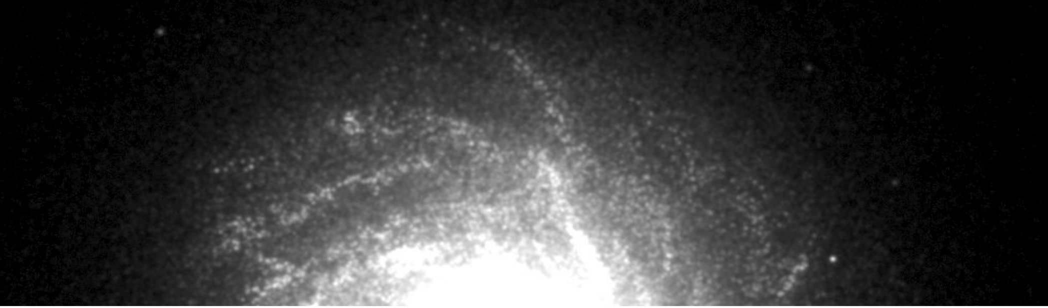

Dark Ghosts
Brussels 2018

Astrophysical uncertainties on Dark Matter Capture by the Sun and the connection with Cosmological Simulations

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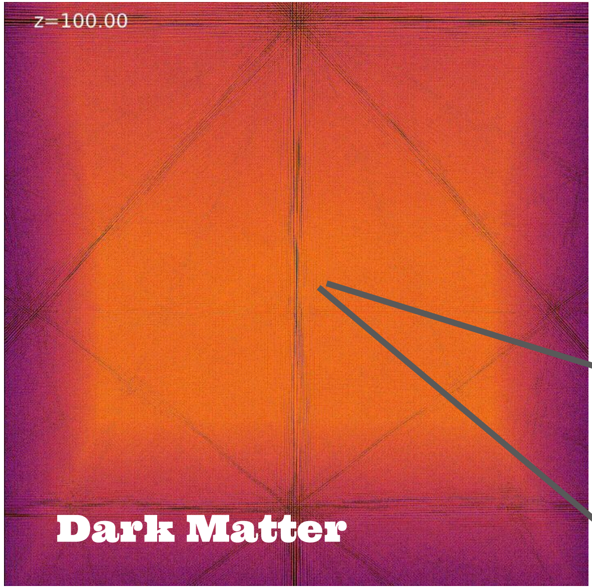
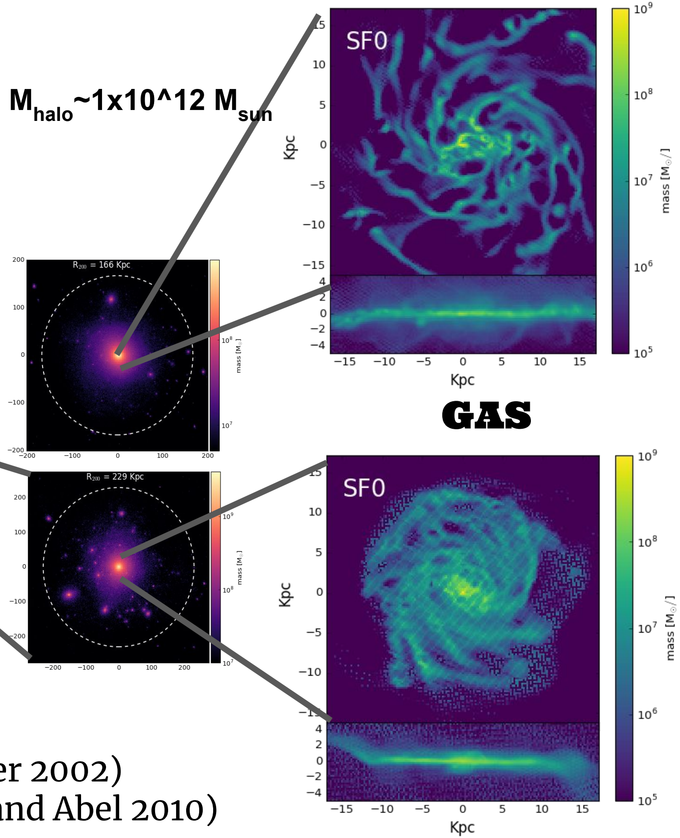
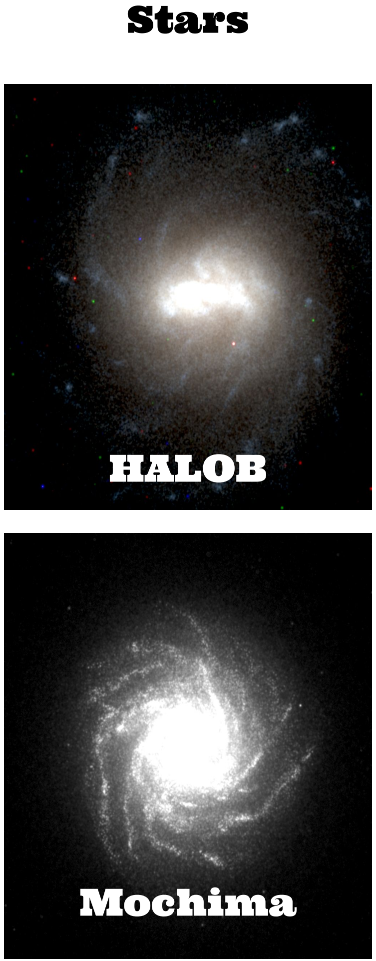
Cosmological simulations

Cosmological hydrodynamical Zoom-in Simulations

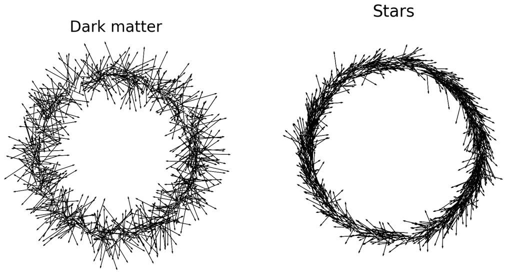


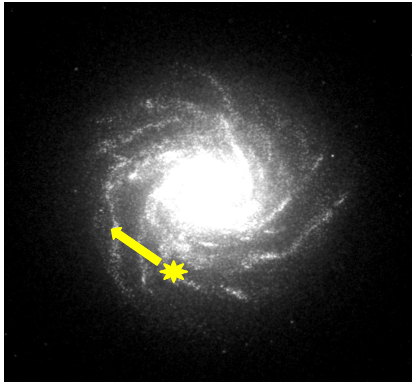




Code: Ramses AMR (Teyssier 2002)
Initial Conditions: MUSIC (Hahn and Abel 2010)

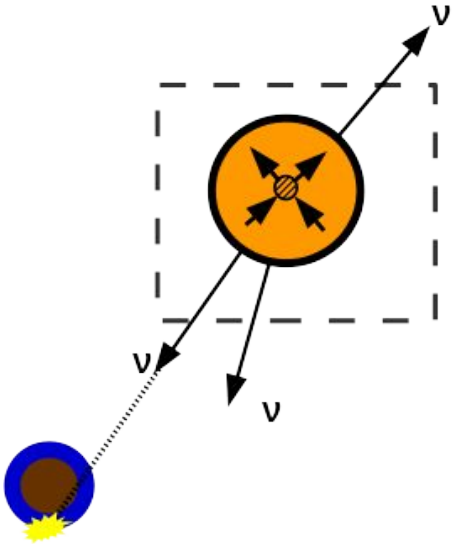
DM capture by the Sun





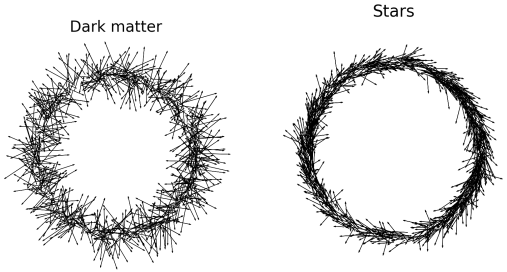
$$\frac{dC}{dV} = \frac{\rho}{M_\chi} \int_0^{u_m} du \frac{f(u)}{u} w\Omega(w)$$

