Phase-space of dark matter particles in the Galaxy halo

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Motivation

- Knowledge of DM phase-space distribution is a key for the interpretation of direct search experiments.
- But
  - Different galaxies have different histories
  - Violent relaxation after major merging may give rase to isothermal distribution.
  - Phase-space may be very different for isolated galaxy like MW.

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Outline

- Phase-space in a semi-analytical model of self-similar infall.
- Emerging phase-space in N-body simulations.

Hubble diagramm

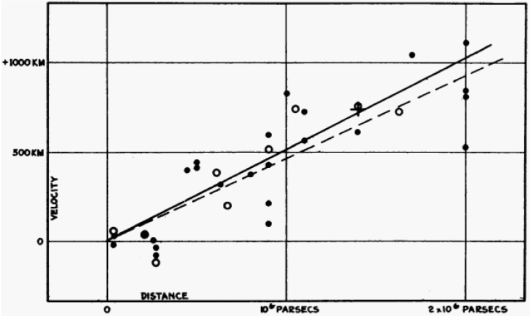

FIGURE 1

Velocity-Distance Relation among Extra-Galactic Nebulae.

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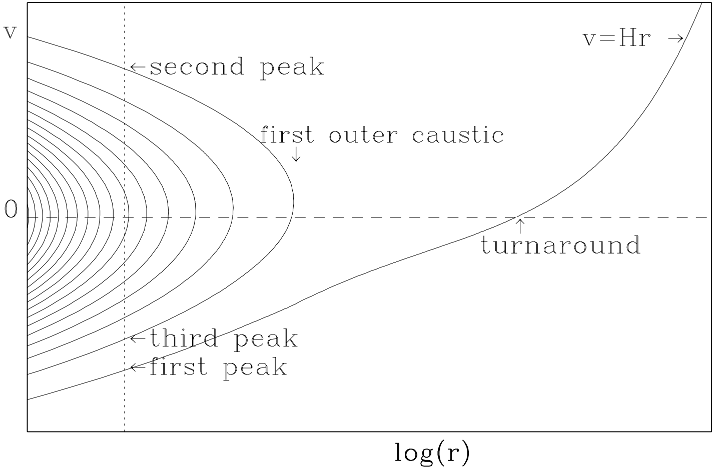
Phase space around isolated perturbation



Sikivie, Yun Wang & I.T., 1996

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.

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

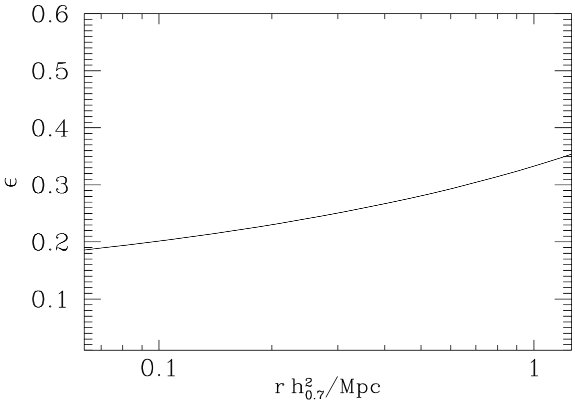
$$r(r_i,t) = R(t)\lambda(t/t_*)$$

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

Infall model

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

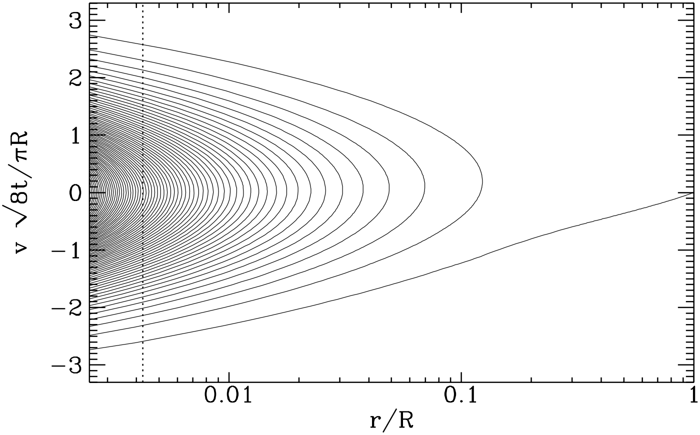
For the point-like mass excess, $\epsilon = 1$.



Value of the shape parameter ϵ as a function of scale in ΛCDM.

