Astronomy 150: Killer Skies
Lecture 33, April 16

Guest Lecturer today!

- Prof. Robert Brunner, expert on galaxies!

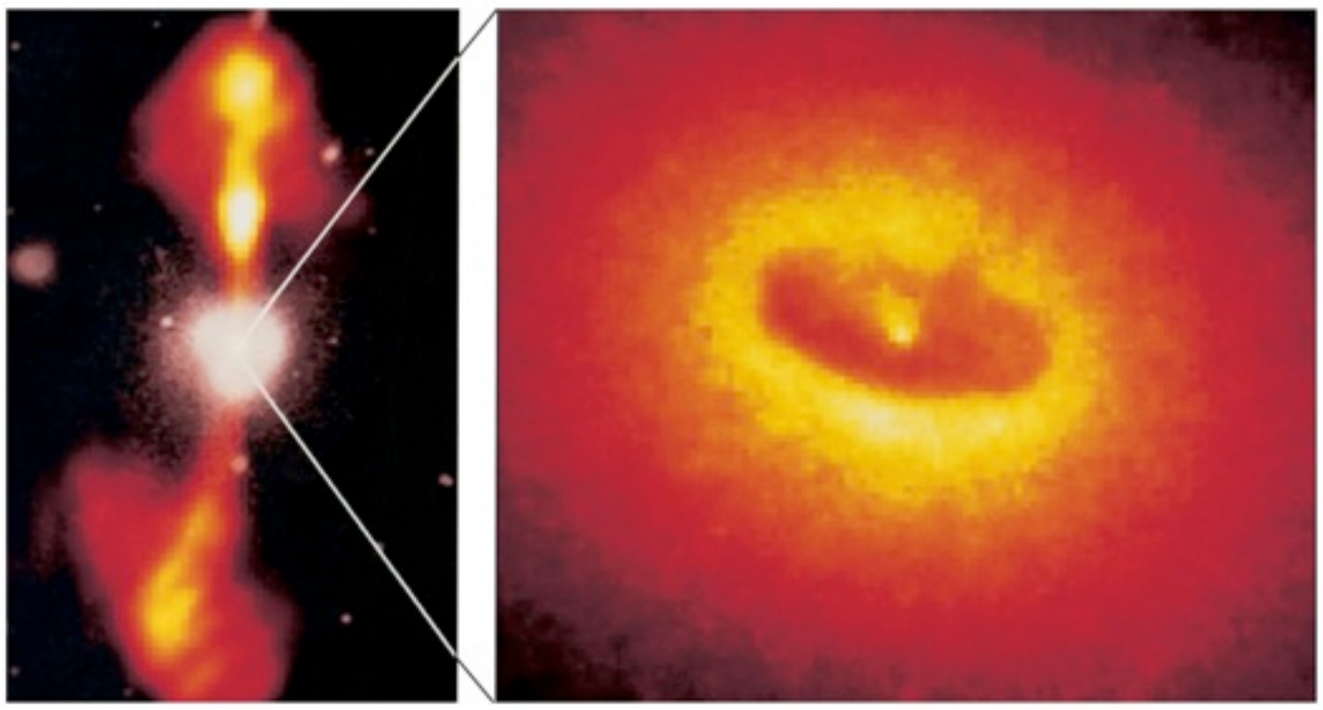
Assignments:

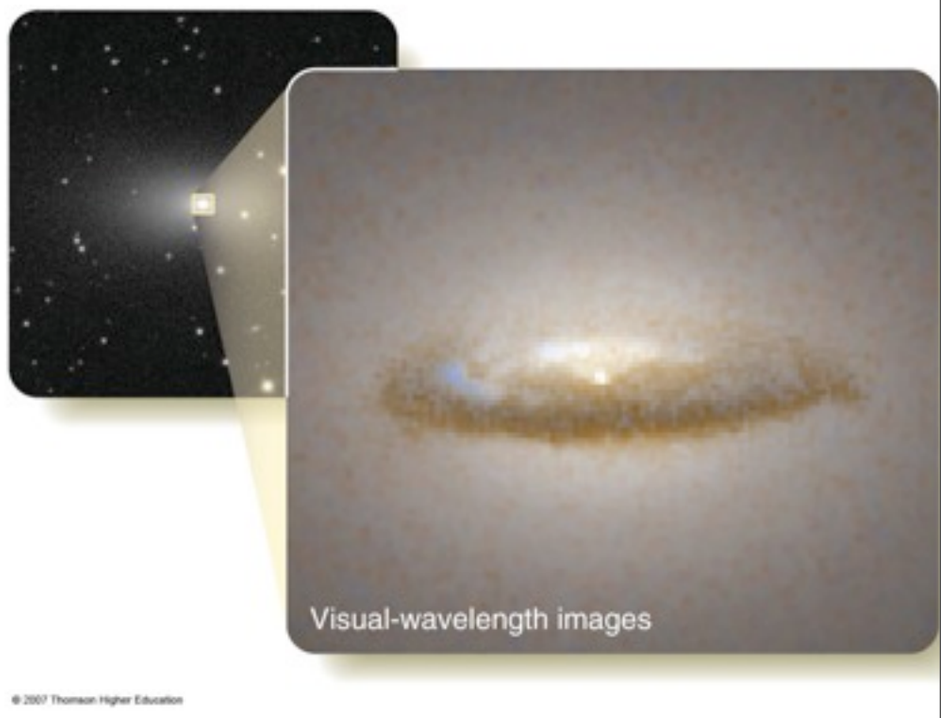
- HW10 due Friday
- Computer Lab 2 also due Friday
- so you can work on this: no lecture on Wednesday!

  see you again on Friday

Last time: Cosmic Blowtorches

Today: Our Milky Way Galaxy





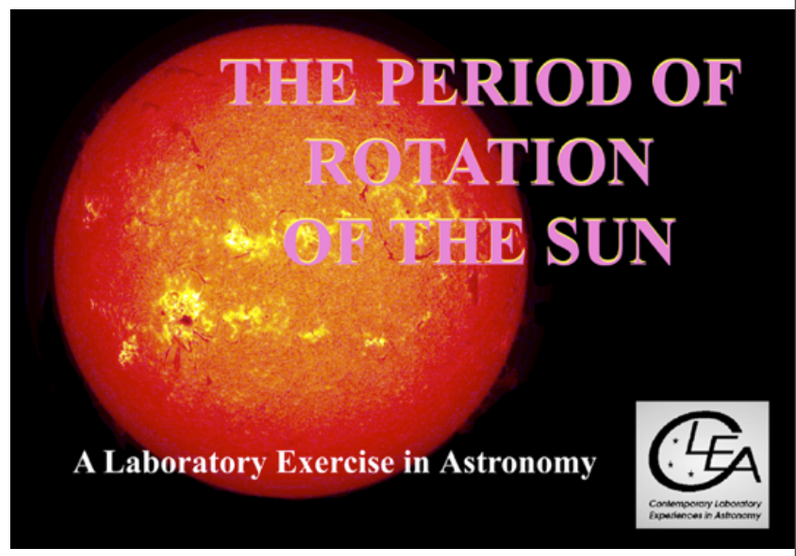
Computer Lab 2

Another chance to analyze real research-grade data and draw conclusions about the cosmos

You can choose one of two:

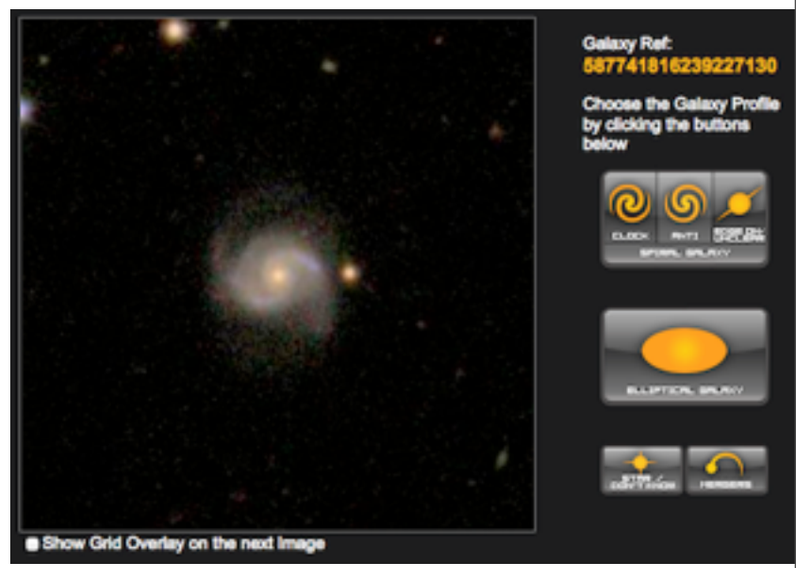
- Solar Rotation
- Galaxy Zoo

details on course website



"Second Chance": If you do both labs then

- higher score will count as your Lab 2 score
  - graded out of 100, counts for 50 points out of 1000 on final grade
- lower score will replace up to 20 points on final grade total for one low Homework, Observing, or Lab 1 score
  - not "extra" points on final point total, only replaces one existing low score
- in practice: maybe worth doing if you have any of these
  - a homework score < 20 out of 20
  - a Lab 1 score < 40 out of 100
  - an Observing or Planetarium score < 20 out of 25



just so we are totally clear...

No lecture Wednesday!

Work on Computer Lab!

See you this Friday when the lab is due.

Recap: Our Milky Way Galaxy

Milky Way in sky (2D):

- irregular diffuse glow
- circles the celestial sphere
- most of MW light is from huge numbers of distant stars

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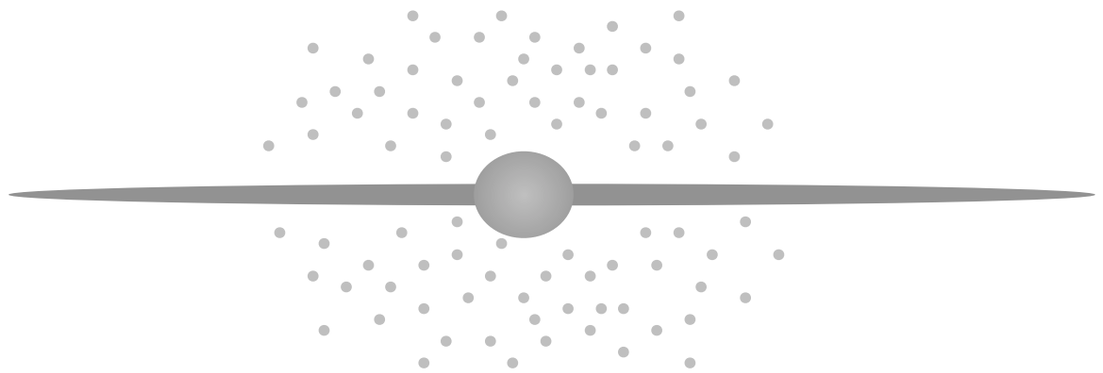

Milky Way disk: edge-on view

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- but: obscuring dust fills MW
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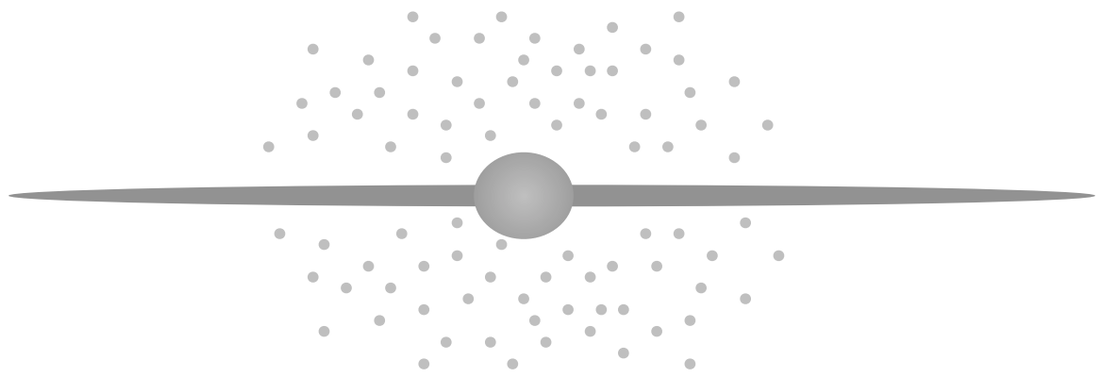

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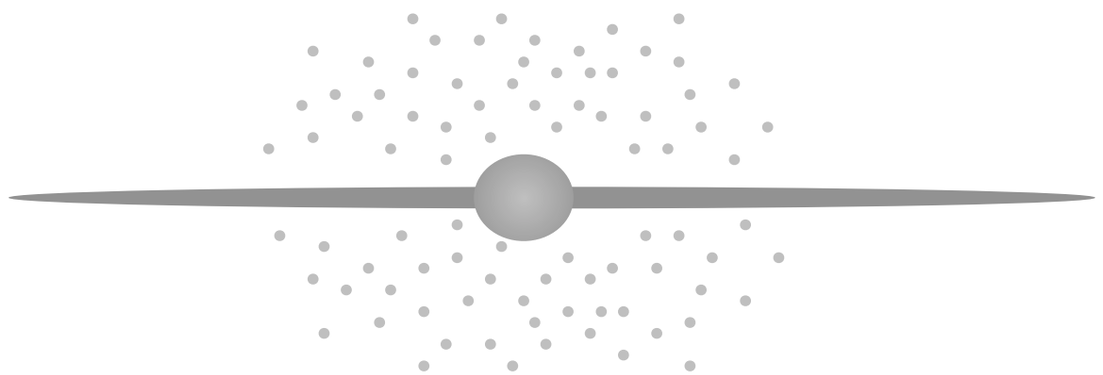
Result: we are off-center!

- we live in Milky Way suburbs!



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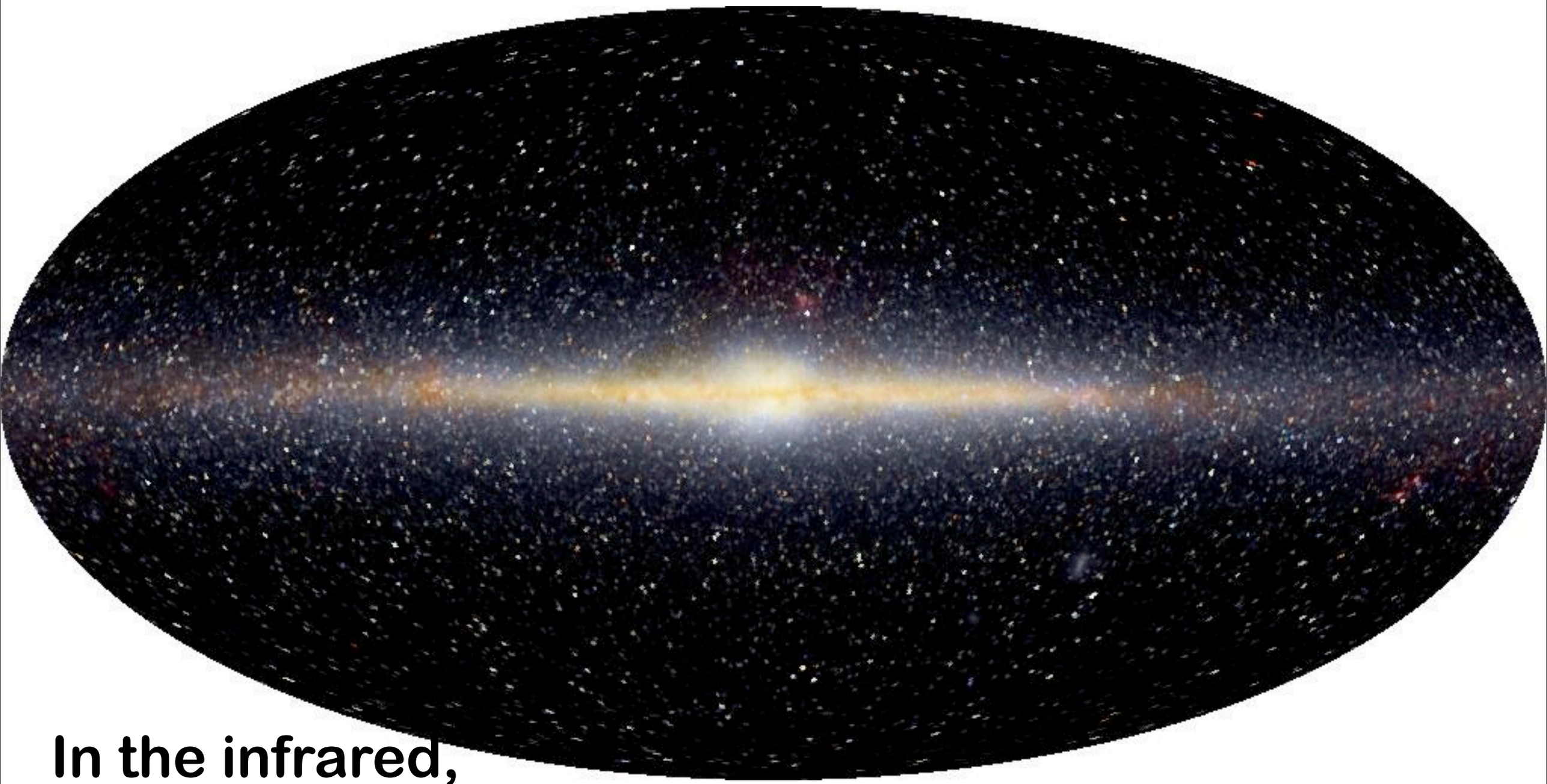

In the infrared,

can see through dust

http://antwrp.gsfc.nasa.gov/apod/image/0001/milkyway_cobe_big.jpg

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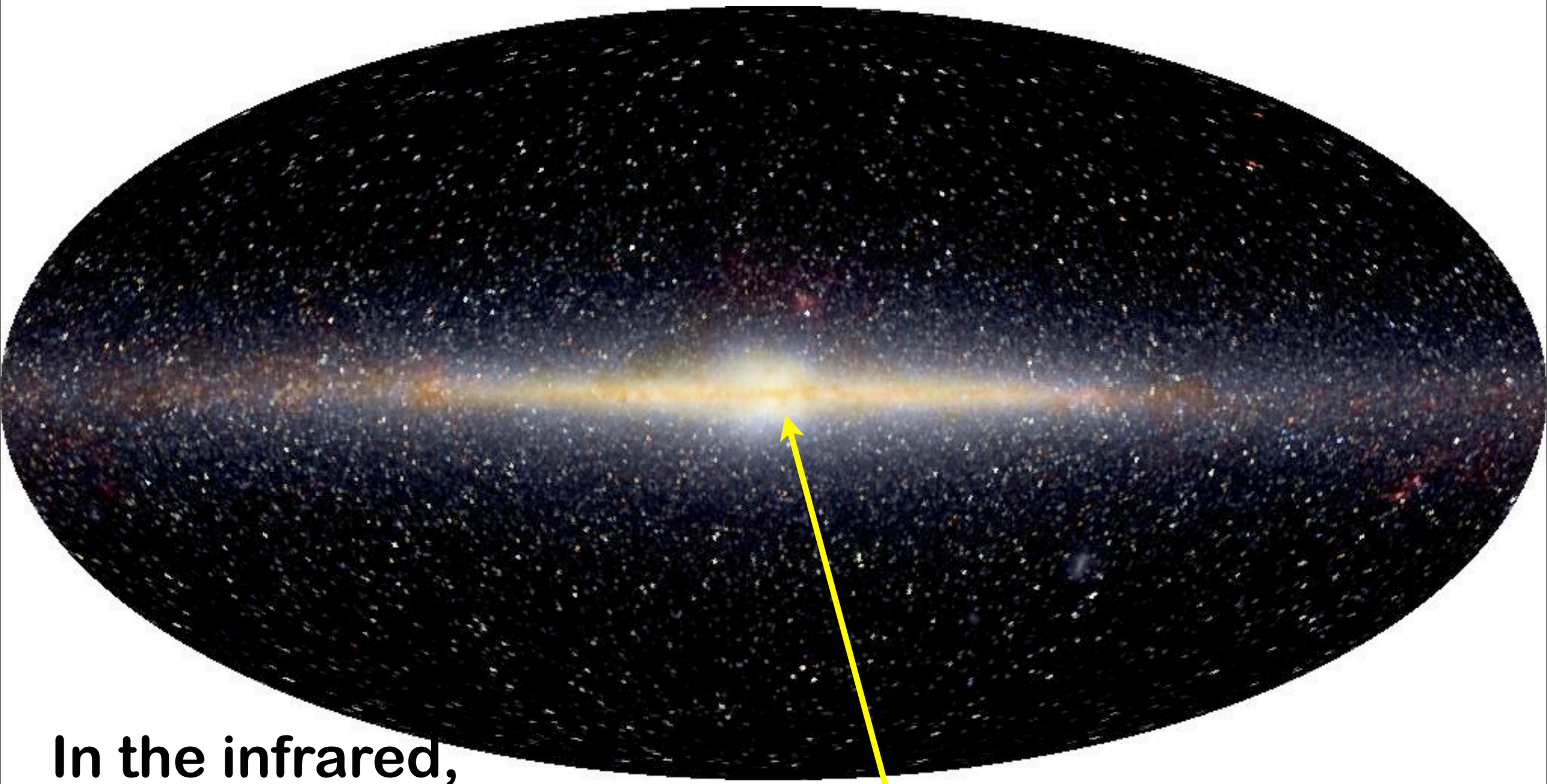

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Center of the Galaxy

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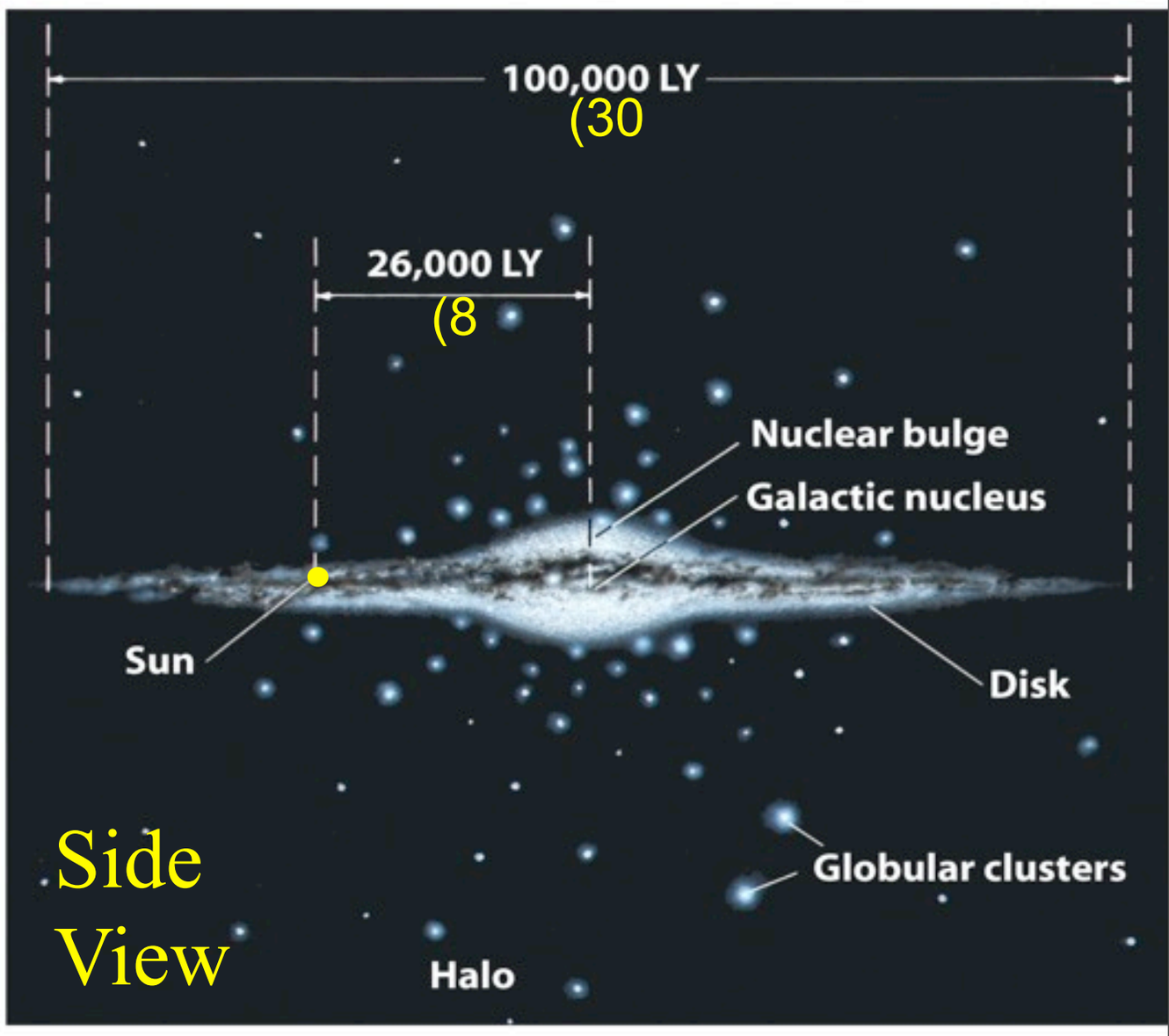
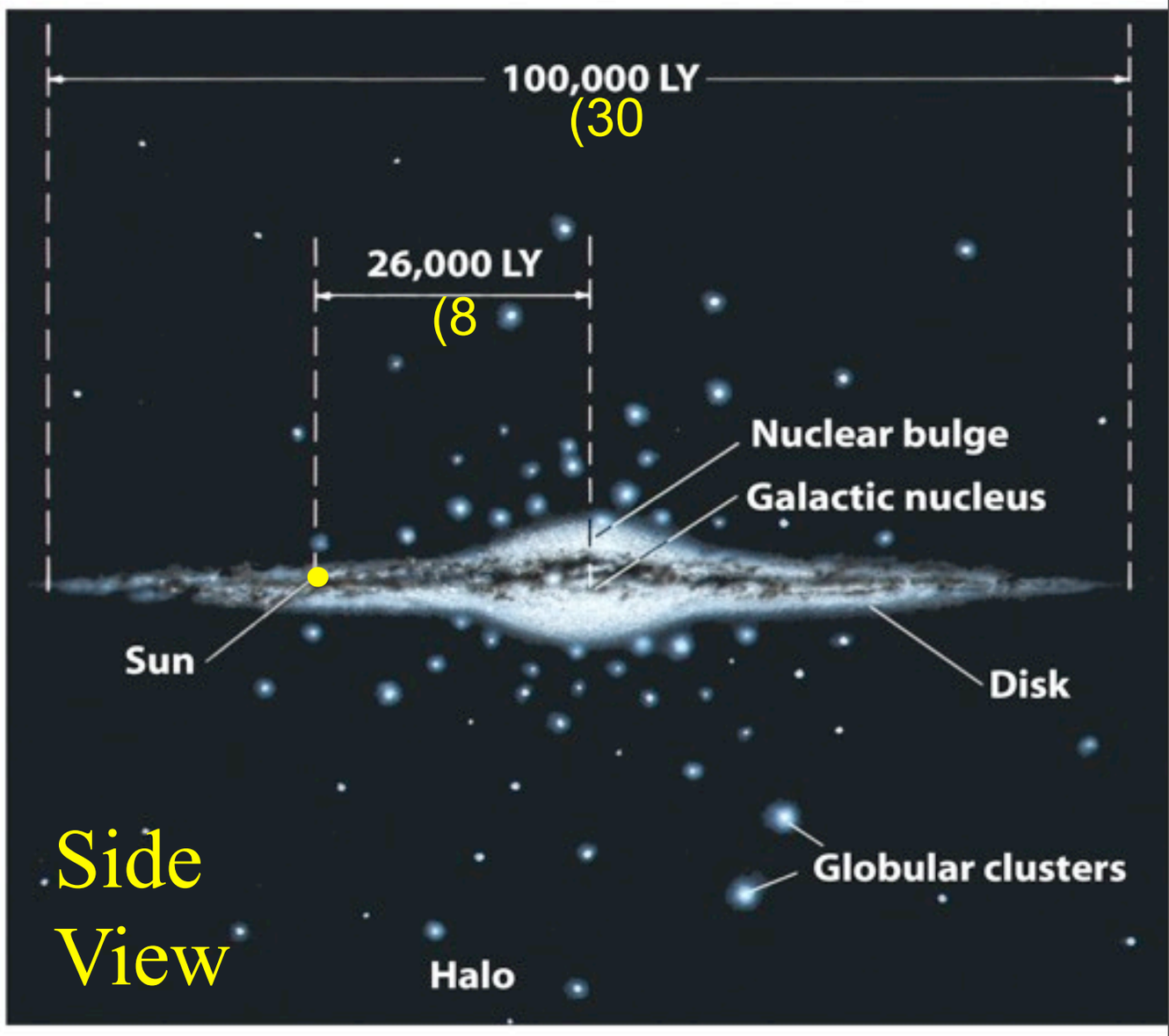
Our Galaxy

- Globular clusters– oldest stars



Our Galaxy

- Globular clusters– oldest stars
- Galactic nucleus– dense collection of stars (center of Galaxy)



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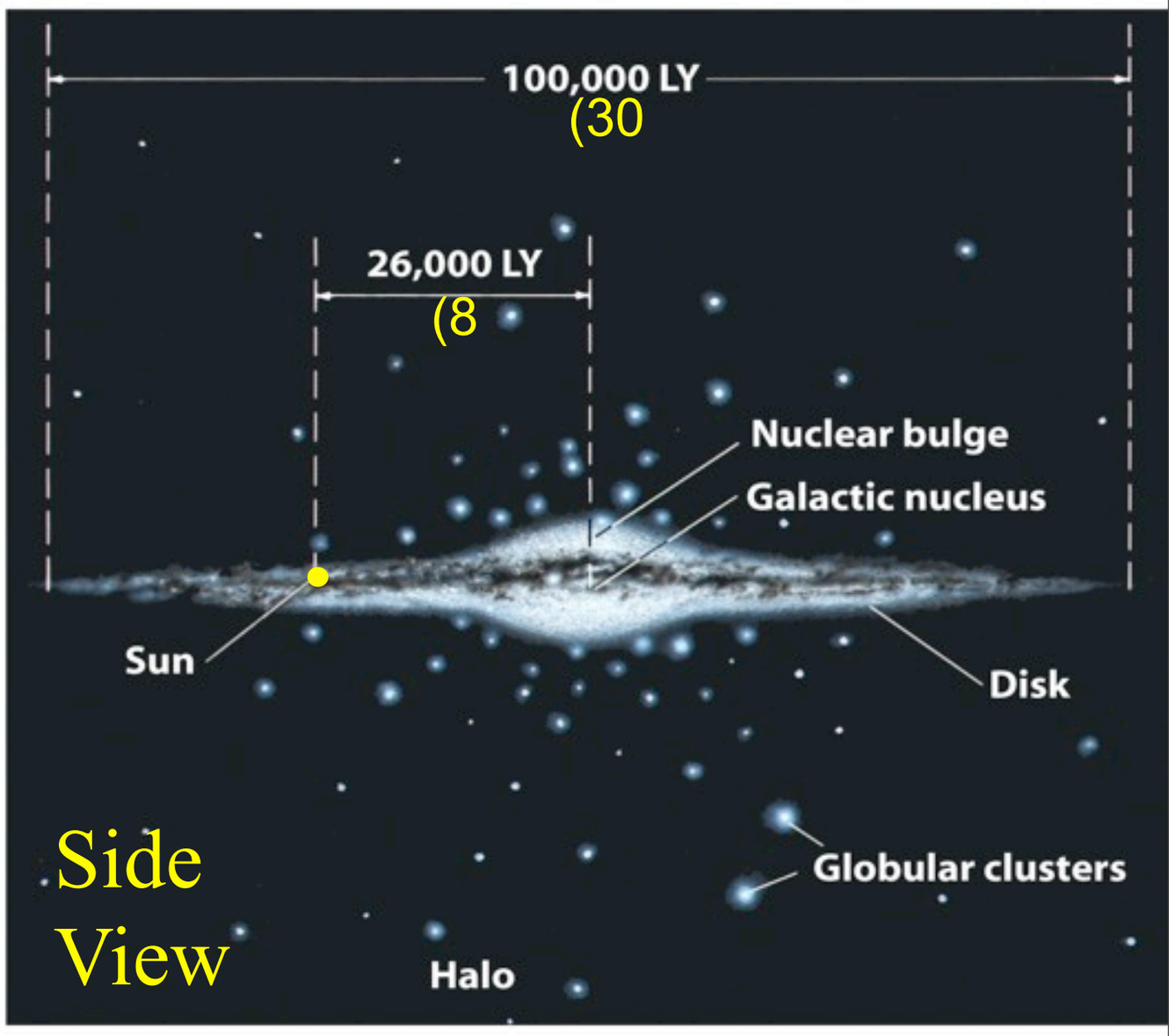

Side View

Our Galaxy

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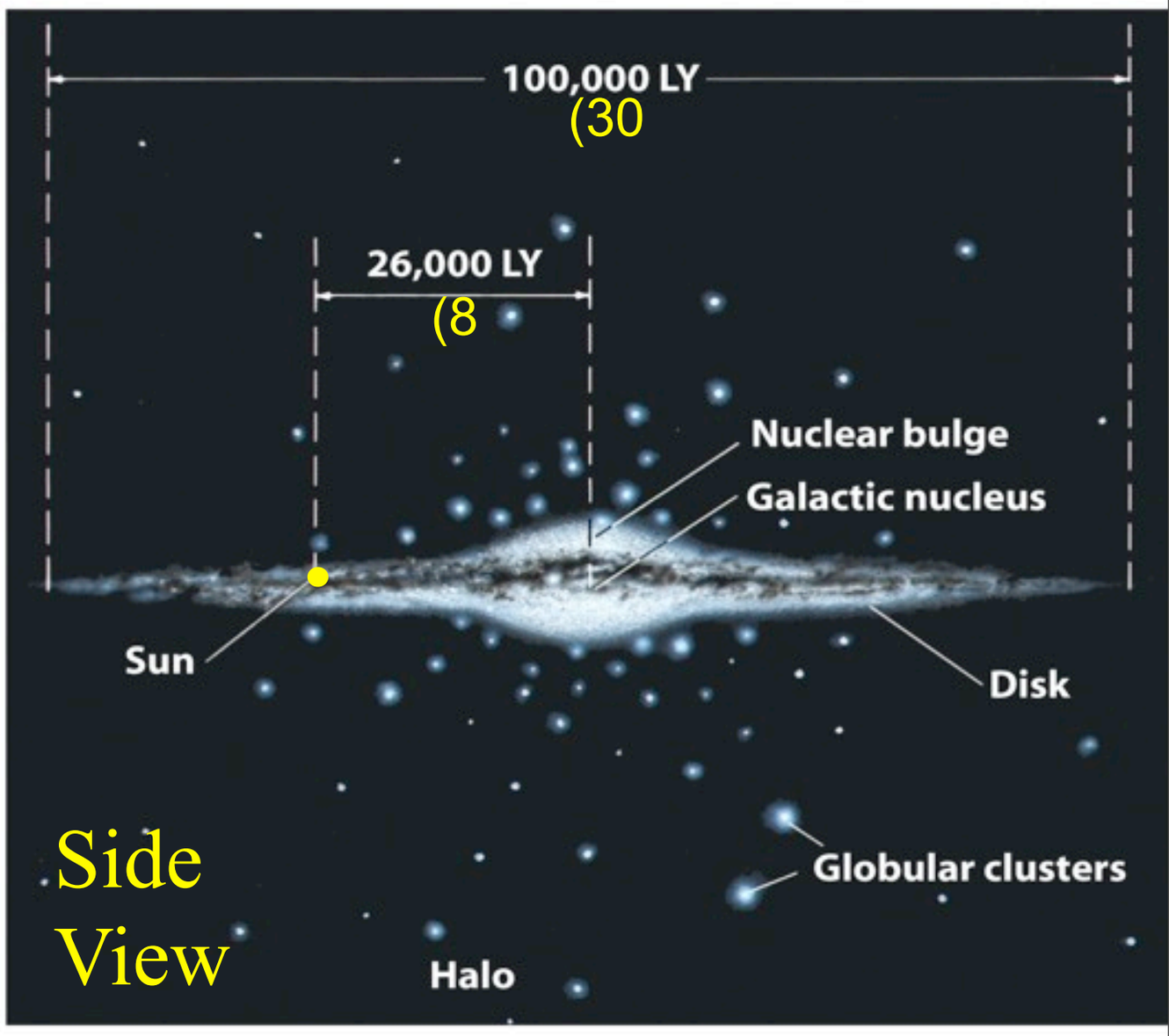
- Galactic nucleus– dense collection of stars (center of Galaxy)
- Nuclear bulge– mostly old stars, but very densely packed
- Spiral arms and the disk– mostly young stars and lots of dust



