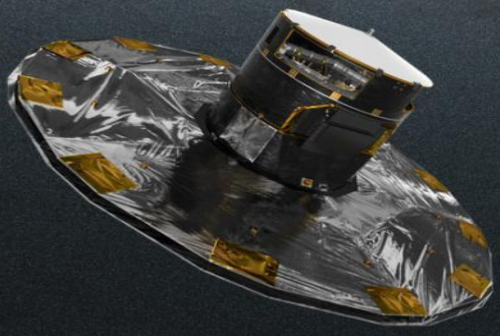
New features of phase spiral from Gaia DR3



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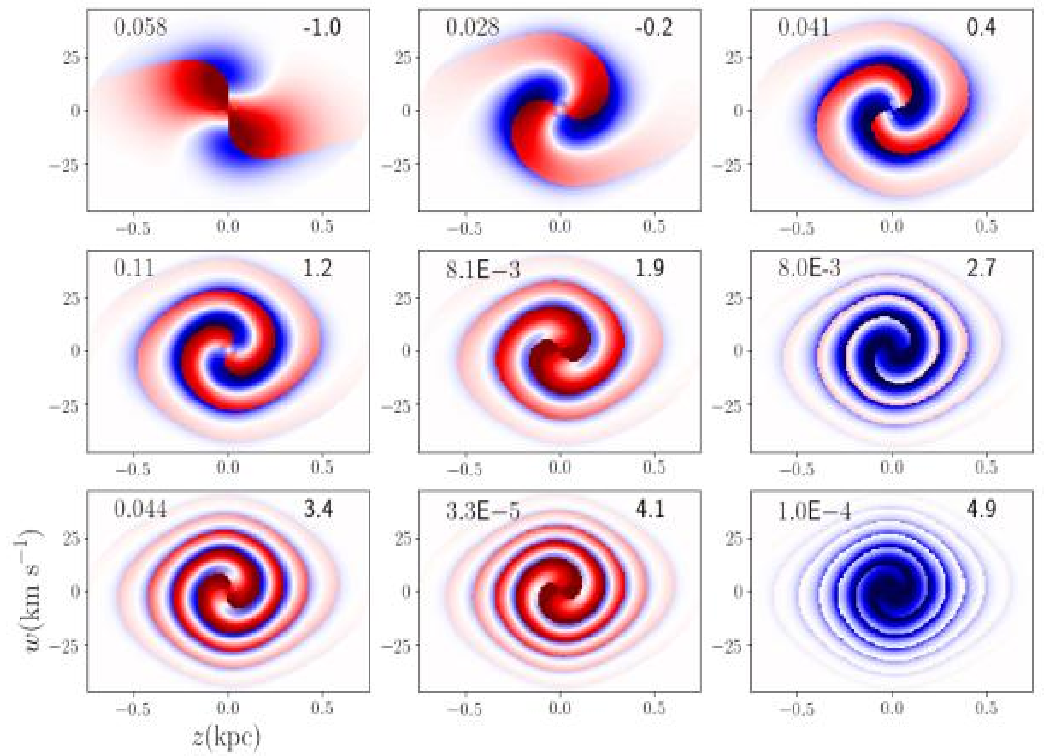
Outlines

- What is the phase space spiral pattern
- What kind of spiral patterns do we observe in the Galaxy
- What are the possible mechanisms to the spiral feature

What is the phase spiral

- A curled spiral or “snail shell” shape distribution for disc stars in phase space $z - v_z$ map

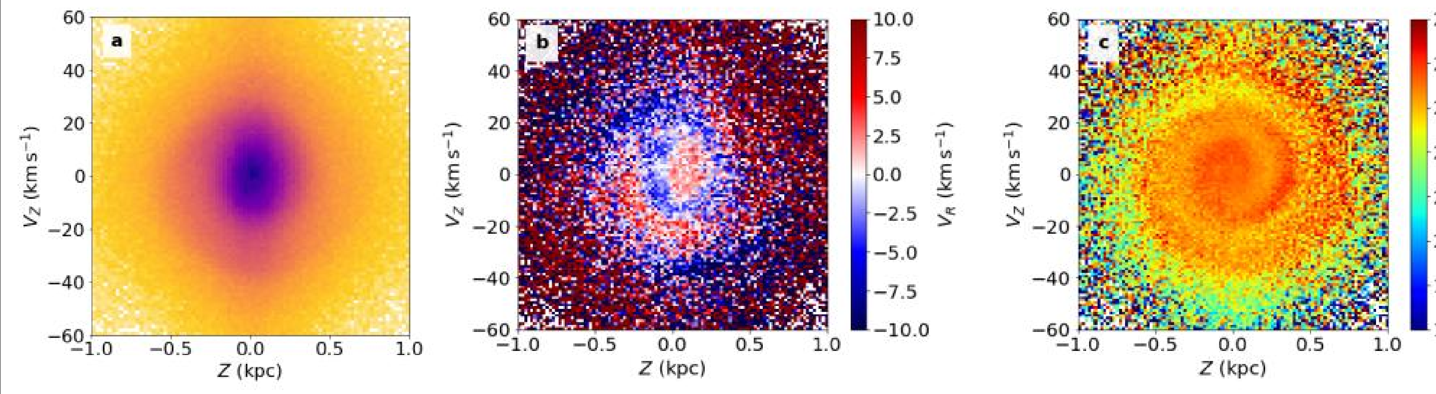
- The spiral pattern is prominent via ρ, $< v_R >$, $< v_\varphi >$ plot



