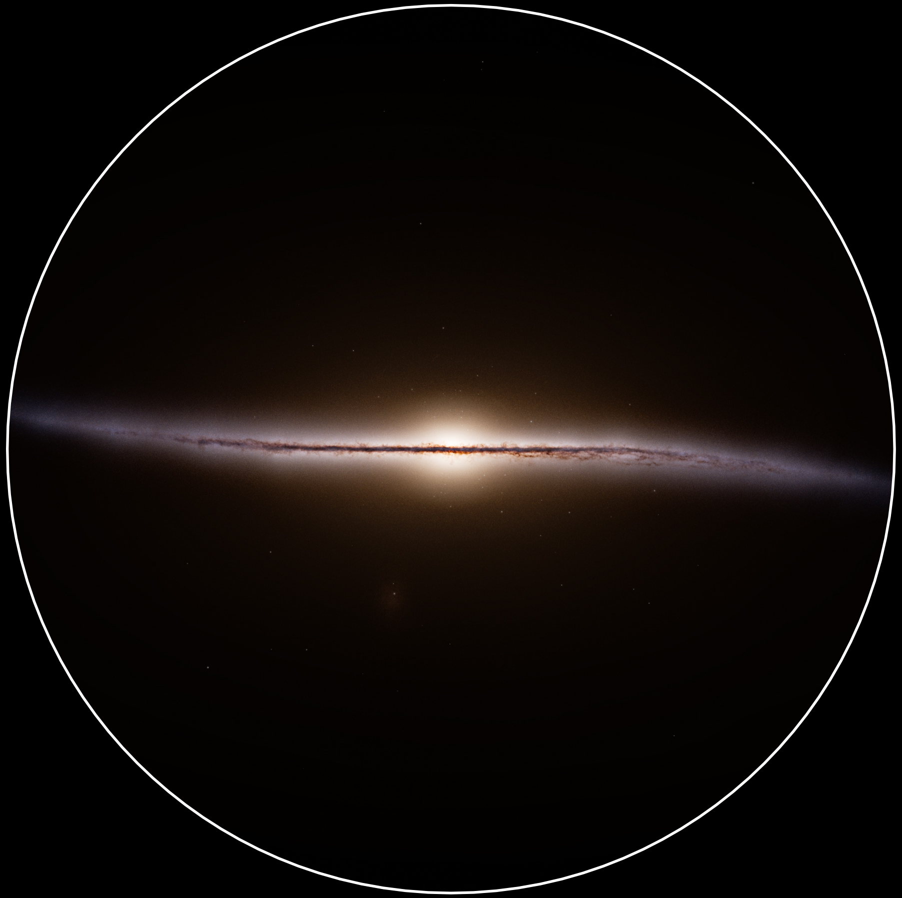
# Gaia时代的银河系盘：

# 震荡、扰动与动力学历史

汇报人：田桂婷

2026.8.14



# 我们如何认识银河系？

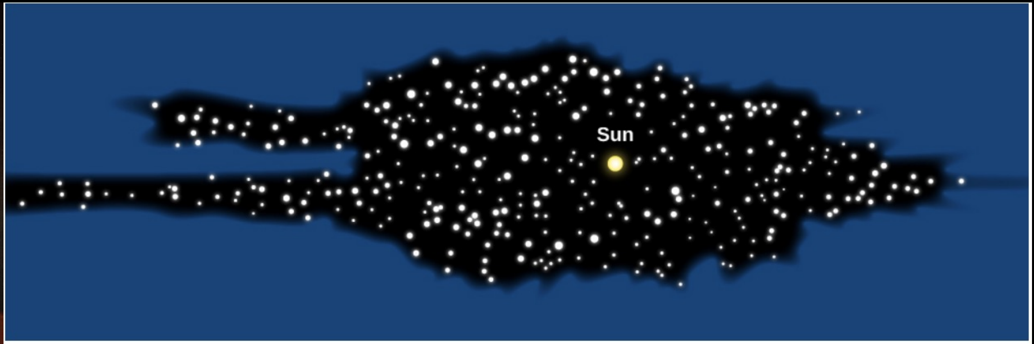



**Figure 25.3 Herschel's Diagram of the Milky Way.** Herschel constructed this cross section of the Galaxy by counting stars in various directions.

Image credit: OpenStax, *Astronomy 2e*, Chapter 25 (Rice University)

