

The Spitzer Space Telescope observed 75 galaxies as part of its SINGS (Spitzer Infrared Nearby Galaxies Survey) Legacy Program. The galaxies are presented here in a Hubble Tuning-Fork diagram, which is a plot of galaxies' colors and shapes. The galaxies are arranged in arms. The designation of these galaxies and their placement in the diagram is based on their visible-light appearance. The main goal of the SINGS program is to characterize the infrared properties of a wide range of galaxy types. The images of the galaxies are composed of light from data taken by IRAC (Infrared Array Camera) and SIRS (Spitzer Infrared Spectrograph) and are presented in grayscale. The color images (the Multiband Imaging Photometer for Spitzer) at 24  $\mu$ m.

The infrared range probed by these and other observations taken for the SINGS project allows for the detailed study of star formation, dust emission, and the distribution of stars in each galaxy. Light from old stars appears as blue in the images, while the lumpy knots of green and red light are produced by dust clouds surrounding newly born stars. The SINGS project will study the formation and evolution of stars, while spiral galaxies like our own Milky Way are rich in young stars and the raw materials for future star formation.

More information can be found at:  
<http://sing.sstsci.edu/>



# Galaxies

## Ellipticals

## Irregulars

## Unbarred Spirals

## Intermediate Spirals

## Barred Spirals

Poster and composite images created from  
SINGS observations by Karl D. Gordon (Oct 2007):  
Blue=IRAC 3.6 $\mu$ m (stars)  
Green=IRAC 8 $\mu$ m  
(aromatic features from dust grains/molecules)  
Red=MIPS 24 $\mu$ m (warm dust)

SINGS Team

Robert Kennicutt, Jr. (Principle Investigator), Daniela Calzetti (Deputy Principle Investigator), Charles Engelbracht (Technical Contact), Lee Armus, George Bendo, Caroline Bot, Brent Buckalew, John Cannon, Daniel Dale, Bruce Draine, Karl Gordon, Albert Grauer, David Hollenbach, Tom Jarrett, Lisa Kewley, Claus Leitherer, Aigen Li, Sangeeta Malhotra, Martin Meyer, John Moustakas, Eric Murphy, Michael Regan, George Rieke, Marcia Rieke, Helene Roussel, Kartik Sheth, J.D. Smith, Michele Thornley, Fabian Walter & George Helou



# Spiral galaxies

---

- Blue to white in color—young stars
- Spiral arms with halo and bulge
- Medium to large in size



# Spiral galaxies

---





# Spiral galaxies

---



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy



# Spiral galaxies

---



# Spiral galaxies

---



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy



# Spiral galaxies

---



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy

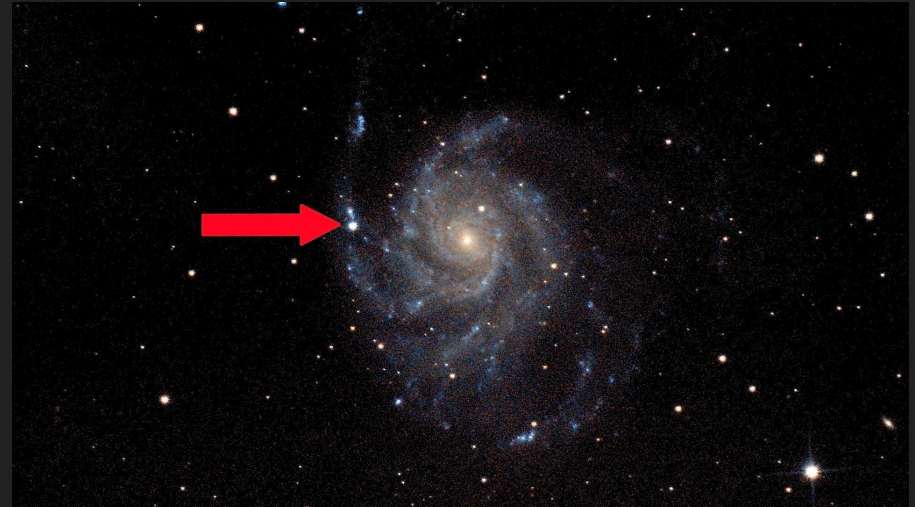




# Spiral galaxies

---

- Young stars means massive stars
- We can see supernovae in distant spiral galaxies
- Type Ia Supernovae are used as standard candles to find distances (more on this later)





