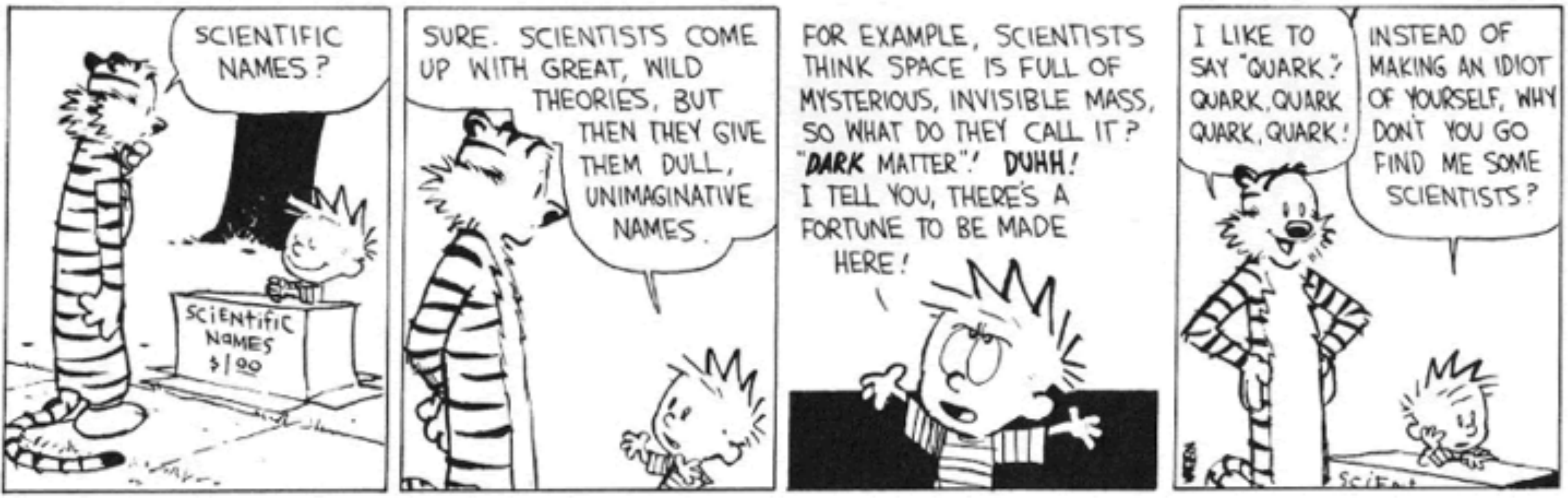
# Killer Skies




- Homework 9 due tonight
- Solar Obs due Friday
- Last time: Center of the Milky Way
- Today: Dark Matter

Music: *Galaxies* – Laura Veirs

# Special Extra Credit Opportunity

- A View of the Moon: Lecture by Jim Kaler
- Attend lecture and Moon viewing at Obs.
- Write ~1.5 page paper of interesting aspect, what you learned, etc. plus image of Moon through telescope
- Worth 1% on final grade

7pm Nov 19th, Rare Book and Manuscript Library on the 3rd floor of the UIUC Main Library (room 346).

# Top 10 Ways Astronomy Can Kill you or your Descendants

1. Impacts! Splat.. Boom… Watch out for space rocks!
2. Solar storms - Magnetic bubble, coil, and trouble
3. Death of the Sun - Burn the land and boil the sea
4. Nearby Supernova - Sirius danger?
5. Gamma Ray Bursts - Cosmic Blowtorches

# Top 10 Ways Astronomy Can Kill you or your Descendants

6. Rogue compact objects - Black holes don't suck, but if they get too close it sucks
7. Relativistic beam - the Galaxy is trying to kill us?
8. Galaxy Collisions - Milky Way vs. Andromeda

# Imagine

After getting flung 1 billion years into the future in a DeLorean, you notice that the sky is different.

The sky is full of a galaxy, up close and personal.

As you keep traveling into the future, you notice that it is changing position as it interacts with the Milky Way.

You sigh in hope as you notice that the Earth and Sun are fine.

Actually, the sky is prettier than before.  This ain’t so bad!

# Imagine

But, in a few million years you realize that the Solar System has been knocked out of its usual Galactic orbit.

And the Solar System is headed straight for the center of the Galaxy….. And there are many dangers there..

As you die from lethal amounts of UV radiation, you wonder why Leslie didn't mention the beauty of the event.

# Top 10 Ways Astronomy Can Kill you or your Descendants

Our sibling galaxy Andromeda is heading right for us, on a collisions course at 120 miles/second! In about 2 billion years, they will collide. Train wreck!

Remember Galaxies mostly empty space, so stars will not impact.

# Cannibalism?


http://www.youtube.com/watch?v=zgAdDDdNOqO



If it keeps getting bigger, the ring near the center of the galaxy will fall in.

# Recap: Our Milky Way Galaxy

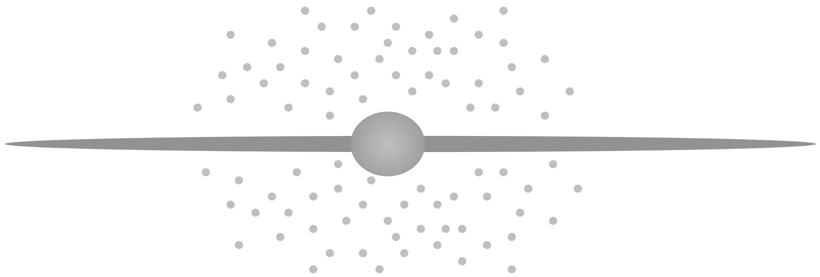
## Milky Way in sky (2D):

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

## Milky Way in 3D space:

- a disk of stars
- razor-thin: like stack of 3 DVDs

## Where are we in disk?



Milky Way disk: edge-on view

## Result: we are off-center!

- we live in Milky Way suburbs!

# Question

**In the Milky Way, the Sun is located**

a) in the halo.
b) in the disk.
c) in the center.
d) in a globular cluster.
e) in the bulge.



Answer: B

# Milky Way: Motions

## Milky Way contains about 100 billion stars

- and thus has mass of **at least $10^{11}$ $M_{sun}$**

  *Q: why at least this big? why might it be bigger?*

## Huge mass = large gravity

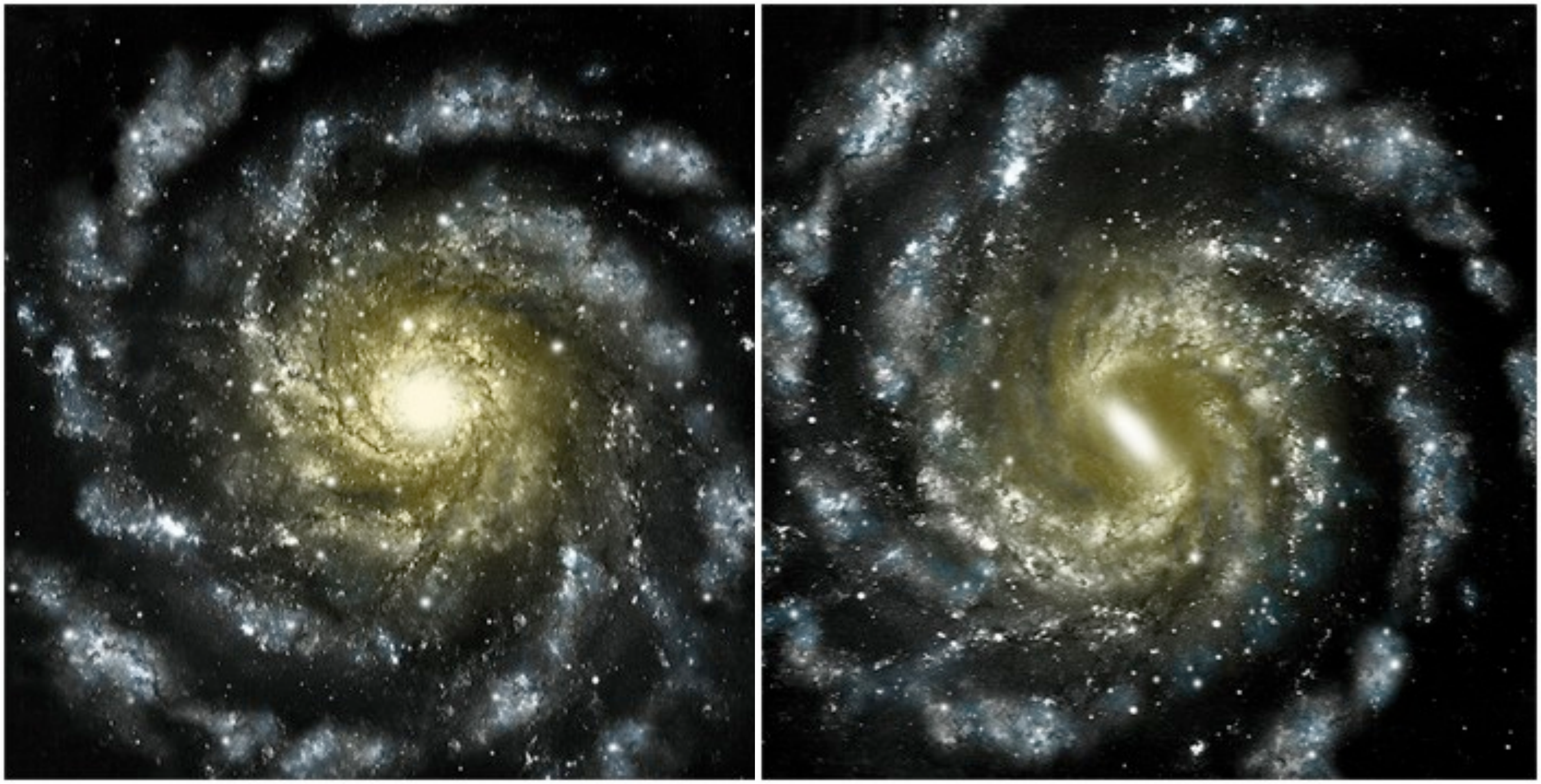
- all stars pull on all other stars
- gravity binds the galaxy together!
- large force must mean large accelerations

  remember: **F = ma**!