Our Galaxy

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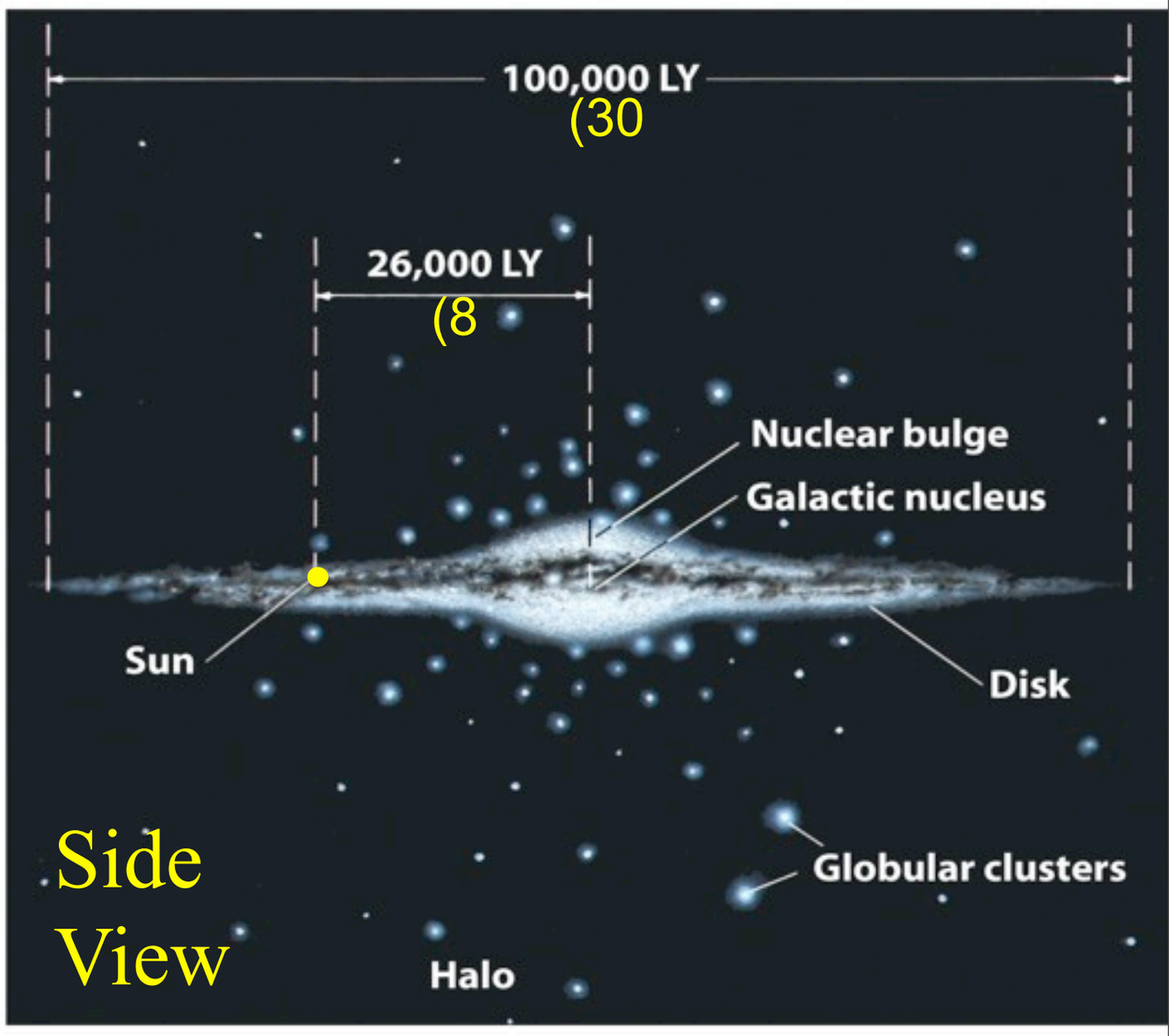
- Note position of the Sun, just over half way out.



The Disk

The disk of our Galaxy contains most of its visible mass

- 90% of the Galaxy's stars

It's where "the action" occurs

- Star formation, nebulae, etc..

Relatively thin

- 1,000 lyrs thick vs. 100,000 lyrs across

Spiral Arms?

Other disk galaxies show spiral arms

- Made massive stars, diffuse nebulae, and most of the giant molecular clouds

How do we know our Galaxy has them?

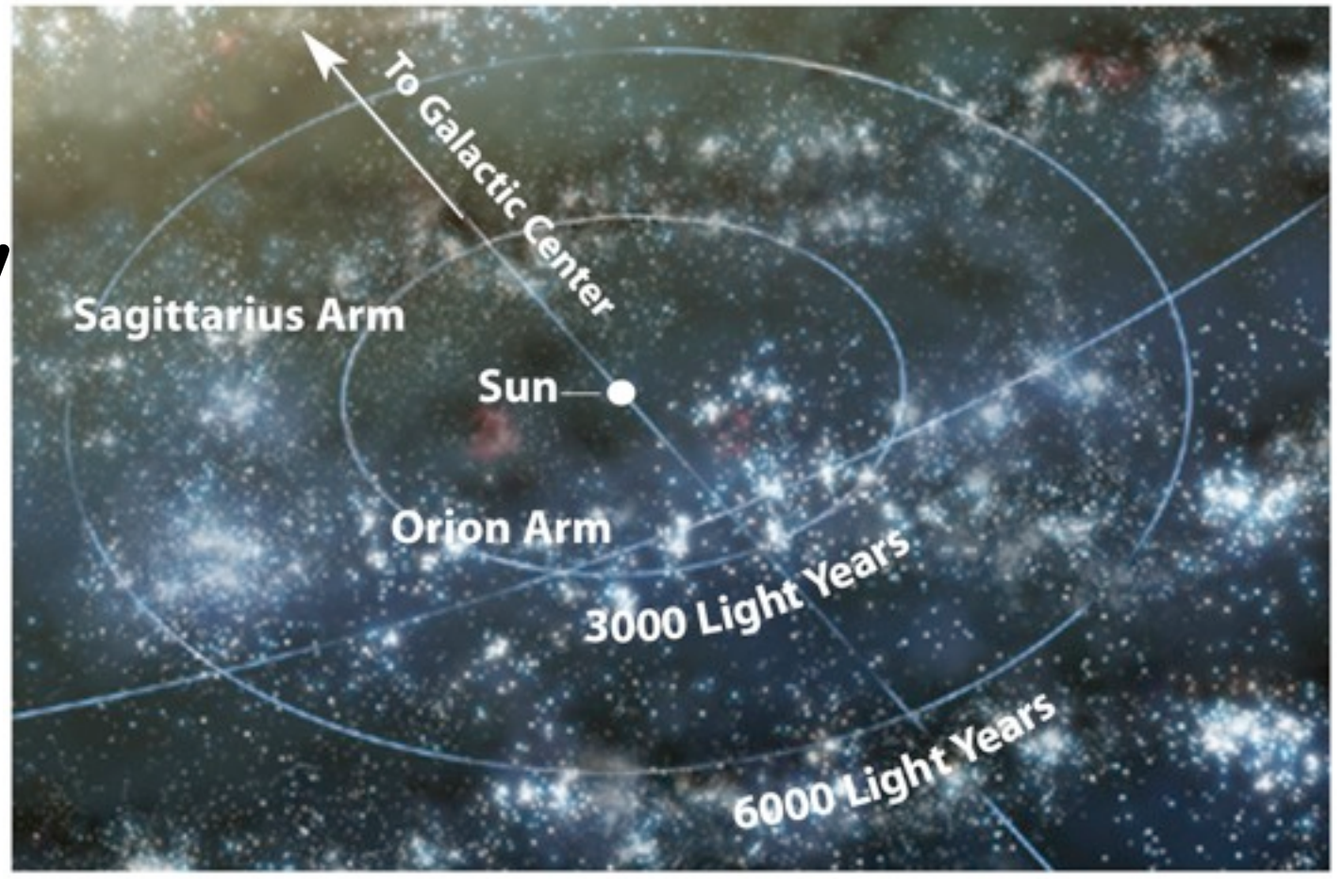
It's the problem of not seeing the forest for the trees

Hints of Spiral Arms

We plot the locations of nearby massive, bright stars in our Galaxy

Find the stars are arranged in arms

Our Sun is in-between spiral arms



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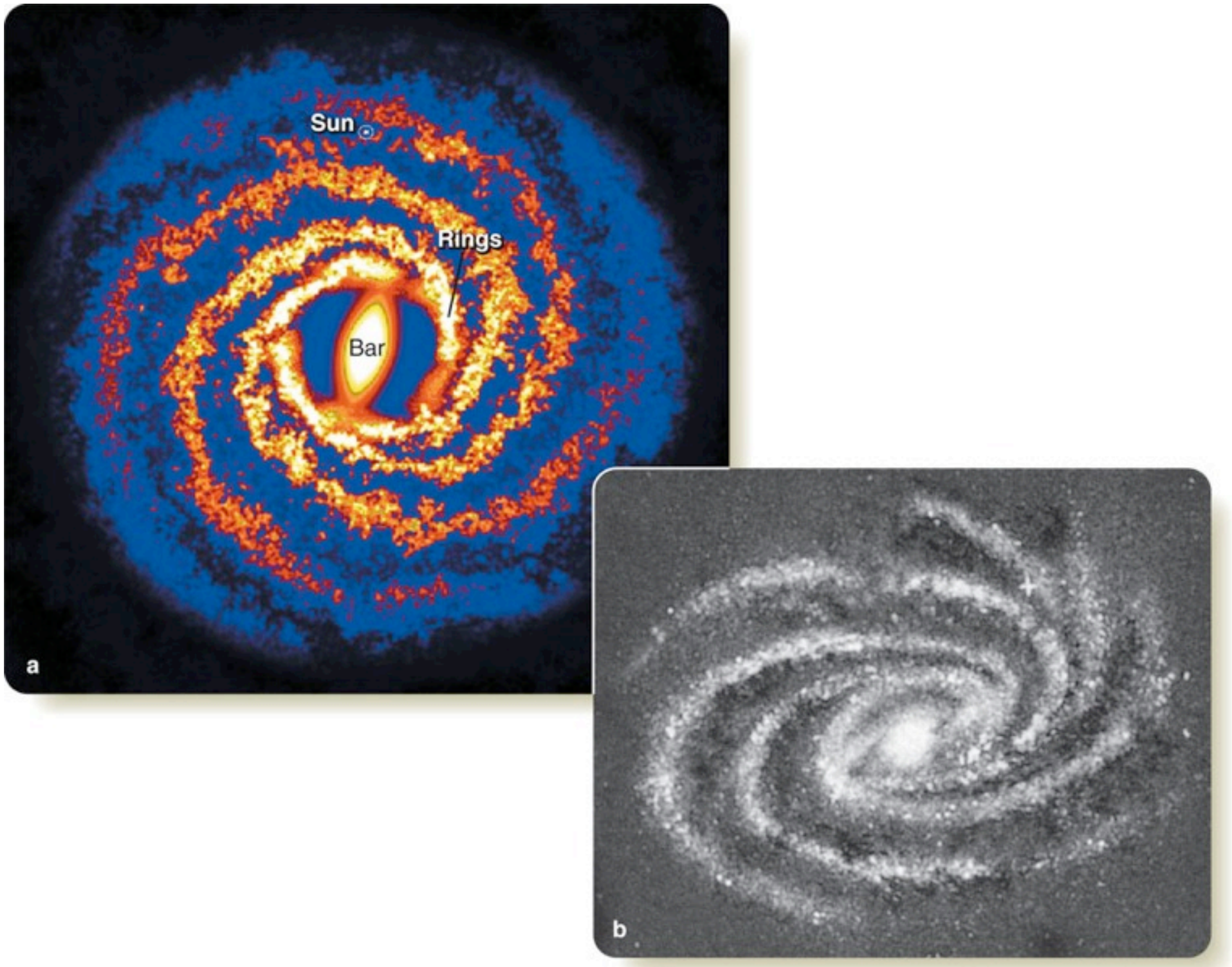

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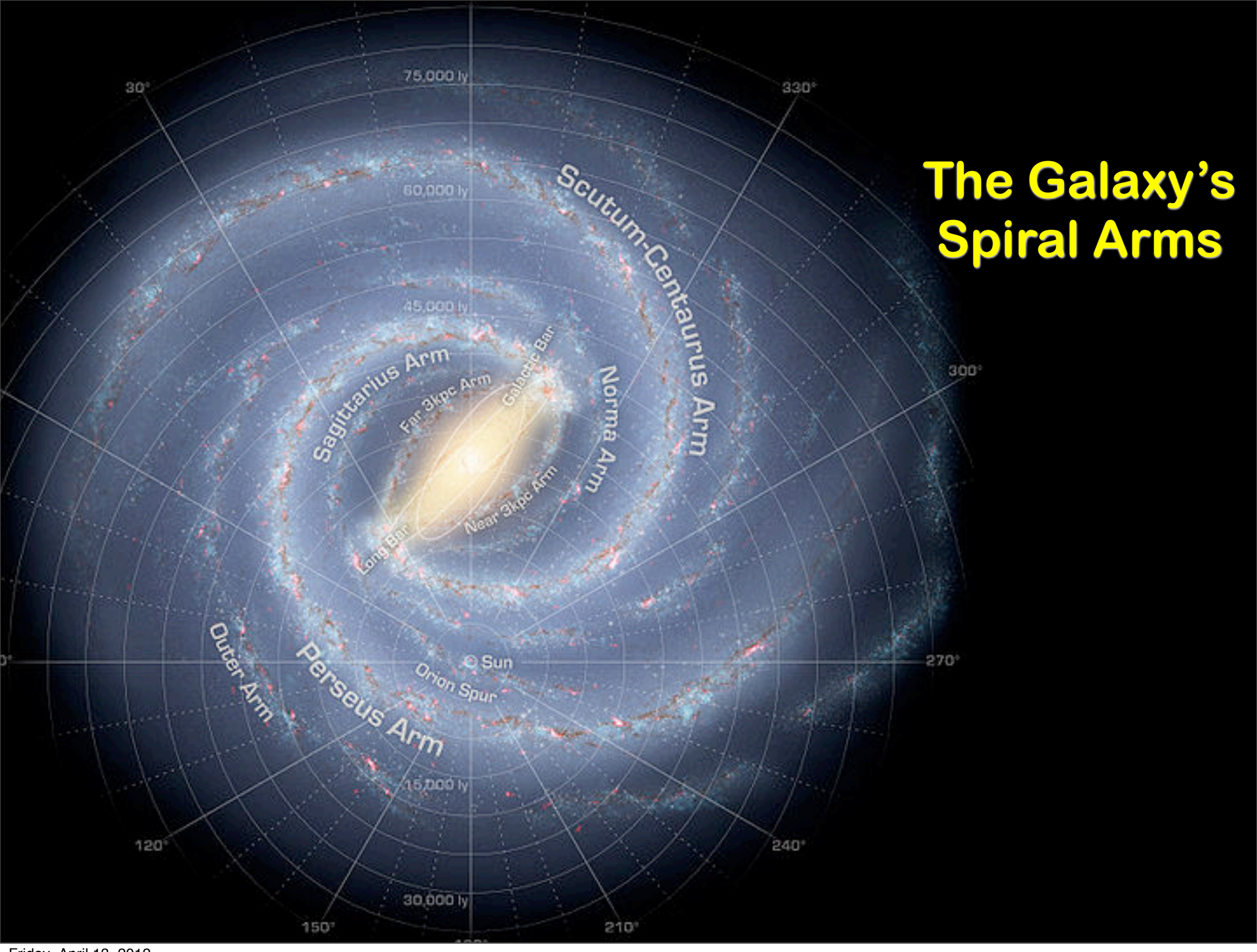

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But what is the pattern of motion?

Do Galaxies Spin?

Spiral galaxies really suggest it. Our Galaxy probably looks more like the right galaxy.

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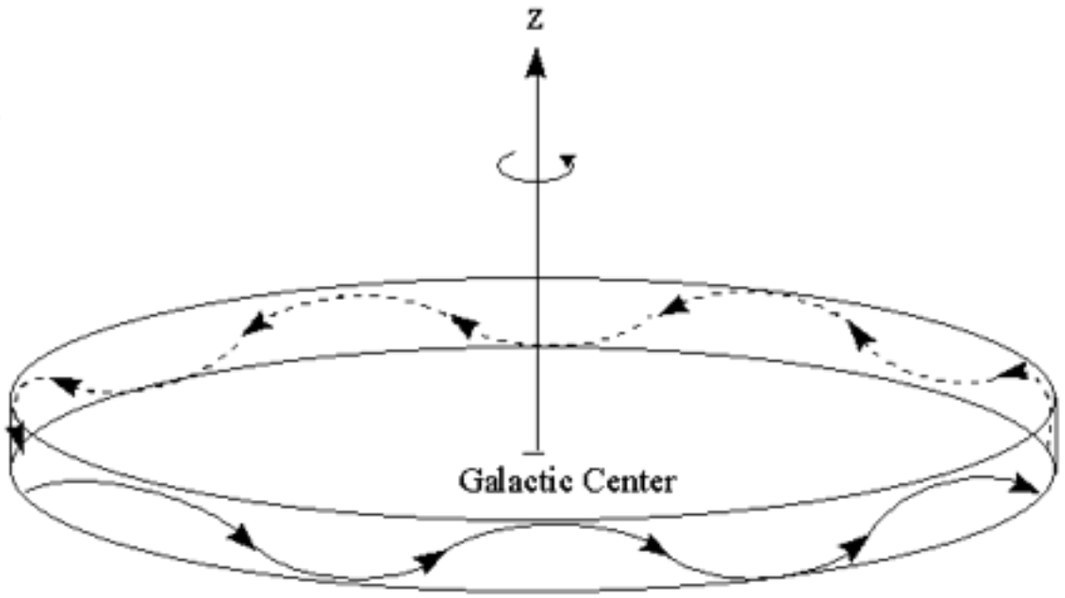
Rotation of the Galaxy

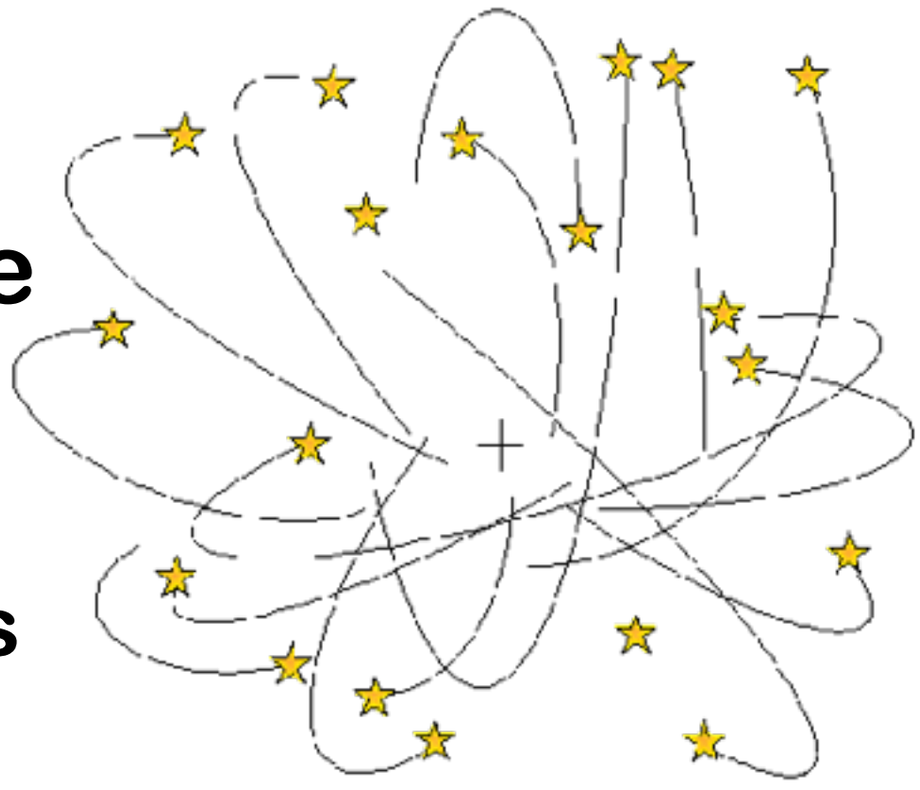
Stars in the disk all orbit the Galaxy in the same direction

- organized pattern
- Stay in the disk (they may bob up and down)
- Orbits roughly circular

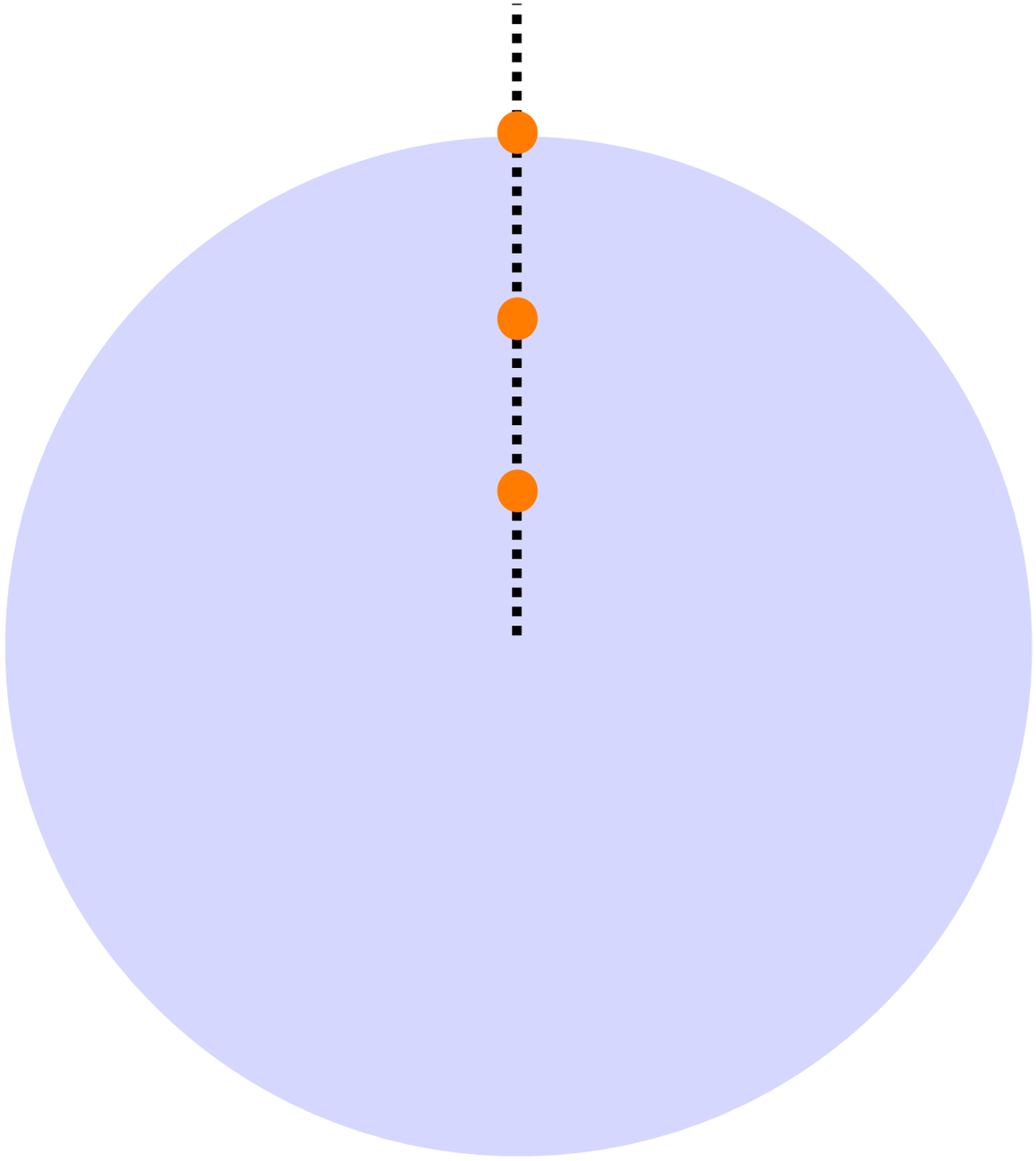


Stars in the halo and bulge orbit the Galactic nucleus randomly

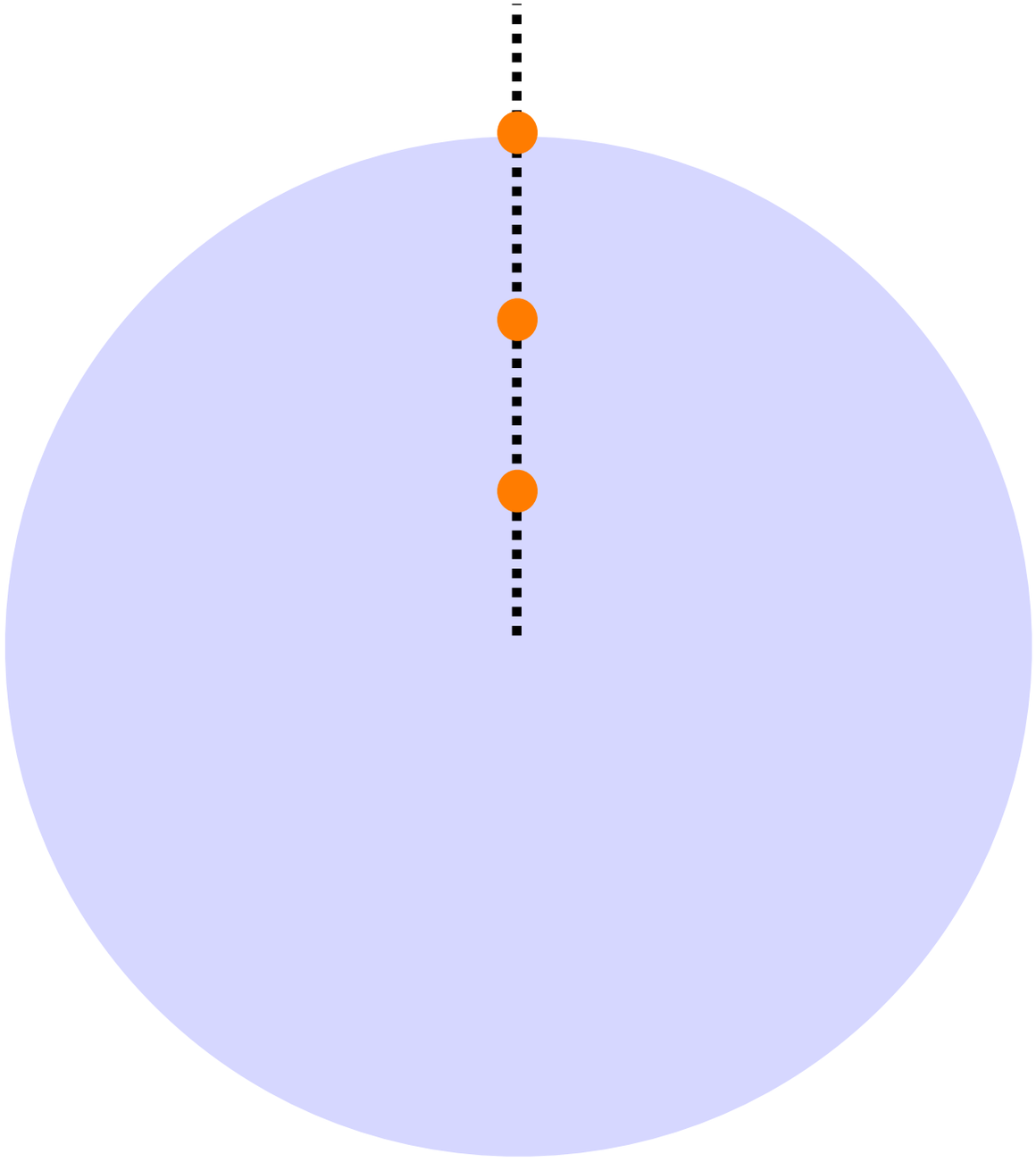
- No organization to the orbits
- Many very elliptical orbits
- collection of random orbit appears spherical



Solid vs. Differential Rotation



Same angular speed
(degrees per year)



Same linear speed
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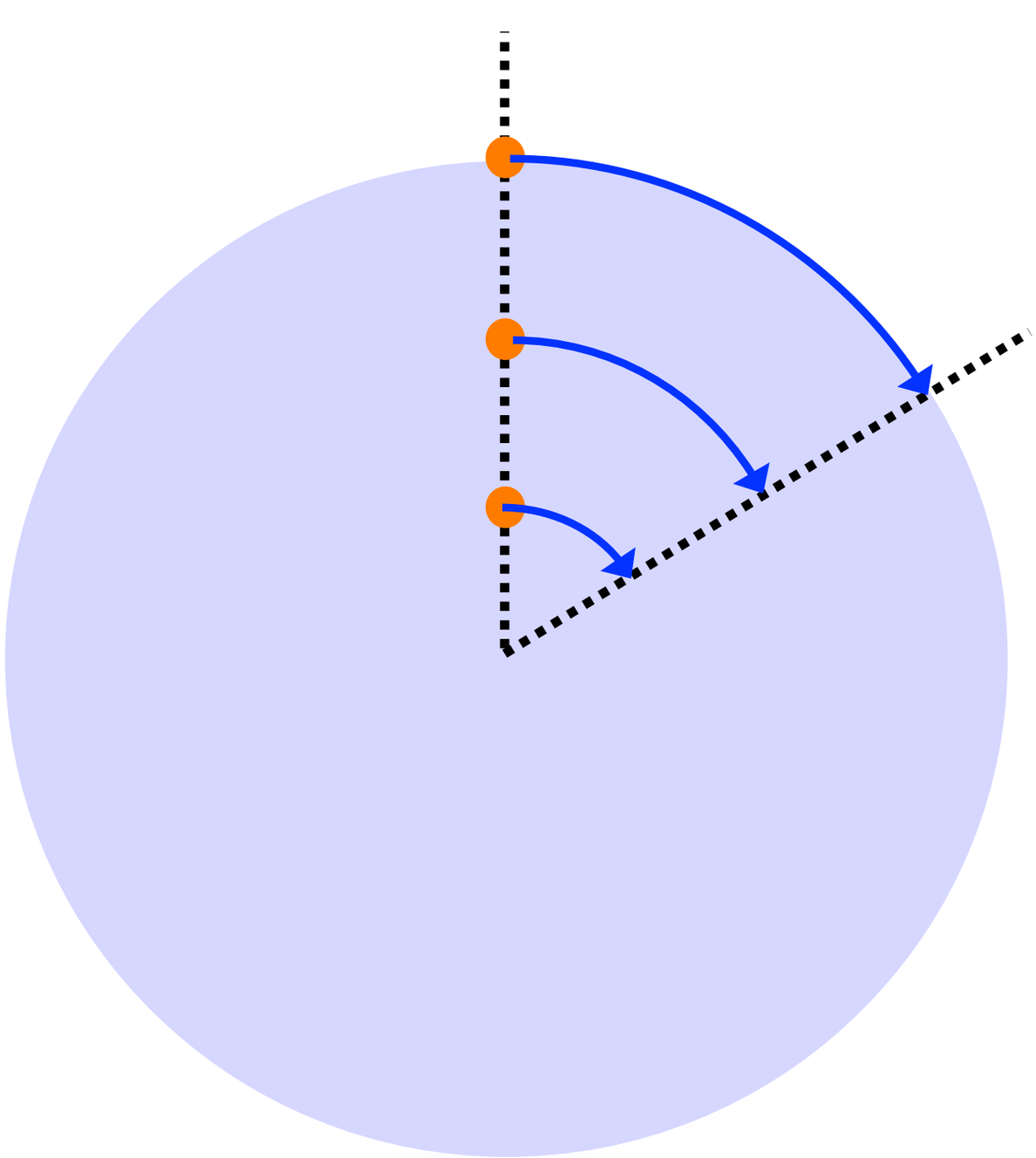