Sikivie, Yun Wang & I.T., 1996

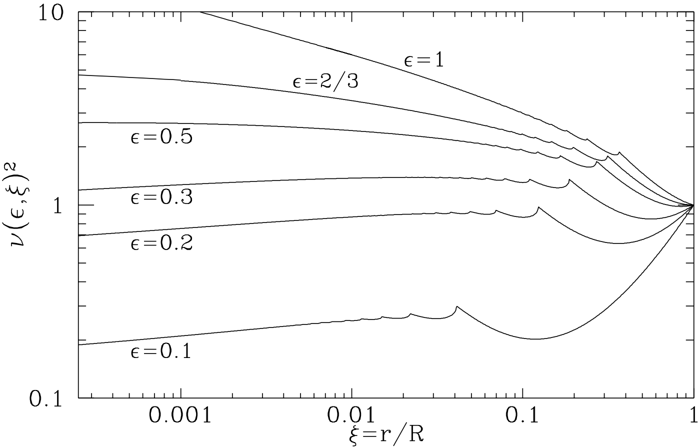
Infall model



Phase-space for $\epsilon = \mathbf{0.2}$ and zero angular momentum.

Sikivie, Yun Wang & I.T., 1996

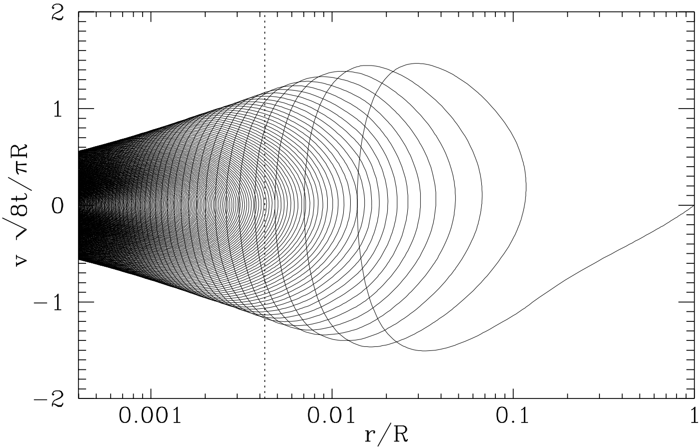
Infall model



Rotational velocity curves for different values of $\epsilon = 0.2$ and $j = 0$.

Sikivie, Yun Wang & I.T., 1996

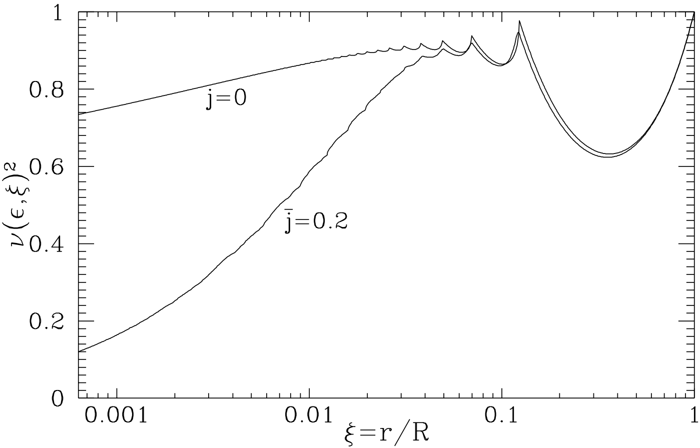
Infall model



Phase-space for $\epsilon = 0.2$ and angular momentum $j = 0.2$.

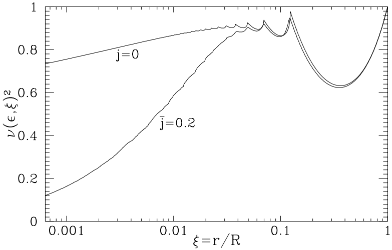
Sikivie, Yun Wang & I.T., 1996

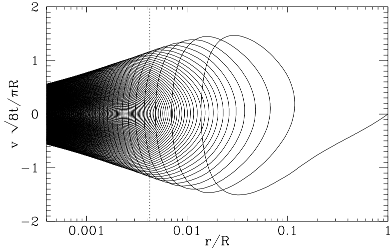
Infall model



Rotational velocity curves for different values of j and $\epsilon = 0.2$.