## so: objects in Milky Way must be in motion

## But what is the pattern of motion?

# Do Galaxies Spin?



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

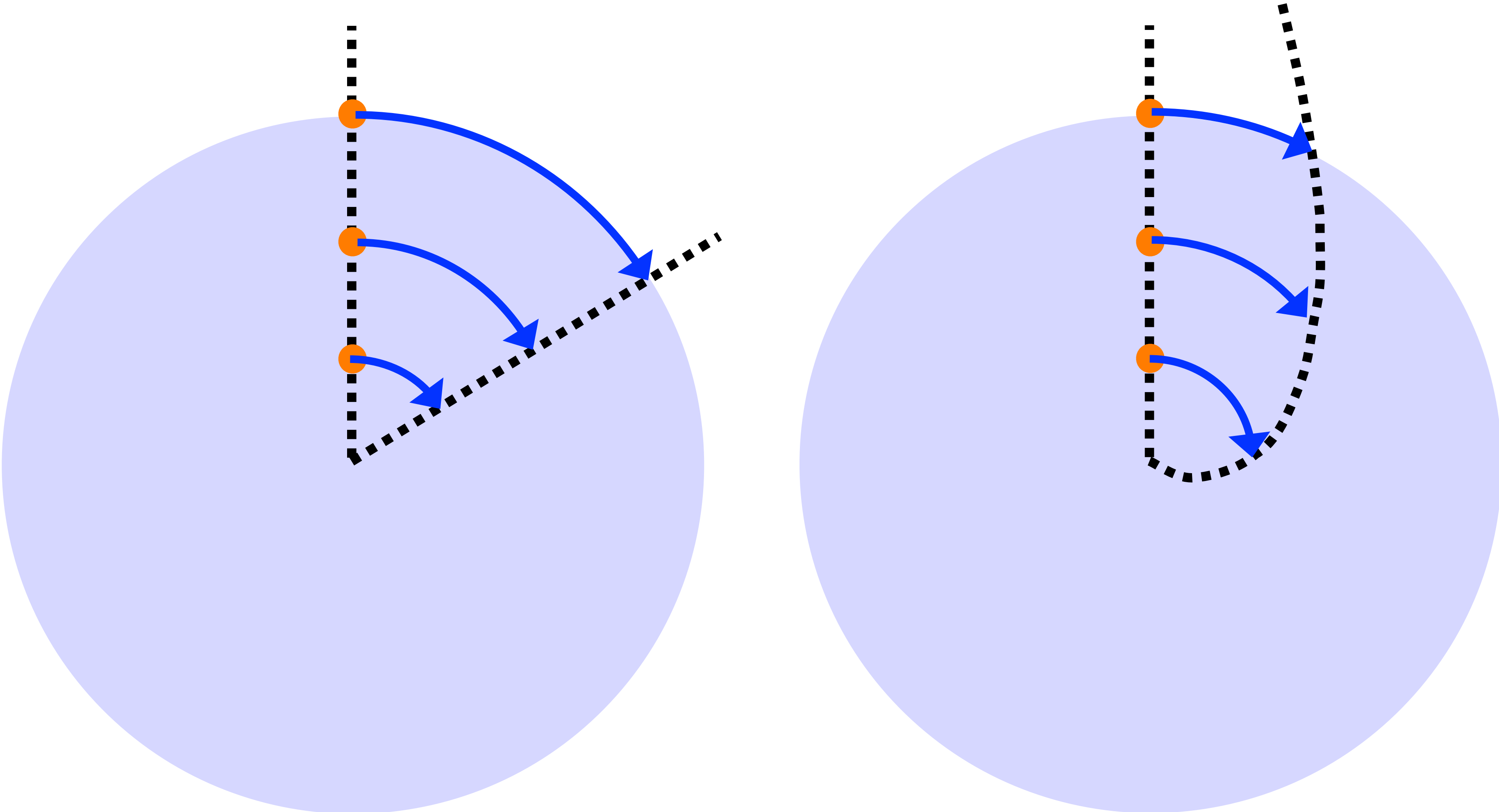
# Rotation of the Galaxy

Similar to the planets orbiting the Sun, the stars and gas of the Galaxy orbit the nucleus

How does the Galaxy rotate?

Like a DVD?

# Solid vs. Differential Rotation



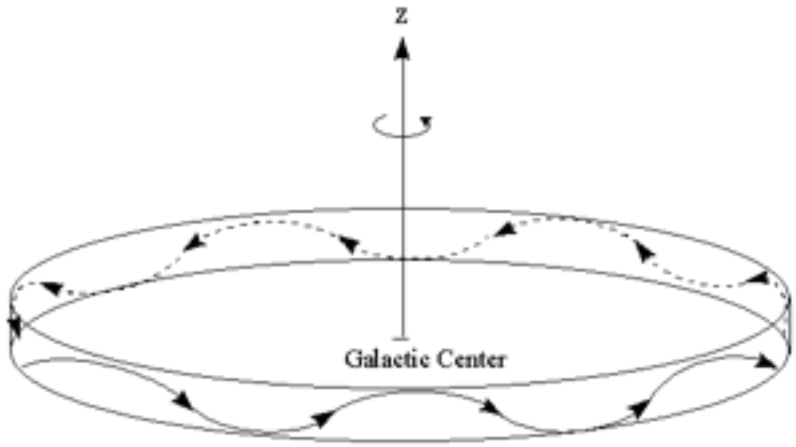
Same angular speed
(degrees per year)

Same linear speed
(lyrs per year)

