

Greeks: Galaxias kuklos = "Milky Band"

Romans: Via Lactea = "Road of Milk"

# ASTR 1120

## Star and Galaxies

# The Milky Way

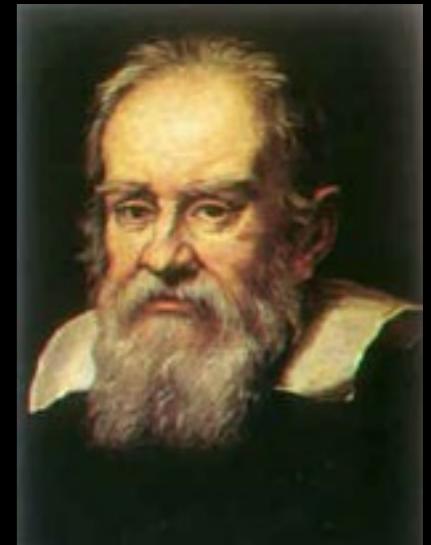
## Home sweet home

Adam Ginsburg & Devin Silvia  
July 2010

# Learning Goals

- Where are we located in the Milky Way and how did we figure it out?
- What are the structural properties of the Milky Way?
- How do things move about in the Milky Way?
- How did the Milky Way form and what evidence do we have to support this?

# History of Discovery



Galileo published "Siderius Nuncius" ("The Sidereal Messenger") in 1610, the first systematic look at the night sky with the recently invented telescope.

“For the galaxy is nothing else than a congeries of innumerable stars distributed in clusters. To whatever region of it you direct your spyglass, an immense number of stars immediately offer themselves to view, of which many appear rather large and very conspicuous but the magnitude of small ones is truly unfathomable.”

# Mixing it up!

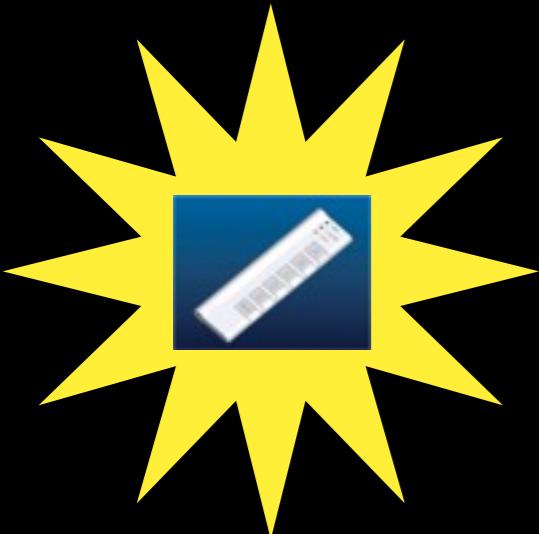
## Tutorial Time

- Milky Way Scales, pg. 123
- You'll have ~15 minutes
- Reminder, you should be talking to each other!

## Ponder this:

Suppose you stood outside on Farrand Field, and were asked to estimate where you were in the field (middle, edge, etc.). Without moving, how could you do this? How could you determine the center?





Now, suppose you're standing on Norlin Quad and it's really crowded (maybe a little hazy) and you were somewhere inside (you couldn't see the edge), how would that affect your position estimate?

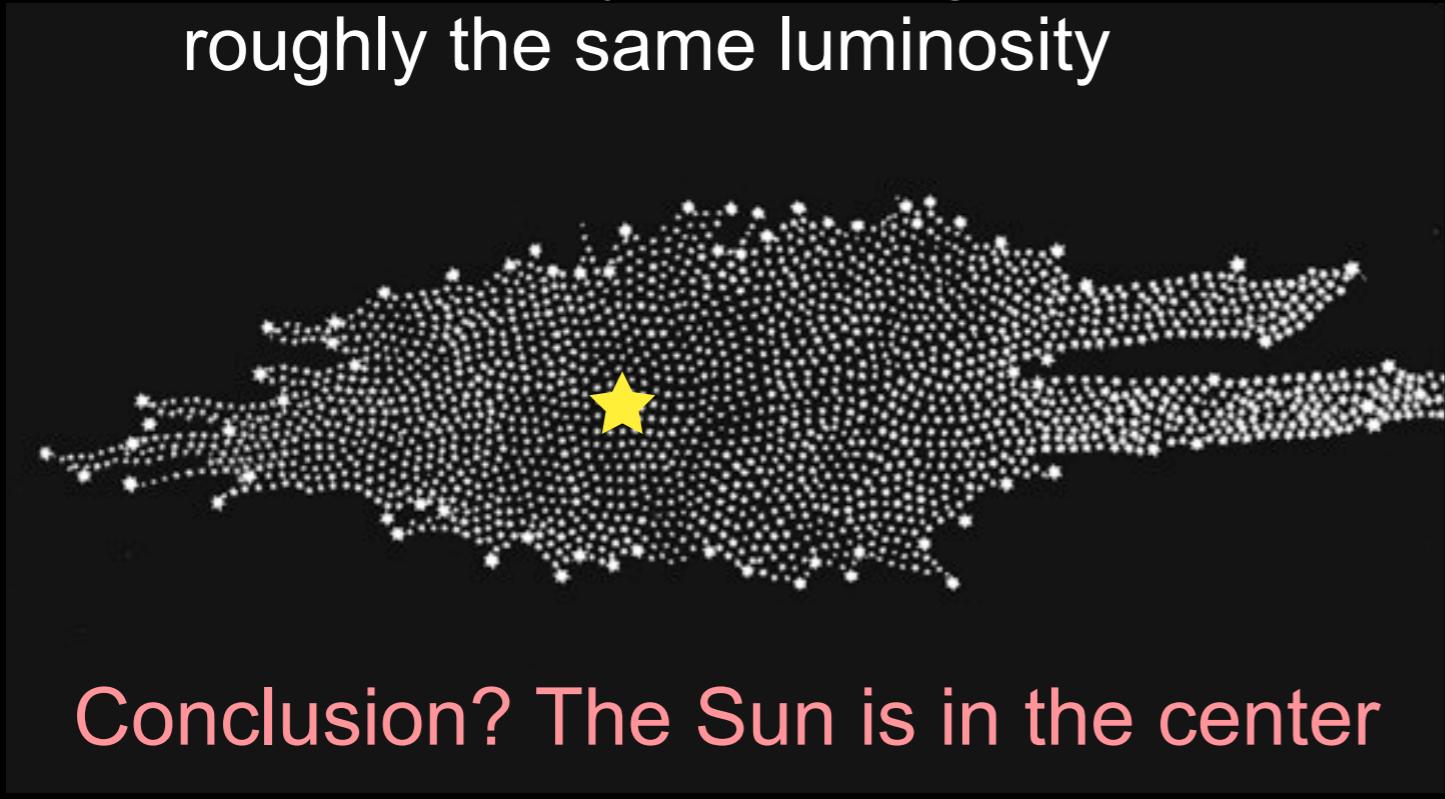
- A) You might think you were in the center no matter where you were
- B) You might think you were on the edge no matter where you were
- C) You would still be able to tell exactly where you were



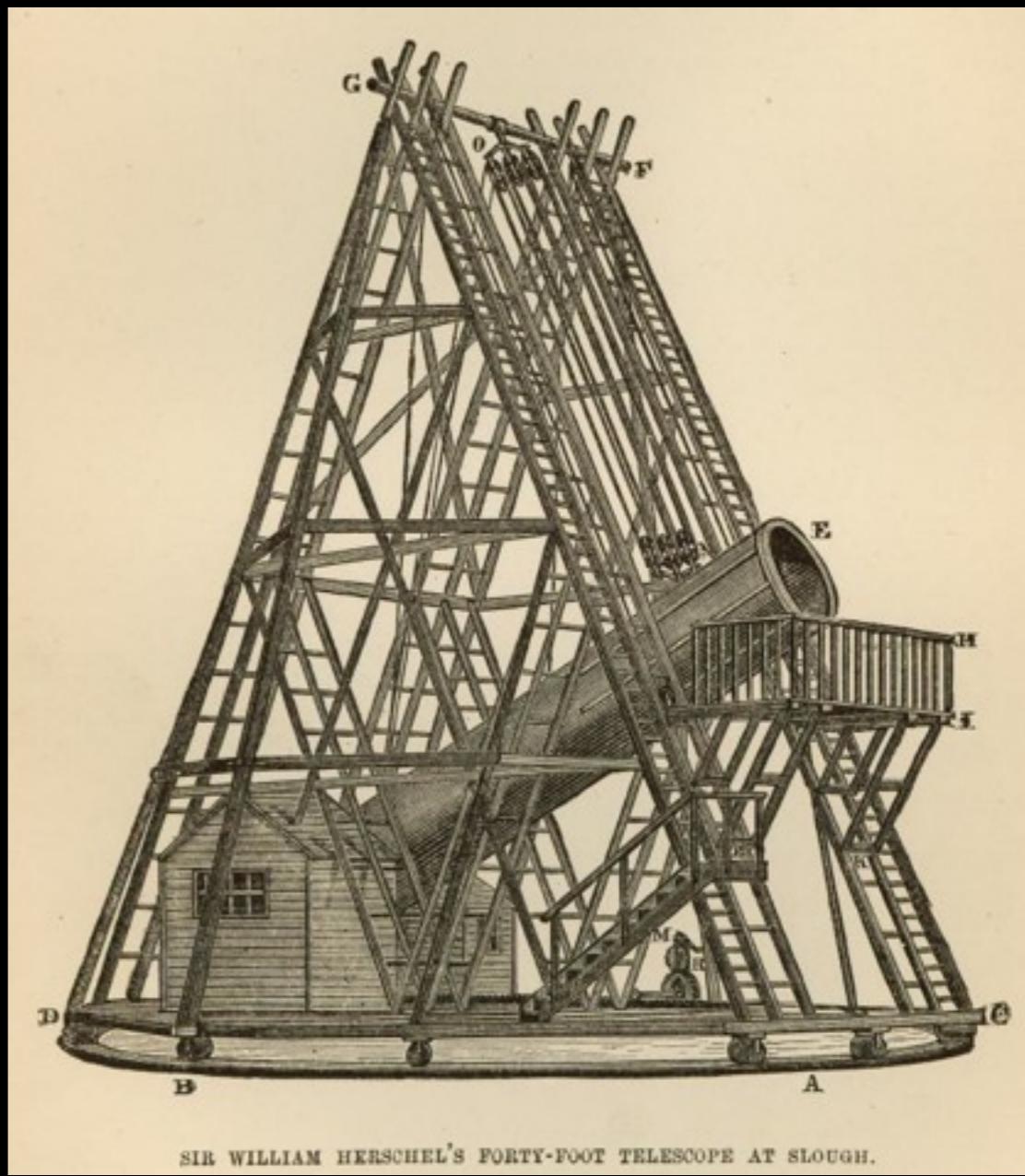
# Mapping the Milky Way



- William & Caroline Herschel (1785):
  - Counted stars along 683 lines of sight using their 49-inch telescope.
  - They did not know the distances, but made map by assuming all stars have roughly the same luminosity

