Heidelberg Institute for Theoretical Studies

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Disc dynamics in cosmological zoom simulations of MW sized galaxies (The Auriga project)

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Discs in galaxies
ESO, Garching b. München
July, 2016

Content -
to study drivers of disc dynamical evolution:

- **What controls the stellar and gas disc thickness** and relations like the Age-velocity dispersion relation (AVR)?

- **How do spiral arms/bars affect disc chemo-dynamics**
  e.g., peculiar velocities, radial migration, predictions

Why cosmological zoom sims?

- To study the discs of galaxies evolved in a full cosmological context with a GFM capable of modelling a realistic galaxy population, in as much detail as isolated N-body sims

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Code & Galaxy formation physics model (Vogelsberger+2013, Marinacci+ 2014)

AREPO - moving mesh MHD code (Springel 2010)

Cooling and metal enrichment

- Primordial cooling
- Metal line cooling (CLOUDY), density, temperature & redshift dependent
- Mass and metal return to Interstellar medium based on population synthesis models

Star formation and winds

- Sub-resolution model for star formation (Springel+ 2003)
- Cold dense gas stabilised by pressurised ISM
- Thermal and kinetic energy from Supernovae modelled by isotropic wind - launched outside of SF region

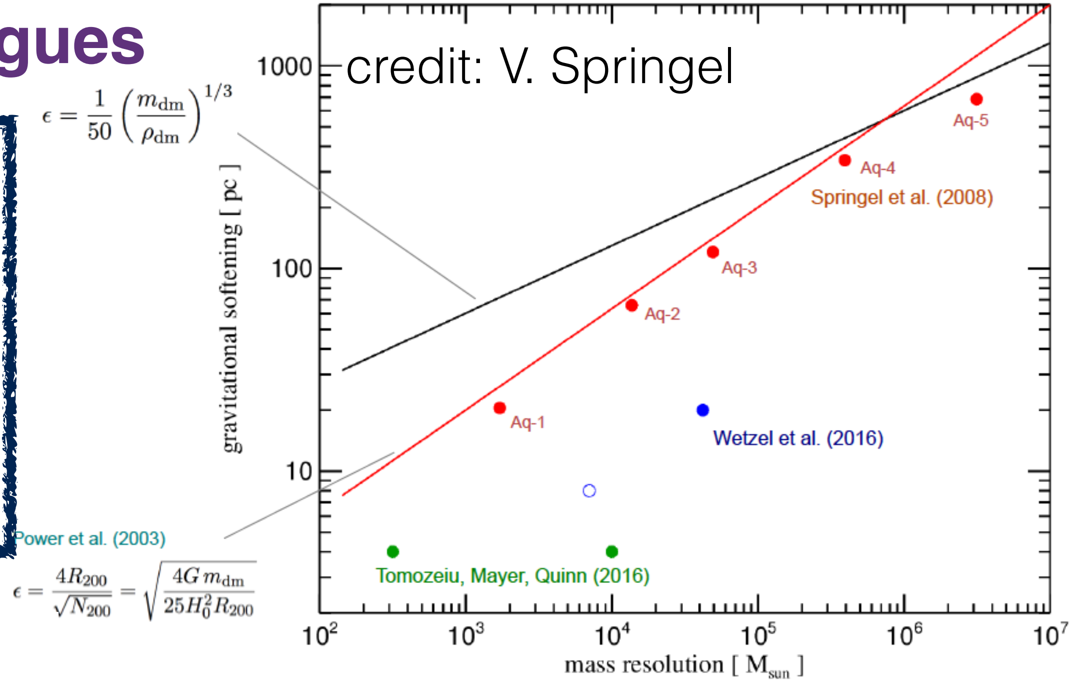
Black Hole feedback & magnetic fields

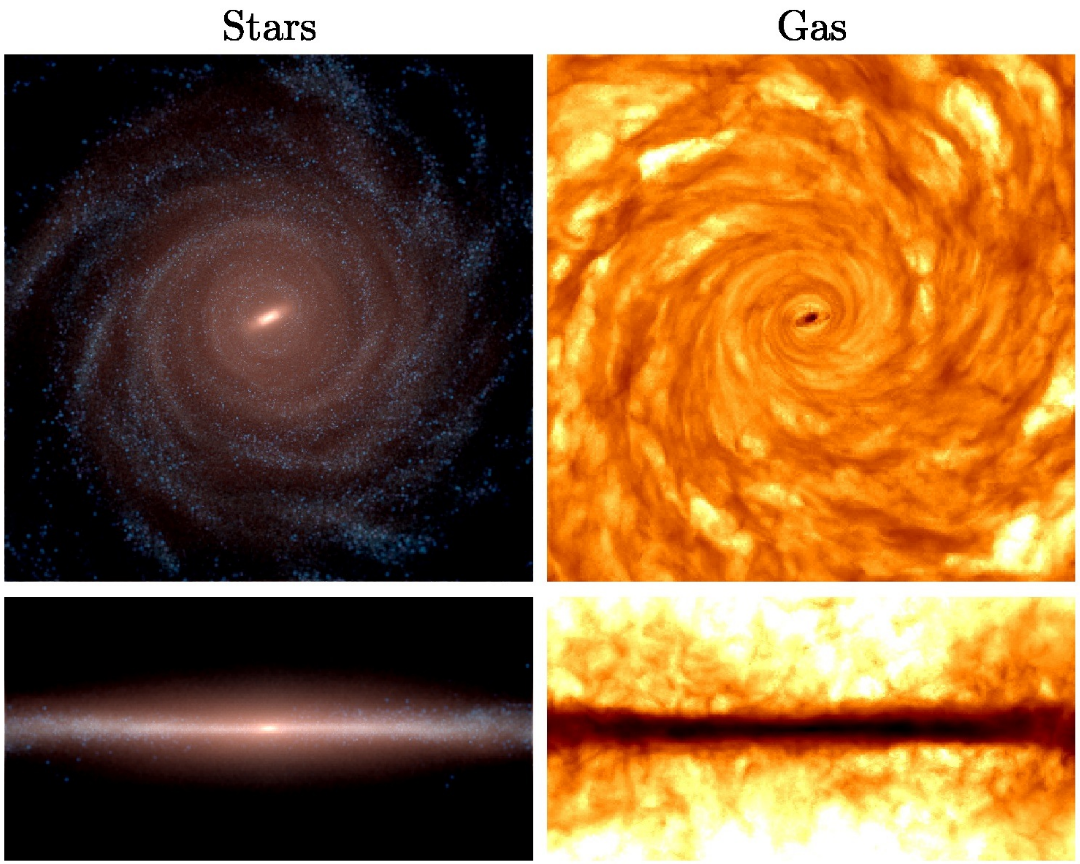
- Black Hole seeding and accretion model (Springel+ 2005)
- Thermal feedback from AGN in 2 channels: Radio and Quasar
- Magnetic fields seeded as homogeneous at 10^-14 Gauss (Pakmor 2013+)