1785年，**威廉·赫歇尔**与他的妹妹**卡罗琳·赫歇尔**一起，对天空中不同方向的恒星数量进行了统计。

他们发现，大多数可见恒星分布在一个环绕全天的扁平结构中，太阳所属的恒星系统具有盘状或轮状结构

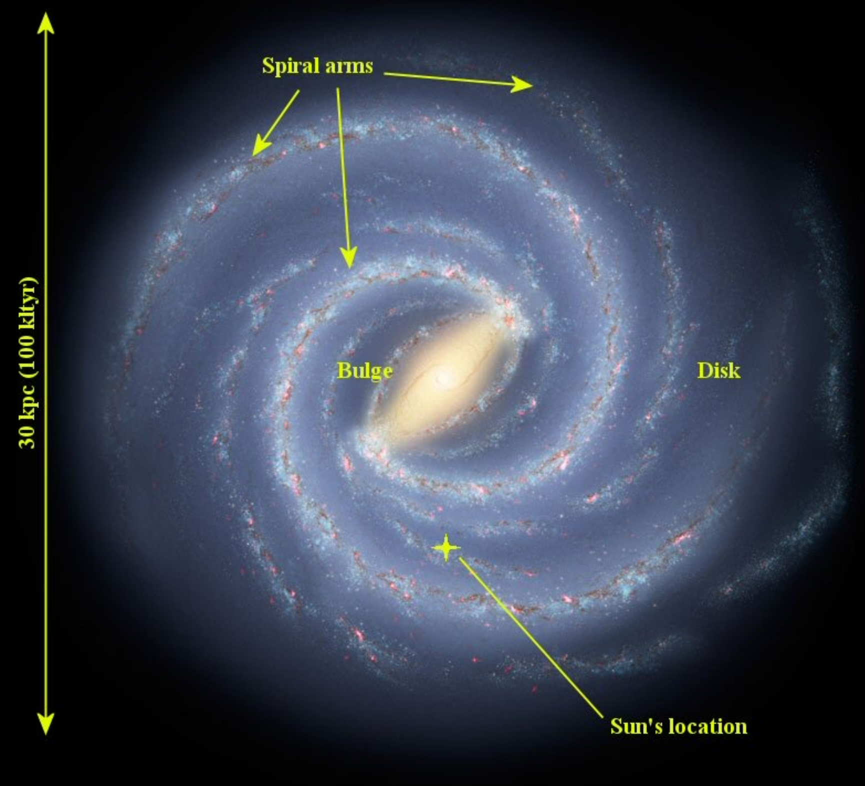



Image credit: Morgan S., University of Northern Iowa

20世纪

- 银河系——棒旋星系
- 棒内部结构研究

# 今天我们知道银河系盘是什么样？

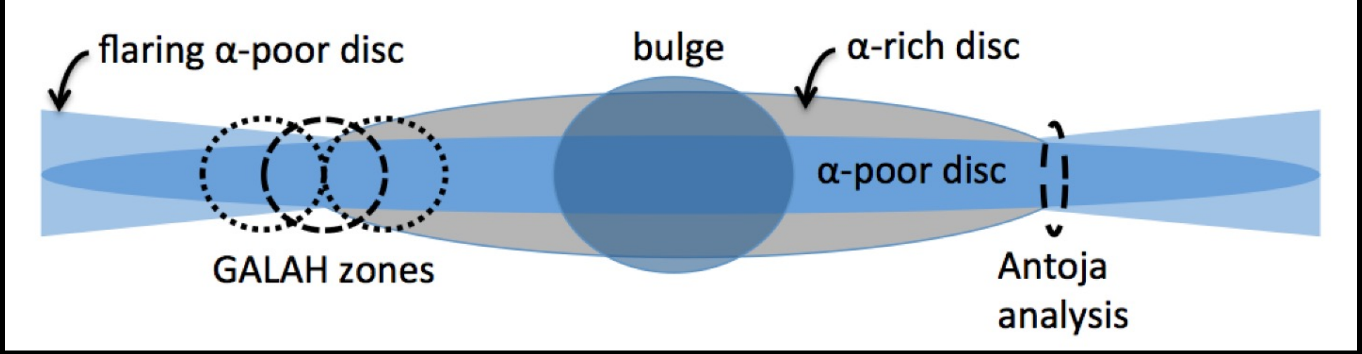

Xing-Wu Zheng & Mark Reid BeSSeL/NJU/CFA

人们通常将银河系盘描述为薄盘和厚盘两个组成部分。
薄盘：年轻恒星为主；α-poor；几何尺度更薄
厚盘：老年恒星为主；α-rich；几何尺度更厚

现在...

- 区分几何（薄/厚）和化学（α-贫/富）
- α-rich或者厚盘，可能贡献超过1/4甚至是贡献主要的恒星总质量（e.g. Lian+2022; Vieira+2023; Khanna+2024; Xiang+2024）
- 银河系盘的径向密度不是简单指数下降；标高不再固定（e.g. Lian et al., 2024）
- 速度弥散整体随年龄增长而增加，但有一些明显特征可能与动力学扰动有关（ Das et al. 2024 ）
- 速度弥散随半径增大而减小的趋势在外盘变弱甚至反转（ Sanders and Das, 2018; Mackereth et al., 2019; Sharma et al., 2021 ）

