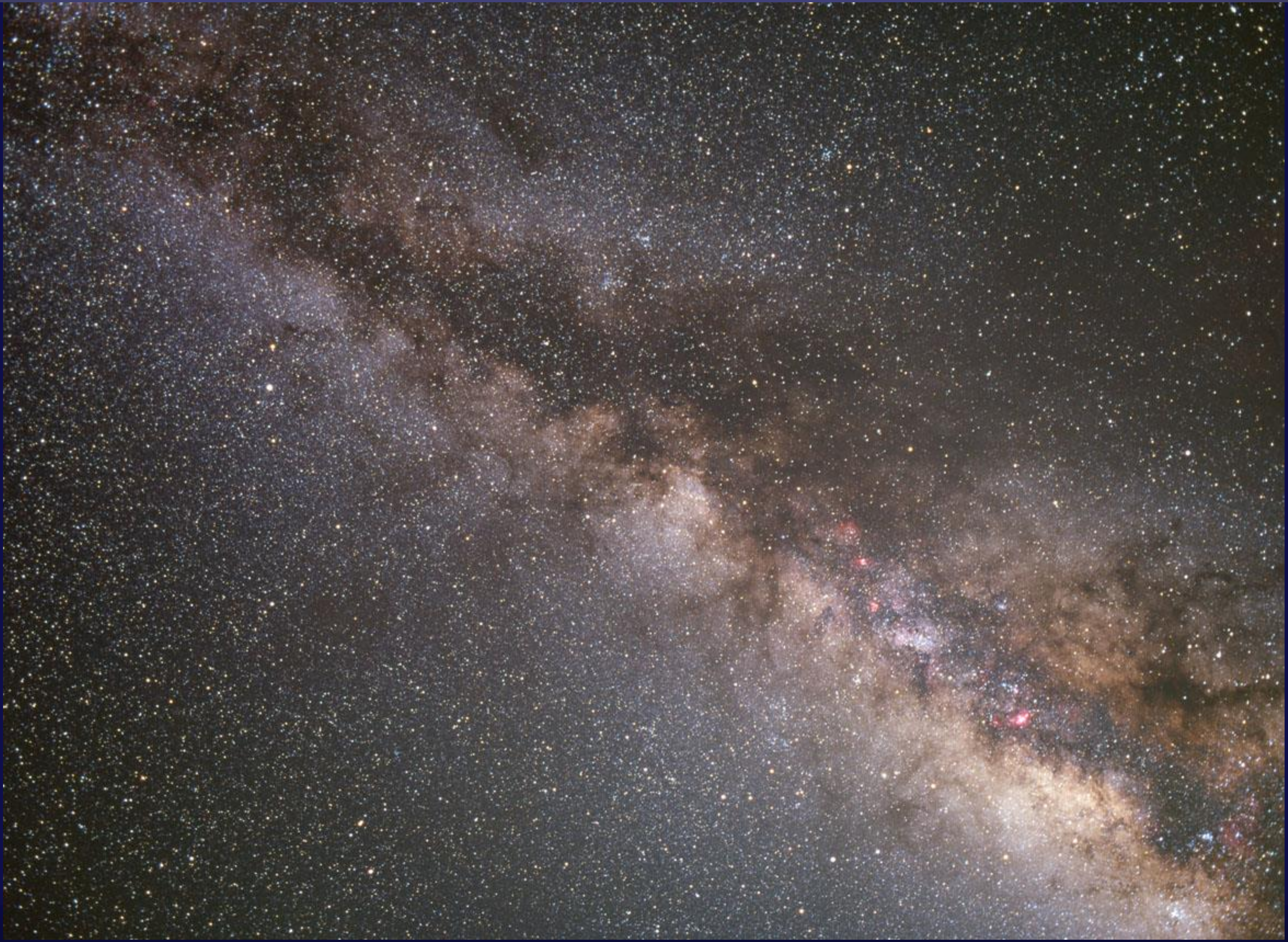
The Milky Way



Overview

A. Distance
   1. Three ways of measuring distance.
      1. Light Travel time.
      2. Parallax
      3. Standard Candles.
   2. Main Sequence Distances.

B. The Shape of the "Universe" (Milky Way Galaxy)
   1. What was the technique for each and why was it wrong?
      1. William Herschel
      2. Kapteyn
      3. Shapley

Overview

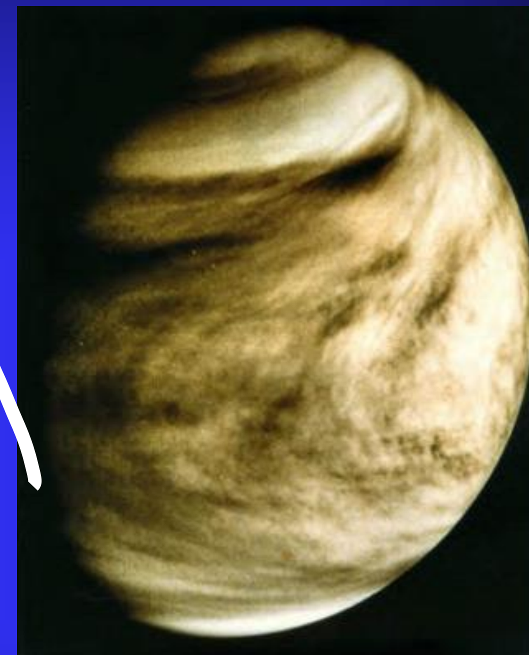
C. The Milky Way
   1. Three Main Components
      1. Disk
      2. Bulge
      3. Halo
   2. Morphology of each component
   3. Age of each component
   4. Composition of each component
   5. Dynamics of each component

Overview

C. The Dark Matter
   1. Rotation Curves
   2. Mass versus Orbital Velocity
   3. The Milky Way Rotation Curve
   4. Dark Matter

Distances

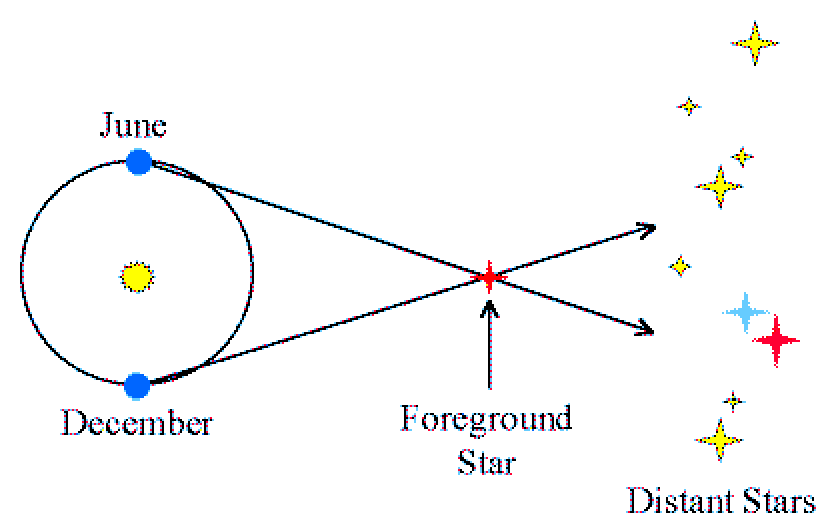
Method #1
Use a Photon!



- Know the speed of light
- Measure the light time
- Calculate the distance

Distances

Method #2
Parallax



- Know the distance to the Sun
- Measure the angular shift of a foreground star
- Calculate the distance

Distances

Method #3
Standard Candles

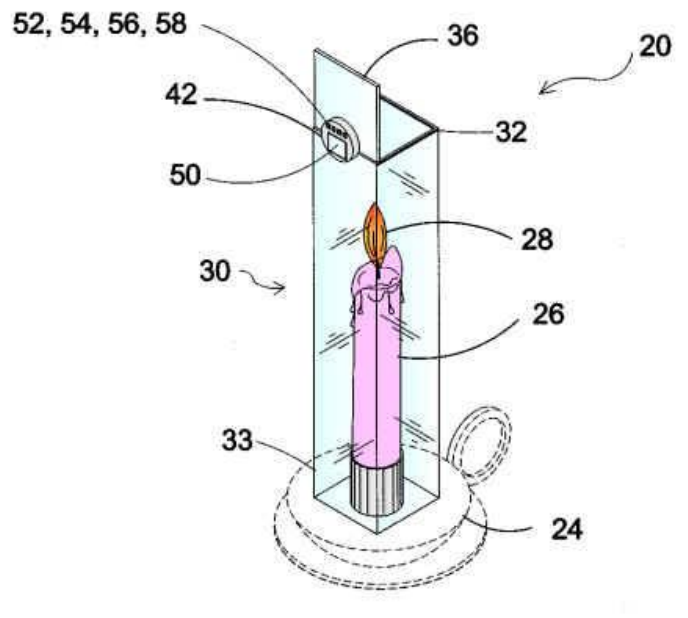


FIG 3

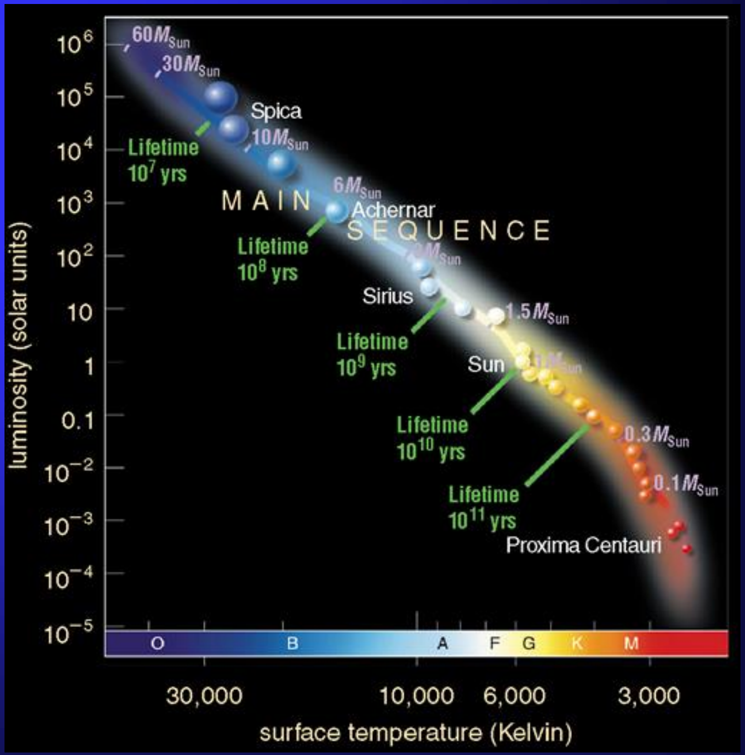
Standard Candle:
An object whose true Luminosity is known.