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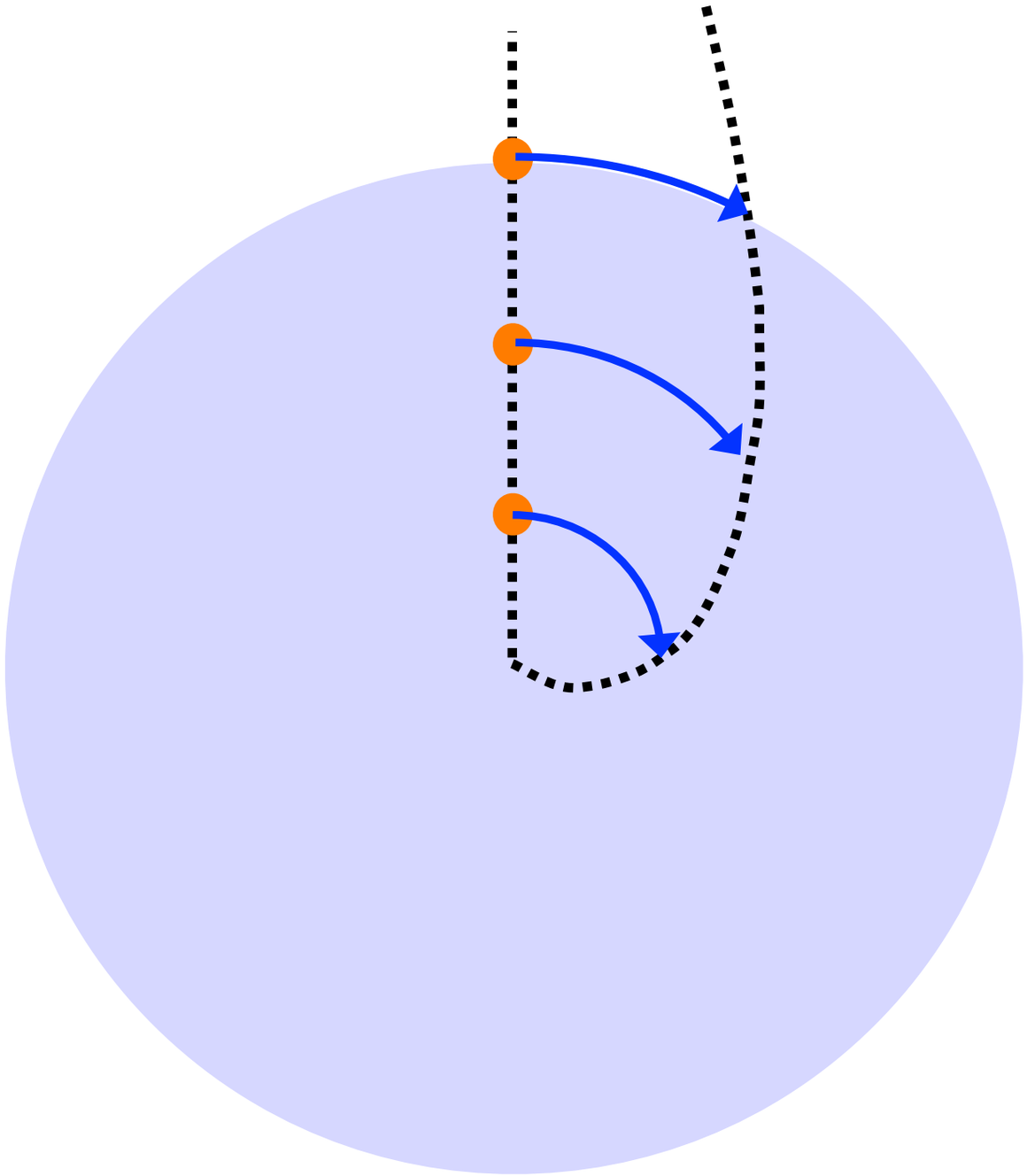

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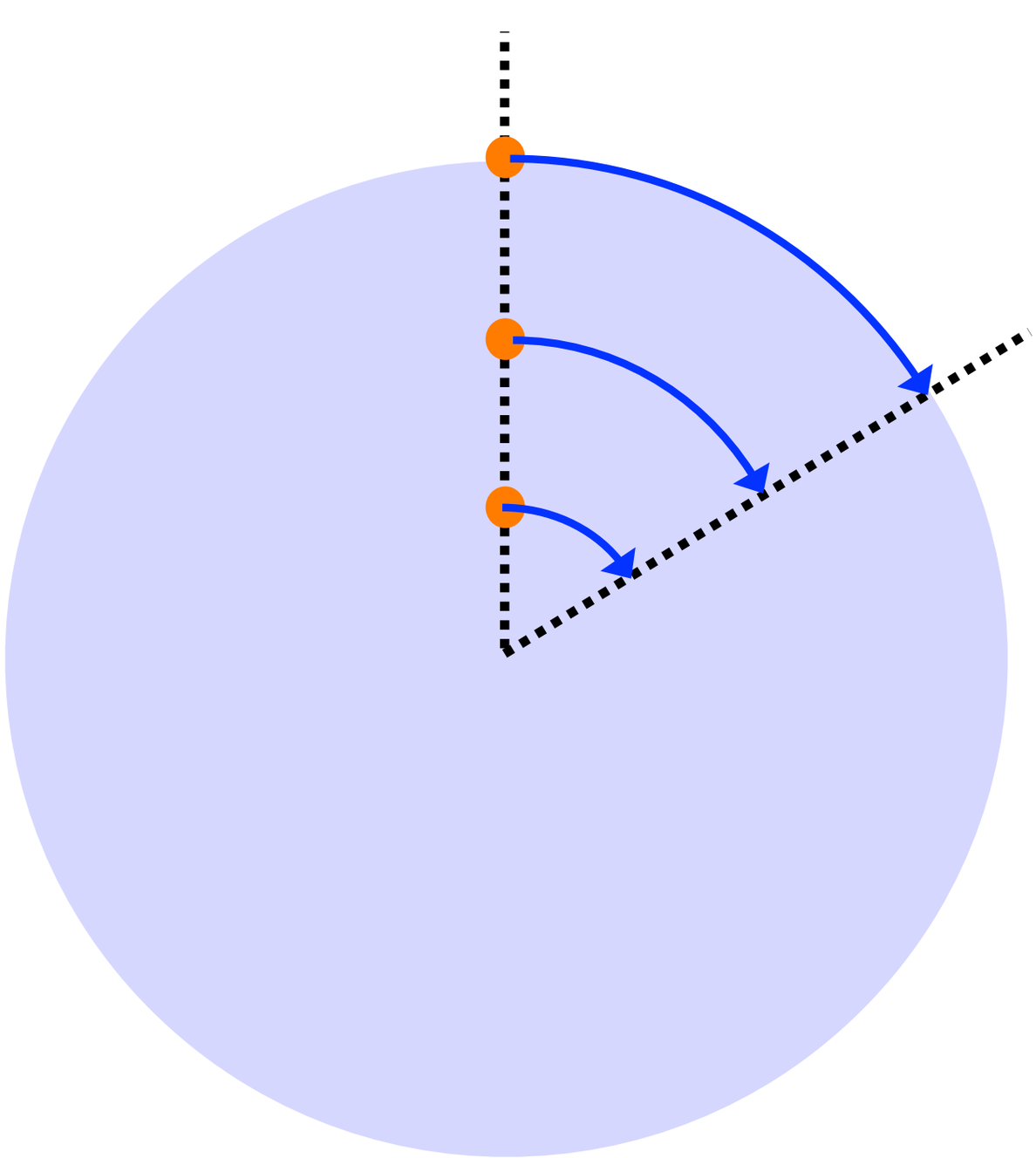

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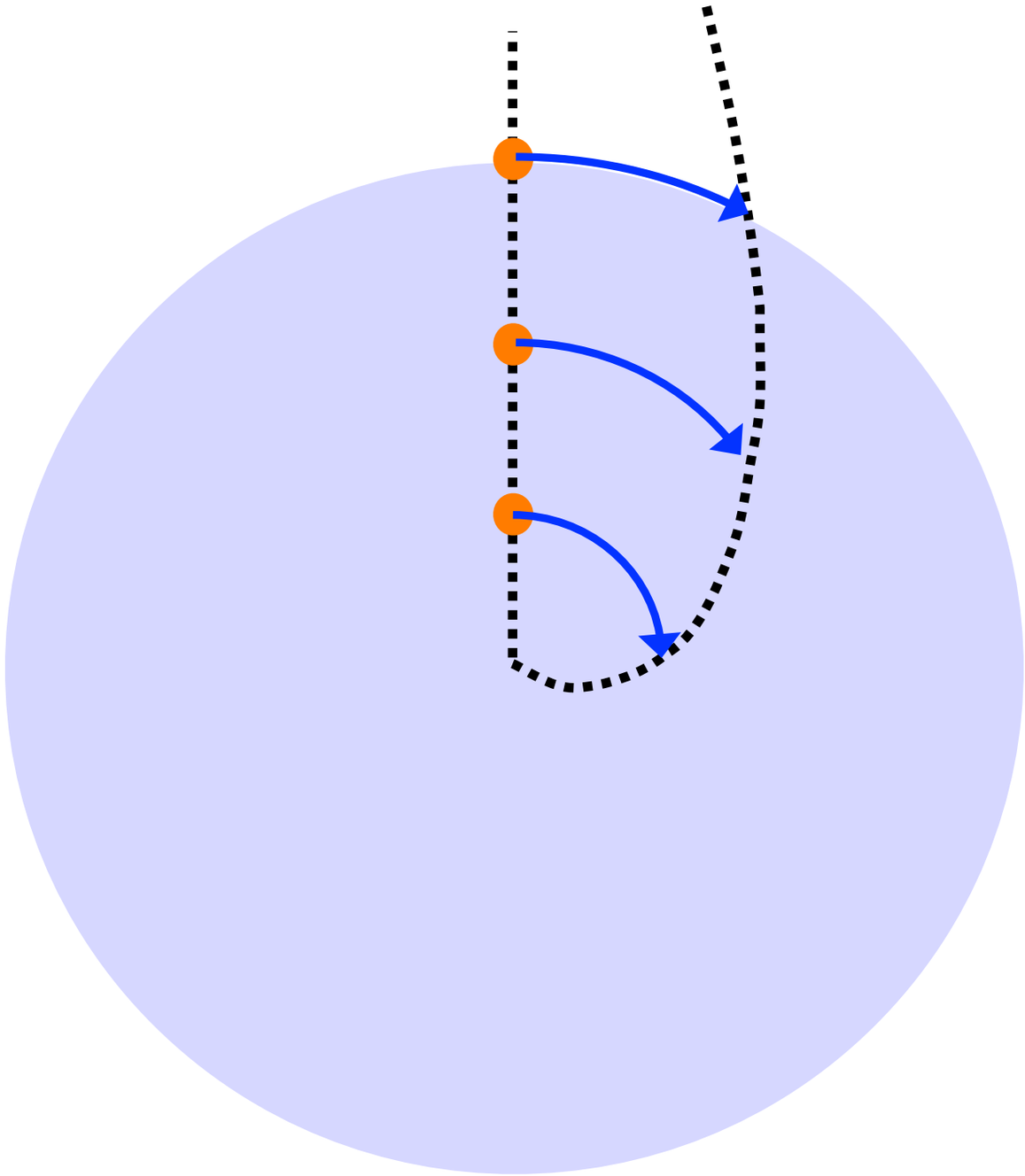

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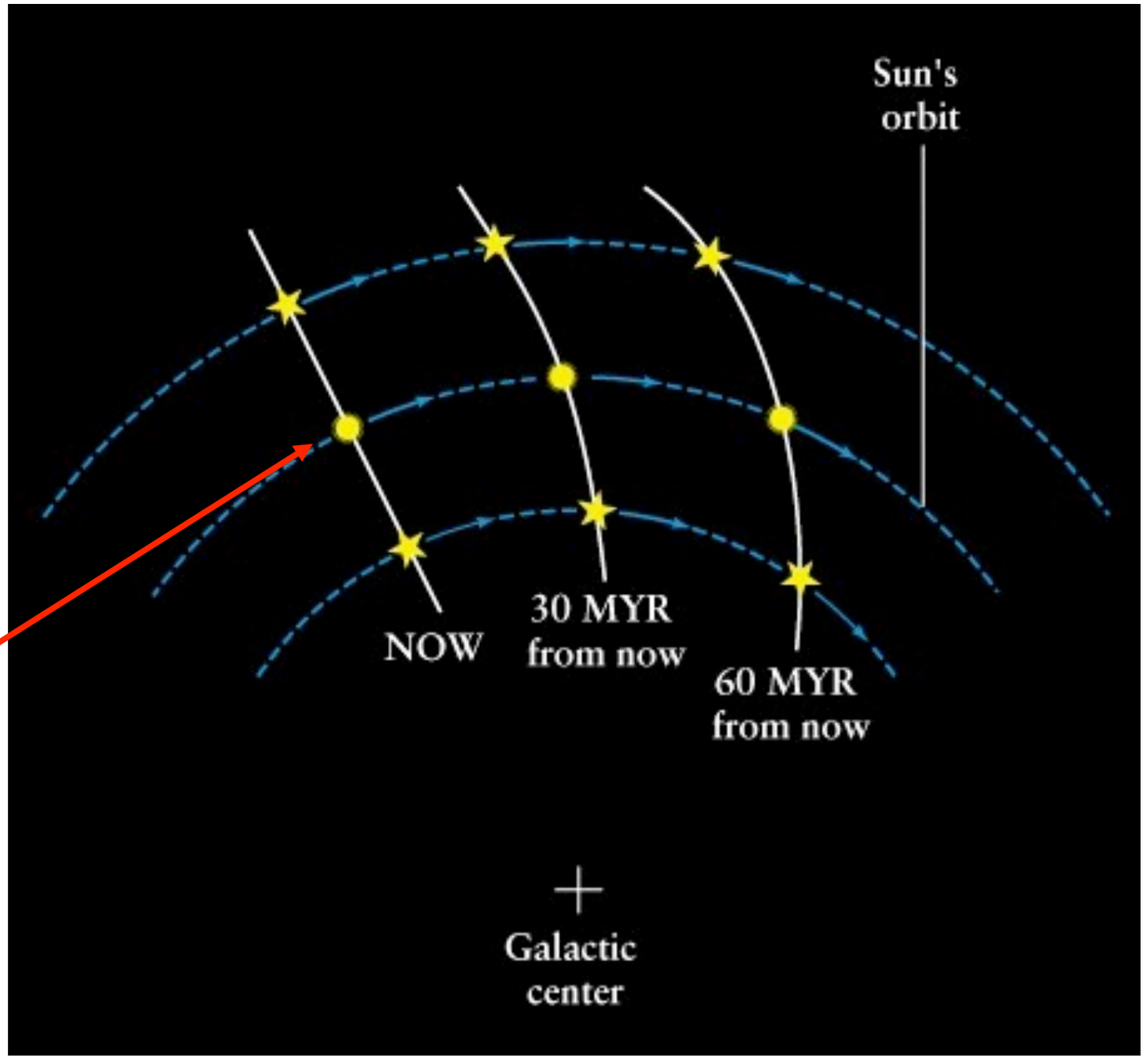
Is the Solar System Moving Too?

Yes… the whole Galaxy has differential rotation– us included



The Sun orbits at 220 km/s or about 500,000 mph– 230 million years per orbit!

Wow! That's fast!

Stop and think about it.

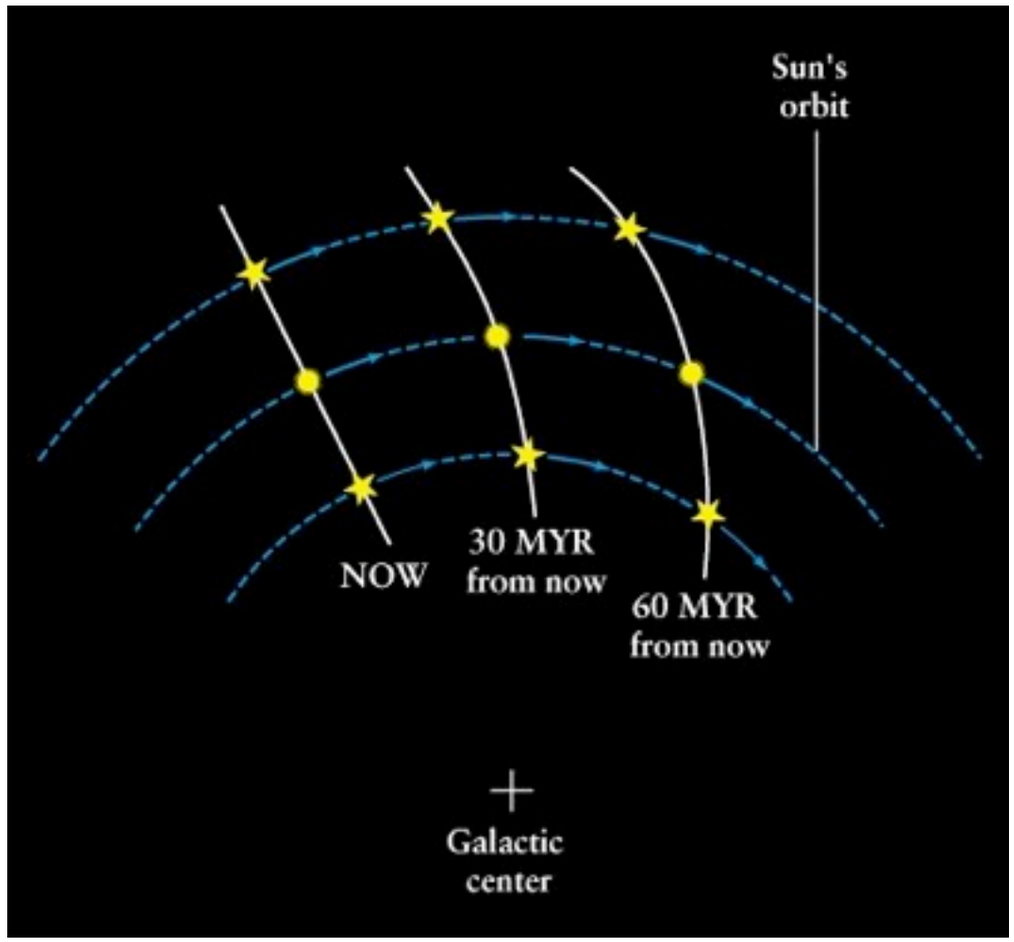
That's traveling to Chicago in 1 second!

But Milky Way is big!

Earth has only orbited 50 times!

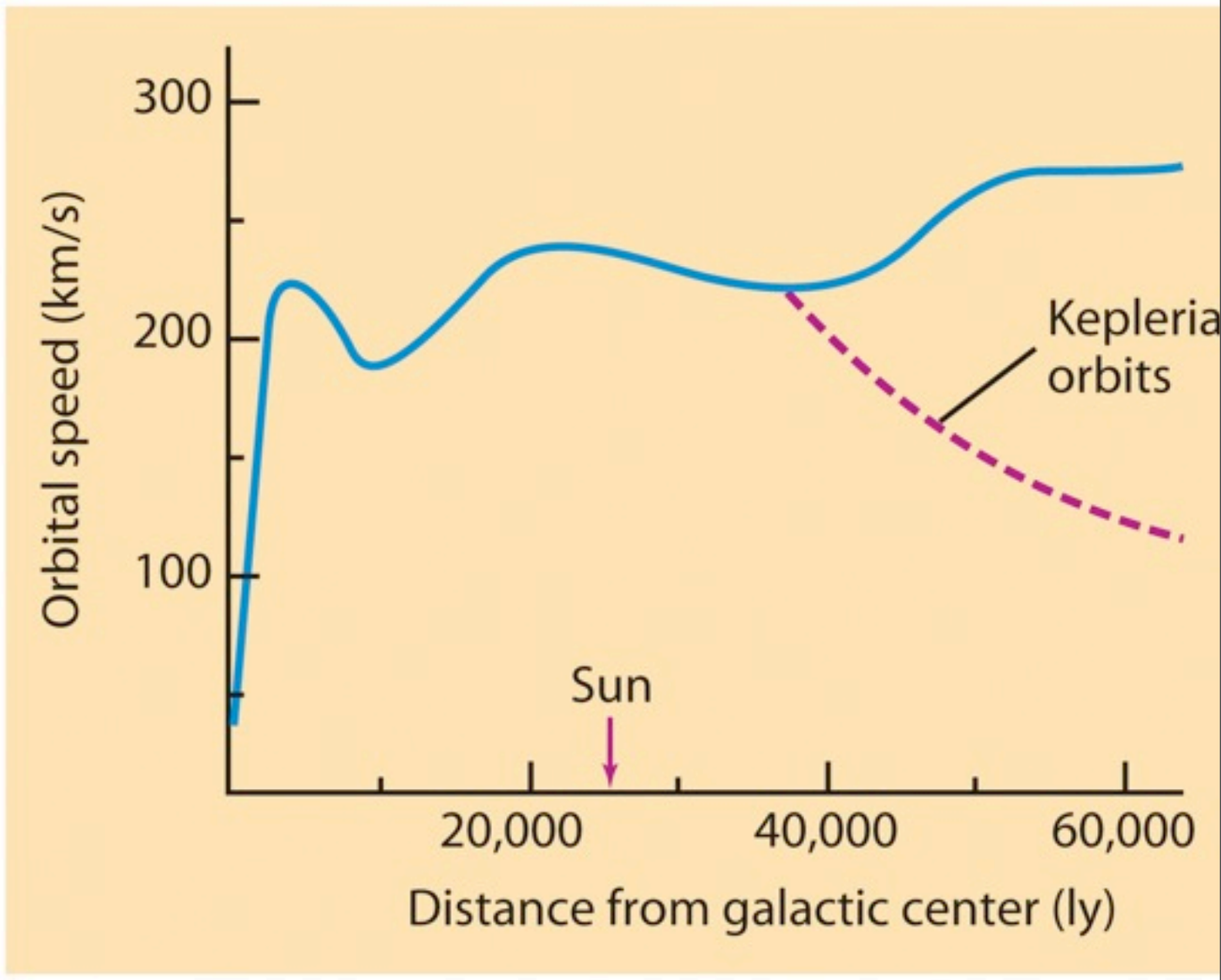
Last time the Sun was where at this spot in the Galaxy, the dinosaurs were just starting out.

¼ way around, they were extinct!



The Rotation of the Galaxy

Can measure rotation speeds at different distances from Milky Way center



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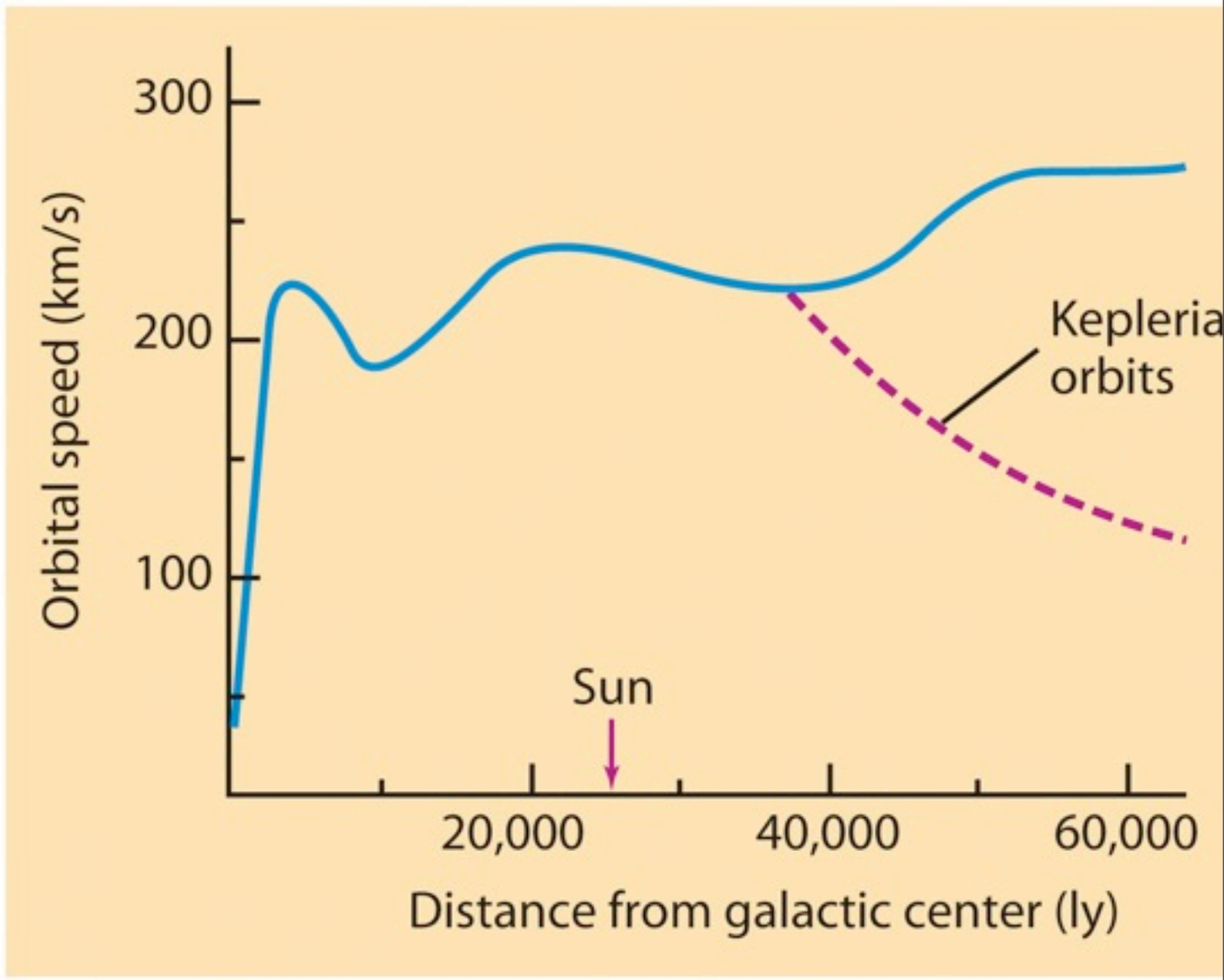

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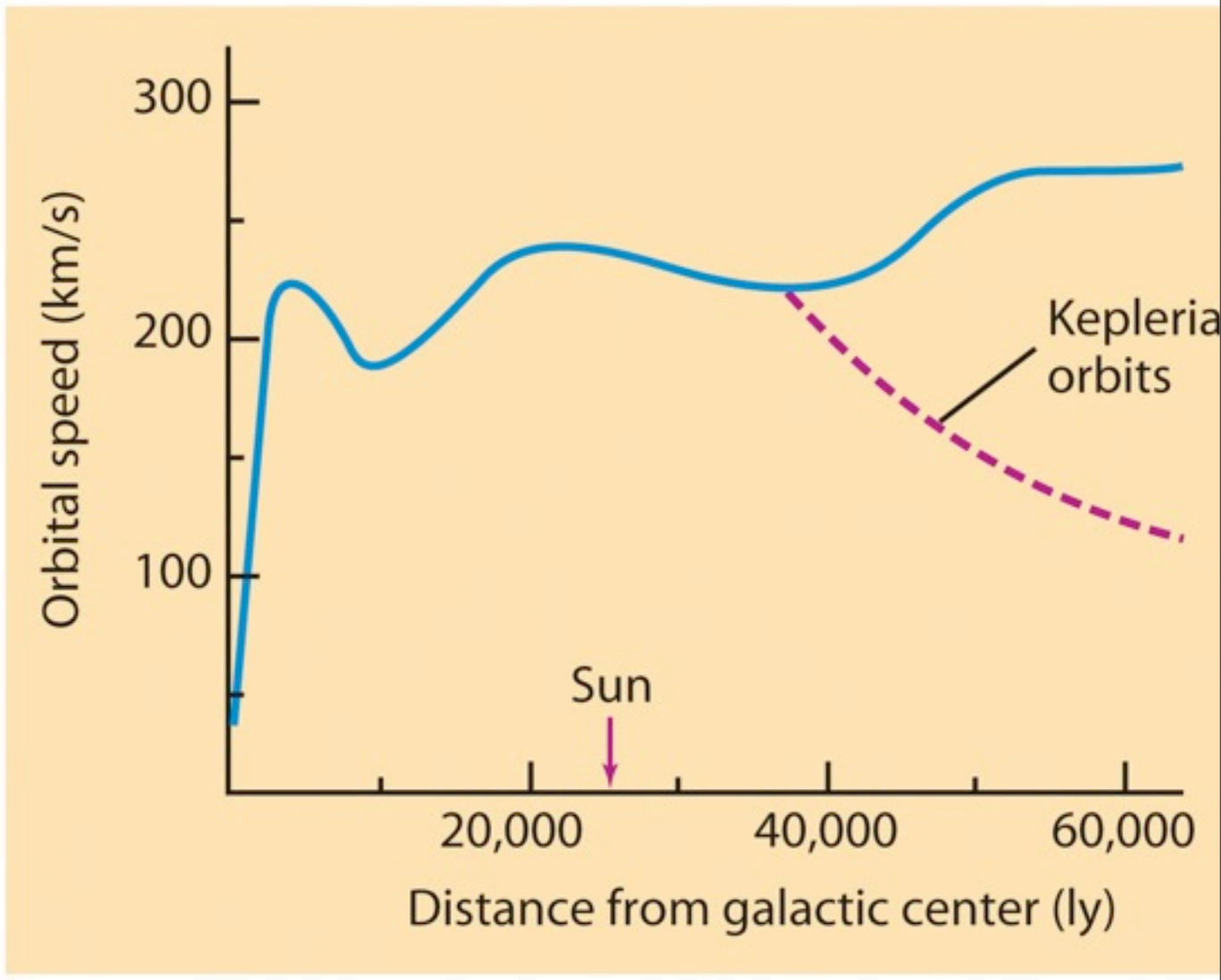

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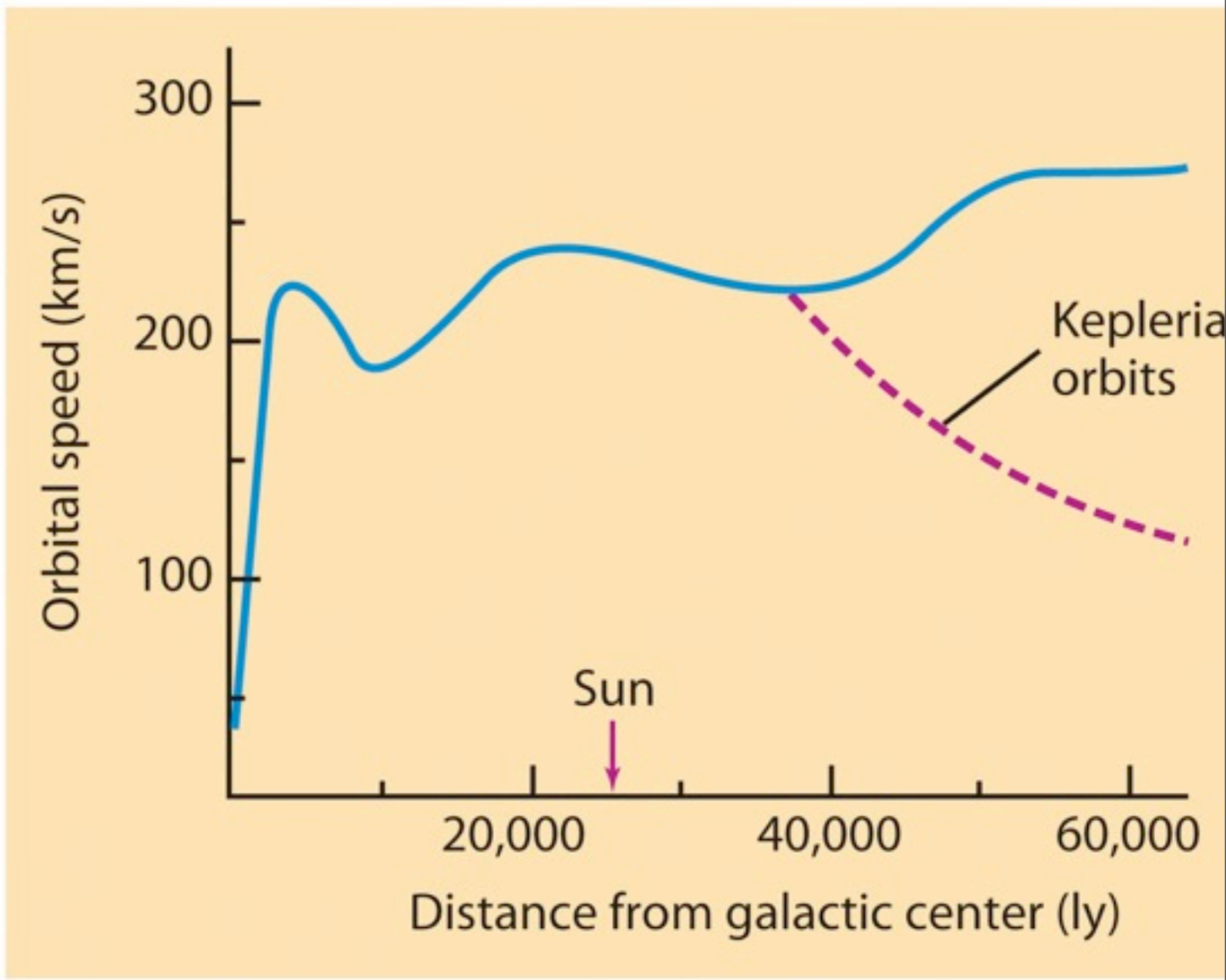

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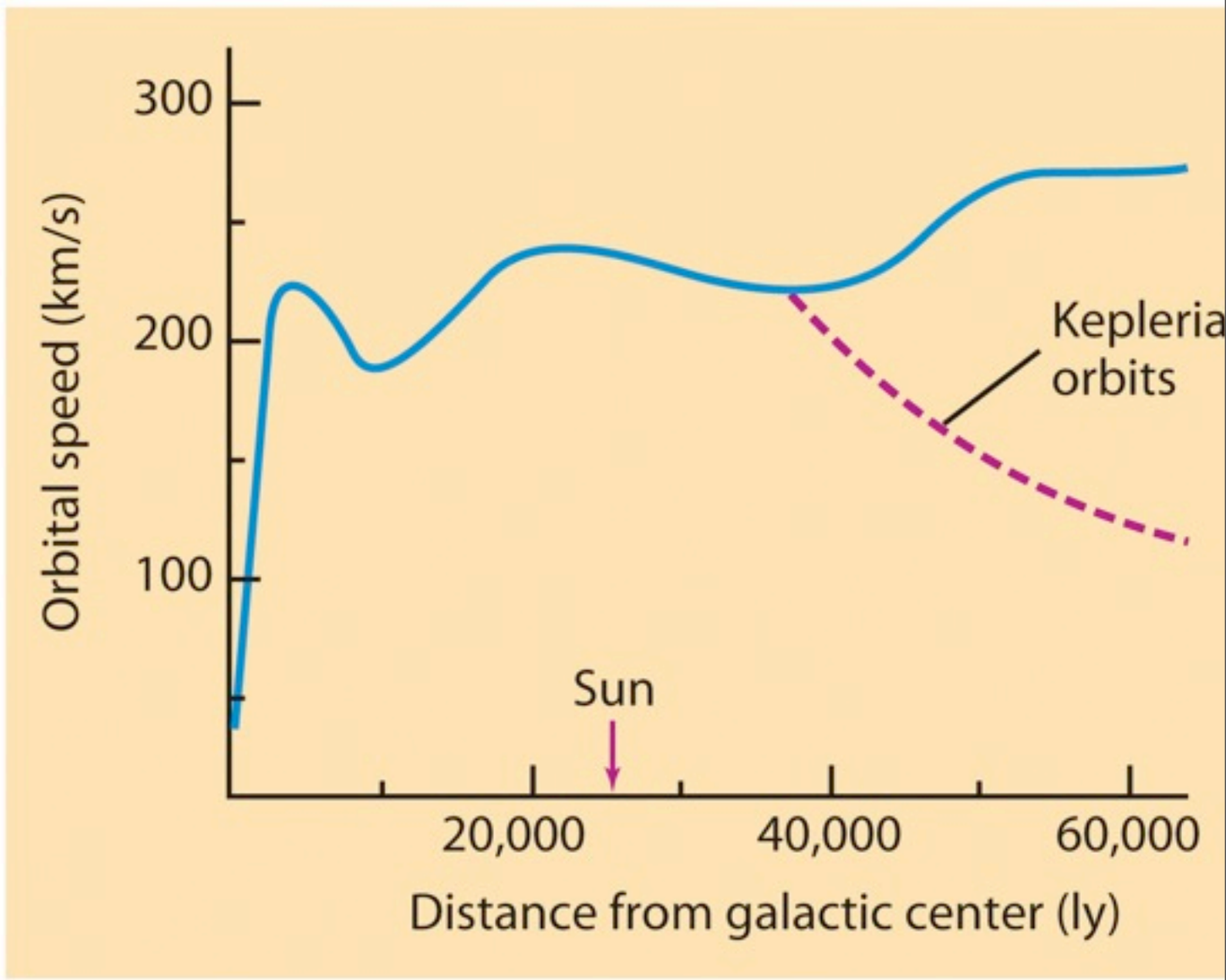

