Dark Matter in Fractional Gravity. Astrophysical Tests on Galactic and Clusters Scales

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The two papers

Dark Matter in Fractional Gravity. I. Astrophysical Tests on Galactic Scales

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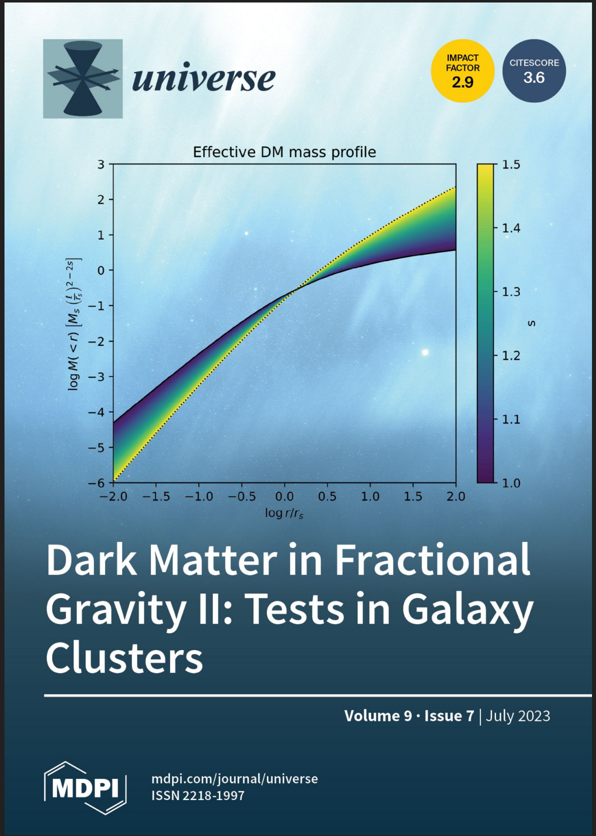
Abstract

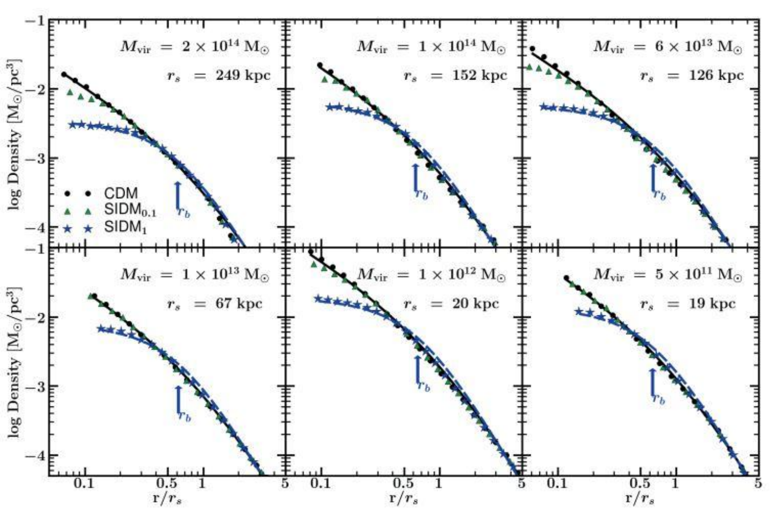
We explore the possibility that the dark matter (DM) component in galaxies may originate fractional gravity. In such a framework, the standard law of inertia continues to hold, but the gravitational potential associated with a given DM density distribution is determined by a modified Poisson equation including fractional derivatives (i.e., derivatives of noninteger type) that are meant to describe nonlocal effects. We analytically derive the expression of the potential that in fractional gravity corresponds to various spherically symmetric density profiles, including the Navarro–Frenk–White (NFW) distribution that is usually exploited to describe virialized halos of collisionless DM as extracted from cosmological simulations. We show that in fractional gravity, the dynamics of a test particle moving in a cuspy NFW density distribution is substantially altered with respect to the Newtonian case, mirroring what in Newtonian gravity would instead be sourced by a density profile with an inner core. We test the fractional gravity framework on galactic scales, showing that (i) it can provide accurate fits to the stacked rotation curves of spiral galaxies with different properties, including dwarfs; (ii) it can reproduce to reasonable accuracy the observed shape and scatter of the radial acceleration relation over an extended range of galaxy accelerations; and (iii) it can properly account for the universal surface density and the core radius versus disk scale length scaling relations. Finally, we discuss the possible origin of the fractional gravity behavior as a fundamental or emerging property of the elusive DM component.