- Know the Luminosity
- Measure the Apparent Brightness
- Calculate the distance

Distances

Method #3.1
The Main Sequence as a Standard Candle

- Measure the Temperature
- Infer the Luminosity
- Calculate the distance



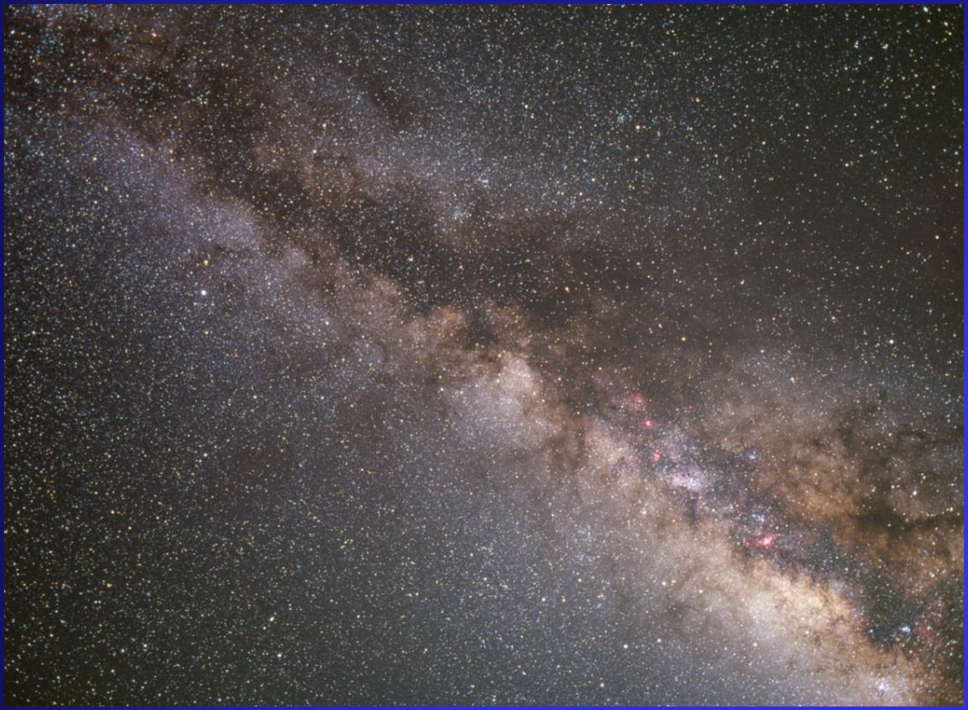
We can use Main Sequence Stars to determine distance because:

A) They have a Temperature Luminosity relationship and we can measure Luminosity.
B) They have a Temperature Luminosity relationship and we can measure Temperature.
C) They have a Distance Luminosity relationship and we can measure distance.
D) Main Sequence Stars are useless.

If the real speed of light is slightly faster than we think

A) our distances derived from the Main Sequence would be too small.
B) our distances derived from the Main Sequence would be too large.
C) only our Earth-Venus distance would be effected.
D) No distances would be effected.

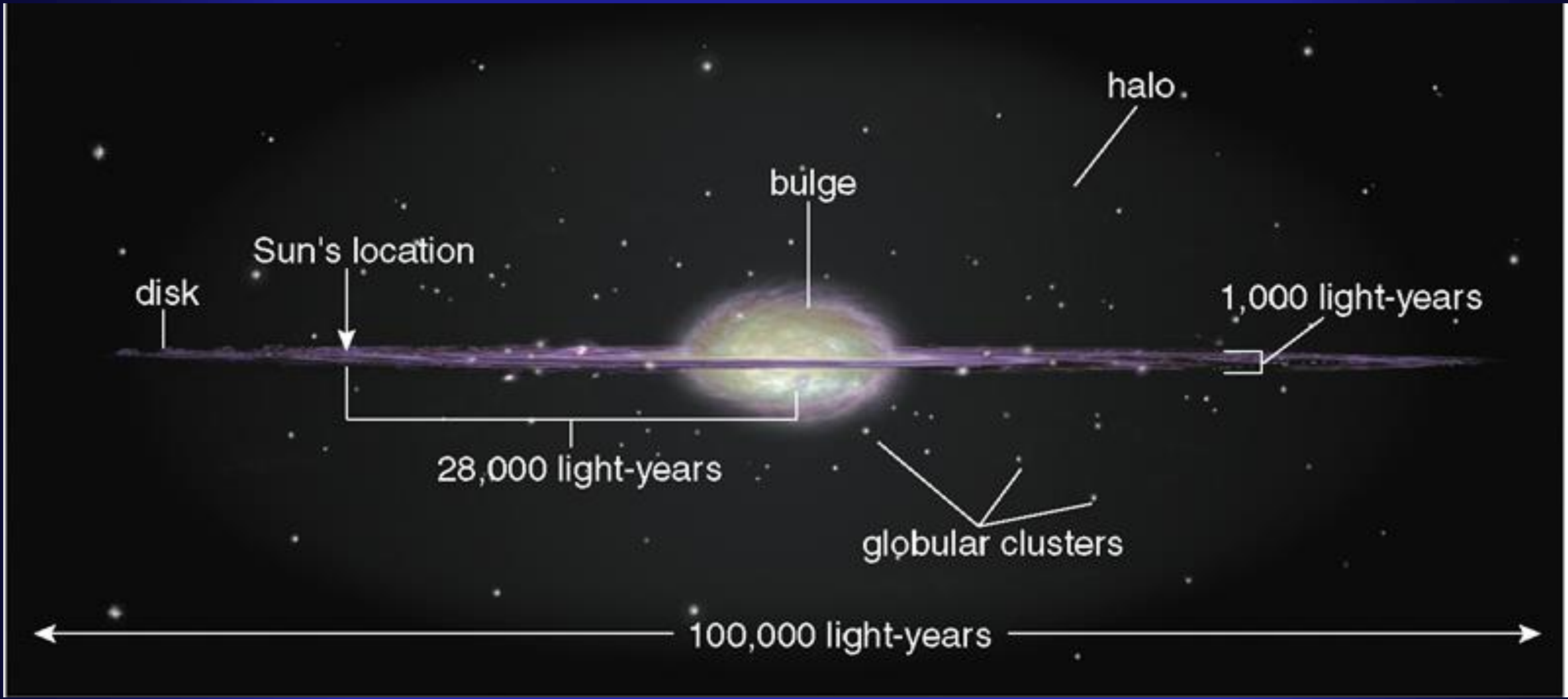
The Shape of the Universe



Gallileo

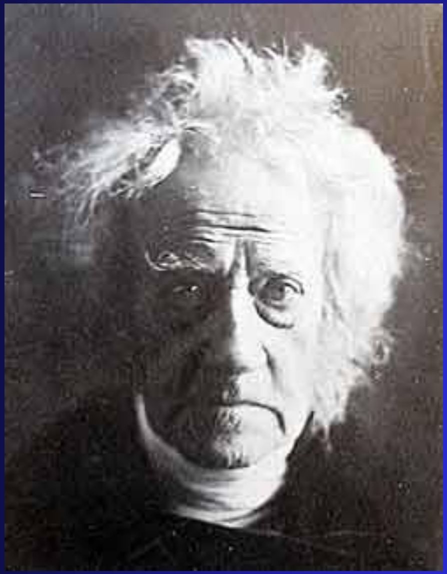
The Milky Way is composed of innumerable stars

The Modern View



Where Are We?

Herschel's View

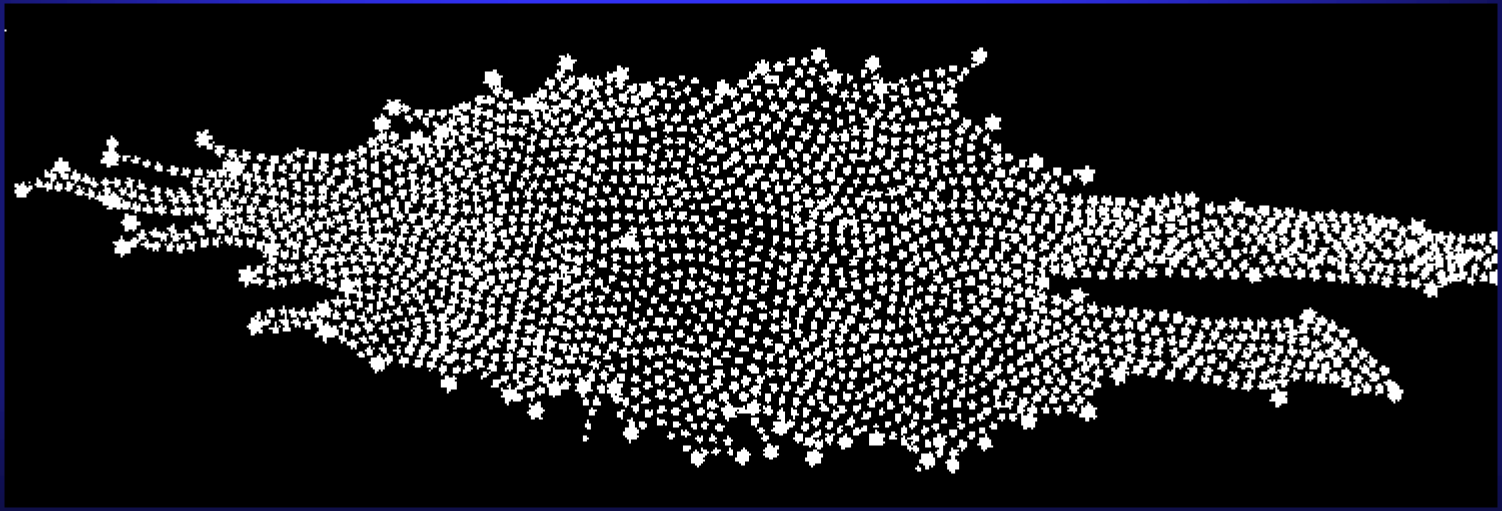


William Herschel

Assumes L=1 for all stars

The "Universe" is a flat disk 5 times wider than thick

We're near the center



Looking at an object through dust makes it appear ____________ it would appear without dust