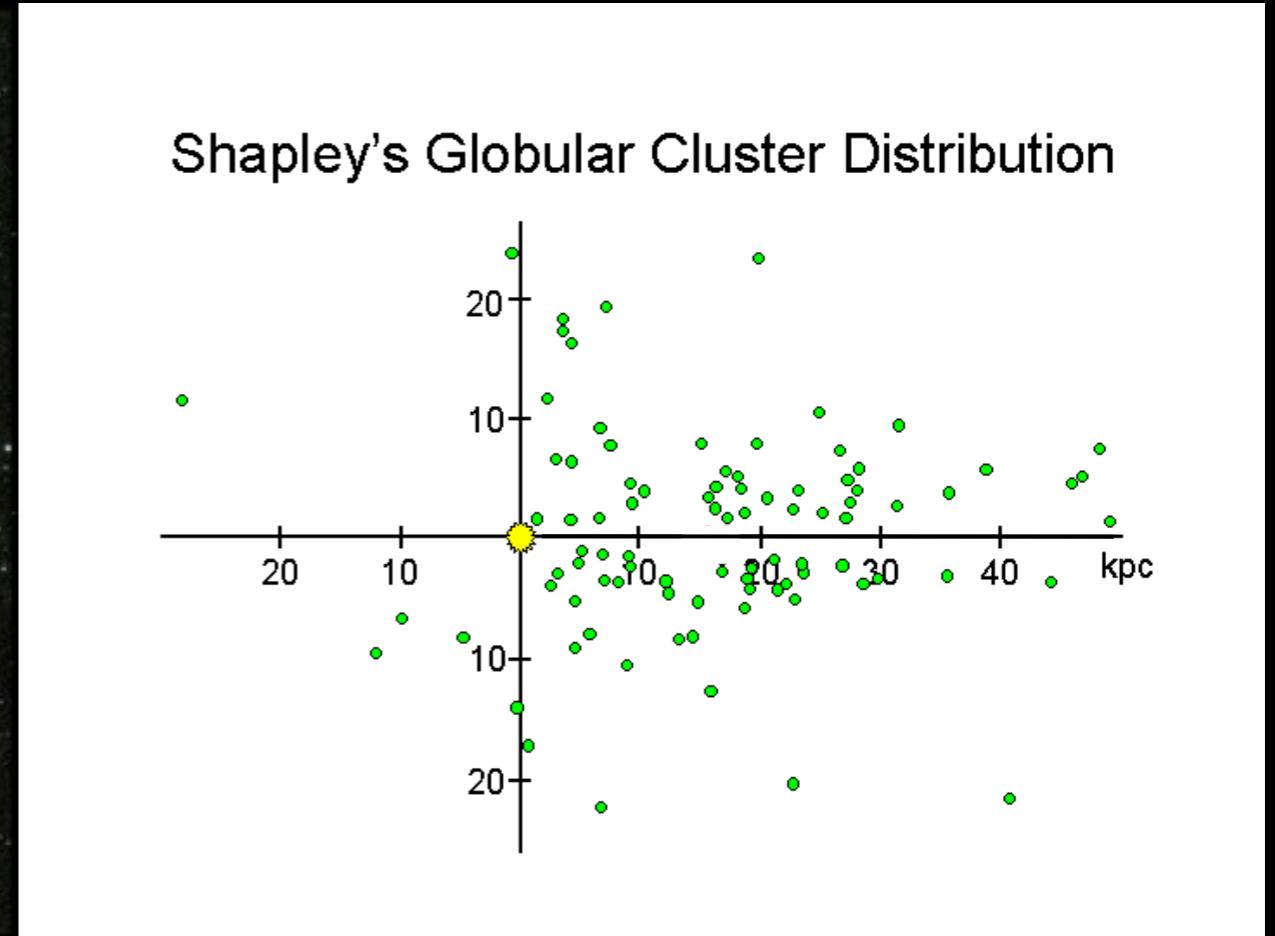


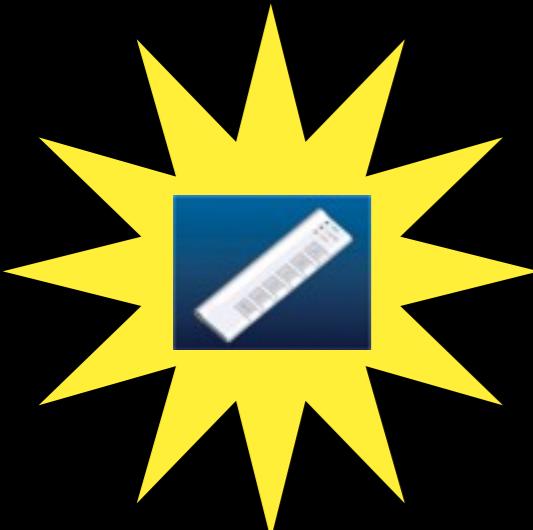
Conclusion? The Sun is in the center



SIR WILLIAM HERSCHEL'S FORTY-FOOT TELESCOPE AT SLOUGH.

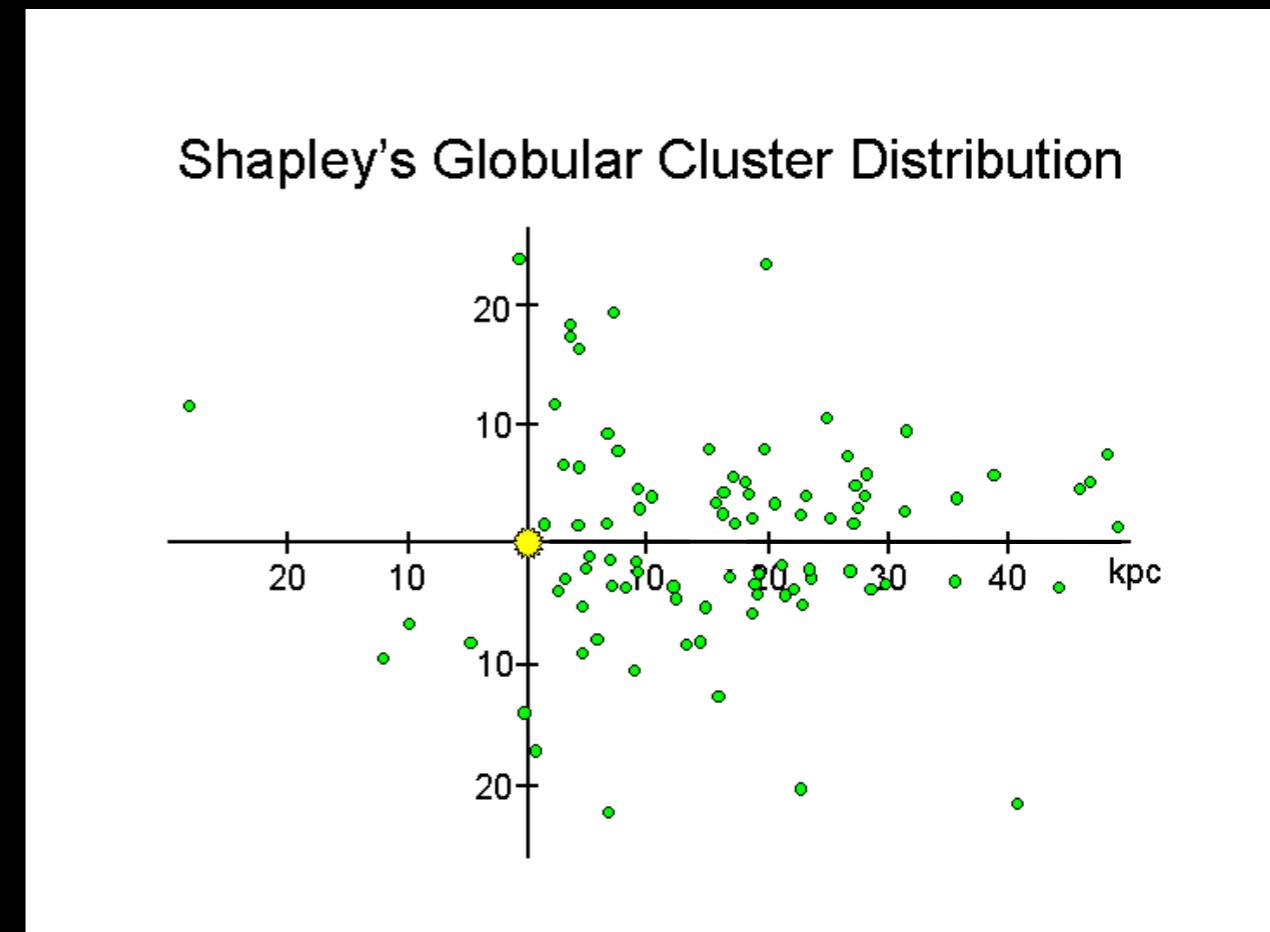
# Harlow Shapley takes a stab at it



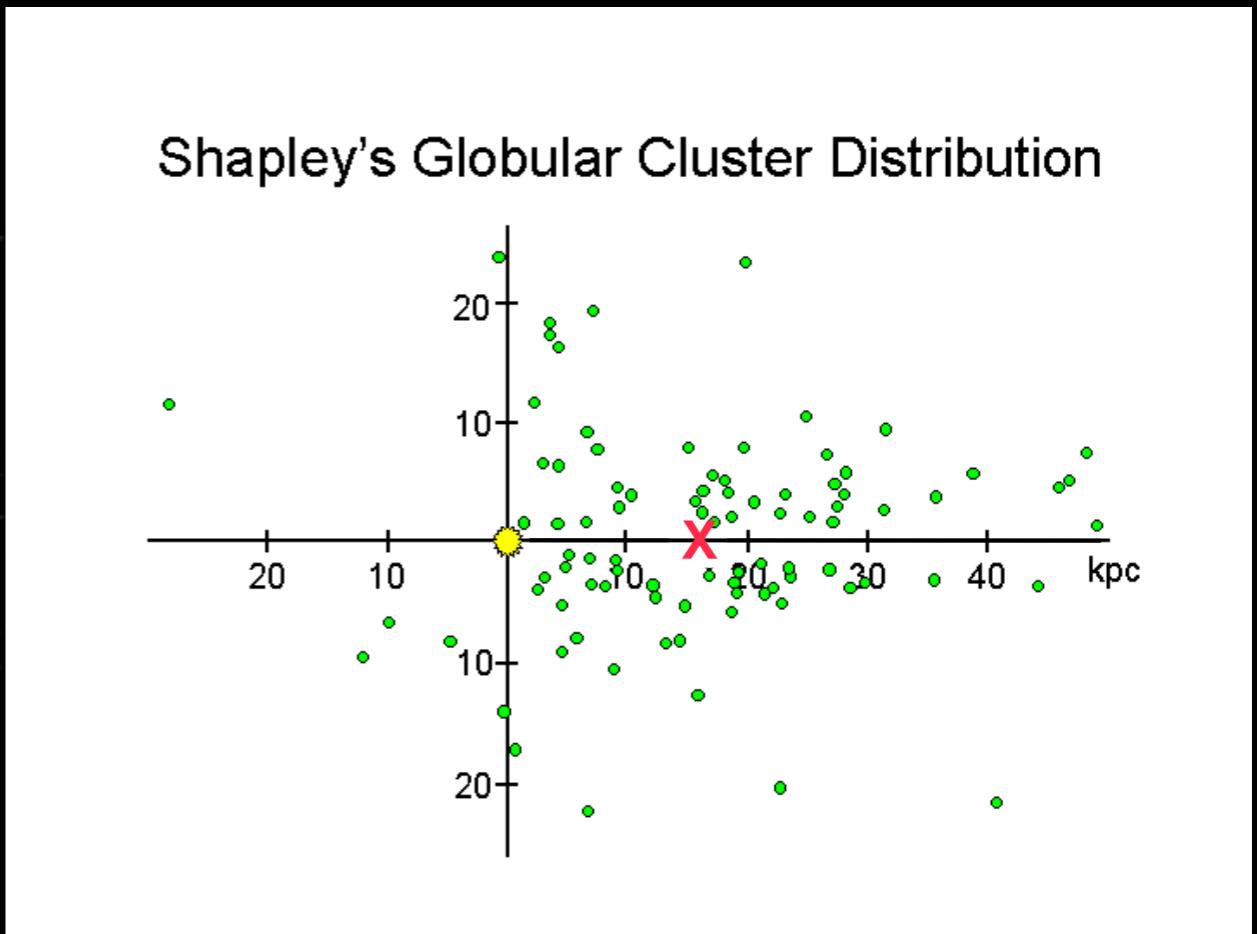


# Where is the Galactic Center according to Shapley's measurements?

- A) About 8 kpc away
- B) About 20 kpc away
- C) About 30 kpc away
- D) About 50 kpc away
- E) Duh, we're the most important. The Sun is at the center

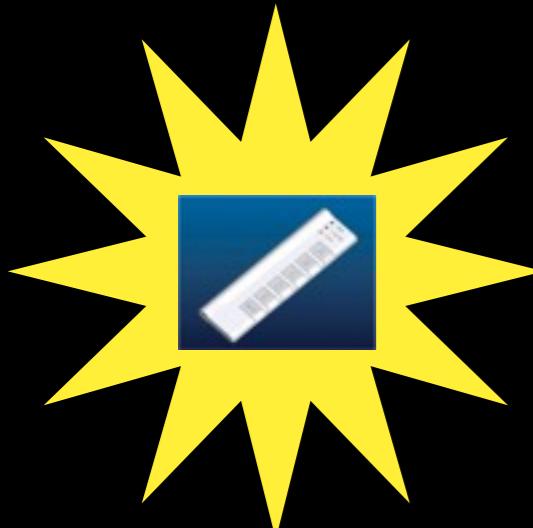


# Shapley's New Picture



- Made estimates of distances to globular clusters
  - Used known luminosities of variable stars and their apparent brightness (application of inverse square law!)
  - They appeared to be centered on a location tens of thousands of light years away