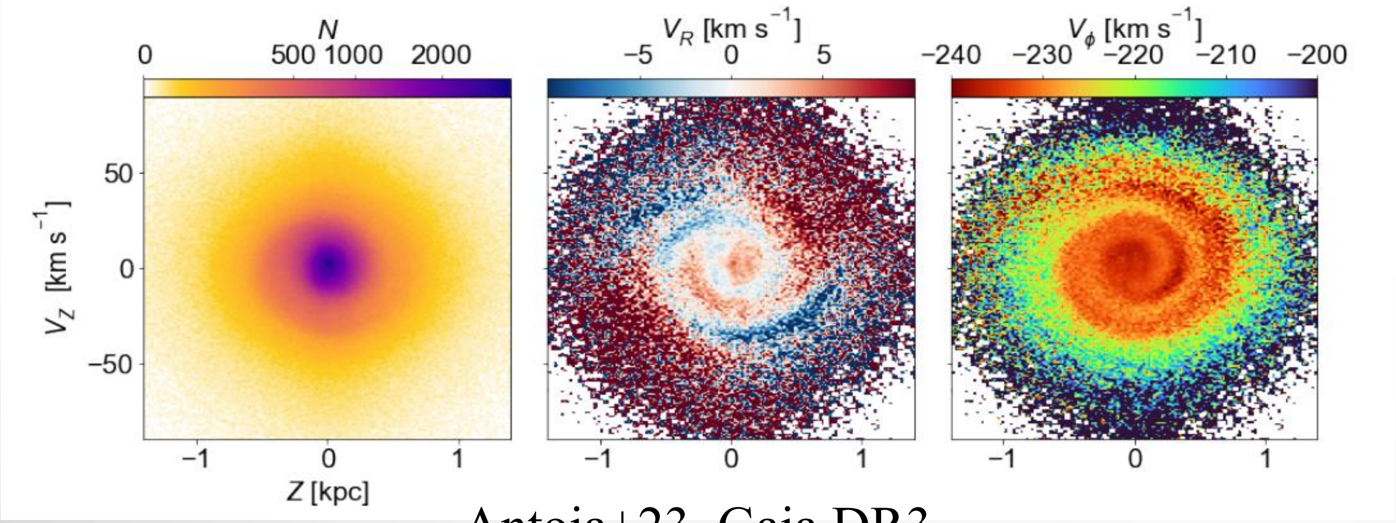
Widrow 2023

How the phase space spirals observed in the Milky Way

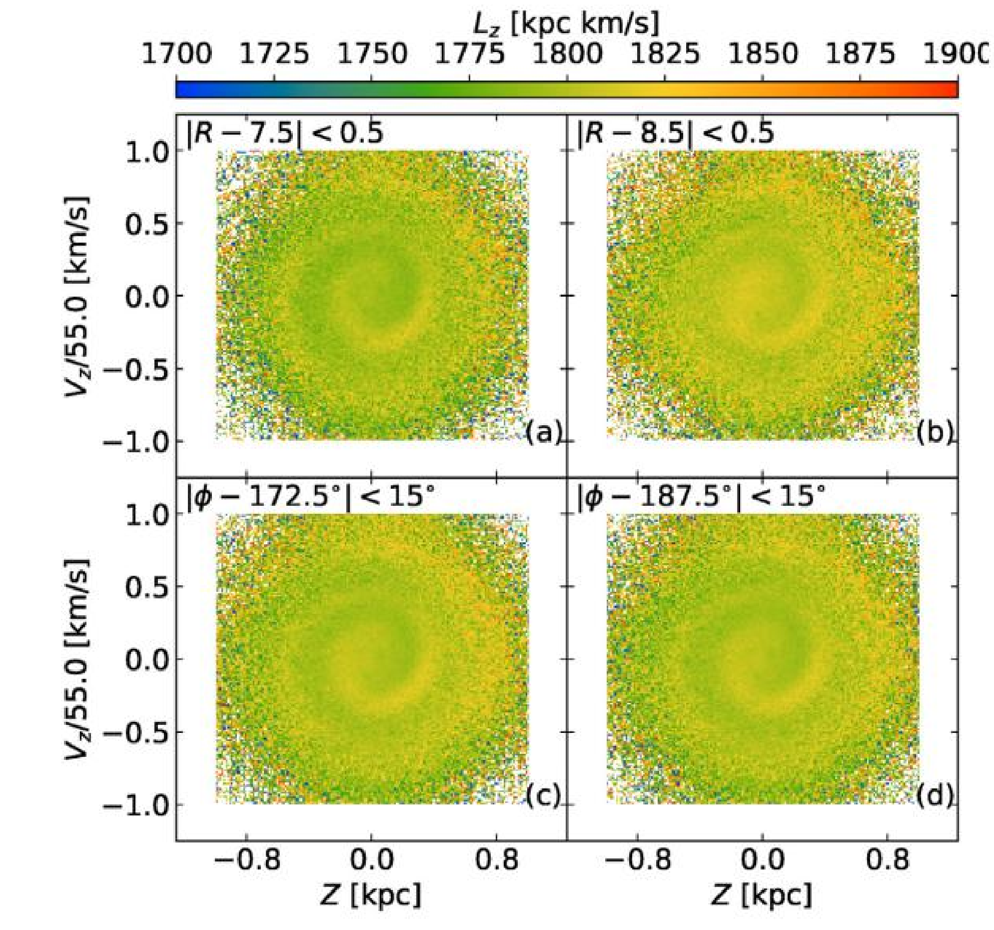
- Single armed phase spirals revealed by stars in solar vicinity