A sizeable sample of MW analogues

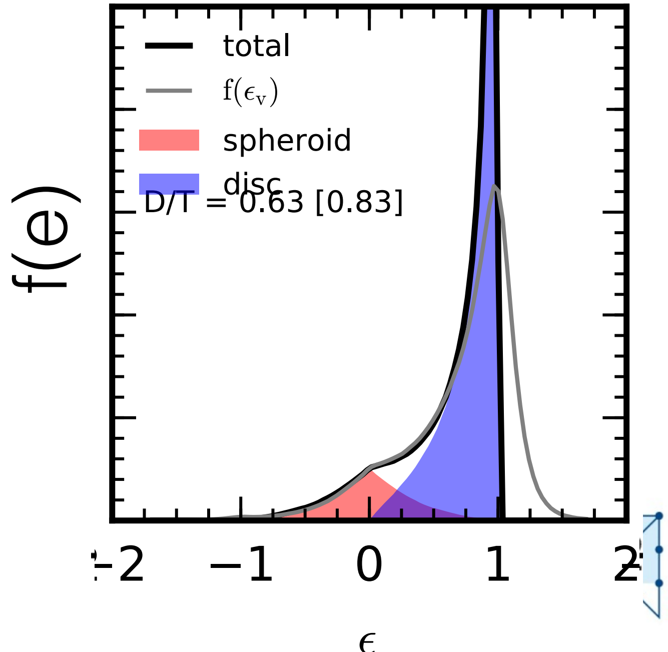
Current simulation suite

- 30 sims at level4 (standard):
  - ~10 million gas/DM elements
  - star mass res ~10^4 Msun, spatial ~369 pc
- 4 sims at level3 (x8 mass, x2 spat)





- Thin discs with high disc:total mass ratio
- Well-resolved bar and spiral arms



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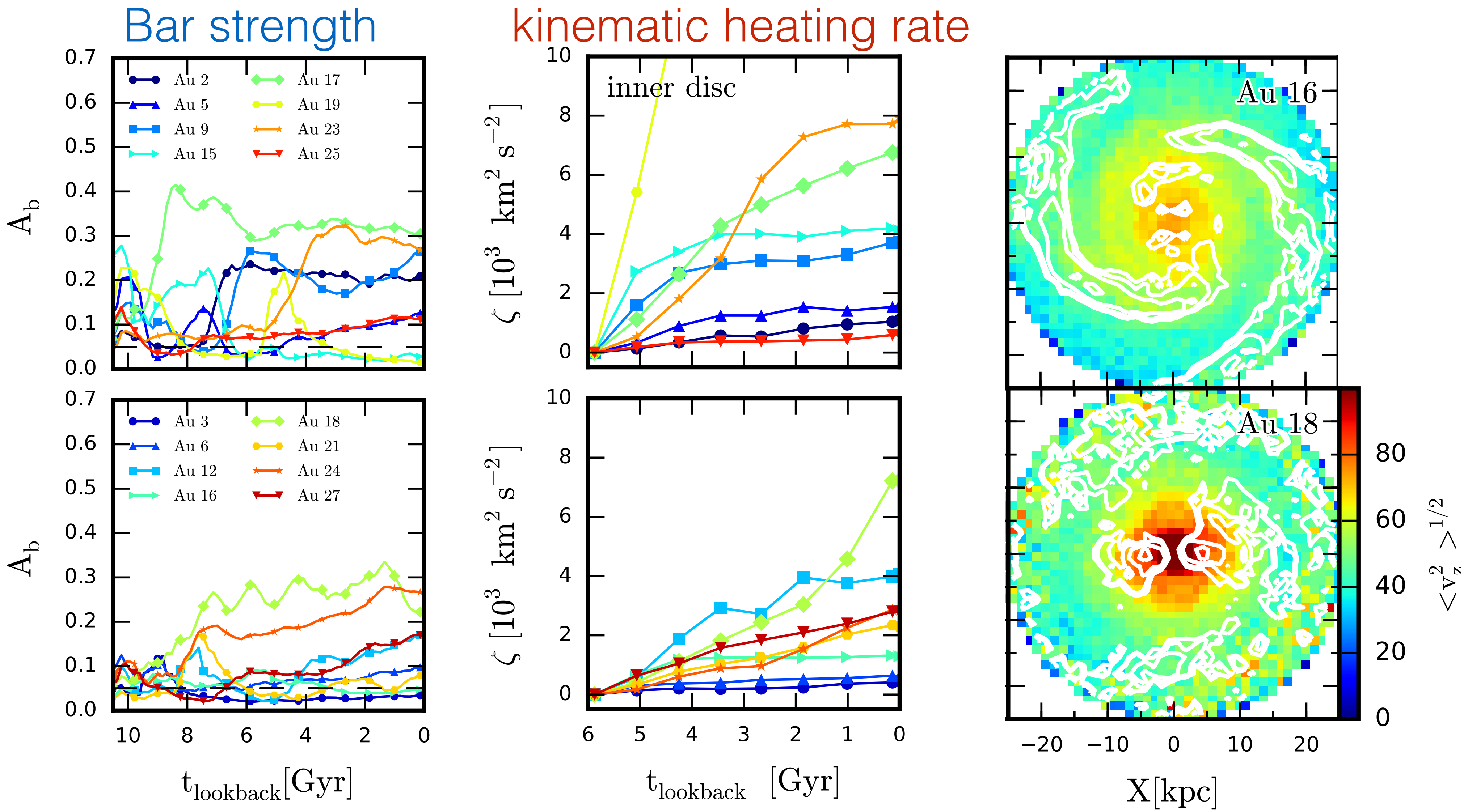
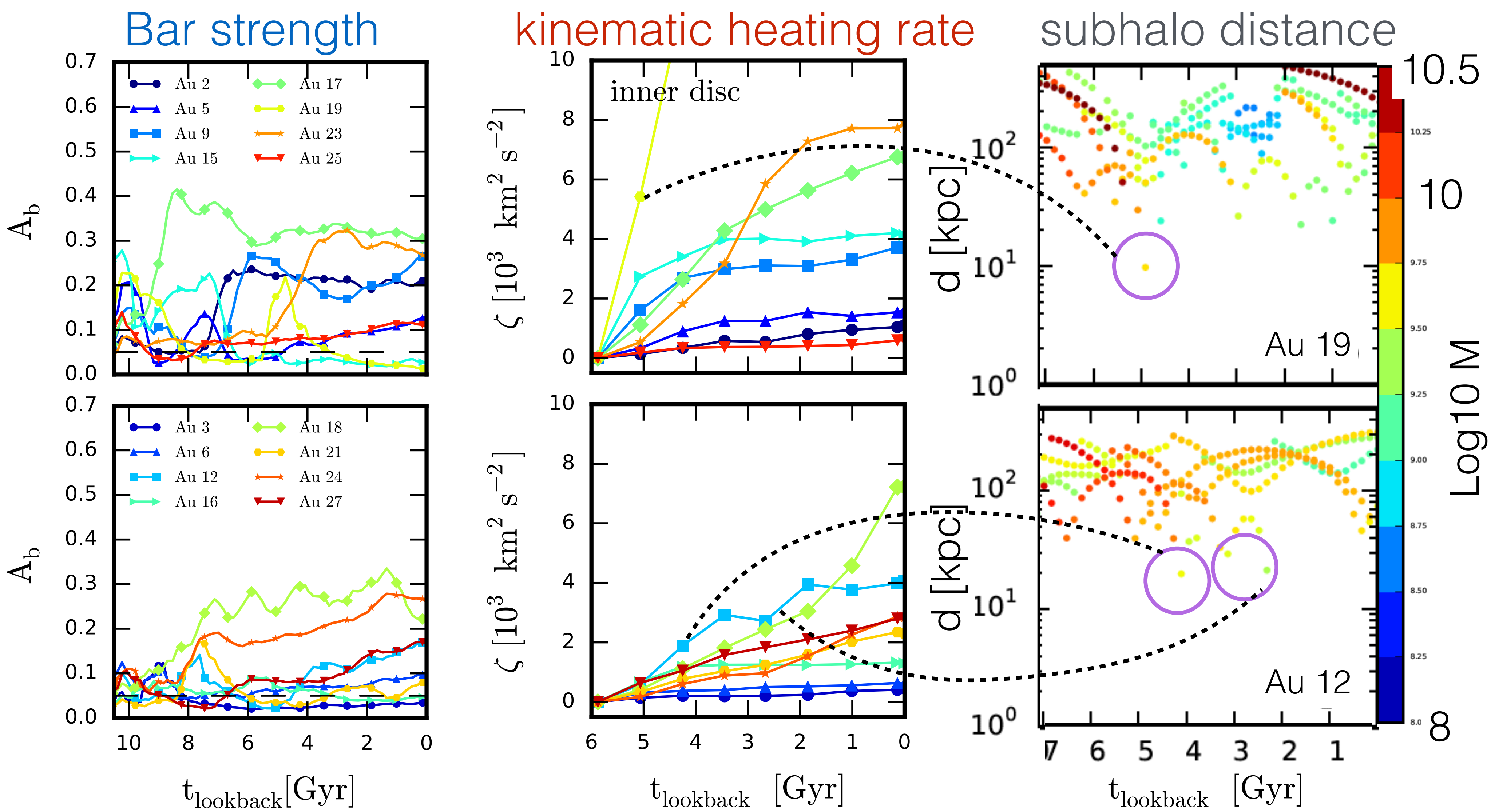
What are the main dynamical mechanisms of disc heating?

