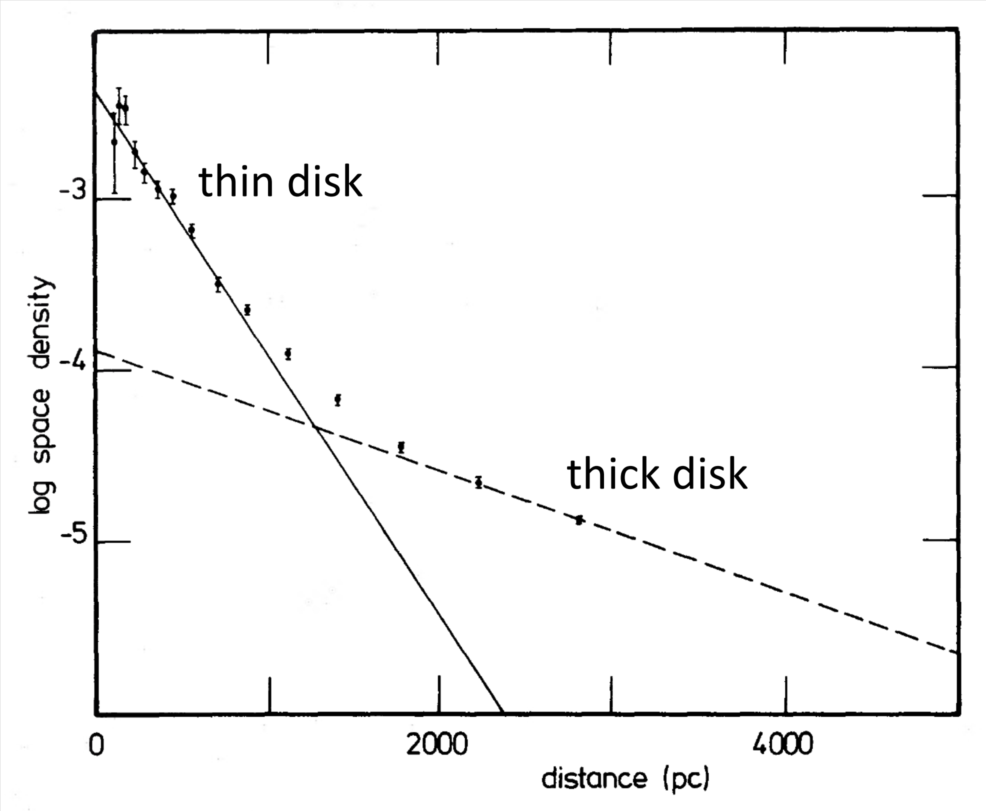
Thin and Thick Disk

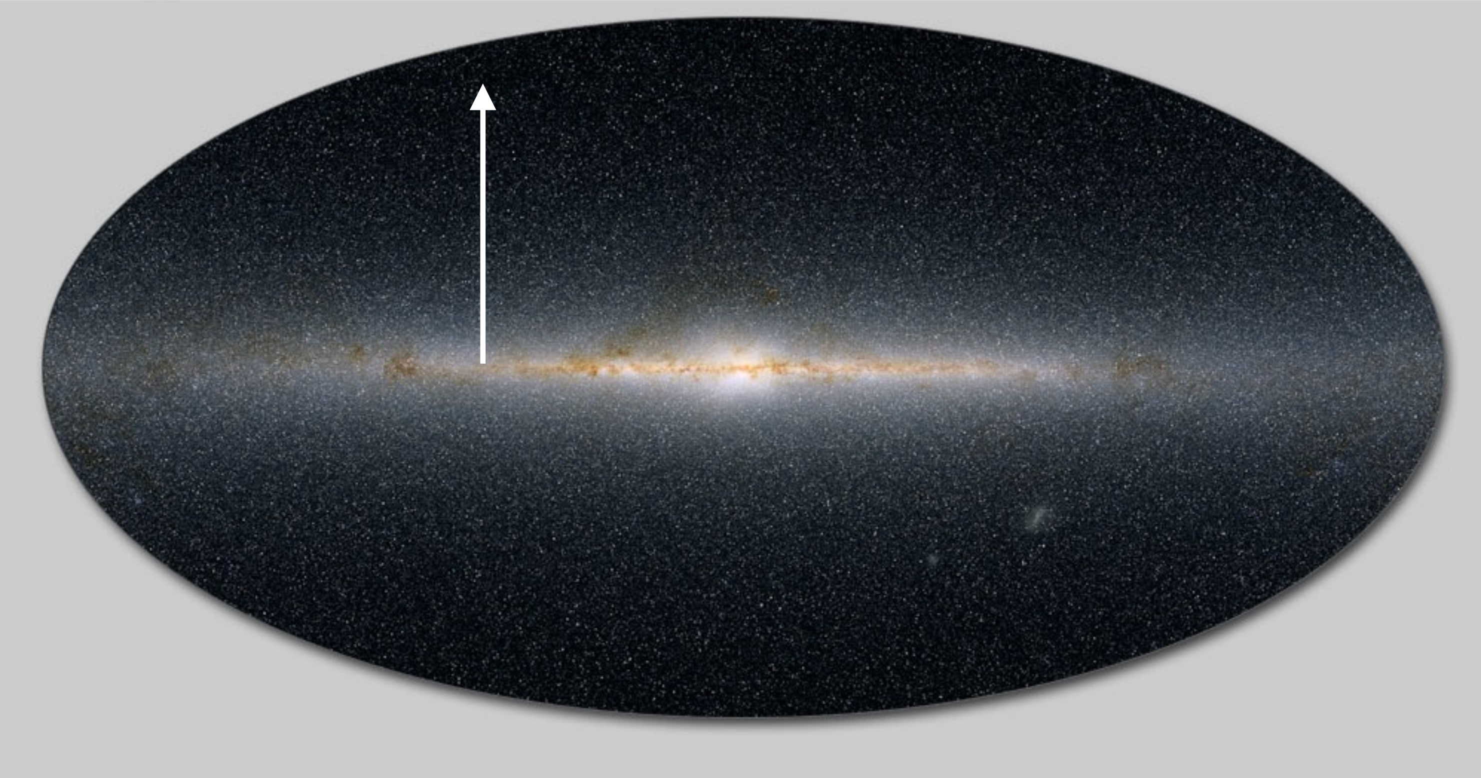
Scale height can be better fitted as a combination of two exponentials:
- Thin disk: $h_z \approx 300$ pc
- Thick disk: $h_z \approx 1$ kpc

[Gilmore & Reid 1983]



vertical height from midplane

2MASS near-IR map



Thick Disk

The thick disk is thicker but more centrally concentrated than the thin disk.

It is kinematically hotter than the thin disk.

It is older and more metal-poor than the thin disk.

	Thin Disk	Thick Disk
Scale height (h_z)	300 pc	1 kpc
Scale length (h_R)	3–4 kpc	2 kpc
$(\sigma_U, \sigma_V, \sigma_W, v_a)$ Kinematics	≈ (30, 20, 20, 15) km/s	≈ (60, 40, 40, 30) km/s
Stellar pops	Mix of stellar ages, more metal-rich stars	Old stars, somewhat more metal-poor

