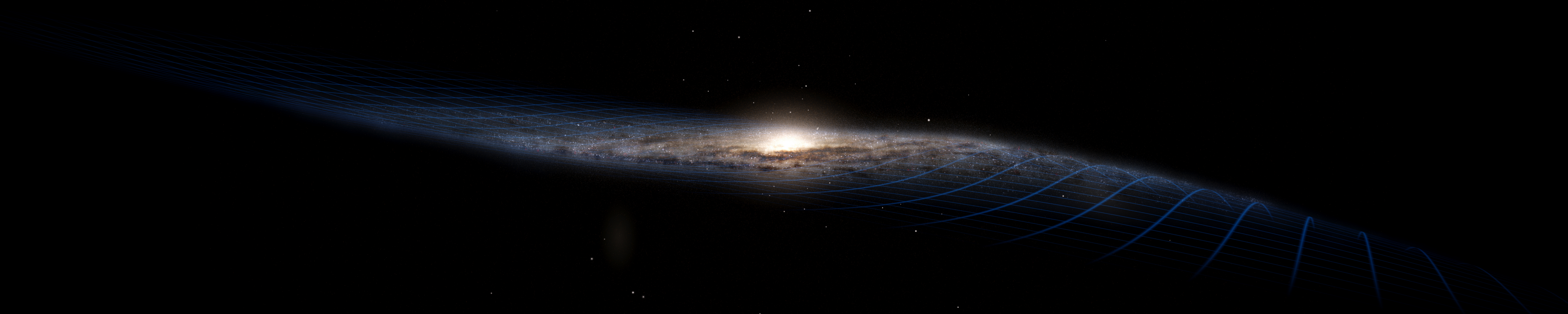
Three-dimensional structure and chemo-dynamical evolution of the Milky Way



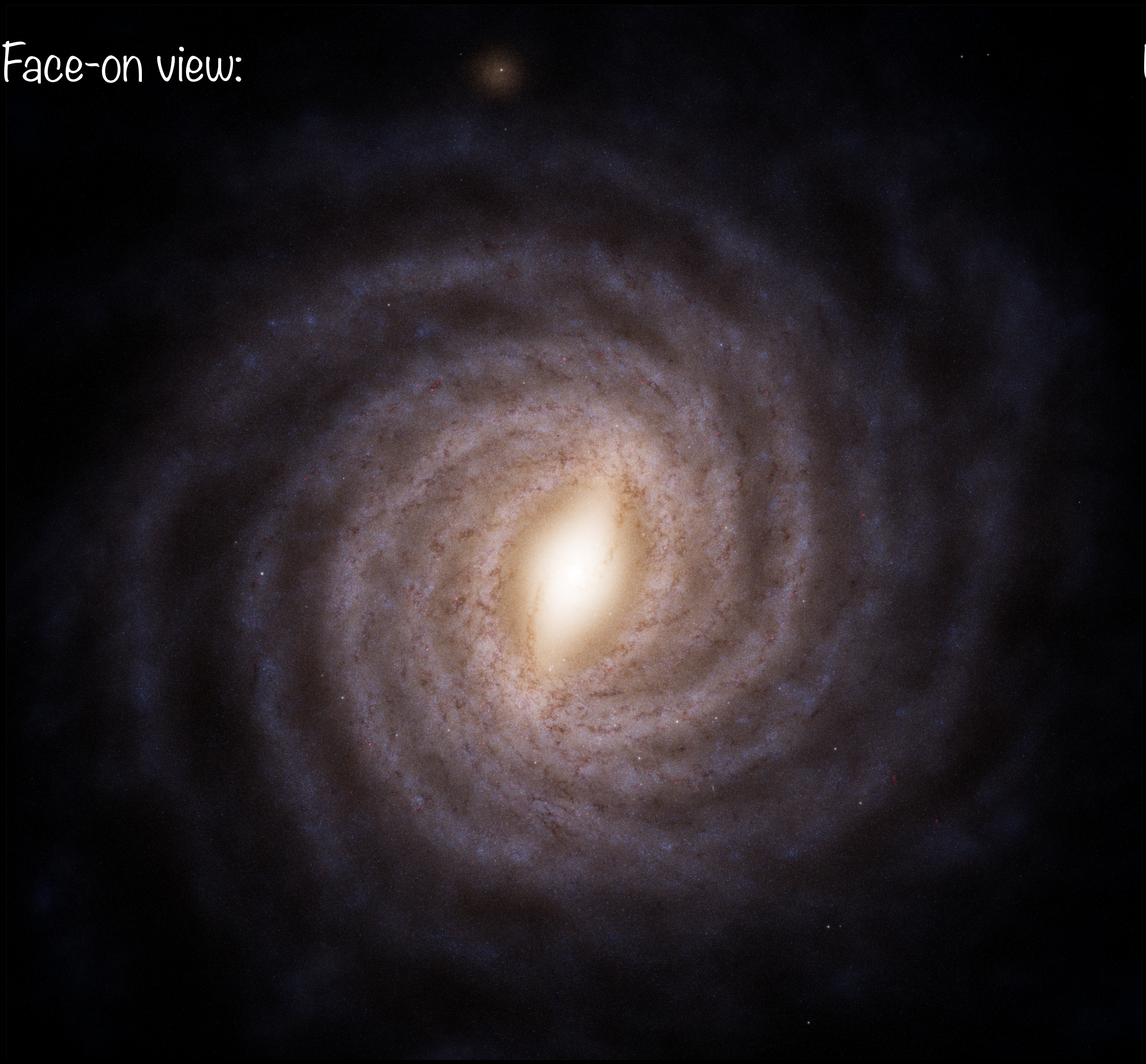
ELOISA POGGIO

INAF - Osservatorio Astrofisico di Torino

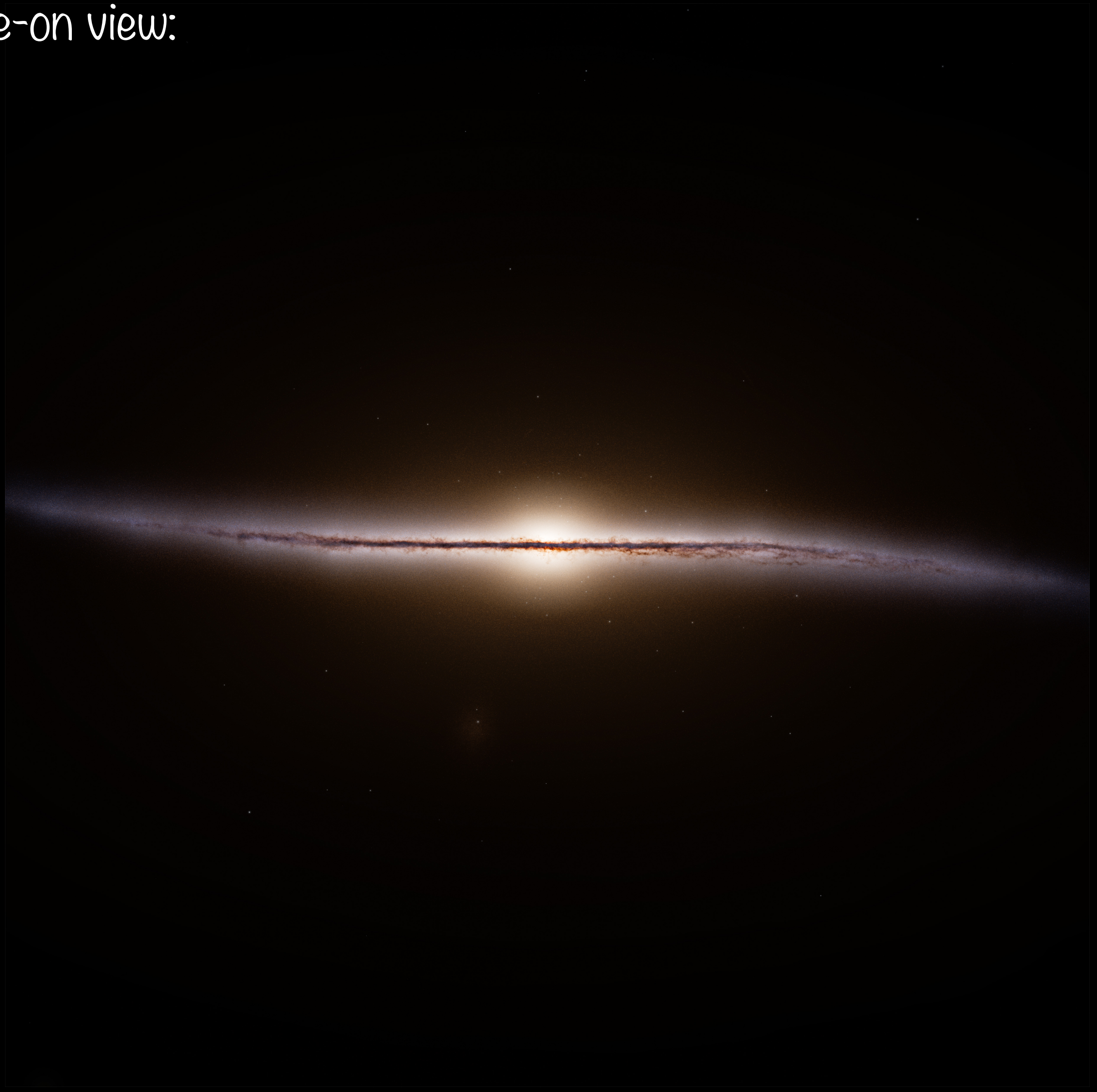
How does the Milky Way look like?

Three-dimensional structure

Face-on view:



Edge-on view:

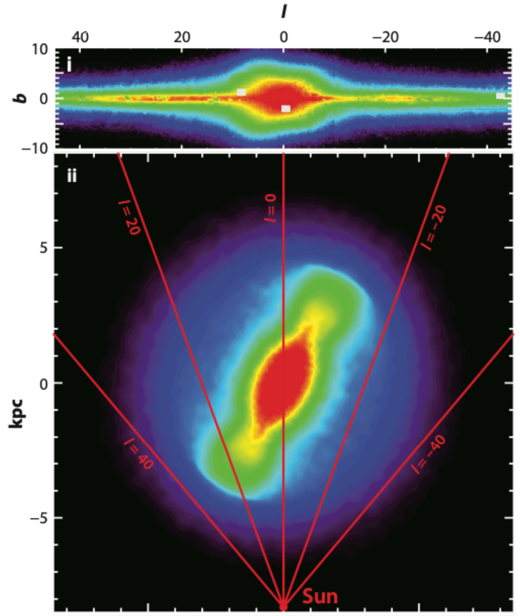


Credits: ESA/Gaia/DPAC, Stefan Payne-Wardenaar

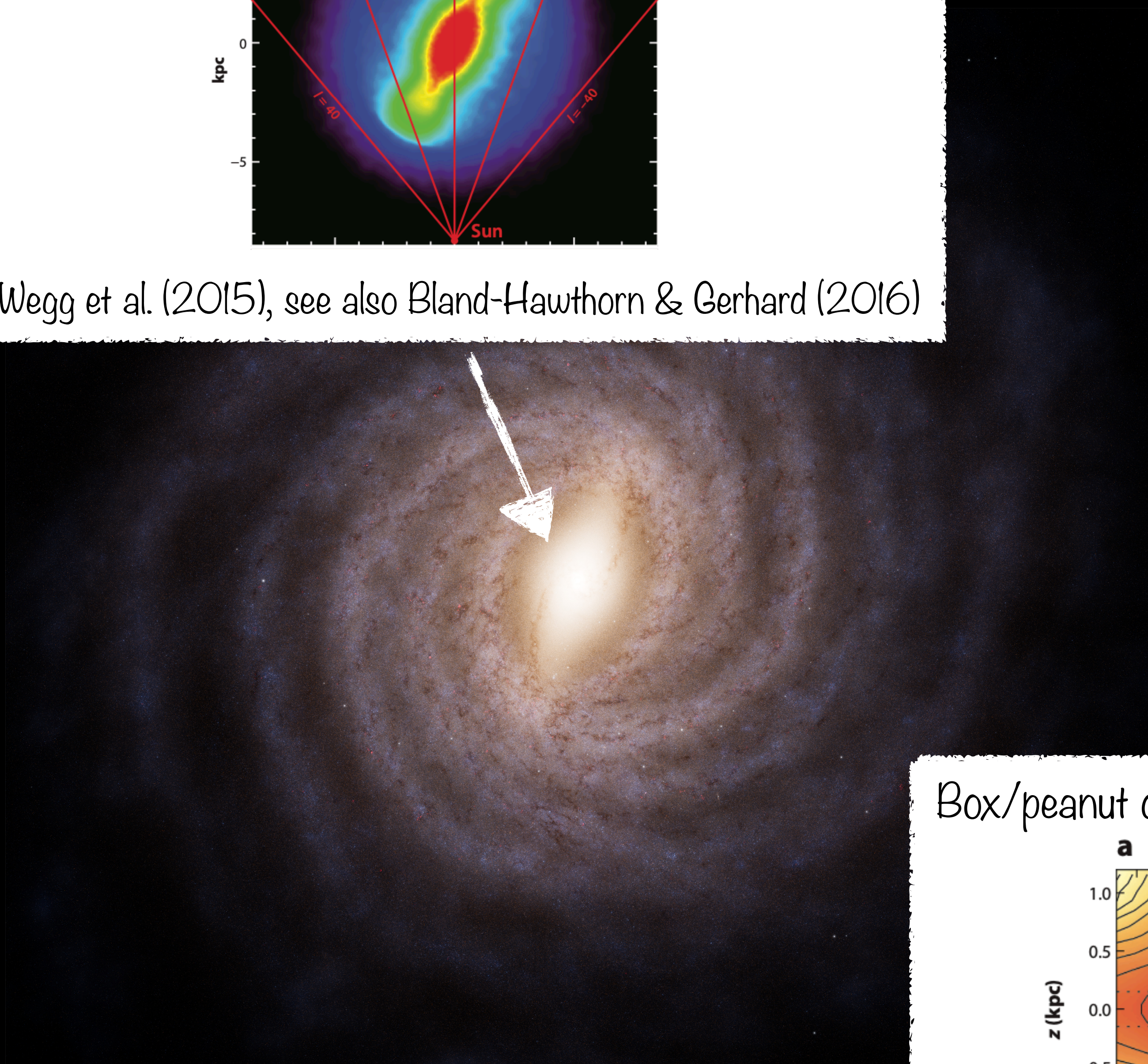
Artist impression based on data from ESA's Gaia space telescope