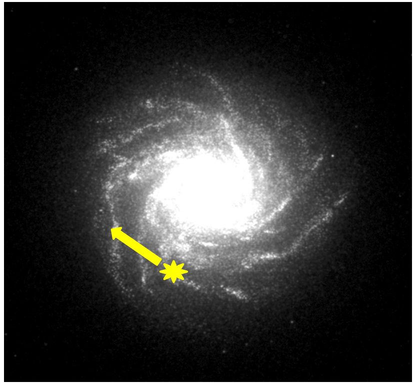
Astrophysics and **Particle Physics** come together

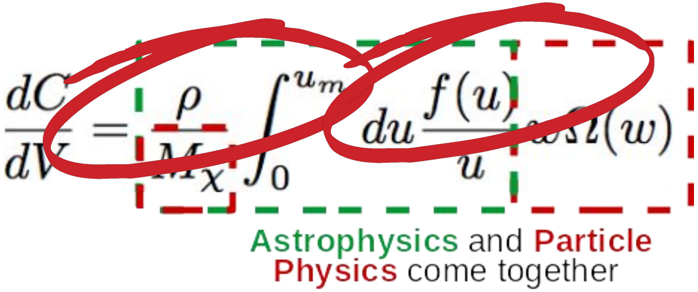


(Press and Spergel 1985)
(A. Gould 1987)
(G. Jungmann, M. Kamionkowski, K. Griest 1996)
(Ling 2010)
(Choi et al 2014)
(Garani et al 2017)

DM capture by the Sun







Main source of uncertainties:

- Local Dark Matter velocity distribution
- Local Dark Matter density

Press and Spergel 1985
(A. Gould 1987)
(G. Jungmann, M. Kamionkowski, K. Griest 1996)
(Ling 2010)
(Choi et al 2014)
(Garani et al 2017)

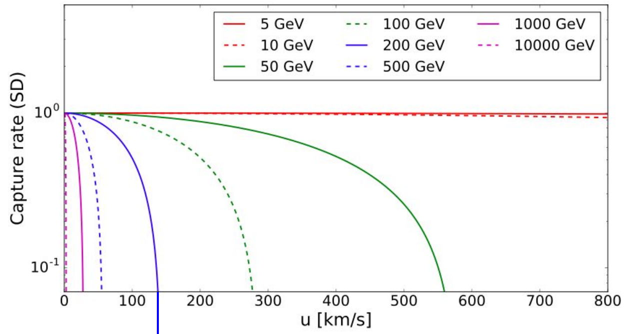
$$f(u) \to \delta(u - u')$$

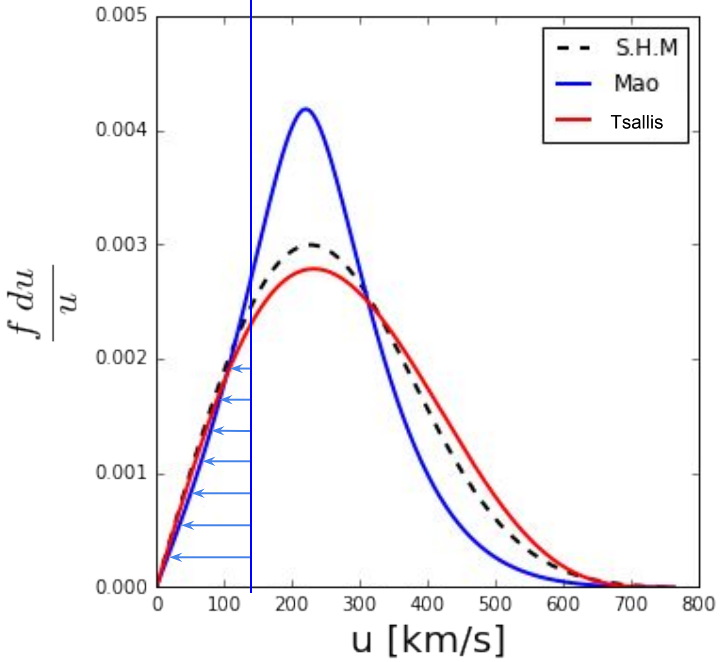
DM capture by the Sun

$$\frac{dC}{dV} = \frac{\rho}{M_\chi} \int_0^{u_m} du \frac{f(u)}{u} w\Omega(w)$$

Astrophysics and Particle Physics come together

Is there equilibrium between the capture and annihilation?





The Standard Halo Model

Uncertainties in Dark Matter distribution features

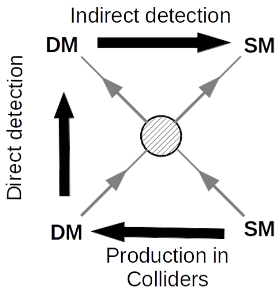
Standard Assumptions:

- Mass profile = NFW (DMO motivated)
- Phase space distribution = Maxwellian Distribution

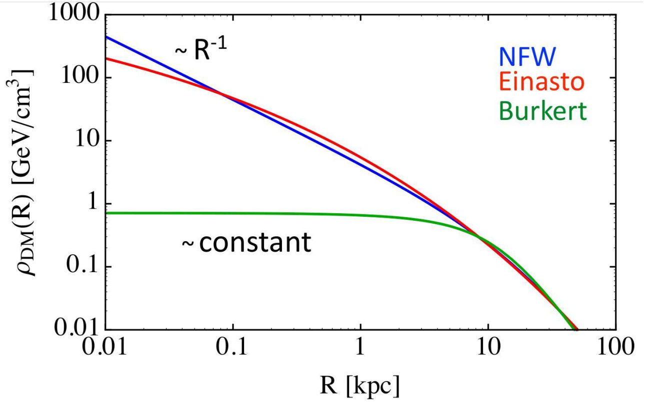
(Solar neighbourhood)

- ρ_o~0.3 - 0.4 Gev/cm^3
- v_{esc}~544 km/s
- V_c~220 - 270 km/s

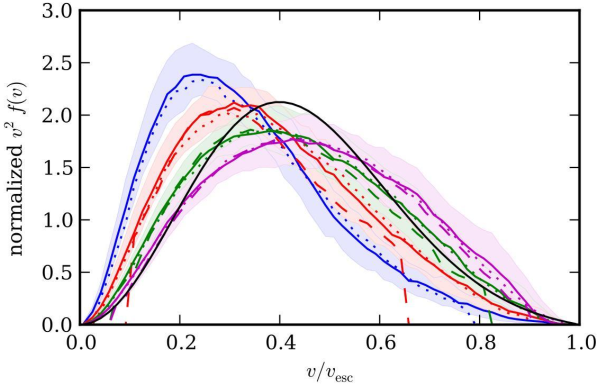
...Often used as input for dark matter detection limits and theoretical predictions but not really agreeing with galactic dynamics and/or cosmological simulations...