Total luminosity of thick disk ≈ 10% that of the thin disk

Edvardsson+ 93

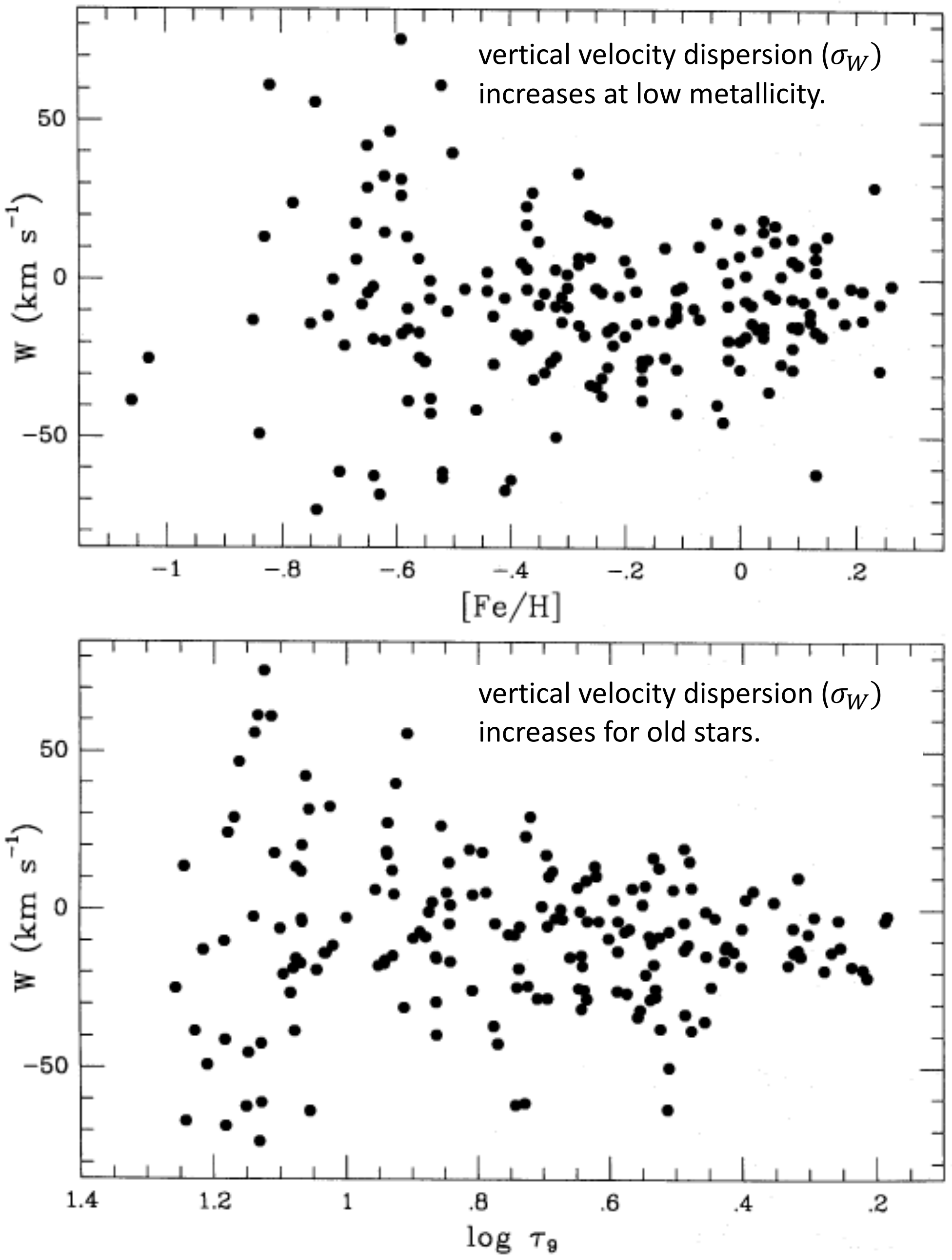


Fig. 16a and b. Stellar velocities perpendicular to the galactic plane, W, vs iron abundance **a** and age **b**, τ_9 is the age in 10^9 years

Metallicity structure of the thin and thick disk

Hayden+15

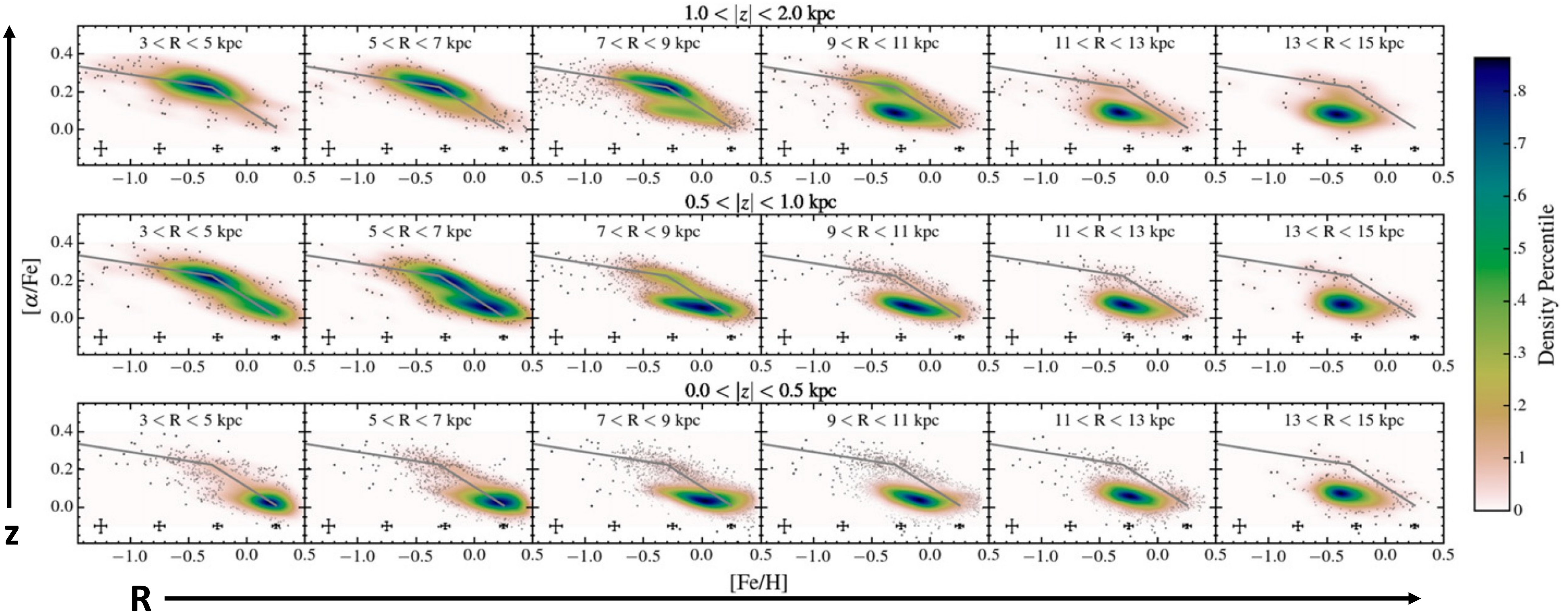


Figure 4. Stellar distribution of stars in the [α/Fe] vs. [Fe/H] plane as a function of R and $|z|$. The typical uncertainty in the abundances is shown as a function of metallicity across the bottom of each panel. The size of individual points is inversely related to the density at that location, to avoid saturation. Top: observed [α/Fe] vs. [Fe/H] distribution for stars with $1.0 < |z| < 2.0$ kpc. Middle: observed [α/Fe] vs. [Fe/H] distribution for stars with $0.5 < |z| < 1.0$ kpc. Bottom: observed [α/Fe] vs. [Fe/H] distribution for stars with $0.0 < |z| < 0.5$ kpc. The gray line on each panel is the same, showing the similarity of the shape of the high-[α/Fe] sequence with R. The extended solar-[α/Fe] sequence observed in the solar neighborhood is not present in the inner disk ($R < 5$ kpc), where a single sequence starting at high [α/Fe] and low metallicity and ending at solar [α/Fe] and high metallicity fits our observations. In the outer disk ($R > 11$ kpc), there are very few high-[α/Fe] stars.

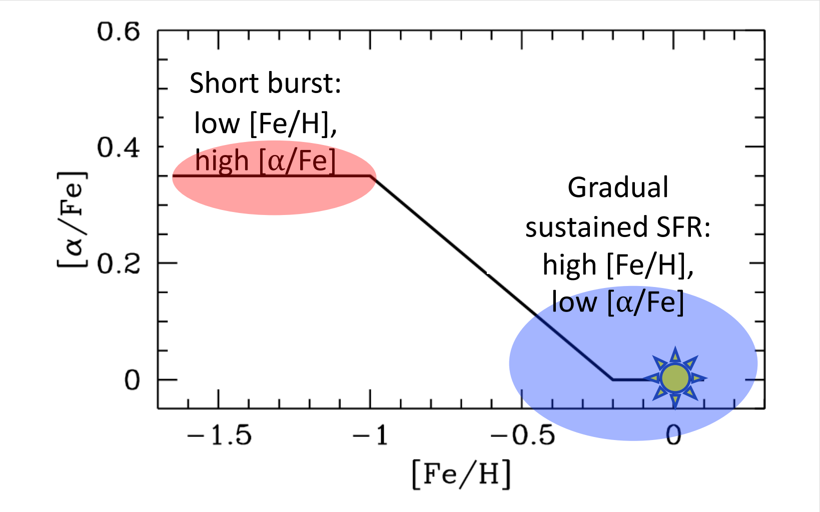
Metallicity structure of the thin and thick disk

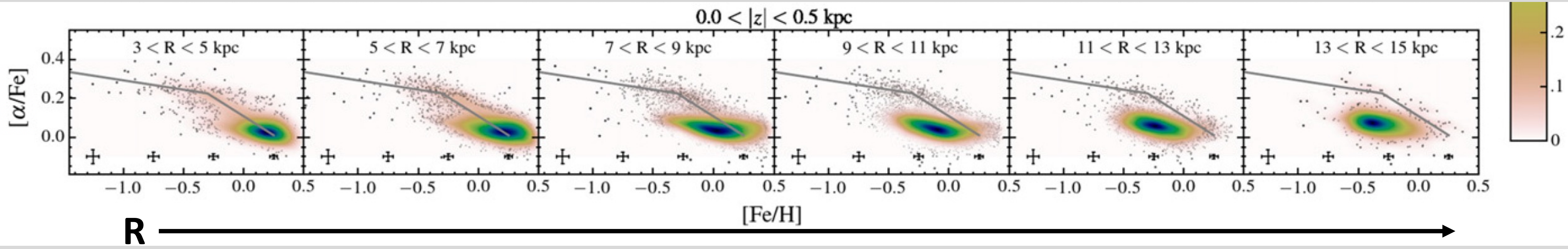
Look at radial metallicity trends for stars in the disk plane.

