

ASTR 511

Galactic Astronomy

Lecture 07

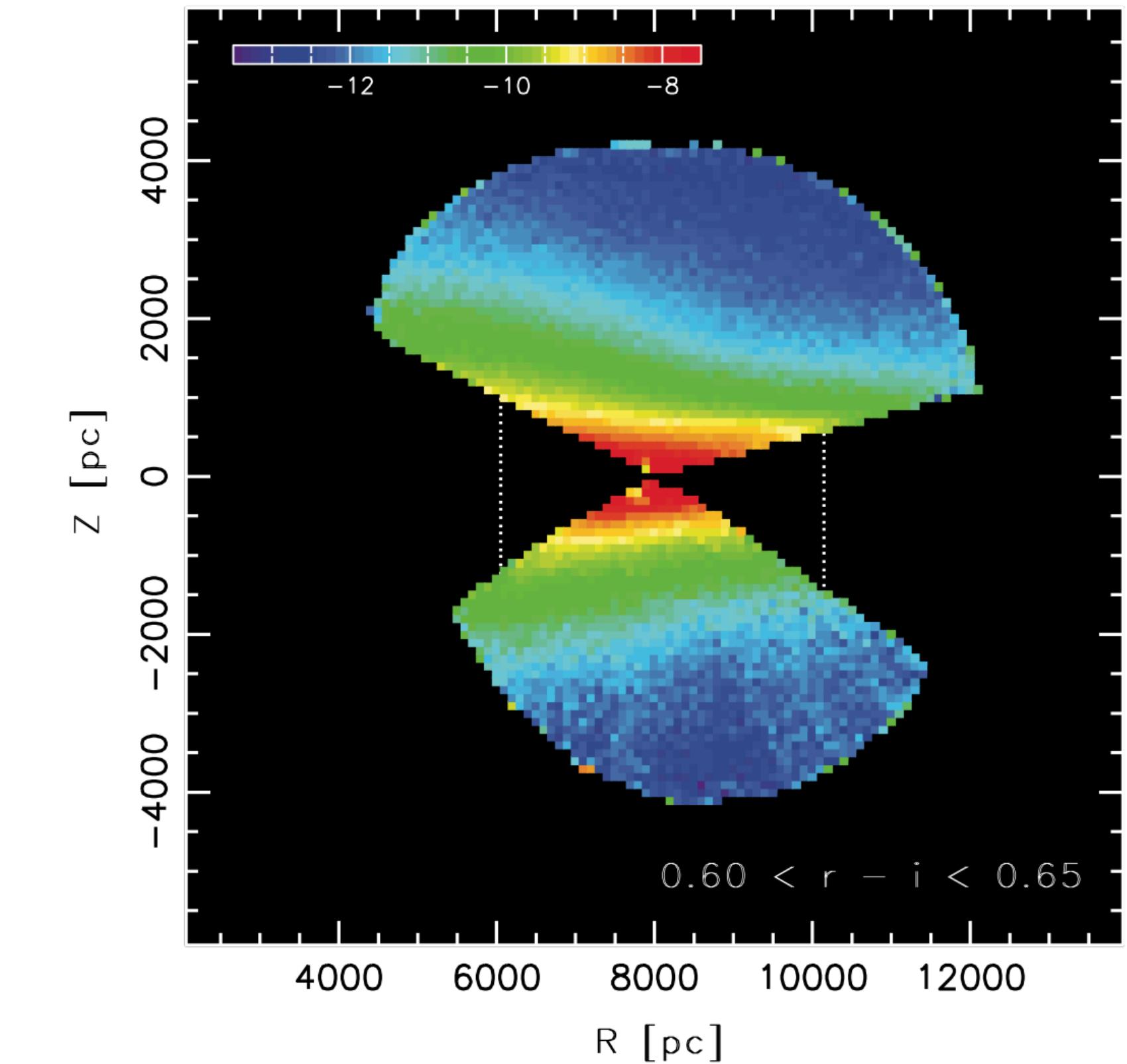
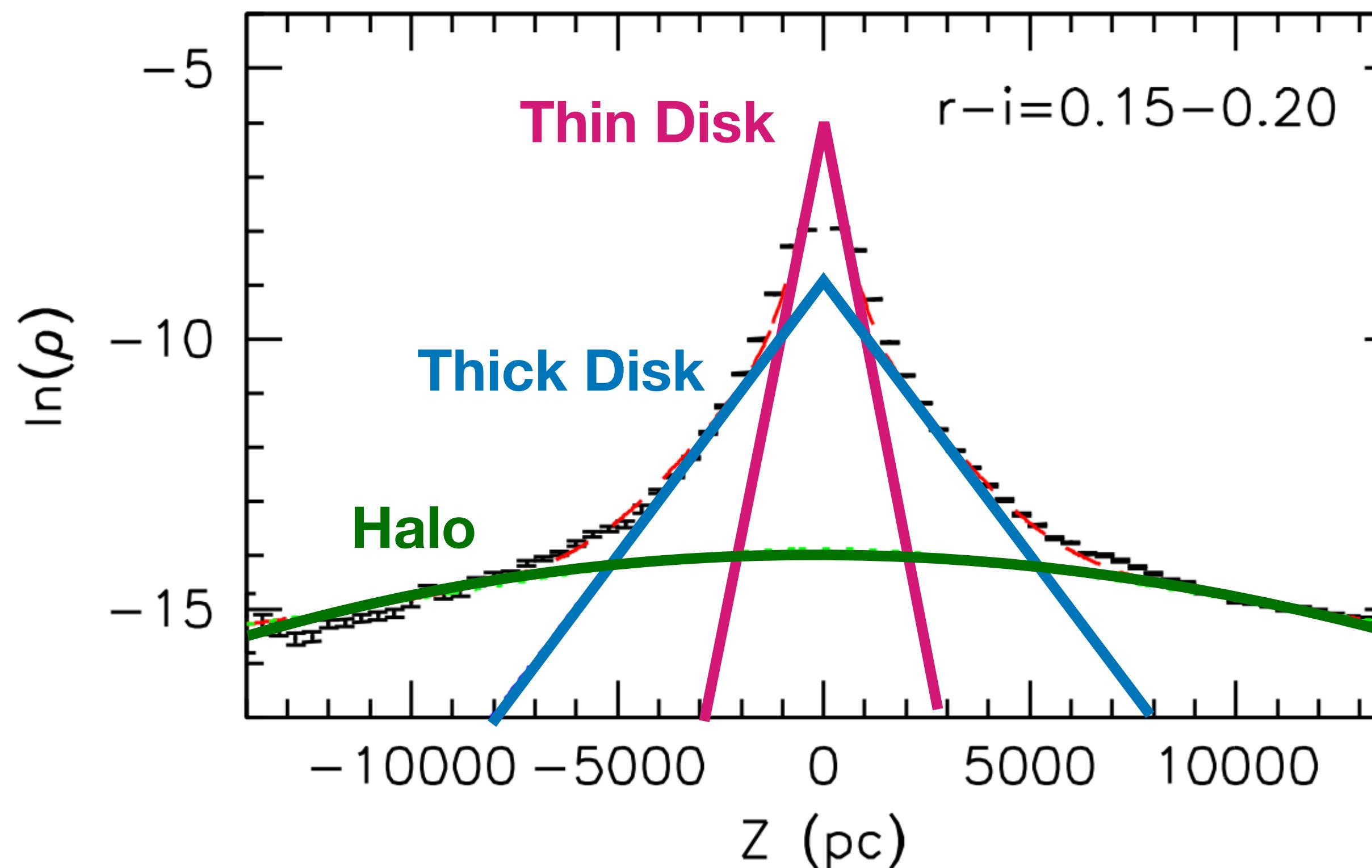
Structure & Properties of the Milky Way: Part II

Prof. James Davenport (UW)

Winter 2023

The Milky Way's Disk

- in (R, Z) space:
An “exponential disk”, e.g. Jurić+2008



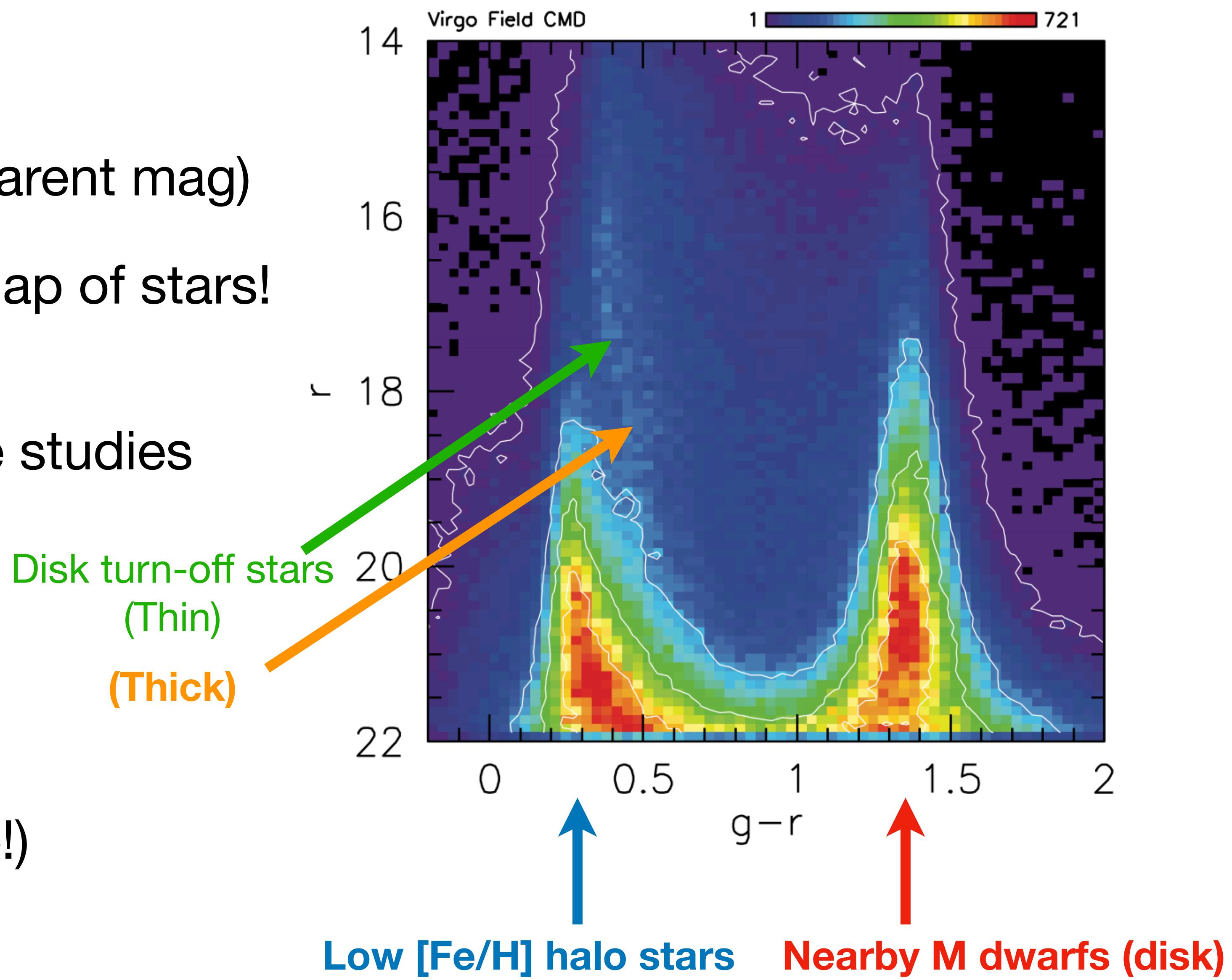
neighborhood within ~ 2 kpc. They show a striking simplicity in good agreement with a double exponential disk model,

$$\rho(R, Z) = \rho(R_\odot, 0) e^{R_\odot/L} \exp\left(-\frac{R}{L} - \frac{Z + Z_\odot}{H}\right), \quad (19)$$

where ρ is the number density of disk stars, R_\odot and Z_\odot are the cylindrical coordinates of the Sun, and L and H are the exponential scale length and scale height, respectively. This model pre-

Hess Diagram

- A CMD *without* distances (apparent mag)
 - NOT just a heat or density map of stars!
e.g. wrong here
- Important for galactic structure studies
e.g. Jurić+2008
- A few key features...
(e.g. Gao+2012)
- You see this in your HW2, w/
cluster distinctly on top (I hope!)



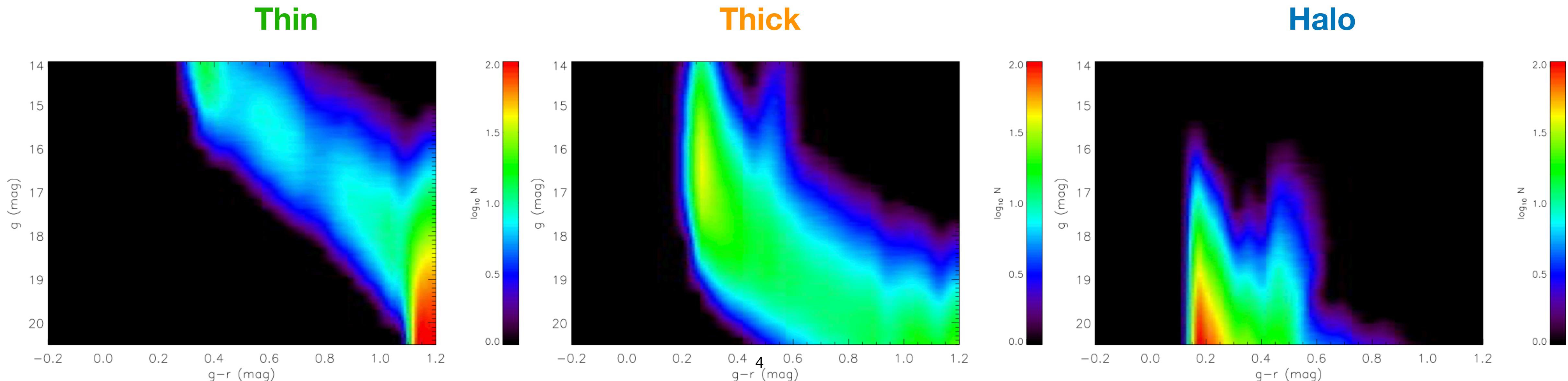
Hess Diagram

- Use stellar models (isochrone + IMF, binary frac), star formation history assumptions, gal structure model (e.g. Besançon, galfast) to forward-model Hess Diagram

(Gao+2012)

