Stellar radial migration as a subdiffusive process

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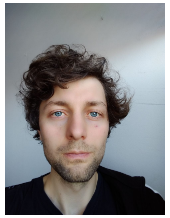
Simulations of Milky-Way like galaxies suggest that stellar radial migration does not happen continuously, but in episodes. However, in observational works migration is typically treated as a diffusive process. We use a new suite of cosmological Milky-Way-like simulations, NIHAO-UCD, to show that radial migration should not be approximated as one-dimensional diffusion along the radial axis of a galaxy. In particular we show that 1.) the net migration shows characteristic quasi-periodic oscillations, 2.) the power spectrum of radial migration is significantly different from white noise, and 3.) the migration efficiency depends both on age and on the birth position of a star, with a power-law coefficient around 1/4. We conclude that on Galactic evolution timescales radial migration should rather be described as a subdiffusive than as a diffusive process.



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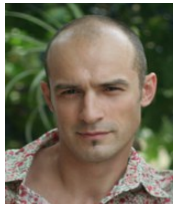
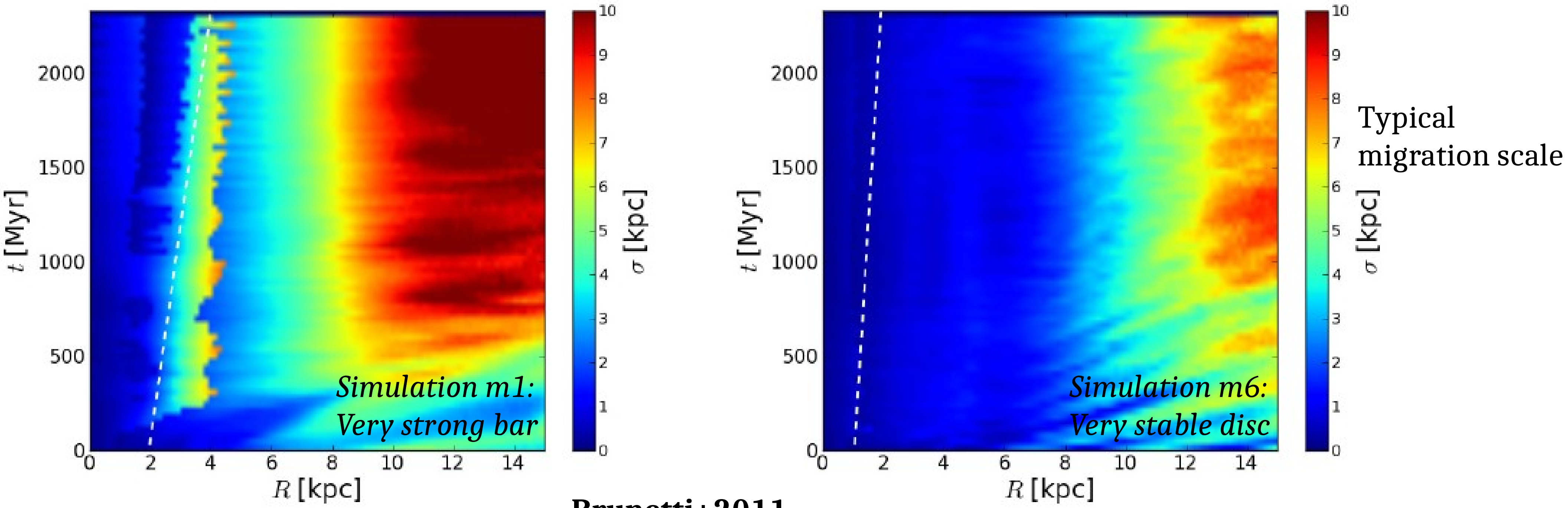


Problem: how do we treat stellar radial migration correctly?

