Universal properties of dark matter halos and Infall Model

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Cargese, May 10, 2011

Motivation

- The flux from DM decay

$$F_{DM} = \frac{\Gamma\Omega_{fov}}{8\pi}\int_{los} dr\,\rho_{DM}(r)$$

- Average DM column density

$$S = \frac{2}{r_*^2}\int_0^{r_*} r' dr' \int dz\,\rho(\sqrt{r'^2 + z^2})$$

- We can parametrize it as $S \propto \rho_* r_*$
- S looks to be the same, from dwarfs to clusters
- It is essentially insensitive to the choice of fitting DM profile

Boyarsky et. al., 2006

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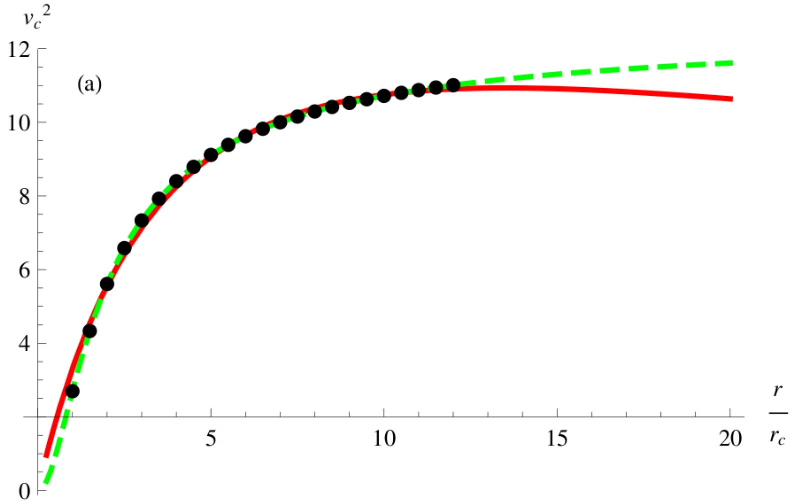
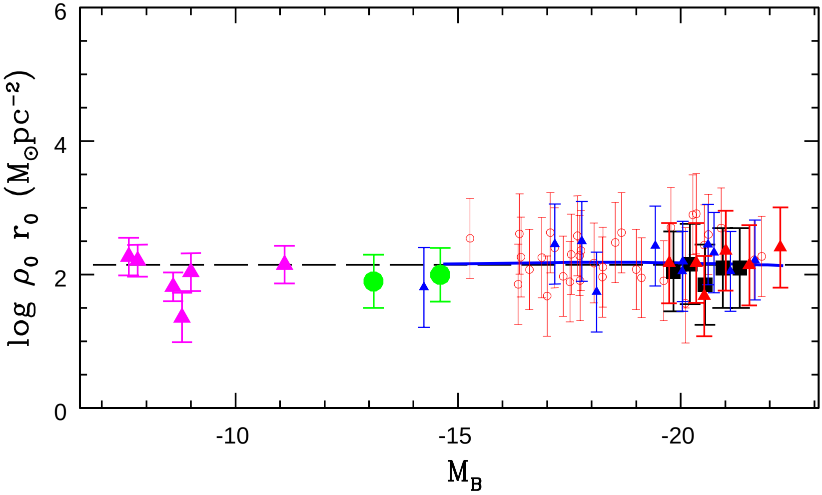
Boyarsky et. al., 2006