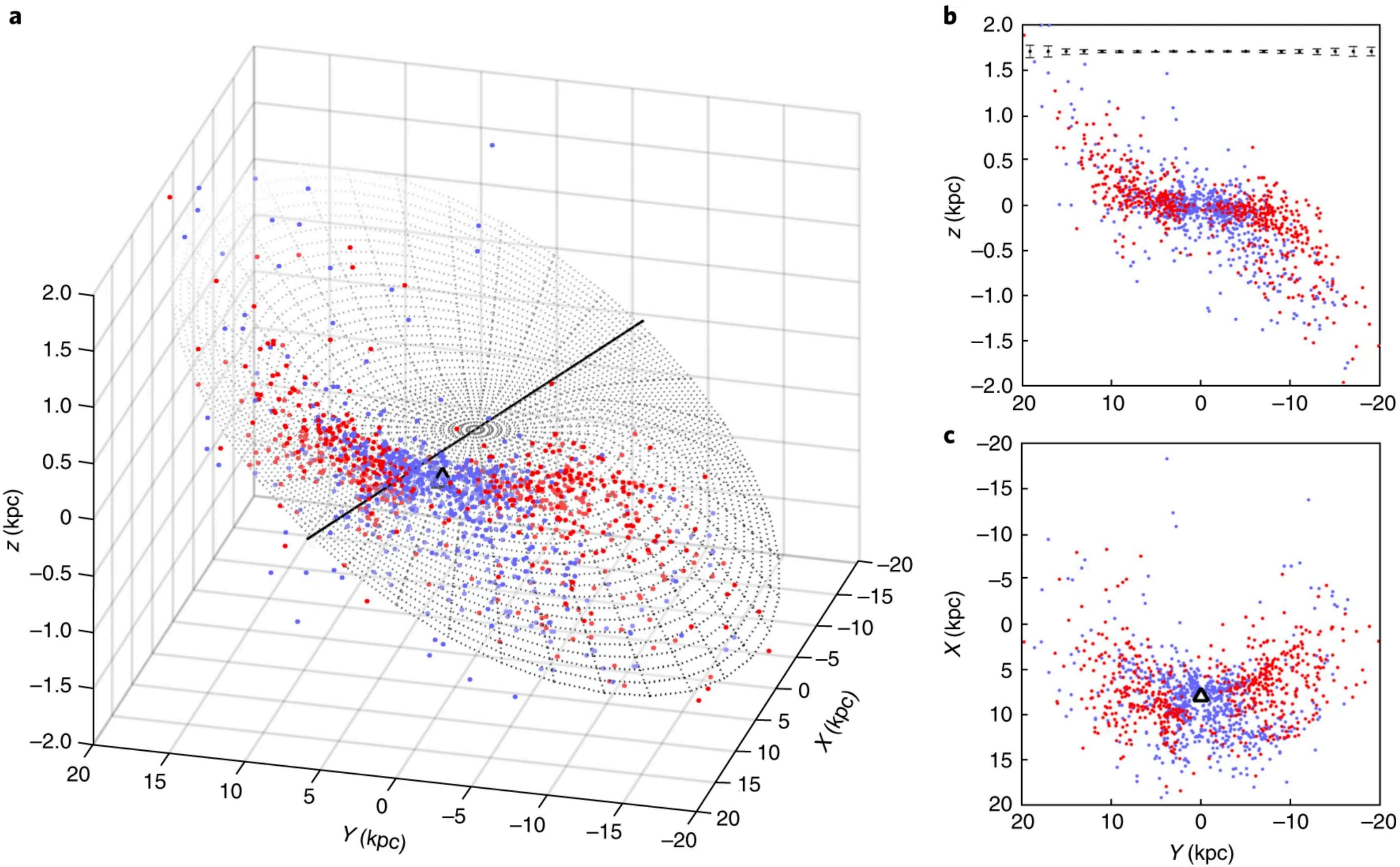
- Hess Diagram not very popular right now b/c of Gaia...

- Prediction:
As we reach limits of Gaia distances, & especially when LSST comes online, Astronomers will rediscover this handy framework!



Warped Disk

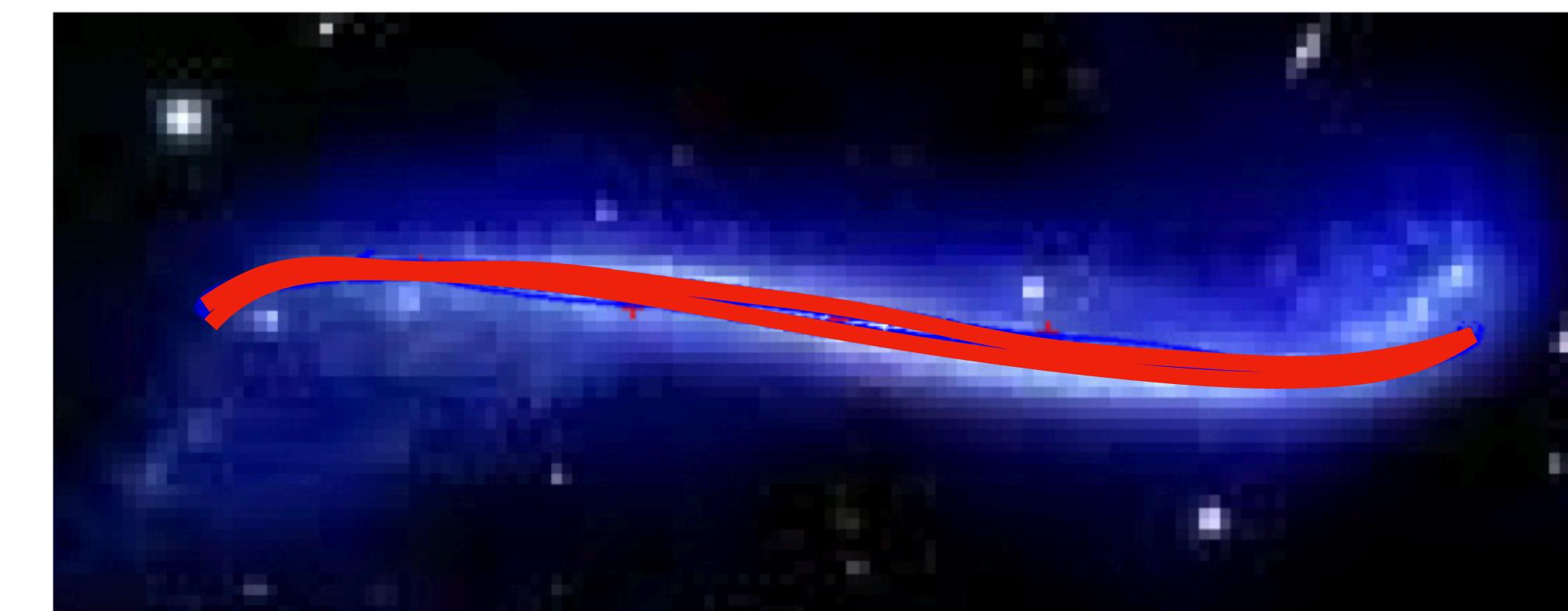
- Long seen in gas (HI)
- Now traced w/ stars
- Here: Cepheids from WISE + Gaia DR2
- Likely caused by merger from dwarf galaxy... but which?!
 - Sagittarius ?



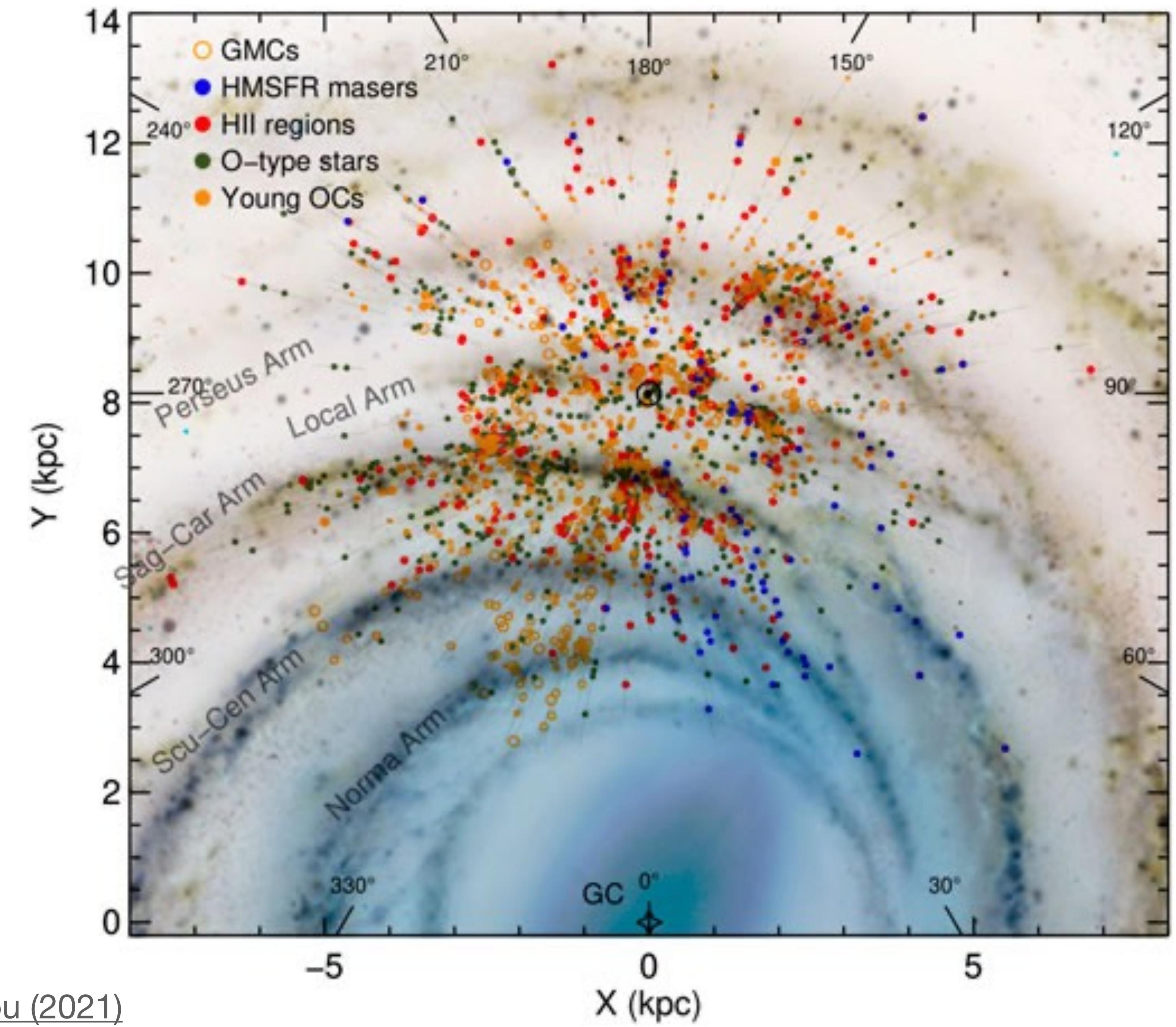
Chen+2019

Warped Disk

- Warped disks are very common!
- ~50% of edge-on spirals show evidence for a warp (Sánchez-Saavedra+2003)
- Warps may be caused by merger events, OR could be long-lived features... e.g. a generic outcome of disk+bar orbital dynamics (Sánchez-Martín+2016)



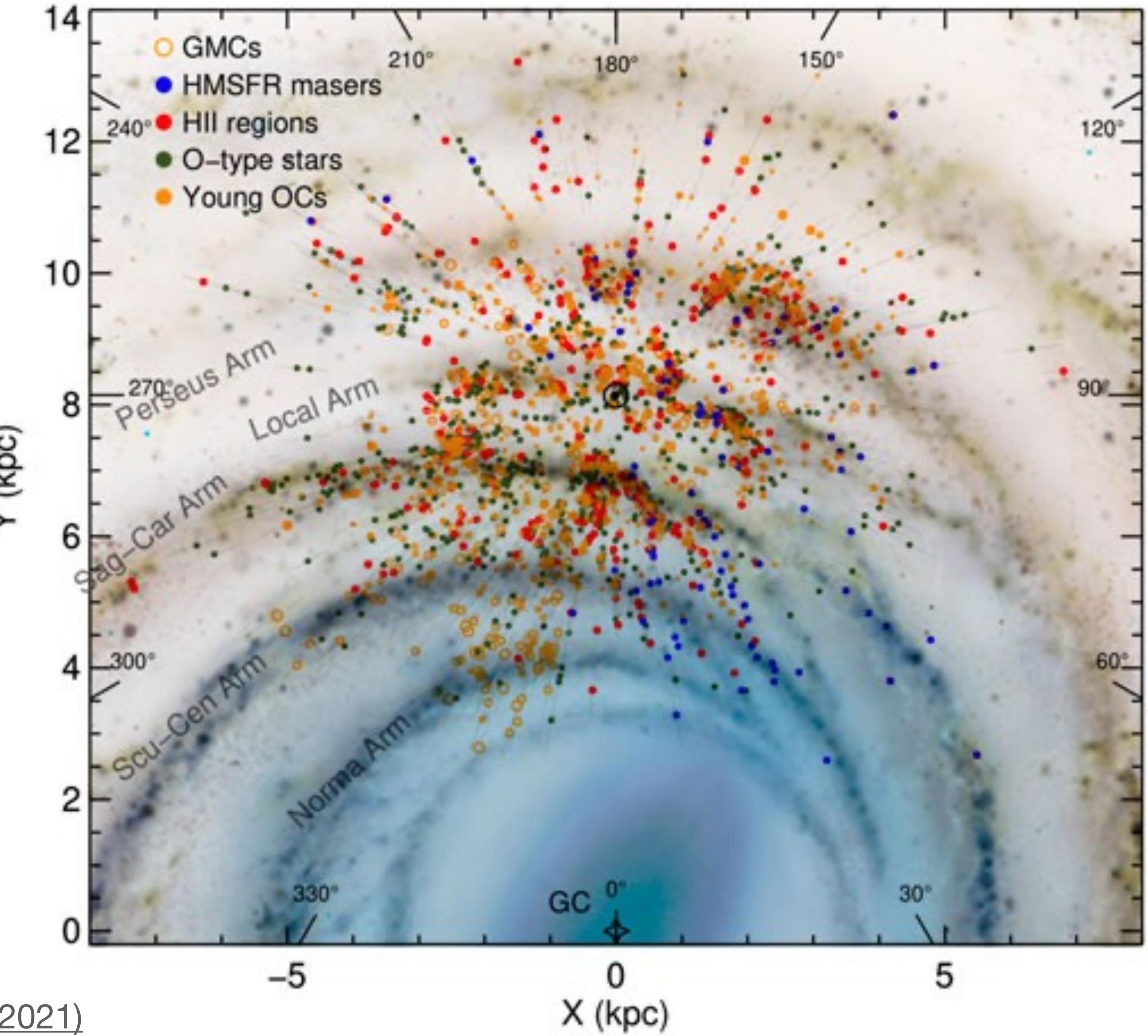
From Lecture 2
 $d > 500\text{pc}$



Hou (2021)

