

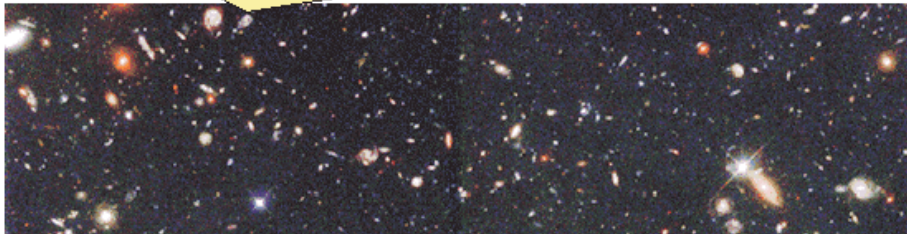
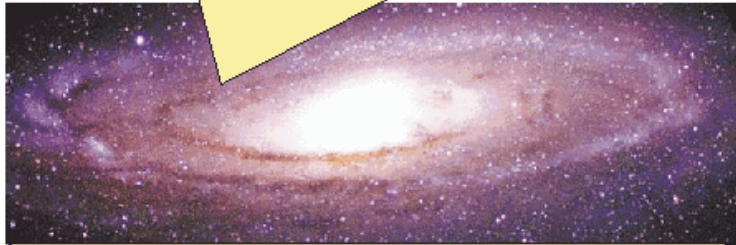
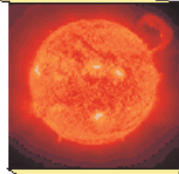
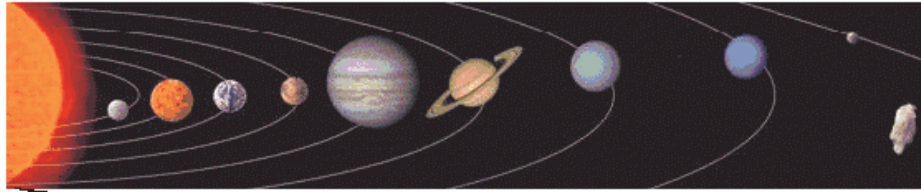


- I decided to cancel class next week!
- No homework until you get back.
- Honor credit– need to have those papers soon!
- Exam 2 Grades are posted.
- Nighttime observing should be posted today.
- Interest in grade at present?.
- THE FINAL IS DECEMBER 15th: 7-10pm!
 - Style...

Outline



- What is Dark Matter?
- Hubble showed that the Spiral Nebulae are “island universes”
- Galaxies are the Fundamental “Ecosystems” of the Universe.
- Morphology
 - Spirals
 - Barred Spirals
 - Ellipticals
 - Irregulars

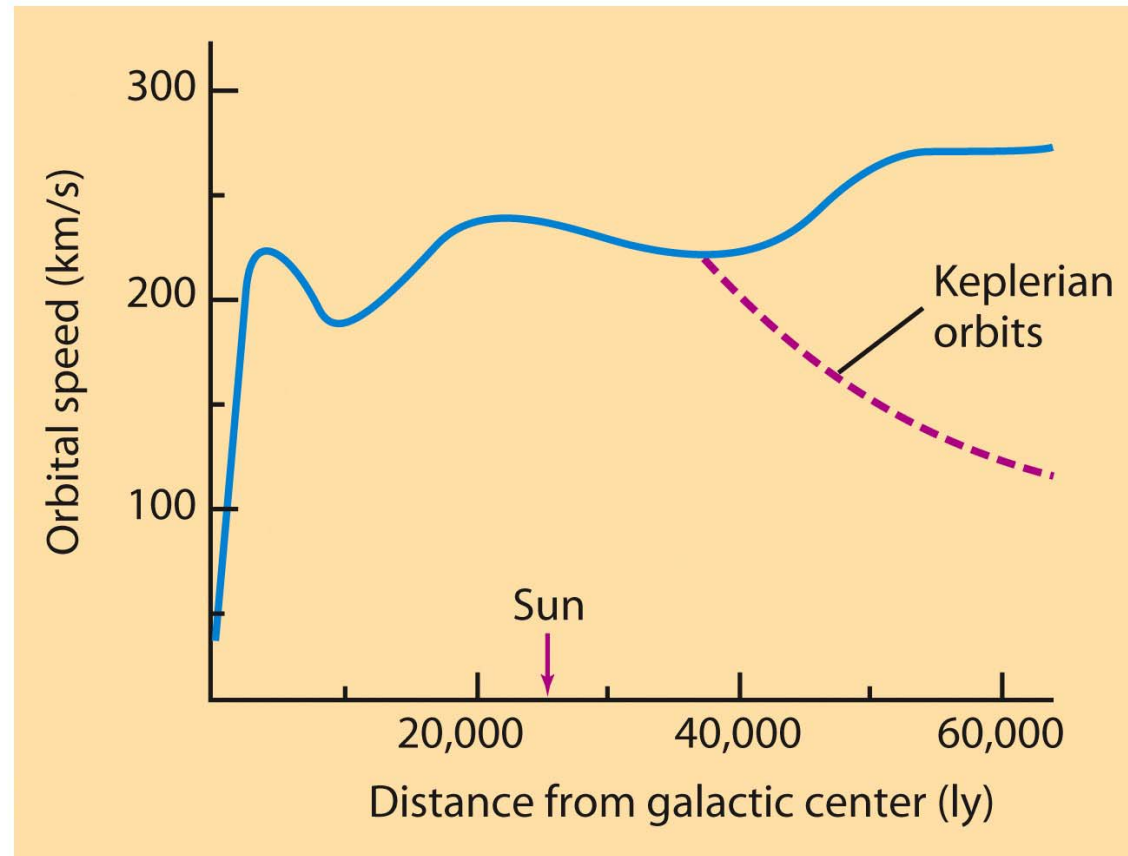


Astronomy: The Big Picture

The Rotation of the Galaxy



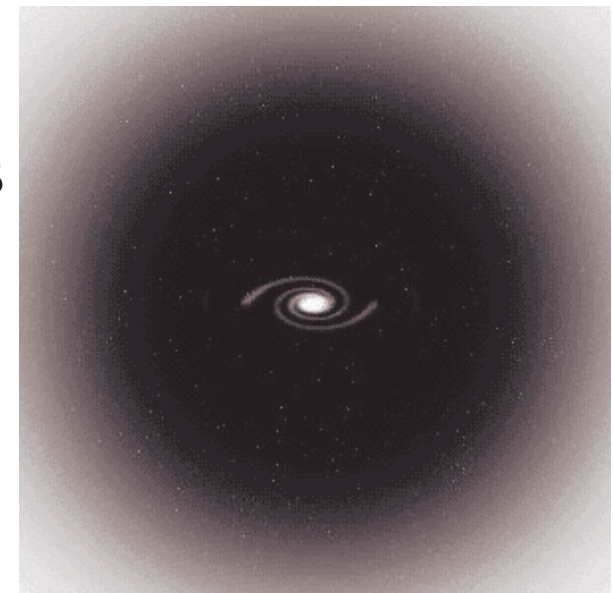
- According to Kepler's 3rd Law, the farther a star is from the center, the slower it should orbit
- Observations show that speed actually increases or is constant with distance from the center
- There is mass outside of the Galaxy that we can't see!
- In fact, 90% of the mass of the entire Galaxy ($>10^{12}$ solar masses) is Dark Matter!