Evolution of a coeval (t_b = 6 Gyr) stellar population (Grand+ 16a)



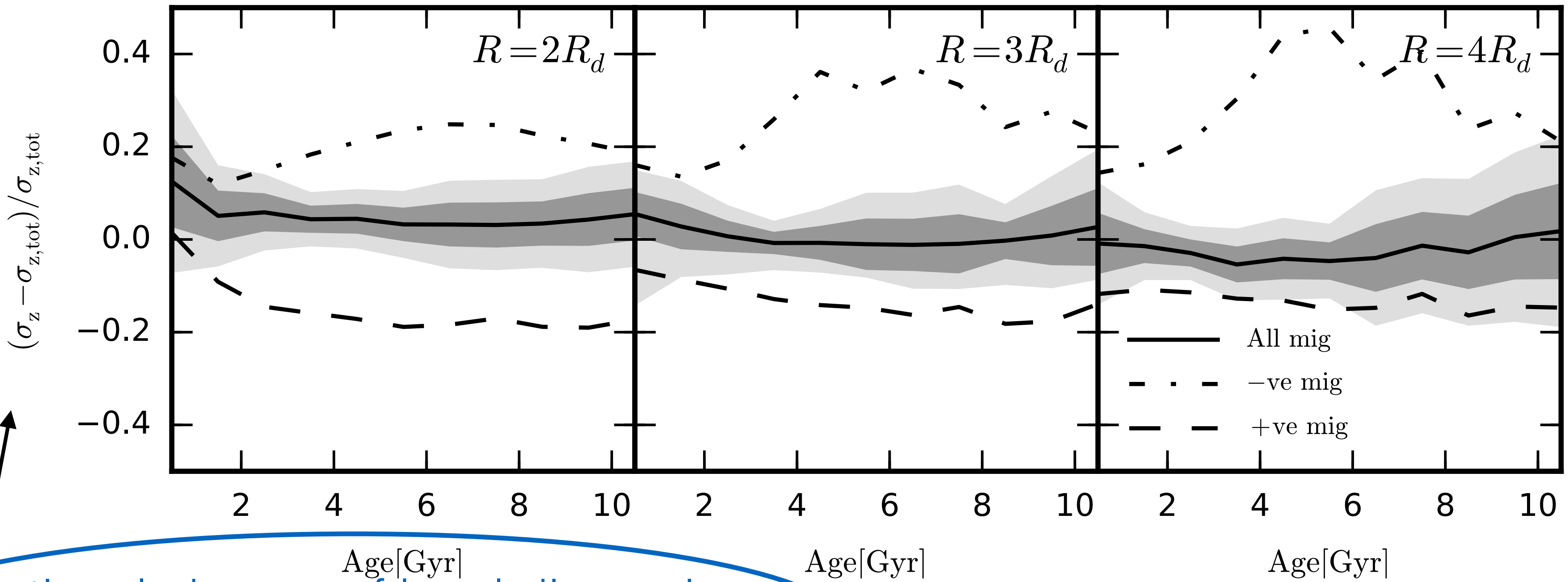
- Bars can stir up central stars dynamically, with little effect on outer disc

Evolution of a coeval (t_b = 6 Gyr) stellar population (Grand+ 16a)



