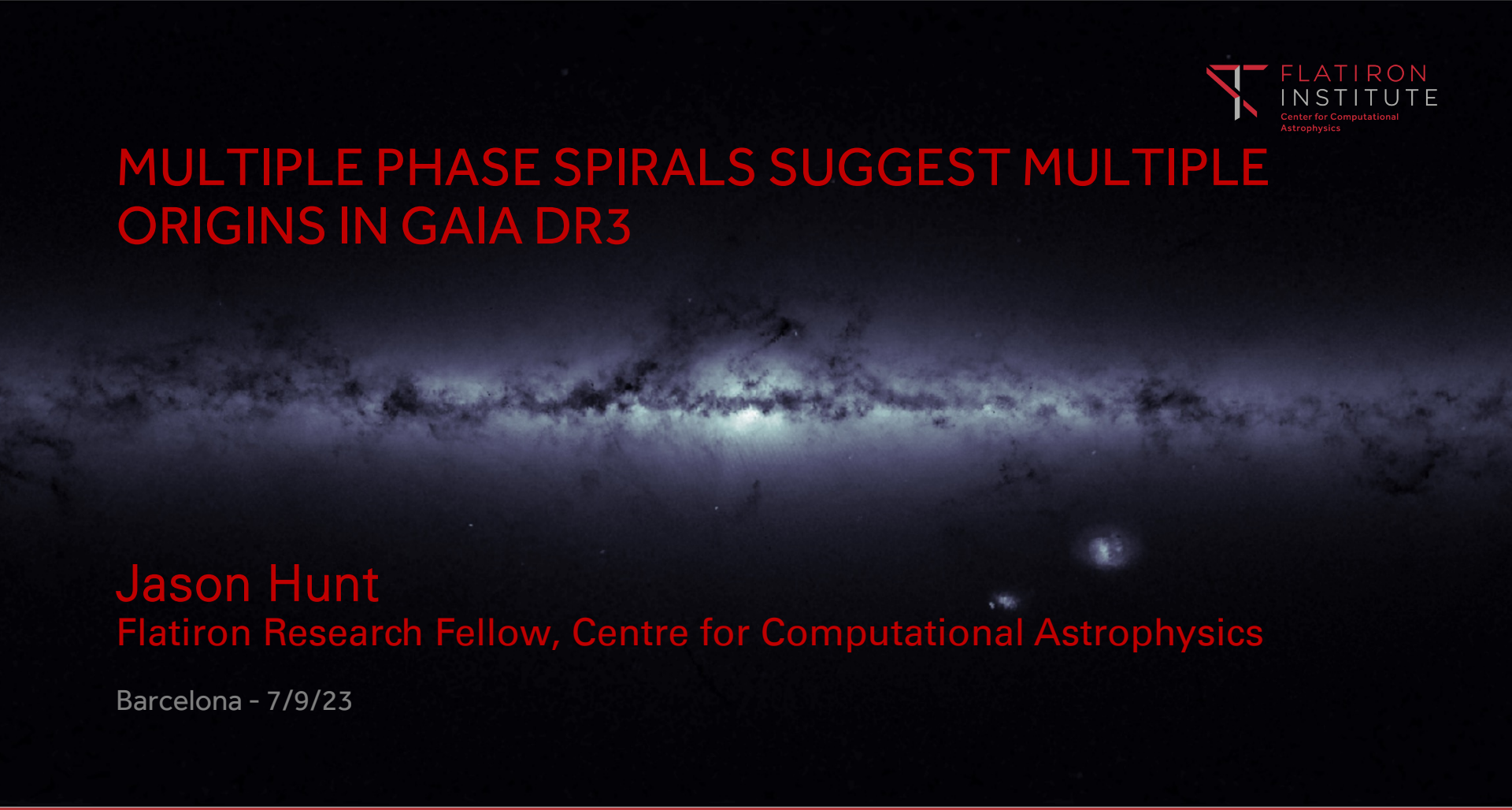

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MULTIPLE PHASE SPIRALS SUGGEST MULTIPLE ORIGINS IN GAIA DR3

Jason Hunt

Flatiron Research Fellow, Centre for Computational Astrophysics

Barcelona - 7/9/23

Striking spiral patterns in z-v_z

- Phase spiral, or snail shaped features in vertical position vs. motion suggest ongoing vertical phase mixing.

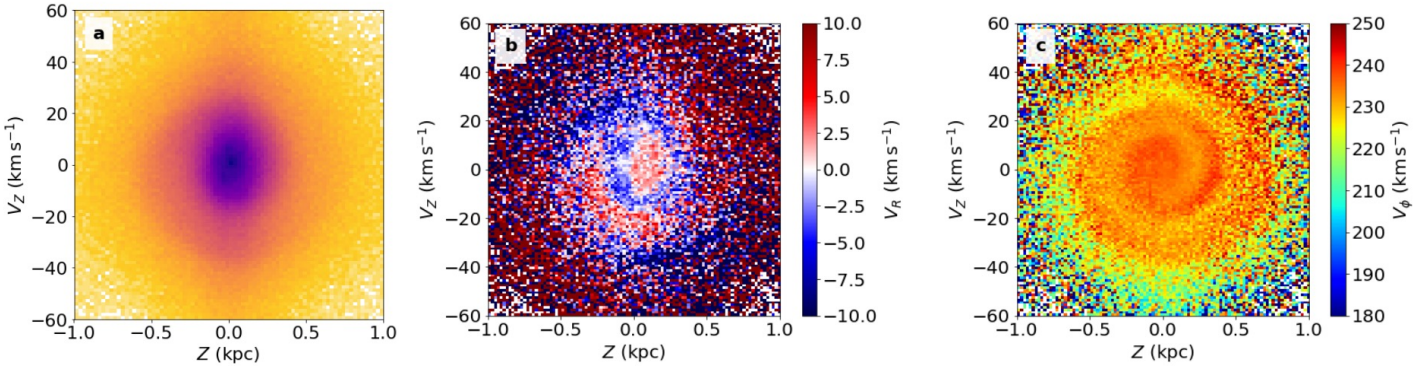
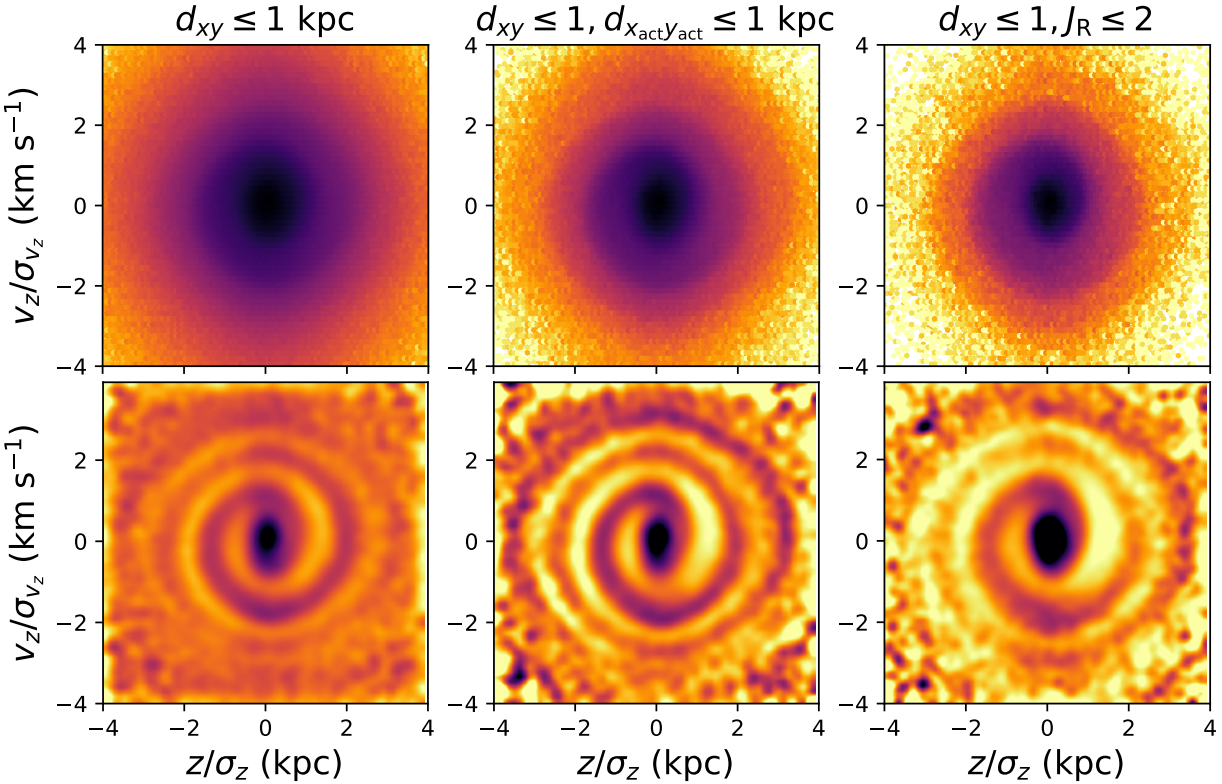


Figure 2. Distribution of stars in the vertical position-velocity plane Z-V_Z for stars selected as in Fig. 1. a) Two-dimensional histogram in bins of $\Delta Z = 0.01$ kpc and $\Delta V_Z = 0.1\,\mathrm{km\,s^{-1}}$; b) Z-V_Z plane coloured as a function of median V_R in bins of $\Delta Z = 0.02$ kpc and $\Delta V_Z = 1\,\mathrm{km\,s^{-1}}$; c) Same as b) but for V_ϕ.