As radius increases, [Fe/H] decreases, but stars remain relatively solar in [α/Fe].

This is a sign of slow "inside-out" formation of the thin disk. Star formation and chemical evolution may have been going on longer in the inner disk, but overall everything has been built-up slowly over time.

Remember how [α/Fe] and [Fe/H] track star formation and enrichment history.

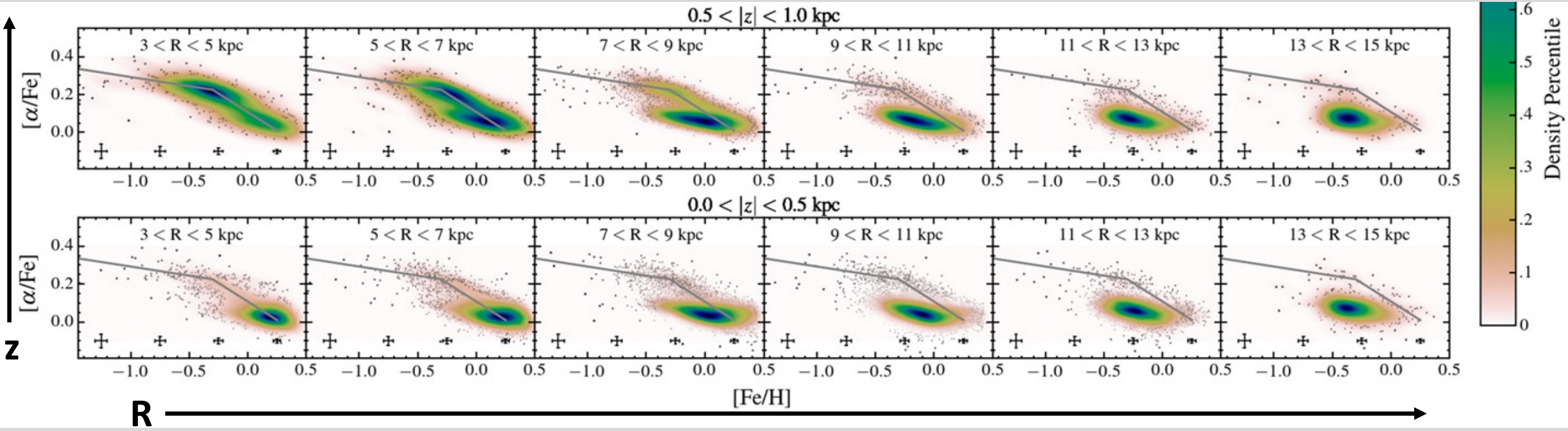




Metallicity structure of the thin and thick disk

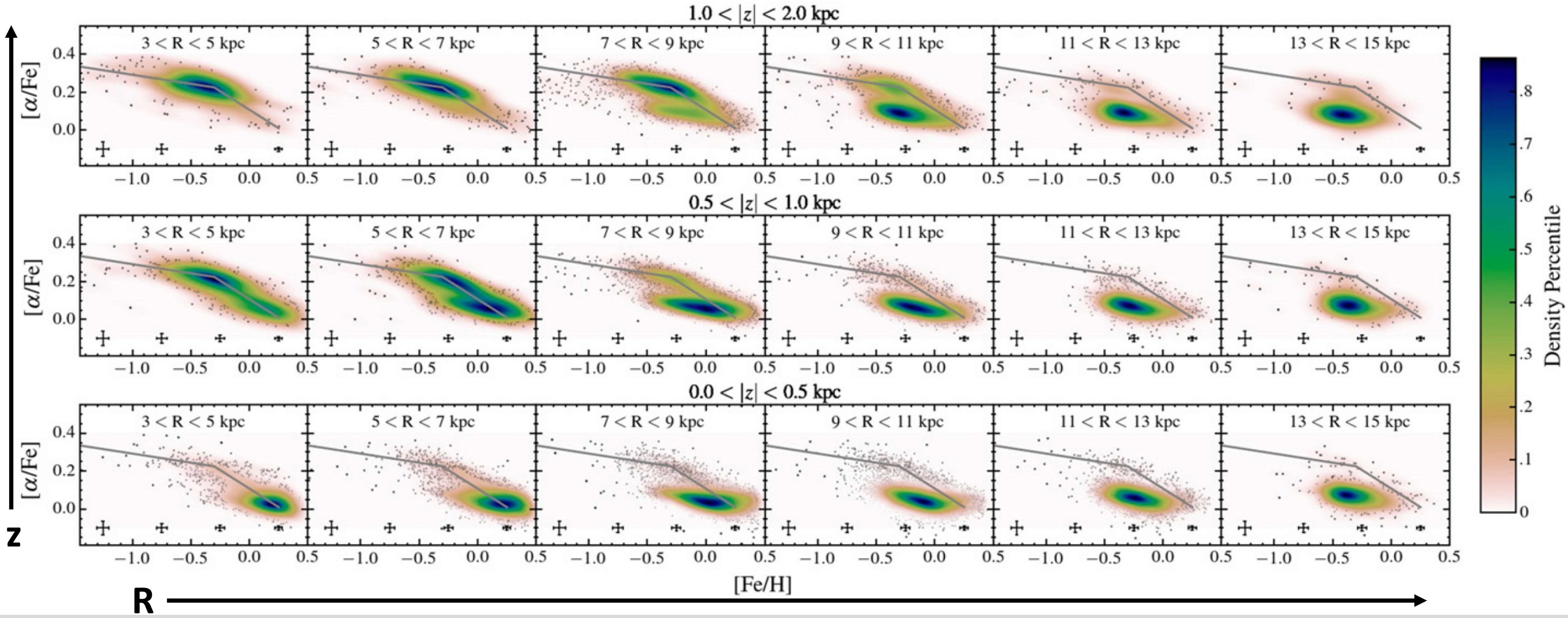
Now compare to stars over the same radial range, but higher up in height (z).

Inner parts look very different – lower metallicity and strong α-enhancement. But only the inner parts. Outer parts still look "normal". This is the signature of the thick disk -- built up earlier and faster than the thin disk, but also not as radially extended.



This argues that the thick disk is not just scattered thin disk stars, or else the thick disk would have the same metallicity pattern as the thin disk.

Metallicity structure of the thin and thick disk



At even higher distances from the plane, inner regions are almost all thick disk. Outer regions still look similar at all heights; high Z stars in the outer disk are not thick disk stars, they are probably just scattered thin disk stars.