Sellwood & Binney 2002: Radial mixing = blurring + churning. To 1st approximation: churning=diffusion
Kubryk+2015, Frankel+2018, Sharma+2020: Churning modelled as diffusion in R
Frankel+2019, 2020: Churning modelled as diffusion in action space

Brunetti+2011: you can locally assume diffusion, but this will only be valid over ~ 1 rotation…



Brunetti+2011

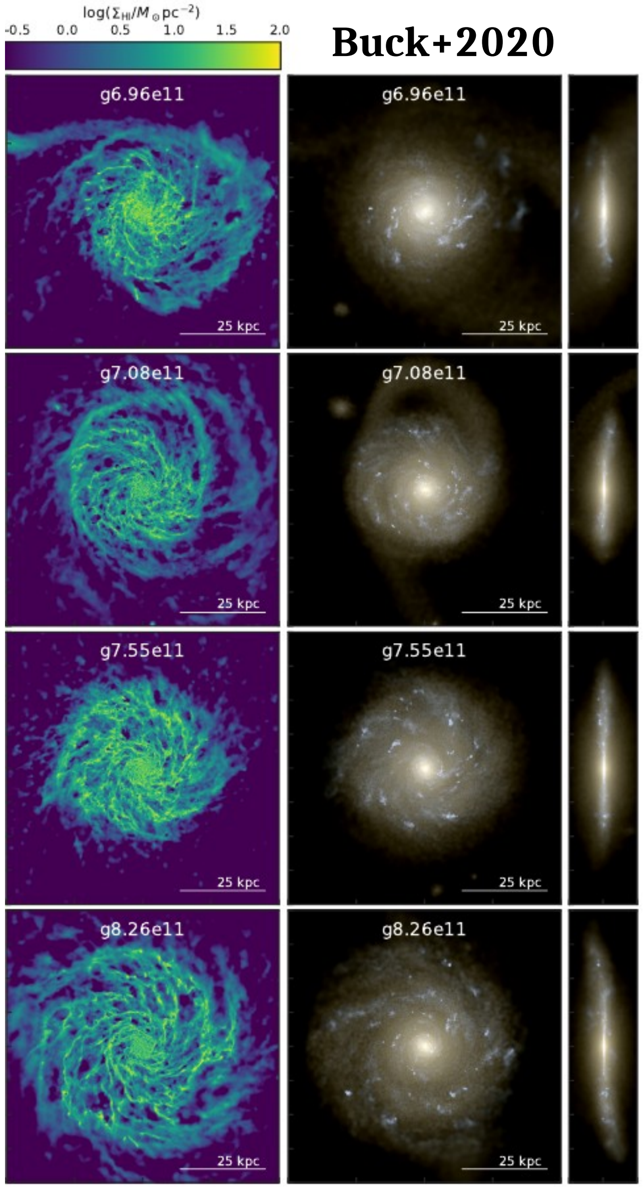
Migration in the NIHAO-UHD simulations

Simulations:
- 5 cosmo zoom-in SPH discs that bracket the MW mass (Buck et al. 2020)
- Stellar chemo-dynamics studied in more detail in Buck 2020 (explaining the alpha/Fe disc bimodality present in the MW)

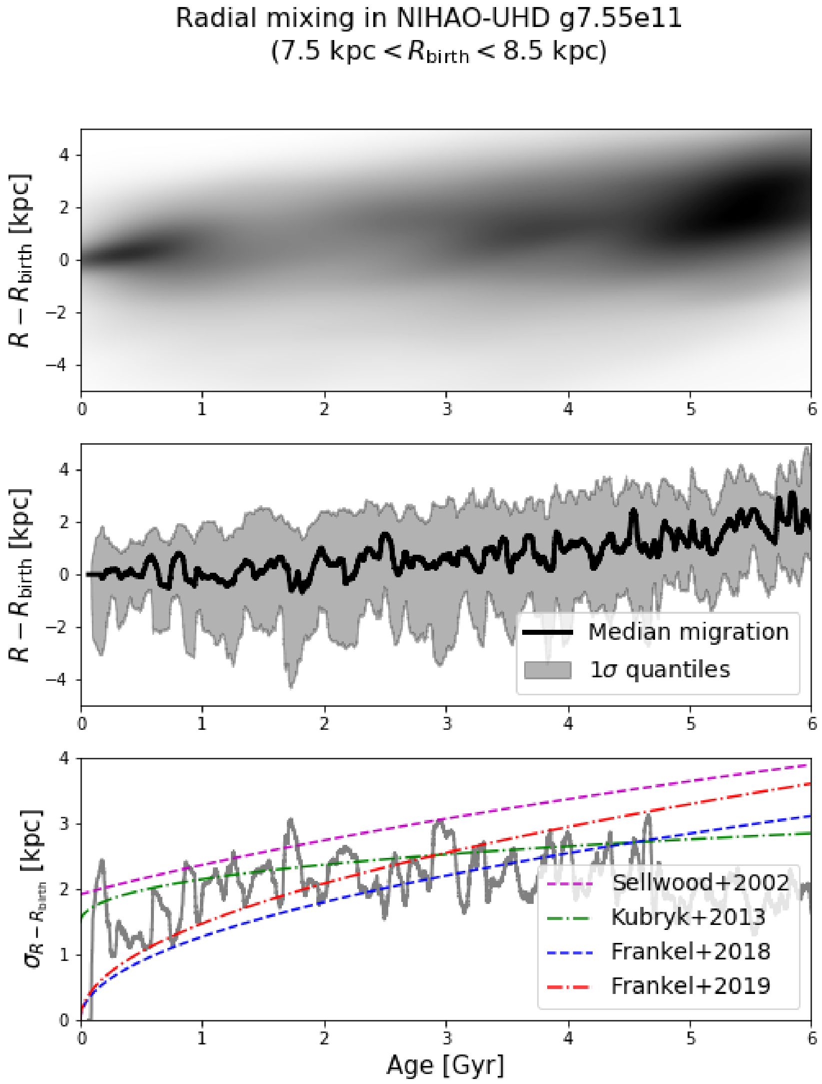
Data used:
- z=0 snapshots
- birth radii for each particle
- focussing on the stellar disc component born in-situ ($|Z_{birth}| < 2$, $|Z|<3$, $R<20$, $R_{birth}<20$)
- to study migration we look at the distribution {R, R_{birth}, age} in various projections. This relies on the following **assumptions** (which might also be broken!):