Antoja et al., 2018, Nature, 561, 360

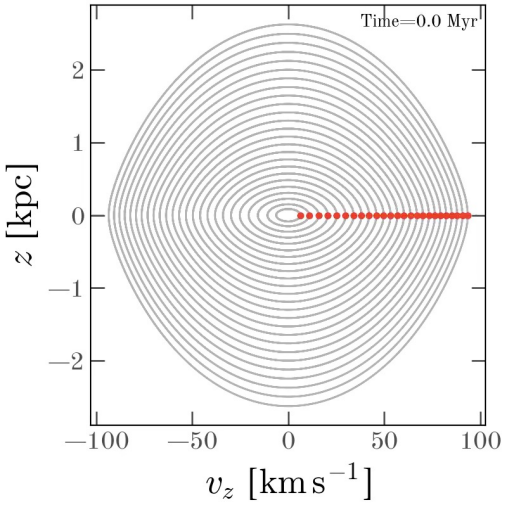
Updated for Gaia DR3

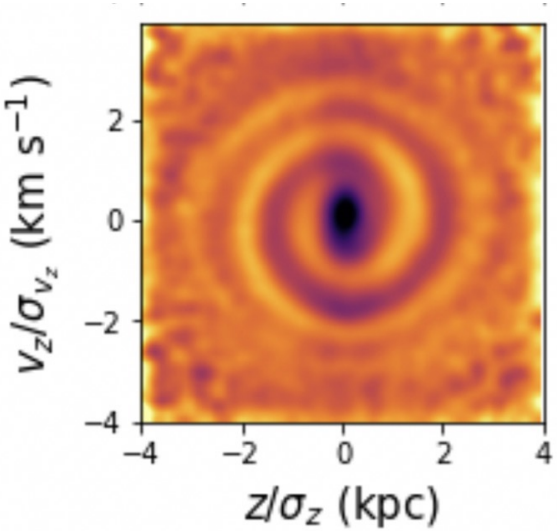


Hunt et al. 2022, MNRAS, 516, 7

How/why do such spirals form?

(Price-Whelan et al.)





Higher vertical action -> Lower vertical frequency

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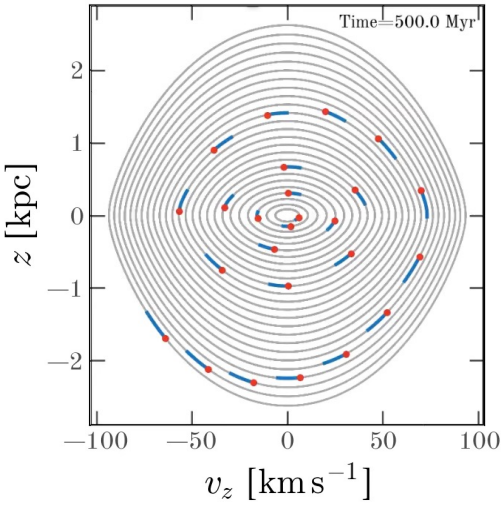
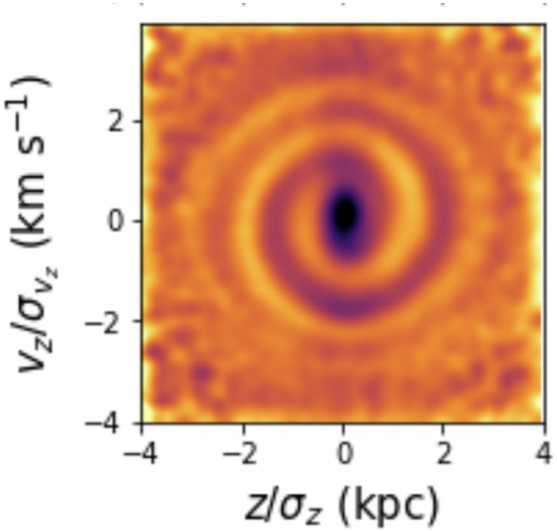
How/why do such spirals form?

(Price-Whelan et al.)





Higher vertical action -> Lower vertical frequency

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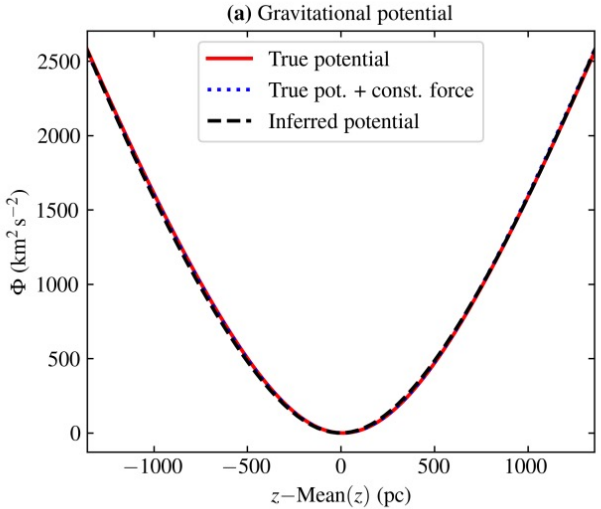
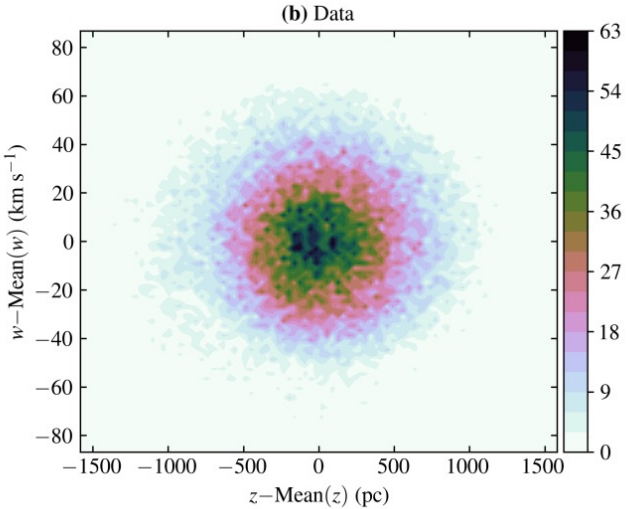
These spirals contain information about our Galaxy

- The spiral can be used to infer information about the potential

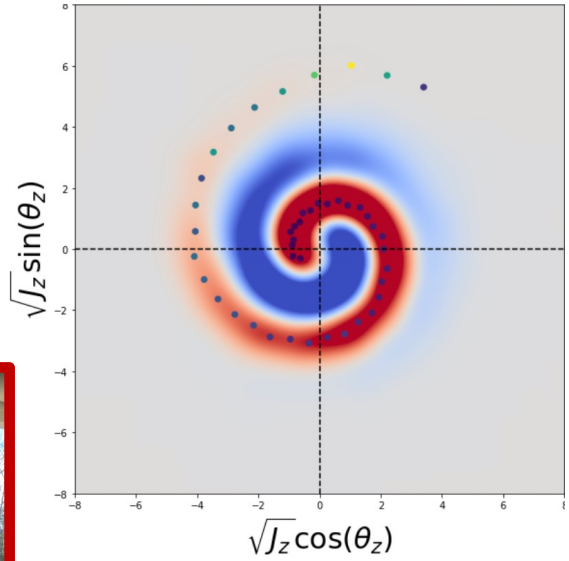


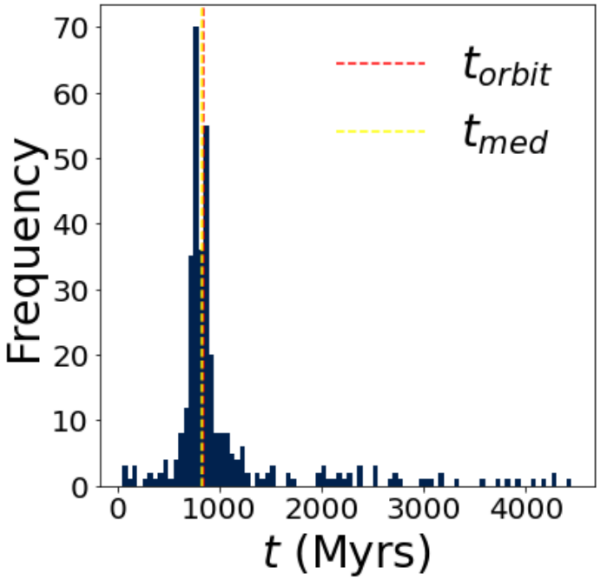


Widmark, Hunt et al. (2022b), + Widmark et al. (2021a,b, 2022a)

These spirals contain information about our Galaxy

- If we know the potential, we can unwind the spiral (in theory)





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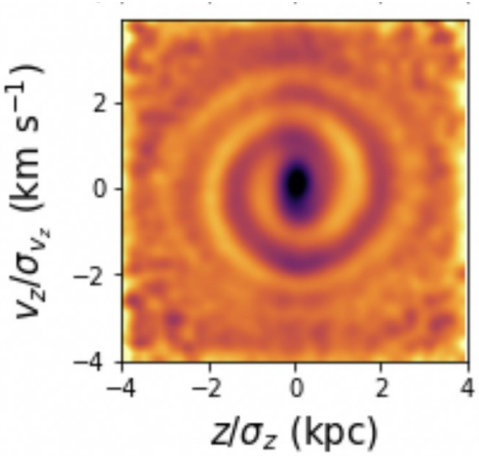
Darragh-Ford, Hunt, Price-Whelan & Johnston (2023)

In practice, it’s not quite this simple

- Self gravity of the disc (e.g. Widrow 2023)
- Older structure / previous interactions
- GMC’s causing diffusion & erasing spirals (Tremaine+ 2022)
- Multiple perturbations? (Hunt+ 2022)
- Superposition of spirals (Li+ 2021, Hunt+ 2021, Gandhi+ 2022)

A given volume contains many spirals!

