations shorter than VLA and MERLIN resolutions. In order to be able to look for lensed images with separations in the range 3 to 300 mas, we used Radio Fundamental Catalogue[1] of 16,845 sources detected with VLBI and identified 741 visually binary objects, i.e. objects with two or more distinct components in their VLBI images at 3–300 mas separations. Further, we stroke out the objects that had multiple components with obviously different surface brightness, or spectral indices between components, or whose morphology was not consistent with lensing. Among remaining objects, we selected those that are considered the most promising for being classified as gravitational lenses. We observed 12 visually binary objects with VLBA in 2018 at 15 and 23 GHz. We have detected two compact components in six of them. We have been awarded 140 hours at the EVN in 2019 to observe 43 more gravitational lenses at 5 and 22 GHz in order to get high fidelity images, estimates of the spectral index, and determine the frequency dependent position shift between components.

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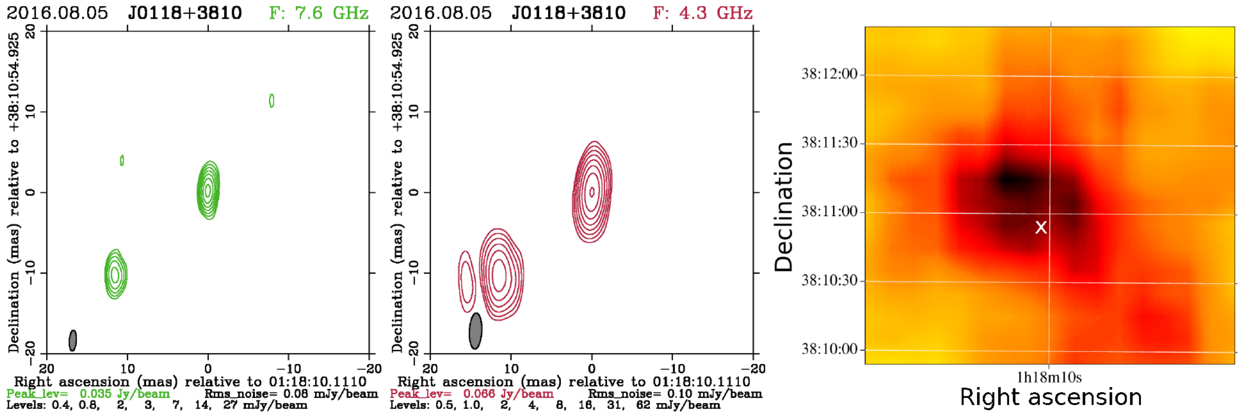
[1] Available at `http://astrogeo.org/rfc`

Fig. 2: Target source J0118+3810. *Left* and *center* images are made with VLBA. The position angle of the symmetry axis is 312°. *Right* image is made at VLA at 2–4 GHz under VLASS program. White cross denotes the source core detected with VLBI.



2 Proposed observations

We propose complimentary L-band MERLIN observations of eight candidate gravitational lenses sources with declinations > −20°. Of them, six show several components at 15 and 23 GHz and the 7th, J0118+3810, shows extended structure at VLASS image, and the 8th, J0348+3353, is triple. We do not see a jet in neither VLBA images (see Figure 3) because a jet is completely resolved out, not in VLASS images (See Figure 2) because of their insufficient resolution. Proposed eMERLIN observations at an intermediate resolution will help us to detect jets. Jet detection and determination of its direction will help us to classify the sources and understand their nature.