Antoja+18, Gaia DR2

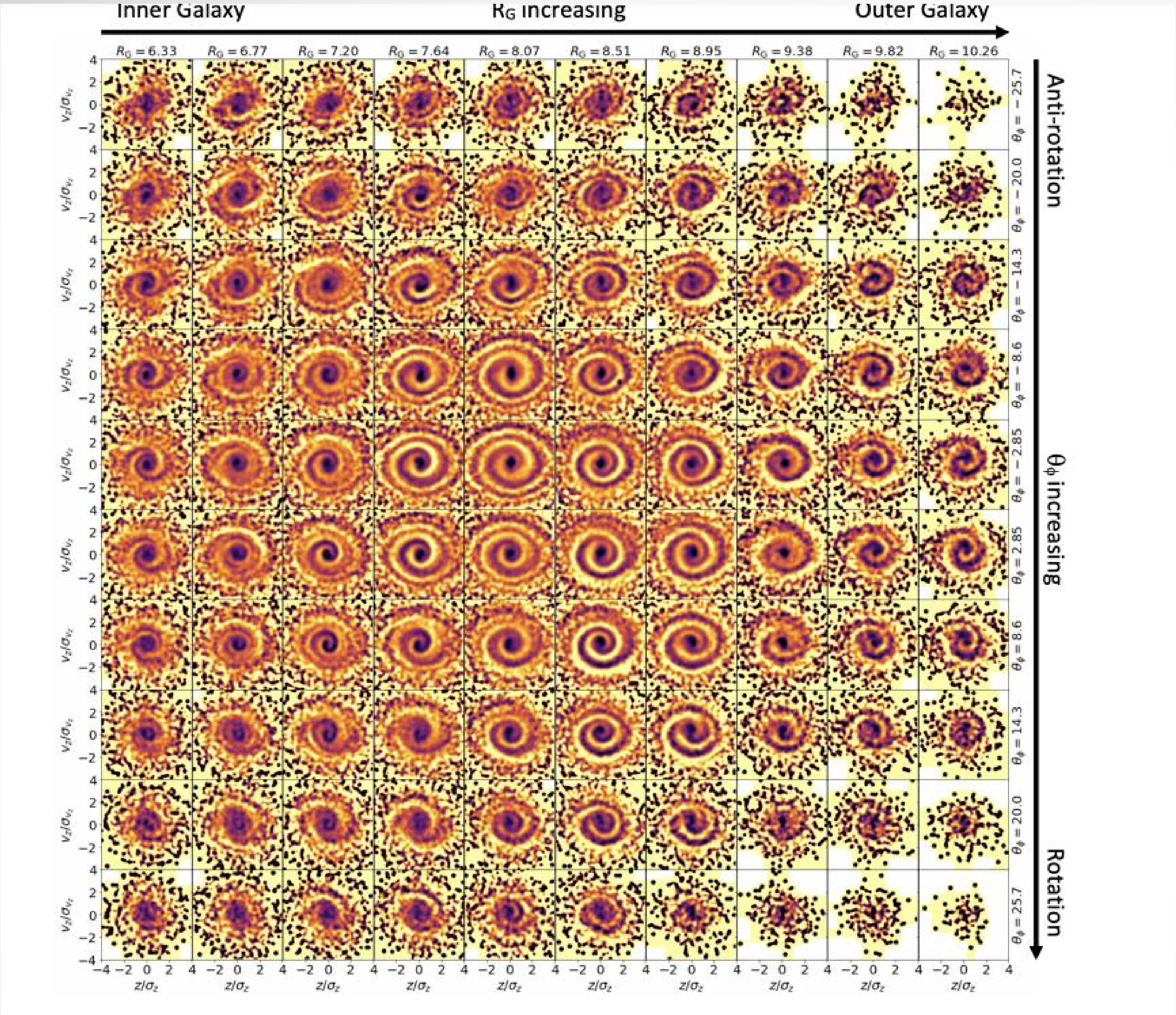


Antoja+23, Gaia DR3

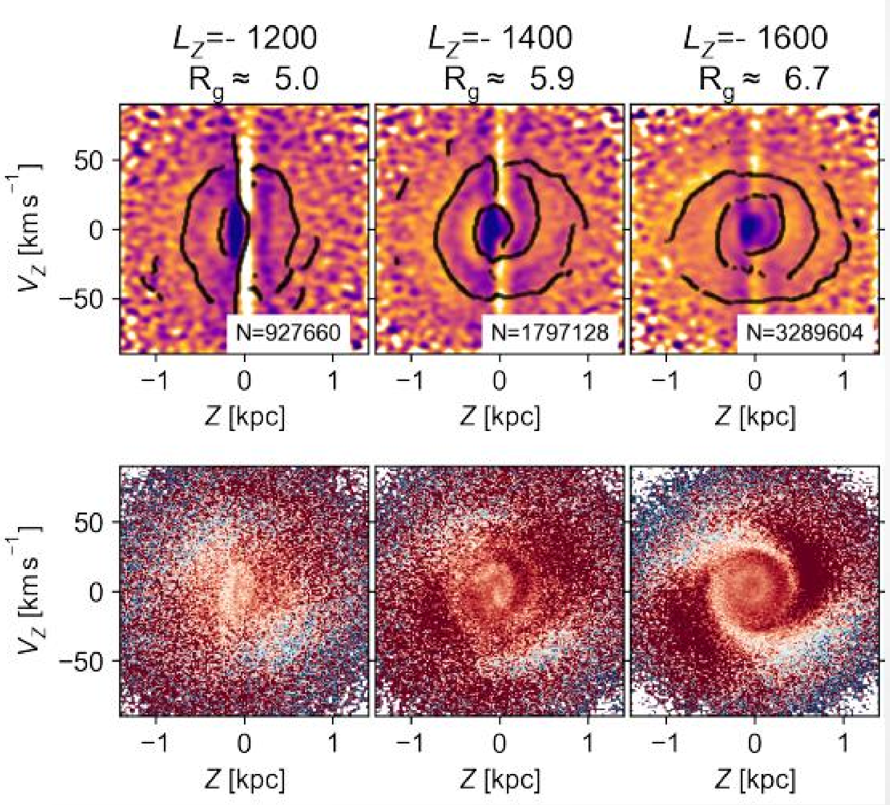


Khanna+19

Double armed phase spirals found by density and <v_R> contrast inside solar radius



Hunt+22



Antoja+23

Interpretations to the phase spiral

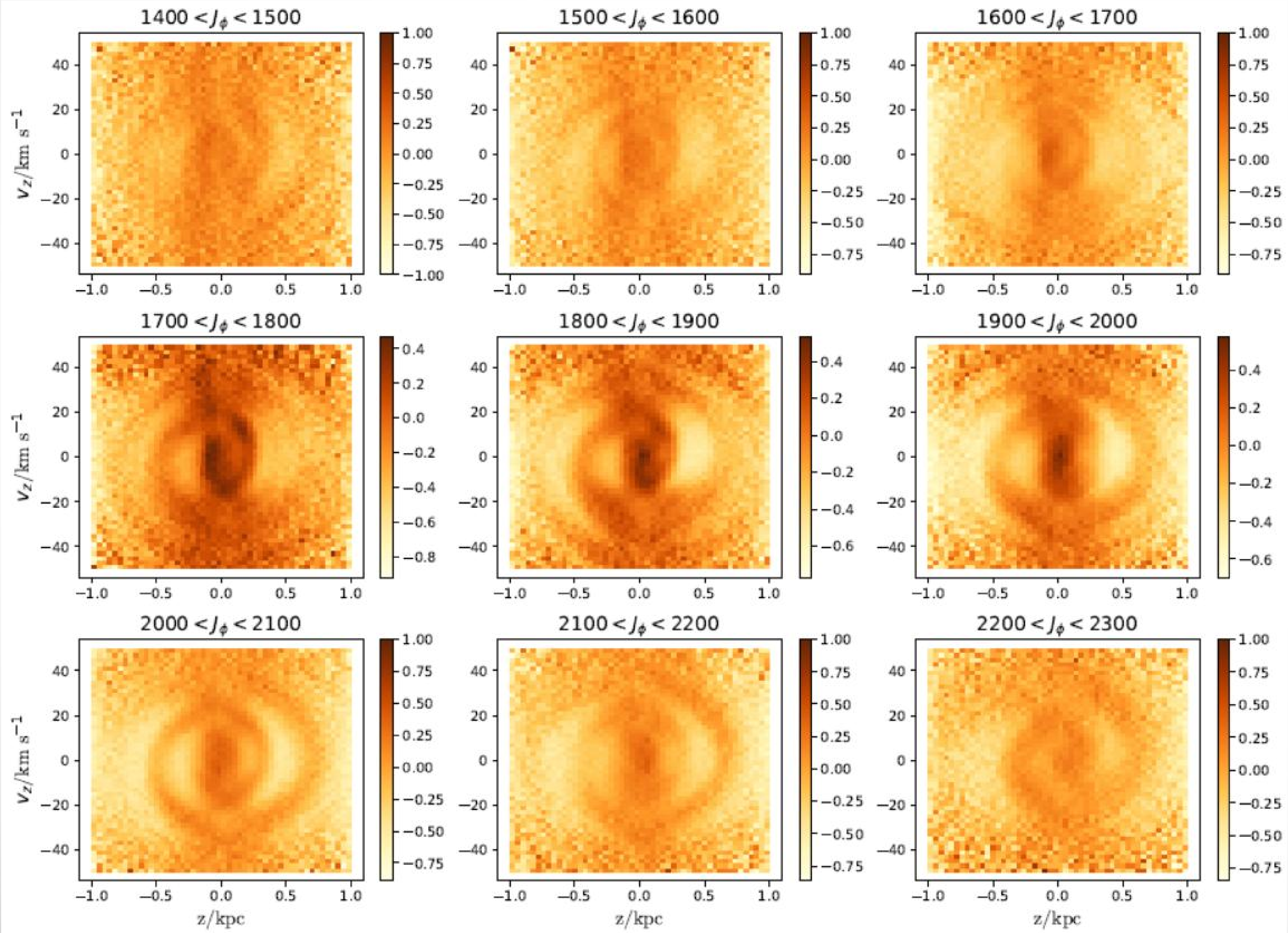
- One-amed spirals:

1. Passing satellite interaction with the disc (Binney+18, Laporte+19...)
2. Vertical oscillations driven by bar buckling (Khoperskov+19)
3. Wakes or substructures from dark matter halo (Grand+22, Tremaine+22)

- Two-armed spirals:

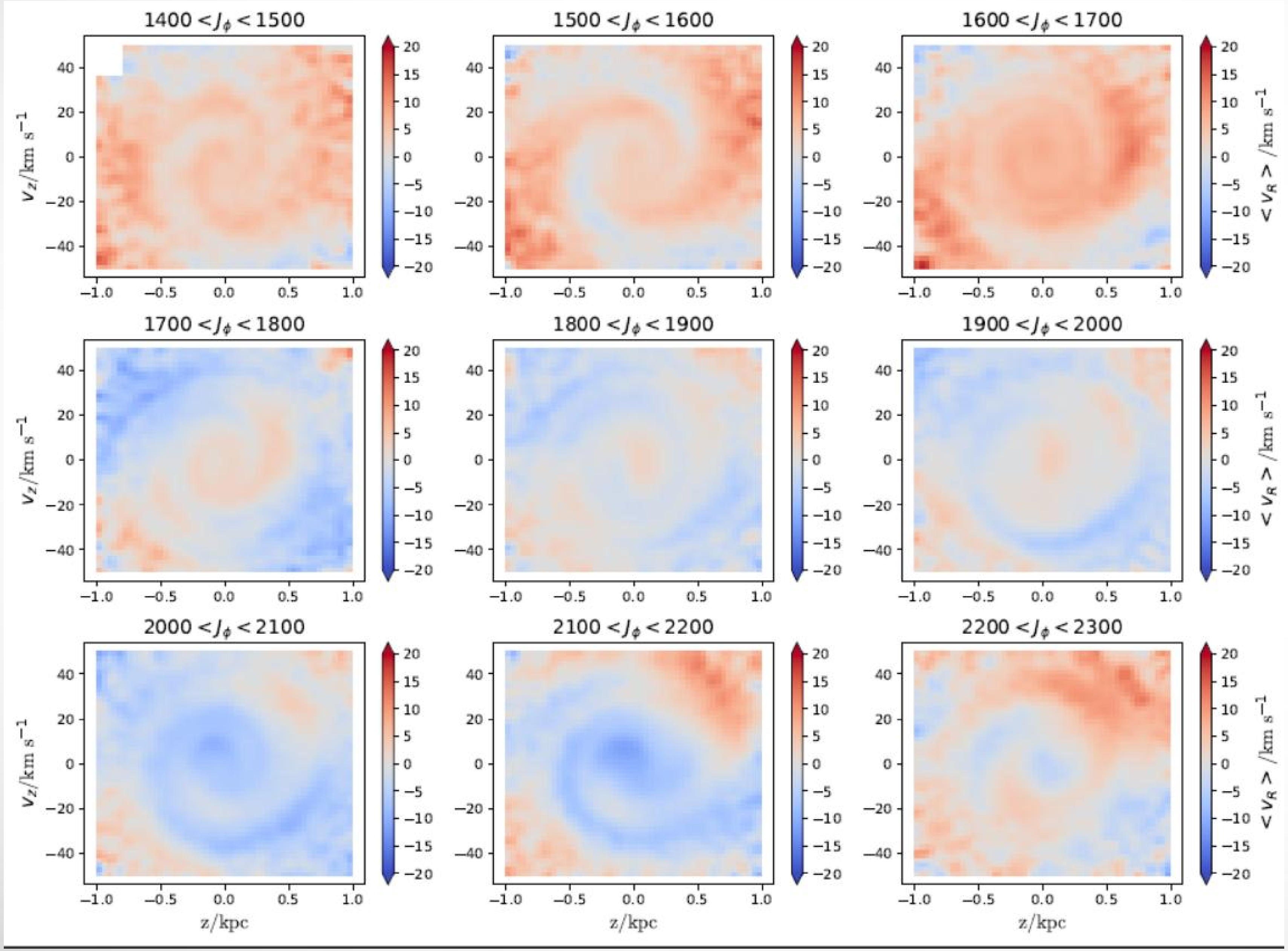
1. Possible merger events (Hunt+21)
2. Fast, impulsive perturbations symmetric about the mid-plane (Banik+22, Widrow23)

Observations from Gaia DR3



One-armed spiral pattern revealed by density contrast

Observations from Gaia DR3



- 2-armed spirals in the first panel
- A transition between 1&2 armed features in solar vicinity
- 1-armed feature in outer disc

Theoretical interpretations

Test particle simulation method

- Pseudo stars generated under initial conditions
- Orbital integration under joint potential of bar&spiral arm models
- Phase space features derived

Modelling frameworks

Axisymmetric DF based model (Binney&Vasiliev 2023)