Conclusion? The Sun is not in the center, its about 2/3 out

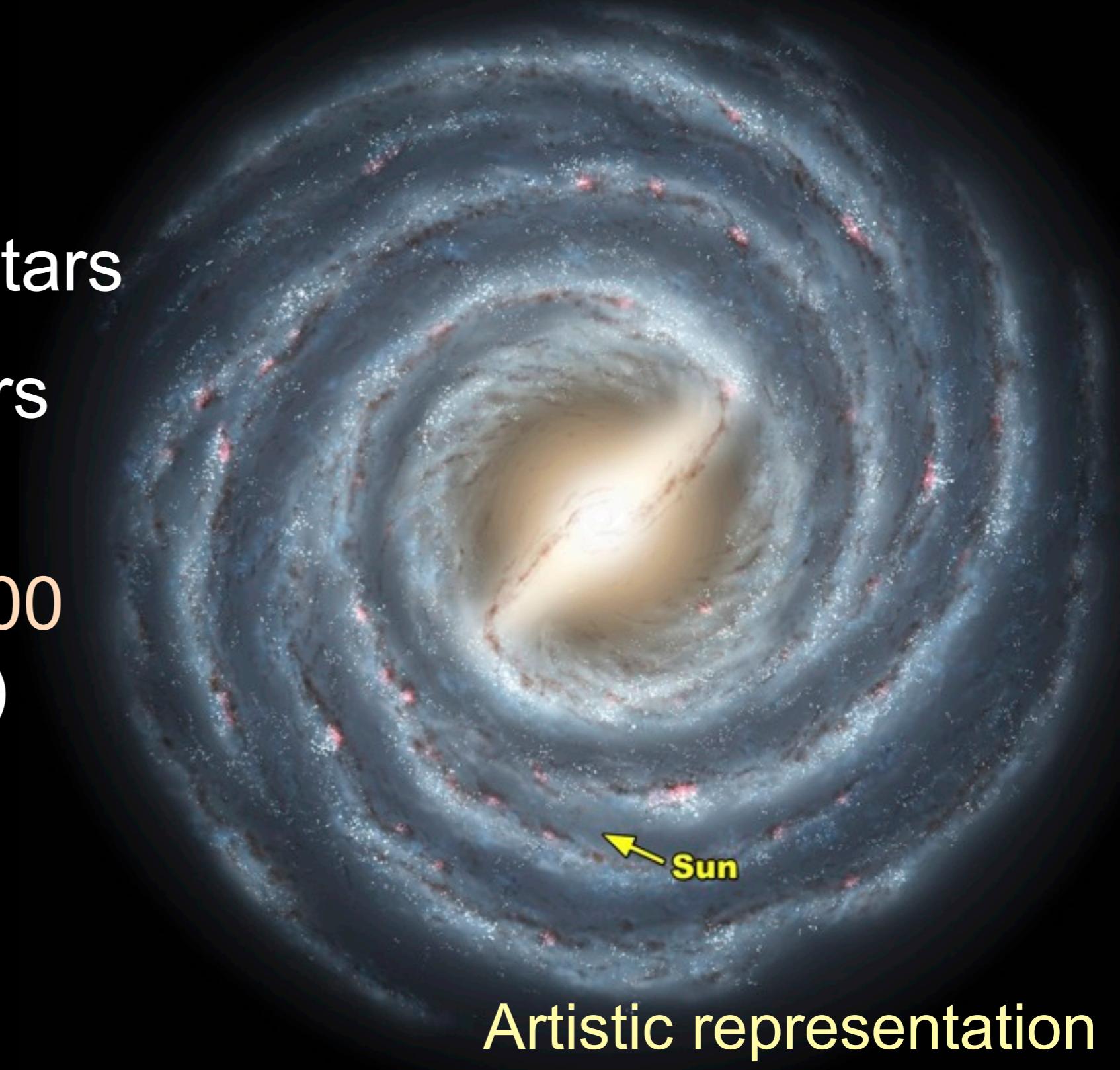


## How would interstellar dust and gas affect Harlow Shapley's distance measurement?

- A) His measurements would be too large due to the dust/gas dimming the clusters' brightnesses
- B) His measurements would be too small due to the dust/gas dimming the clusters' brightnesses
- C) His measurements would be too large due to the dust/gas hiding some stars in a cluster
- D) His measurements would be too small due to the dust/gas hiding some stars in a cluster
- E) It wouldn't affect his measurements at all.

# Milky Way: The Basics

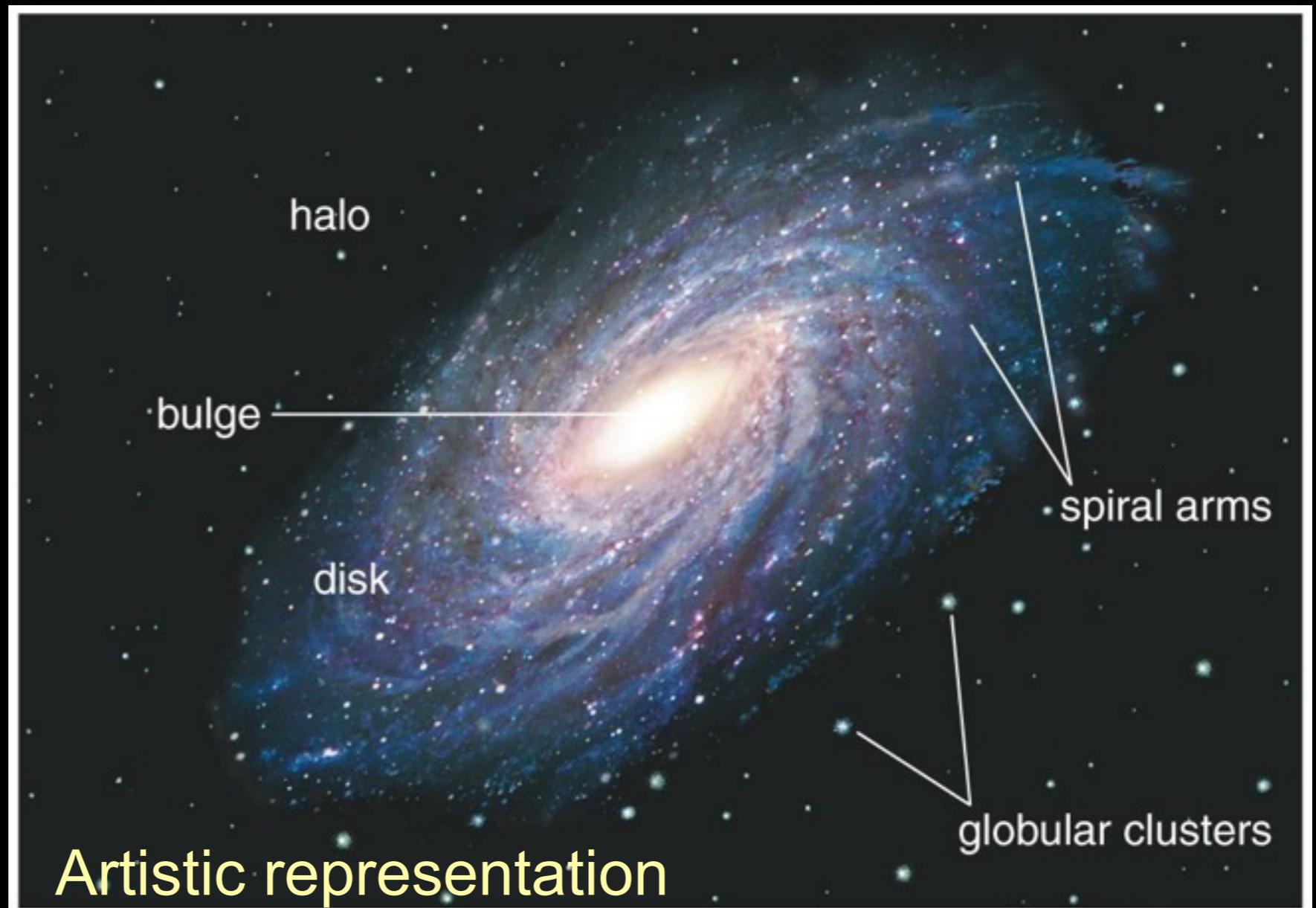
- 100 - 400 billion stars
- 100,000 light-years in diameter
- The Sun is ~28,000 light-years (8 kpc) from the center



Artistic representation

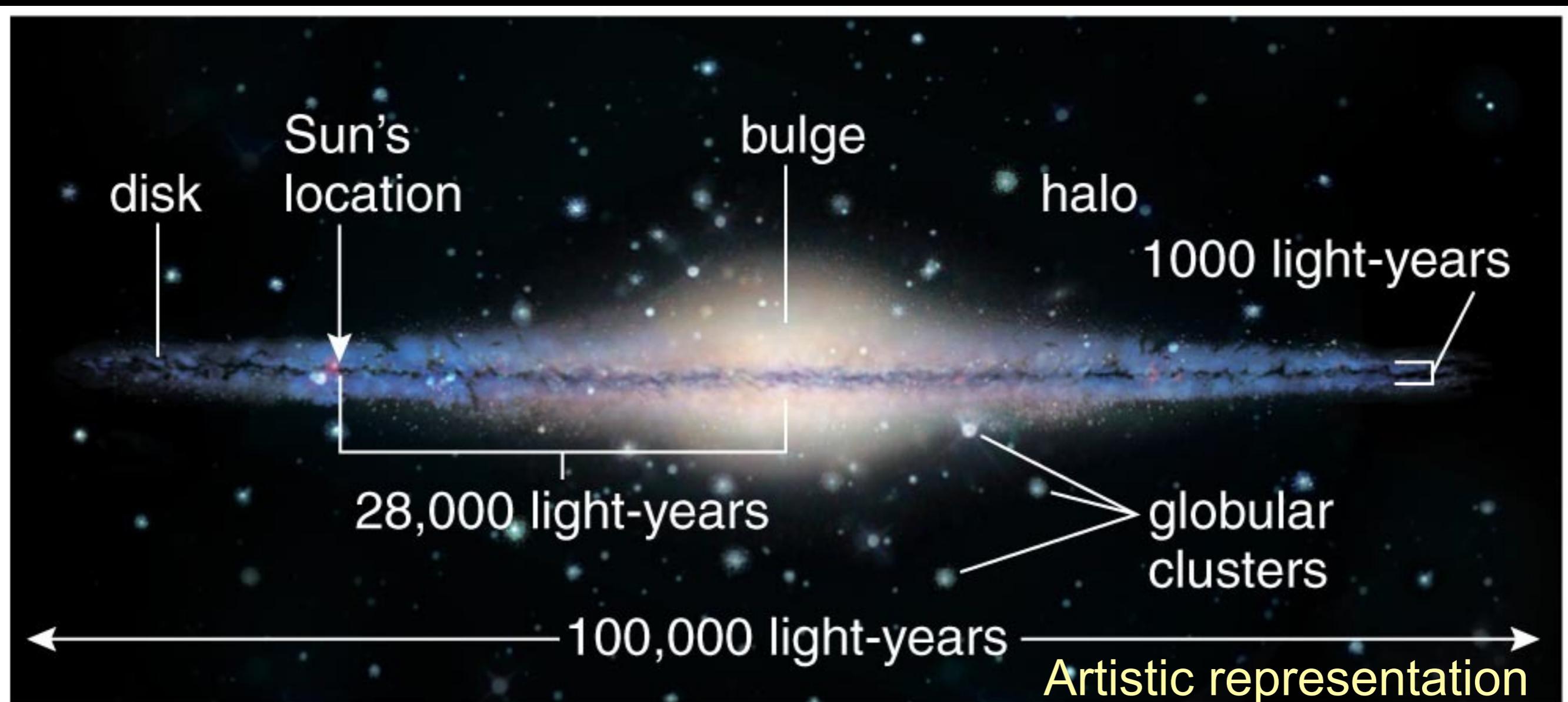
# Milky Way: Anatomy

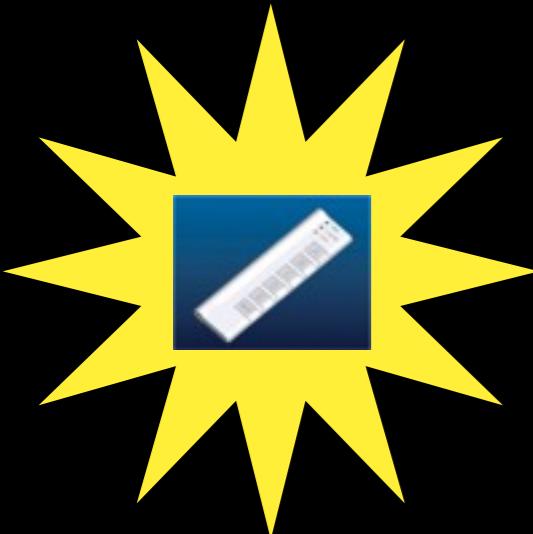
- The Disk: fairly flat, contains the spiral arms, location of young star formation
- The Bulge and Halo: older stars, globular clusters



# Milky Way: Anatomy

- The Disk is very thin compared to its span





# Why are all these pictures “artistic representations”?

- A) Because they combine multiple wavelengths that can't be normally combined
- B) Because we haven't had time to see the current light from the very edge of our Galaxy
- C) Because we don't actually know the exact structure of our Galaxy since we can't see through all the dust.
- D) Because we don't have a telescope with a wide enough field of view to capture the whole Galaxy at one time.
- E) Because we can't send a satellite to get a bird's eye view of our own Galaxy.

