Resonant stirring of disky dwarf galaxies orbiting the Milky Way

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Tidal stirring of dwarf galaxies

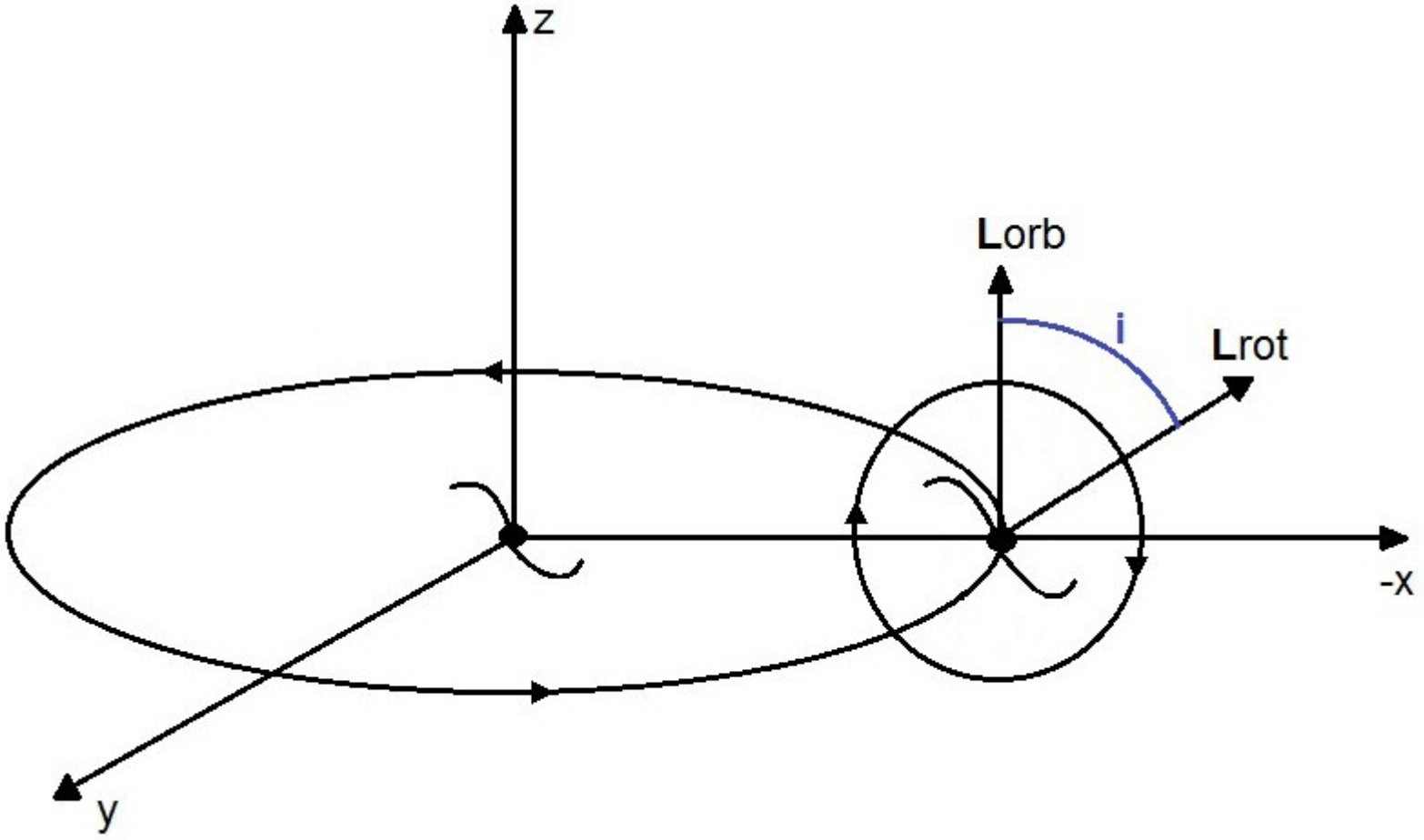
- Most promising scenario for dSph formation (Mayer et al. 2001)
- Efficiency of this mechanism previously investigated (e.g. Klimentowski et al. 2009)
- Not all parameters explored in these studies

NGC 5907 (source: apod.nasa.gov)