Metallicity structure of the thin and thick disk

Hayden+15

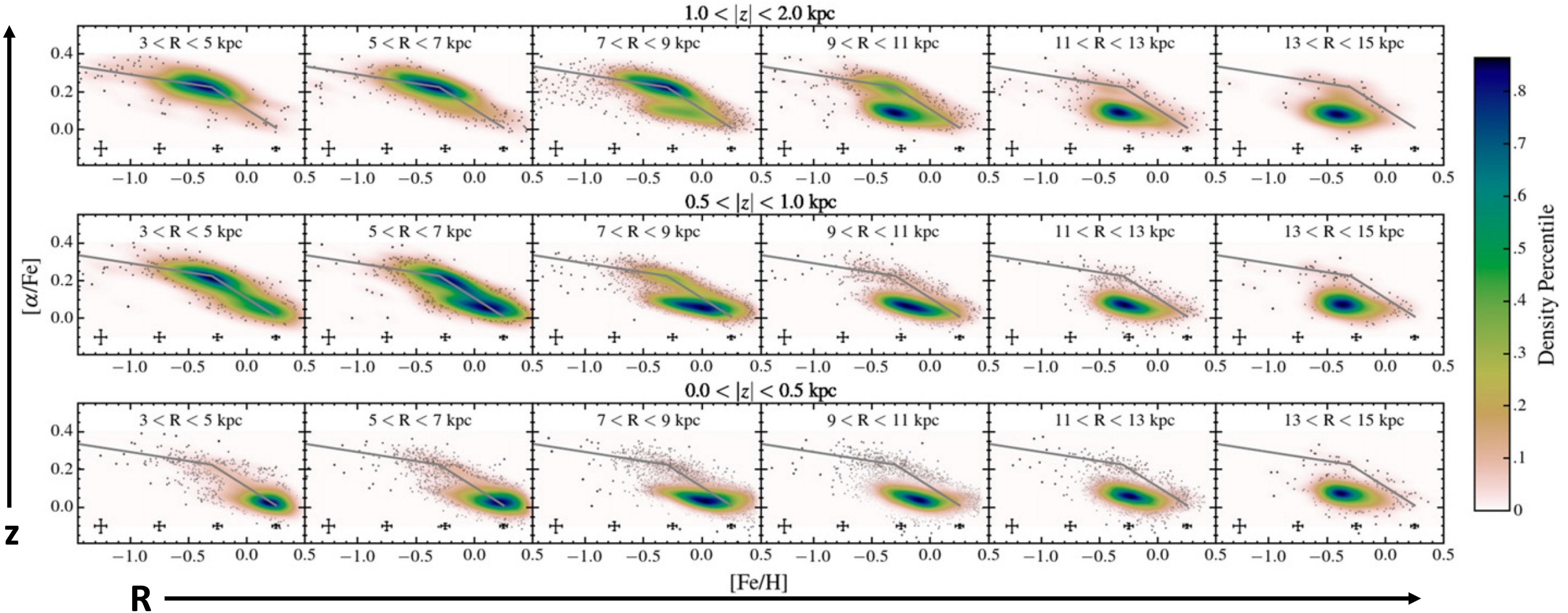


Figure 4. Stellar distribution of stars in the [α/Fe] vs. [Fe/H] plane as a function of R and $|z|$. The typical uncertainty in the abundances is shown as a function of metallicity across the bottom of each panel. The size of individual points is inversely related to the density at that location, to avoid saturation. Top: observed [α/Fe] vs. [Fe/H] distribution for stars with $1.0 < |z| < 2.0$ kpc. Middle: observed [α/Fe] vs. [Fe/H] distribution for stars with $0.5 < |z| < 1.0$ kpc. Bottom: observed [α/Fe] vs. [Fe/H] distribution for stars with $0.0 < |z| < 0.5$ kpc. The gray line on each panel is the same, showing the similarity of the shape of the high-[α/Fe] sequence with R. The extended solar-[α/Fe] sequence observed in the solar neighborhood is not present in the inner disk ($R < 5$ kpc), where a single sequence starting at high [α/Fe] and low metallicity and ending at solar [α/Fe] and high metallicity fits our observations. In the outer disk ($R > 11$ kpc), there are very few high-[α/Fe] stars.

Milky Way Disk: Inferences on Formation and Evolution

Thin disk

- Formed through continuous, on-going star formation: Mix of stellar ages, smooth metallicity distribution, solar [α/Fe] ratios
- Hints of “inside-out” formation: metallicity gradient (maybe also the age-metallicity relationship?) shows inner regions more chemically evolved, maybe formed a bit faster than outskirts
- Dynamically calm process (low velocity dispersion)

Thick disk

- Formed earlier (lower metallicity) and faster (higher [α/Fe] ratios) than the thin disk.
- More centrally concentrated process (shorter radial scale length)
- More “dynamically active” process (higher velocity dispersion)

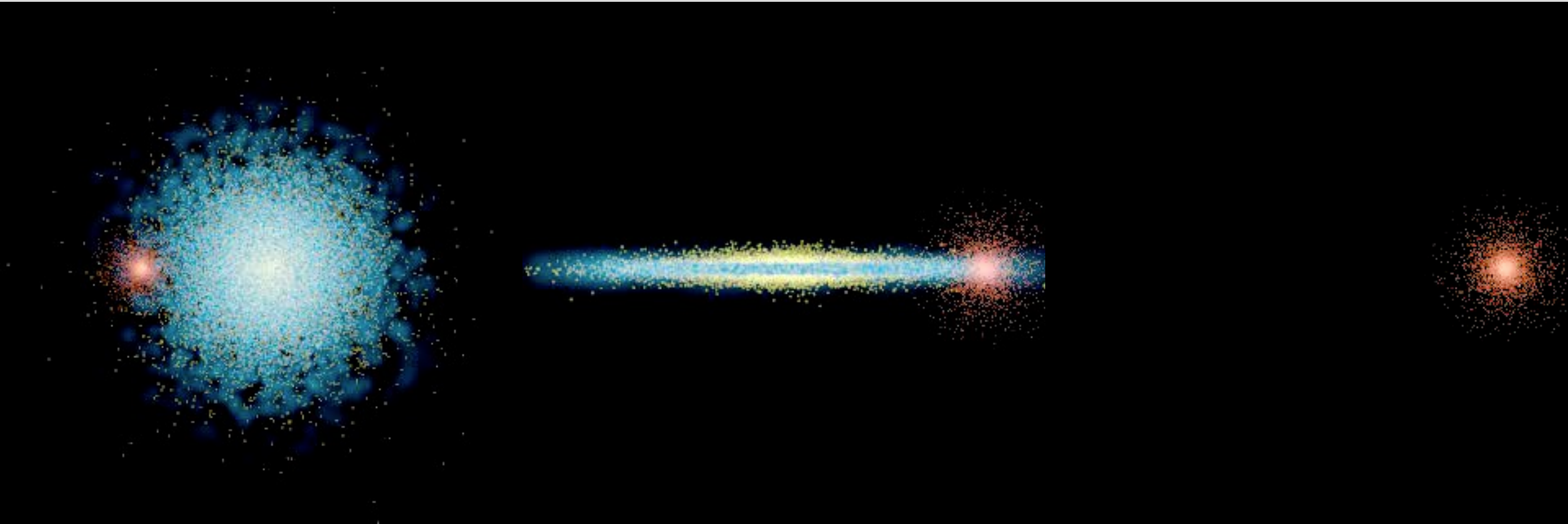
Thick Disk Formation Scenarios I : Early Satellite Accretion

Astronomy lingo*: in terms of dynamics, "cold" means ordered motion with low velocity dispersion, while "hot" means disordered motion with high velocity dispersion. Disks are "cold", bulges and ellipticals are "hot".*

Early in the Milky Way's history, a LMC-ish satellite fell in and heated (scattered) existing disk stars. ⇒ thick disk

Afterwards, the gas re-settles into the disk and continues forming stars. ⇒ thin disk