# What might the Milky Way really look like?

NGC 4414



NOT an Artistic representation

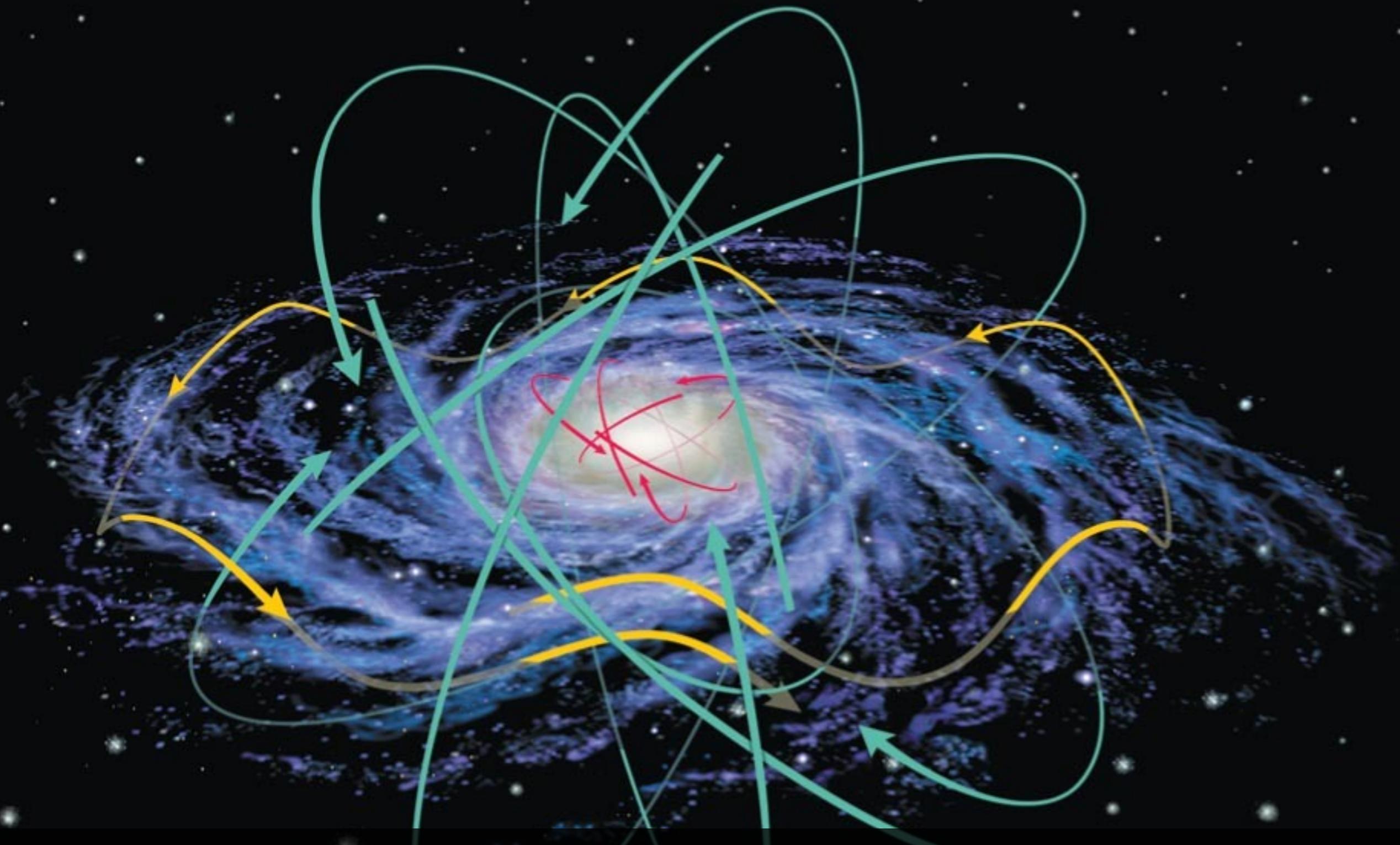
# What might the Milky Way really look like?

NGC 4565



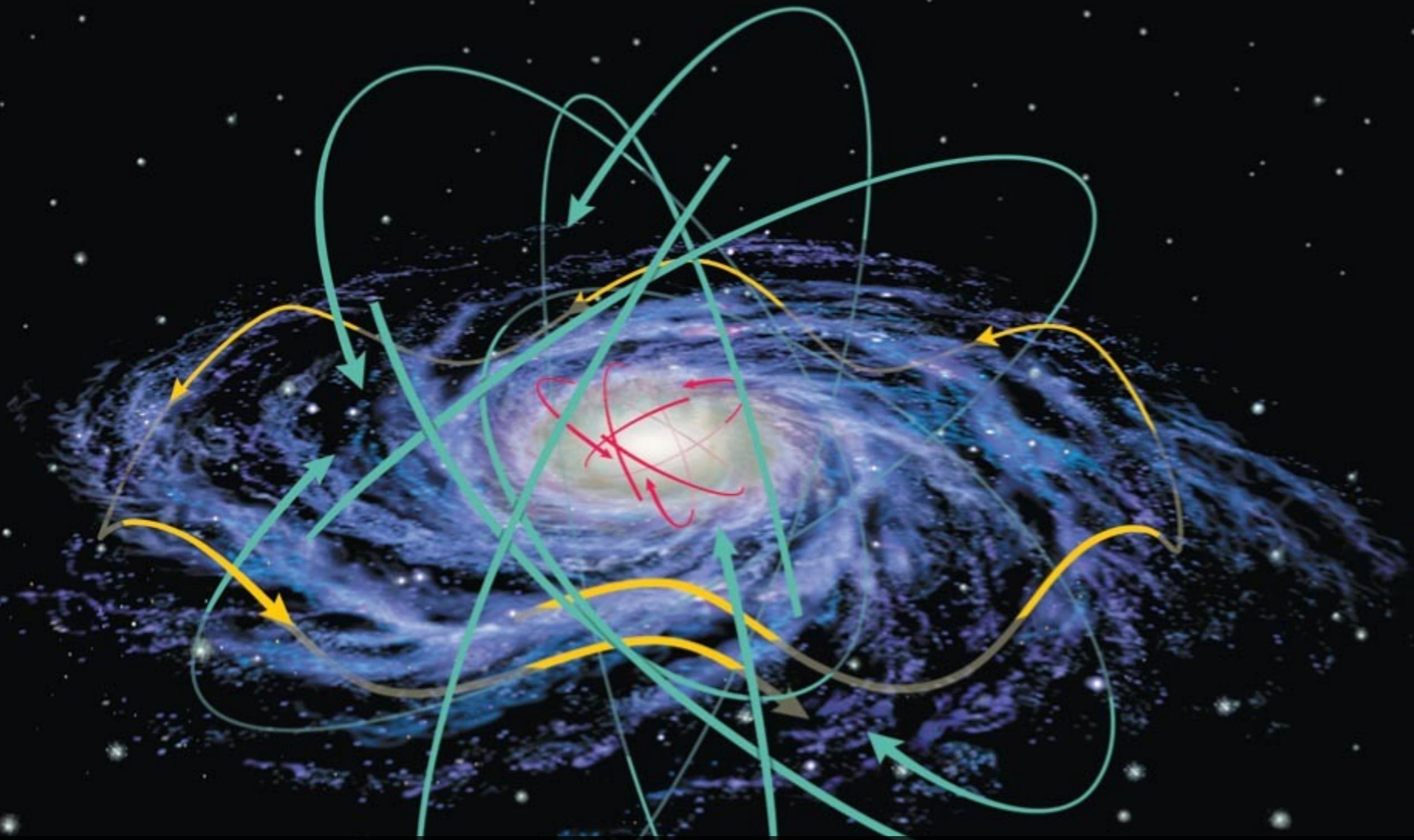
NOT an Artistic representation

# How do stars move about the galaxy?



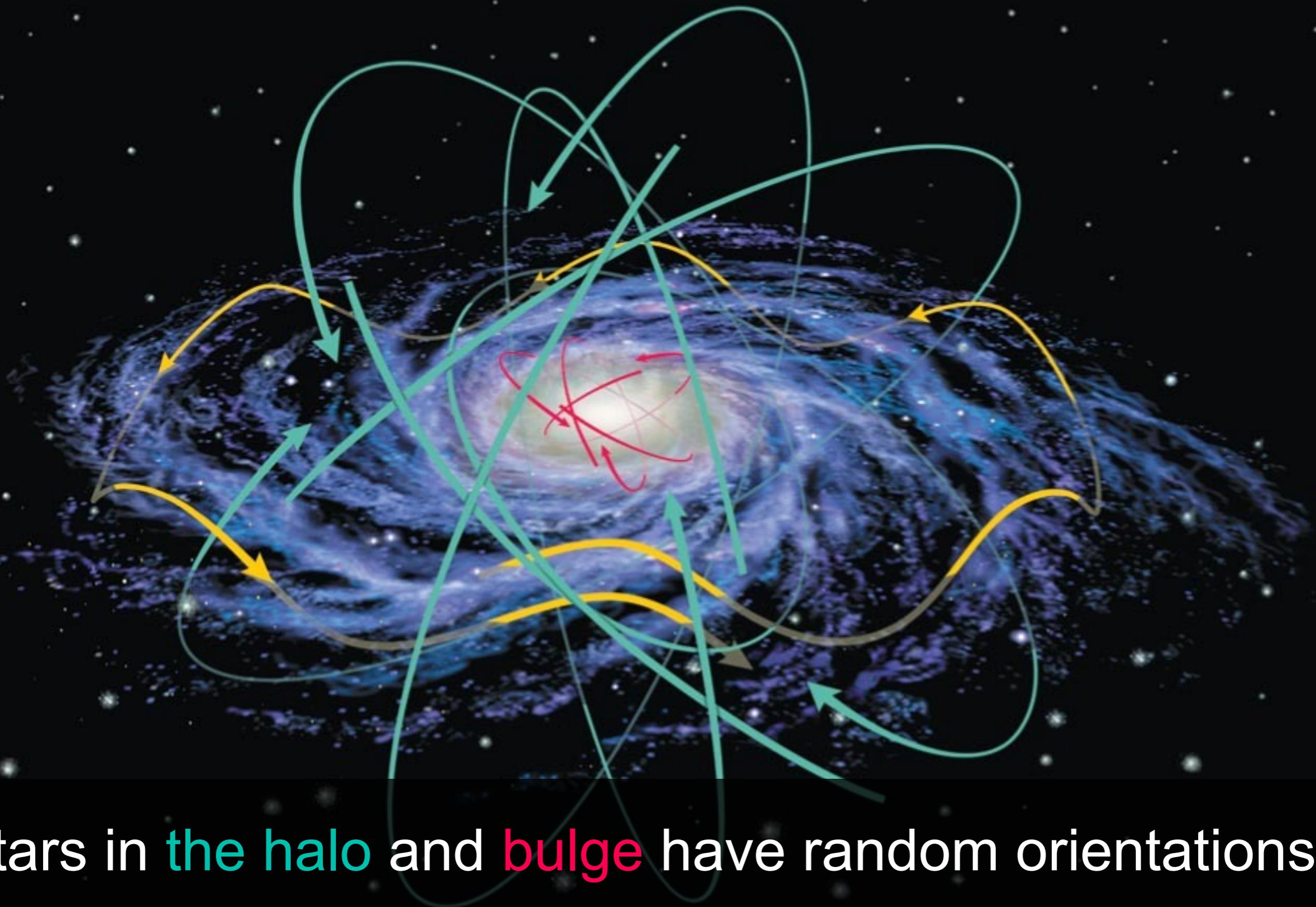
Stars in the disk all orbit in the same direction, while bobbing a little up and down

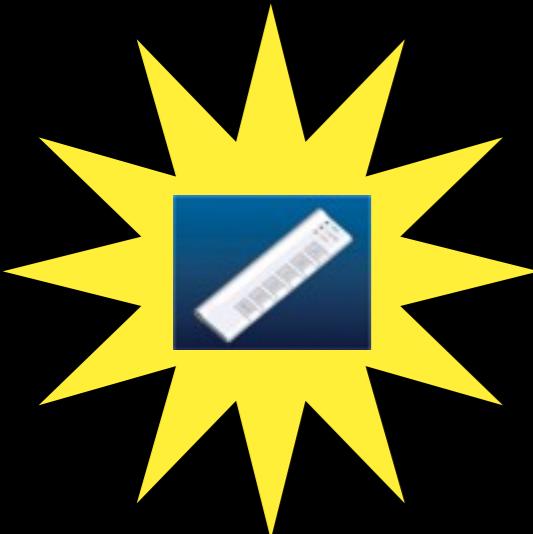
# How do stars move about the galaxy?



Bobbing is due to pull of gravity from the disk, if they drift up, they're pulled back down, overshoot, and so on...

