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Spiral arms and radial migration in Milky Way-sized galaxy simulations

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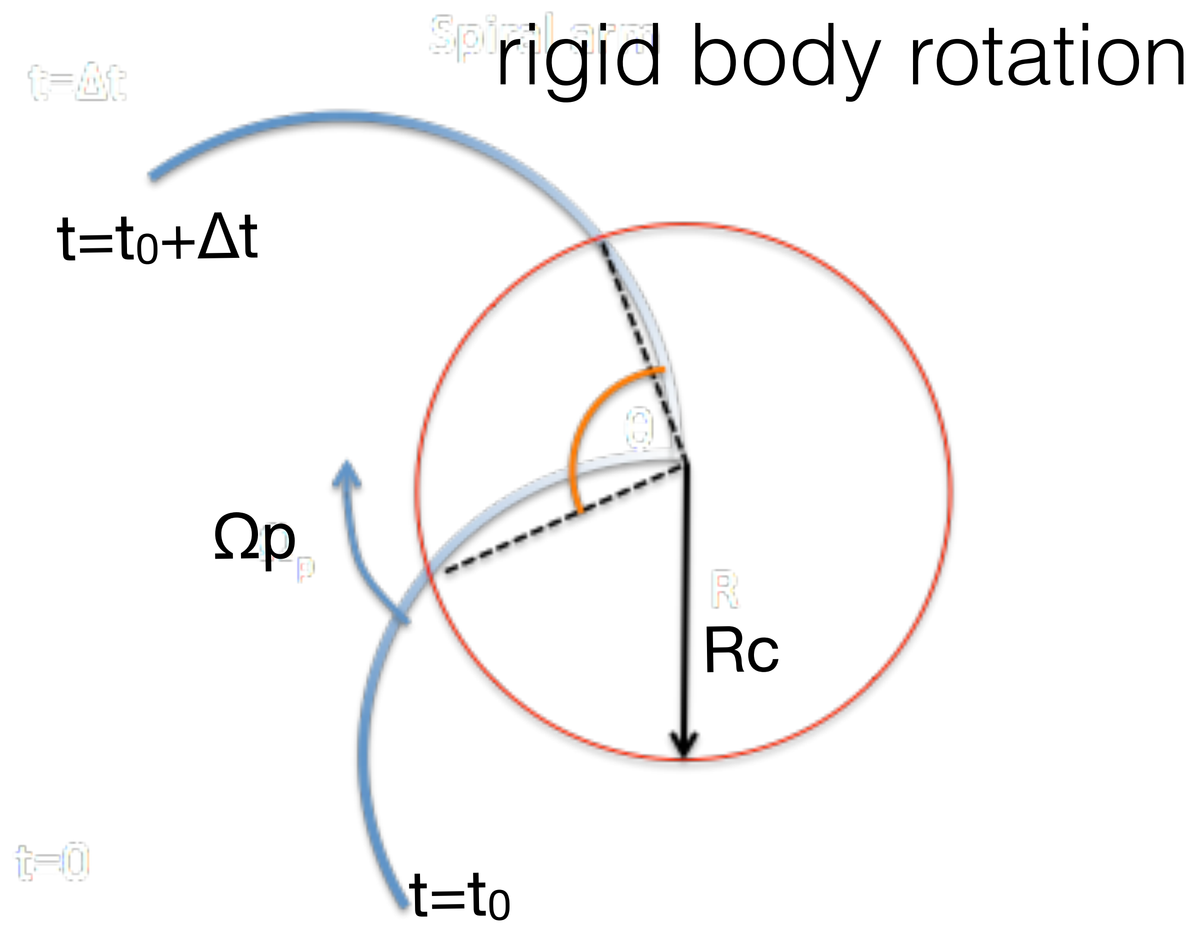
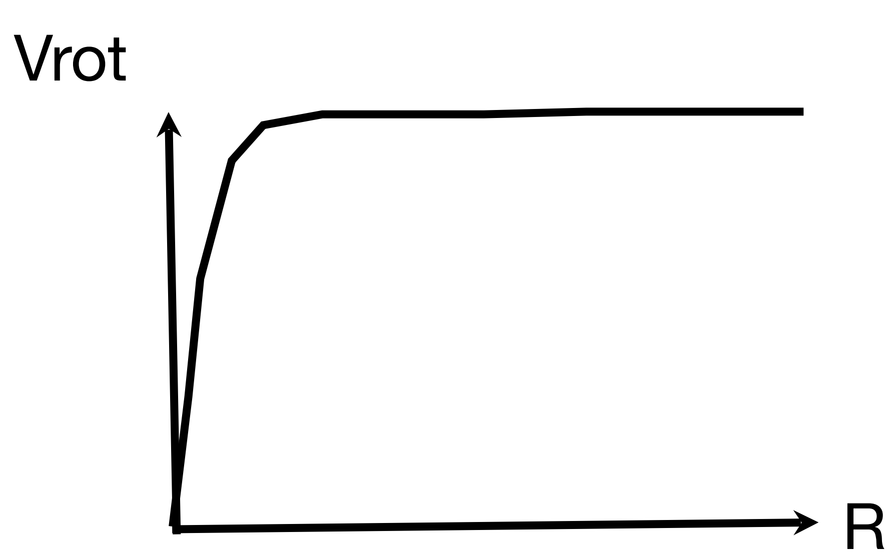
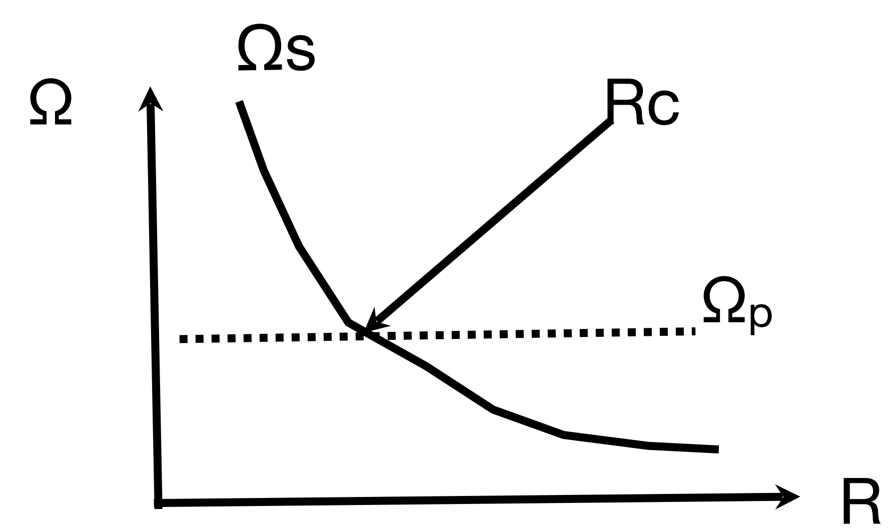
Reconstructing the Milky Way's History
Bad-Honnef
4th of June, 2015