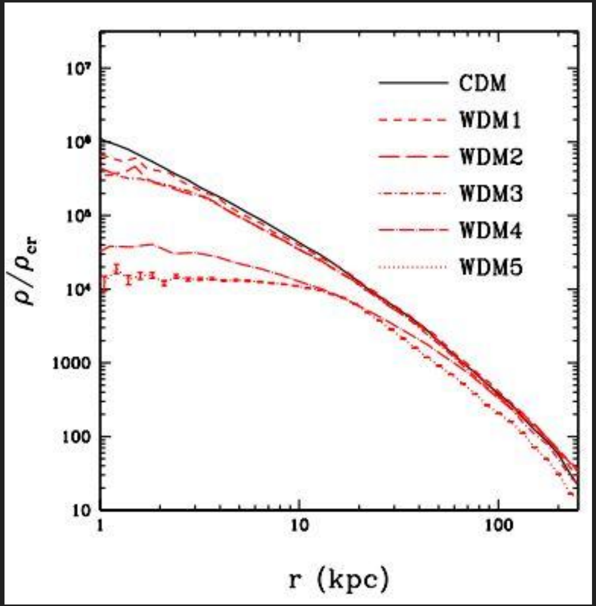


Motivation: The CPP of CDM

Cold Dark Matter simulations agree with observations at large scales, but suffer issues in the center of small dwarf galaxies: Cusp Core Problem (CCP).

$$\rho_{NFW}(r) = \frac{\rho_0 r_s^3}{r(r+r_s)^2}$$





Theoretical framework

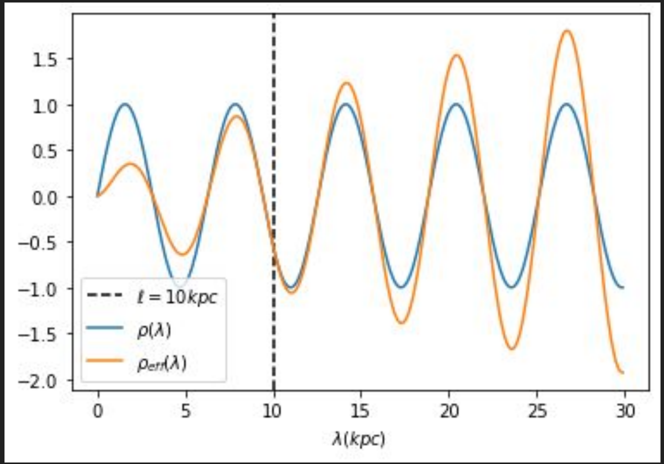
Hypothesis: Dark Matter in galaxies interacts through a non-local Fractional Poisson Equation (FPE).

$$(-\Delta)^s \Phi_{DM} = -4\pi G l^{2-2s} \rho_{DM} \qquad s \in [0, 3/2]$$

The resulting potential can be re-interpreted as generated by a non-local density distribution through a classical Poisson Equation.

$$\Delta \Phi_{DM} = 4\pi G \rho_{eff}$$

$$\mathcal{F}[\rho_{eff}] = \left(\frac{\lambda}{\ell}\right)^{2s-2} \mathcal{F}[\rho]$$



Analytical results

For a point particle

$$\Phi(r) = -\frac{GM}{r}\frac{\Gamma\left(\frac{3}{2}-s\right)}{4^{s-1}\sqrt{\pi}\Gamma(s)}\left(\frac{\ell}{r}\right)^{2-2s}, \quad s < \frac{3}{2}$$

$$\Phi(r) = \frac{2GM}{\pi\ell}\ln\left(\frac{r}{\ell}\right), \quad s = \frac{3}{2}$$