# How do stars move about the galaxy?

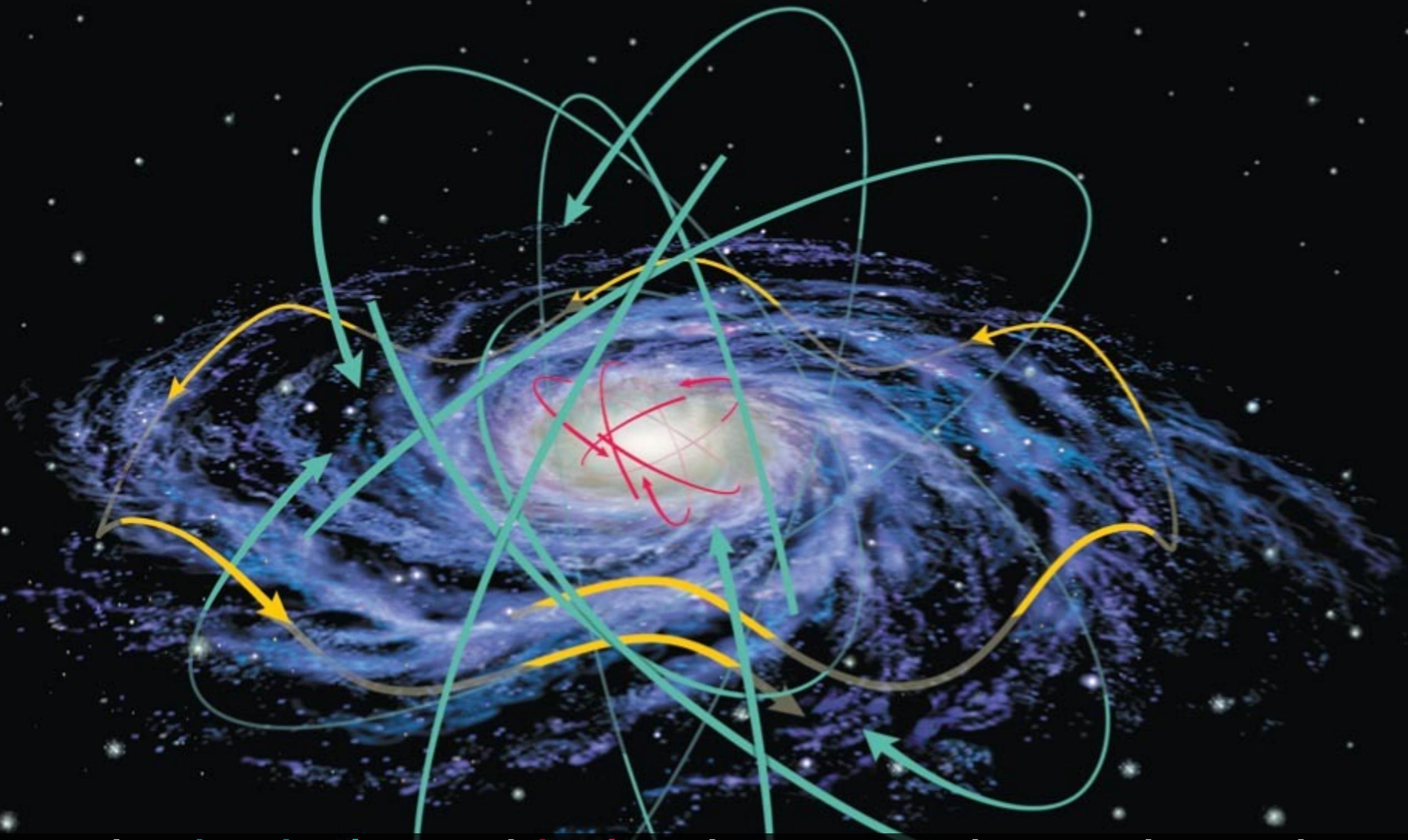




Based on the orbital appearance of the stars they contain, which formed first, the disk or the bulge/halo?

- A) The disk
- B) The bulge/halo
- C) They both probably formed at the same time

# How do stars move about the galaxy?



Stars in the **halo** and **bulge** have random orientations

This suggests that the bulge and halo formed before the disk existed since the stars aren't greatly affected by the gravity of the disk

# What's the galaxy made of?

Everything that Adam talked about yesterday!

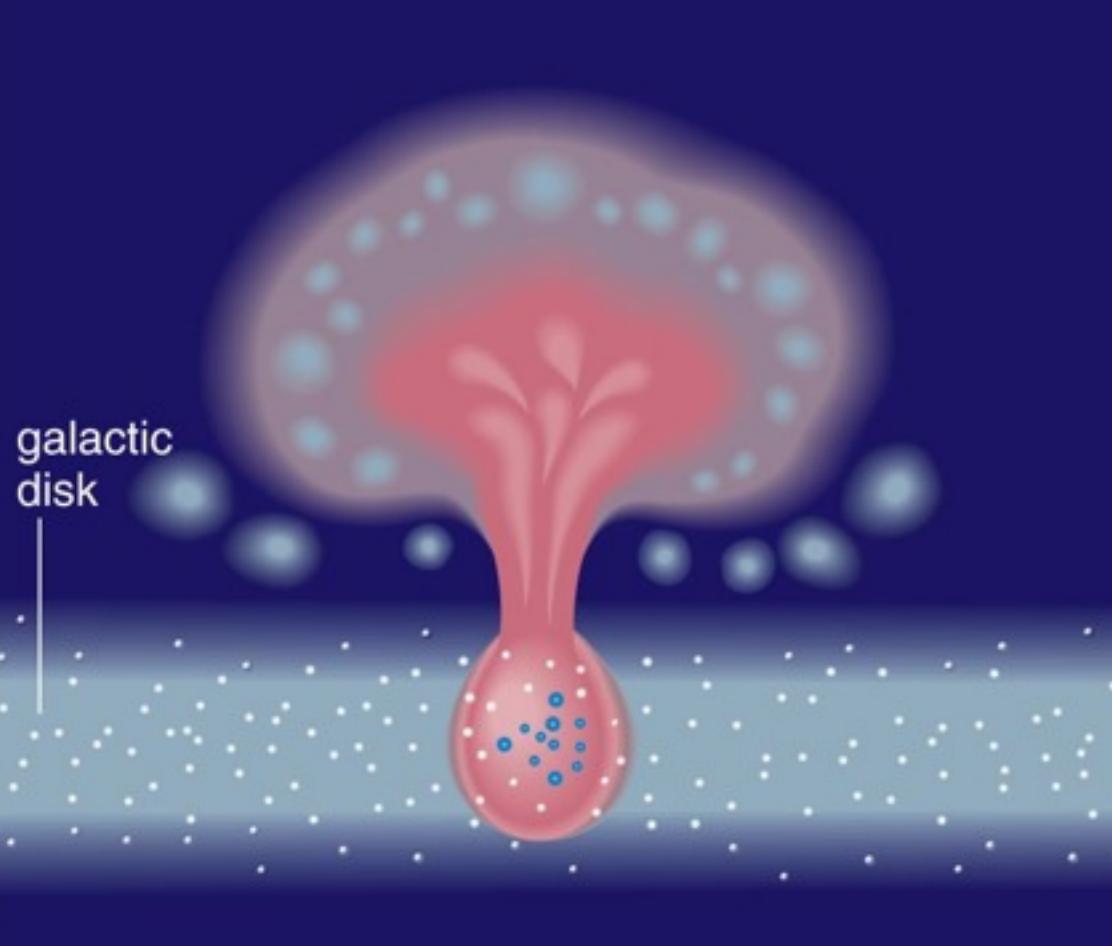
(plus stars.)



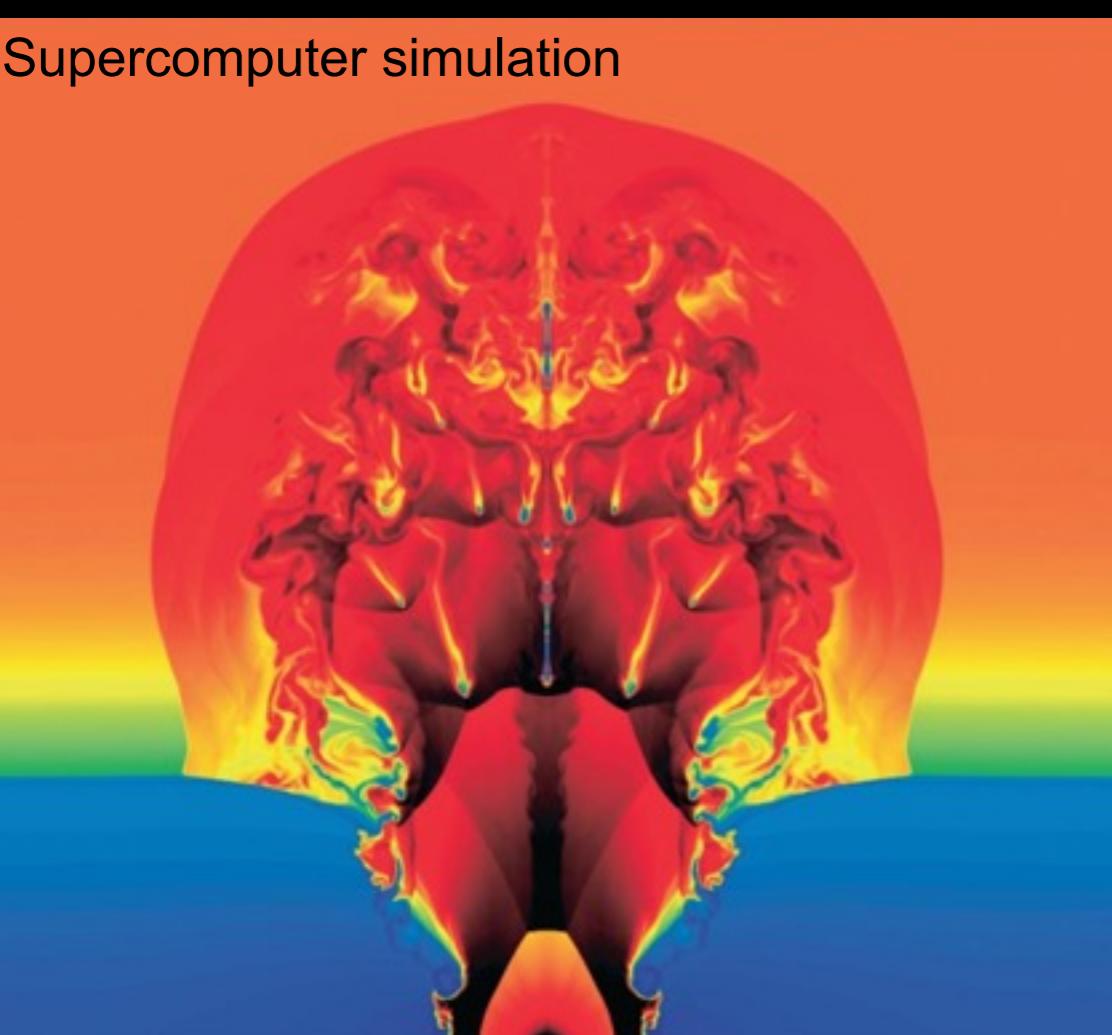
Adam is sad that he can't see the stars right now.

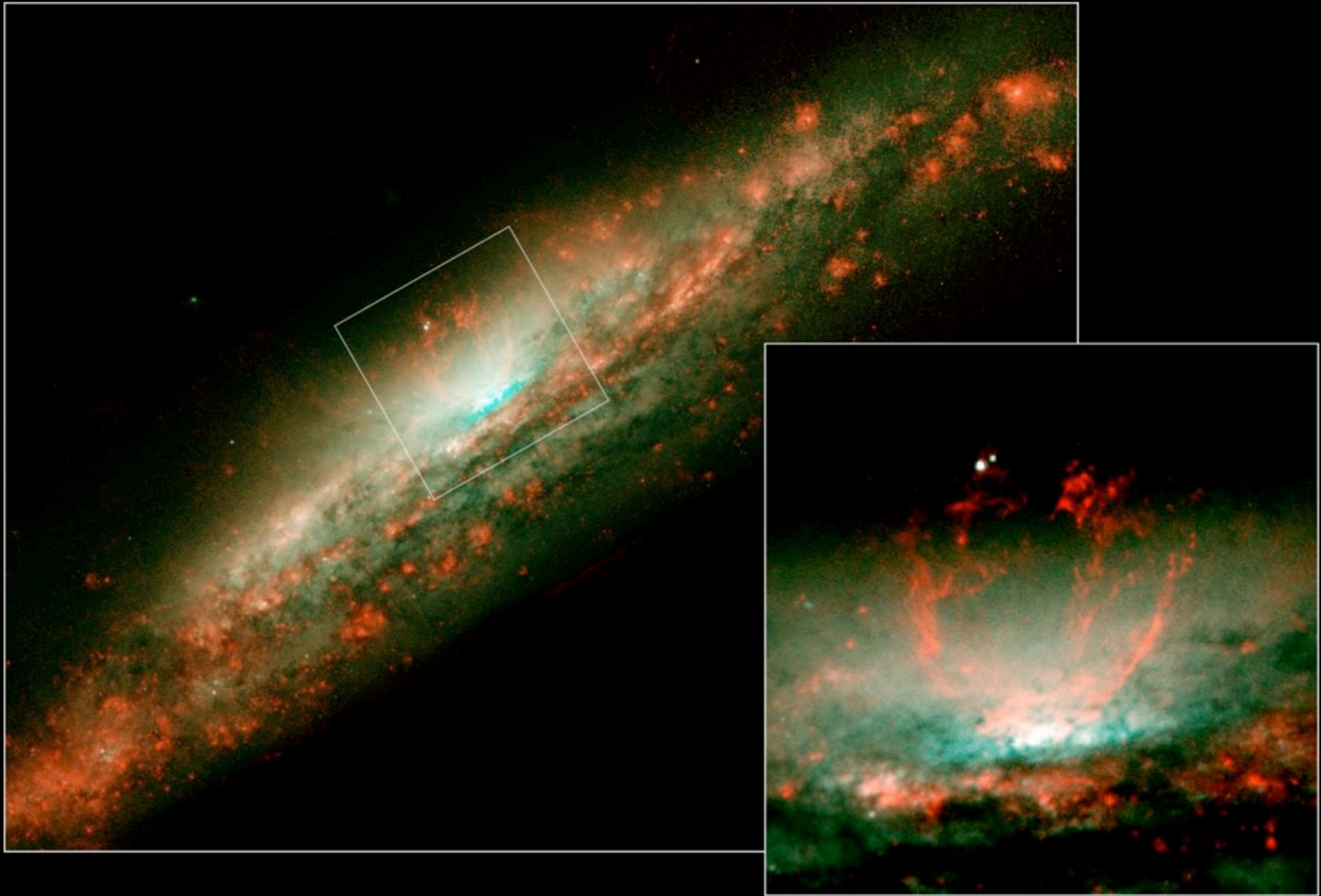
# Superbubbles and Galactic Fountains

- When multiple bubbles join (from a star cluster) they can create **superbubbles**.
- If the superbubble reaches the edge of the disk, it can blast hot gas out of the Galaxy!
  - Some will rain back down and mix into the galaxy -- **galactic fountain**



