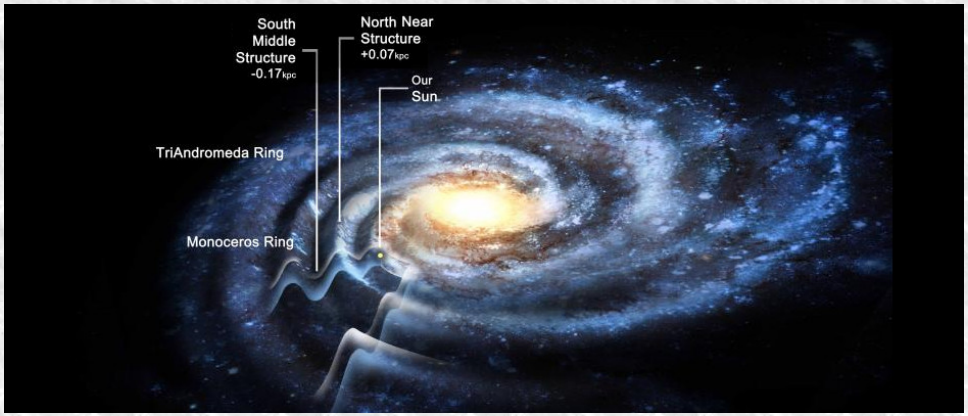
Linking ridges, arches and vertical waves in the kinematics of the Milky Way

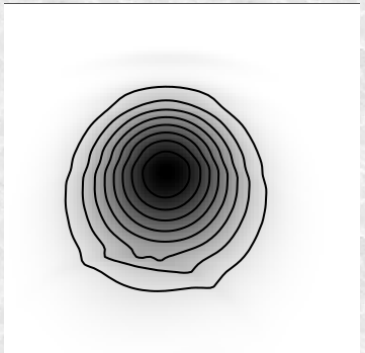


Shourya Khanna

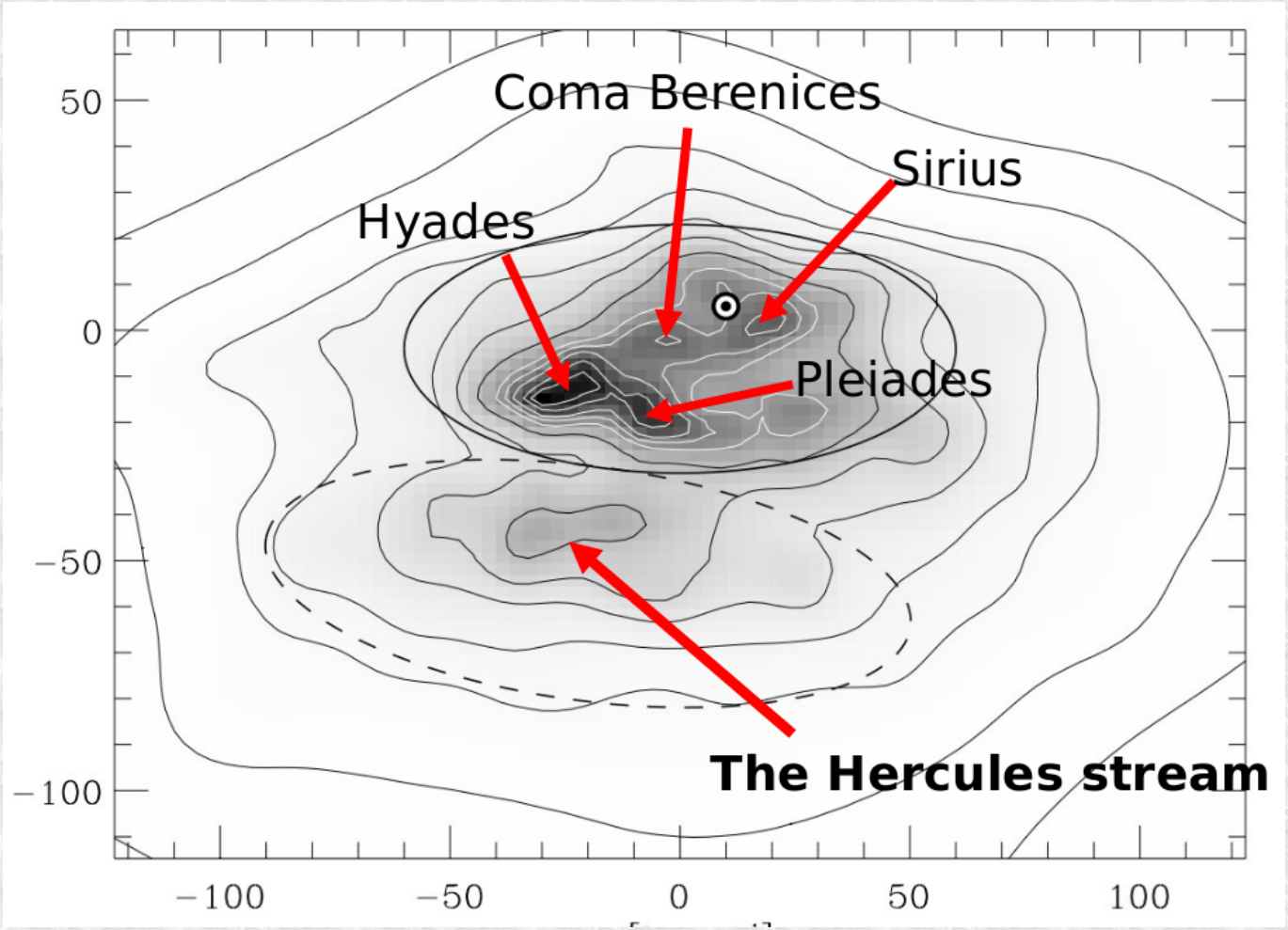
Sanjib Sharma, Joss Bland-Hawthorn, Michael Hayden,
Thorsten Tepper-Garcia + GALAH

Substructure in the Solar neighbourhood

Expect ~ Gaussian blob



Local (d<200 pc) moving groups with Hipparcos.



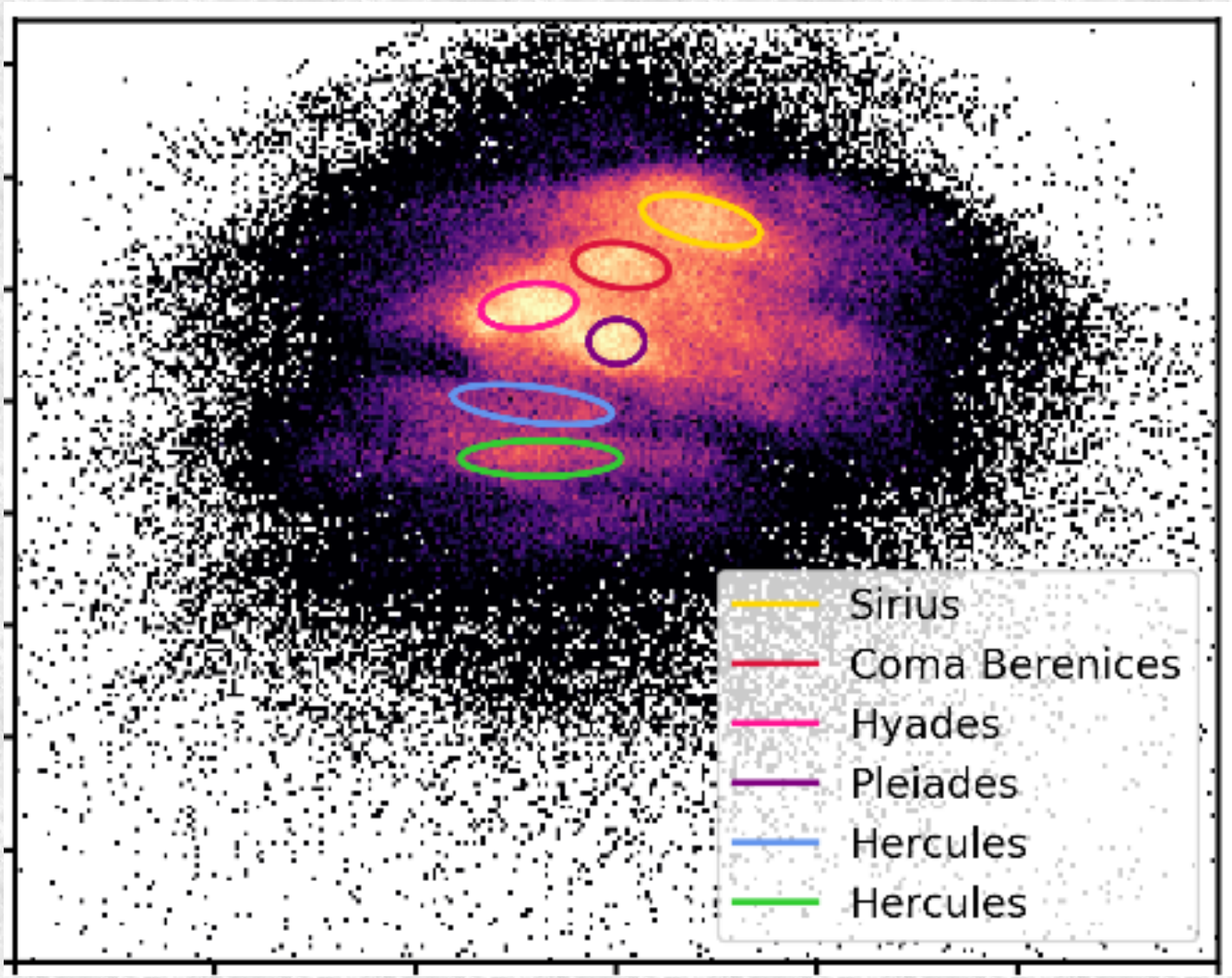
V [km/s] (tangential in the direction of rotation)

U [km/s] (radial towards Galactic center)

Dehnen (2000)

Substructure in the Solar neighbourhood (d<200 pc)

Gaia DR2 (2018)