# Why do we see spiral arms?

---



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy

- They are easily seen because the spiral arms contain numerous bright O and B stars
- Luminous stars in the spiral arms illuminate the dust in the arms
- Stars however are evenly distributed throughout the disk
  - They are old and dim



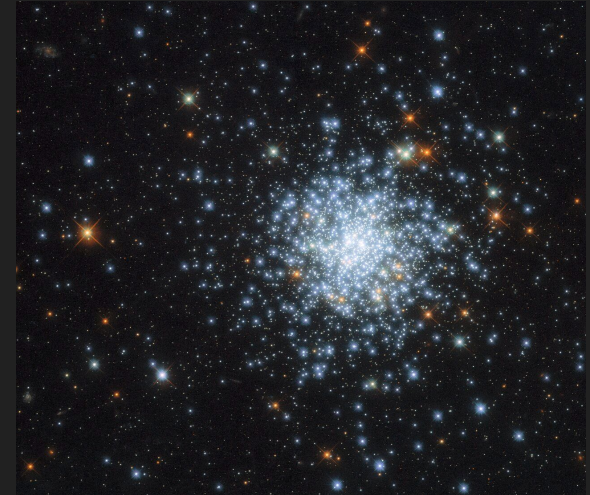
# Poll Everywhere



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy

1. A giant gas cloud enters the spiral arm of a galaxy, which makes it collapse and triggers star formation. The cloud forms a large cluster of many stars, which all reach the main sequence at about the same time. About 50 million years later, the cluster of stars leave the spiral arms, which main sequence stellar types still exist in the star cluster?
  - a. O, F, G, and M stars (no B, A or K stars)
  - b. O and B stars (no A, F, G, K, or M stars)
  - c. B, A, and K stars (no O, F, G, or M stars)
  - d. A, F, G, K and M stars (no O or B stars)



When poll is active respond at [PollEv.com/nikhilpatten355](https://poll-ev.com/nikhilpatten355)

Send [nikhilpatten355](#) to **22333**



# Poll Everywhere

---

results

# Poll Everywhere



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy

Mass (solar masses)	Time (years)	Spectral type
60	3 million	O3
30	11 million	O7
10	32 million	B4
3	370 million	A5
1.5	3 billion	F5
1	10 billion	G2 (Sun)
0.1	1000s billions	M7





# Poll Everywhere

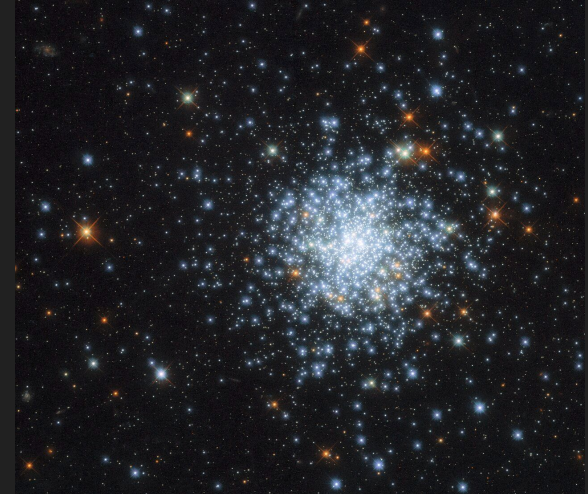
---



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy

1. A giant gas cloud enters the spiral arm of a galaxy, which makes it collapse and triggers star formation. The cloud forms a large cluster of many stars, which all reach the main sequence at about the same time. About 50 million years later, the cluster of stars leave the spiral arms, which main sequence stellar types still exist in the star cluster?
  - a. O, F, G, and M stars (no B, A or K stars)
  - b. O and B stars (no A, F, G, K, or M stars)
  - c. B, A, and K stars (no O, F, G, or M stars)
  - d. **A, F, G, K and M stars (no O or B stars)**



# Viewing Angle Effects

---



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy

Face-on



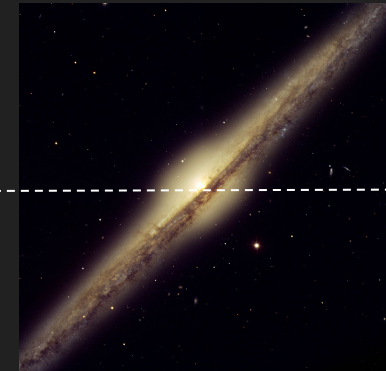
Easier to see the  
spiral arms



Edge-on



Easier to see the  
dust in the disk and  
the bulge



# Spiral subclassifications



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy

- Spiral galaxies are classified by the amount of bulge and how tightly wound the arms are
- These designations are Sa, Sb, and Sc, in order of decreasing bulge