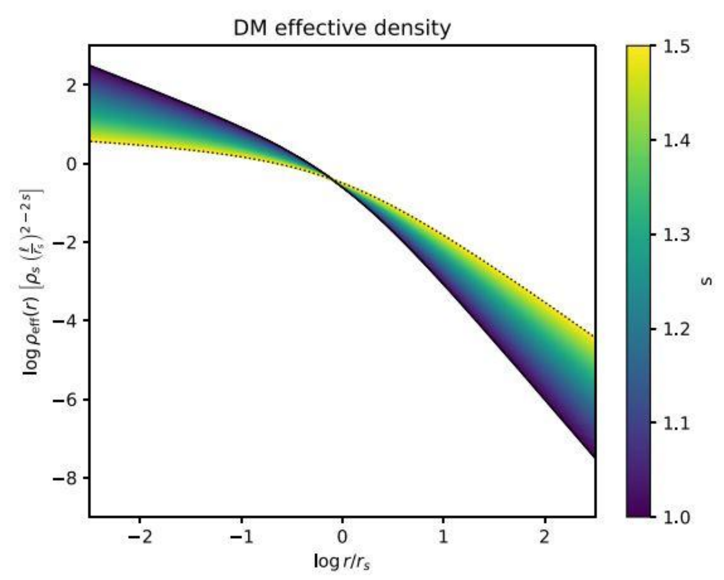
What would be localized particles, behave as de-localized distributions

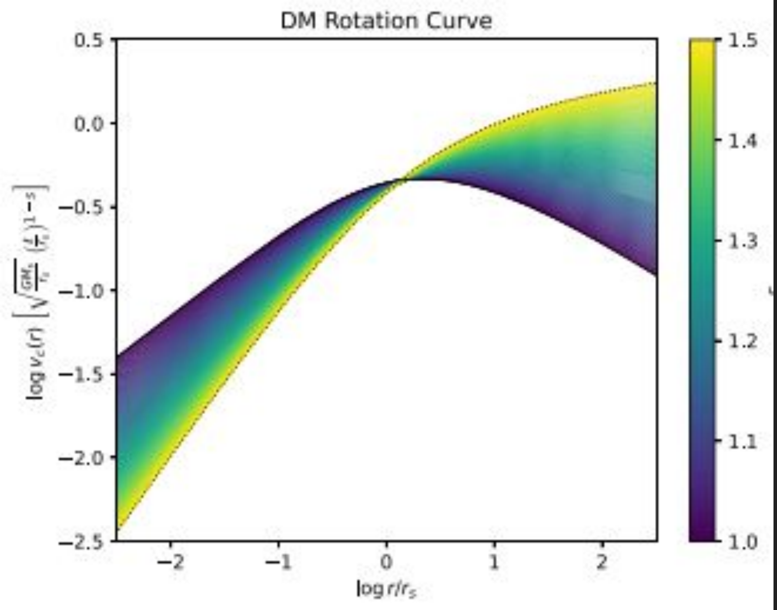
$$\rho_{eff}[\delta, s](r) = \frac{M}{4^{s-1}\pi^{3/2}r^3}\frac{\Gamma\left(\frac{5}{2}-s\right)}{\Gamma(s-1)}\left(\frac{\ell}{r}\right)^{2-2s}$$