Mass profile



Phase space distribution



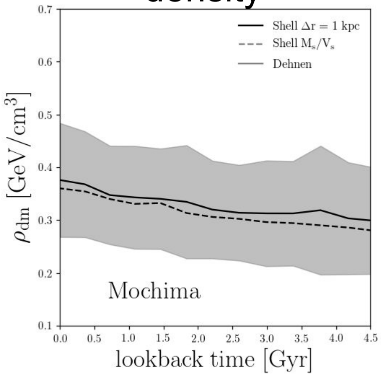
Mao et al.(arxiv:1210.2721)

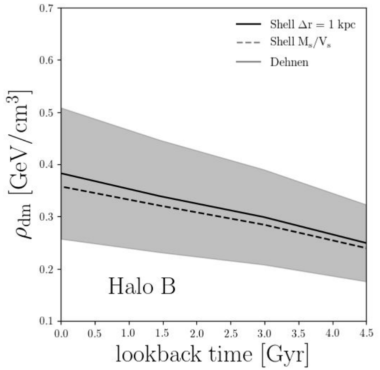
Equilibrium

Are ρ_{DM} and f(v) constant in time throughout the life of the solar system?

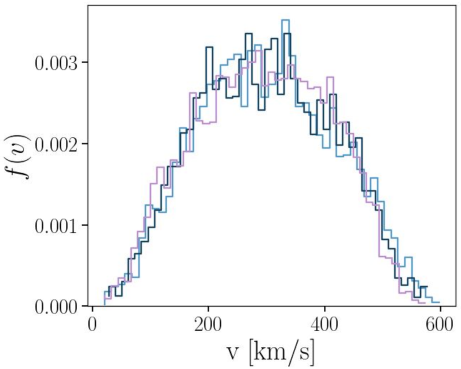
Time evolution in the solar system lifetime

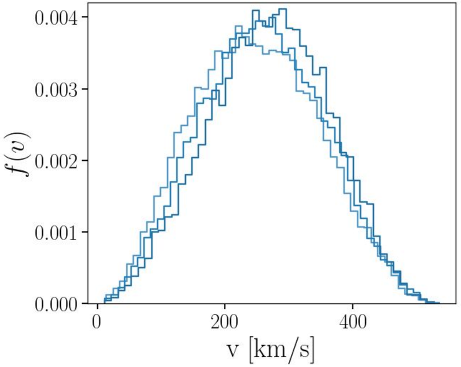
Local DM density



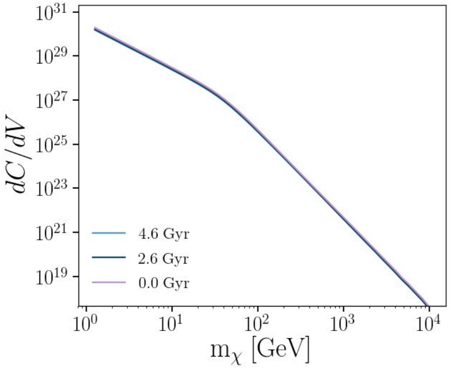


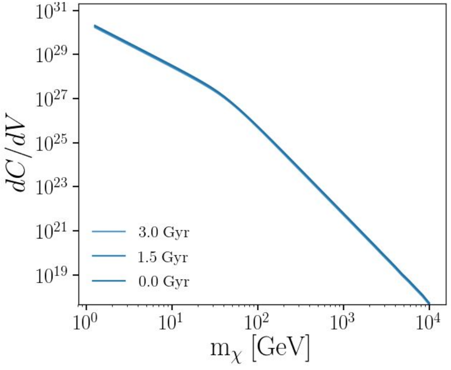
Velocity distribution





Capture by the Sun





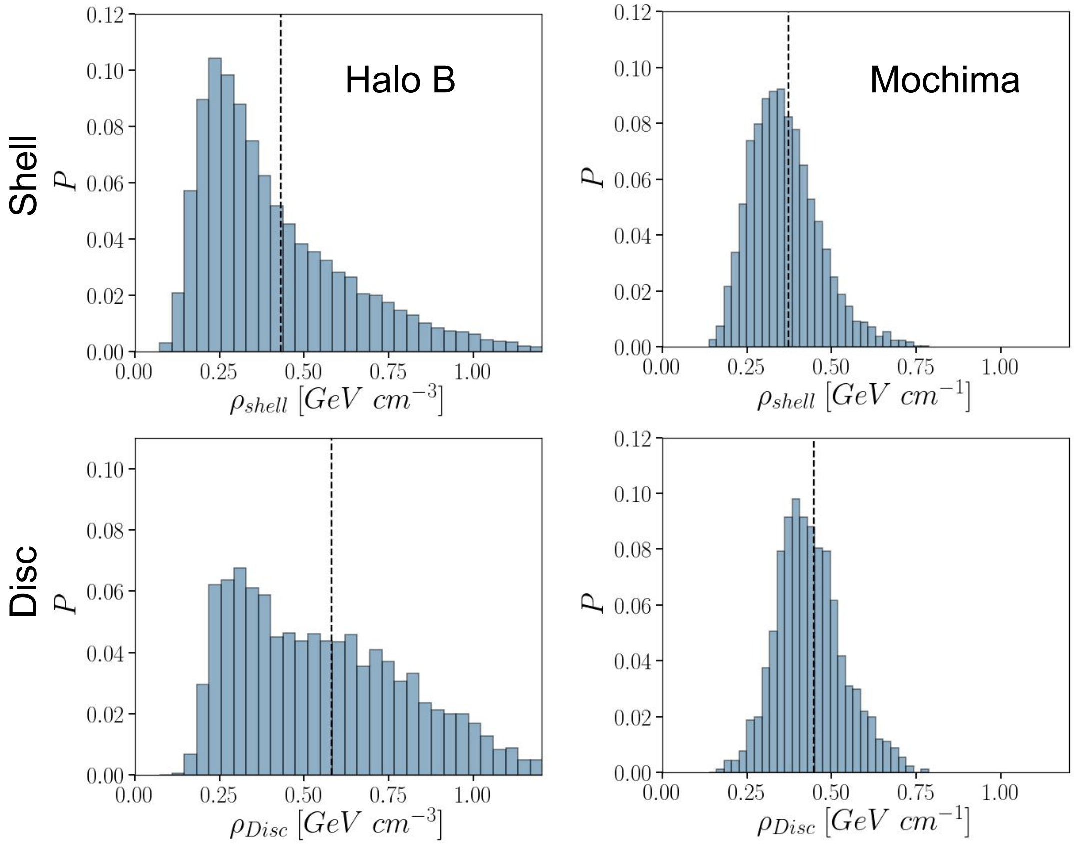
Uncertainties in ρ_{DM}

Local Dark Matter density

Different uncertainties from observations

0.3 ± 0.1 [arxiv:1205.4033]
0.30 ± 0.03 [arxiv:1810.09466]
0.39 ± 0.03 [arxiv:0907.0018]
0.46+-0.08 [arxiv:1708.07836]
0.542 ± 0.042 [arXiv:1406.6896]
0.88 ± 0.46 [arxiv:1808.05603]

From Simulations



Uncertainties in f(v)

Velocity distribution

- **Fitting the velocity distribution:**
  Fitting on the simulation data fails to reproduce the tail and/or the hat of the distribution