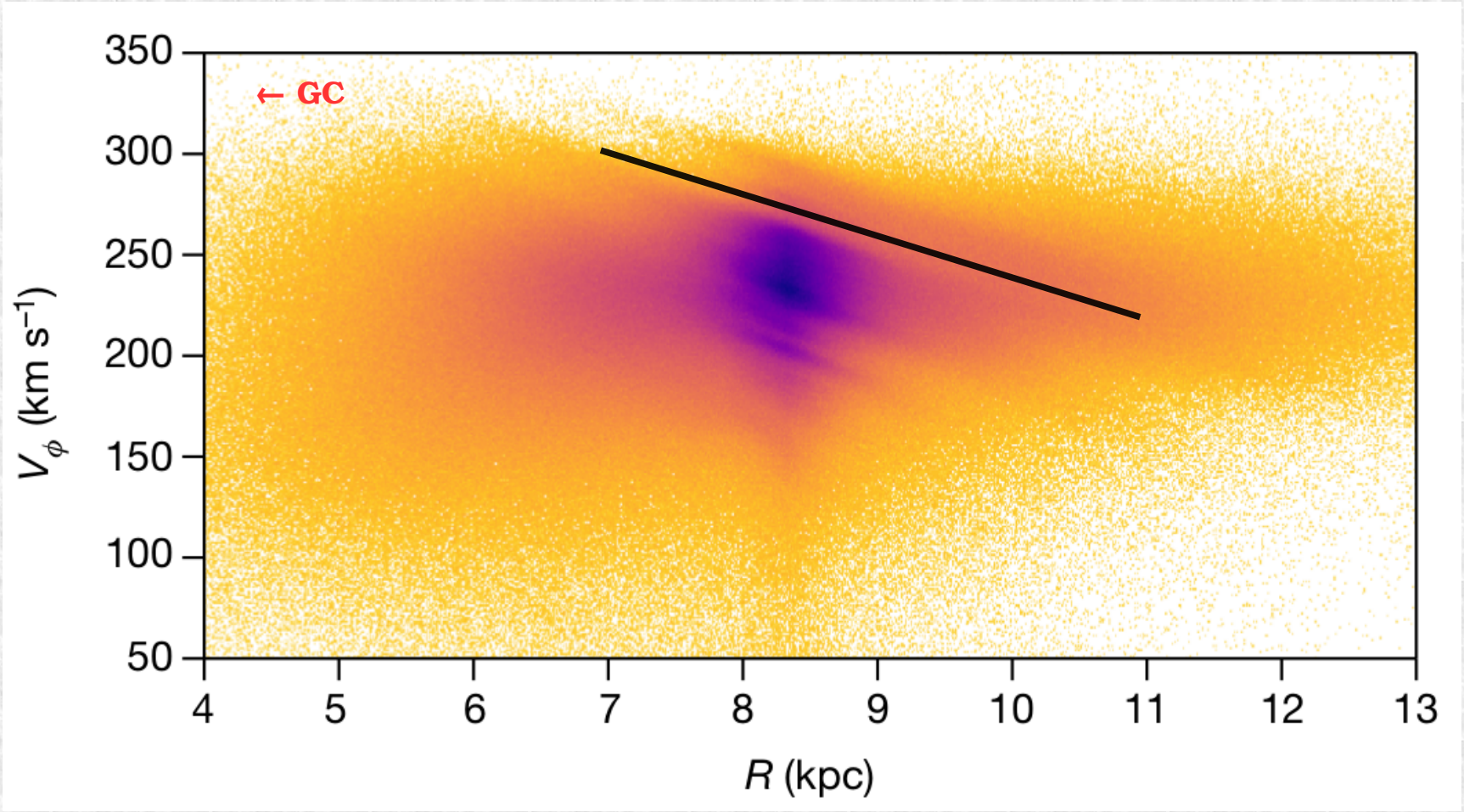
V [km/s] (tangential)

U [km/s] (radial)

Trick et al. (2018)

Diagonal Ridges in R-Vphi

- **New substructure!**
- **Extend over several kpc**



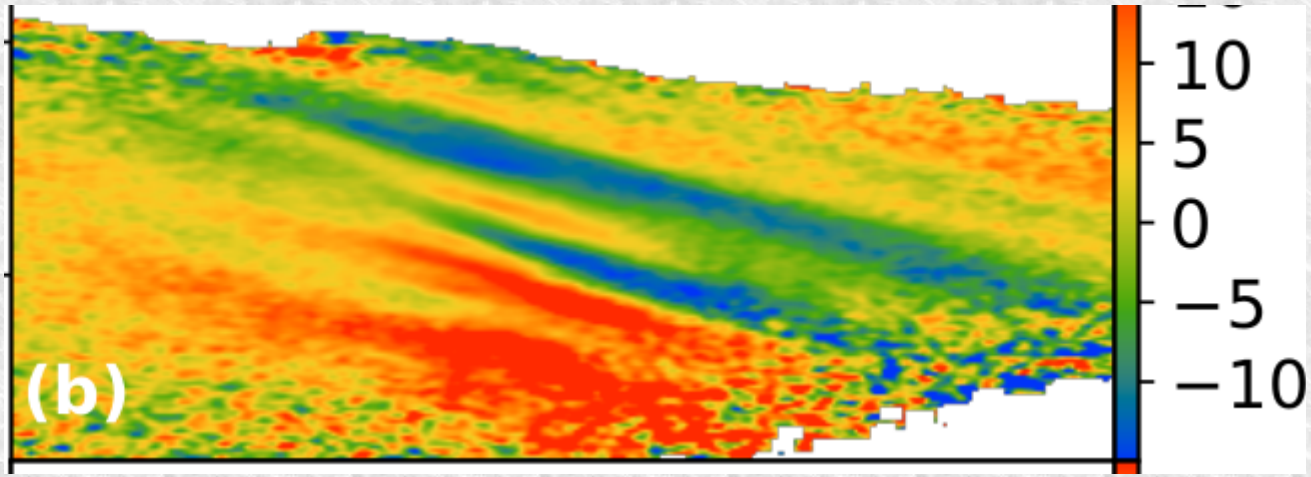
Galactocentric Rotation

Galactocentric Radius

Antoja et al. (2018)

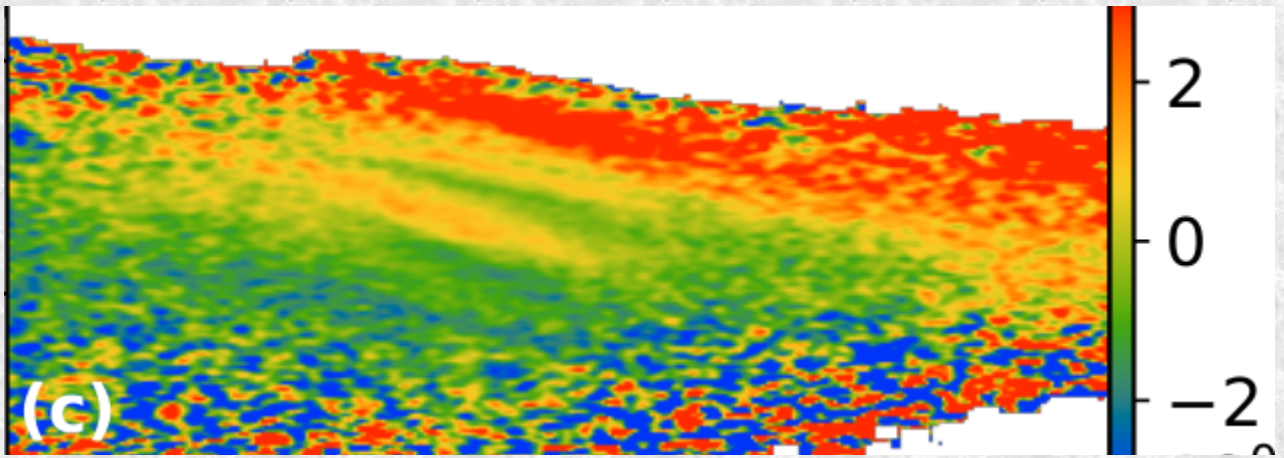
Diagonal Ridges in R-Vphi

Also prominent in maps of radial and vertical velocity



<V_R> [km/s]

Also Fragkoudi et al. (2019)
Ramos et al. (2018)



<Vz> [km/s]

Also Laporte et al. (2019)

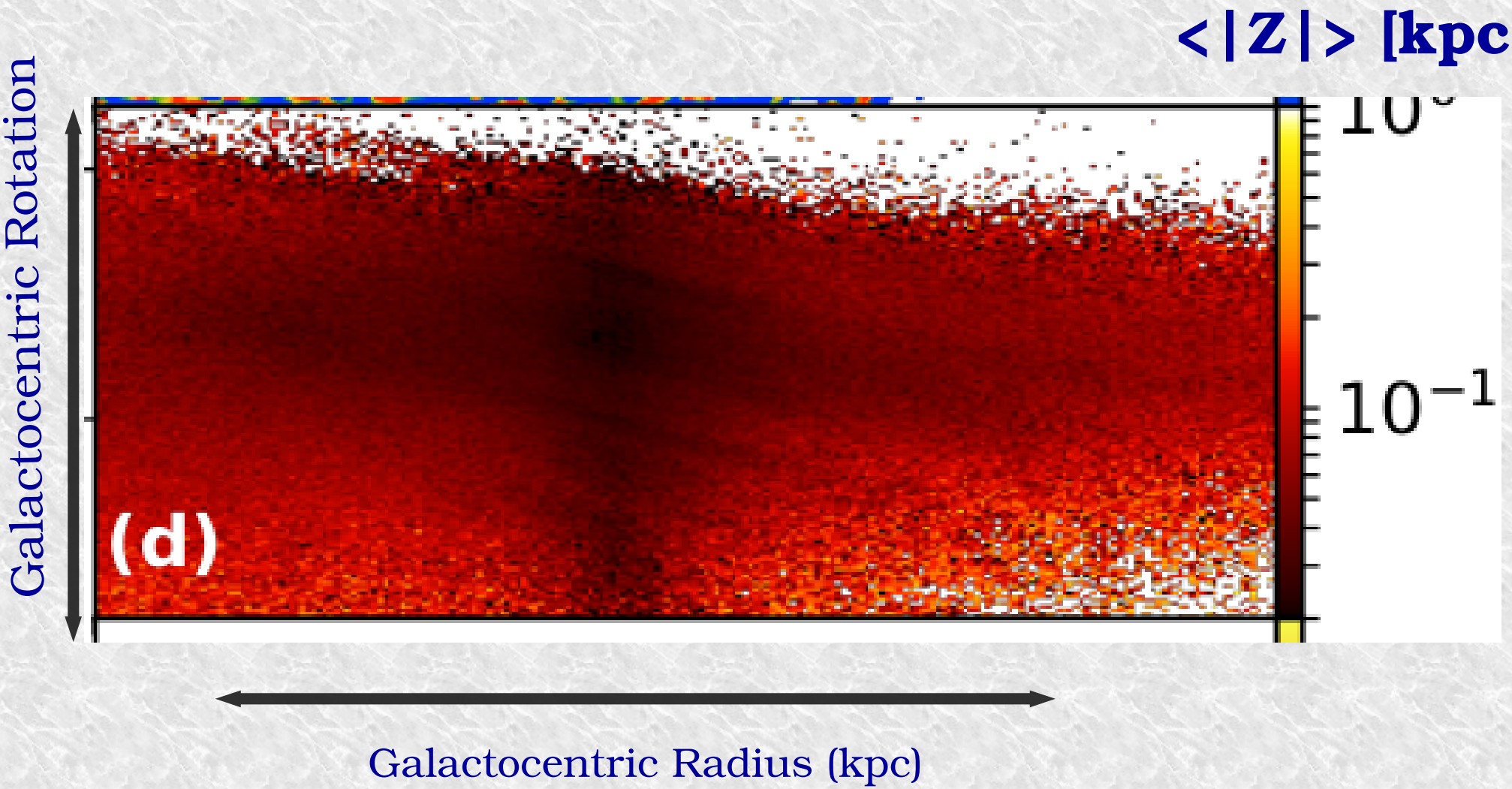
Galactocentric Rotation

Galactocentric Radius (kpc)