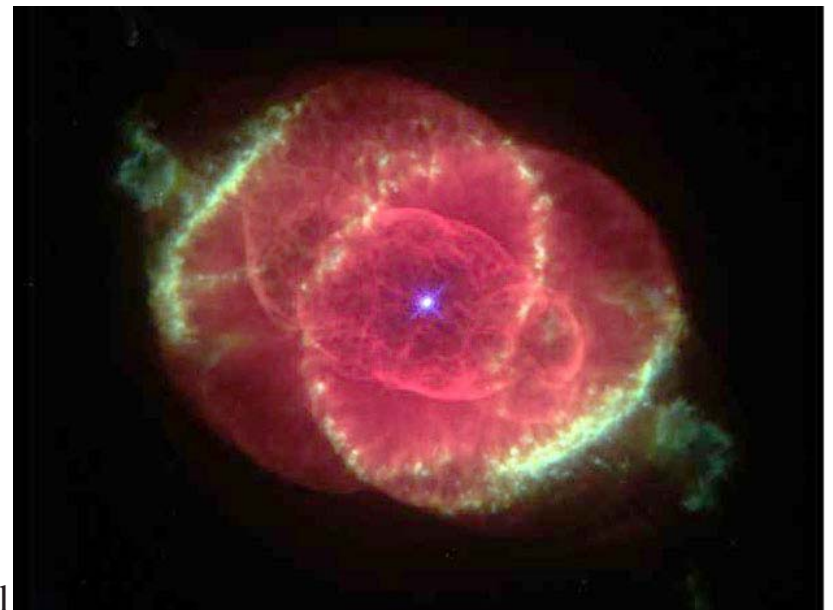
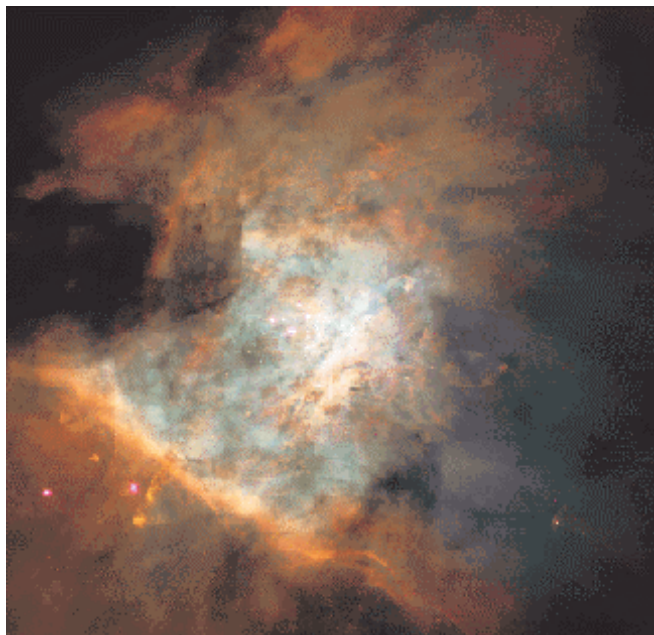
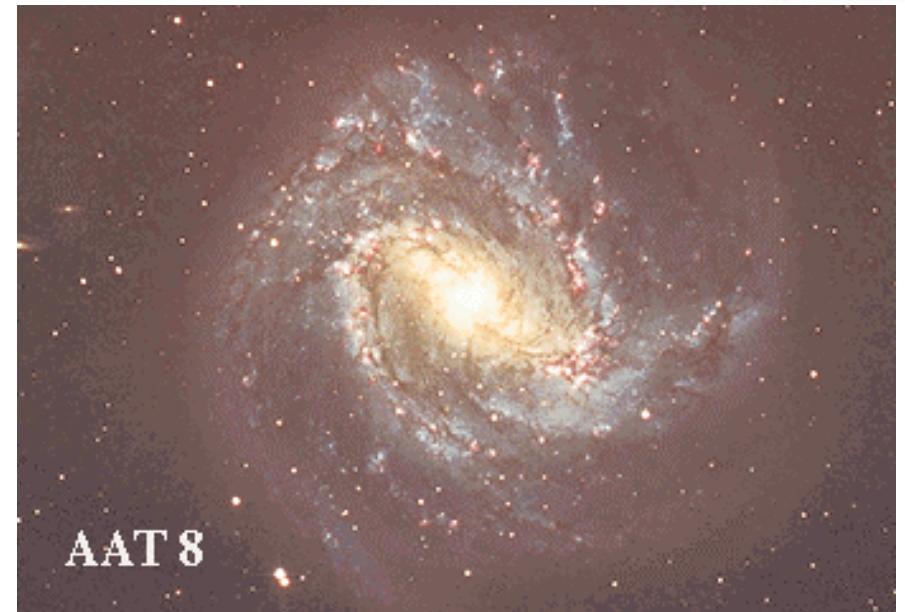


What is Dark Matter?