N-body simulations

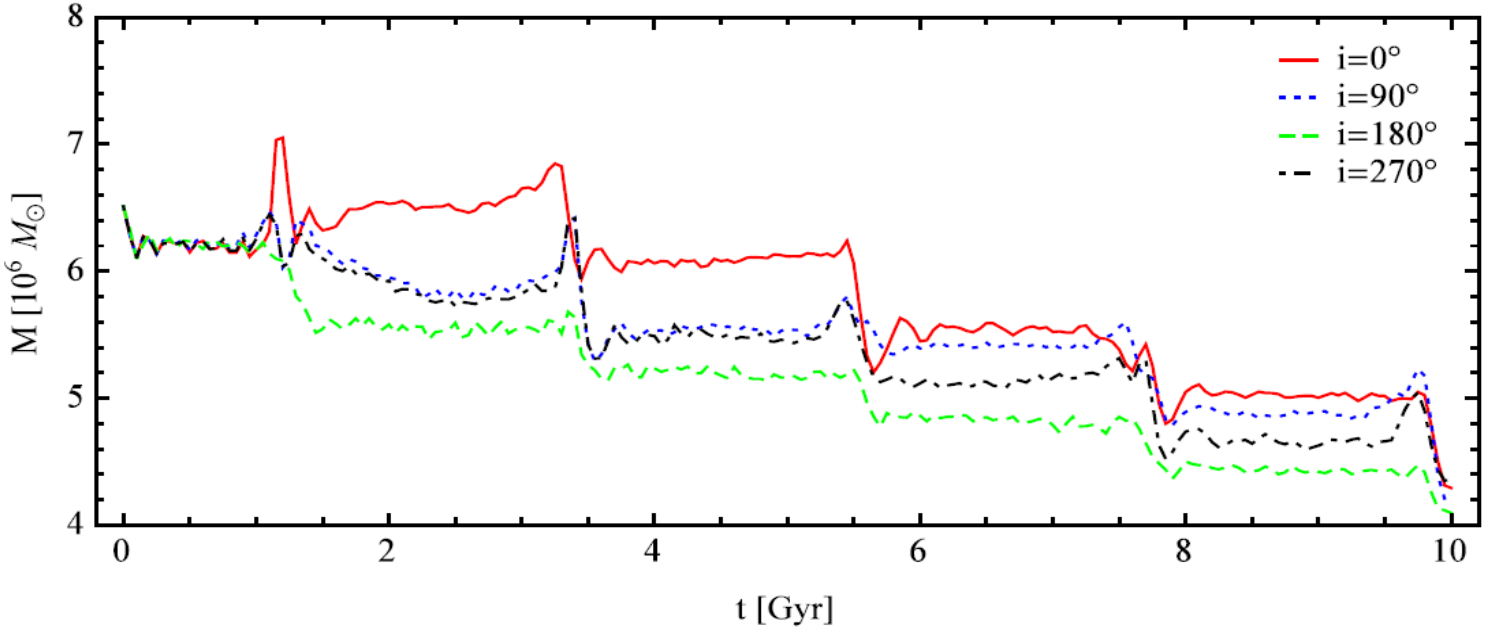
- Milky Way-like host and satellite galaxy were both exponential stellar disks embedded in NFW dark matter halo (Navarro et al. 1997)
- Total number of particles: 4*10^6
- Set of 4 simulations, each with different inclination
- Evolution followed for 10 Gyr using GADGET-2 code (Springel et al. 2001, Springel 2005)