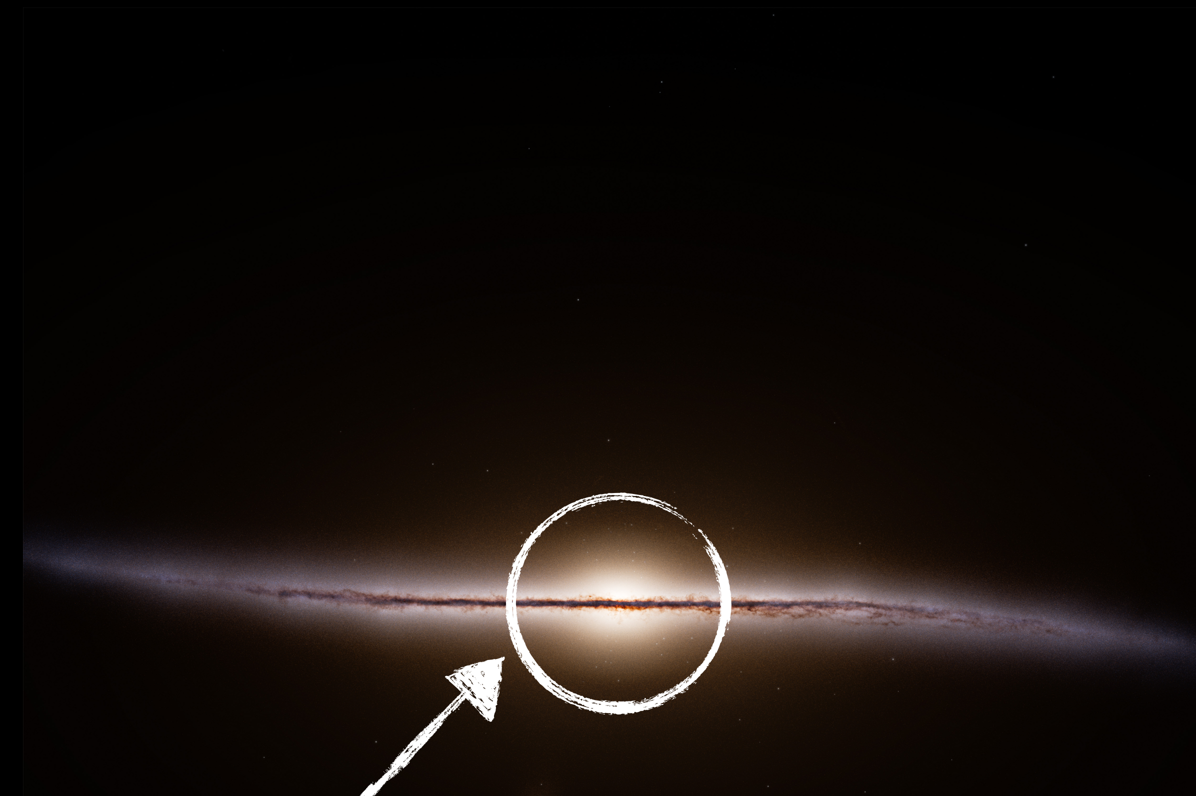
Three-dimensional structure

Central bar:

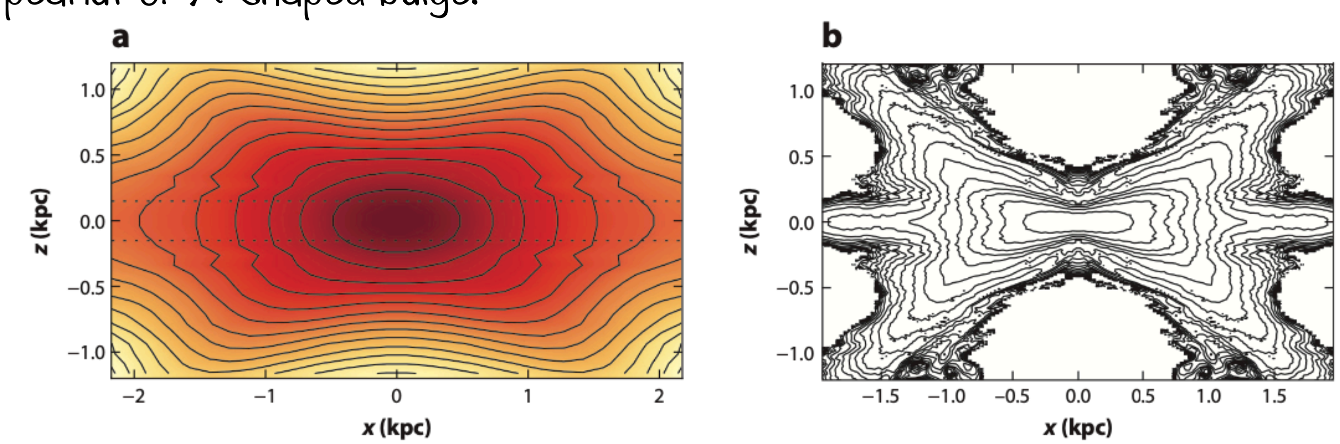


Wegg et al. (2015), see also Bland-Hawthorn & Gerhard (2016)





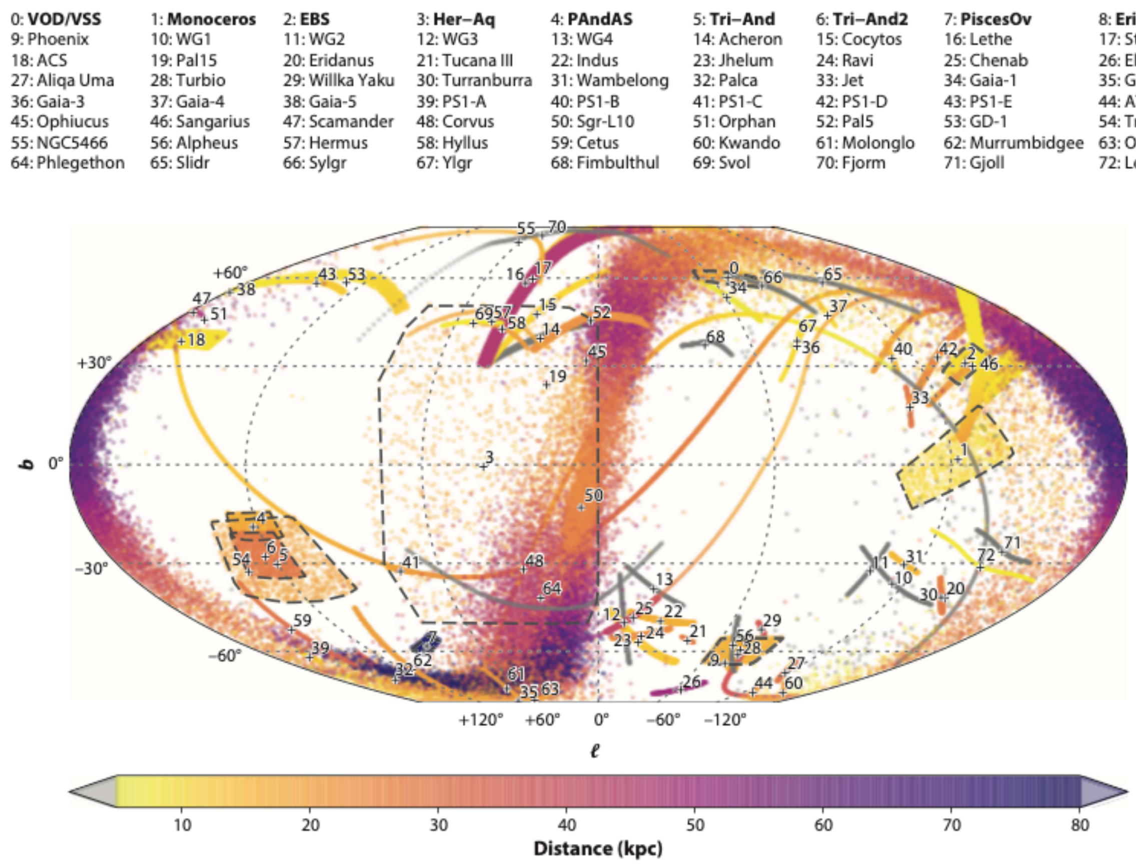
Box/peanut or X-shaped bulge:



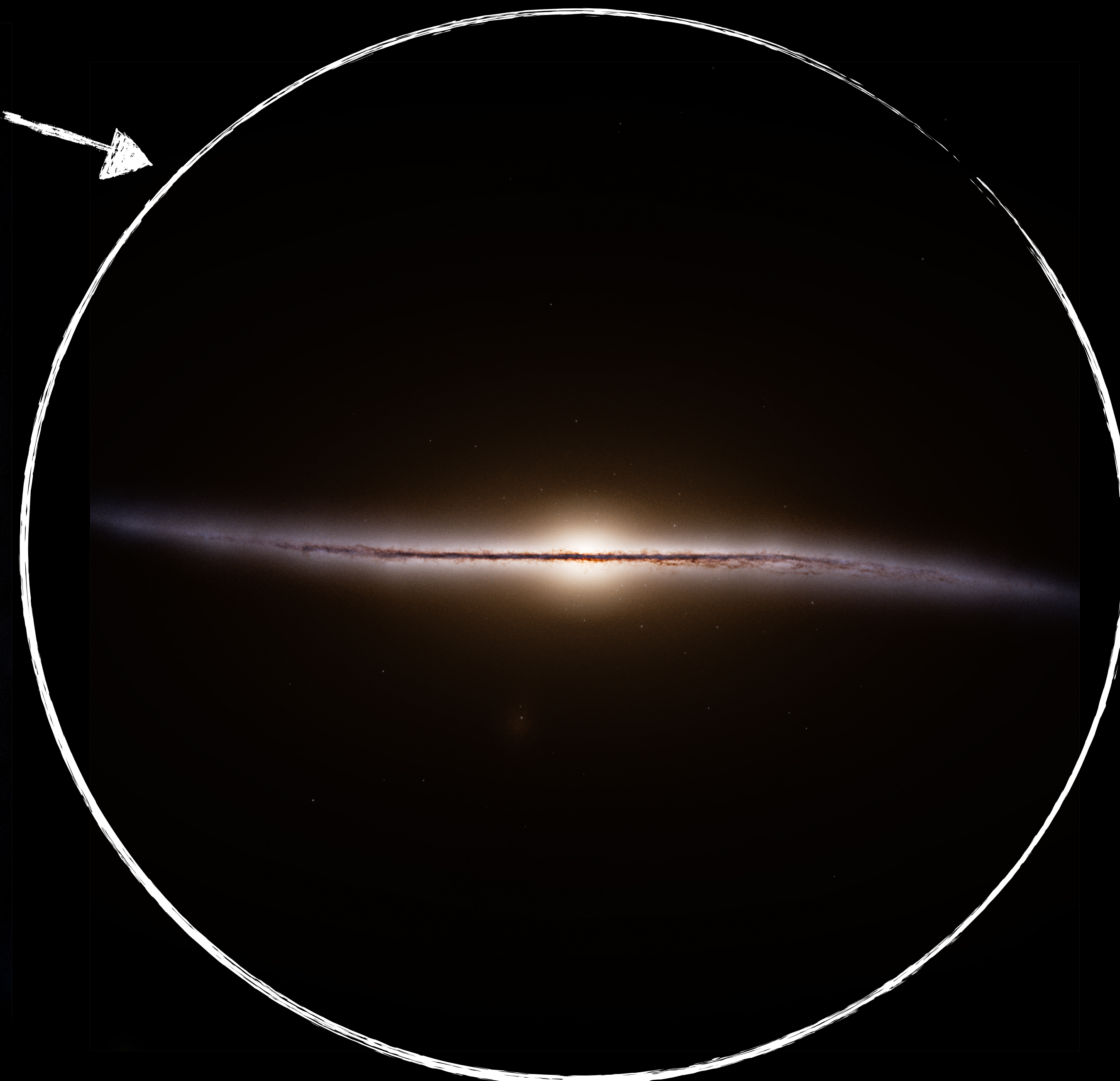
Portail et al. (2015), data from Wegg & Gerhard (2013)

Three-dimensional structure

Known streams and overdensities in the stellar halo:



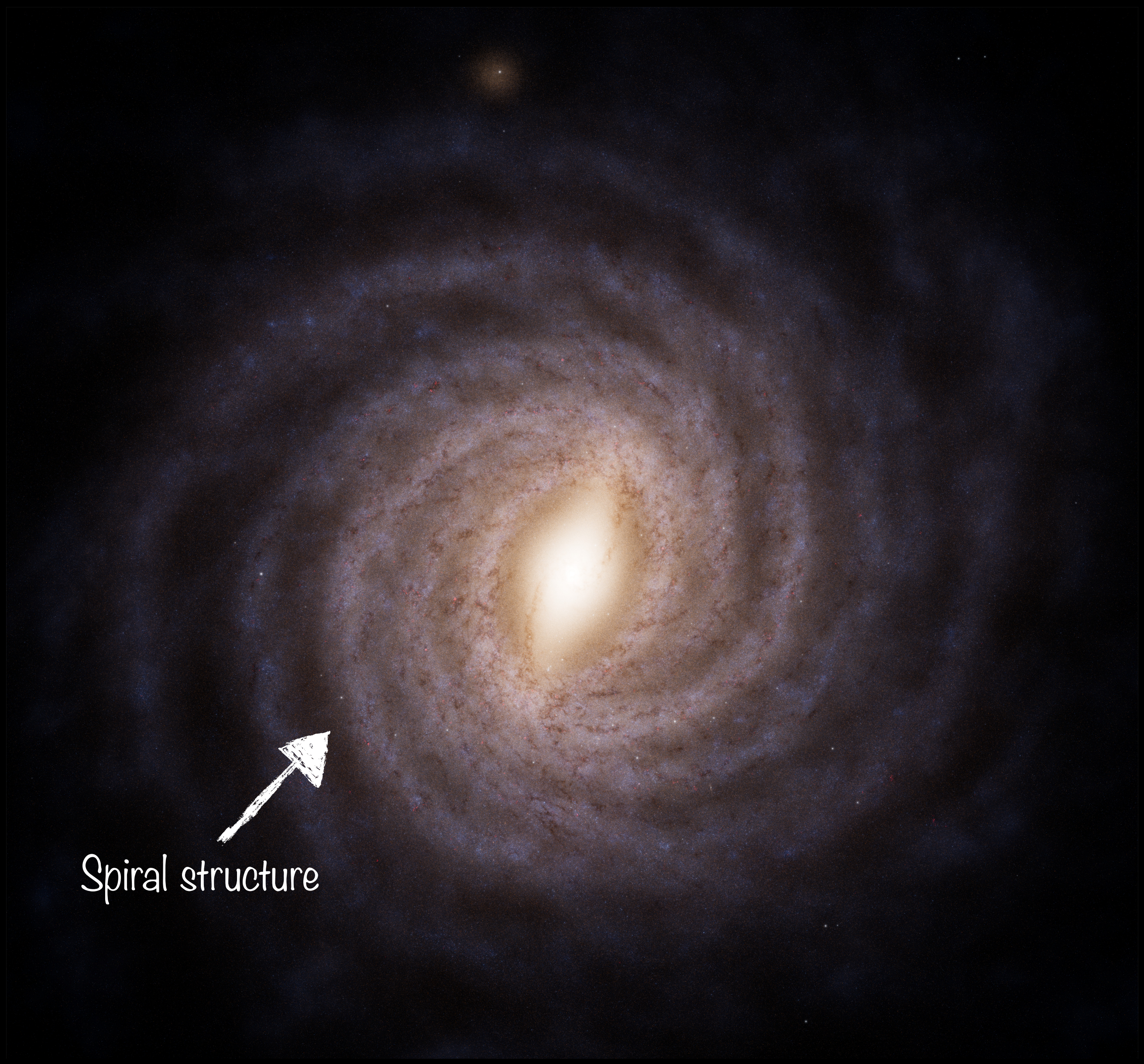
Helmi (2020), based on the Galstreams package by Mateu et al. (2018)



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

Artist impression based on data from ESA's Gaia space telescope

Three-dimensional structure

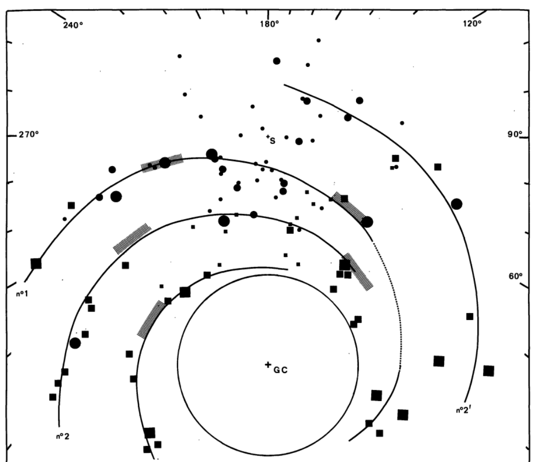


Credits: ESA/Gaia/DPAC, Stefan Payne-Wardenaar

Artist impression based on data from ESA's Gaia space telescope

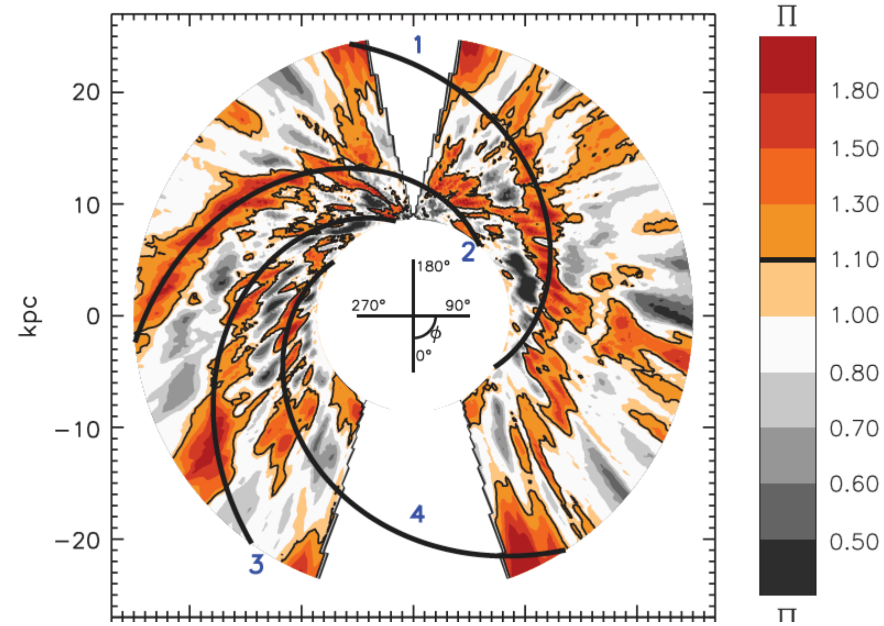
Galactic spiral structure

HII regions



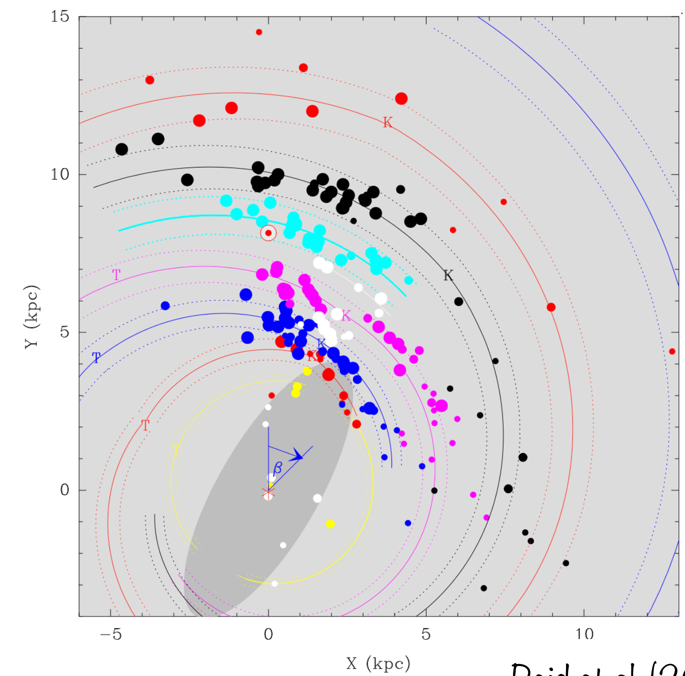
Georgelin & Georgelin (1976)
See also: Taylor & Cordes (1993)
Bland-Hawthorn & Maloney (2002)

HI density



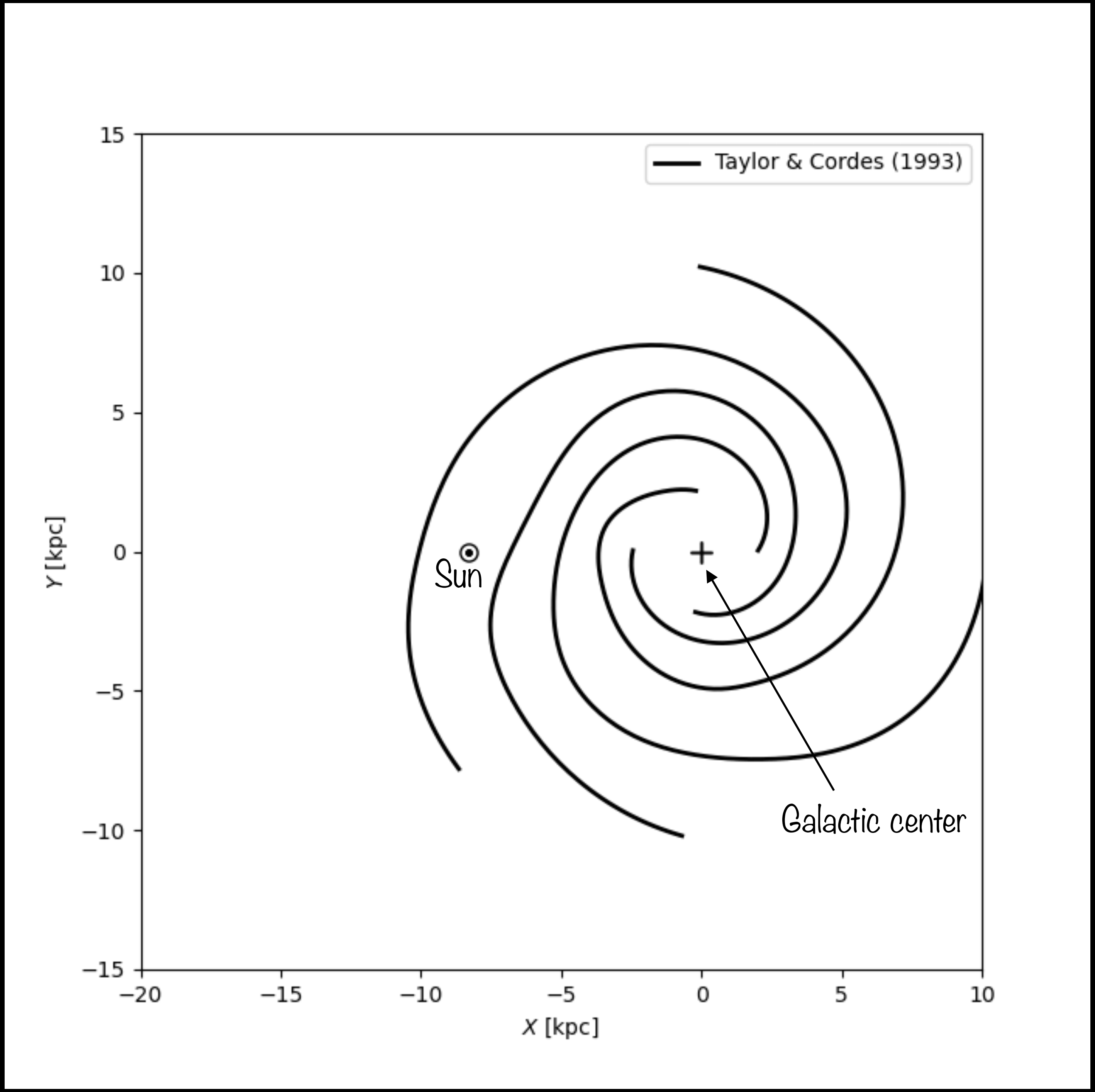
Levine et al. (2006)

Masers



Reid et al. (2019)

Galactic spiral structure

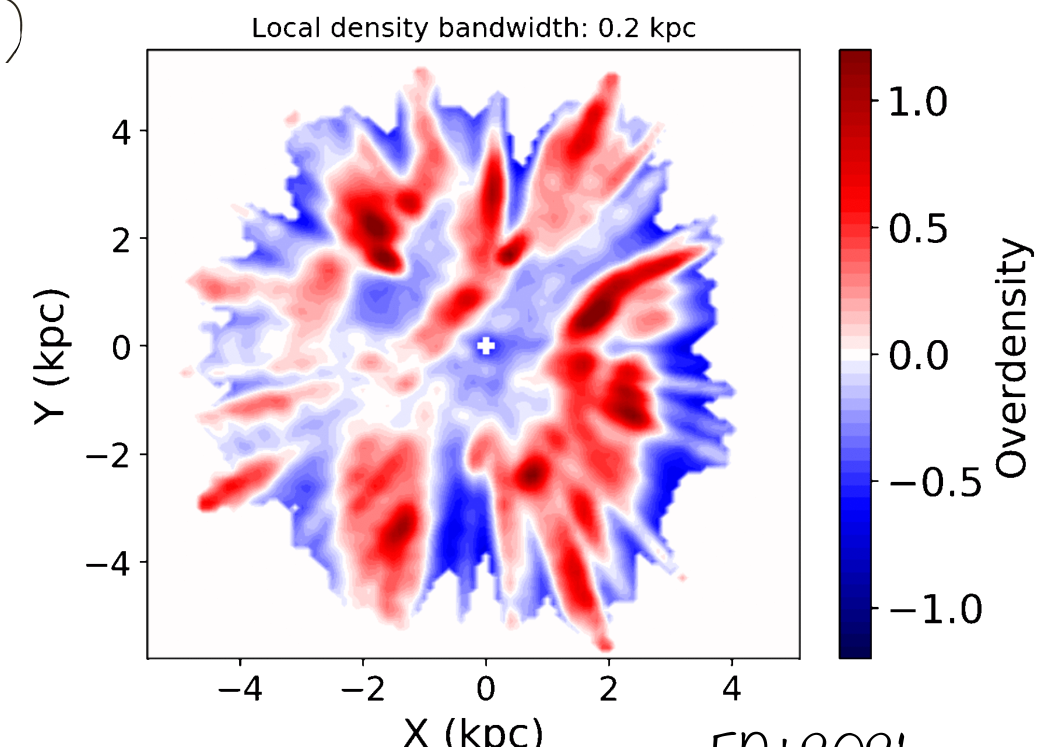


Mapping the spiral structure with Gaia

Young stellar populations → See talks by Mario Giuseppe Guarcello, Giuseppe Germano Sacco and Da Eun Kang

~ 600 000 Upper Main Sequence (UMS) stars

Map of the relative over/under-dense regions



EP+2021

3 (possibly 4) clumpy but coherent segments

"Shadow cones" produced by foreground extinction

The Local arm is not so local! (at least 8 kpc!)