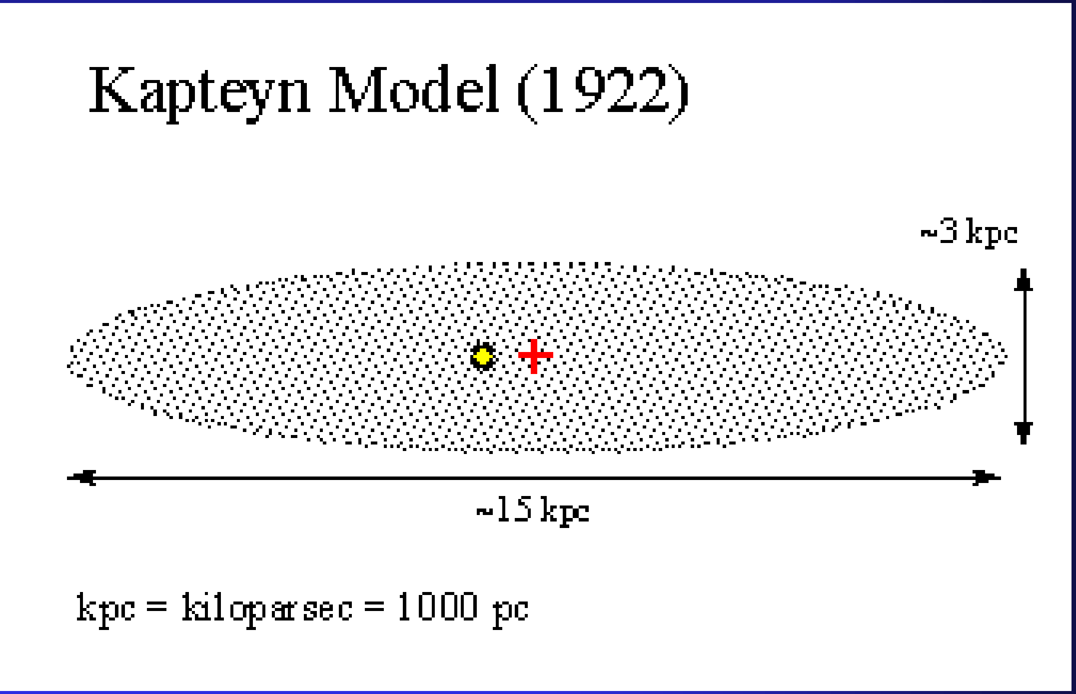
A) brighter
B) dimmer
C) the same as

Looking at an object through dust makes it appear ____________ it would appear without dust

A) closer
B) further
C) the distance as

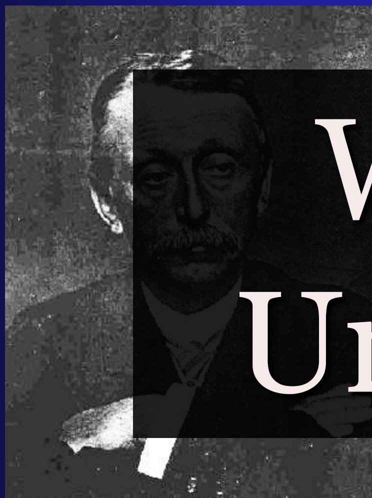
Kapteyn's View

Kapteyn



- Short and squat (Lentil)
- Sun is near the center
- 40,000 lyr across

Kapteyn's View



Kapteyn

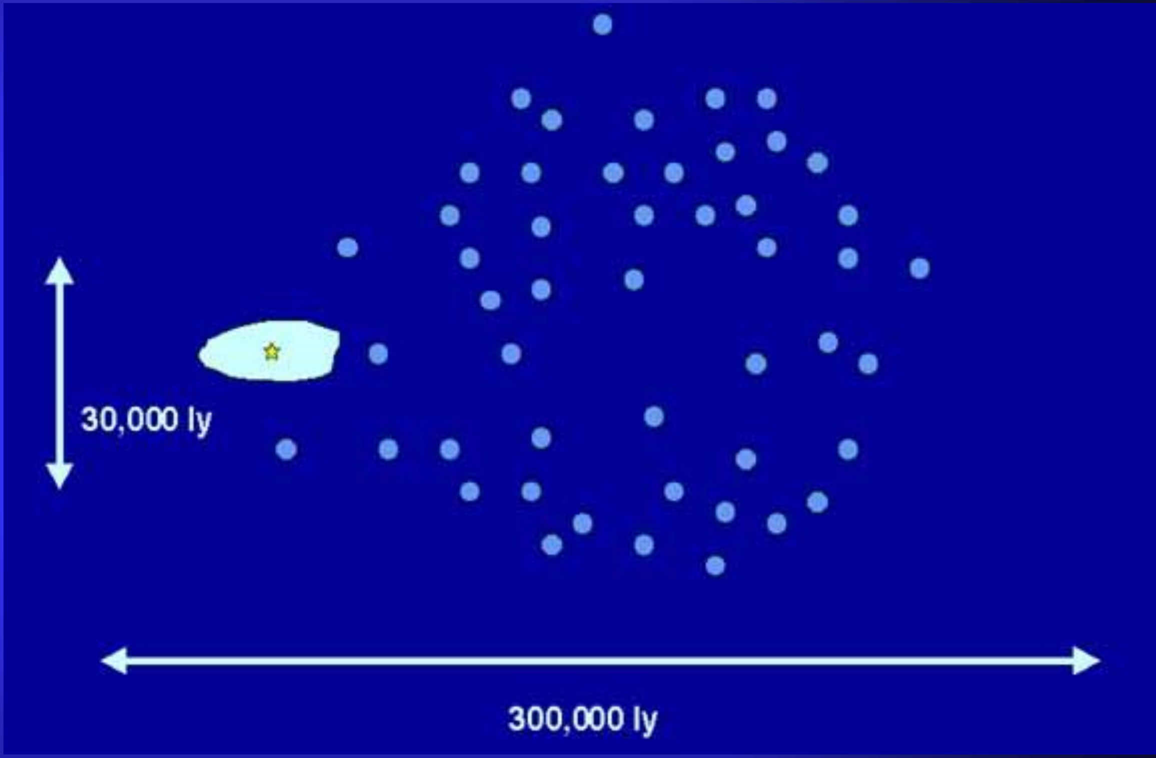
Why Is Kapteyn's Universe too Thick?

Why Is Kapteyn's Universe so Short?

- Short and fat (Lentil)
- Sun is near the center
- 40,000 lyr across

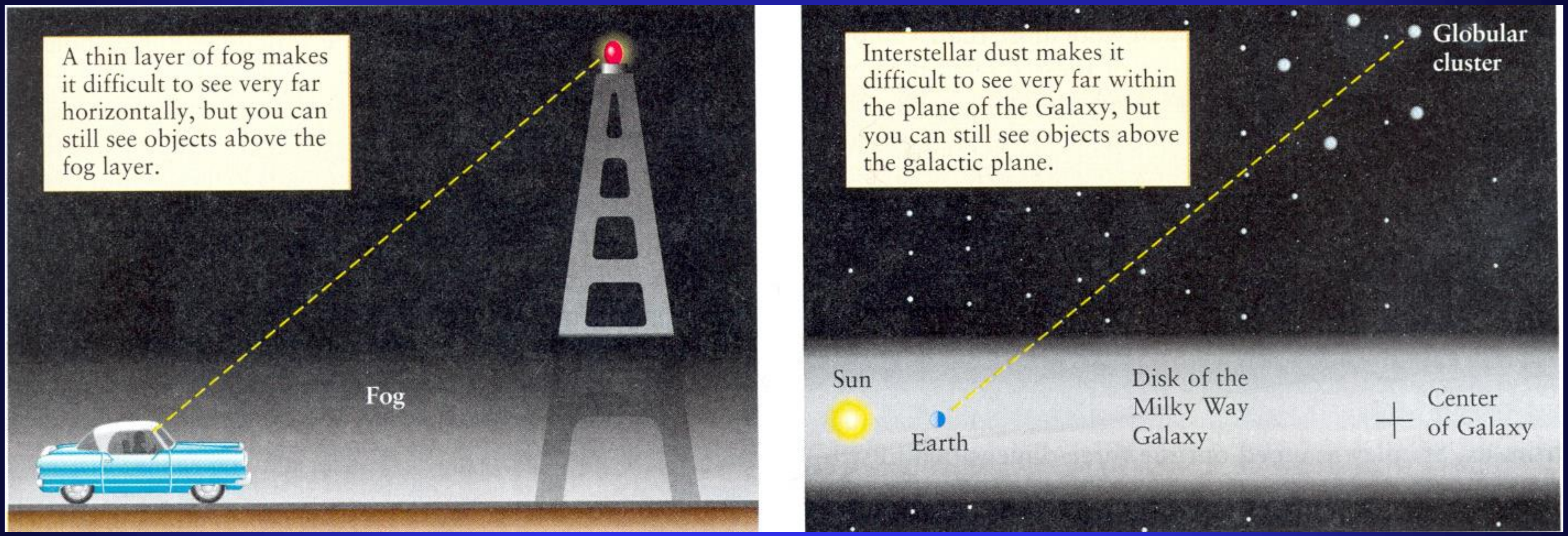
Shapley's View

Shapley



- Globulars are in a spherical "halo"
- Center is 45,000 lyr away

Shapley was "less wrong"

