Role of substructure in gravitational lens system: MG 2016+112

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MG 2016+112

- Image separation ~ 3.4 arcsec
- Lensed quasar is at $z = 3.273$
VLBI Images of A and B at 1.7, 5 and 8.4 GHz
VLBI Images of Region C
Images A and B show opposite parity

Astrometric anomaly in region C
Images A and B show opposite parity. Astrometric anomaly in region C.
Satellite galaxy G1 - primary cause of the astrometric anomaly

Mass of G1 -- $10^{10} M_\odot$ – 0.8 % of the lens galaxy D within their Einstein radii
Subhalo abundance

Subhalo mass function:

\[
\frac{dn}{dm} \simeq 10^{-3.2} (\frac{m_{\text{sub}} h}{M_\odot})^{-1.9} h M_\odot^{-1}
\]

Gao++ ‘04 (1)

Number density profile:

\[
n(r) = 2n_H \left[1 + \left(\frac{r}{r_H}\right)^2\right]^{-1},
\]

Diemand++ ‘04 (1)

* Abundance of subhalos \((10^7 - 10^{10} M_\odot)\) at projected separation of the lensed images
  * 1/100  ==> 100x100 mas²
  * 1-2    ==> within the annulus
Substructure mass fraction

Comparison with simulations of sub-halo population in halos (Mao et al. 2004)

- Satellite mass fraction -- lensing > simulations
- Caveats -- Selection bias / Low statistics
Summary

* Gravitational lensing can be used as a probe to detect substructure

* New mass models --> region C is
  * A counterpart to the component 5  OR
  * Unseen structure to the north-west of component 5

* Satellite galaxy G1 --> responsible for the astrometric anomaly in region C (also, see Kochanek et al. 2004 and Chen et al. 2007)

* Subhalo abundance seems to be in agreement with CDM predictions

* Satellite mass fraction in MG 2016+112 --> higher end of the predicted fraction from simulations of Mao et al. (2004)