In-plane perturbation models

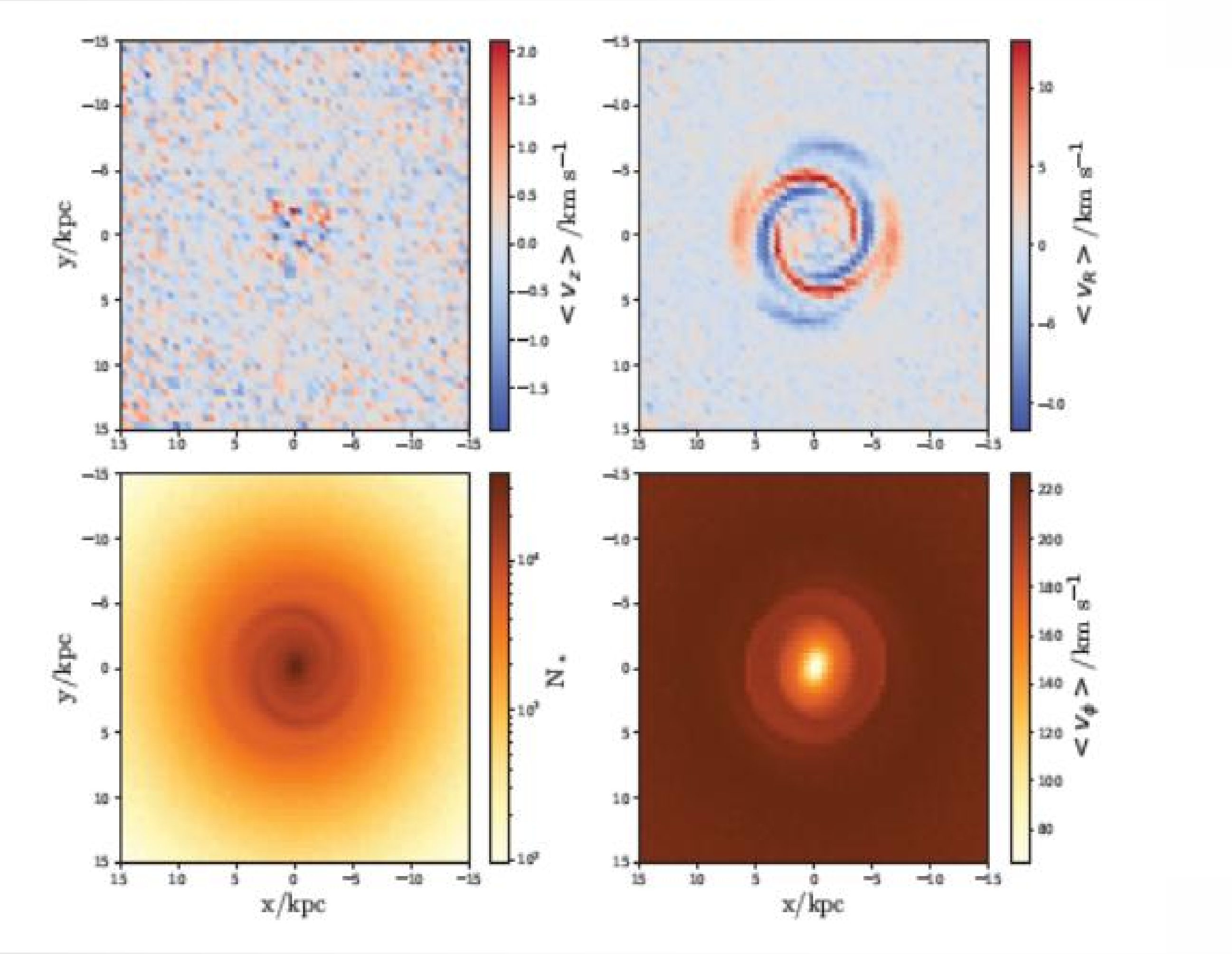
- bar model

1. Bar with constant pattern speed and radial profile (Chiba+21)
2. Bar with decreasing pattern speed and increasing mass (Sormani+22)

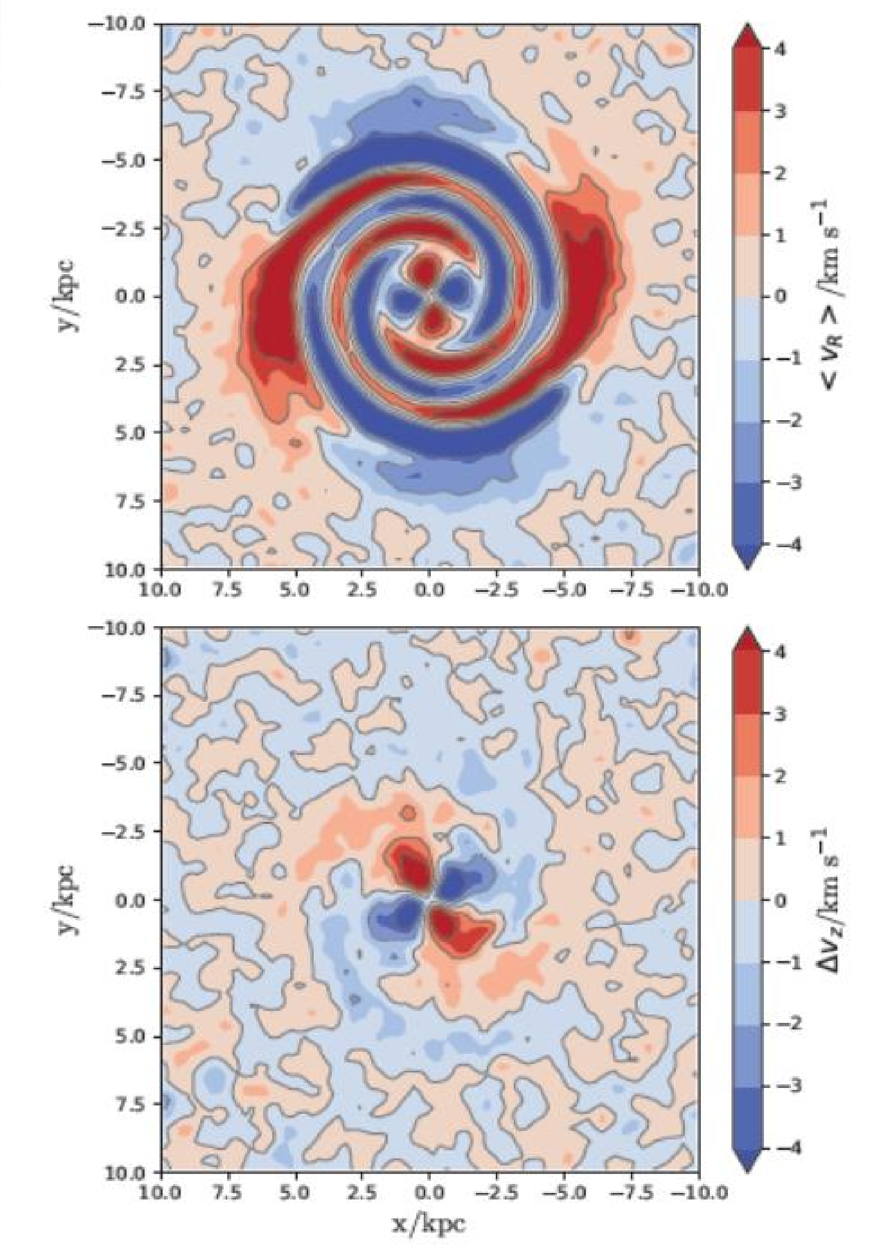
- spiral-arm model

2-armed spiral arm with constant pattern speed (Cox&Gomez 2002)