Spiral Density Wave Theory (Lin & Shu 1964)

- Spiral arms are a **permanent feature**
- **constant pattern speed**, Ωp, at all radii
- Avoids winding dilemma
- stars rotate faster (slower) than the pattern inside (outside) the co-rotation radius, Rc

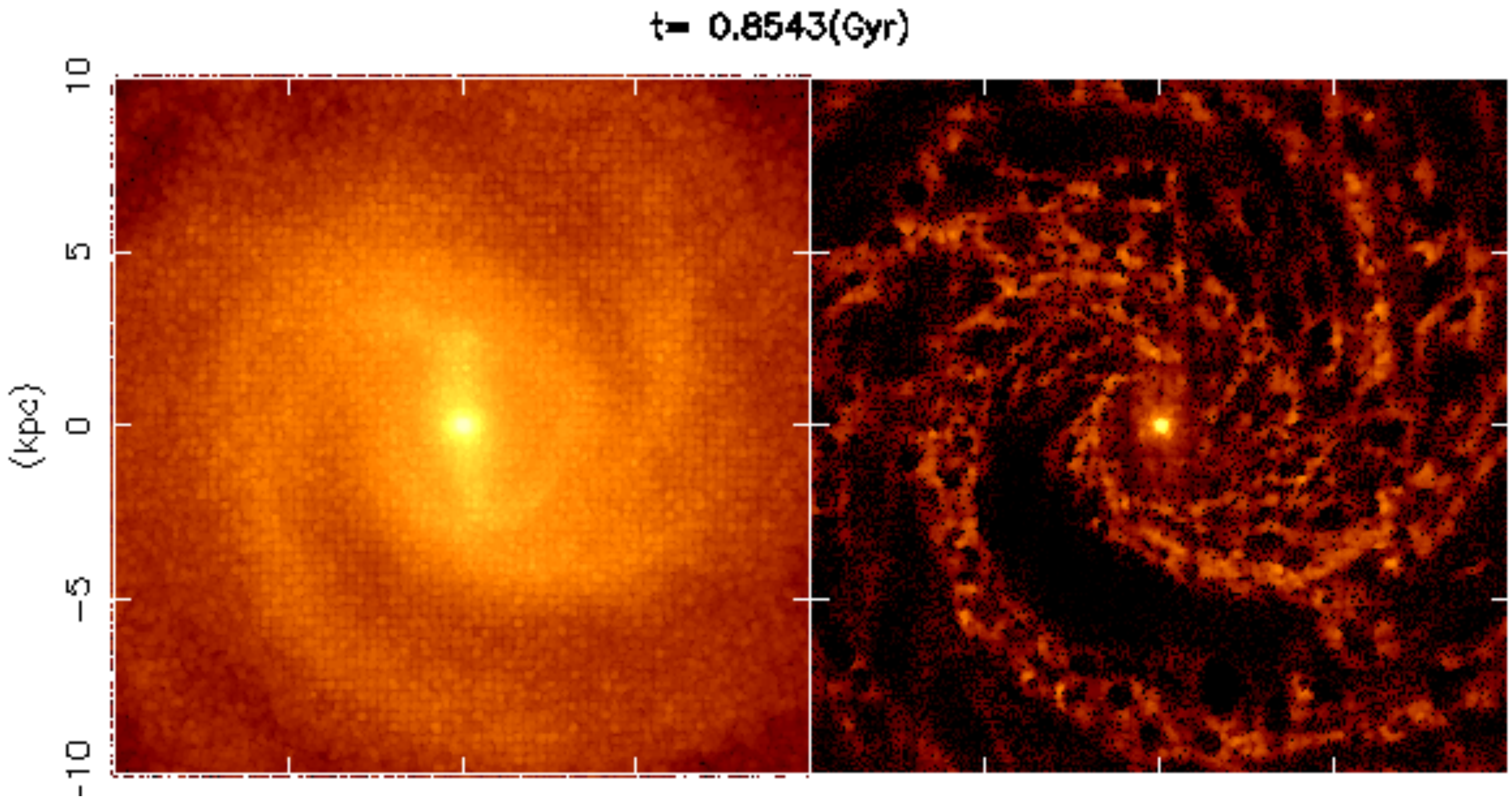






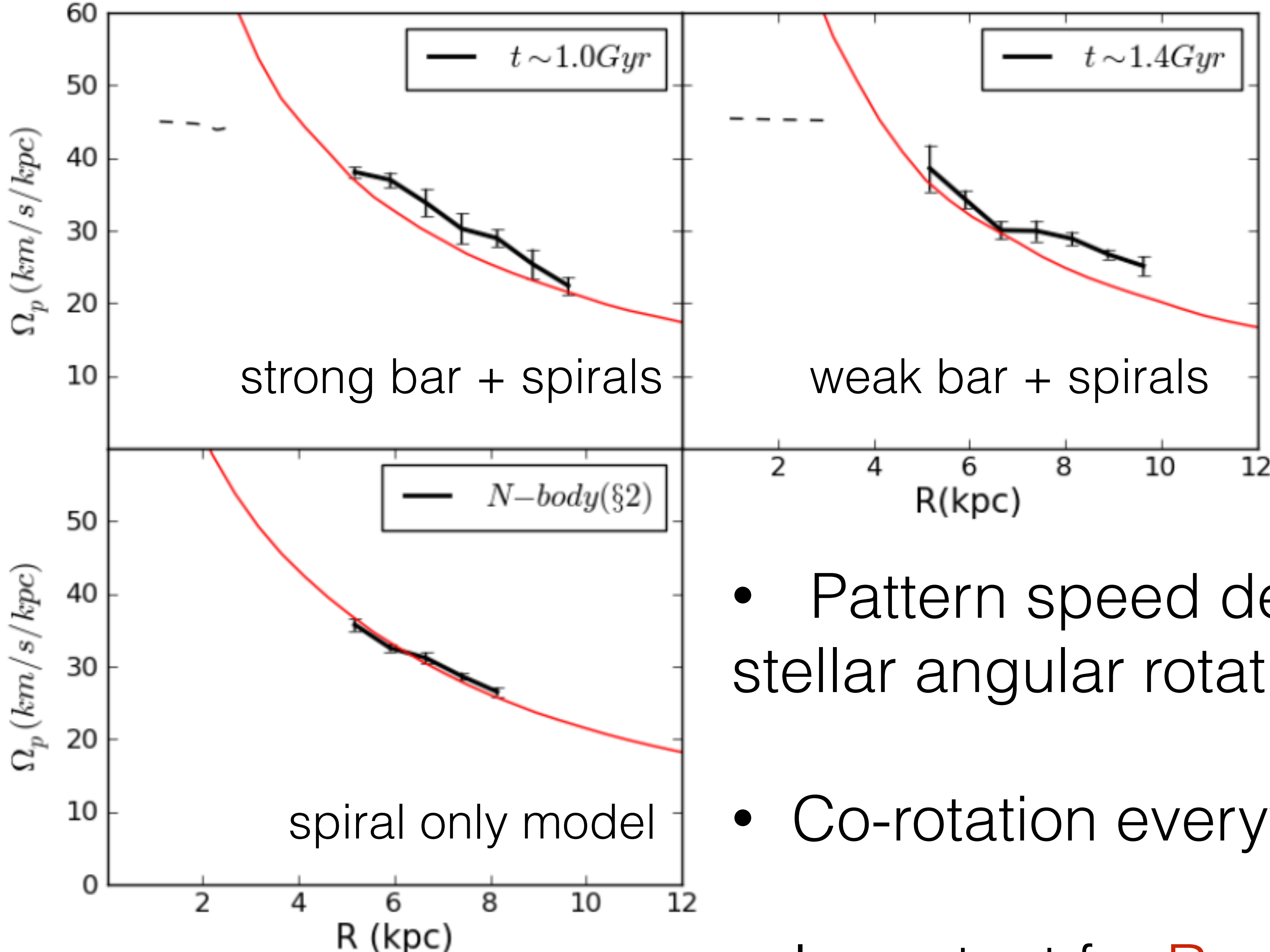
Transient spirals in isolated numerical simulations (N-body+SPH)