空间结构复杂，动力学复杂




Bland-Hawthorn et al. 2019

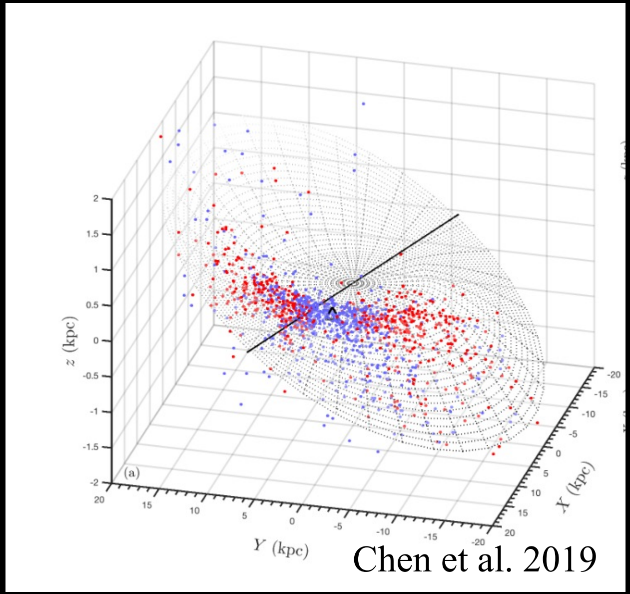
# Gaia时代：银河系的动态演化系统

Milky Way dynamics in light of *Gaia*

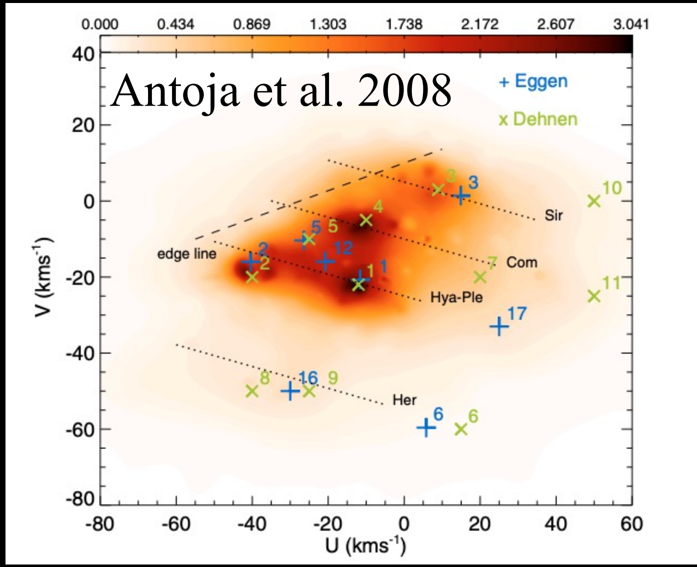
Jason A. S. Hunt, Eugene Vasiliev

[a] *University of Surrey, Guildford, GU2 7XH, UK*

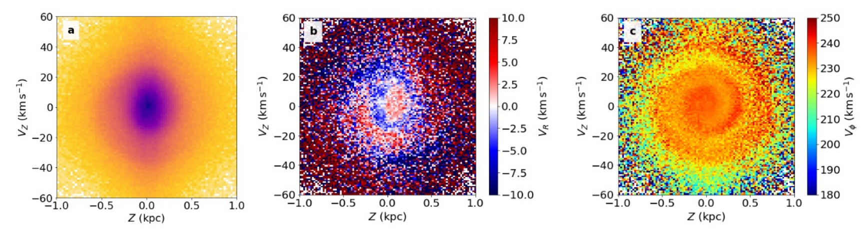
## 结构空间

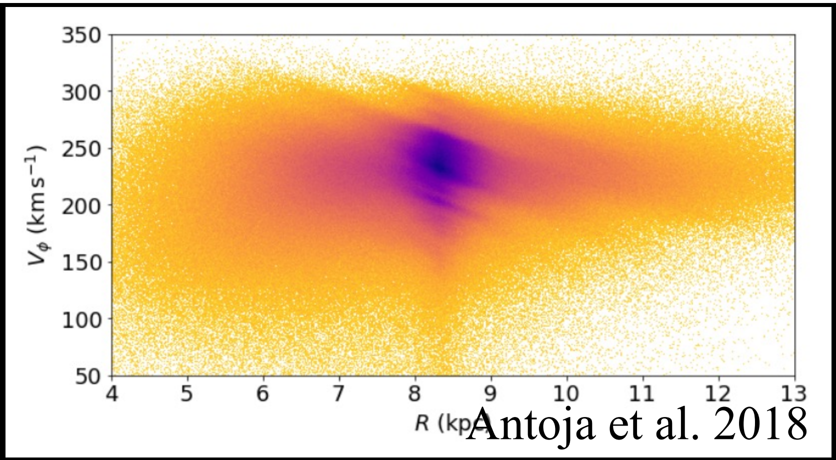



## 速度空间




## 相空间



# 盘内的扰动

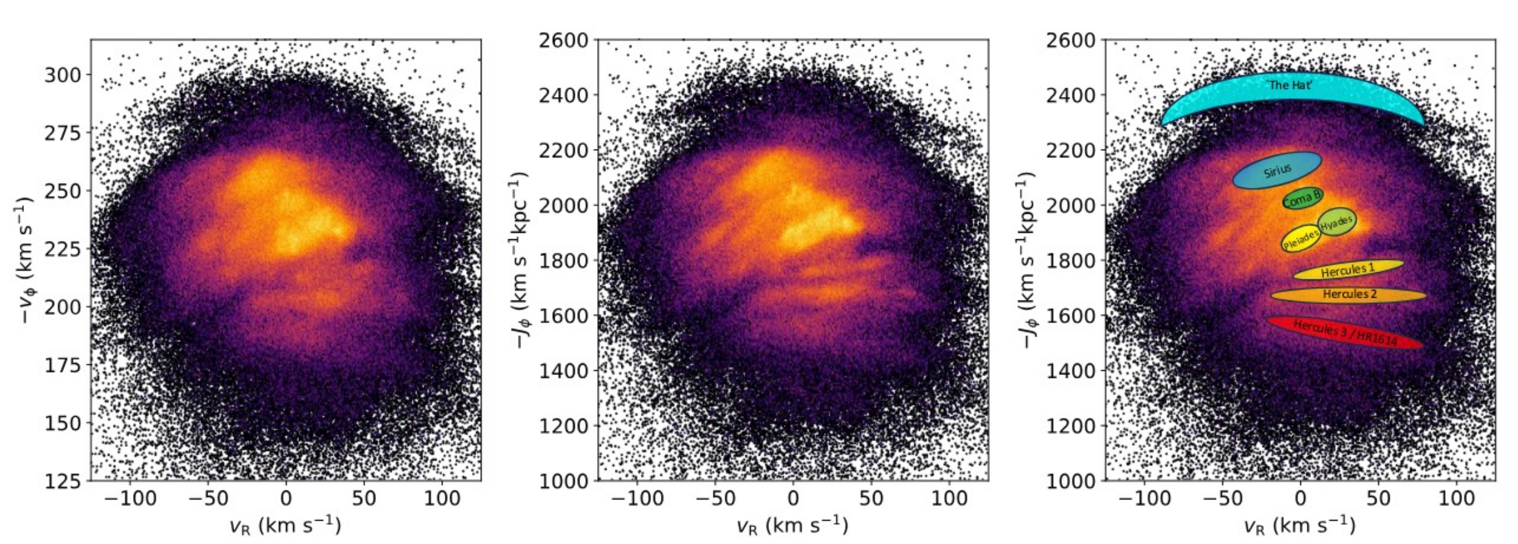
## Moving groups

**Moving group** A group of stars sharing a similar position and motion in the phase space. The classical ones are the groups of stars identified in the radial and rotation velocity distribution of the solar neighborhood stars.

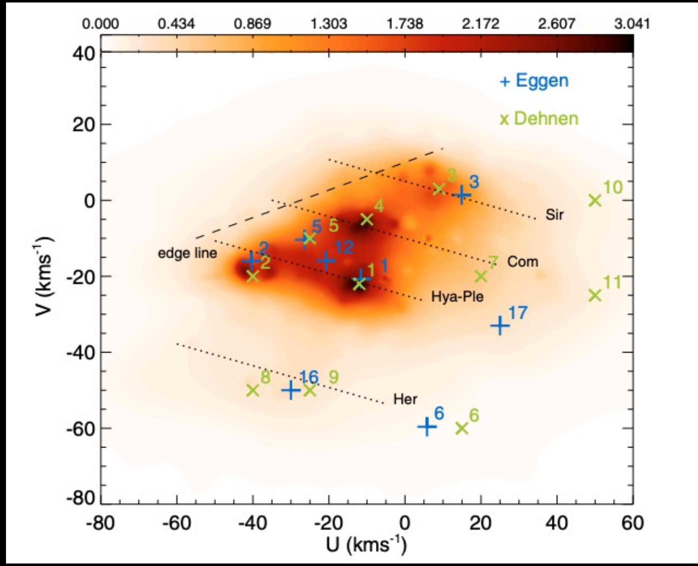
Kawata et al. 2024

Dynamical origin: (possible)

- 被bar共振捕获
- 被spiral arms共振捕获
- 扰动导致的相角混合(phase mixing)