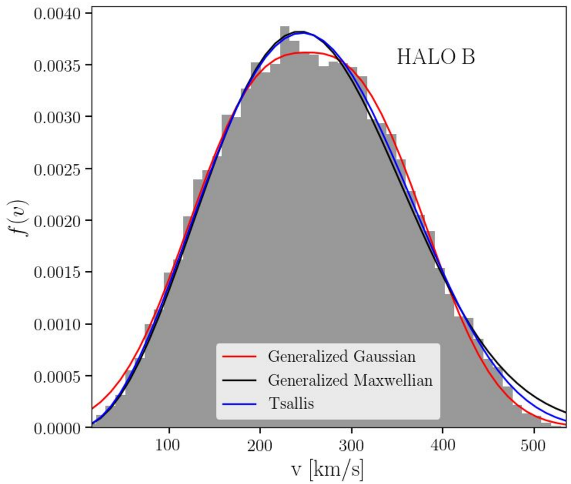
Generalized Gaussian
$$f(v) = \frac{1}{N(v_0,\alpha)} e^{-((v-\mu)^2/v_0^2)^\alpha}$$

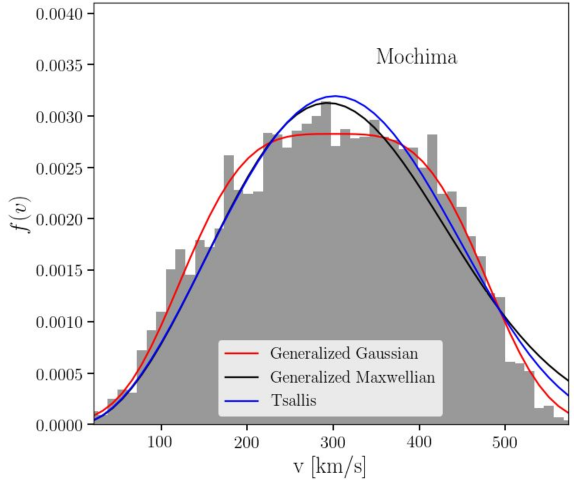
Generalized Maxwellian
$$f(\vec{v}) = \frac{1}{N(v_0,\alpha)} e^{-(\vec{v^2}/v_0^2)^\alpha}$$

Tsallis
$$f(\vec{v}) = \frac{1}{N(v_0,q)} \left(1-(1-q)\frac{\vec{v}^2}{v_0^2}\right)^{q/(1-q)}$$

[arxiv:9511007],[arxiv:0909.2028]

Having several MW-like simulations would allow to do statistics to understand the behavior of f(v)

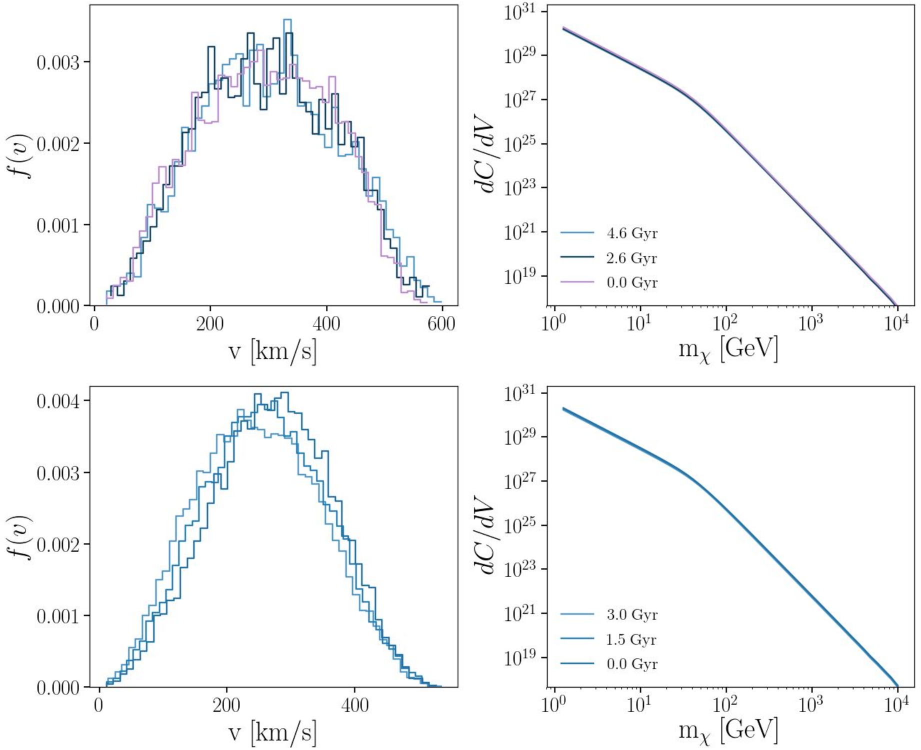




Velocity distribution

- **Fitting the velocity distribution:**
  Fitting on the simulation data fails to reproduce the tail and/or the hat of the distribution

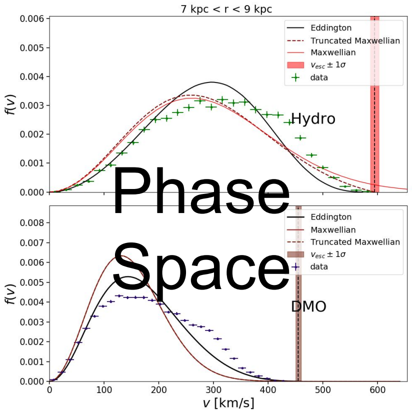
- **Using directly the Simulation data:**
  Each galaxy has different dynamics, therefore extrapolating the results of one to the other has no real meaning



Eddington inversion

Dynamically self consistent approach

Velocity distribution inferred from gravitational potential



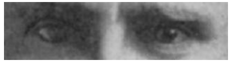
$$\rho_{DM}(r) + \rho_{baryons}(r)$$

From the simulation

$$f(\mathcal{E}) = \frac{1}{\sqrt{8}\pi^2}\left(\frac{1}{\sqrt{\mathcal{E}}}\left[\frac{d\rho}{\Psi}\right]_{\Psi=0} + \int_0^{\mathcal{E}} \frac{d\Psi}{\sqrt{\mathcal{E}-\Psi}}\frac{d^3\rho}{d\Psi^3}\right)$$

$$f(\vec{r},\vec{v}) = f(\mathcal{E}, L)$$

Eddington inversion



Predictions from the Eddington method as studied by Lacroix et al. (Lacroix et al and from Binney - Tremaine) of f(v)

vs

fully consistent objects build in a Zoom-in Cosmological Simulation.\

$$f(\vec{r},\vec{v}) = f(\mathcal{E}, L)$$

Density profile → Eddington inversion → f(ε) → f(v)

