SMILE: Search for MIlli-LEnses

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SMILE

Abstract

Dark Matter (DM) halos with masses below ~ $10^9 M_\odot$, which would help to discriminate between DM models, may be detected through their gravitational effect on distant sources. The same applies to primordial black holes, considered as an alternative scenario to DM particle models. With the aim of finding supermassive compact objects (SMCO), i.e. compact objects in the mass range ~ 10^6 - 10^9 $M_\odot$, we search for strong gravitational lenses on milli (mas)-arcseconds scales (< 150 mas). For our pilot search, we used the Astrogeo VLBI FITS image database – the largest publicly available database, containing multi-frequency VLBI data of 13828 individual sources. We found 40 sources with multiple compact components on mas-scales and apparent surface brightness ratio between components < 7, that are therefore judged to be milli-lens candidates.

Introduction

In gravitational lens modelling, CO are usually well approximated by point mass lenses. Strong lensing from a point mass lens produces two images of the source in background, with an angular separation given by the following formula:

$$\theta_E \approx \left(\frac{M_{lens}}{10^6 M_\odot}\right)^{1/2} \left(\frac{D}{Gpc}\right)^{-1/2} milliarcseconds$$

For a lens at cosmological distance, and for order-of-magnitude estimates, SMCO are expected to produced lensed images on milli-arcsecond angular scales (**MILLI-LENSES**).

Standard CDM halos, in the mass range of interest, appear to be significantly more concentrated than galaxy clusters [1] so their cores should be able to cause strong lensing of background sources. Alternative viable DM models (e.g., fuzzy dark matter, dissipative dark matter, warm dark matter) also produce subhalos but predict a different number of them and with different density profiles. For this reason, milli-lensing can yield information not only on the mass function of DM at this mass range, but also on the DM nature. However, *no gravitational lenses on such compact scales have yet been found.*

Results of a pilot search for MILLI-LENSES

ID	RA h:m:s	DEC d:m:s
J0010−0740	00:10:50.60	−07:40:12.10
J0011+3443	00:11:17.01	+34:43:33.64
J0024−4202	00:24:42.99	−42:02:03.95
J0044+2858	00:44:21.55	+28:58:33.84
J0052+1633	00:52:36.17	+16:33:00.45
J0118+3810	01:18:10.14	+38:10:55.10
J0132+5211	01:32:18.92	+52:11:30.70
J0139+0824	01:39:57.16	+08:24:26.80
J0203+3041	02:03:45.36	+30:41:29.11
J0210−2213	02:10:10.06	−22:13:36.90
J0213+8717	02:13:57.85	+87:17:28.8
J0222+0952	02:22:15.61	+09:52:37.80
J0232−3422	02:32:30.03	−34:22:03.10
J0237+1116	02:37:13.59	+11:16:15.48
J0502+1626	05:02:47.39	+16:26:39.32
J0527+1743	05:27:23.21	+17:43:25.10
J0616−1957	06:16:01.57	−19:57:16.20
J0732+6023	07:32:50.97	+60:23:40.06
J0923−3435	09:23:53.88	−34:35:26.10
J1132+5100	11:32:50.39	+51:00:19.92
J1143+1834	11:43:26.07	+18:34:38.36
J1218−2159	12:18:58.82	−21:59:45.4
J1306+0341	13:06:16.00	+03:41:40.80
J1340−0335	13:40:13.30	−03:35:20.80
J1344−1739	13:44:03.42	−17:39:05.50
J1632+3547	16:32:31.25	+35:47:37.74
J1653+3503	16:53:53.16	+35:03:27.03
J1721+5207	17:21:36.26	+52:07:10.40
J1805−0438	18:05:31.12	−04:38:09.69
J2010+1513	20:10:08.20	+15:13:58.84
J2044+6649	20:44:49.19	+66:49:02.30
J2114+4036	21:14:10.01	+40:36:42.19
J2209+6442	22:09:30.49	+64:42:20.70
J2214−2521	22:14:46.39	−25:21:16.00
J2225+0841	22:25:43.48	+08:41:57.20
J2259+4037	22:59:04.04	+40:37:47.10
J2312+0919	23:12:28.07	+09:19:26.70
J2324−0058	23:24:04.62	−00:58:54.20
J2337−0622	23:37:29.19	−06:22:13.20
J2347−1856	23:47:08.63	−18:56:18.86

