The dark halo/galaxy mass ratio - ellipticity relation in spheroids in the light of MOND

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Context

Deur (2014,2020) and Winters et al. (2022) claimed having found an empirical linear relation between mass-to-light ratio and ellipticity ($\epsilon = 1 - c/a$) in elliptical galaxies

$$M/L_{\epsilon_{\rm app}=0.3} \approx (14.1 \pm 5.4)\epsilon,$$

where $\epsilon_{\rm app} = 1 - \sqrt{(1-\epsilon)^2 \sin^2\theta + \cos^2\theta}$. The equation above can be rewritten in terms of total mass (in units of baryon mass) vs ellipticity as

$$4M_{\rm tot}/M_{*} \approx (14.1 \pm 5.4)\epsilon$$

The sample

A sample of 237 elliptical galaxies from independent surveys that includes

- Medium sized galaxies $10^{10} M_{\odot} < M < 5 \times 10^{11} M_{\odot}$
- Undistrubed galaxies (Both criteria are relaxed for distant galaxies)

and rejects

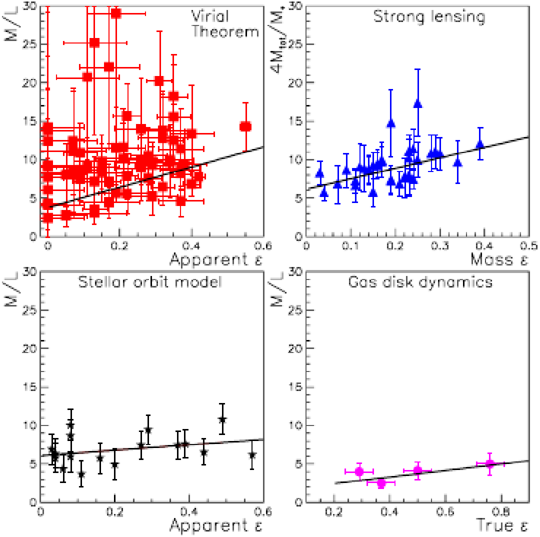
- Compact ellipticals (cE, cD, D, BrClG)
- Active galaxies (AGN, NELG, Sy, BLLAC, LINER)
- Peculiar galaxies
- High σ galaxies at large z to exclude S0

The methods

M/L is evaluated from

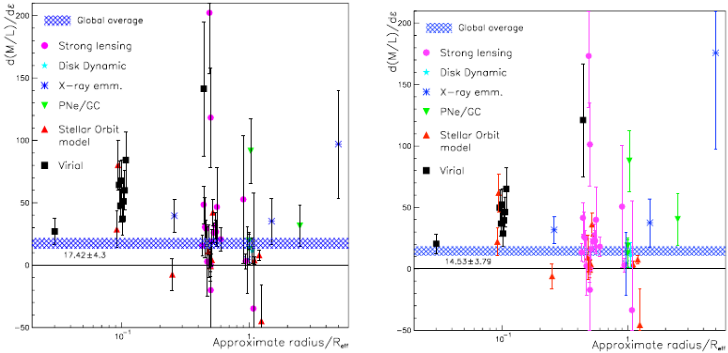
- Virial theorem
- Stellar dynamical models
- X-ray emission
- Planetary nebulae and globular cluster dynamics
- Gas disk dynamics
- Lensing

Examples



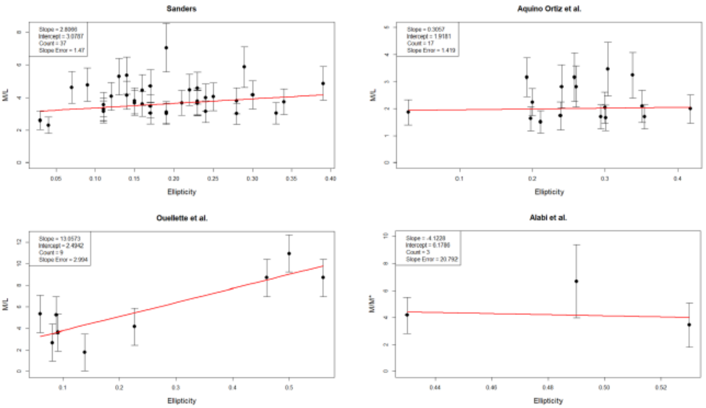
From Deur MNRAS (2014)