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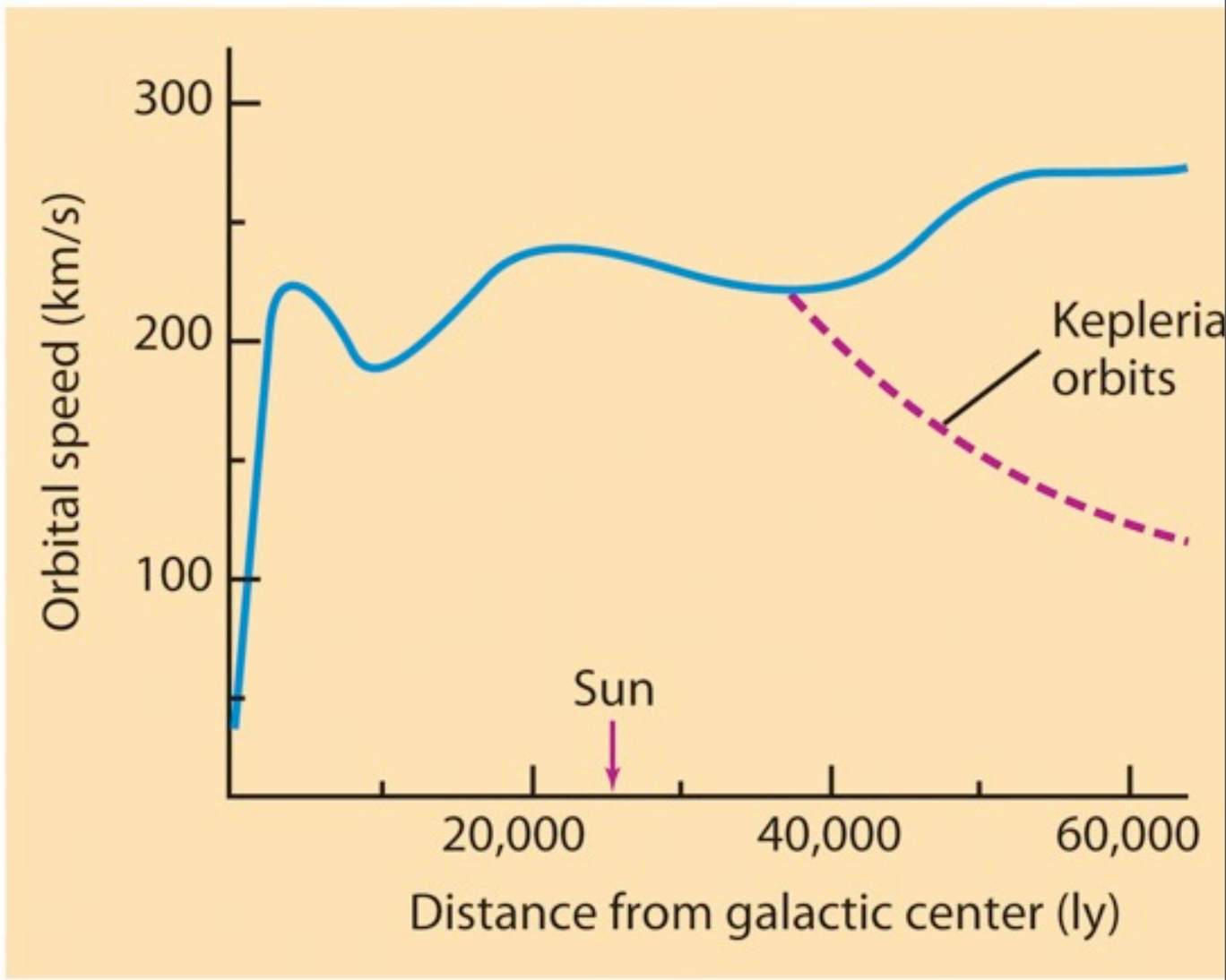

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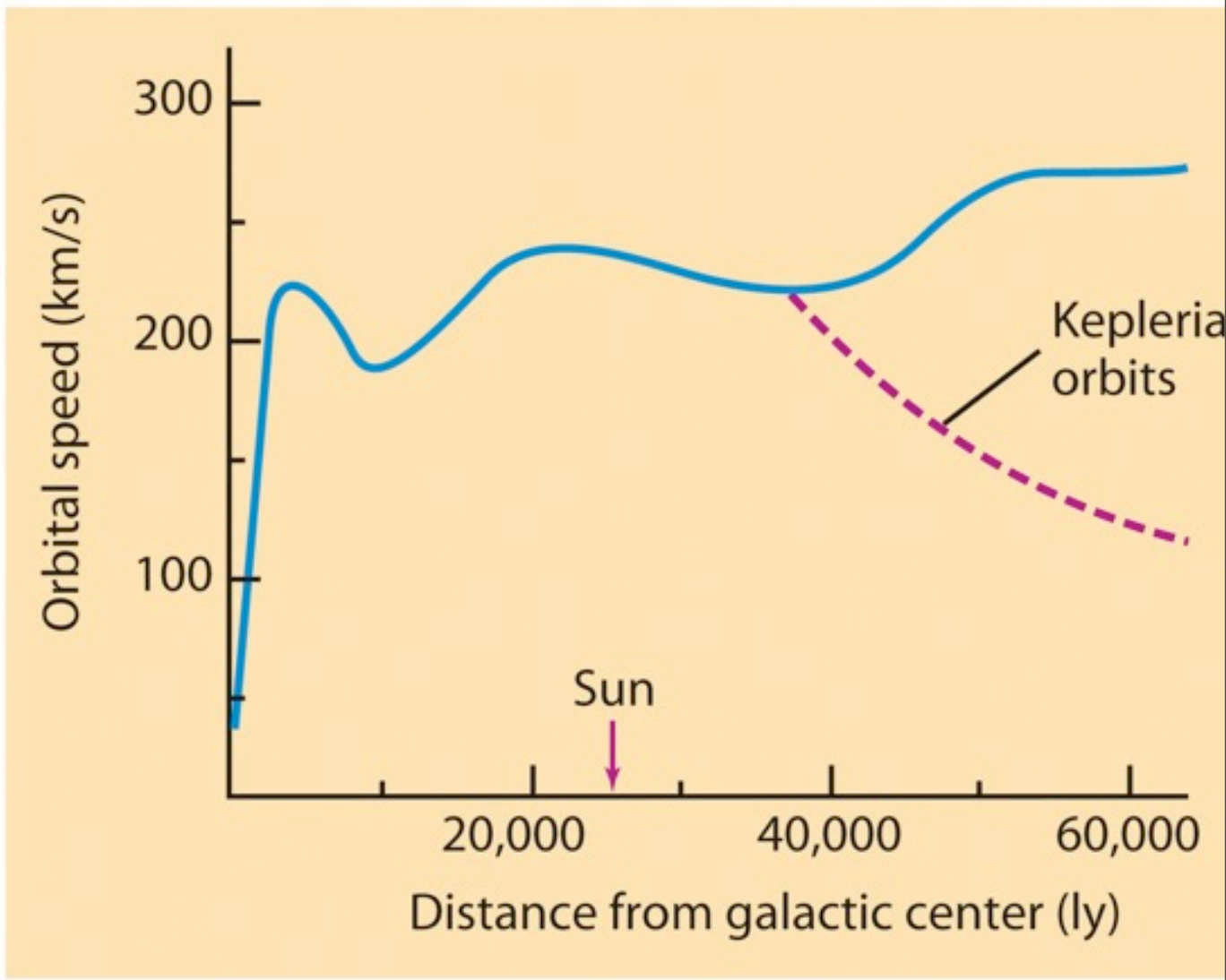

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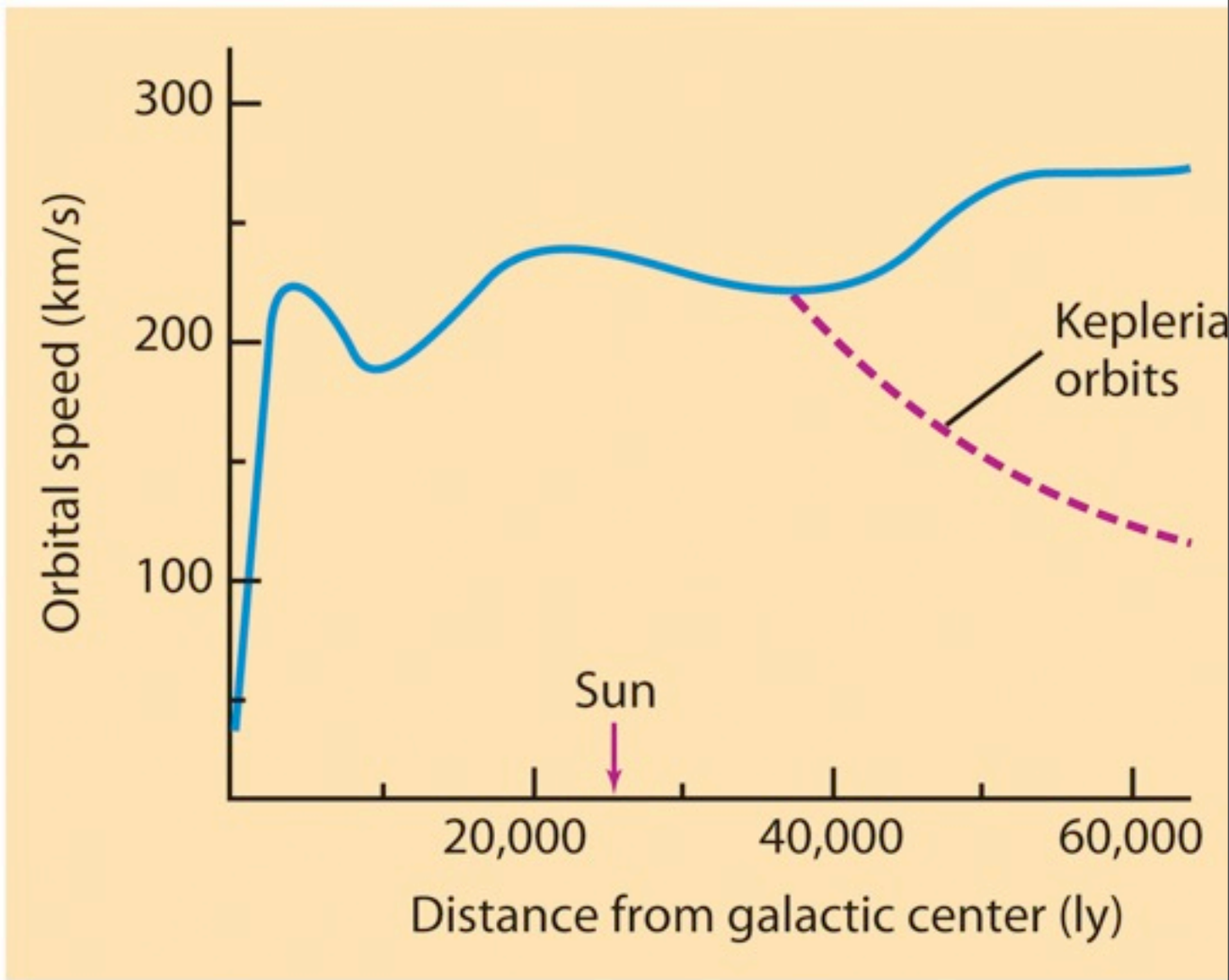

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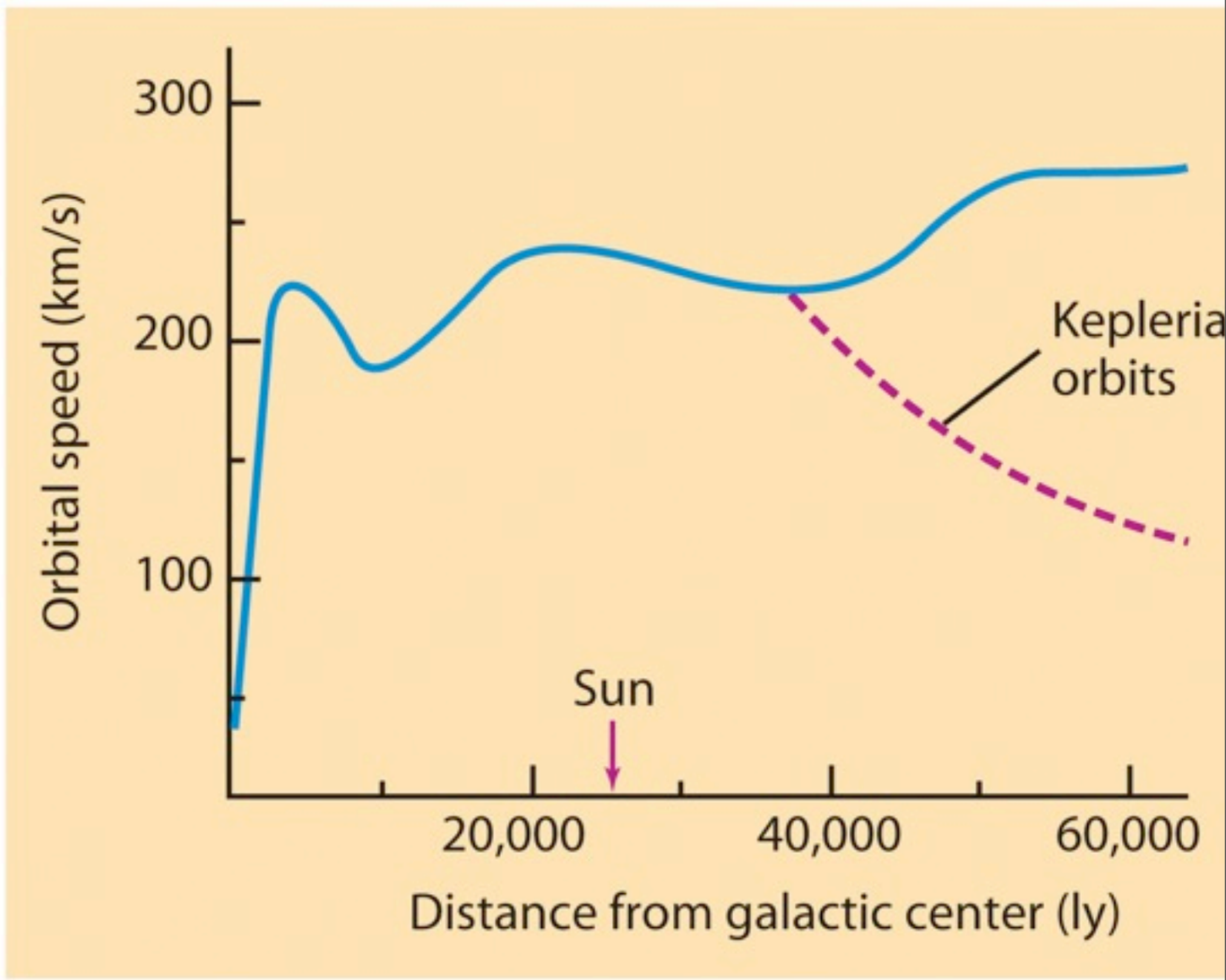

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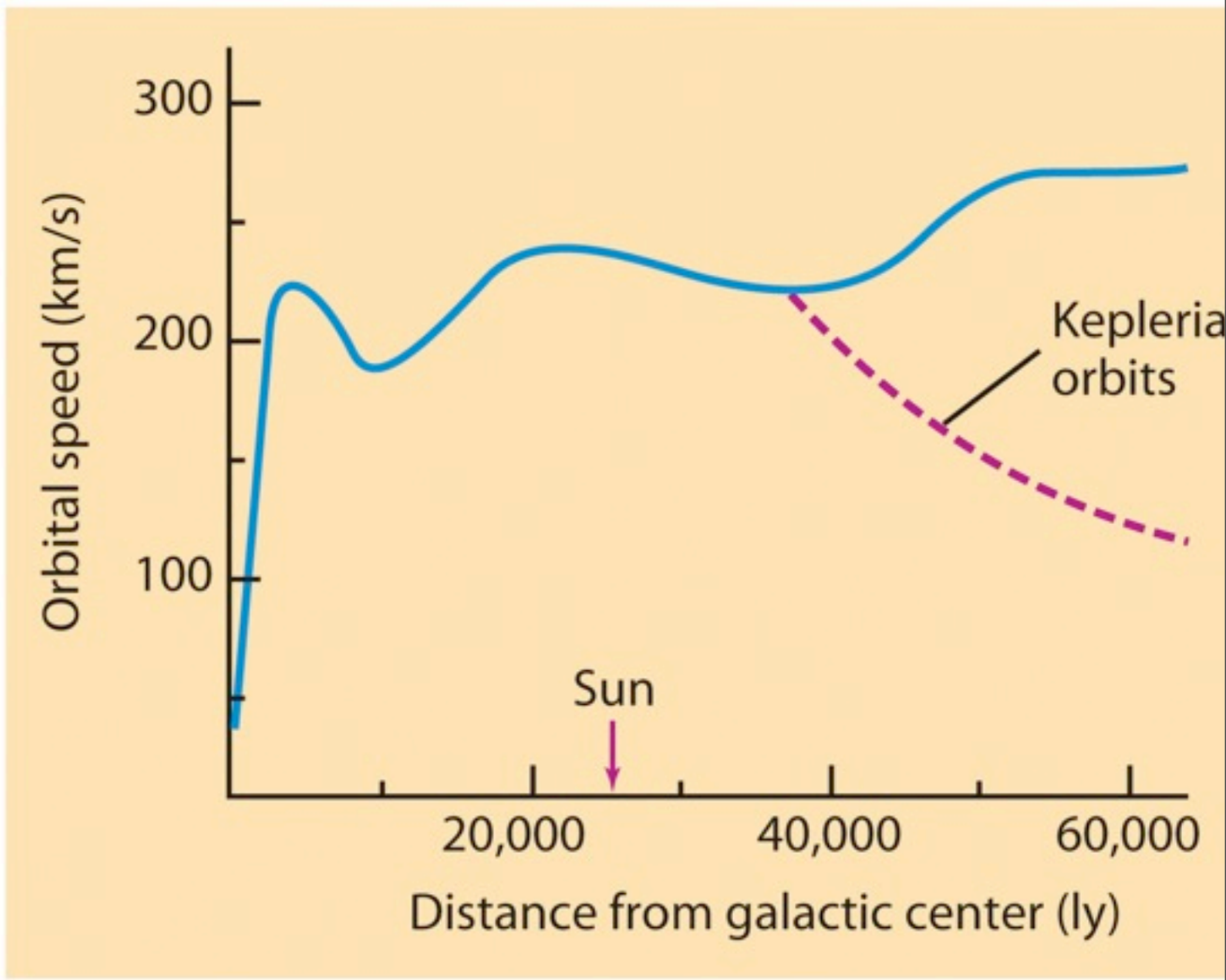
speed is constant from 5000 lyrs out.



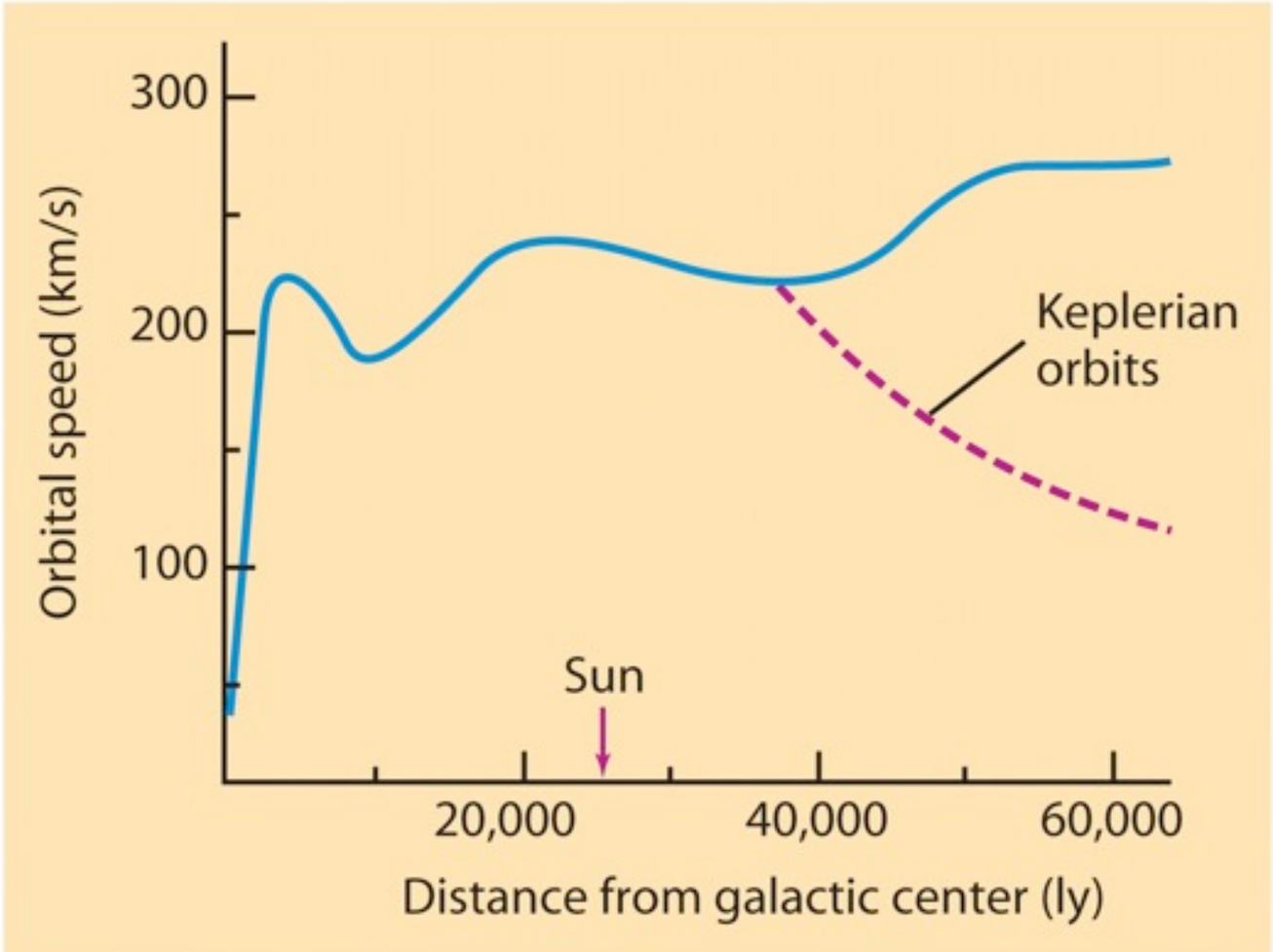
Whaa?

Something weird.

Rotation speed does not drop off in the outer Galaxy

- rotation curve is "flat"
- yet in the outer galaxy there is a huge dropoff in stars, gas, and dust

Instead: rotation speed remains constant, or even slightly increasing!



Rotation Curve Shows Hidden Mass

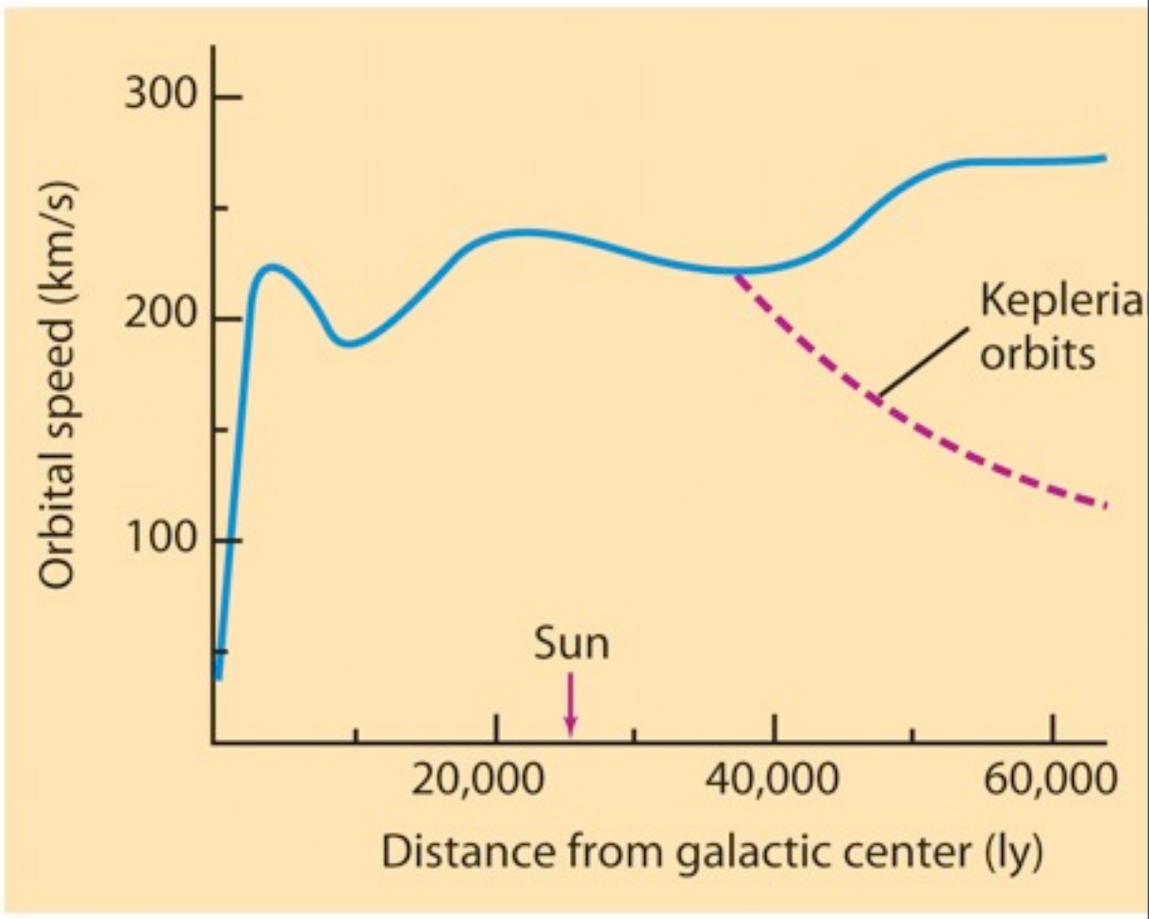
In the Solar System:

- >99% of mass is in Sun
- the farther away from the mass, the slower something orbits.

  Compare Pluto and Mercury's orbital speed.

But in the Galaxy:

- orbit speed of stars in the outer Galaxy actually increases or is constant with distance from the center!



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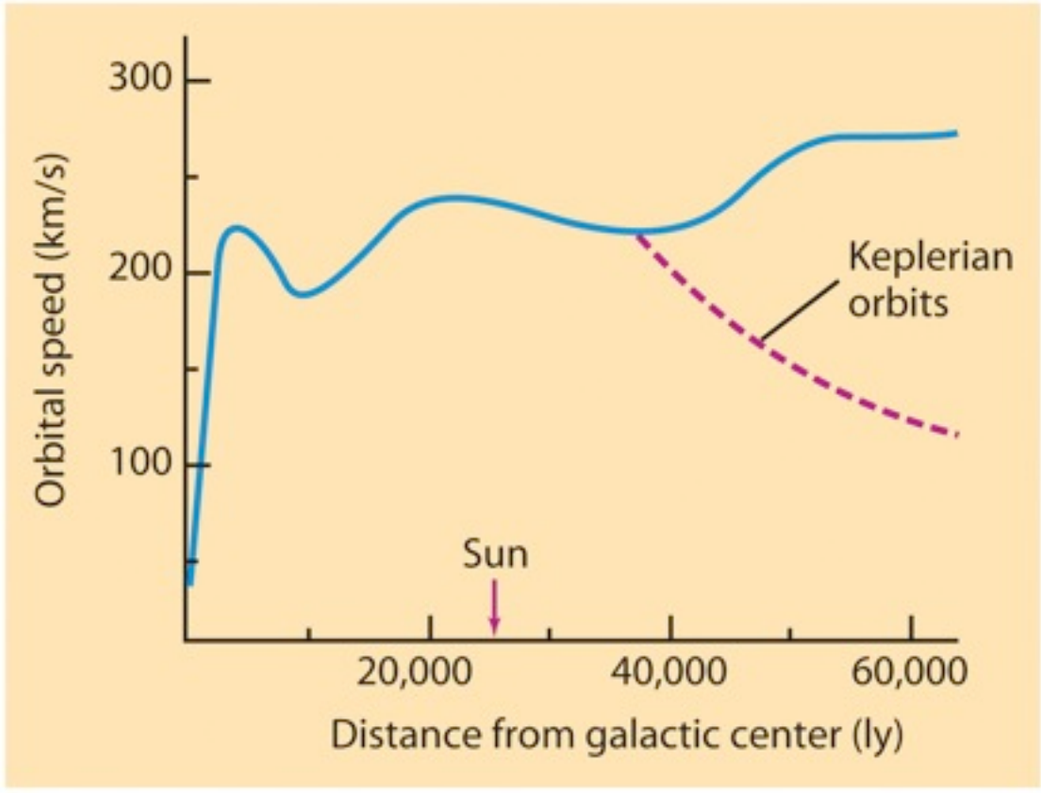

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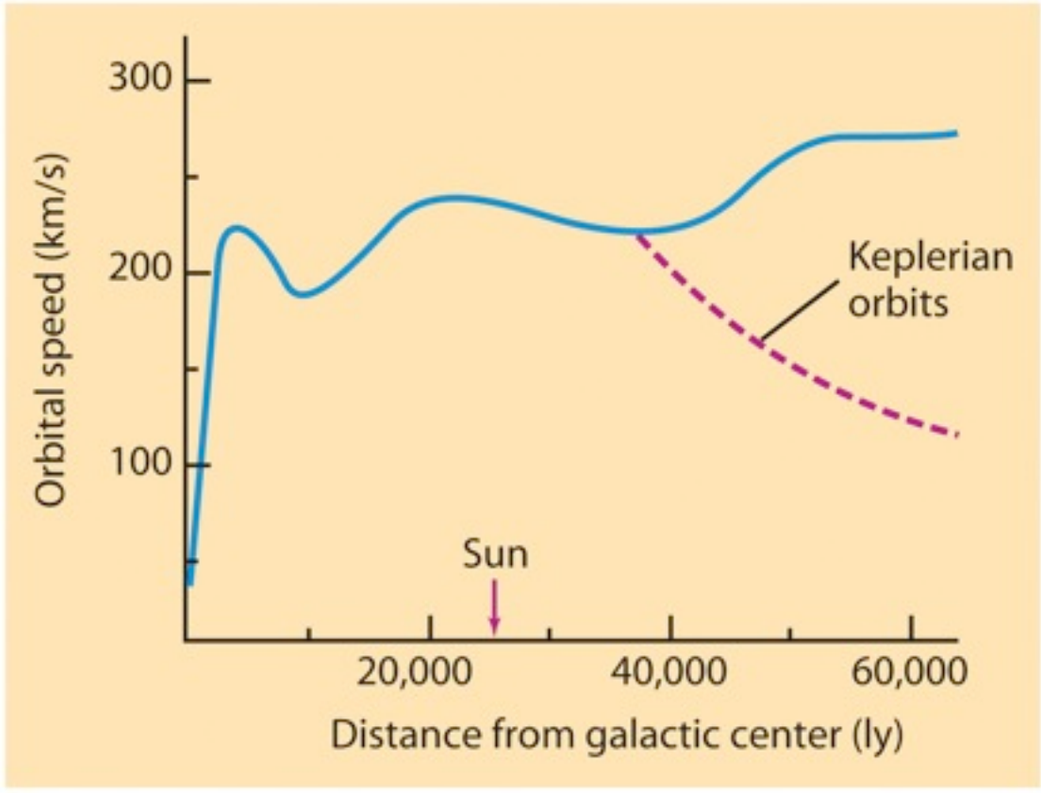

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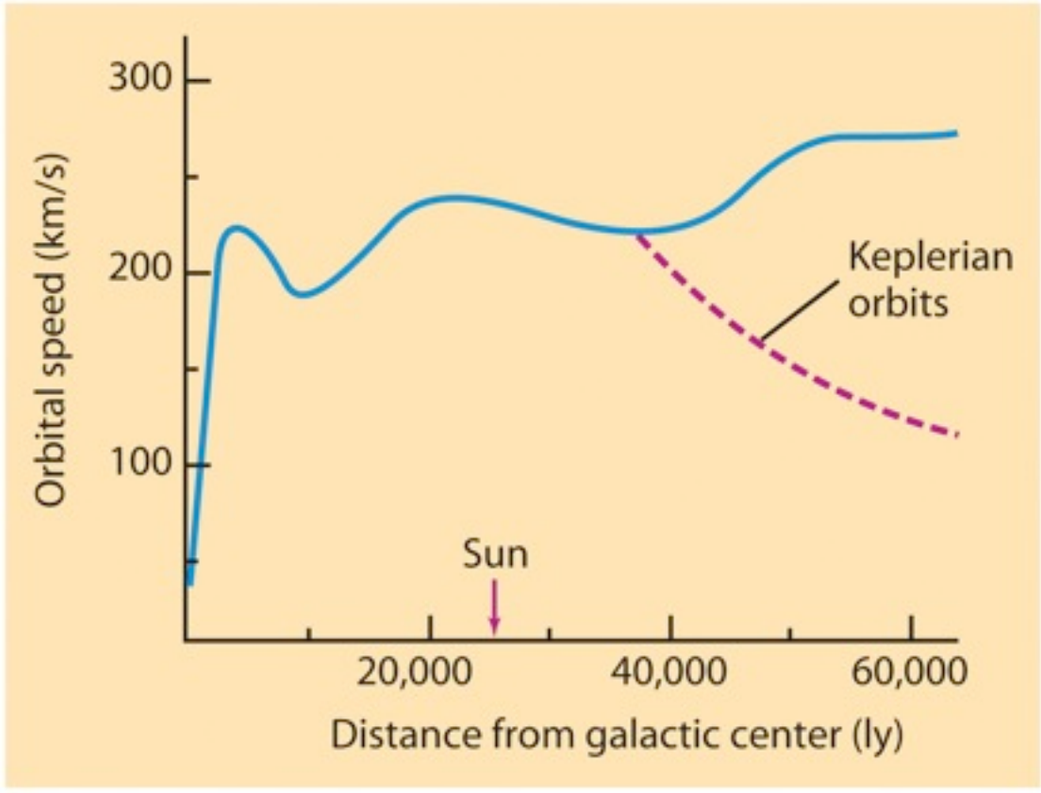

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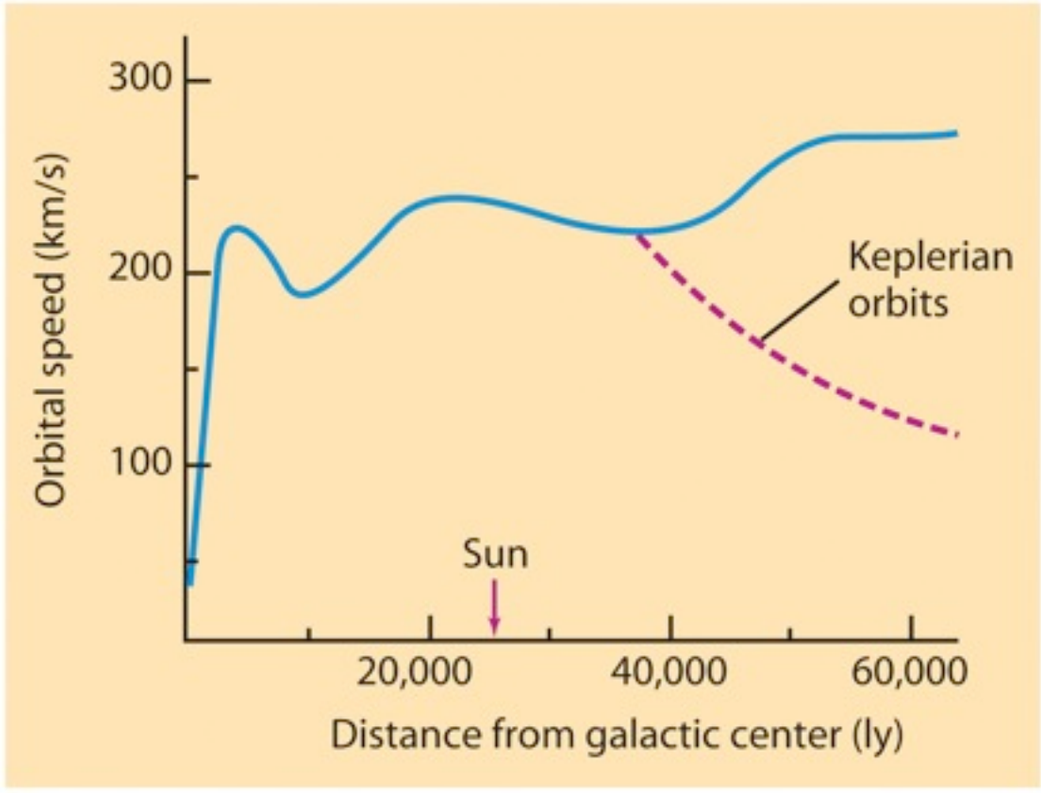

So: The mass in the outer part of the Galaxy must be something dark.