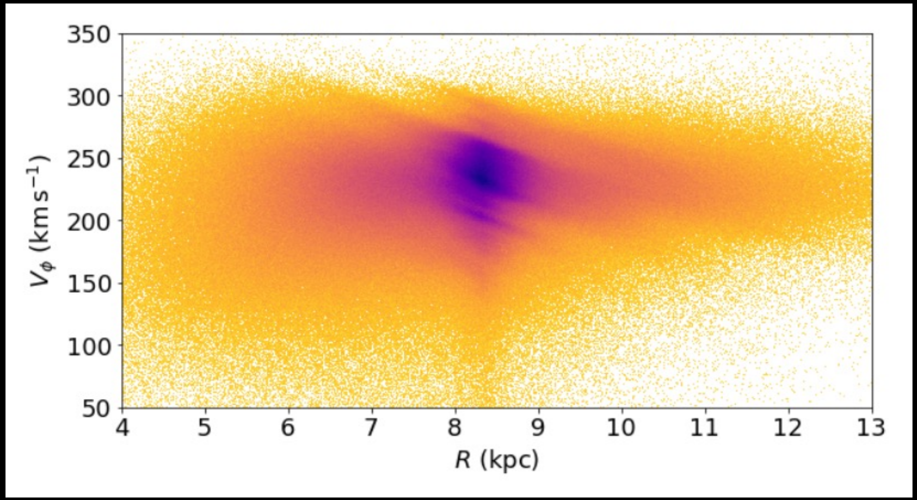

Hunt & Vasiliev 2025



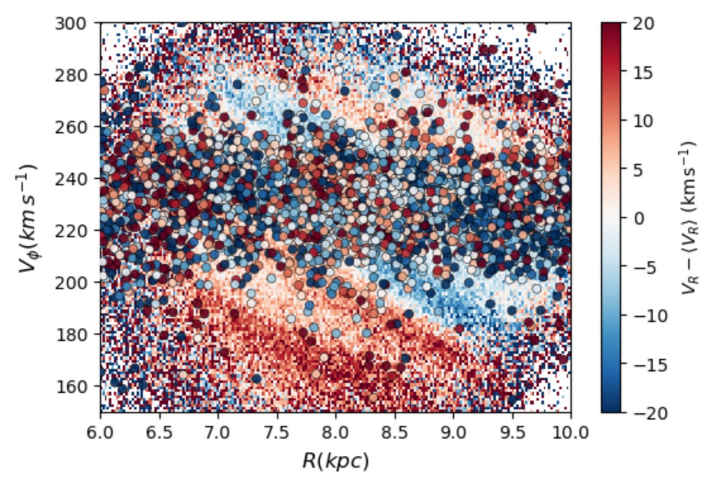

Antoja et al. 2008

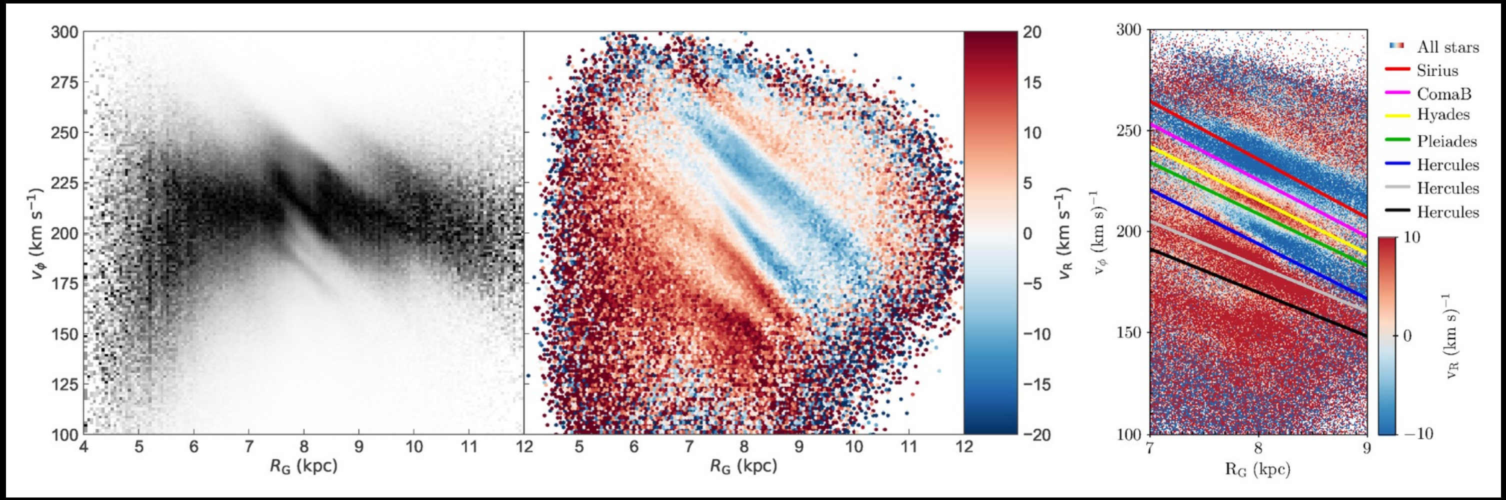
# 盘内的扰动

## Ridge lines

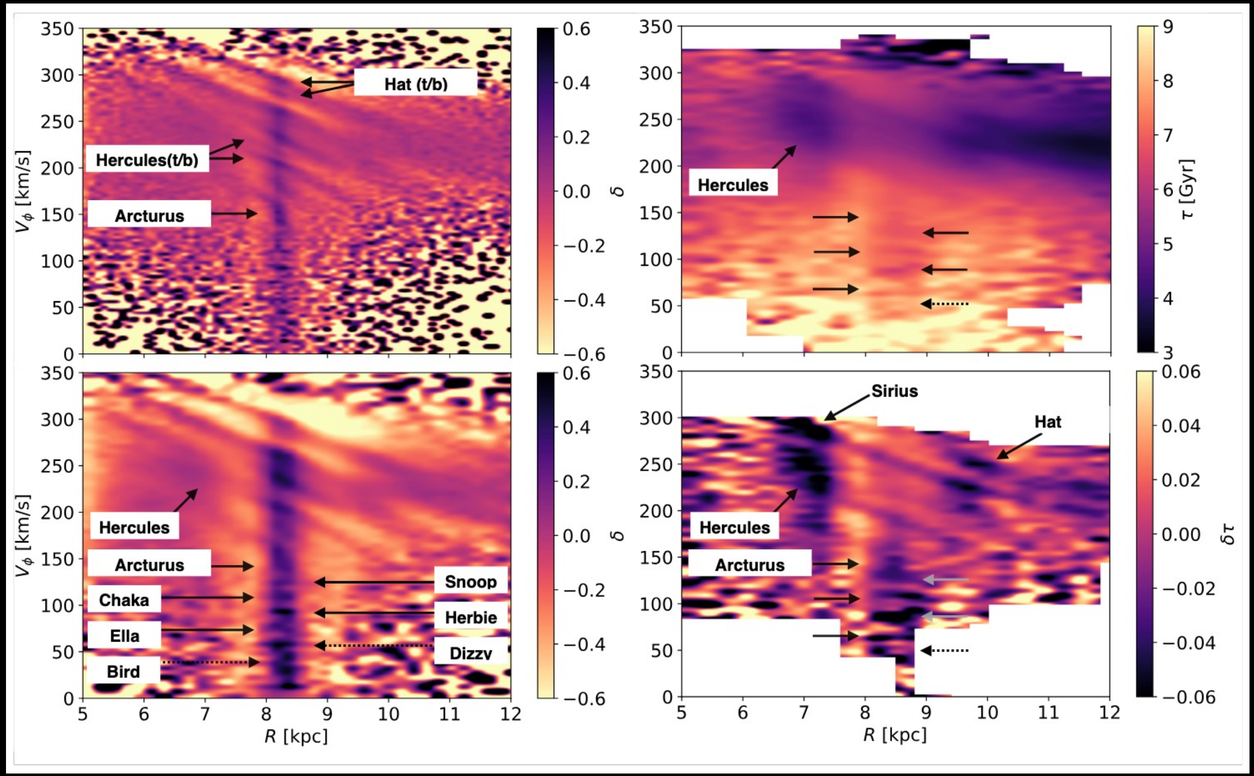



Antoja et al. 2018




Hunt et al. 2019



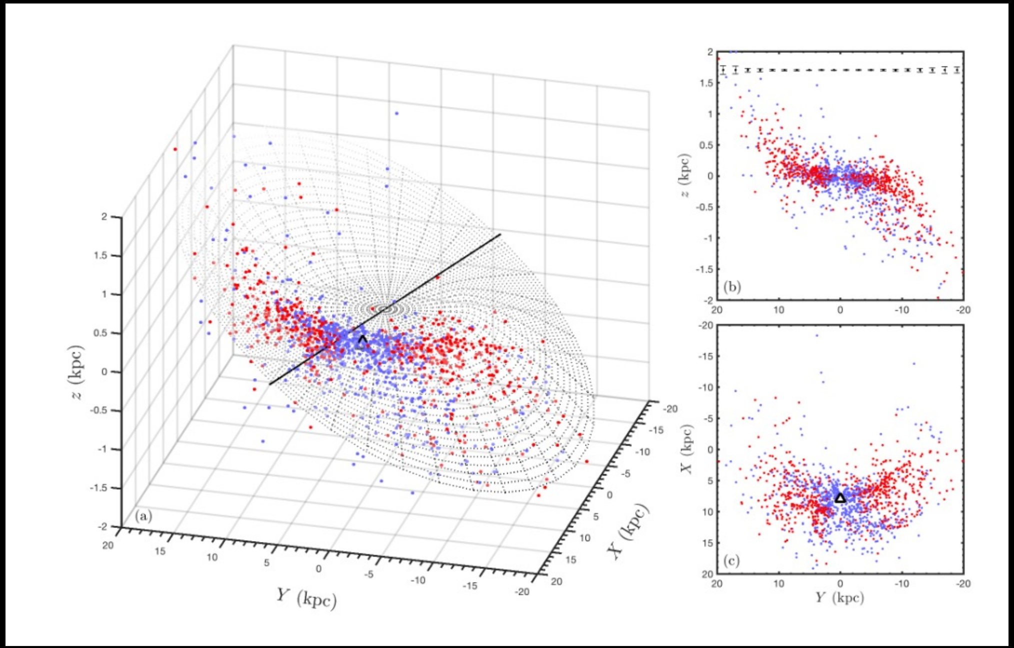

Laporte et al. 2021

# 垂直的扰动

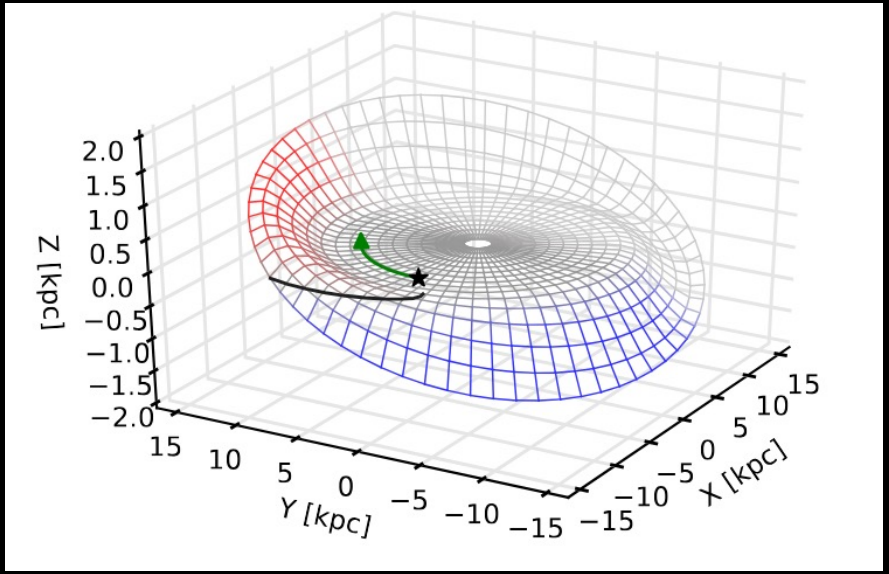
## The Galactic Warp

翘曲（Warp）

- 外盘偏离理想银河平面（z=0），呈现大尺度垂向弯曲结构
- Chen et al. 2019: 用1300颗造父变星示踪warp的空间结构。