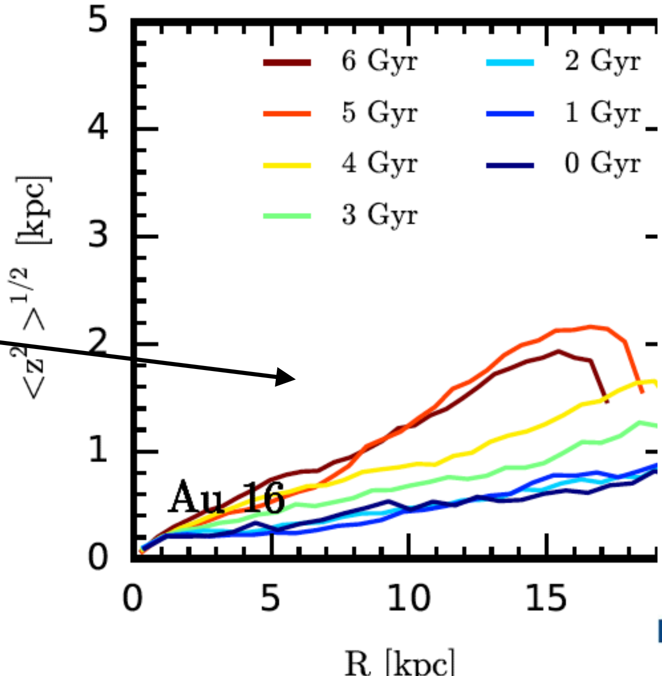
- Bars can stir up central stars dynamically, with little effect on outer disc
- Mergers and sub-halo ints. of log M > 10 heat whole disc (also Gomez+16)

Radial migration - Migrated stars from inner (outer) regions decrease (increase) velocity dispersion



fractional change of local dispersion due to migrated stars

Coeval pops. born on flaring dist. that decreases with time



No effect on vertical structure overall!

(see also Martig+14, Minchev+14, Vera-Ciro+15)

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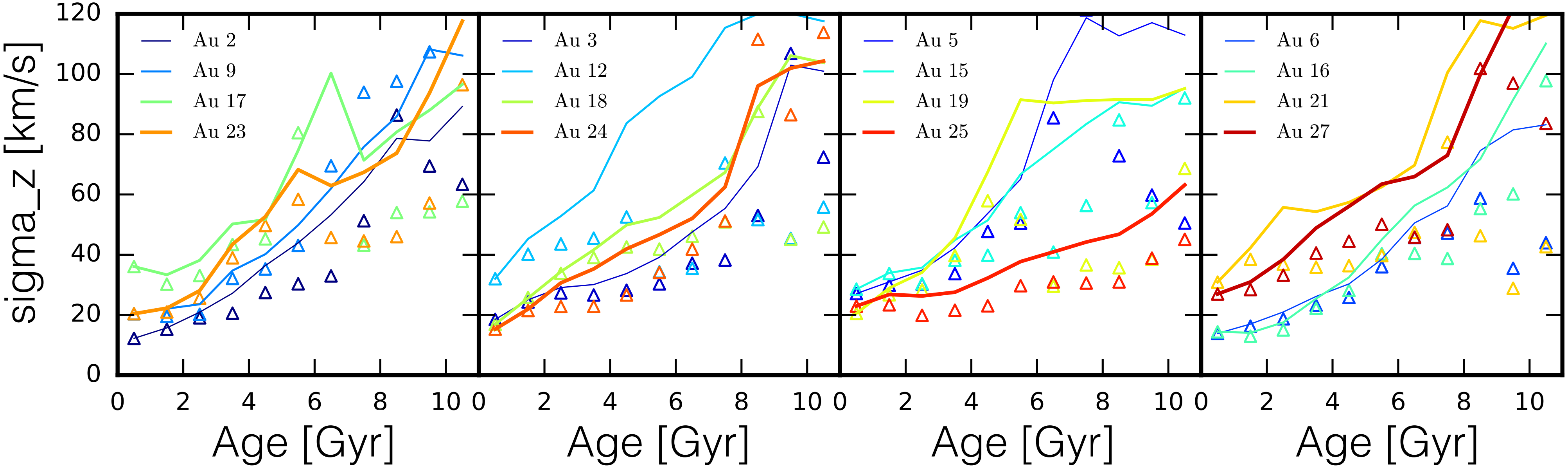
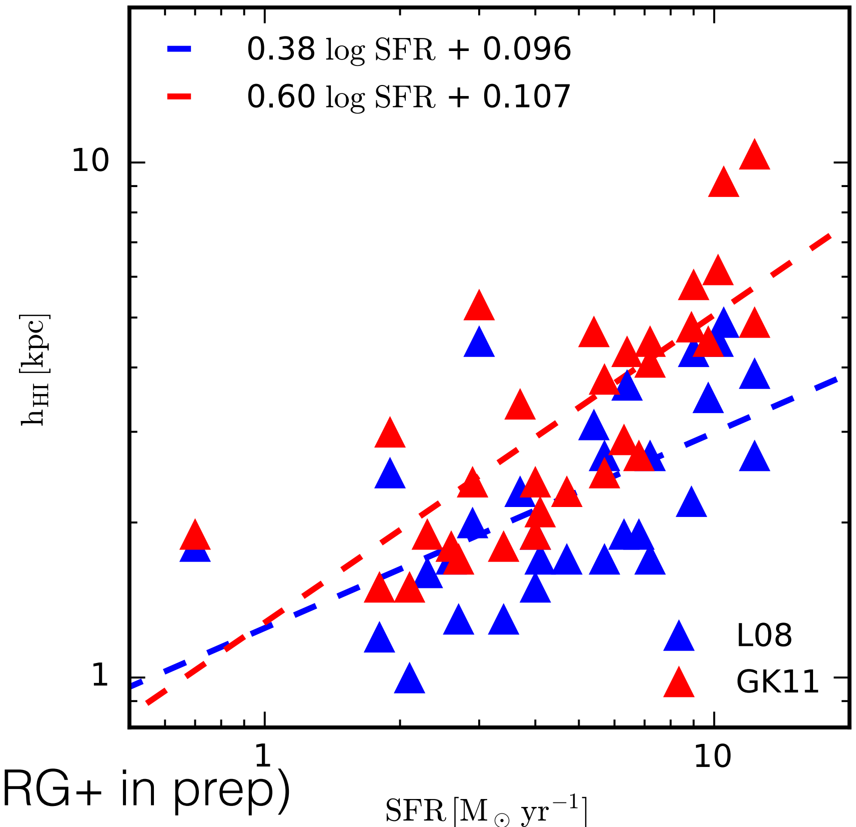
Discs grow thinner with time (Upside-down formation)



- Birth dispersions decrease with time

Successive generations of newborn star particles have lower scale heights

- Driven by declining SFR
  - fountain flow?