Inclination

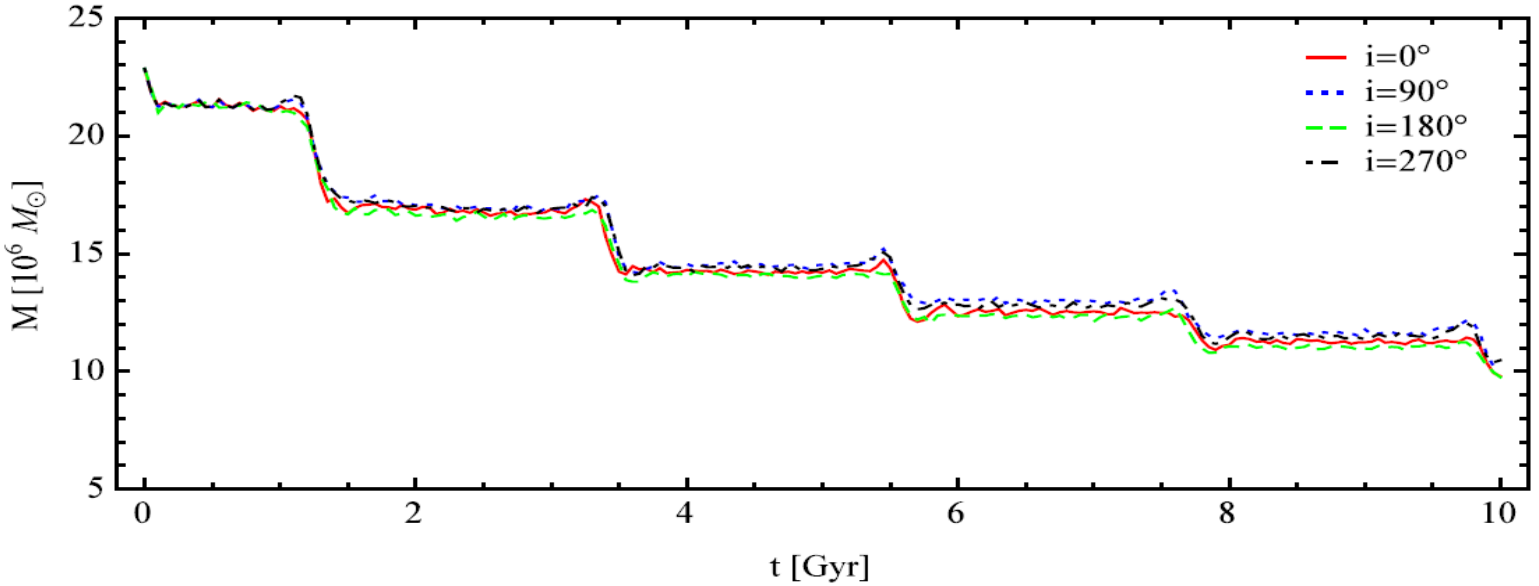


Initial inclination was equal to 0, 90, 180 and 270 deg

Mass content

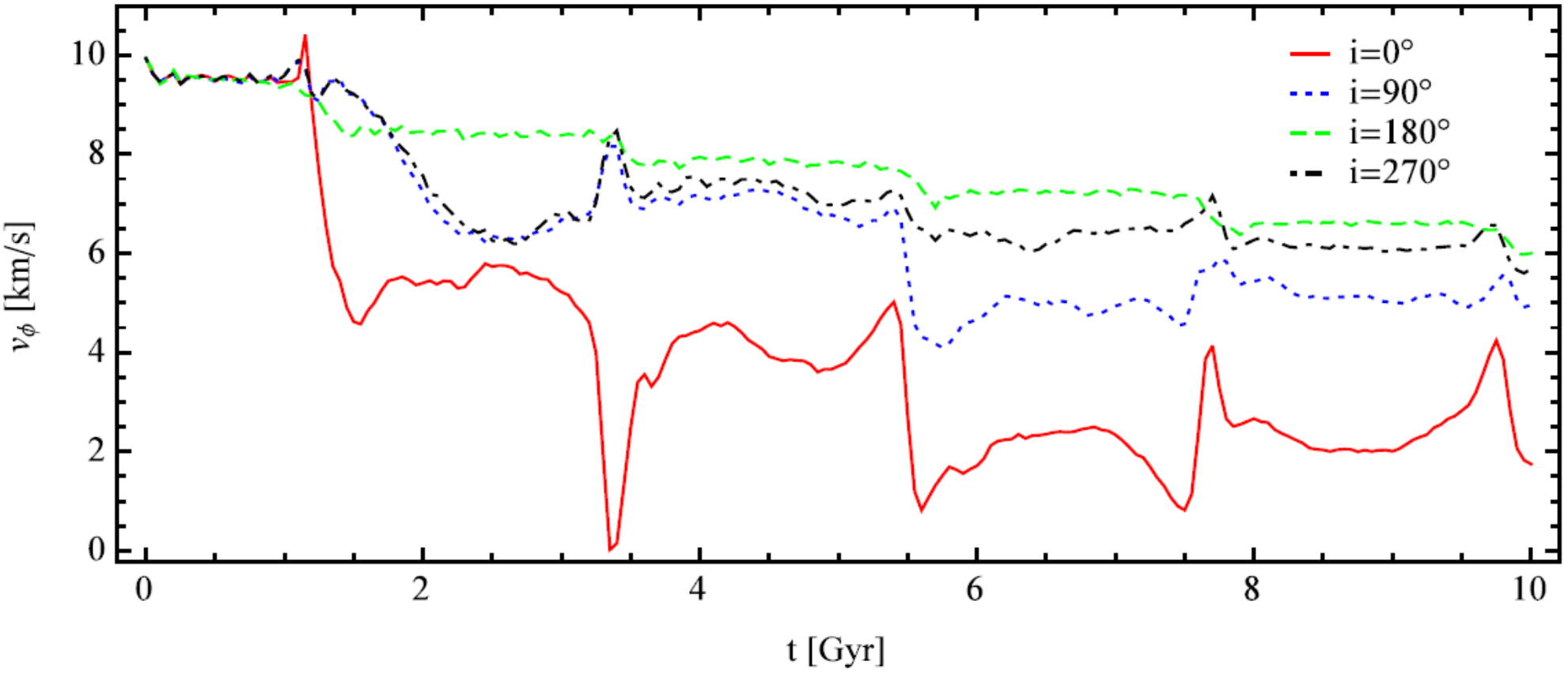