# 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

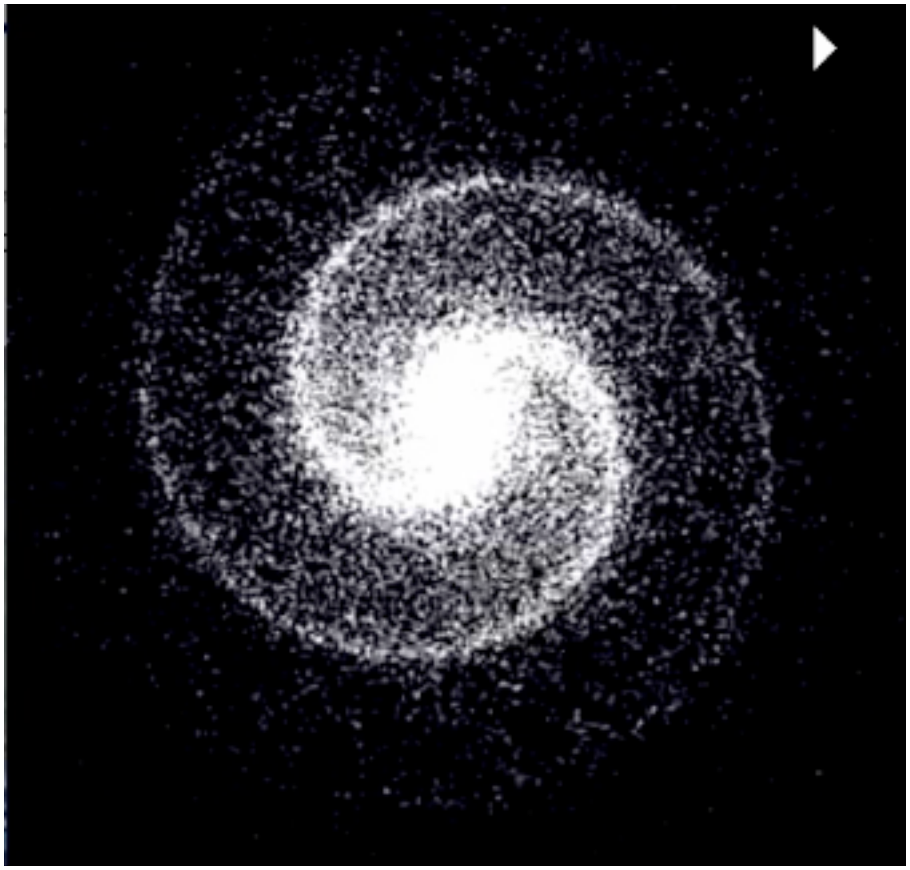


# Rotation of the Galaxy

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

# Are the Galaxy's spiral arms physically connected structures?

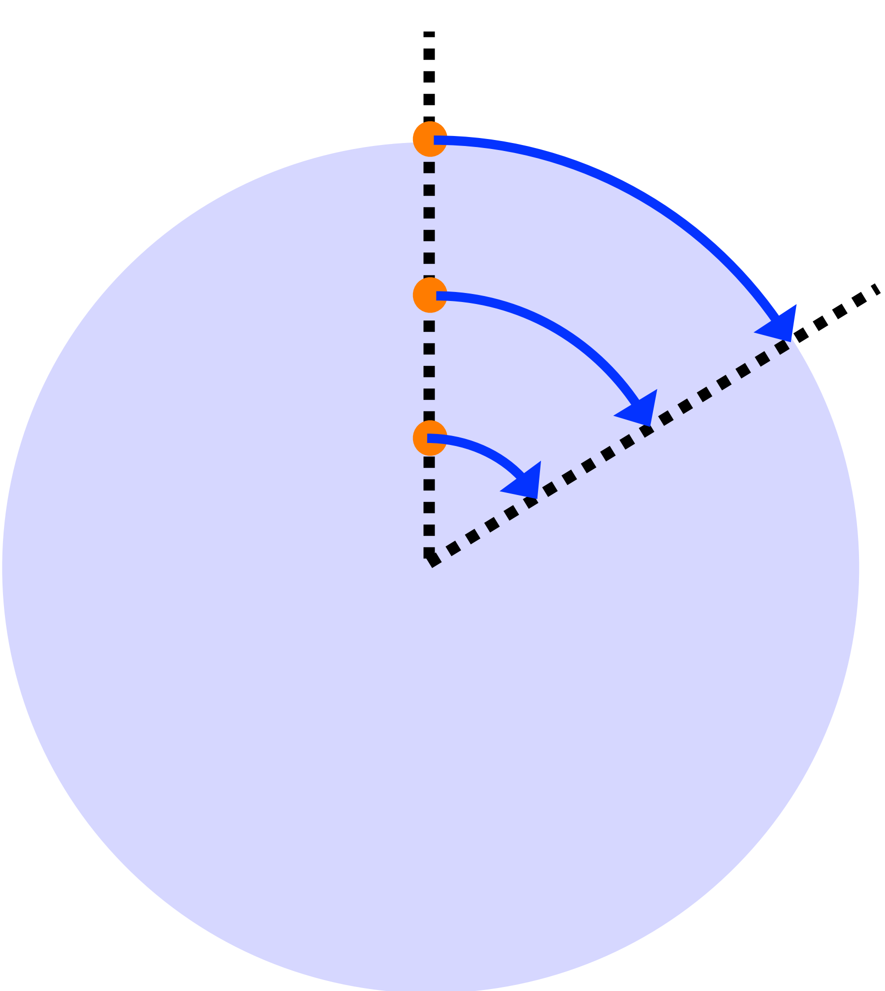


**If they were, the Galaxy would rotate like a solid body (think wheel), but we don't observe that.**

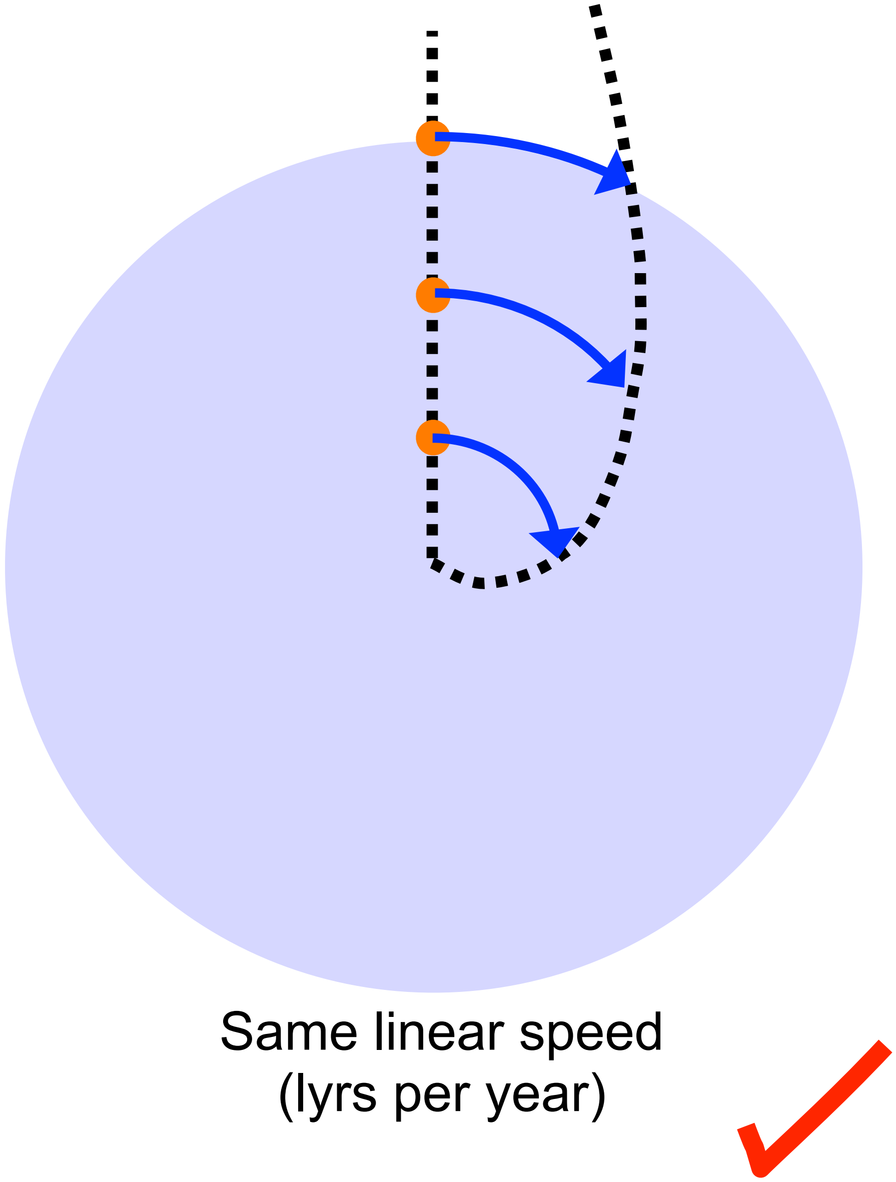


We can observe the motions of stars and we do not see them move as solid body rotation.

# Solid vs. Differential Rotation



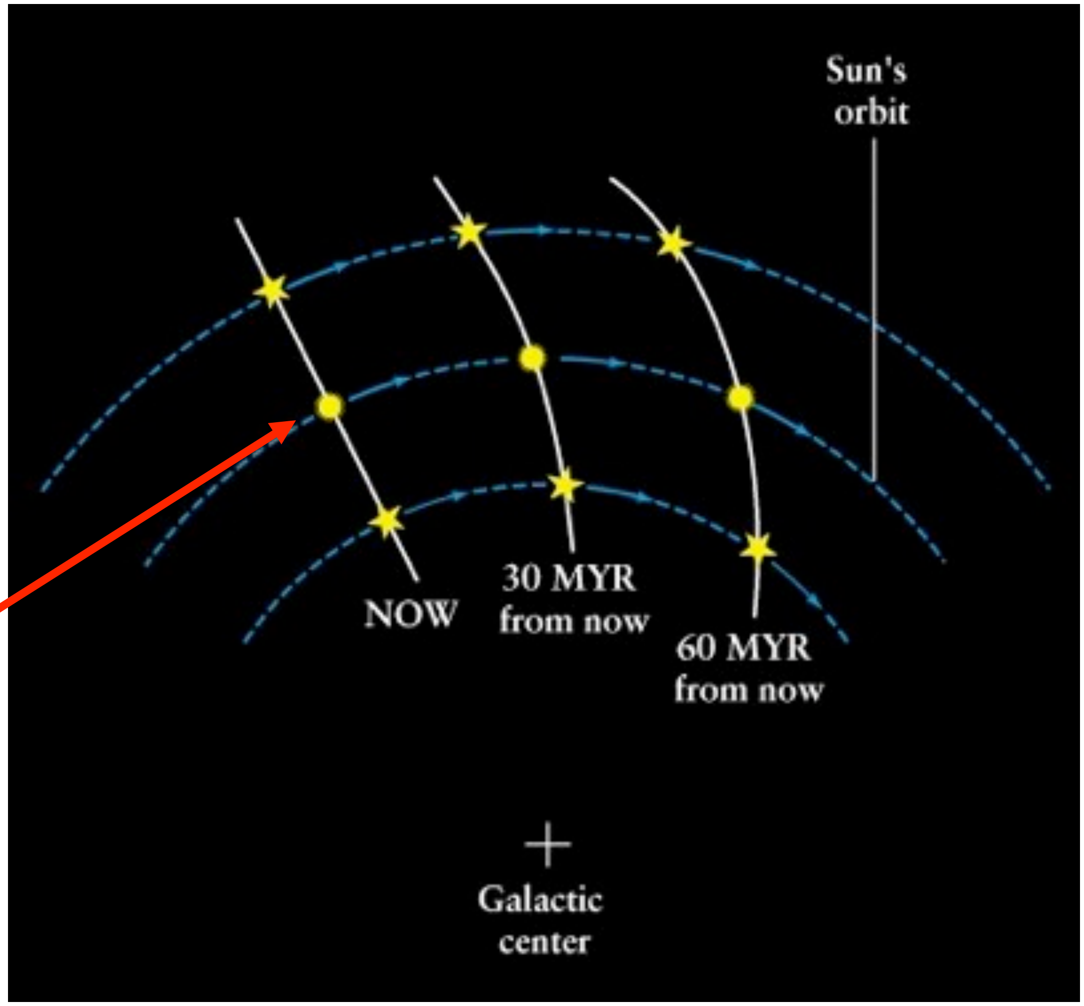
Same angular speed
(degrees per year)



Same linear speed
(lyrs per year)

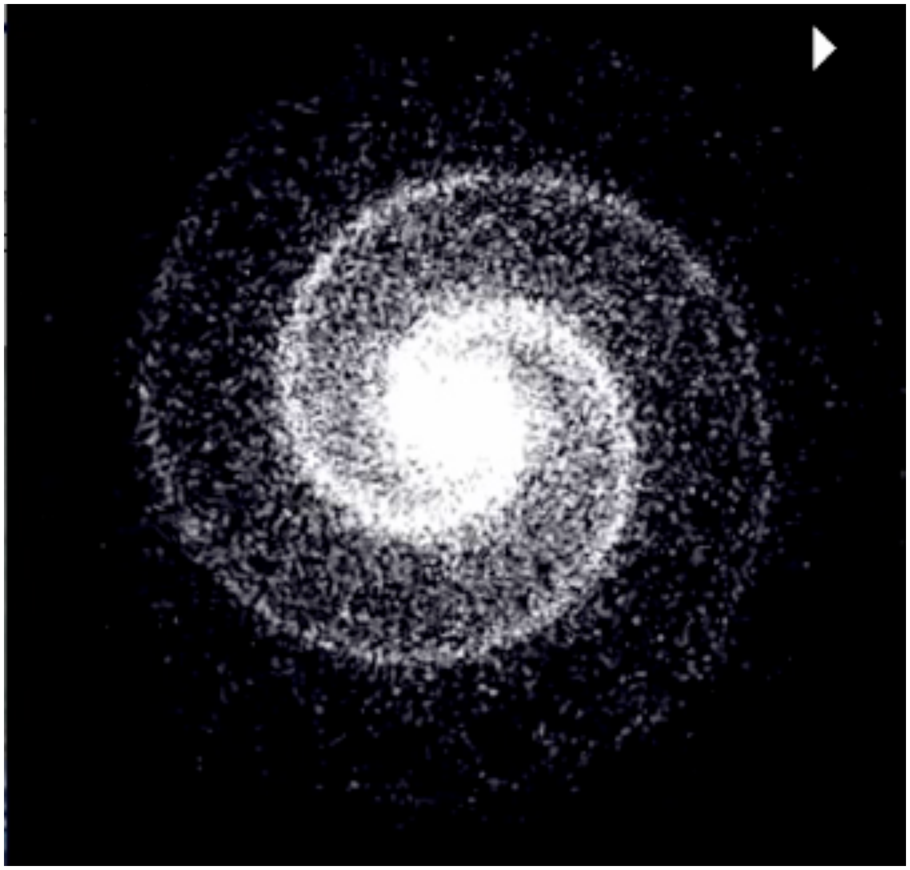
# We are Differential

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!