Khanna et al. (2019)

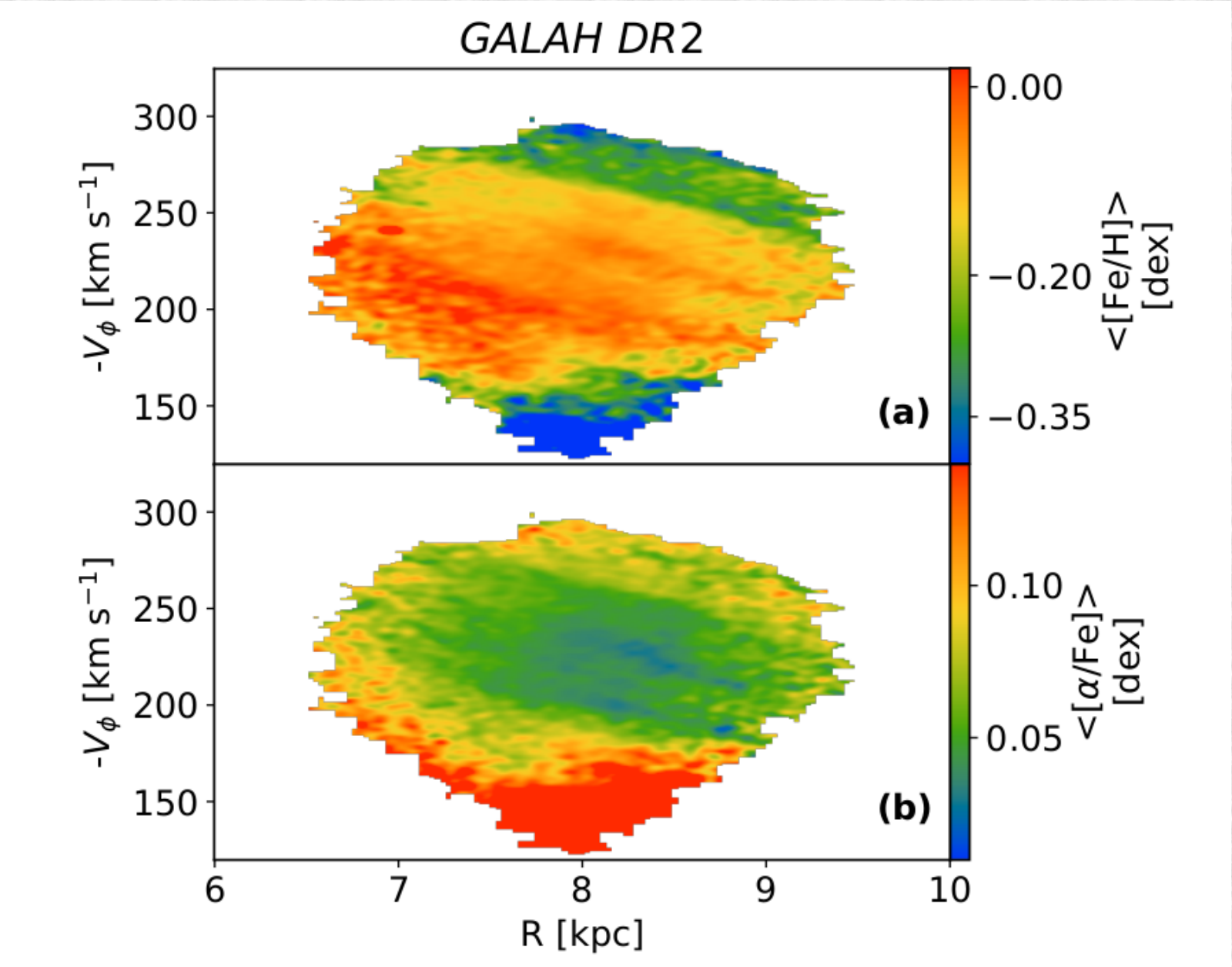
Diagonal Ridges in R-Vphi

Ridge stars within 0.2 kpc from the mid-plane ?



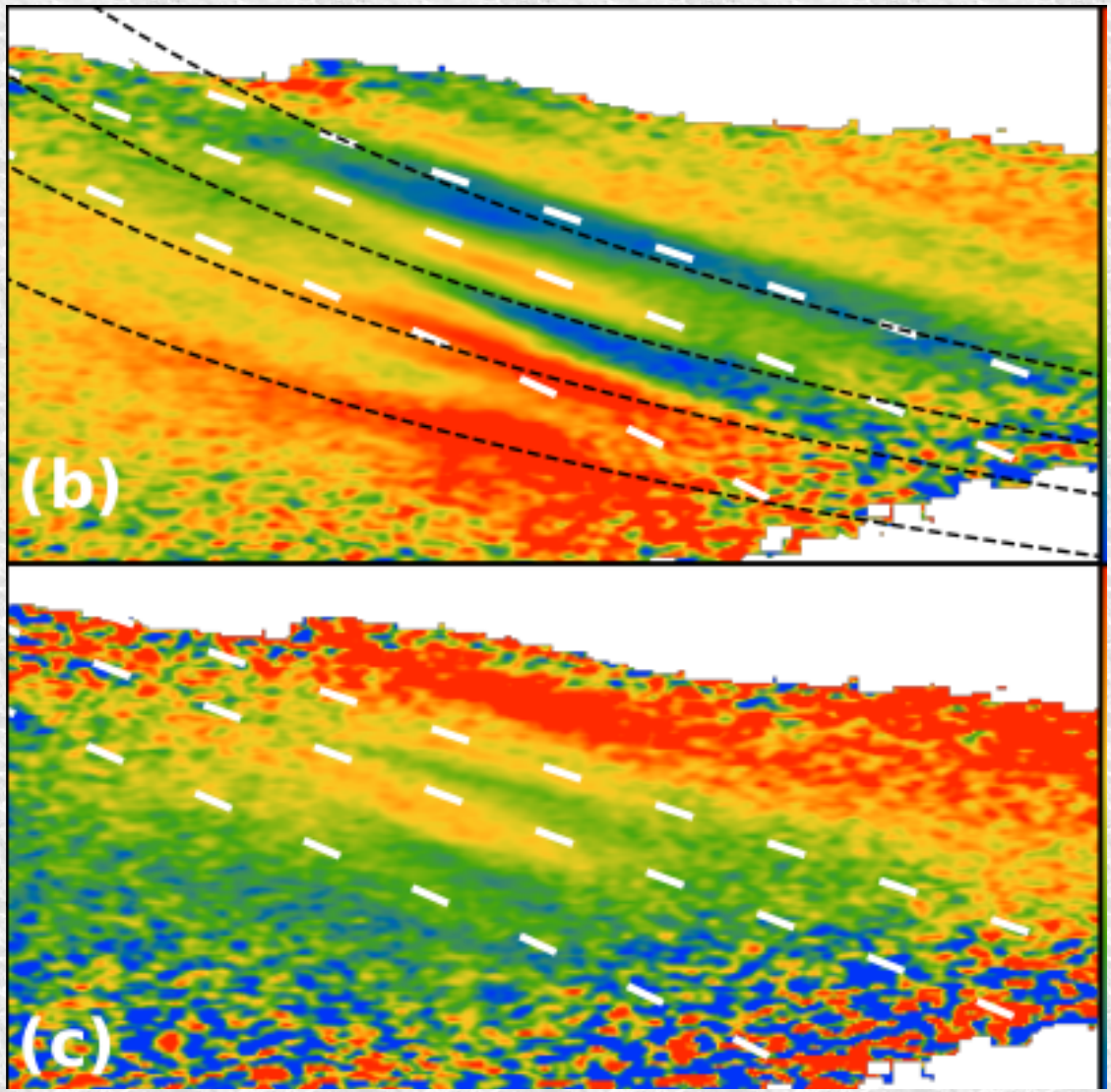
Khanna et al. (2019)

Metal rich → young stars?