Spiral Arms

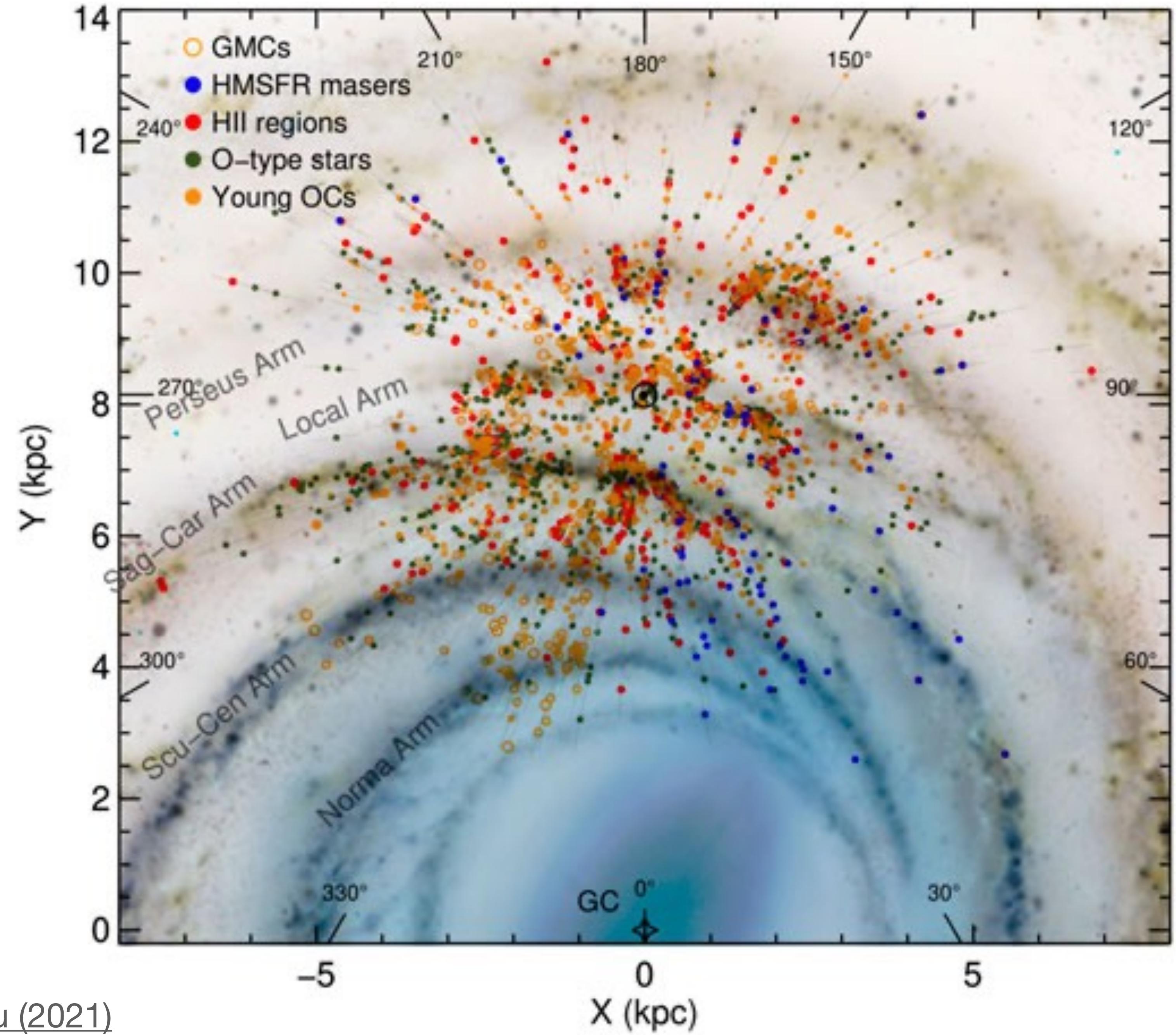
- Arm-like features seen with *many* tracers: gas, GMC's, clusters, cepheids, stars, masers...
- Shape is usually described as a **logarithmic spiral**



Hou (2021)

Spiral Arms

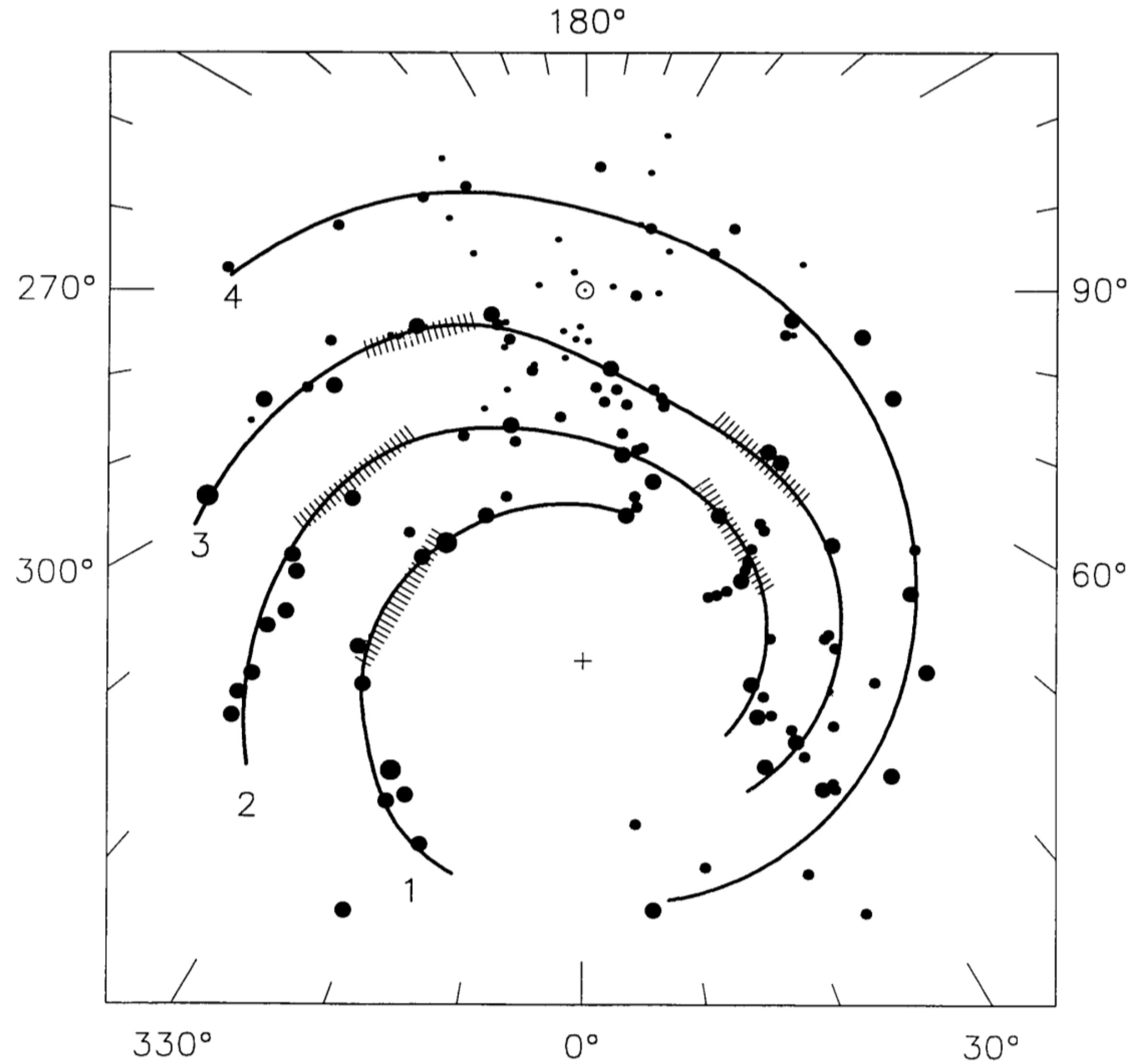
- Typical Description:
MWY has **4 spiral arms** in solar neighborhood
- Or maybe 2? Long debated, esp. for a Spiral+Bar galaxy...
- Or maybe (probably) has a bunch of “spurs” between strong spiral features
- We maybe live on the edge of a spur



Hou (2021)

Spiral Arms

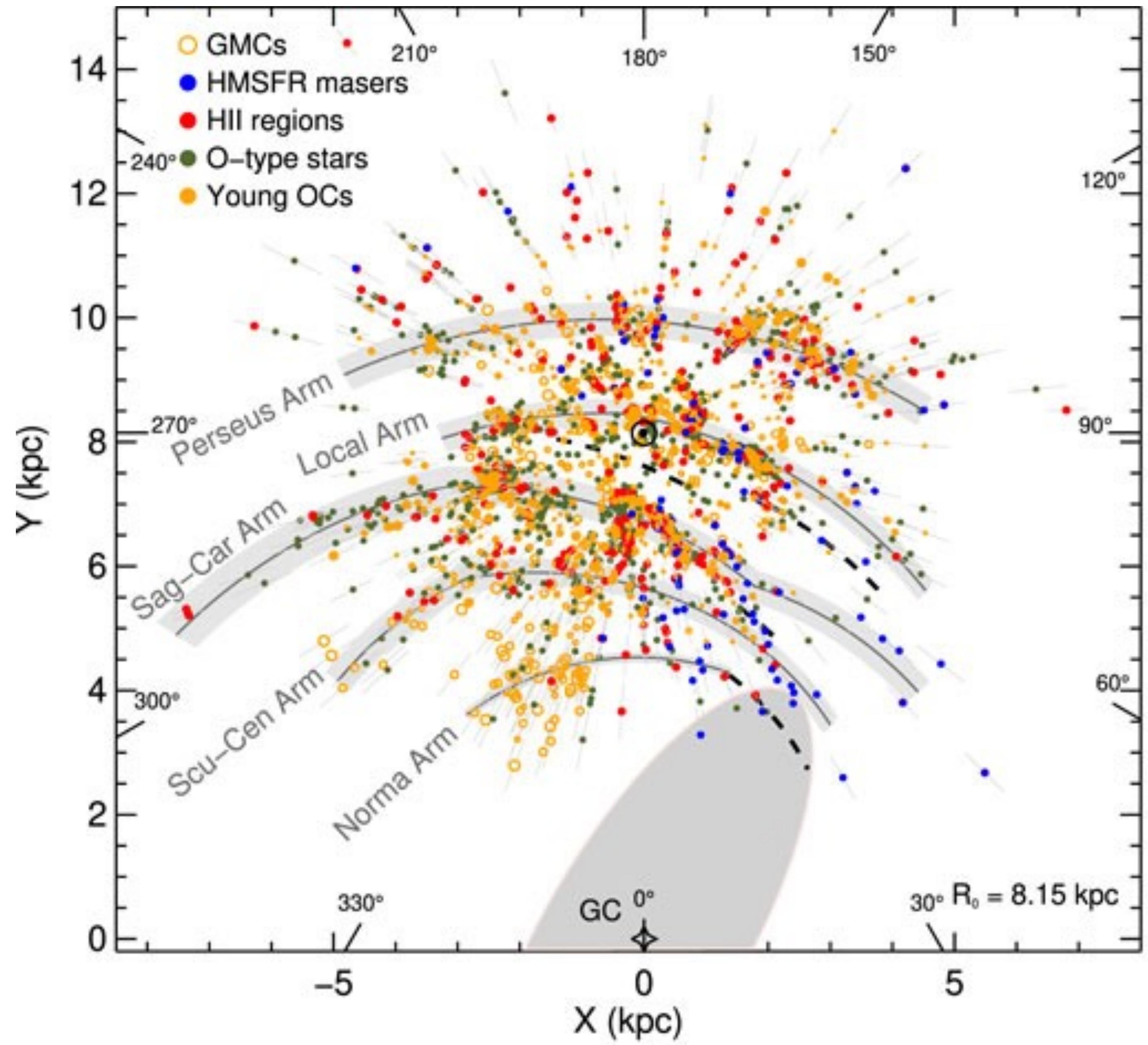
- Basic 4-arm model,
very popular for ~30yrs



Pulsar distances: Taylor & Cordes (1993)

Spiral Arms

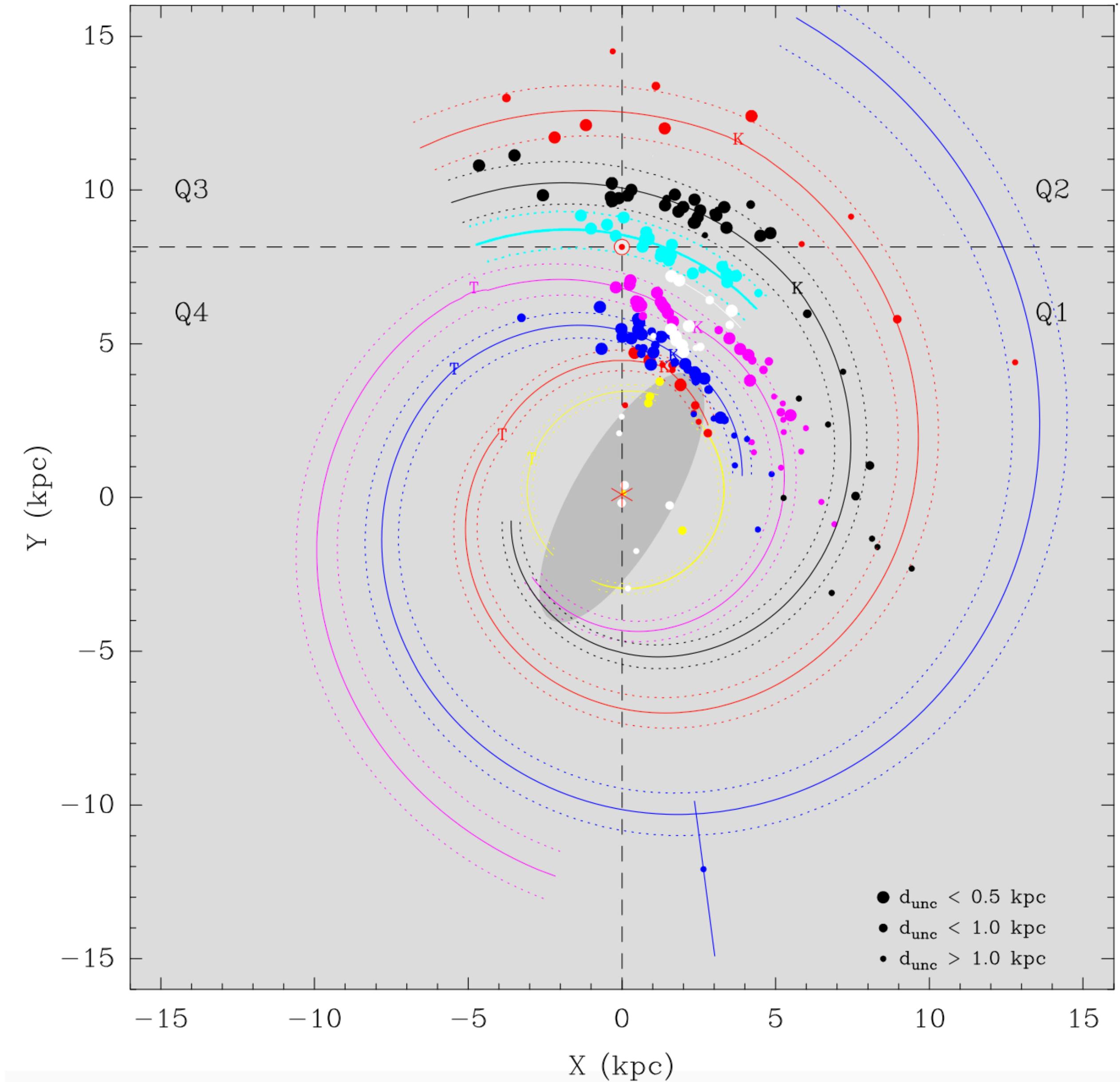
- Scu-Cen Arm
- Sag-Car Arm
- Local Arm (“Orion”)
 - Is it really an Arm, or a spur?
- Perseus Arm
- Norma-Outer Arm