# Differential and Arms: Winding Problem

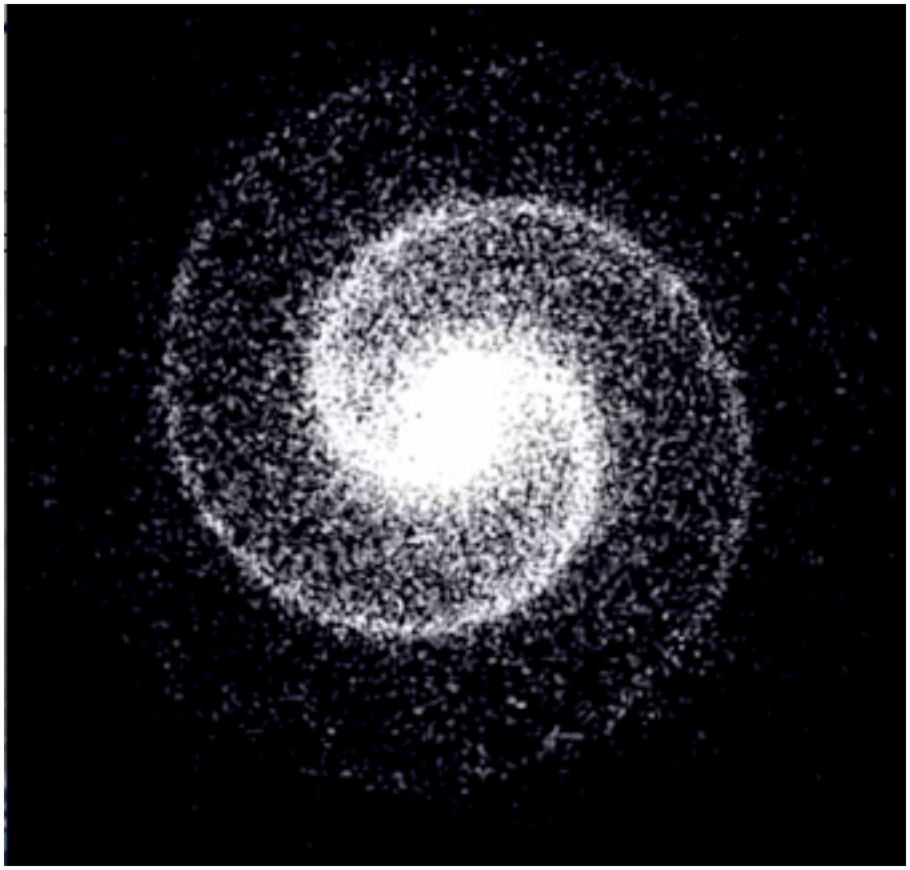


**Differential rotation should mean that spiral arms would dissipate quickly, and they do not. So how do spirals last?**



The stars in the galaxy rotate differentially – stars closer to the center complete a greater fraction of their orbit in a given time. But differential rotation is too efficient in making the spiral arms. After only 500 million years, the arms should be so wound up that the structure disappears. The observations of other galaxies contradicts this: the spiral arms in spiral galaxies rarely have more than two turns. Galaxies are billions of years old so the spiral pattern must be a long-lasting feature. What keeps the spirals "loose"?

# Are the Galaxy's spiral arms physically connected structures?

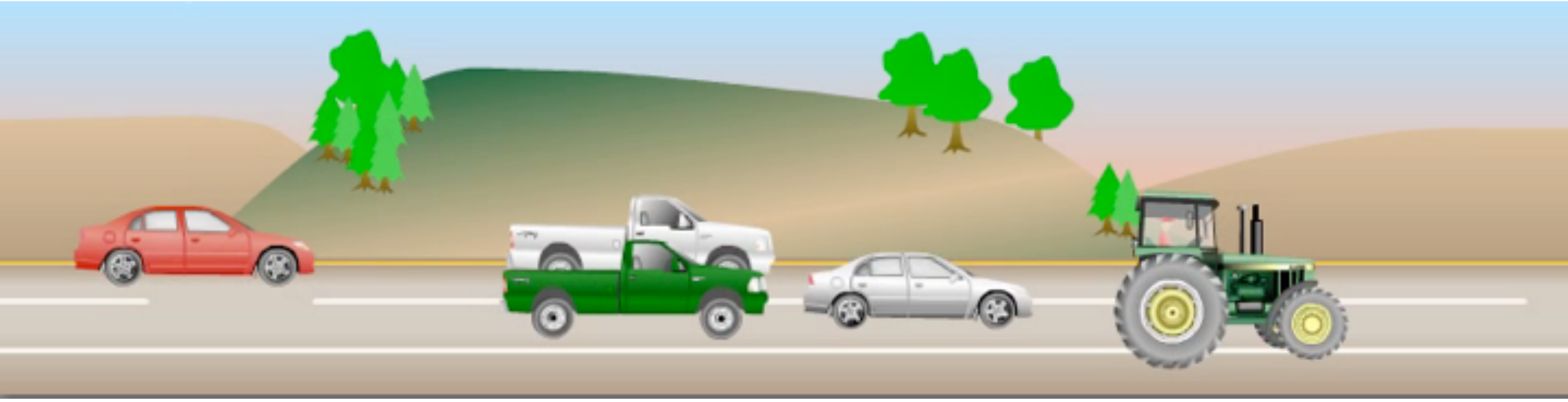


**To fit observations, spiral arms must be a density wave. Stars move into, then out, of the spiral arm as they orbit. A spiral arm is a traffic jam of material. Note that the spiral arms do not rotate, the galaxy does.**



The spiral arms must not be a physical structure but rather a density wave.

# Arm = Traffic Jam

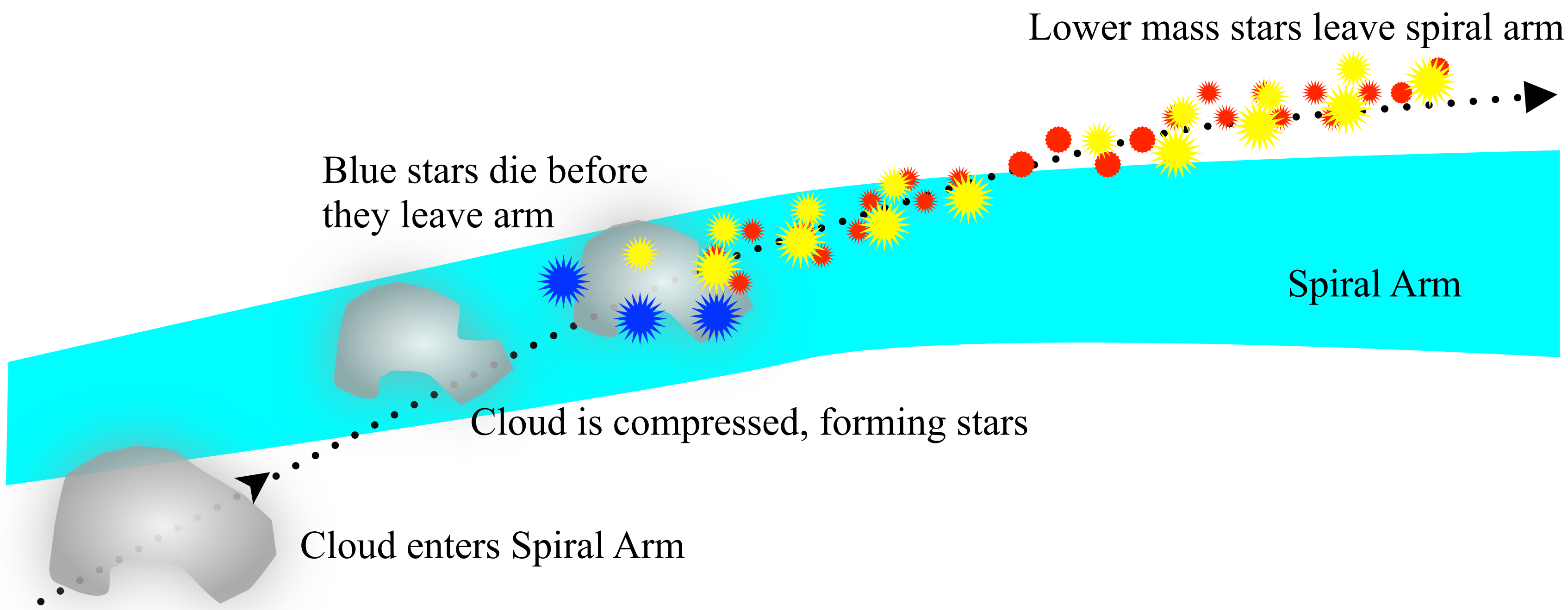


**The tractor causes a brief compression of movement, but the cars in the jam are not permanently stuck. The stars of the spiral arm are not stuck there.**



You can think of the spiral density wave as a temporary compression of movement, like a traffic jam.

# Spiral arms are *density waves*




**Spiral arms are waves of compression that move around the galaxy, triggering star formation**



- Gas clouds get squeezed as they move into spiral arms
- Squeezing of clouds triggers star formation
- Young stars flow out of spiral arms
- The massive blue stars die quickly – within a few million years, so they remain close to the spiral arms in which they formed
- Lower mass stars live much longer lives, so they disperse out of the spiral arms and populate the entire disk

http://youtu.be/O7bbl86rz00

http://youtu.be/c5Us-jonCLA

# Thought Question

Why are spiral arms bright?