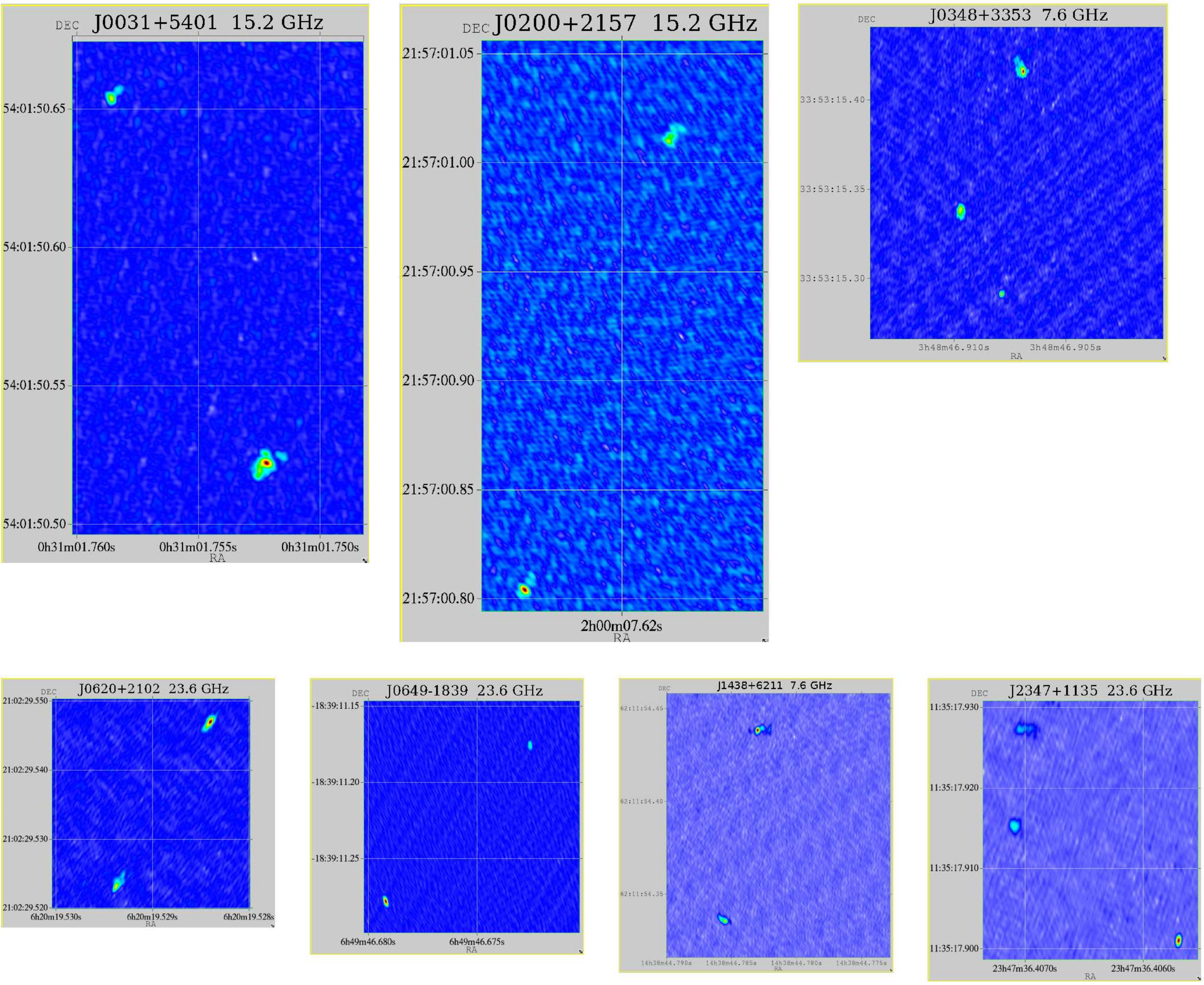
The goal of the proposed observations is to get images of kiloparsec structure with a resolution of 150 mas. In general, among visually binary objects there are sources with core/hot-spot morphologies, compact symmetric objects (CSO), binary black holes, and gravitational lenses. For objects with core/hot-spot morphology we expect jet directions from the kiloparsec structure be in general aligned with the direction of their parsec-scale structure, i.e. the direction between components at their VLBI images. Assuming compact symmetric objects are young, no kiloparsec scale structure is expected for these objects. Detection of X-shape jets will be a strong argument in favour of a true binary.

MERLIN provides resolution intermediate between VLA and VLBI. Compact features within 150 mas of the central part will be captured with VLBI, although extended features will be resolved out. MERLIN images will show extended emission at scales 0.15–100 arcsec.

Our major concern in the search of gravitational lenses is that we may fail to weed out sources with core/hot-spot morphology. Resolution of VLASS is insufficient to trace features smaller than 4–5″. A curved jet may explain a misalignment of kiloparsec scale features and parsec-scale features. We select the low frequency in order to better trace jets. A jet along the symmetry axis of VLBI images will indicate that the second component at the VLBI image is likely be a hot spot at a jet. A jet with significant misalignment will support the hypothesis that a given object is a gravitational lens or a binary black hole.

VLBA images of proposed targets

Fig. 3: VLBA images of seven visually binary targets at X, U and K bands



3 Bibliography

Foot R and Vagnozzi S 2016 J. Cosm. & Astroparticle Phys. 7, 013
Mo H J, Mao S and White S D M, 1998 MNRAS 295, 319–336.