ISO vs NFW

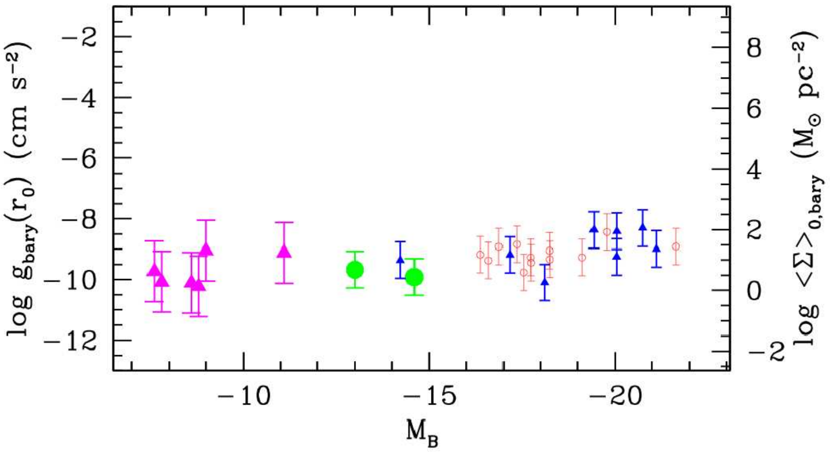


Constant DM surface density?



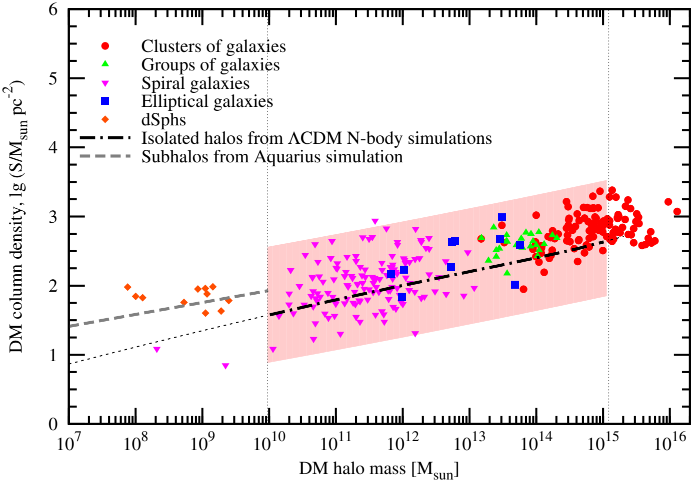
Donato et al., 2009

An evidence in favour of MOND?