* Time reversibility: age == -time
* Ergodicity: Average over all particles at 1 age in an initial volume = average of all trajectories that are in volume at time t=t0

Buck+2020



(Preliminary) Results: Signs of subdiffusive behaviour

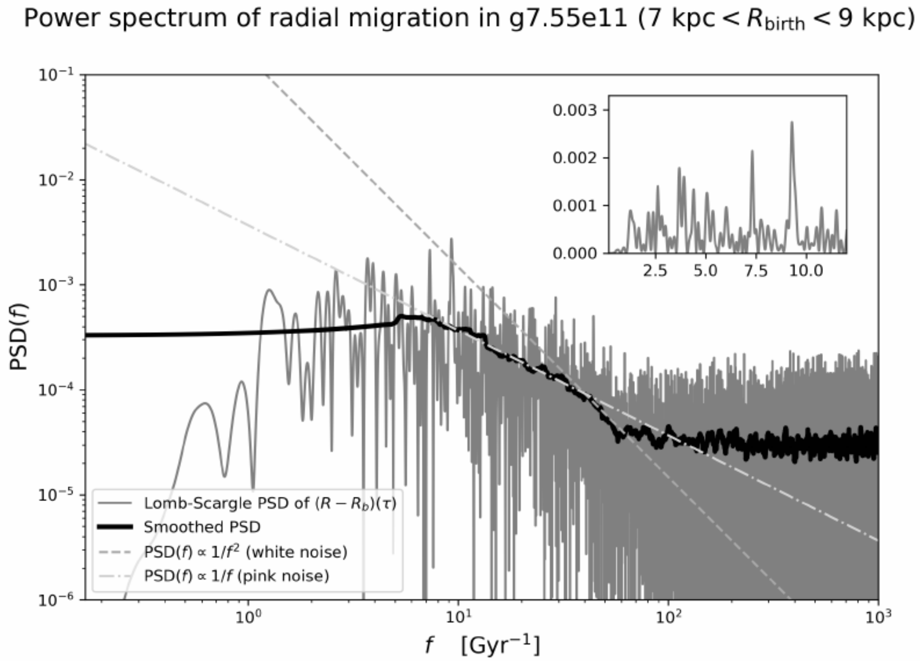


We study the R-R_{birth} distribution as a function of age, p(R-R_{birth} | age) in bins of R_{birth} :

→ we look at the median trend + the dispersion around the median

→ both the median trend & the dispersion show conspicuous wiggles

→ the dispersion does not seem to follow a diffusion law



The power spectrum of p(R-R_{birth} | age) gives clues about the underlying dynamics:

→ If migration = diffusion, then we would expect a white-noise-like spectrum PSD(f) ~ $1/f^2$. However, we see some interesting low-frequency peaks and a pink-noise-like (~1/f) behaviour up to intermediate frequencies.

