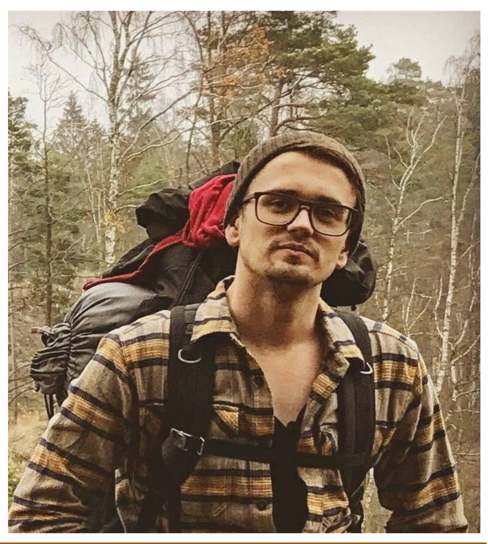
Radial migration and vertical action in *N*-body simulations



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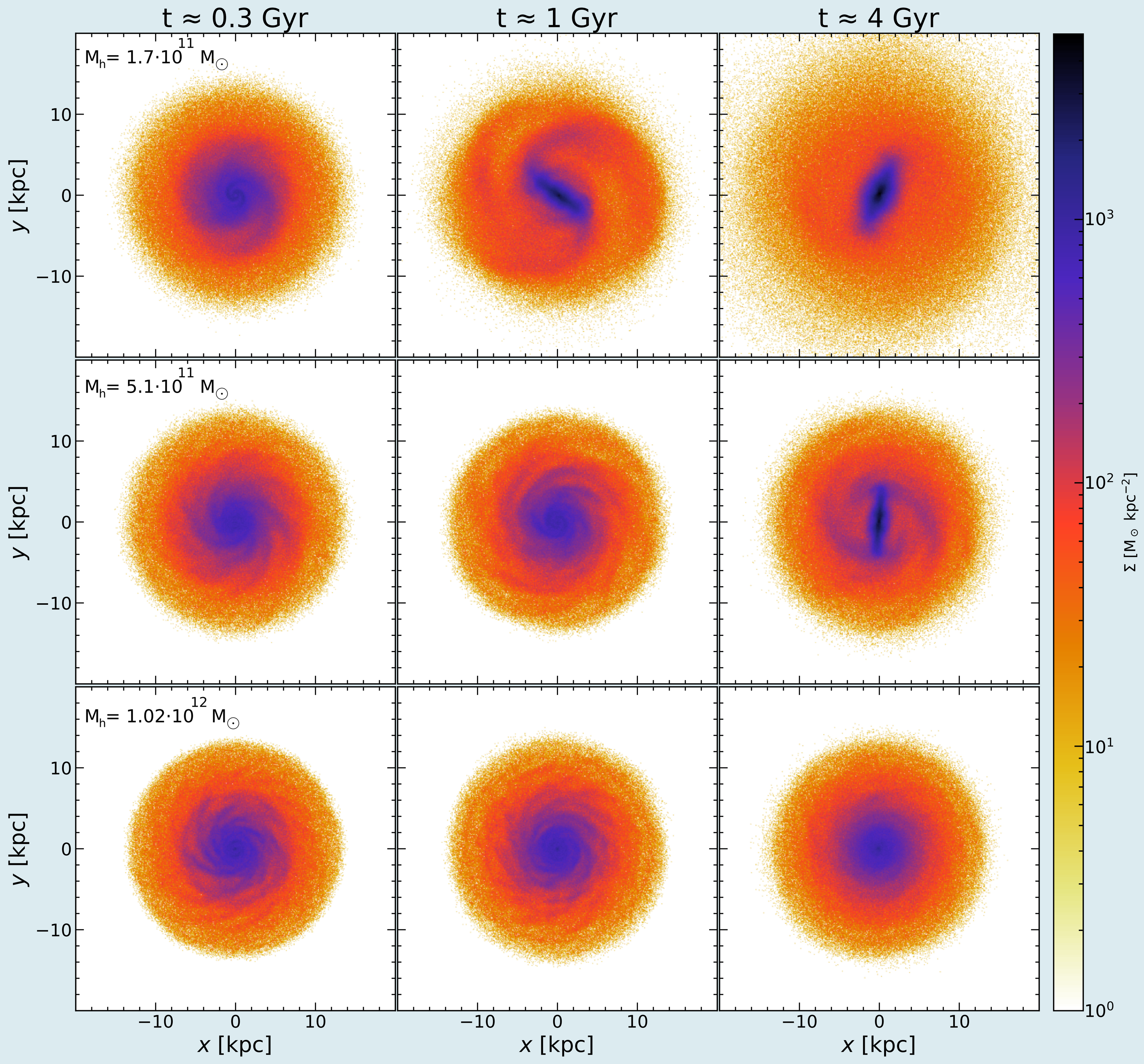
Key message