Gentile et al., Nature'09

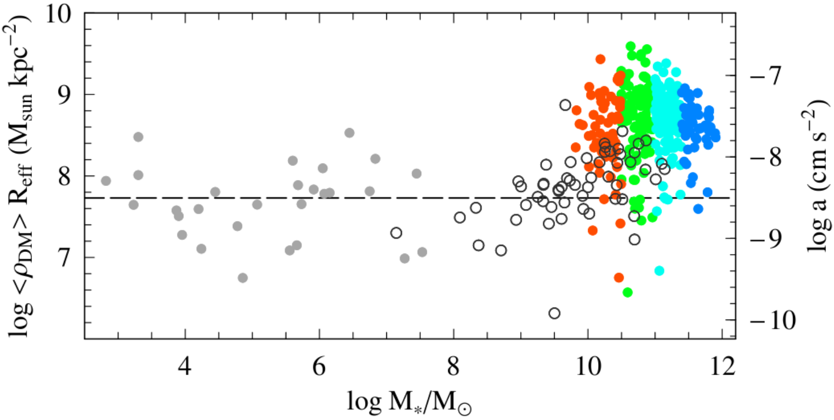
Scaling of DM column density



$$\mathcal{S} \propto M_{\mathbf{halo}}^{\mathbf{0.2}}$$

Boyarsky et al., 2009

Scaling of DM column density



Napolitano et al., 2010

Infall model

Position of each particle in the halo obey

$$\frac{d^2r}{dt^2} = -\frac{G\,M(r,t)}{r^2}$$

For initial perturbations with power-law profiles

$$\frac{\delta M_i}{M_i} = \left(\frac{M_0}{M_i}\right)^{\epsilon}$$

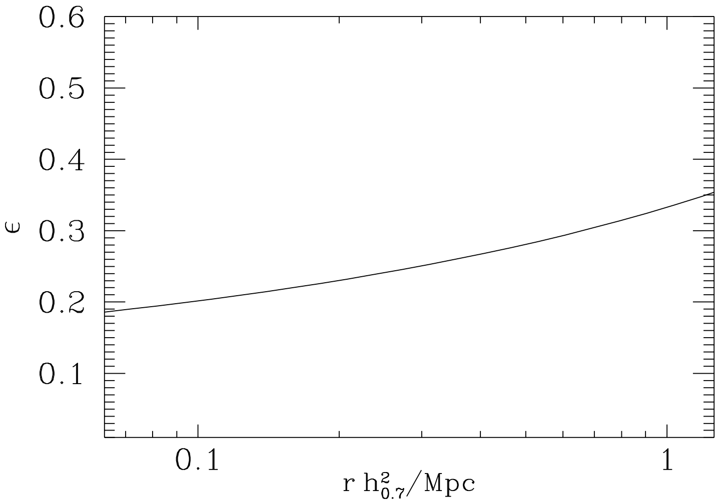
the halo evolves in a self-similar manner, e. g.

$$M(r,t) = M(t)\mathcal{M}(r/R(t))$$

$$r(r_i,t) = R(t)\lambda(t/t_*)$$

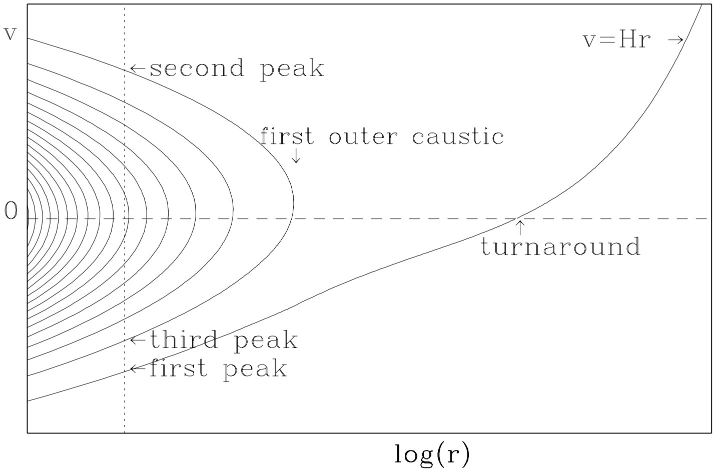
$$\rho(r,t) = \frac{M(t)}{R^3(t)} \times F\left(\frac{r}{R(t)}\right)$$

Infall model



Sikivie, Yun Wang & I.T., 1996

Infall model



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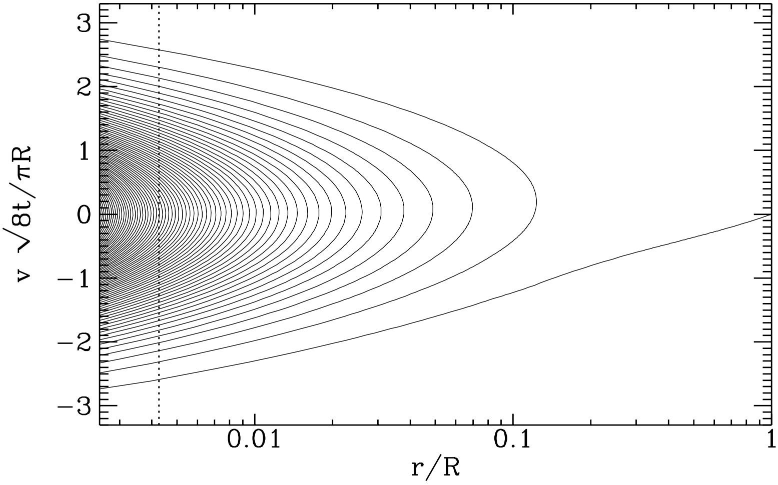