Isolated, Milky way-sized disc (GCD+, Kawata et al. 2013)



- Spiral arms are transient features (Lifetime ~ 100 Myr)

Co-rotating spiral arms



Grand, Kawata+ 2012a,b

- Pattern speed decreases with stellar angular rotation curve
- Co-rotation everywhere
- Important for Radial Migration!

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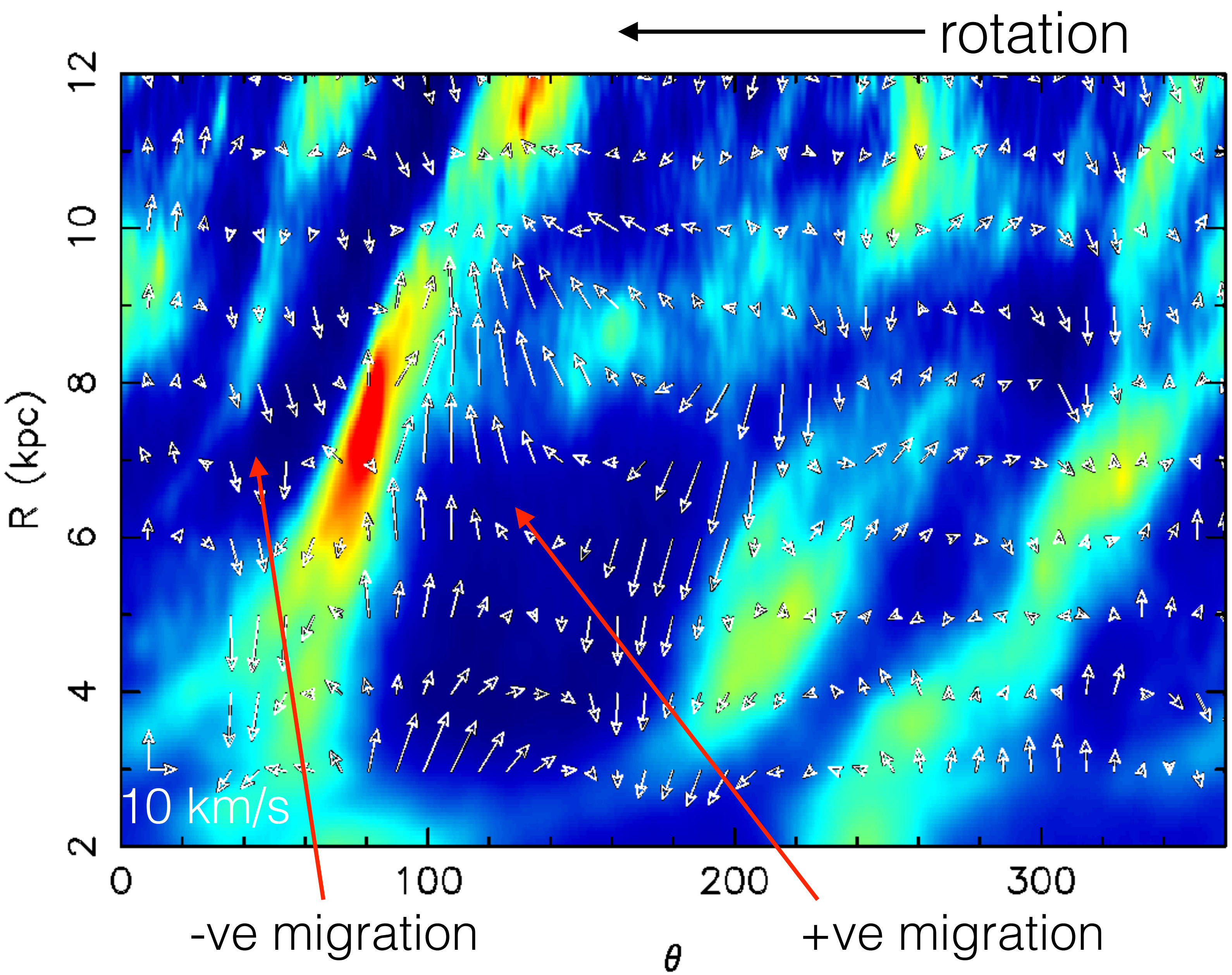
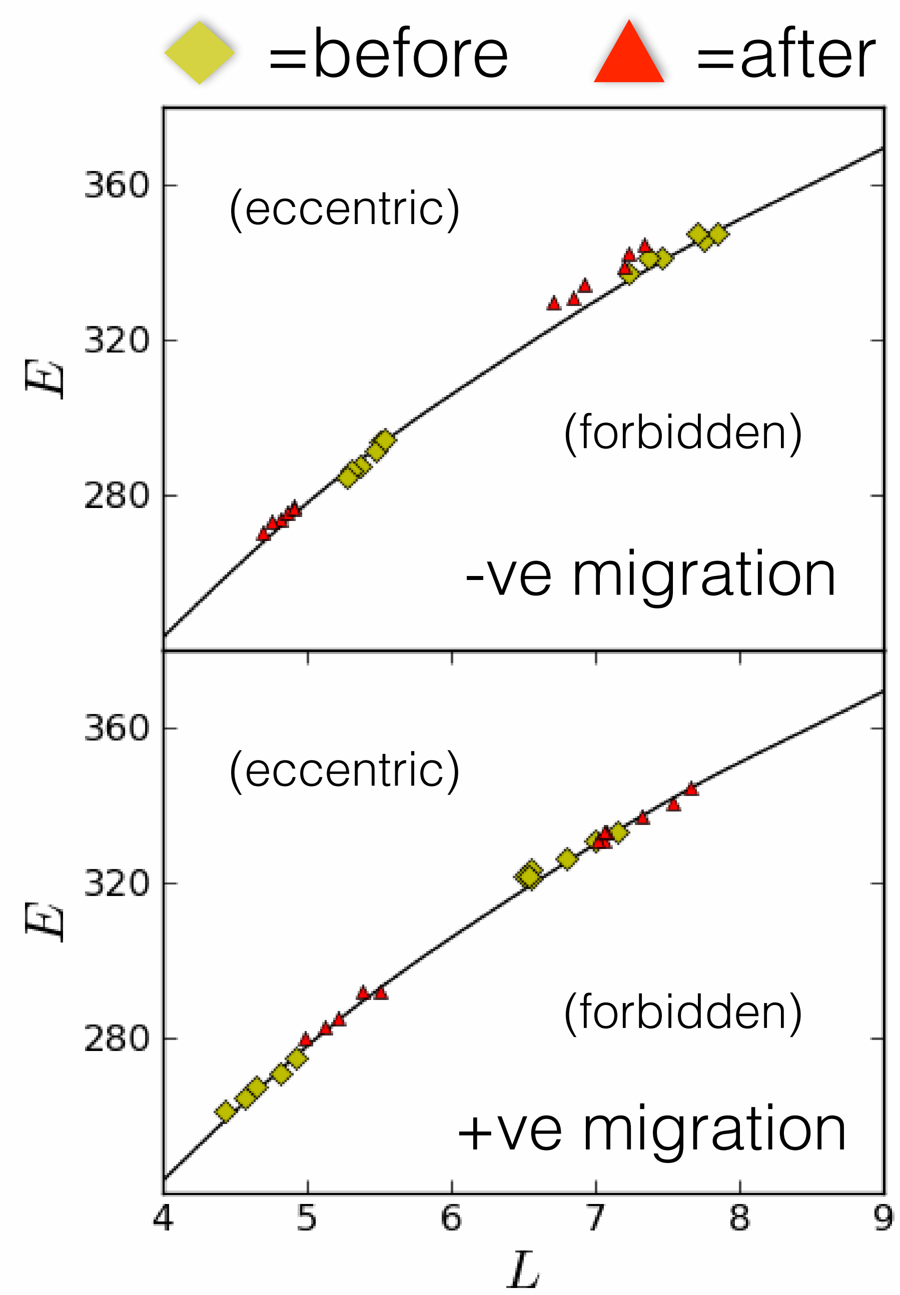
Radial migration and Vpec fields