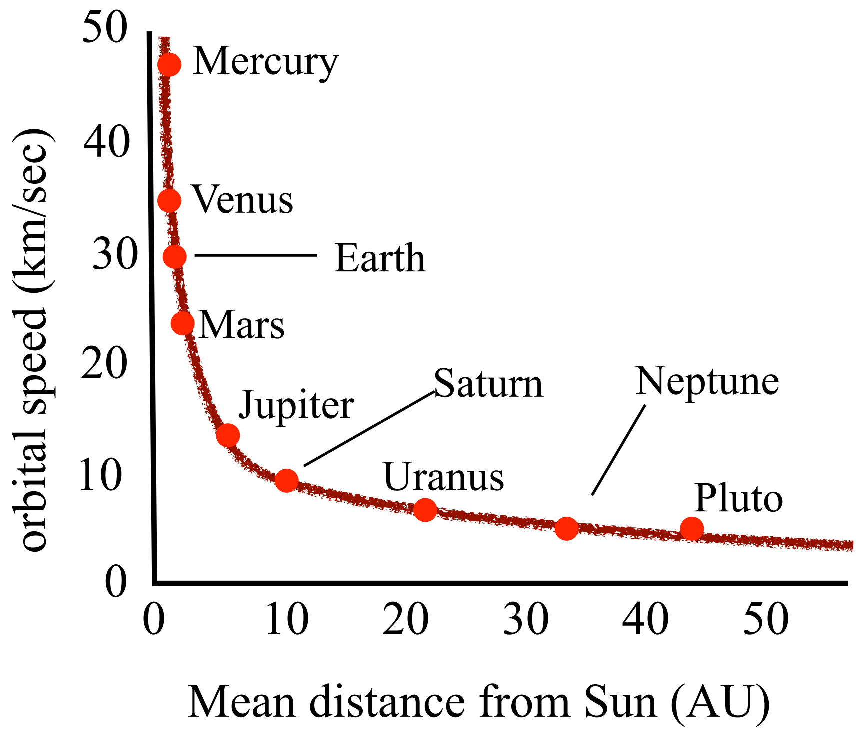
A. Because they contain far more stars than other parts of the galactic disk
B. Because they are the only places where we find stars within the disk of the galaxy
C. Because they contain more hot young stars than other parts of the disk
D. Because they contain more molecular clouds than other parts of the disk



Answer: C.  Red and orange stars are found evenly spread throughout the galactic disk, but blue (brighter) stars are typically found in the spiral arms.

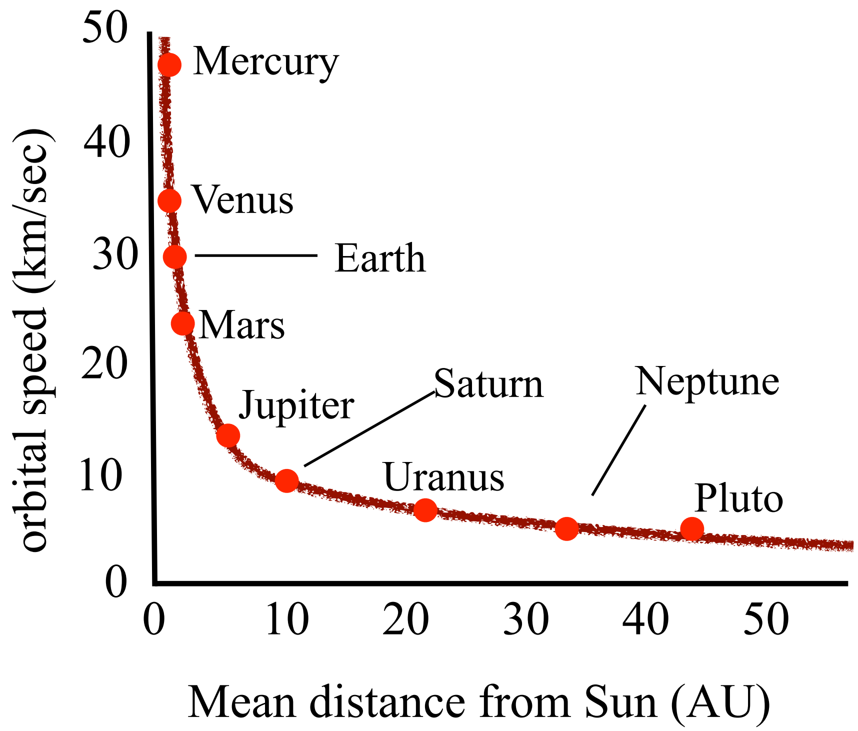
# Rotation Curves

- A rotation curve is a graph that plots orbital speed vs. the distance from the center
- Example: rotation curve of the solar system

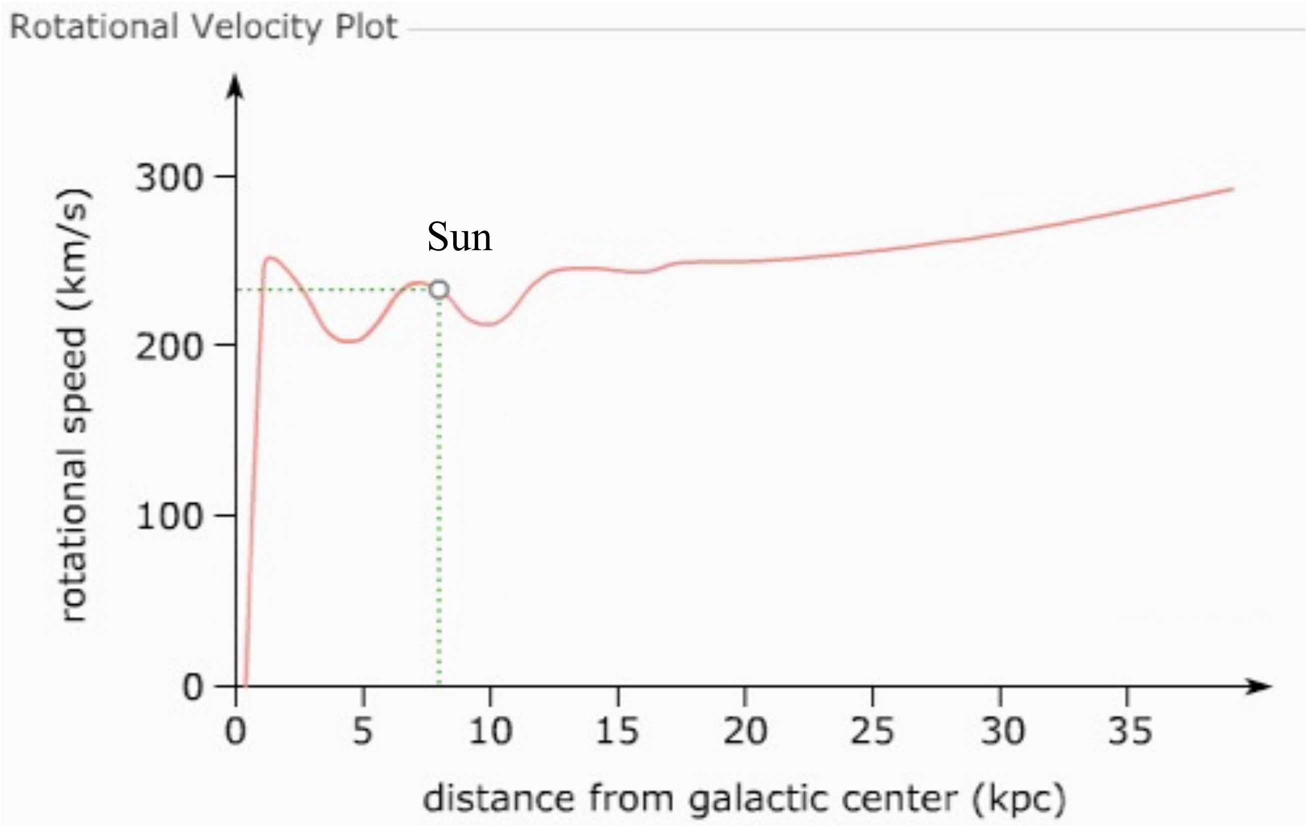


# Rotation Curves

- Since the mass of the Sun dominates, the speed drops, like Kepler would tell us.
- How does it look in the Galaxy?



# The Galaxy's Rotation Curve




**Notice that orbital velocities remain approximately constant beyond the inner few thousand light-years**



How can the speeds remain constant or even slightly increasing the farther away from the center. The light of the Milky Way **drops off**, so it can't be more stars.

1 parsec (pc) = 3.26 light year

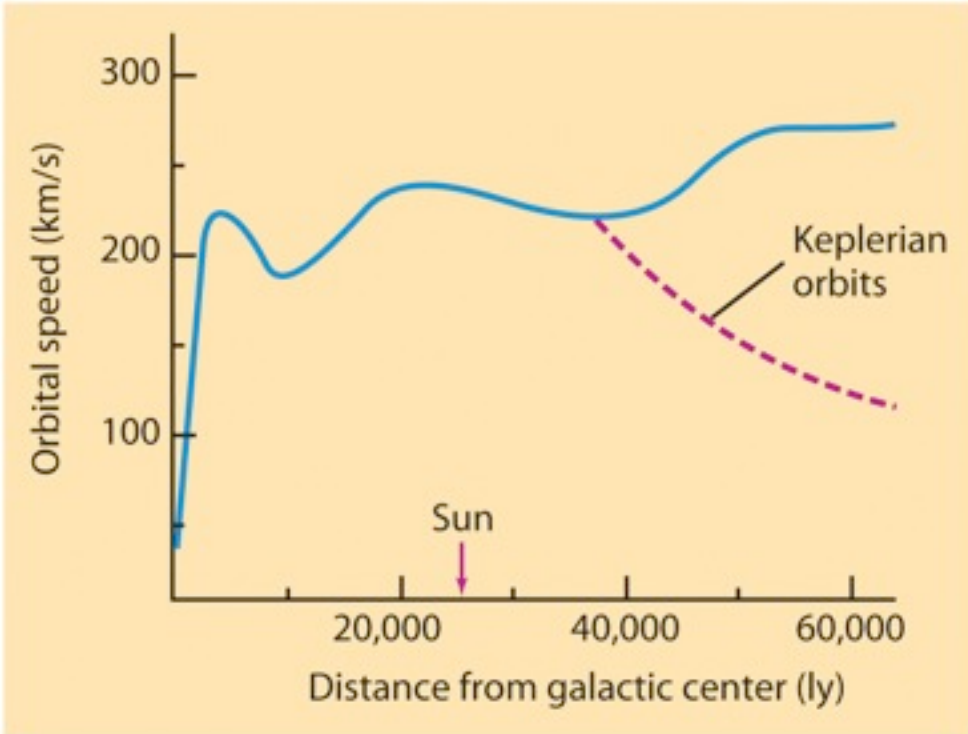
# Whaa?

