Halo scale probes of Cosmology-
Splashback and halo profiles in Modified gravity and SIDM

Cosmic visions meeting
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Small scale probes and simulations

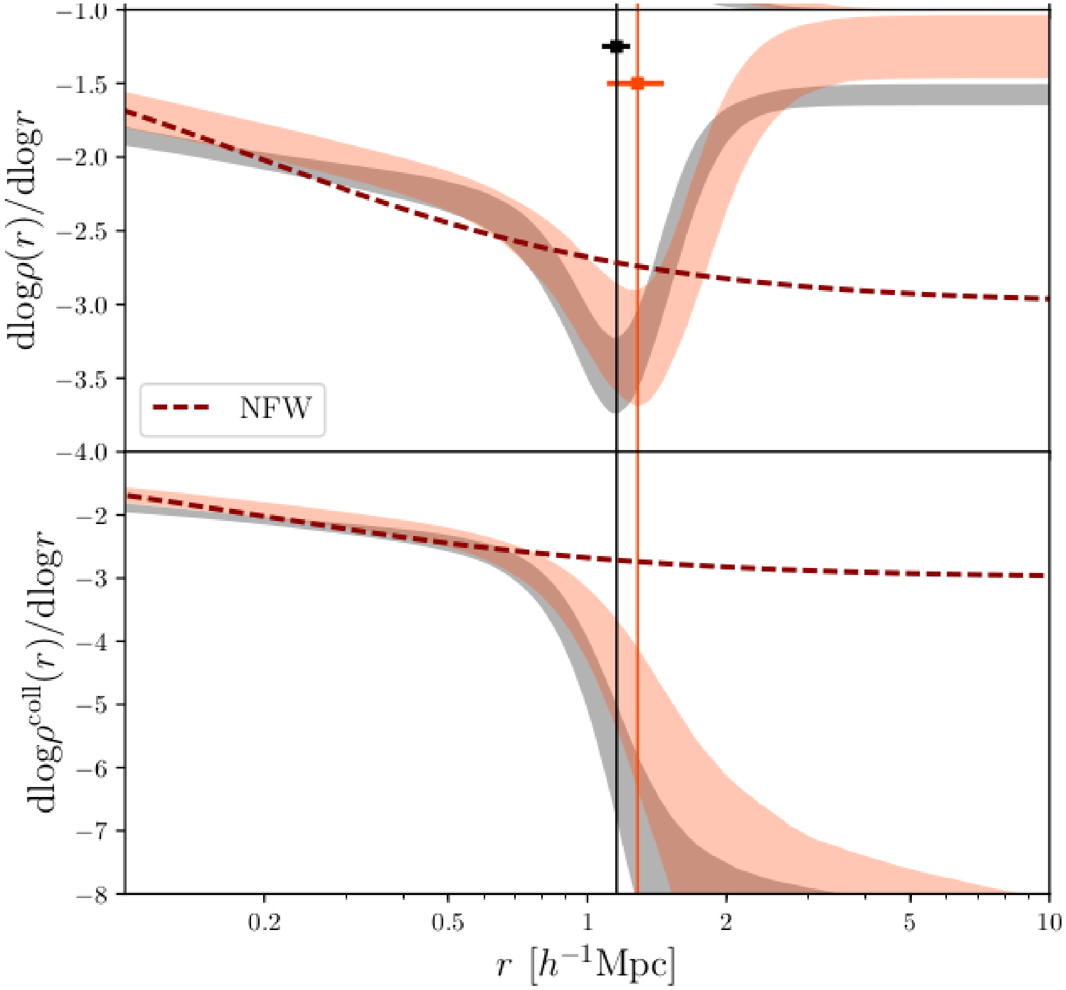
- Signatures of modified gravity

- Interactions of dark matter – Isotropic and Anisotropic interactions

Probes :

- Halo/Void profiles
- Splashback radius
- Shapes
- Velocity profiles
- Galaxy morphology

Splashback radius - current status of measurements (DES)