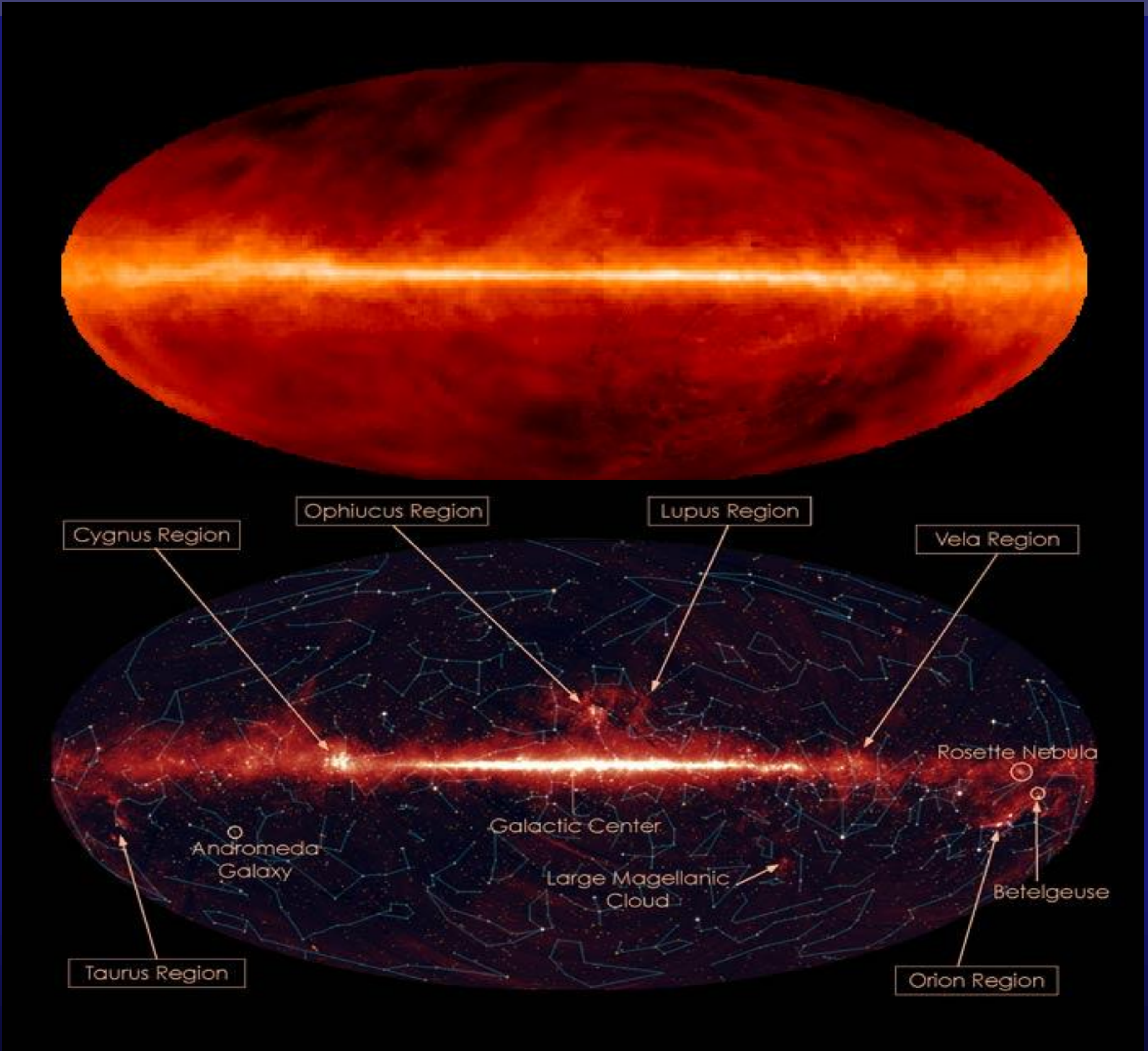


Shapely's distances were ALSO too big because of dust.

He could see further because:

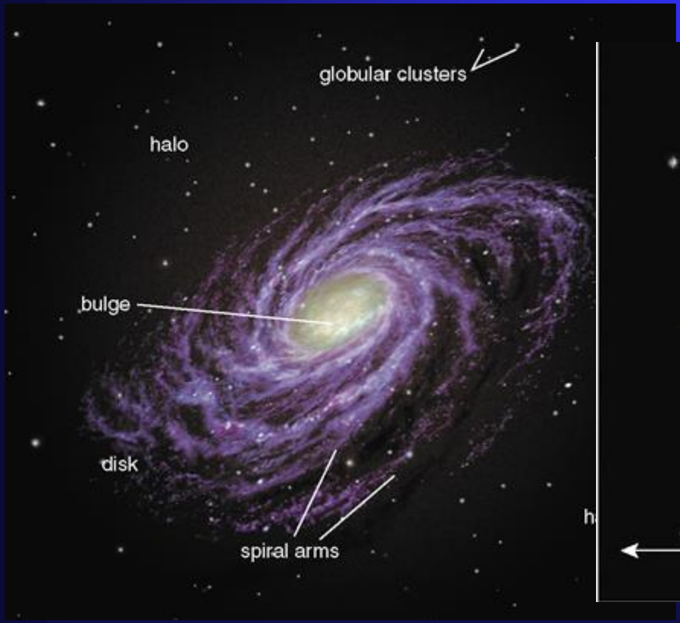
- Globulars are BRIGHT
- He was looking out of the plane