The NFW profile in Fractional Gravity

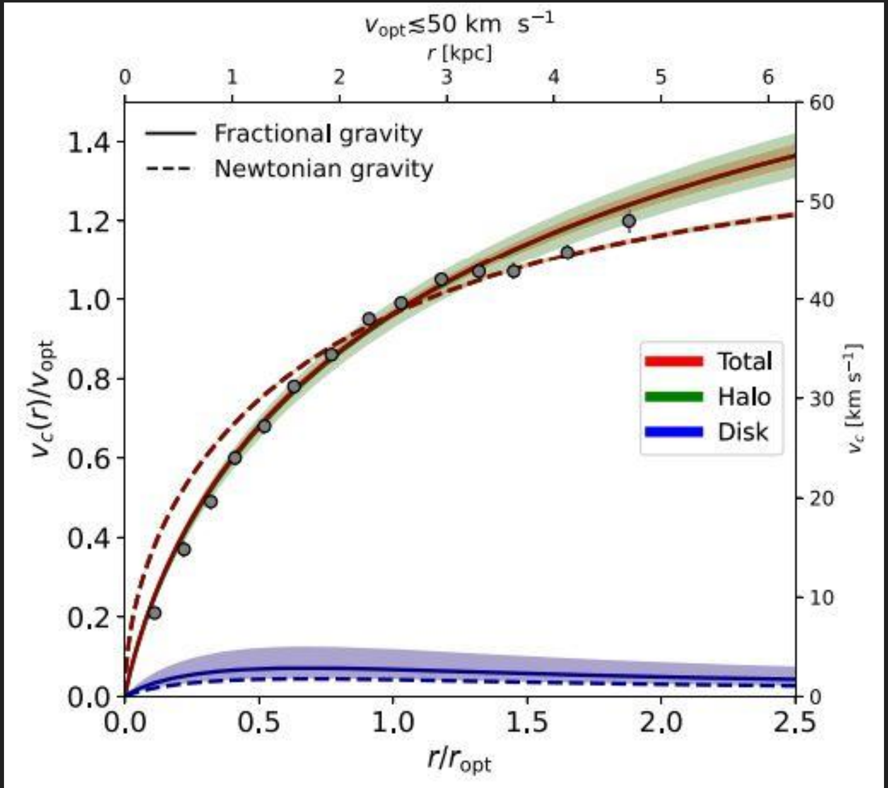
We have solved the equation for the NFW density:

$$\rho_{eff,s=3/2}(r) = \frac{2\rho_s r_s}{\pi \ell} \frac{\ln(r/r_s)}{(r/r_s)^2 - 1}$$