Examples



From Deur MNRAS (2014)

Examples



From Winters, Deur & Zheng MNRAS (2023)

Astrophysical implications in ΛCDM and MOND

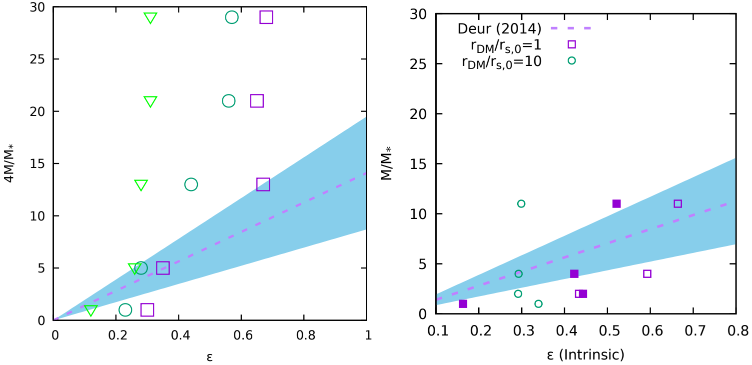
- More dark matter → larger departure from spherical symmetry
- Apparent contradiction with standard galaxy formation scenario
- More massive halos are less spherical?
- In MOND, larger spheroids should depart more from spherical symmetry
- So far, no evidence of M/L or M/M_* vs ϵ in $N-$body simulations (i.e. never looked at)

Simulations and results: Initial conditions

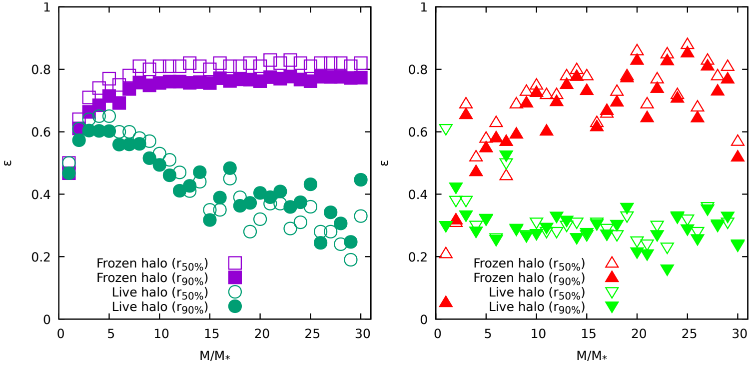
$N-$body simulations performed in Newtonian and MOND gravity using NMoDY, (Nipoti, Ciotti & Londrillo 2007)

- Isolated cold ($-2K_0/W_0 \lesssim 0.5$) collapse in spherical (live or frozen) halos
- Clumpy collapse (virialized or non virialized clumps) in spherical halo
- Merging of virialized galaxies in parent halo
- Unstable multi component Osipkov-Merritt models (Radial orbit instability)
- Cold spherical and Clumpy MOND collapses
- Unstable single component Osipkov-Merritt models in MOND

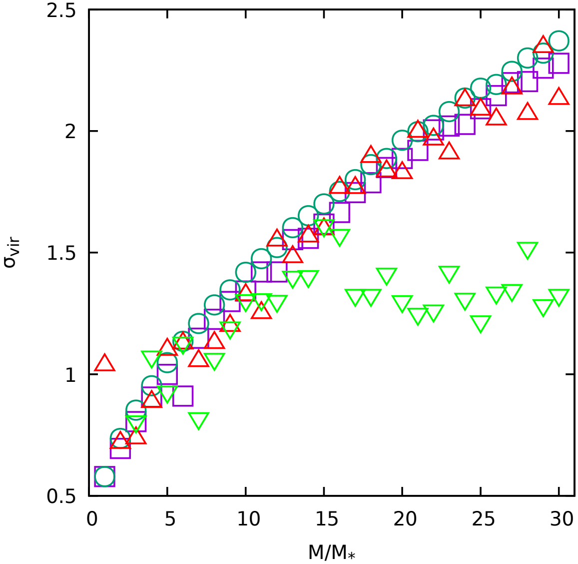
Simulations and results: Spherical cold collapses