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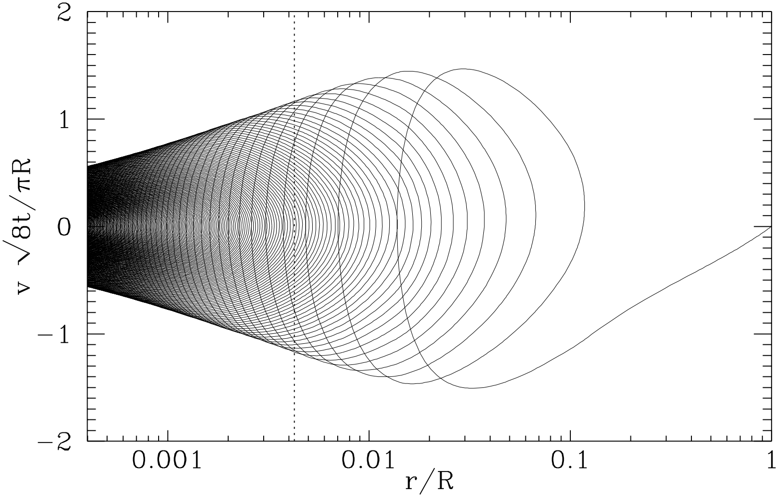

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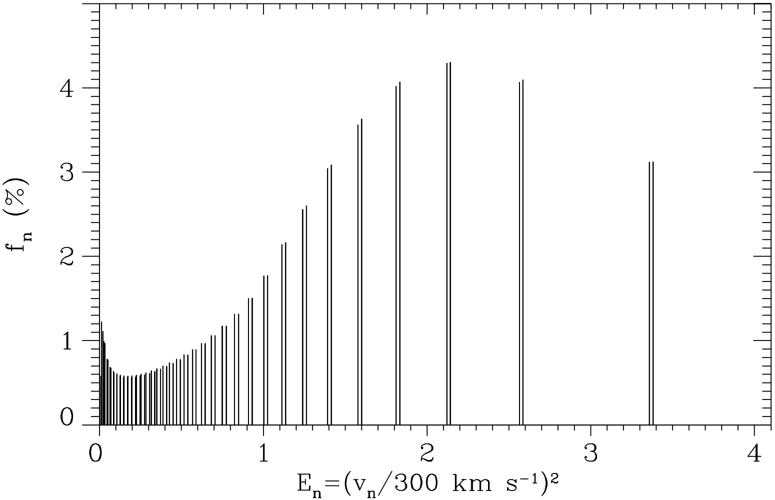

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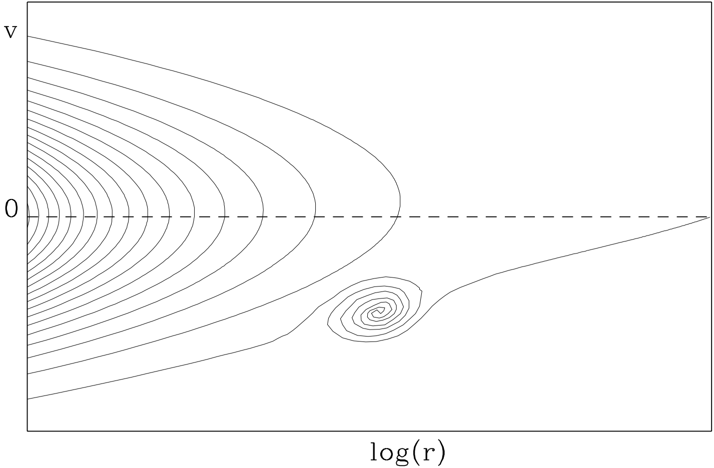