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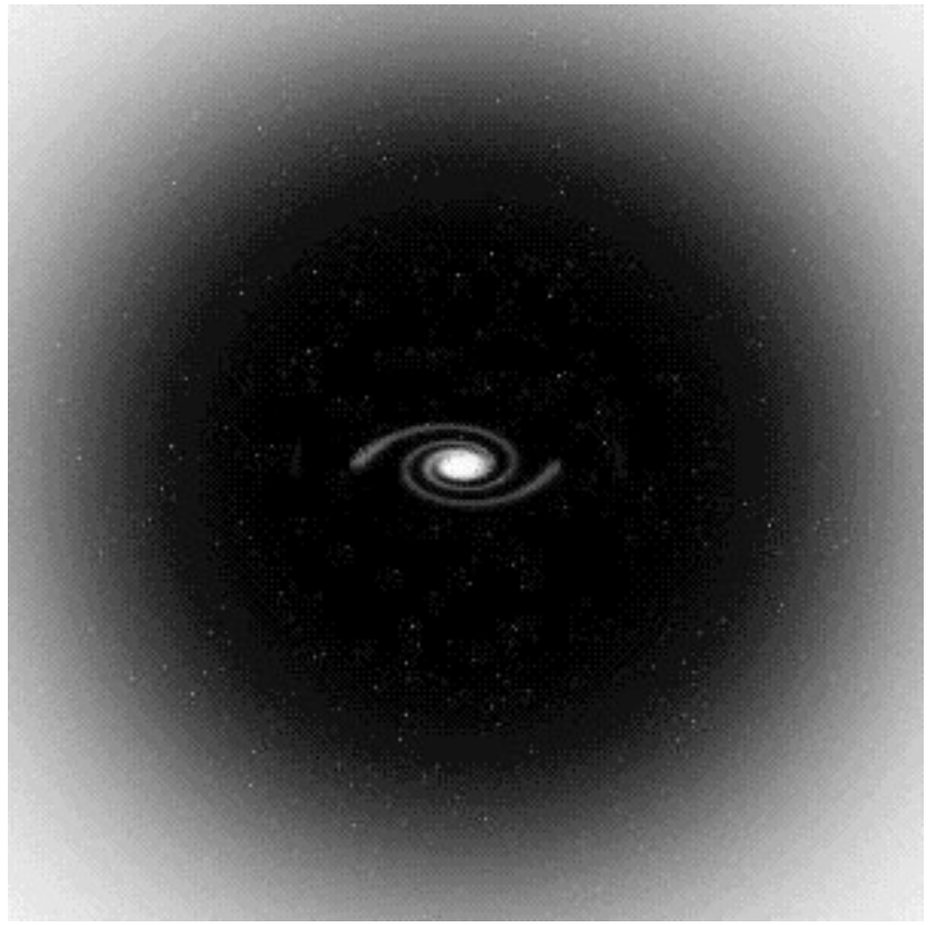
Milky Way much more massive, larger, than meets the eye!

Dark Matter

The dark matter in the Galaxy is in greatly extended halo

- Up to 90% of the Galaxy's mass is dark matter!
- Galaxy may have over a trillion solar masses total!



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Will return to dark matter soon....

"Spiral Nebulae"

All stars you can see by eye or with small telescopes are in Milky Way

- as are stellar remains:
  - white dwarfs, neutron stars, black holes
  - and planetary nebulae

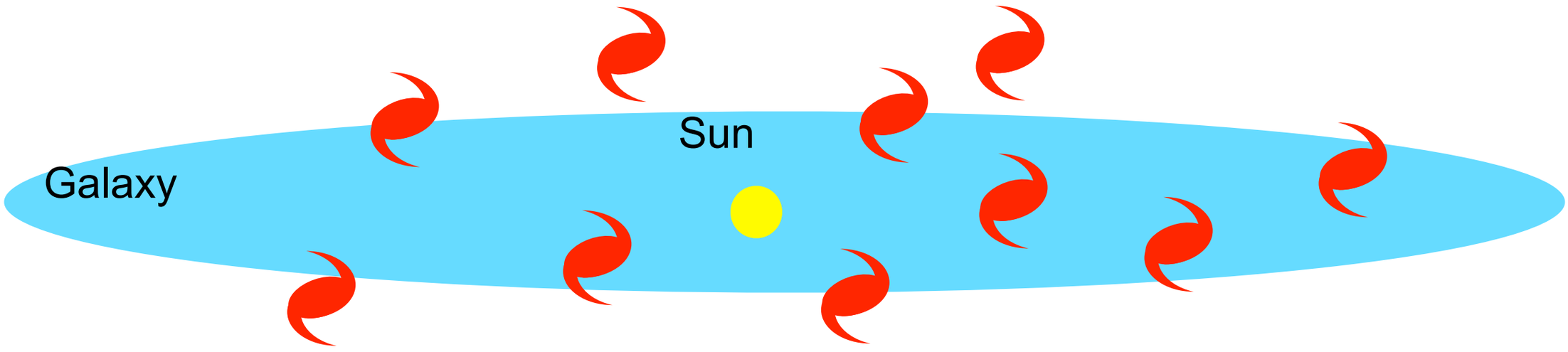
But by 1800's, other dim, diffuse "nebulae" seen

- with spiral patterns
- Spiral structures catalogued mid-1800s by Lord Rosse (Ireland)

Rosse's M51 sketch

"Leviathan"
1.8 m telescope

Those weird Spiral Nebulae?



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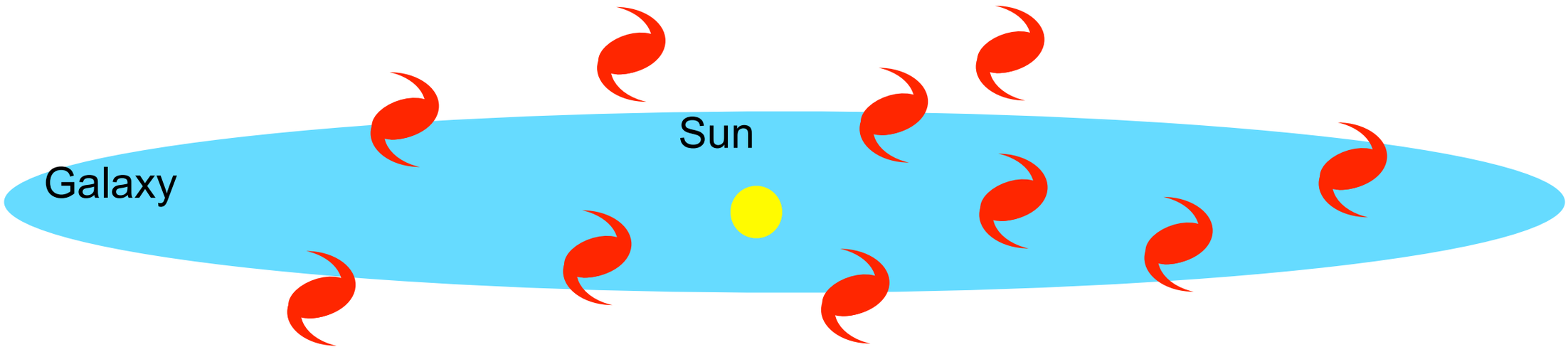

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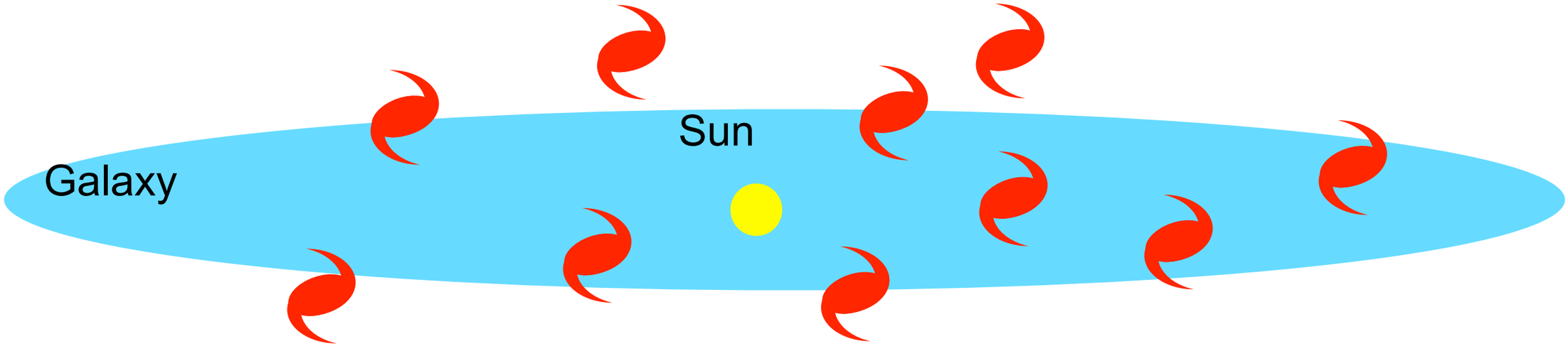
Some disagreement on what they were.

- Kant: Our galaxy is a spiral "island universe" and the other spiral nebulae are the same and far away
- Herschel and others: Milky Way is all there is in the Universe, and the spiral nebulae are nearby. More prevalent idea.



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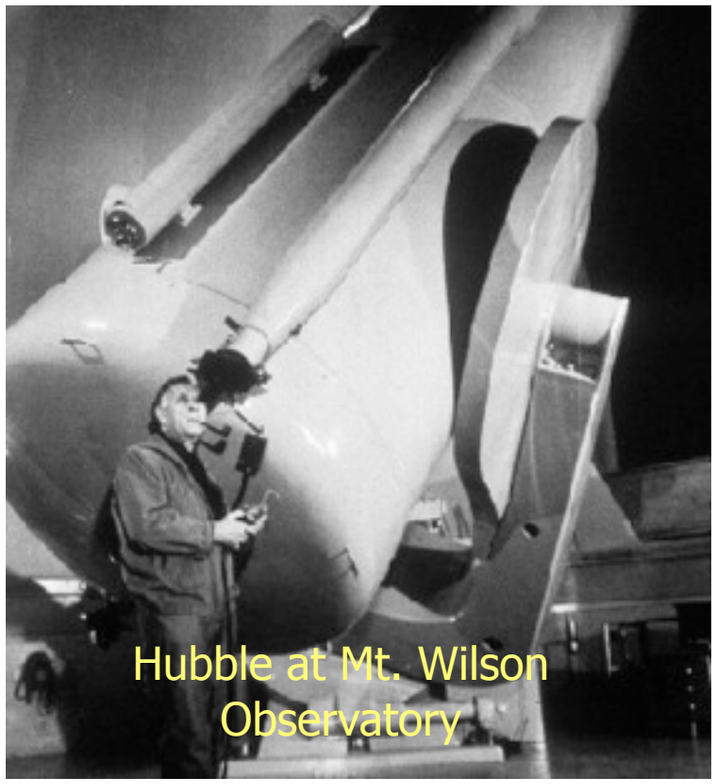

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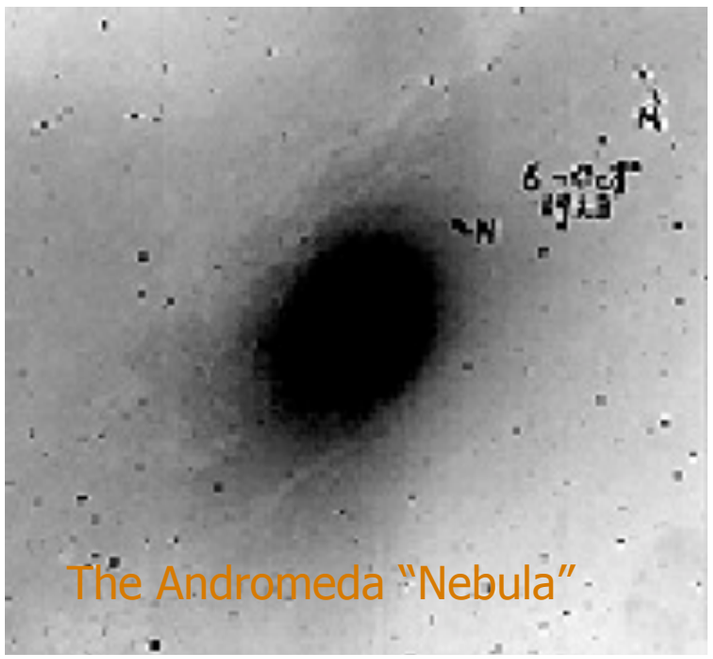

The Andromeda "Nebula"

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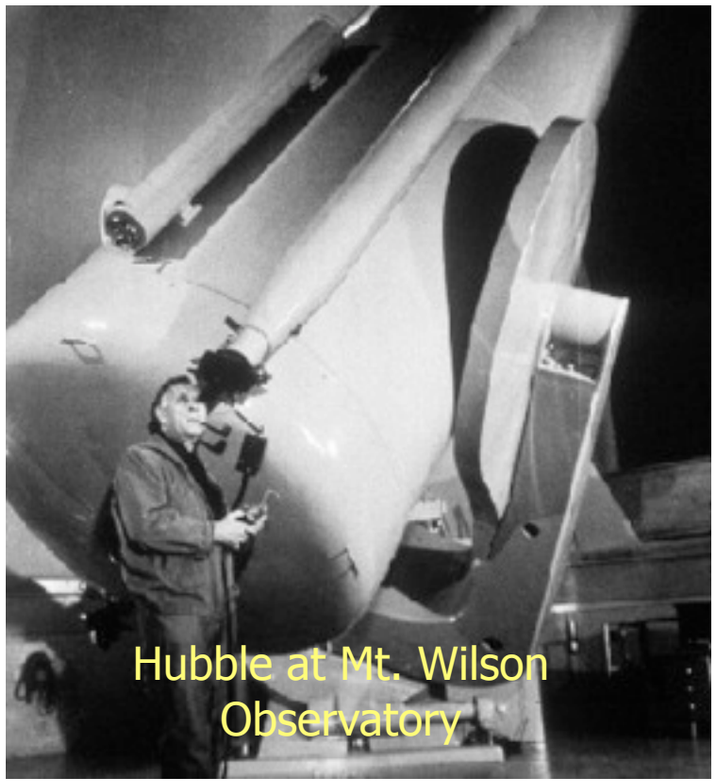
Finally solved, as it often is in astronomy, with a BIGGER telescope!

- **The old 100 inch trick!**



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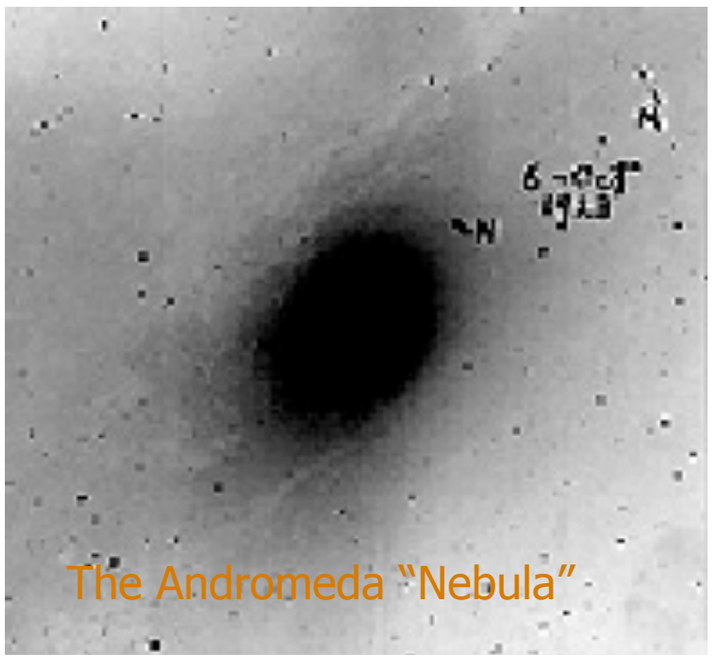

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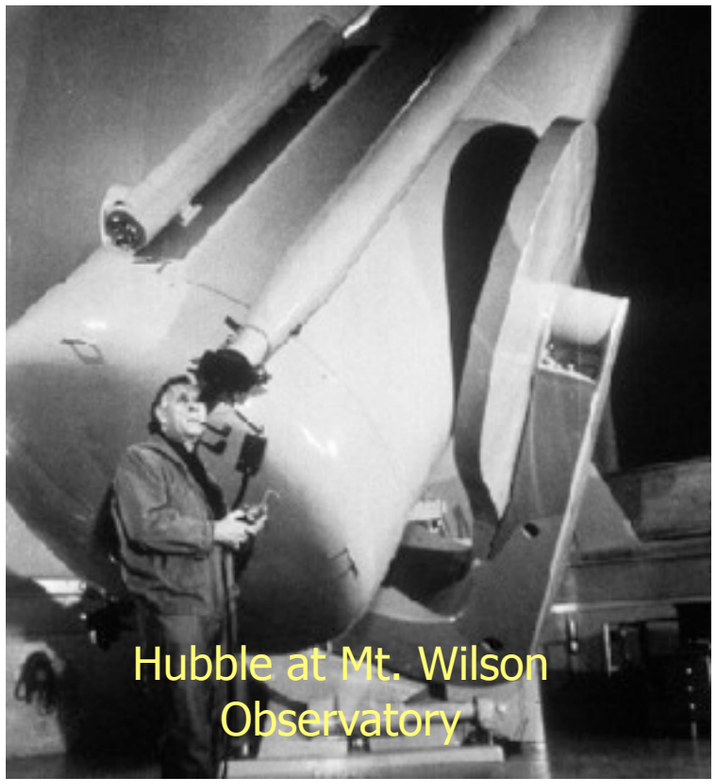

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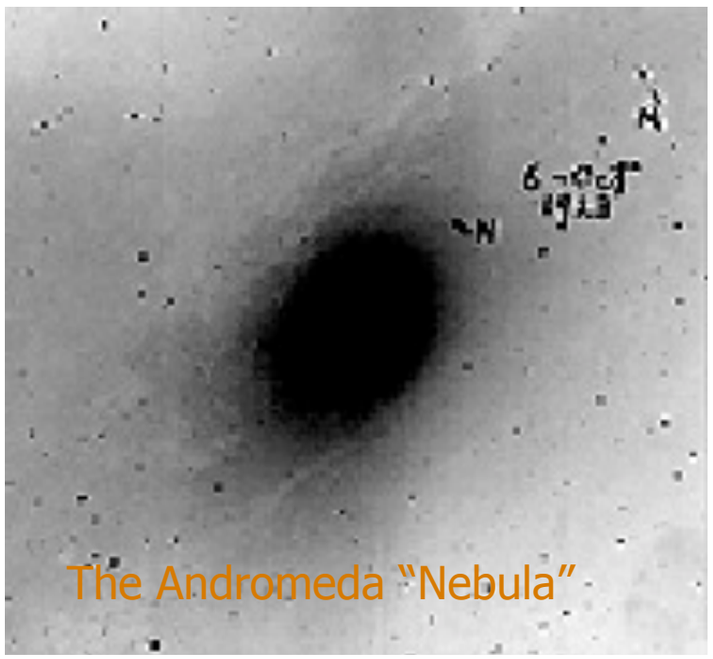

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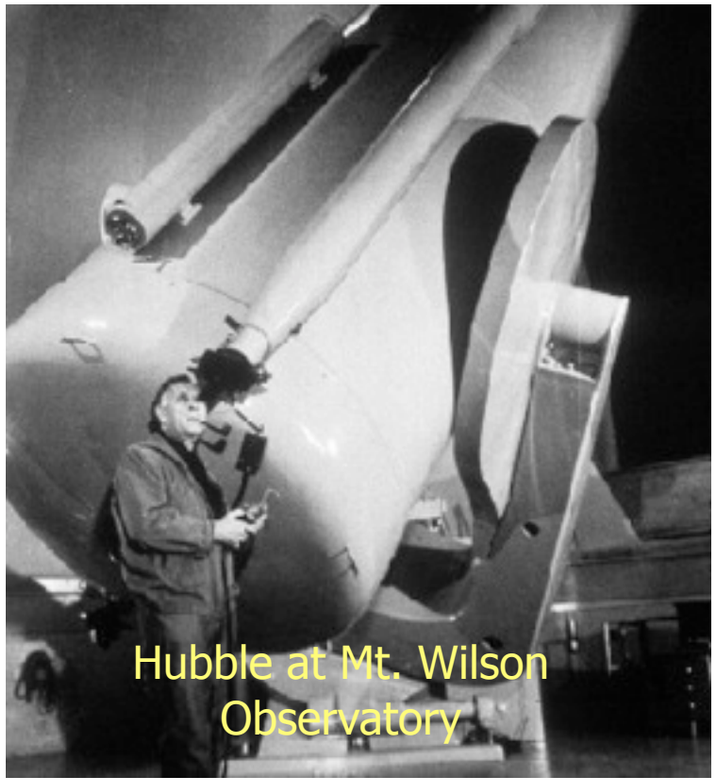

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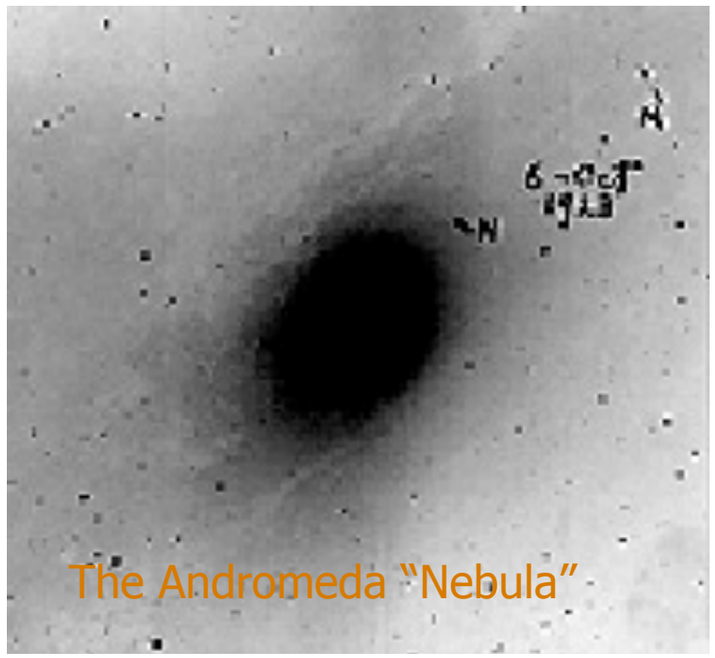

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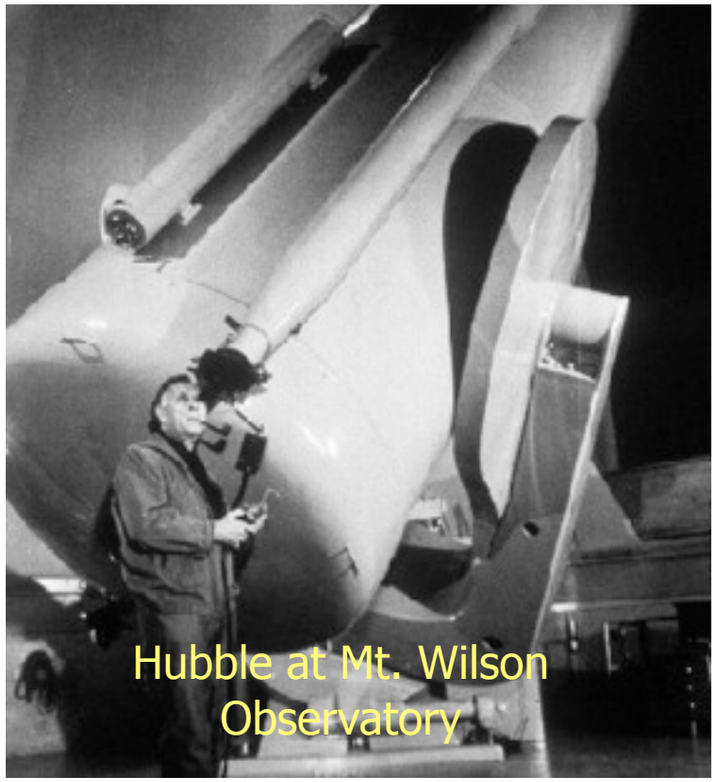

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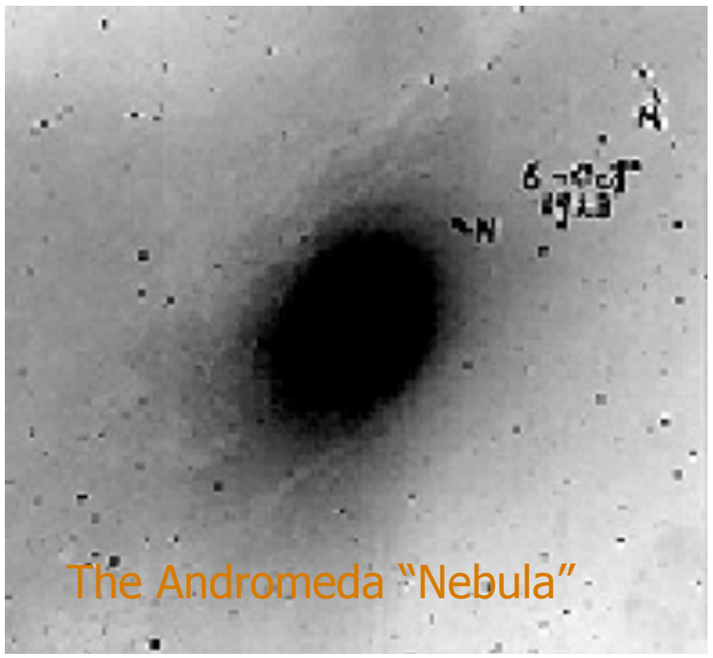

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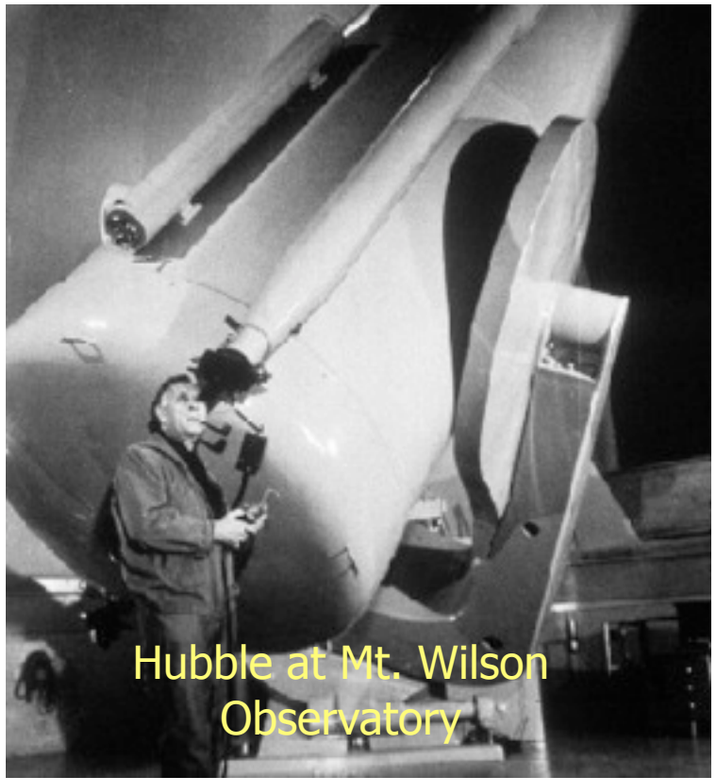

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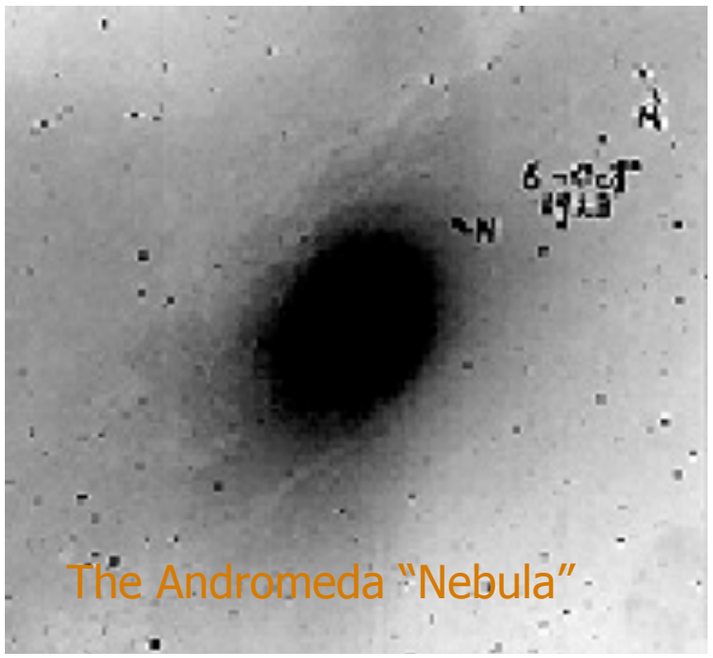

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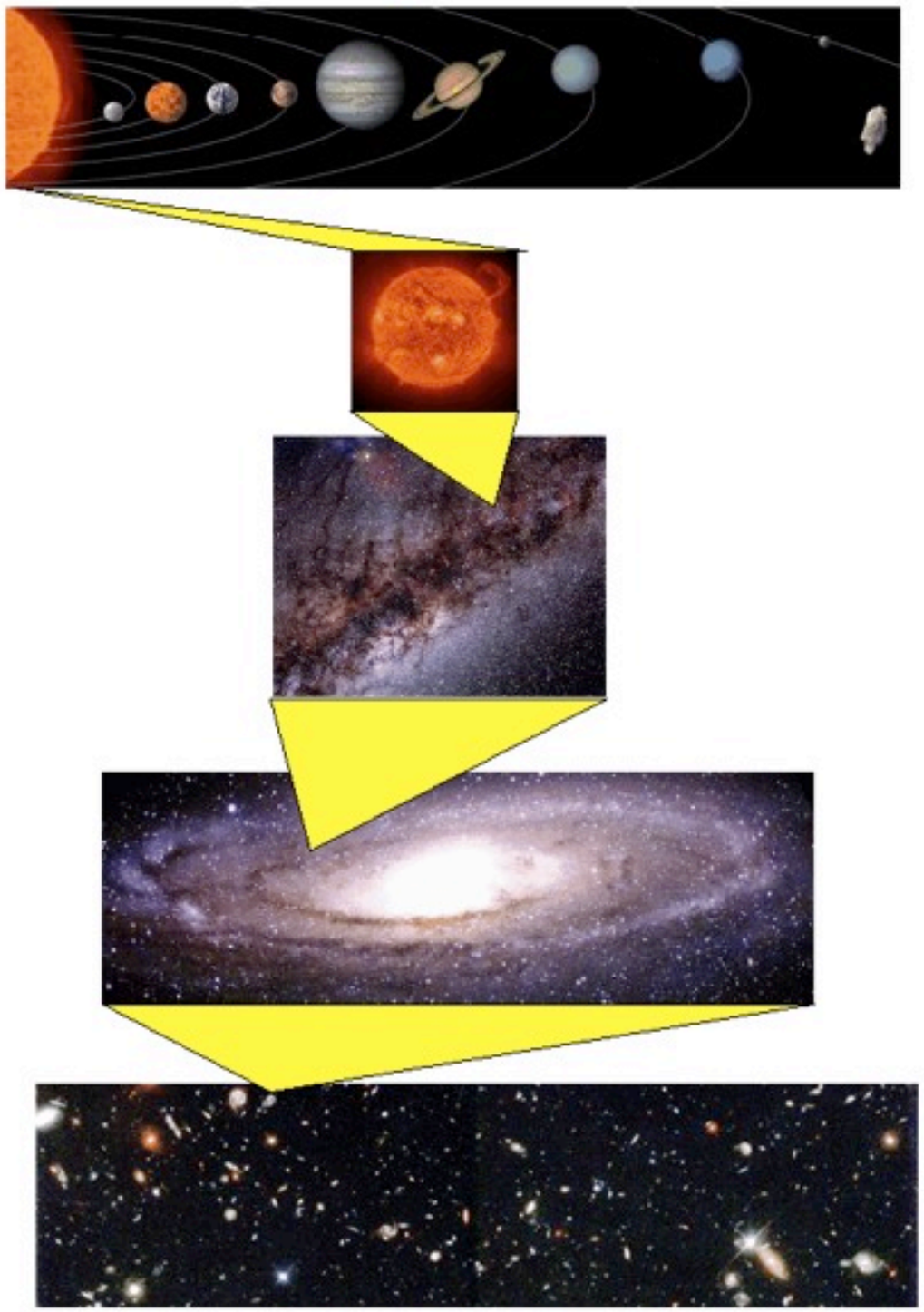