stars



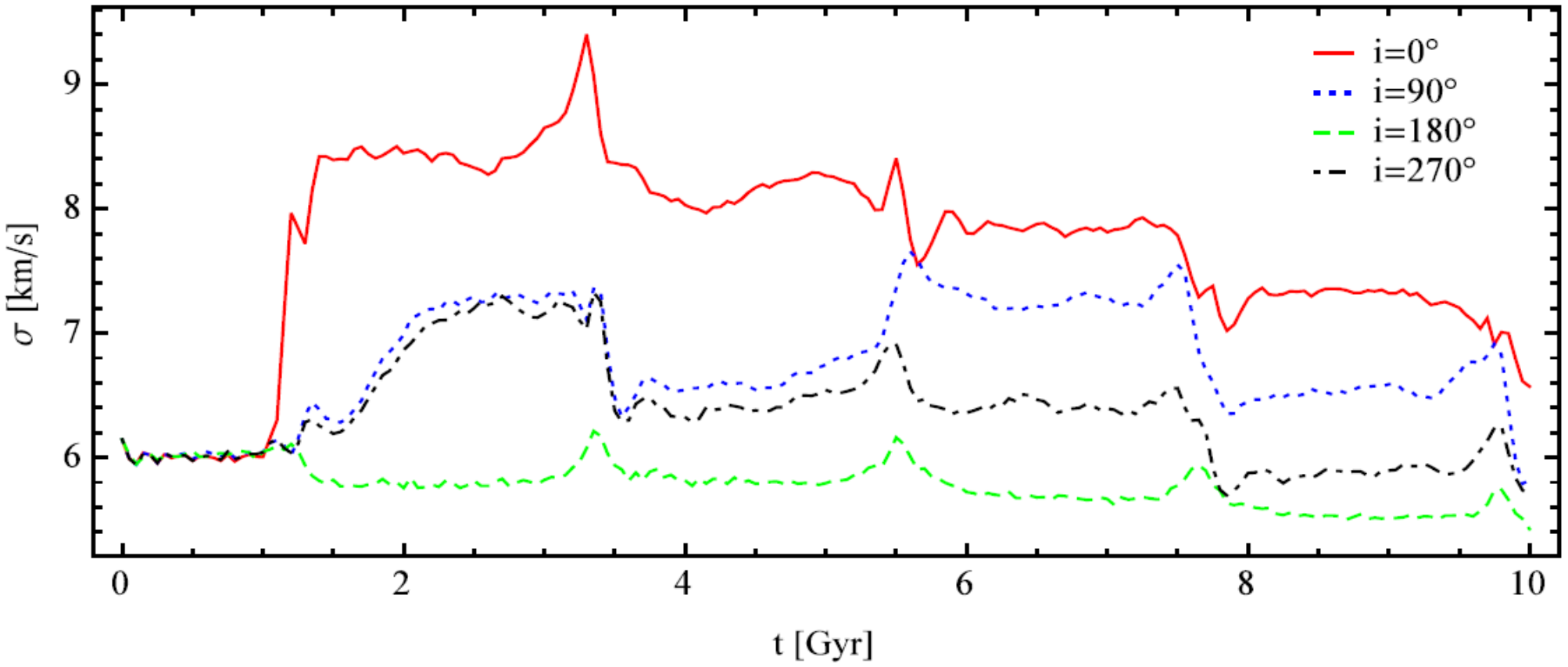
dark matter

Rotation



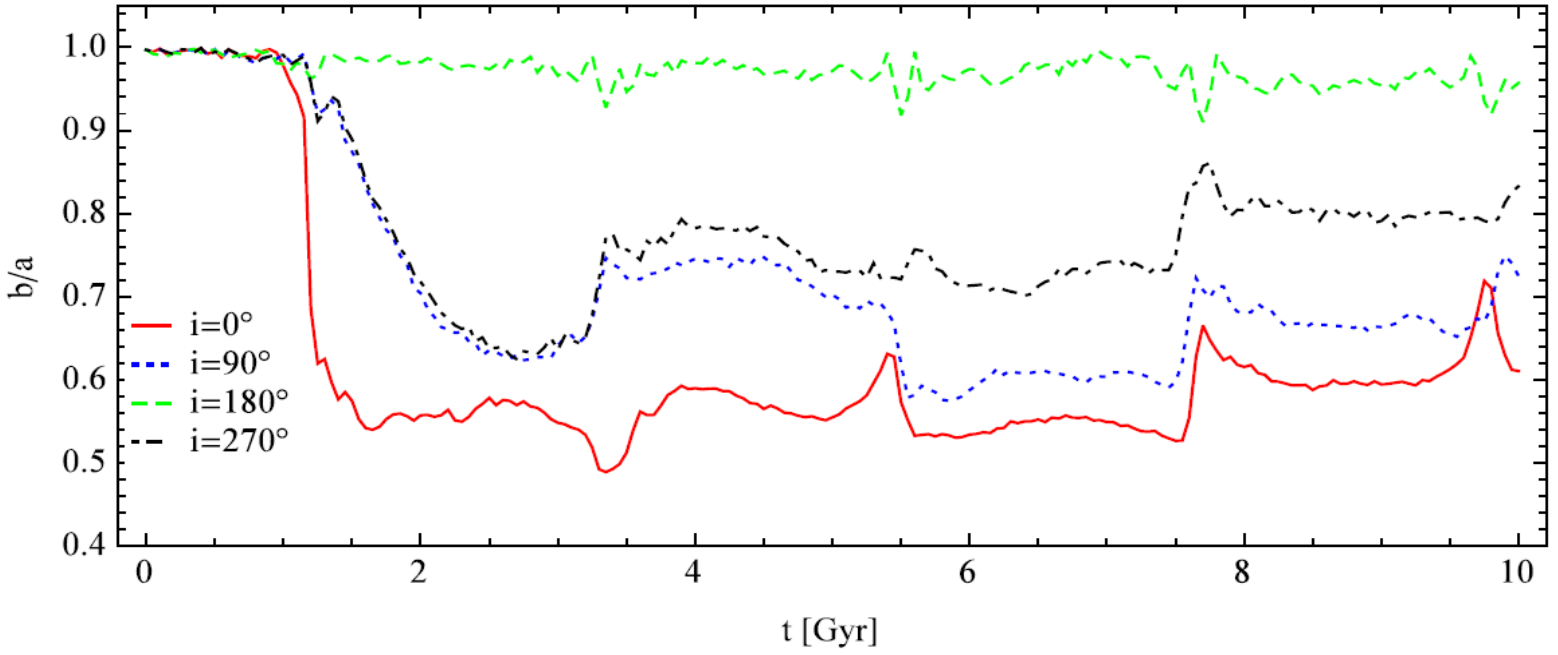
Φ – azimuthal angle in the plane of longest and medium axis