Hou (2021)

Spiral Arms

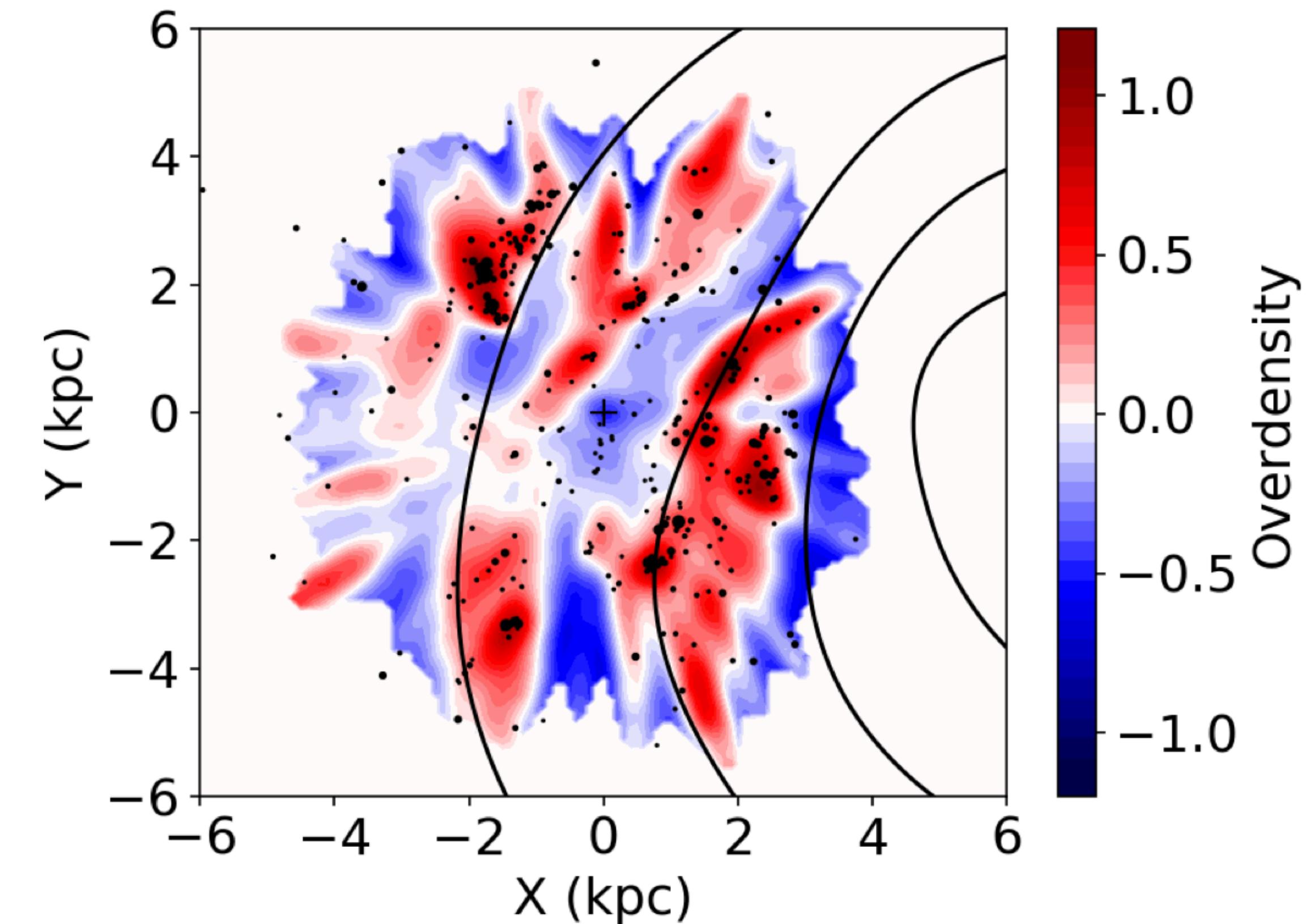
- Scu-Cen Arm
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Star forming regions: [Reid+2019](#)

Spiral Arms

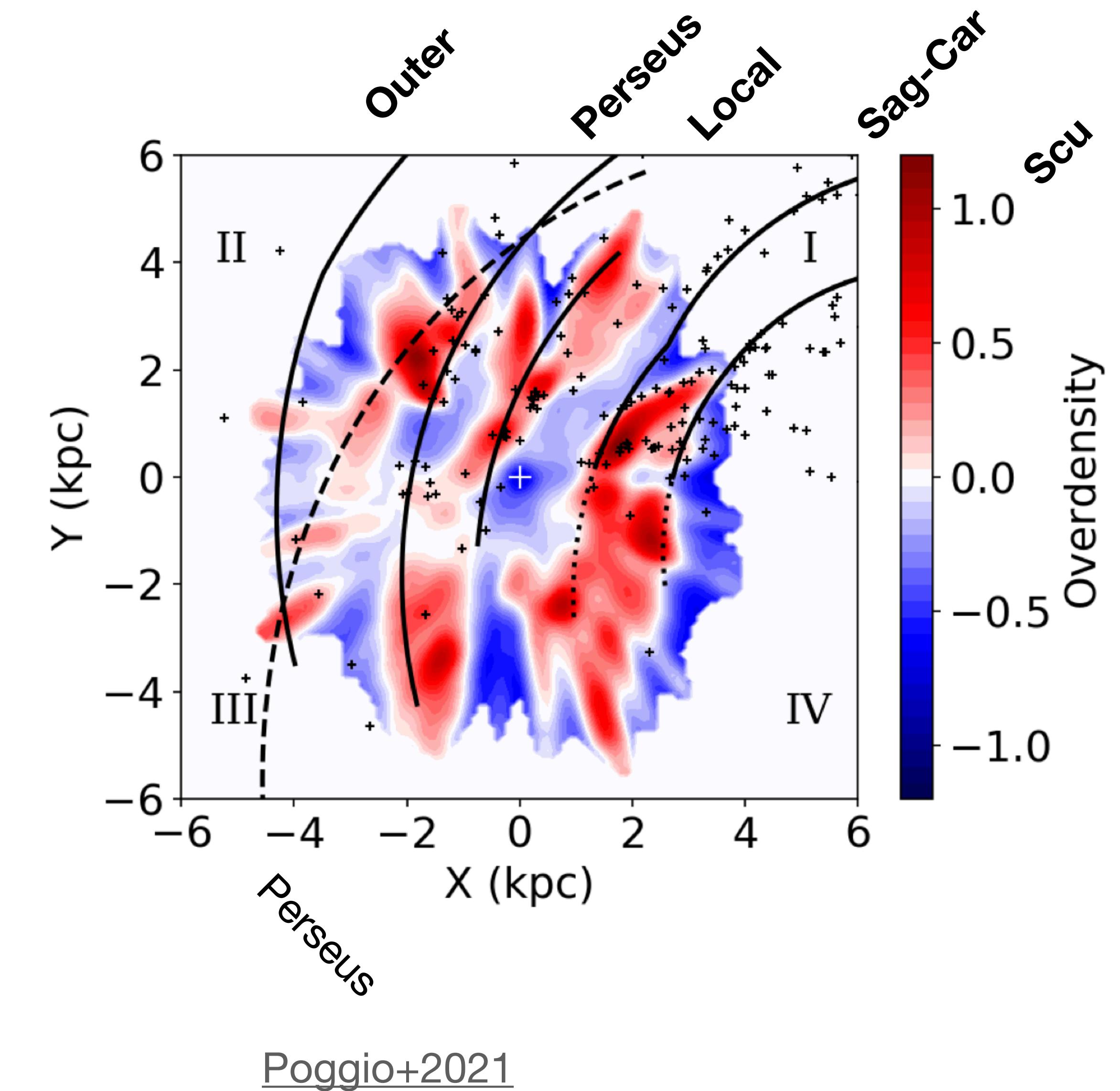
- Gaia traces out structure with young field stars!
- Not a *great* fit to some standard arm models (e.g. Taylor & Cordes 1993)



Poggio+2021

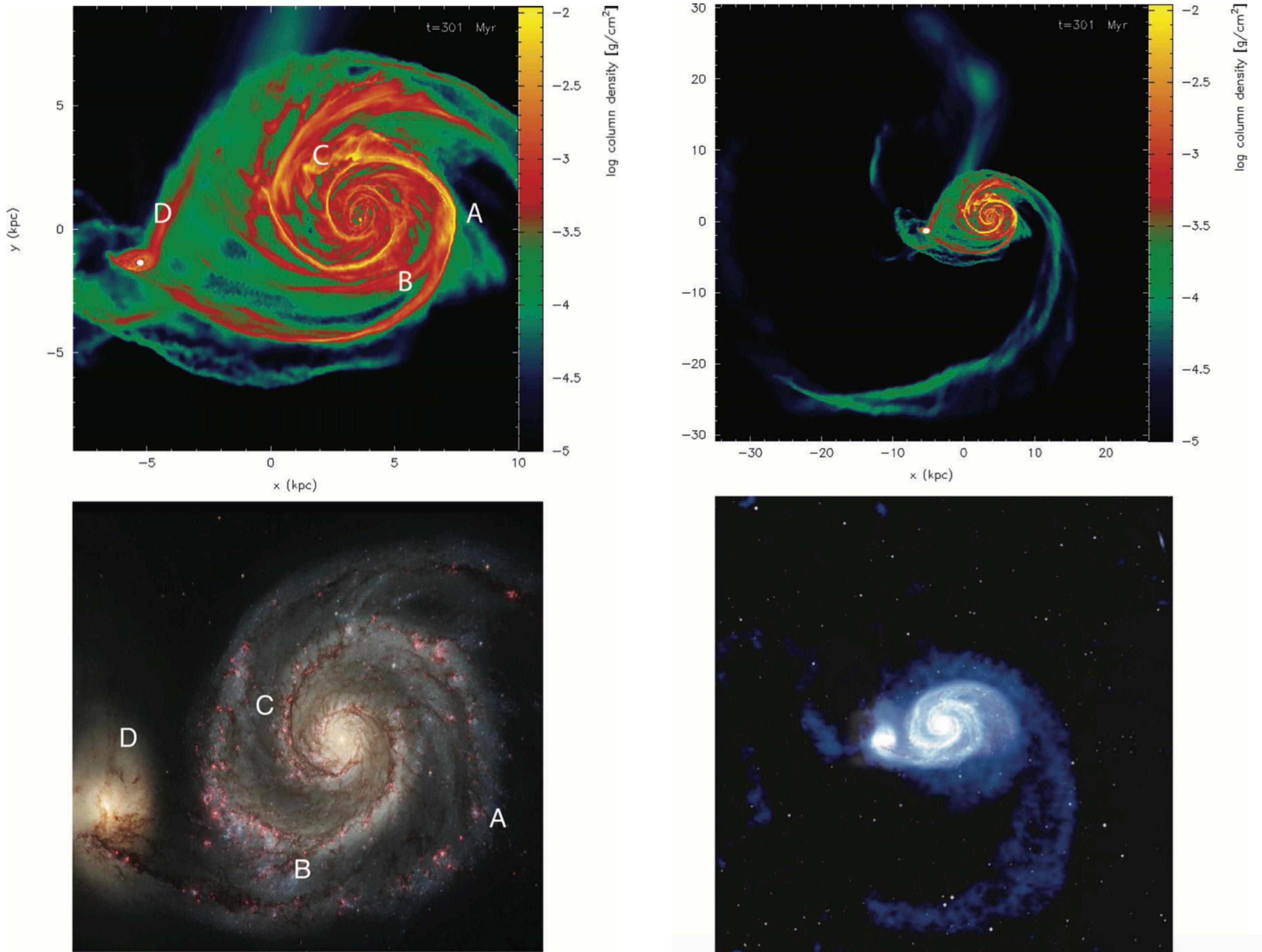
Spiral Arms

- Some better alignment with Reid+2019 model (black lines)
- Except Perseus arm looks more like Levine+2006
- Lots of pure cartographic exploration to still be done here!