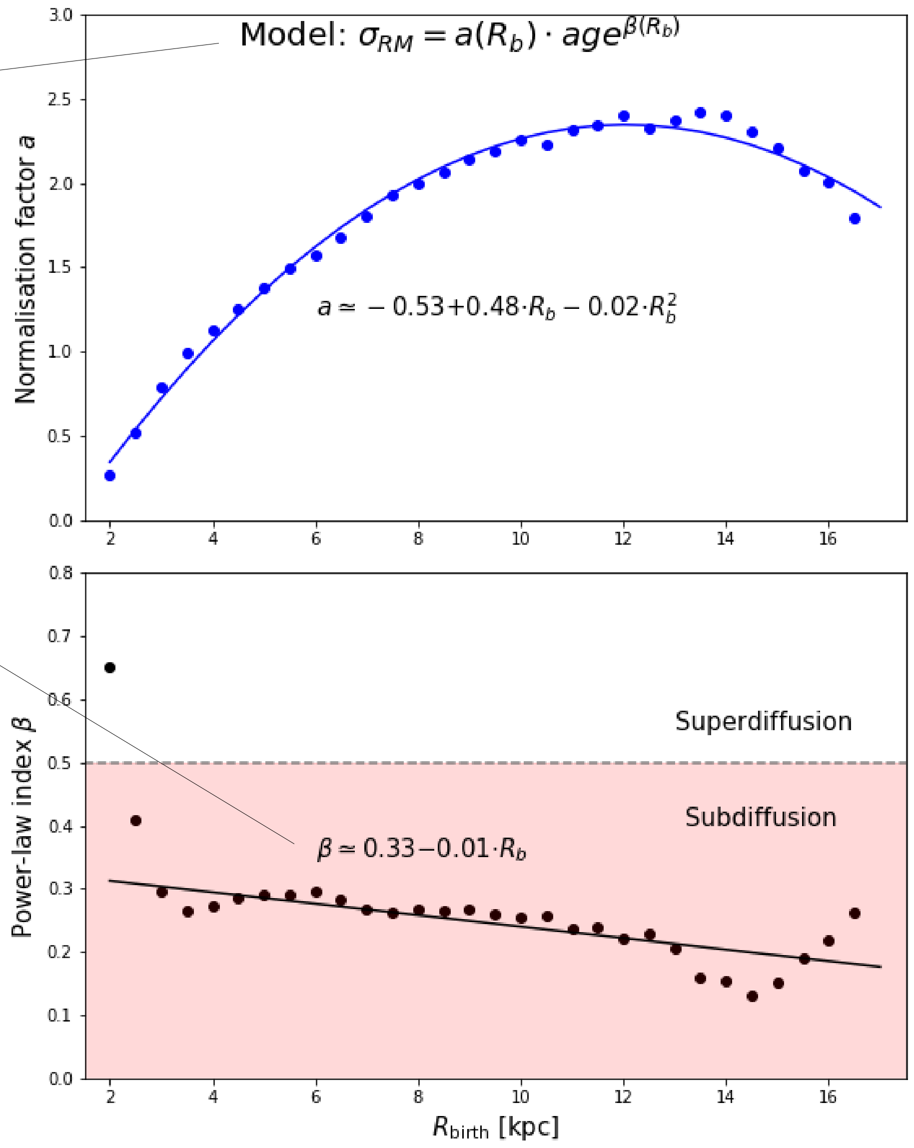
(Preliminary) Results: Signs of subdiffusive behaviour

Migration efficiency can be modelled well as a product of a term depending on R_{birth} and an age-dependent power-law term.

For all but the innermost R_{birth} bin, the dispersion dependence on age has a power-law index ~ 0.2-0.3 (similar values for all 5 NIHAO-UHD disc galaxies), which indicates subdiffusive behaviour.

This is a normal behaviour in complex dynamical systems (especially in non-equilibrium).

(e.g. Bak, Tang & Wiesenfeld 1987)



Implications

1. When fitting Milky Way data with semi-analytic models (e.g. Frankel+2020), we should **use more flexible descriptions** for radial migration (that can account for the observed subdiffusive behaviour).

2. The importance of this **effect on star-formation history** inferences (e.g. Mor+2019 , Isern 2019, Ruiz-Lara+2020) could potentially be sizeable.

Future

1. We need to verify that the behaviour is **not a peculiarity of the NIHAO-UHD simulations**, but a universal feature in Milky-Way simulations.

2. The analysis will be extended to **action space**.

3. Subdiffusive behaviour usually implies **broken ergodicity.** This can be verified by comparing our analysis to a similar one studying the particle trajectories over all snapshot.