Khanna et al. (2019)

Constant energy & Lz curves



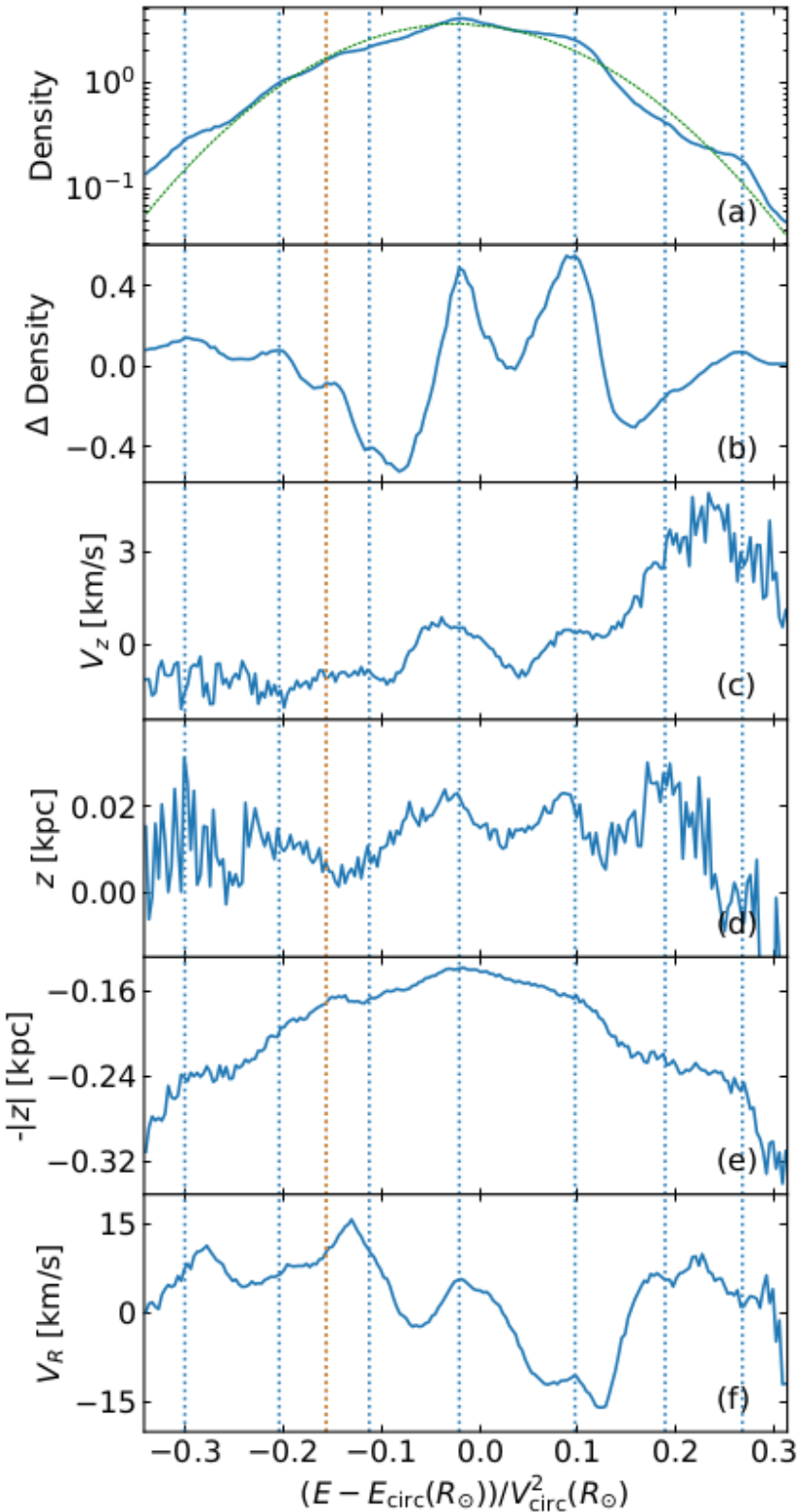
Galactocentric Rotation

Galactocentric Radius

<V_R> [km/s]

<Vz> [km/s]

Khanna et al. (2019)

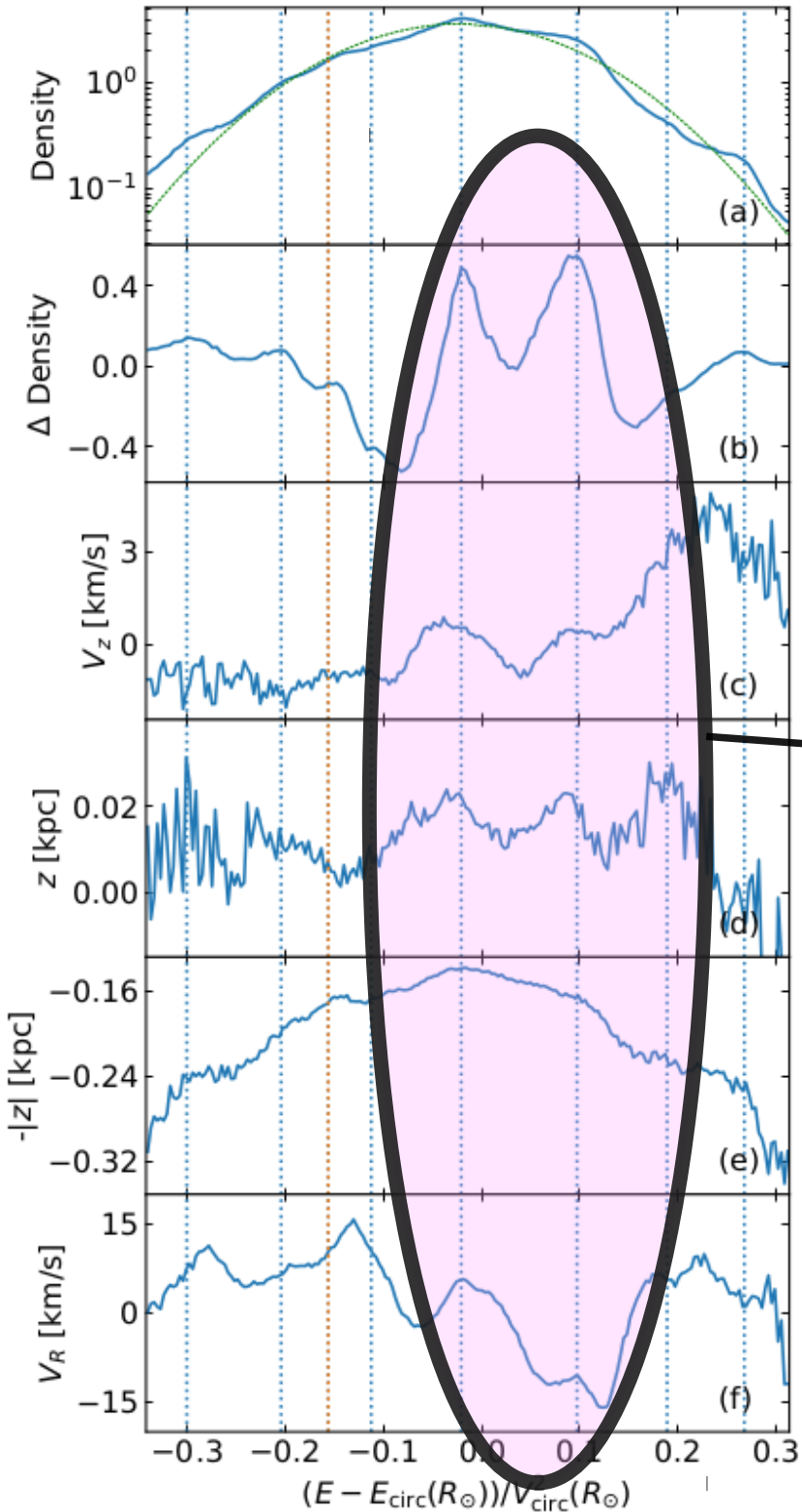


Correlations?

$$(|R - R_\odot| < 1.0)\&(|\phi - \phi_\odot| < 25)$$

8 peaks in density

Khanna et al. (2019)



Correlations?