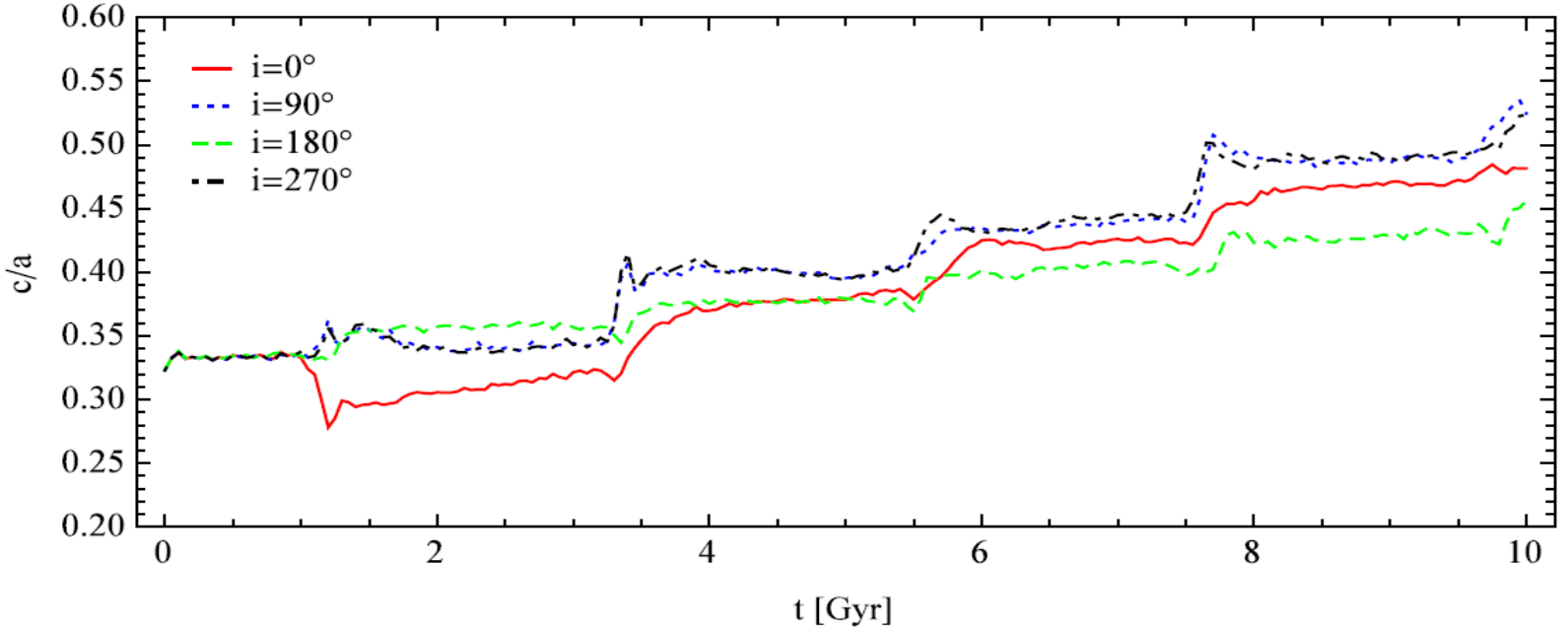
Velocity dispersion



σ – 1D velocity dispersion calculated as RMS

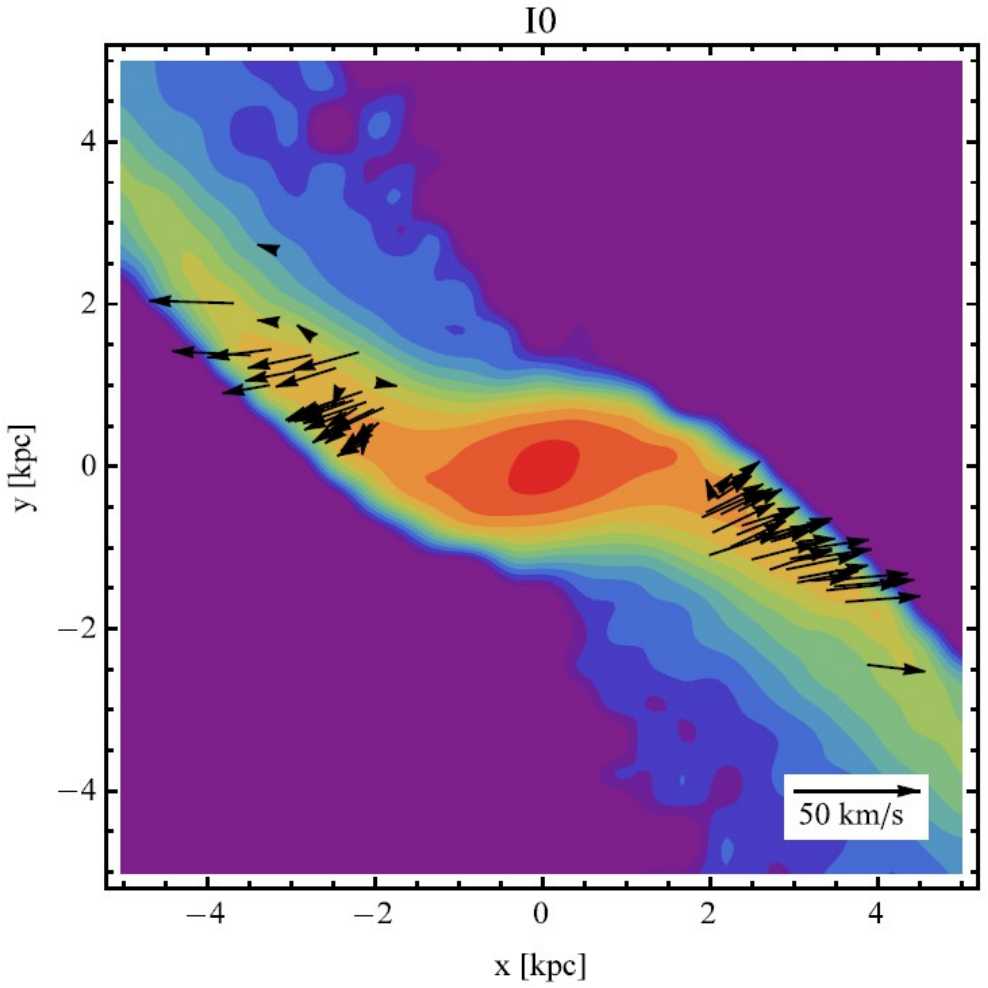
Morphology

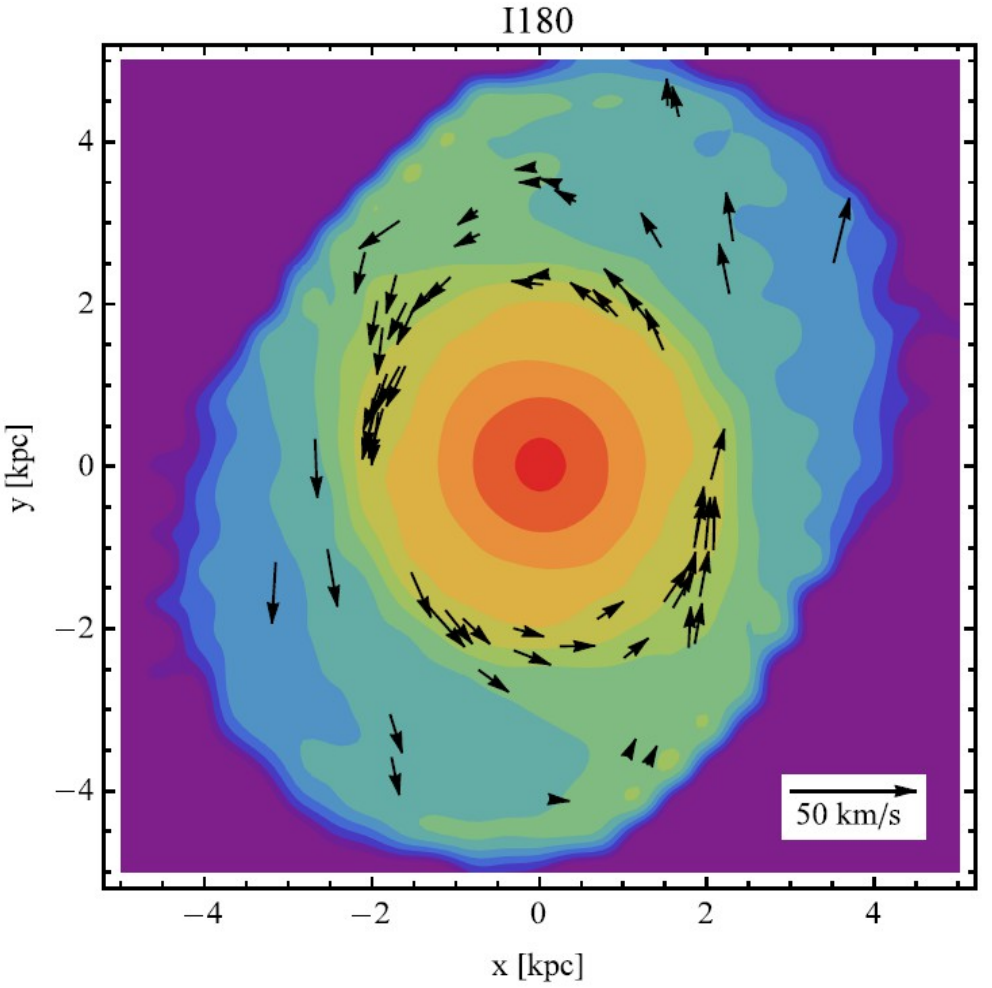




a, b, c – longest, medium and shortest axis

Pericenter passage





Modified impulse approximation

- Newtonian equations of motion

$$\dot{v}_k = -\frac{\partial \psi}{\partial x_k} + \frac{1}{M} \int \rho(\mathbf{x}') \frac{\partial \psi}{\partial x'_k} d^3 x'$$

- After expanding into Taylor series

$$\dot{v}_k = -\left. \frac{\partial^2 \psi}{\partial x_k \partial x_j} \right|_{\mathbf{x}=0} x_j$$