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Technical justification

Here is the source table:

Table 1: Properties of observed sources. Column "Sep" shows component separation in mas.

Name	RA	DEC	NVSS 1.4 GHz	VLBA 5GHz	VLBA 8 GHz	Sep	Dur
			Jy	Jy	Jy	mas	hr
J0031+5401	00:31:01.7521	+54:01:50.522	1.389	0.332	0.214	146	8.0
J0118+3810	01:18:10.1110	+38:10:54.925	0.303	0.115	0.061	16	8.0
J0200+2157	02:00:07.6232	+21:57:00.804	1.010	0.202	0.061	216	8.0
J0348+3353	03:48:46.9069	+33:53:15.416	2.365	0.153	0.072	126	8.0
J0620+2102	06:20:19.5284	+21:02:29.547	0.897		0.248	26	8.0
J0649-1839	06:49:46.6791	-18:39:11.278	0.862	0.230	0.140	140	3.0
J1438+6211	14:38:44.7830	+62:11:54.438	2.410		0.307	105	8.0
J2347+1135	23:47:36.4057	+11:35:17.901	0.340	0.149	0.107	25	8.0

The target sources are bright. We will observe all sources for 8 hours, except J0649-1839 that has low declination. We selected L-band because we need detect jet and/or extended emission. Since the jet was not discernible at NVSS images, we assume jet is weak. We do not need resolve the components with eMERLIN, since we have already resolved them with VLBI.

Observation details

Field	RA	Dec	Equinox	Exposure (hrs.)	Receiver
J0031+5401	00:31:01.75	+54:01:50.5	J2000	8.00	L-band (1230-1740 MHz)

No required scheduling constraints

Preferred scheduling constraints

Comment:

NVSS (1.4 GHz): 1.389 Jy VLBA (4.3 GHz): 0.332 Jy VLBA (8 GHz): 0.214 Jy Component separation: 146 mas

Peak Flux :	1389.0 mJy/bm	***Total field to be imaged :***	100.0 arcsec
Total Flux:	1389.0 mJy/bm	***Three sigma noise level :***	0.06 mJy/bm
Largest angular size :	100.0 arcsec		

Calibration sources defined by Merlin staff

Continuum Correlator details

Central Frequency	*Polarisation Products*	*Bandwidth*	*Channels*
Default	LL + RR	512.0 MHz	16 x 1000.00 kHz channels

Field	RA	Dec	Equinox	Exposure (hrs.)	Receiver
J0118+3810	01:18:10.11	+38:10:54.9	J2000	8.00	L-band (1230-1740 MHz)

No required scheduling constraints

Preferred scheduling constraints

Comment:

NVSS (1.4 GHz): 0.303 Jy VLBA (4.3 GHz): 0.115 Jy VLBA (8 GHz): 0.061 Jy Component separation: 16 mas

Peak Flux :	303.0 mJy/bm	***Total field to be imaged :***	100.0 arcsec
Total Flux:	303.0 mJy/bm	***Three sigma noise level :***	0.06 mJy/bm
Largest angular size :	100.0 arcsec		

Calibration sources defined by Merlin staff

Continuum Correlator details

Central Frequency	*Polarisation Products*	*Bandwidth*	*Channels*
Default	LL + RR	512.0 MHz	16 x 1000.00 kHz channels

Field	RA	Dec	Equinox	Exposure (hrs.)	Receiver
J0200+2157	02:00:07.62	+21:57:00.8	J2000	8.00	L-band (1230-1740 MHz)

No required scheduling constraints

Preferred scheduling constraints

Comment:

NVSS (1.4 GHz): 1.010 Jy VLBA (4.3 GHz): 0.202 Jy VLBA (8 GHz): 0.061 Jy Component separation: 216 mas

Peak Flux :	1010.0 mJy/bm	***Total field to be imaged :***	100.0 arcsec
Total Flux:	202.0 mJy/bm	***Three sigma noise level :***	0.06 mJy/bm
Largest angular size :	100.0 arcsec		

Calibration sources defined by Merlin staff

Continuum Correlator details

Central Frequency	*Polarisation Products*	*Bandwidth*	*Channels*
Default	LL + RR	512.0 MHz	16 x 1000.00 kHz channels

