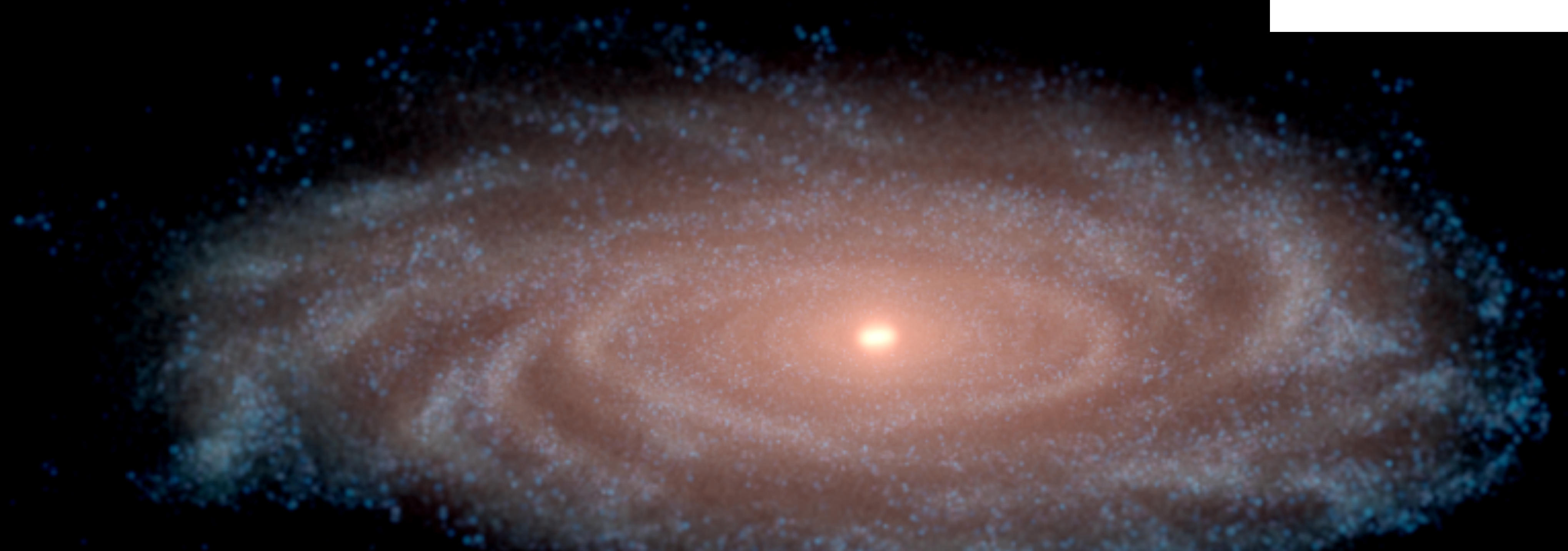

Disc dynamics in cosmological zoom simulations of MW sized galaxies (The Auriga project)

Rob Grand (HITS, ZAH)

Volker Springel (HITS, ZAH), Rüdiger Pakmor (HITS), Facundo Gomez (MPA), Federico Marinacci (MIT), Adrian Jenkins (Durham), Dave Campbell (Durham) Carlos Frenk (Durham), Simon White (MPA)

The Milky Way and its environment, IAP, September, 2016

Scope of this talk:

1. Introduce a new suite of cosmological simulations
   Large number of high resolution MHD simulations that reach realistic outcomes, and well-converged across resolution
2. Study dynamical aspects important to the formation of Milky Way-like haloes
   - What are the most important mechanisms governing vertical disc structure? e.g., AVR
   - How do spiral arms/radial migration affect disc chemo-dynamics?

Why cosmological zoom sims?

- Cosmological timescales & environment
- Resolution sufficient to study internal (& external) dynamic effects
- Galaxy formation model shown to reproduce realistic galaxy populations in large scale cosmo sims (Illustris)

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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+)

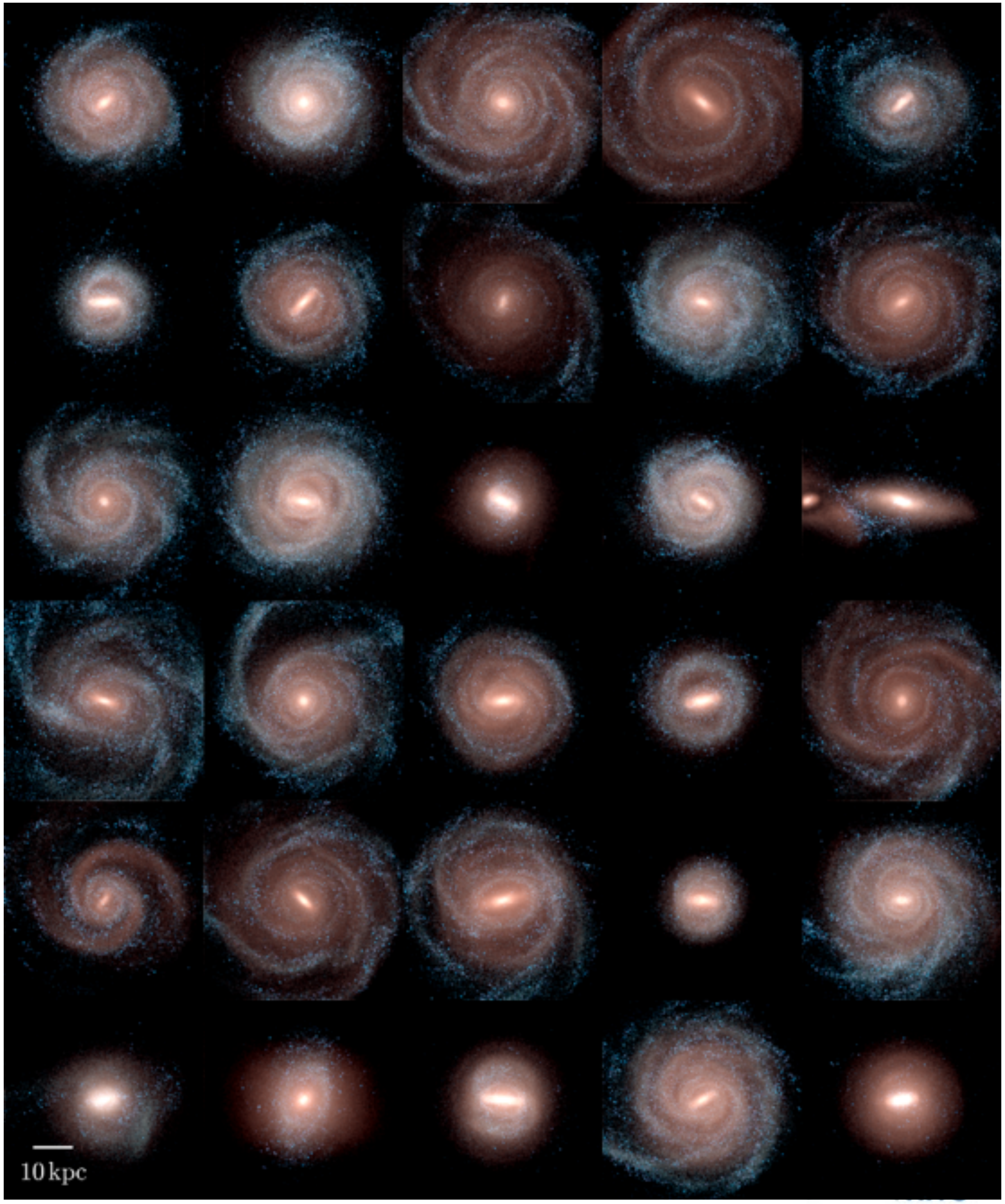
The Auriga Project: A sizeable sample of MW analogues (Grand+ in prep.)

- 30 sims at level4 (200,000 core hours):
  - ~10 million gas/DM elements
  - star mass res ~10^4 Msun

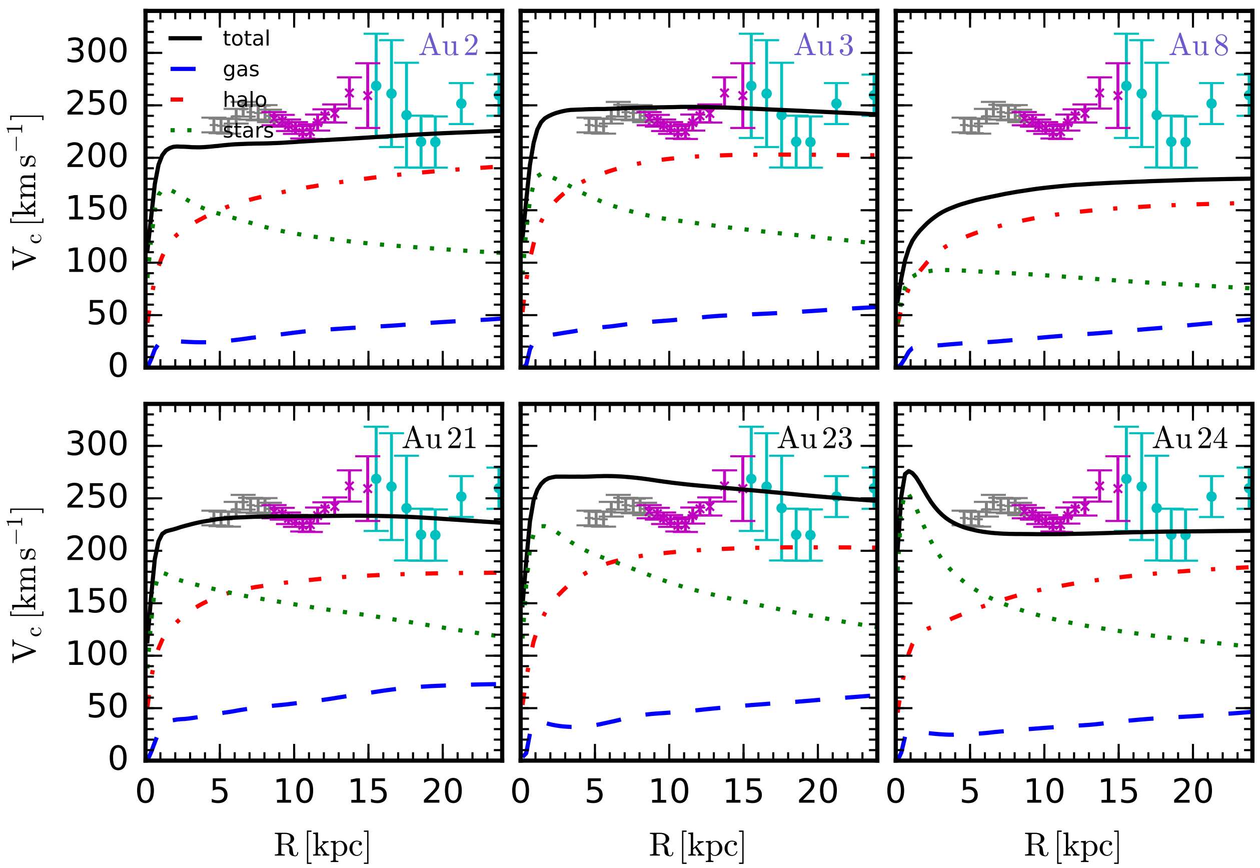
- 3 sims at level3 (x8 mass)