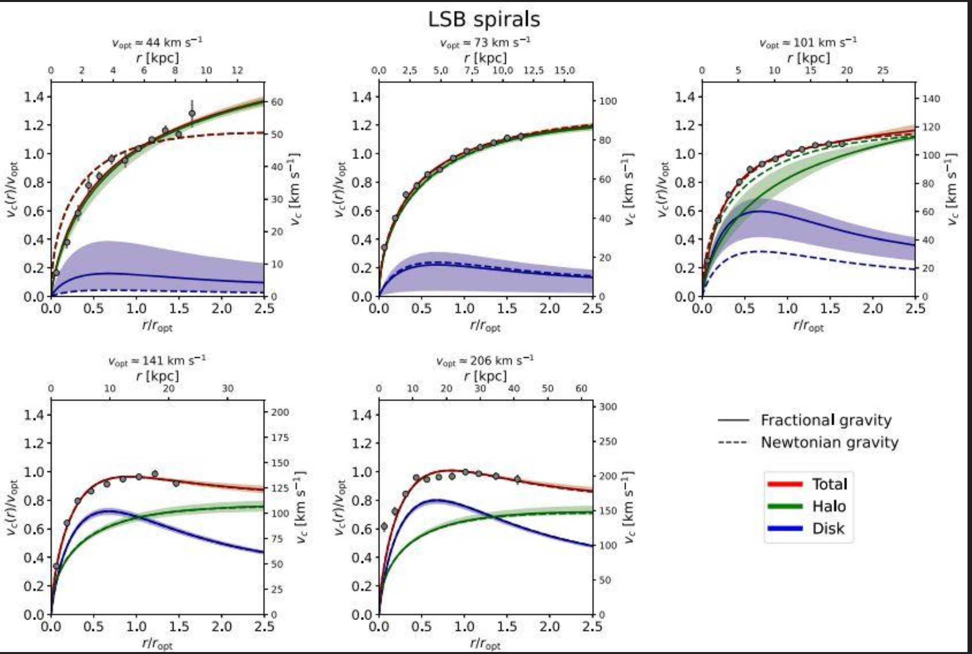




Fits to real galaxies

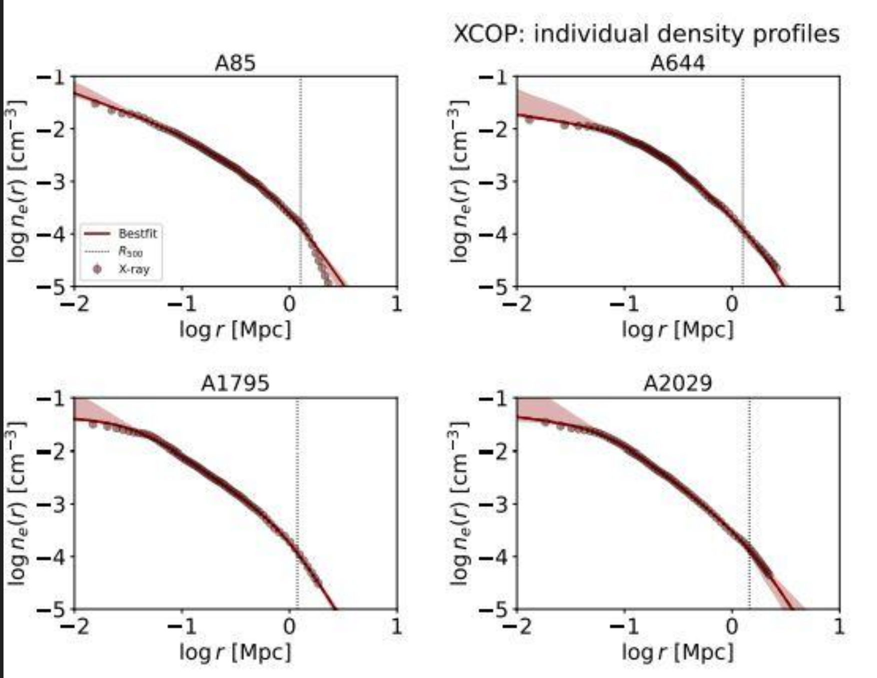


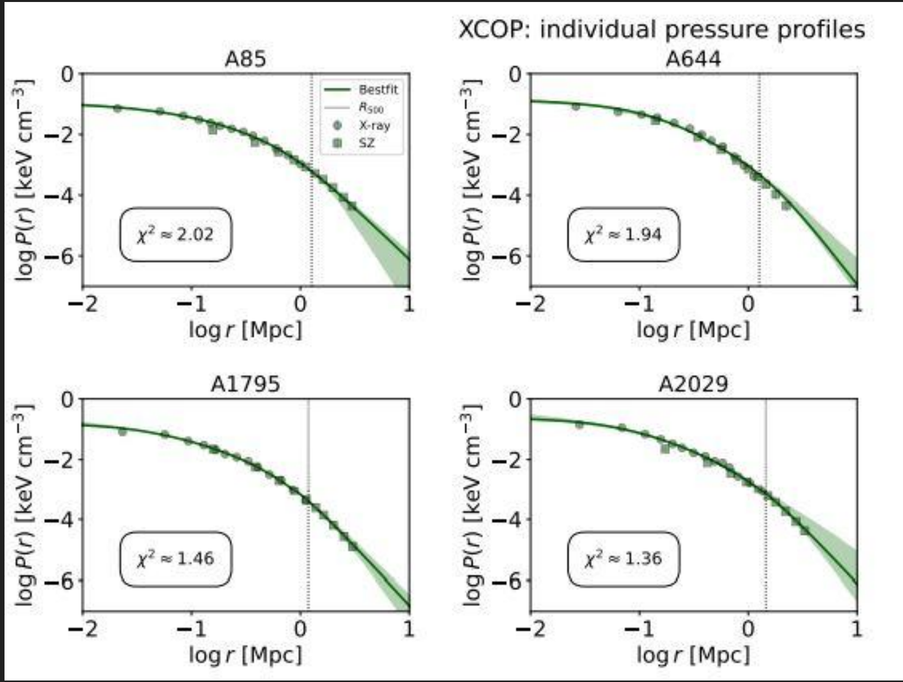
We have fitted spirals of various types: Dwarfs, LSB and HSB.