$$\rho_{DM}(r) + \rho_{baryons}(r)$$

$$\frac{d\rho}{d\Psi}$$

Assuming spherical symmetry and isotropy

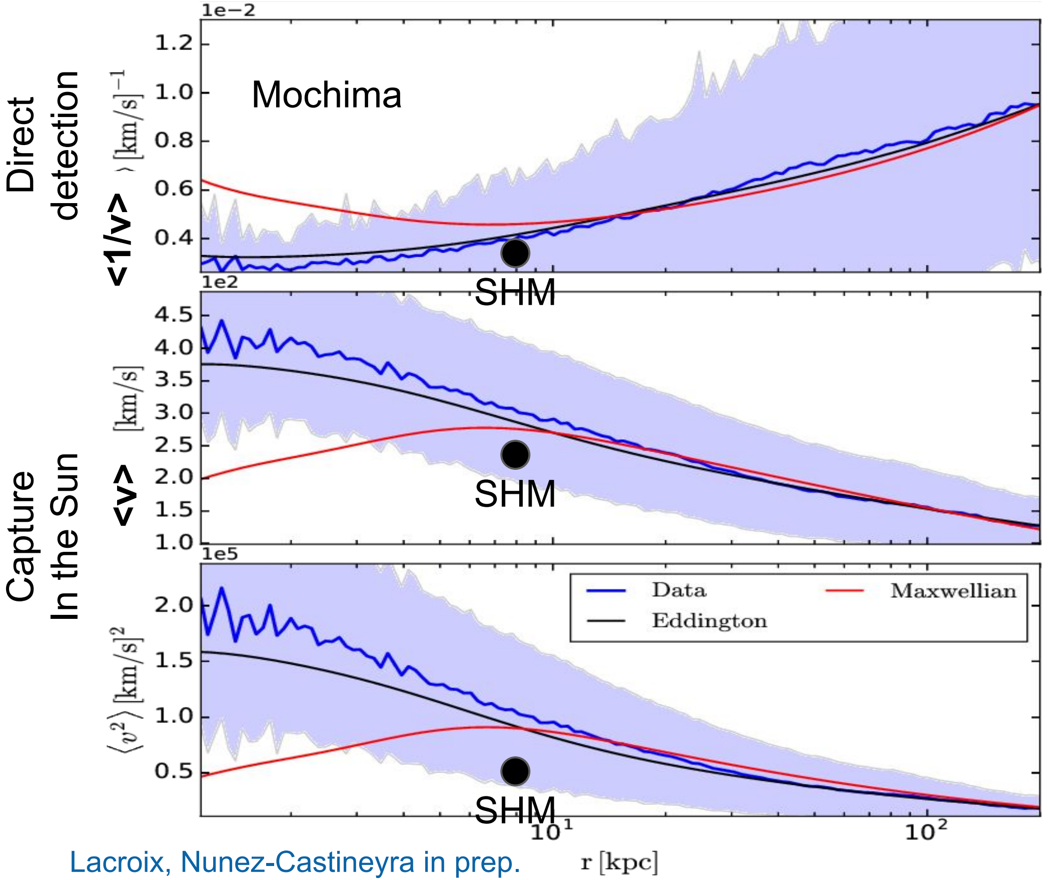
$$\mathcal{E} = \Psi(r) - \frac{v^2}{2}$$

$$\Psi = \Phi(r) - \Phi(r_{max})$$

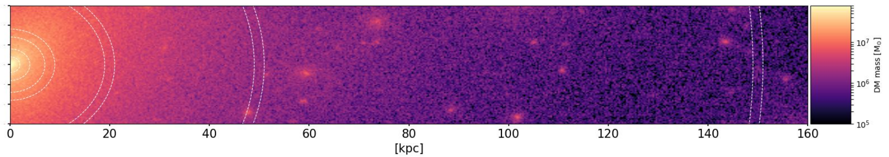
$$f(\mathcal{E}) = \frac{1}{\sqrt{8}\pi^2}\left(\frac{1}{\sqrt{\mathcal{E}}}\left[\frac{d\rho}{\Psi}\right]_{\Psi=0} + \int_0^{\mathcal{E}} \frac{d\Psi}{\sqrt{\mathcal{E}-\Psi}}\frac{d^3\rho}{d\Psi^3}\right)$$

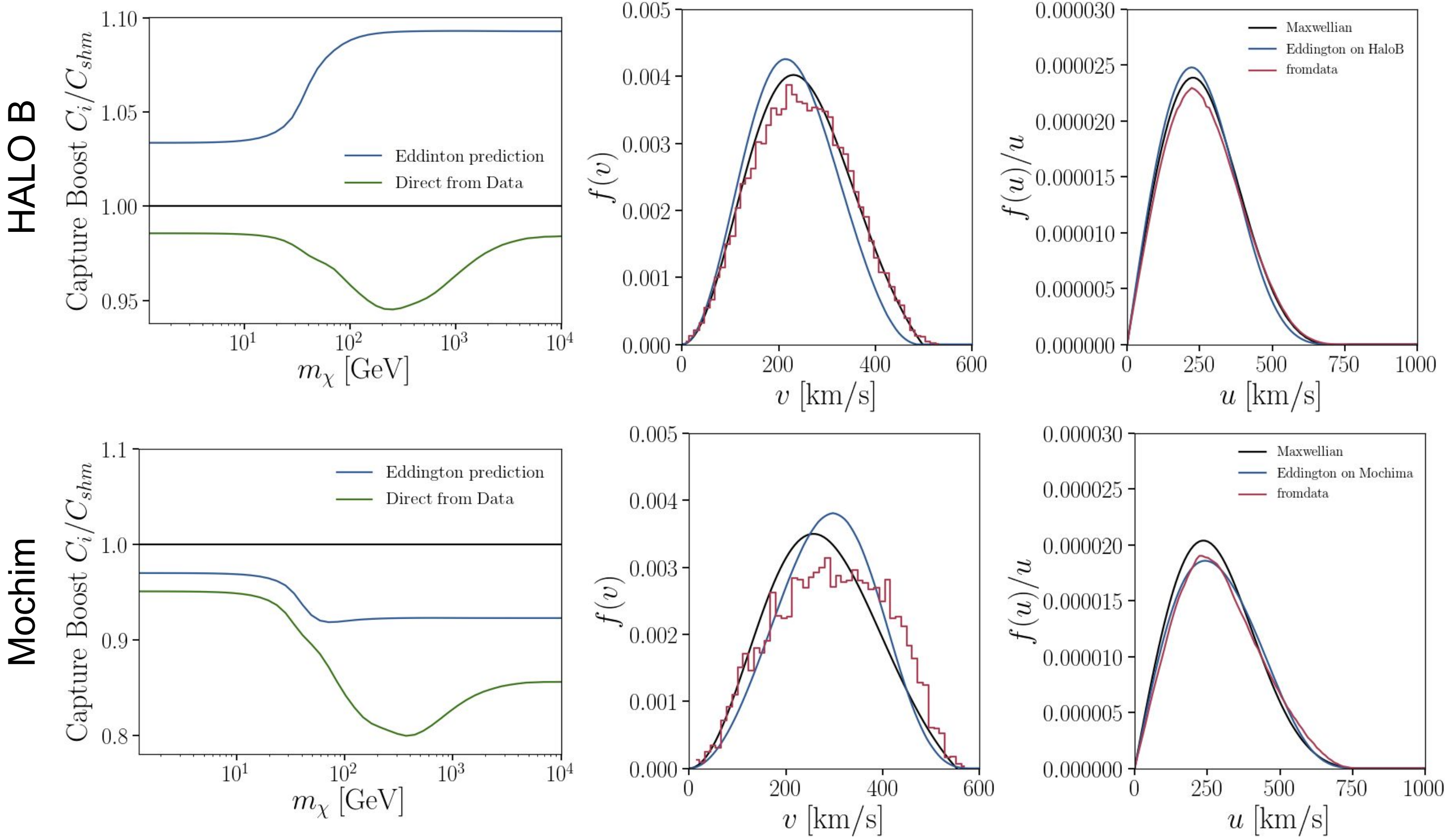
Statistical moments of the velocity distributions

Direct and Indirect DM detection relevant quantities



Lacroix, Nunez-Castineyra in prep.