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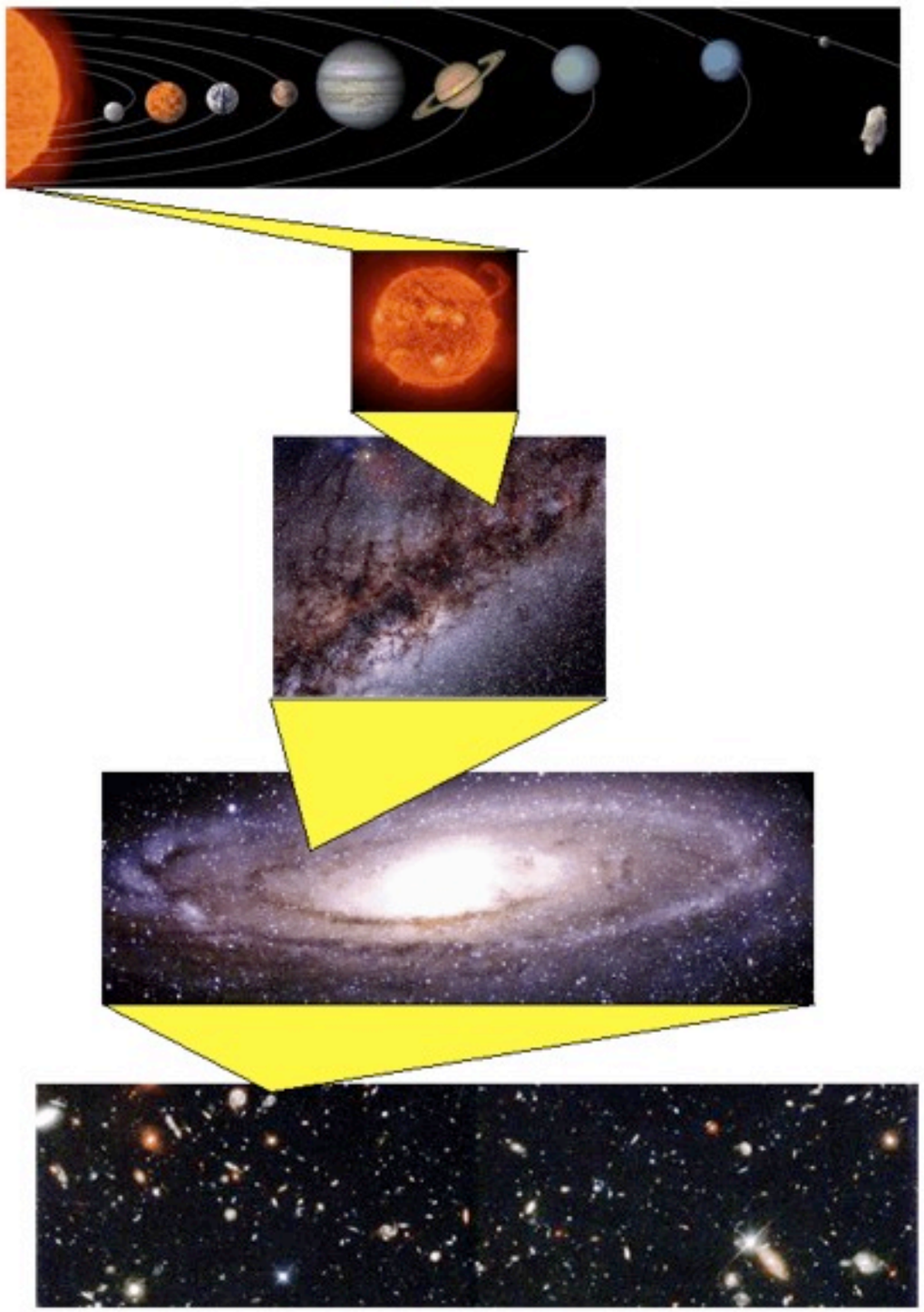

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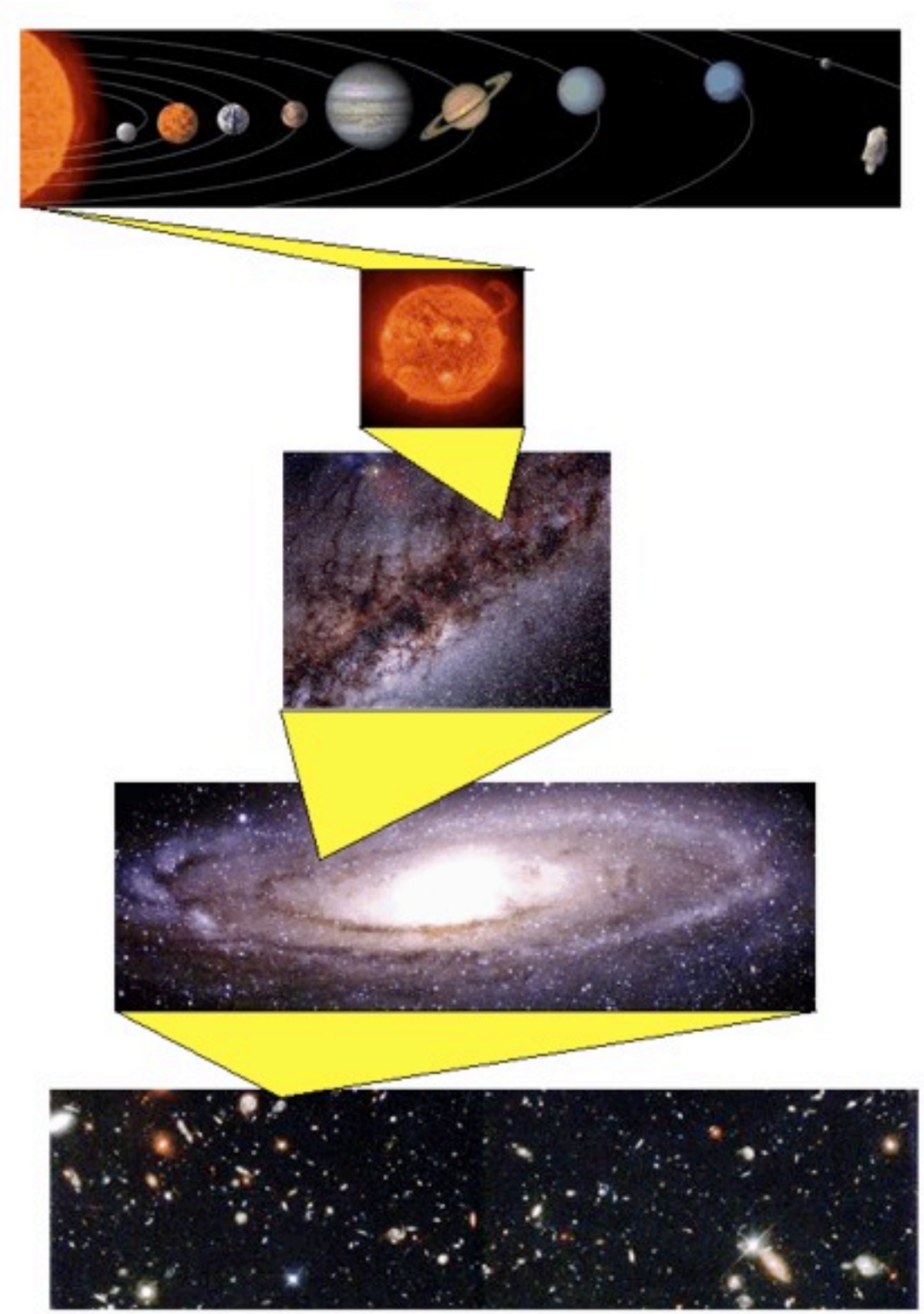

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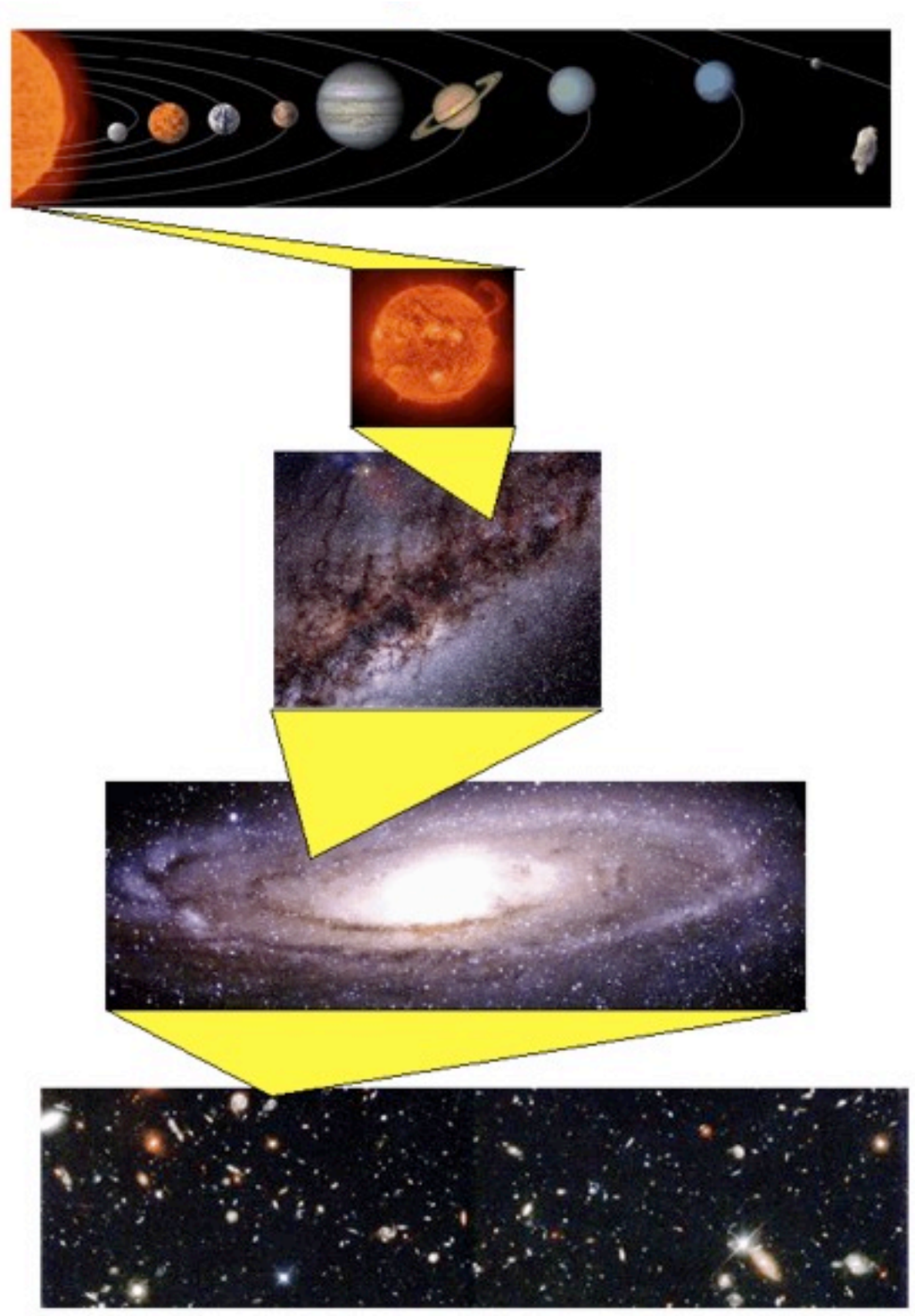

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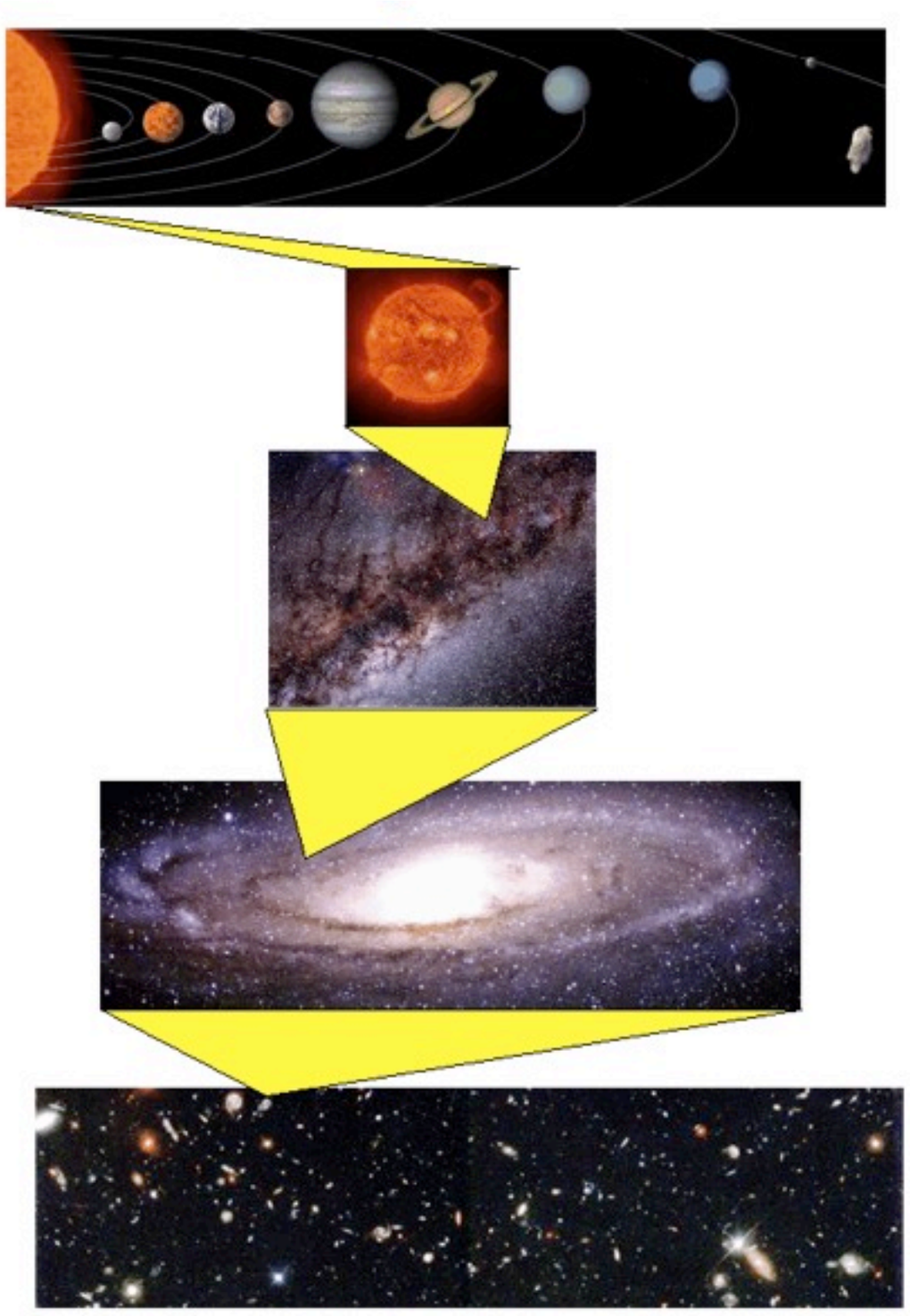
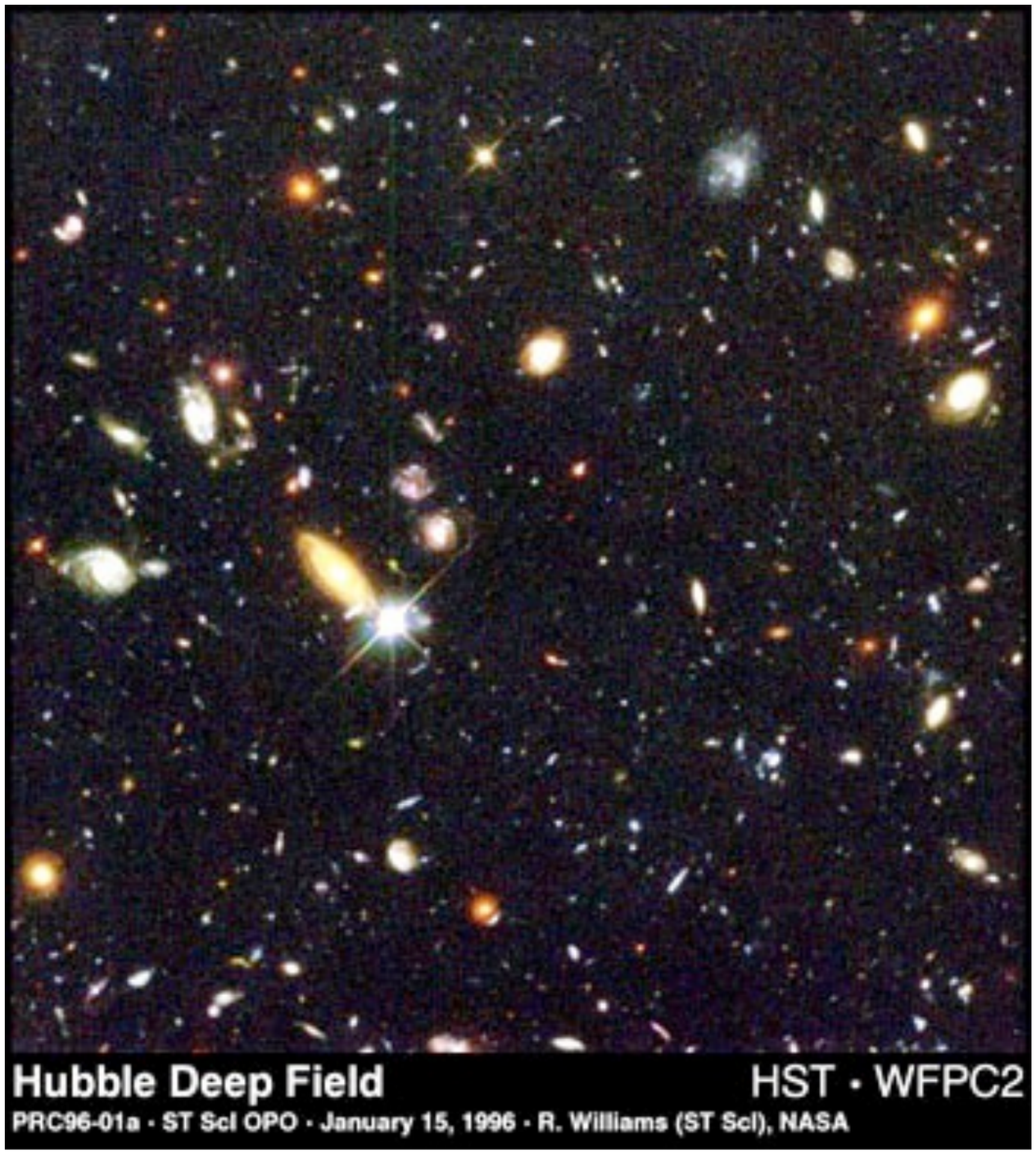
1 galaxy of the 100 billion galaxies in the observable Universe.



Galaxies – Fundamental "Ecosystems" of the Universe



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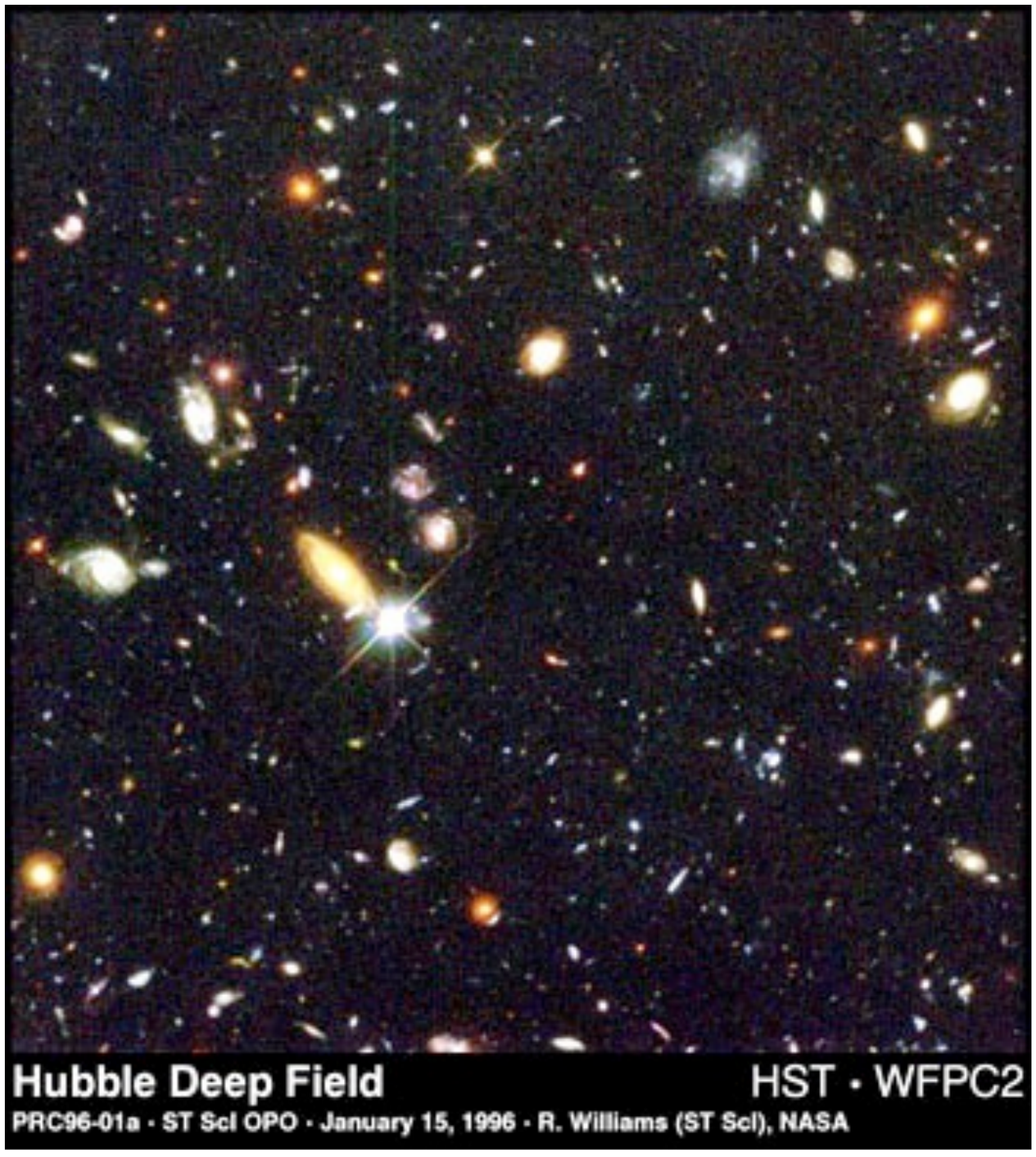
Galaxies "fill" universe.



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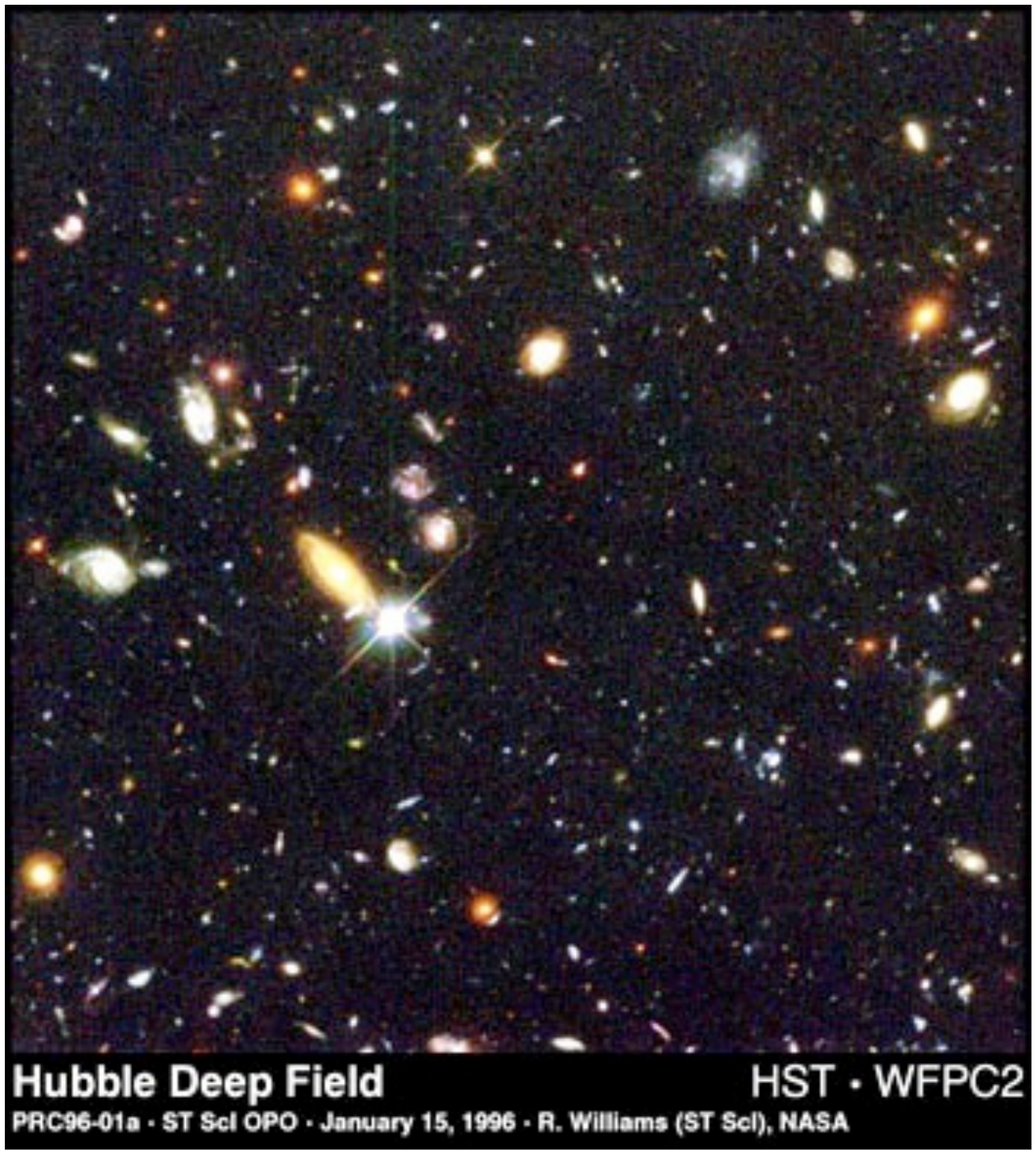
Galaxies "fill" universe.
Typical separation
~ 3.2 million light years!



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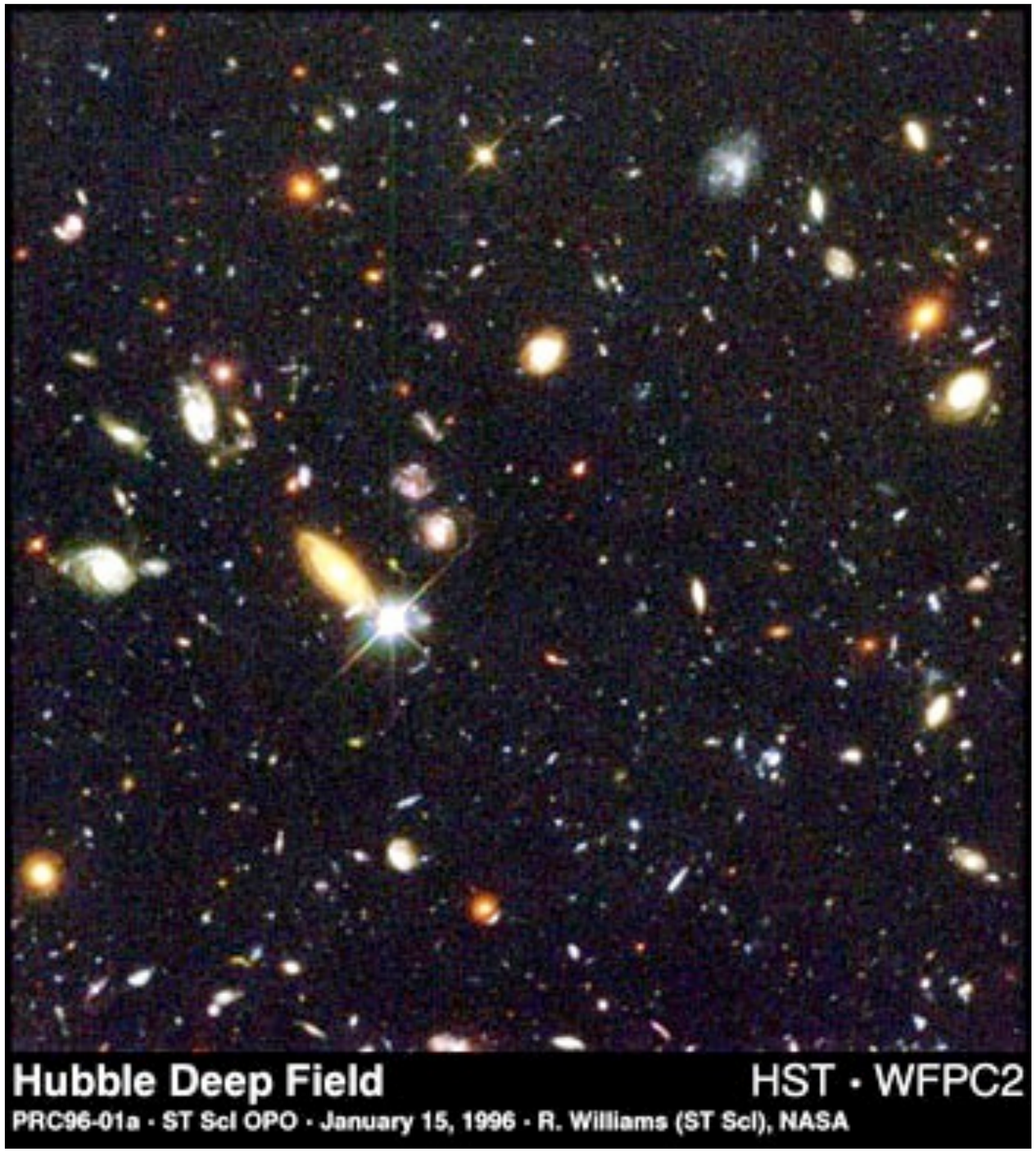

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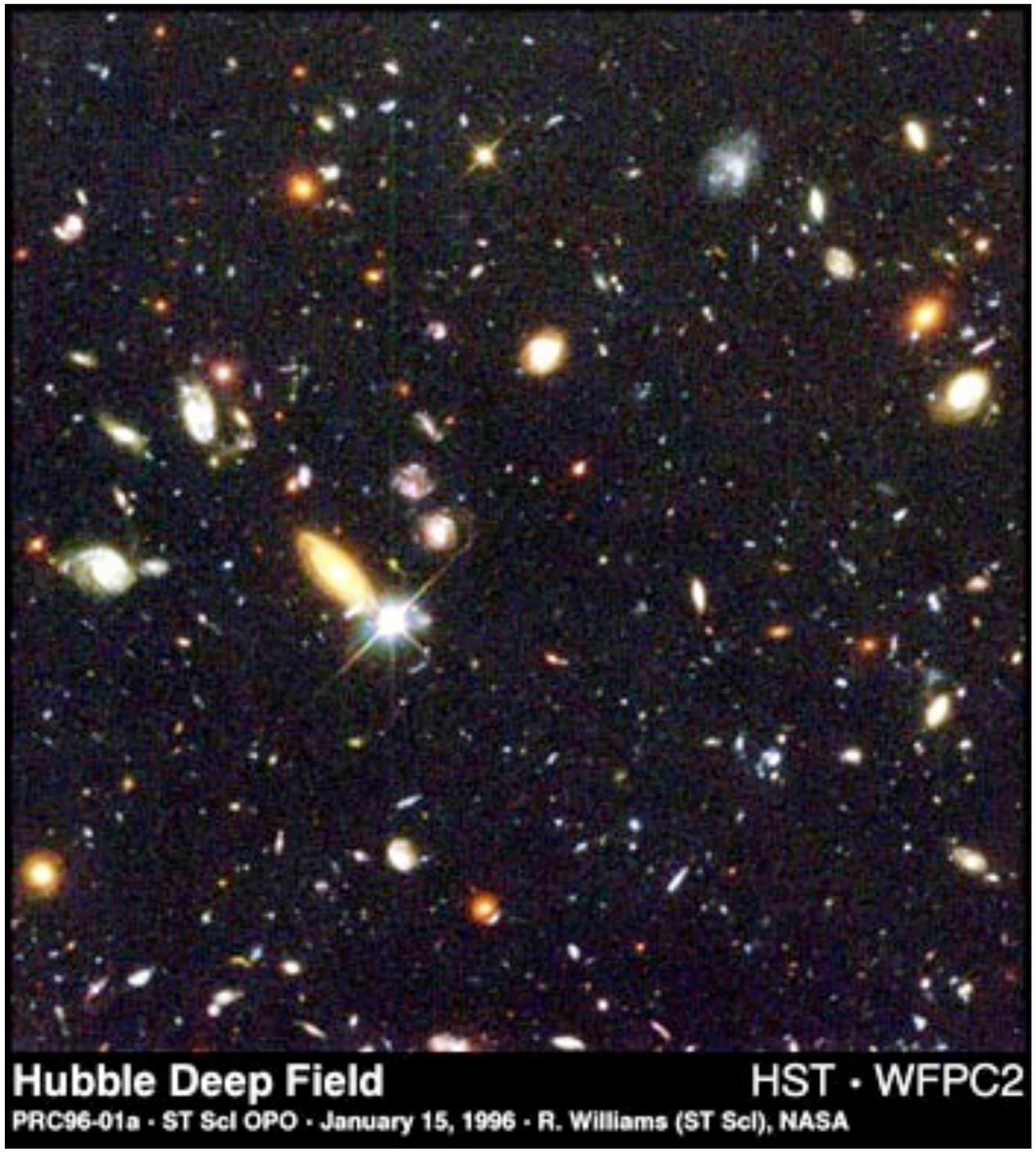

