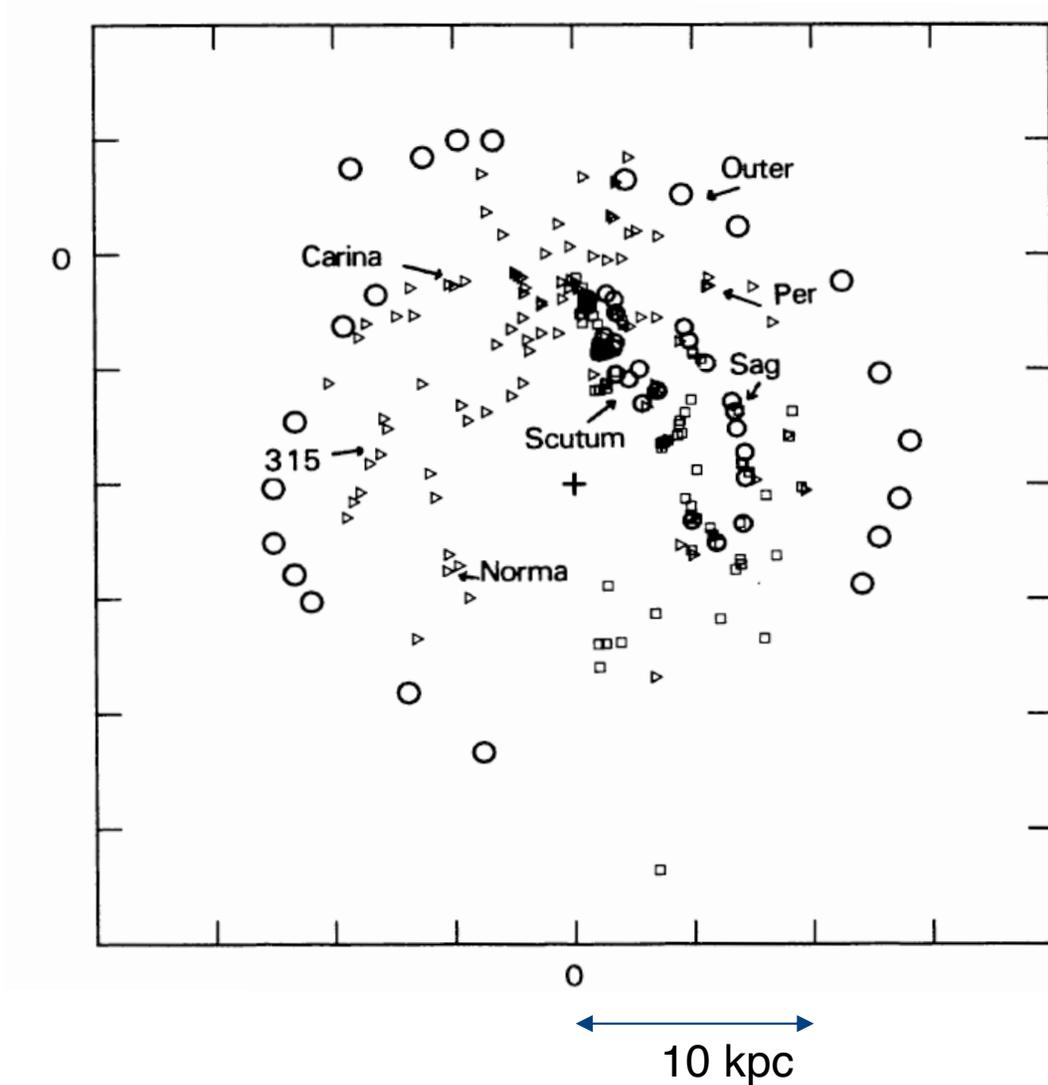


Spiral structure of the Milky Way

Clear in HI, GMC, HII regions, OB stars, and young clusters. The exact shape is hard to infer from within the Galaxy.



Large scale

Open circles: giant HI clouds

Squares: GMCs

Triangles: optical HII regions

Small boxes: radio HII regions

Elmegreen 1985

Gaia's Milky Way map



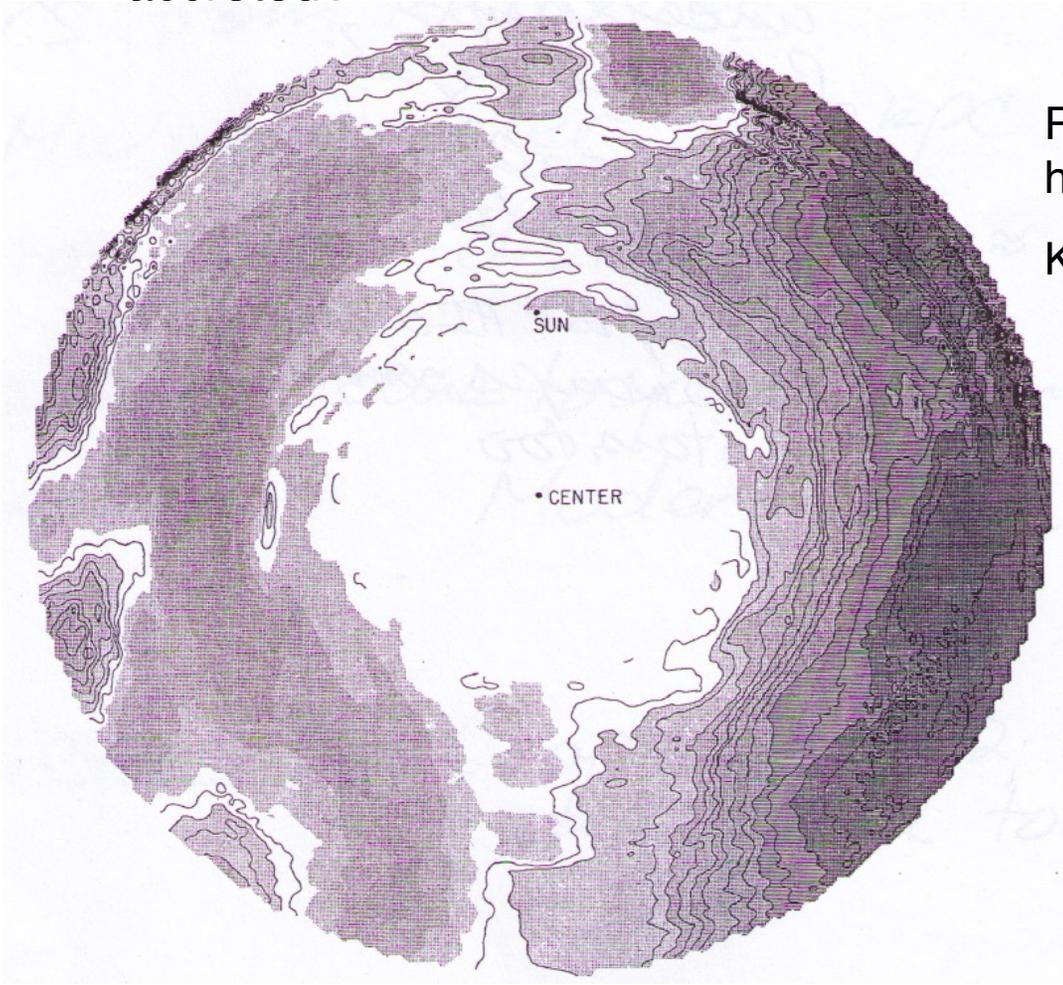
www.esa.int/gaia

Credit: ESA/Gaia/DPAC, Stefan Payne-Wardenaar

Credit: ESA/Gaia/DPAC, Stefan Payne-Wardenaar ([source](#))