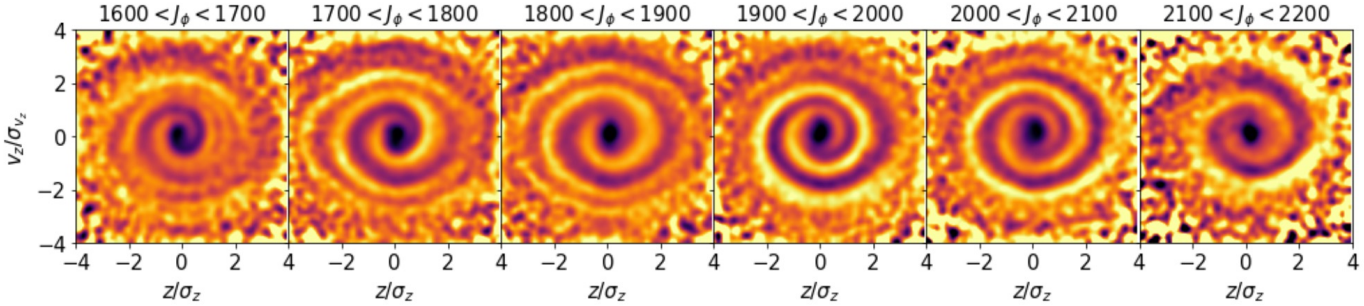
- Gaia DR3 data within 1 kpc -->
- Stars on many different orbits
- Split by angular momentum



Hunt et al. (2022)

From further in

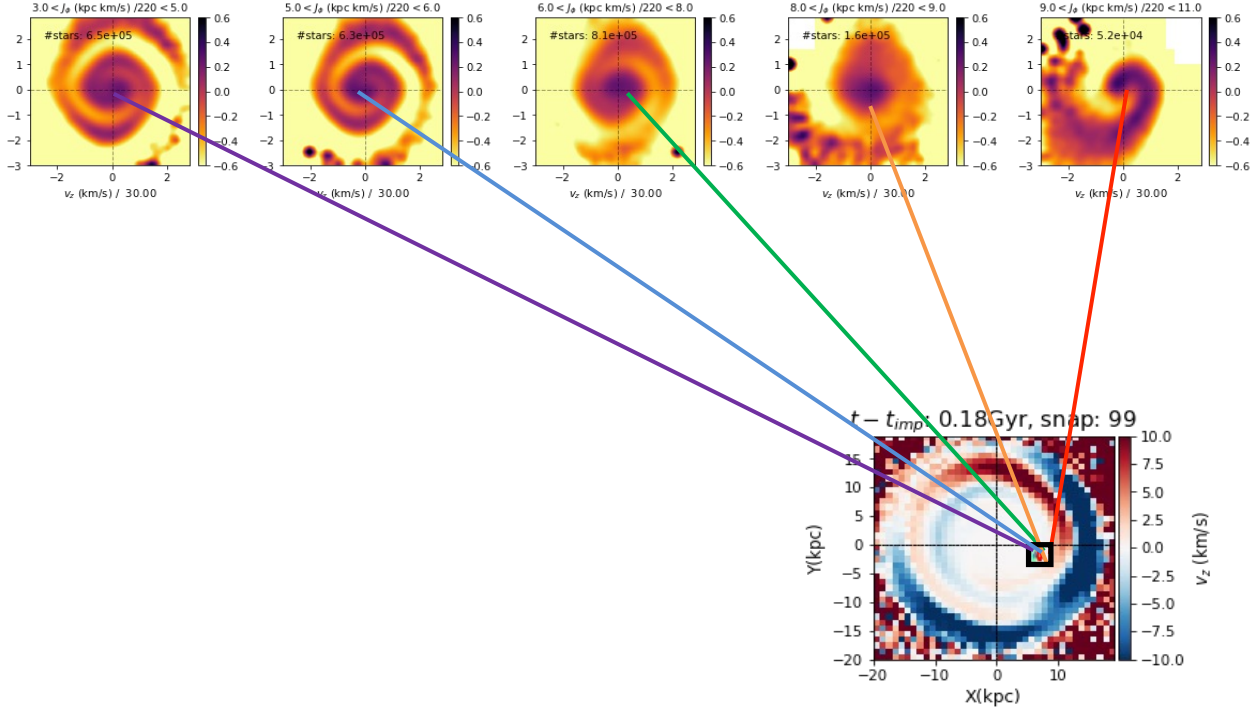
From further out



See also Li (2021) and Gandhi, Johnston, Hunt et al. (2022)

They probe other regions of the disc

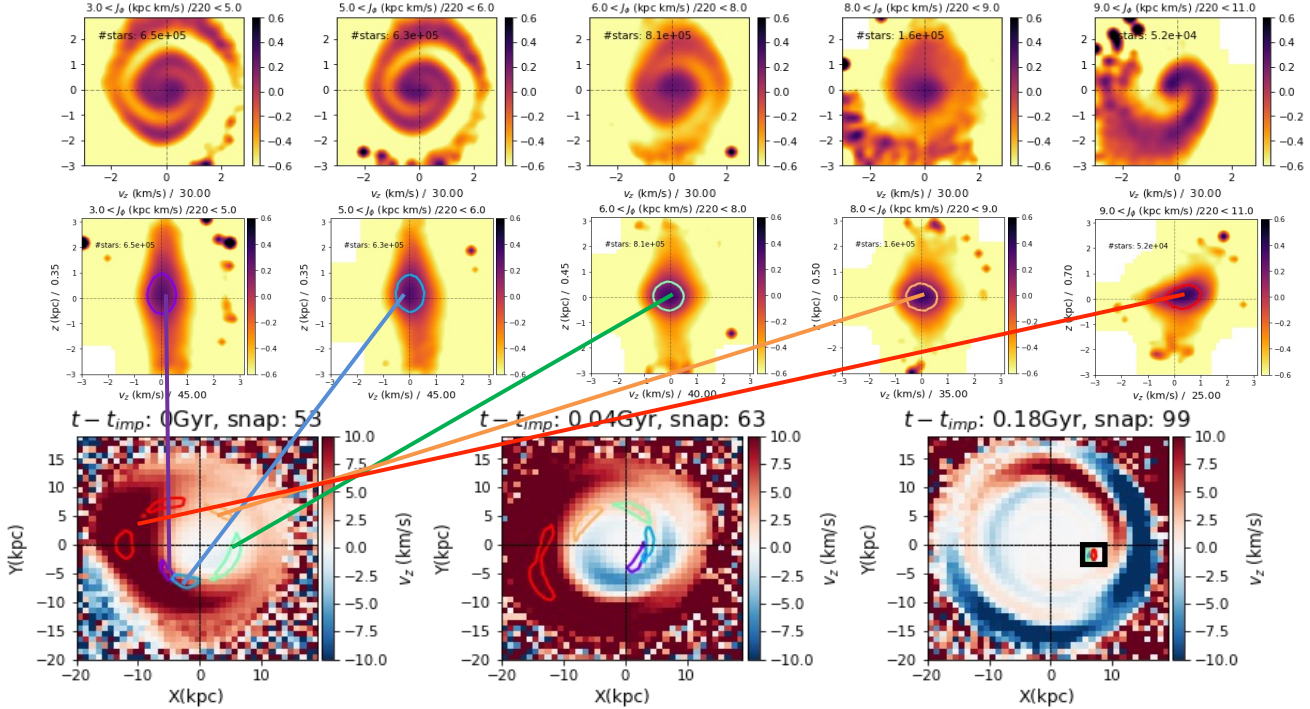
- High resolution test particle model from Gandhi et al. (2021)
- Split by angular momentum, different morphology and strength



Gandhi, Jonhston, Hunt et al. (2021)

They probe other regions of the disc

- High resolution test particle model from Gandhi et al. (2021)
- Stars near the Sun today were spread across the disc at the time of impact