- We're not completely sure, but normal stuff may only make 10% of the Universe.
- It's spherically distributed all around the Galaxy in a huge halo
- Contributed bits of
 - Neutrinos
 - Blackholes, brown dwarves, black dwarves
 - MACHOS: Massive Compact Halo Objects
 - Something exotic— particles as yet unknown
 - WIMPS: Weakly Interacting Massive Particles



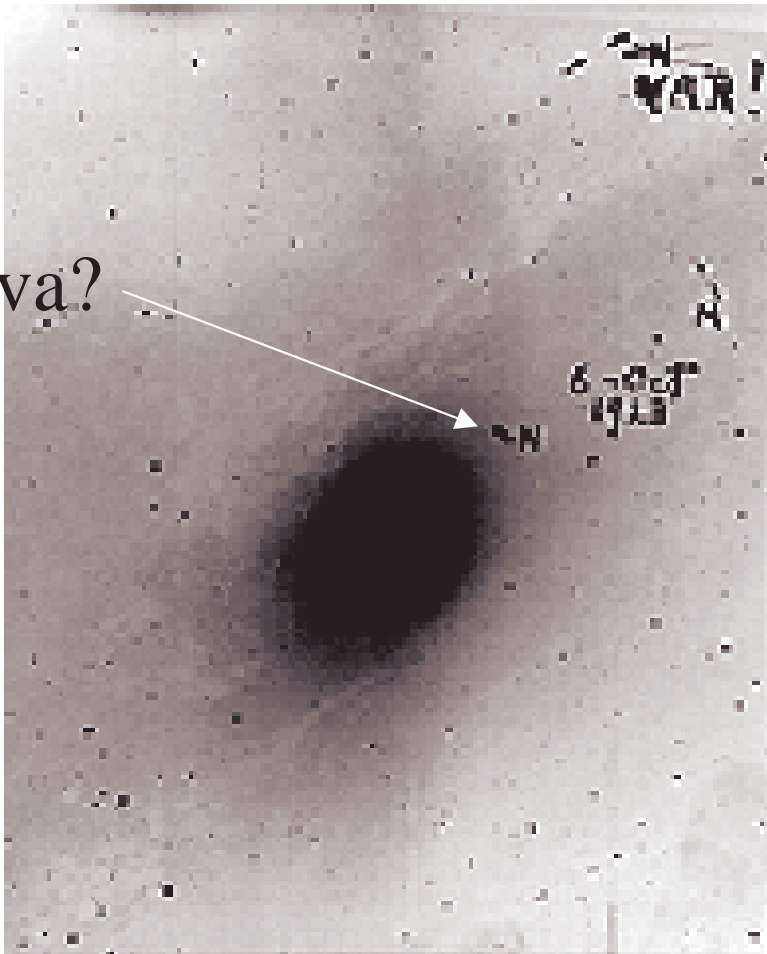
Pesky Spiral Nebulae: Compare



Edwin Hubble



Nova?



Famous Picture of the
Andromeda “Nebulae”

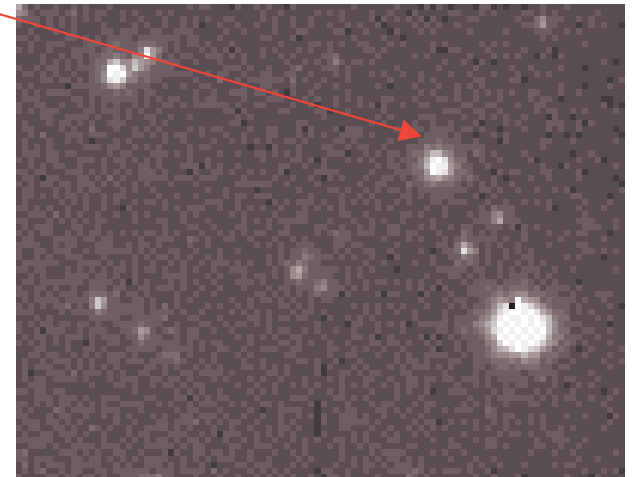
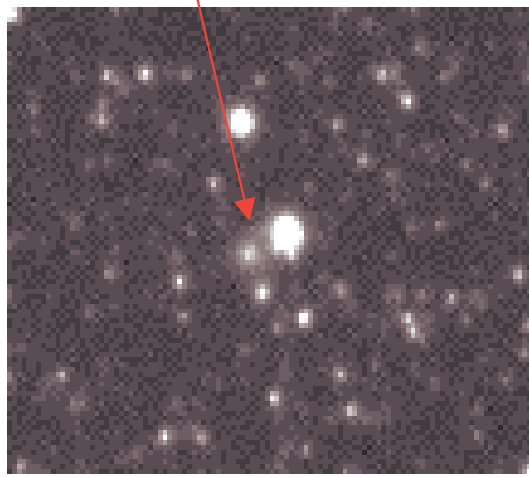
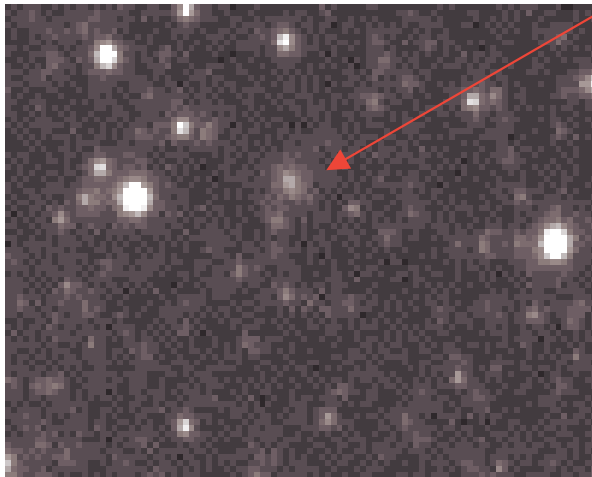


Mount Wilson Observatory

Cepheid Variable Stars



- Variable Stars that regularly vary in brightness, but we know the absolute brightness. A special star.



- So we can determine how far away are they.
- Effectively can show that Andromeda is 2.2 Million light years away.

The Andromeda Galaxy

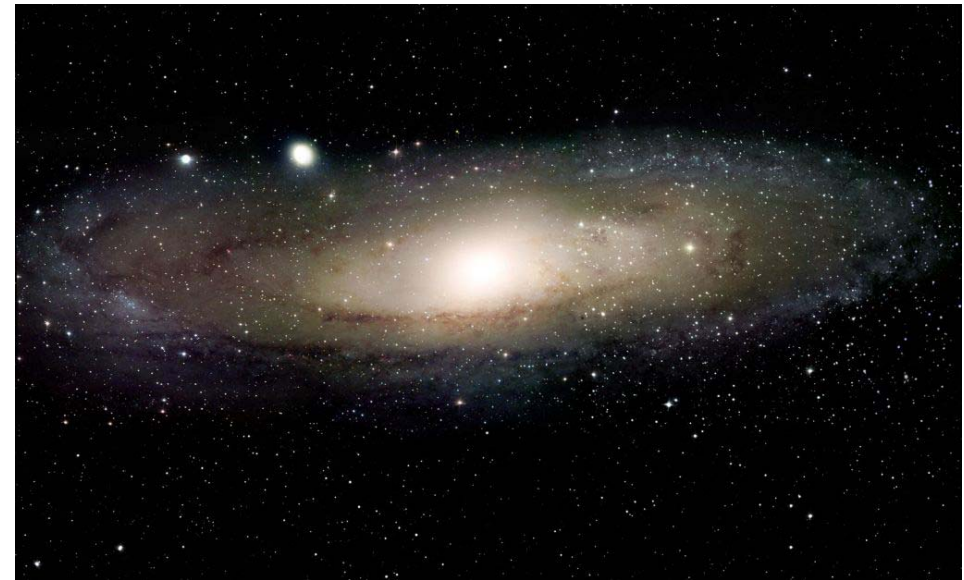


**And you can see it with your naked eye:
50% larger and twice as bright as our Galaxy**

It's coming right for us!