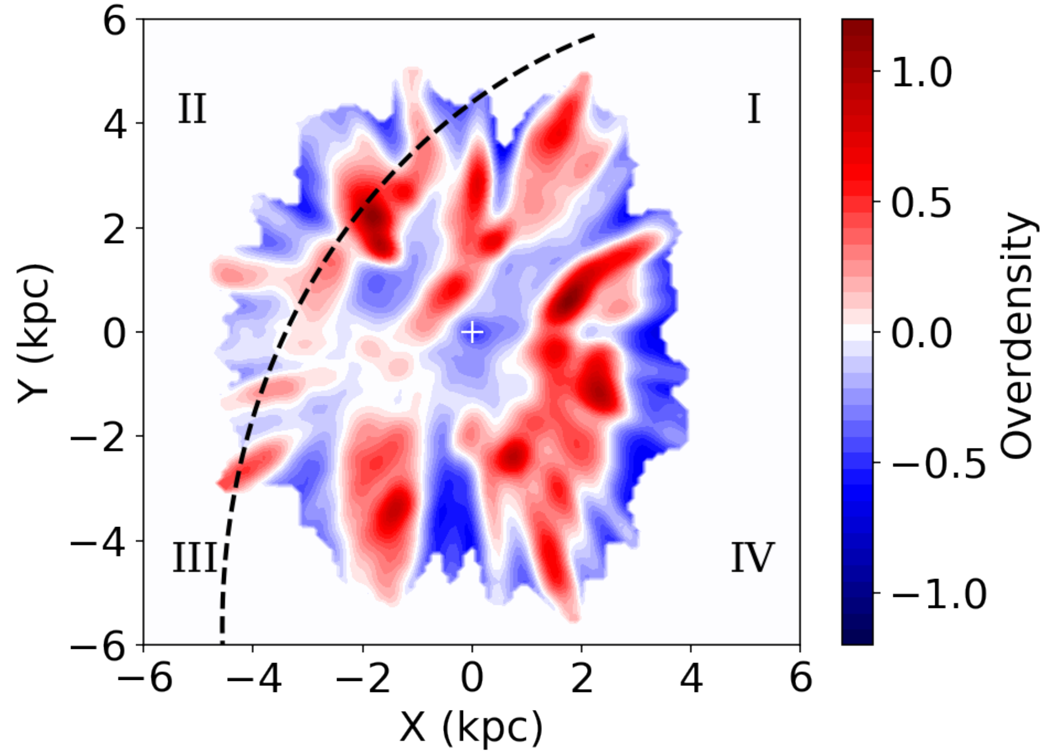
Good agreement with the distribution of young Open Clusters from Cantat-Gaudin+2020, Hunt+2023, Cavallo+2024

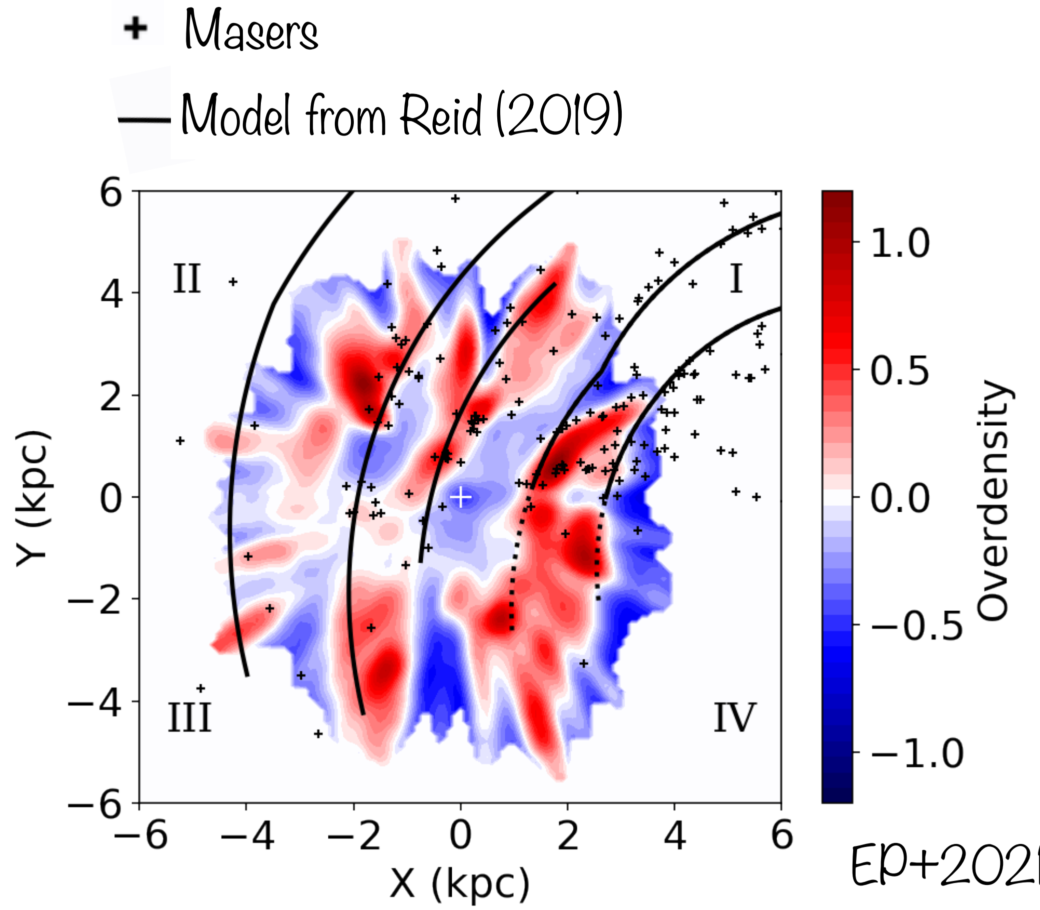
Mapping the spiral structure with Gaia

Young stellar populations → See talks by Mario Giuseppe Guarcello, Giuseppe Germano Sacco and Leonardo Testi

Comparison with previous models:

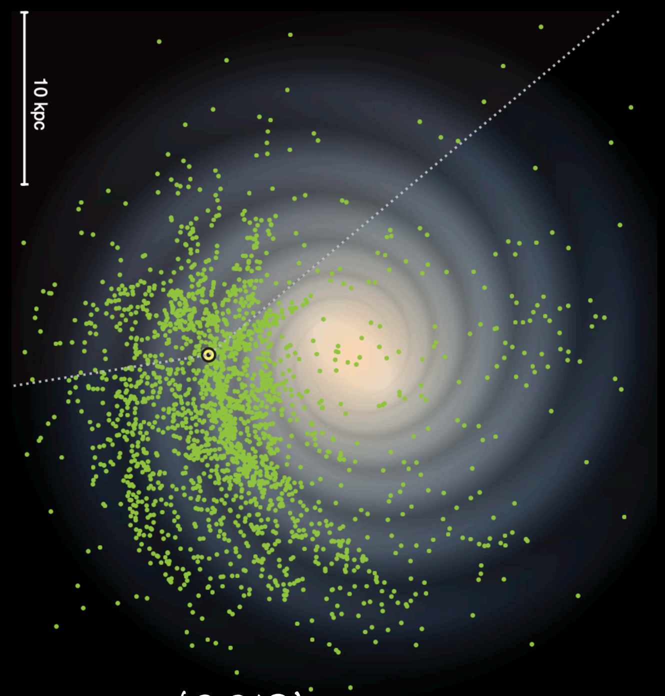
Levine et al. (2006), Arm n.2





EP+2021

Spiral structure based on Cepheids

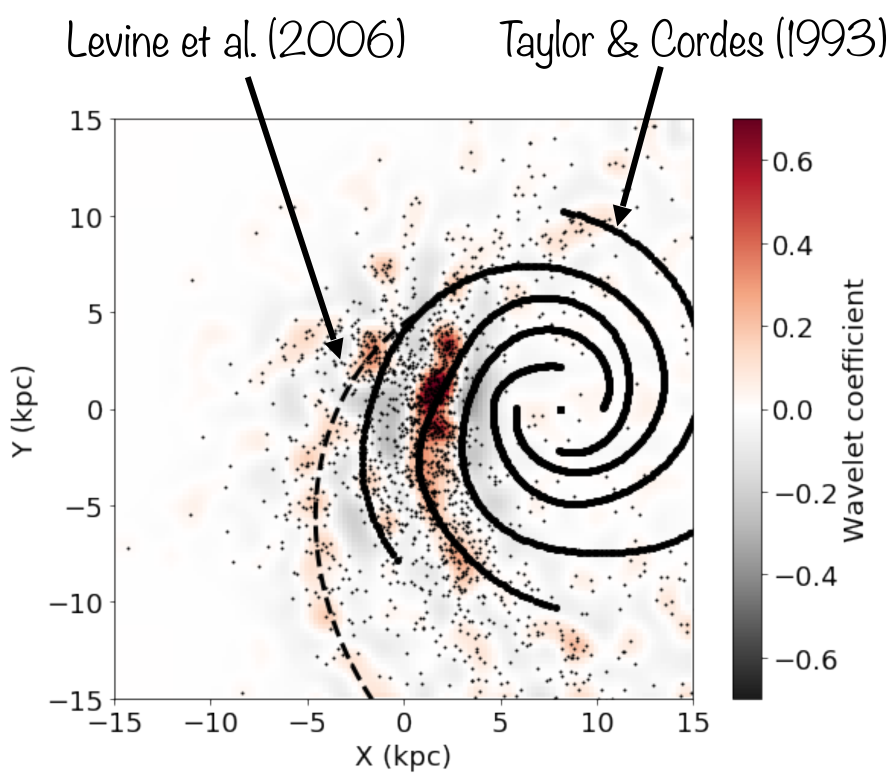


Skowron et a. (2019)

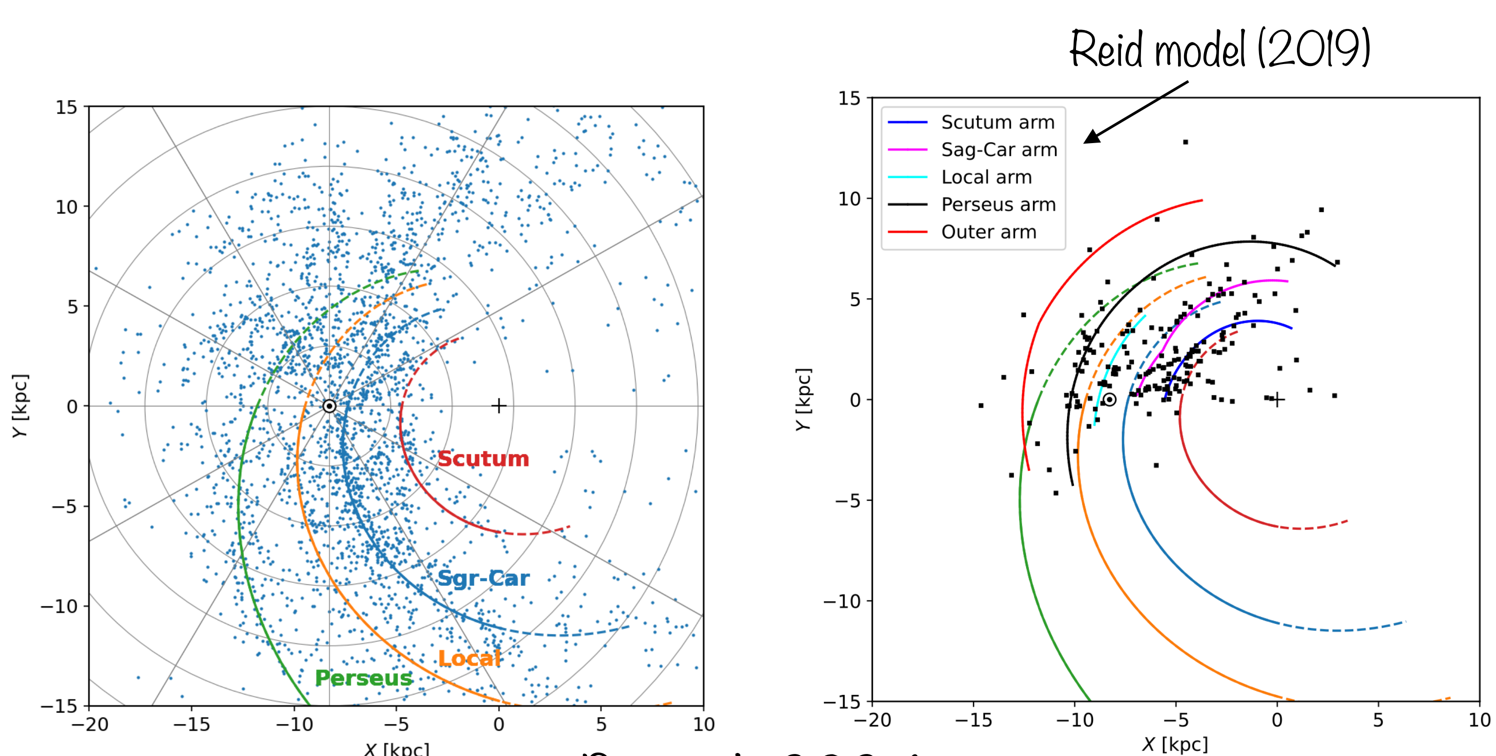
Classical Cepheids: the archetype of the standard candle

(see for example Ripepi+2019, Inno+2021, Bono+2024 and others)