  - 翘曲从R～10kpc开始，到R=16kpc达到0.8kpc
  - a twist of line of nodes：不同半径的圆环（ring）朝不同方向倾斜。(later confirmed by Dehnen et al. 2023, Cabrera-Gadea et al. 2024b)
- 翘曲幅度——更大or更小？
  - Cheng et al. 2020：在R = 15 kpc，z ~2 kpc
  - Uppal et al. 2024：在R = 15 kpc，z ~1.5 kpc
  - Wang et al. 2020b 和 Li et al. 2023b：翘曲幅度随着年龄增大而减小
- 产生翘曲：暗晕与银河系盘错位、卫星星系引力扰动、星系际气体的吸积、GSE……



Chen et al. 2019



Hunt & Vasiliev 2025

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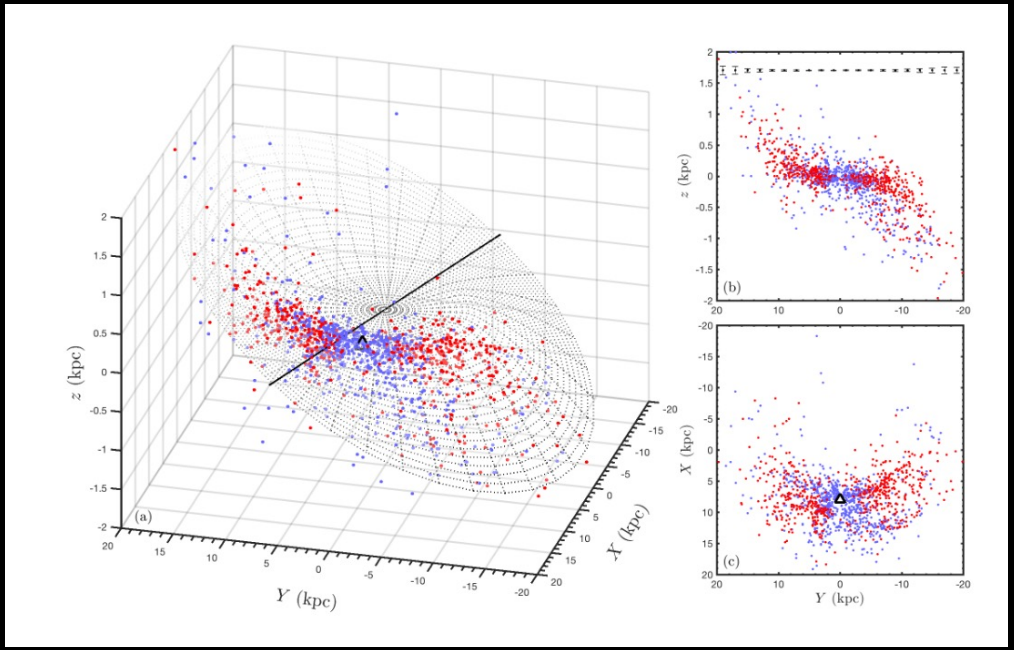
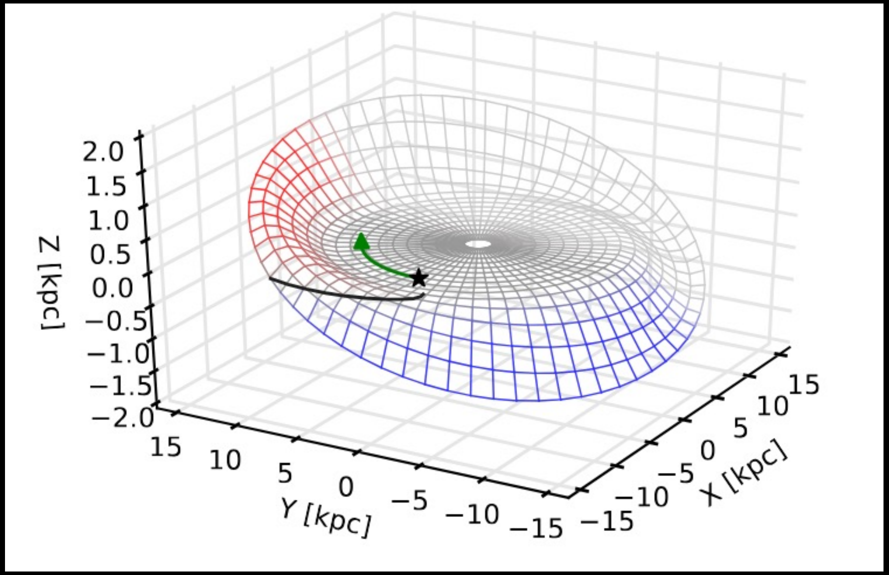


