SMILE: The search for milli-lenses

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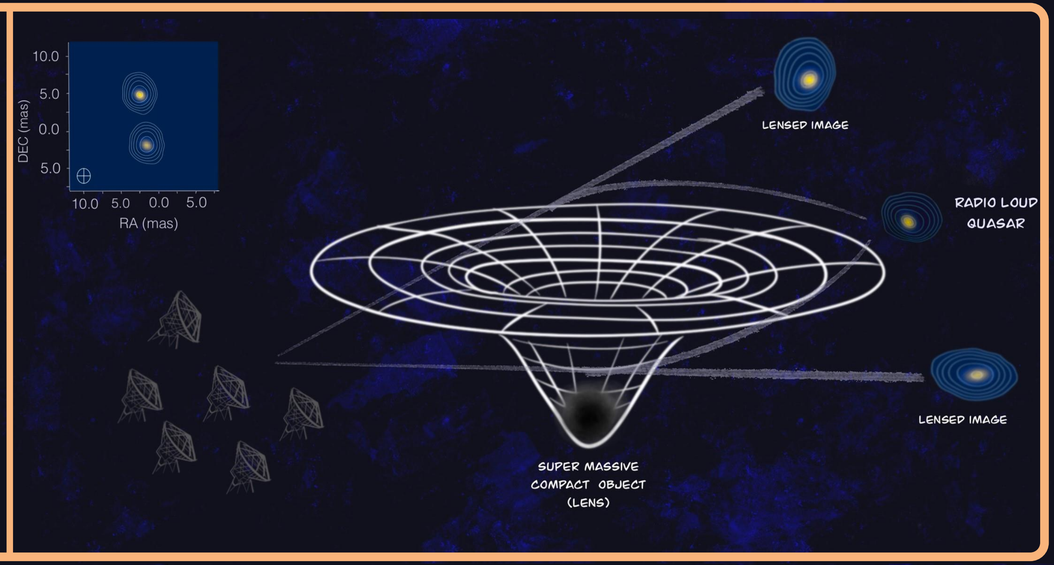
Dark matter and gravitational lensing

The nature of dark matter (DM) remains elusive. While cold DM explains well the large-scale structure and evolution of the universe, discrepancies on smaller scales gave rise to a host of alternative DM models. Diverse predictions of these models on the abundances and density profiles of sub-galactic, and thus dark, halos, can be tested uniquely through gravitational lensing. Supermassive compact objects (SMCOs, including halos and free-floating SMBHs) in the mass range of 10^6 to 10^9 M_{sol} acting as lenses predict image separations of the order of 1-100 mas [1]. The **S**earch for **MI**lli **Le**nses (SMILE) project aims at constraining the number density of such *milli-lenses*.



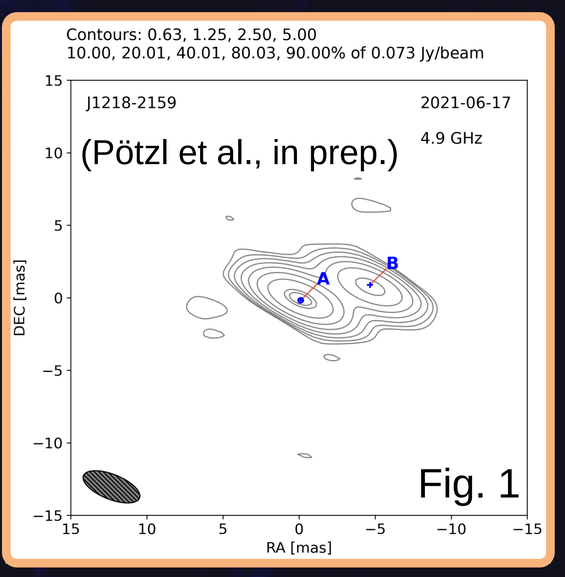


Fig. 1

VLBI observations and the SMILE pilot study

Very-long baseline interferometry (VLBI) is uniquely suited to probe these small scales directly. In a pilot study [2], 40 lens candidates have been selected from the Astrogeo fits image database with 13,828 sources at C- and X-band. The first selection of candidates was made using a citizen-science approach based mainly on the source morphology. For the best 40 candidates, new EVN observations were obtained at both C- and K-band. To filter out contaminant objects like AGN with a core-jet structure, compact symmetric objects (CSOs, see, e.g., [3]) or supermassive black hole binaries (SMBHBs), we applied several criteria to discriminate milli-lens systems. Fig. 1 shows one of our surviving lens candidates at C-band. We are currently planning more follow-up observations of the remaining candidates (see next section) to reject or confirm them as lens candidates.