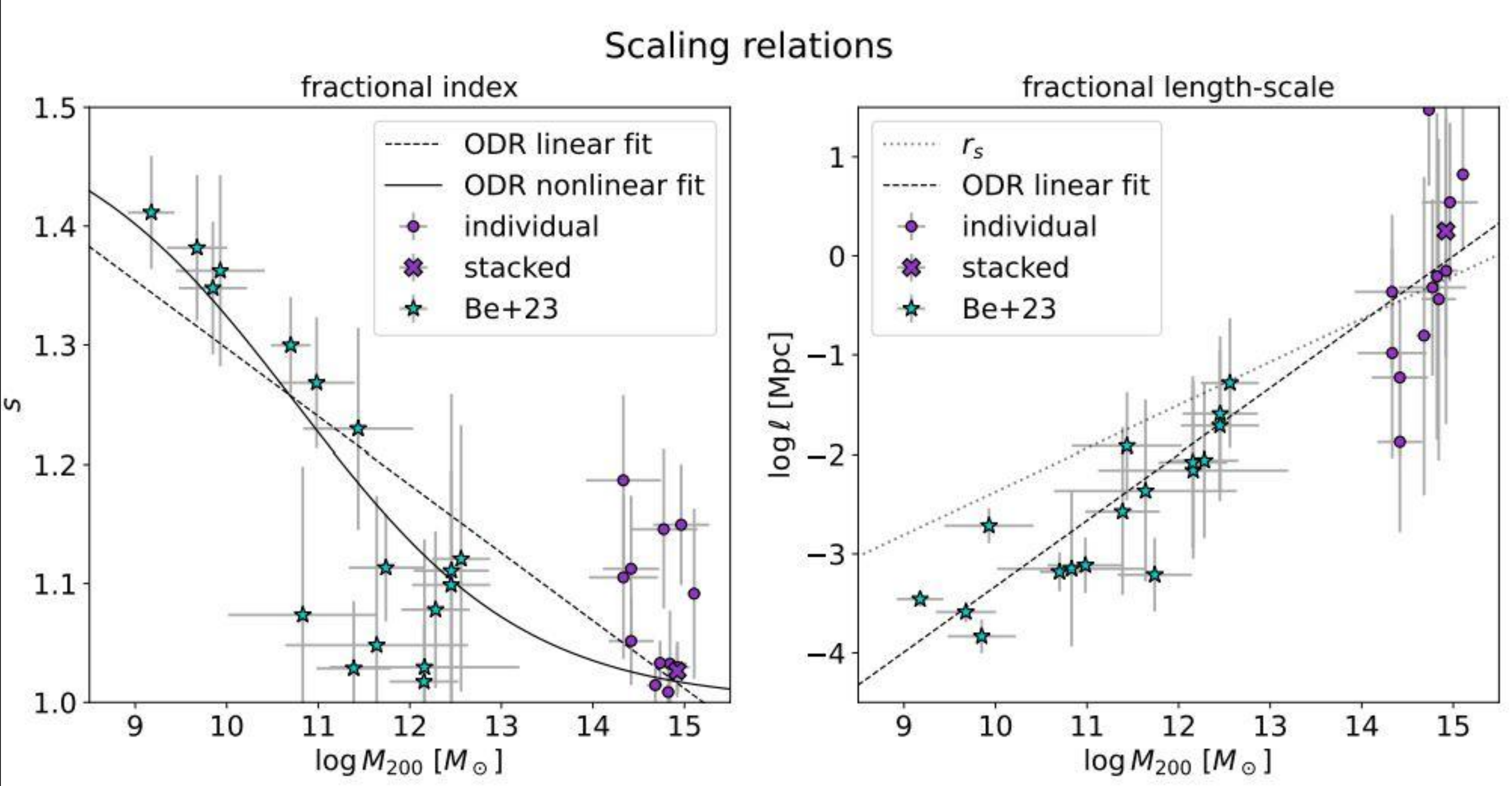
Clusters of galaxies

As a sanity check, we have tested the model in Clusters and we have verified that it reproduces the Newtonian results on such large scales.