- What will happen to the Milkyway?
 - It will continue to grow as it cannibalizes the smaller galaxies.
 - The Andromeda galaxy is on a collision course.
 - Eventually (billions of years) we will end up a combined galaxy.
 - Probably look like an elliptical galaxy.

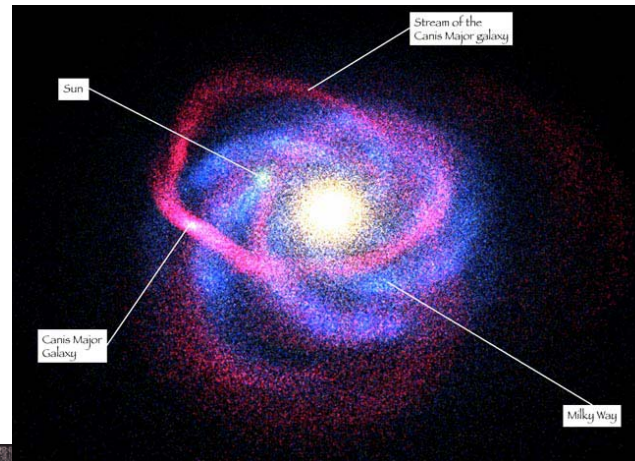


<http://www.seds.org/messier/small/m87.gif>

Is the Milkyway Alone?



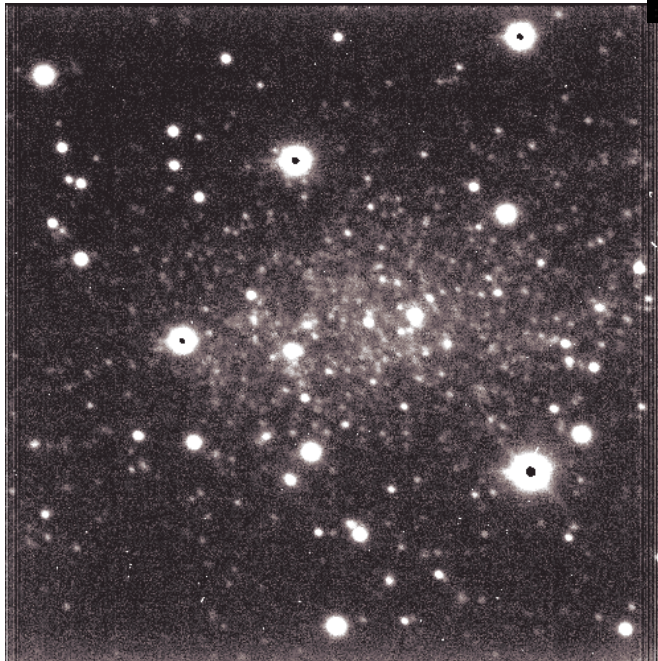
We have lots of
neighbor galaxies



Canis Major
(42,000 ly away)

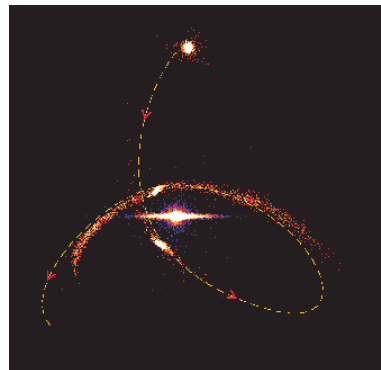


Large Magellanic Cloud
(180,000 ly away)

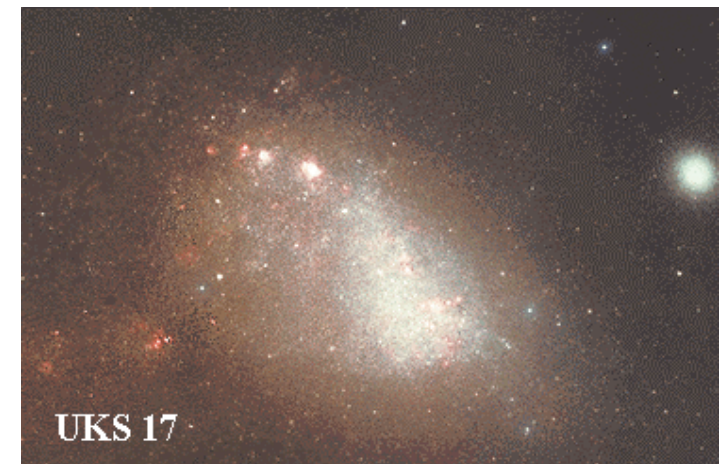


Sagittarius Dwarf Elliptical
(80,000 ly away)

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Small Magellanic Cloud
(250,000 ly away)

And Many Galaxies in the Same Town



Milky Way

0.7 Mpc

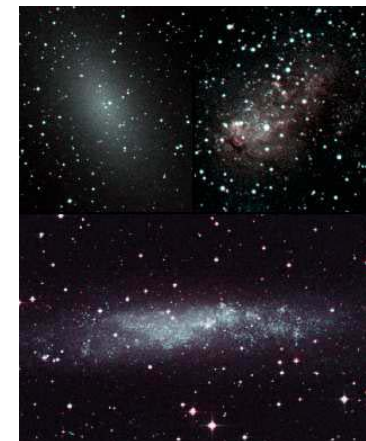


Andromeda (M31)