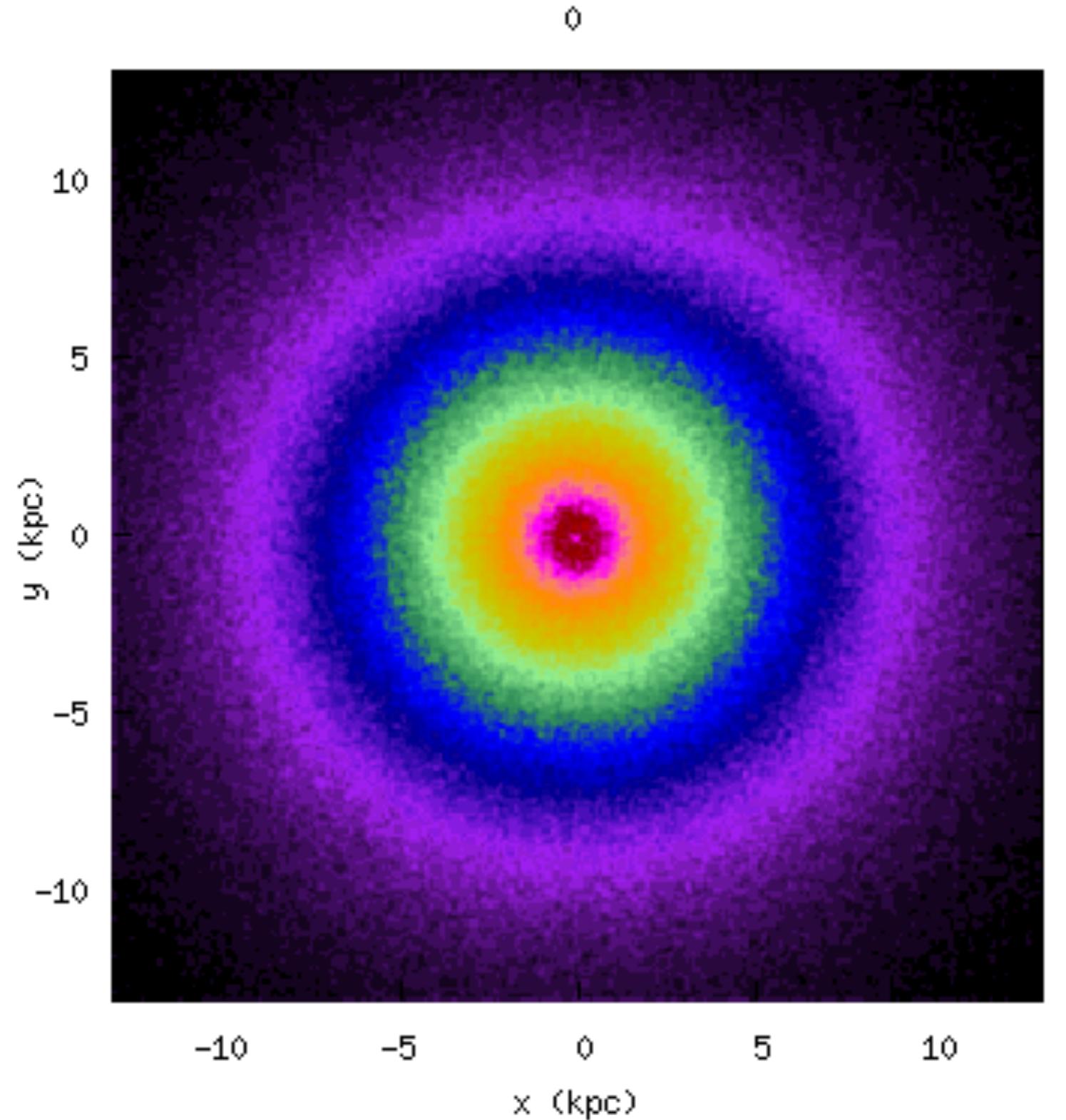
Spiral Arms

- M51 grand spiral structure, with lots of spur-like features reproduced well with Galaxy+merger model
- No strong bar though



Spiral Arms

- Lots of simulation work in this space
- Exploring bar, resonances, mergers...



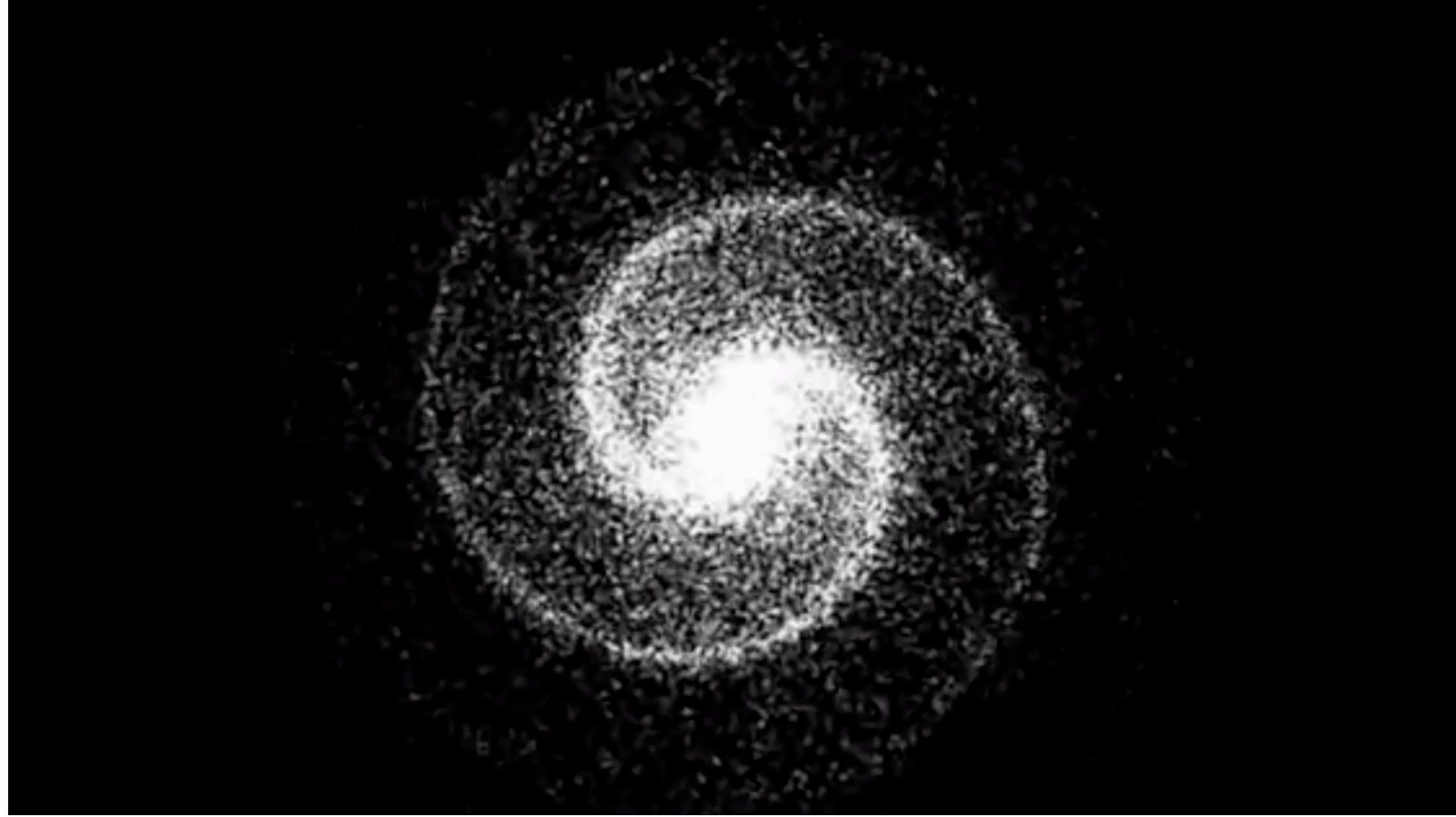
Quillen+2011

Spiral Arms

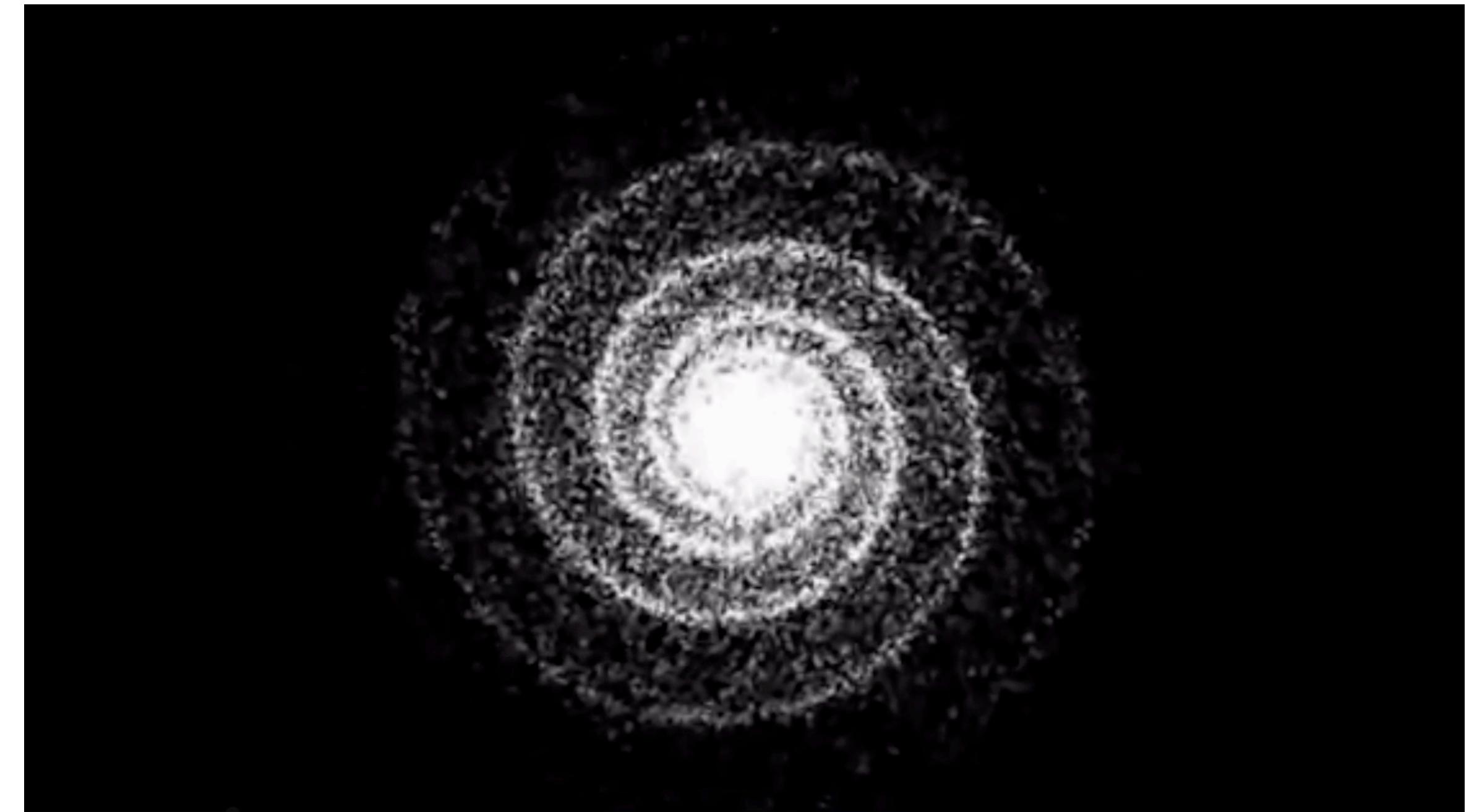
- Density Wave Theory: Lin & Shu (1964)
- Spiral structure long lived, due to a propagating density wave, NOT a fixed structure
- Critically: NOT due to shear or differential rotation of the disk (which IS there)
- Reminds me of: traffic jam propagation

Spiral Arms

Fixed Pattern

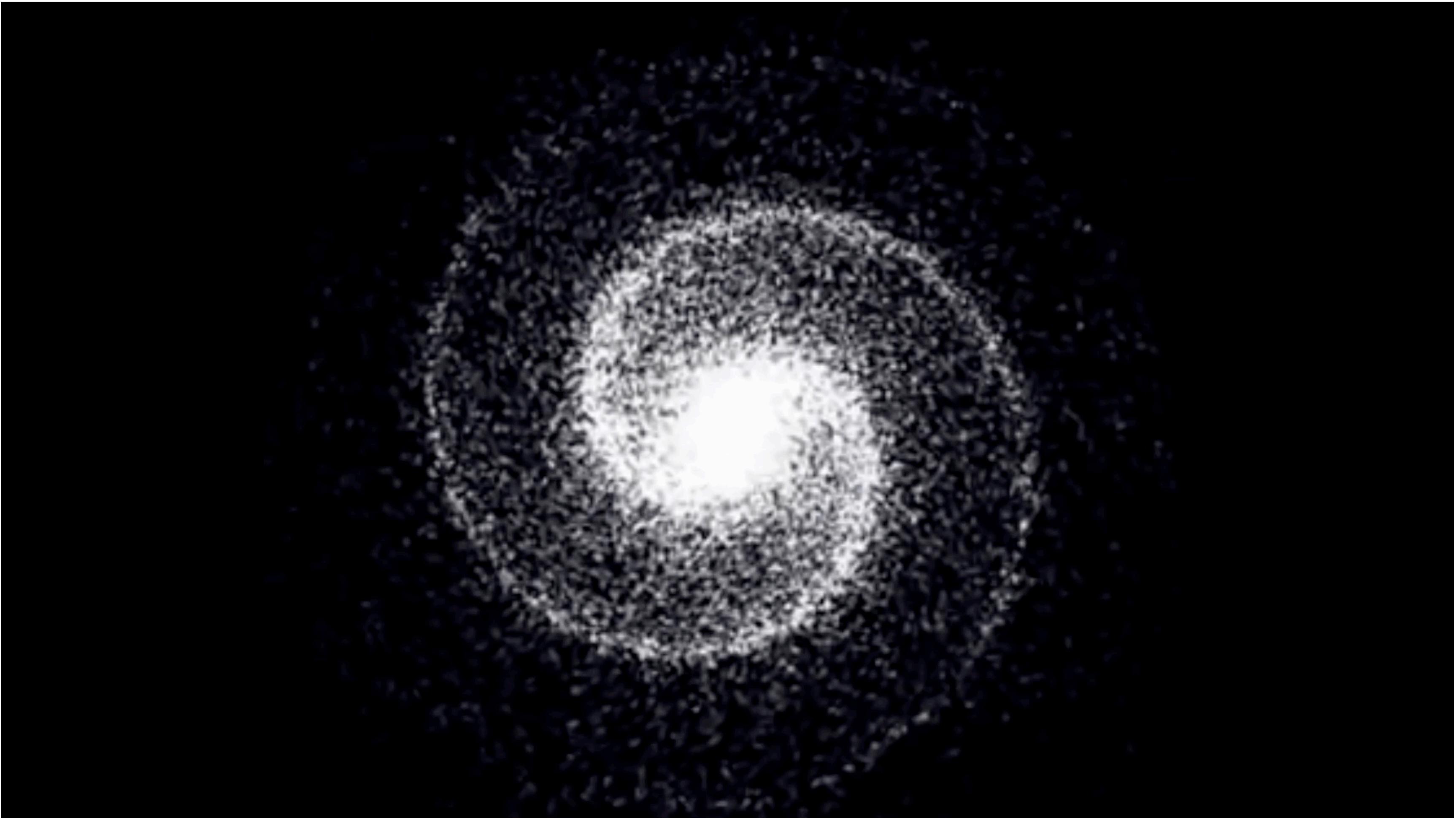


Diff. Rot.