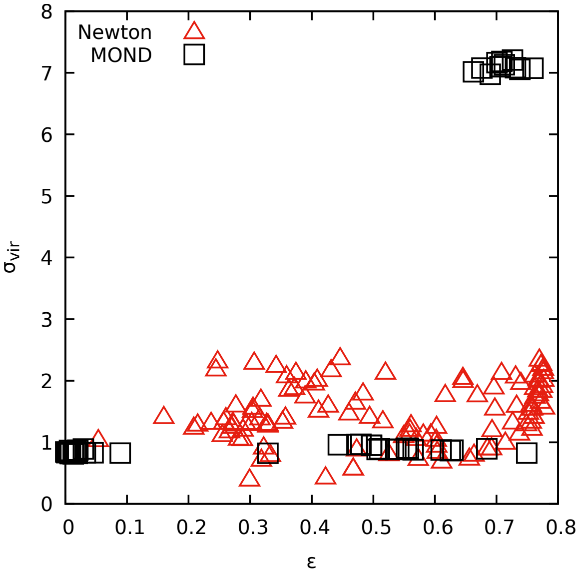
Simulations and results: Live and frozen halo



Simulations and results: virial velocity dispersion



Simulations and results: virial velocity dispersion



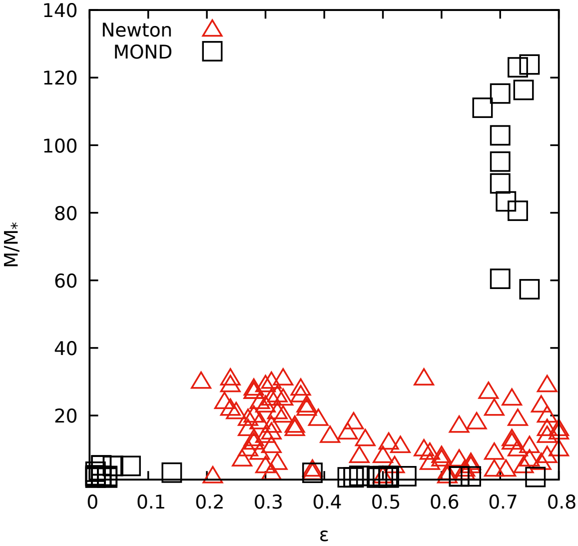
Simulations and results: ENS

For MOND simulations we recover the phantom DM density of the circularized equivalent Newtonian system as

$$\rho_{DM} = (4\pi G)^{-1}\nabla \cdot (\mathbf{g}_M - \mathbf{g}_N)$$

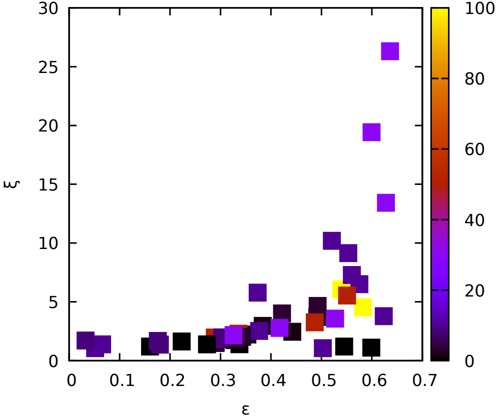
where the Newtonian force field g_N has been evaluated and averaged on the radial coordinate. Integrating ρ_{DM} one gets the DM mass of the ENS. (Check also Federico Re's poster)