HI layer is 'warped' at radii beyond $R \sim 15$ kpc.

The origin of this warp is unclear: interactions? But isolated galaxies also exhibit warps. Bending modes? Halo changing shape as new material accreted?



Plan view showing z-heights of HI.

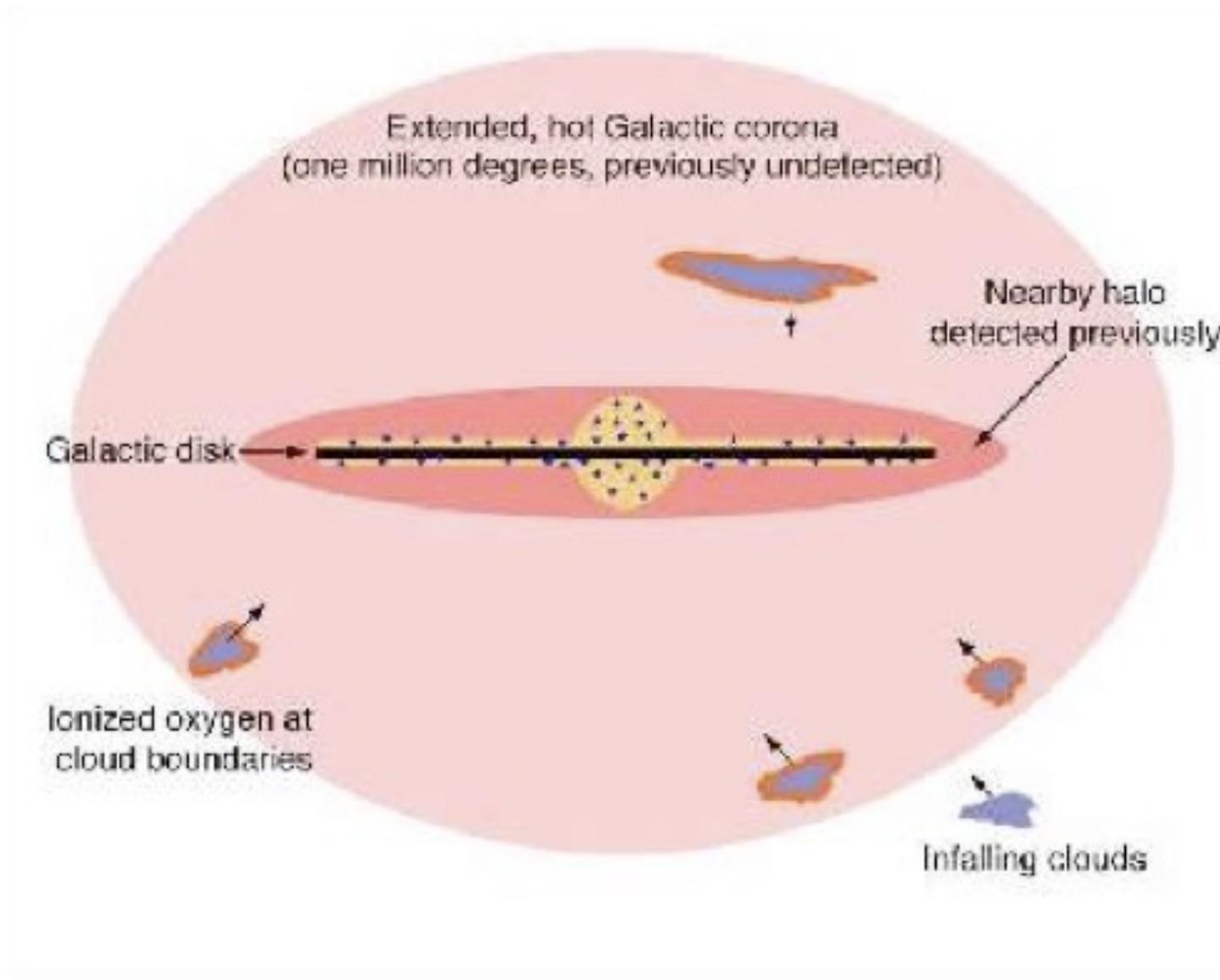
Kwee et al.



UGC 3697

Coronal gas

Observed in highly ionized lines, e.g. far-UV OIV (absorption).



Astronomy 537



Lecture 3: The Milky Way Galaxy Stars

Key concepts:

Gaia mission

Stellar orbits

Journal Class reminder:

- Everybody reads paper (skip the appendices)
- Leader (for Paper 1 **Pavel**)
 - Gives a summary of the important points in the paper (~ 10 min) referring to interesting figures
 - Defines any unusual terminology
- Group discussion
 - Is the paper well motivated?
 - Points out any major assumptions or flaws
 - Are the results plausible? Important?