Discriminating milli-lenses

Gravitational lensing conserves properties such as surface brightness and spectra of the images. In addition, for milli-lensing, we expect lensing time delays to be much smaller than typical VLBI observing times, so the flux ratio (FR) between the supposed lensed images should not change significantly across epochs. Also, no significant proper motion is expected [4]. Applying all criteria, we reject 32 out of 40 lens candidates from [2] (see Fig. 2). Our primary rejection criteria are the spectra and surface brightness conservation (Pötzl et al., in prep.)

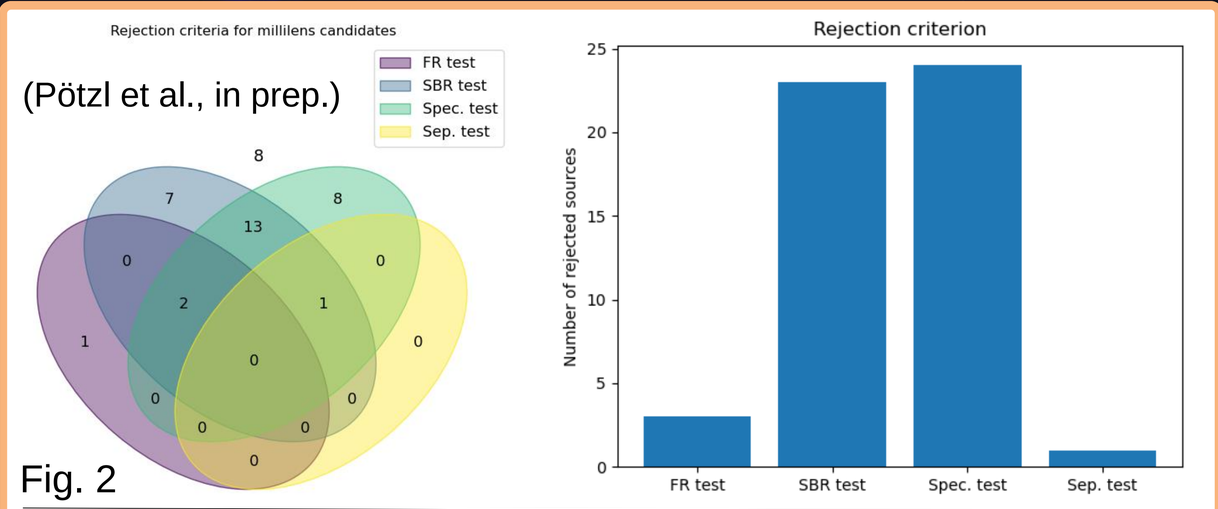


Fig. 2

Four tests are applied: surface brightness ratio (SBR), flux ratio (FR), spectrum and separation of components.