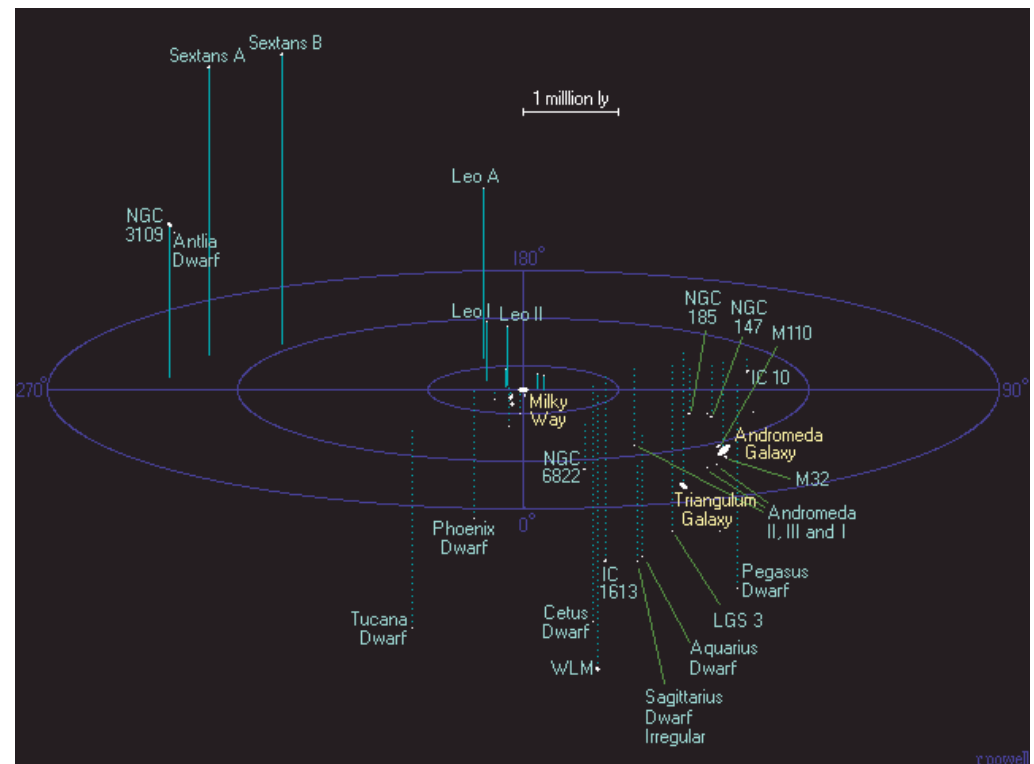
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Triangulum (M33)



Local Group Dwarf galaxies



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Galaxies are the Fundamental “Ecosystems” of the Universe



- The cosmic engines that turn gas into stars and stars back into gas.
- In between no star formation occurs— “nothing happens” in intergalactic space.
- Are recently discovered (by Edwin Hubble in late 1920’s)
- Can be classified by morphology (shapes and sizes).

Galaxies are the Fundamental “Ecosystems” of the Universe



Three Main Types of Galaxies:

- **Spirals** - Barred and unbarred galaxies contain varying amounts of disk component. The disk has the young blue stars, while the bulge has older red stars.
- **Ellipticals** - Galaxies are pure bulge, no disk component. All older red stars.
- **Irregulars** - Galaxies are... well. Odd. Young blue stars.

Types of Galaxies



- Spiral: —————→
< 20%



- Barred Spiral:
> 57% —————→

- Elliptical: —————→
> 20%



- Irregular: —————→
< 3%

Spirals: Pattern?



NGC
4114

Spirals: Pattern?



M51: The
Whirlpool
Galaxy



Spirals: Pattern?



Sombrero
Galaxy

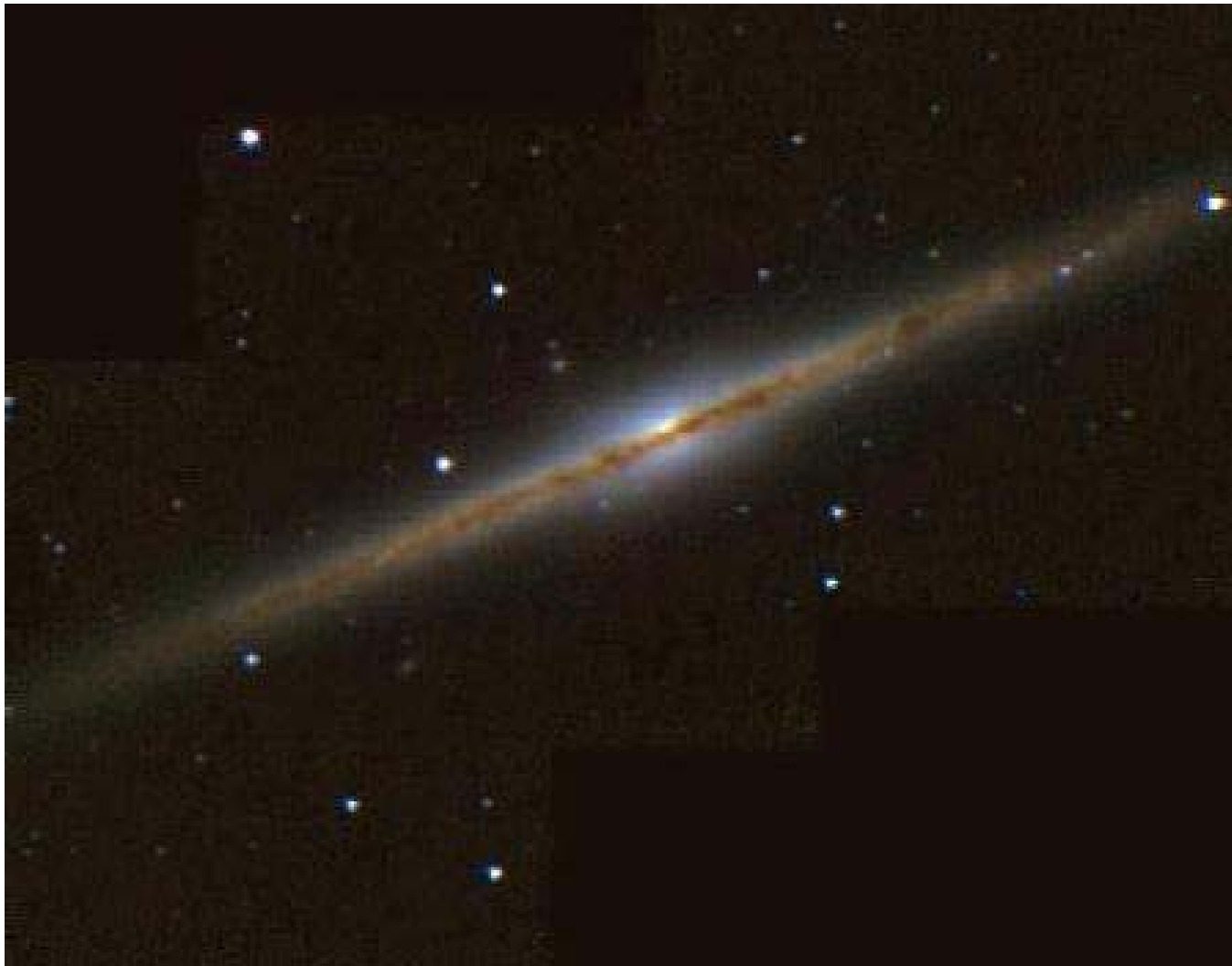


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<http://antwrp.gsfc.nasa.gov/apod/ap011021.html>

Spirals: Pattern?