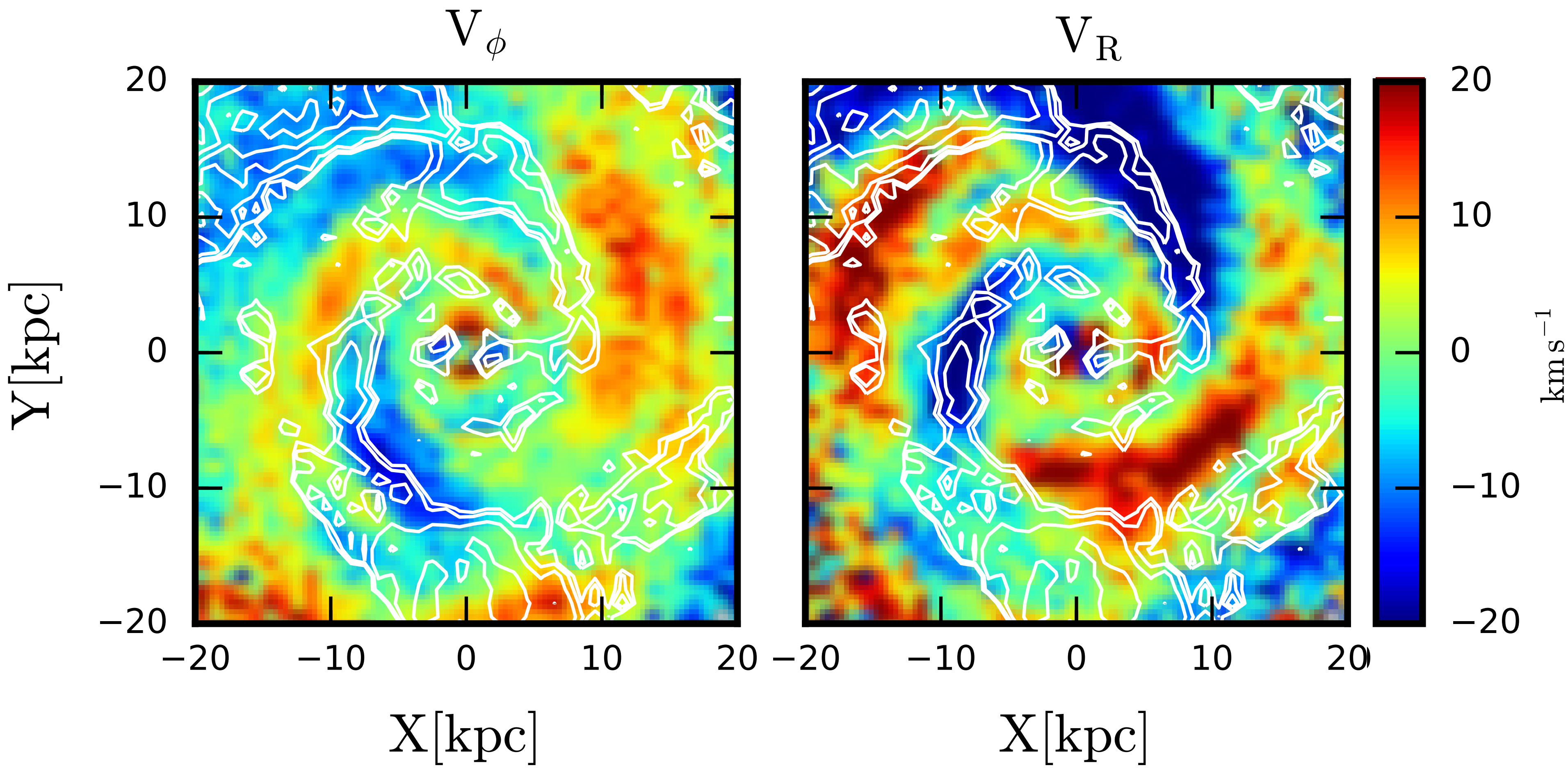


(Marinacci, RG+ in prep)

What can we learn about spiral arm dynamics?
(radial migration, observational features….)

Spirals drive systematic radial migration (Grand+ 2016b)

Mean-subtracted peculiar velocity fields:



- stars 'surf' tangentially backward and radially outward **behind** spiral and tangentially forward and radially inward **in front** of spiral
- in agreement with isolated sims with transient, winding spirals

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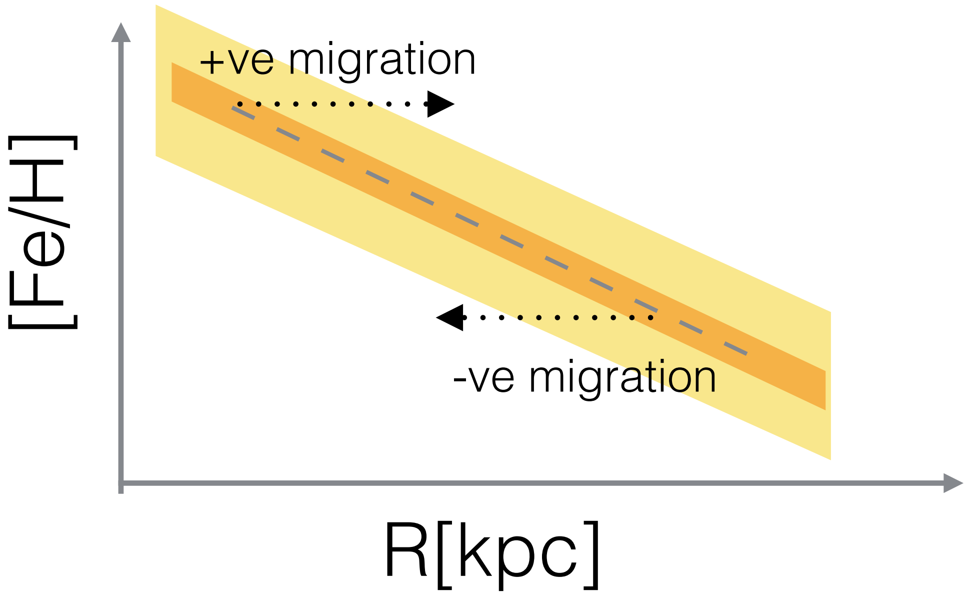
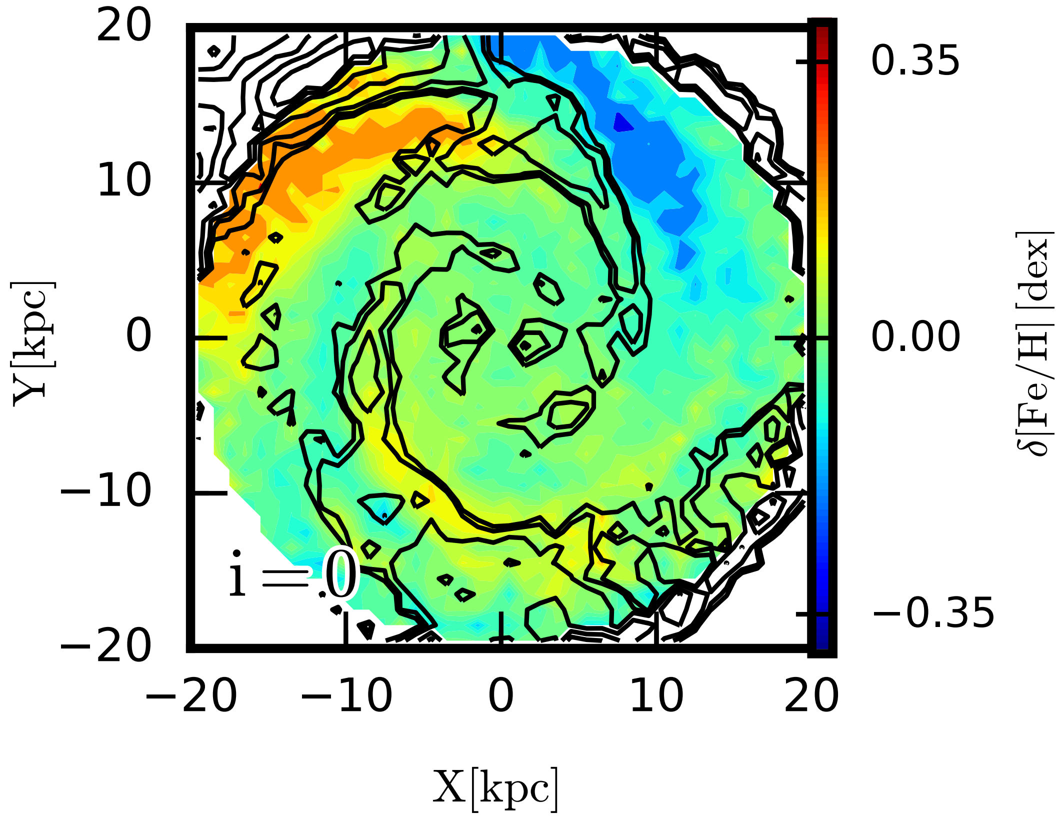
Signatures of migration in residual metallicity distribution