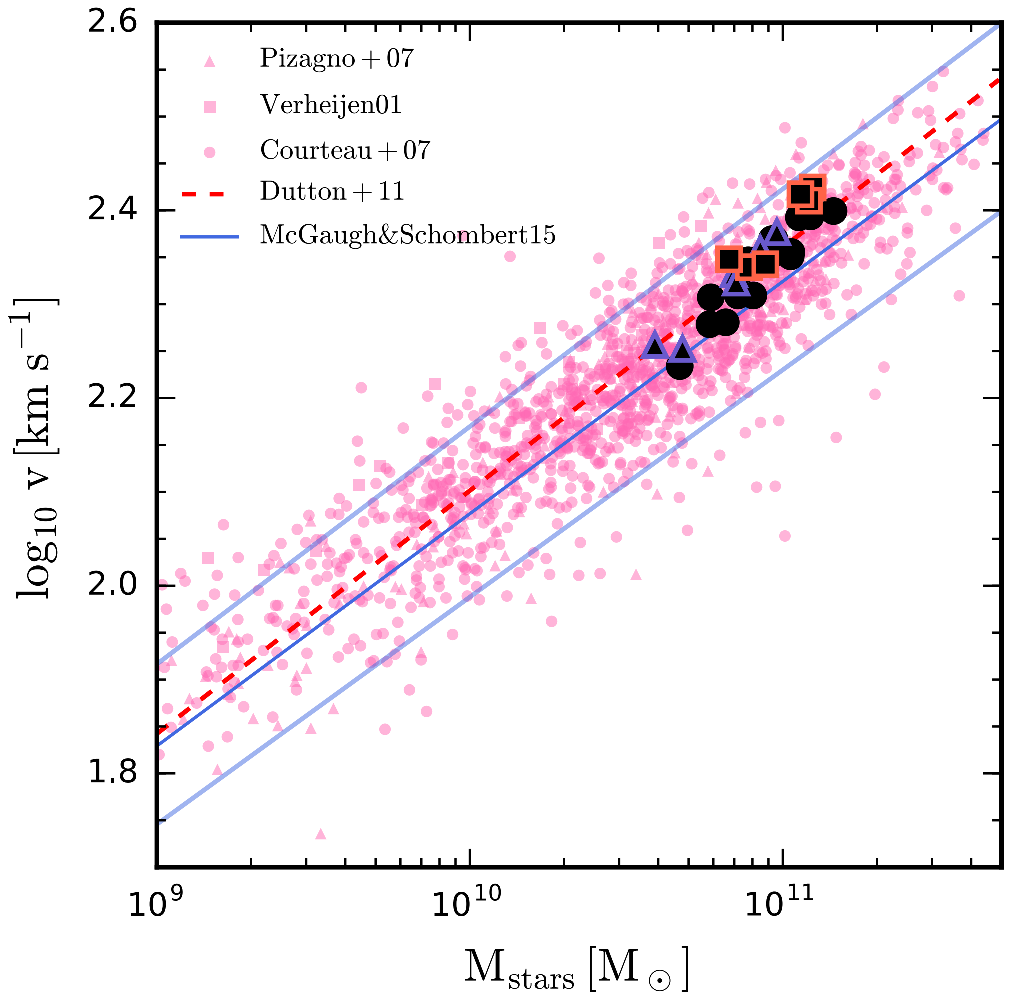
  (~4,000,000 core hours)

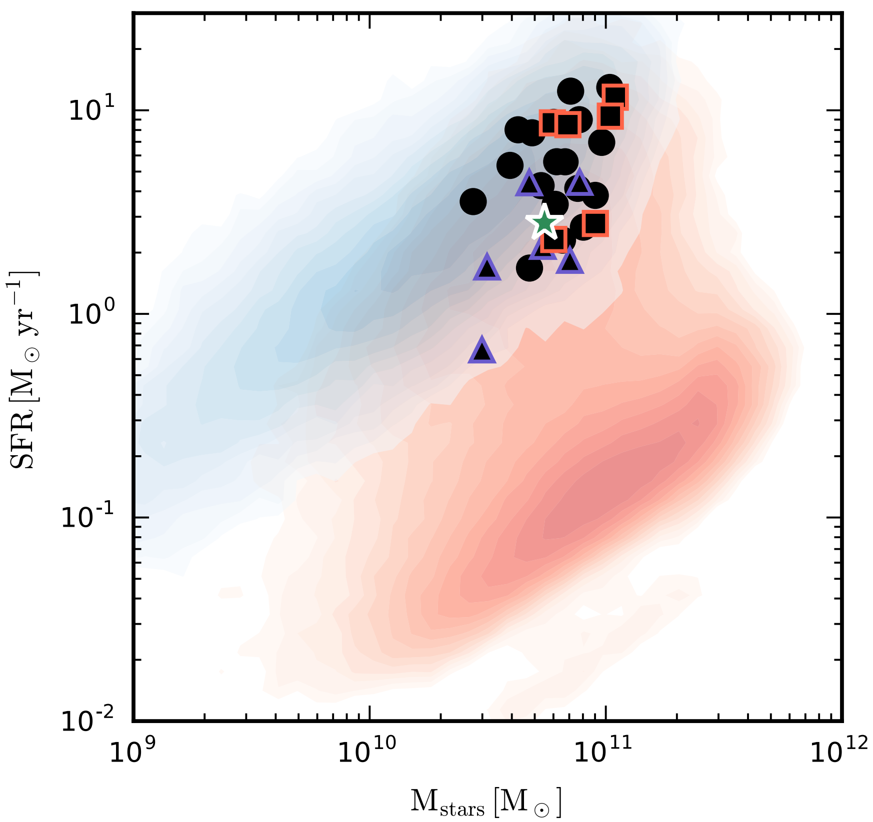
@superMUC (LRZ, Garching)
@hornet (Stuttgart)
@hazelhen (Stuttgart)