→ See Erasmo Trentin's talk

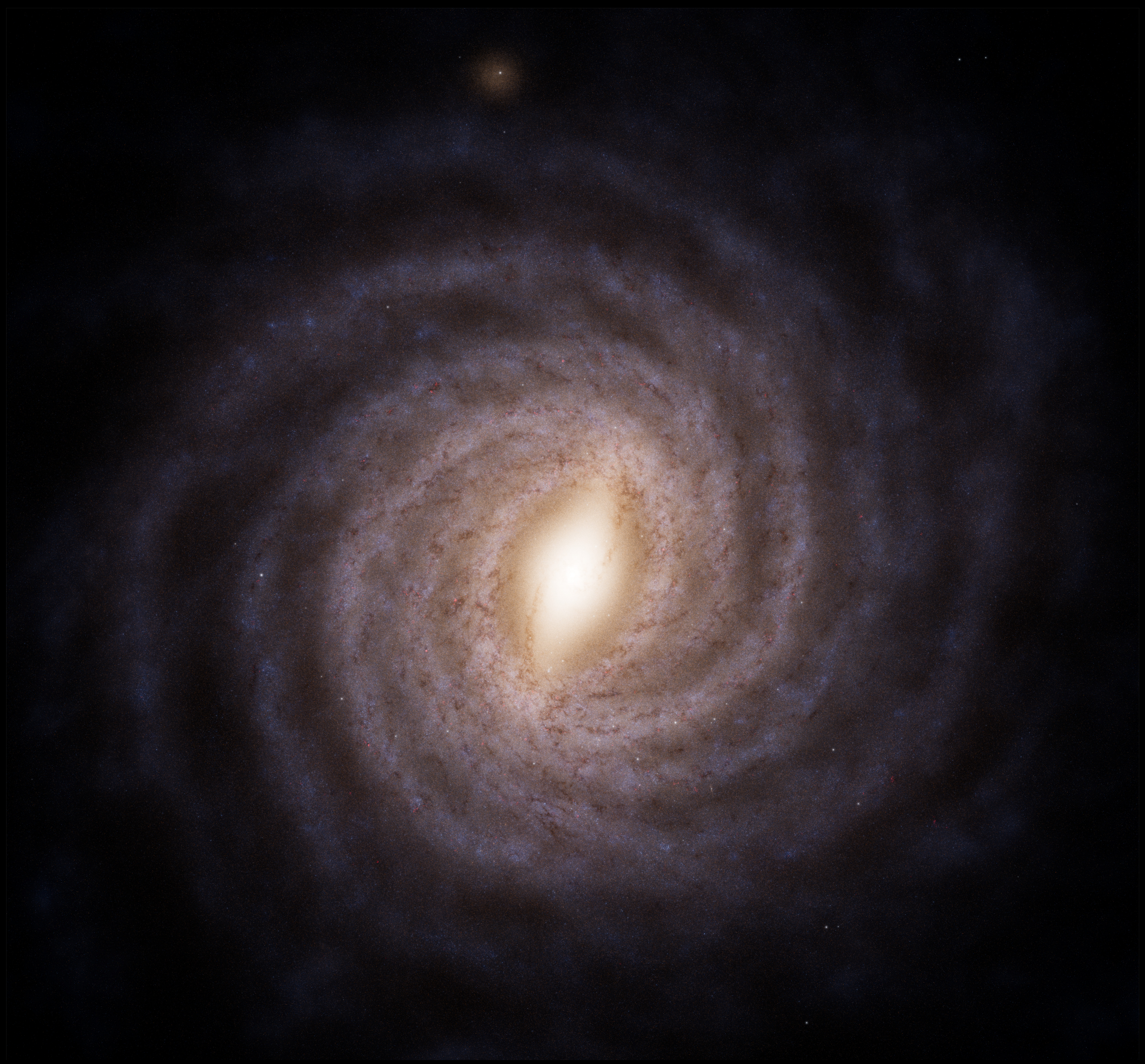


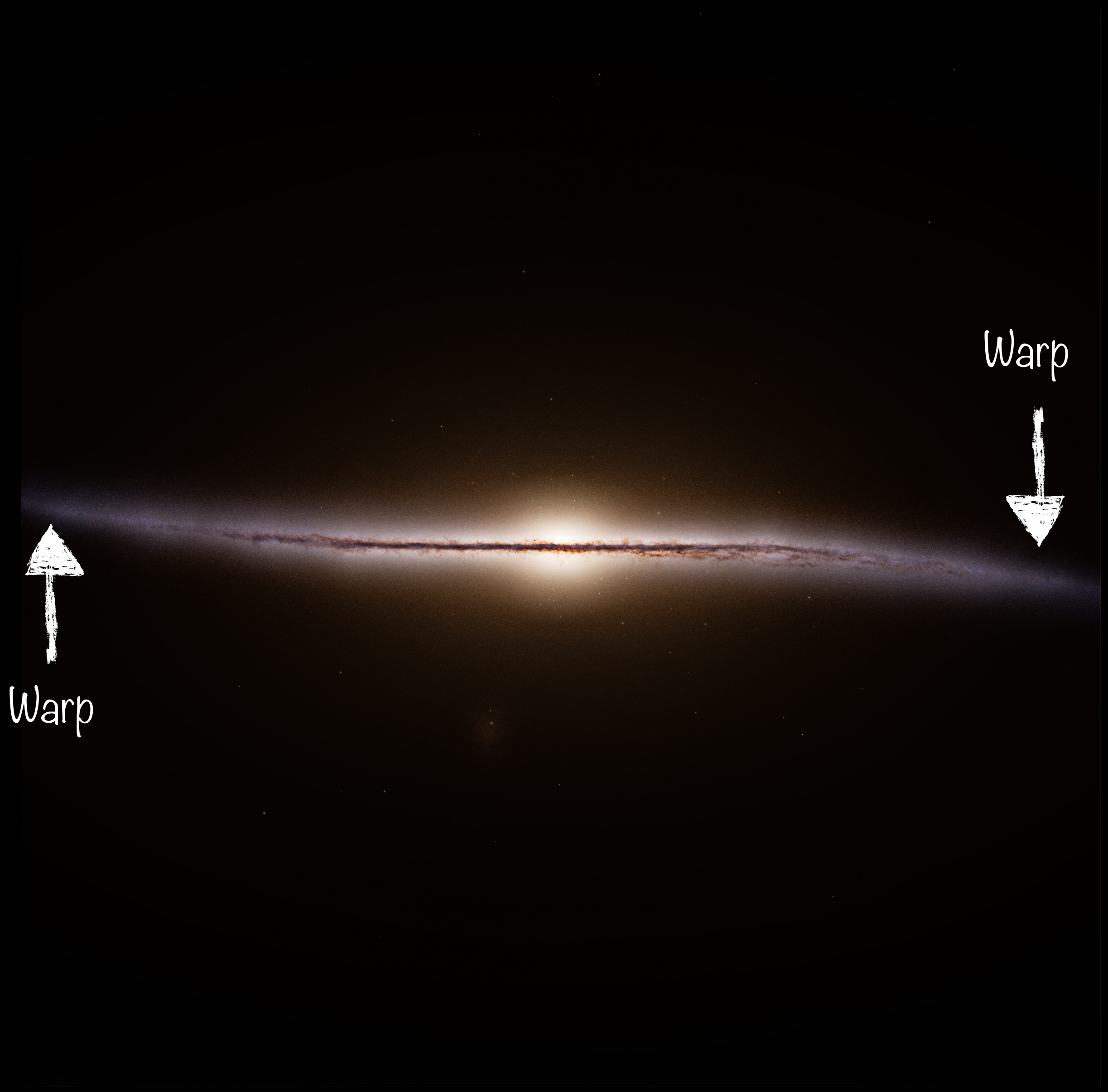
EP+2021



Drimmel+2024

Three-dimensional structure



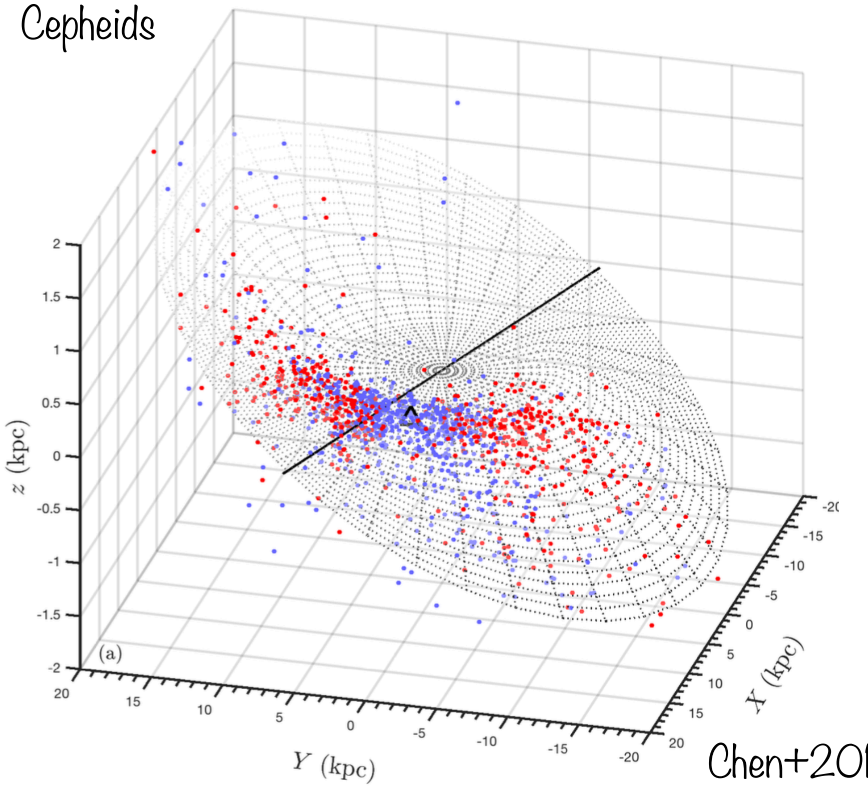


Credits: ESA/Gaia/DPAC, Stefan Payne-Wardenaar

Artist impression based on data from ESA's Gaia space telescope

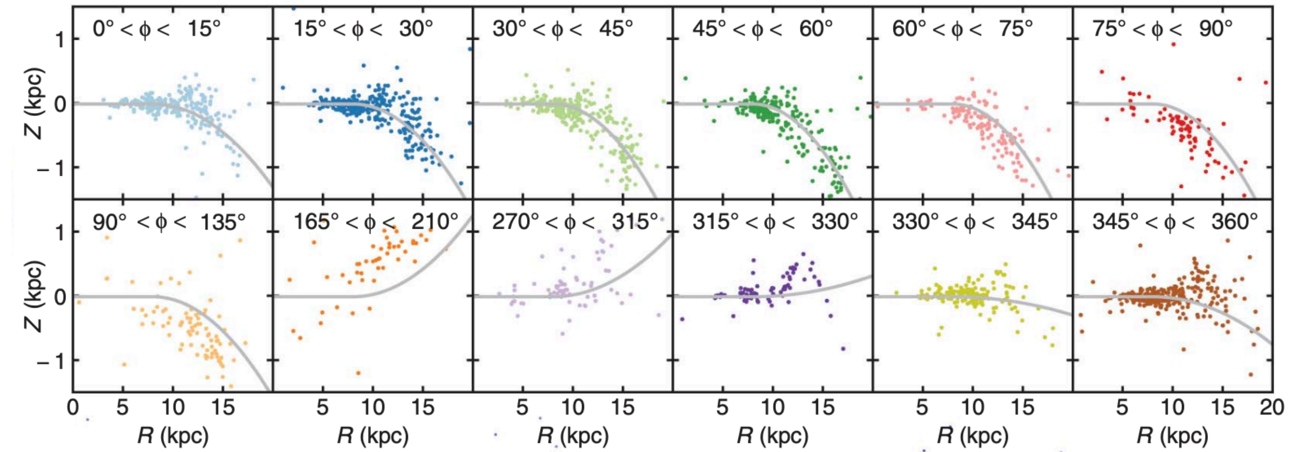
Vertical structure: the Galactic warp

Cepheids



Chen+2019

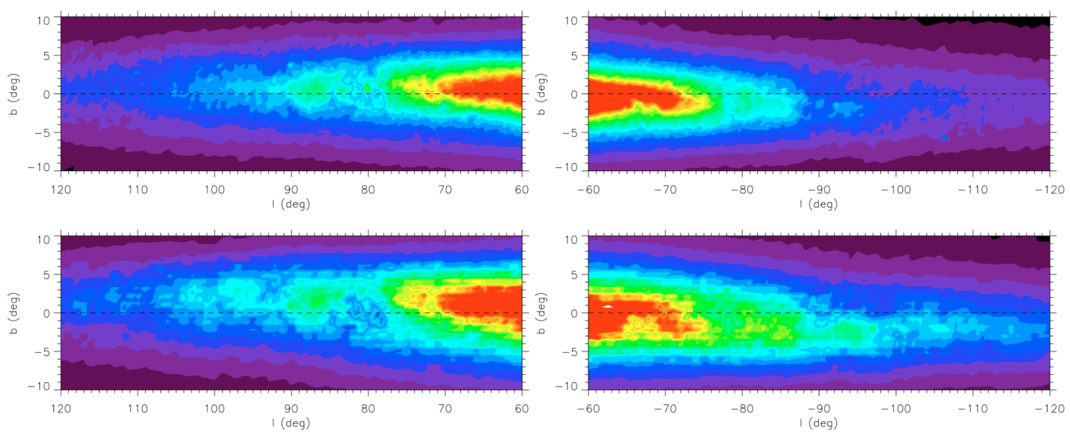
Cepheids



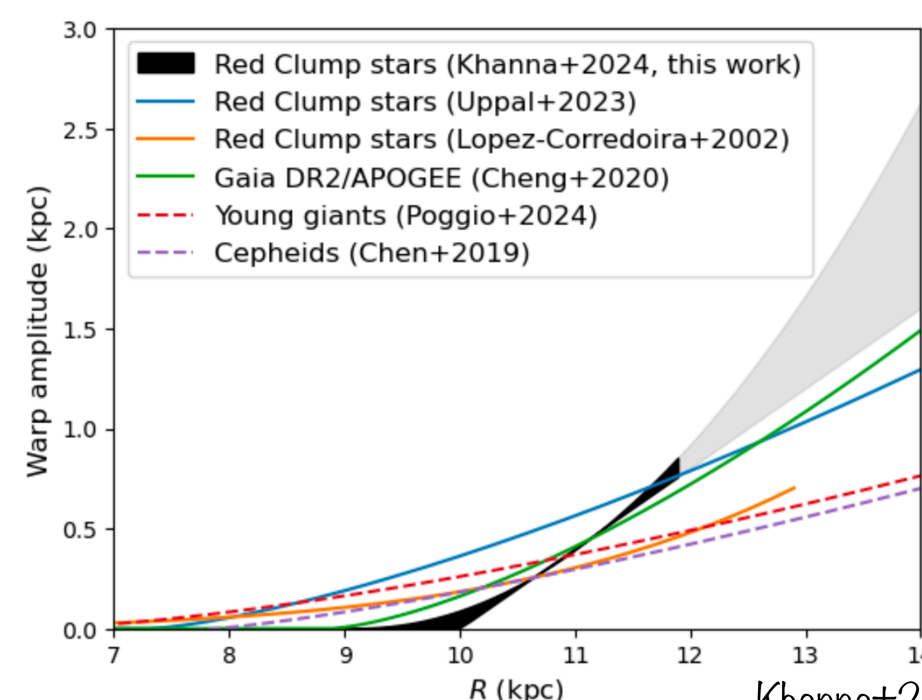
Skowron+2019,

see also Ripepi+2019, Dehnen+2023, Cabrera-Gadea+2024

2MASS star counts



Reylé + 2009

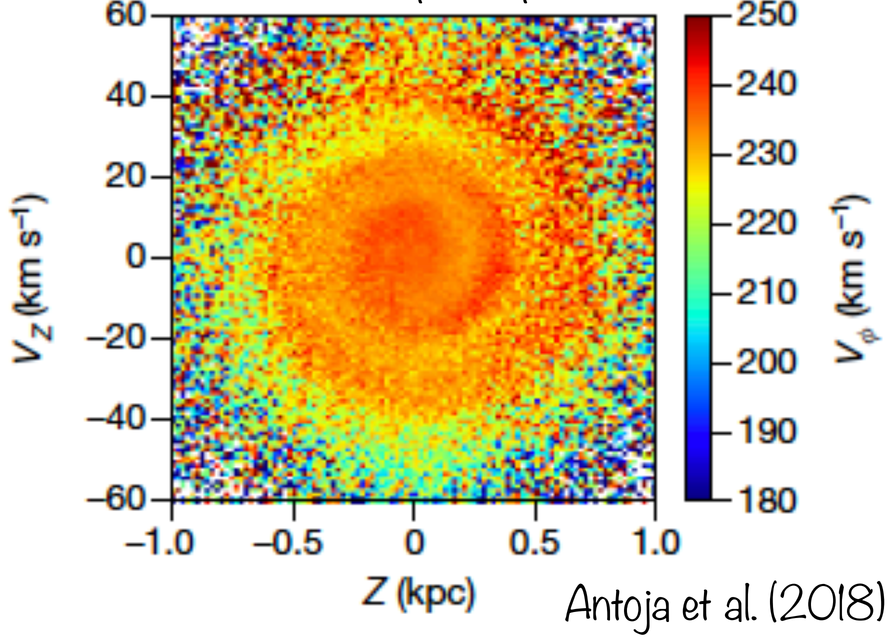


Khanna+2024

How does the Milky Way evolve?