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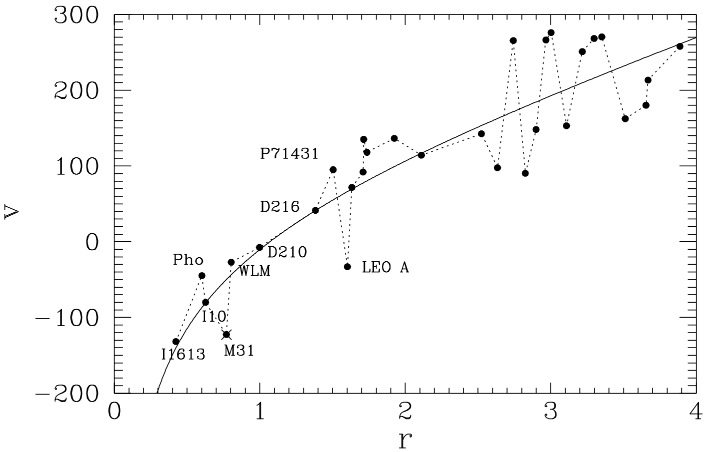
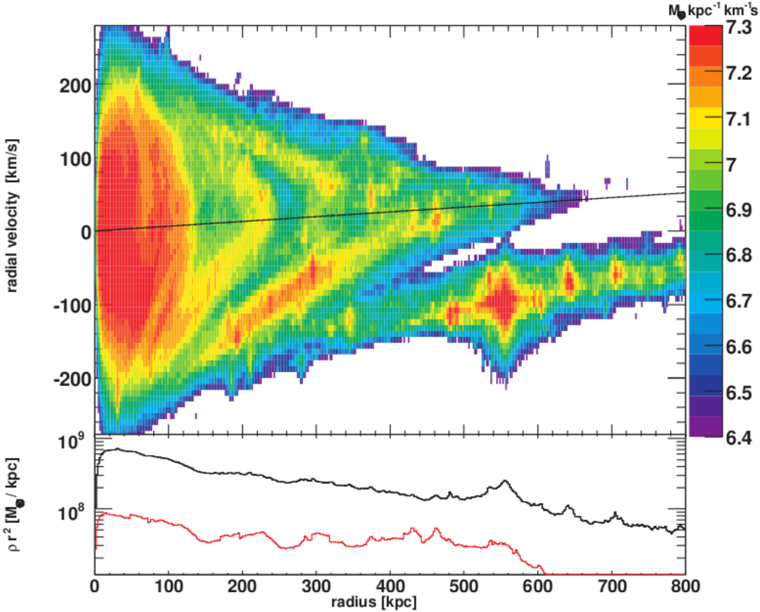
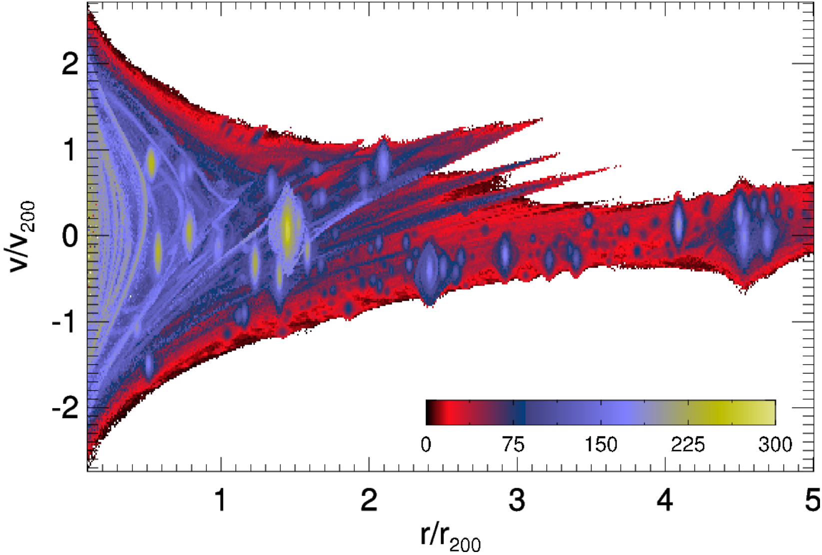