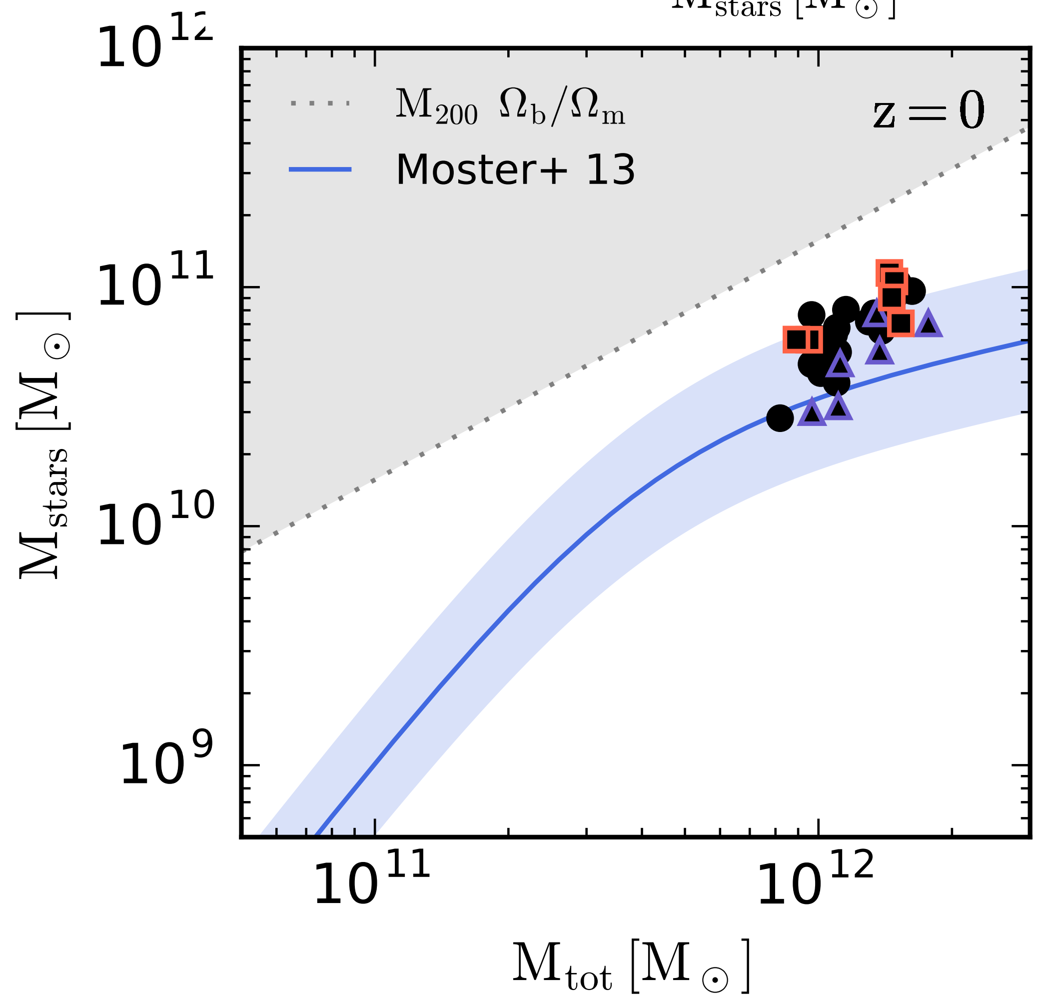


Match a wide range of observables









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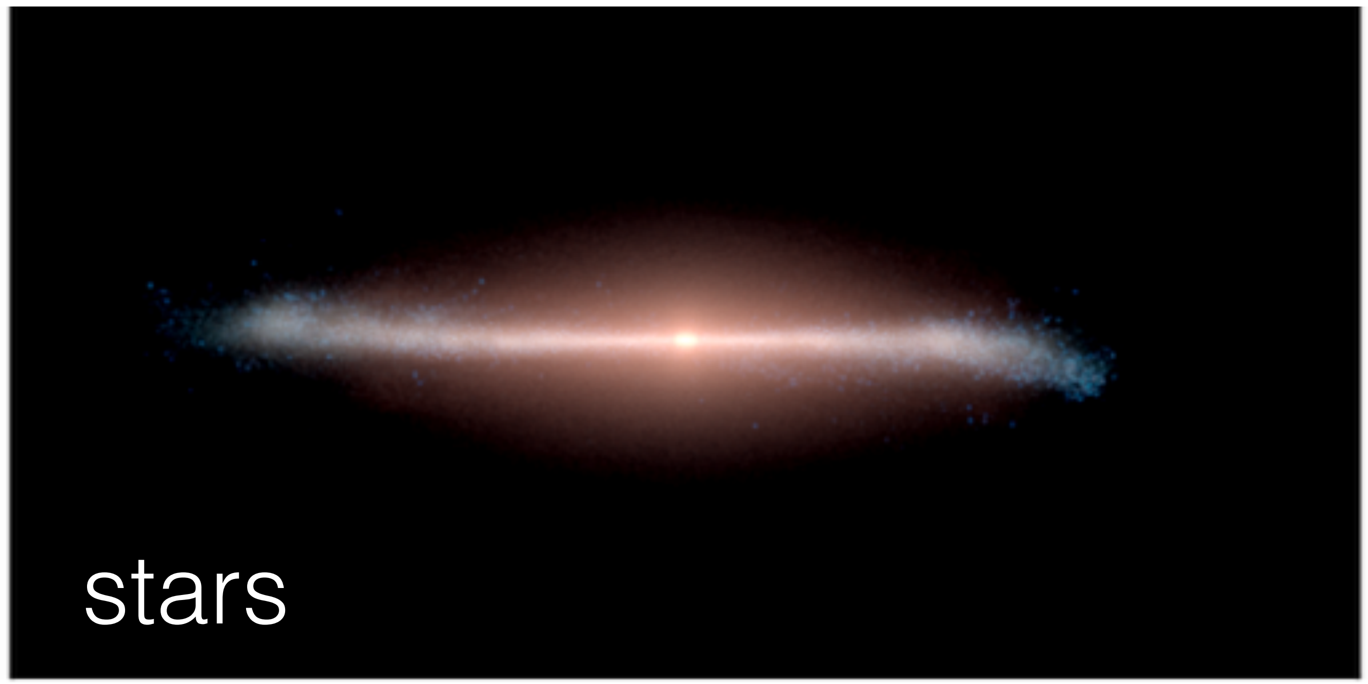
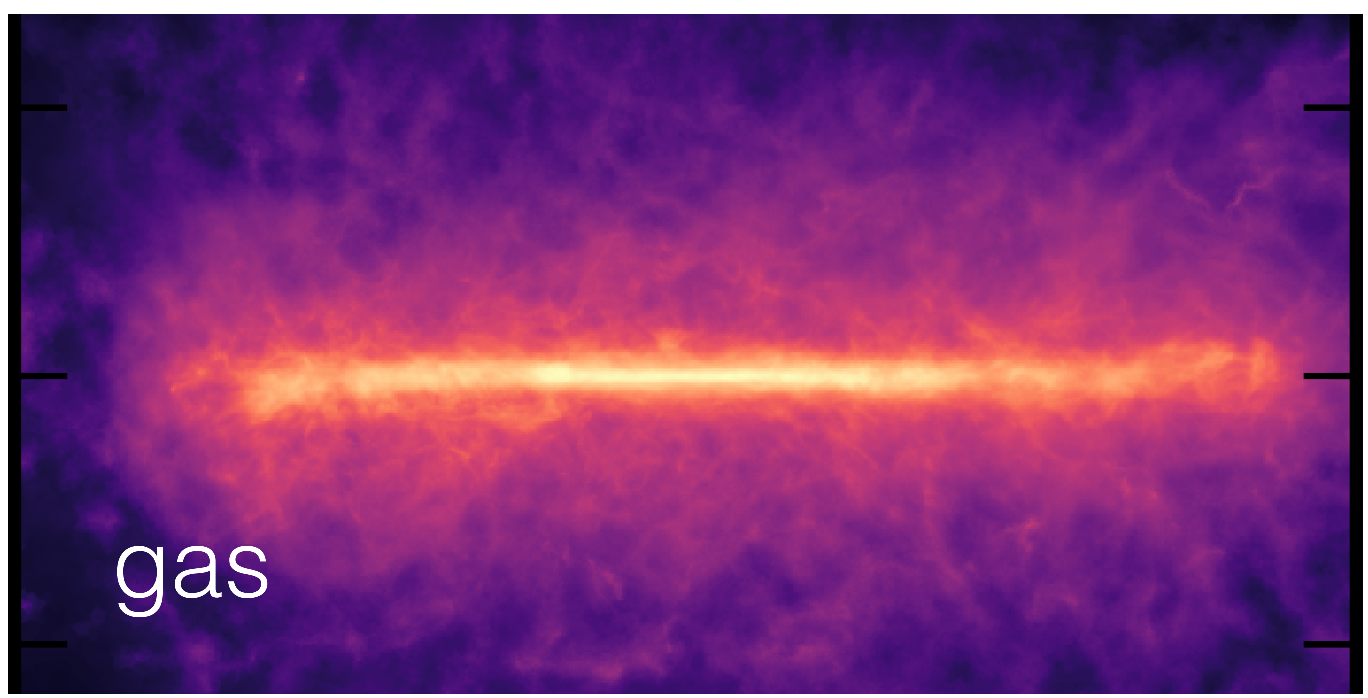
Vertical disc structure:

What are the main dynamical mechanisms of disc heating?

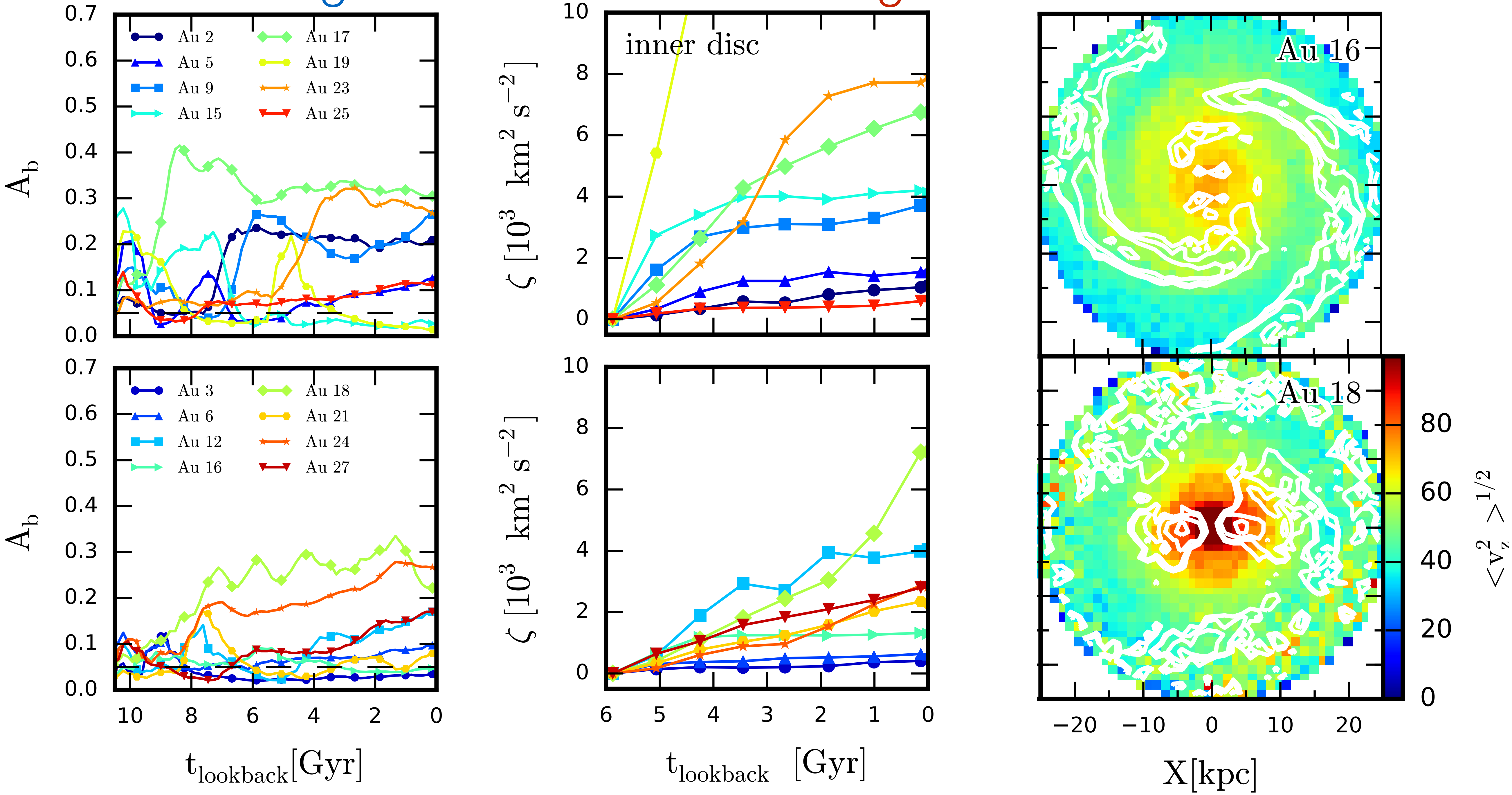




Heating history of a coeval (t_b = 6 Gyr) stellar population

(Grand+ 16a)