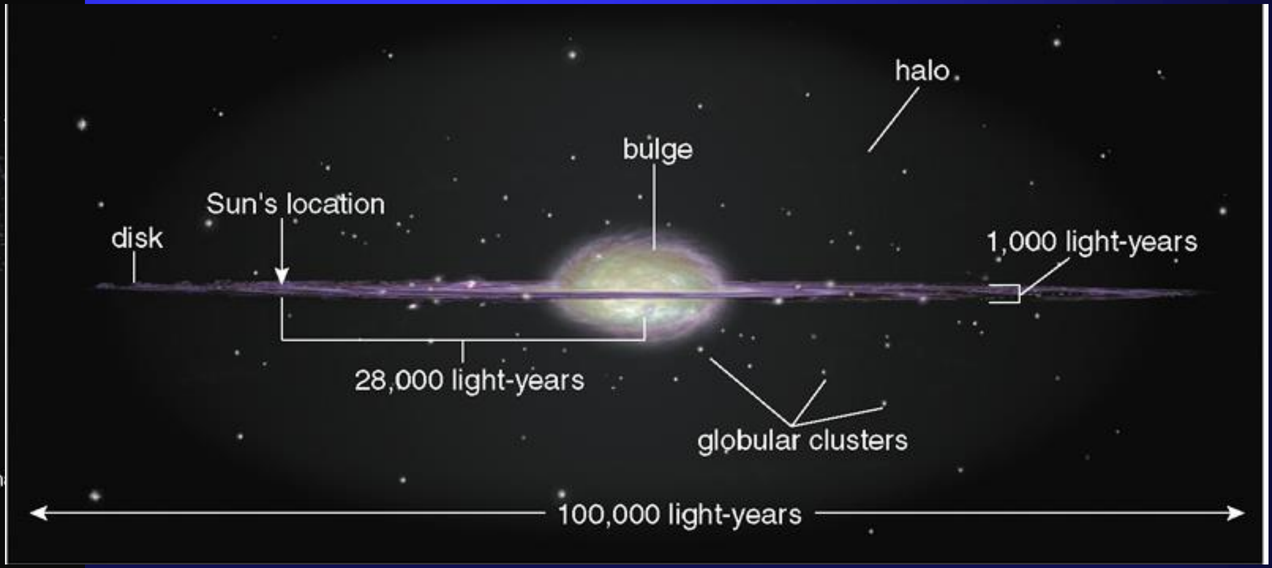
Modern Measurements



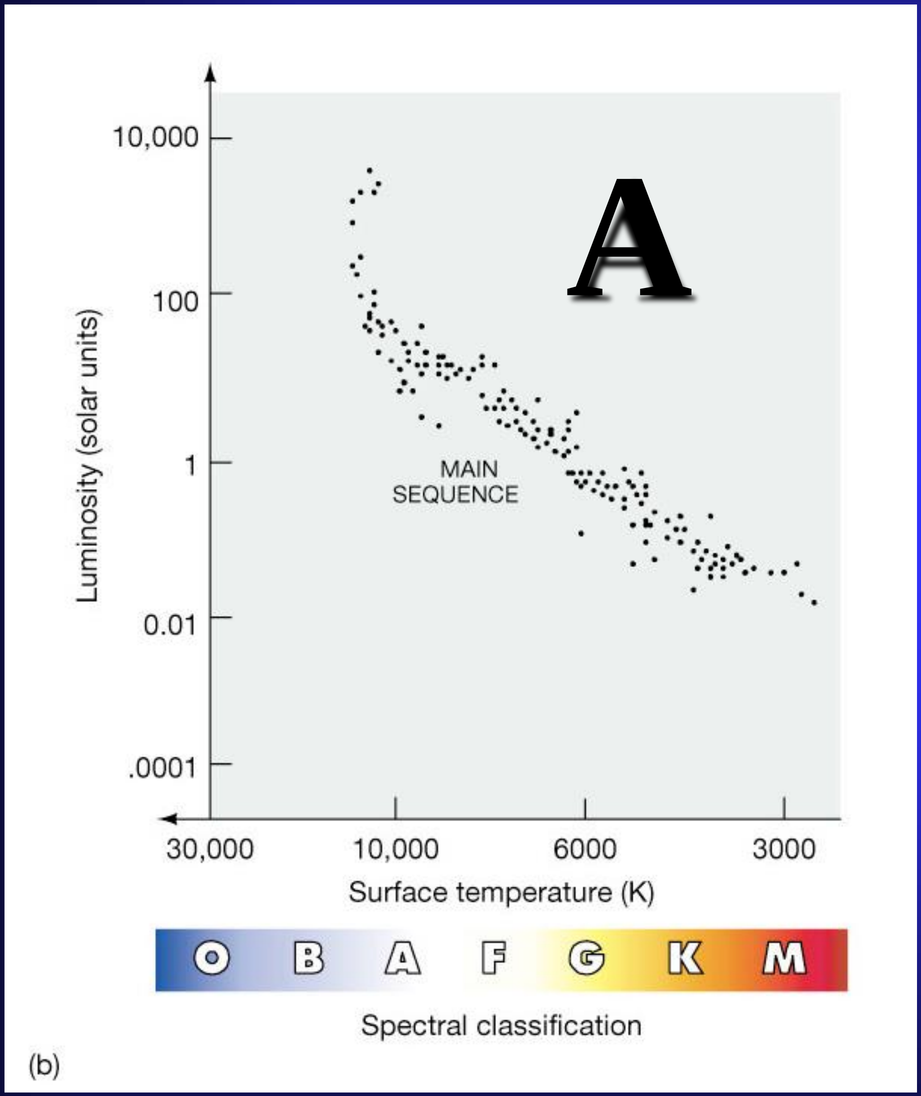
Basic Structure

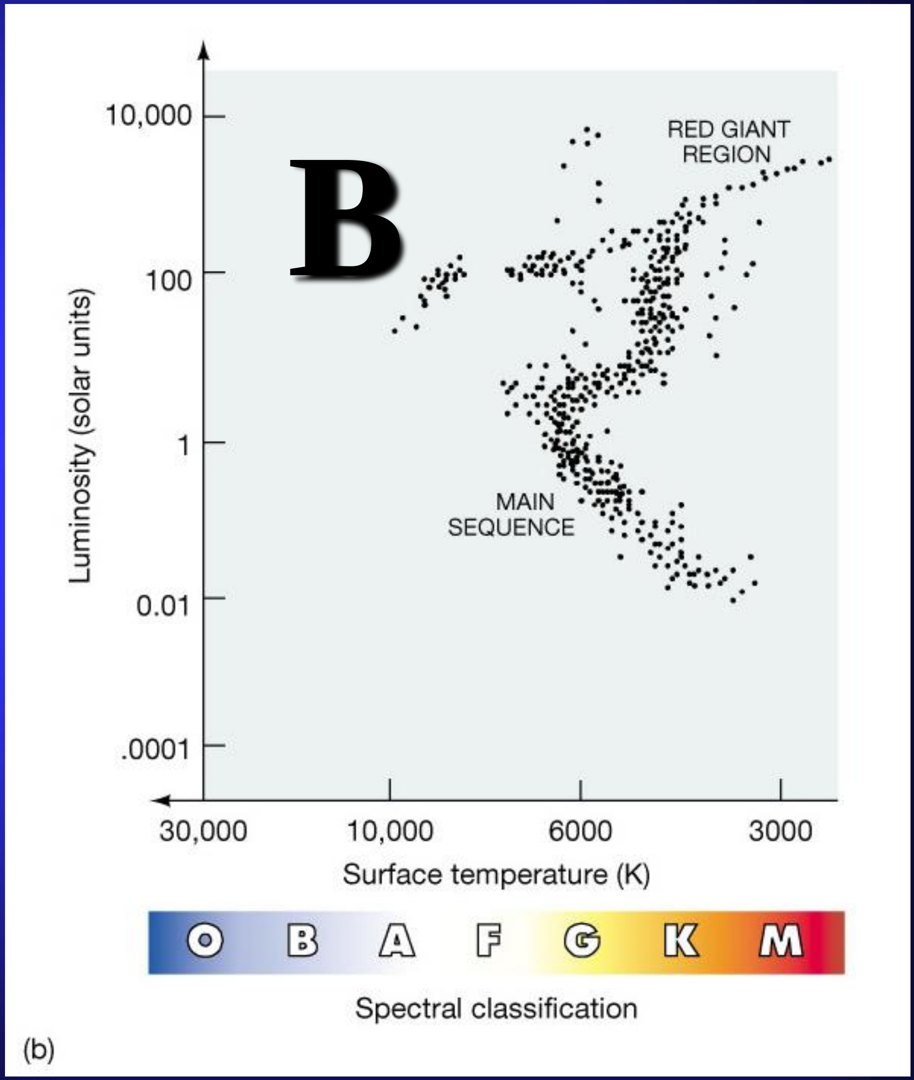
Disk – Flat circular, in the mid-plane
Bulge – Spherical Central Region
Halo – Spherical surrounding Disk and Bulge





Which Cluster is Younger?

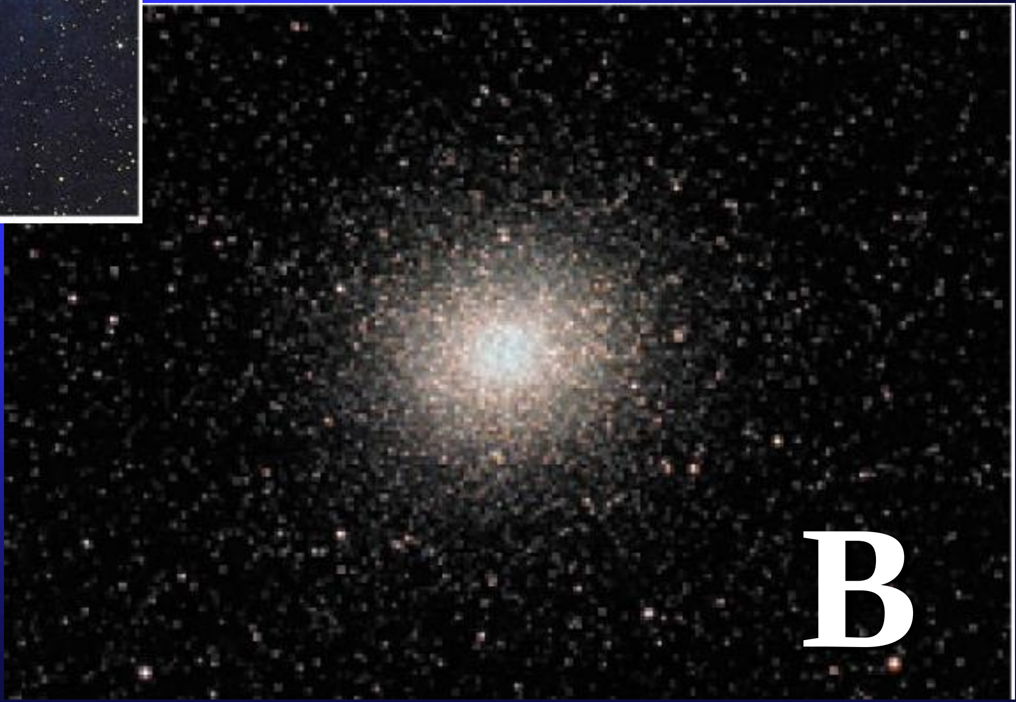




Which Cluster is Younger?

Globular Cluster
Age = 10 billion Years
(Halo)

Open Cluster
Age = 1 million Years
(Disk)