**Something weird.**

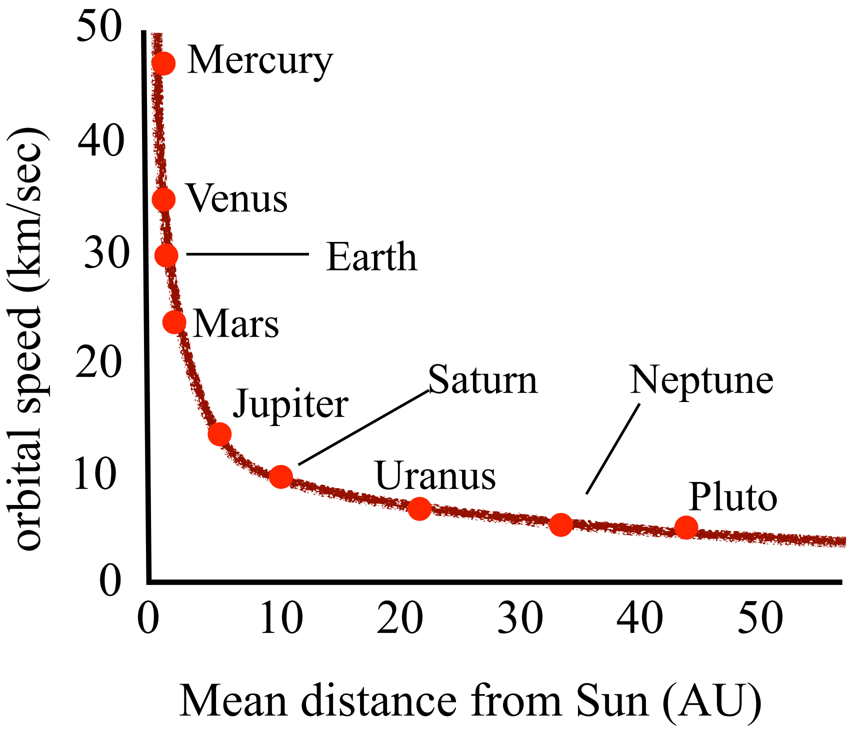
**Rotation speed does not drop off in the outer Galaxy**

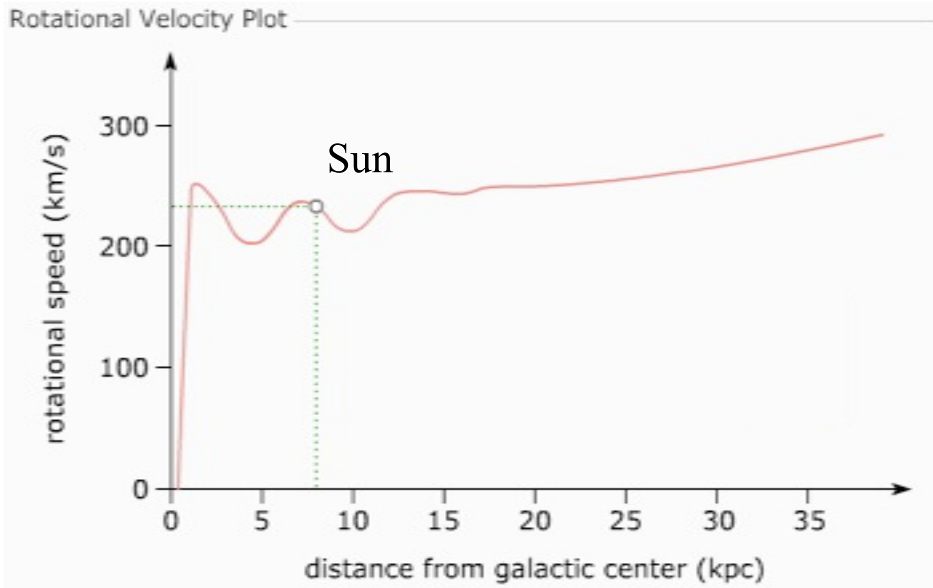
- rotation curve is "flat"
- yet in the outer galaxy there is a huge dropoff in stars, gas, and dust

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



# Rotation curve shape tells us the distribution of mass




**Solar system's rotation curve falls because the mass is in the center (in the Sun)**

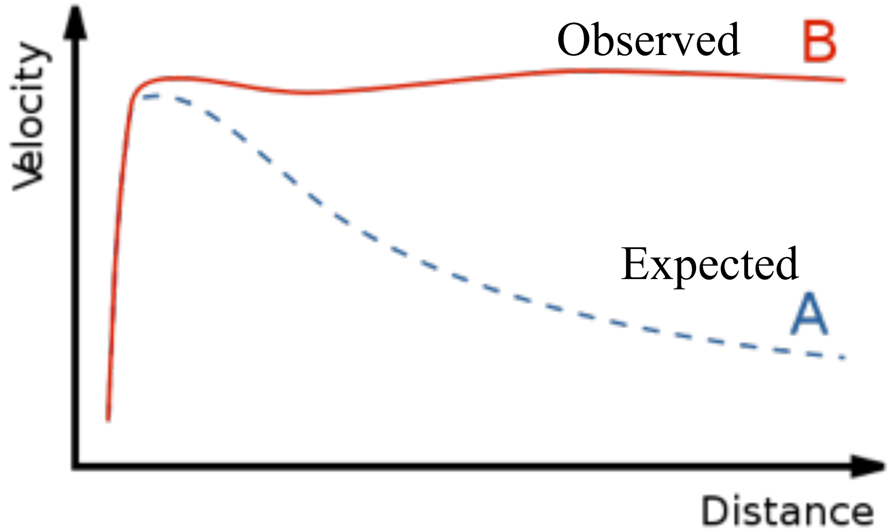
**Galaxy's rotation curve is flat because the mass is spread out**



Curve shape tells us distribution of mass. Mass in the center = falling curve. Mass spread out = flat curve

# Galaxy's rotation curve also shows *hidden mass*

- 80% of the Galaxy's **visible** mass is inside the Sun's orbit
- **Expectation**: Orbital speeds should *decline* with distance
- **Observation**: orbital speeds stay *high*
- **Conclusion**: Distant orbits enclose great amounts of ***unseen mass***




**Rotation curve of the Galaxy**



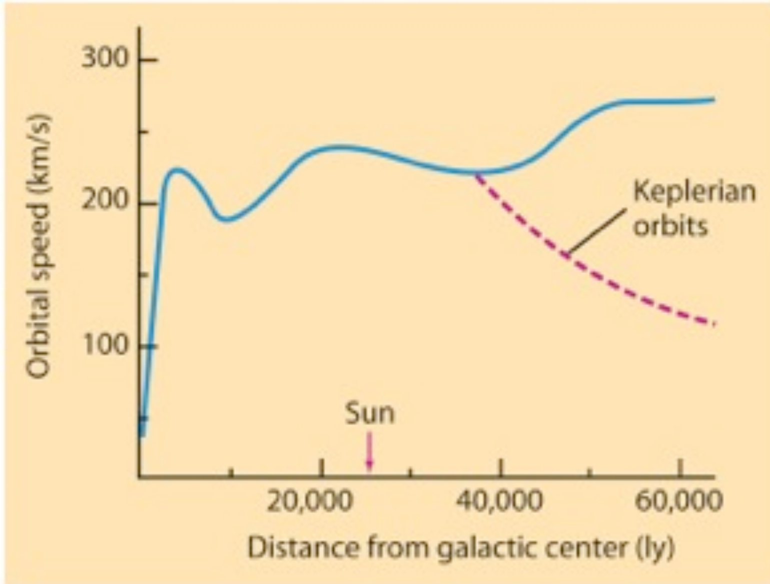
If the galaxy's mass were concentrated at its center, then orbital velocity would be high near the center and would decline away from the center. Of course, the galaxy's mass is not all concentrated at its center. Nevertheless, if most of the mass is inside the orbit of the sun, then orbital velocities should decline at greater distances. Shows most of the Galaxy's mass is hidden – and spread out over a larger region than the stars.