Simulations and results: ENS

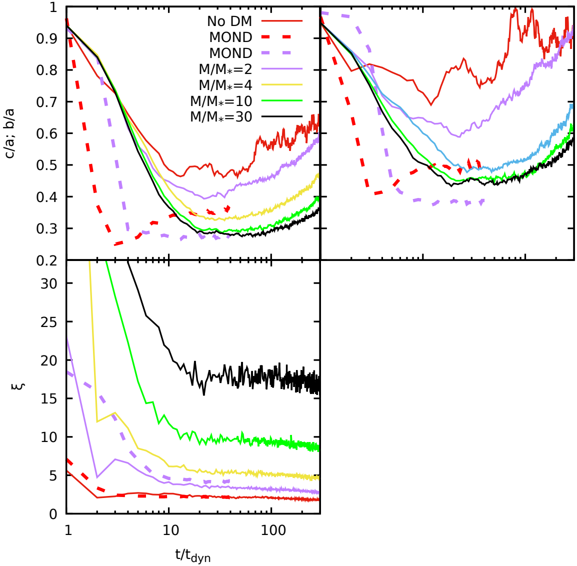


Simulations and results: anisotropy index

$\xi = 2K_r^2 / K_t^2$



Simulations and results: anisotropy index



Radial orbit instability

1. Collisionless equilibrium systems with a significant fraction of the kinetic energy stored in low angular momentum orbits are violently unstable. The amount of radial orbits is quantified by introducing the Fridman-Polyachenko-Shukhman parameter

$$\xi = 2K_r/K_t, \tag{1}$$

   as function of the radial and tangential components of the (initial) kinetic energy T_r and T_t

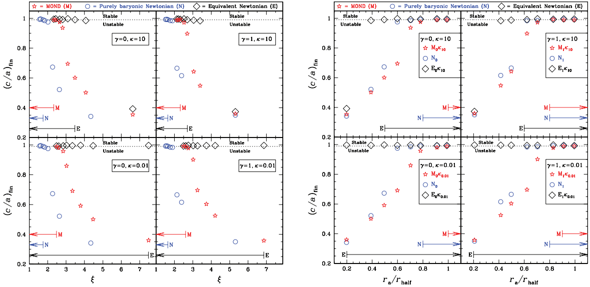
2. For approximately $\xi > 1.5$ Newtonian systems appear to be unstable, leading to triaxial end-states.

Radial orbit instability

1. Analytical stability results exist for the isotropic case. It is also known that phase-space distribution functions with $\mathrm{d}f(\mathcal{E})/\mathrm{d}\mathcal{E} \leq 0$ correspond to stable systems (Antonov theorem)
2. ROI is triggered by particles with orbital frequencies close to satisfying the condition $\Omega_P \equiv 2\Omega_\nu - \Omega_r \simeq 0$, where Ω_ν is the azimuthal frequency, Ω_r the radial frequency and Ω_P the precession frequency
3. Once a small non-spherical density perturbation is formed in a system dominated by low Ω_P orbits, it will grow more and more, as more and more particles tend to accumulate to it.

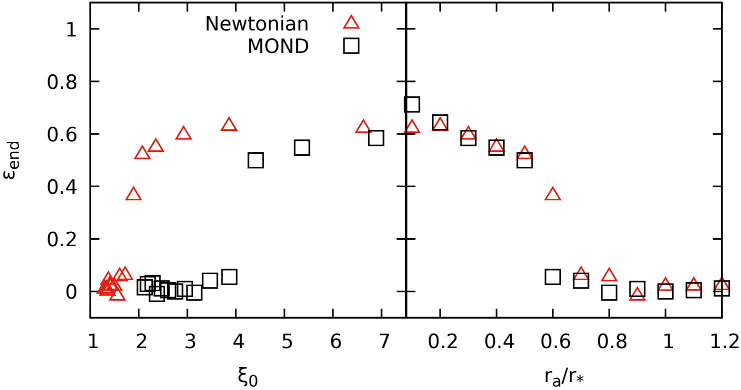
Radial orbit instability in MOND

- MOND systems are *more* stable than single component Newtonian systems with the same initial density profile and same ξ.
- MOND systems are *less* stable than their equivalent Newtonian counterparts (Same phase-space distribution for stars + Dark Matter halo).



From Nipoti, Ciotti & Londrillo MNRAS (2011)

Radial orbit instability in MOND



(Preliminary) Conclusions

1. In Newton + DM a correlation between $M_{\rm dark}$ and ϵ appears in simulated galaxies for some initial conditions.
2. In MOND the (spherical cow) halo of the ENS recreates a similar relation
3. So far the observed linear trend is never reproduced by the simulations
4. Initial anisotropy seems to play a role and (in both cases) could be ascribed to of radial orbit instability
5. In the context of MOND implies a mass-anisotropy-flattening relation