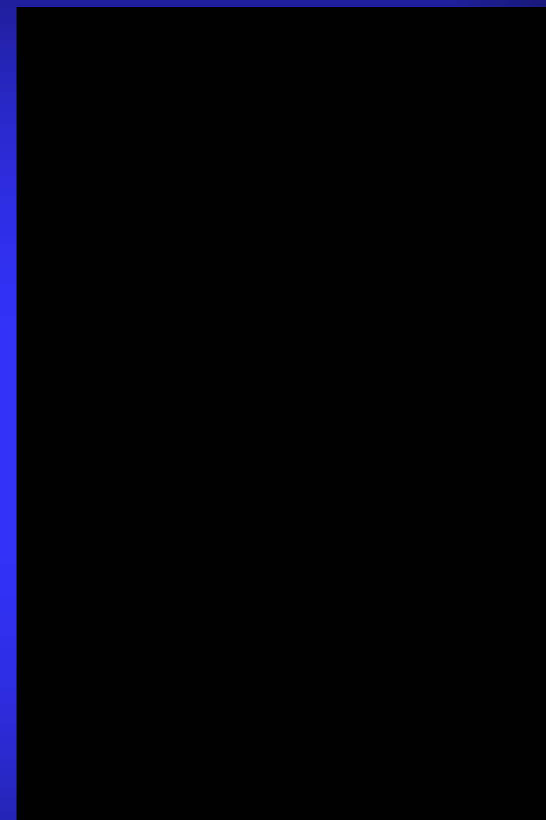


Disk Stars Versus Halo Stars

Age of the Galaxy = 10 Billion Years

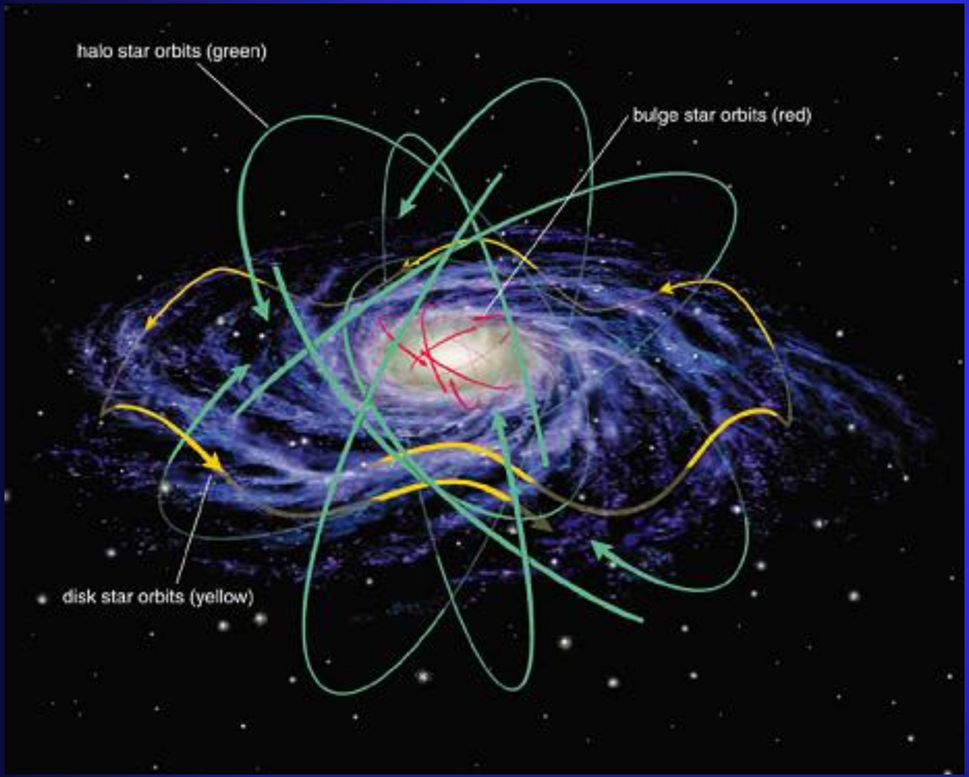
Gas and Dust

The disk contains a lot of gas and Dust.



The Halo contains almost no gas or Dust.

Orbital Motions



Disk
Mostly circular orbit about the galactic center

Halo and Bulge
Swarming orbits
Not coplanar

Kepler's Second Law

Kepler

$$p^2 = a^3$$

Newton

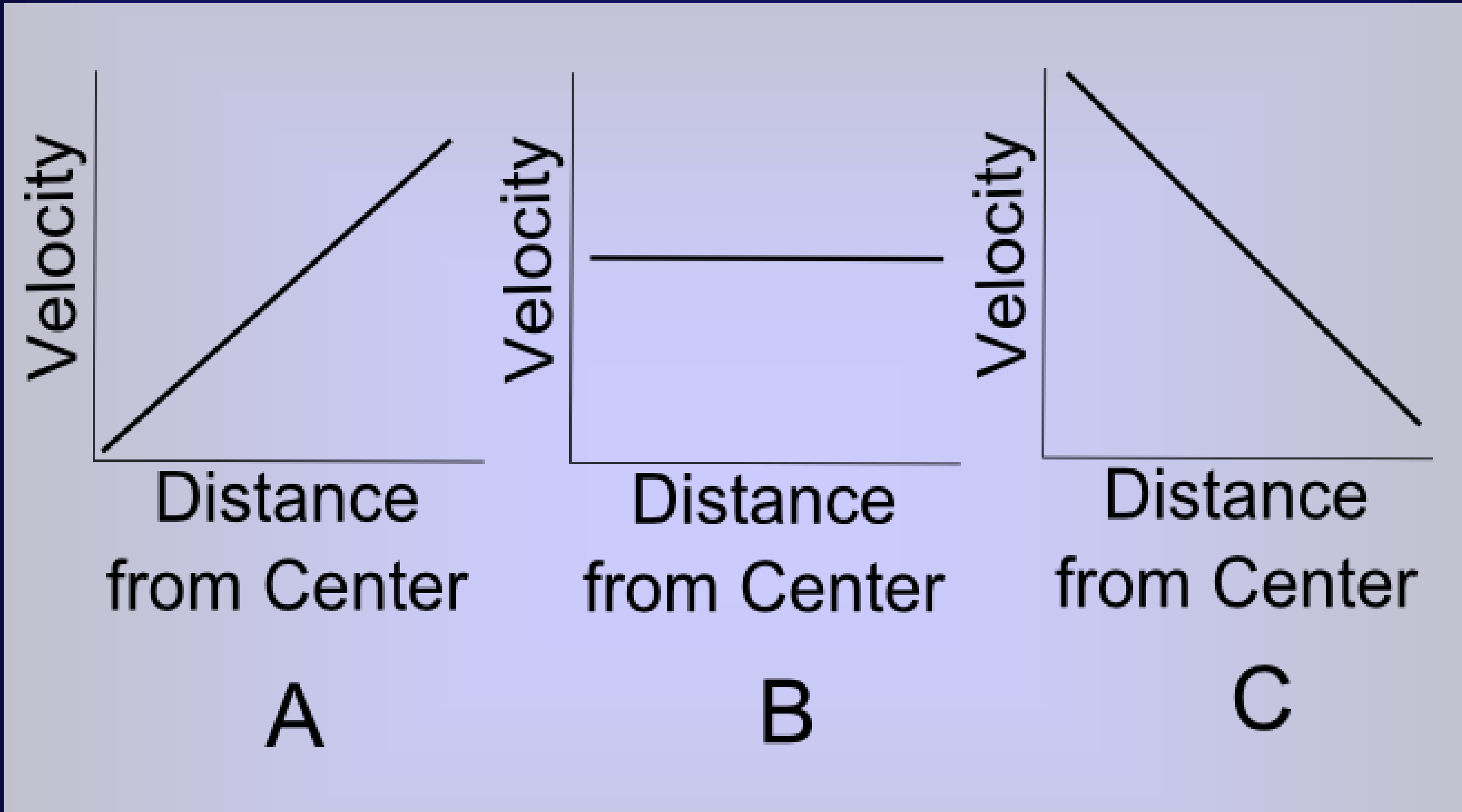
$$p^2 = \frac{4\pi^2}{G(M_1 + M_{enc})} a^3$$

Orbital period depends on the ENCLOSED mass

(Mass enclosed by the orbit)

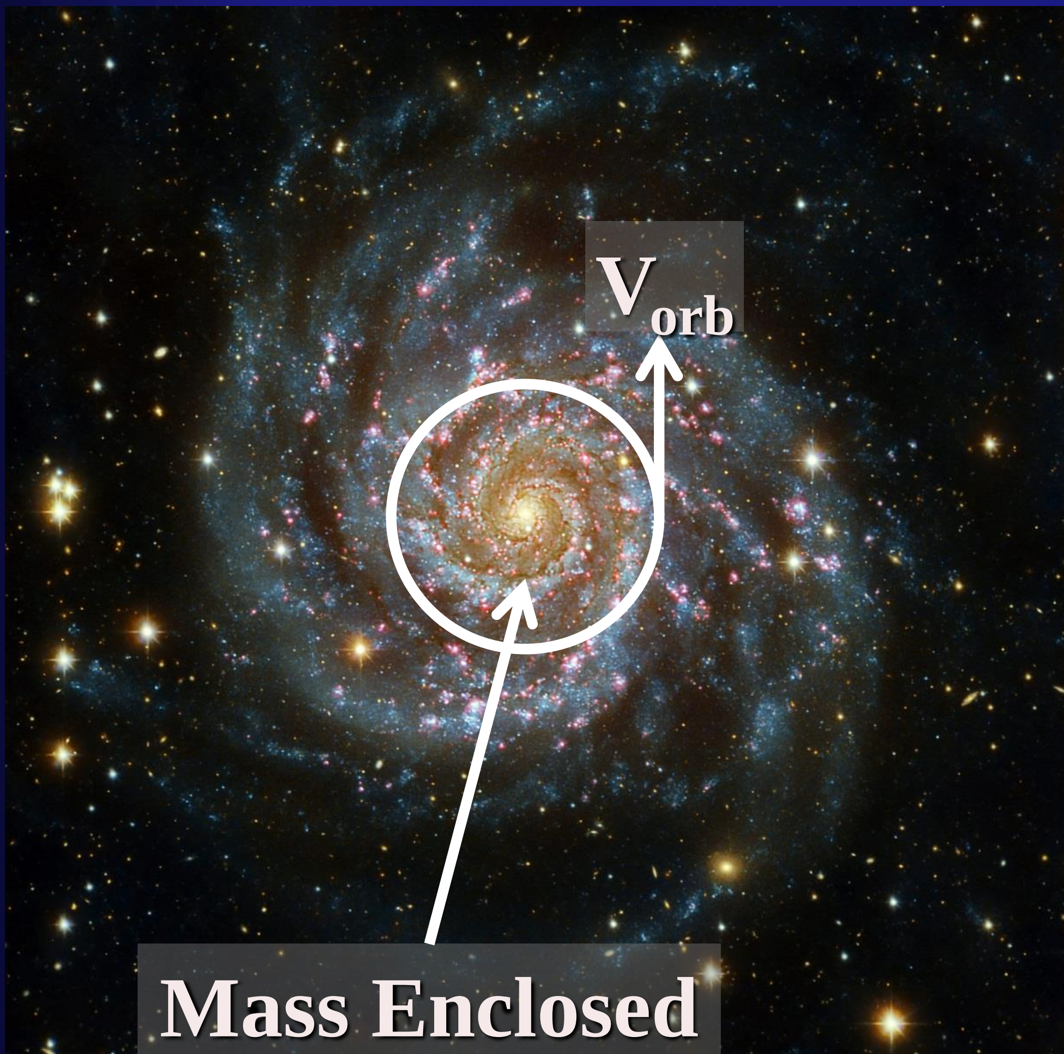
If the Sun were 2 solar masses instead of 1 solar mass and the Earth were still in a circular orbit,