Baxter et al. 2017

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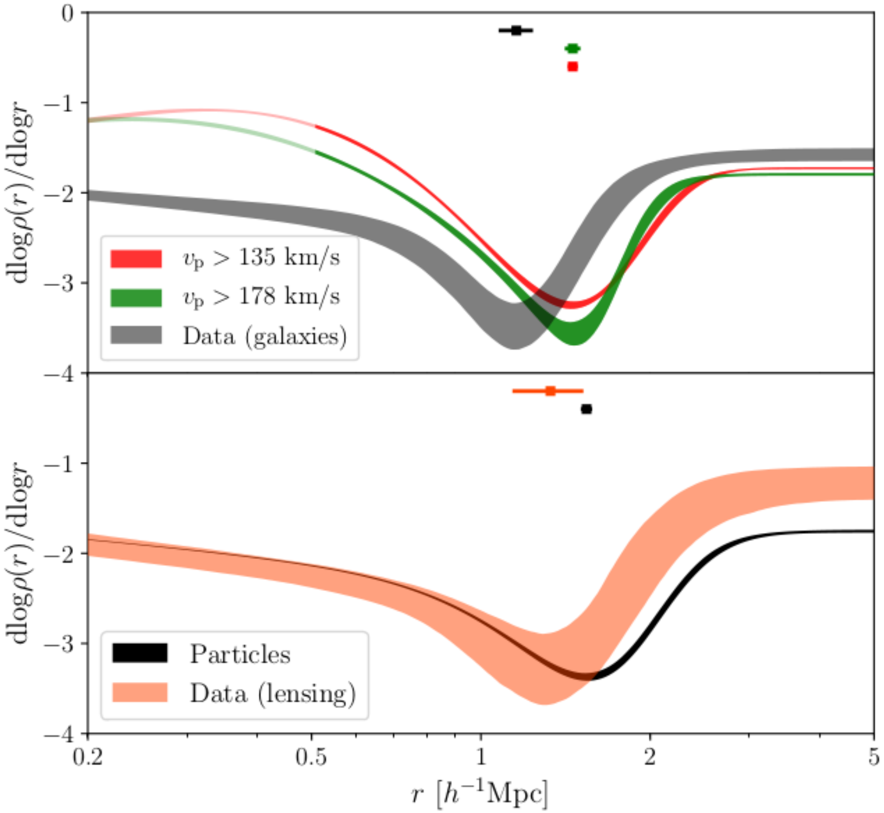
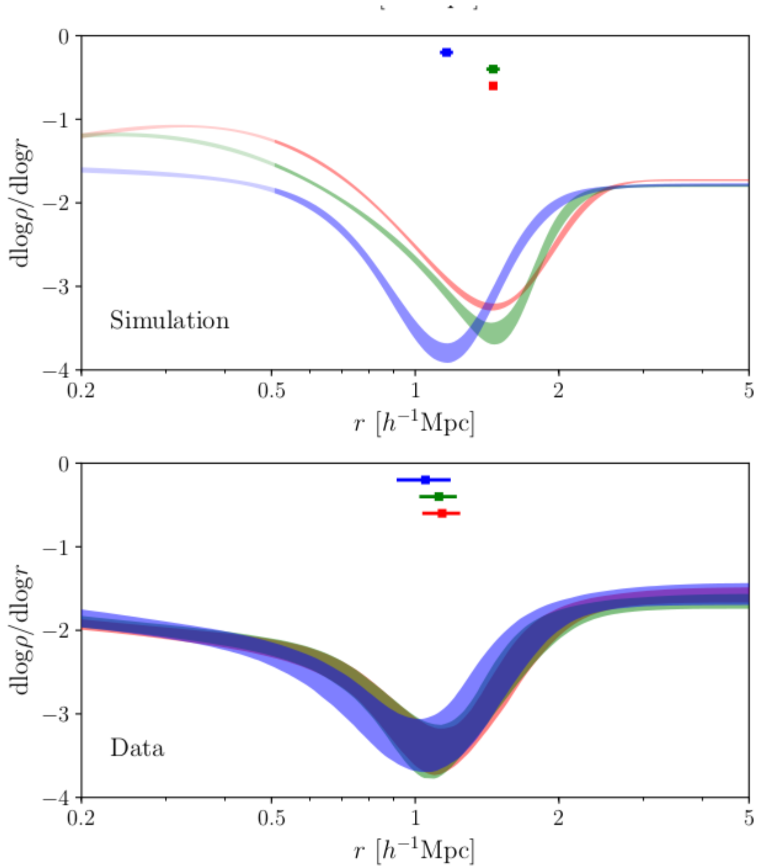


Baxter et al. 2017



Baxter et al. 2017

- Measured in galaxy profiles around RedMaPPer clusters and in lensing
- Differences with simulations in ΛCDM – Smaller than predicted and no movement with galaxy magnitude

Splashback radius in Modified Gravity

(with Jeremy Sakstein, Bhuvnesh Jain, Neal Dalal, Baojiu Li)

- Does the location of splashback radius change in modified gravity?

Splashback in nDGP models :

Extra scalar degree of freedom :

$$\nabla^2\pi + \frac{r_c^2}{3}\left[(\nabla^2\pi)^2 - \nabla_i\nabla_j\pi\nabla^i\nabla^j\pi\right] = 8\pi\alpha G\rho$$

$$F_\pi = -\alpha\pi' = -4\alpha^2\frac{GM}{r^2}g\left(\frac{r}{r_*}\right)$$

$$g(\zeta) = \zeta^3\left(\sqrt{1+\zeta^{-3}} - 1\right)$$

- Splashback radius is a scale inside the halo that can be predicted from simple Newtonian dynamics

- Orbit of an infalling shell of matter in an accreting halo in an expanding universe

- Acceleration modified in nDGP by extra force:

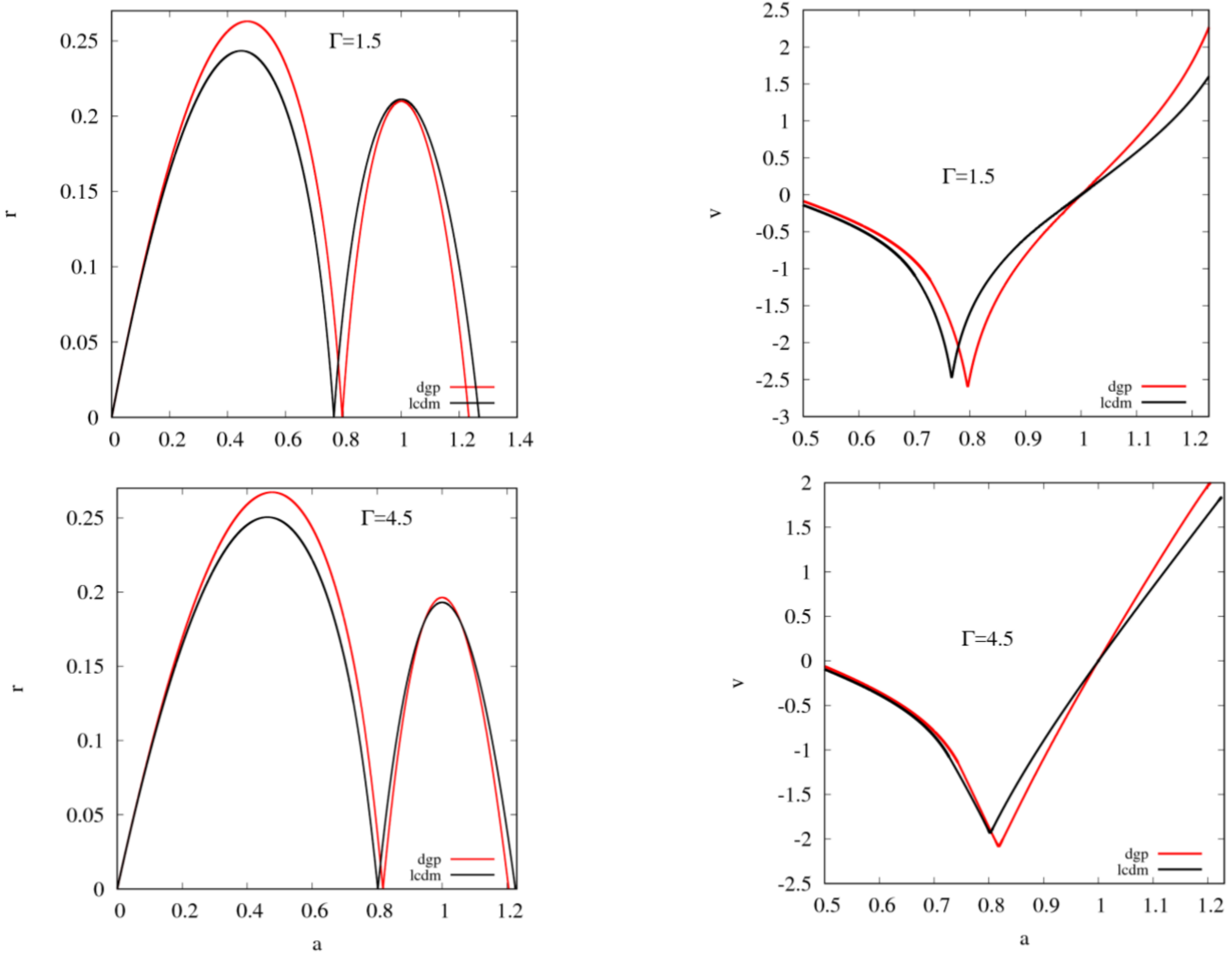
$$\ddot{r} = -\frac{GM}{r^2} + \frac{\Lambda r}{3} + F_\pi.$$

$$M_{tot} = a^s \qquad\qquad M = M_{\rm tot}\frac{f_{\rm NFW}(r/r_s)}{f_{\rm NFW}(R/r_s)}.$$

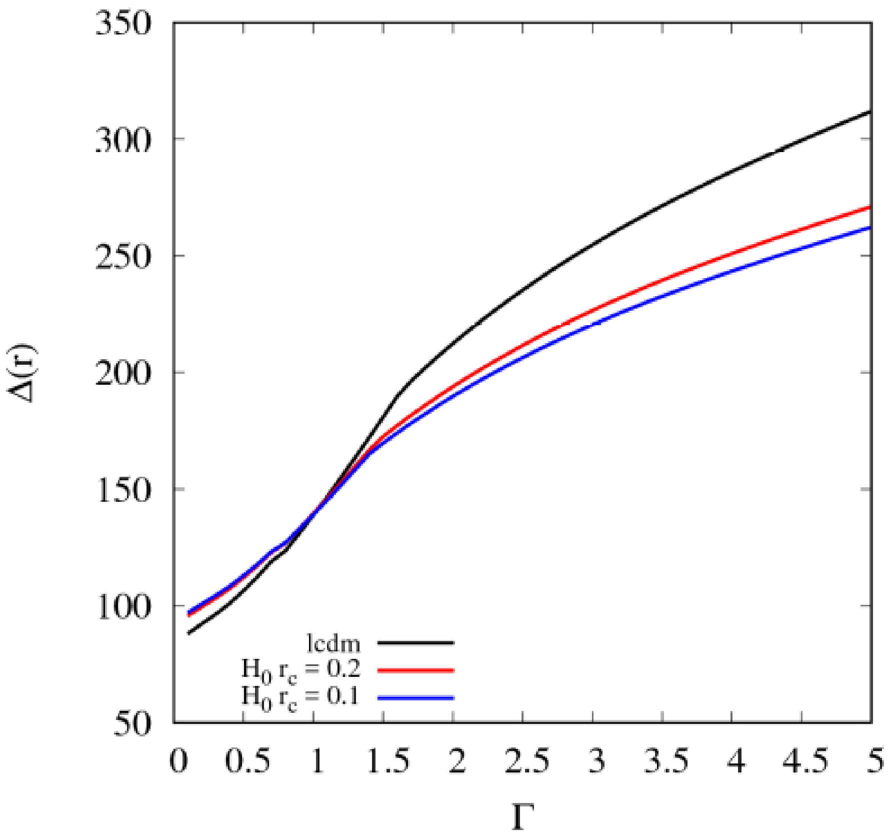
$$F_\pi = -\alpha\pi' = -4\alpha^2\frac{GM}{r^2}g\left(\frac{r}{r_*}\right)$$