We performed a pilot search for milli-arcsecond gravitational lenses to probe the existence of SMCO, using VLBI multi-frequency data of 13828 radio-loud sources taken from the Astrogeo VLBI FITS image database (http://astrogeo.org/vlbi_images). Following the idea of "citizen-science" projects, we visually inspected all images creating a web-page and involving 5 PhD scientists and 9 undergraduate Physics students from the University of Crete. People were asked to mark as "Lens" sources showing multiple compact components (the putative lensed images of a source in background) in at least one of the available observing bands, and as "No Lens" the rest of the sources. After multiple visual inspection steps, sources were finally discarded based on the surface brightness preservation criterion, i.e. secondary compact components should be smaller than the primary brighter component.

Here we list the *40 sources* which passed the multiple-stage selection and have been judged milli-lens candidates.

The results of this study have been presented in **Casadio, C., Blinov, D., Readhead, A. C. S., et al. 2021, MNRAS, 507, L6.** These lens candidates were subsequently followed-up with European VLBI Network (EVN) observations at 5 and 22 GHz (Project ID: EC071; PI: Casadio). We expect multi-frequency and/or multi-epoch VLBI observations to be fundamental for finally confirming or rejecting the lens nature of these candidates, based on flux density ratios and spectral indexes of the putative lens images.

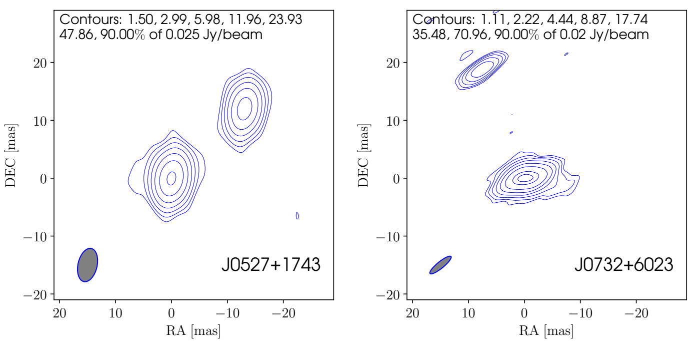

Figure 1. New EVN 5 GHz images of two milli-lens candidates

Any source that is finally rejected as a milli-lens candidate can still be investigated as candidate for *binary supermassive black hole* or a *compact symmetric object* (CSO). The latter is thought to be the young counterpart of extended radio radio galaxies.

Future goal: Constraining the abundance of *SMCO*

Applying a similar search on a complete sample of ~ 5000 radio loud source, and using VLBI data, we could constraint the abundance of SMCO in the Universe, with an order of magnitude better precision than in previous studies [2].

For this purpose, we selected a complete flux-limited sample of sources, starting from the complete sample in CLASS (the Cosmic Lens All Sky Survey; [3]). We will obtain VLBI images of all sources and perform the same type of search.

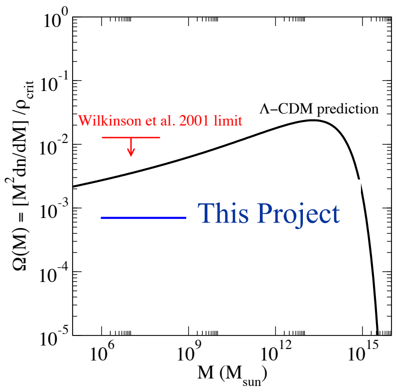

Figure 2. Λ CDM prediction of the abundance of collapsed objects of a certain mass (free-floating in the field), in units of the critical density ρ_{crit}.

If no genuine gravitational lens system is found, we will constrain the contribution of SMCOs with mass in the range 10^6–$10^9 M_\odot$ to the overall content of matter and energy in the Universe (Ω_{total}=1) to be *less than the abundance of sub-galactic halos in this mass range predicted by the ΛCDM model, providing Mhalo = Mlens* (see Fig.2). For PBHs in this mass range, the constraint will be *below the amount of the baryonic matter currently enclosed in stars and galaxies (Ω_* ~ 0.004 – 0.005, [4]).*

References

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