Dark Matter Lost and Found

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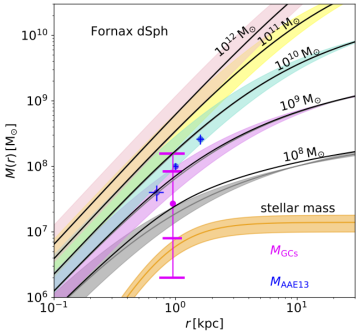
Overview

Two branches:

1. Dark Matter in dwarf galaxies in the Local Universe: fainter and farther out
2. Dark Matter in "small" lens galaxies, out to $z \approx 1$

Let's start with a well-known dSph:

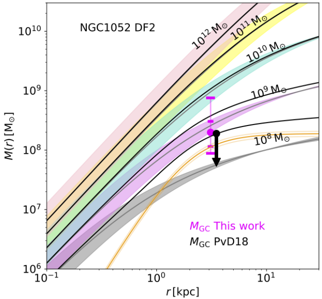


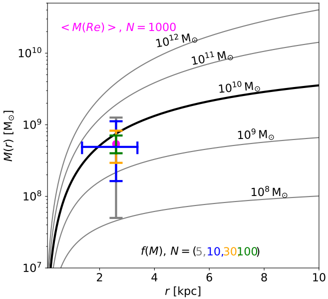
(Laporte, AA, & Navarro 2018; Amorisco, AA, & Evans 2013)

1. Mass profile well determined from kinematics of stars (cusp/core problem).
2. Kinematics of Globular Cluster (GC) underestimate the mass content
3. GC abundance (slighly) overestimates halo mass.

NGC1052-DF2

UDG ‘lacking dark matter’: striking galaxy[1] or tragic mistake[†]?



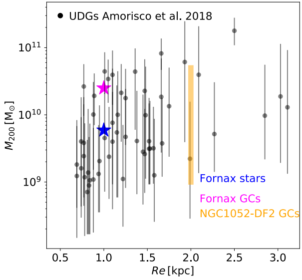


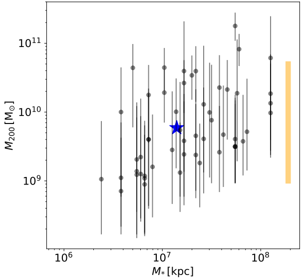
Misleading results from GC kinematics (also wrong sigma, possibly wrong distance...)

Few tracers ⇒ ***not*** virialized! Order-of-magnitude uncertainties on masses.

You can get any mass you want from 10 or 11 GCs.

[1] van Dokkum et al. (2018); [†] Laporte, AA, & Navarro (2018).





Scientific results:[a]

1. Fornax and NGC1052-DF2 are not so special
2. Discrepant mass estimates from GC abundance and kinematics
3. Need starlight kinematics, and/or more GCs (at least 30)

Warnings:[b]

- get your kinematics right
- get your distances right

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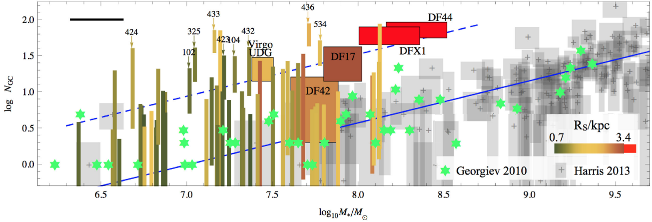
[a](Laporte, AA & Navarro 2018)
[b](Laporte +2018; Martin +2018; Trujillo +2018)

A 'mixed bag' of UDGs[2]?



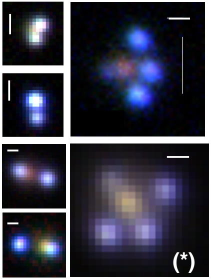
UDGs in Coma and their GC content
(data from HST Coma Cluster treasury program),
compared to other galaxies in the Local Universe.
Similar 'mixed bag' in Virgo galaxies (Peng et al. 2008).
A robust and comprehensive interpretation is still missing.

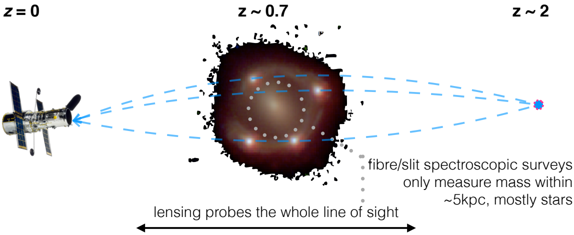
[2] Amorisco, Monachesi, AA & White 2018

So why 'giant' telescopes?

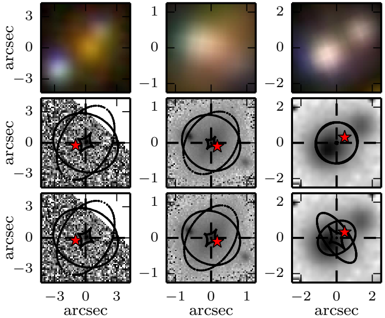
1. Need more GCs per system ⇒ must go faint ($i \approx 24$)
2. Need more systems, possibly stacking ⇒ sample larger volume
3. Need kinematics of stars! And on many galaxies.