Constant bar model

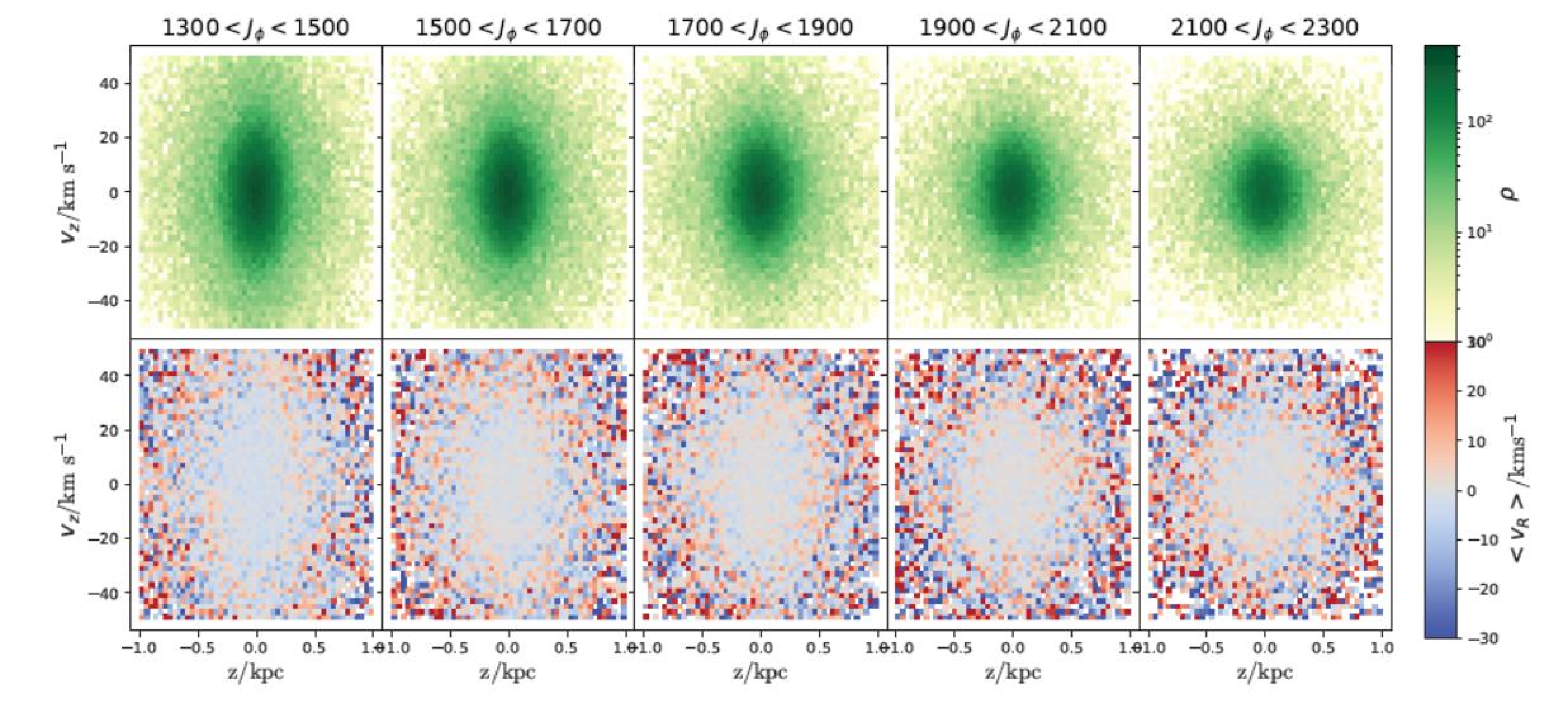


The distribution of the density ρ, $<v_R>$, $<v_\varphi>$, and $<v_z>$ in the x-y plane at T = 5.0 Gyr.



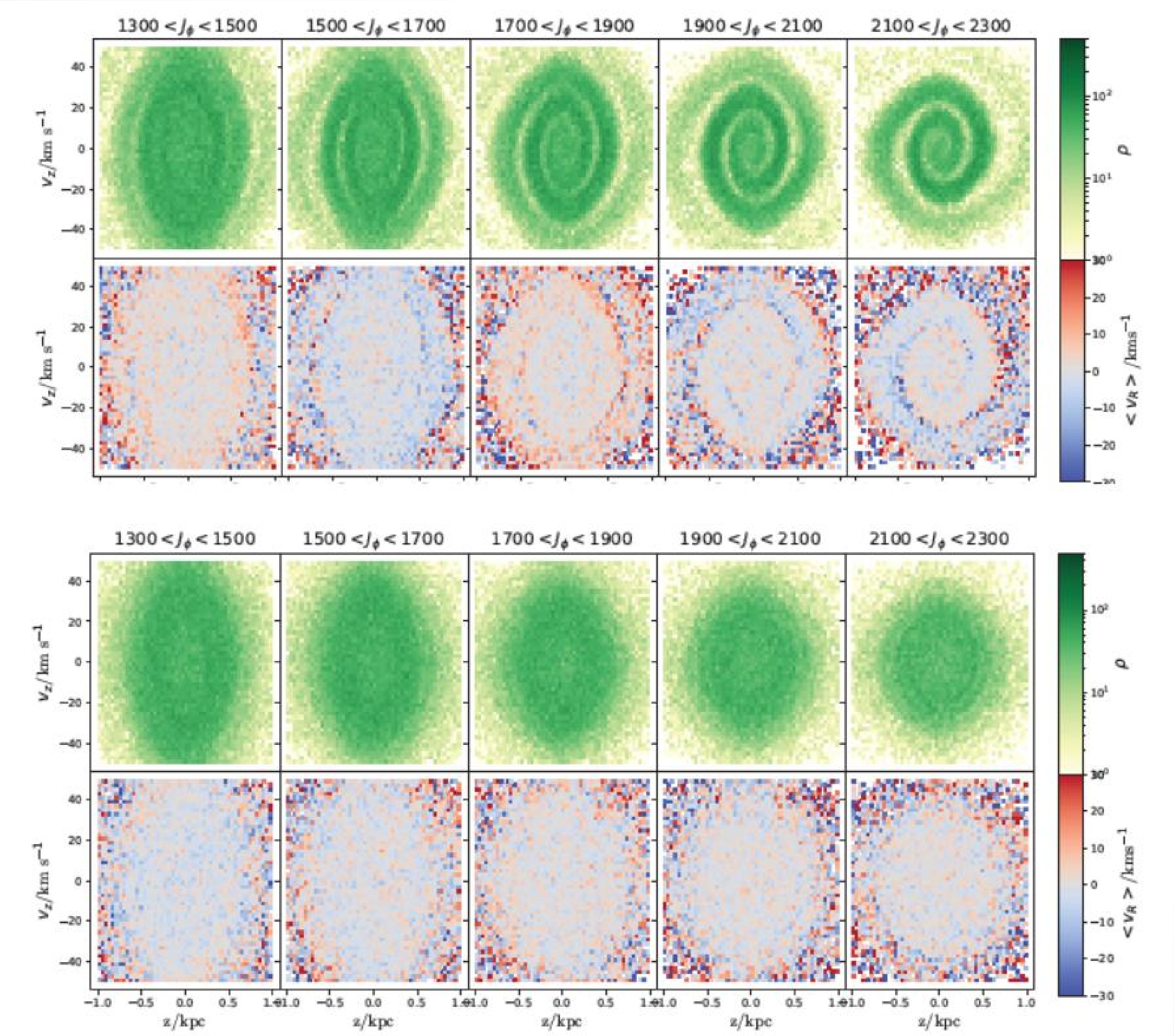
The face-on contour map of $<v_R>$ and Δv_z for the test particles at T = 2.0 Gyr