More bulge and tightly wound

More disk means more star formation



More disk and loosely wound





# Barred Spirals

- About 20% of 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 SB rather than S
- Subclasses of barred spirals the same as regular spirals: SBa, SBb and SBc





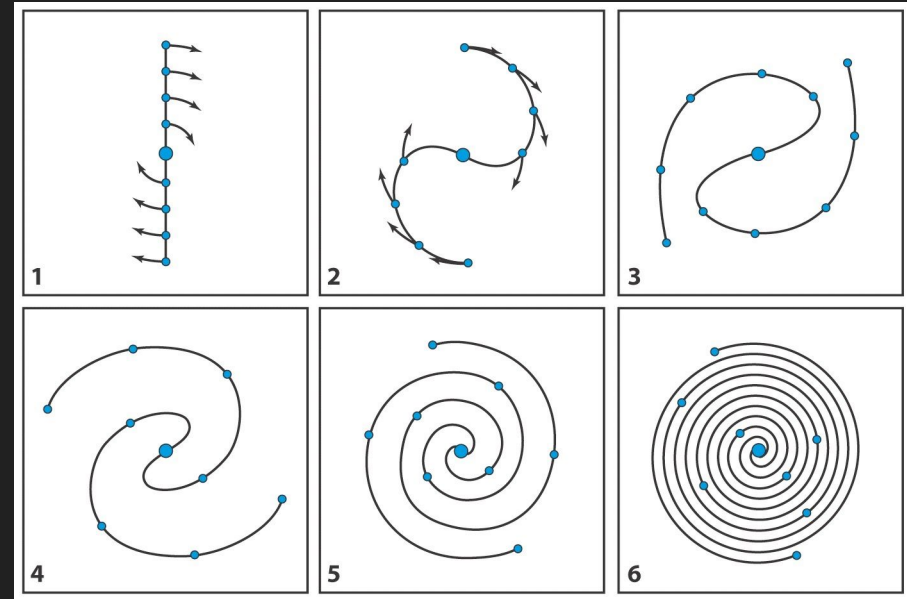
# The Winding Problem



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy

- If the spiral arms are stationary, they should wind up and disappear as stars orbit
- We observe many spiral galaxies
- Spiral arms are not a permanent collections of stars
- Stars, gas and dust pass through the spiral arms. Spiral arms are standing density waves



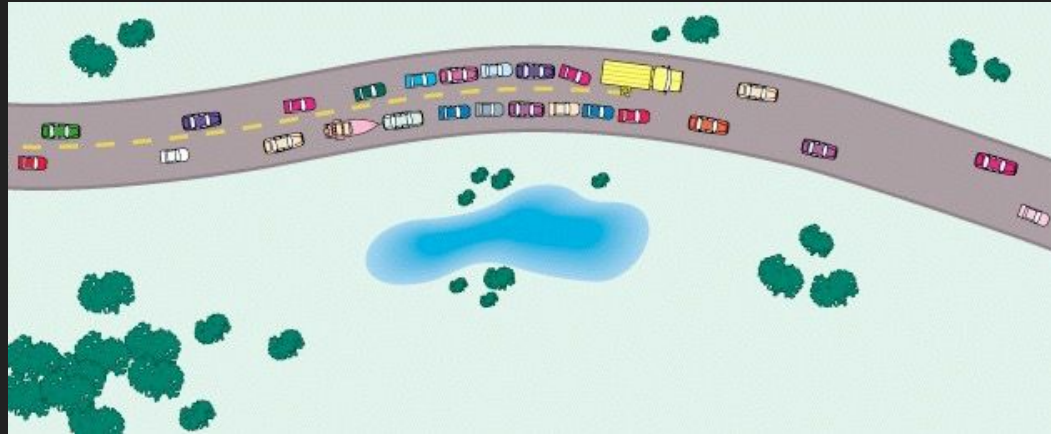
# Density waves



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy

- Spiral arms are caused by waves in the gas and dust
- Makes the gas clump
- Like an interstellar traffic jam
- Increased density of gas and dust sparks formation of new O- and B-type stars that illuminate the spiral arms