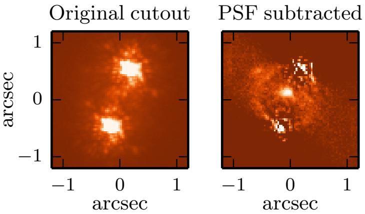
Strong lensing by galaxies

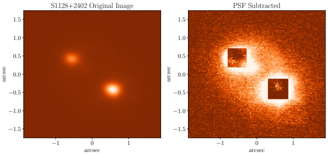




A range of image separations

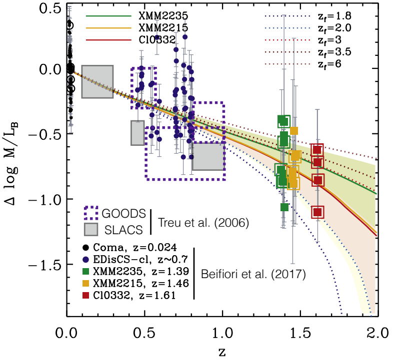






(Williams et al. 2017;
Molina et al. in prep.)

Lensing and the fundamental plane



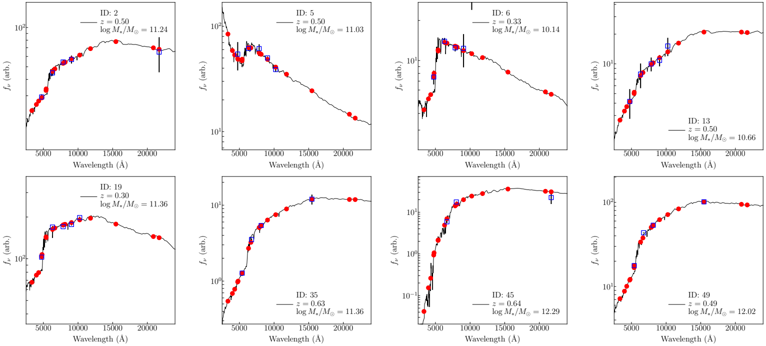
1. What is the $M_\star - M_h$ relation of lens galaxies?
2. Do we understand FP evolution?
3. What about 'small' galaxies in lensing clusters?

NB: some ***adopt*** $\sigma = \sigma_{sis}$, with

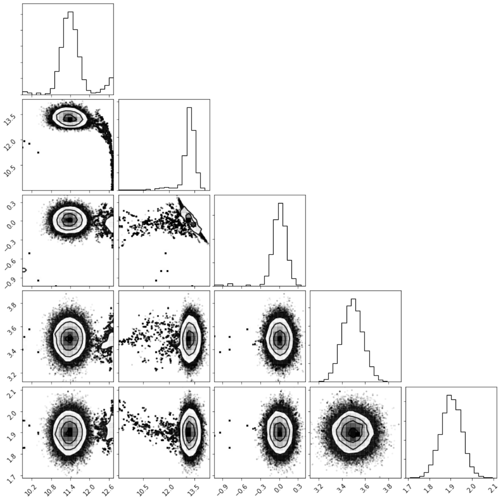
$$\sigma_{\rm sis}^2 = \frac{c^2 \theta_{\rm E} D_s}{4\pi D_{ls}} \; ; \qquad (1)$$

this is far from adequate at the massive end ($\sigma \approx 0.7\sigma_{sis}$), and probably at small masses too.

What is needed?[3]
Good multi-band photometry (stable PSF), ***redshifts***, accurate lens models (to within ≈ 10% in θ_E).

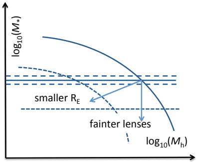


[3] Molina et al. in prep. Masses courtesy of T. Morishita.



Currently[a] crunching a sample of

- ≈ 60 quasar lenses[b]
- $0.3 < z_l < 0.7$,
- $9.5 < \log_{10}(M_\star) < 11.5$



[a] In collab. with A. J. Shajib (UCLA).
[b] Molina et al. in prep.

So why giant telescopes?

- Small image separations, down to $\approx 0.6''$.
- Faint lens galaxies, that may not be targeted otherwise.
- Challenging for current AO IFU: done on just a handful with OSIRIS@Keck in the NIR; MUSE-NFM strongly depends on seeing, even with the brightest.
- Need redshifts of faint deflectors, over large samples

Summing up...

- Dark matter in dwarfs of the Local Universe, out to Coma Cluster
- Direct $M_\star - M_h$ in single galaxies, at cosmological redshift, over multiple decades in $M_\star$
- Need models that are worthy of giant telescopes
- (...provided insruments are understood as much as the data)