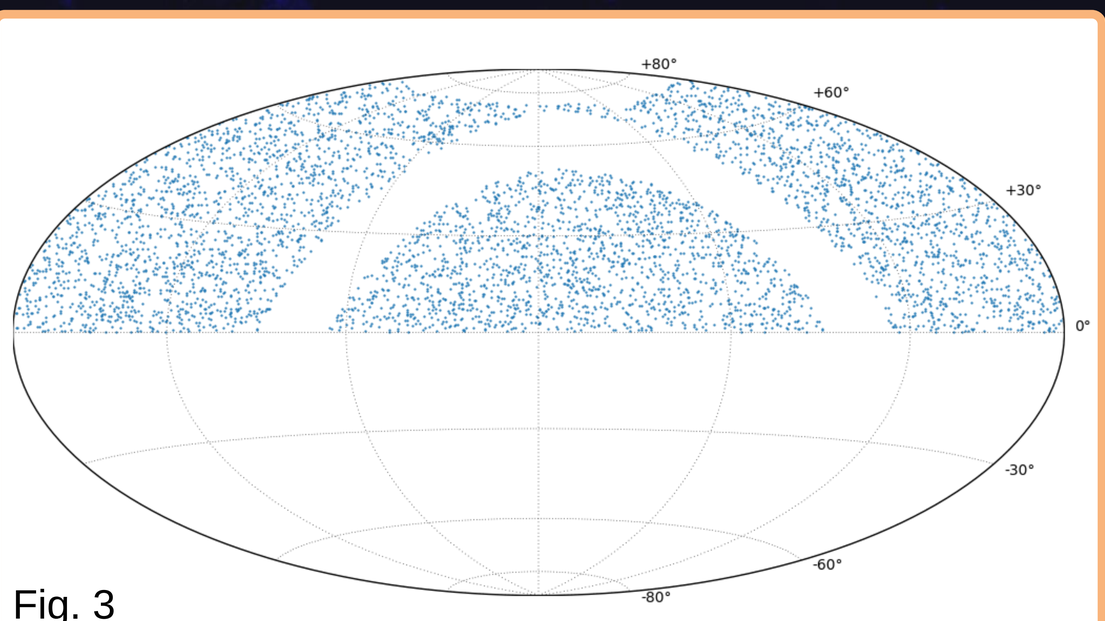


Fig. 3

The SMILE project

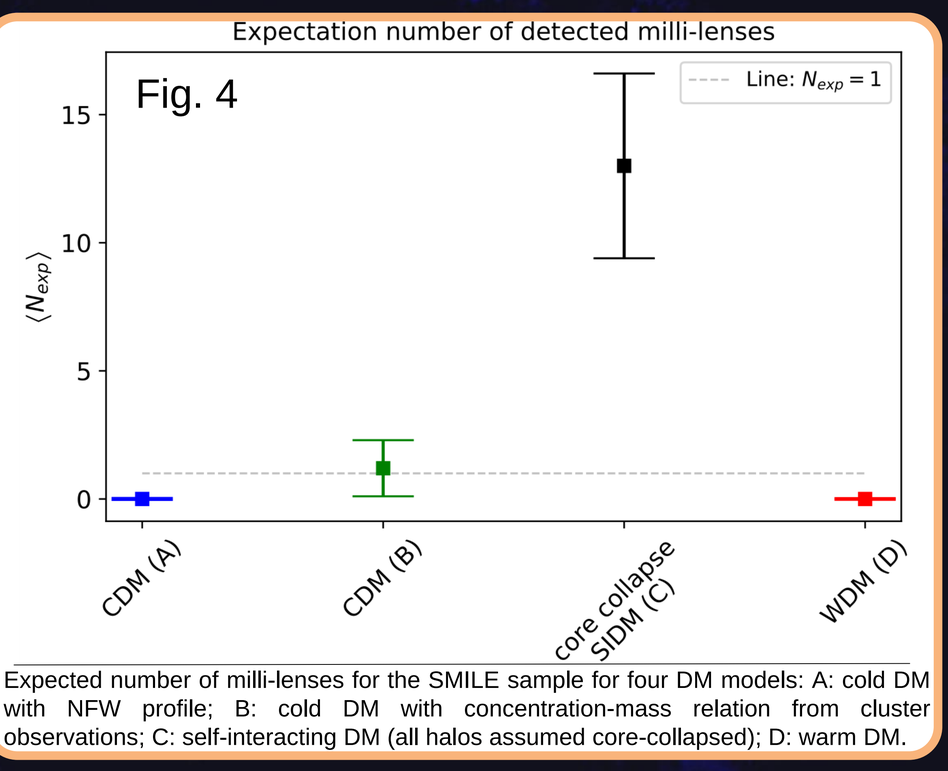
To constrain DM models, SMILE aims to consistently calibrate and image VLBI data of 4,968 sources from the cosmic lens all sky survey (CLASS), which is a complete sample of flat-spectrum sources (α<-0.5 between 1.4 and 5 GHz). Our subsample is complete with S_ν>50 mJy, and declination [0, +75°] (Fig. 3). We have obtained redshifts for 80 % of the sample. Using this, one can calculate the lensing optical depth and thus the expected number of lensed images for the sample. Following this approach, [5] tested predictions of four distinct DM models, demonstrating our constraining power with SMILE (Fig. 4). Our calibration pipelines in both CASA and AIPS, as well as all final calibrated data and images will be made publicly available.

References

[1] Press & Gunn 1974, ApJ, 185, 397; [2] Casadio et al. 2021, MNRAS, 507, L6; [3] Kielmann et al. 2024, ApJ, 961, 240; [4] Wilkinson et al. 2001, Phys. Rev. Lett., 86, 584; [5] Loudas et al. 2022, A&A, 668, A166.

Acknowledgements

The European VLBI Network is a joint facility of independent European, African, Asian, and North American radio astronomy institutes. Scientific results from data presented in this publication are derived from the following EVN project code(s): EC071. We would like to thank Leonid Petrov for maintaining the Astrogeo VLBI FITS image database: https://astrogeo.org/



Expected number of milli-lenses for the SMILE sample for four DM models: A: cold DM with NFW profile; B: cold DM with concentration-mass relation from cluster observations; C: self-interacting DM (all halos assumed core-collapsed); D: warm DM.

SMILE is hiring soon! Check for PostDoc position openings on https://smilescience.info/jobs