Most galaxies show a negative radial metallicity gradient



azimuthal residual metal map



- Stars transported from inner to outer region along trailing edge —> metal over-density on trailing edge
- First time predicted in cosmo-zoom sims!

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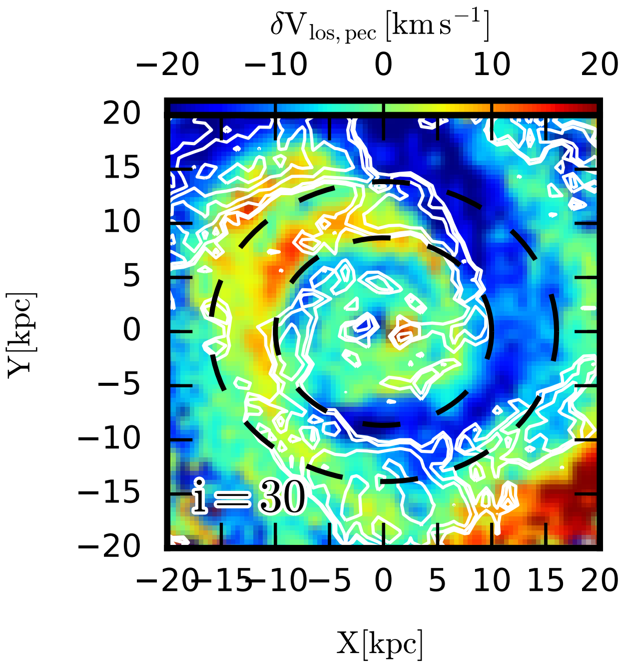
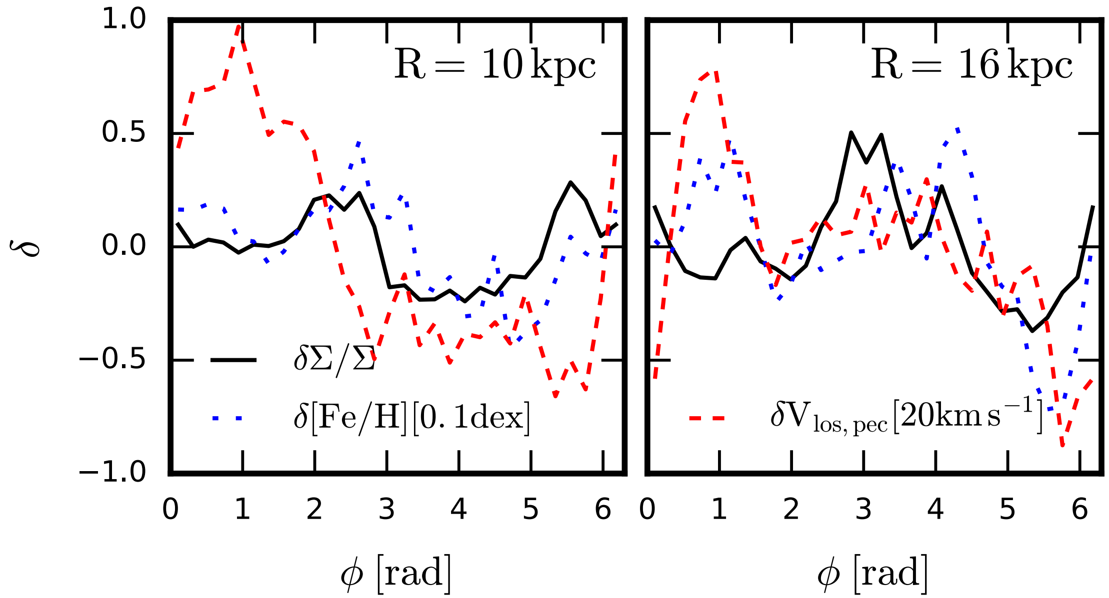
Observational predictions for migration