NGC 891

Edge on

Spirals: Pattern?



Flocculent Spiral
“Fleecy”

Grand Design
“Crisp”



Spirals

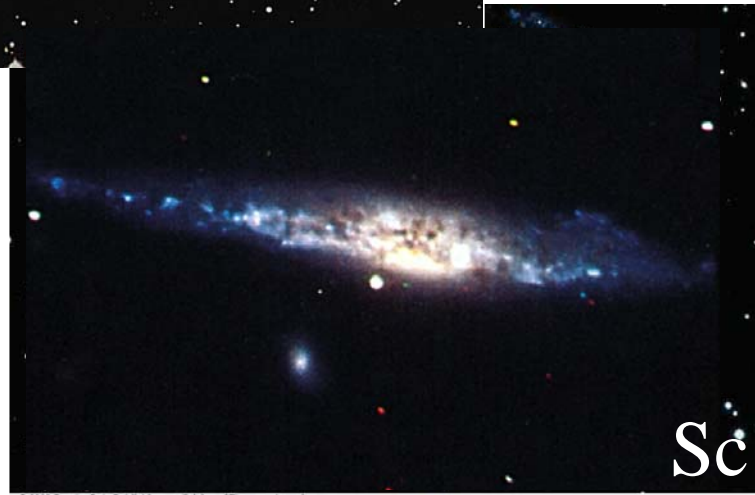
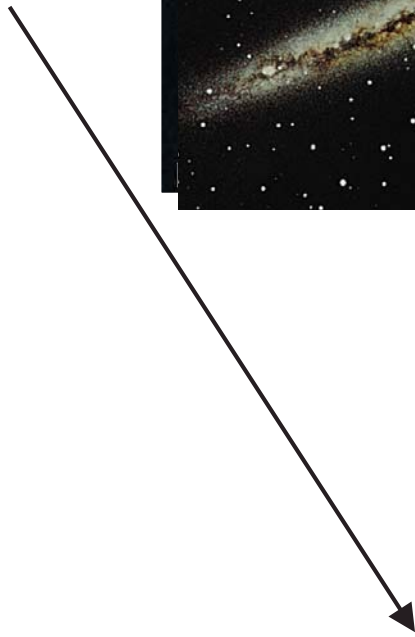


Spirals are classified on the amount of bulge component (how tightly the arms are wound).

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



More bulge
and tightly
wound.



More disk and loosely wound.

More disk means
more ongoing star
formation!

Why do we see Spiral Arms?



They are easily seen as the arms contain numerous bright O and B stars that illuminate dust in the arms



However, stars in total seem to be evenly distributed throughout the disk.