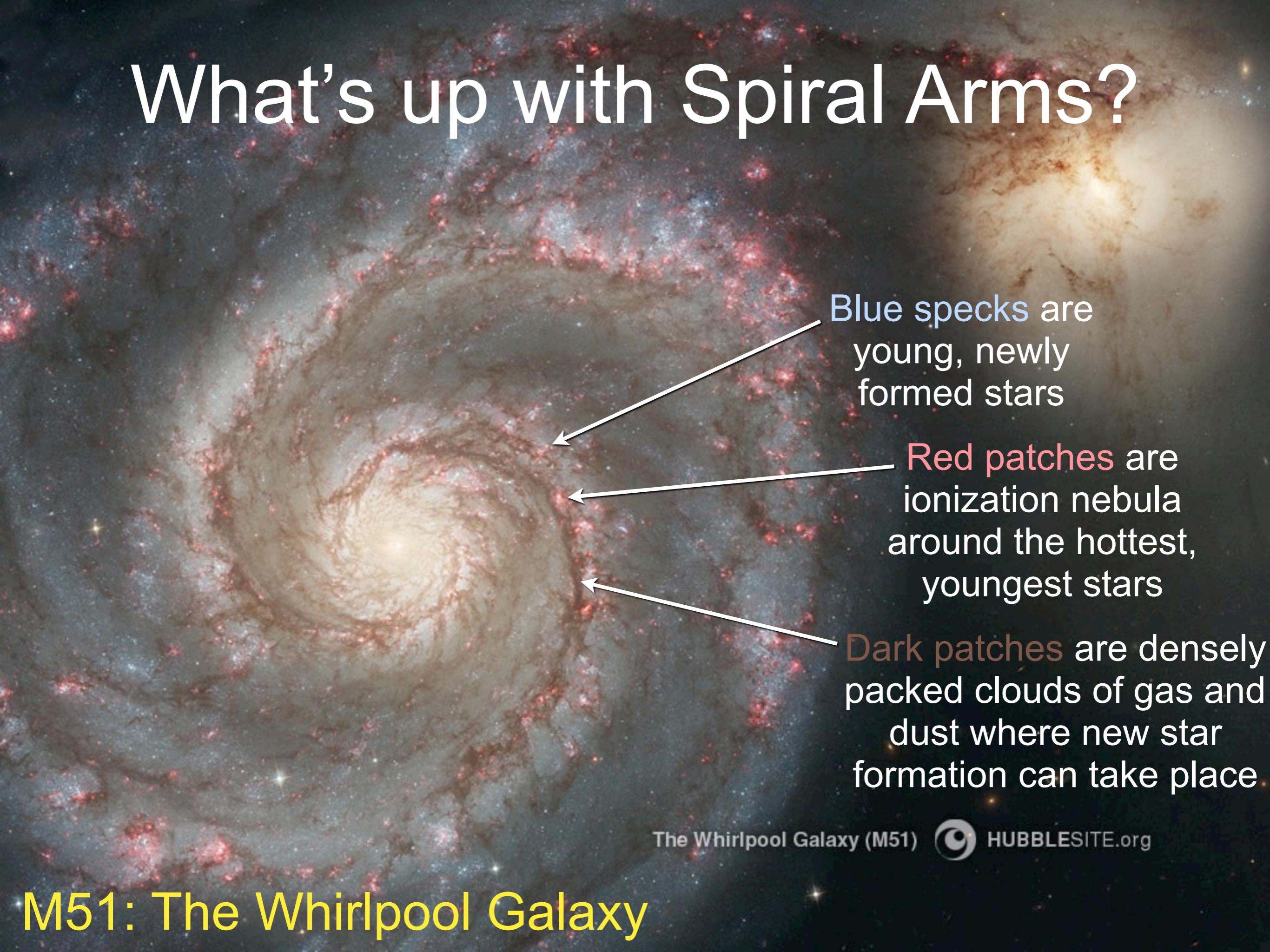
Supercomputer simulation





**Galaxy NGC 3079**  
**Hubble Space Telescope • WFPC2**

# What's up with Spiral Arms?

- 
- Blue specks are young, newly formed stars
  - Red patches are ionization nebula around the hottest, youngest stars
  - Dark patches are densely packed clouds of gas and dust where new star formation can take place

The Whirlpool Galaxy (M51)



HUBBLESITE.org

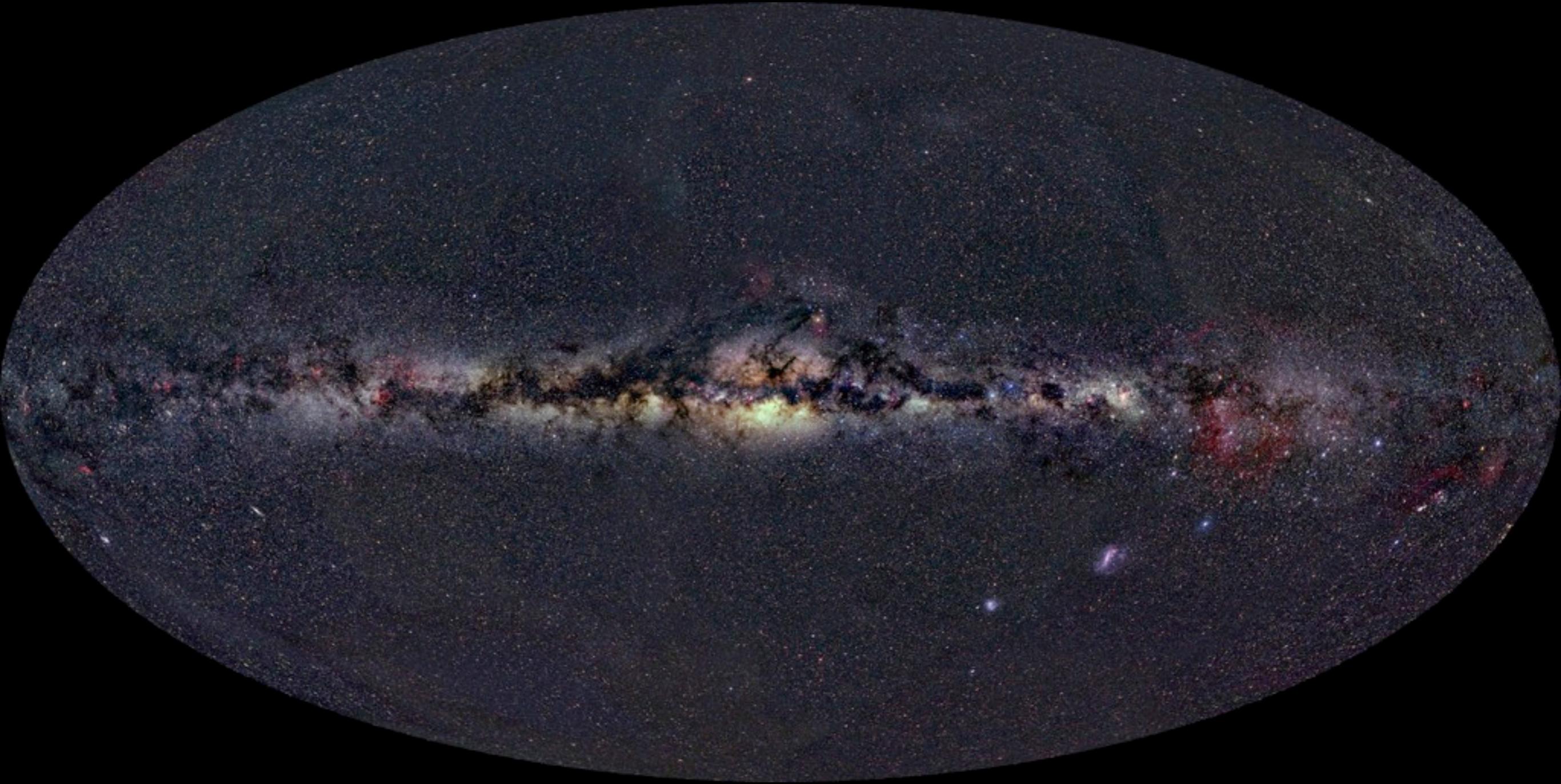
M51: The Whirlpool Galaxy

# Spiral Density Waves

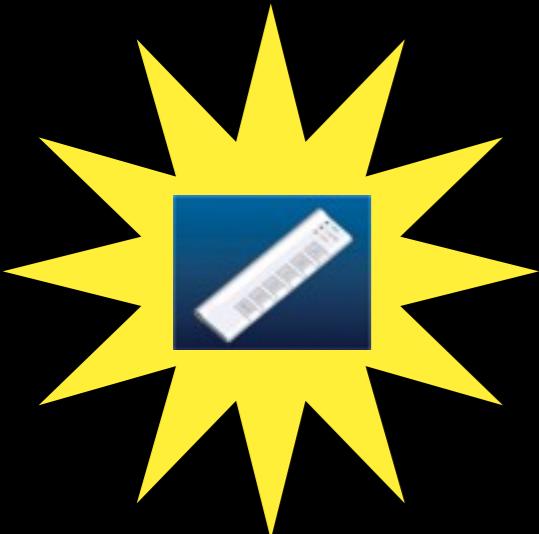
- The spiral arms don't rotate around the center like the stars (they would get super wound up!)
- Models suggest that the arms are caused by disturbances called **spiral density waves**
  - create an extra gravitational “tug”
- Gas clouds and stars feel the tug and **pile up** in these **density waves**
  - like a traffic jam
- This pile up **triggers** star formation



# What story do halo stars tell?



The halo consists almost entirely of old yellow/red stars



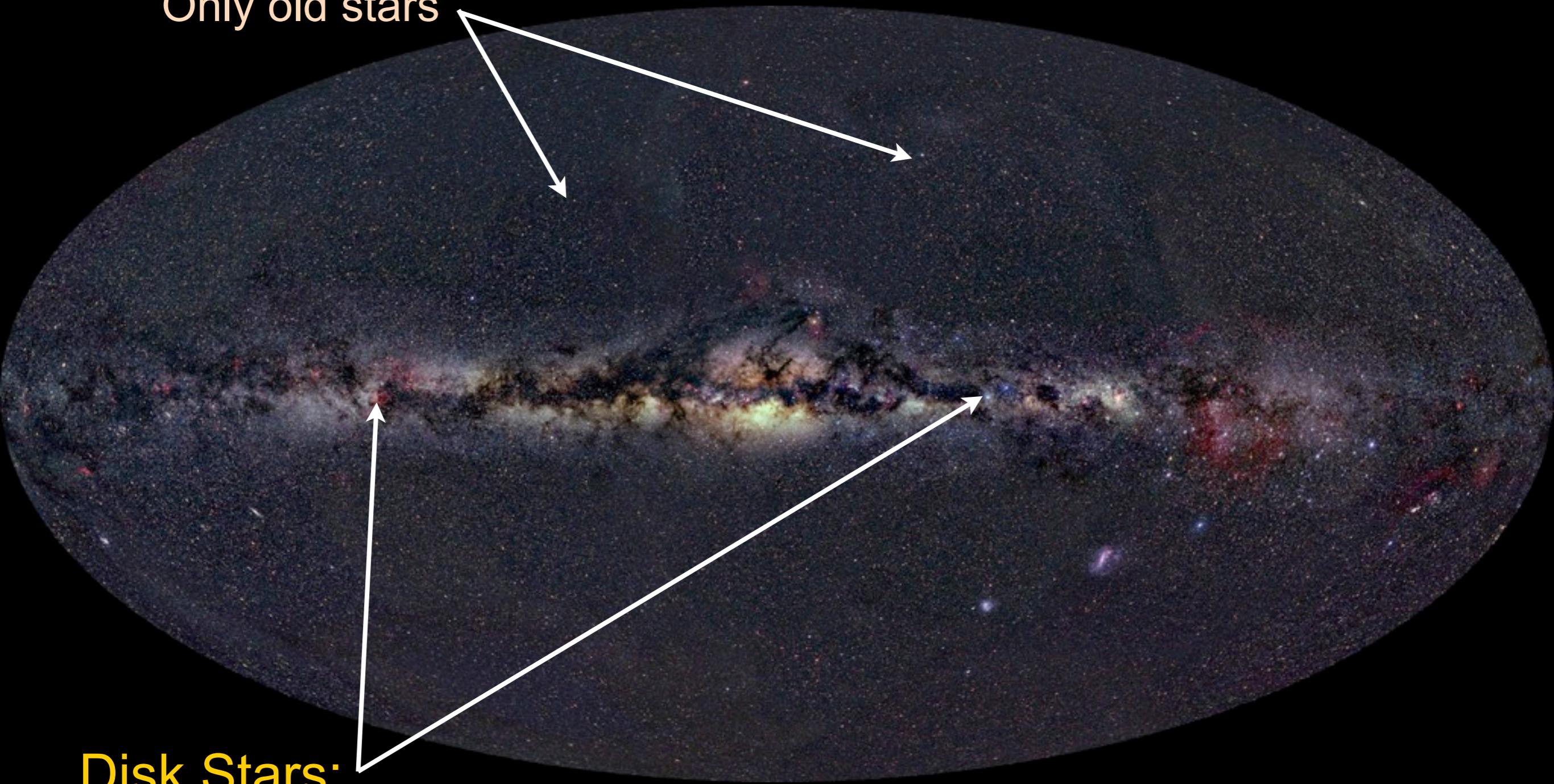
The ages of stars suggest that the bulge and halo of the Milky Way formed before many of the stars in the disk. Which would you expect to have more heavy elements?