$$(|R - R_\odot| < 1.0)\&(|\phi - \phi_\odot| < 25)$$

8 peaks in density

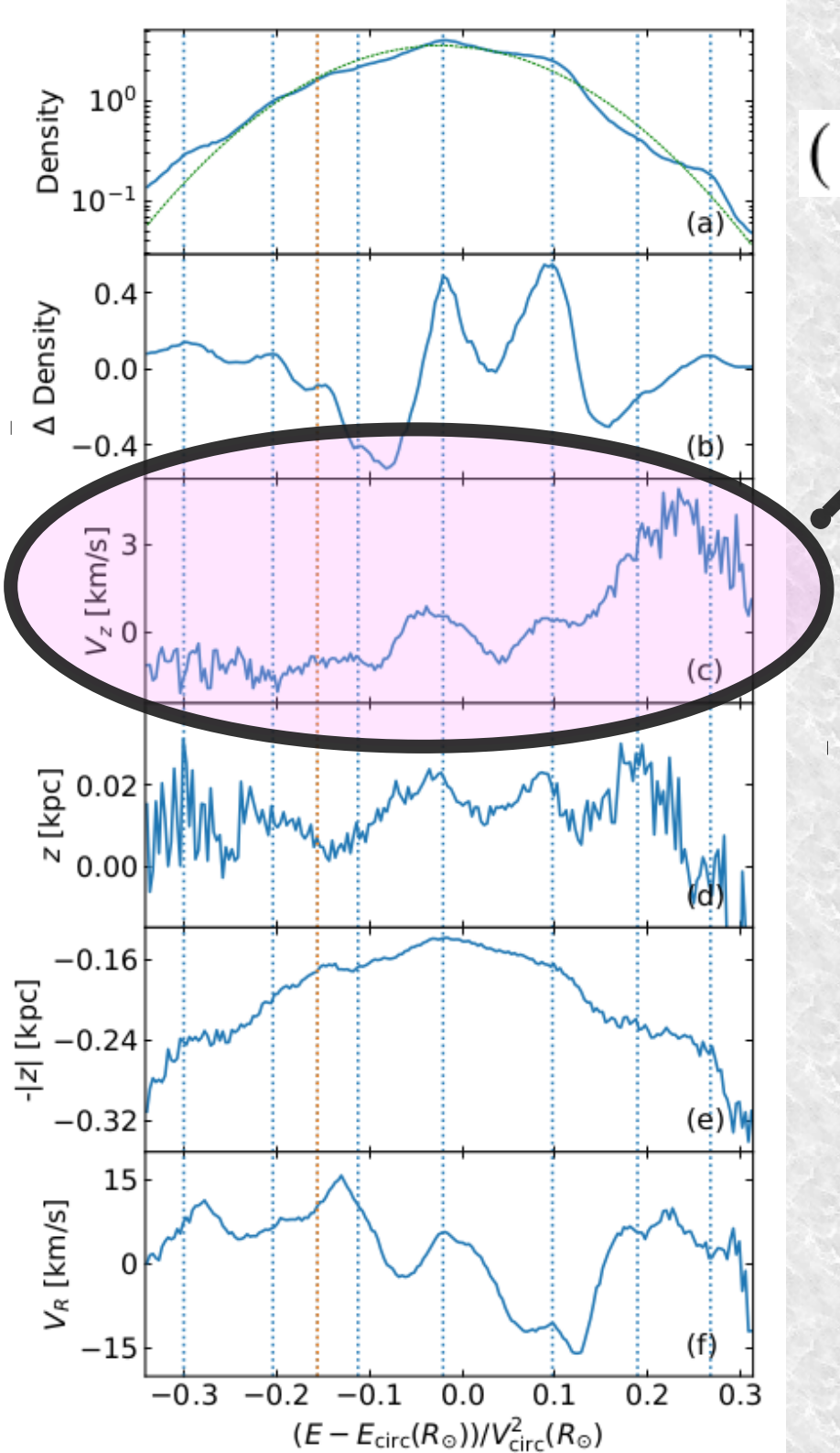
Correlate in density/Z/Vz/VR

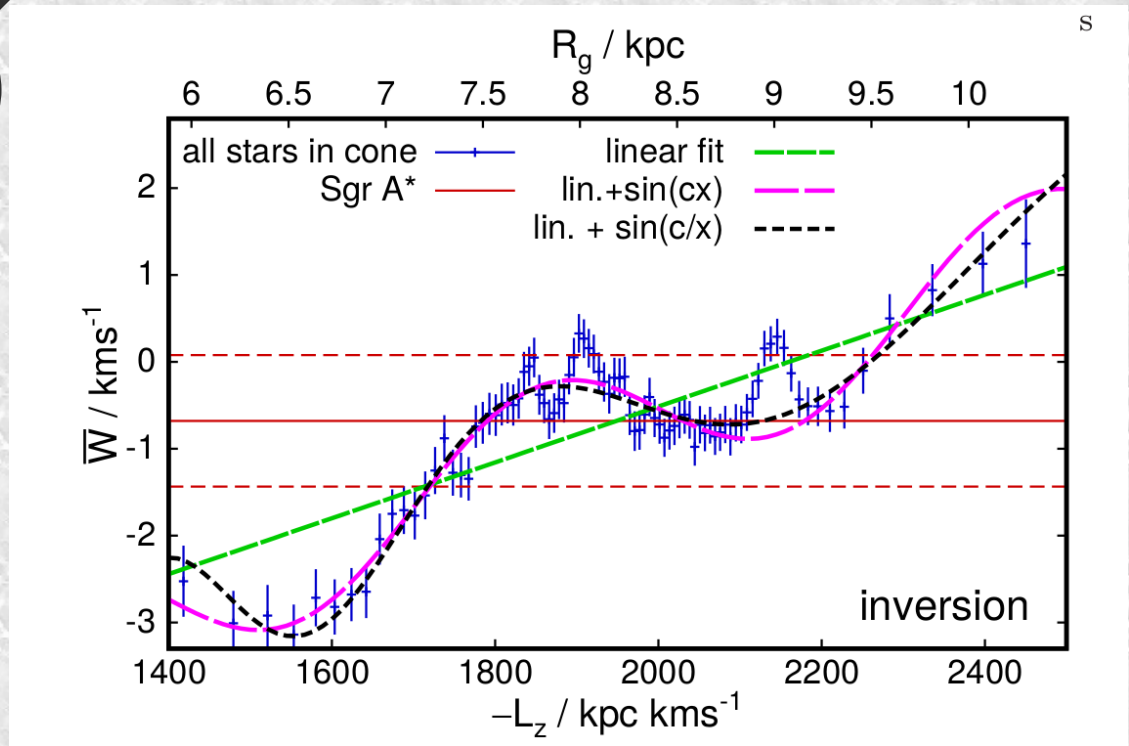
Khanna et al. (2019)

Correlations?

$$(|R - R_\odot| < 1.0)\&(|\phi - \phi_\odot| < 25)$$

Warp?



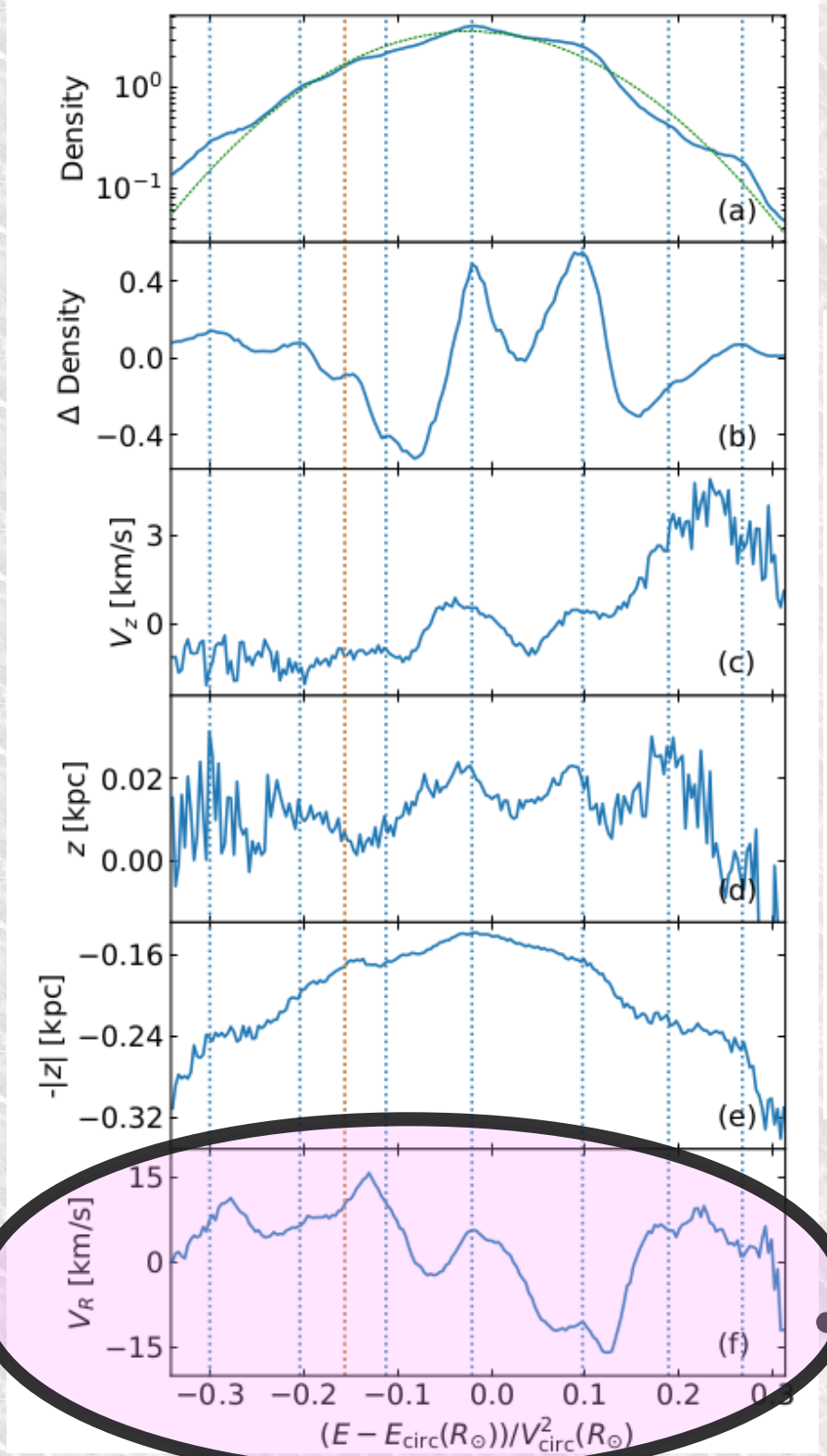


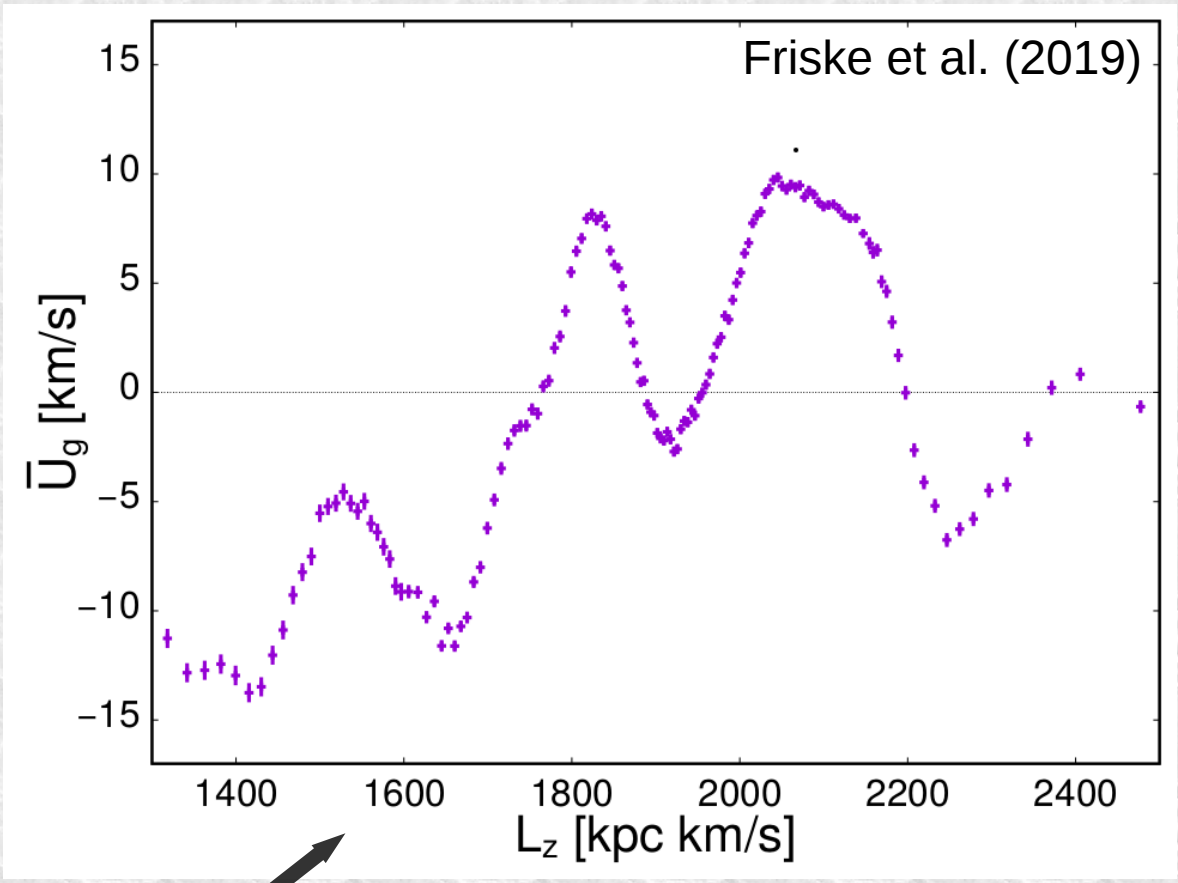
Schonrich & Dehnen (TGAS, 2017)