Binney & Tremaine 1987

- Integration over finite time period

$$\Delta v_k = \int_0^{\Delta t} \dot{v}_k \, dt$$

- Trajectories of stars approximated with circular orbits

$$\mathbf{x} = (r\cos(\Omega t + \phi_0), r\sin(\Omega t + \phi_0), 0)$$

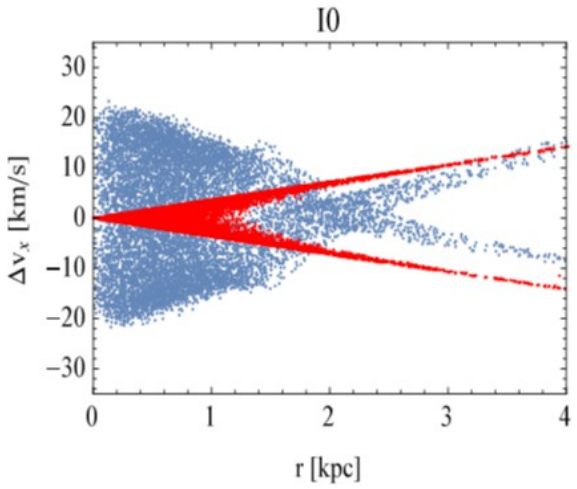
- Trajectory of MW approximated with straight line

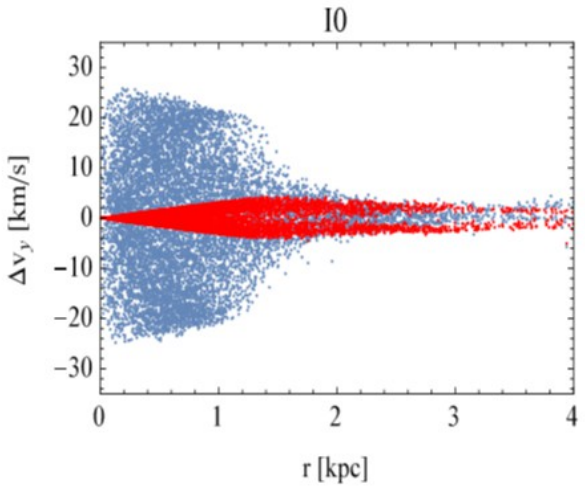
$$\mathbf{X} = \mathbf{V}t + \mathbf{X_0}$$

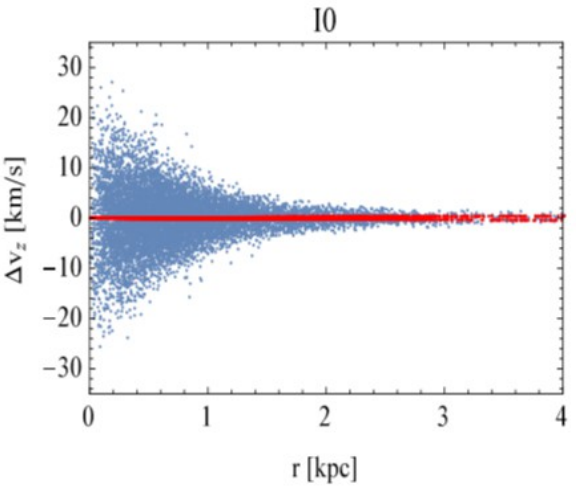
- Potential of MW: NFW (dm halo) + point mass (stars)