- A) Halo and bulge stars
- B) Disk stars
- C) They should both have the same

## Halo Stars:

0.02 - 0.2% Heavy elements (Fe, O, etc...)

Only old stars



## Disk Stars:

~2% Heavy elements

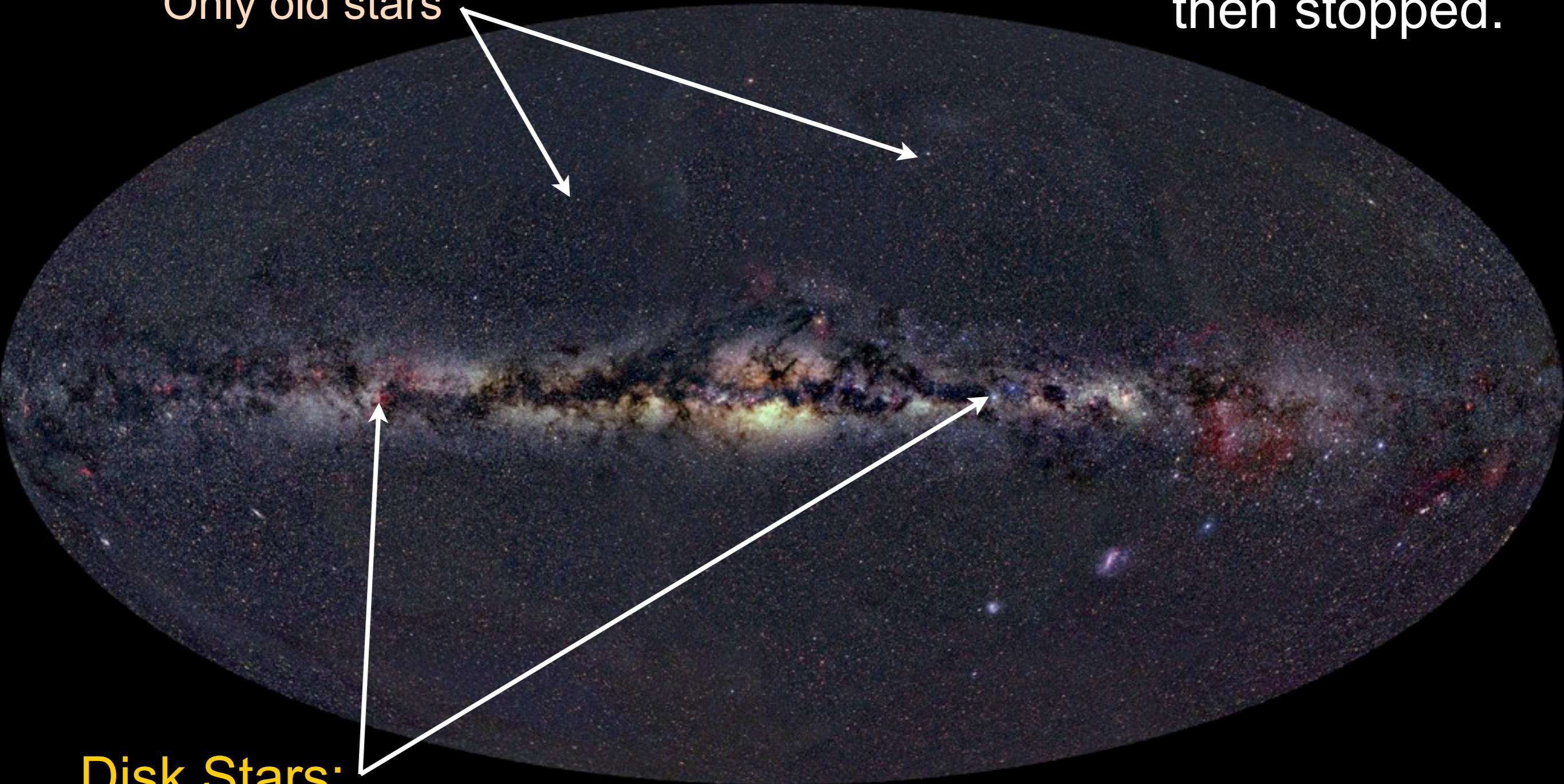
Stars of all ages

## Halo Stars:

0.02 - 0.2% Heavy elements (Fe, O, etc...)

Only old stars

Halo stars formed first and then stopped.



## Disk Stars:

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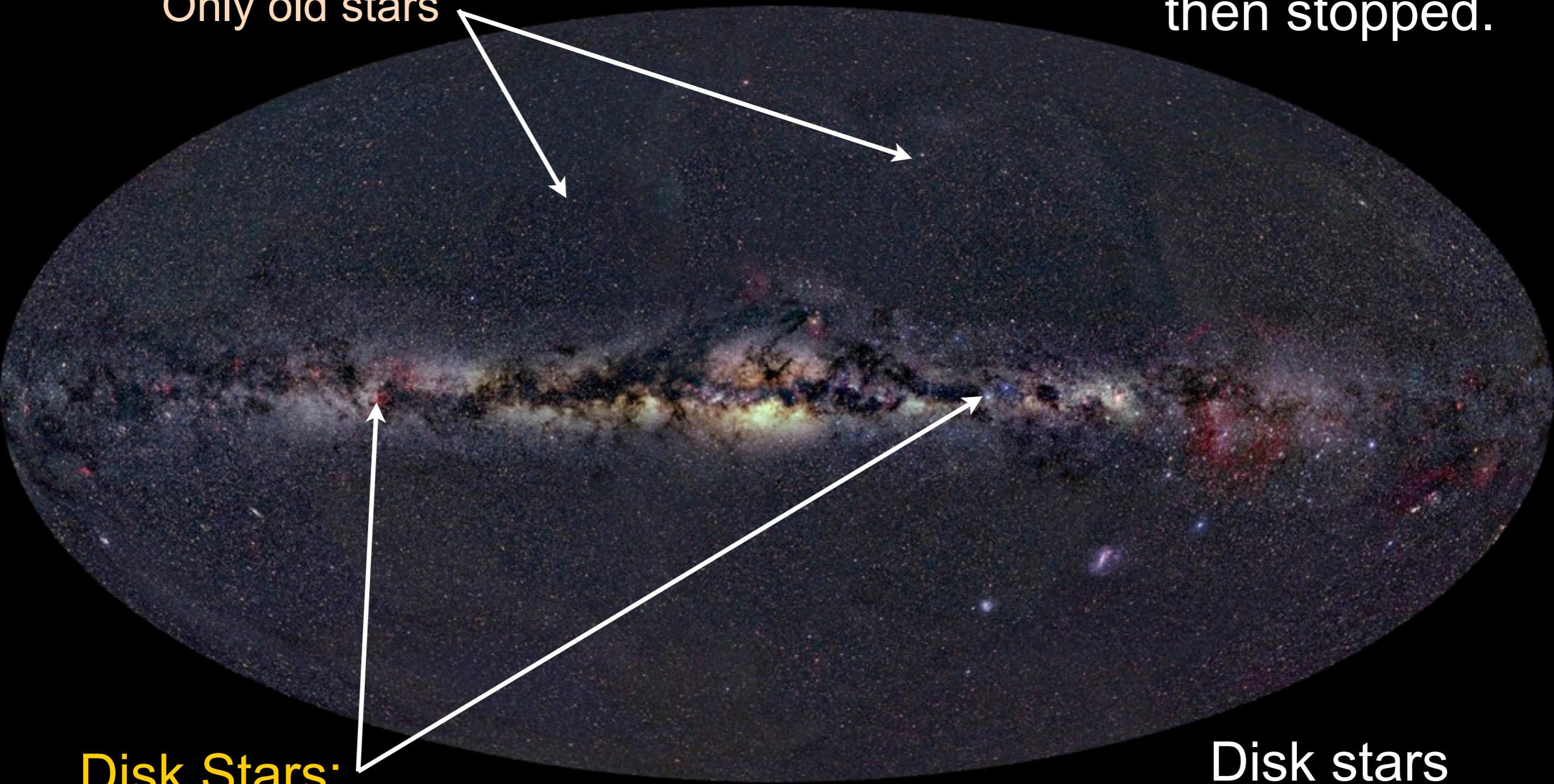
Stars of all ages

## Halo Stars:

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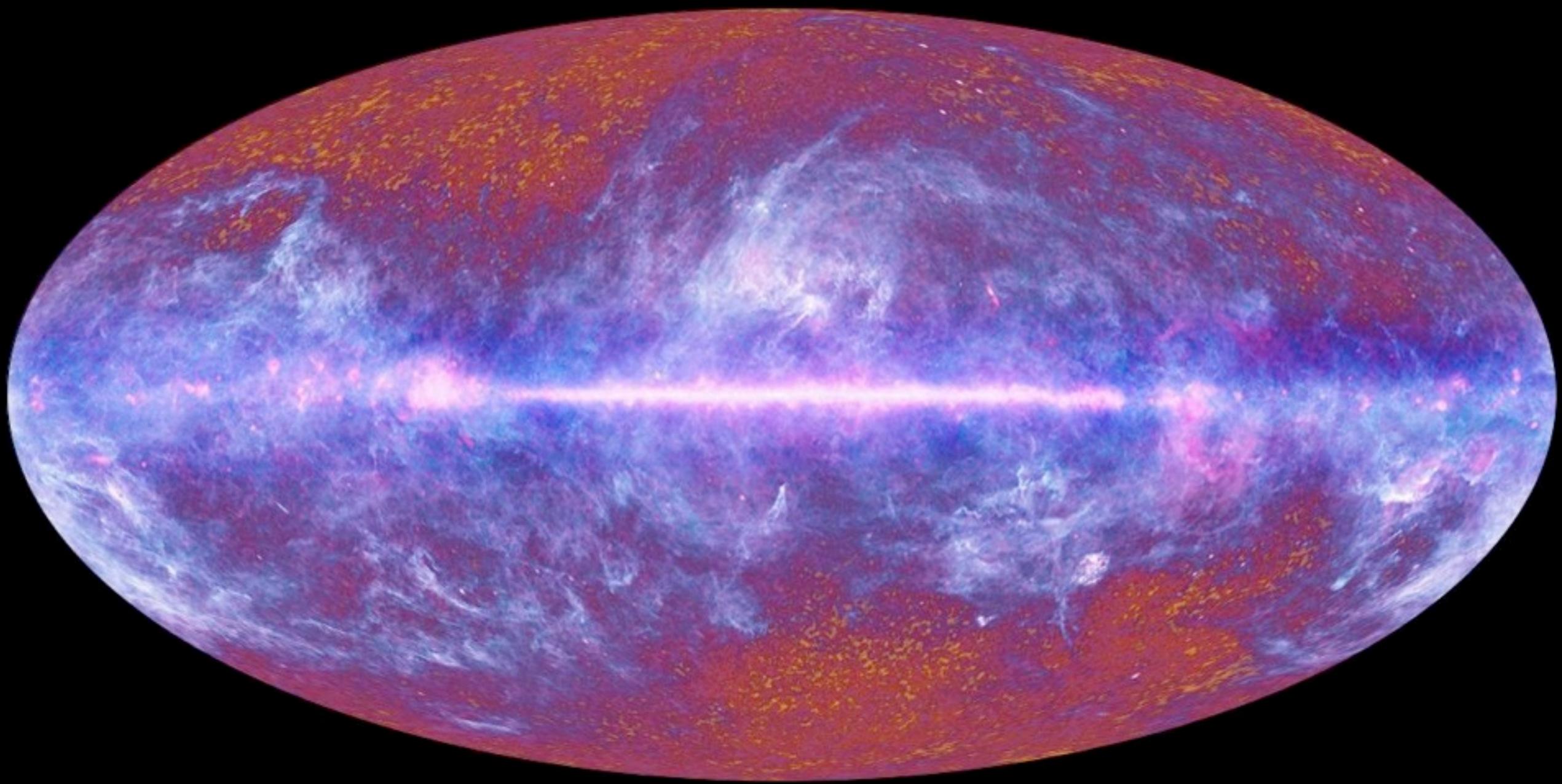
## Disk Stars:

~2% Heavy elements

Stars of all ages

Disk stars formed later and kept forming

This begs the question,  
how did this all come to be?