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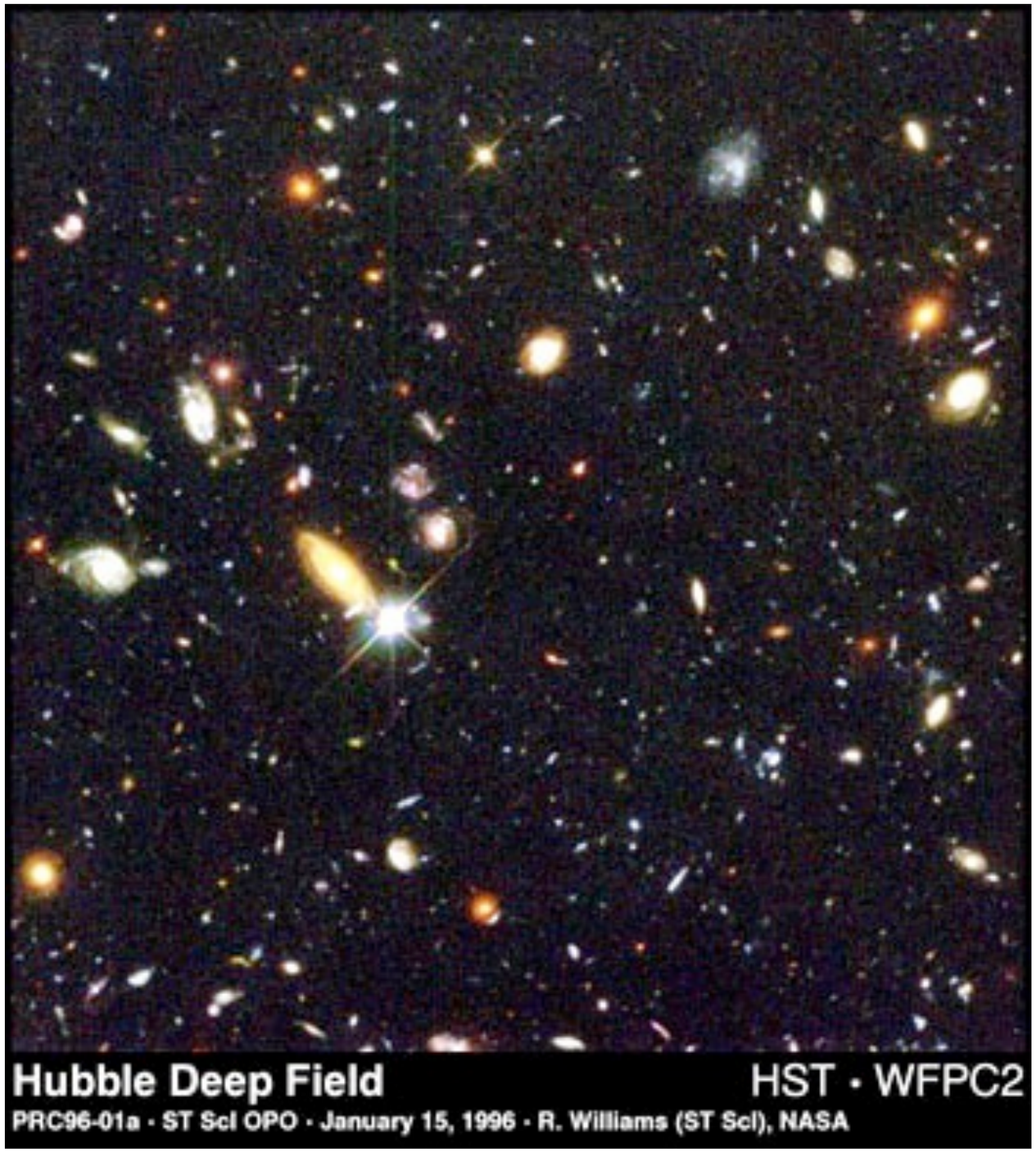
Range in size from large (MW-like) to small "Dwarf"

- 1 billion to 500's billions of stars

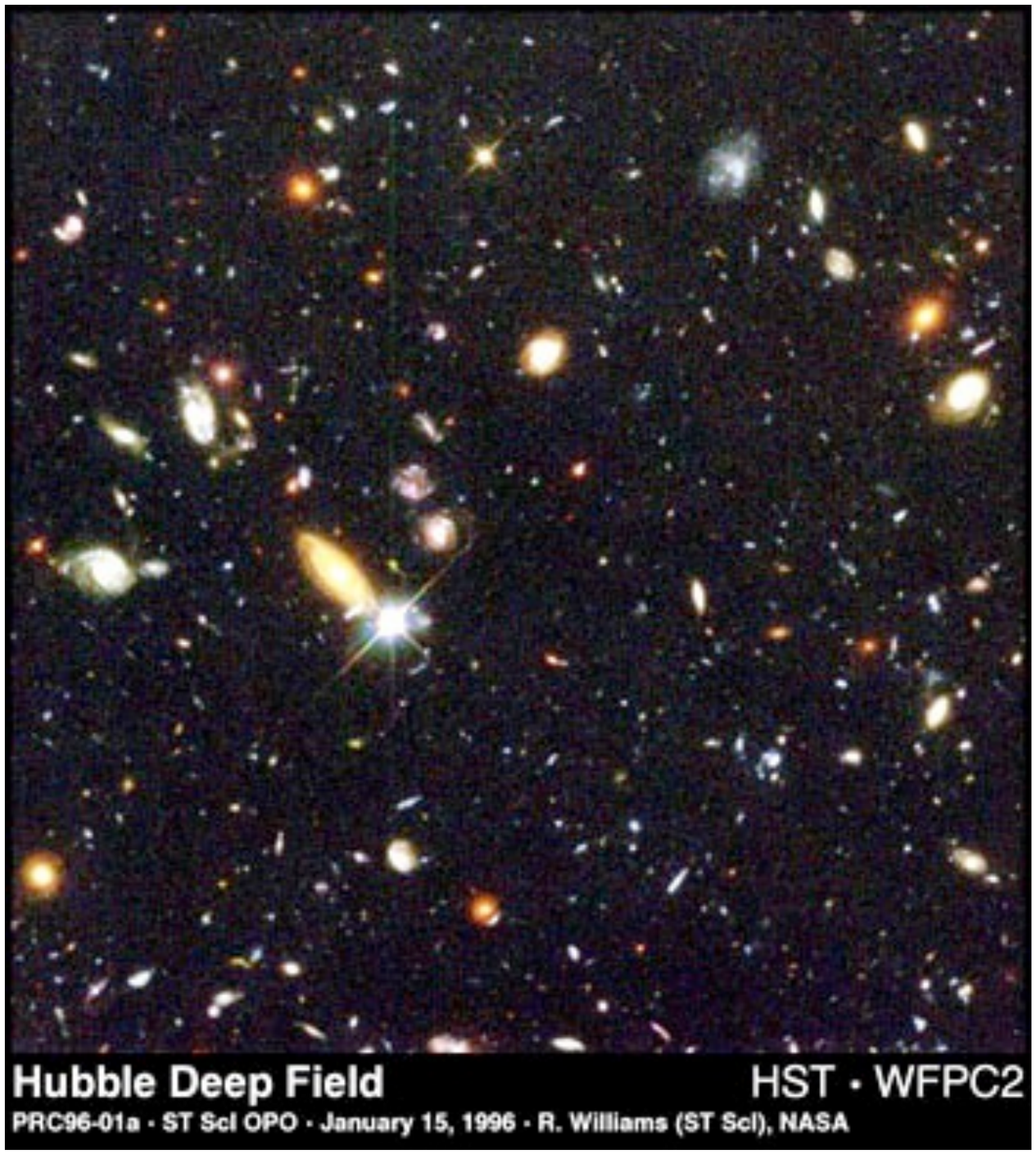


Galaxies – Fundamental "Ecosystems" of the Universe

Galaxies are the cosmic engines that turn gas into stars, then recycles the gas the stars eject back into stars, around and around.

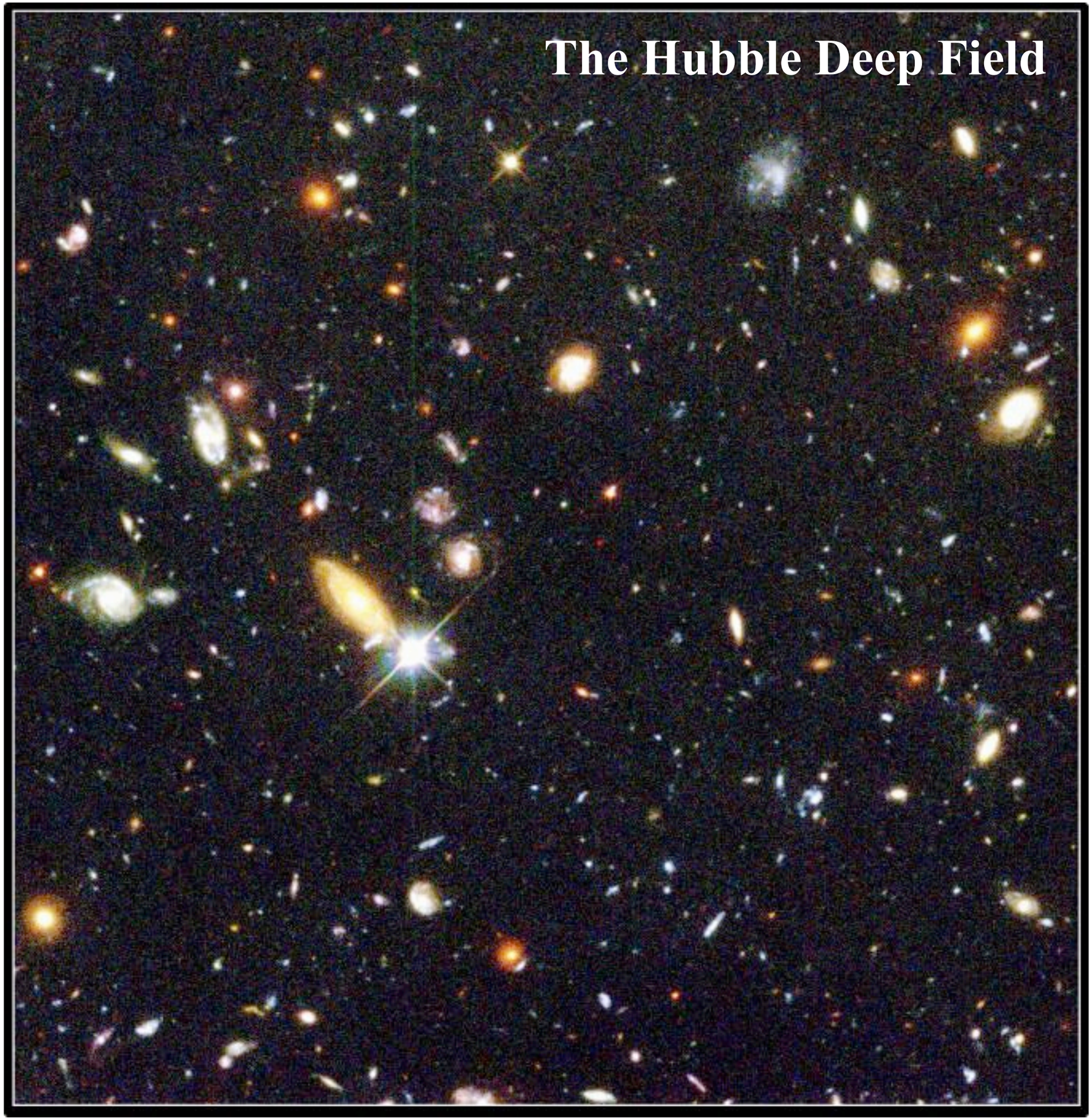
In between galaxies, no star formation occurs – "nothing happens" in intergalactic space.

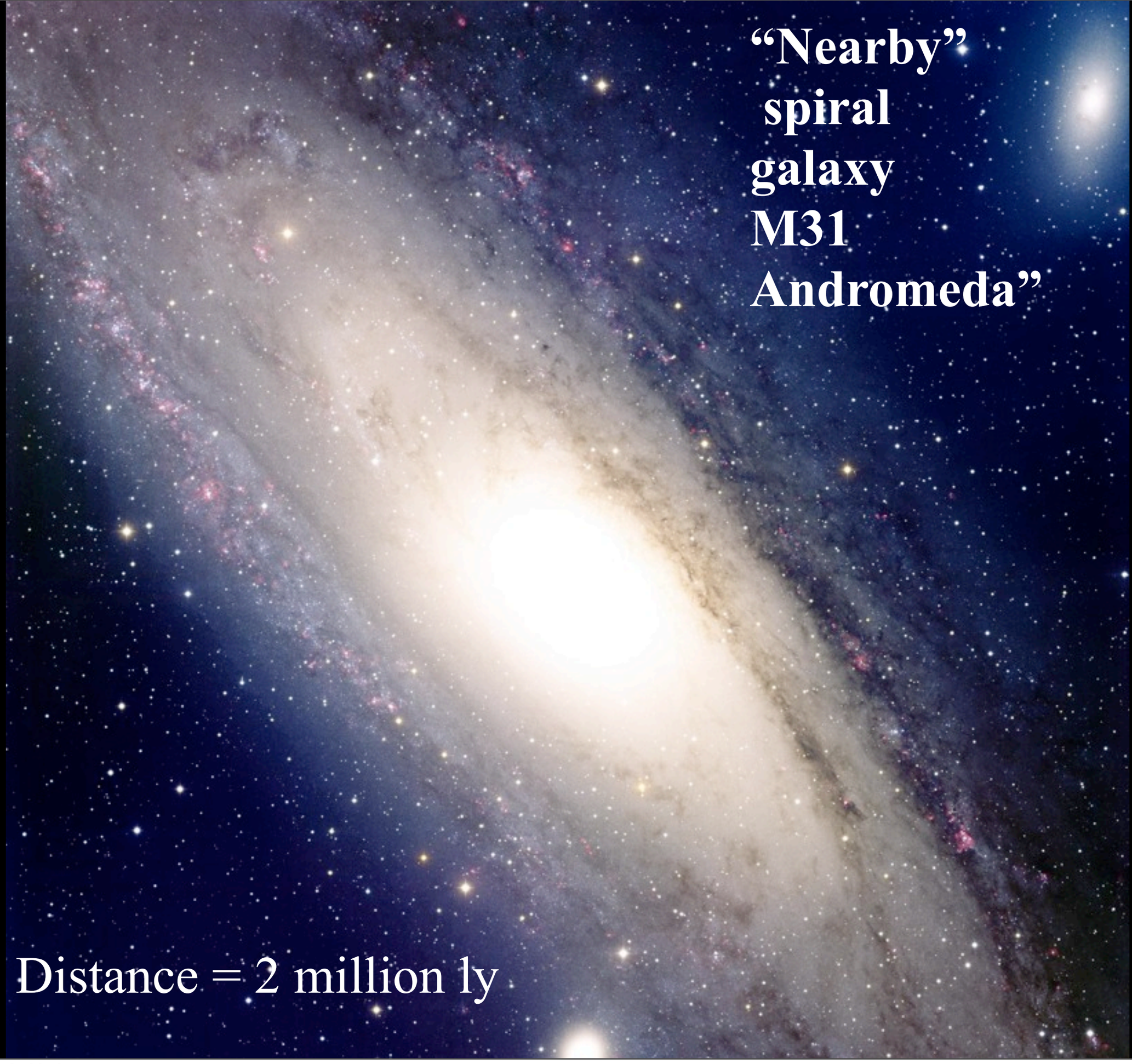
- Caveat is galaxy clusters

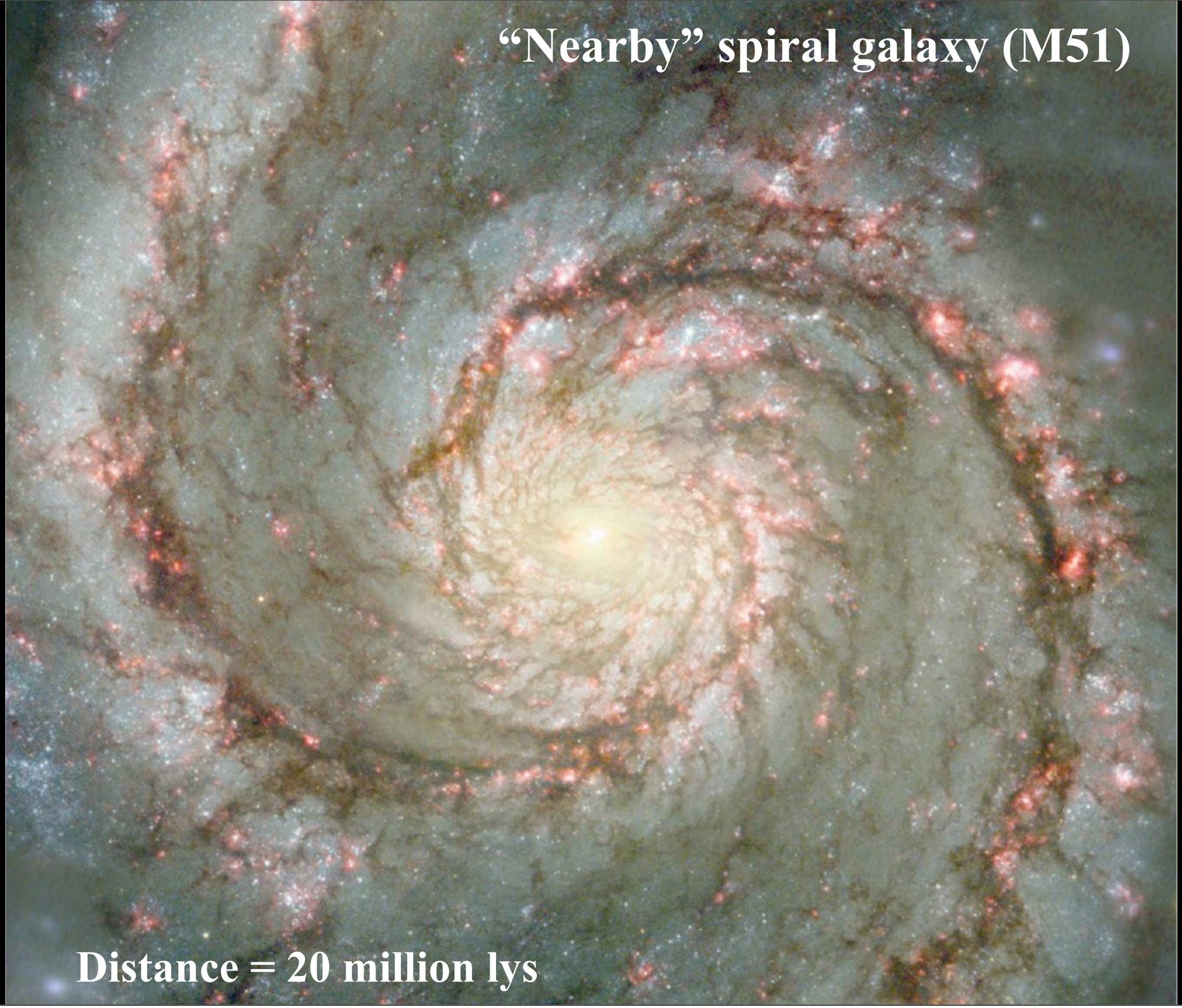


Distant galaxies:

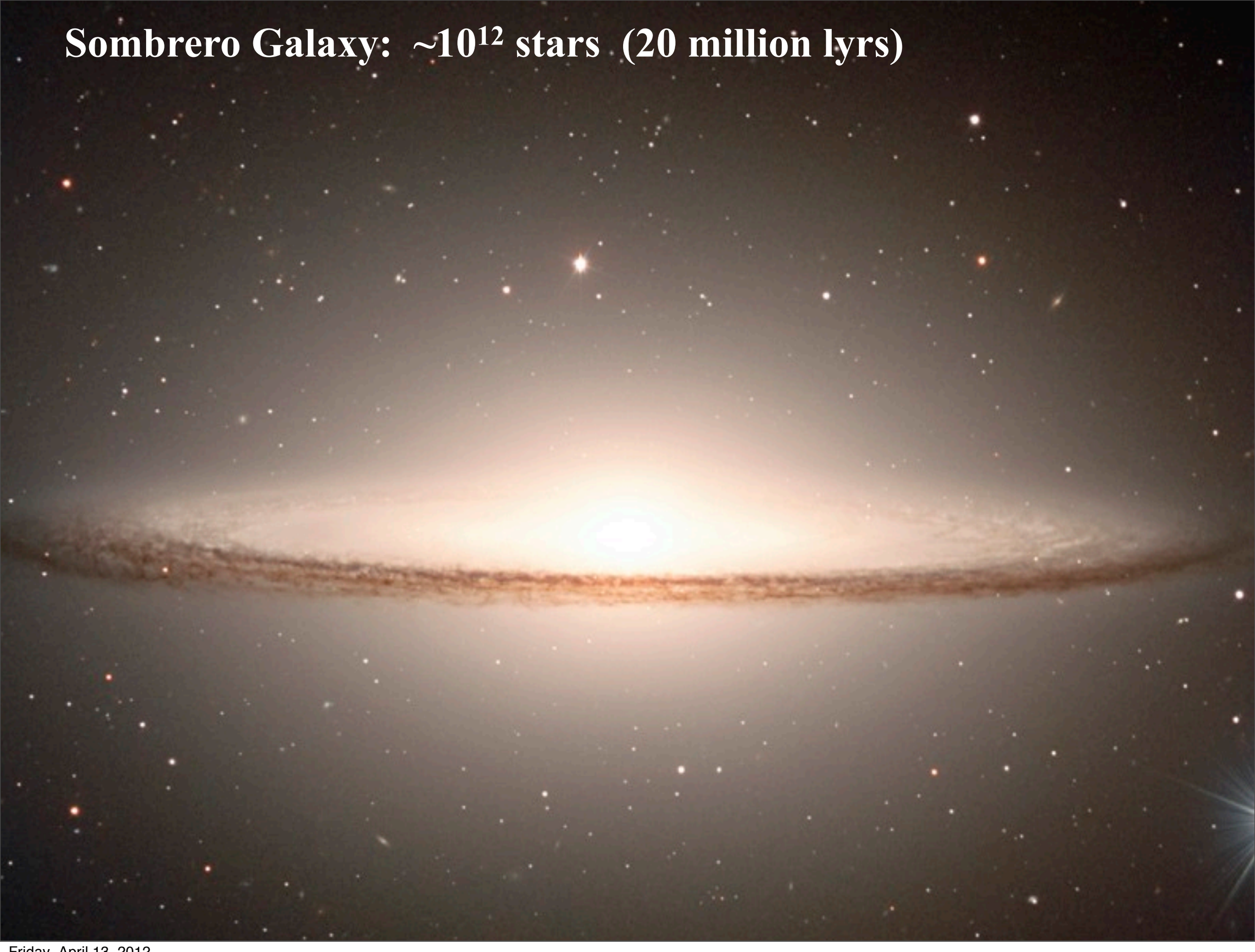
- The deepest optical image of a patch of sky
  - Like looking back in time …
  - Galaxies as they were, 1 to 10 billion years ago.




“Nearby”
spiral
galaxy
M31
Andromeda”
Distance = 2 million ly


“Nearby” spiral galaxy (M51)
Distance = 20 million lys

Sombrero Galaxy: ~10^{12} stars (20 million lyrs)

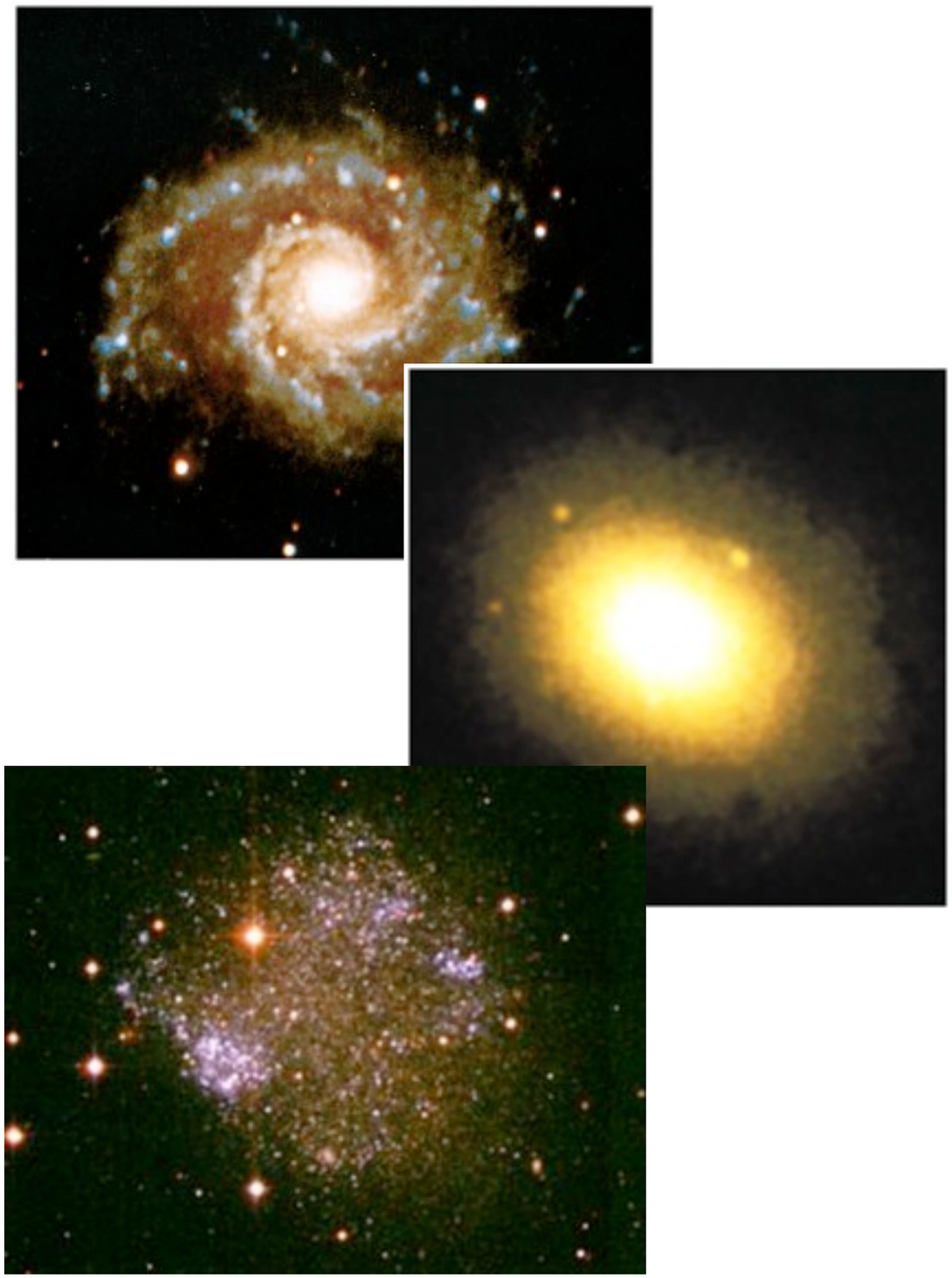


Galaxies are the Fundamental "Ecosystems" of the Universe

Three Main Types of Galaxies:

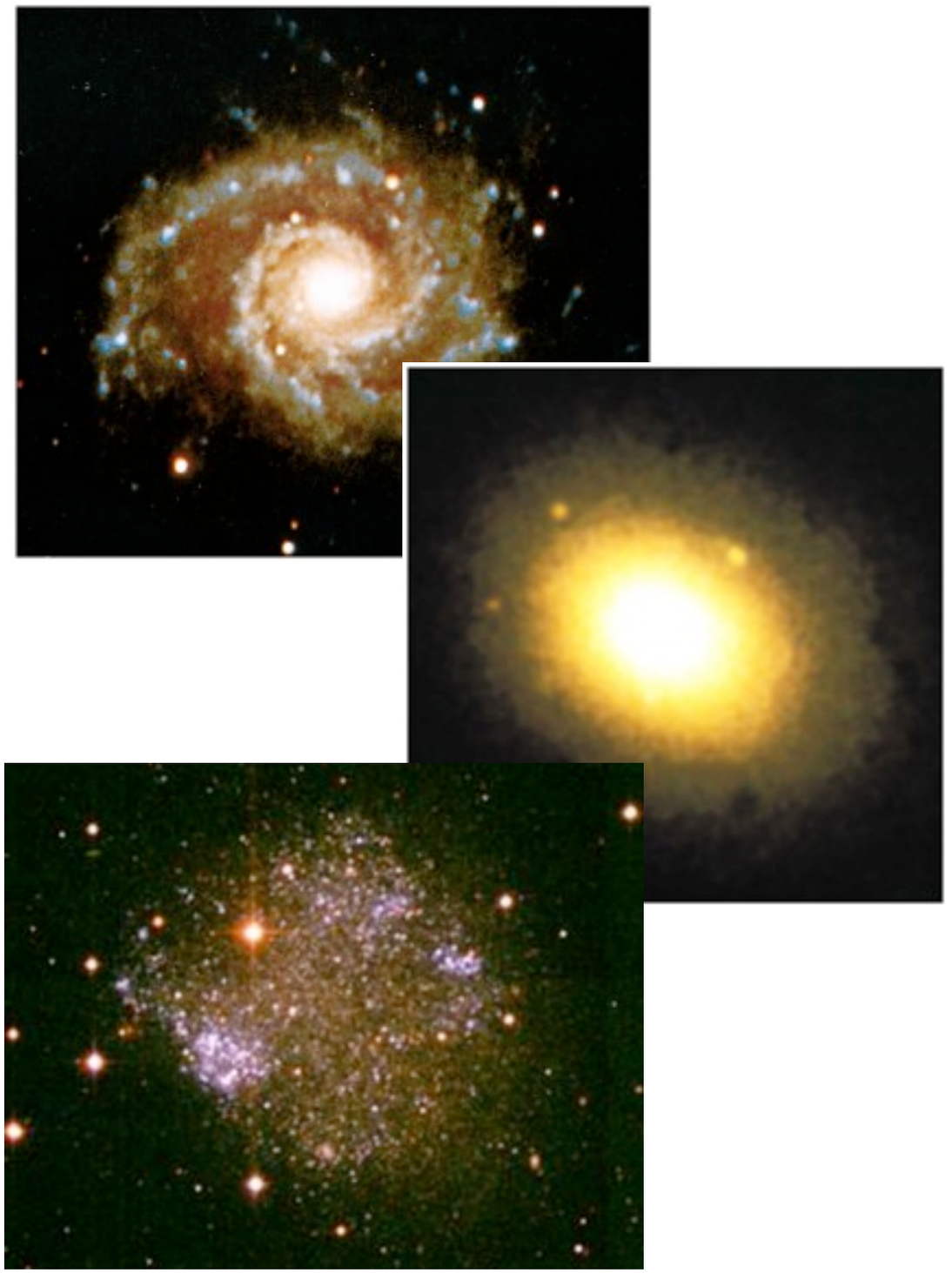
- Spirals (77%)
- Ellipticals (20%)
- Irregulars (3%)

Classes of Galaxies



Classes of Galaxies

- Spirals (S)
  - Basic structure: disk and bulge
  - Medium to large galaxies
  - The disk has the young blue stars, while the bulge has older red stars



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Irregulars (Ir)

- Well… odd, irregular structure
- Smaller galaxies
- Mostly young blue stars

Spiral Galaxies

More bulge and tightly wound

Spirals are classified on the amount of bulge component (and how tightly the arms are wound)

These are designated as Sa, Sb, Sc, in order of decreasing bulge

More disk and loosely wound

More disk means more ongoing star formation!