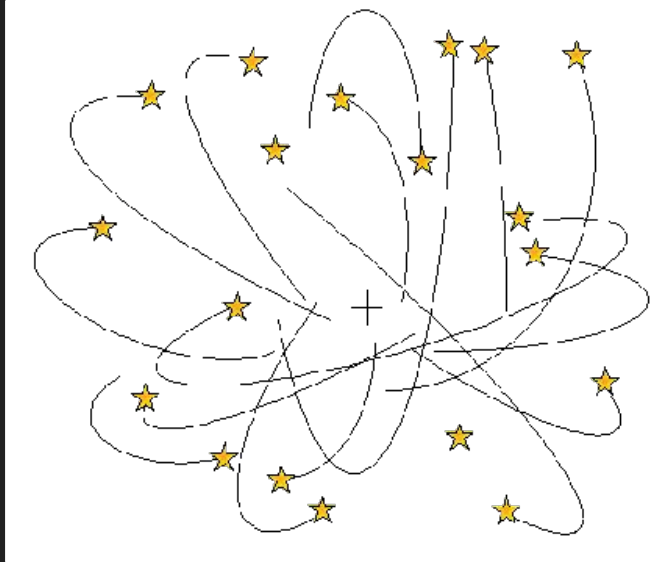


# Stellar orbits



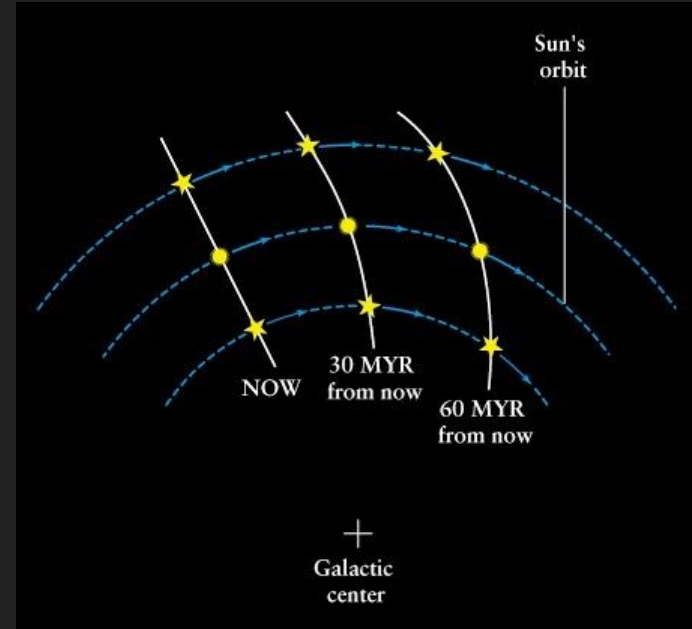
UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy



Elliptical or  
spiral bulge  
stellar orbits

## Spiral disk stellar orbits



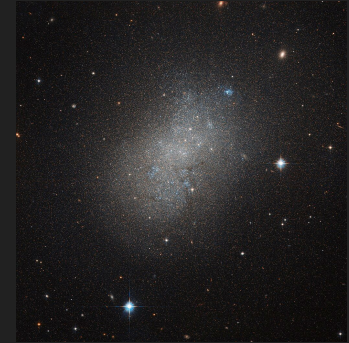
# Irregular Galaxies



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy

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



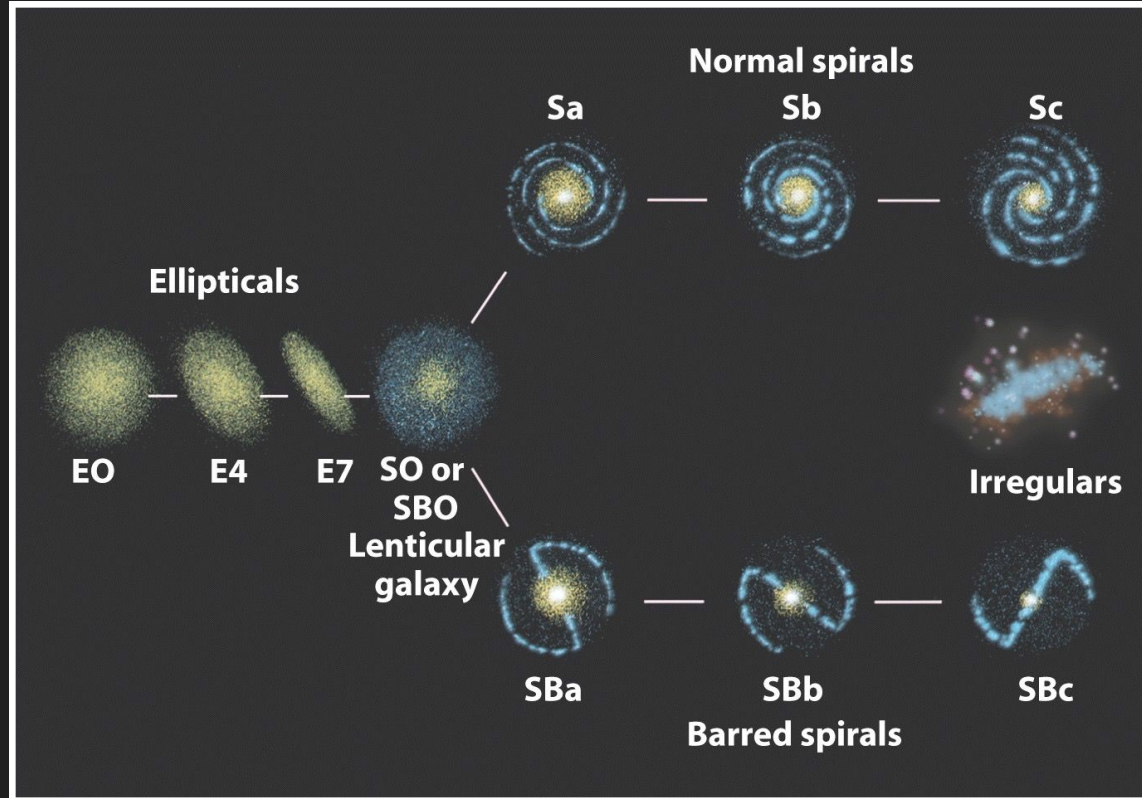


# Hubble's Tuning Fork



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy



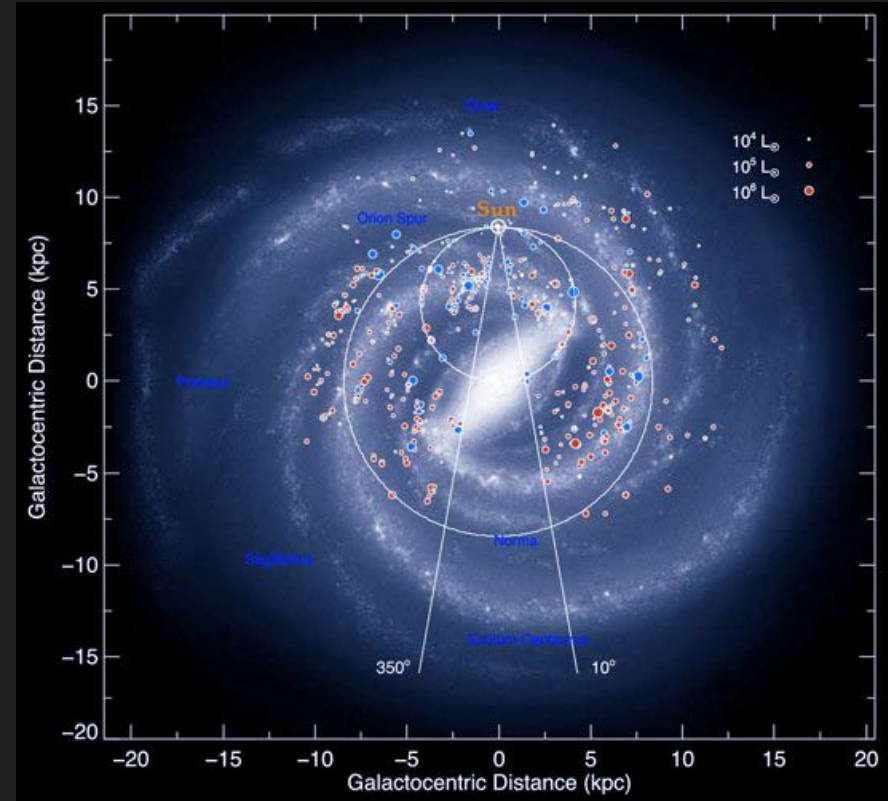
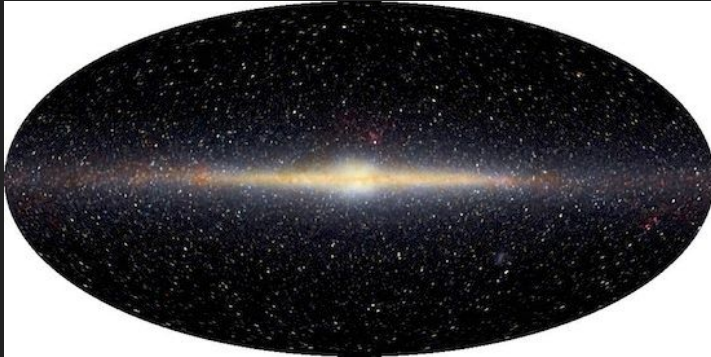
# The Milky Way