- A) Our orbital velocity would be higher
- B) Our orbital velocity would be the same
- C) Our orbital velocity would be lower



Velocity
Distance from Center
A
Velocity
Distance from Center
B
Velocity
Distance from Center
C

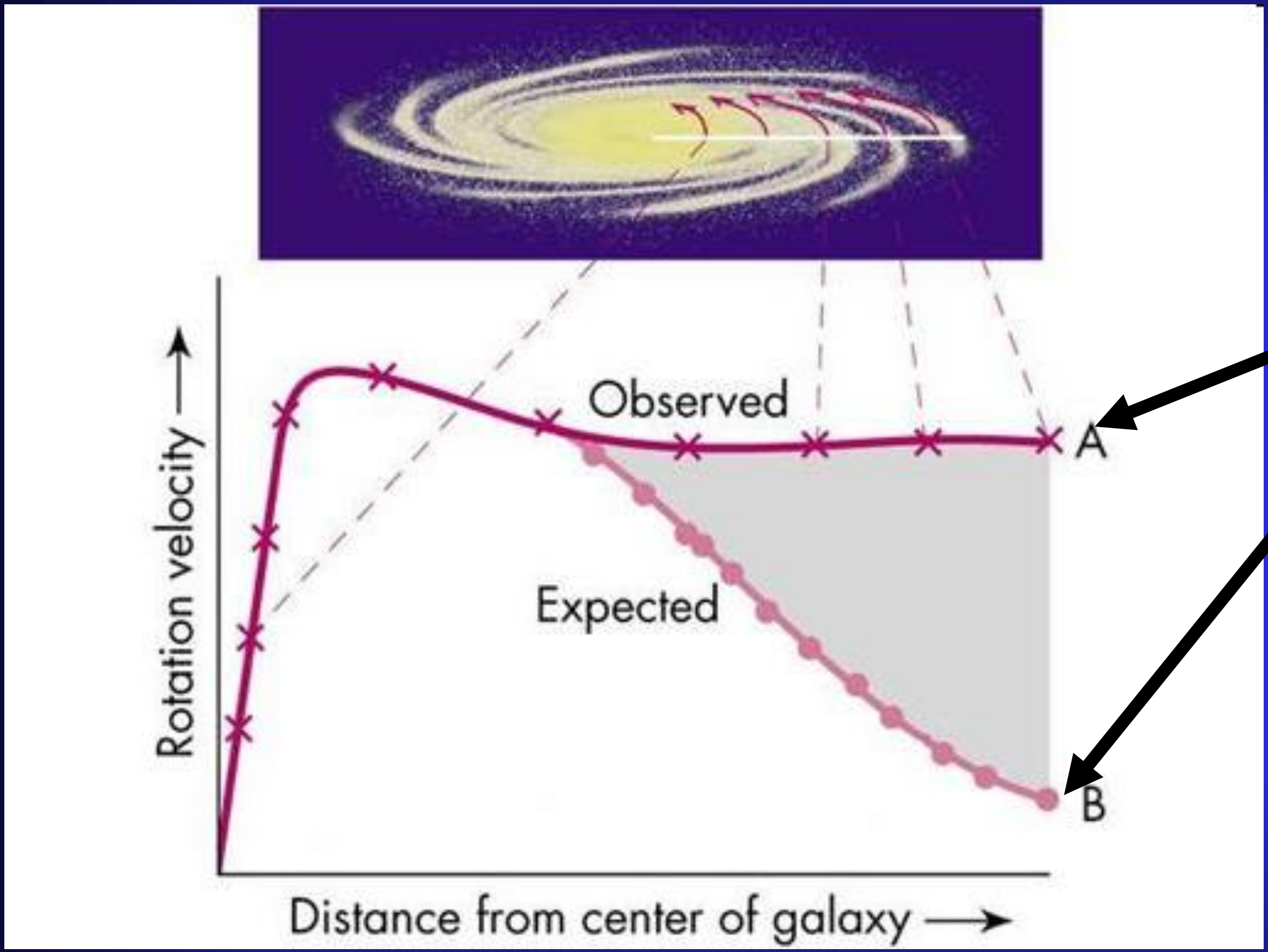
Stellar Orbital Velocity



Solar System
As orbital radius increases, enclosed mass stays constant

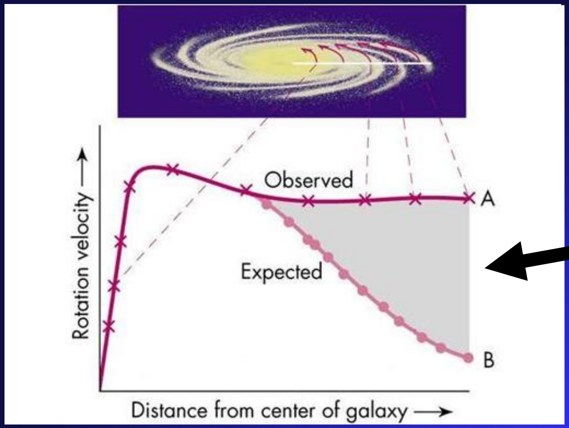
Galaxy
As orbital radius increases, enclosed mass increases

What do we expect?



Hmm…

When we add up all the mass that we can see, we expect curve B but SEE curve A



Hmm…

This velocity discrepancy implies

A) The galaxy contains more mass than we can see.

B) The galaxy contains less mass than we can see.

C) Newton's Laws are wrong

History of Matter

The Galaxy's metal content

A) has been decreasing since its formation

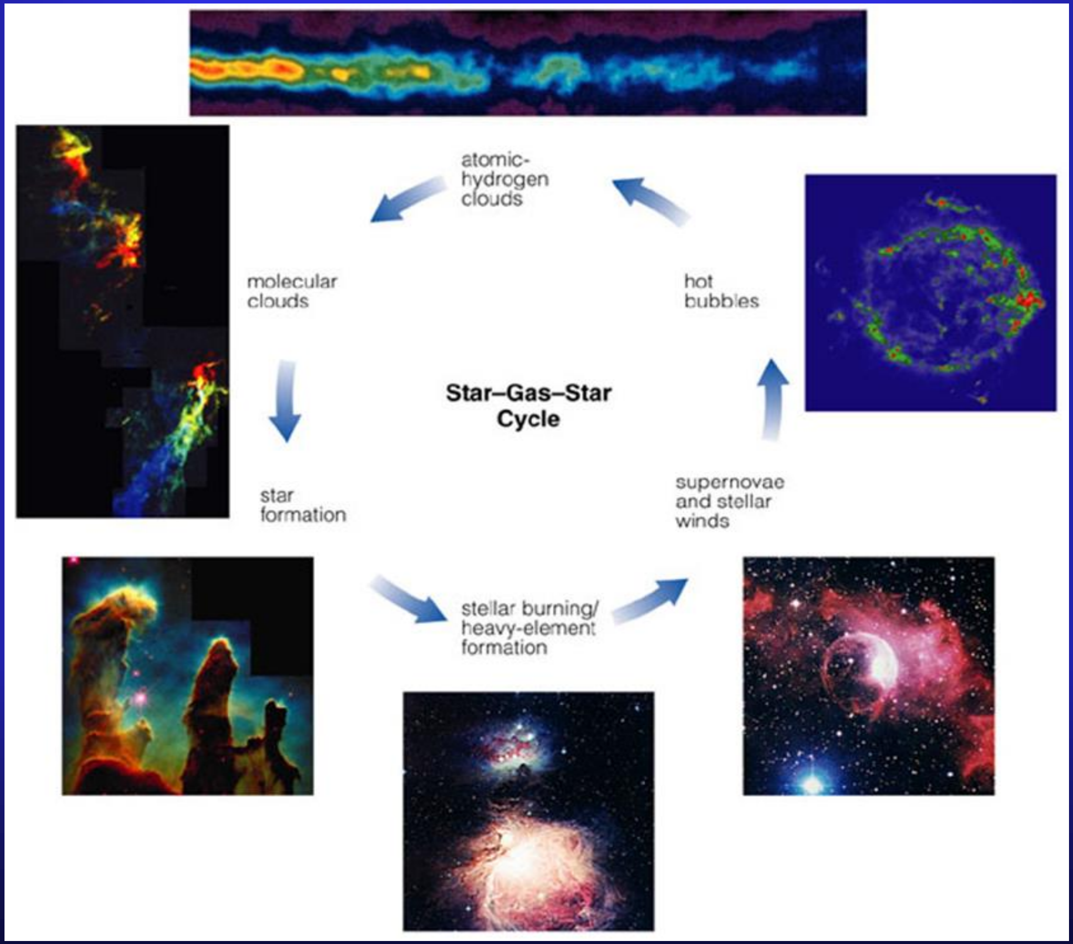
B) has not changed since its formation

C) has been increasing since its formation

D) is not something we can measure

Galactic Recycling Program

Material gets cooked in stars and ejected back into the ISM



Halo Stars?