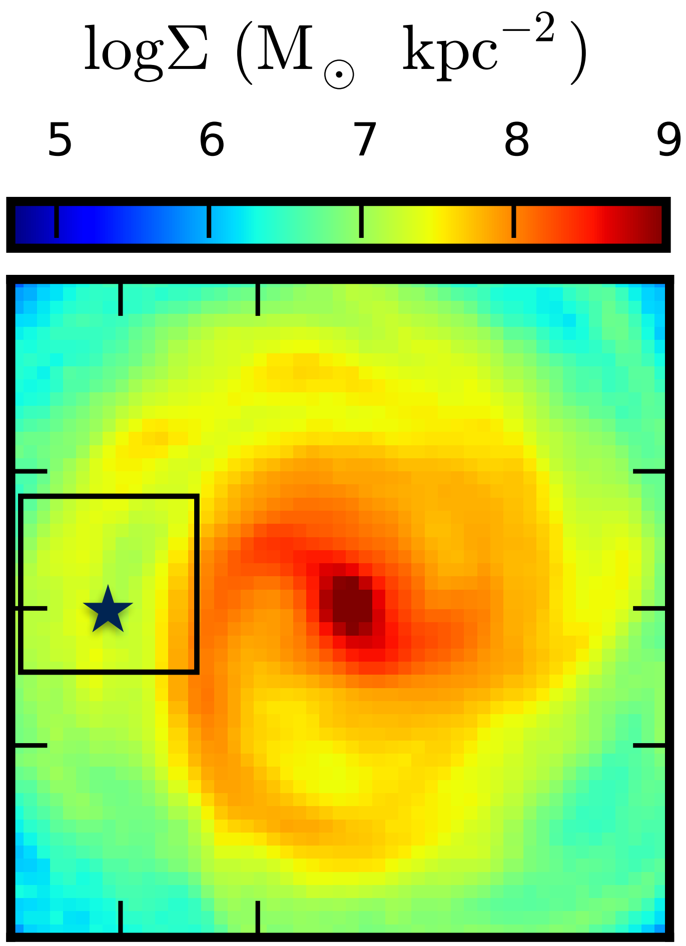




- Co-rotating spirals —> radial migration everywhere!
- Stars behind (in front of) spiral gain (lose) angular momentum
- Migrated stars gain little random energy (Sellwood&Binney2002)

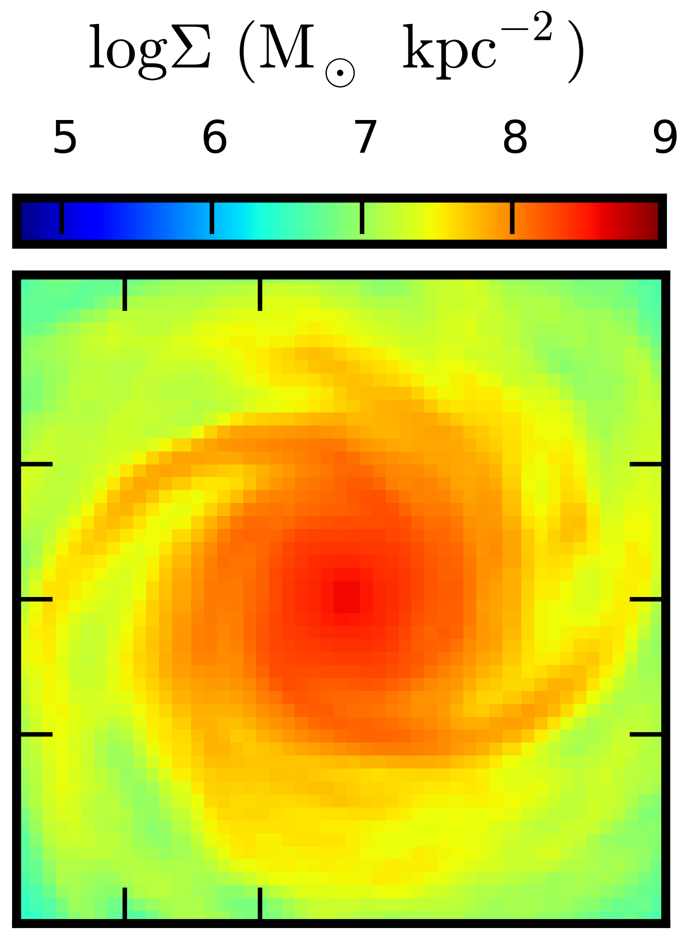
How do Vpec fields vary between spiral models?