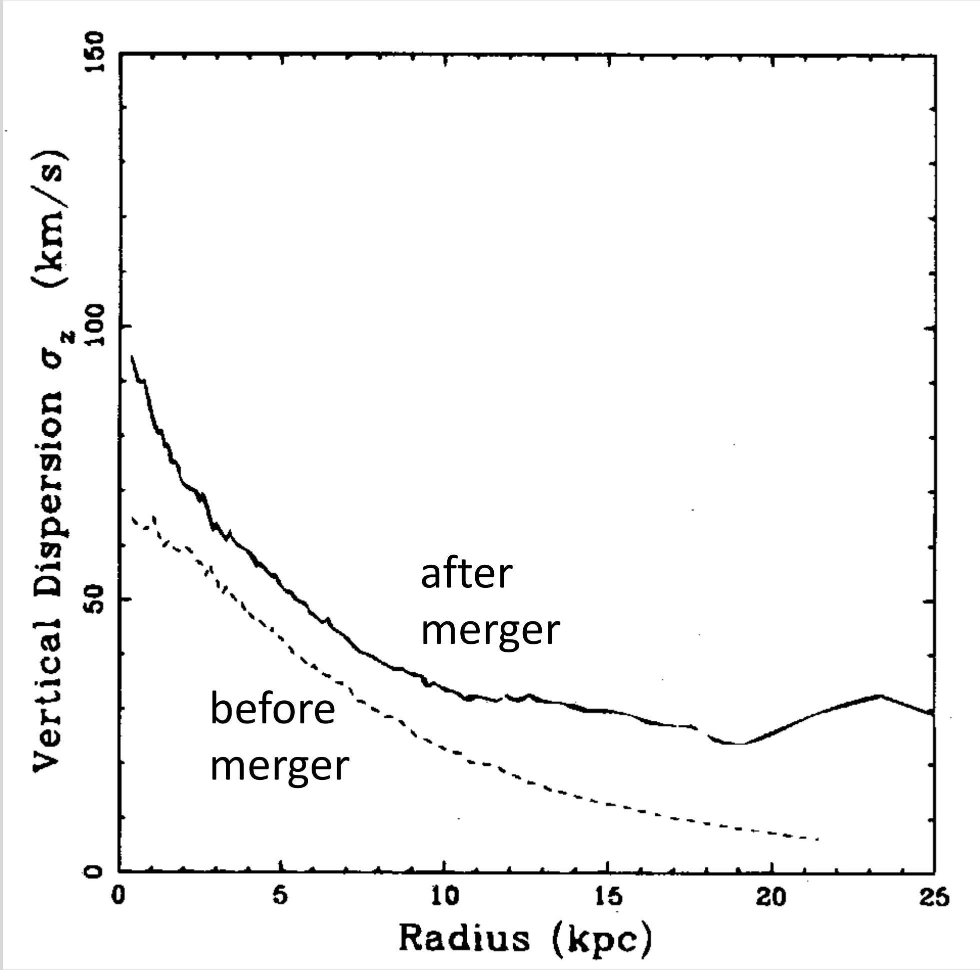
Mihos & Hernquist 1995



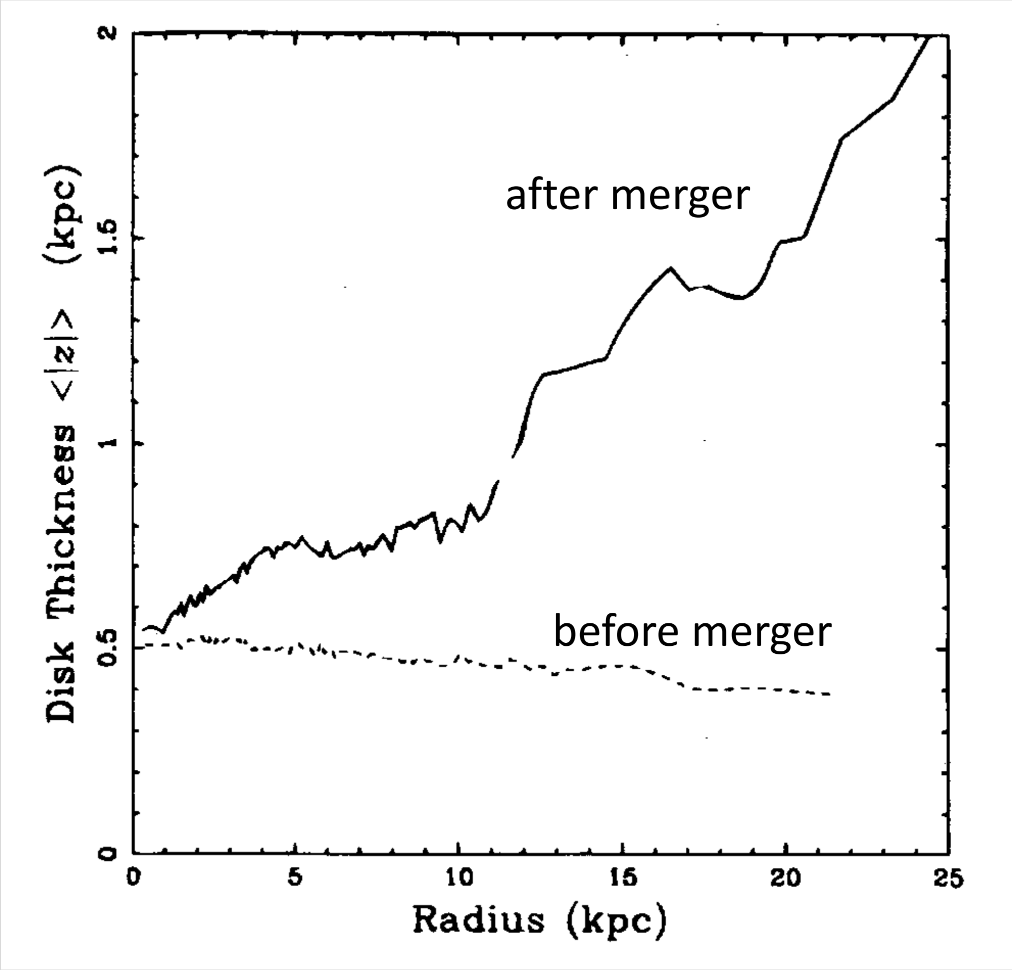
Thick Disk Formation Scenarios I : Early Satellite Accretion

As the satellite falls in, it stirs up the orbits of stars and increases their velocity dispersion (random motion).

This ”disk heating” puffs up the existing disk and makes it thicker.