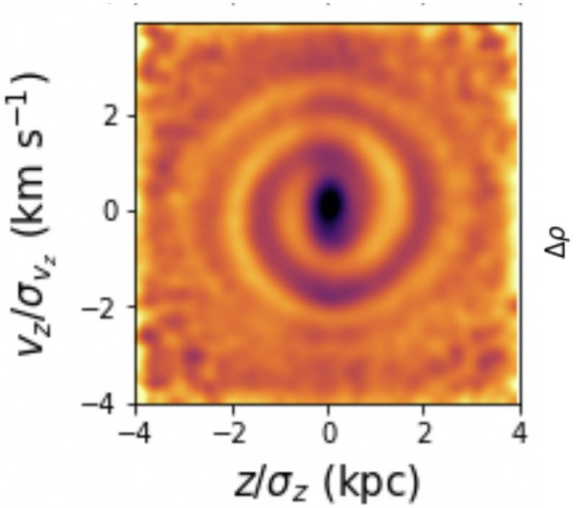


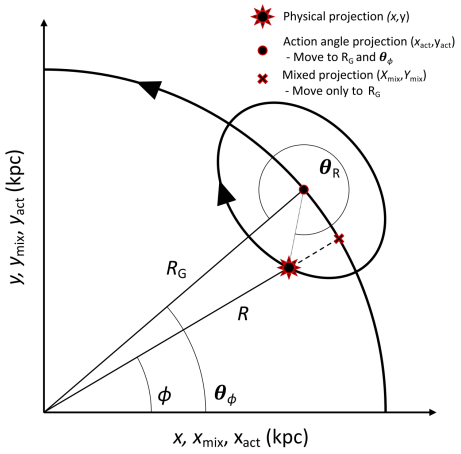
Gandhi, Jonhston, Hunt et al. (2021)

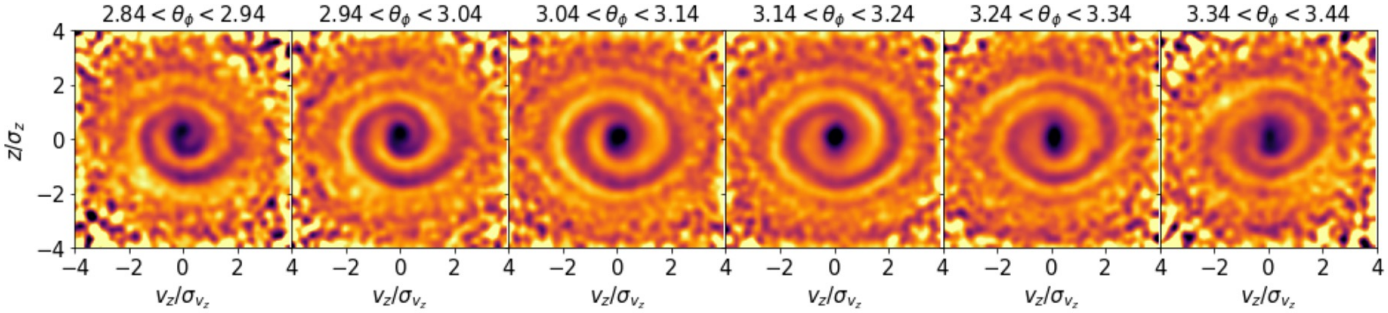
Suroor Gandhi; Graduate student at Columbia

A given volume contains many spirals!

- Gaia data within 2 kpc from the Sun ->
- It contains stars on many different orbits
- Split by $\boldsymbol{\theta}_\phi$ ->

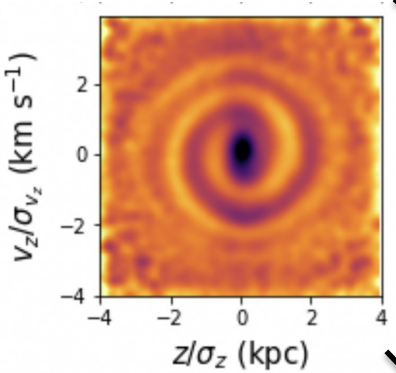


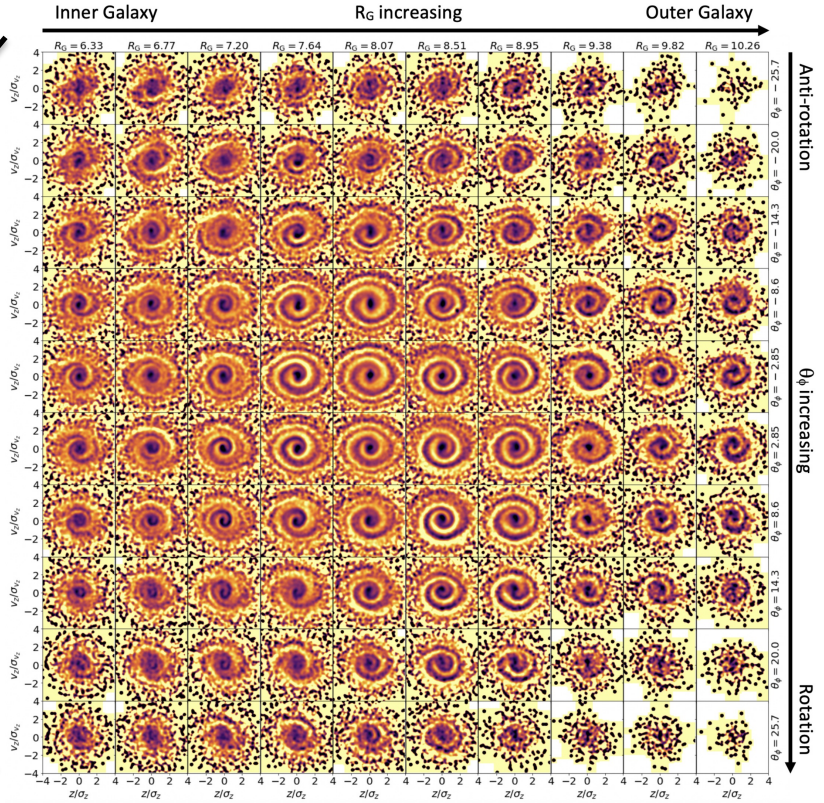




So if we split up the data in L_z and $\boldsymbol{\theta}_\phi$

Local selection





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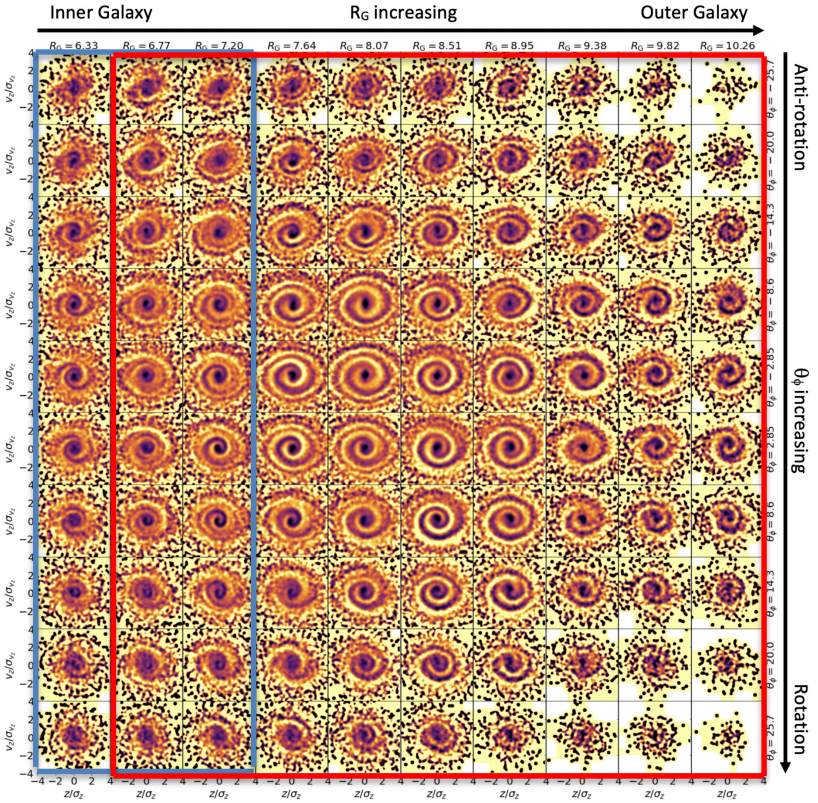
Hunt et al. (2022, MNRAS, 516, 7)

The spirals in the inner disc are 2-armed

(In the inner disc…)



Breathing mode
(inner galaxy)

(E.g. Williams et al. 2013, Carrillo et al. 2018)

Bending mode
(Solar neighborhood & outer Galaxy)

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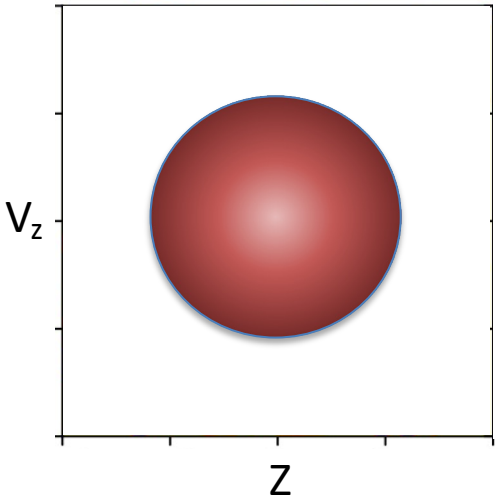
Hunt et al. (2022, MNRAS, 516, 7)