Journal Class

Monday, Feb 2

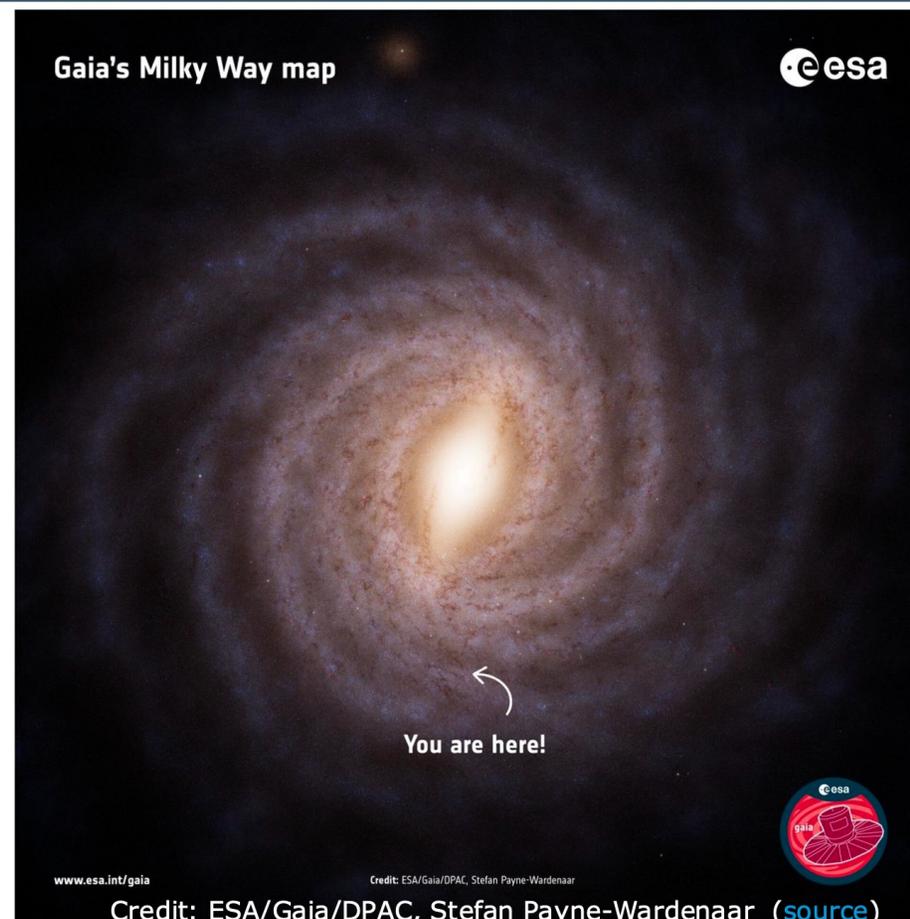
**The debris of the 'last major merger'
is dynamically young**

Donlon et al. 2024

Discussion leader: **Pavel**

Gaia reveals the origin and evolution of the Milky Way

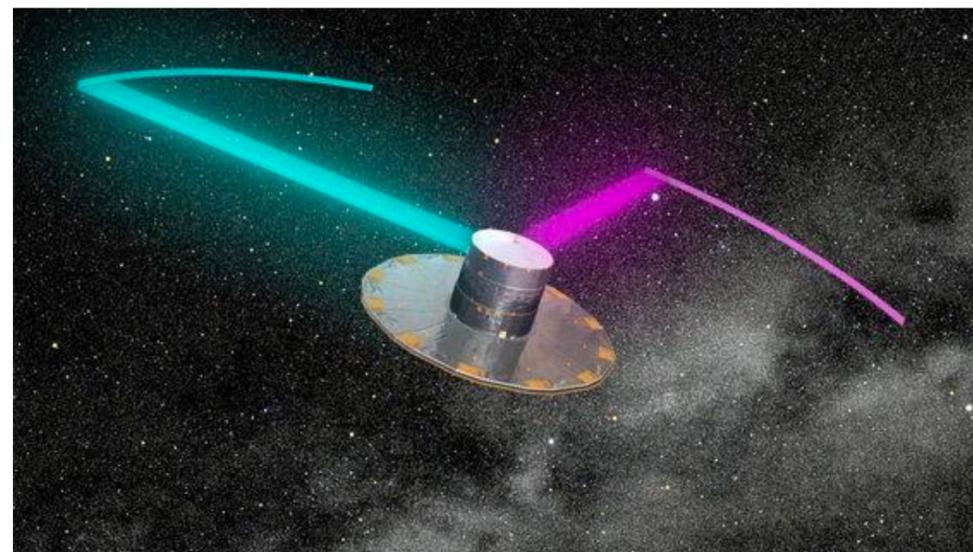
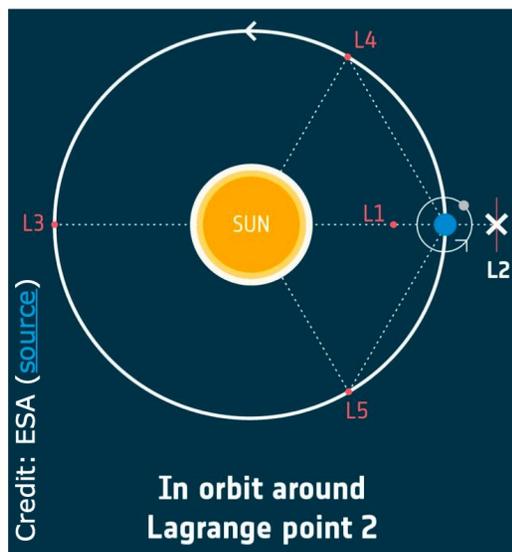
- Stellar positions and distances
➔ Galactic structure
- Stellar motions
➔ Galactic kinematics
- Stellar parameters, compositions, ages
➔ Galactic evolution
- Optical all-sky survey with 3 instruments:
Astrometry, Photometry, Spectroscopy
- Gaia observes ~1% of the stars in the Galaxy
- Gaia survey enables rich complementary science



Gaia was launched to L2 in December 2013



- 10.5 years of science observations from July 2014 to January 2025
- Gaia was constantly spinning and scanning the sky
- Surveying star-like sources, e.g. stars, galaxies, quasars, asteroids, ...
- Magnitudes range $G \approx 3-21$