N-body, barred spiral



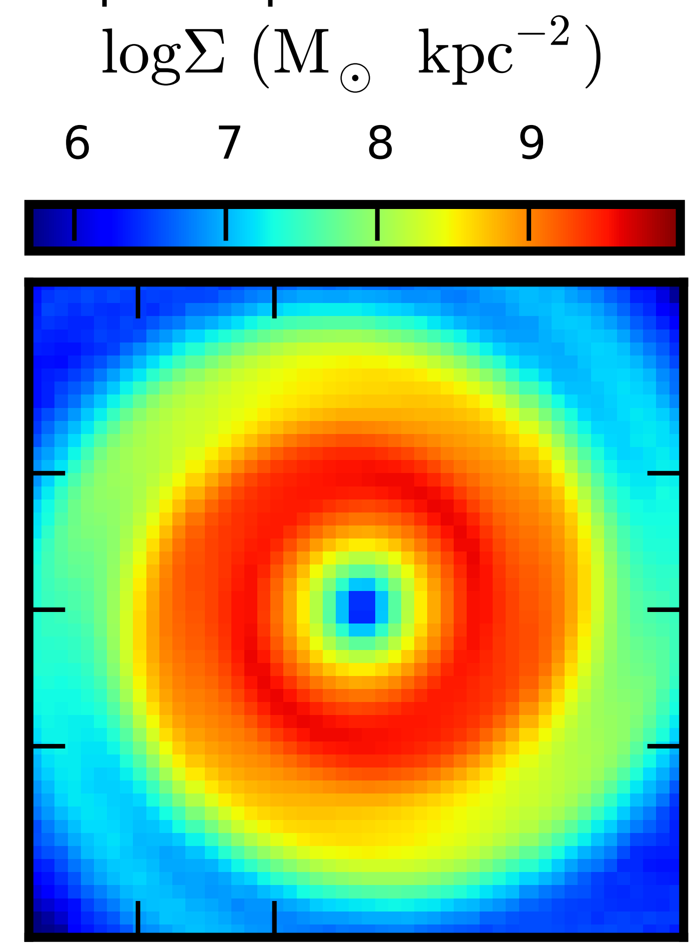
Kawata+ 2014

N-body, spiral only



Grand+ 2013

Test particle, rigid spiral potential



Monari+ in prep

Pitch angle	= 10.0	= 19.0	= 10.0

- Select an APOGEE-like volume
- Calculate a grid of mean LOS peculiar velocities

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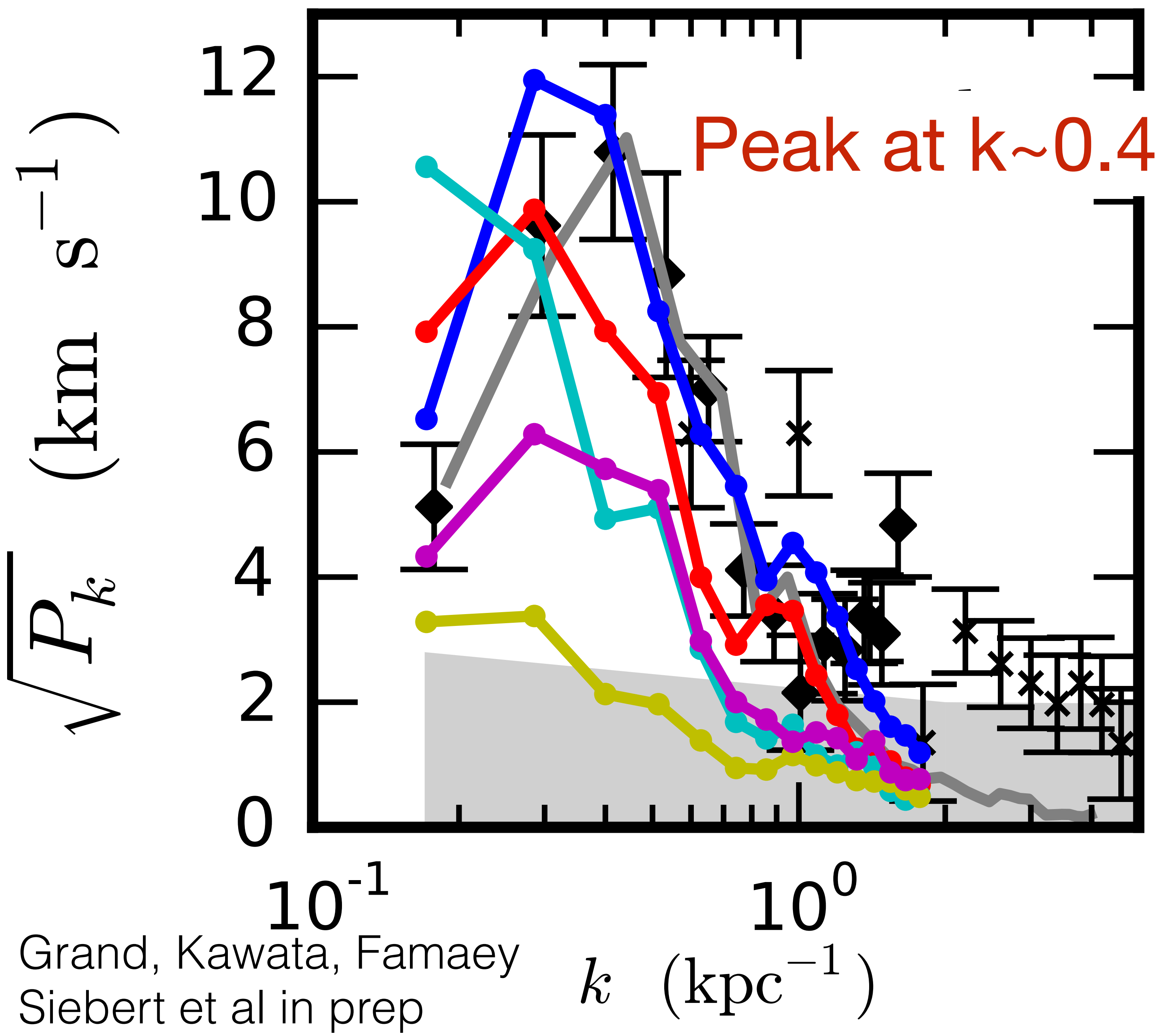
Characterising the velocity fields - 1D power spectrum