- Shells are initialized from half the turnaround radius from the spherical collapse model.

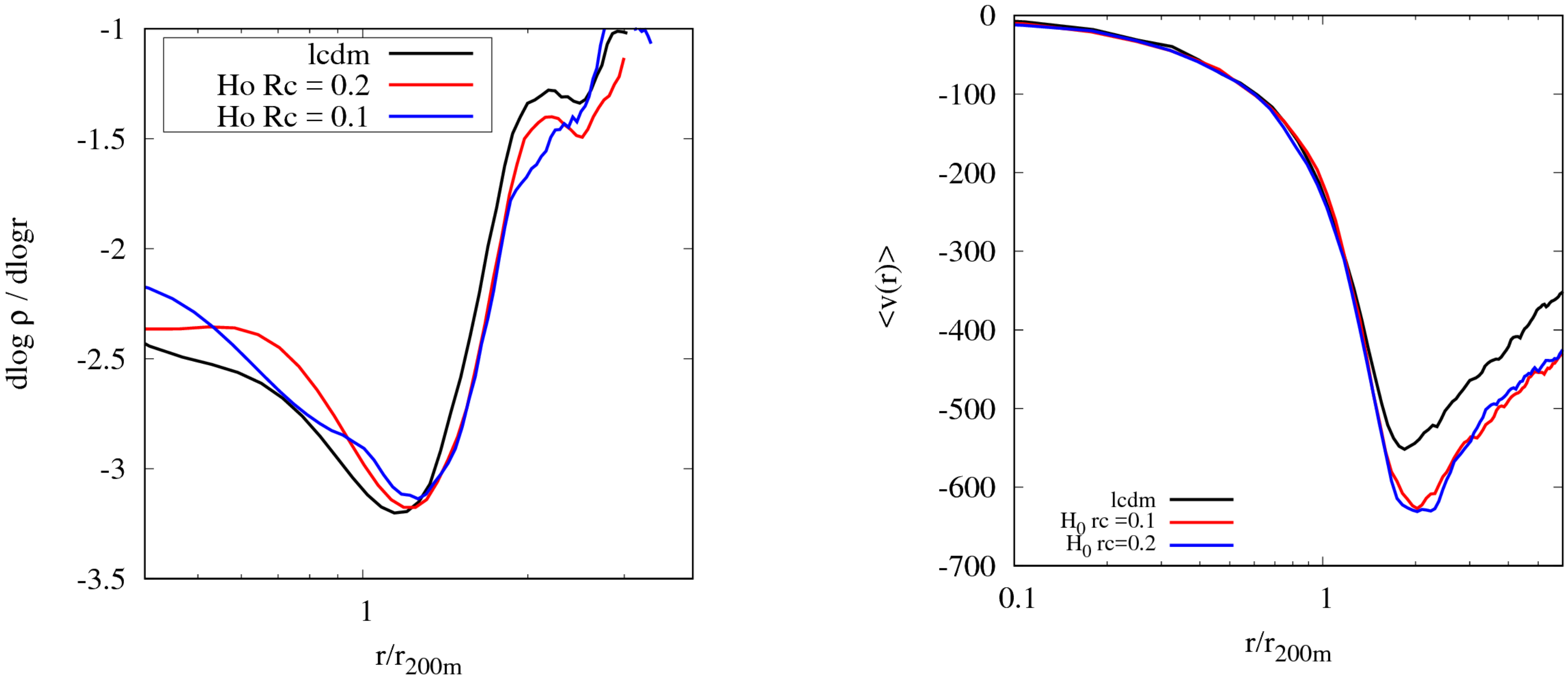
Orbits of shells in nDGP



Enclosed density at splashback as a function of accretion rate of the halo



Results from simulations

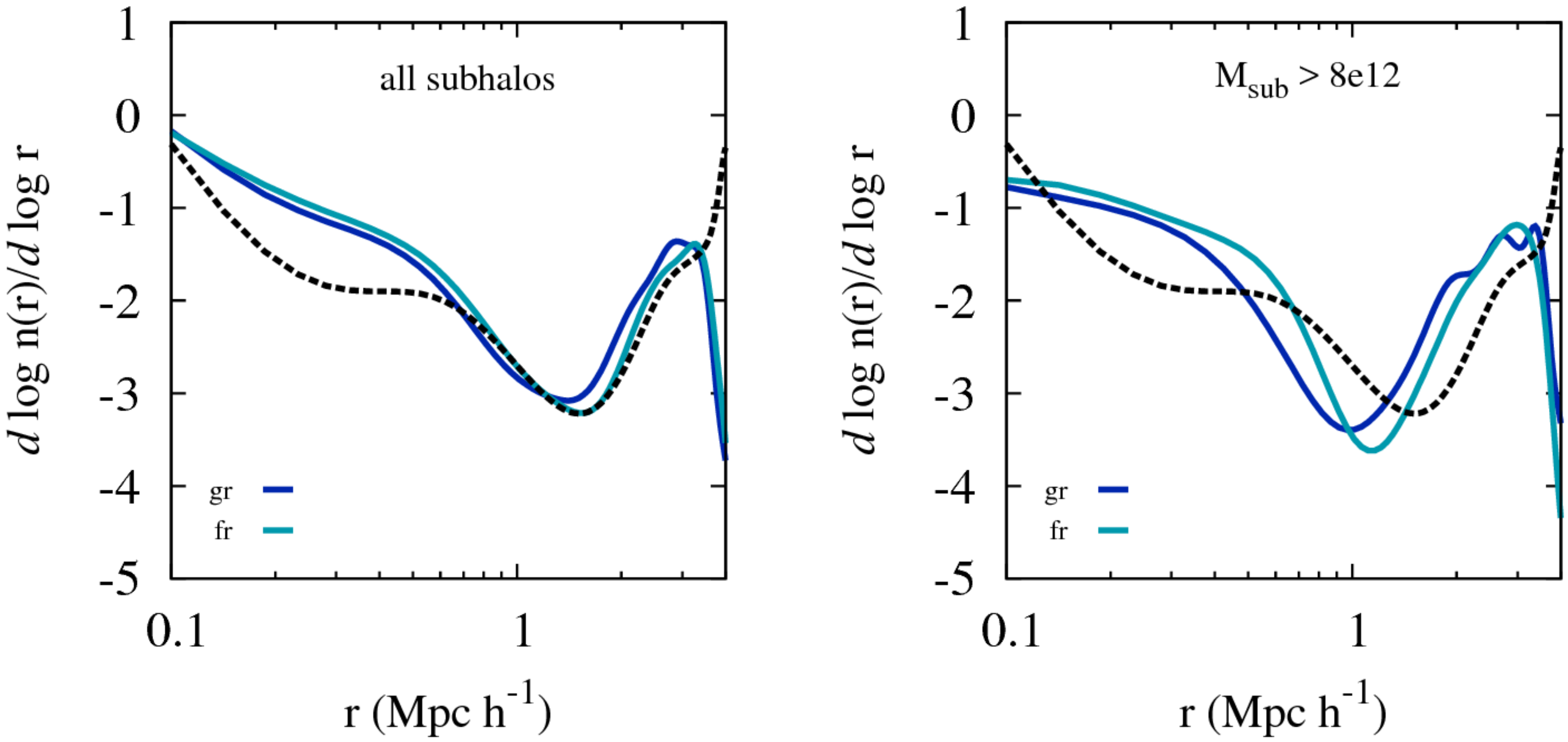


Splashback radius and velocity profile of halos stacked in mass bins of 1-4e14 M_{sun} h^{-1}

ECOSMOG – Efficient code for simulating modified Gravity (*Baojiu Li et al. 2011*)