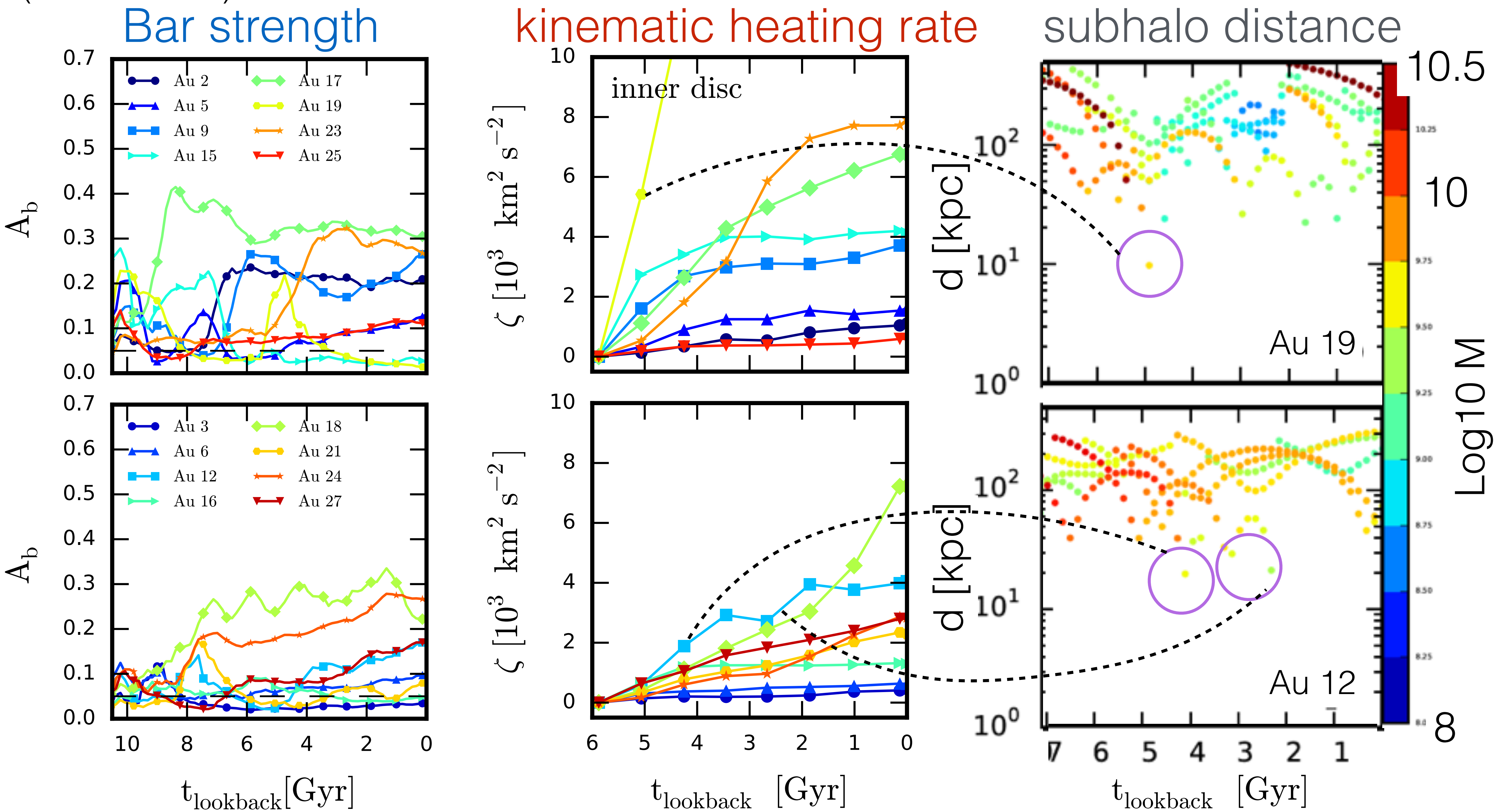
Bar strength kinematic heating rate



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

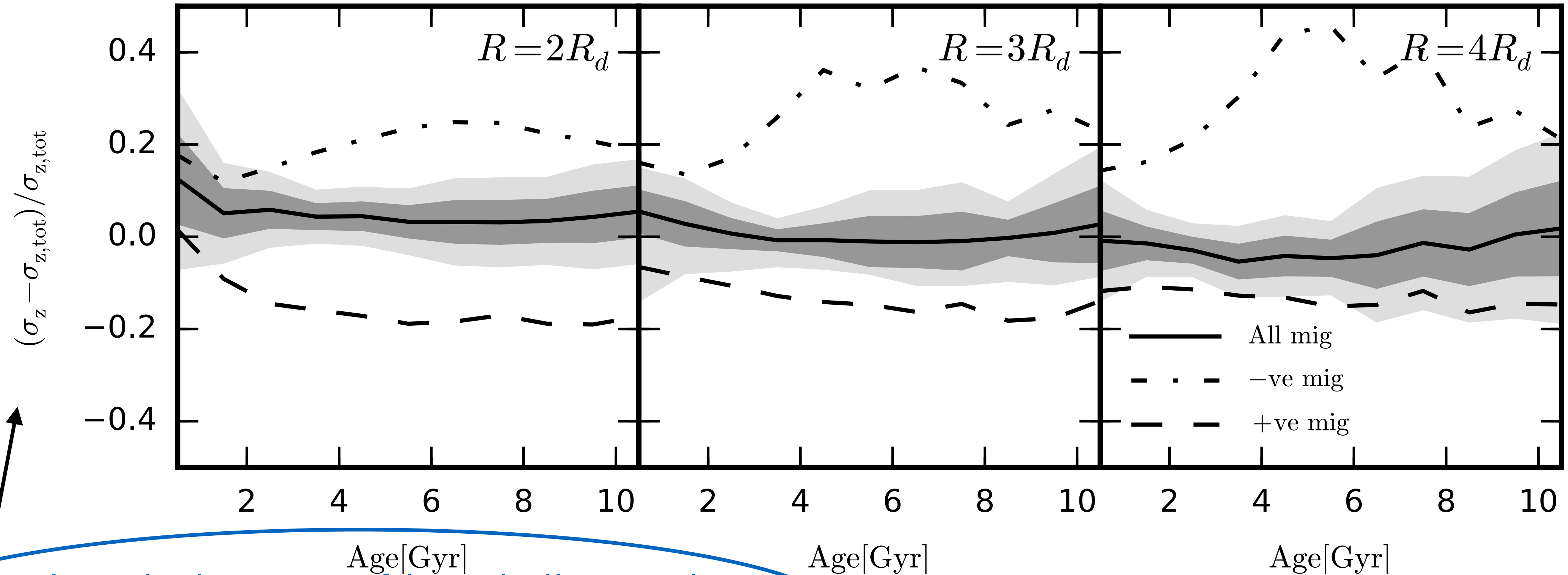
Heating history of a coeval (t_b = 6 Gyr) stellar population

(Grand+ 16a)

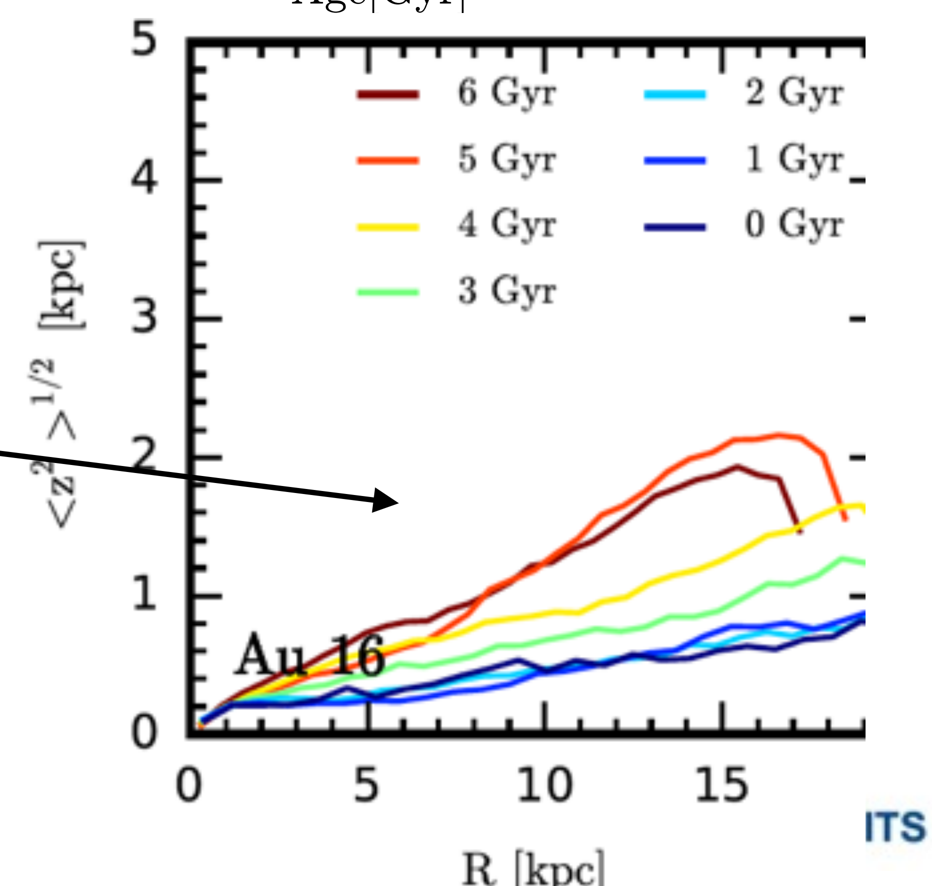


- Bars can stir up central stars dynamically, with little effect on outer disc
- Mergers and sub-halo ints. of log M > 10 heat whole disc (also Gomez+16)