Spiral Arms

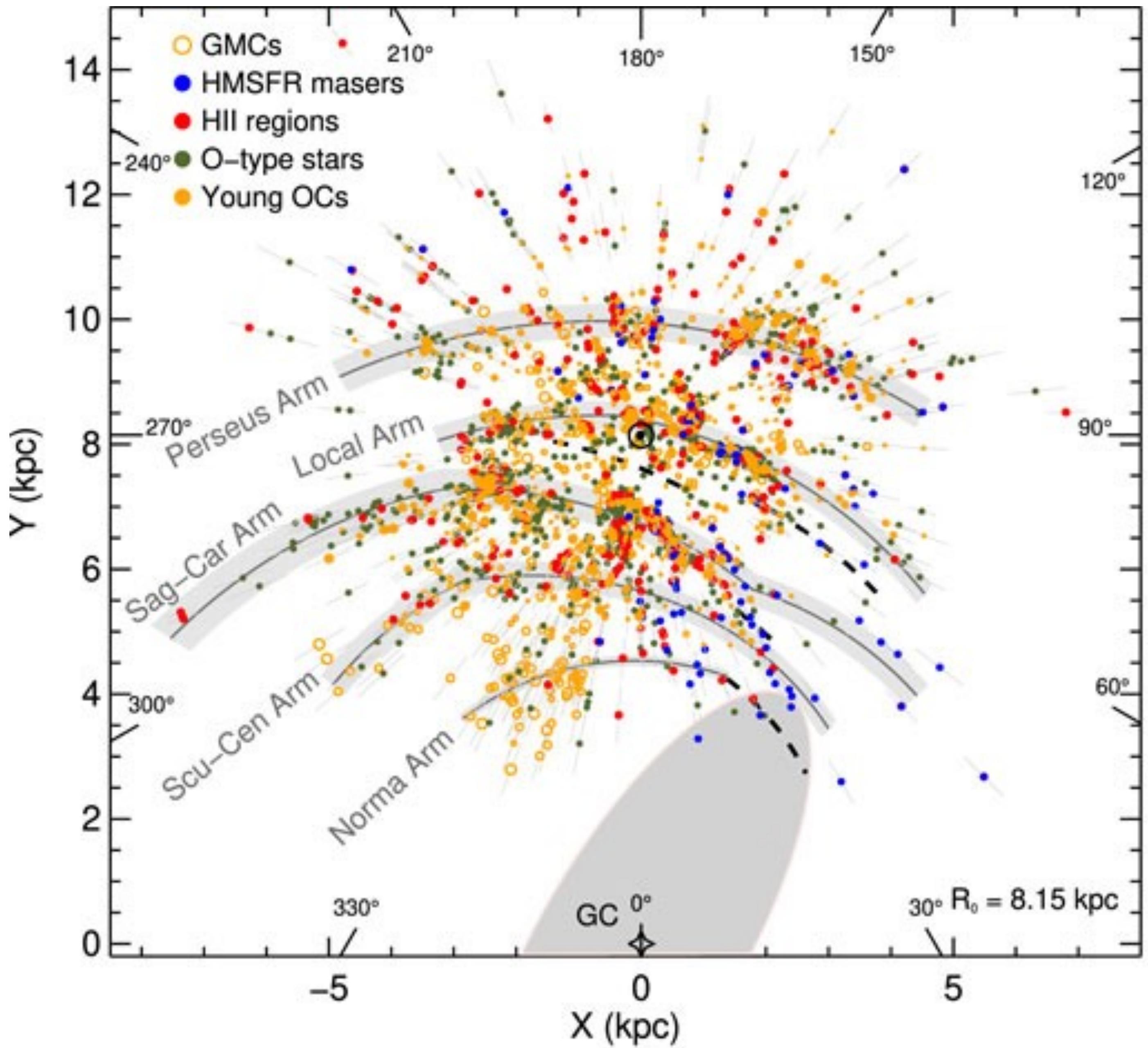
Density Wave



Kinda freaks me out
see also: [Shepard tones](#)

Bulge + Bar

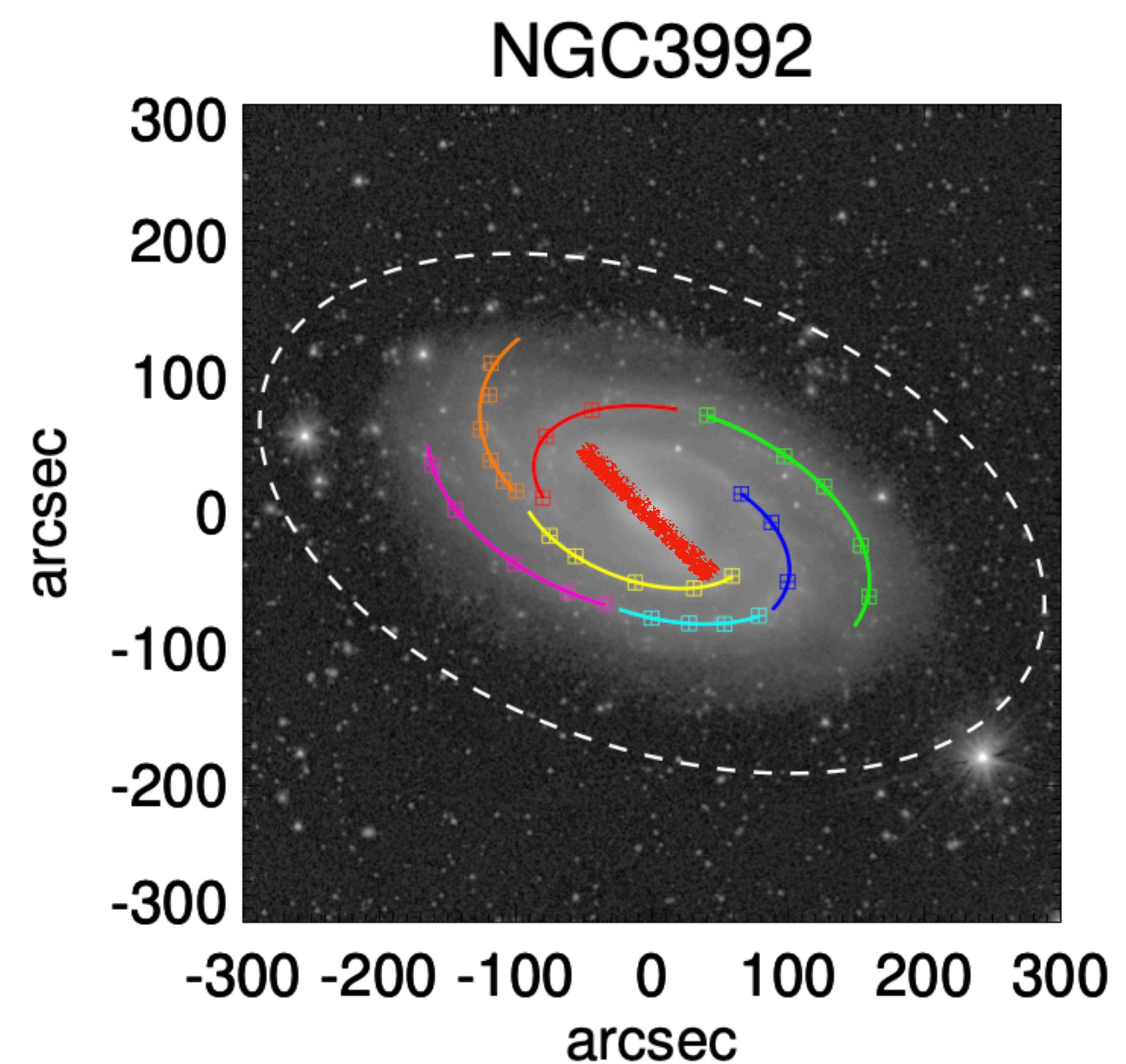
- MWY seems to have a fairly large bar, 4-5kpc half-length
- See how far the bar extends, way into the disk!
- Norma Arm might be connected to the bar



Hou (2021)

Bulge + Bar

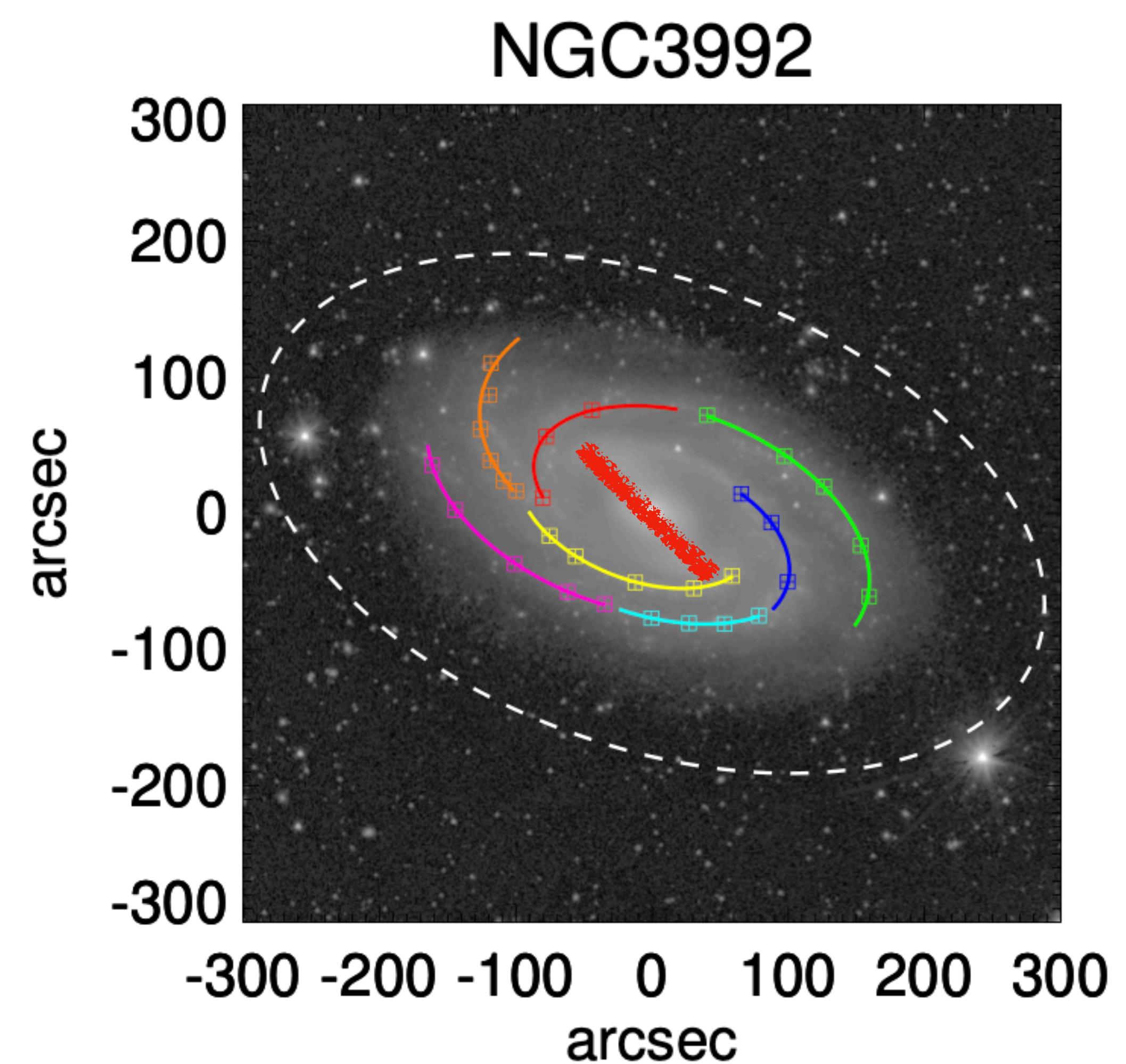
- Resonance w/ bar invoked to be driver of “grand spiral” structure and spiral strength
- Bars could drive density waves that form spirals
(Normandy & Norman 1979)
- Bars might govern orbital “manifolds” that dictate spiral structure (e.g. Athanassoula+2009)



Díaz-García+2019

Bulge + Bar

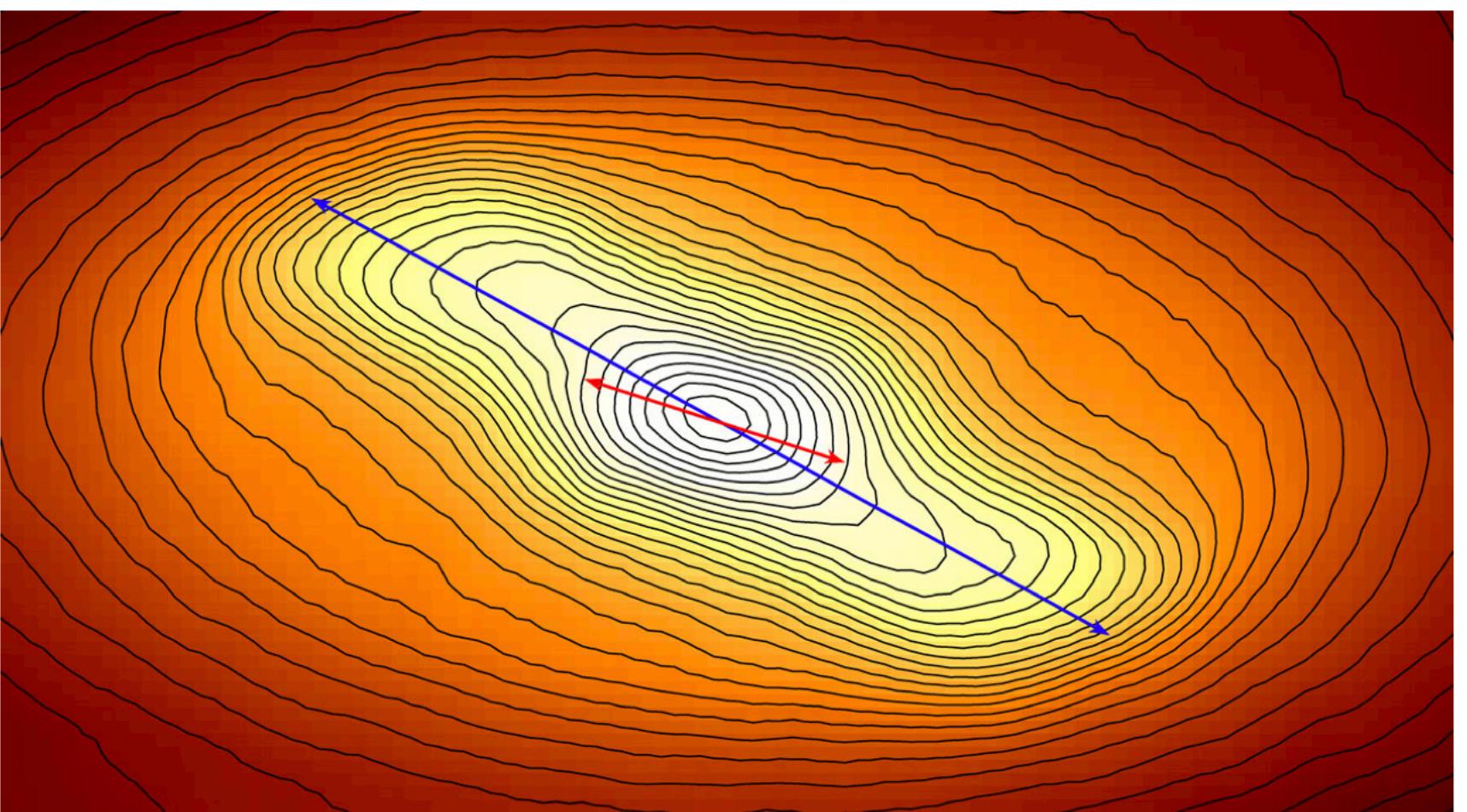
- New surveys of galaxy properties find weak/no evidence that spiral arms are driven by bars, but bar & spiral strength may correlate (e.g. Díaz-García+2019)
 - “Most likely, discs that are prone to the development of strong bars are also reactive to the formation of prominent spirals, explaining the observed coupling between bar and spiral amplitudes.”
- Bars relatively common for all kinds of spiral galaxies. (e.g. Sarkar+2023)