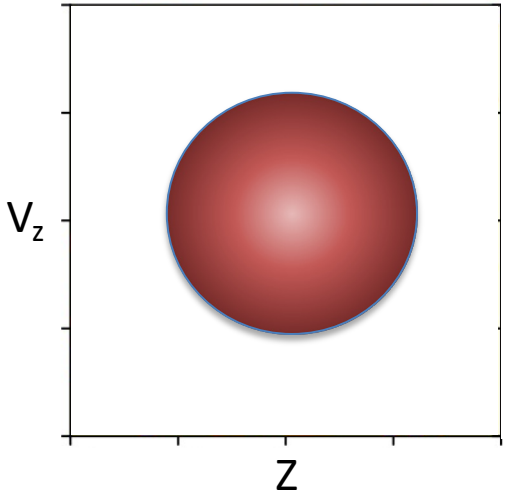
Bending vs. Breathing

Pre-interaction, everything nice and symmetric

Breathing mode



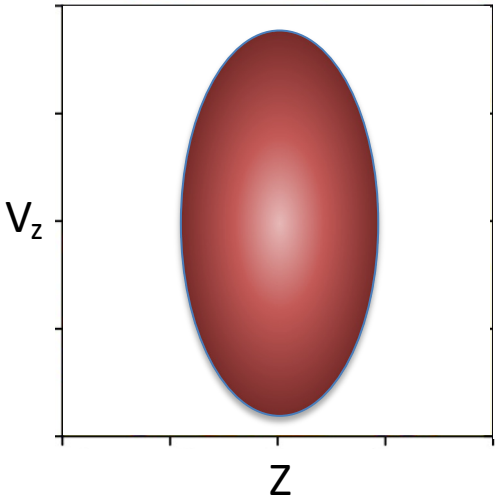
Bending mode



Bending vs. Breathing

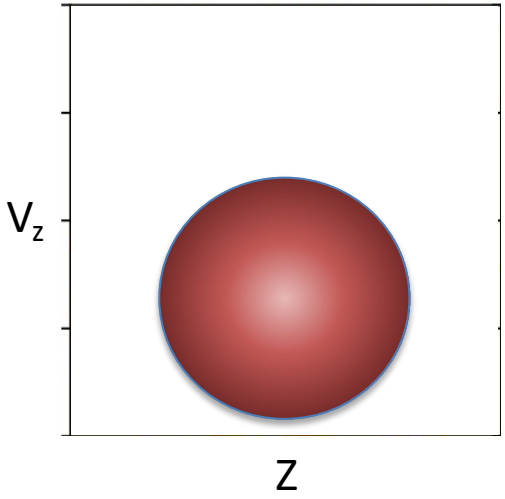
Immediately post-interaction

Breathing mode



Dynamically fast interaction

Bending mode



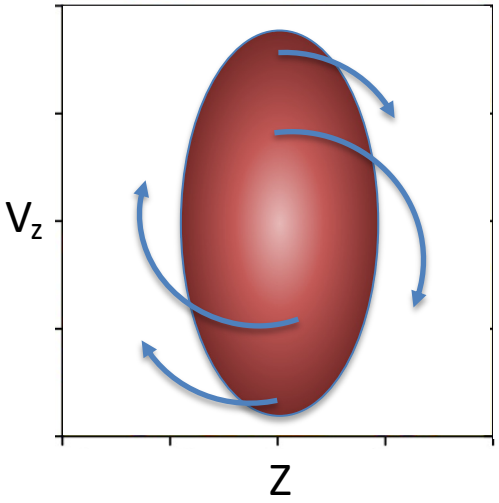
Extended interaction

Explained very nicely in Widrow et al. (2014)

Bending vs. Breathing

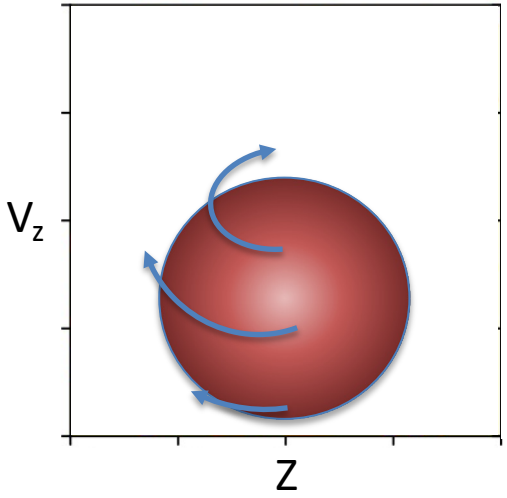
Immediately post-interaction

Breathing mode



Dynamically fast interaction

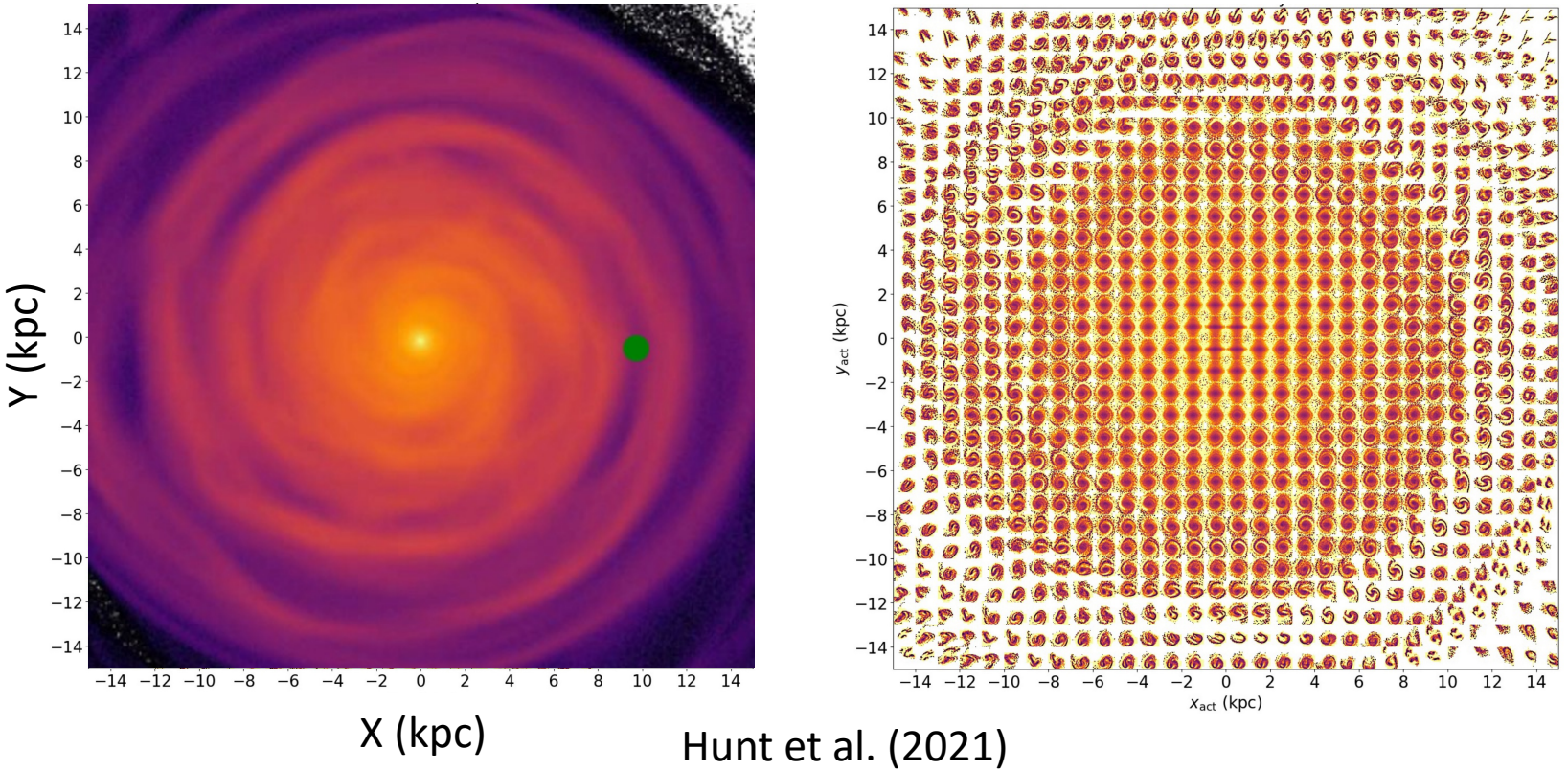
Bending mode



Extended interaction

Explained very nicely in Widrow et al. (2014)