Khanna et al. (2019)

Correlations?

$$(|R - R_\odot| < 1.0)\&(|\phi - \phi_\odot| < 25)$$





Khanna et al. (2019)

Usual suspects

Bar

Trick/Monari etc

Spiral arms

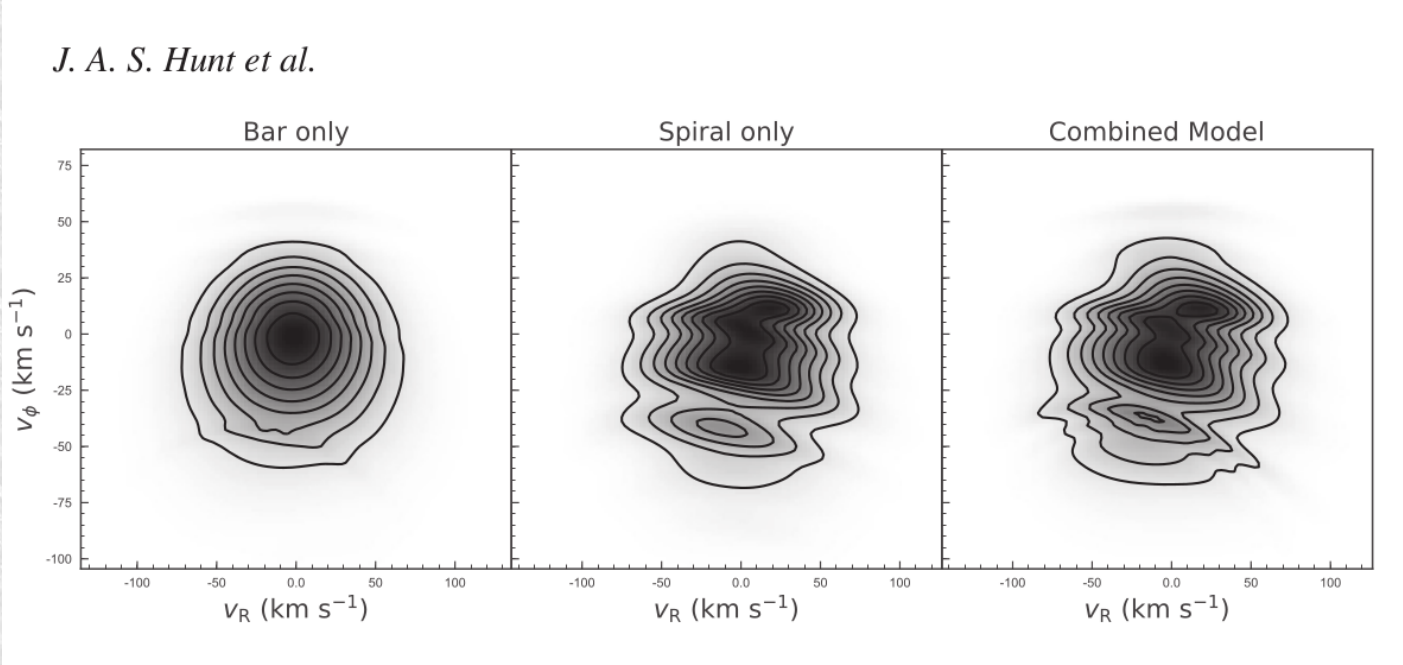
Long-lived (density wave)?

Transient structures (N-body sims)

Usual suspects

Spiral arms

Long-lived (density wave)?
Transient structures (N-body sims)

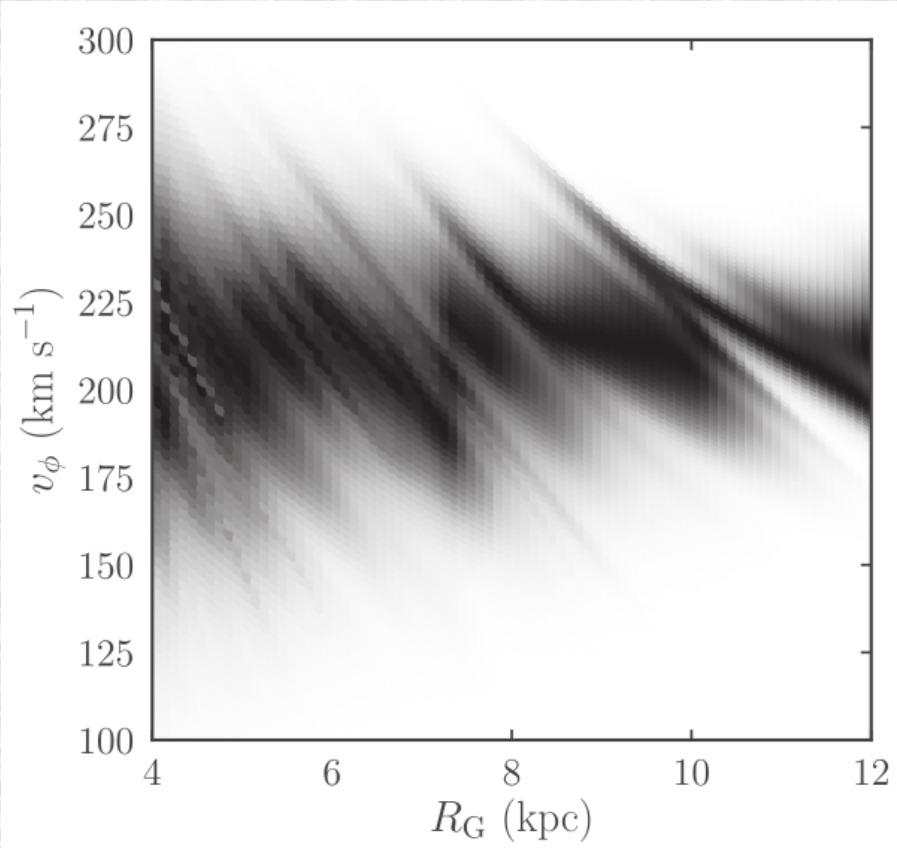


Long slow bar + transient spirals

Usual suspects

Spiral arms

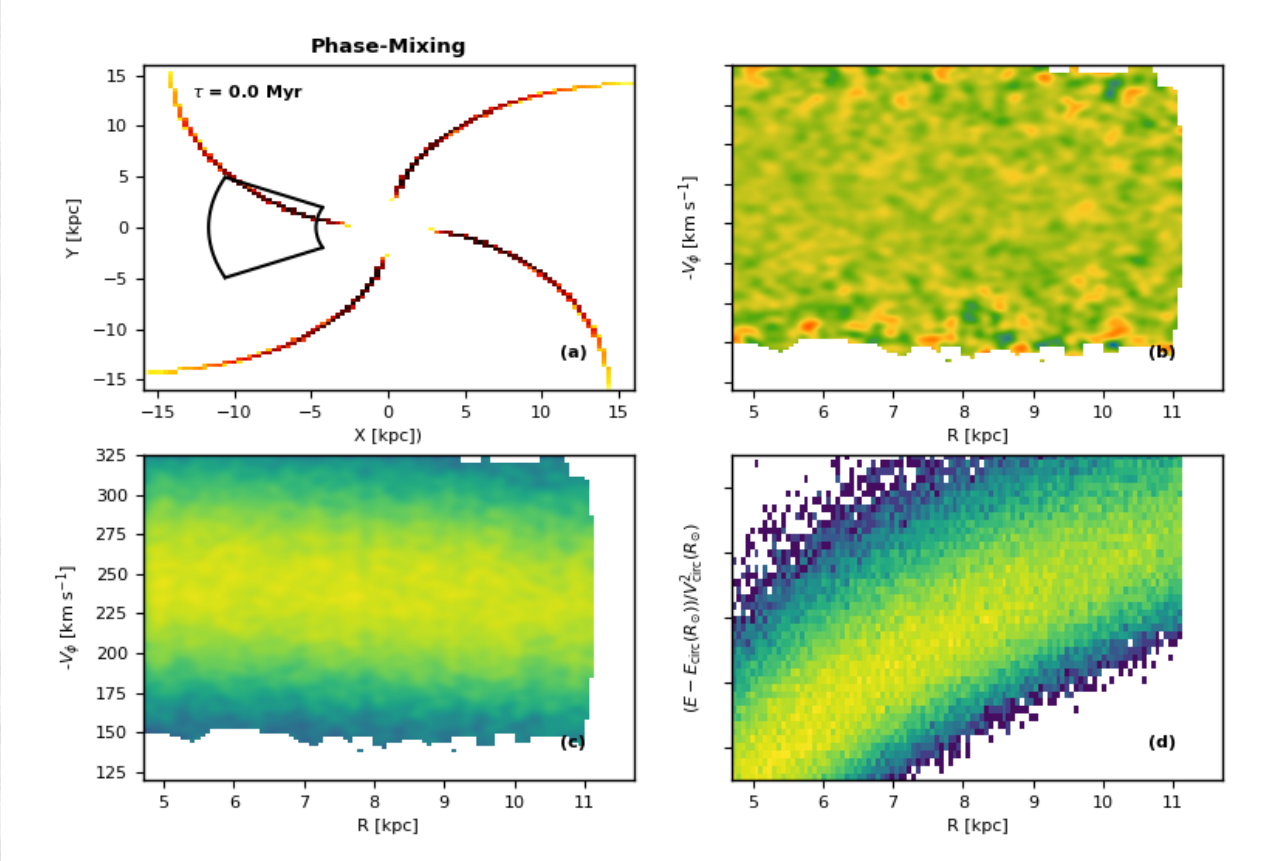
Long-lived (density wave)?
Transient structures (N-body sims)



Long slow bar + transient spirals

Hunt et al. (2018)

1. Simulating R-vphi plane (phase-mixing simulation)



Initial distribution: four thin spiral arms

Radial velocity N(0,20)

Azimuthal N(Vc,20)