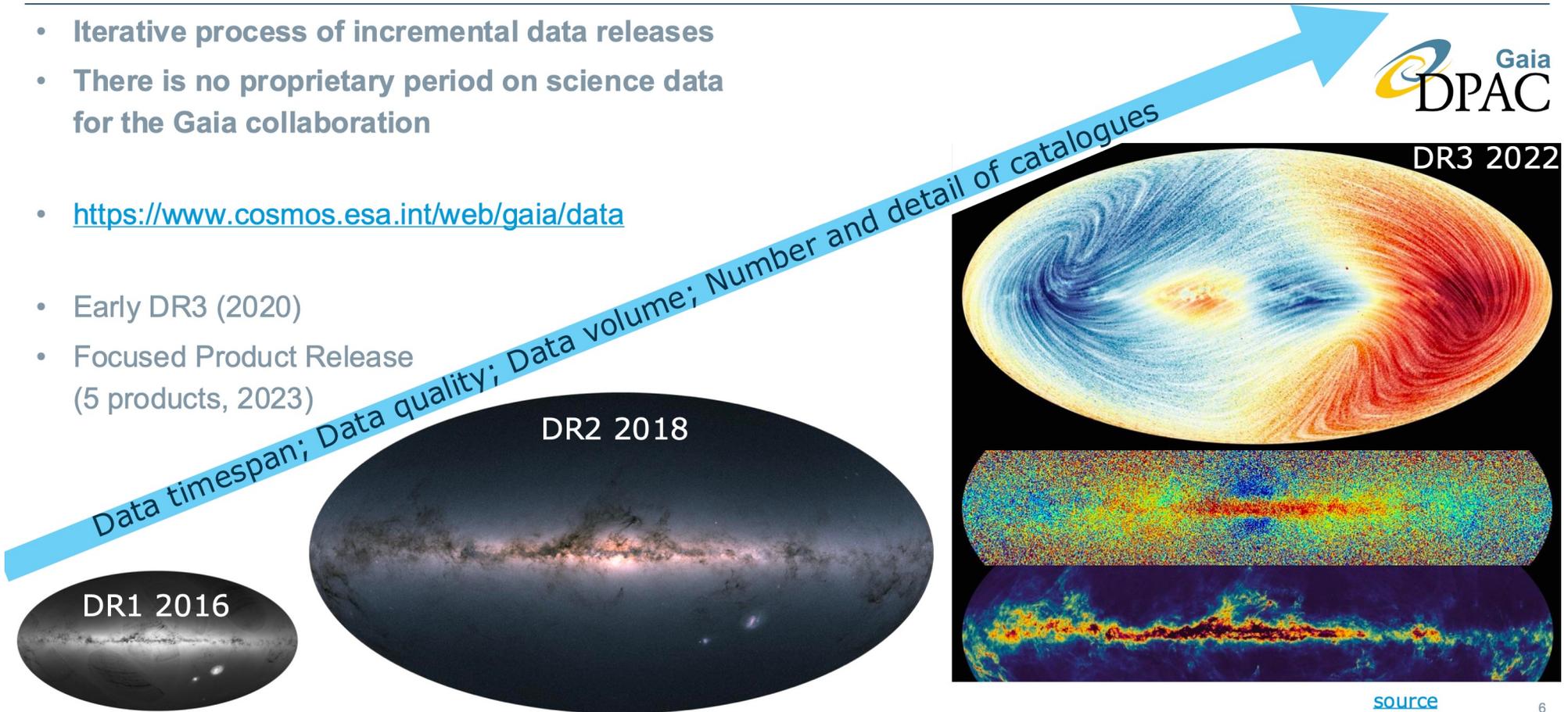
There were 3 intermediate Gaia data releases so far



- Iterative process of incremental data releases
- There is no proprietary period on science data for the Gaia collaboration

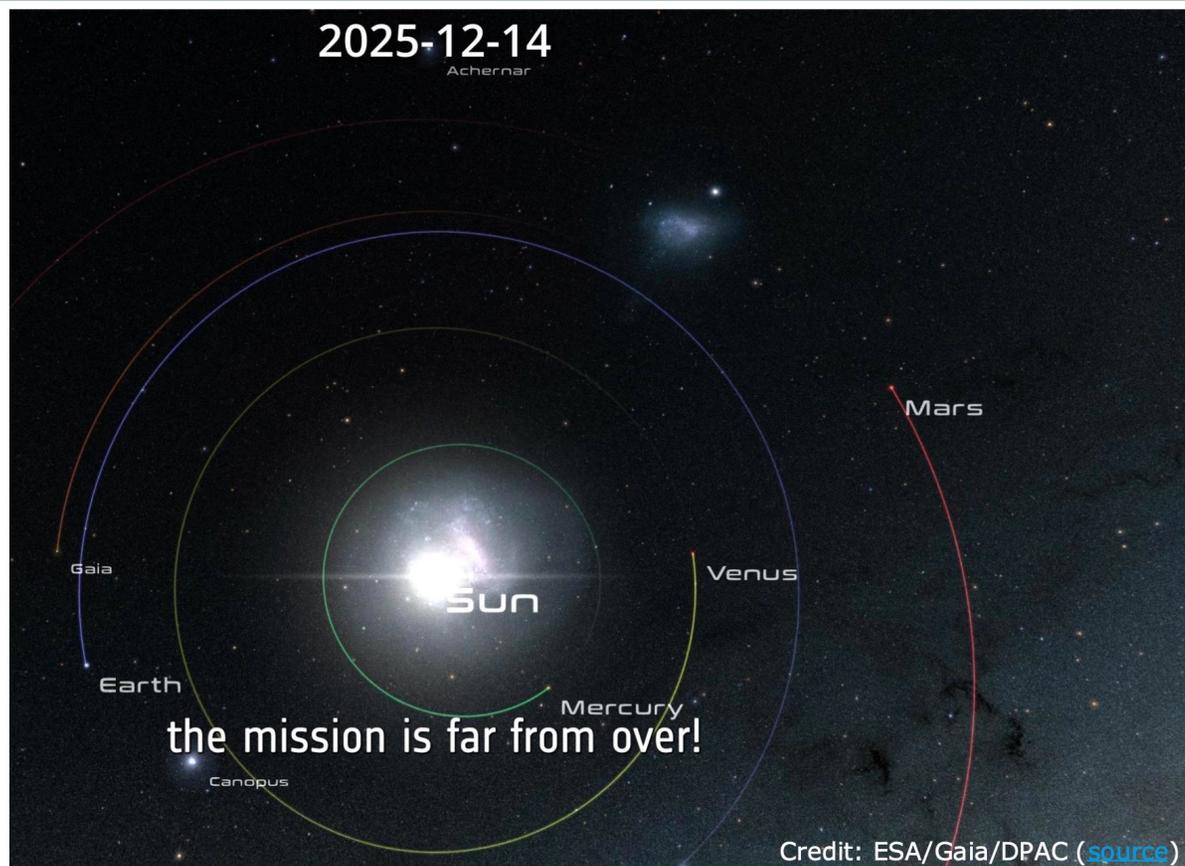
• <https://www.cosmos.esa.int/web/gaia/data>

- Early DR3 (2020)
- Focused Product Release (5 products, 2023)