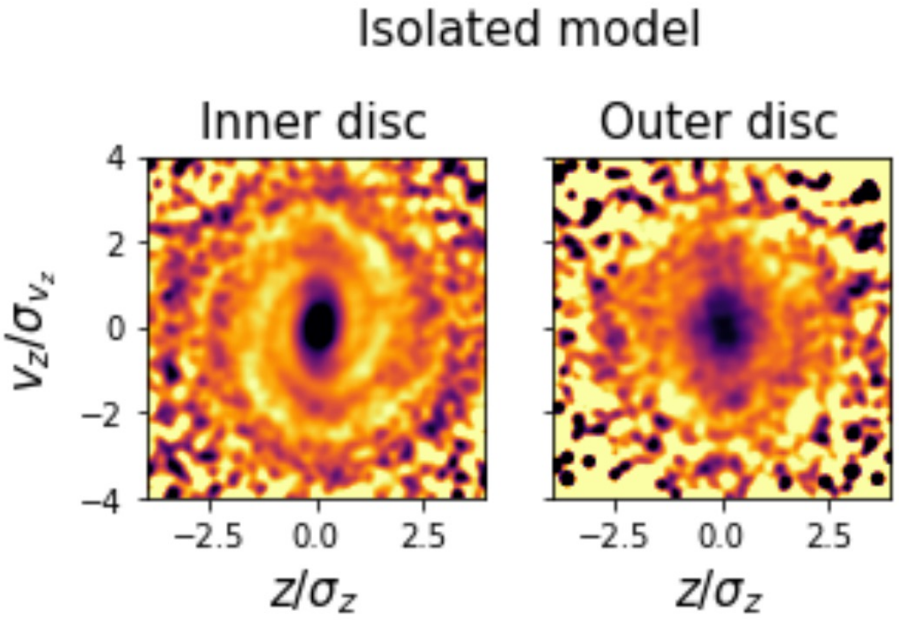
Simulations of satellite mergers make phase spirals



Hunt et al. (2021)

See also many other groups; Antoja, Laporte, Bland-Hawthorn, Li, Grand and more…

(Some) Isolated models make 2-armed spirals



- Barred spiral N-body model which generates a breathing mode in the inner disc
- (The bar does not buckle)
- They grow and decay periodically

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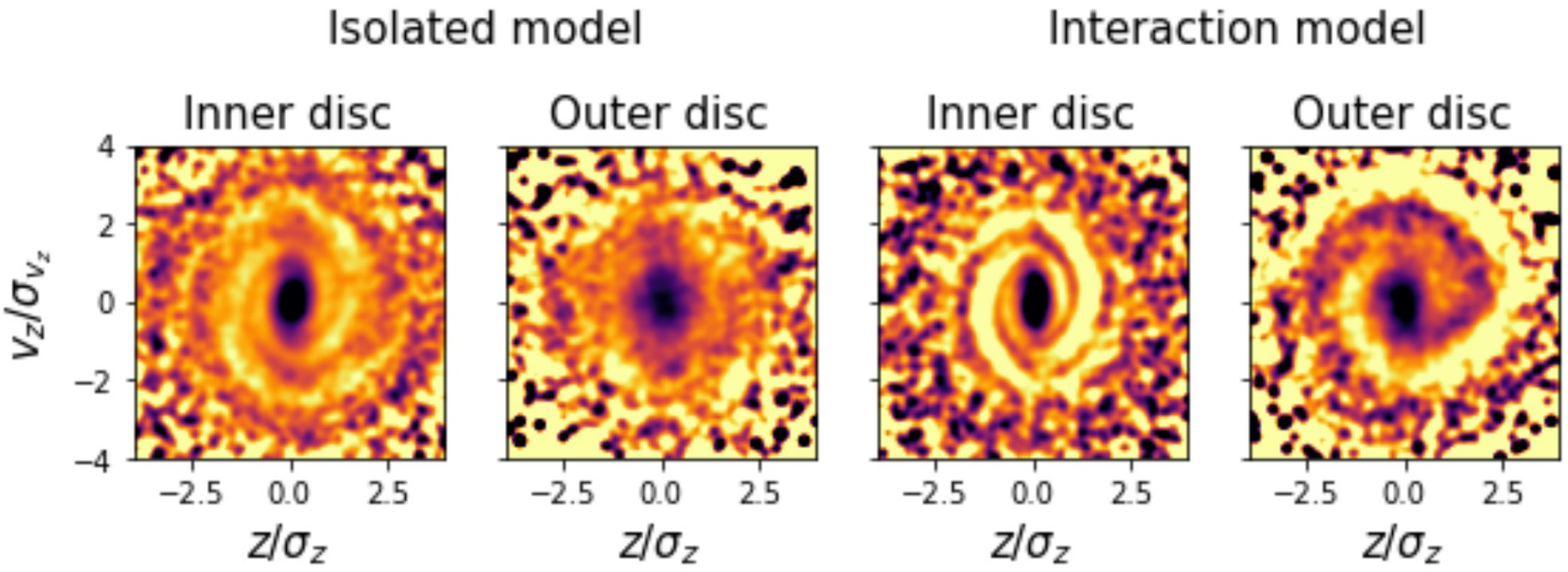
Hunt et al. (2022, MNRAS, 516, 7)

(Some) Isolated models make 2-armed spirals



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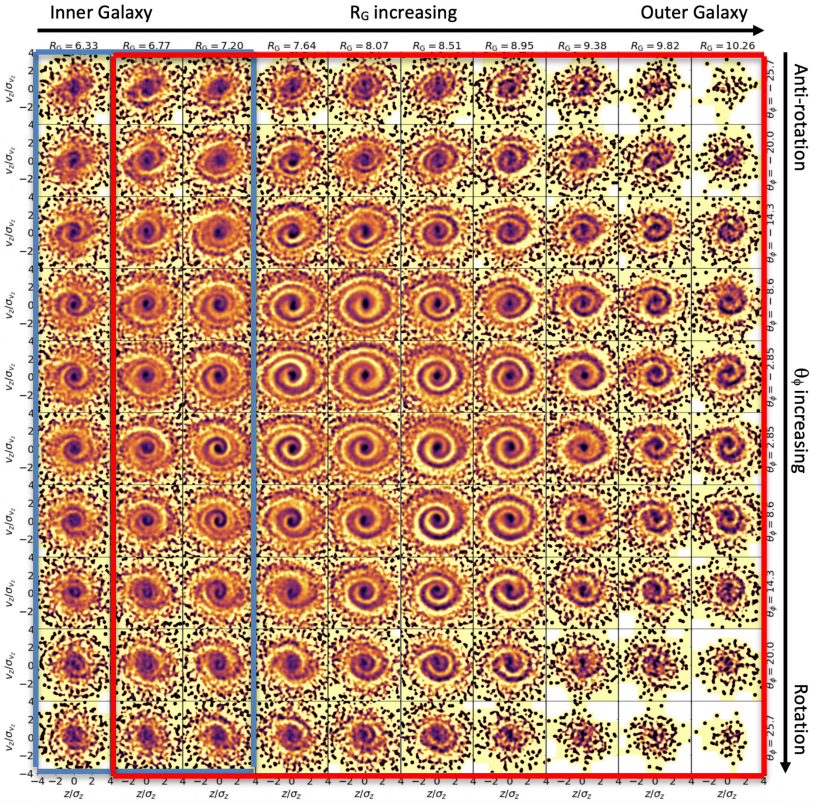
Hunt et al. (2022, MNRAS, 516, 7)

Transition from internally to externally induced

Bar/spiral arm induced?

Breathing mode
(inner galaxy)



Satellite induced?

Bending mode
(Solar neighborhood
& outer Galaxy)

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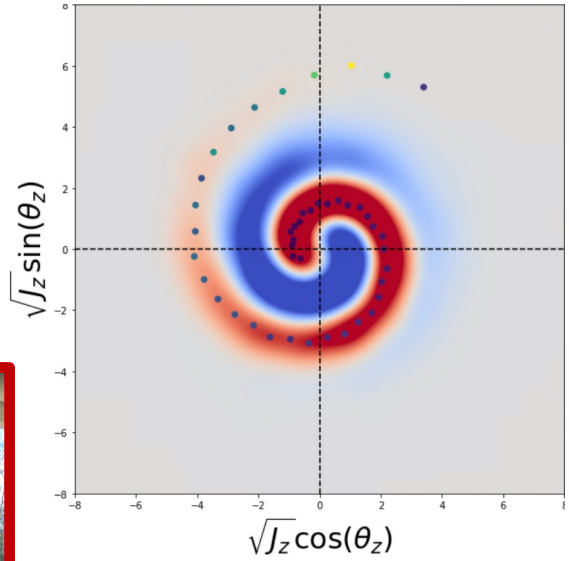
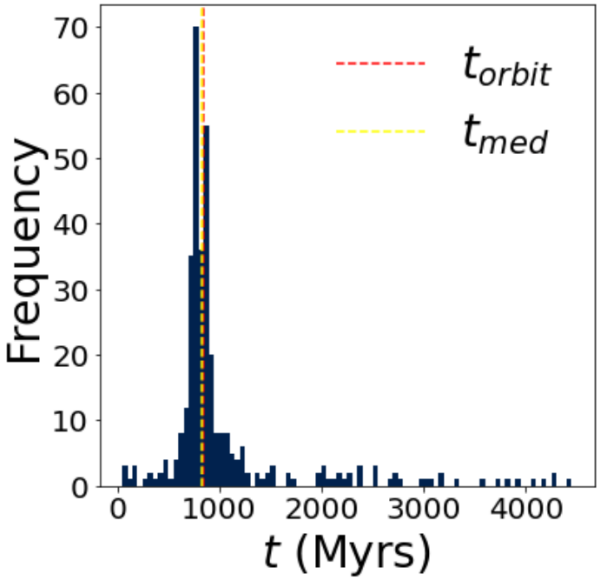
Hunt et al. (2022, MNRAS, 516, 7)

These spirals contain information about our Galaxy

- If we know the potential, we can unwind the spiral (in theory)