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

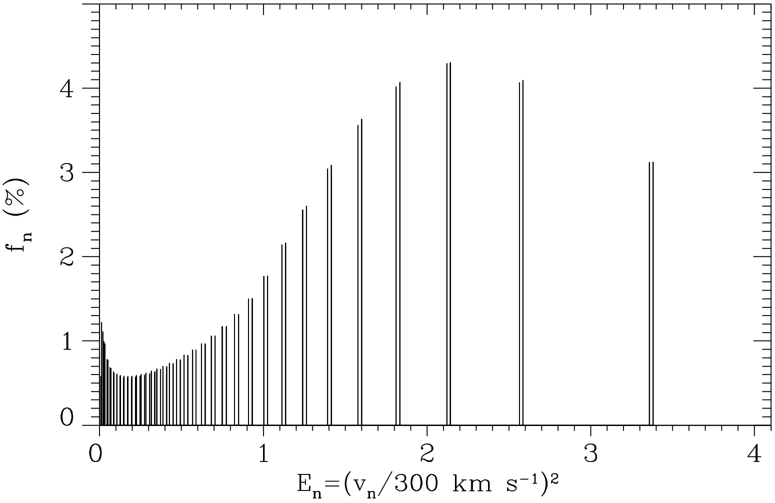
$$\gamma = \frac{9\epsilon}{3\epsilon + 1}$$

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

NFW cusps are derived analytically.

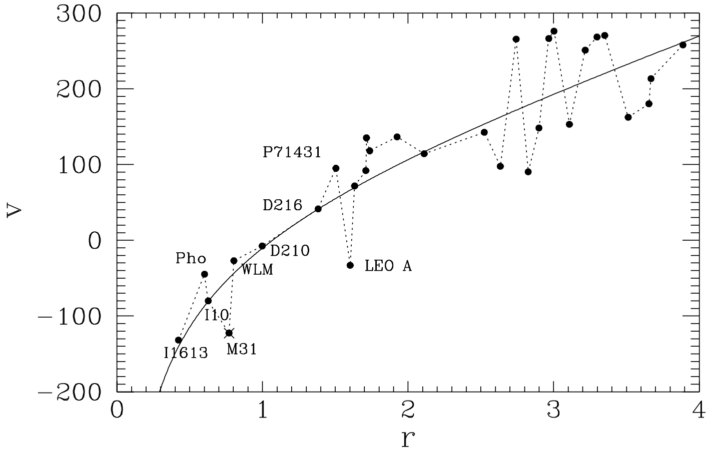
Sikivie, Yun Wang & I.T., 1996

Infall model



Velocity distribution at Sun position, $\epsilon = \mathbf{0.2}$ and angular momentum $j = \mathbf{0.2}$

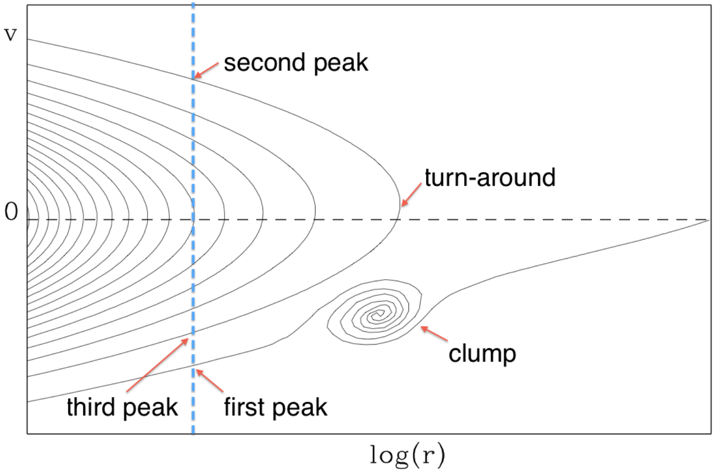
Signature of infall in the Local Group.



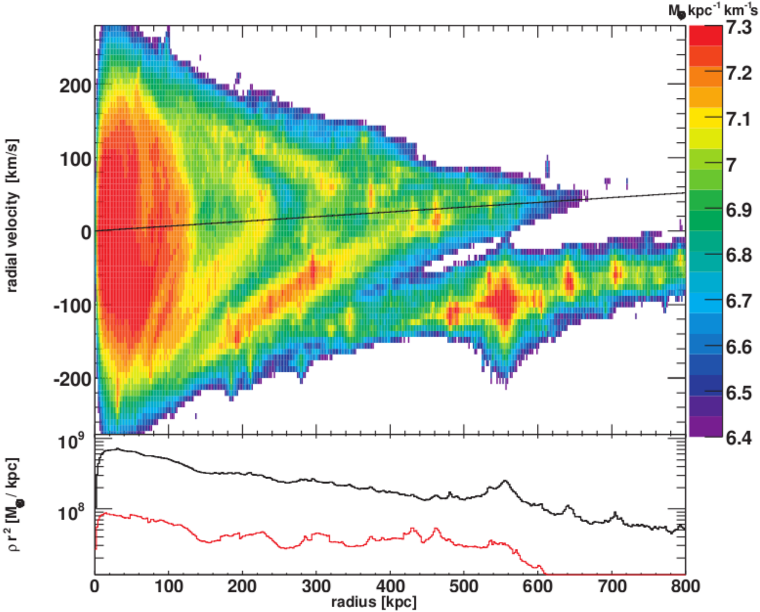
Best fit: $R = 1.07 \pm 0.14$ Mpc, $h = 0.71 \pm 0.5$

