Radial Wave in the Galactic Disk: New Clues to discriminate different Perturbations

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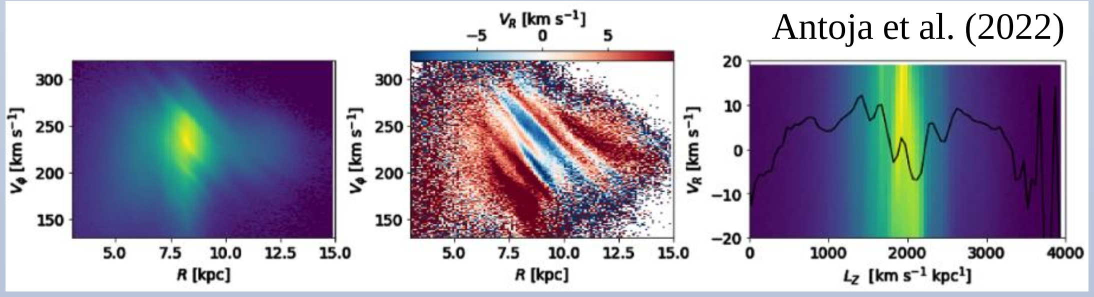
Introduction

Decoding the key dynamical processes that shape the Galactic disk structure is crucial for reconstructing the Milky Way's evolution history. The second Gaia data release uncovers a new wave pattern in the $L_Z - < V_R >$ **space** accompanied by a richness of phase space substructures, signifying the Galactic disk in dynamical disequilibrium. However, its formation mechanism remains elusive due to the complexity of involved perturbations and the challenges in disentangling their effects.

Key Questions

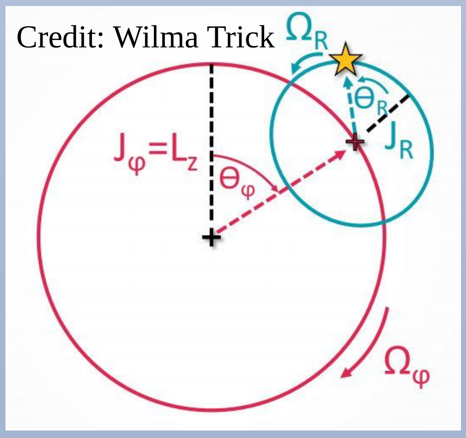
- What are the dominant perturbers / mechanisms?
- How to discriminate different perturbations?
  Possible clues in: How does disk response vary with dynamical hotness?

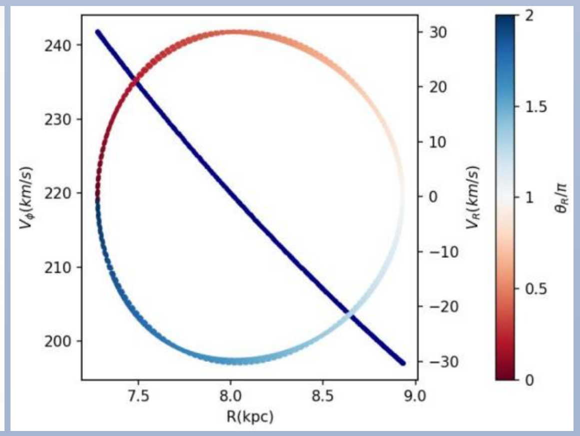
2D diagonal ridges (color-coded in $< V_R >$) binned in L_Z → 1D wave



Disk orbit dynamics

Radial oscillation around guiding center (determined by $L_Z = R \times V_\phi$) : inverse function in $R - V_\phi$, closed ellipse in $R - V_R$, vertical line in $\Omega_R - \theta_R (= \Omega_R \times T)$





Methods

- Conduct **controlled experiment**: **$2.5 \times 10^{10} M_\odot$ satellite galaxy** , **steadily rotating bar ($\Omega_b = 40$ km/s/kpc)** and **transient spiral** each serve as the sole perturber in test particle simulations
- Calculate **phase shift amplitude ΔL_Z** (difference in extrema location of $L_Z - < V_R >$ wave pattern) between stars of different orbit hotness
- Compare with **observation data**: Gaia DR3 x StarHorse distance(Anders et al. 2022) divided into dynamically "cold" ($J_Z < 3$ km*kpc/s) and "hot" ($J_Z > 12$ km*kpc/s) populations

Reference

Antoja, T., Nature, vol. 561, no. 7723, pp. 360–362, 2018. doi:10.1038/s41586-018-0510-7

Friske, J. K. S. and Schönrich, R.,MNRAS, vol. 490, no. 4, pp. 5414–5423, 2019. doi:10.1093/mnras/stz2951

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Results

Data: ΔL_Z increases with decreasing L_Z when $L_Z > 2000$ km*kpc/s, stays approximately constant at a small value in the lower L_Z range

