Gravitational lensing at the highest angular resolution

John McKean
(SHARP) Matus Rybak, Cristiana Spingola, Simona Vegetti, Matt Auger, Chris Fassnacht, Neal Jackson, David Lagattuta, Leon Koopmans

(mJIVE-20) Adam Deller, Minju-Lee, Javier Moldon
Dark matter only simulation of a Milky Way like halo (Diemand et al. 2007)
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\[ dN \propto dm m^{-\alpha} \quad (=1.9 \pm 0.1) \]
Dark matter only simulation of a Milky Way like halo (Diemand et al. 2007)

\[ dN = (1.9 \pm 0.1) \]

i) Something wrong with the galaxy formation model?

ii) The low mass dwarfs are dark (did not form stars at early epoch)?

iii) The Milky Way is a special case?
Dark matter halo of mass $\sim 10^{12} M_{\text{sun}}$ (Lovell et al. 2012)

Cold dark matter

Warm dark matter
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Cold dark matter

Warm dark matter

The cut-off in the mass function is directly related to the model for dark matter.
Top end of the substructure mass function

Dwarf companion galaxies (luminous substructures) make up ~1% of total halo mass.
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The LMC is not unique!
JVAS B1938+666 ($z = 0.881$; Keck adaptive optics; psf 65 mas).

$$M_{\text{sub}} = (1.9 \pm 0.1 \times 10^8 \, M_{\odot})$$

(Vegetti, Lagattuta, JPM et al. 2012, Nature)

SDSS J0946+1006 ($z = 0.222$; HST F814W; psf 75 mas)

$$M_{\text{sub}} = (3.5 \pm 0.2 \times 10^9 \, M_{\odot})$$

(Vegetti et al. 2010)
Using the two dark substructures,

\[ f_{\text{CDM}} = 3.3^{+3.6}_{-1.8} \% \quad \text{and} \quad \alpha = 1.1^{+0.6}_{-0.4} \%
\]

Simulations predict

\[ f_{\text{CDM}} < 0.4 \% \quad \text{and} \quad \alpha = 1.9 \pm 0.1
\]

Key Result: The mass fraction and the slope of the mass function from 2 lenses are just consistent with what we expect from simulations (95% confidence level).

Can we go orders of magnitude lower in mass to test WDM models? → need mas resolution for \(10^6\) M\(_{\text{sol}}\) haloes
The Global VLBI Array

NOW!!

- European VLBI Network (EVN)
- Very Long Baseline Array (VLBA)
- High Sensitivity Array (HSA)
MG J0414+0534 ($z = 2.64$)
Beam size 9 x 3 mas
300 uJy / beam rms

(Volino et al., in prep)
JVAS B1938+666 (z = 2.056)
Beam size 4 x 2 mas
30 uJy / beam rms

(McKean et al., in prep)
MG J0751+2761 (z = 2.056)
Beam size 7 x 2 mas
10 uJy / beam rms

(McKean et al., in prep)
Need to find more lenses in the radio with extended structure!
mJIVE-20: The mJy Imaging VLBI Exploration at 20 cm (Deller & Middelberg 2013).

Instrument: VLBA (filler time)

Area: 200 deg$^2$ (200 h)

Resolution: 5--10 mas

Sources: 14812 (FIRST)

Detections: 3057

Potential lenses: 4 ± 2
mJIVE-20: The mJy Imaging VLBI Exploration at 20 cm (Deller & Middelberg 2013).

First lens candidate found in brightest 1492 sources.
Proof concept!
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CLASS B1127+385
(Koopmans, de Bruyn et al. 1999)

Proof concept!
mJIVE-20: The mJy Imaging VLBI Exploration at 20 cm (Deller & Middelberg 2013).

Proposal for a 8000 deg$^2$ survey to be completed in VLBA filler time being prepared.

Expect to find ~ 150 new radio-loud gravitational lenses.

First lens candidate found in brightest 1492 sources.

Proof concept!

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Summary

• The level of low mass substructure around massive galaxies is sensitive to the nature of the dark matter particle.

• Gravitational lenses can be used to measure the substructure mass function out to redshift ~ 1 (actually any lens redshift).

• The level of ‘high mass’ substructure within lenses is consistent with the over abundance seen in the Local Group (e.g. LMC and SMC).

• Current best constraints suggest a total mass fraction and flat-slope to the mass function consistent with CDM (large errors).

• VLBI imaging of a few select gravitational lenses will directly confirm or rule out the CDM model; combining with optical data will test WDM models.

• Wide-field VLBI surveys have the potential to quickly increase the number of radio-loud lenses by factors ~ 5.