Gaia spacecraft was passivated on 27 March 2025

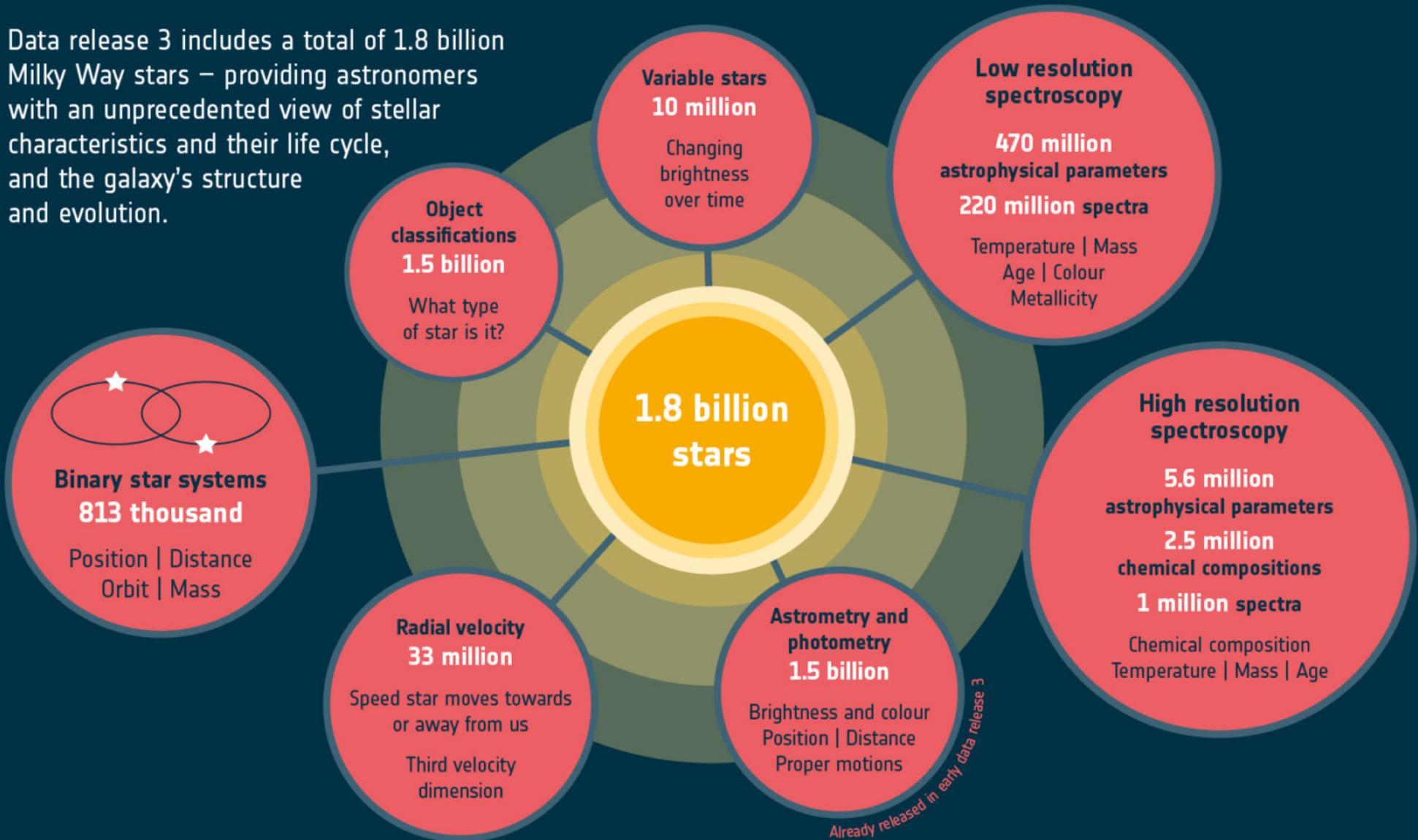
- Gaia exhausted its cold gas and stopped science observations on 15 January 2025
- Gaia was put in a heliocentric orbit and permanently switched off
- ESA news release: https://www.esa.int/Enabling_Support/Operations/Farewell_Gaia!_Spacecraft_operations_come_to_an_end
- Additional information: https://www.cosmos.esa.int/web/gaia/iow_20250327
- This is not the end of the mission



MILKY WAY STARS



Data release 3 includes a total of 1.8 billion Milky Way stars – providing astronomers with an unprecedented view of stellar characteristics and their life cycle, and the galaxy's structure and evolution.



Gaia DR4 preview: astrometric timeseries of Gaia BH3



GAIA: BLACK HOLES

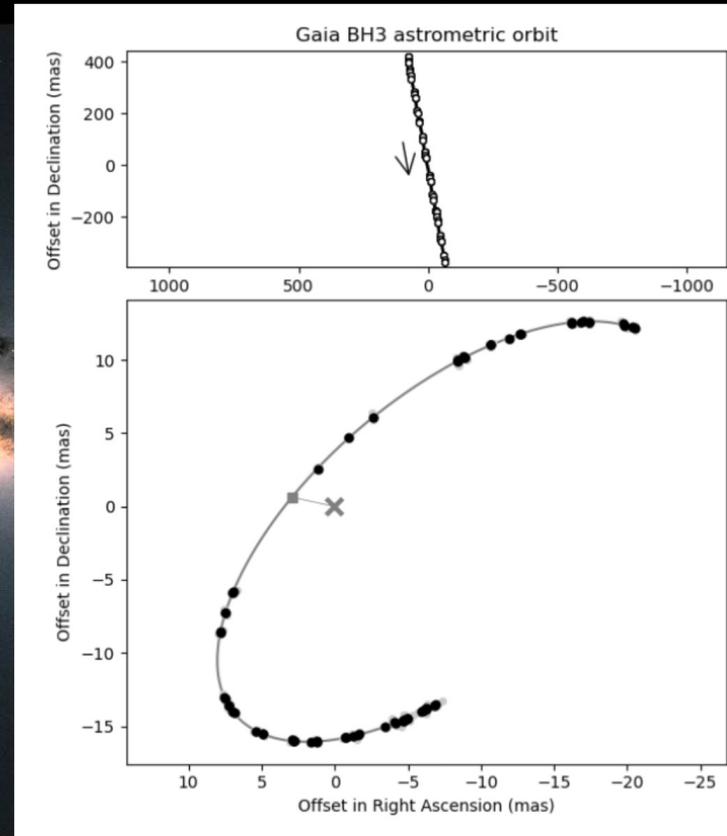
Preliminary astrometric timeseries of Gaia BH3 and an orbit-fitting notebook are public:

<https://github.com/esa/gaia-bhthree>



https://www.cosmos.esa.int/web/gaia/iow_20240416

https://www.esa.int/Science_Exploration/Space_Science/Gaia/Sleeping_giant_surprises_Gaia_scientists



Gaia and ESA resources at your fingertips



- Please acknowledge the use of Gaia data in your research: <https://www.cosmos.esa.int/web/gaia-users/credits>
- Information for Gaia scientific community: <https://www.cosmos.esa.int/web/gaia>
- Receive Gaia data user notifications by signing up for the Gaia Bulletin emailing list: <https://www.cosmos.esa.int/web/gaia/bulletin>
- Interested in boosting the visibility of your Gaia-related research with an ESA news release? See <https://www.cosmos.esa.int/web/gaia/communicating-your-results>
- Information on **ESA Archival Research Visitor Programme**: <https://www.cosmos.esa.int/web/esdc/visitor-programme> (next deadline 31 October 2025)
- Information on **ESA Research Fellowships in Space Science**: <https://www.cosmos.esa.int/web/space-science-faculty/opportunities/research-fellowships> (next call end August with a deadline mid-September 2025)