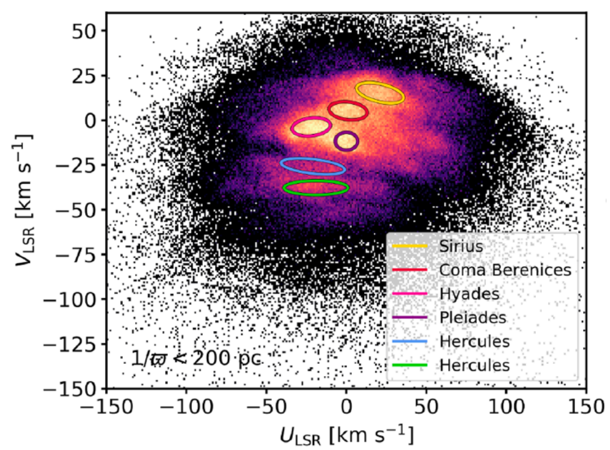
A dynamically active Galactic disc

Phase - space spiral



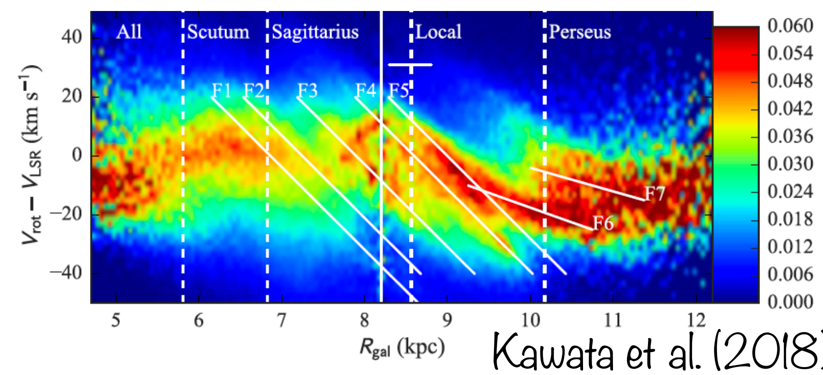
Antoja et al. (2018)

Moving groups



Trick et al. (2018)

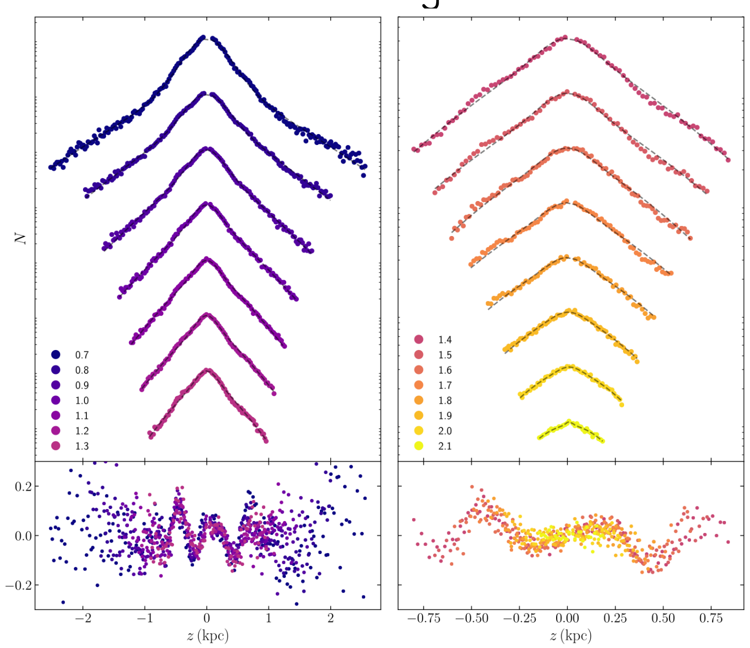
Ridges in Vphi vs R plane



Kawata et al. (2018)

Antoja et al. (2018)

Vertical asymmetries



Bennett & Bovy (2018)

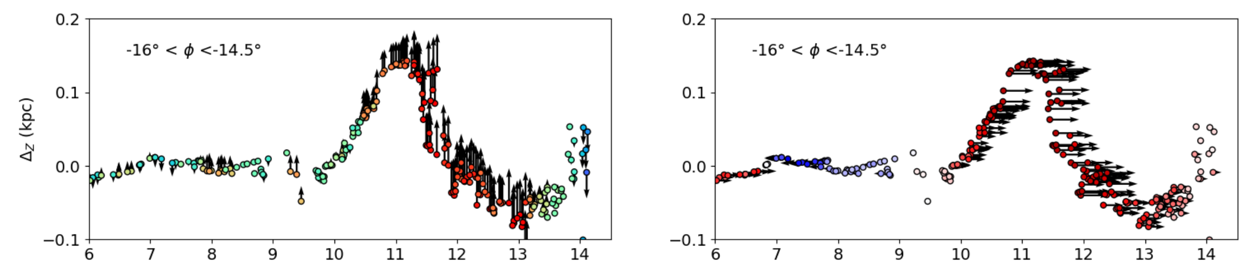
see also

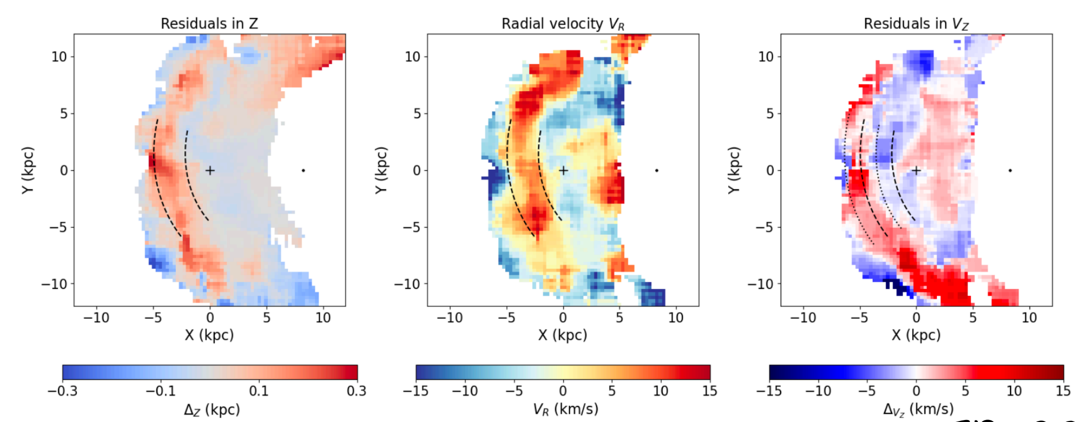
Widrow+2012,

Williams+2013,

Widrow+2014

The Great Wave

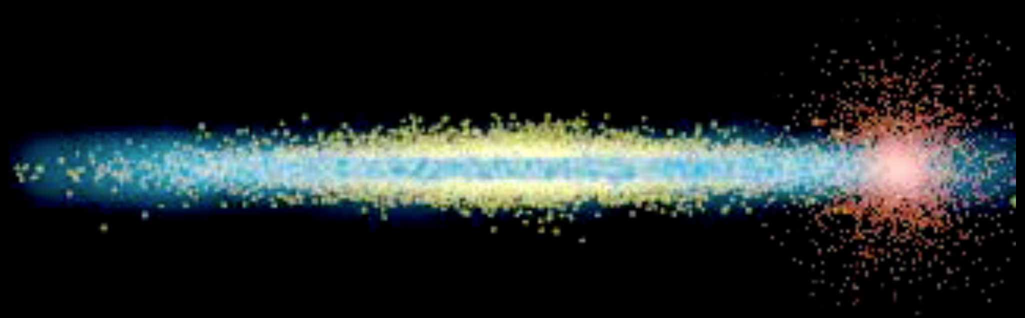




EP+2024

The perturbed Milky Way

Interaction with satellite galaxies:



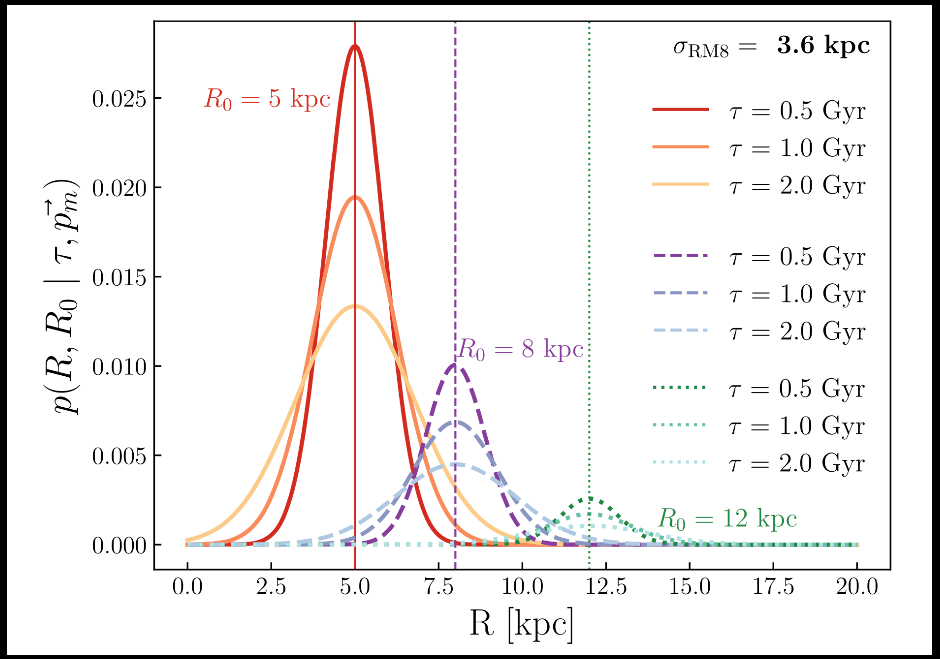
Credit: Chris Mihos and Sean Maxwell (Case Western Research University)

Radial migration (Sellwood & Binney, 2002):

1. Blurring: perturbations -> increase epicycles (orbital heating)

2. Churning: non-axisymmetric features -> change in the mean orbital radius

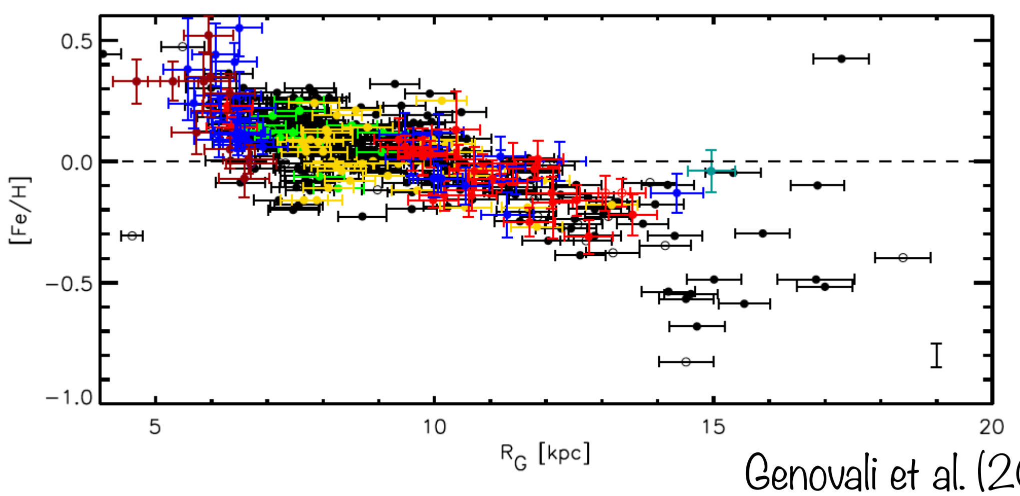
Combined effect of churning and blurring:



Frankel+2018

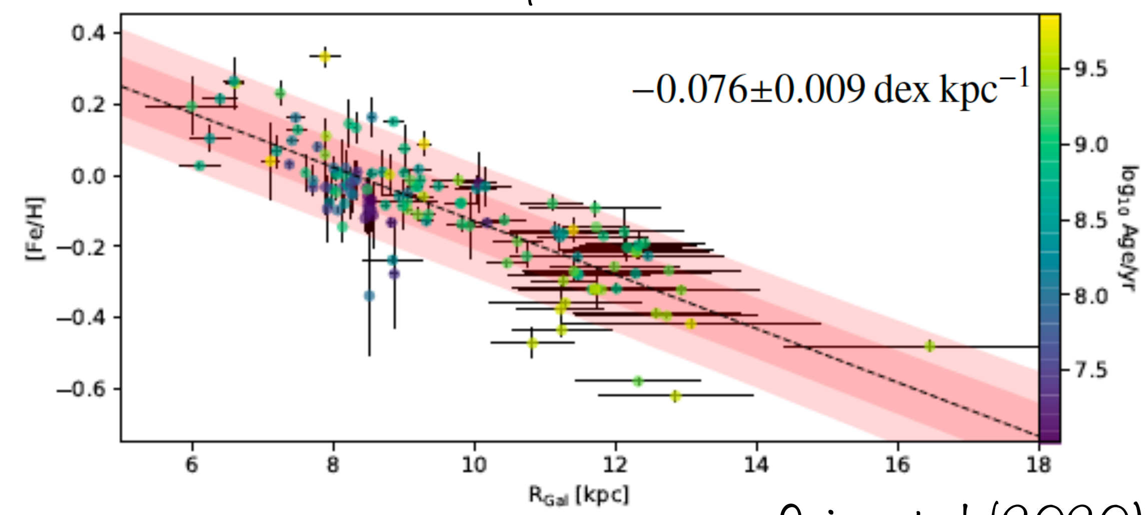
The radial metallicity gradient

Cepheids



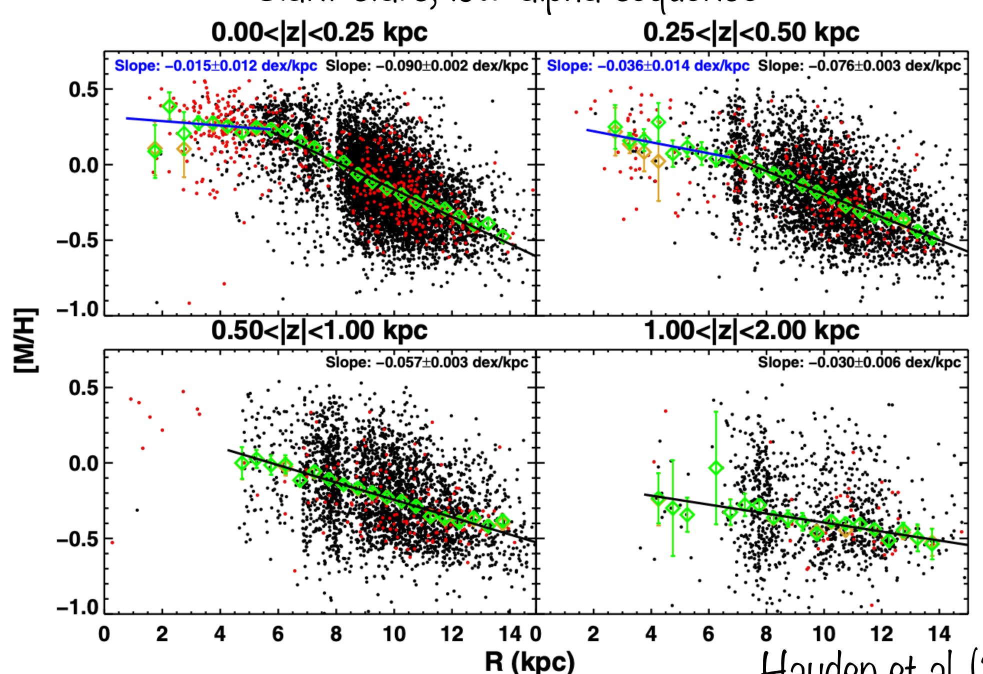
Genovali et al. (2014)

Open Clusters



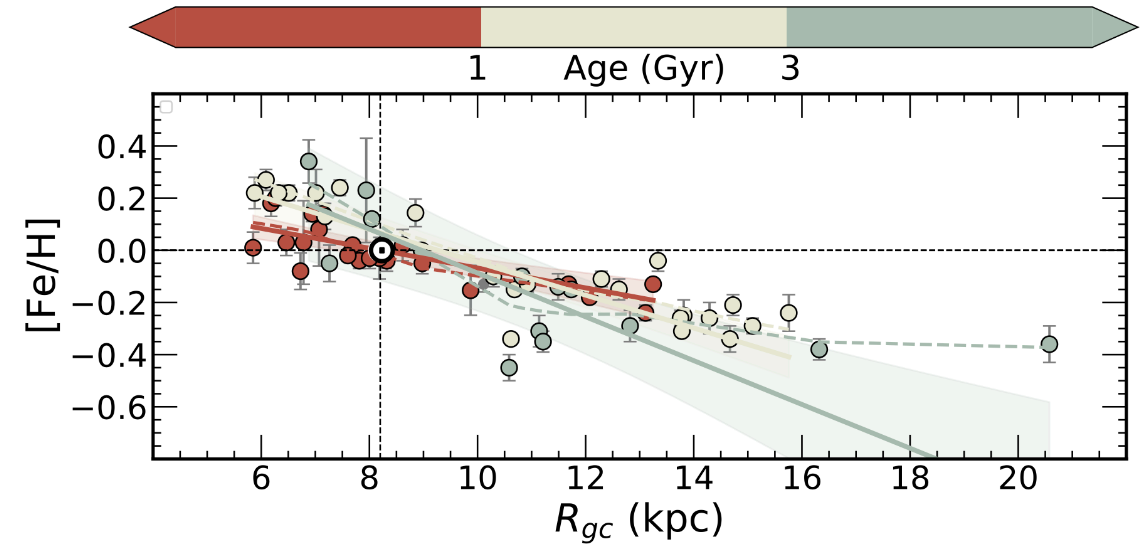
Spina et al. (2020)

Giant stars, low-alpha sequence



Hayden et al. (2014)

Open Clusters

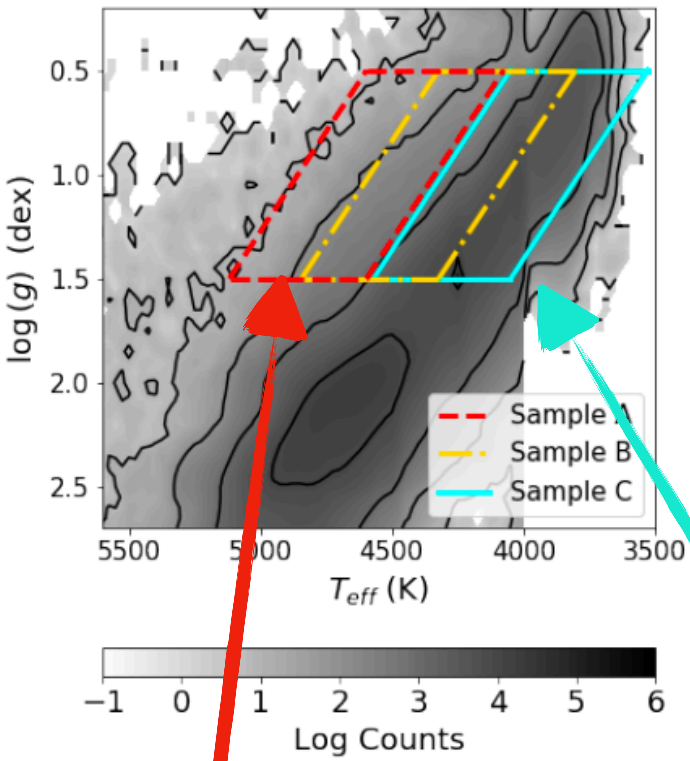


Magrini et al. (2023)

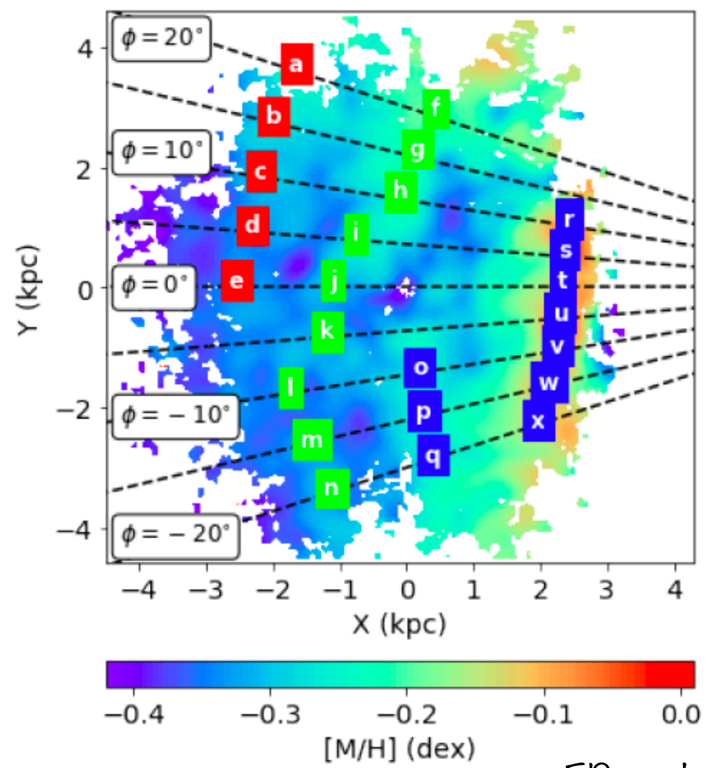
See also Hayden+2015, Gaia Collaboration, Recio-Blanco et al. (2023)

Chemical azimuthal variations: observations

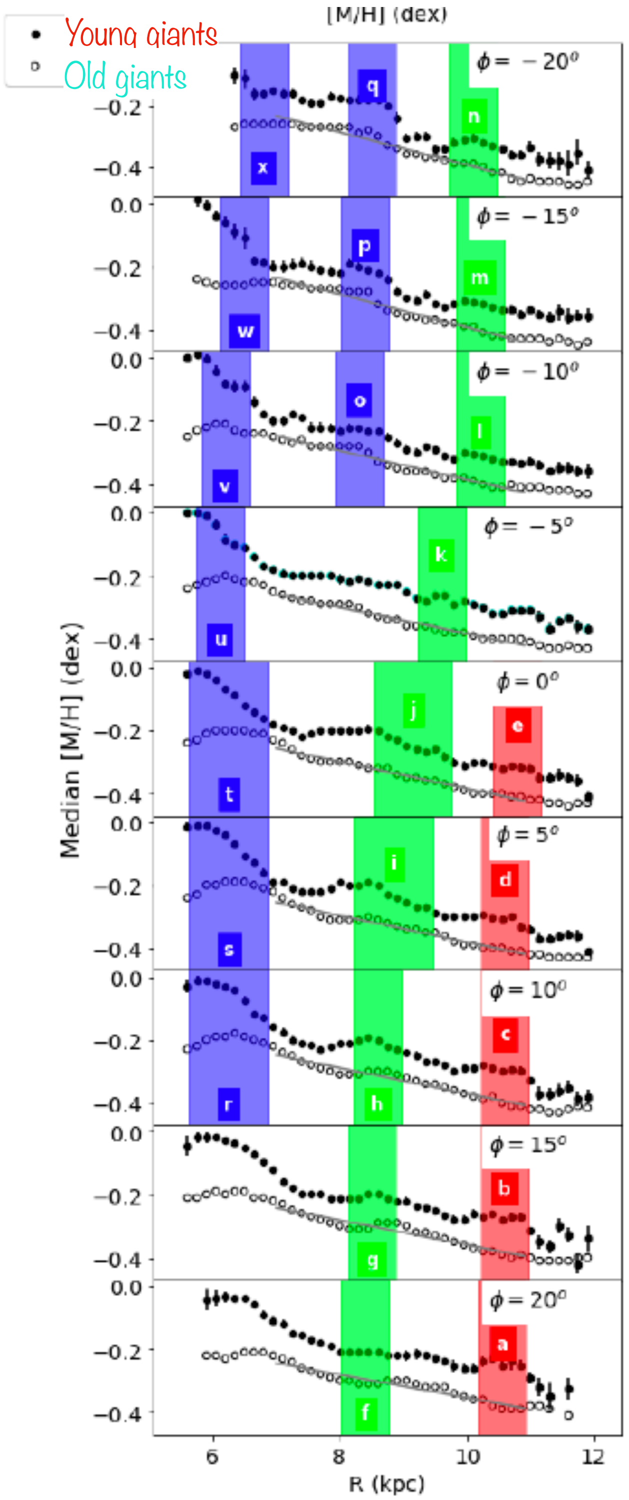
Gaia DR3 GSP-spec data:



Young giants:



EP et al. (2022)



Young giants:

- ~20-200 Myr
- bumps up to 0.05-0.1 dex on top of the observed radial metallicity gradients