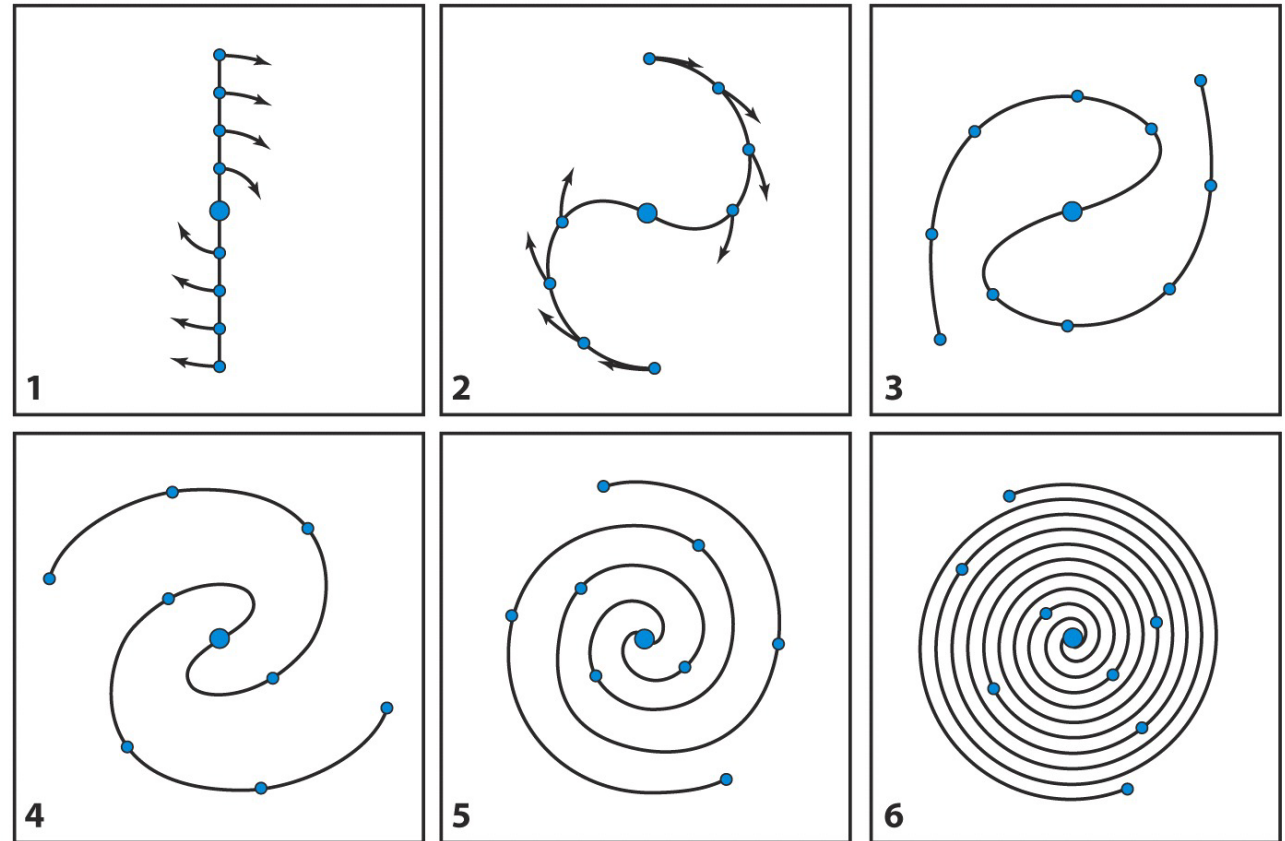
Important Question



The Winding Problem

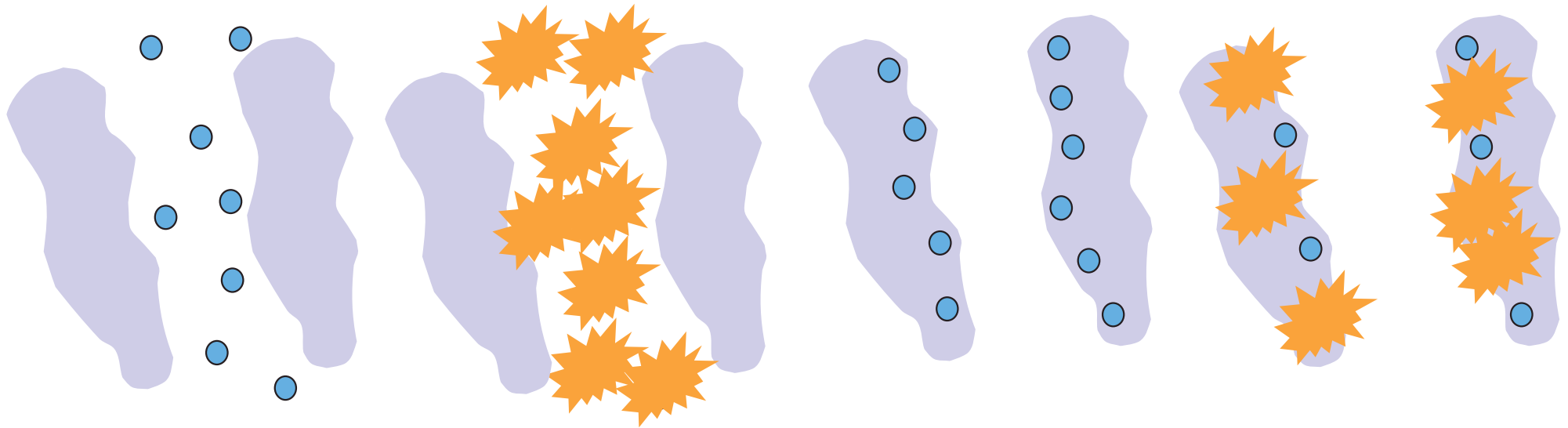


- If the arms are stationary, they should wind up—the galaxy orbits with the same linear speed.
- This is not observed.
- The arms must be a pattern that quickly dissipates after a few orbits.



What makes the Spiral Arms?

I: Self-Propagating Star Formation



1 Massive stars
and gas clouds

2 Supernovae

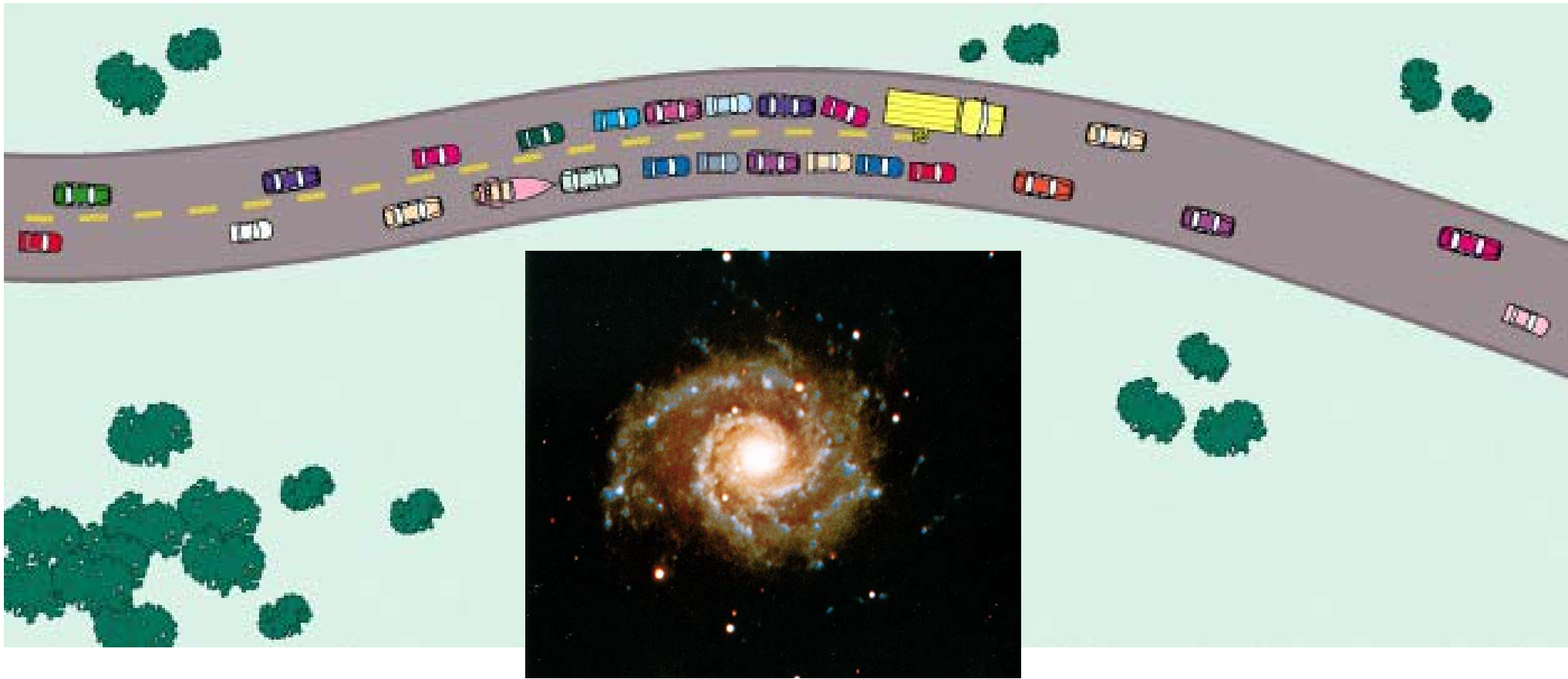
3 New stars form as
blast waves
compress gas

4 Repeat

As stars orbit the galaxy the stars closer in orbit faster and form a spiral shape. Works best for Flocculent Spirals.

What makes the Spiral Arms?

II: Spiral Density Waves



The truck represents dust and gas that slows the stars (the other cars) down, That increases the density of the clouds, creating new O and B stars that light up the spiral arm.