Motions of stars

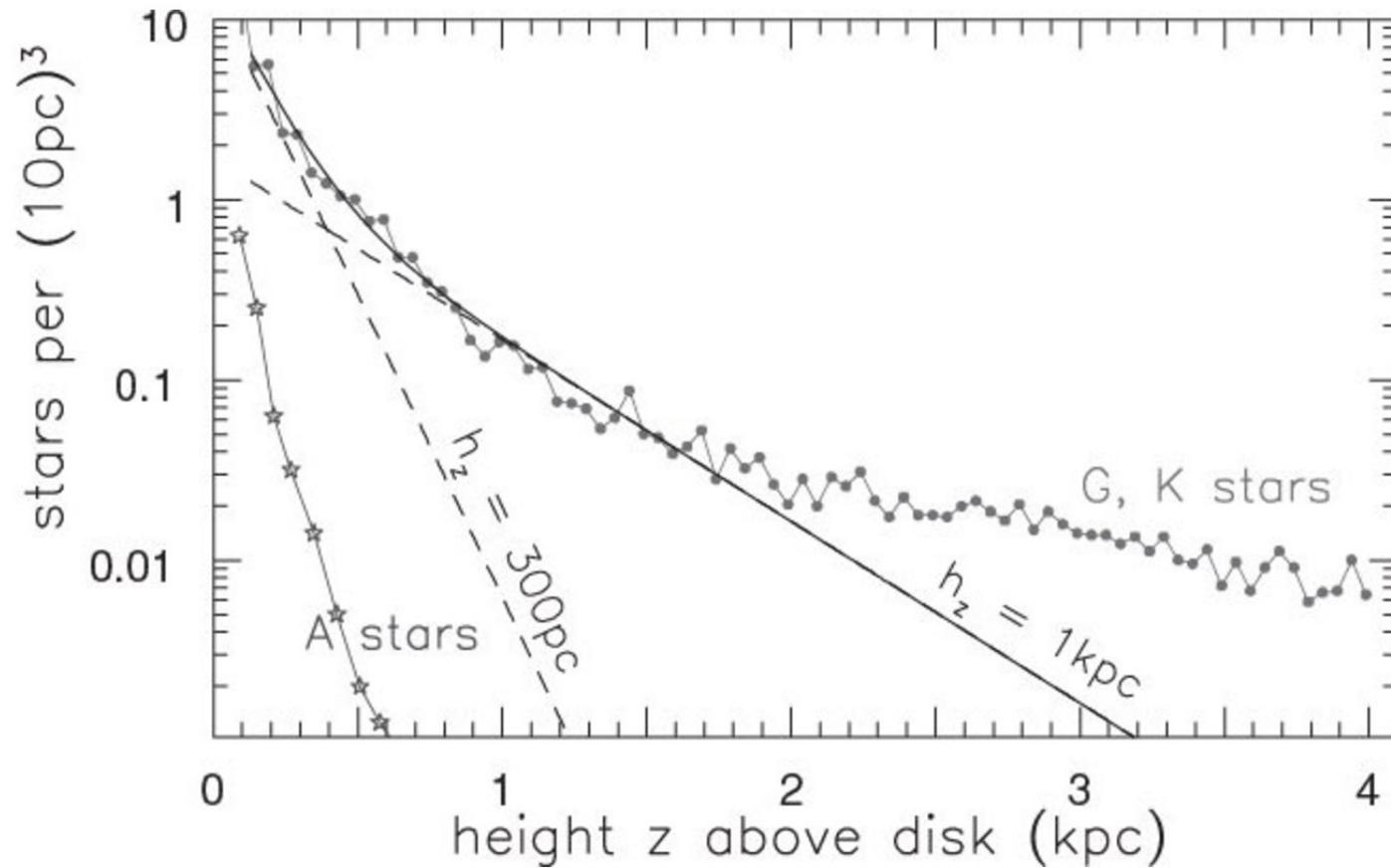
Radial velocities can be obtained from Doppler shifts

Transverse velocities require measuring the proper motion in the sky

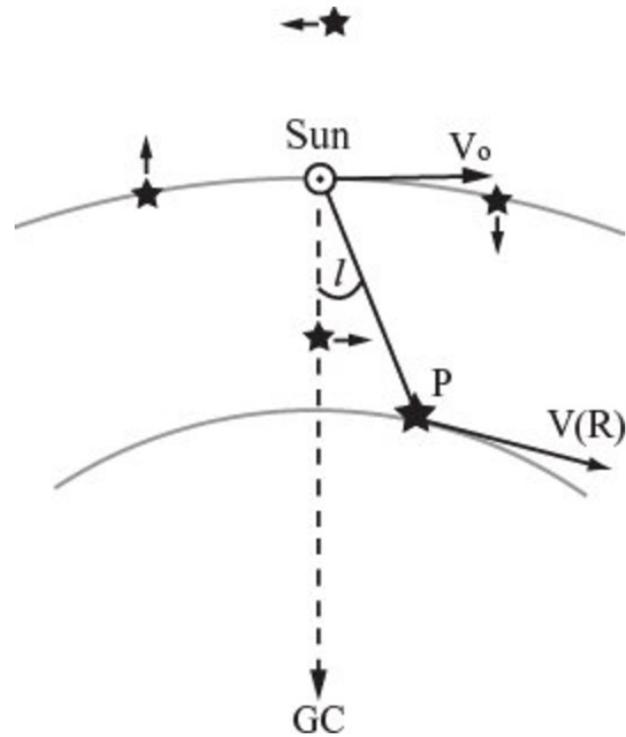
$$V_t = \mu \text{ (radians/time)} \times d, \text{ or } \mu \text{ (0.001''/year)} = \frac{V_t \text{ (km s}^{-1}\text{)}}{4.74 \times d \text{ (kpc)}}.$$