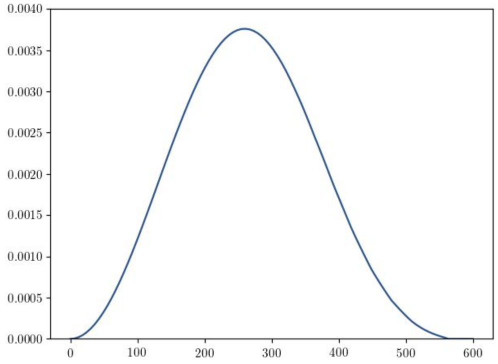




Nunez-Castineyra,Bertin, Nezri in prep.

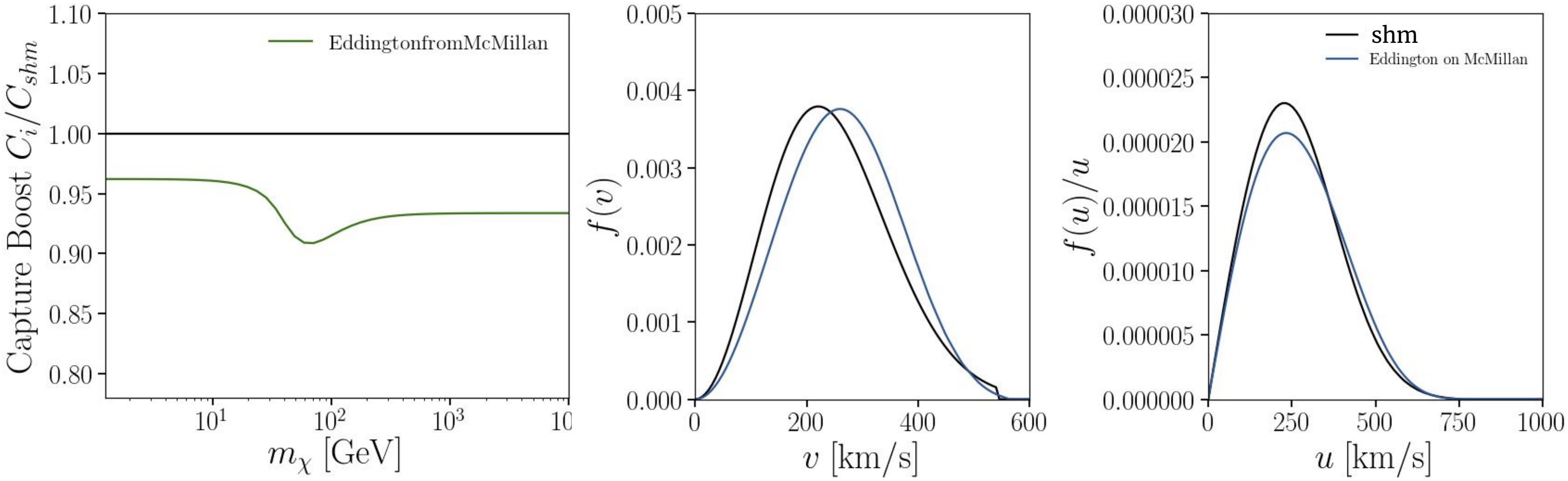
Eddington inversion

Milky way dynamical models:
McMillan [arxiv:1102.4340/1608.00971]
Gaia data



Phase space

Eddington inversions on dynamical Models of the Milky way



Nunez-Castineyra,Bertin, Nezri in prep.

Summary

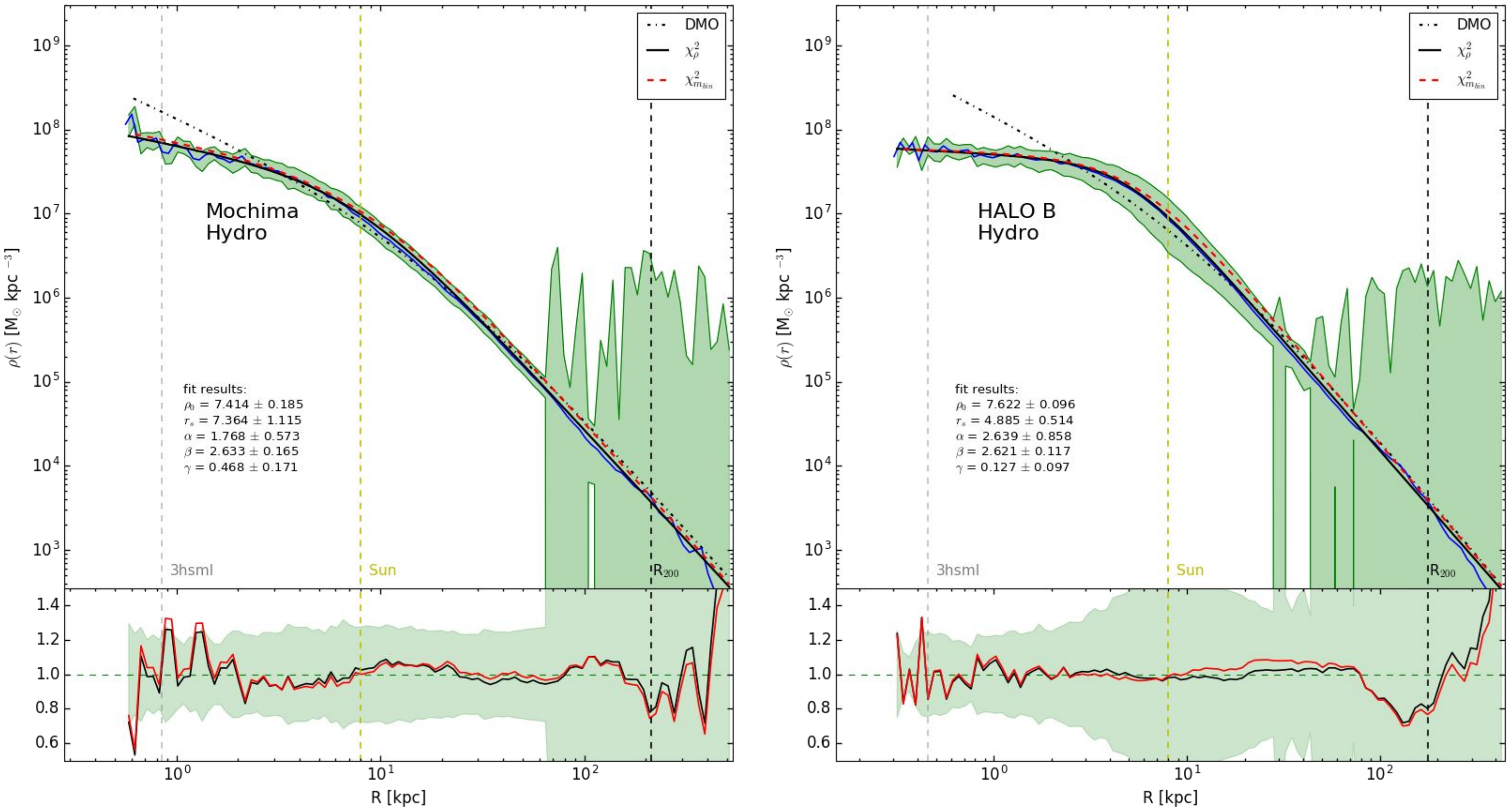
- ρ_{local} fluctuations in time fall within the uncertainty bands, f(v) fluctuations are not dramatic. (beware of recent merger histories.)