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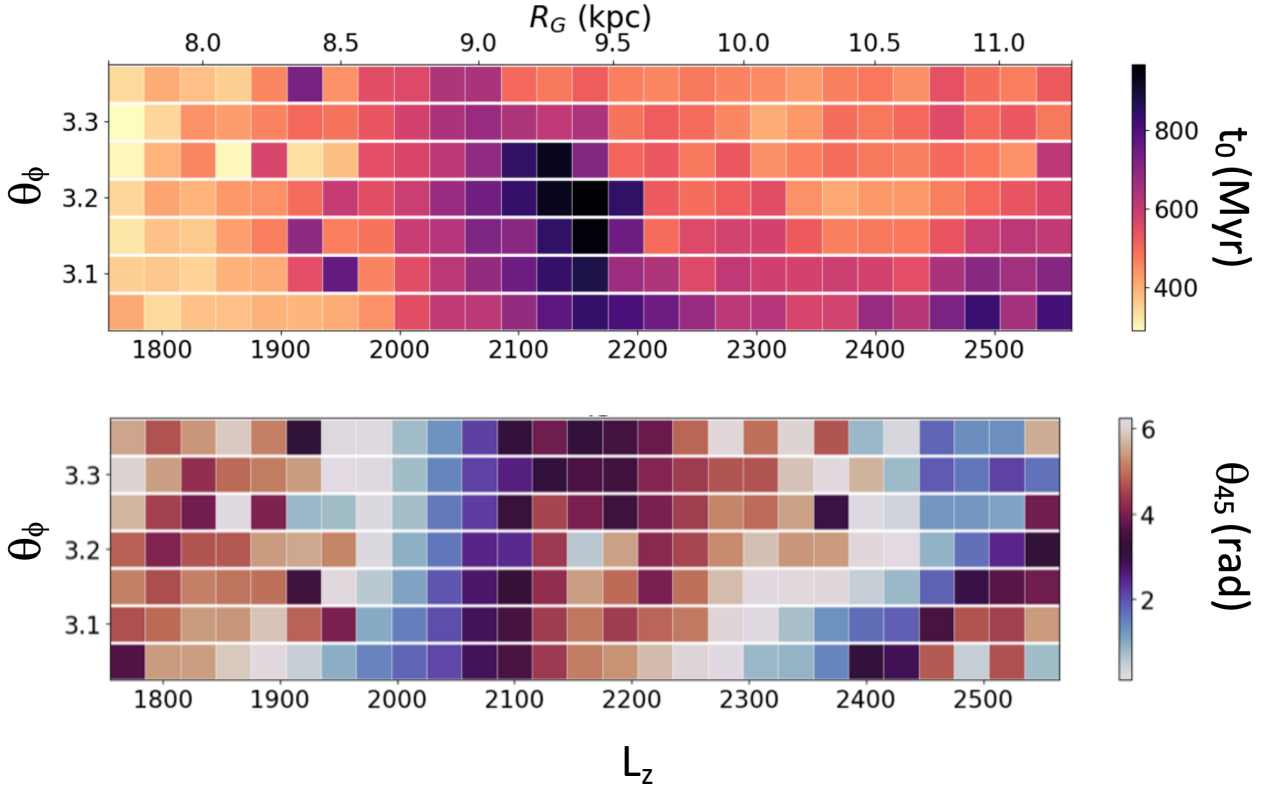
Darragh-Ford, Hunt, Price-Whelan & Johnston (2023)

Phase spirals in Gaia DR3 show coherent patterns

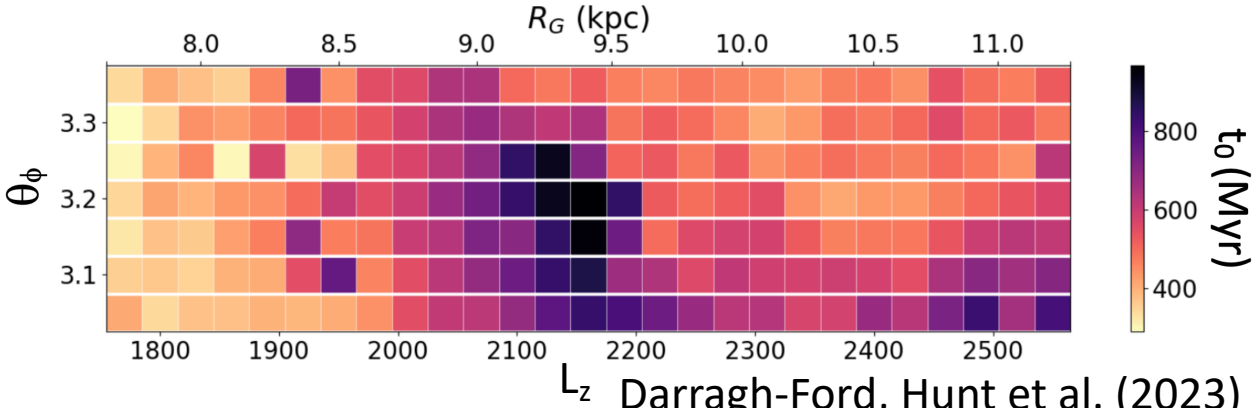
(in the one-armed spirals)

- Range of impact times
- Multiple events, or a complex response

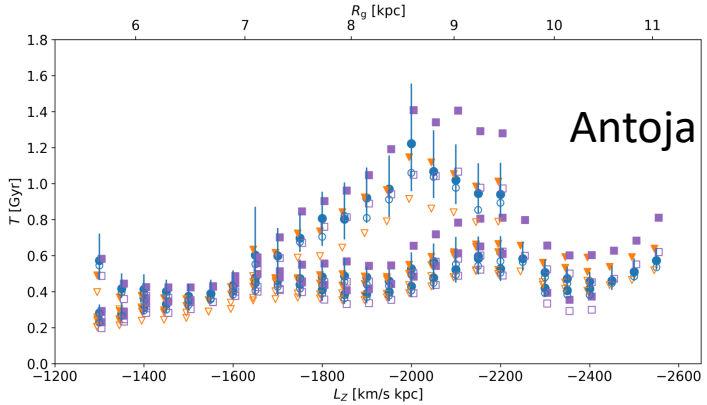


Darragh-Ford, Hunt, Price-Whelan & Johnston (2023)

Independent estimates find similar patterns

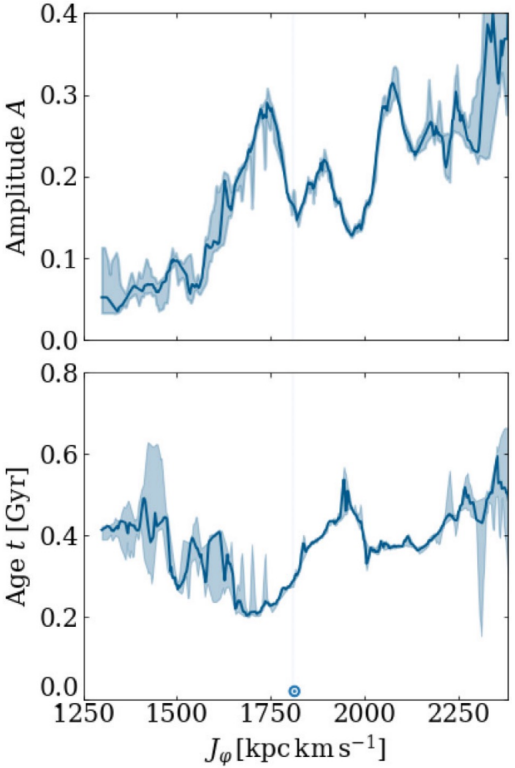


Darragh-Ford, Hunt et al. (2023)



Antoja et al. (2023)

Frankel, et al. (2023)

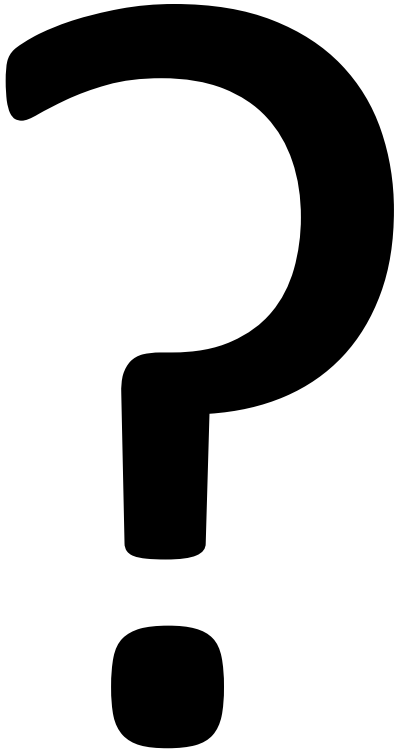


So, what's making the spirals?