Grand, Kawata, Famaey Siebert et al in prep

- Take 2D Fourier transform of peculiar velocity fields in APOGEE volume (Bovy+ 2015)
- Estimate 1D azimuthally averaged power spectrum

NB-bar+sp (Kawata+ 2014)
NB-sp only (Grand+ 2013)
Test-sp only (Monari 2015)
Test-sp only (Faure+ 2014)
Test-bar only (Bovy+ 2015)
Data(APOGEE, RAVE)

- N-body barred-spiral fits data well
- N-body spiral only reproduces characteristic peak
- Test particle density wave-like spirals do not fit at all

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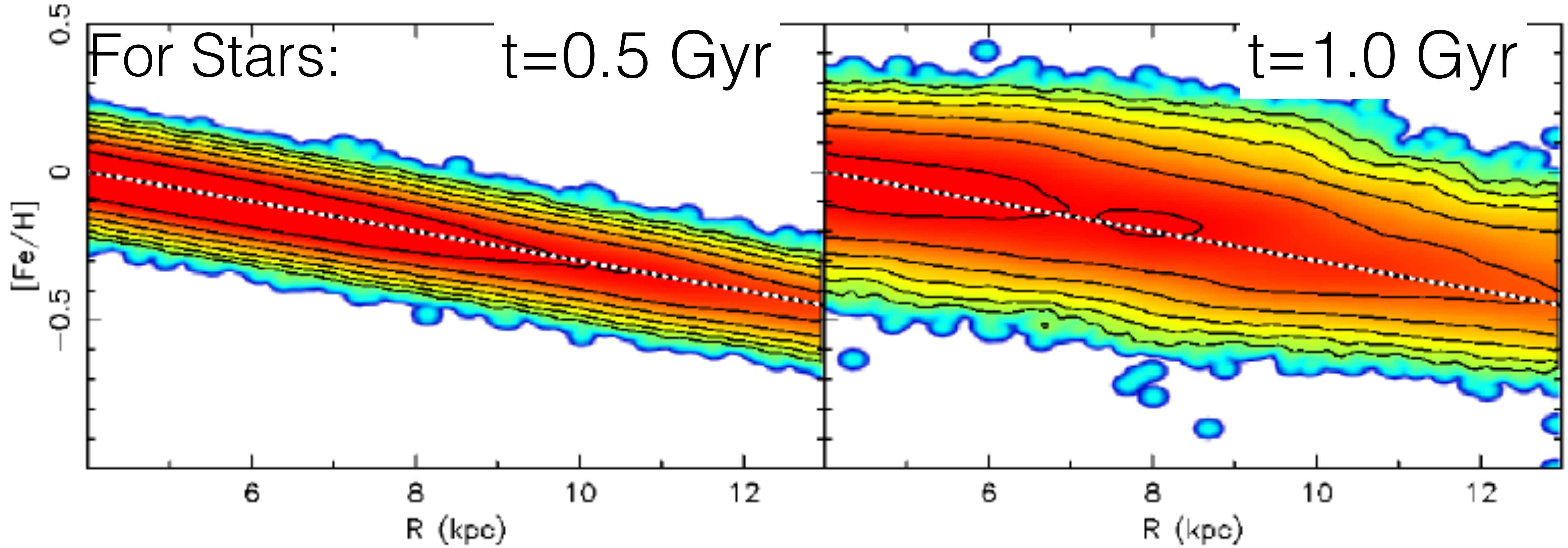
Evolution of the stellar and gas radial metal distribution (RMD):

Effects of radial migration

Radial migration impact on metallicity distribution



- Set up stars with artificial radial metallicity distribution (RMD) with negative radial metal gradient

Mean [Fe/H] set by: $$[\mathrm{Fe/H}](R) = 0.2 - 0.05\left(\frac{R}{1\mathrm{kpc}}\right)$$

MDF at each radius: Gaussian of 0.05 dex disp.

- Radial migration broadens MDF at each radius
- No change in radial metallicity gradient (see also Kubryk+ 2014, Minchev + 2014)

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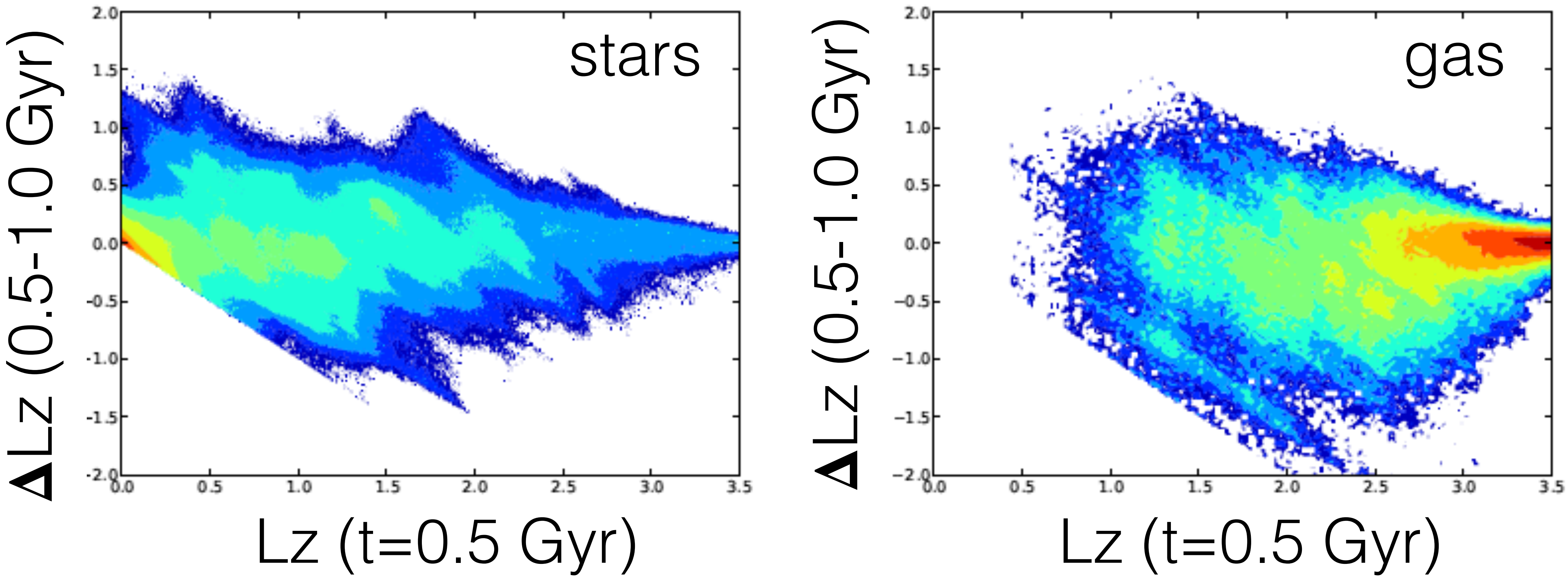
Radial migration impact on metallicity distribution