Constant bar model



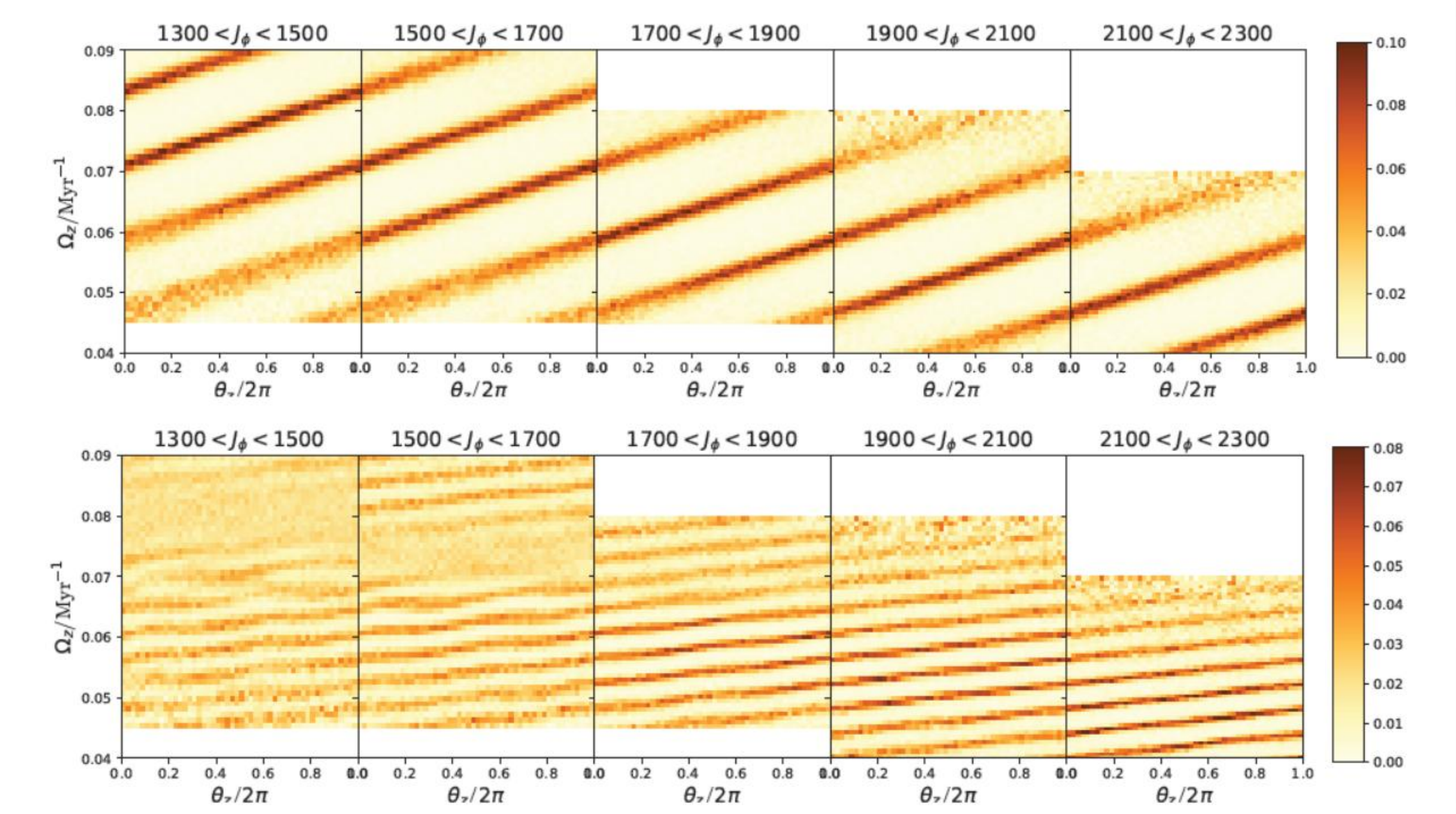
No spiral features seen throughout the simulation

Constant bar with external impulse



- An external intruder can cause 1-armed spirals in both $\langle v_R \rangle$ and ρ
- Spiral pattern eliminated inside-out
- With steady bar model, no new phase spirals appear