False color microwave image from the Planck Spacecraft

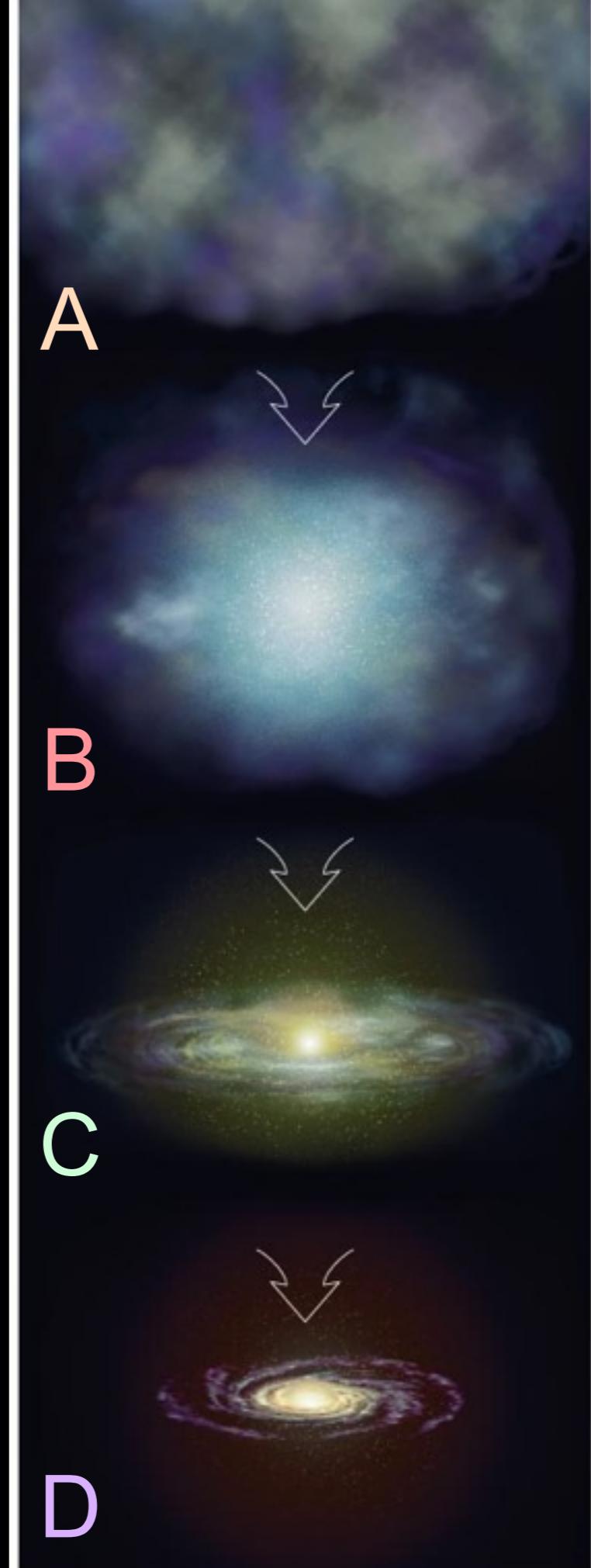
# Milky Way Formation Theory

A: Start out with a giant protogalactic cloud containing only hydrogen and helium

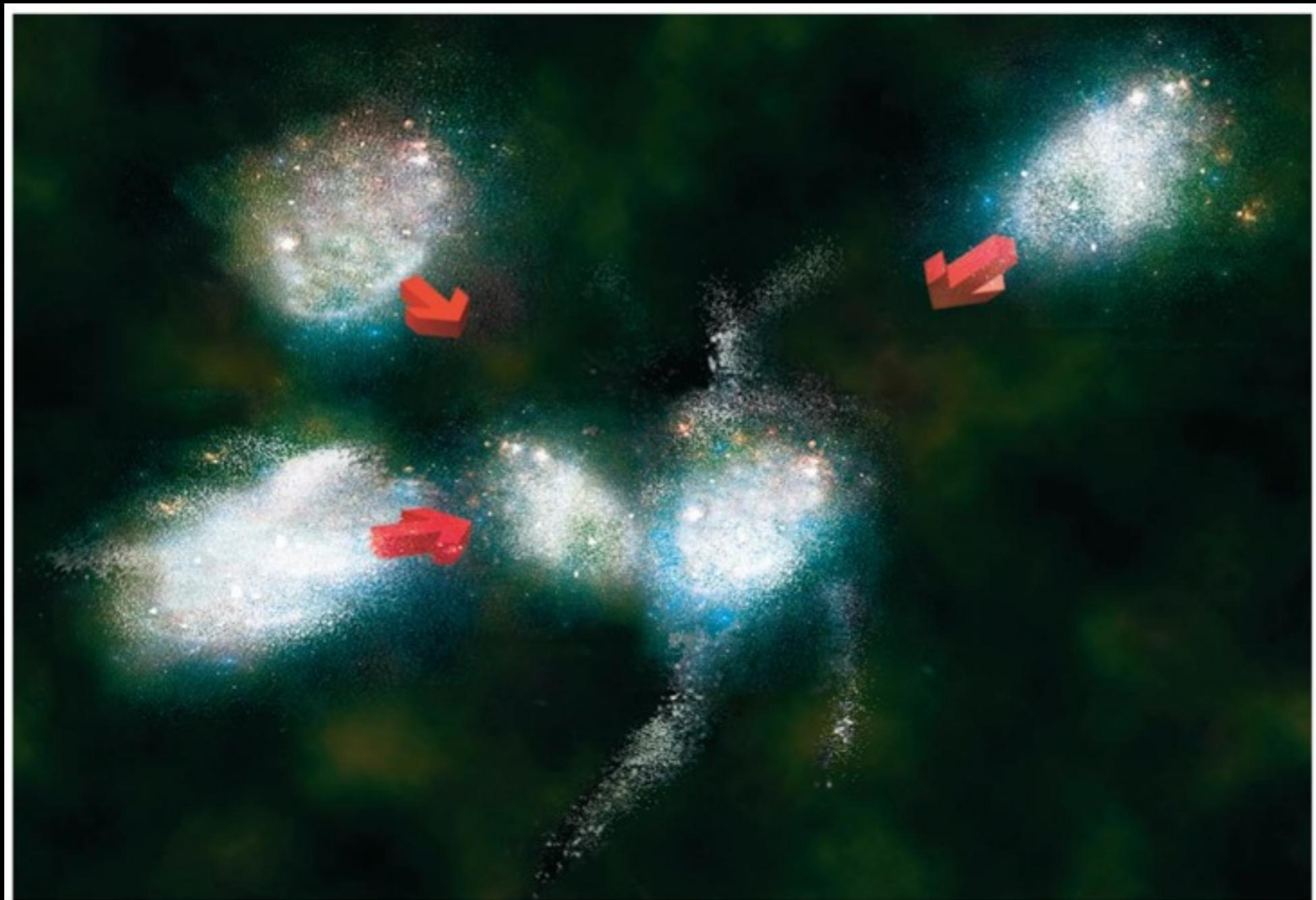
B: Gravity will cause the cloud to collapse and fragment, which will lead to early star formation

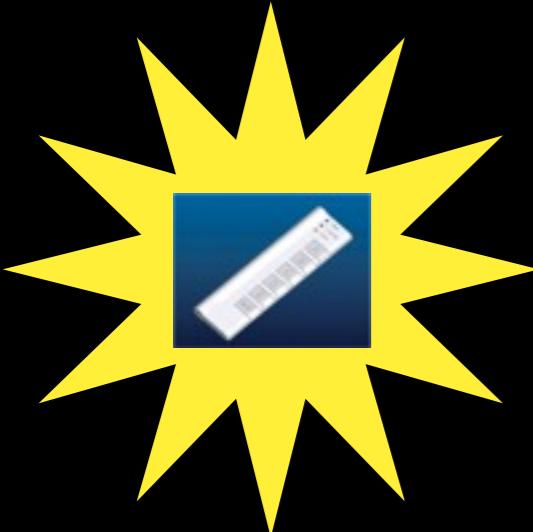
C: As it collapses, the cloud will flatten out into a spinning disk (**why?**), additional star formation can occur

D: As time goes on, repeated star formation will occur as part of the star-gas-star cycle, slowly enriching the disk with heavy elements



That's seems pretty simplified, what if the Milky Way had formed out of multiple protogalactic clouds?





What kind of evidence would help prove that the MW was formed out of multiple clouds and not just one large cloud?

(Hint: Which results would still happen even with a single collapsing cloud model?)

- A) Studies revealing that halo stars' percentage of heavy elements depend on distance from the Galactic Center
- B) Studies showing that some halo stars orbit backwards compared to other halo stars
- C) Studies showing that halo stars' percentage of heavy elements varied randomly throughout the halo
- D) Studies showing that most halo stars actually had more heavy elements than the disk stars
- E) How am I supposed to know?

# Milky Way Formation Theory

Attention:  
This problem is  
not completely solved.

One “little” piece left...

# The Galactic Center

Supernova  
Remnants

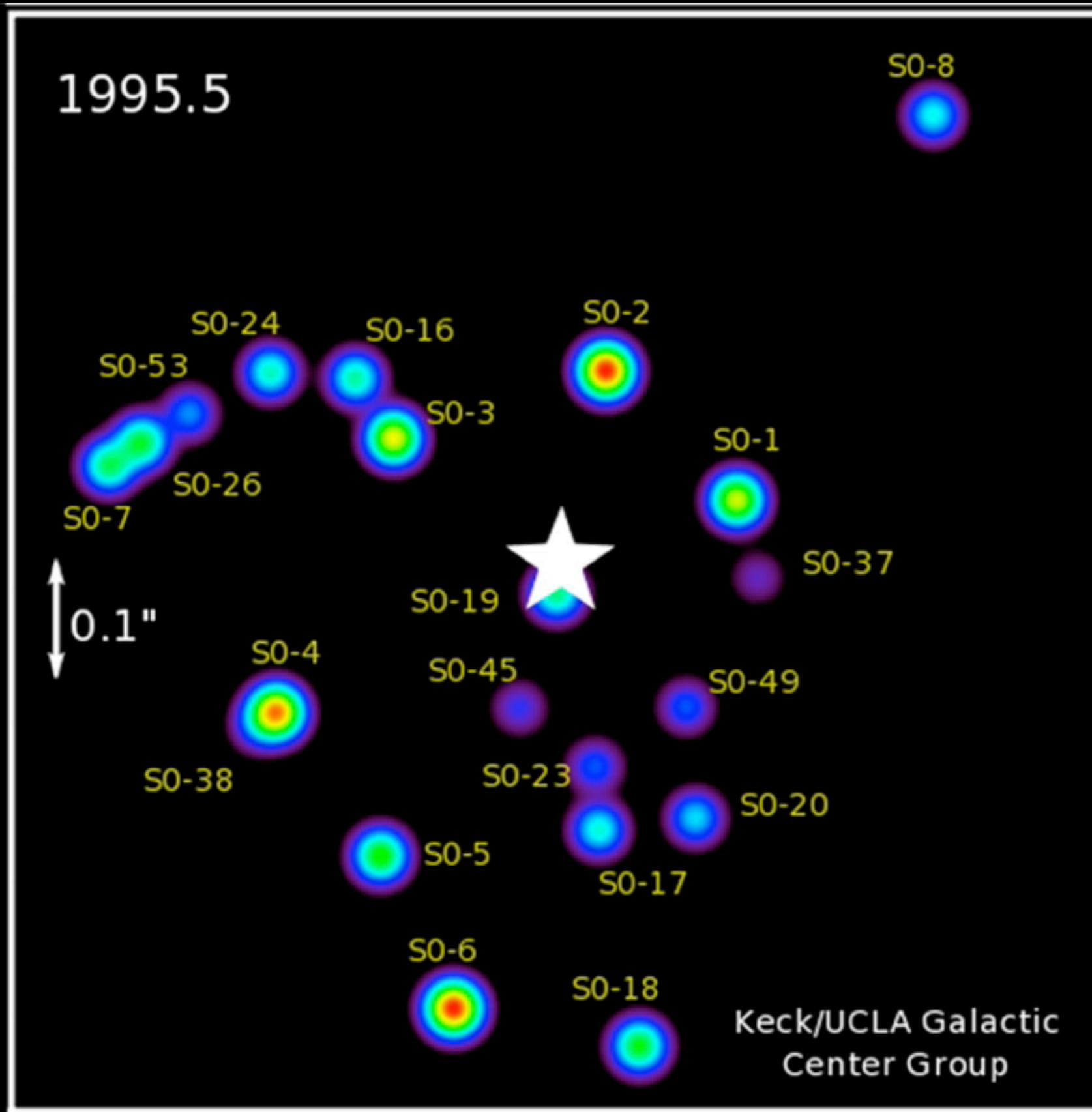
A lima bean

Gobs of gas and dust  
(along with a sun's mass  
worth of ethanol)

Arches. Are  
they from  
magnetic fields?

Supermassive  
Black Hole

# Supermassive Black Hole



Stars appear to be orbiting something massive but invisible ... a black hole!

Orbits of stars indicate a mass of about 4 million  $M_{\text{Sun}}$  within 45 AU (600  $R_{\text{Schwarzschild}}$ )

# Summary

- We sit ~2/3 (28,000 ly) out from the Galactic Center
- The Milky Way consists of a **disk**, a **bulge**, and a **halo**
- The disk is made up of **spiral arms**, which are generated by **spiral density waves**
- Material in the disk of the Milky Way orbits the center in an **ordered way**, while stars in the halo and bulge tend to have **random trajectories**
- The Milky Way likely formed from multiple **protogalactic clouds** that merged together and formed the old halo stars early on and as the material collapses into a disk additional star formation occurred and continues to this day