Spiral arms become fewer and stronger as the dominance of the disc is made larger

Radial migration is strong function of J_z only when halo dominates and spiral influence does not extend to large vertical excursions

Figure 1



Radial Migration

Radial migration is a key ingredient in the restructuring of galaxies and will occur in galaxies with spiral arms/bar. It is a suggested explanation for features of the Milky Way like the thick and thin discs (Toyouchi & Chiba 2016) and co-eval flaring in the outer disc (Minchev et al. 2012, 2015).

Radial migration has to be understood to be properly used in analytical models. A part of this is **understanding which stars undergo migration**. Previous results have established that **migrators have preferentially low vertical excursions**. The idea is that stars that spend more time near the mid-plane of the disc migrate more readily.

However, if a spiral arm is strong enough, it could migrate stars at larger vertical excursions too. This would require a more disc dominated system.

Churning

The most common form of radial migration is churning and occurs when a torque exerted by a spiral arm/bar changes the angular momentum of a star at **co-rotation**, i.e. when star and spiral angular speeds match.

$$\Delta J_R = \frac{\Omega_p - \Omega}{\omega_R} \Delta L_z$$

This equation shows how a change in the angular momentum ΔL_z will lead to a change in radial action ΔJ_r, and therefore eccentricity, if the migration does not occur at co-rotation ($\Omega = \Omega_p$). Because of this, churning **leaves no dynamical trace**.

Simulations `mkgalaxy` (McMillan & Dehnen 2007)

To study radial migration and its effect on stars of various vertical excursions, we generate *N*-body simulations of a number of galaxies and create initial conditions for different disc dominances and for different spiral morphologies.

- 100+ Full *N*-body simulations with disc, bulge, halo.
- 11 base simulations, 11 random seeds for each.
- **Change disc dominance through halo mass.** Cover large span of force ration between halo and disc.
- Investigate occurrence of spiral arm strength and number and compare migration as a function of vertical action.

Figure 2: The radial force from the halo divided by the radial force from the disc over all radii for each of the 11 base simulations. The numbers give the mass of the halo in each other simulation in units of $10^{11}\ M_\odot$. When the halo mass increases, the fraction does as well and this leads to a **decrease in disc dominance**.