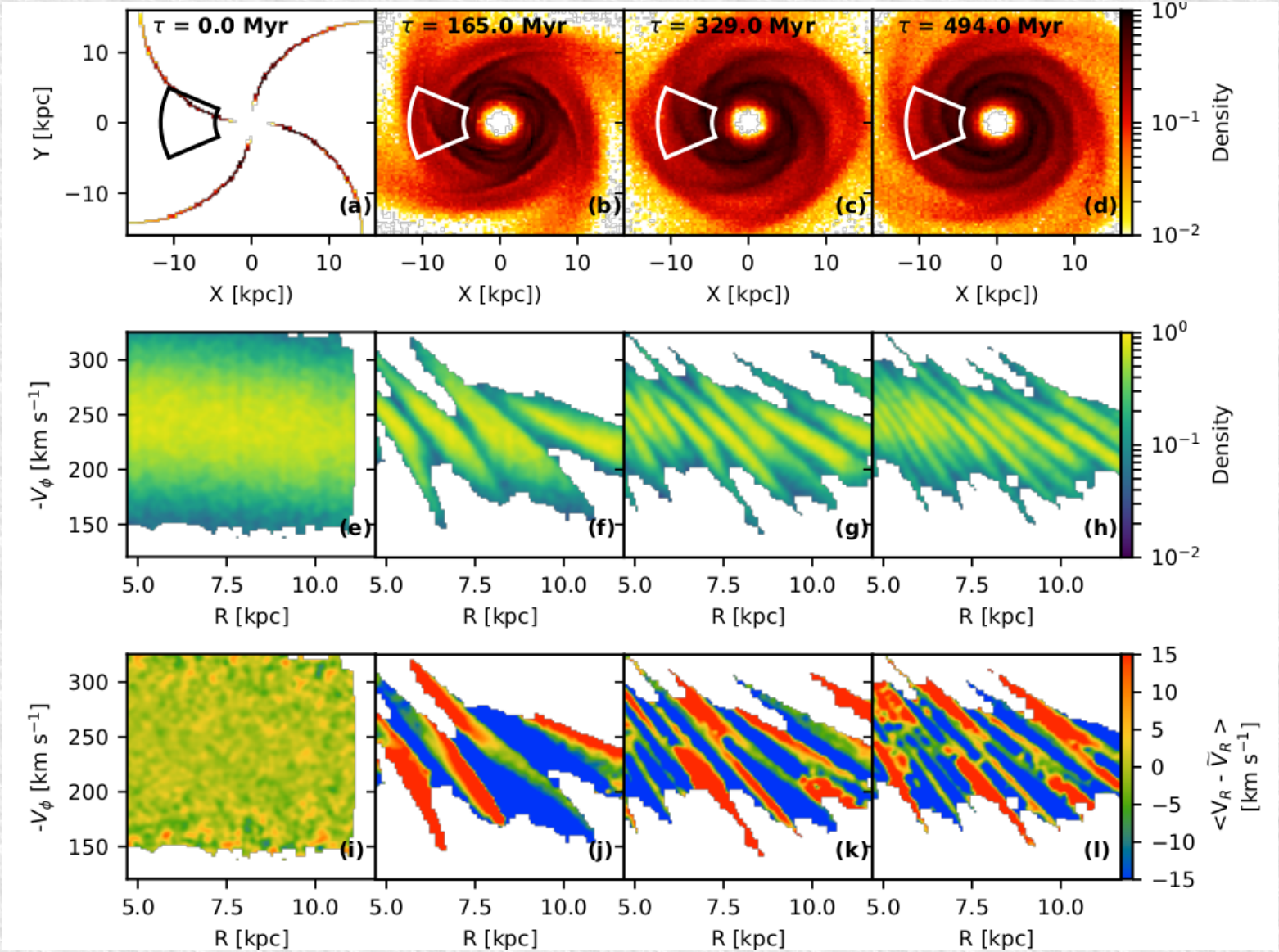
- **Evolve in axisymmetric potential (disc+bulge+spherical halo)**
- **MWPotential 2014 Galpy (Bovy 2015)**

Khanna et al. (2019)

Liouville's theorem

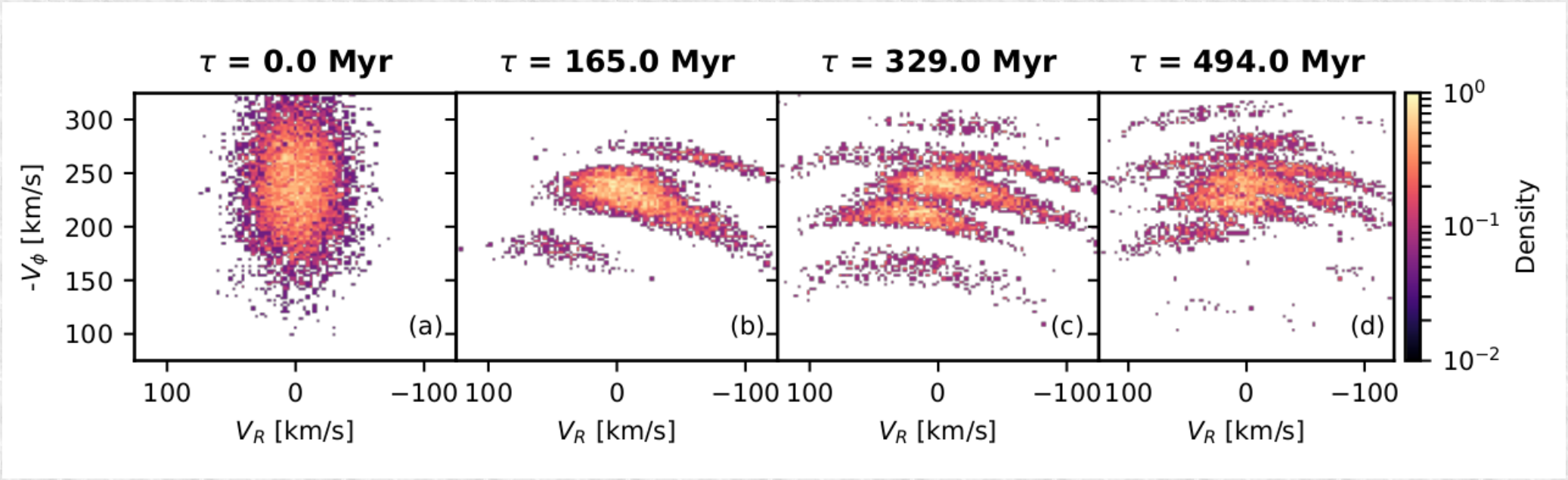
full phase-space density (or volume) of a system evolving in a fixed potential is conserved (X,Y, VX,VY)