- Radial migration affects star and gas particles (Grand, Kawata+ 2015)



- Large changes in Angular momentum seen over large ranges in initial Angular momentum (radius)

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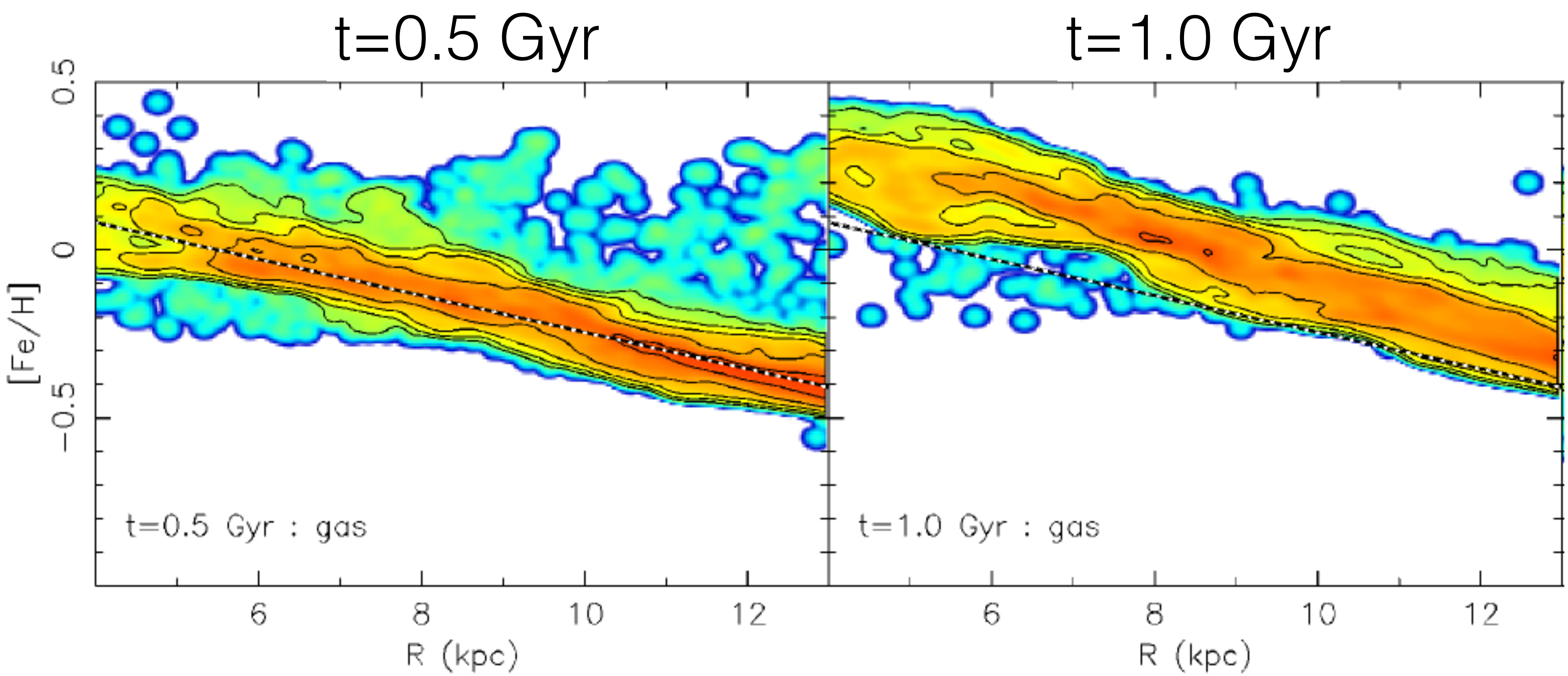
Radial migration impact on metallicity distribution

For gas:



- No gas infall —> artificial systematic increase in metallicity
- Efficient metal diffusion —> Metallicity dispersion kept narrow

The Giga-Galaxy:

Hi-resolution full cosmological zoom simulations

Summary of Zoom simulations

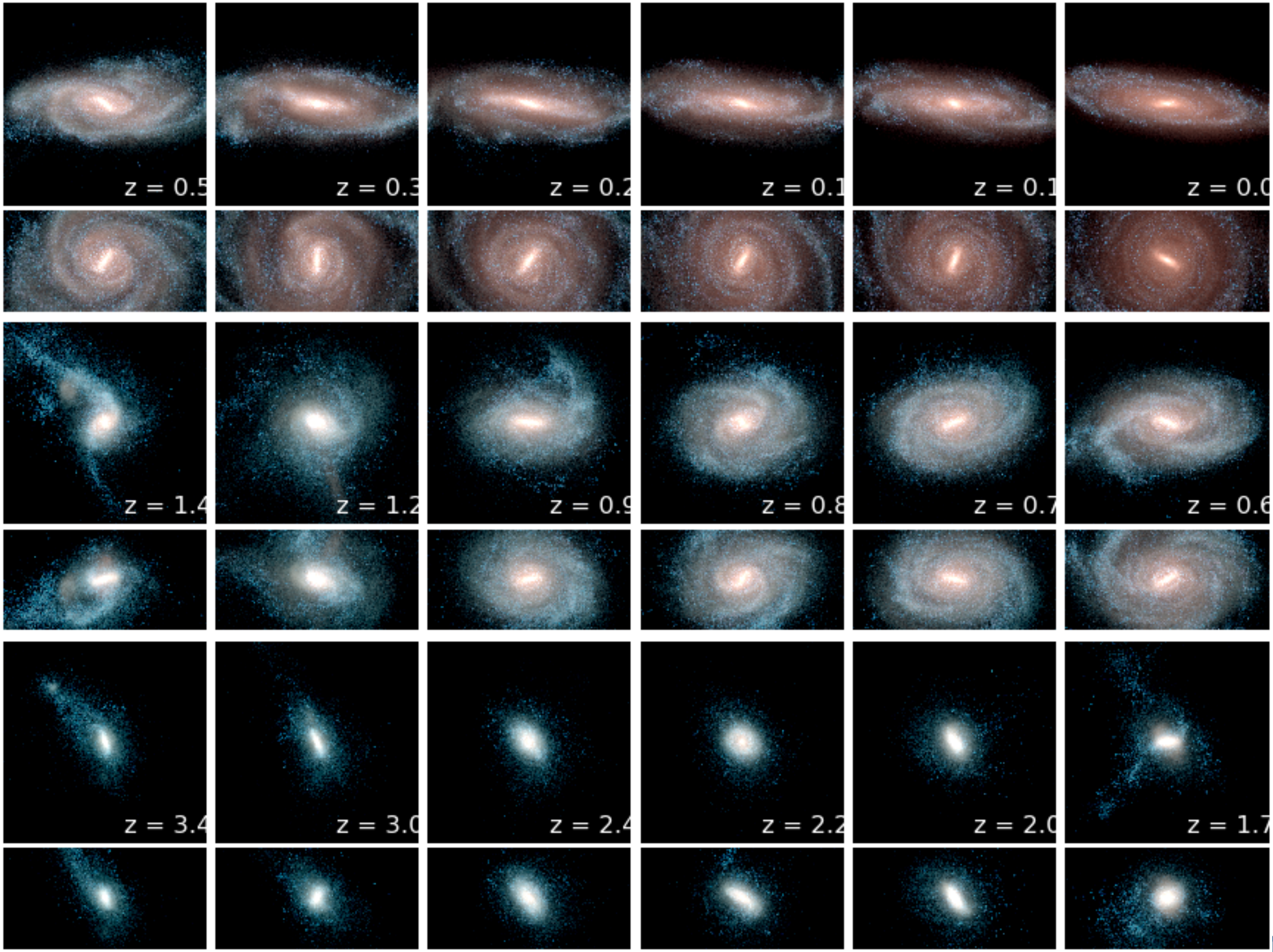
- Cosmological zoom sims of Milky Way mass halos
- Run with moving mesh hydrodynamics code AREPO (Springel 2010)