If we know how V_r and V_t are related then V_r and V_t give distance

Distribution of Stars



Galactic Rotation



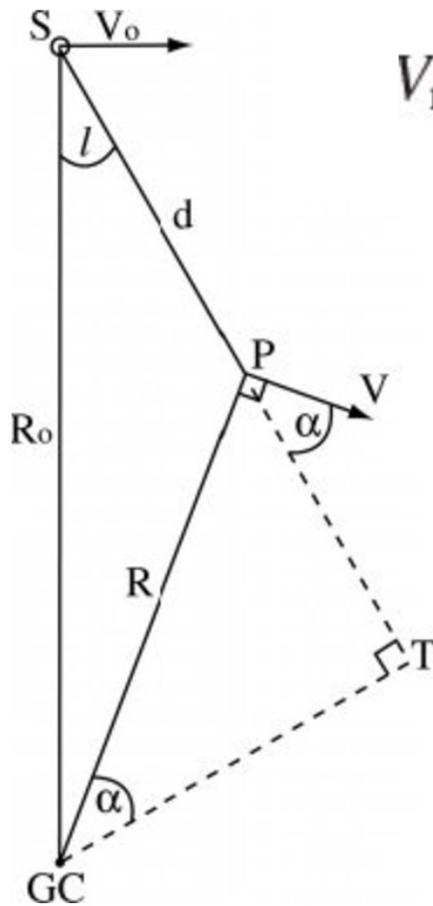
R_0 = distance to galactic center = 8 kpc