Spirals with Bars of Stars



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Barred Spirals

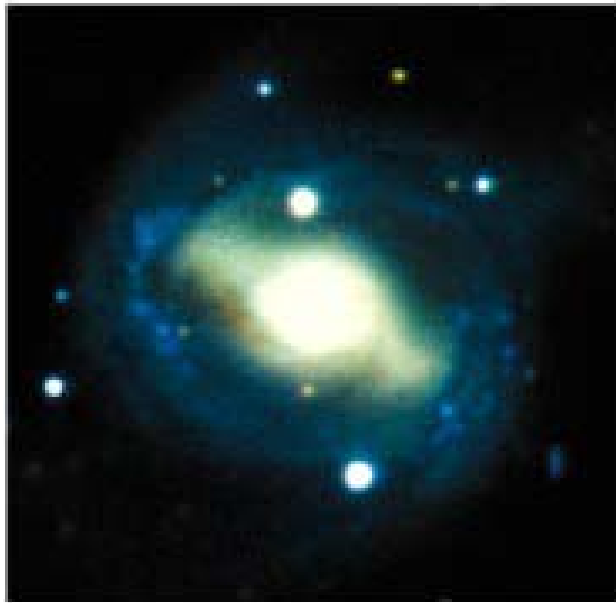


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Bars of stars in the nuclear bulges of barred spiral galaxies



SBa

NGC 4650

Type SBa



SBb

M83

Type SBb



SBc

NGC 1365

Type SBc

Spiral arms originate from bar end.

Elliptical Galaxies



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Elliptical Galaxies



E0

M105

Type E0
Spherical



E3

NGC 4365

Type E3



E6

NGC 3377

Type E7
Elongated

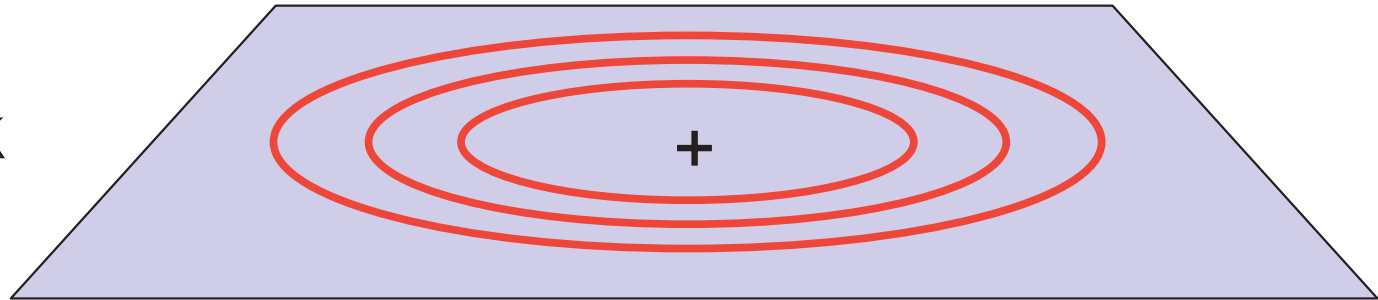
Can be huge (20 times larger than Milkyway) or small.
Very common are dwarf ellipticals with as few as a million stars.



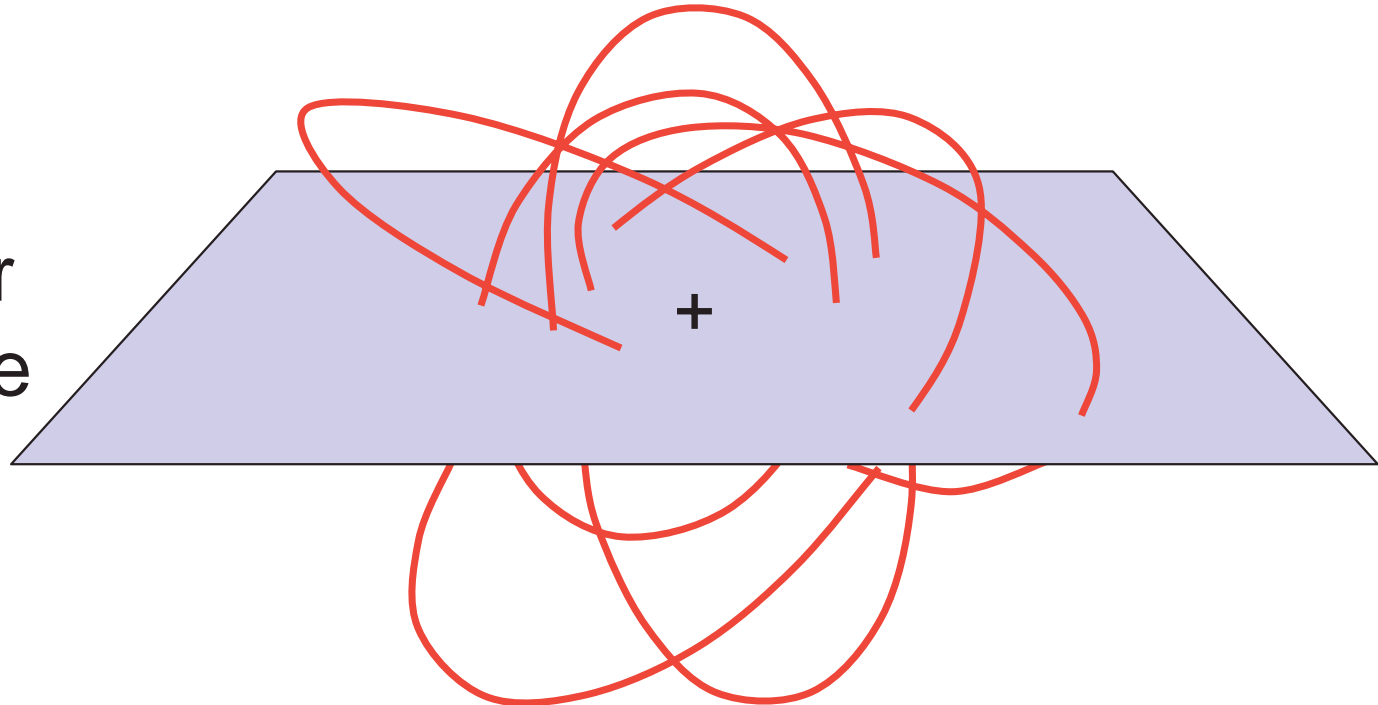
Are the Stellar Orbits different?



Spiral disk



Elliptical or
Spiral bulge



Irregulars



*Small Magellanic
Cloud*

*Large Magellanic
Cloud*



Sextans

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