- Inclination of ~30 degrees gives optimal VLOS projection signatures

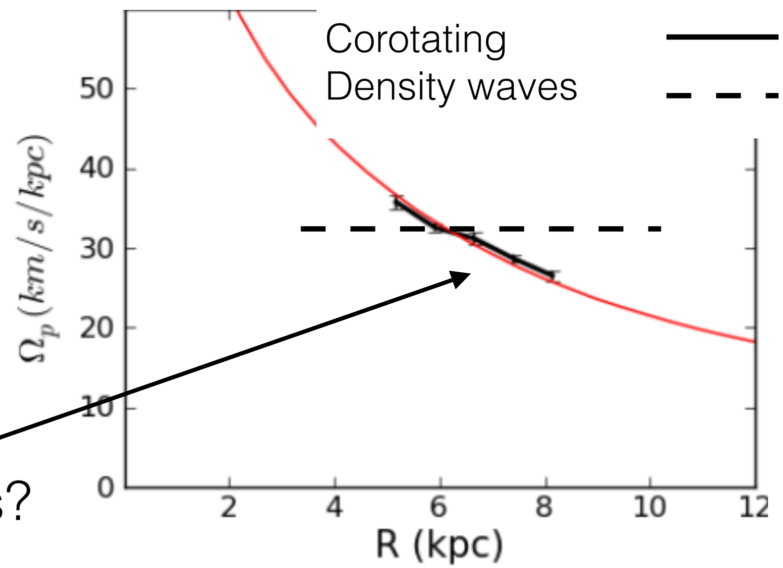




- Ideal for IFU (VLT/MUSE) obs. of external galaxies —> evidence of migration

- May also constrain spiral arm nature and parameters

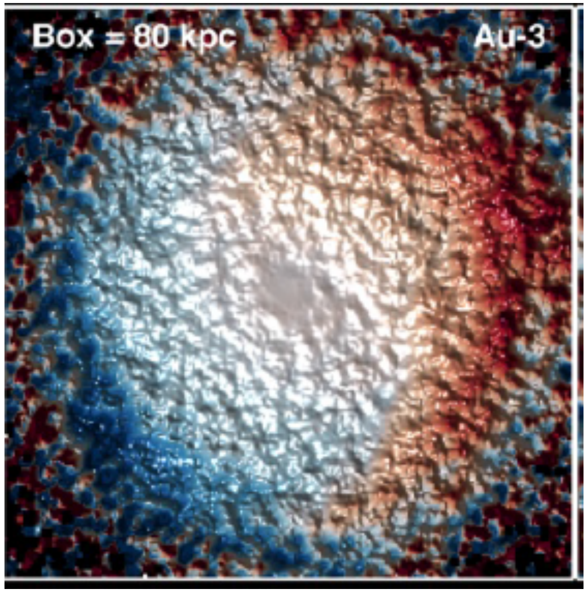
where are the resonance/migration points?



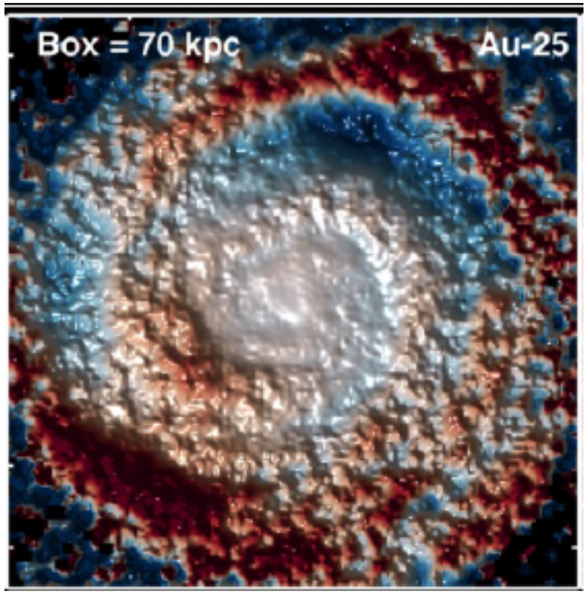
Disc warp statistics in Auriga

(Gomez, RG+ 2016ab)

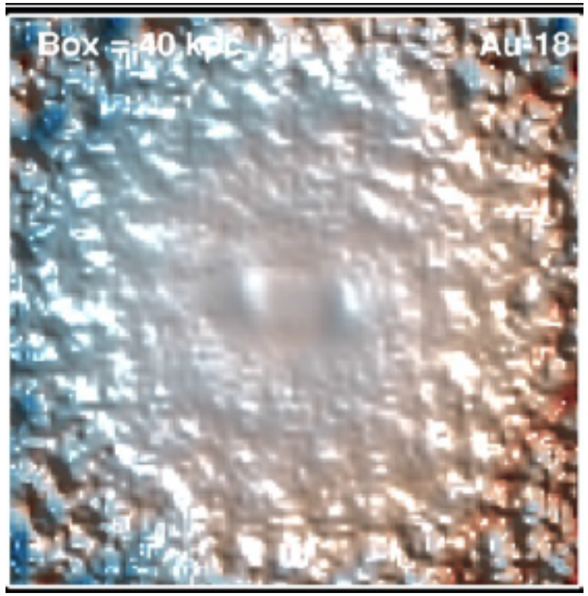
<z> (kpc) -2 +2



S-shaped - 30%



Spiral-shaped - 30%



Relaxed - 30%

No U-shaped warps

Most warped discs have experienced strong tidal interactions with satellite of log M > 10

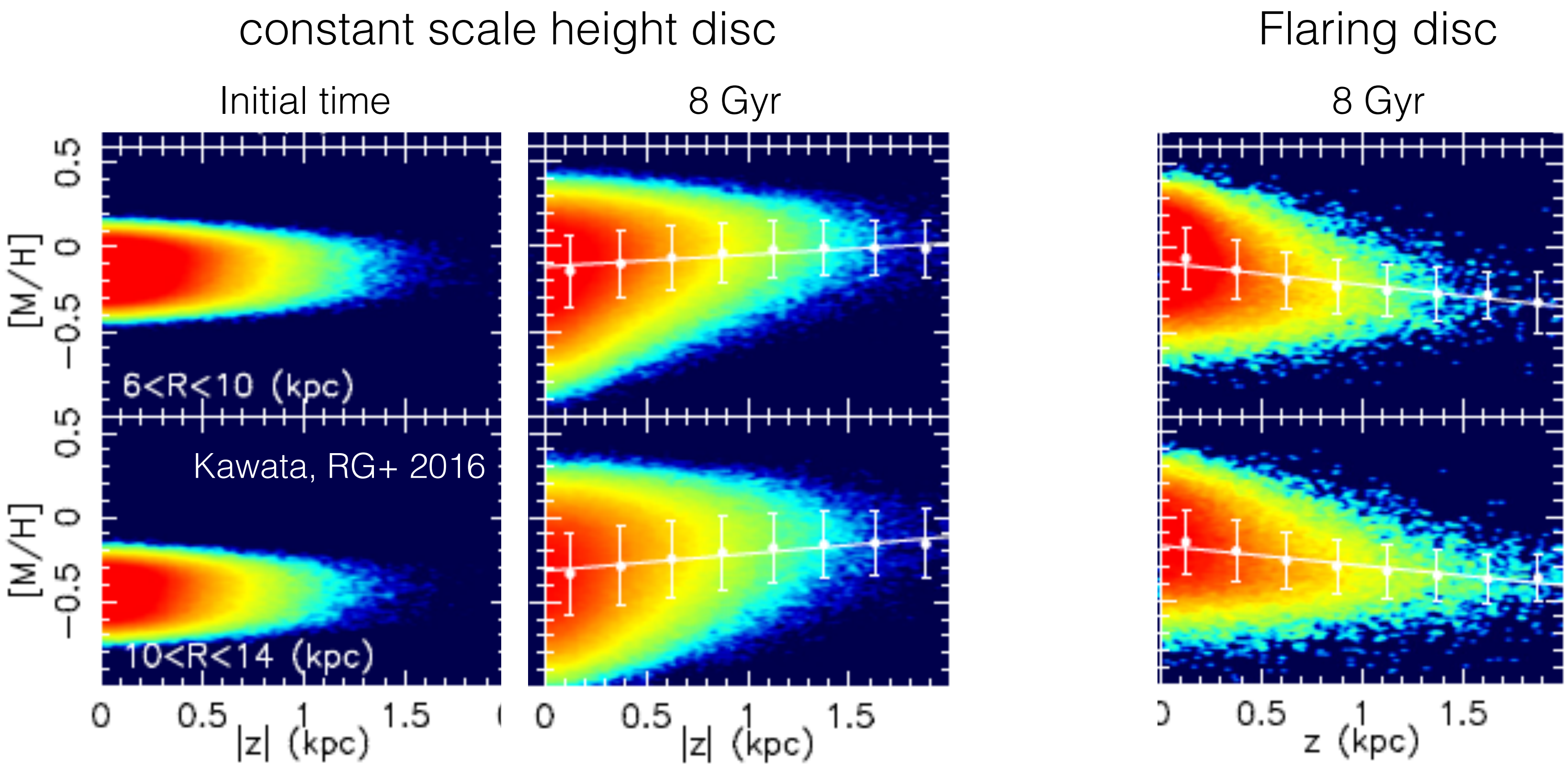
2 cases of misaligned gas accretion - only in young stars