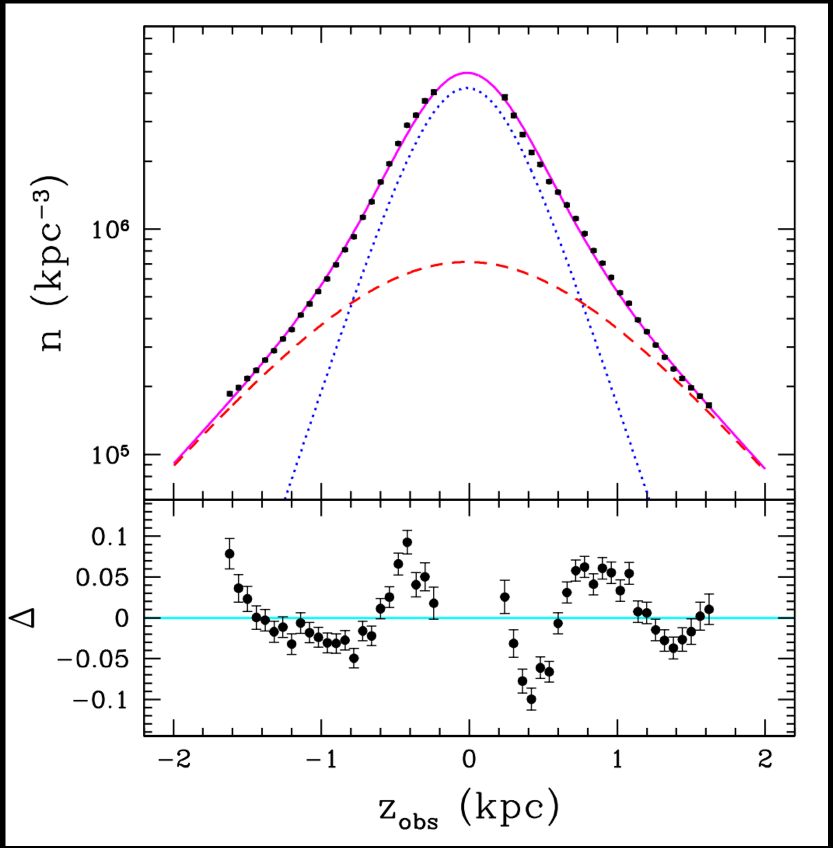

Chen et al. 2019



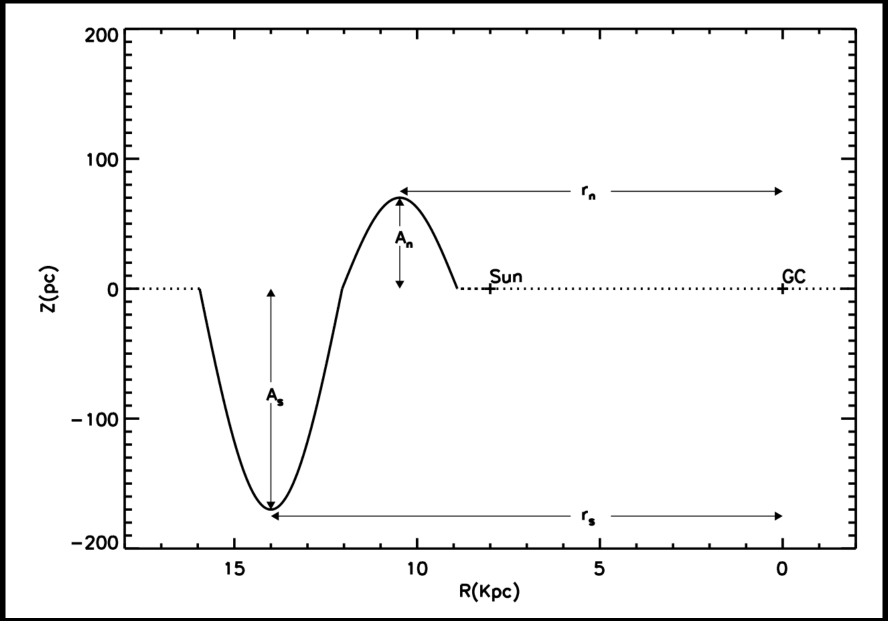

Hunt & Vasiliev 2025

# 垂直的扰动

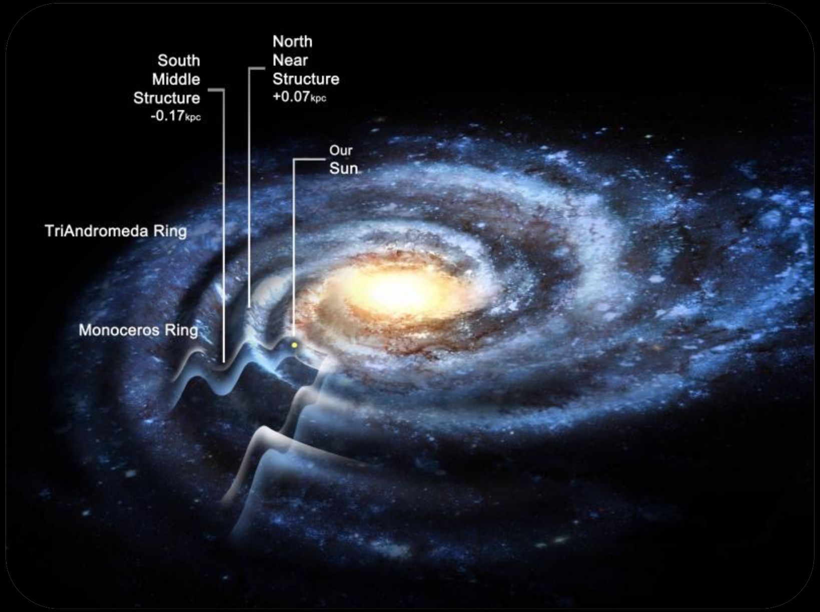
## The Ripples, corrugations and feathers