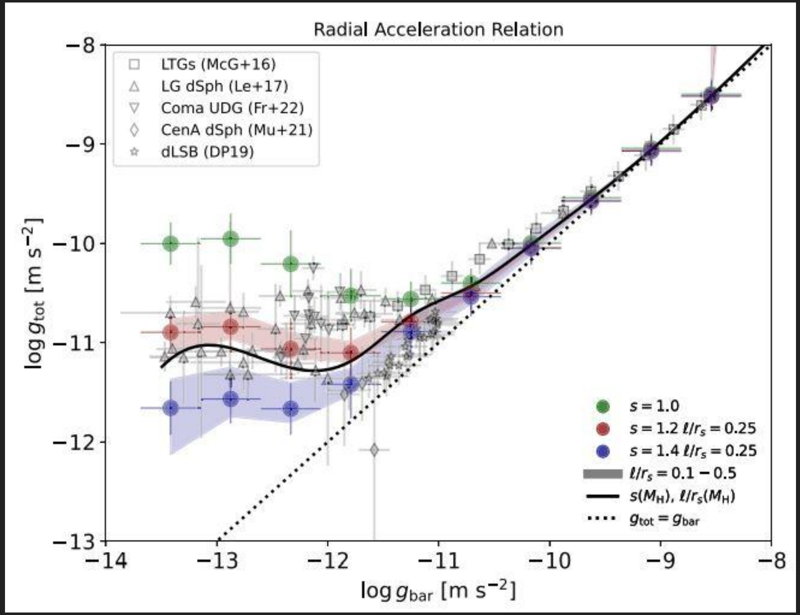


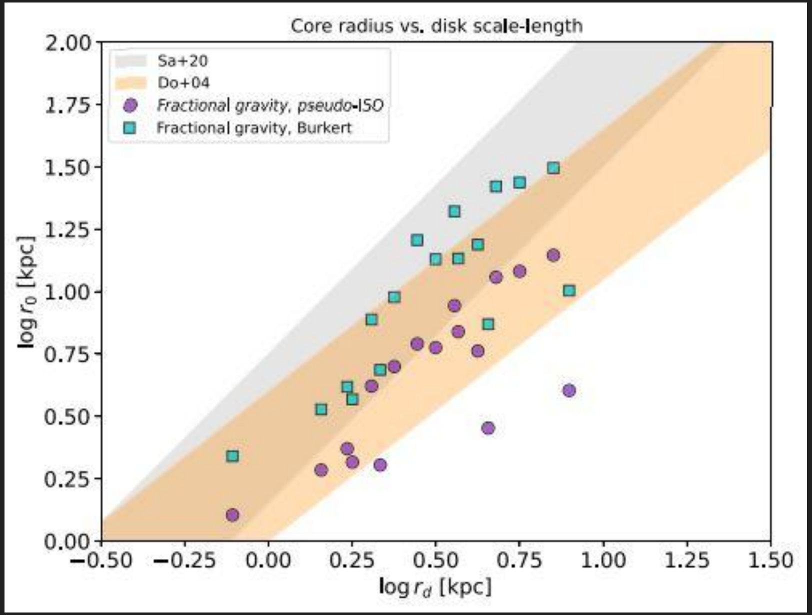
Scaling relations of the parameters



Recovering relations in Galaxies

Fractional Gravity is able to reproduce several relations observed in spiral galaxies.





Future outlooks

In future works we are going to investigate the following issues:

- Spirals and elliptical dwarfs in which non-locality is stronger.

- Gravitational lensing in Fractional Gravity.

- Theoretical investigations on the nature of the non-local interaction.

- GR extension of the theory.