Physics model includes:

- (Magneto-) hydrodynamics
- Star formation and Stellar evolution
- SNe Type II and Ia feedback
- Stellar winds with metal loading
- AGN feedback (winds)
- Black hole accretion
- Gas recycling+Chemical enrichment

Resolution:

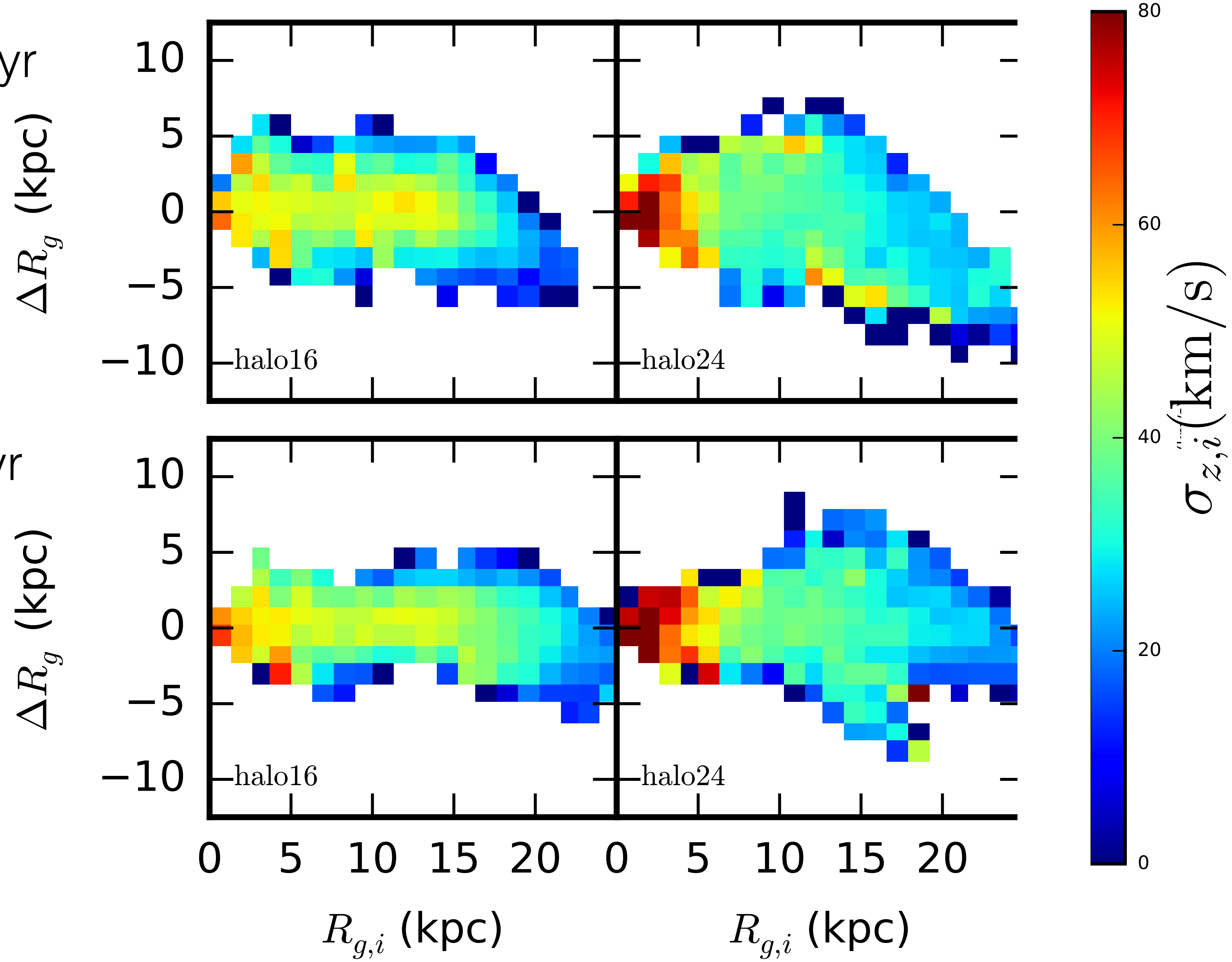
Level	N_disc	Mass_p
5	~10^5	~10^5
4	~10^6	~10^4
3	~10^7	~10^3
2	~10^8	~10^2
1	~10^9	~10


z = 0.5
z = 0.3
z = 0.2
z = 0.1
z = 0.1
z = 0.0
z = 1.4
z = 1.2
z = 0.9
z = 0.8
z = 0.7
z = 0.6
z = 3.4
z = 3.0
z = 2.4
z = 2.2
z = 2.0
z = 1.7

Radial migration and scale height

tini=3.0 Gyr, tfin=1.3 Gyr

tini=1.3 Gyr, tfin=0 Gyr



- Colder stars preferentially migrate (see e.g., Vera-Ciro+ 2014)
- Outward (inward) migrating stars cool (heat) intrinsically (Minchev 2012)

—> reduced disc thickening from radial migration?

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Conclusions

- Transient, co-rotating spiral arms cause systematic streaming motions along the spiral arm

- Peculiar velocities induced by N-body spirals matches well APOGEE-LOS data - density wave-like spirals do not

- Radial migration broadens the stellar MDF at all radii, but keeps the radial metallicity gradient constant

- Gas particles migrate a substantial amount, but efficient metal mixing keeps MDF narrow everywhere

- Realistic cosmological zoom simulations will resolve stellar and gas dynamics extremely well. Coming soon….

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