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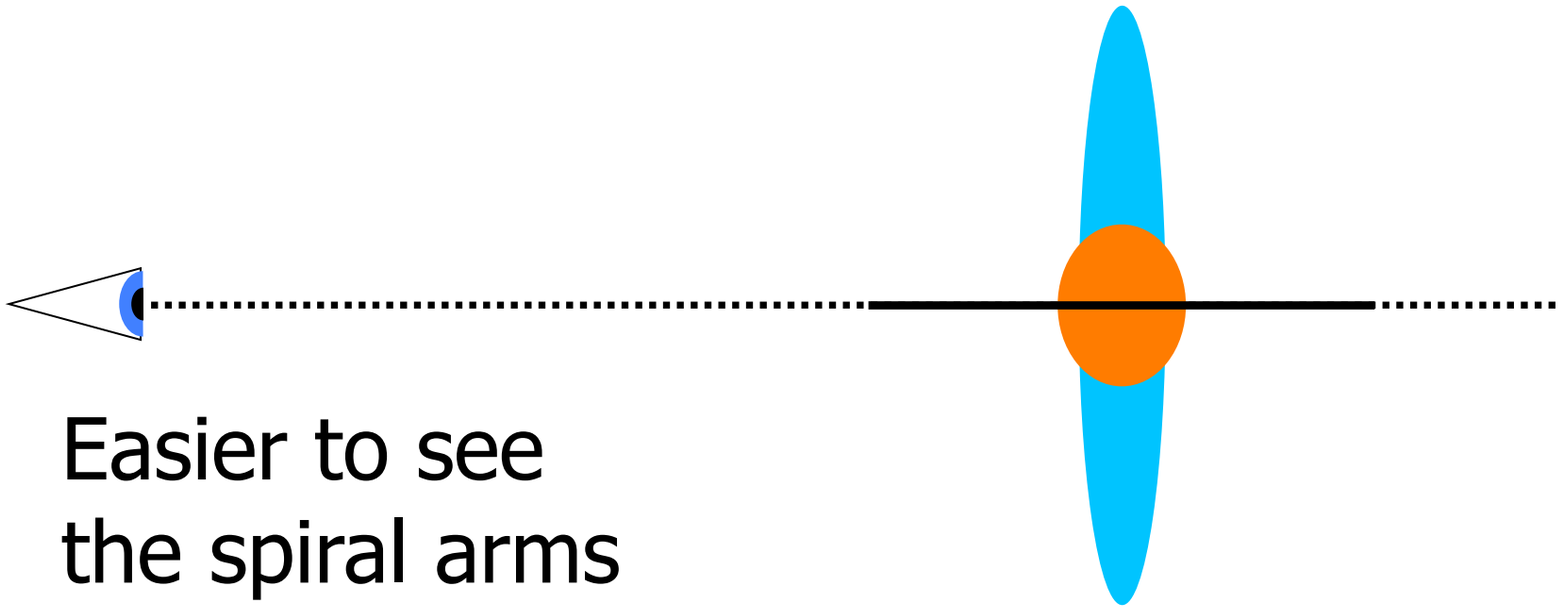
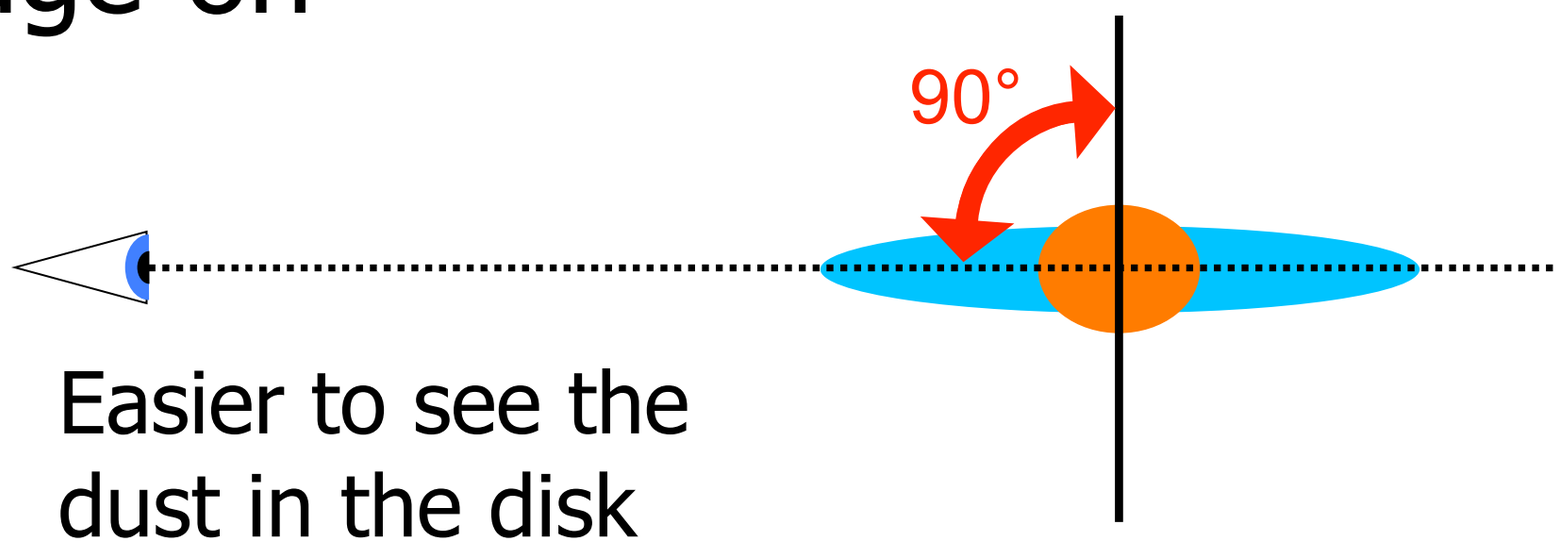
Effect of Viewing Angle

Face-on



Easier to see
the spiral arms

Edge-on



Easier to see the
dust in the disk

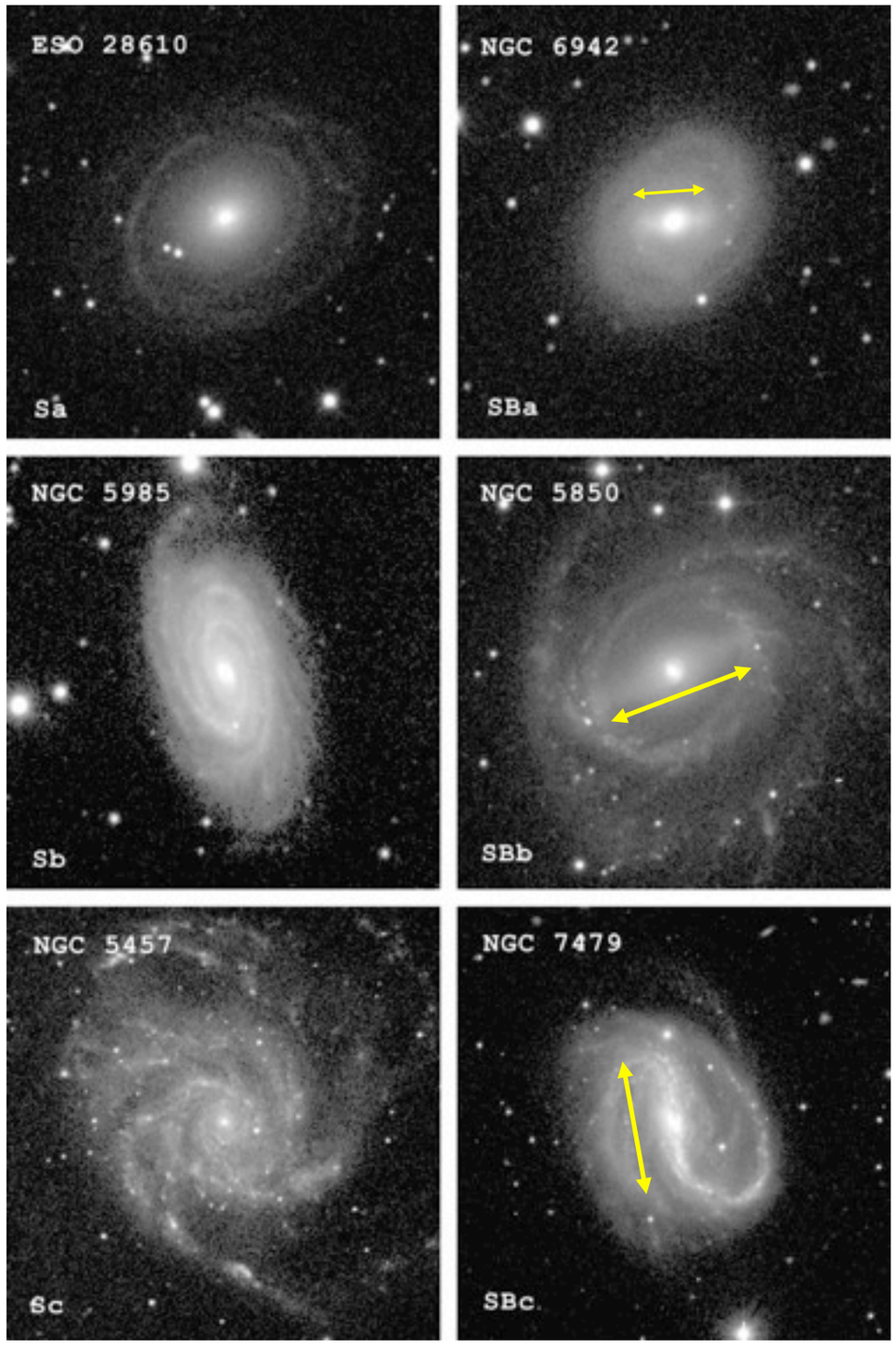
Barred Spirals

About 20% of all spirals are
barred spirals

The spiral arms branch off from a straight bar of stars that passes through the central bulge

They are designated with an “SB” rather than the usual “S” for spiral galaxies

The classes of barred spirals are SBa, SBb, and SBc



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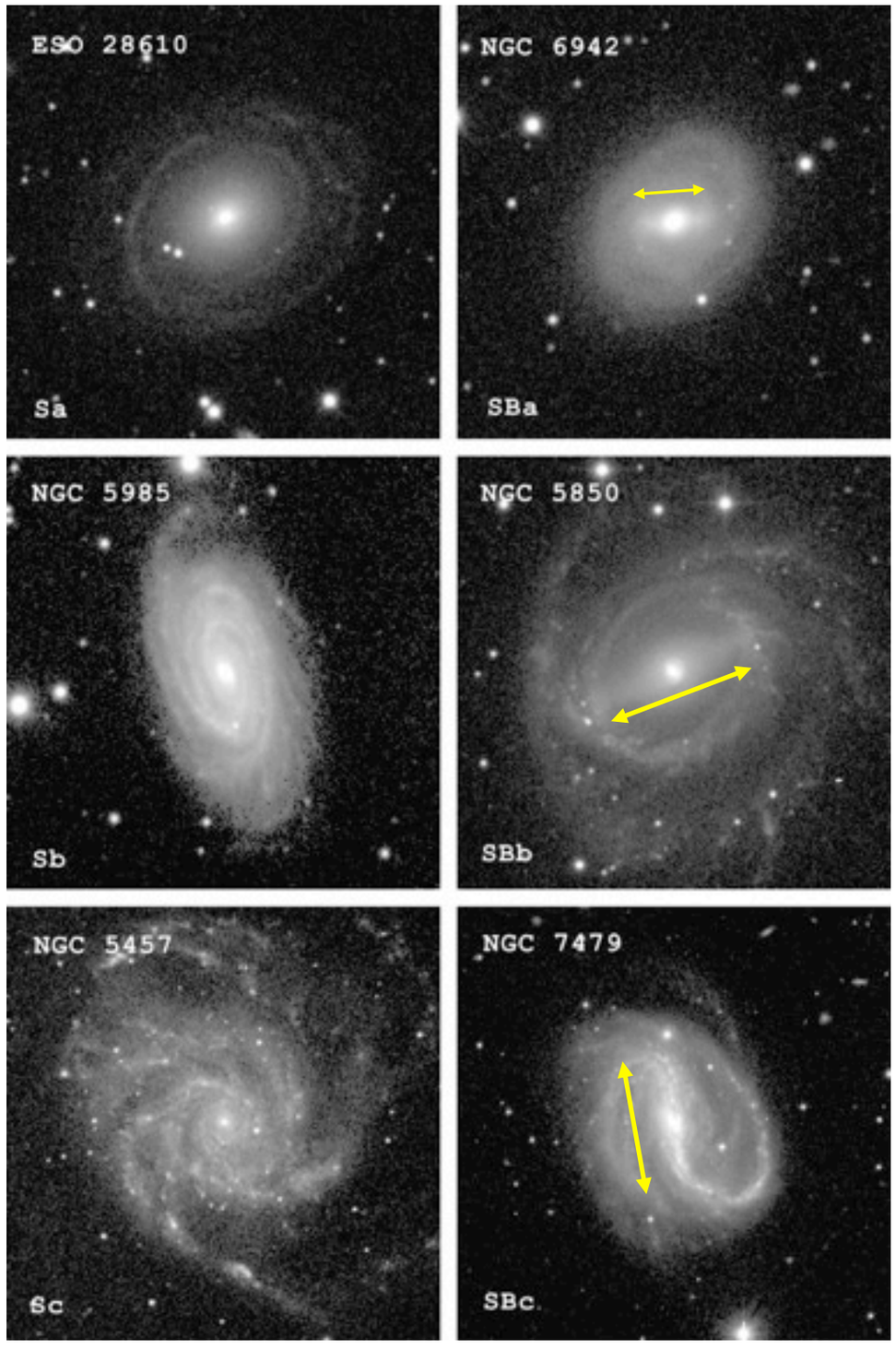
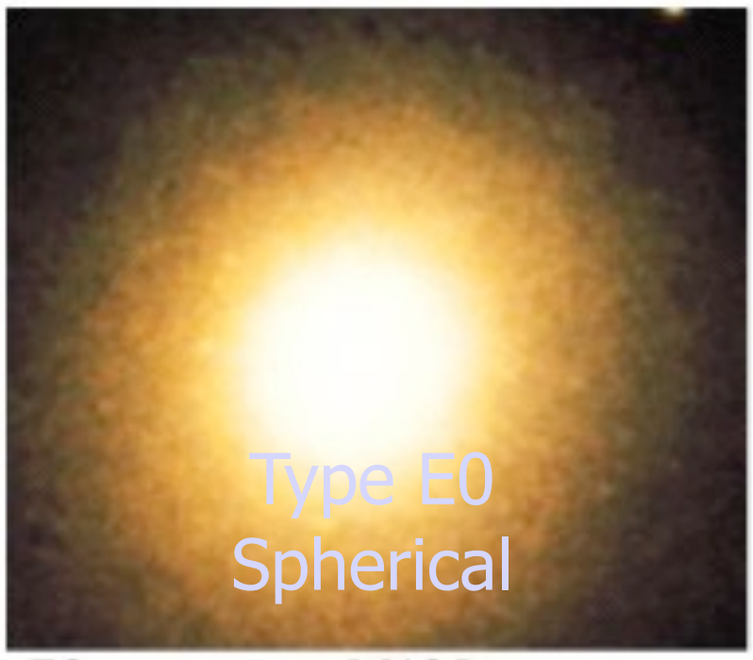
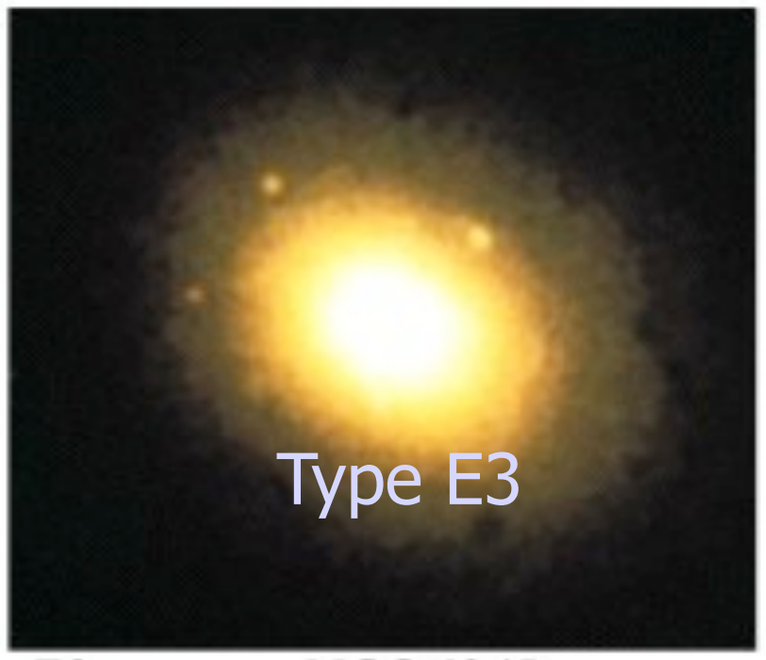


Elliptical Galaxies

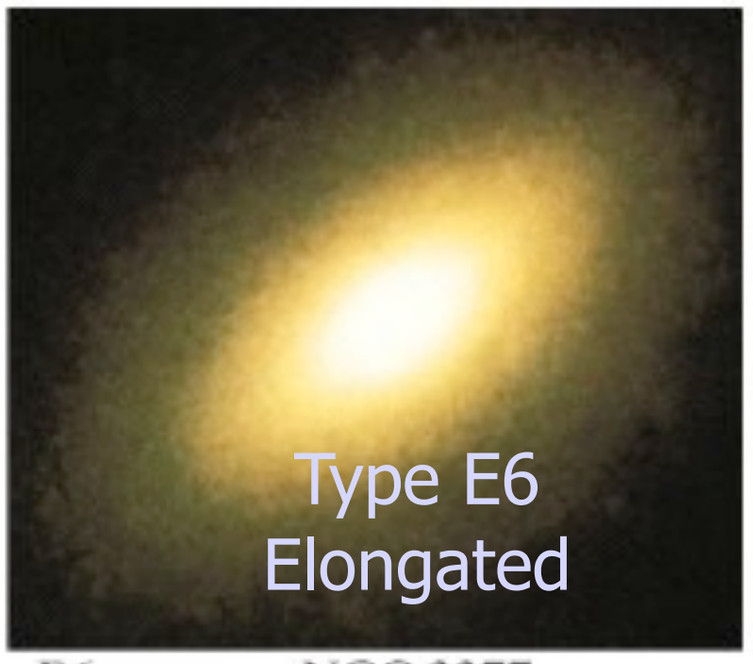
- Like a spiral galaxy's bulge
  - Mostly old, redder stars, little gas and dust
  - No disk organization, stars on random orbits
- Classified by how elliptical they appear
  - E0 (spherical) to E7 (elongated)



E0 M105



E3 NGC 4365

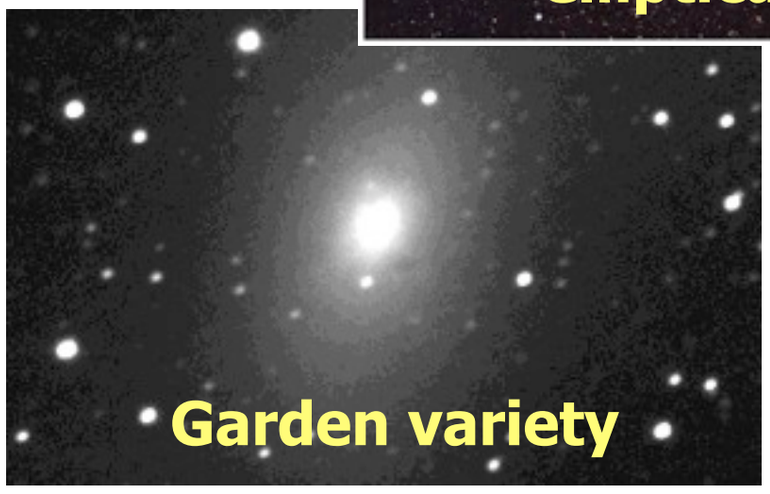


E6 NGC 3377

Varieties of Elliptical Galaxies

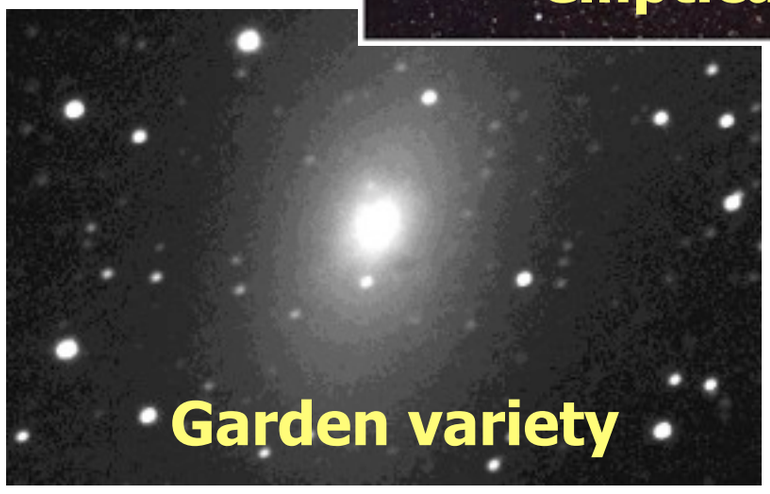
Varieties of Elliptical Galaxies

Ellipticals come in a great range of masses



Varieties of Elliptical Galaxies

- Ellipticals come in a great range of masses
- The largest are giant ellipticals
  - Up to 100+ times more massive than the Milky Way



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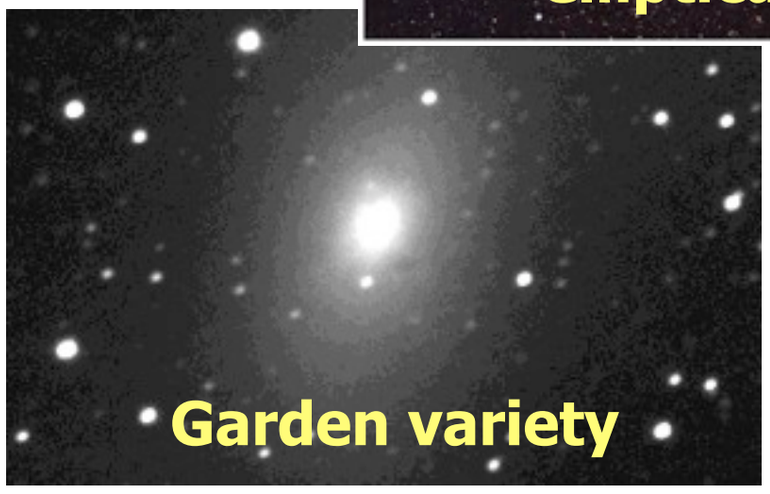
- The smallest are the dwarf ellipticals
  - 10,000 to a million times less massive than the Milky Way
  - Some only a few times larger than a globular cluster!



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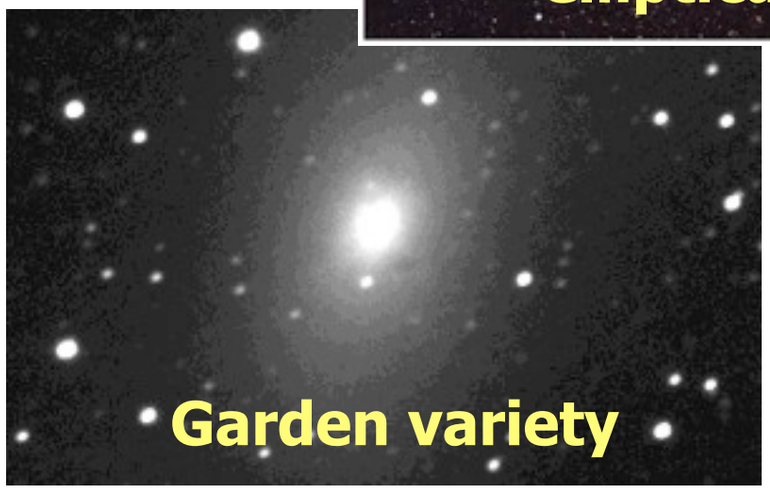
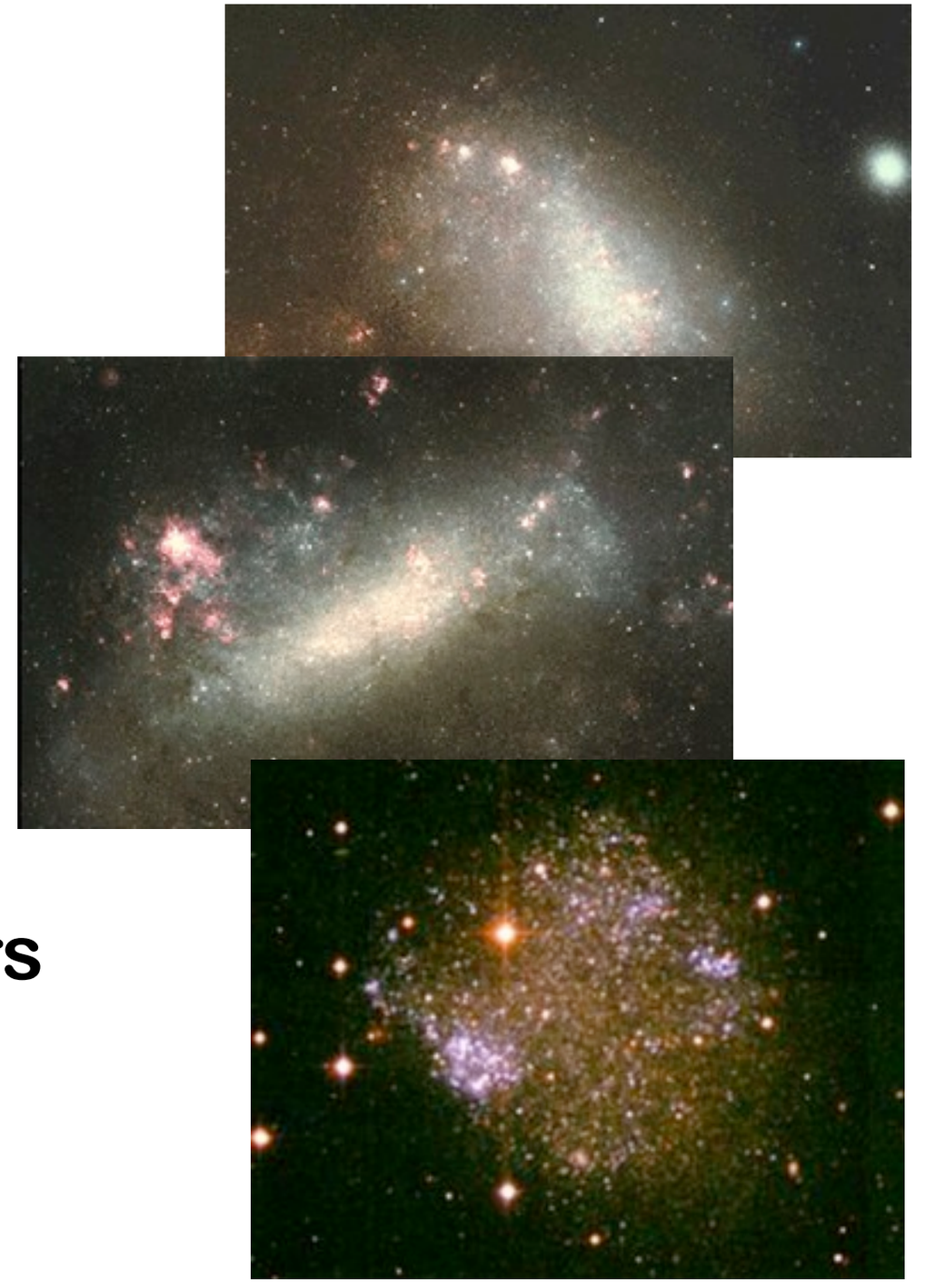
- Of course, there are also "garden variety" ellipticals
  - About 100 times smaller than to equal in size to the Milky Way



Irregular Galaxies

- Chaotic systems of stars
- Prominent examples: The Magellanic Clouds
  - Two of the Milky Way's satellite galaxies
- Generally smaller galaxies
  - Thousands to tens of times smaller than the Milky Way
- Chaotic systems of stars
  - No disk, no elliptical structure
- Dominated by young, blue stars



What Type of Galaxy is the Milky Way?

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- The Milky Way is a spiral galaxy
  - Probably type Sb

What Type of Galaxy is the Milky Way?

The Milky Way is a spiral galaxy

- Probably type Sb

But is likely a barred spiral!

- So, type SBb

Measure other Galaxies
Rotation Curves

What do you think we find?

a)No other galaxies have dark matter

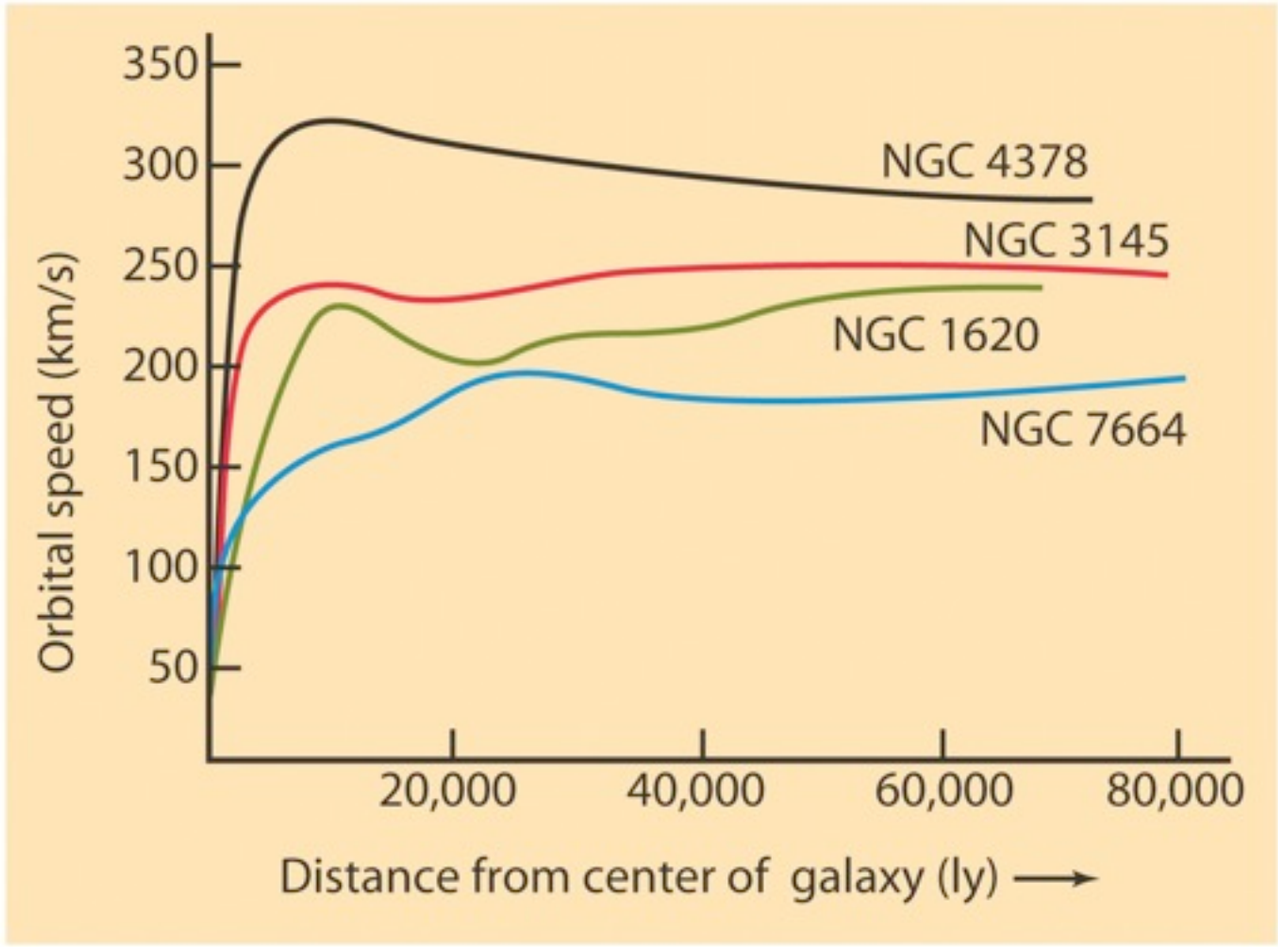
b)Some other galaxies have dark matter

c)All other galaxies have dark matter

Masses of Galaxies

As with the Milky Way, we measure the speed of a galaxy's rotation

Like the Milky Way, other galaxies have a flat rotation curve

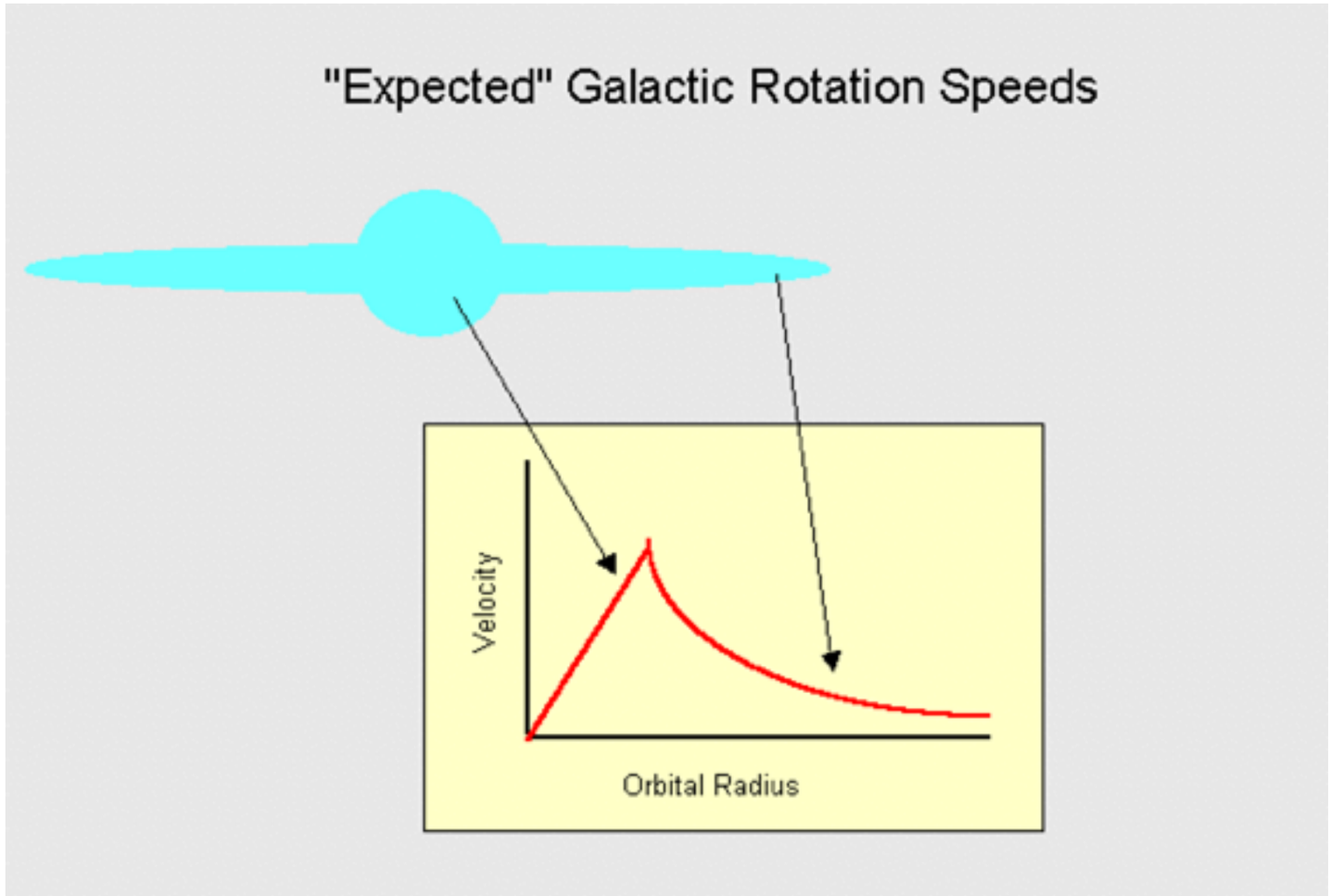


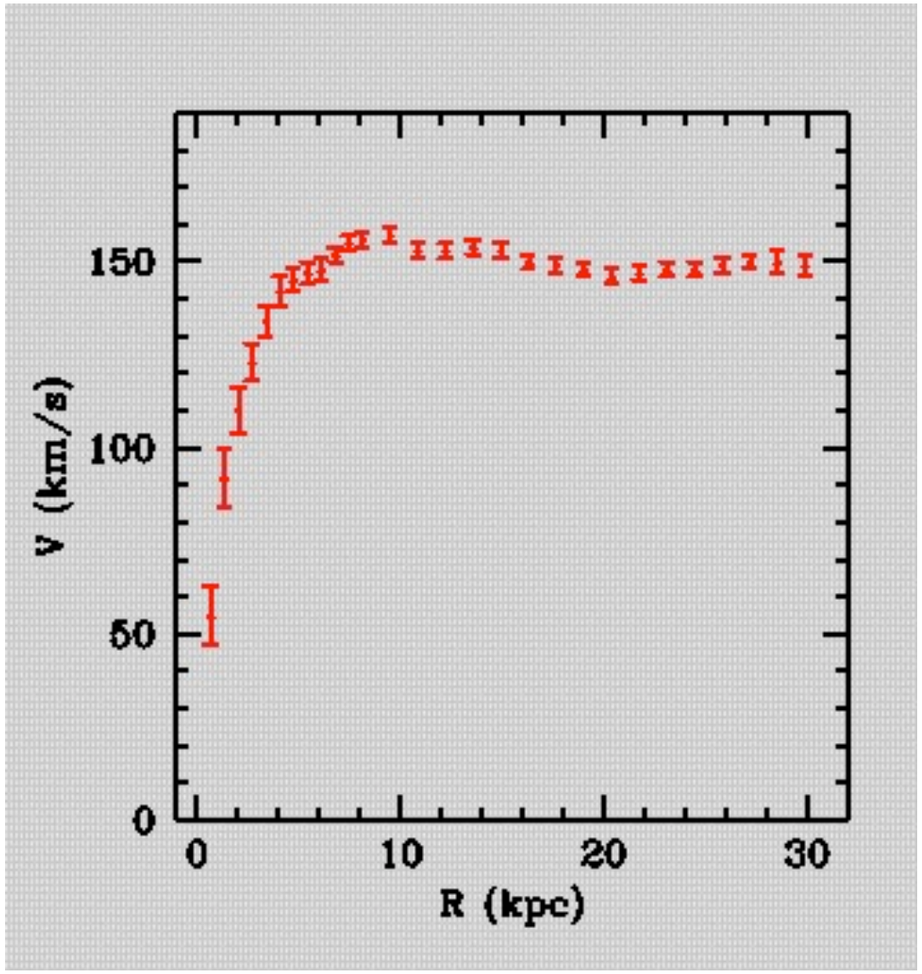
Indicates a halo of dark matter

We aren't special that way either.

Dark matter fills the Universe!

Galaxy Rotation Curve





Where's the matter?