400 Mpc h^{-1} box with 512^3 particles

Subhalos in f(R) simulations with $f_R = 10^{-5}$



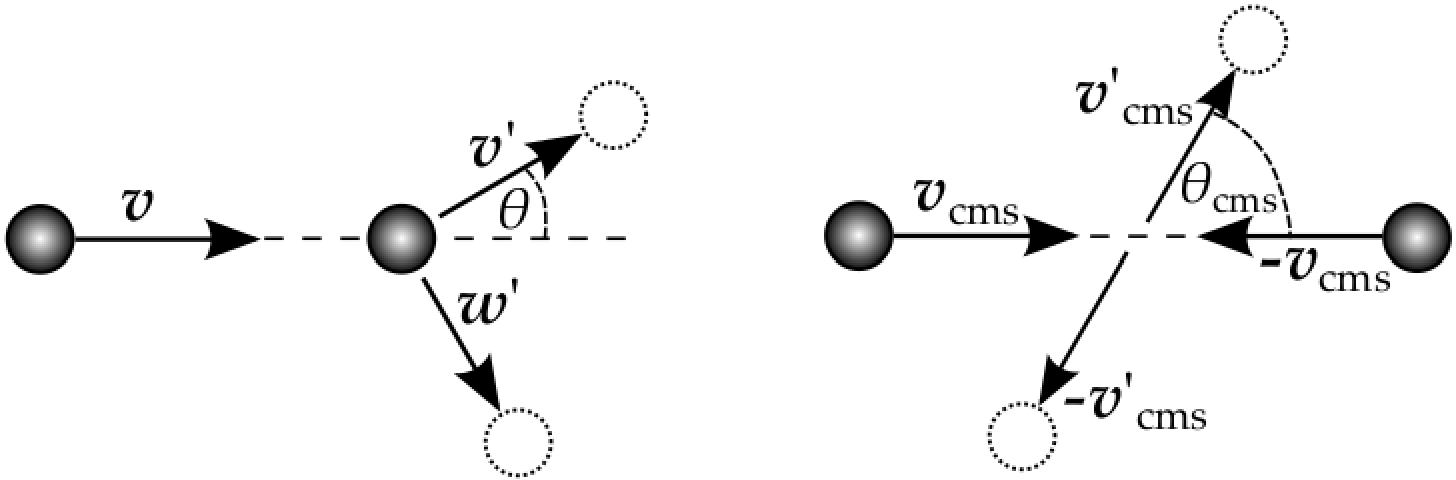
- 1024^3 particles, 1Gpc h^{-1} box
- Massive subhalos splashback at different locations in GR and f(R)
- Differences in strength of dynamical friction?

Further work

- Run larger simulation boxes to get better statistics for massive clusters.
- Follow the dynamics of subhalos to check effects of dynamical friction.
- Extend analytical calculations to other models, eg. beyond Horndeski.
- Cosmological simulations are available for f(R) and DGP mostly.

Dark Matter Self-Interactions

(with Arka Banerjee, Neal Dalal, Suhrud More, Andrey Kravtsov)



Possible signatures:

i) Evaporation of subhalos

ii) Displacement of lensing profile and light profile

iii) Halo profiles (Splashback, velocity structure)

iv) Warping of disks (**NEW**)

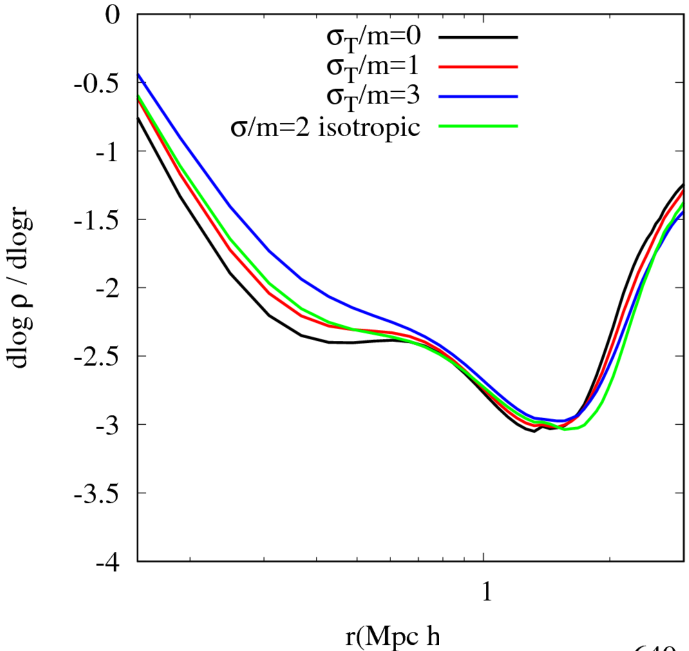
Anisoropic scattering vs. Isotropic scattering

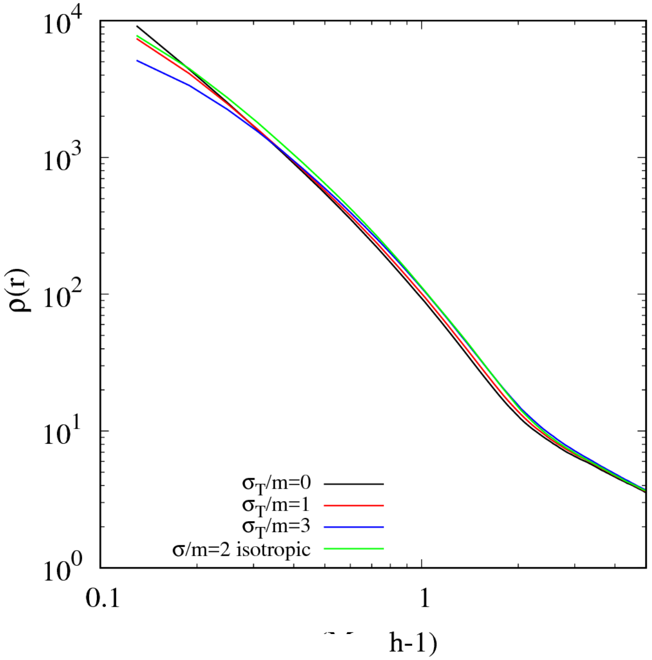
- Scattering probability is high only at small angles
- Small momentum transfer at each interaction
- Net drag force $$\frac{F_{\rm drag}}{m_{\rm DM}} = \frac{\tilde{\sigma}}{4\, m_{\rm DM}} \rho\, v_0^{2m}$$
- Cumulative evaporation still important but not as strong as isotropic scattering