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



fractional change of local dispersion due to migrated stars

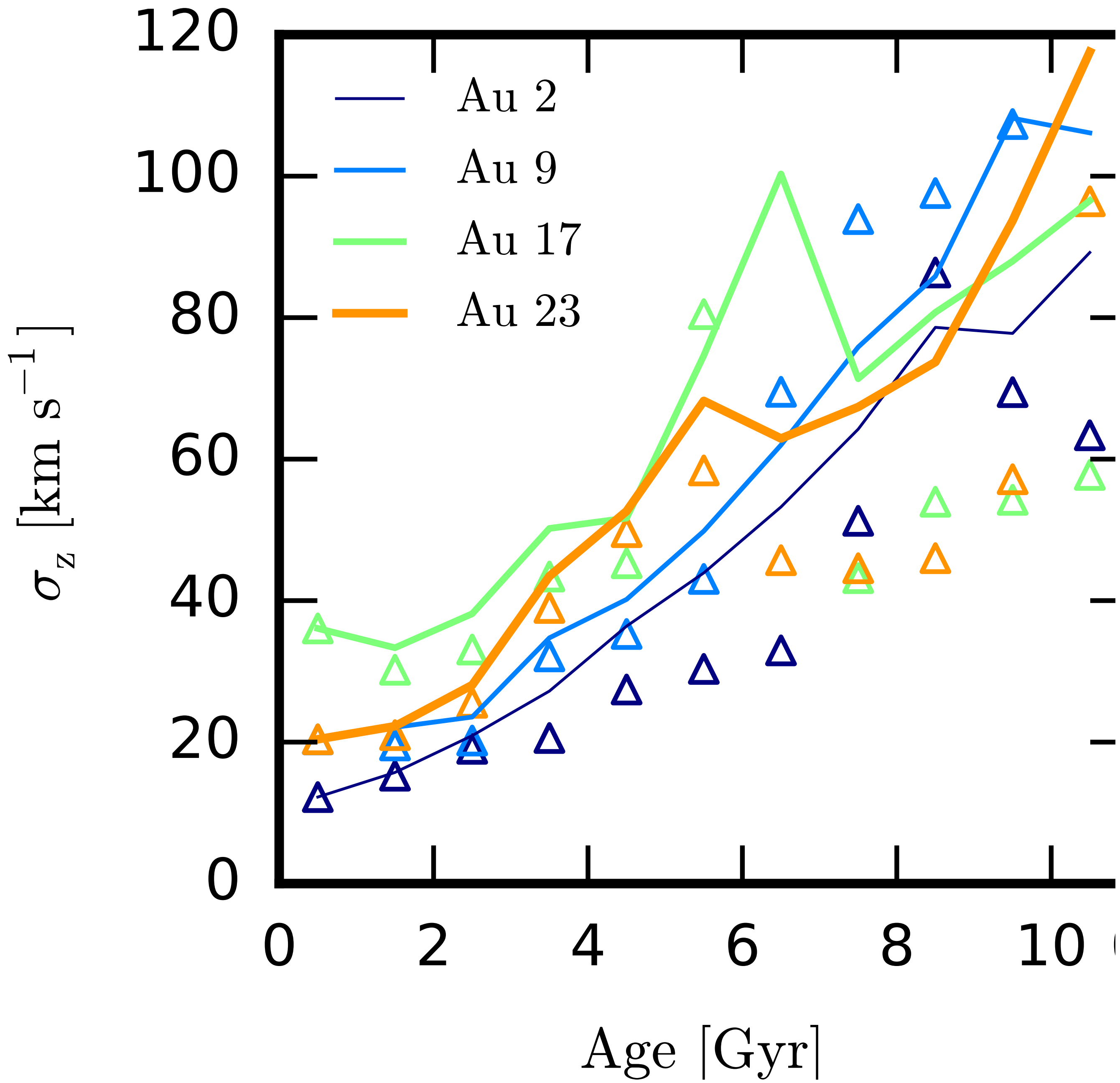


Young star pops. born on flaring dist. that decreases with time

No effect on vertical structure overall!

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

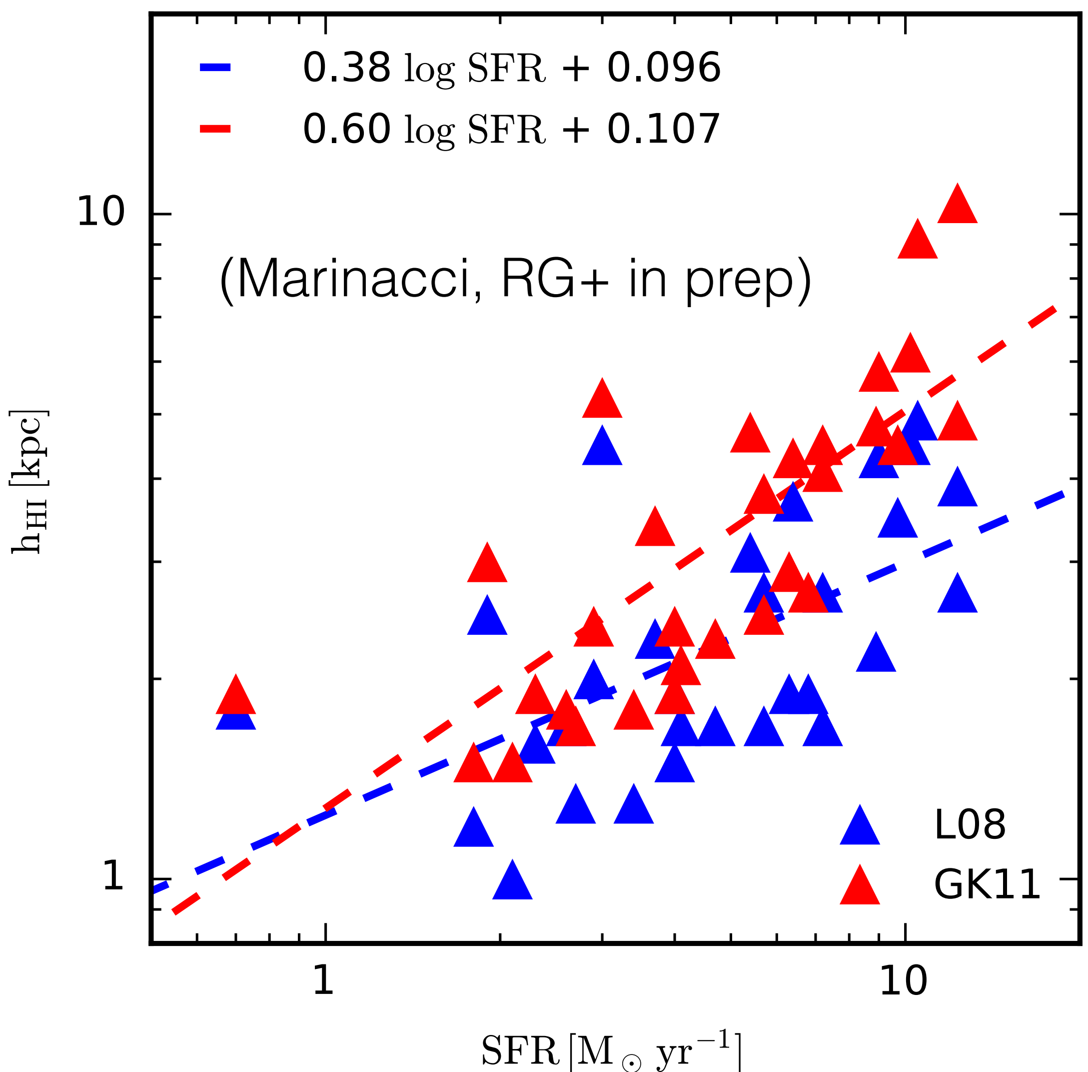
Discs grow thinner with time (Upside-down formation)



- Birth dispersions decrease with time

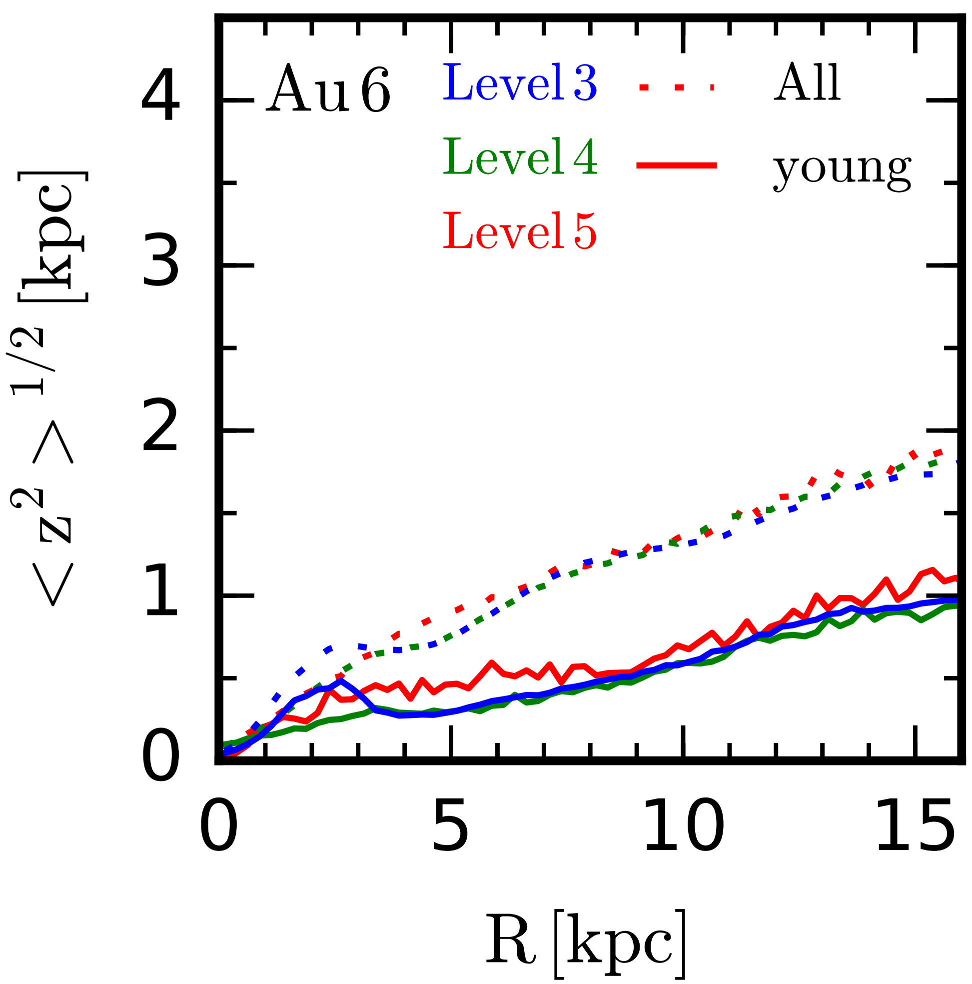
Successive generations of newborn star particles have lower scale heights