Transient spiral: No systematic ΔL_Z variation with L_Z, negligible in amplitude

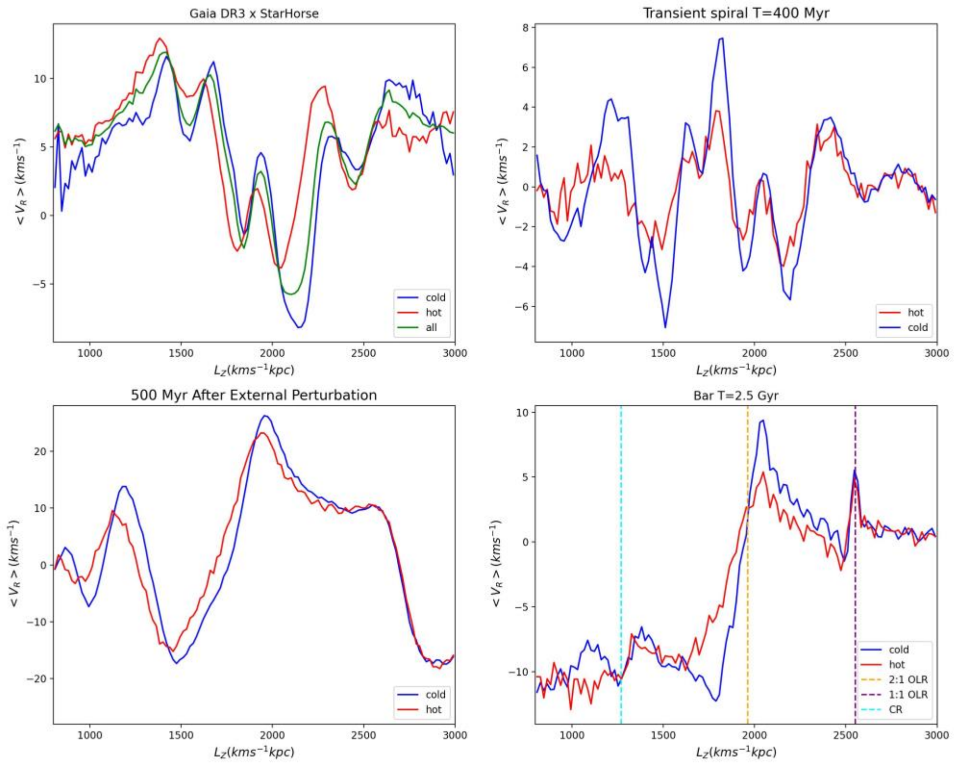
Bar (at Lindblad Resonance): Phase alignment at higher L_Z extrema, larger ΔL_Z at lower L_Z extrema; or negligible ΔL_Z

External perturbation:

ΔL_Z increases with decreasing L_Z

ΔL_Z amplitude displays little variation with time

Interpretation in terms of toy model



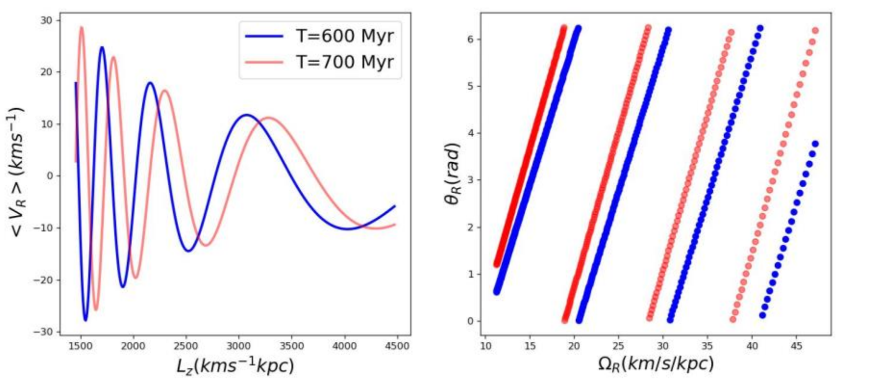
Toy Model

Radial phase mixing after **external perturbations**:

Parallel diagonal line series in frequency-angle space ($\Omega_R - \theta_R$ plane) translates into corrugation in $L_Z - < V_R >$ space

Difference in phase mixing rate ($\Omega_R - \theta_R$ slope)→ Phase shift in $L_Z - < V_R >$ space

Time evolution: $\Delta\theta_R$ accumulation and narrower characteristic wavelength cancels out → nearly constant ΔL_Z



Conclusion

- Systematic increase of phase shift amplitude with decreasing L_Z is unique signature of **external perturbation**; **steadily rotating bar** produces a different phase shift pattern at Lindblad resonances, **transient spiral** generates no systematic trends
- Influence of external perturber is stronger in the outer disc, but single impact scenario is insufficient to explain the whole phase shift pattern of $L_Z - < V_R >$ wave
- **Investigating the dependence of disk response on orbit hotness could help uncover the nature of associated perturbations**