- The effect of changing f(v) is of ~5-10 % while ρ_{local} uncertaities are higher thatn 30-40%. this could have a much bigger effect on the detection limits. (waiting for improvements from GAIA data)

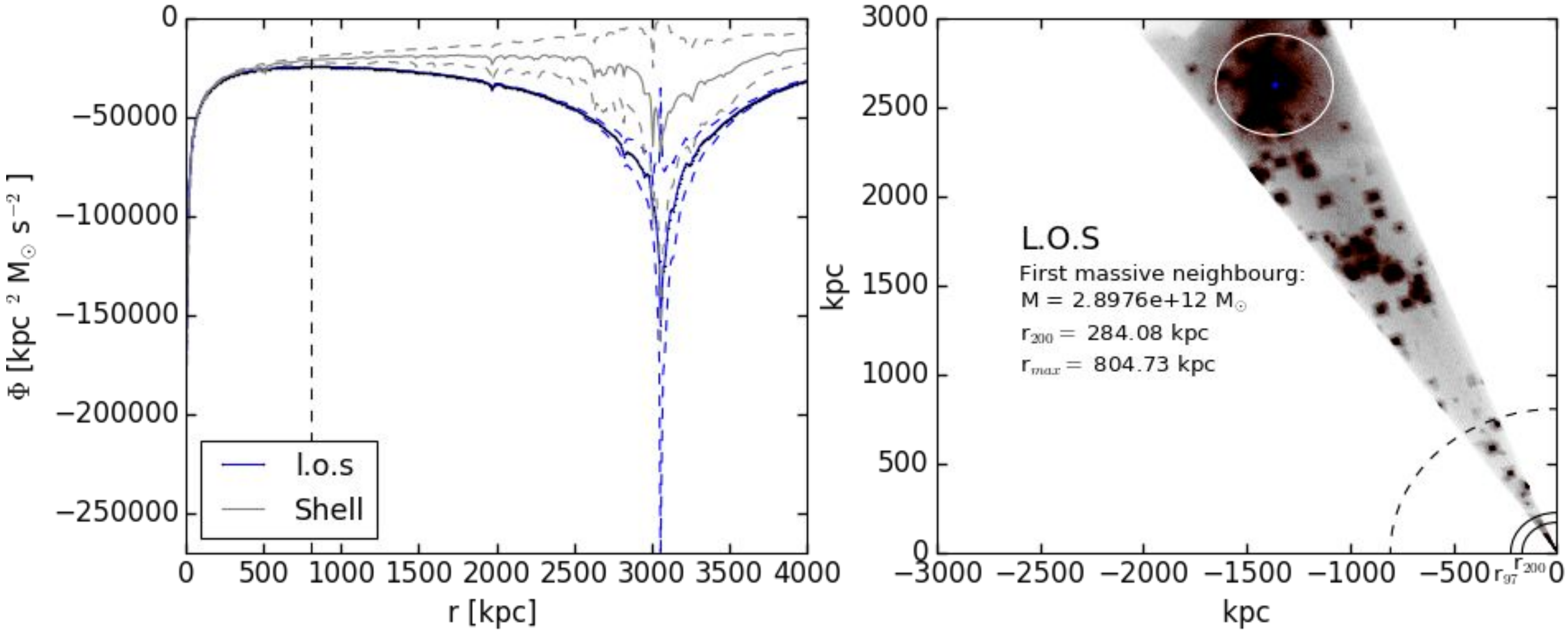
- Extrapolating directly the DM features in MW-like Simulations (= first step)

- Comfronting Simulations and dynamical methods is much more consistent (= educated use of simulations.)

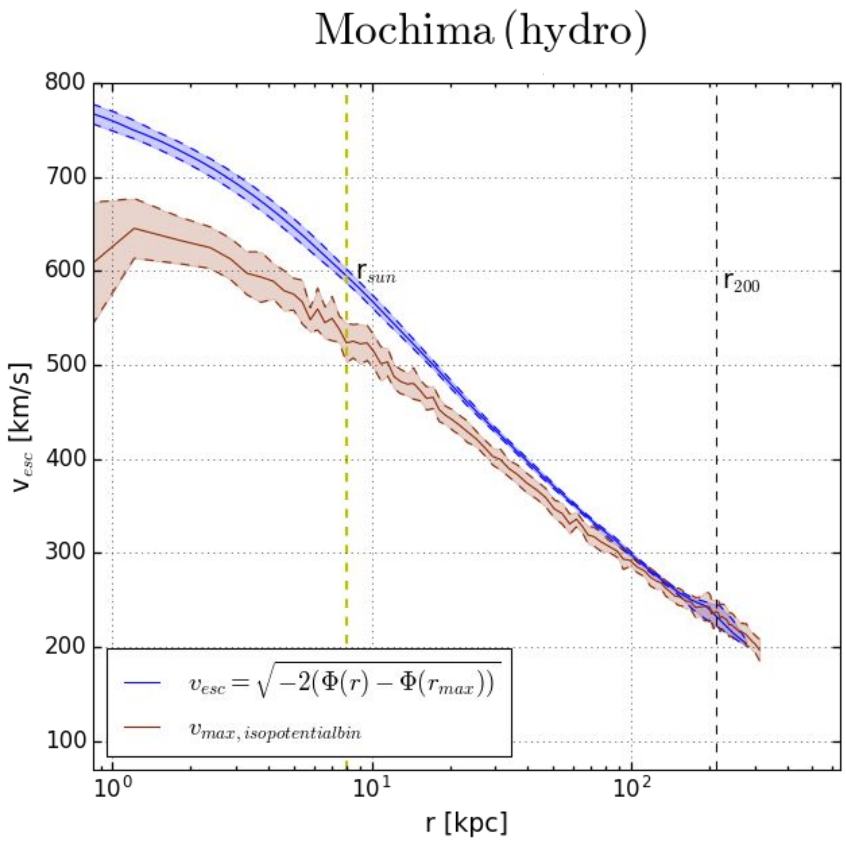
Back Up



DMO
χ^2_ρ
$\chi^2_{m_{bin}}$
Mochima Hydro
fit results:
ρ_0 = 7.414 ± 0.185
r_s = 7.364 ± 1.115
α = 1.768 ± 0.573
β = 2.633 ± 0.165
γ = 0.468 ± 0.171
3hsml
Sun
R_{200}
$\rho(r)$ [$M_\odot$ kpc^{-3}]
R [kpc]
HALO B Hydro
fit results:
ρ_0 = 7.622 ± 0.096
r_s = 4.885 ± 0.514
α = 2.639 ± 0.858
β = 2.621 ± 0.117
γ = 0.127 ± 0.097