Summary Points

- Auriga galaxies make good discs (with good convergence)
- Good resolution of disc structure (bar, spirals) enables the of dynamical phenomena and their impact
  - Spiral arms drive coherent, systematic motion consistent with transient, winding spirals
  - Azimuthal metallicity patterns are visible and can be detected with IFU instruments
  - Bar and satellite interaction are main drivers of heating (migration not so much…)
  - Upside-down formation of discs dominates heating mechanisms in many cases

A **flaring star forming** region may be important to maintain a **negative vertical** metal gradient in the outer disc

- Flared distribution keeps migrated stars sub-dominant —>metal rich migrators from inner regions do not make +ve grad



-ve vertical metal gradient in outer regions consistent with MW observations (e.g., Mikolaitis+14, Casagrande+16)

Auriga 'zoom' simulations of MW halos - Galaxy formation model (GFM)

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- Metal line cooling (CLOUDY), density, temperature & redshift dependent
- Mass and metal return to ISM based on population synthesis models

Star formation and winds

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- Quasar and radio mode AGN
- Magnetic fields seeded as homogeneous at 10^-14 Gauss (Pakmor 2013+)

Current simulation suite

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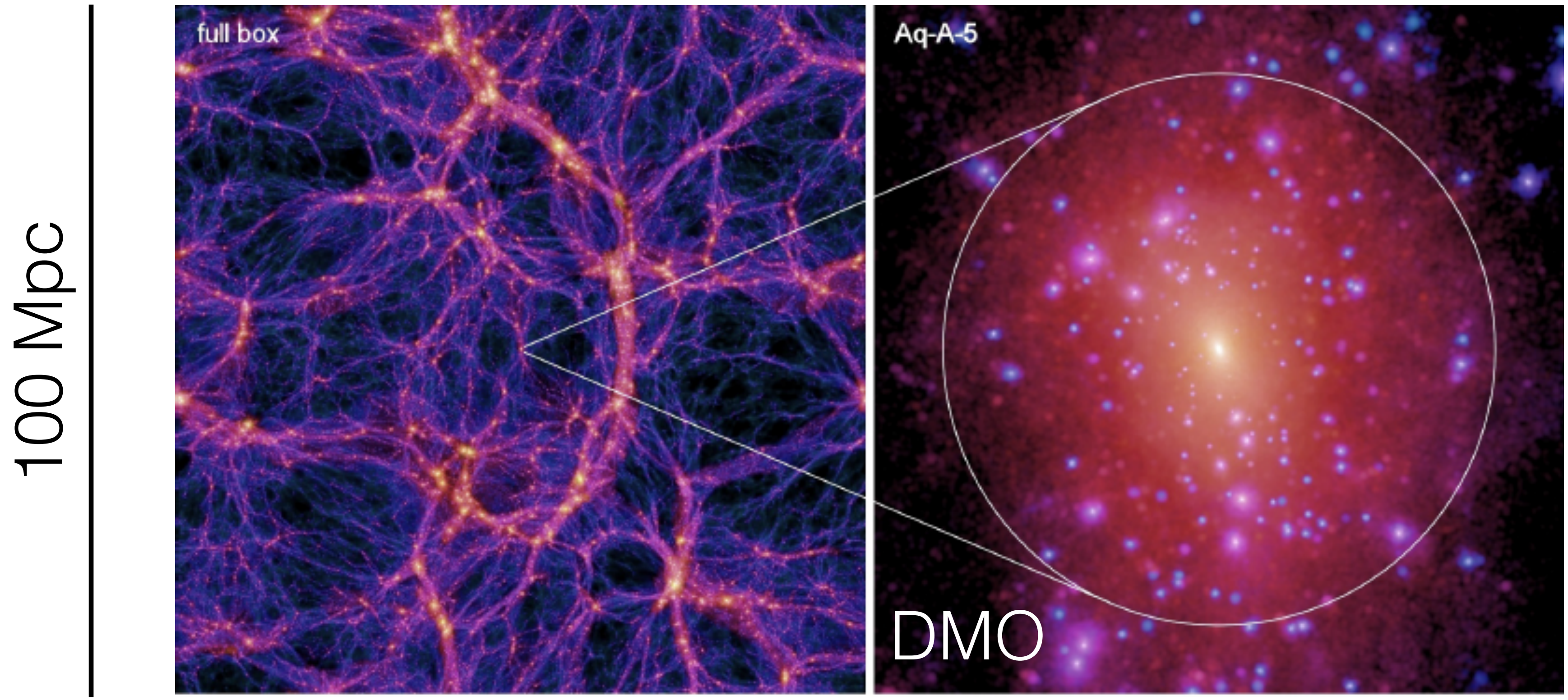
- 4 sims at level3 (x8 mass, x2 spat)
- 1 galaxies at level2(x64 mass res, x4 spatial res)



Setting up the Initial conditions

- Take endpoint of large Dark Matter only cosmological simulation
- Take galaxies of Milky Way mass
- Go back to beginning of Universe, zooming in on this region
- Increase the resolution around galaxy
- Add gas elements and magnetic fields
- Re-run simulation to present day

Current simulation suite (SuperMUC)

30 sims at level4 (standard):

- ~10 million gas/DM elements
- mass res ~10^4 Msun, spatial ~369 pc
- ~250,000 core hours

4 sims at level3 (x8 mass, x2 spat, x20 ch)