Best fit: $R = 1.07 \pm 0.14$ Mpc, $h = 0.71 \pm 0.5$

G. Steigman & I. T., 1998

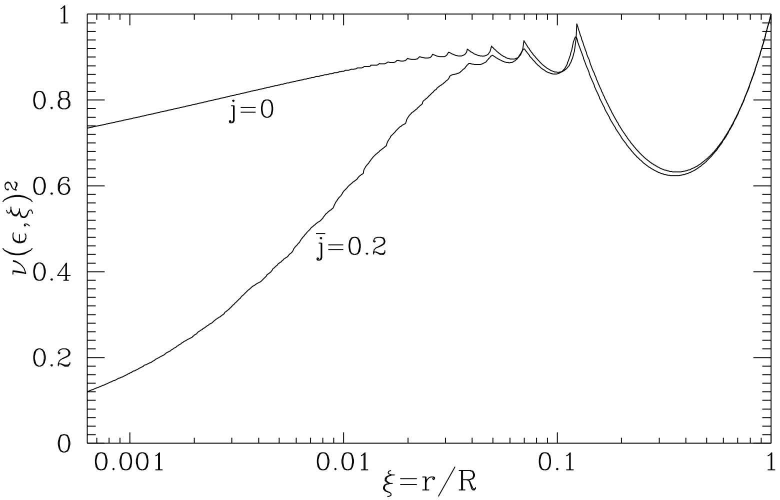


Diemand and Kuhlen, 2008

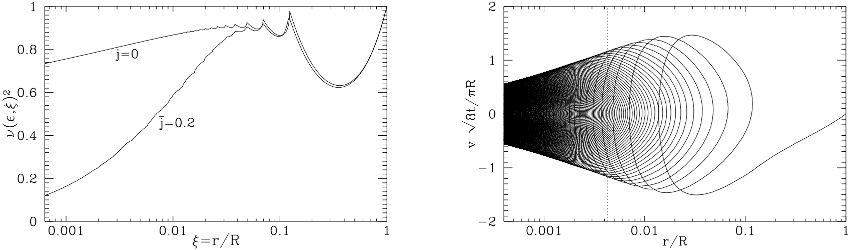


Vogelsberger and White, 2010

Infall model



Sikivie, Yun Wang & I.T., 1996



$\rho \propto r^{-2}$ between first inner and outer caustics

$\rho \propto r^{-\gamma}$ inside first inner caustics, where

$$\gamma = \frac{9\epsilon}{3\epsilon + 1}$$

$\gamma \approx 1.1$ for $\epsilon = 0.2$

Sikivie, Yun Wang & I.T., 1996

DM column density in infall model

Qualitative understanding

- Self-similarity implies

$$S \propto \rho_* r_* \propto \rho_{\rm ta} R_{\rm ta}$$

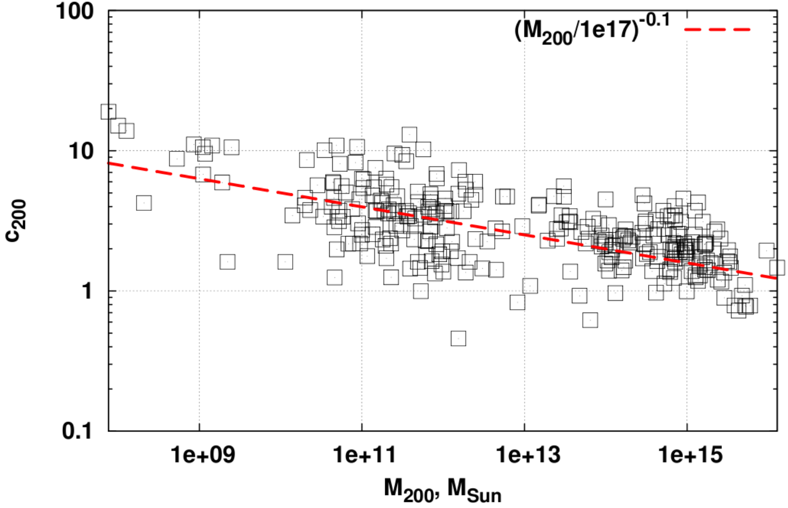
- Infall implies

$$R_{\rm ta} \propto \left(G t^2 M\right)^{1/3}$$

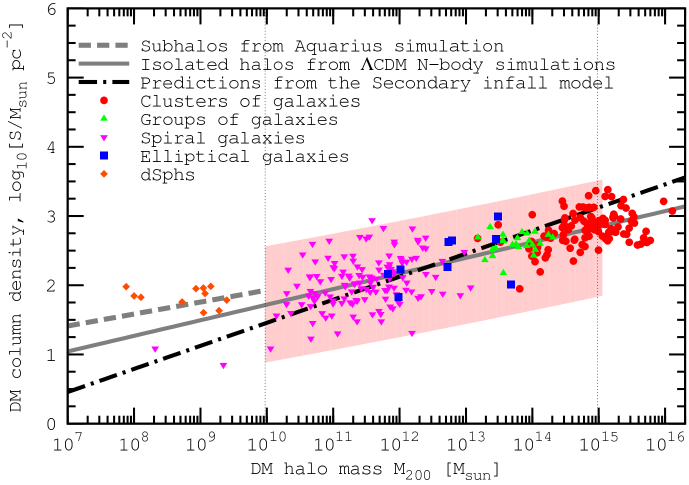
- If there are deviations from self-similarity $S \propto c(M) \cdot M^{1/3}$
- Concentration parameter $c = r_* / R_{\rm ta}$ is a weak function of mass, $c \propto M^{-0.1}$
- Therefore

$$S \propto \frac{M^{0.23}}{t^{4/3}}$$

Concentration parameter



Scaling of DM column density



Infall $\mathcal{S} \propto M_{\rm halo}^{1/3-0.1}$, best fit $\mathcal{S} \propto M_{\rm halo}^{0.2}$