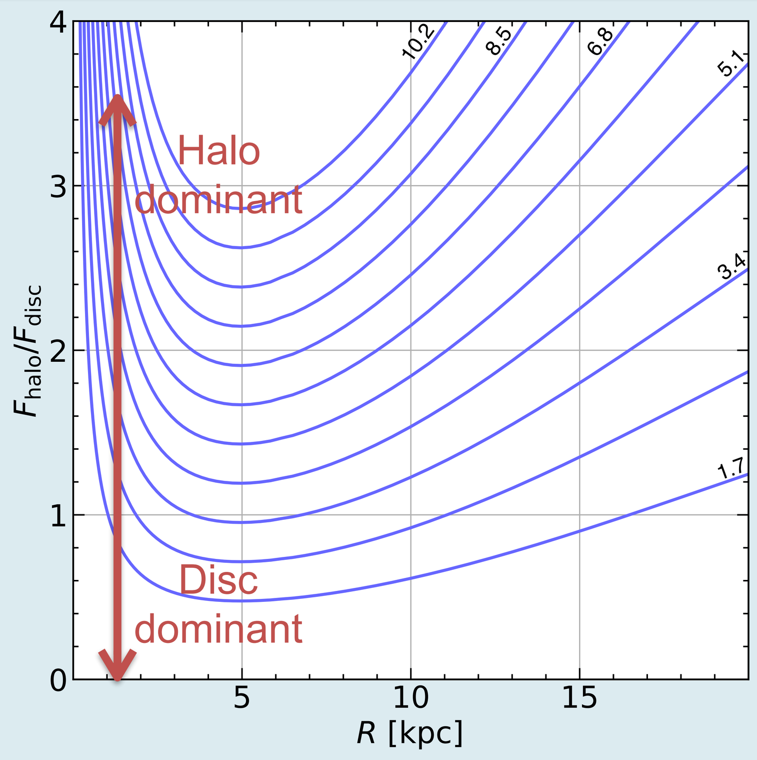
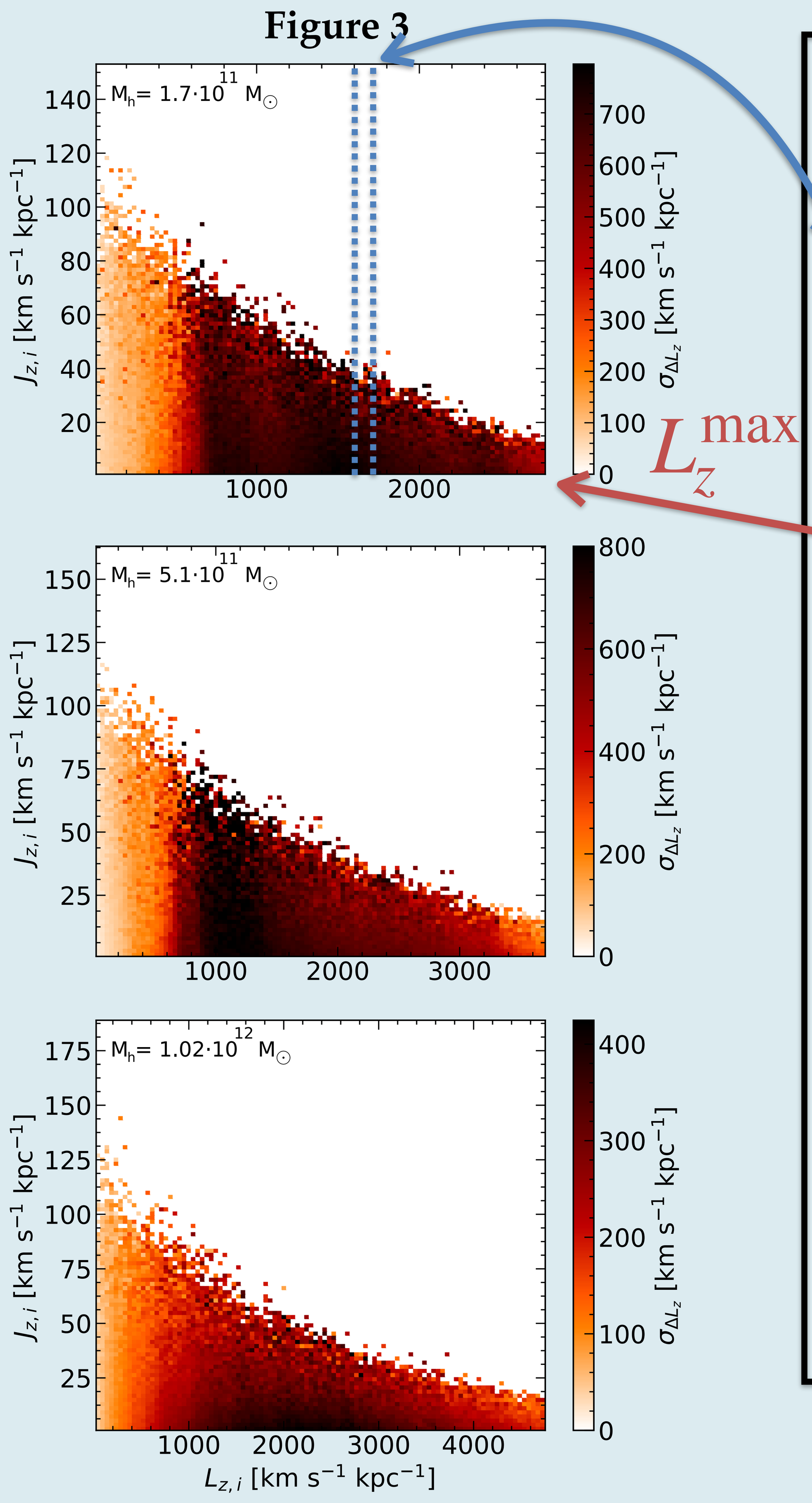