# Rotation Curve Shows Hidden Mass

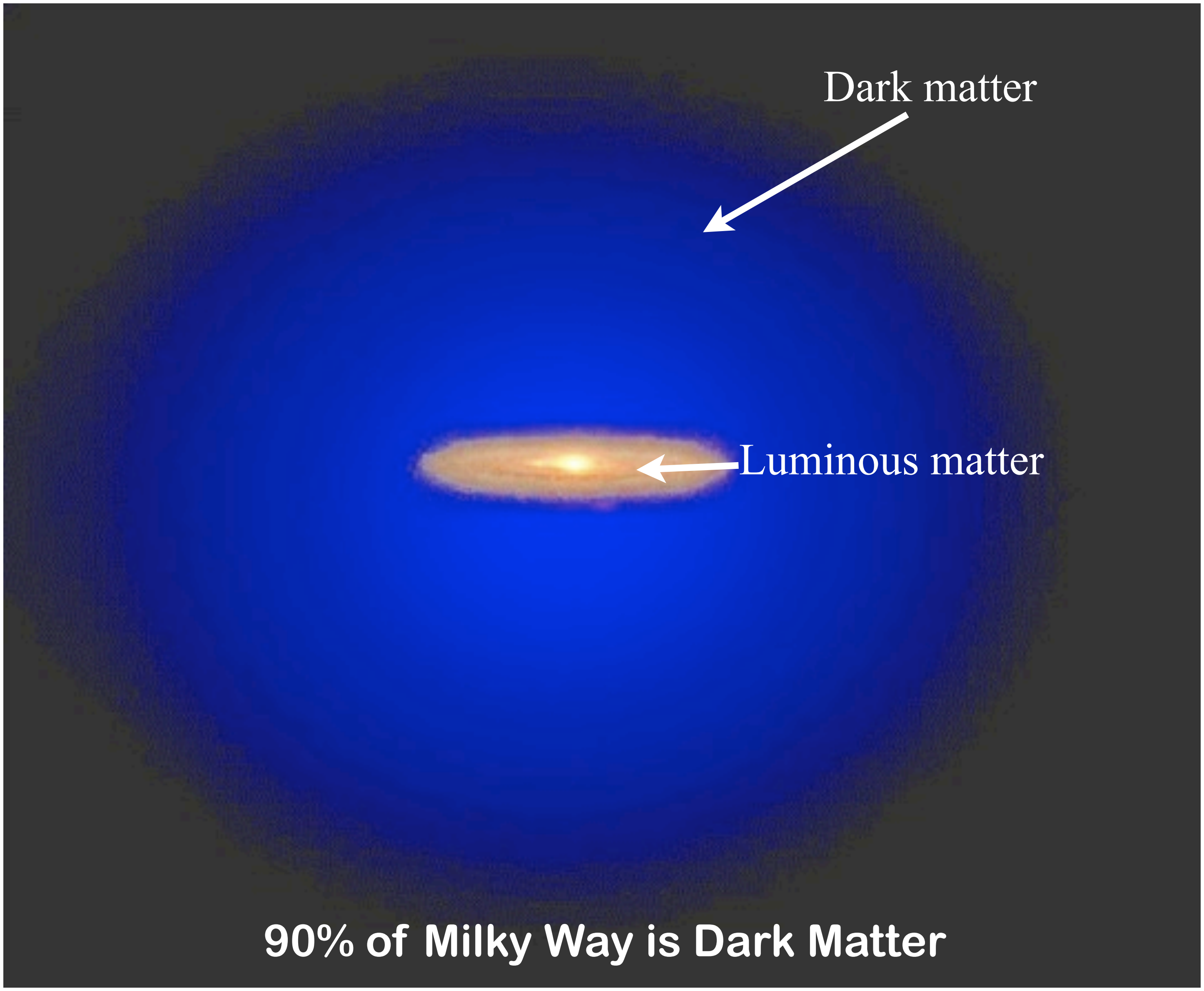
There must be a lot of mass in the outer parts of the Galaxy

- In fact: much more mass beyond the Sun's radius than inside it!
- But only 20% of the Galaxy's light is outside the orbit of the Sun

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



# The visible portion of a galaxy lies deep in the heart of a large halo of *dark matter*






An undetected form of mass that emits little or no light but whose existence we infer from its gravitational influence. It may extend up to 10 times farther than the edge of the visible disk and could contain up to two trillion solar masses. Around ~90% of the galaxy's mass may be dark matter! Some small fraction of this mass is made up of low-luminosity stars and white dwarfs. Most of the matter, though, is not producing light. This is then, the image of the mass of the Milky Way.

# Thought Question

What would you conclude about a galaxy whose rotational velocity **rises** steadily with distance beyond the visible part of its disk?

A. Its mass is concentrated at the center
B. It rotates like the solar system
C. It's especially rich in dark matter
D. It's just like the Milky Way



Answer: C. To have a rising rotation curve past the visible matter, you must have more hidden mass.

# Dark Matter

## What is this dark matter?

One of biggest questions in science today!

## The name says what we know for sure:

- must gravitate = must have mass
- must not glow.

To be precise, must be very dim.

## Dark matter is of unknown origin, although many hypotheses exist

*Q: suggestions?*

*IClicker A when your group is done.*

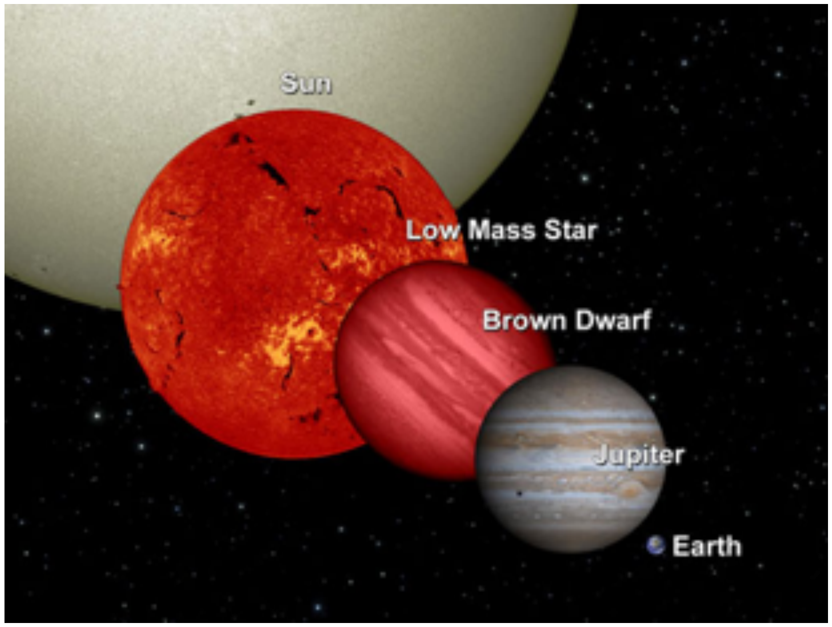
# What might dark matter be made of?

- Dark matter is dark, i.e. not luminous enough to be detected.
- It can not be as bright as a star, but if you were in the galactic halo, you would be considered dark matter.
- But if all the dark matter was all ex-Astronomy 150 students, we would see the blackbody light.
- So it is something more exotic.

**Dark matter could be ?**

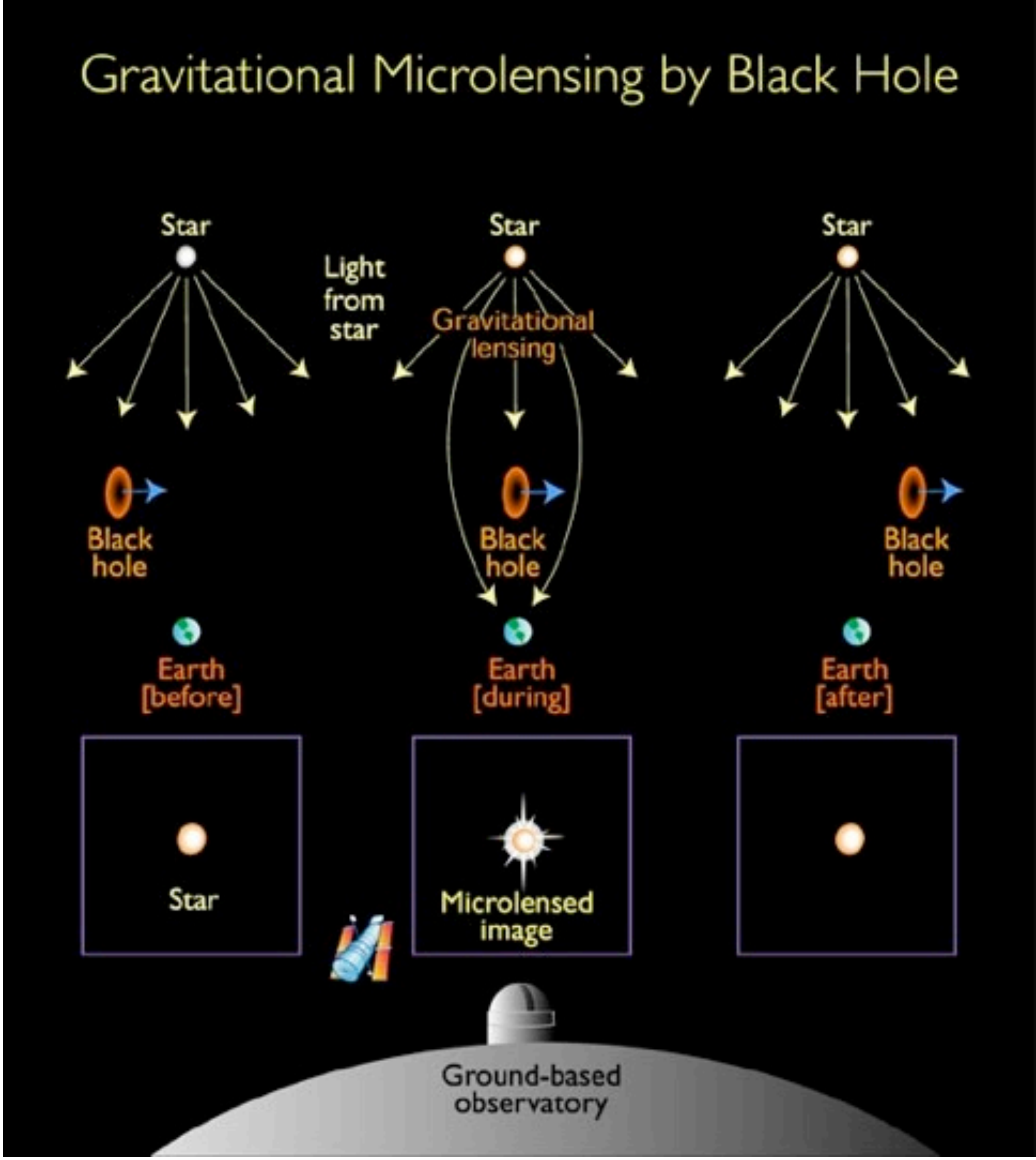
# What might dark matter be made of?