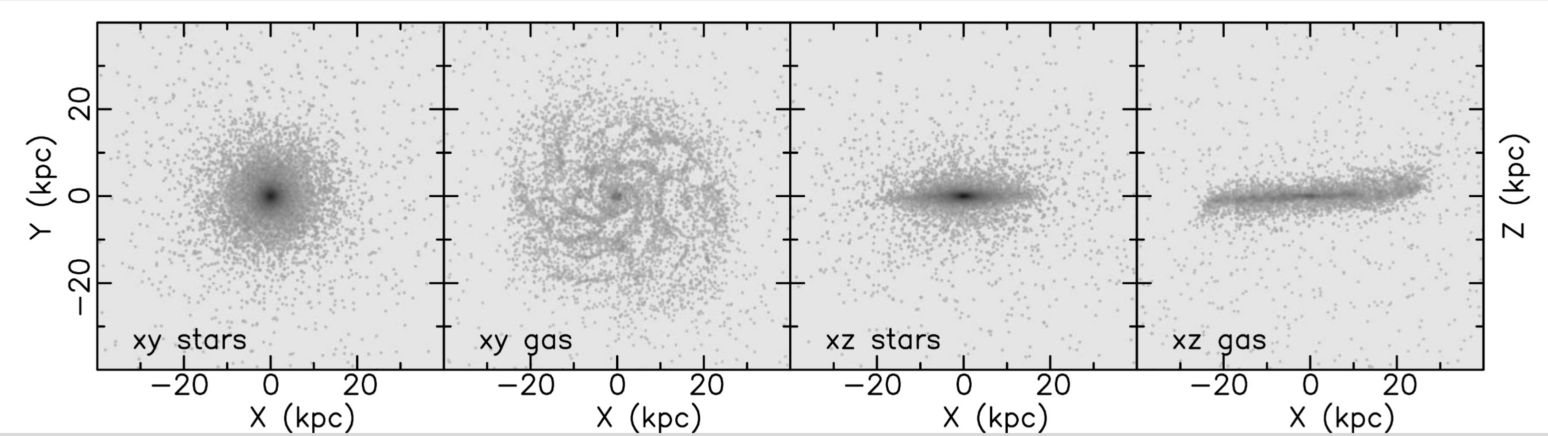


Walker+ 96

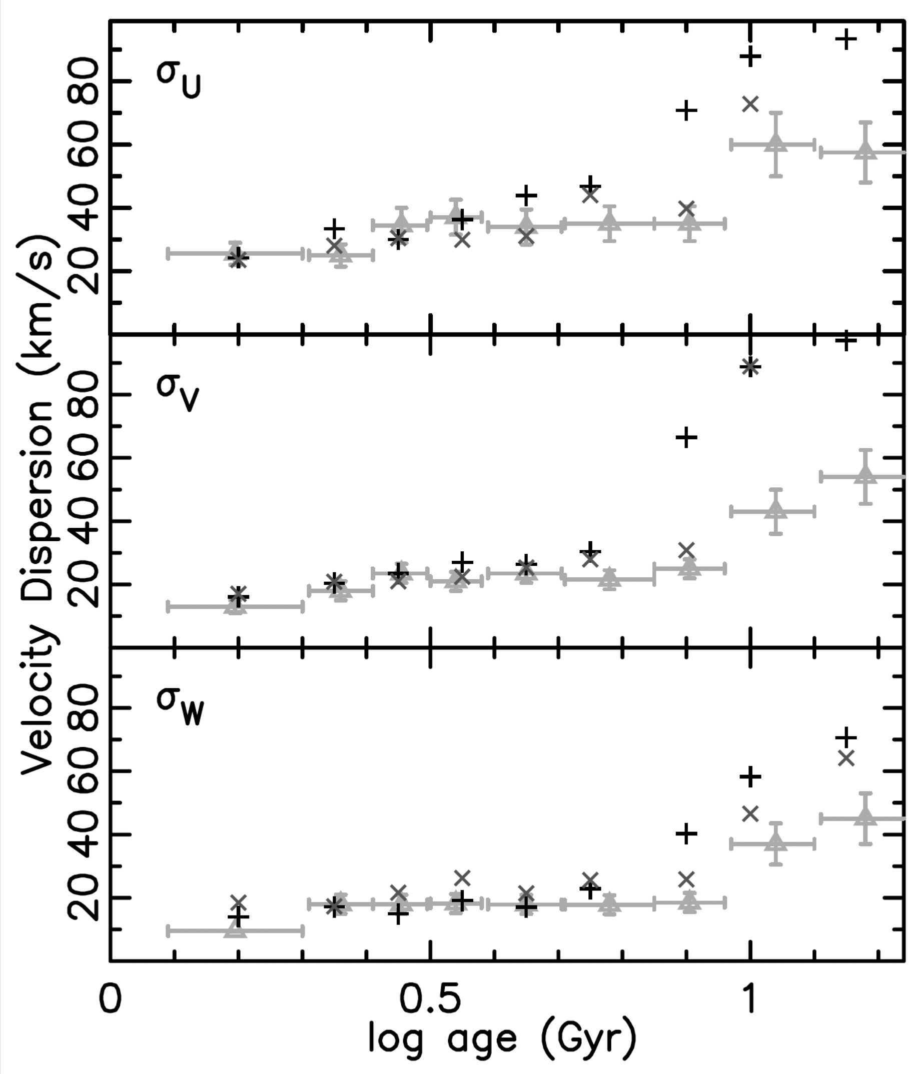


Thick Disk Formation Scenarios II : Turbulent Disk Formation

Simulated galaxy disk **at current time**… (Brook+ 04)



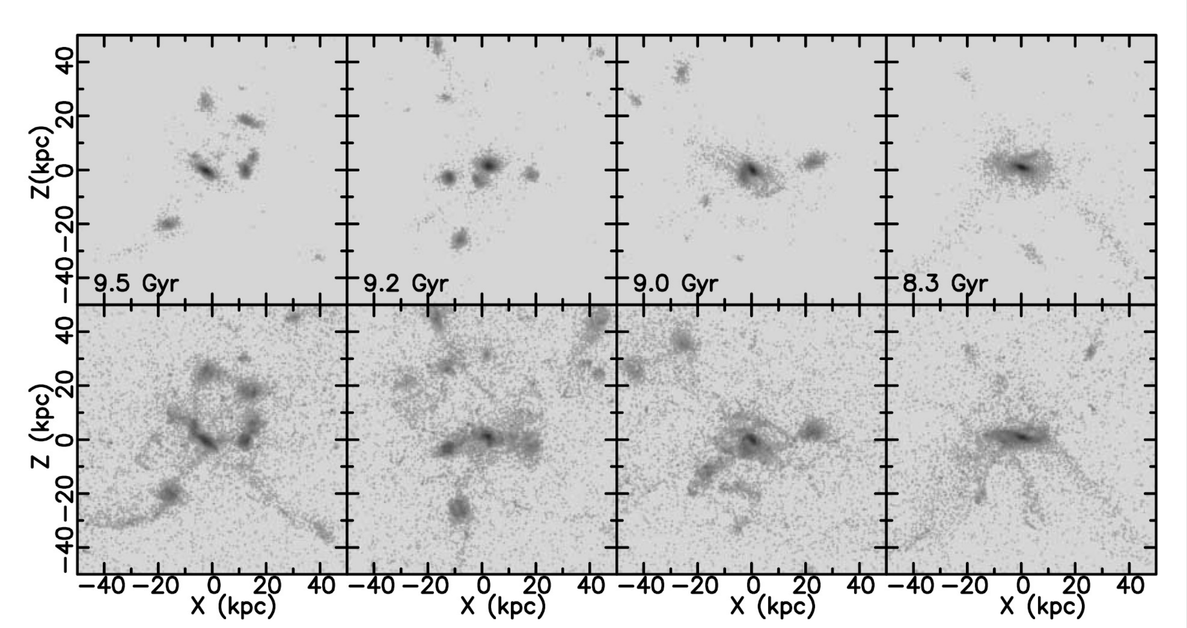
… has a disk that shows a velocity dispersion that increases with stellar age…



Simulations: +, ×

Observations: ▲

…because **back when the disk formed** it was very clumpy and turbulent



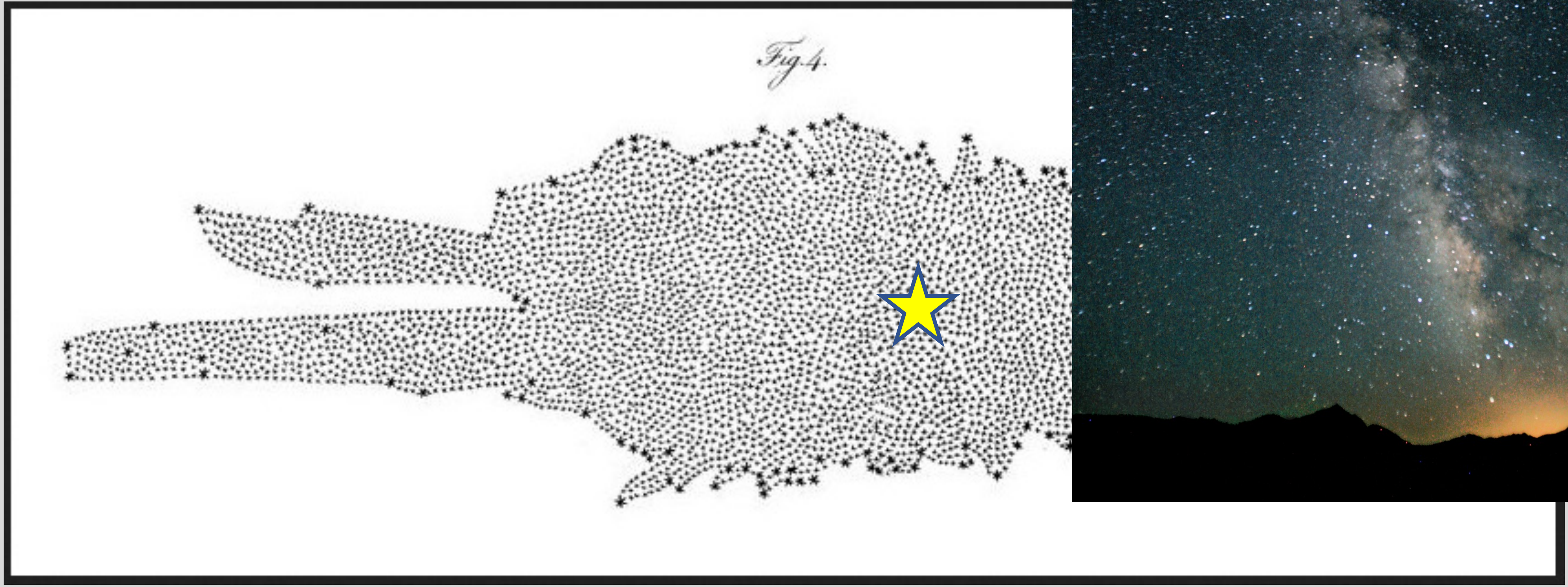
Gas

Stars

The Distance to the Galactic Center

1785: William and Caroline Herschel map the Milky Way using star counts and find the Sun near the center of the Galaxy.

Oops. In hindsight what went wrong?