Widrow et al. 2012



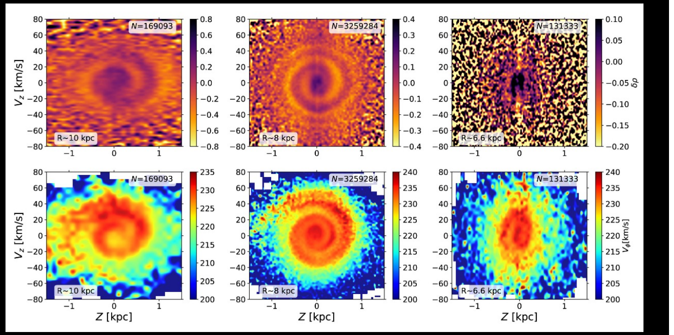

Xu et al. 2015

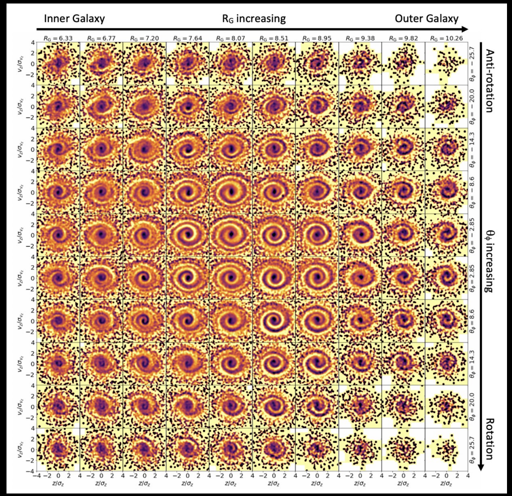


# 垂直的扰动

## Gaia snail

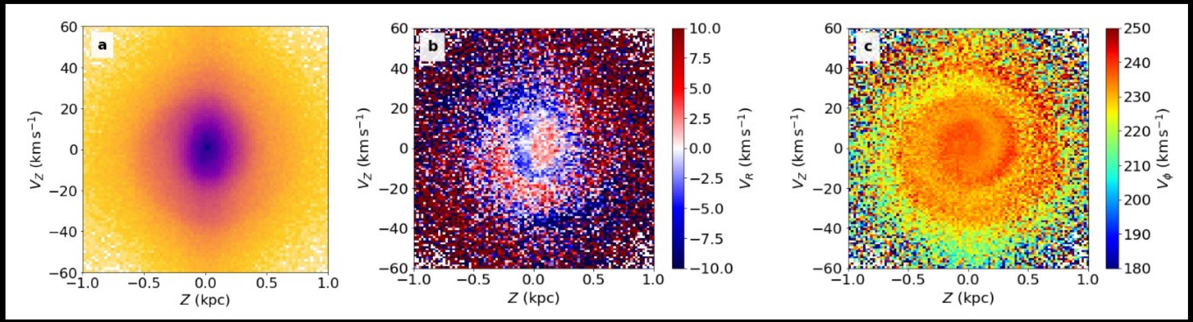
Laporte et al. 2019



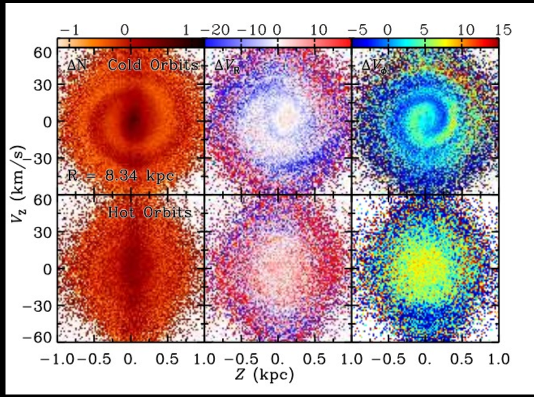




Hunt et al. 2022

位置

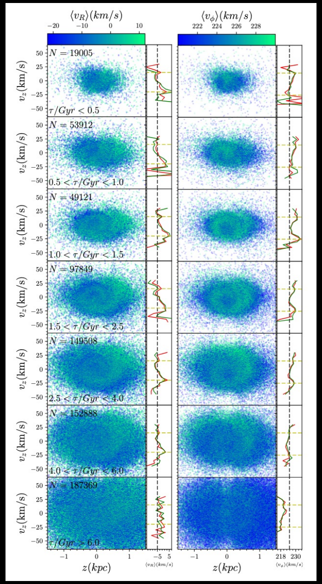



Antoja et al. 2018

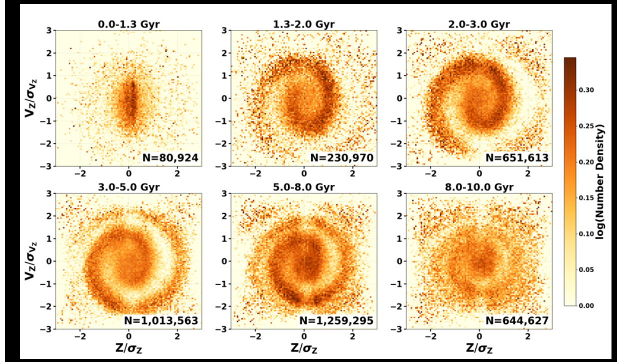



Li & Shen et al. 2020

轨道




Tian et al. 2018




年龄和金属丰度

Gaia snail是银盘受到了垂向扰动导致相角混合后的结果。

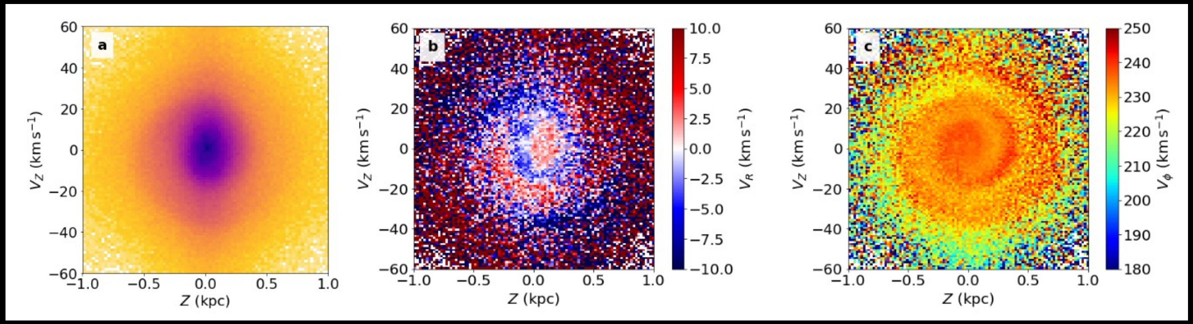
相空间螺旋结构并不是固定不变的，它会随着：

- 银河系不同位置
- 年龄和金属丰度
- 不同恒星轨道

而变化。

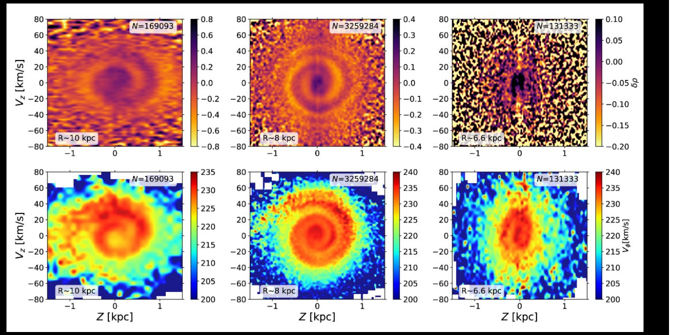
# 垂直的扰动

## Gaia snail

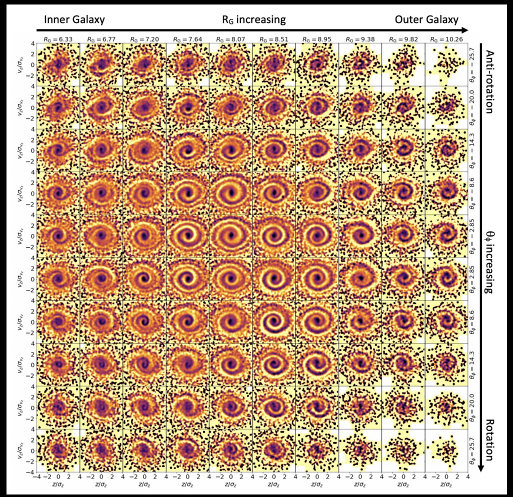



Antoja et al. 2018

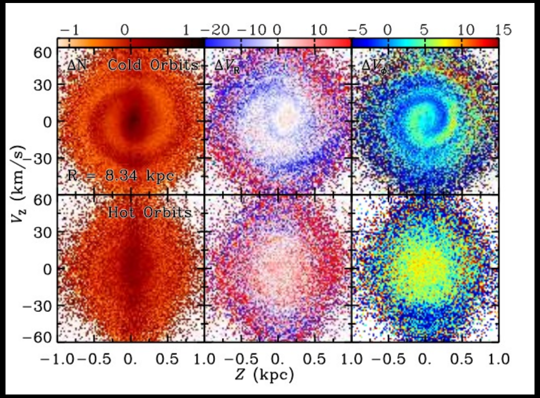
Laporte et al. 2019




位置

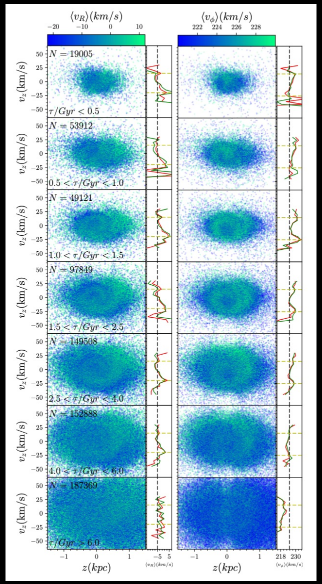



Hunt et al. 2022