V_0 = Sun's orbital motion around GC = 200 km/s

1 "galactic year" = 250 Million years

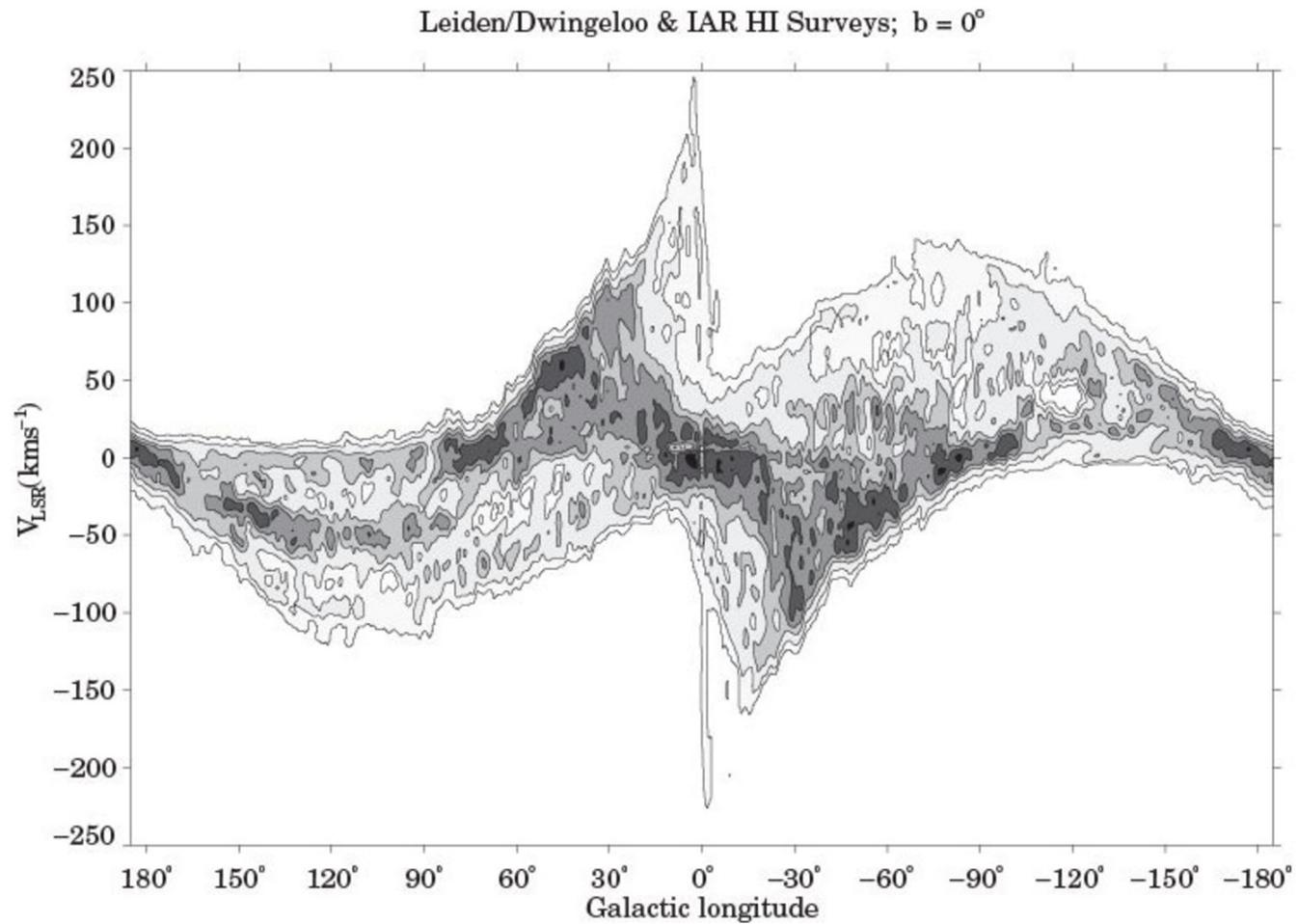
Radial Velocities of Stars/Gas

You are here -->



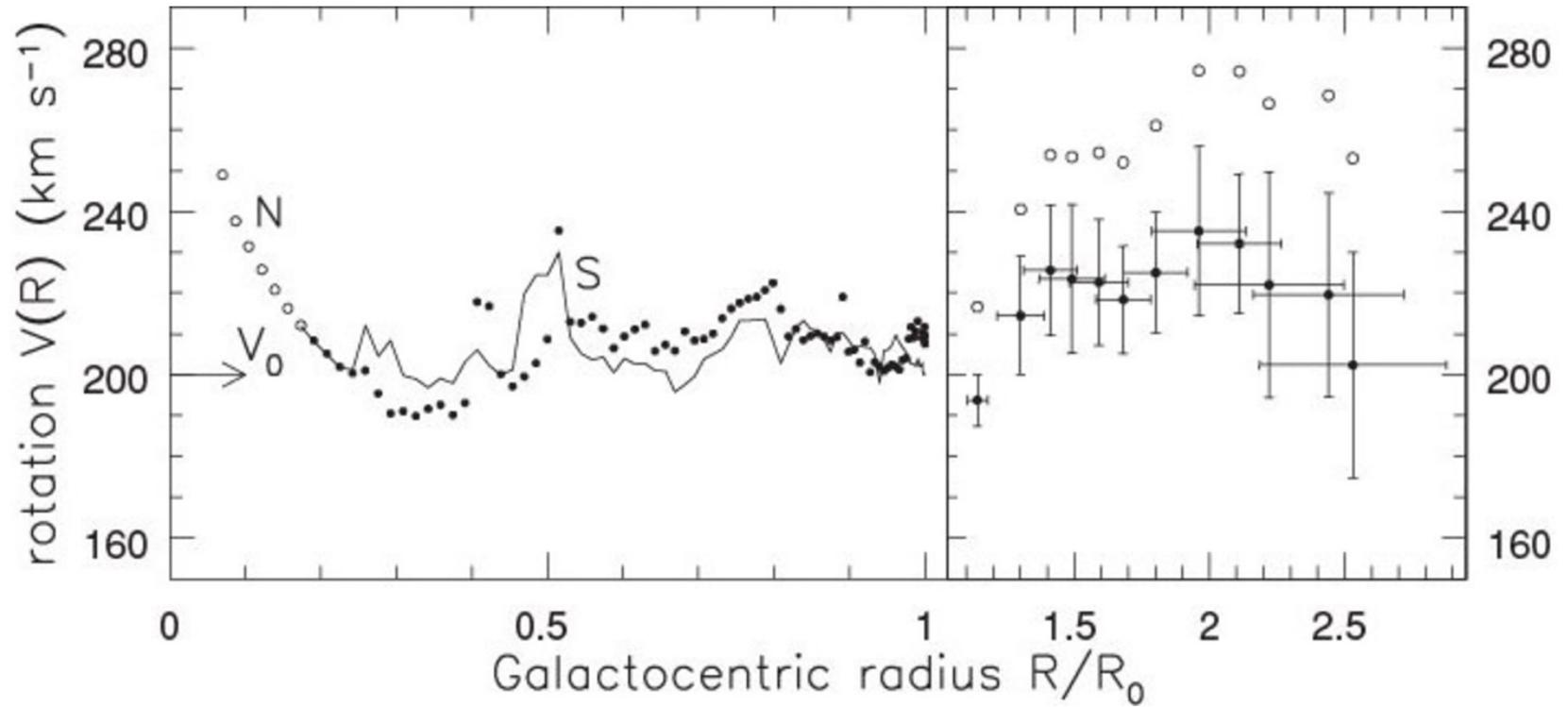
$$V_r = R_0 \sin l \left(\frac{V}{R} - \frac{V_0}{R_0} \right).$$

Observed velocity of HI gas



- **Worksheet:** For a simple model of the Galaxy with $R_0 = 8$ kpc and gas in orbit with $V(R)=220$ km/s everywhere, find the radial velocity we would observe $V_r(l)$ for gas in a circular orbit at $R=4$ kpc and $\phi = \pm 90$ degrees in galactic azimuth. Make a sketch of V_r vs l (galactic longitude).

MW Rotation Curve from HI gas



MW Rotation Curve from Gaia

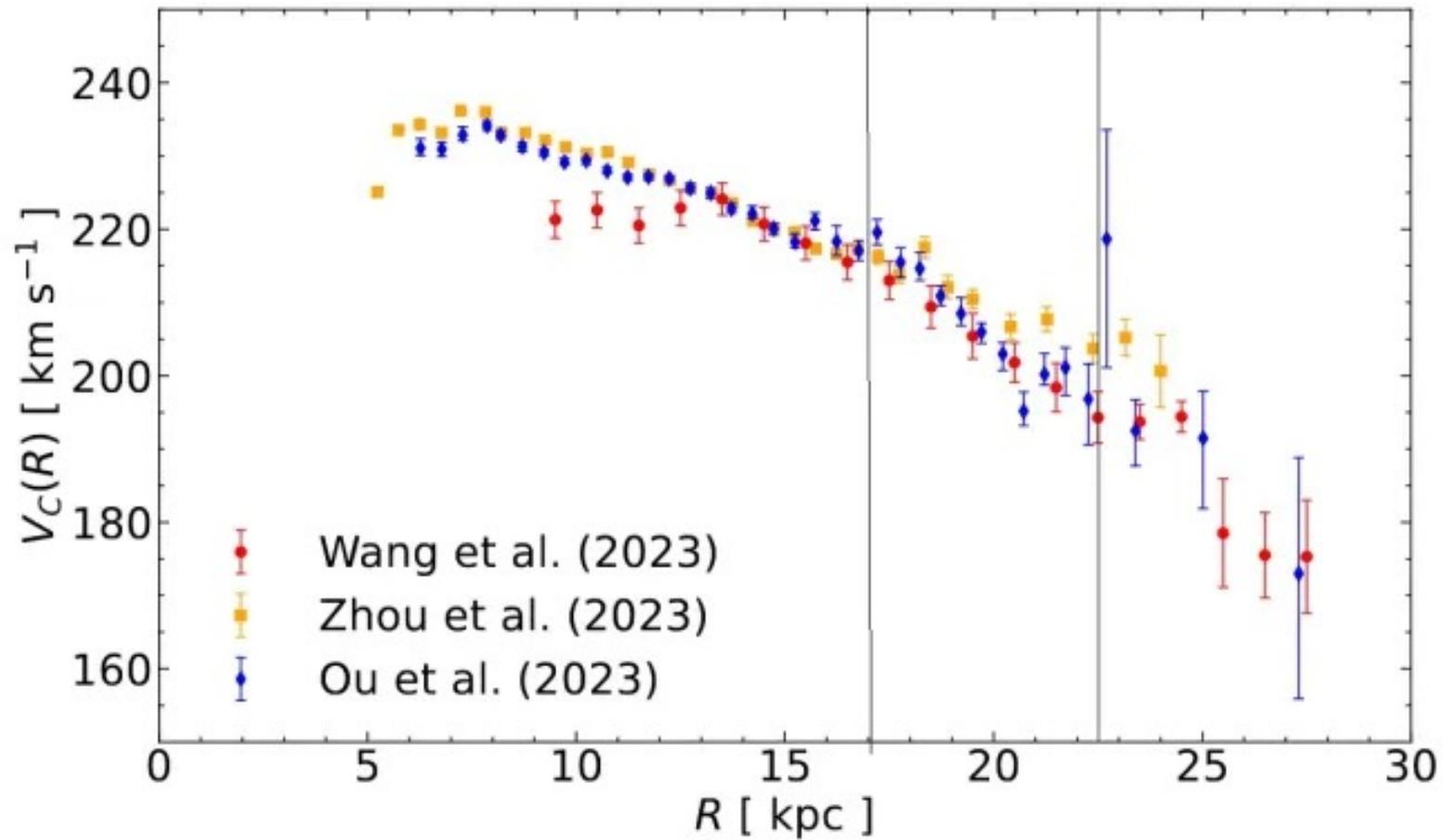


Fig. 1. Comparison of the 3 different measurements of the MW rotation curve based on *Gaia* DR3.

Dark Matter

- Flat rotation curve implies unseen mass in the outer parts of the galaxy.

$$M(<R) = RV^2/G$$

Take for the Sun $M/L = 1$ in the visible

Brown Dwarf ~ 100 in the visible

Galaxy ~ 10 in the visible

Outer parts of the Milky Way ~ 10 (see problem 2.19)