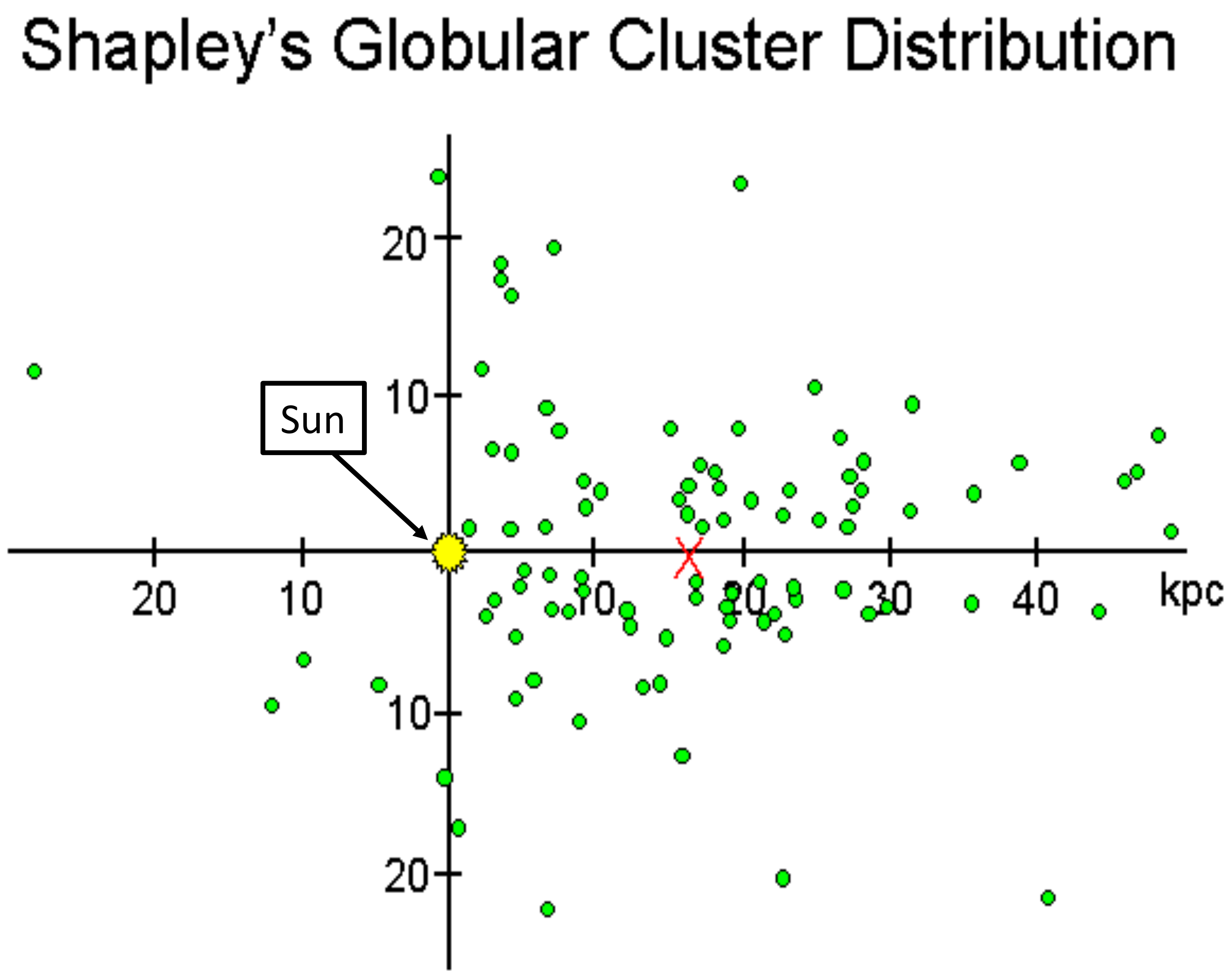


The Distance to the Galactic Center

1920: Curtis Shapley uses spatial distribution of globular clusters, finds that they are centered on a different. spot in the Milky Way.

Correctly reasons that globulars were centered on the location of the Galaxy’s center, but incorrectly placed it 18 kpc away.

Why did he get it wrong?

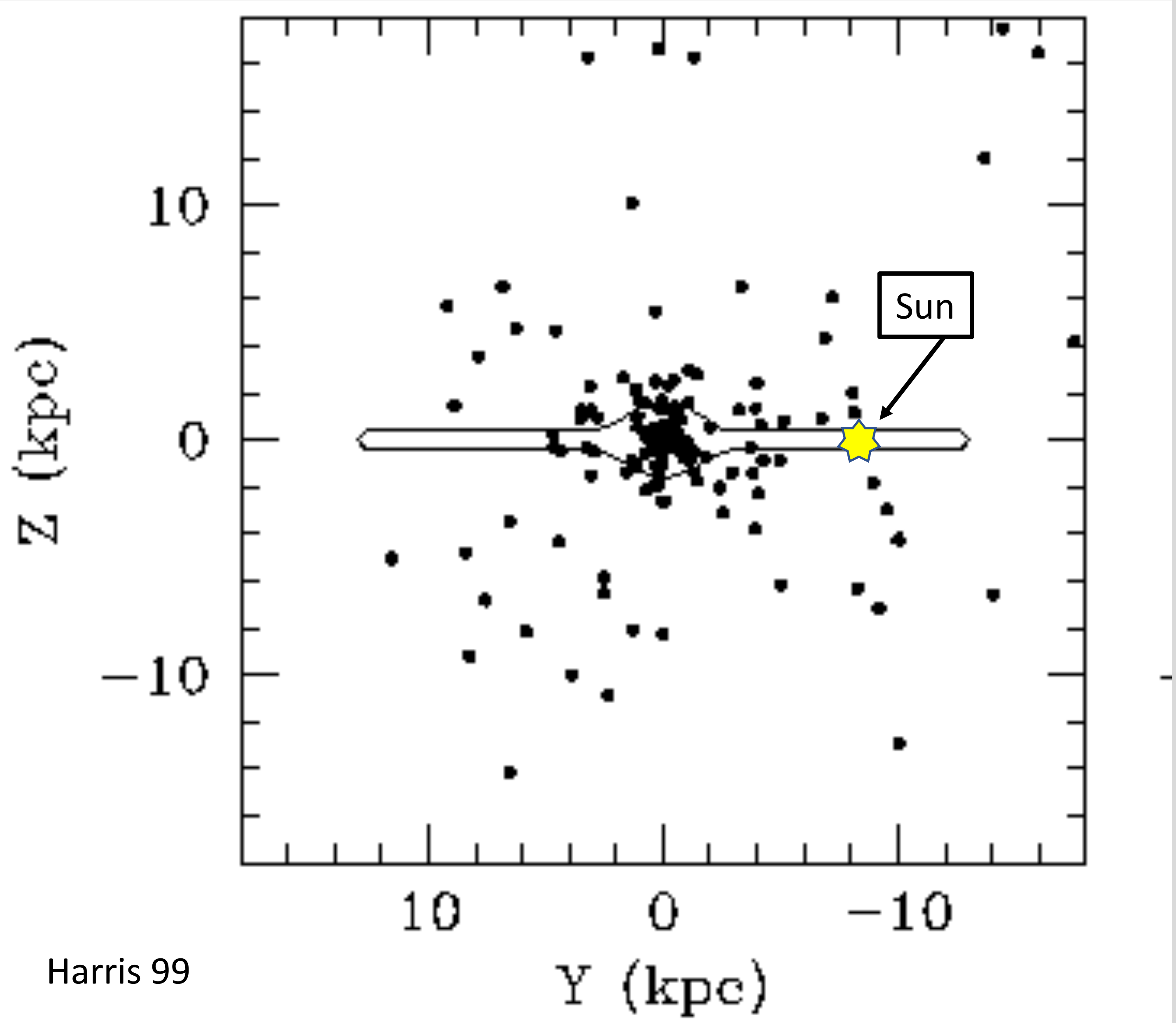


courtesy Rick Pogge, OSU

The Distance to the Galactic Center

Modern view of globular cluster distances and other tracers gives $R_\odot \approx 8 - 8.5$ kpc.

Shapley over-estimated the distance to the globulars because he didn't account for dust. Dust makes the clusters look dimmer, so Shapley thought they were further away.