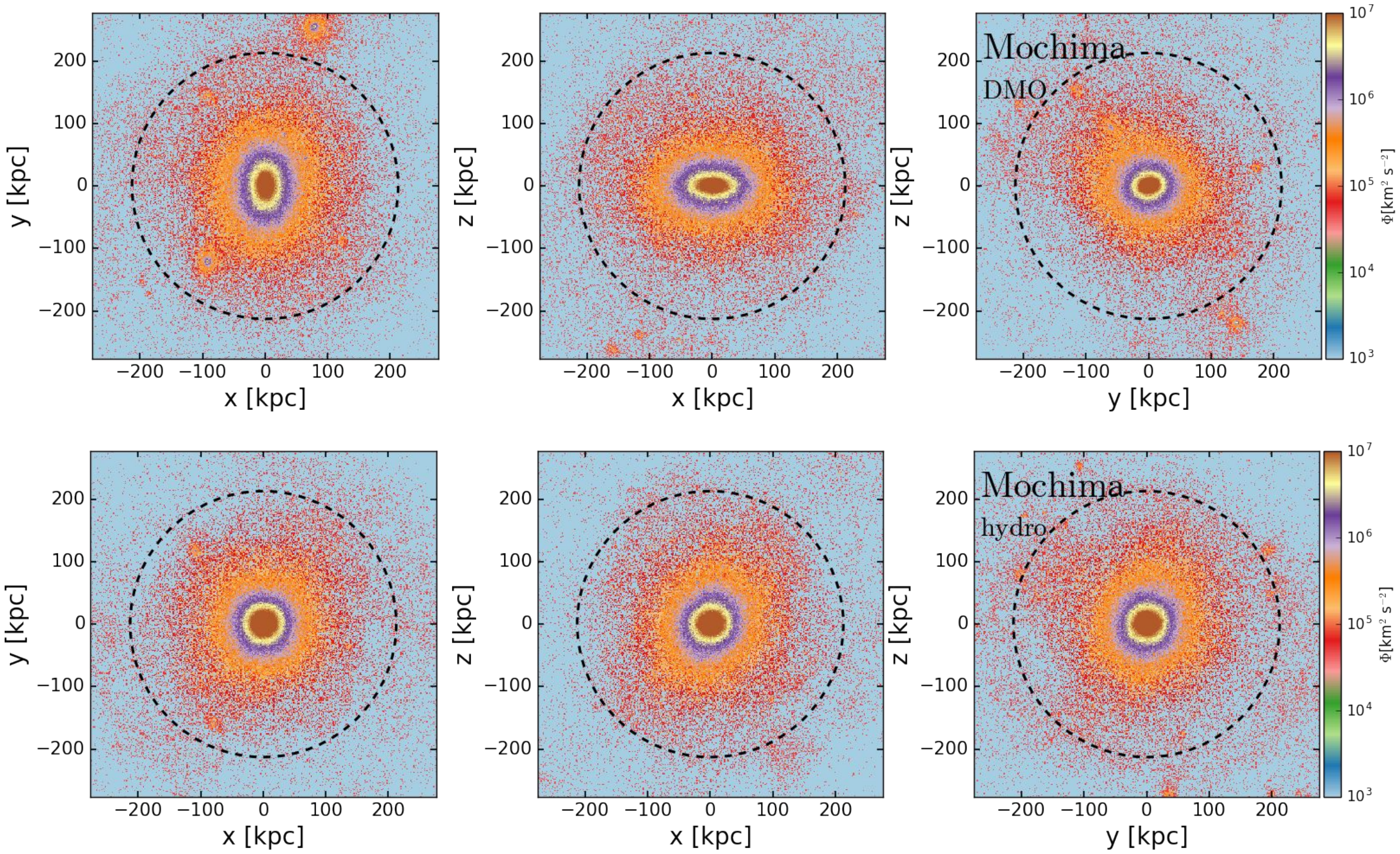
$$\Psi = \Phi(r) - \Phi(r_{max})$$

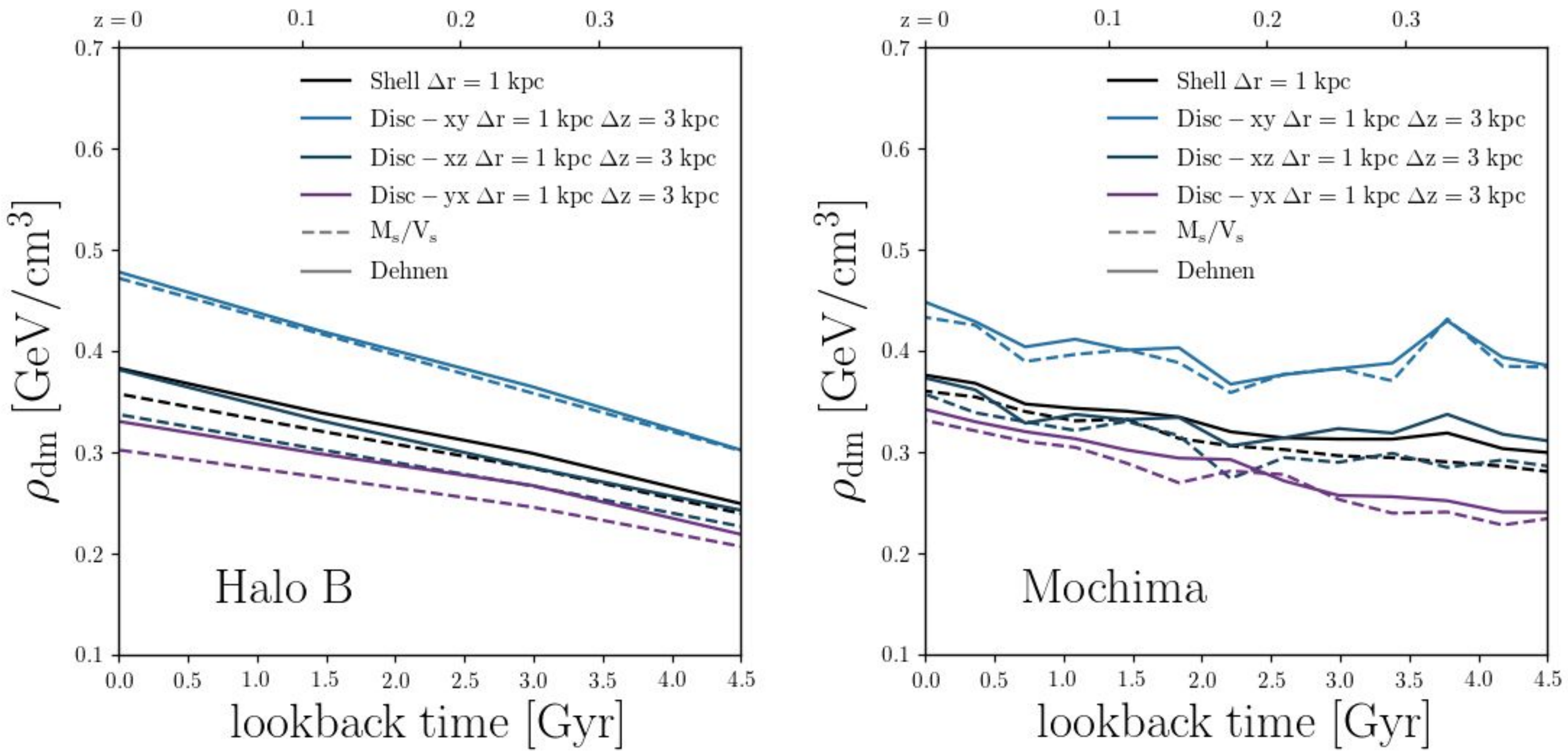


(Blue) The escape velocity computed from the potential.

(Red) the mean velocity of the fastest DM particles present in slices of θ and φ of a shell with radius r.

Shape of the potential





z = 0
0.1
0.2
0.3
Shell Δr = 1 kpc
Disc − xy Δr = 1 kpc Δz = 3 kpc
Disc − xz Δr = 1 kpc Δz = 3 kpc
Disc − yx Δr = 1 kpc Δz = 3 kpc
M_s/V_s
Dehnen
ρ_dm [GeV/cm^3]
Halo B
Mochima
lookback time [Gyr]
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5