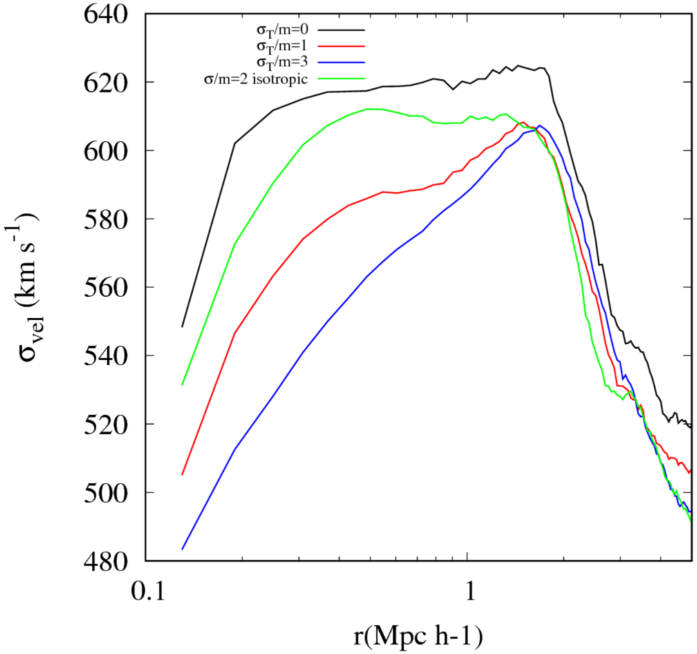
- Cosmological simulations are available for Isotropic scattering cross-sections
- Cosmological simulations for anisotropic scattering (work in progress)