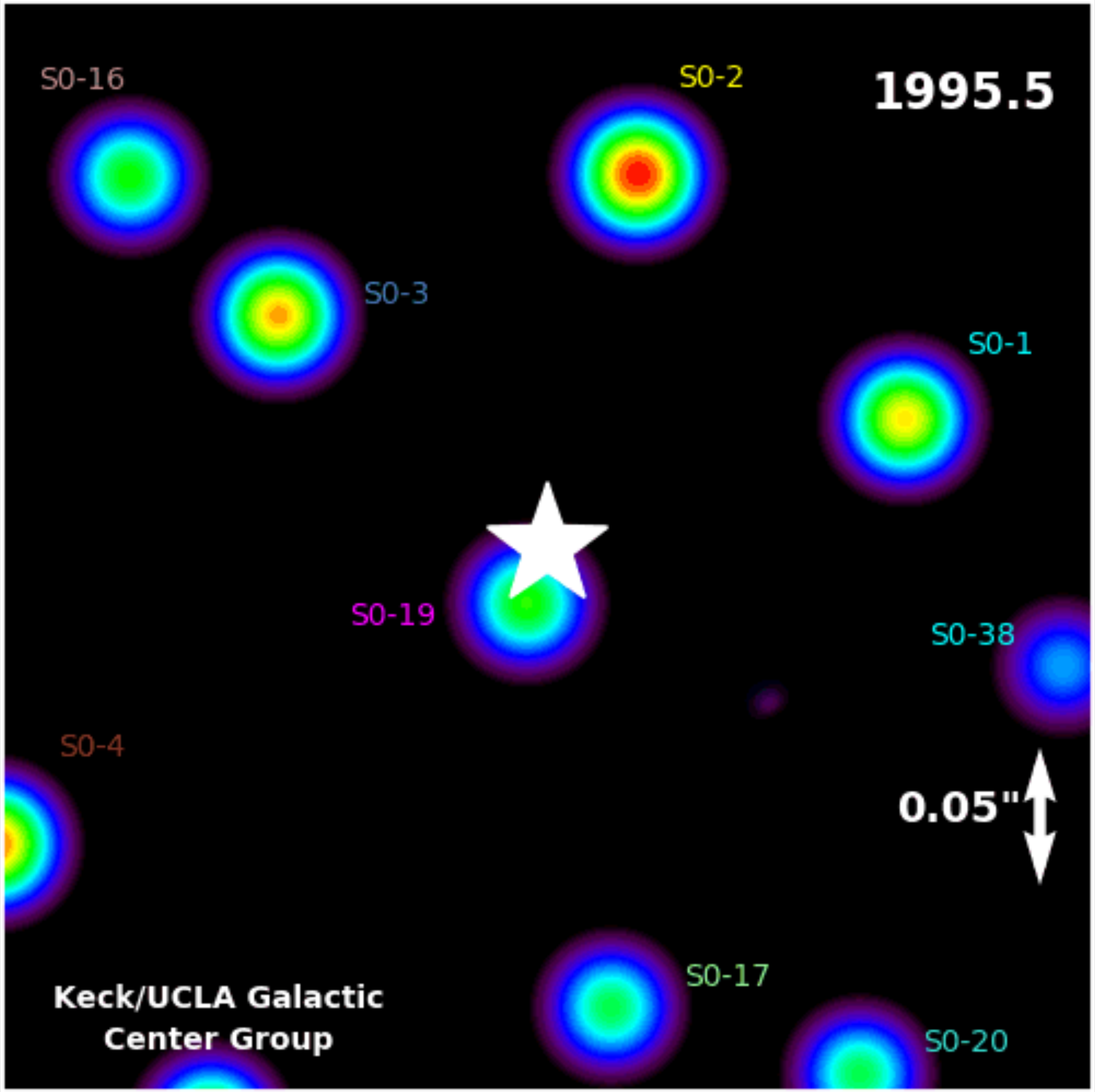
The Distance to the Galactic Center

Geometric distance:

Infrared interferometry follows the proper motion of stars and gas clouds orbiting the black hole at the Galactic center.

Orbits are Keplerian (BH is a point mass).

We can measure the stars orbital proper motion.



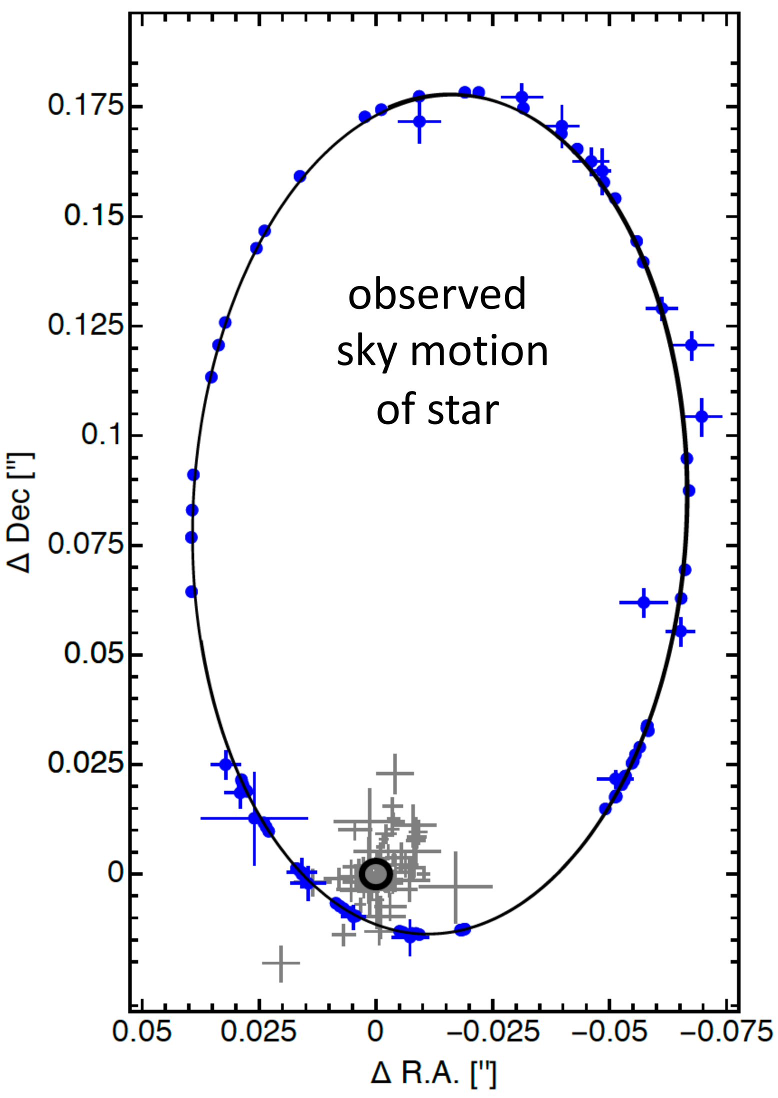
The Distance to the Galactic Center

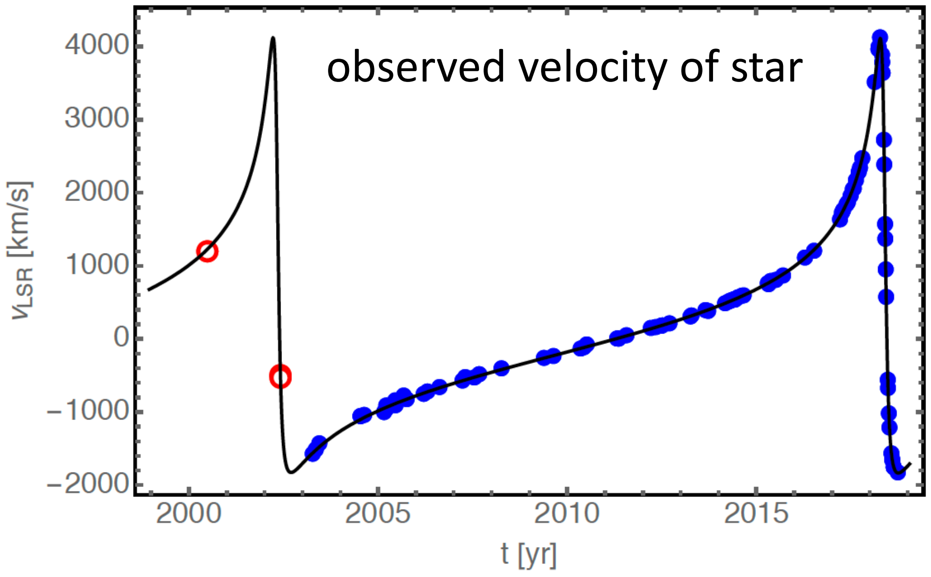
[GRAVITY collaboration (Abuter+ 2019)]

Geometric distance:

Infrared spectroscopy gives velocity of the objects as well.

Velocity and proper motion connected by distance.





d = 8178 pc ± 13$_{\text{stat}}$ ± 22$_{\text{sys}}$.

(that's a 0.3% uncertainty!!!)