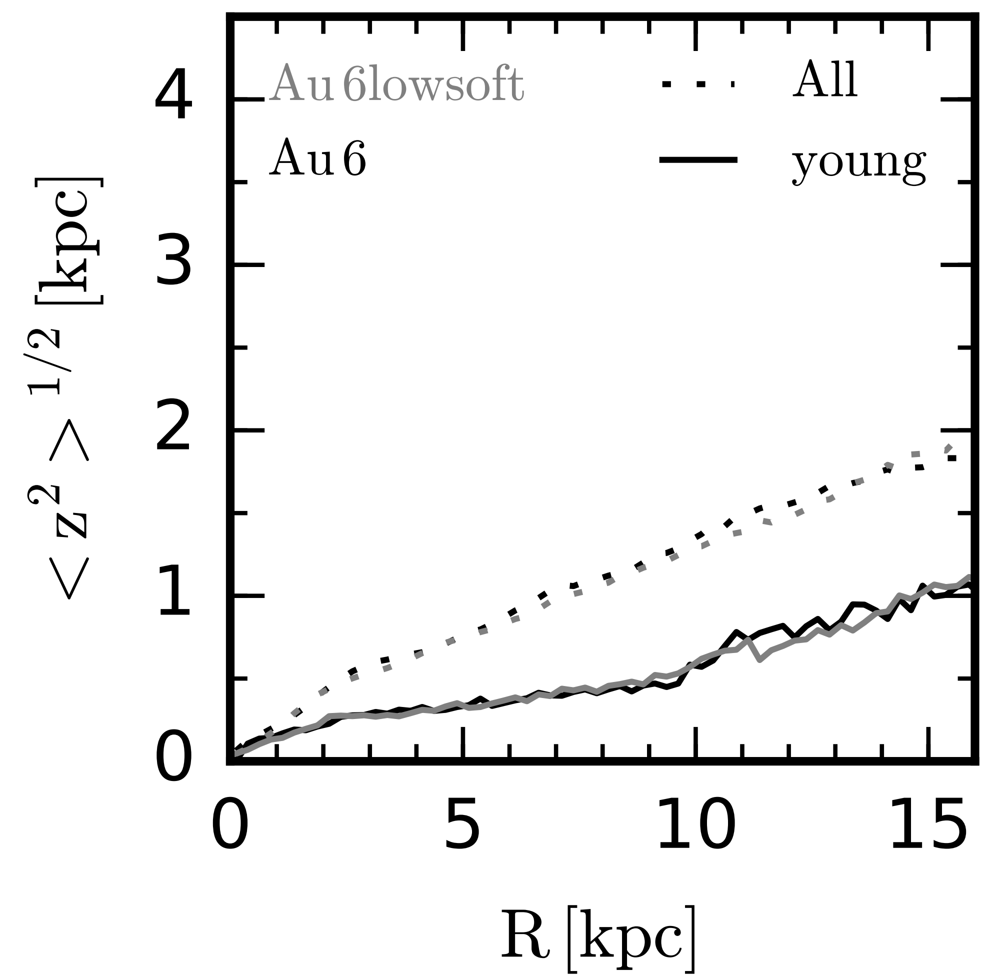
(see also Bird+13, Stinson+13, Martig+ 14)



- Driven by declining SFR - fountain flow?

Side-note: disc thickness well-converged





- Well-converged properties across 3 resolution levels (x64 mass, x4 softening)

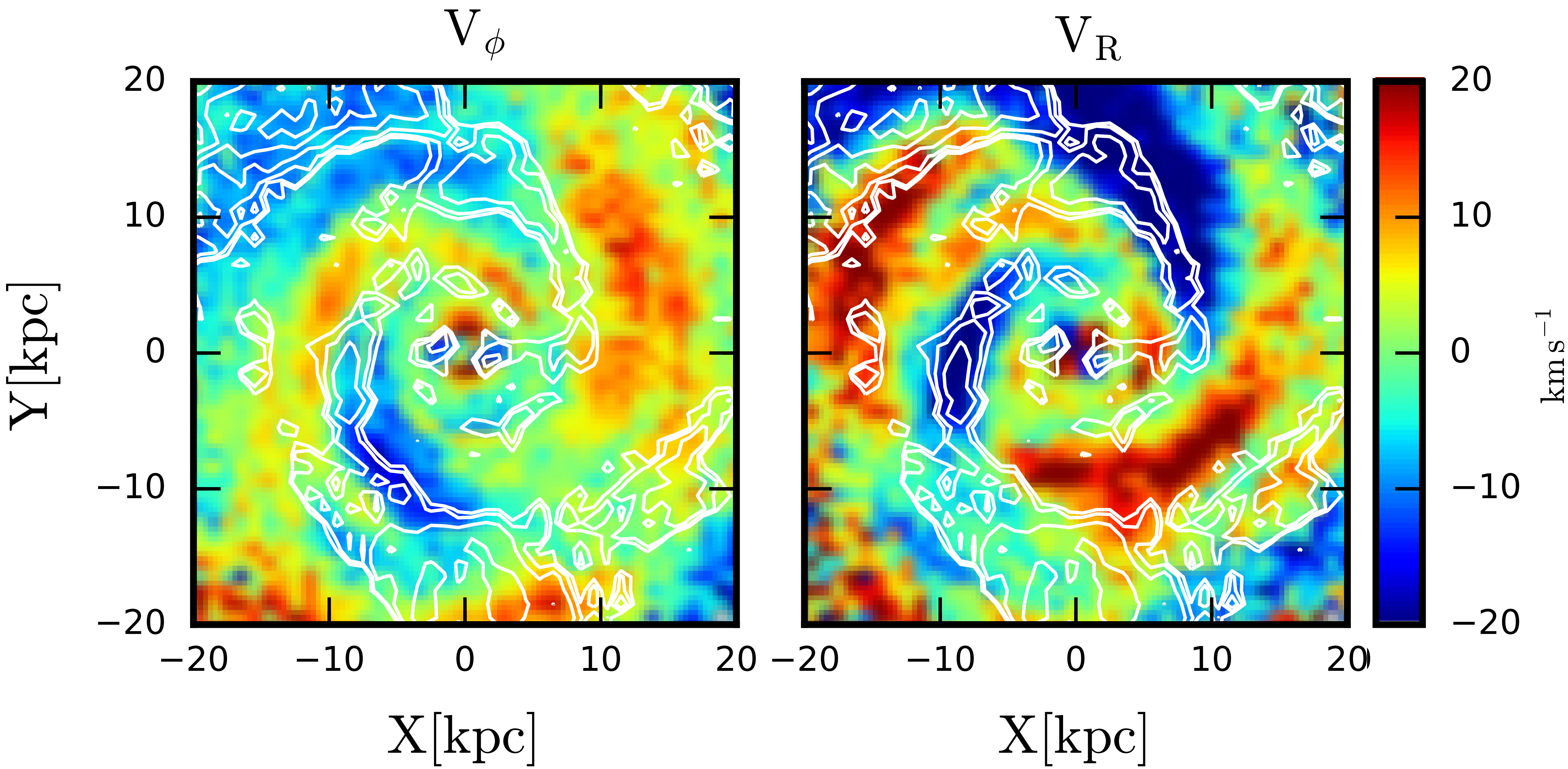
- disc height doesn't get thinner for x10 lower softening (Au 6lowsoft)

Spiral arm dynamics:

Radial migration, observational features….

Spirals drive systematic radial migration (Grand+ 2016b)

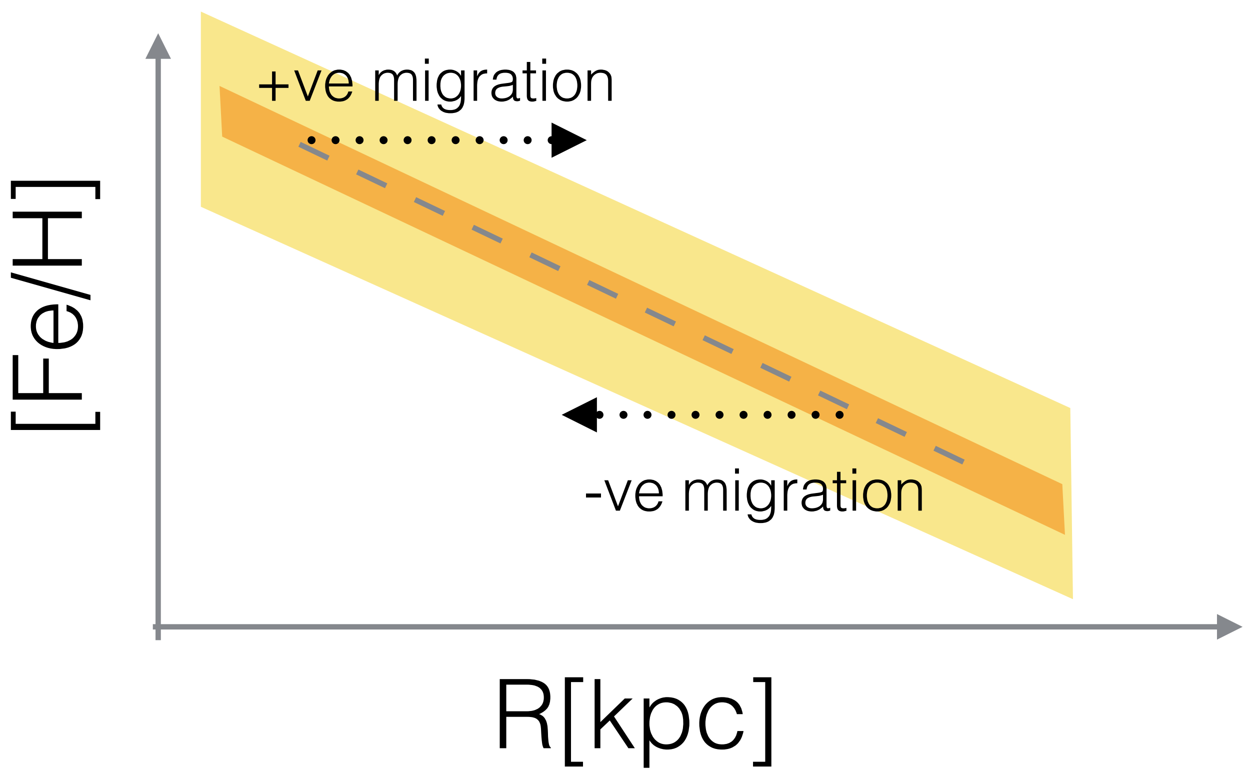
Mean-subtracted peculiar velocity fields:



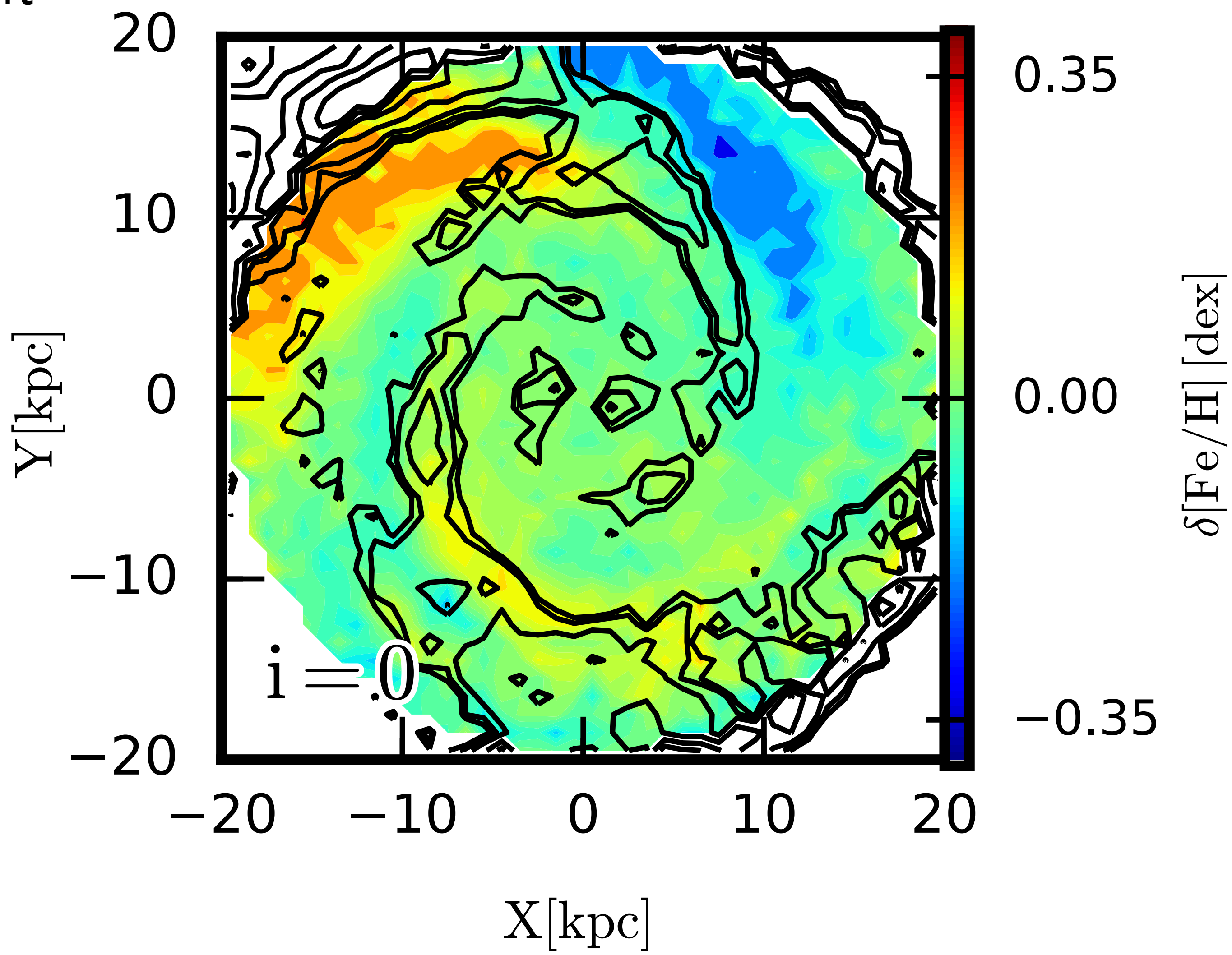
- stars 'surf' tangentially backward and radially outward **behind** spiral and tangentially forward and radially inward **in front** of spiral
- in agreement with isolated sims with transient, winding spirals

Signatures of migration in residual metallicity distribution

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!
- Predictions in agreement with IFU obs. of NGC 6754

Daisuke's talk, Sánchez-Menguiano, DK, RG+ submitted

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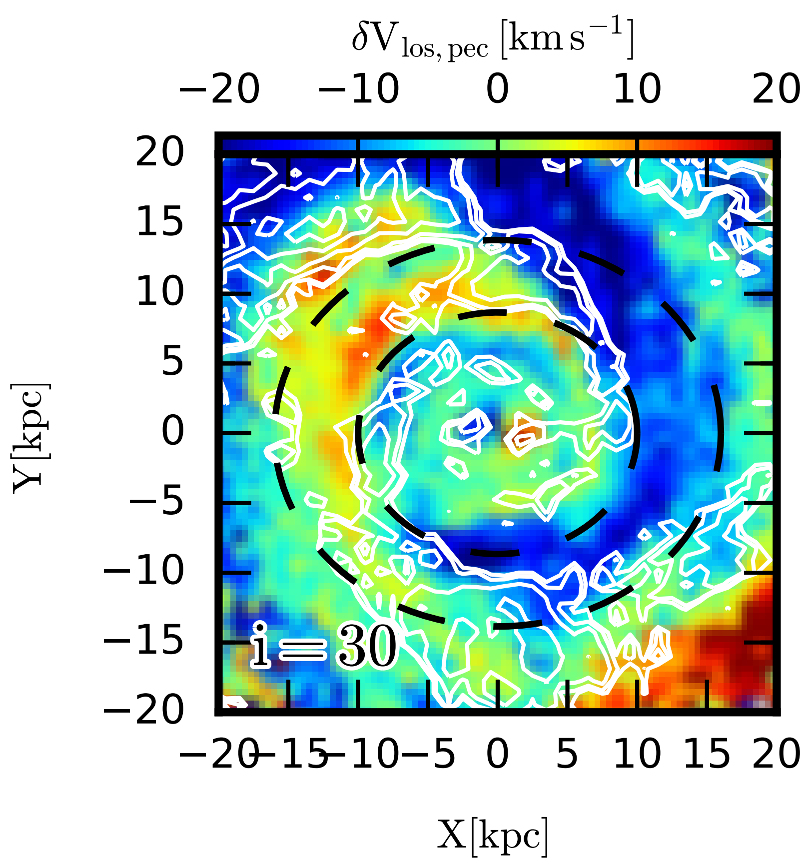
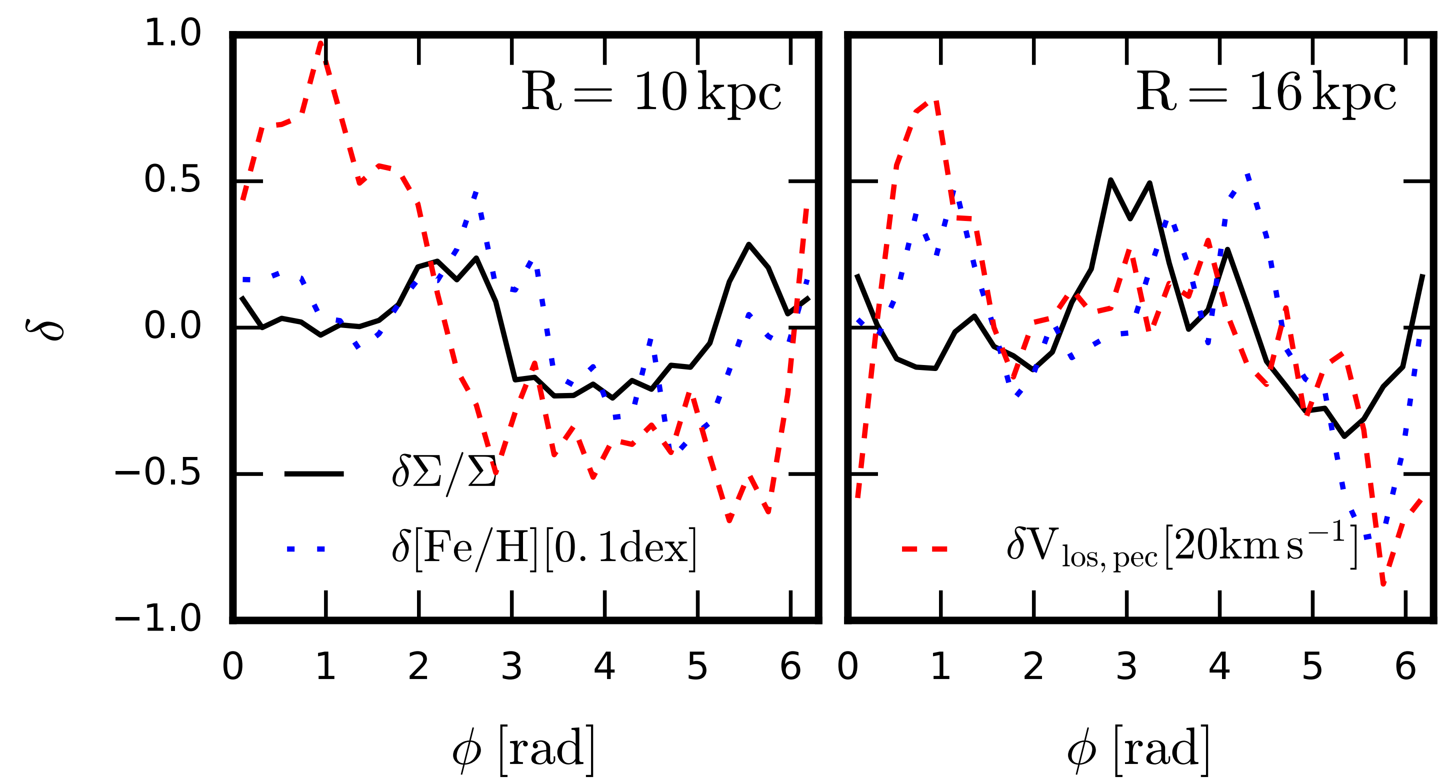
Observational predictions for migration