Field	RA	Dec	Equinox	Exposure (hrs.)	Receiver
J0620+2102	06:20:19.53	+21:02:29.5	J2000	8.00	L-band (1230-1740 MHz)

No required scheduling constraints

Preferred scheduling constraints

Comment:

NVSS (1.4 GHz): 0.897 Jy VLBA (8 GHz): 0.248 Jy Component separation: 26 mas

Peak Flux :	897.0 mJy/bm	***Total field to be imaged :***	100.0 arcsec
Total Flux:	897.0 mJy/bm	***Three sigma noise level :***	0.06 mJy/bm
Largest angular size :	100.0 arcsec		

Calibration sources defined by Merlin staff

Continuum Correlator details

Central Frequency	Polarisation Products	Bandwidth	Channels
Default	LL + RR	512.0 MHz	16 x 1000.00 kHz channels

Field	RA	Dec	Equinox	Exposure (hrs.)	Receiver
J0649-1839	06:49:46.68	-18:39:11.3	J2000	3.00	L-band (1230-1740 MHz)

No required scheduling constraints

Preferred scheduling constraints

Comment:

NVSS (1.4 GHz): 0.862 Jy VLBA (4.3 GHz): 0.230 Jy VLBA (8 GHz): 0.140 Jy Component separation: 140 mas

Peak Flux :	862.0 mJy/bm	***Total field to be imaged :***	100.0 arcsec
Total Flux:	862.0 mJy/bm	***Three sigma noise level :***	0.06 mJy/bm
Largest angular size :	100.0 arcsec		

Calibration sources defined by Merlin staff

Continuum Correlator details

Central Frequency	Polarisation Products	Bandwidth	Channels
Default	LL + RR	512.0 MHz	16 x 1000.00 kHz channels

Field	RA	Dec	Equinox	Exposure (hrs.)	Receiver
J2347+1135	23:47:36.41	+11:35:17.9	J2000	8.00	L-band (1230-1740 MHz)

No required scheduling constraints

Preferred scheduling constraints

Comment:

NVSS (1.4 GHz): 0.340 Jy VLBA (4.3 GHz): 0.149 Jy VLBA (8 GHz): 0.107 Jy Component separation: 25 mas

Peak Flux :	340.0 mJy/bm	***Total field to be imaged :***	100.0 arcsec
Total Flux:	340.0 mJy/bm	***Three sigma noise level :***	0.06 mJy/bm
Largest angular size :	100.0 arcsec		

Calibration sources defined by Merlin staff

Continuum Correlator details

Central Frequency	Polarisation Products	Bandwidth	Channels
Default	LL + RR	512.0 MHz	16 x 1000.00 kHz channels

Field	RA	Dec	Equinox	Exposure (hrs.)	Receiver
J0348+3353	03:48:46.91	+33:53:15.4	J2000	8.00	L-band (1230-1740 MHz)

No required scheduling constraints

Preferred scheduling constraints

Comment:

NVSS (1.4 GHz): 2.365 Jy VLBA (4.3 GHz): 0.153 Jy VLBA (8 GHz): 0.072 Jy Component separation: 126 mas

Peak Flux :	2365.0 mJy/bm	***Total field to be imaged :***	100.0 arcsec
Total Flux:	2365.0 mJy/bm	***Three sigma noise level :***	0.06 mJy/bm
Largest angular size :	100.0 arcsec		

Calibration sources defined by Merlin staff

Continuum Correlator details

Central Frequency	*Polarisation Products*	*Bandwidth*	*Channels*
Default	LL + RR	512.0 MHz	16 x 1000.00 kHz channels

Field	RA	Dec	Equinox	Exposure (hrs.)	Receiver
J1438+6211	14:38:44.78	+62:11:54.4	J2000	8.00	L-band (1230-1740 MHz)

No required scheduling constraints

Preferred scheduling constraints

Comment:

NVSS (1.4 GHz): 2.410 Jy   VLBA (8 GHz): 0.307 Jy Component separation: 105 mas

Peak Flux :	2410.0 mJy/bm	***Total field to be imaged :***	100.0 arcsec
Total Flux:	2410.0 mJy/bm	***Three sigma noise level :***	0.06 mJy/bm
Largest angular size :	100.0 arcsec		

Calibration sources defined by Merlin staff

Continuum Correlator details

Central Frequency	*Polarisation Products*	*Bandwidth*	*Channels*
Default	LL + RR	512.0 MHz	16 x 1000.00 kHz channels