Boyarsky et al., 2010

Gravity vs. cosmological expansion

Let mass M creates a gravitational potential $\phi(r)$

- Turn around time

$$t_{\rm ta} = \frac{1}{\sqrt{2}} \int_0^{R_{\rm ta}} \frac{dr}{\sqrt{\phi(r) - \phi(R_{\rm ta})}}$$

- Any gravitational potential of the form

$$\phi(r) = -\frac{GM}{r} F\left(\frac{\rho(r)}{\rho_0}\right)$$

leads to the scaling $S \propto M^{1/3}$

- Example: Schwarzschild-de Sitter potential

$$\phi(r) = -\frac{GM}{r} - \frac{\Lambda r^2}{6} = -\frac{GM}{r} F\left(\frac{\Lambda}{G\rho(r)}\right)$$

Large scale modifications of gravity

- A possible set of consistent (as a spin-2 field theory) large scale modifications of gravity is described by two parameters - scale r_c and a number $0 \leq \alpha \leq 1$ *Dvali et. al., 2007*
- In these models (DGP, "degravitation")

$$\phi_\alpha(r) = -\frac{GM}{r}\pi(\frac{r}{r_V})$$

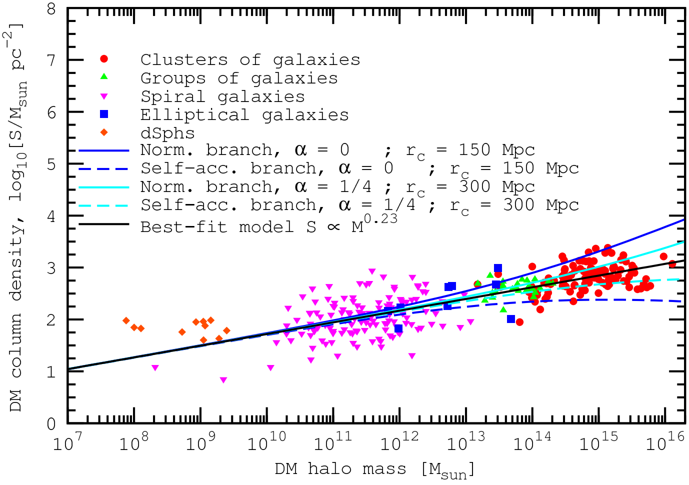
- where the Vainshtein radius:

$$r_V = \left(2GMr_c^{4(1-\alpha)}\right)^{\frac{1}{1+4(1-\alpha)}}$$

- Only for $\alpha = 1/2$

$$\phi(r) = -\frac{GM}{r}F\left(\frac{\rho(r)}{\rho_0}\right)$$

Restrictions on modifications of gravity



Boyarsky & Ruchayskiy, 2010