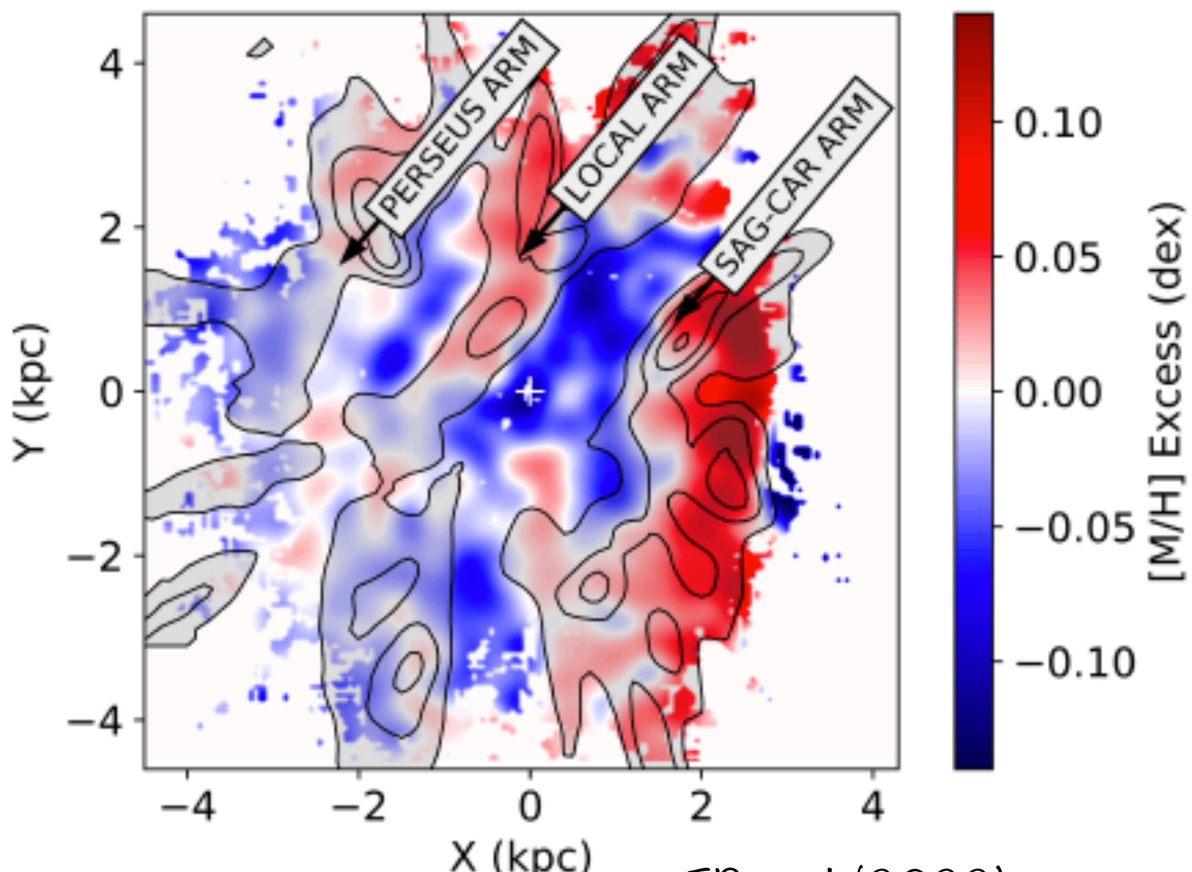
Old giants:

azimuthally-dependent metallicity gradient, with a slope changing from -0.054 dex/kpc to -0.036 dex/kpc

See also Hackshaw et al. (2023), Barbillon et al (2023)

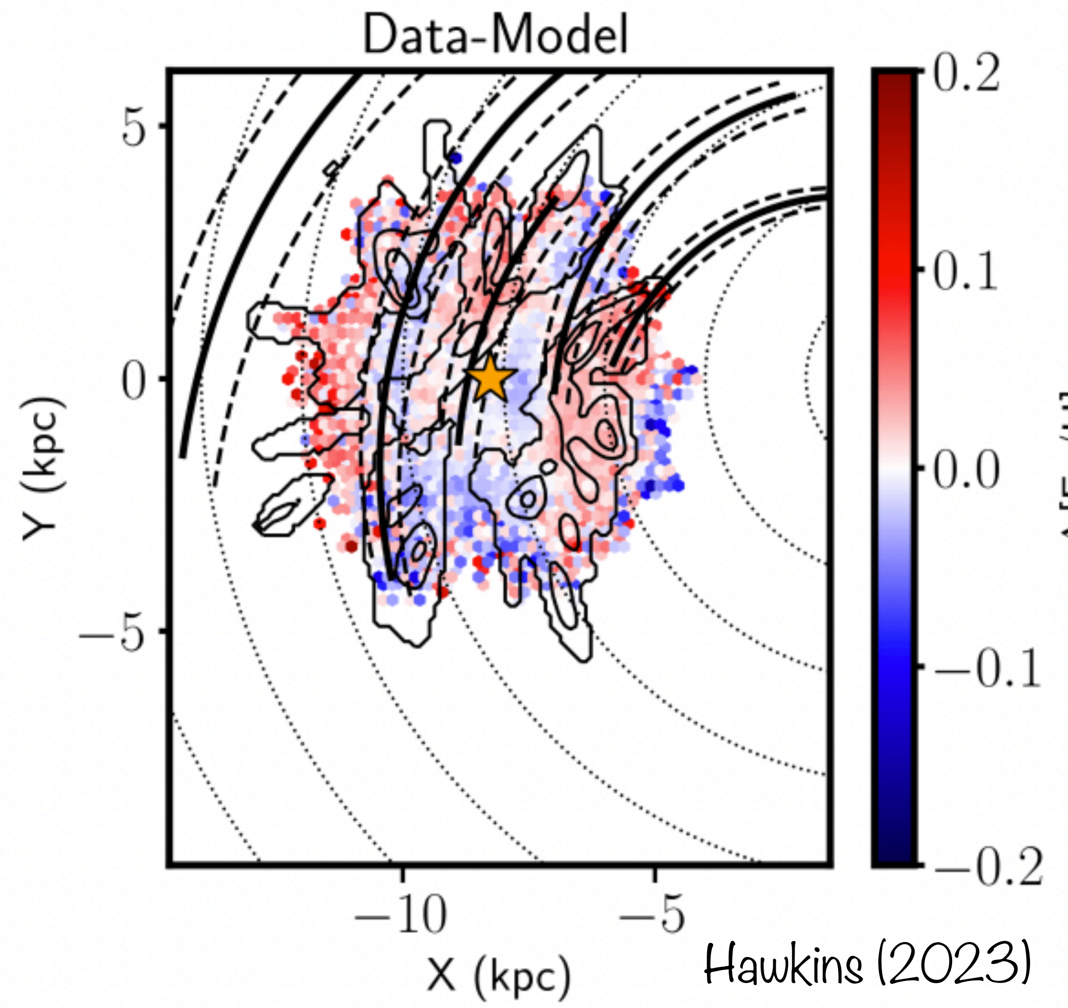
Chemical azimuthal variations: observations

Gaia DR3 GSP-spec data:



EP et al. (2022)

Gaia DR3 GSP-spec data:

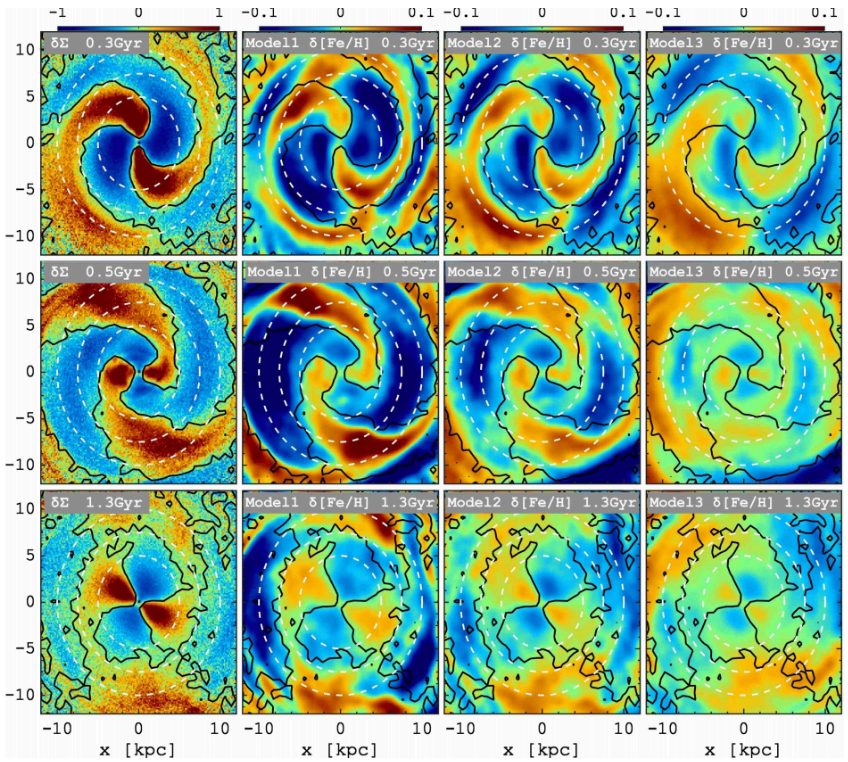


Hawkins (2023)

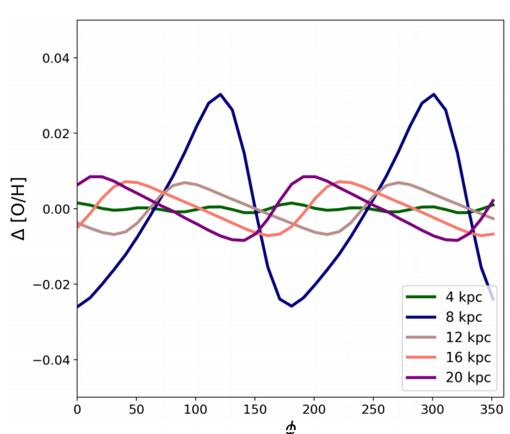
See also Hackshaw et al. (2023), Barbillon et al (2023)

Chemical azimuthal variations: theory

Spiral arms

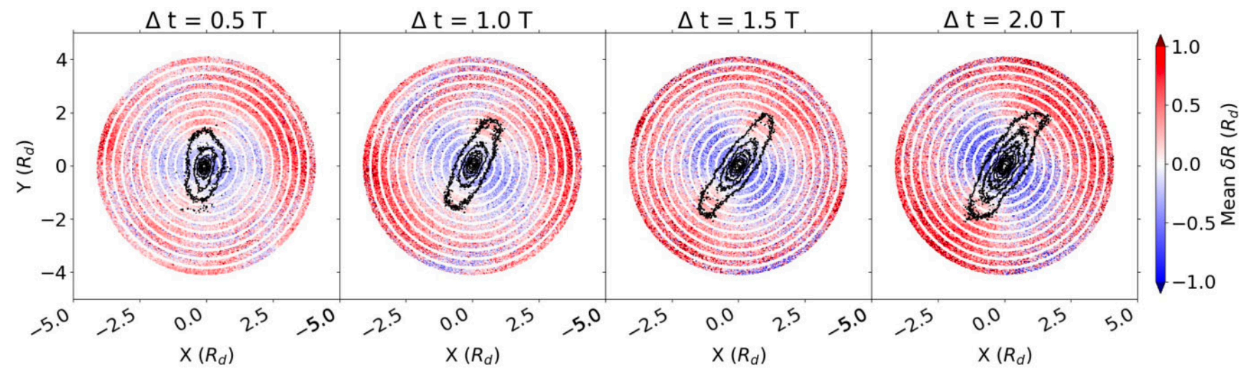


Khopersov+2018 (see also Debattista+2024)



Spitoni+2019,2023

Bar



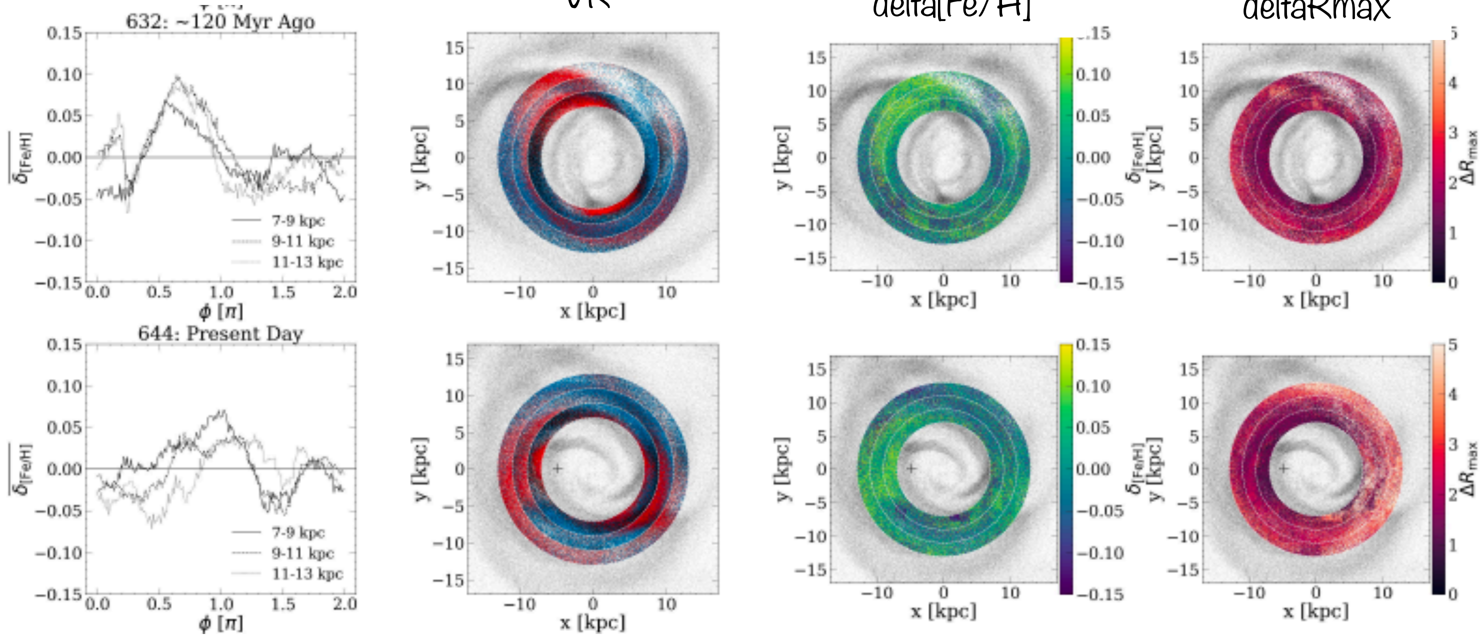
Filion+2023

Sagittarius-like dwarf galaxy

VR

delta[Fe/H]

deltaRmax



Carr+2022

Summary

Three-dimensional structure of the Milky Way:

- **bar**: orientation angle between 20°and 30°, unknown length (long vs. short bar scenarios), bar/spiral arms connection
- **spiral structure**: no consensus on the geometry, number and location the spiral arms. Observations based on Gaia show that the local arm is longer than previously thought and the Perseus arm has a more open geometry (i.e. pitch angle) than suggested from Reid+2019, similar to Levine+2006
- **warp**: amplitude of the young stellar populations (Cepheids, young giants) well constrained. The structure is more uncertain for older stellar populations (e.g. red clump stars)

Chemo-kinematics of the Galactic disc:

- **kinematics**: great wealth of kinematic features, including vertical asymmetries, moving groups, ridges, the Gaia phase-space spiral, warp precession, waves propagating through the Galactic disc
- **chemical cartography**: radial metallicity gradient mapped using different stellar populations, metallicity azimuthal variations up to 0.1 dex, which might be due to spiral arms/bar/radial migration induced by satellites

WST can make a fundamental contribution to our understanding of the physical processes driving Galactic evolution