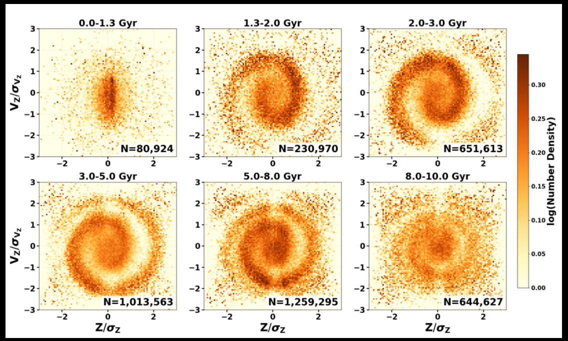



Li & Shen et al. 2020

轨道




Tian et al. 2018




年龄和金属丰度

**扰动源：**

（1）外源：

- 卫星星系（Sgr）
- 暗物质子晕（dark sub-halos）
- 暗物质晕的尾迹（wakes in DM halos）

（2）内源：

- 银河系的旋臂与棒
- 不均匀的星际介质分布
- 银河系暗晕的不对称结构

或这些因素的共同作用

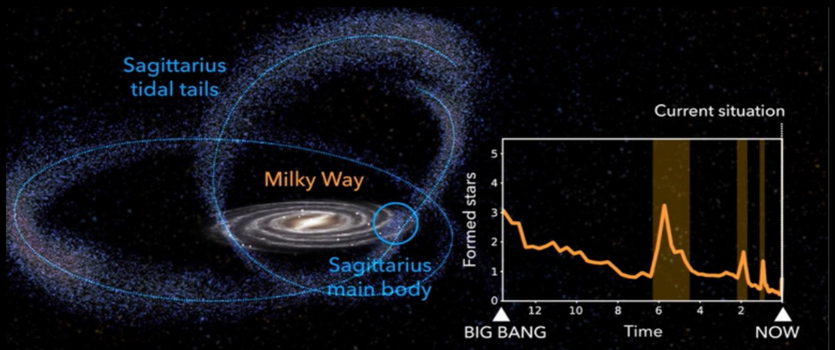
Image credit: ESA / Gaia

# What happened?

空间-沟壑丛生
速度-暗流涌动

## 卫星星系

人马座矮椭球星系, …




The main source of the perturbation is considered to be the Sagittarius dwarf galaxy —— Kawata et al. 2024

## 银河系棒和旋臂

Bar buckling, resonances, …

Kawata et al. 2024

## 暗物质晕・・・

Multiple dark sub-halos, misalignment, substructures, …

Image credit: NASA/APOD, ESA/Gaia

The Gaia journey is not over, and the upcoming DR4 in 2026, alongside with further increase in data quantity and quality, will undoubtedly bring a new round of discoveries.

Hunt & Vasiliev, 2025