- The Sagittarius dwarf? - E.g. Hunt, Antoja, Laporte, Bland-Hawthorn +more
- Any other recent/current dwarfs? - Banik et al. (2022) says no…
- The Galactic bar?
  - Buckling? - Khoperskov et al. (2020)
  - Resonant growth? - Hunt et al. (2022)
- Spiral structure? - Hunt et al. (2022), Li et al. (2023)
- Dark Matter subhalo population - Tremaine et al. (2022)
- MW Dark Matter halo response - Grand et al. (2022)

But also

- GMC's can erase them through J_z diffusion - Tremaine et al. (2022)



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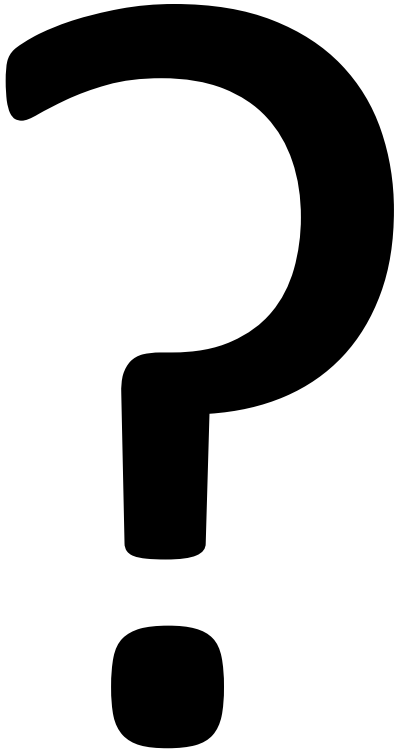
Ask me again after DR4!



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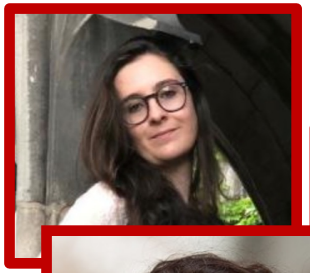
Thanks to my collaborators!

(whose work is relevant to this talk!)


Elise Darragh-Ford, Stanford


Christina Eilers, MIT

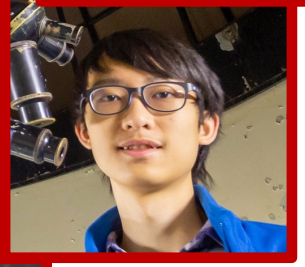

Kathryn Johnston, Columbia


Jo Bovy, Toronto


Mathew Bub, Perimeter


Uddipan Banik, Yale


Suroor Gandhi, NYU


Henry Leung, Toronto


Chervin Laporte, Barcelona


Morgan Bennett, Toronto


David Hogg, NYU


Adrian Price-Whelan, CCA


Ioana Stelea, Columbia


Wilma Trick, MPIA


Daisuke Kawata, UCL

Summary

- Gaia has revealed a Galaxy in disequilibrium
- Features explainable by, the Bar, spiral arms, or mergers
- High resolution models let us examine local phase space structures without selection effects
- Gaia DR3 reveals a transition from ‘breathing spirals’ to ‘bending spirals’ (Hunt et al. 2022)
- Tracking the spirals should inform on the nature of the interaction ***and*** the structure of the disc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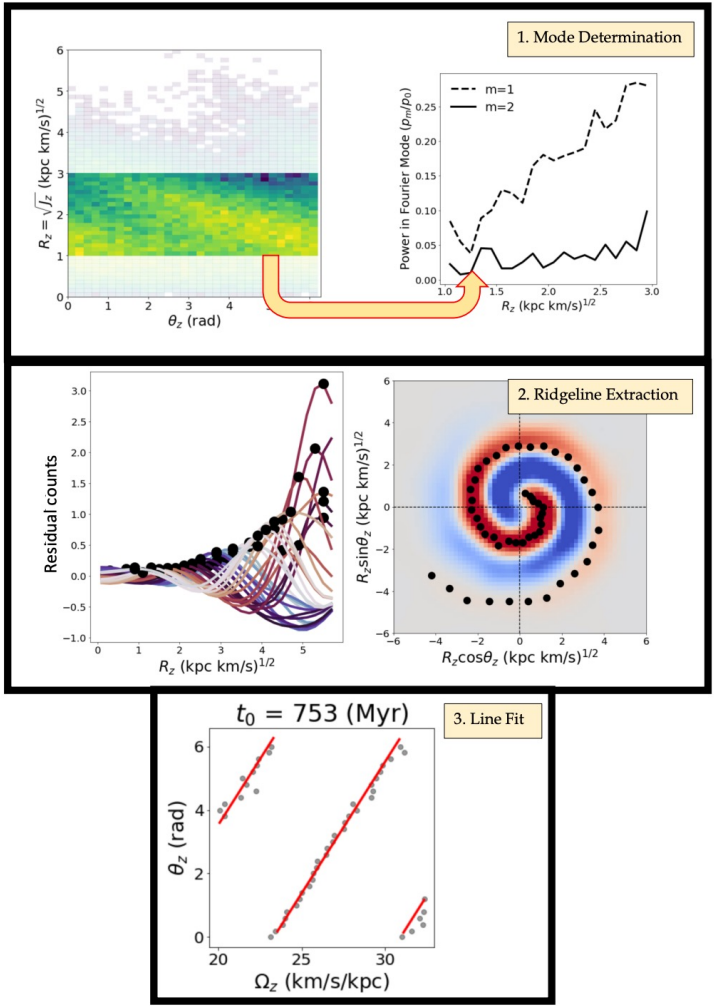

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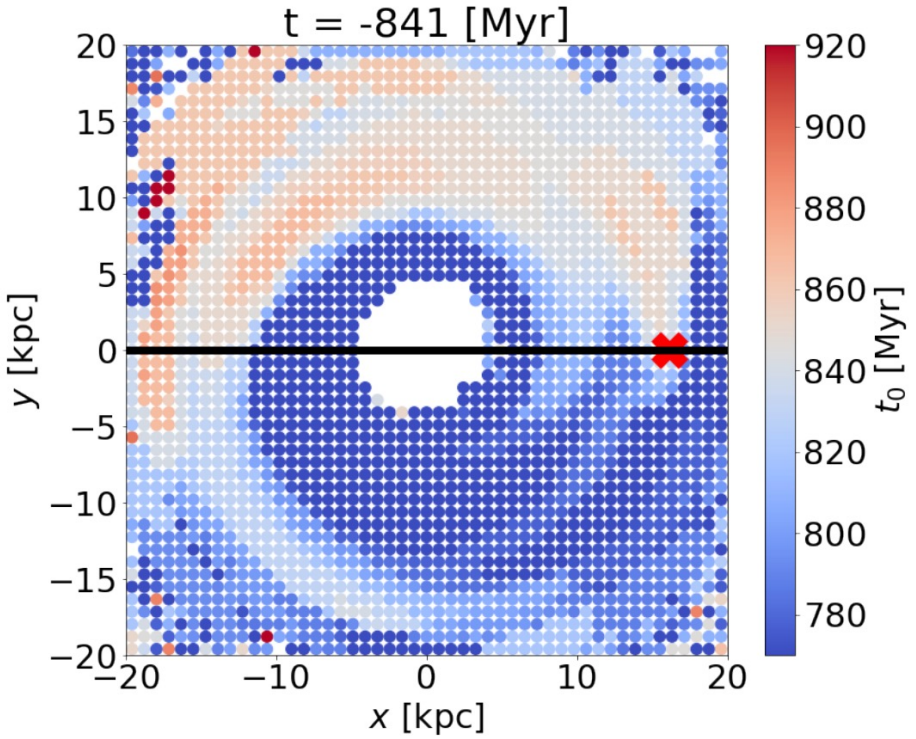
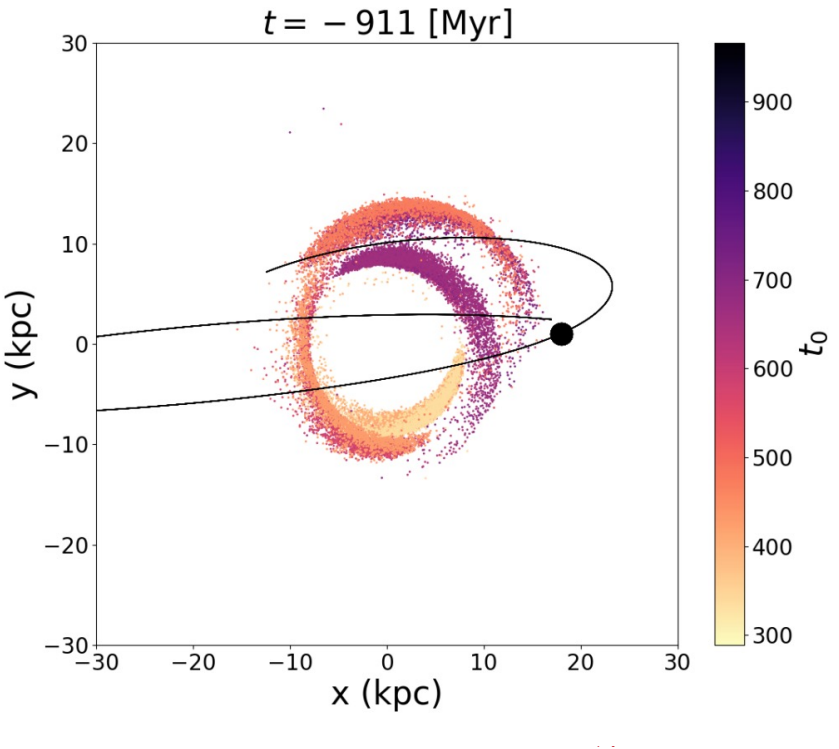
Simulation



Gaia data

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