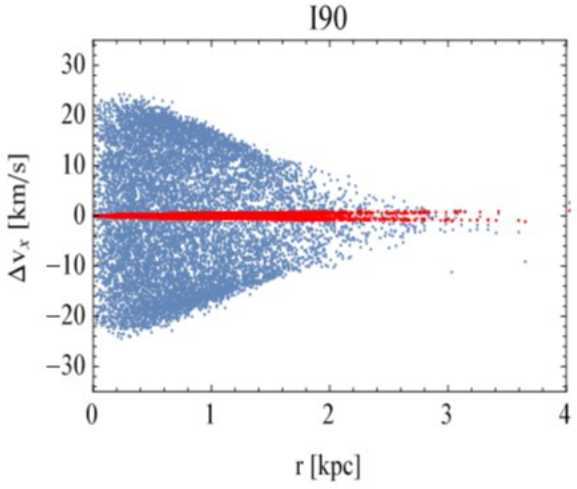
$$\psi = -\frac{GM_*}{|\mathbf{x} - \mathbf{X}|} - g\frac{GM_{vir}\ln(1 + \frac{c|\mathbf{x}-\mathbf{X}|}{r_{vir}})}{|\mathbf{x} - \mathbf{X}|}$$

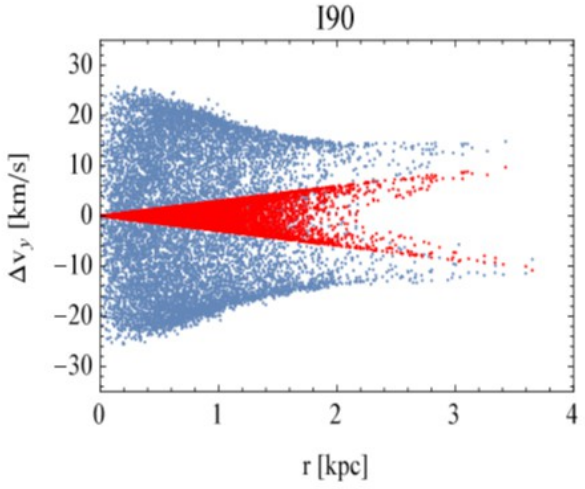
Velocity increments – part I

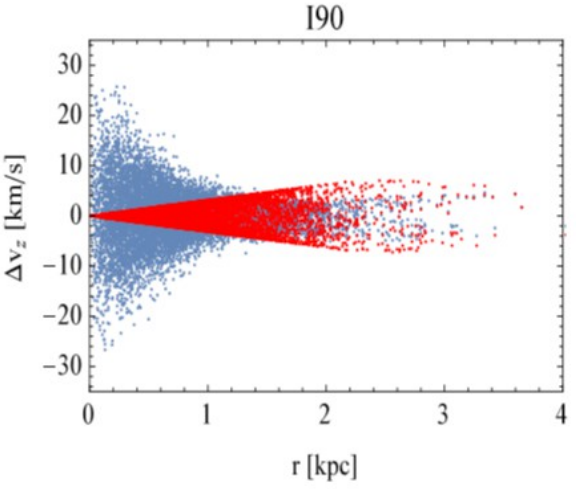






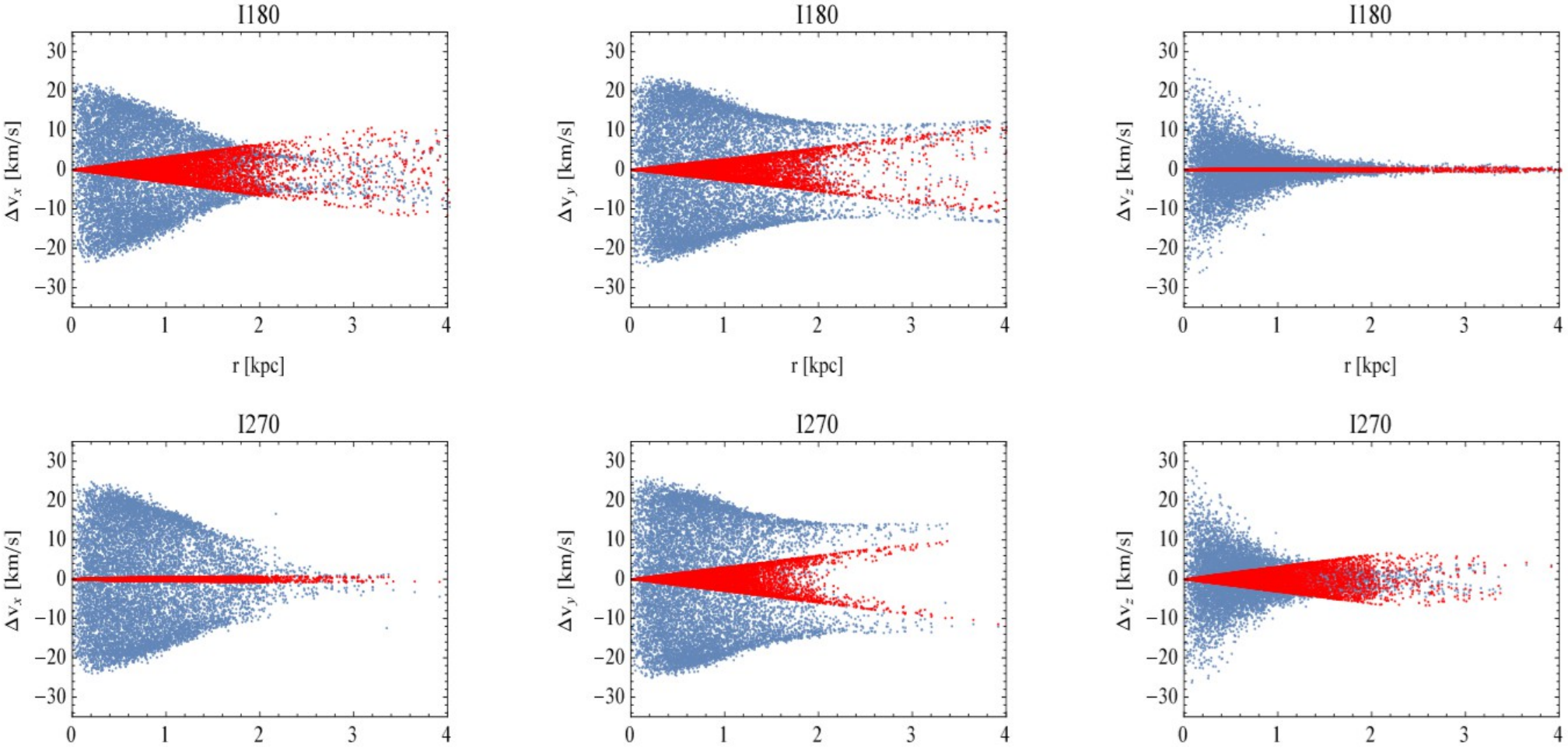






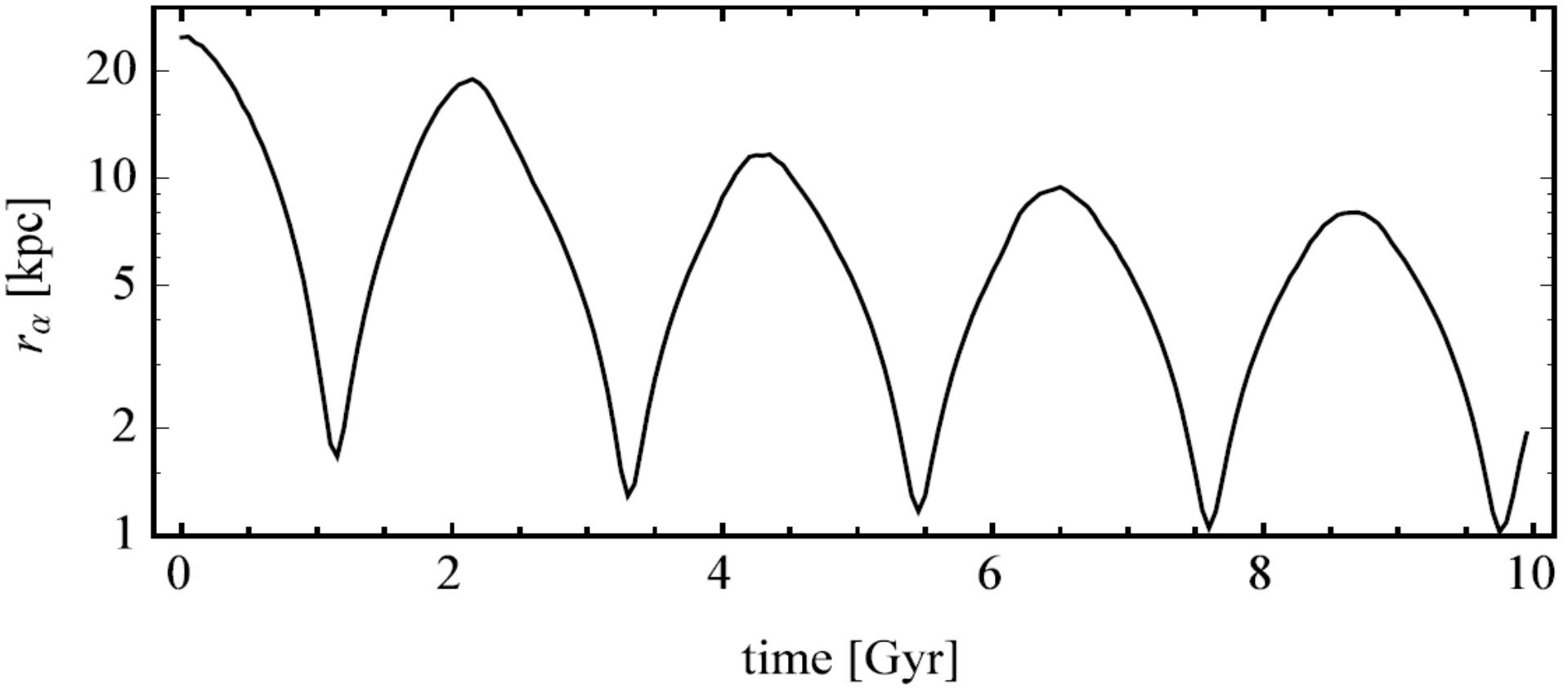
simulations semi-analytic predictions

Velocity increments – part II



simulations semi-analytic predictions

Resonance



$$\alpha \equiv \frac{\Omega}{\Omega_{orb}} \qquad \Omega_{disk} \simeq \Omega_{orb}$$

Summary

- Tidal stirring is more effective for prograde than retrograde orbits (in agreement with Read et al. 2006, D'Onghia et al. 2010)
- Impulse approximation describes well realistic simulations and supports resonant interpretation of tidal encounters (D'Onghia et al. 2010)
- All results and extended discussion contained in the paper: E. L. Łokas, M. Semczuk, G. Gajda, E. D'Onghia, *The resonant nature of tidal stirring of disky dwarf galaxies orbiting the Milky Way*, arXiv:1505.00951, accepted to ApJ