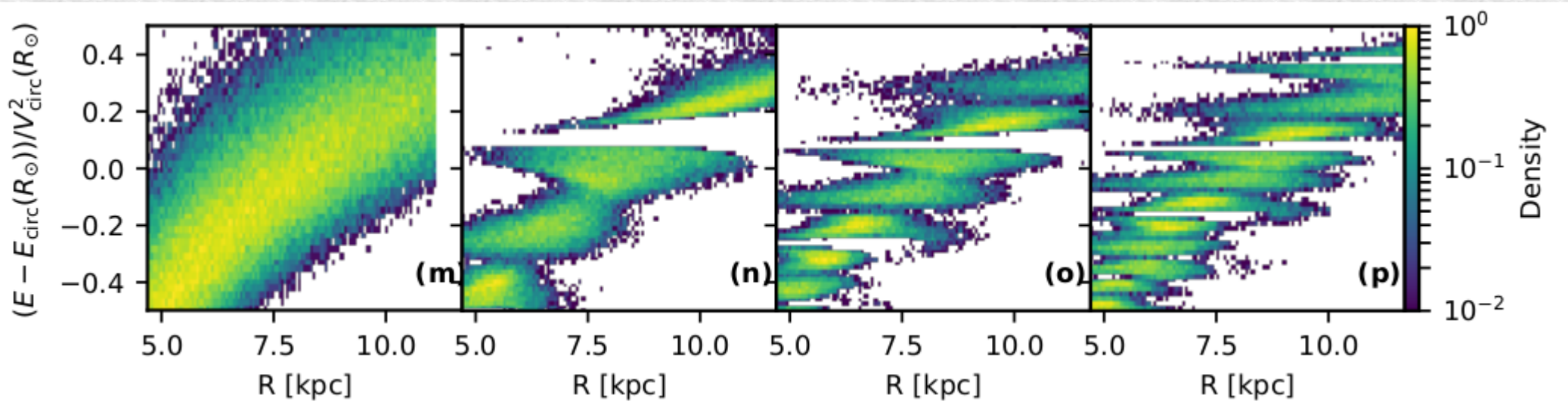
Time



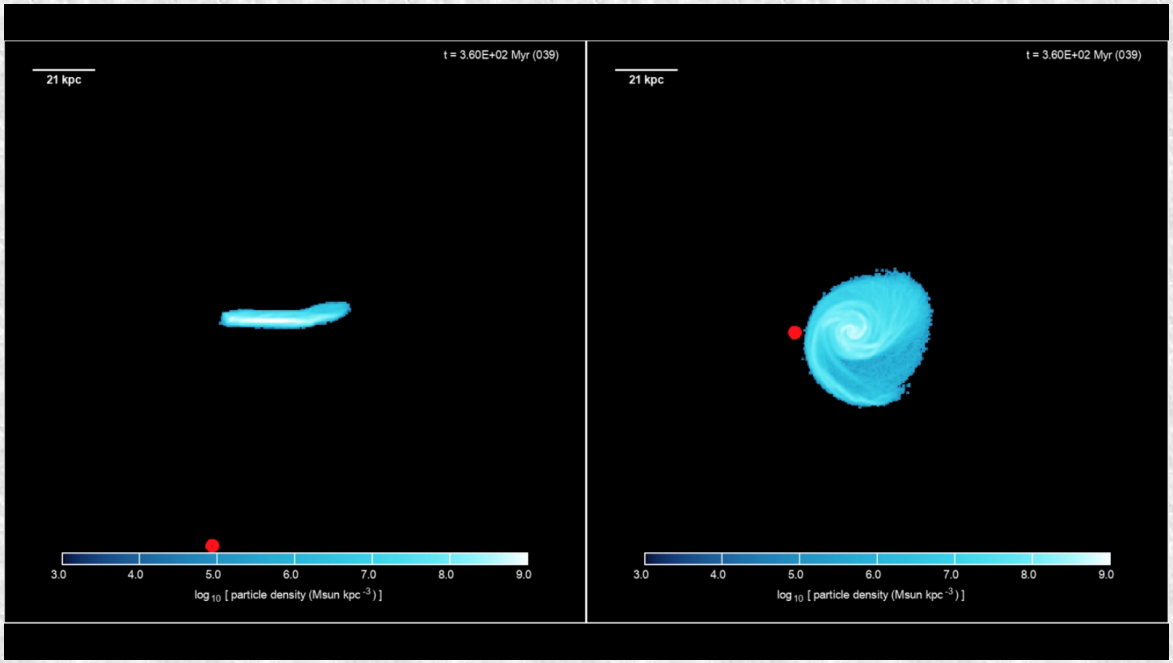
UV arches

Time





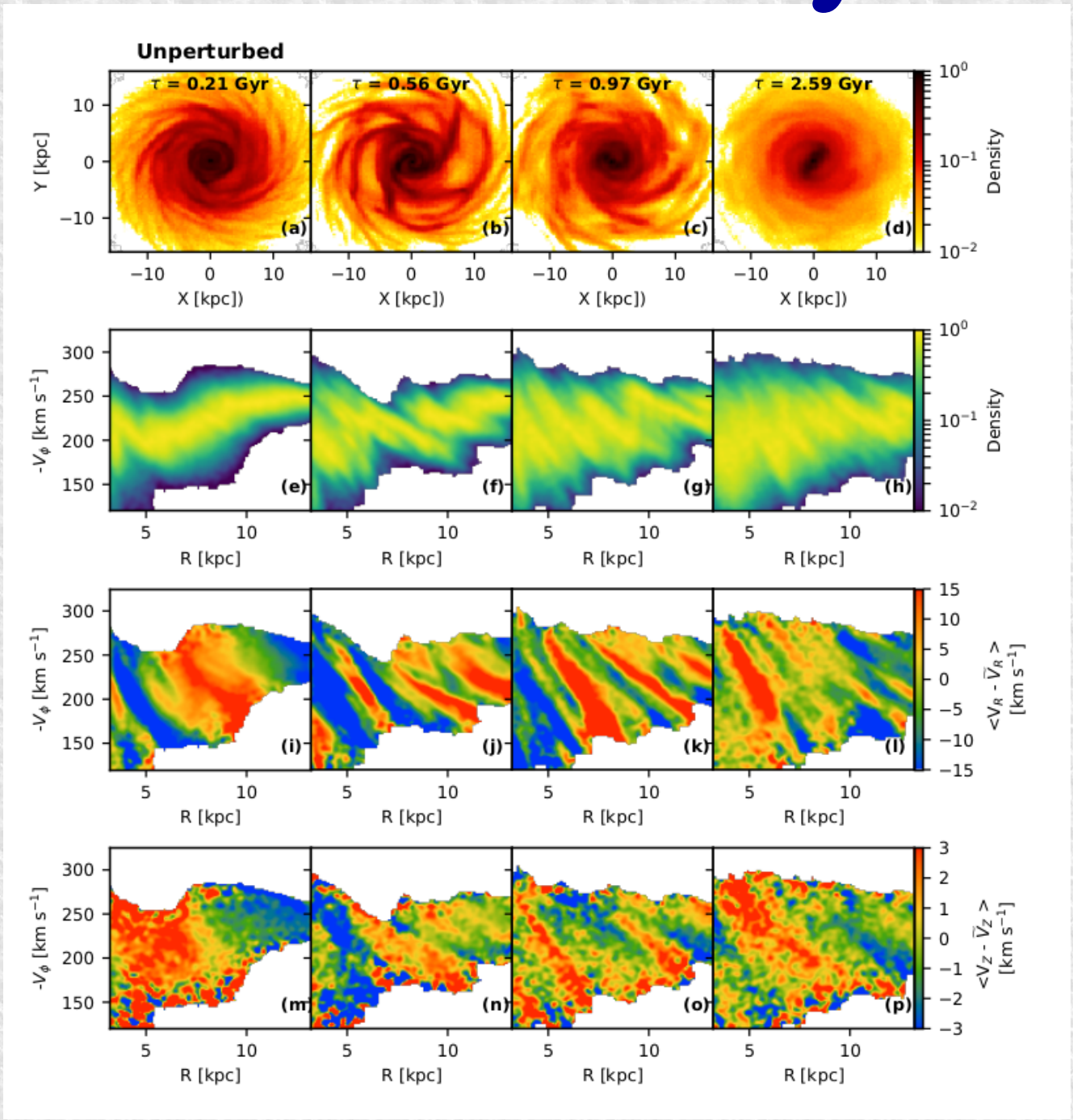
2. Simulating R-vphi plane (N-body simulation)



Thorsten Tepper-Garcia (USyd)

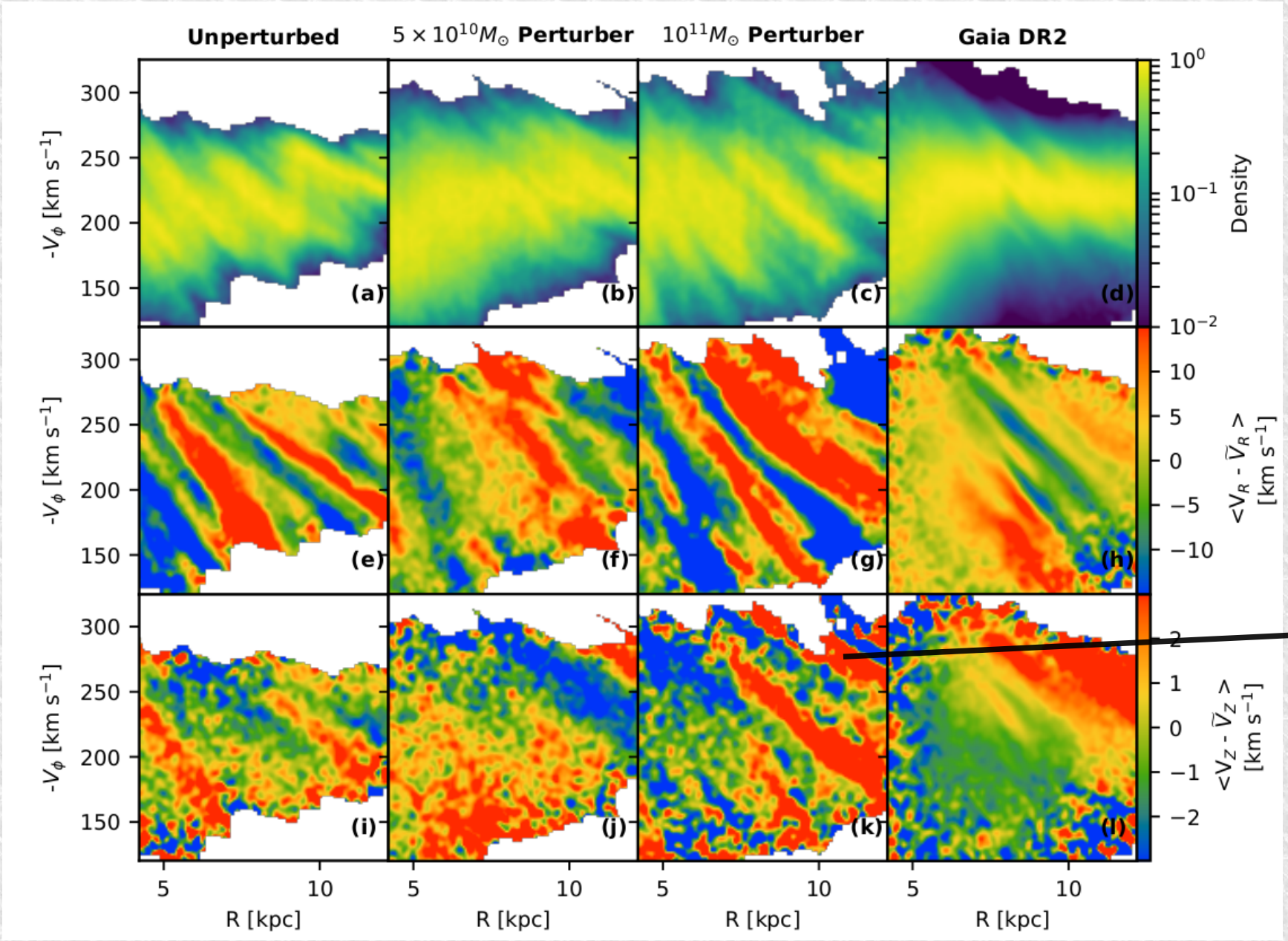
- **Case 1 (isolated Galaxy); case 2 (Galaxy + interaction ex: with Sgr dwarf)**
- **Initial conditions: dynamical equilibrium but instabilities always present (goal)**
- **Positions/velocities set using DICE code, evolved in RAMSES**

Isolated Galaxy



Khanna et al. (2019)

External vs. Internal ?



High Vz

Khanna et al. (2019)

Resonances?

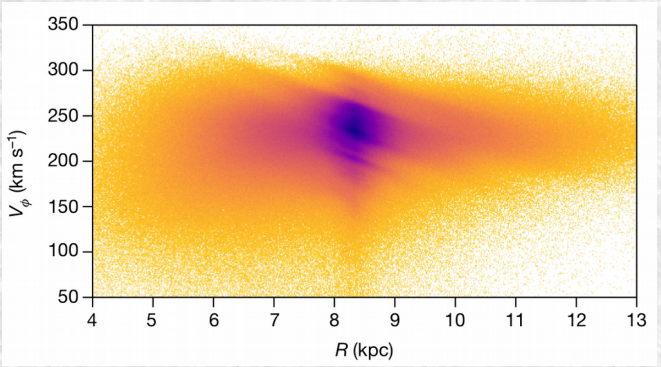
Galactic bar (length = 3-5 kpc)	Features in UV distribution
Short & Fast	Only Hercules stream
Long & slow	low velocity arches but No Hercules stream
Long & faster	Hercules, and very high velocity arches

Resonances alone (bar and/or spirals)
are not enough to explain ALL the features seen by Gaia

Hunt et al. (2019)

To summarize...

Khanna et al. (2019)



- DR2 R-Vphi ridges seen in density/velocity/[Fe/H]/height.
- Simple phase-mixing models → qualitatively reproduce.
- Transient spirals in N-body simulations → also qualitatively reproduce
- Both resonances and phase-mixing are important.

Near Future

- Are Ages (reliable) informative?
- Test with N-body simulations initialised with distribution functions (e.g., AGAMA).
- Perhaps future Gaia releases (deeper than RVS) will reveal many more ridges?
- How are the warp, spirals and corrugations related.