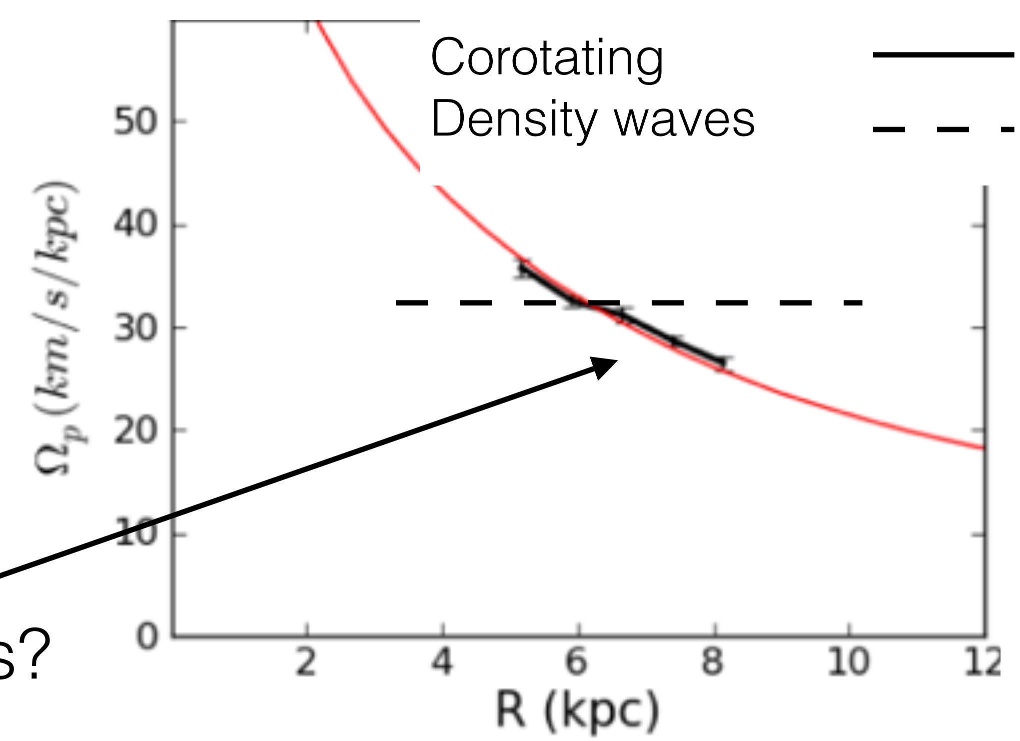
- Inclination of ~30 degrees gives optimal VLOS projection signatures





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

- May also constrain spiral arm nature and parameters

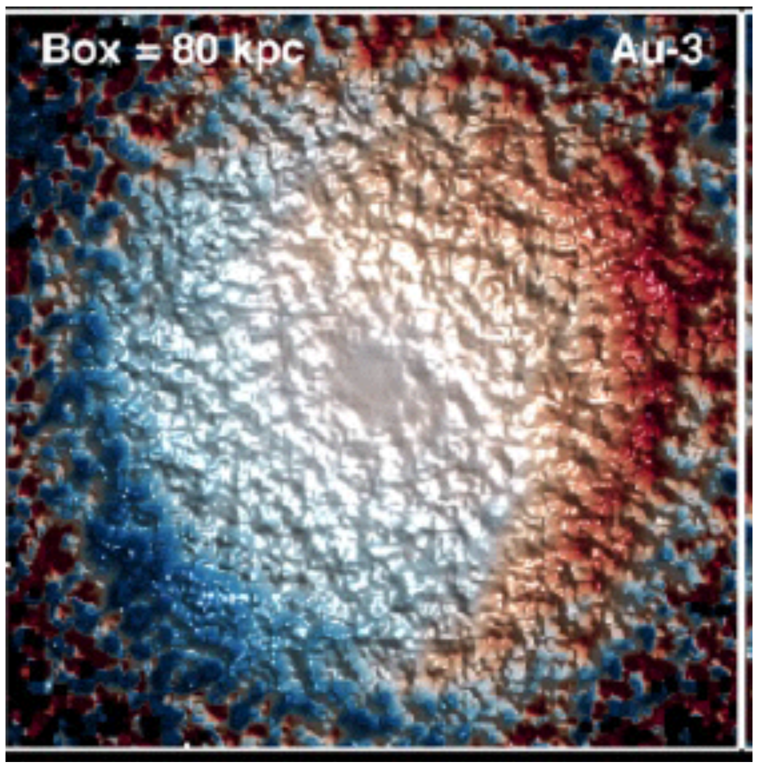


where are the resonance/migration points?

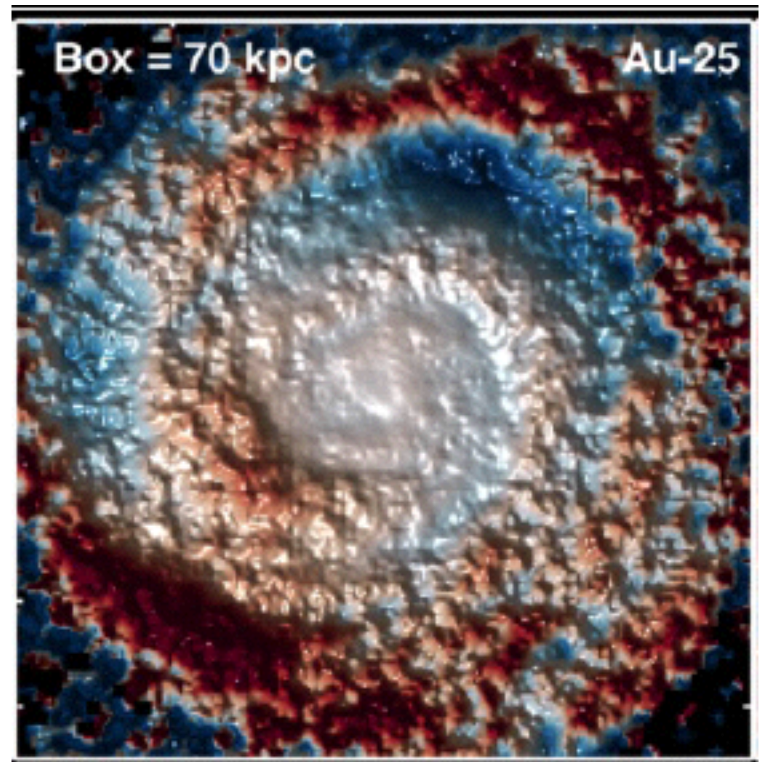
Disc warp statistics in Auriga

(Gomez, RG+ 2016ab)

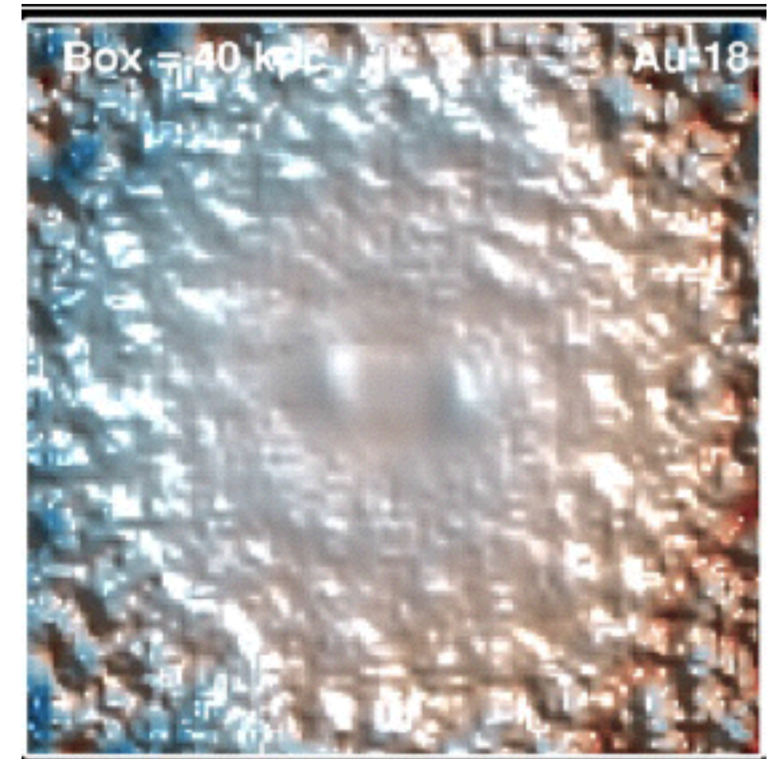
<z> (kpc) -2 +2



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, within the last few Gyr

2 cases of misaligned gas accretion - only in young stars

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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

  - Bar and satellite interaction are main drivers of heating (migration not so much…)
  - Upside-down formation of discs dominates heating mechanisms in many cases
  - Spiral arms drive coherent, systematic motion and azimuthal metallicity patterns