We would expect halo stars to have

A) Higher metal content than the disk stars

B) Lower metal content than the disk stars

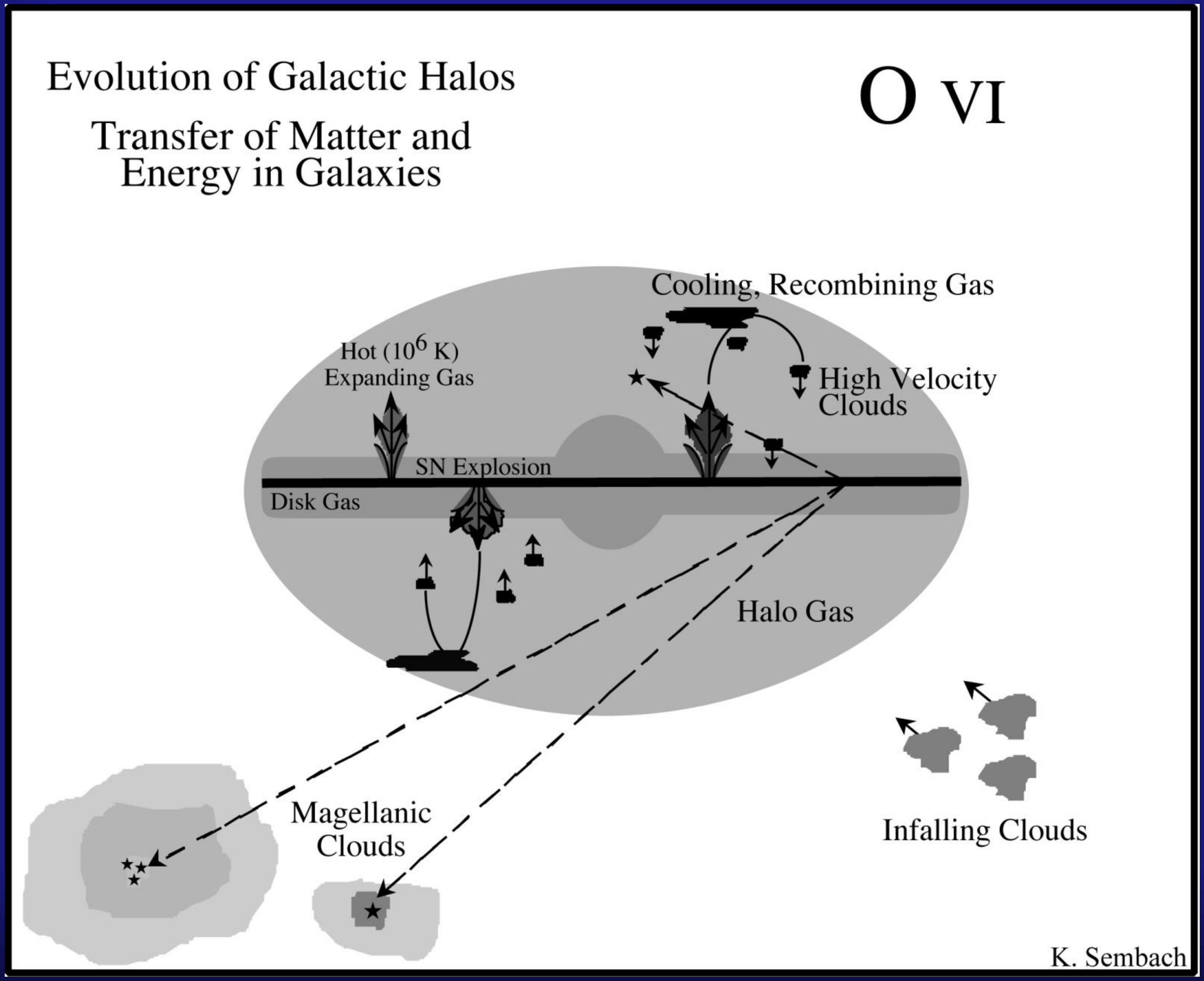
C) The same metal content than disk stars

D) There is no way to know.

Bubbles

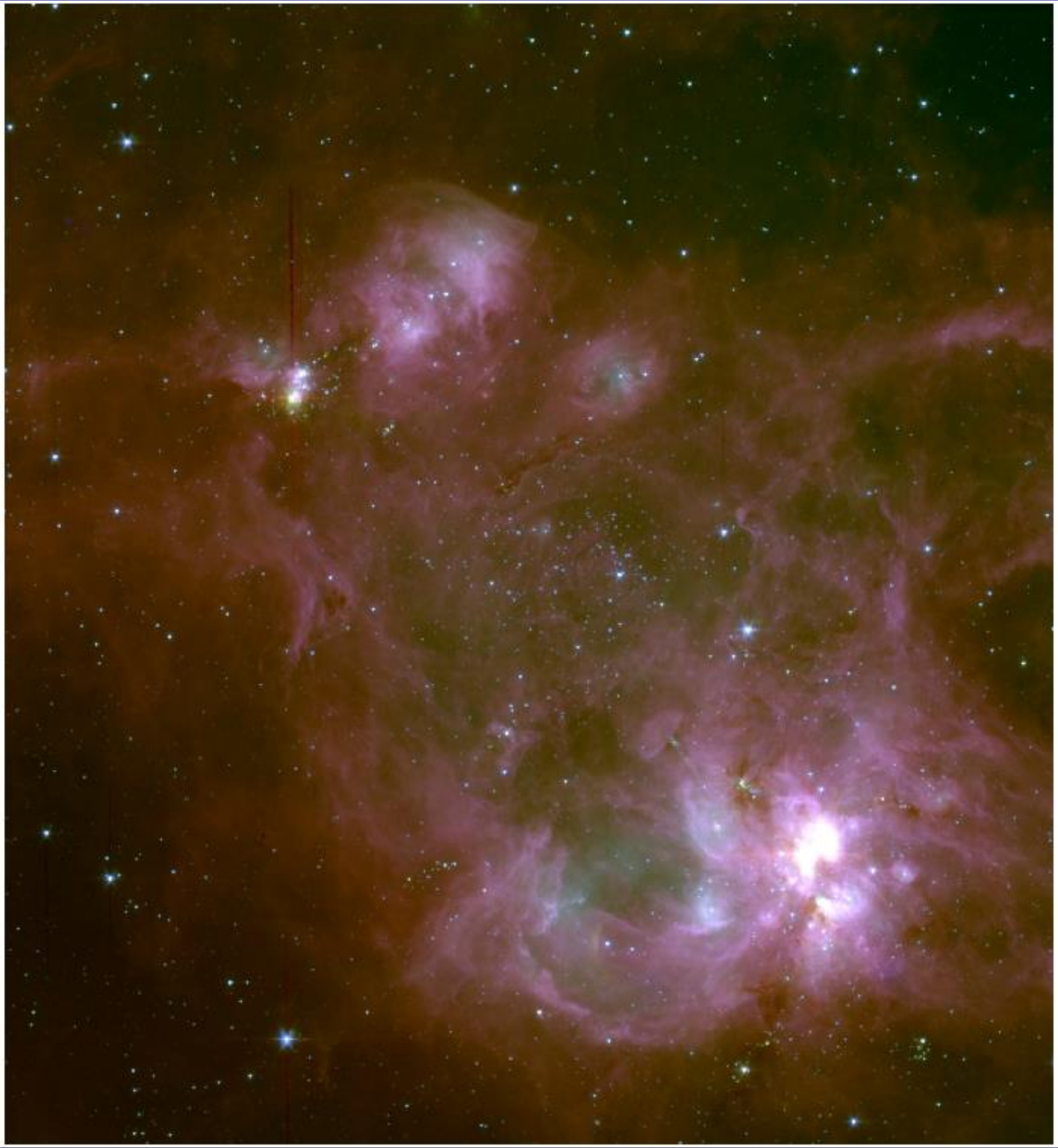
Massive stars blow bubbles in the ISM

Fountains



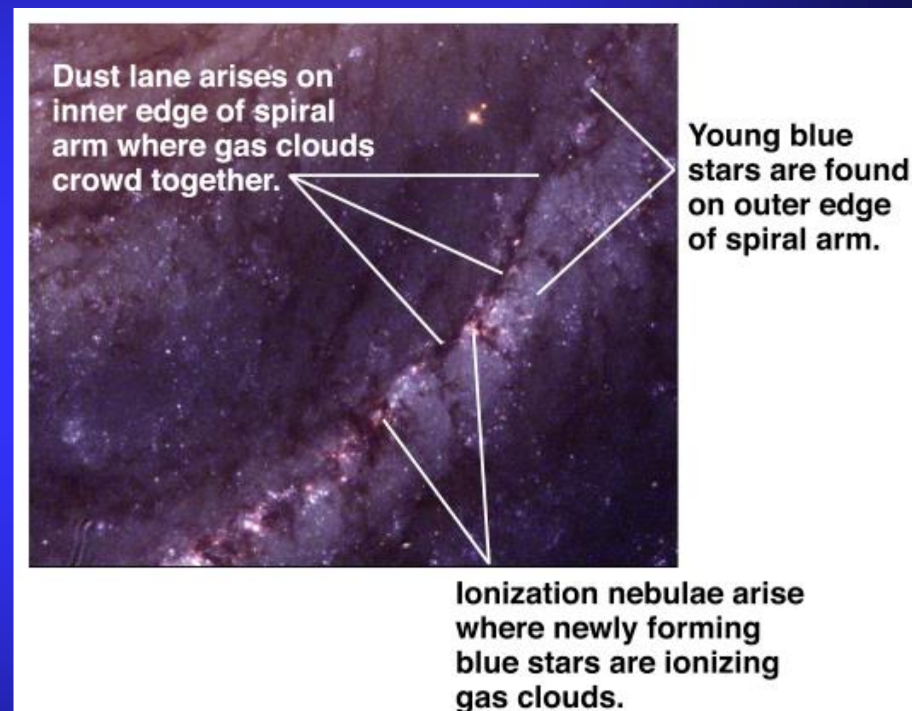
Evolution of Galactic Halos
Transfer of Matter and Energy in Galaxies
O VI
Cooling, Recombining Gas
Hot (10^6 K) Expanding Gas
High Velocity Clouds
SN Explosion
Disk Gas
Halo Gas
Magellanic Clouds
Infalling Clouds
K. Sembach

W3



Spiral Arms

Spiral arms are density waves



The density waves move faster than the disk spins