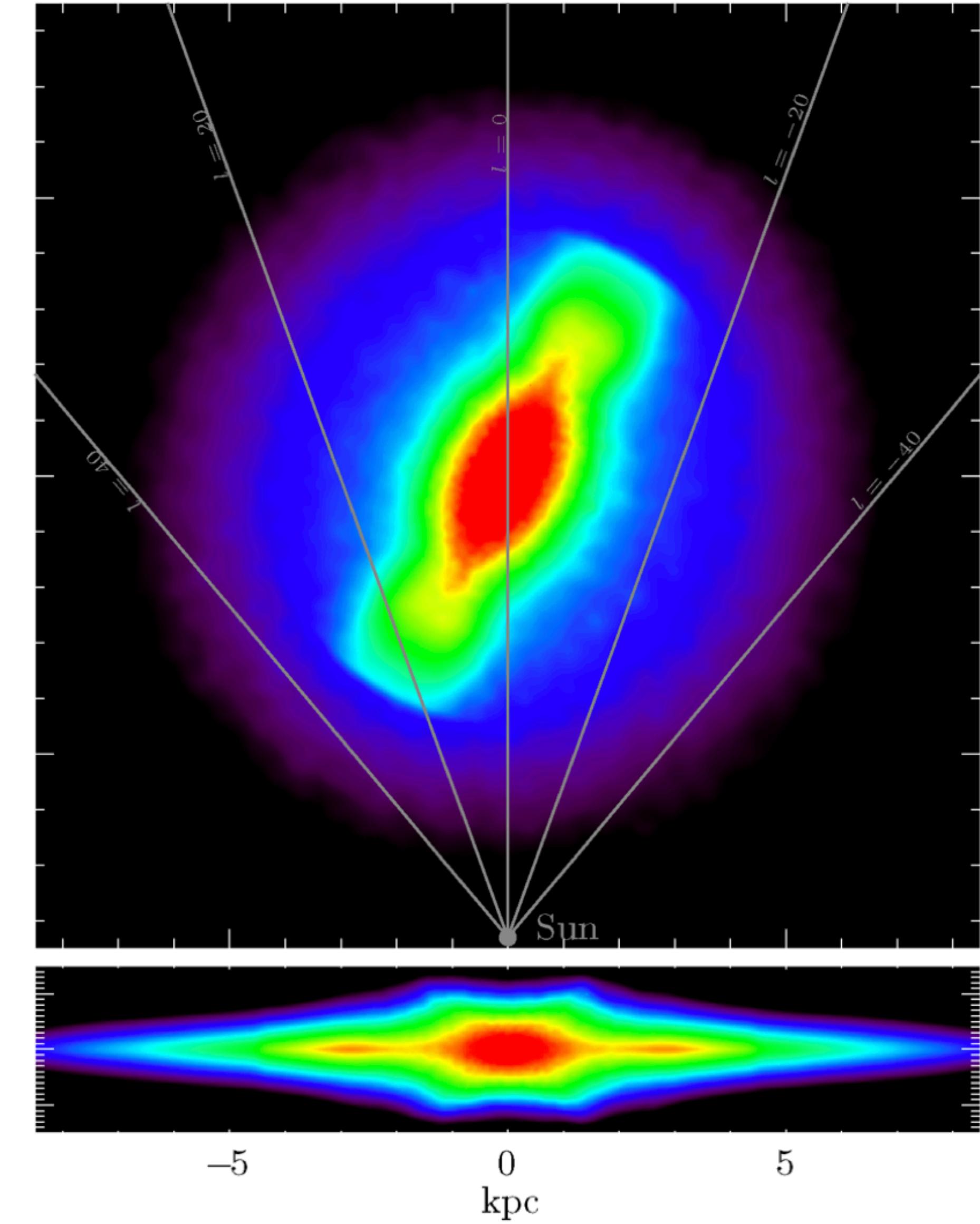
Díaz-García+2019

Bulge + Bar

- Bulge & Bar may be the same thing
- Some evidence of a two-component bar?!
(Wegg+2015)
- Maybe even NO bulge, just disk + bar
(Di Matteo+2015)

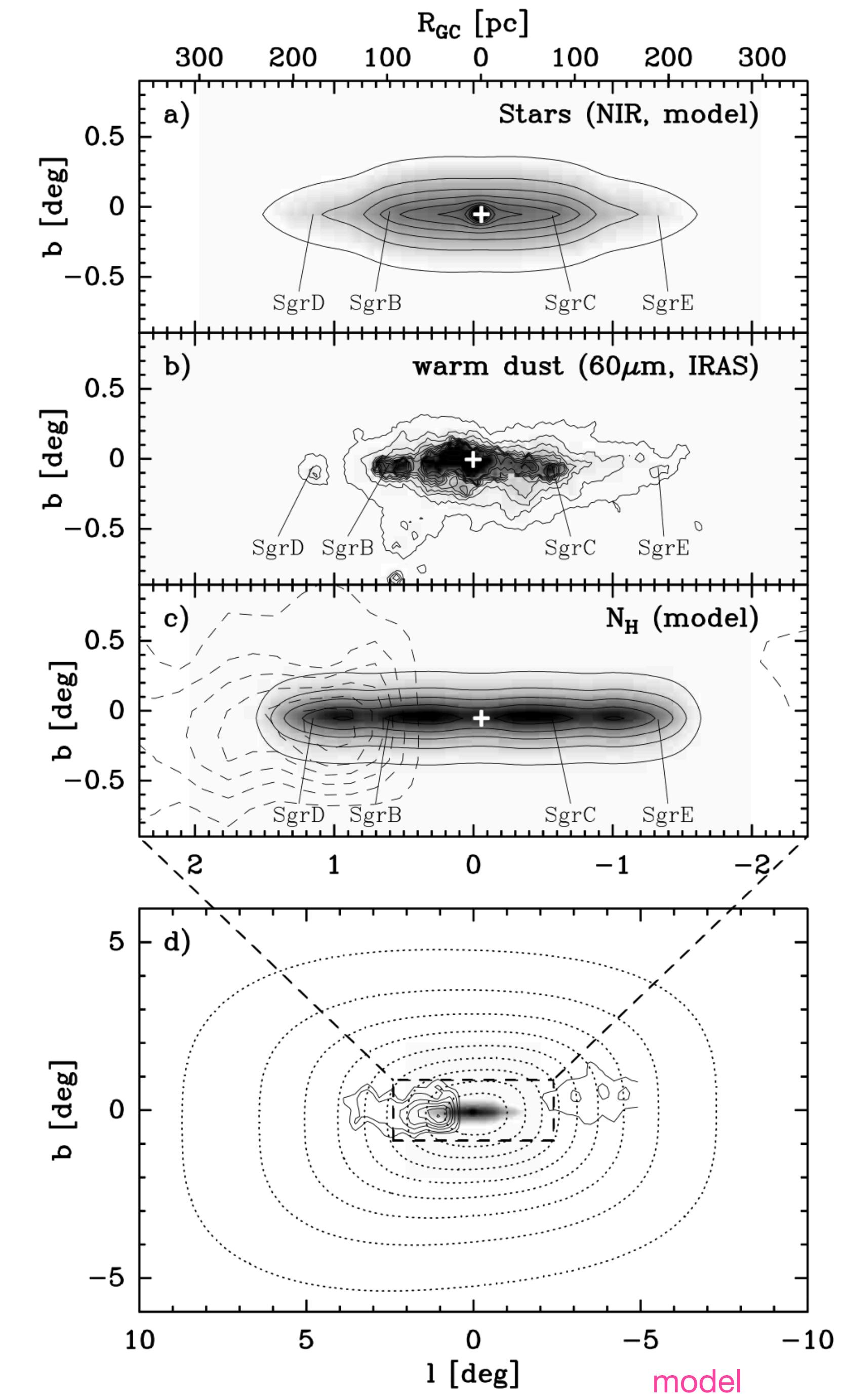
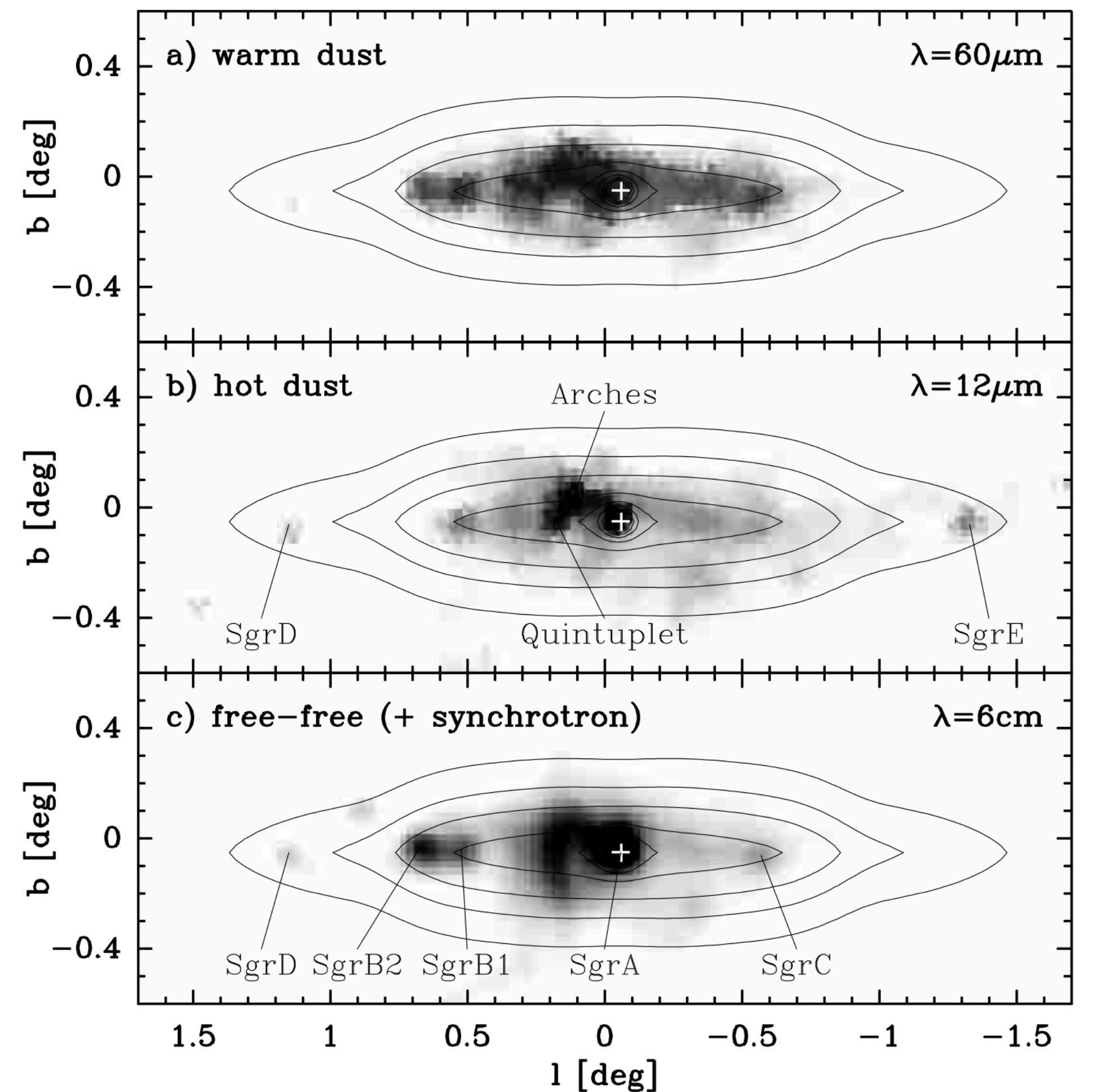


model



Nuclear Cluster

- In the *very* center is the Nuclear Cluster, with a disk-like structure around it (Launhardt+2001)