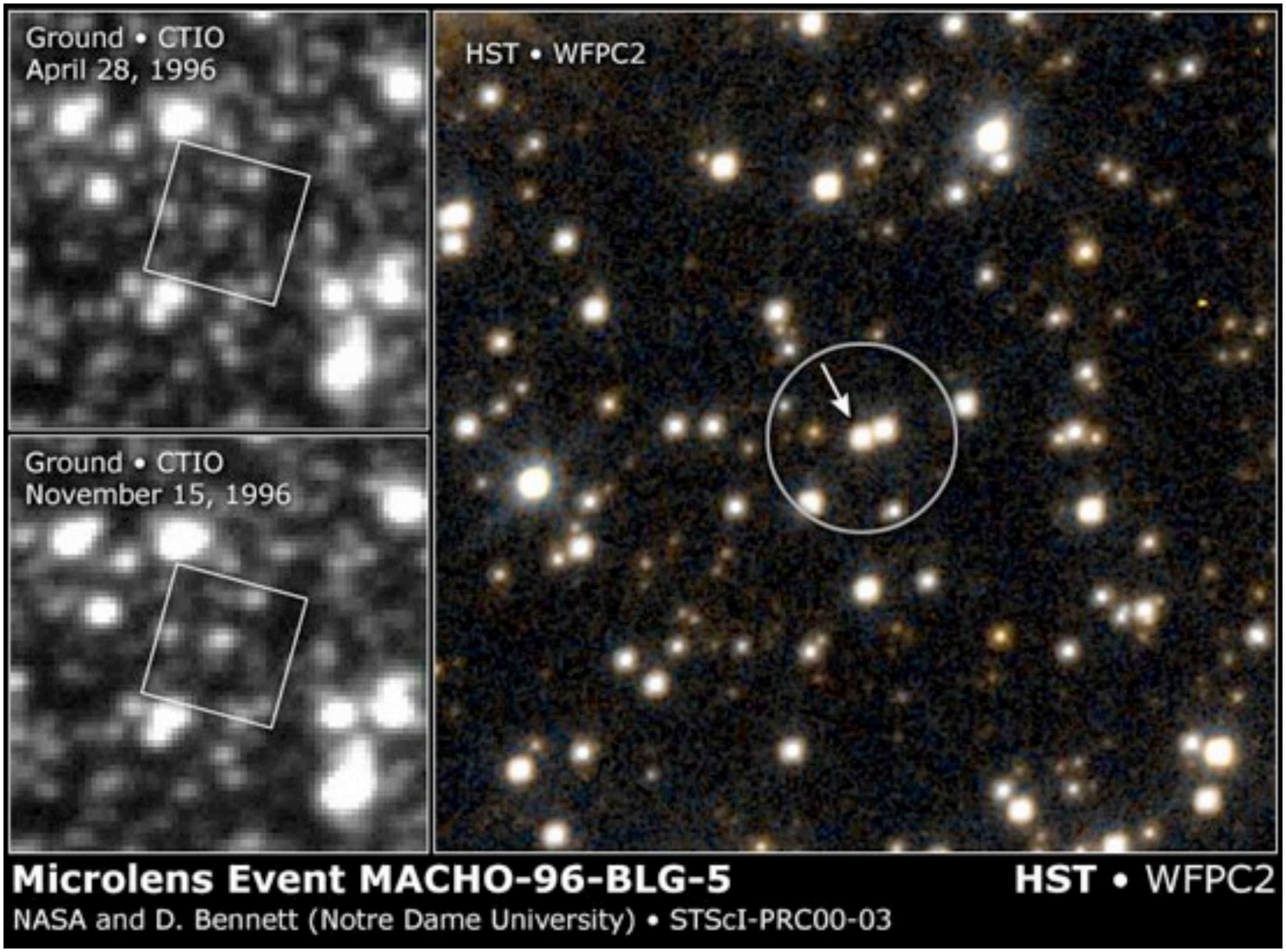
- Conceivable that trillions of very faint stars left over from the formation of the Milky Way could be out there
- Massive Compact Halo Objects (**MACHOs**)
  - Black holes
  - Neutron stars
  - White dwarfs
  - Brown dwarfs
  - Planets




**Dark matter could be made of MACHOs**

- MACHOs have been detected by gravitational lensing
- When the MACHO passes directly between Earth and a distant star
- Enough?






**Gravitational lensing events, such as these, are rare, happening to about one star in a million each year. Not enough mass.**



These events demonstrate that dim starlike objects (MACHOs) do indeed populate our galaxy's halo, but not in large enough numbers to account for all the Milky Way's dark matter. So what is the majority of dark matter?

# What might dark matter be made of?

- More likely dark matter is Weakly Interacting Massive Particles (WIMPs)
  - Mysterious neutrino-like particles, but heavier
  - Not (yet) detected
- Preferred idea of Dark Matter, so whatever it is it makes up most of the matter in the Universe.

**Dark matter could be made of exotic WIMPs**



WIMPs: Neutrino-like, but cannot be made of neutrinos – too low mass, travel at enormous speeds, can easily escape a galaxy's gravitational pull. (Small portion of dark matter in between galaxies is neutrinos)

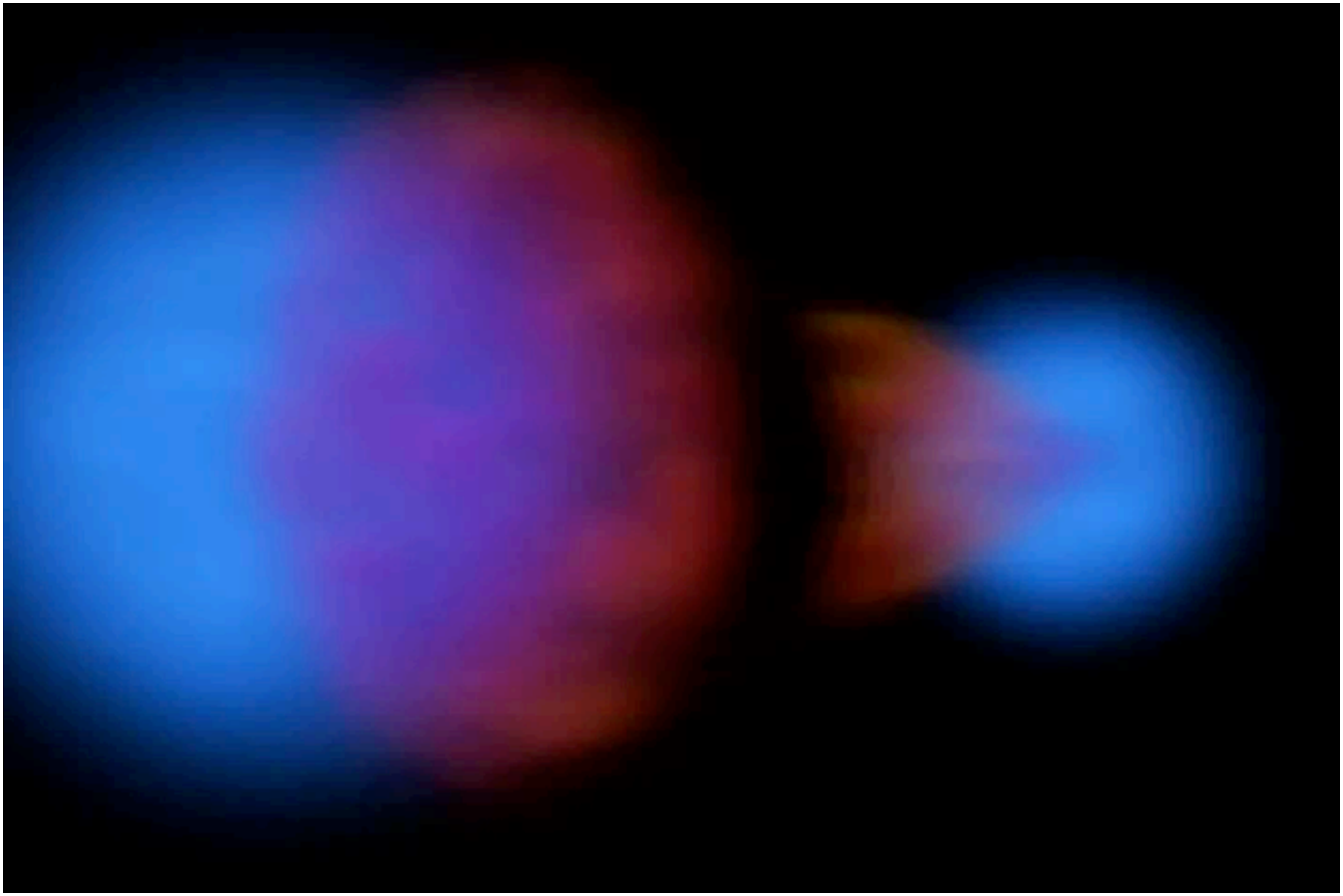
# The Bullet Cluster: Evidence of Dark Matter


**Hot gas seen in X-rays (pink) contains most of the normal matter. Blue areas show most of the mass is found (via lensing)**



The matter in galaxy cluster 1E 0657-56, fondly known as the "bullet cluster", is shown in this composite image. A mere 3.4 billion light-years away, the bullet cluster's individual galaxies are seen in the optical image data, but their total mass adds up to far less than the mass of the cluster's two clouds of hot x-ray emitting gas shown in red. Representing even more mass than the optical galaxies and x-ray gas combined, the blue hues show the distribution of dark matter in the cluster. Otherwise invisible to telescopic views, the dark matter was mapped by observations of gravitational lensing of background galaxies. In a text book example of a shock front, the bullet-shaped cloud of gas at the right was distorted during the titanic collision between two galaxy clusters that created the larger bullet cluster itself. But the dark matter present has not interacted with the cluster gas except by gravity. The clear separation of dark matter and gas clouds is considered direct evidence that dark matter exists.

# What happened in the Bullet Cluster?



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During the collision, the hot gas in each cluster is slowed and distorted by a drag force, similar to air resistance.  The dark matter is not slowed by the impact It does not interact with the gas except through gravity and separates from the normal matter.

The dark matter clumps (blue) from the two clusters move ahead of the hot gas (red), producing the separation of the dark and normal matter.