Figure 3



Migration with vertical action

From our galaxies, we look at the distribution of $\sigma_{\Delta L_z}$ in the space of L_z, which extends to ~15 kpc, and J_z in **Fig. 3**. At a certain L_z we then take four thin vertical slices along all J_z and perform a linear fit to find the dependence of vertical action, J_z, on radial migration. The fitted data is normalised such that $\sigma_{\Delta L_z}(J_z = 0) = 1$ and $J_z^{max} = 1$. We find:

- The number of spirals go down and their strength goes up as we have a more dominant disc and vice versa, as seen in **Fig. 1**.
- Radial migration can be made to decrease with larger vertical action, **but it depends on the dominance of the disc** (see **Fig. 2**). A very disc dominated system will still migrate particles of large vertical action as can be seen below in **Fig. 4**.

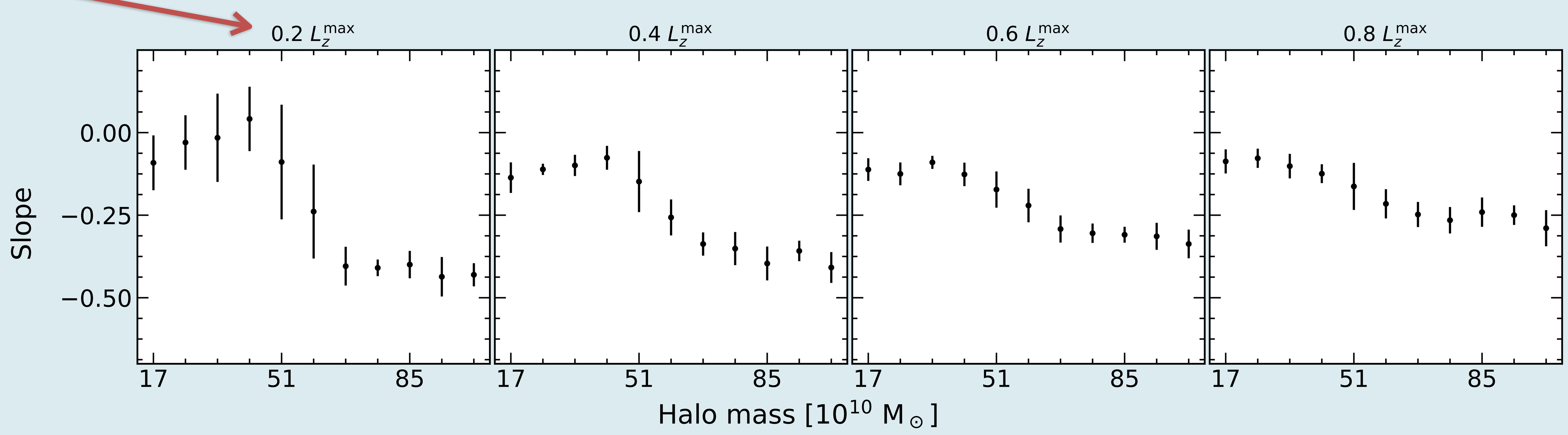


Figure 4: Calculated slope of $\sigma_{\Delta L_z}$ with J_z at four different parts of the galaxy, calculated for each halo mass simulation and random seed. The random seeds for each setup is used to calculate the standard deviation used as uncertainty.

For further information see Mikkola et al. (in prep.)