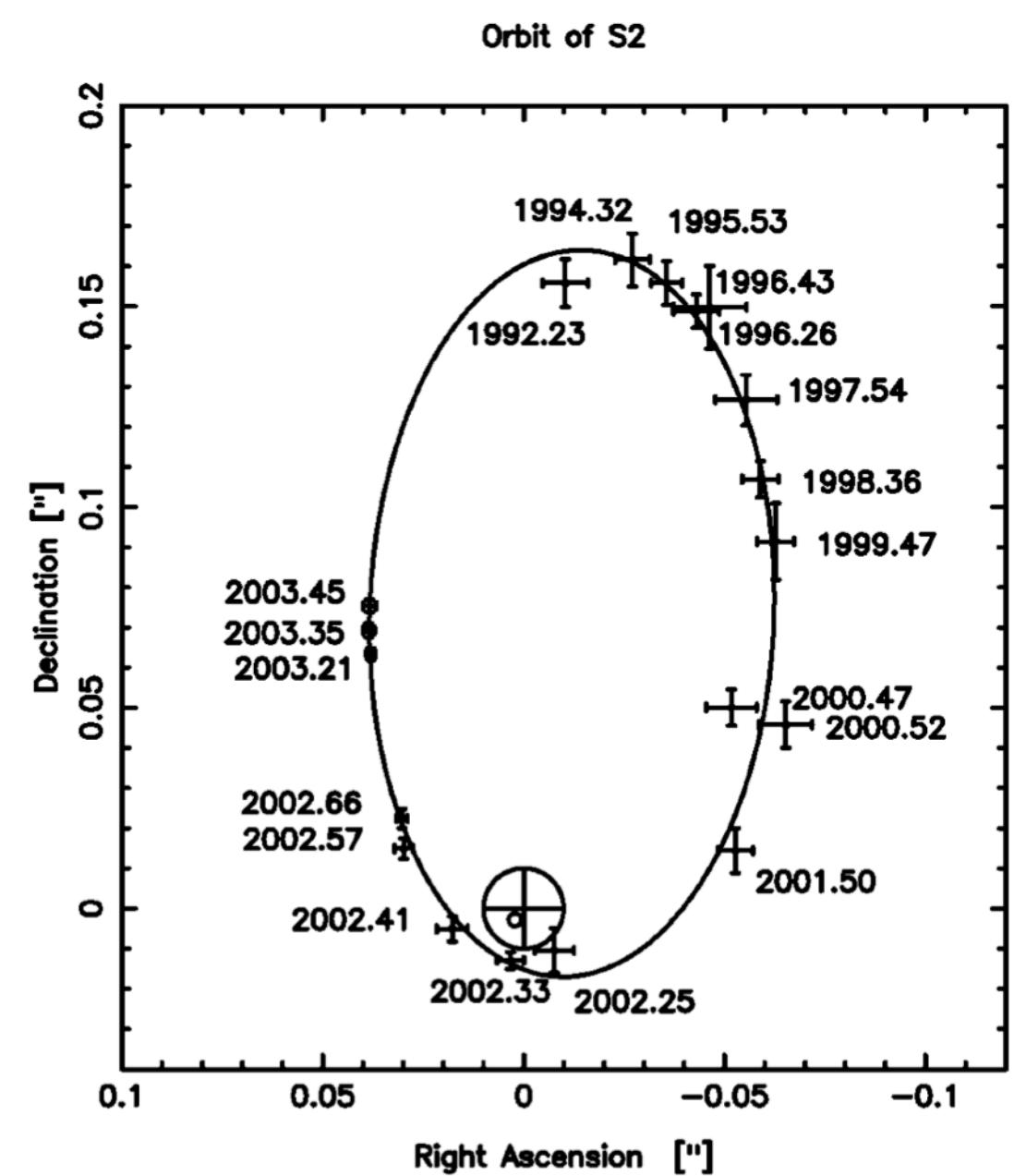
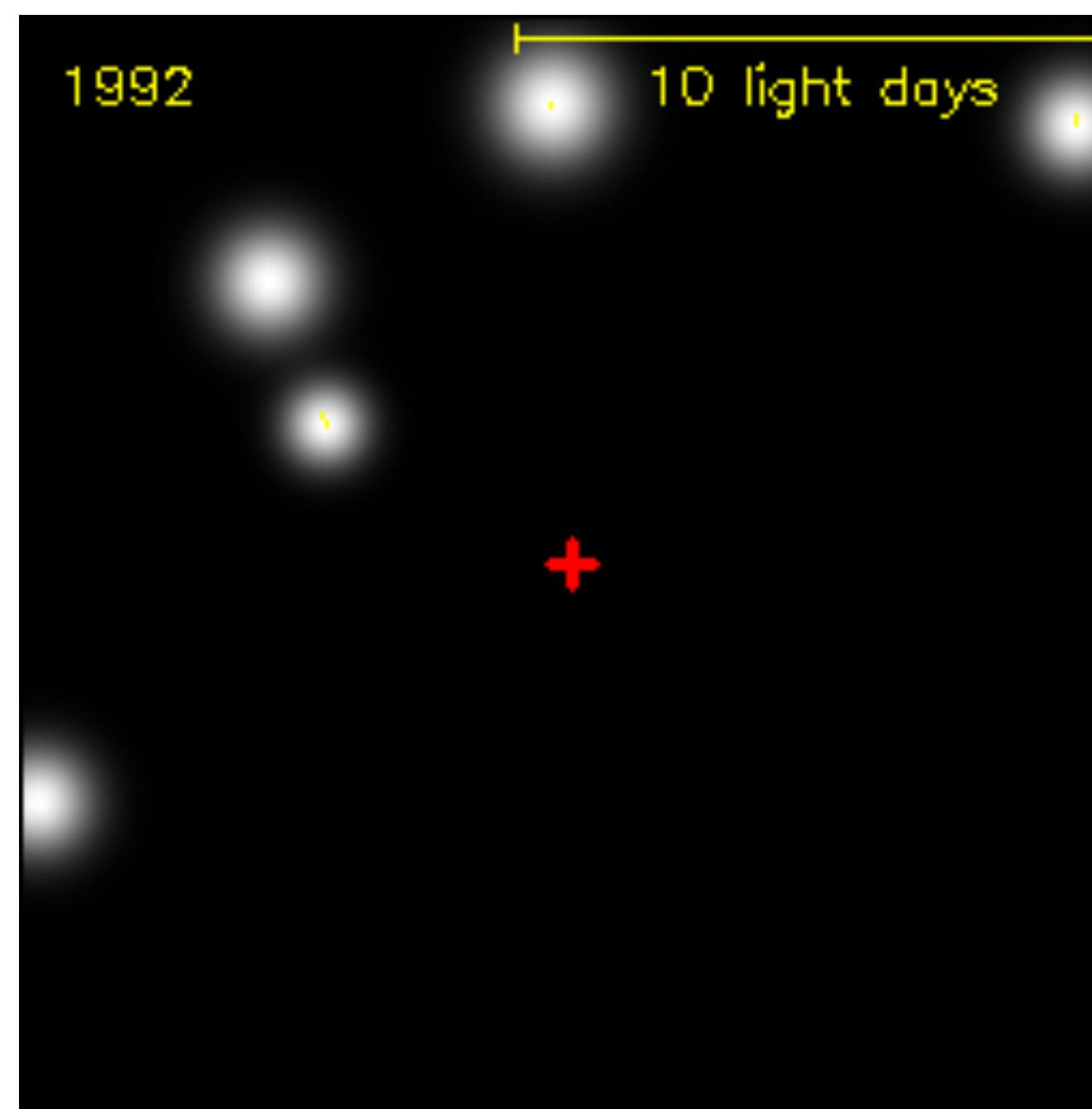


Distance to Galactic Center: R_0

- This number critical to SO MUCH of our geometry... Historically wide range of values considered (though 8kpc favored by some 100yrs ago!)
- IAU standard value has long been $R_0 = 8.5$ kpc, still see this used a LOT (e.g. in the Gaia Catalog of Nearby Stars, using the “Besançon” MWY model)
- People even recently claim much smaller values
 - e.g. $R_0 = 7.5$ kpc by modeling globular cluster distribution: Francis & Anderson (2014)
 - **Best estimate currently seems to be: 8.122 kpc**, measured by modeling orbit of star “S2” at the Galactic Center (GRAVITY collab. 2018)

Distance to Galactic Center: R_0

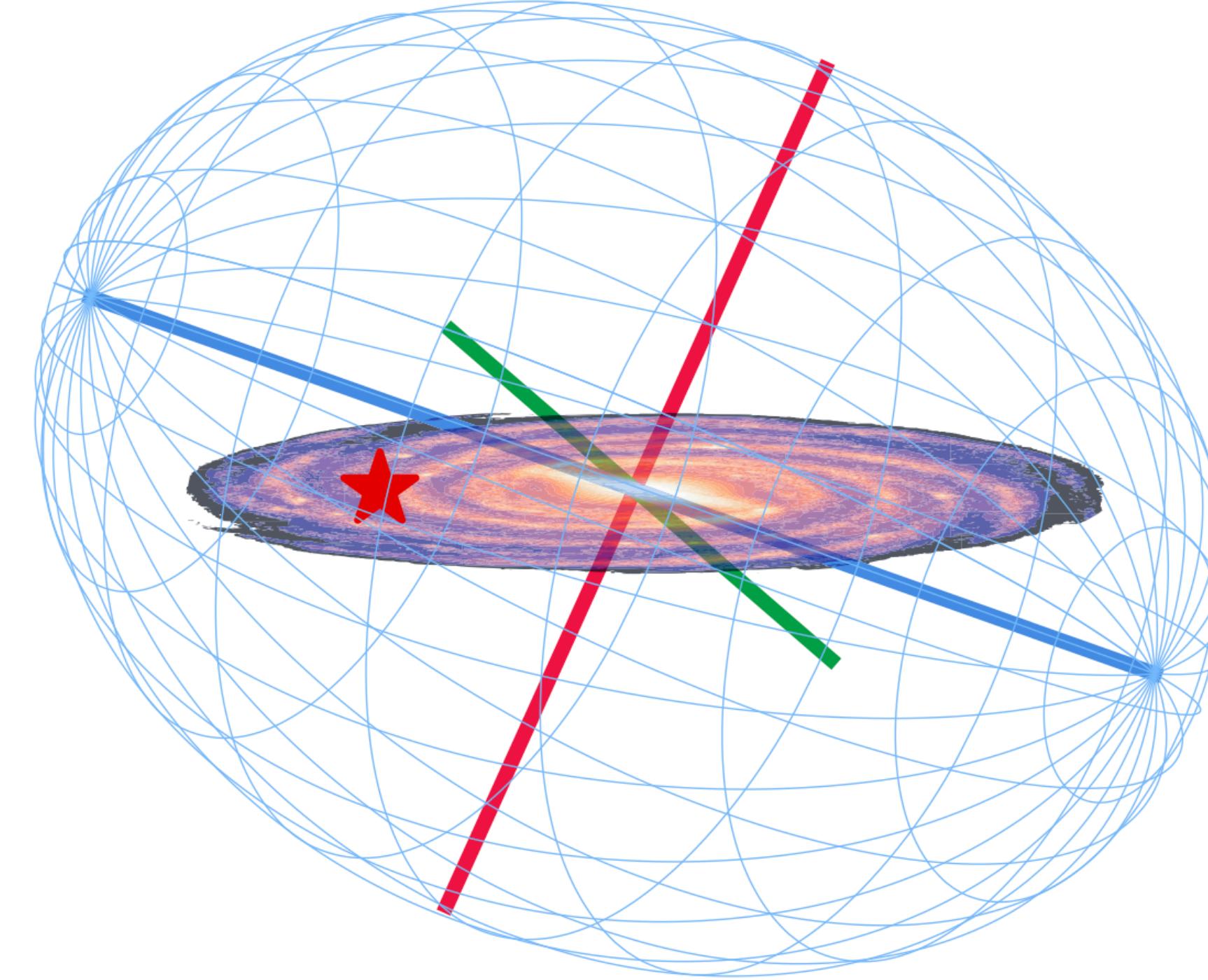
- Best distance comes from fitting the orbit of star S2 around Sag A* (e.g. [Eisenhauer+2003](#))
- This is a classic technique developed for binary stars ([See 1895](#)), if you can measure RV's & astrometric shifts, then solve for binary mass, orbital separation, and distance (Kepler's 3rd Law + geometry!)



Halo (Stellar)

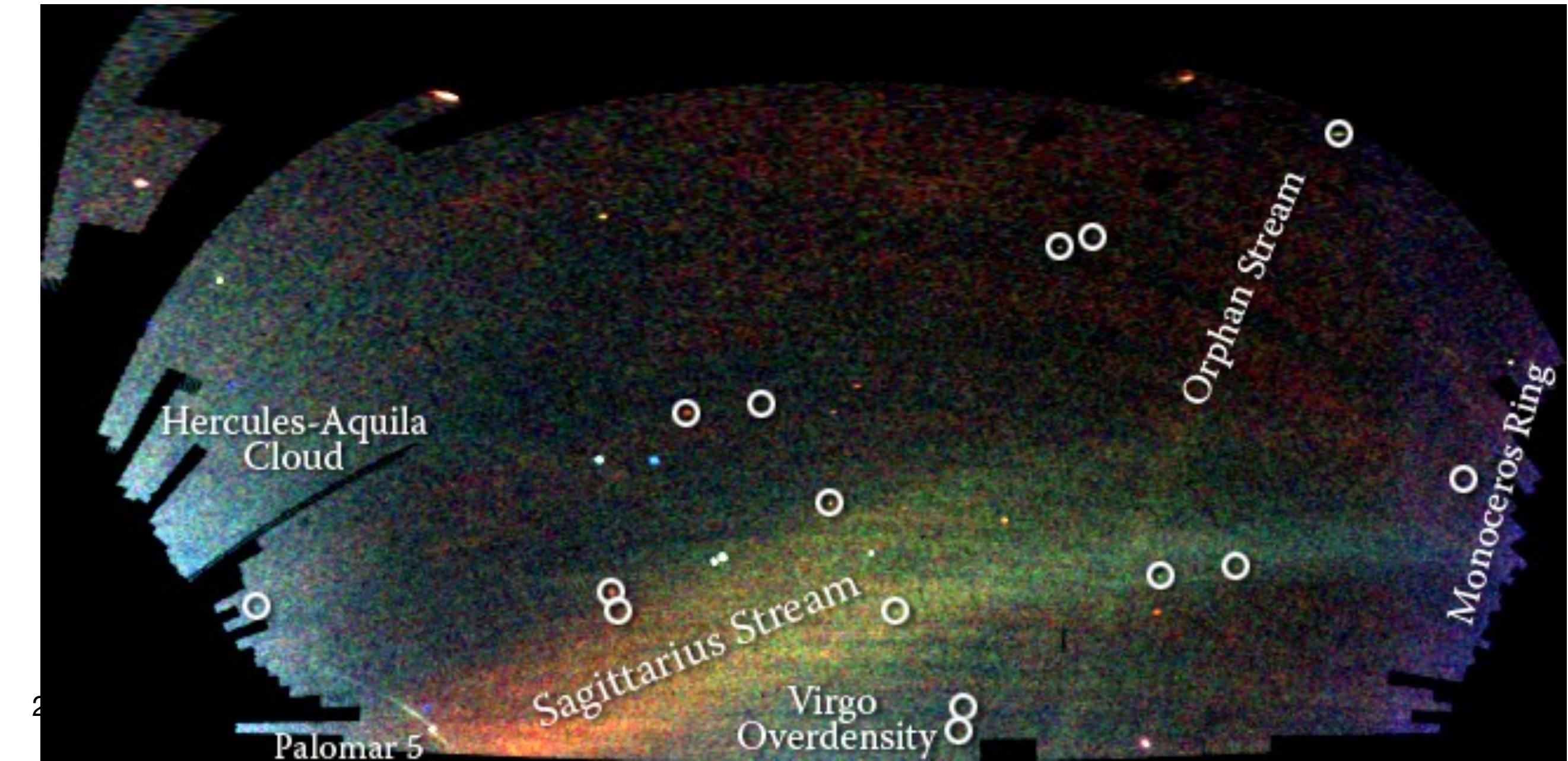
- Triaxial (not spherical!)
- Old, metal poor
- Substructure, hints at origin
 - Globular Clusters
 - Streams
 - (Dwarf) galaxy mergers
 - **Gaia Sausage**

“Field of Streams”
Belokurov+2006



Axis Ratios
10 : 8 : 7

Han+2022



Mass of Components

- Bulge + Bar: $9.1 \times 10^9 M_\odot$
- Disk: $5.2 \times 10^{10} M_\odot$ e.g. from Licquia & Newman (2015)
- Stellar Halo: $\sim 10^9 M_\odot$
- Nuclear cluster region: $3.3 \times 10^6 M_\odot$ e.g. from Genzel+1997
- Dark Matter Halo: $1.4 \times 10^{11} M_\odot$ (within 20 kpc) e.g. from Posti & Helmi (2019)

Next Week:

- Chemical Cartography
- Star Formation History of the MWY