G. Steigman & I.T., 1998

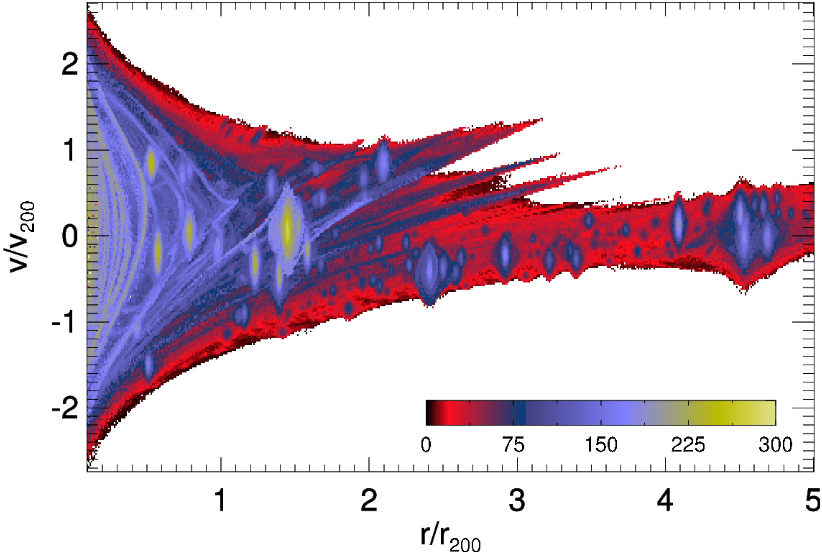
Infall model



Sikivie, Yun Wang & I.T., 1996



Diemand and Kuhlen, 2008



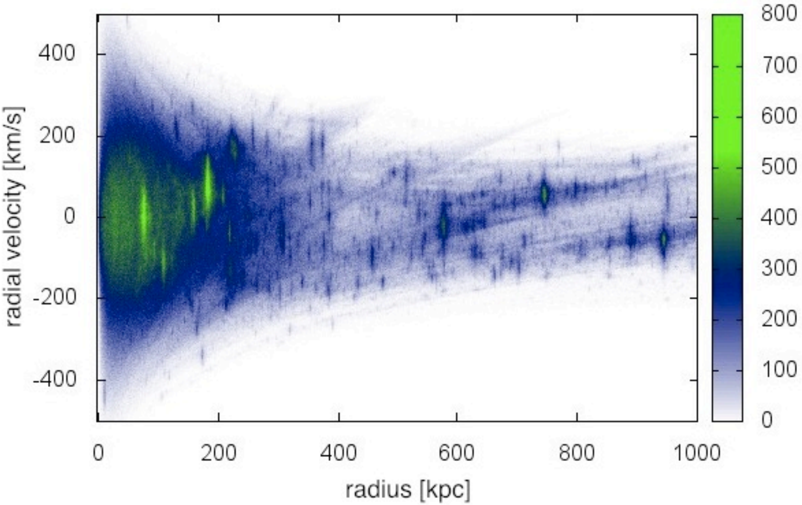
Vogelsberger and White, 2010

N-body simulation

- We employed cosmological N-Body code Gadget with the gravitational softening 0.2 kpc/h.
- "Milky Way"-like halo was selected from cosmological simulation of LSS.
- Cosmological parameters $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, $h = 0.7$ and $\sigma_8 = 0.9$.
- Selected halo:
  - suffered its last major merger at $z > 2$.
  - has rotation velocity similar to MW.
  - was resolved by 10^7 particles within virial radius.
  - total mass of the halo withing this radius was $M_{vir} = 2.3 \times 10^{12}\, M_\odot/h$.