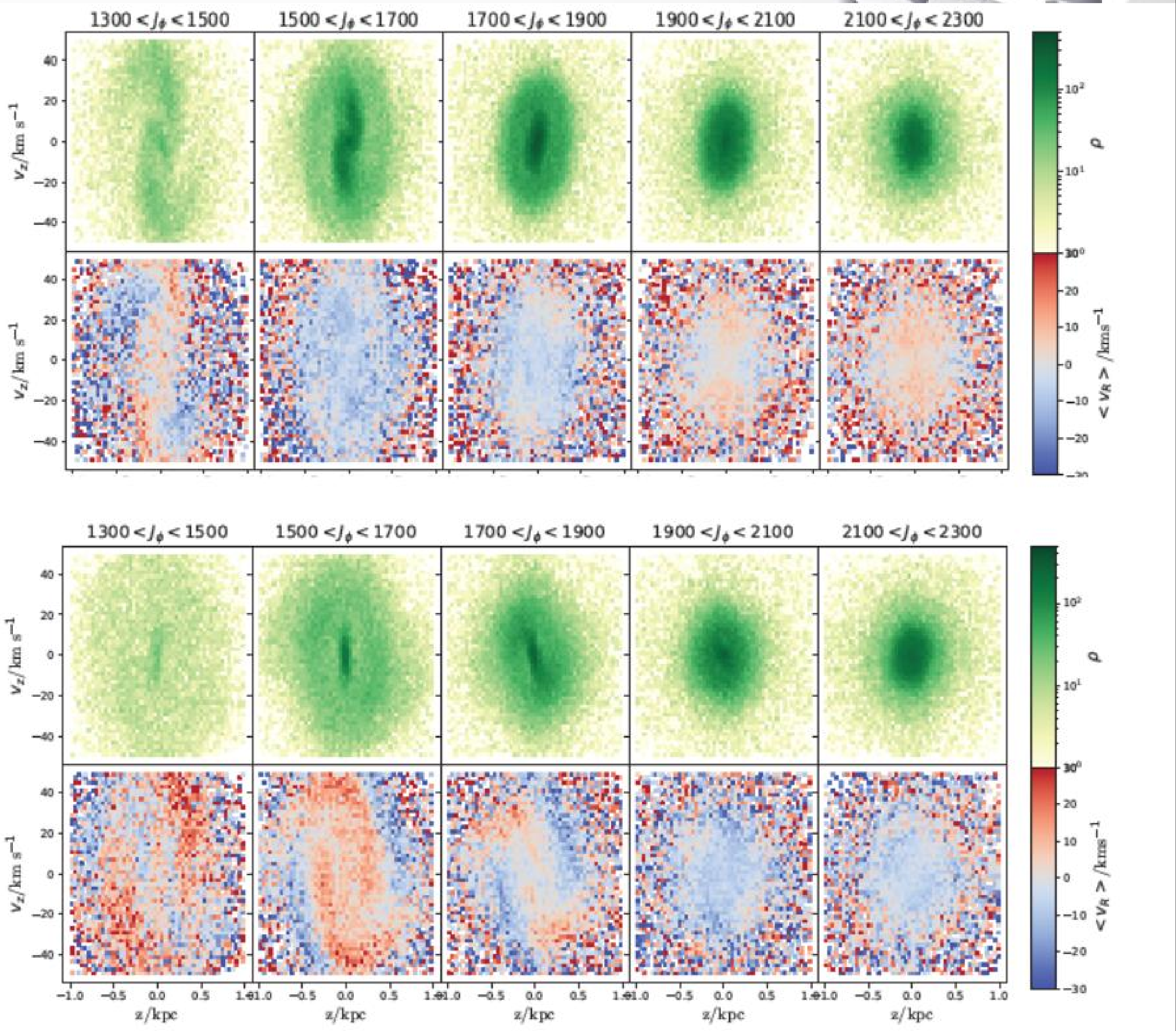
Constant bar with external impulse



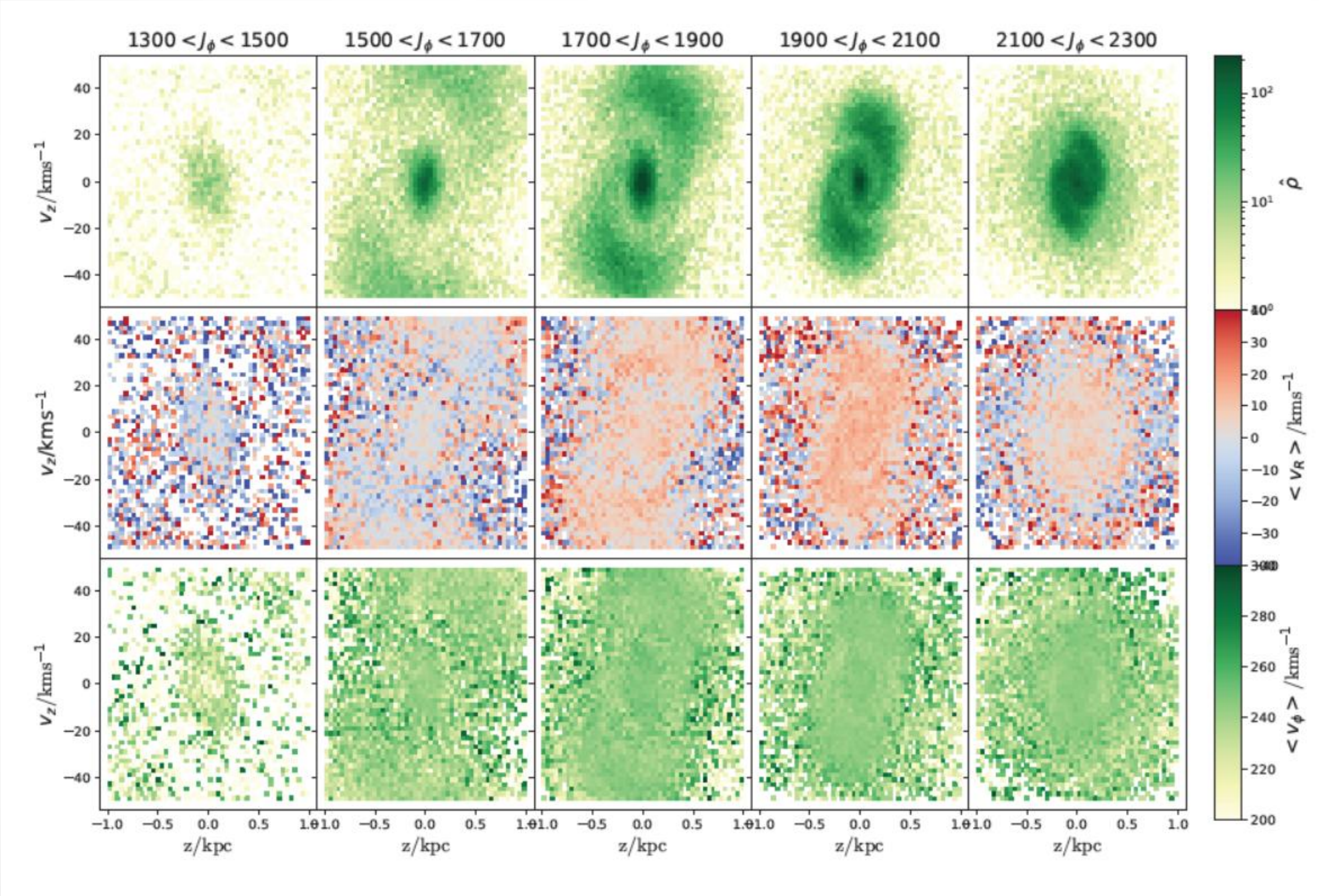
Clear stripes seen in $\theta_z - \Omega_z$ plane for T = 0.5 & 1.5 Gyr

Time-variation model

- 2-armed spiral features seen both colour-coded by density and radial velocity
- The spirals are not as tightly wound as what we observe in the Galaxy
- The spiral pattern lasts longer in $\langle v_R \rangle$ than in ρ



Time-variation model



- T = 5.5 Gyr for time-variation bar model
- 2-armed spirals in ρ can be seen in outer disc

Conclusions

- The phase space spirals are seen throughout the disc from Gaia DR3
- 1-armed spiral pattern locates at outer disc while 2-armed spiral pattern seen at inside solar radius
- 1-armed spiral pattern can be triggered via single impulsive external event
- 2-armed spiral pattern possibly created by the interaction between the disc and decreasing bar