Cosmological simulations of anisotropic SIDM

1Gpc h^{-1} box with 1024^3 particles

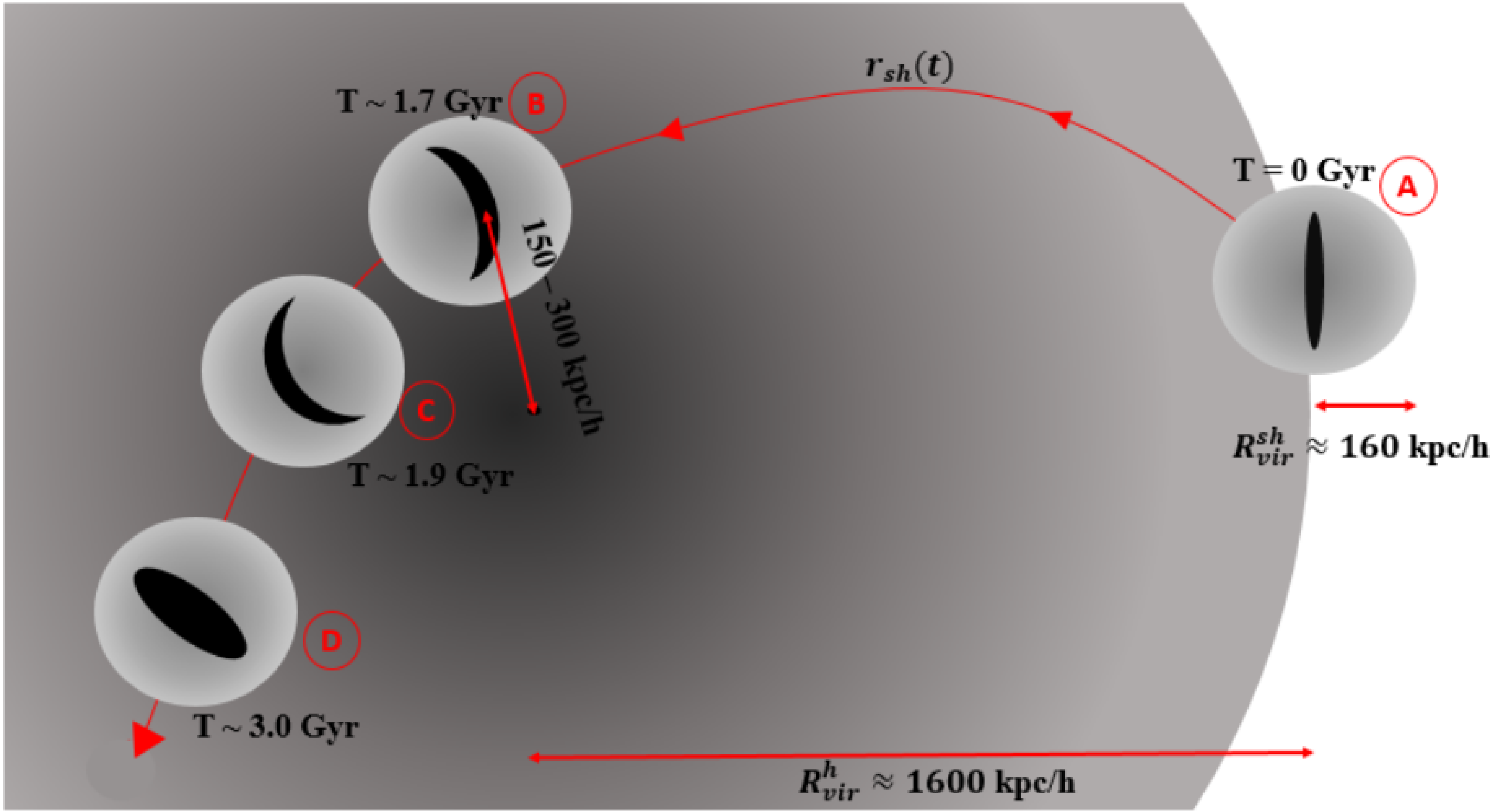




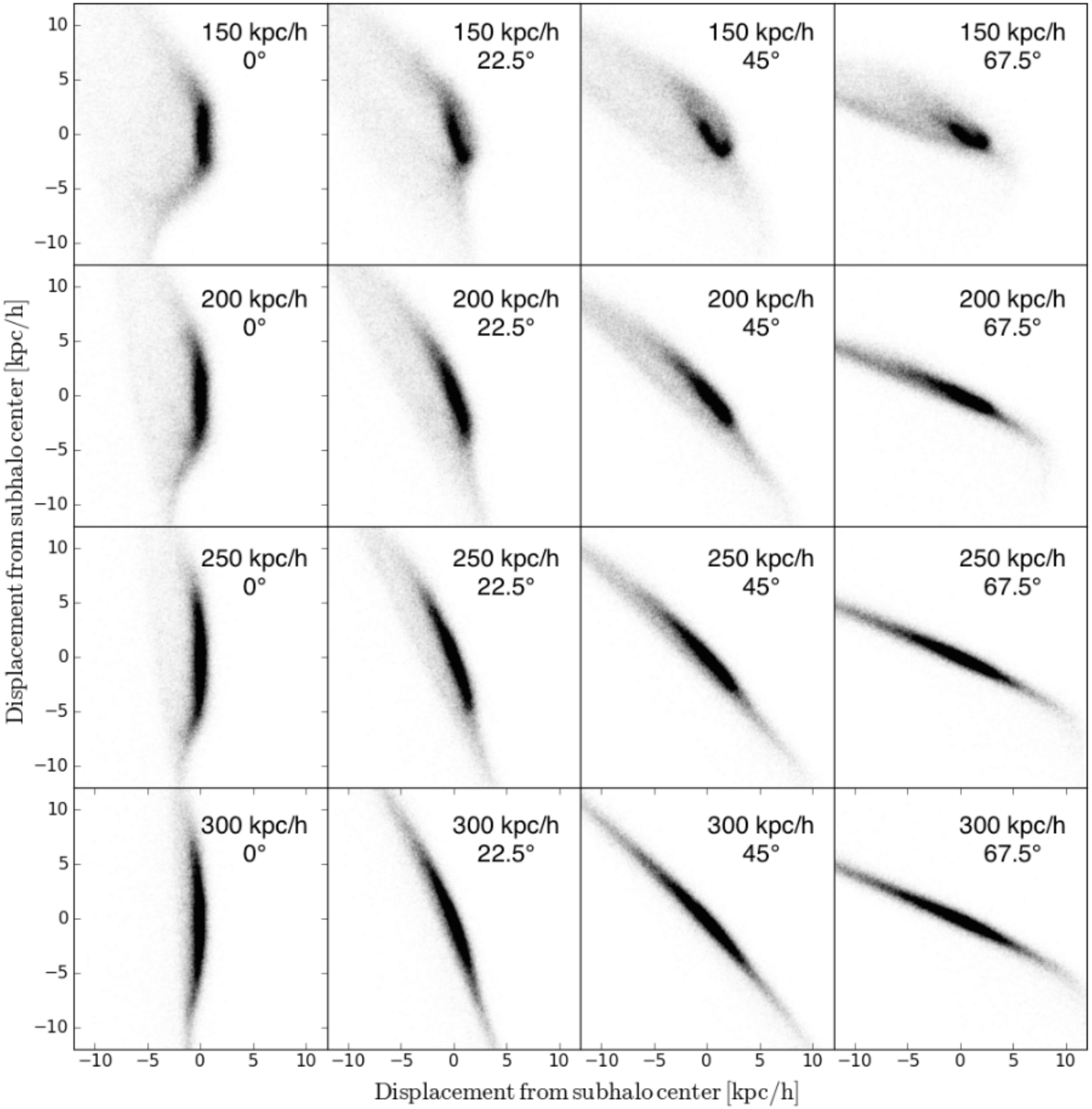


Warping of Disks in anisotropic SIDM

(lead by Lucas Secco)



Edge on galaxies falling in at different impact parameters



Summarizing…

- Simulating Velocity dependent anisotropic cross-sections.

  $1/v^2$ dependence of drag force, becomes important in lower mass halos than clusters

- Zoom in simulations of subhalo+galaxy infalling into clusters to measure displacements.

- Effect of gas on disk morphologies (Illustris+SIDM)

- Orbital kinematics of subhalos and particles in SIDM.