Dolag, Dolgov & I.T., 2013

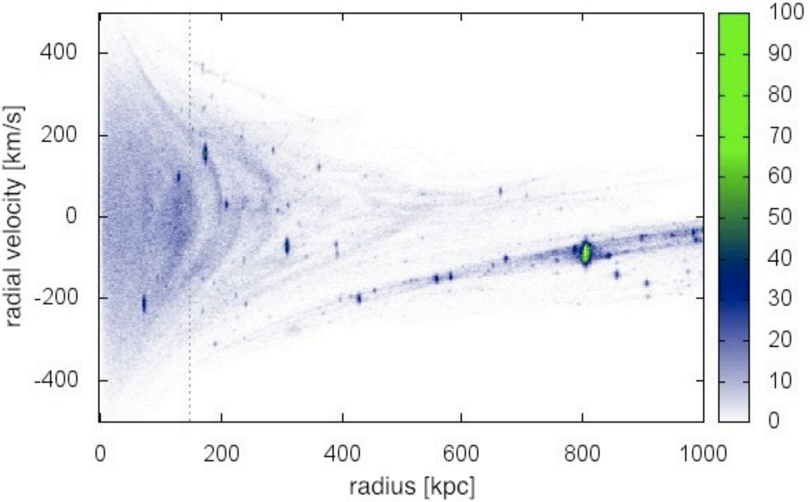
N-body simulation



Phase-space after averaging over all angles in conguration space

Dolag, Dolgov & I.T., 2013

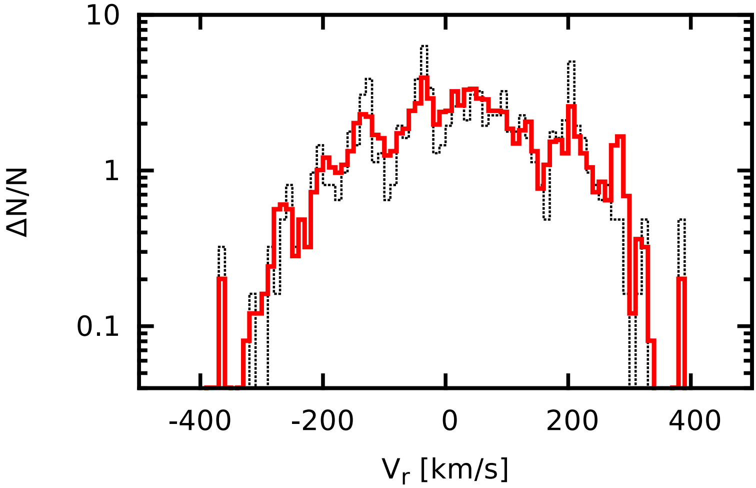
N-body simulation



Phase-space after averaging over solid angle with opening $\theta = 40^\circ$.

Dolag, Dolgov & I.T., 2013

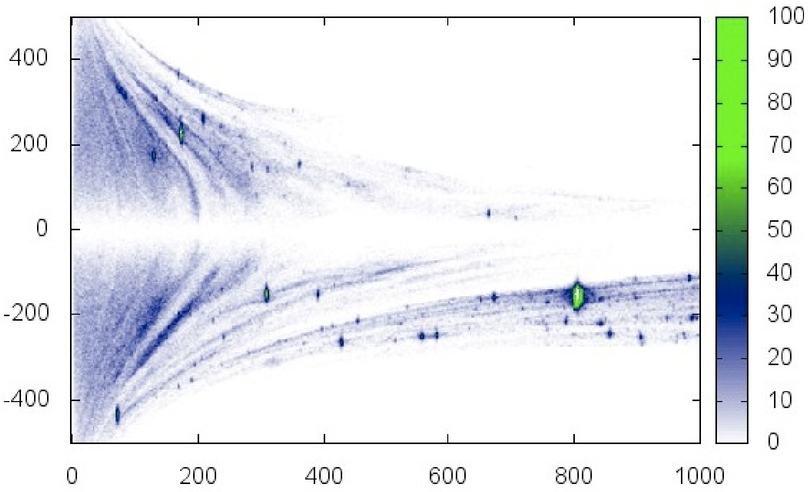
N-body simulation



Velocity distribution at $r = 150$ kpc. Averages are for $\Delta r = 2$ kpc and solid angles with openings $\theta = 40^\circ$ (solid line) and $\theta = 20^\circ$ (dotted line).

Dolag, Dolgov & I.T., 2013

N-body simulation



Phase-space after averaging over solid angle with opening $\theta = 40^\circ$. However, now $|\vec{v}| \cdot \mathbf{sign}(v_r)$ insted of v_r is used.

Dolag, Dolgov & I.T., 2013

Conclusions

- Infall picture do captures main features of the phase space of Dark Matter for a galaxy like the Milky Way.
- Extensive and dedicated simulations are needed to very the extent of its validity