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy

- The Milky Way is a spiral galaxy
- Probably SBb



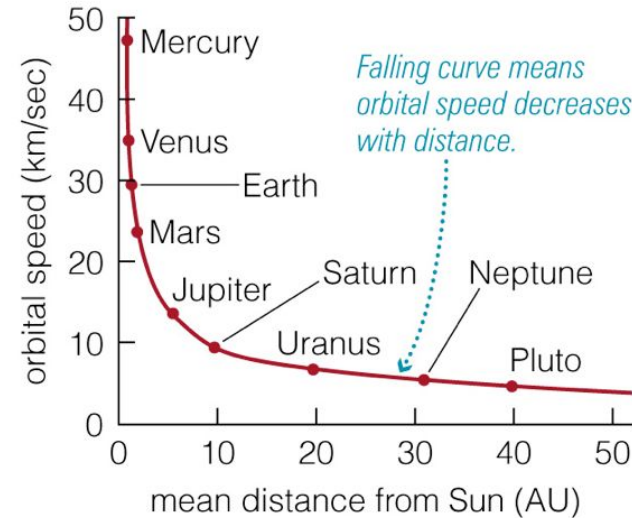
# Rotation Curves



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy

- The speed of orbiting bodies versus distance tells us about how mass is concentrated in a system
- Call this a rotation curve
- Rotation curve for the Solar System drops off exponentially, the mass is concentrated at the center



© 2006 Pearson Education, Inc., publishing as Addison Wesley

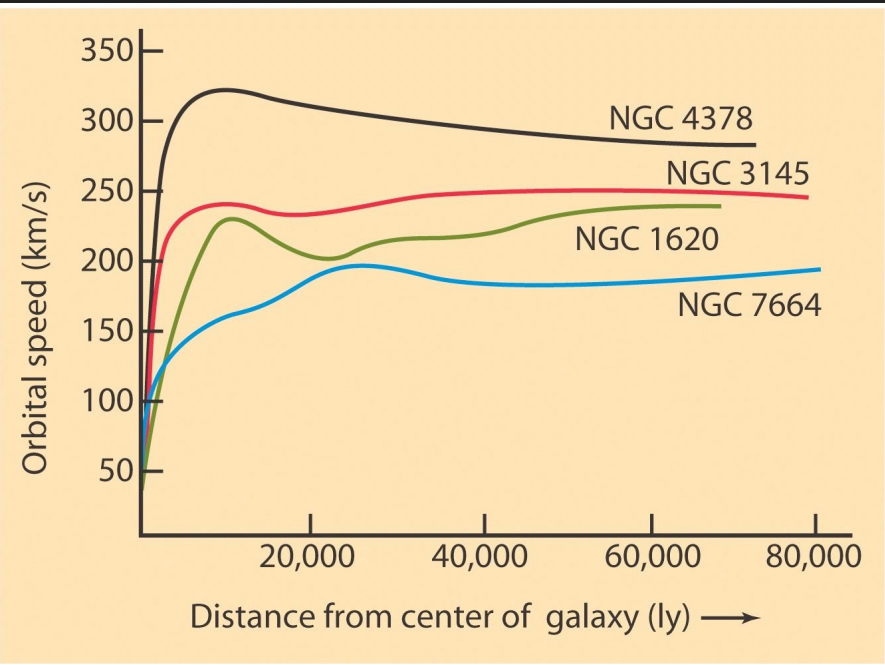
# Rotation Curves



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy

- When we measure the speeds of stars in our's and other galaxies, and use Kepler's Laws, we find something different
- Galaxies have **flat** rotation curves
- As we move out from the center, the mass increases exponentially
- Stars decrease as we move out
- Call this unobserved matter "dark matter"





# Announcements

---



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy

- Meet in planetarium next class
- Homework 8 due Friday

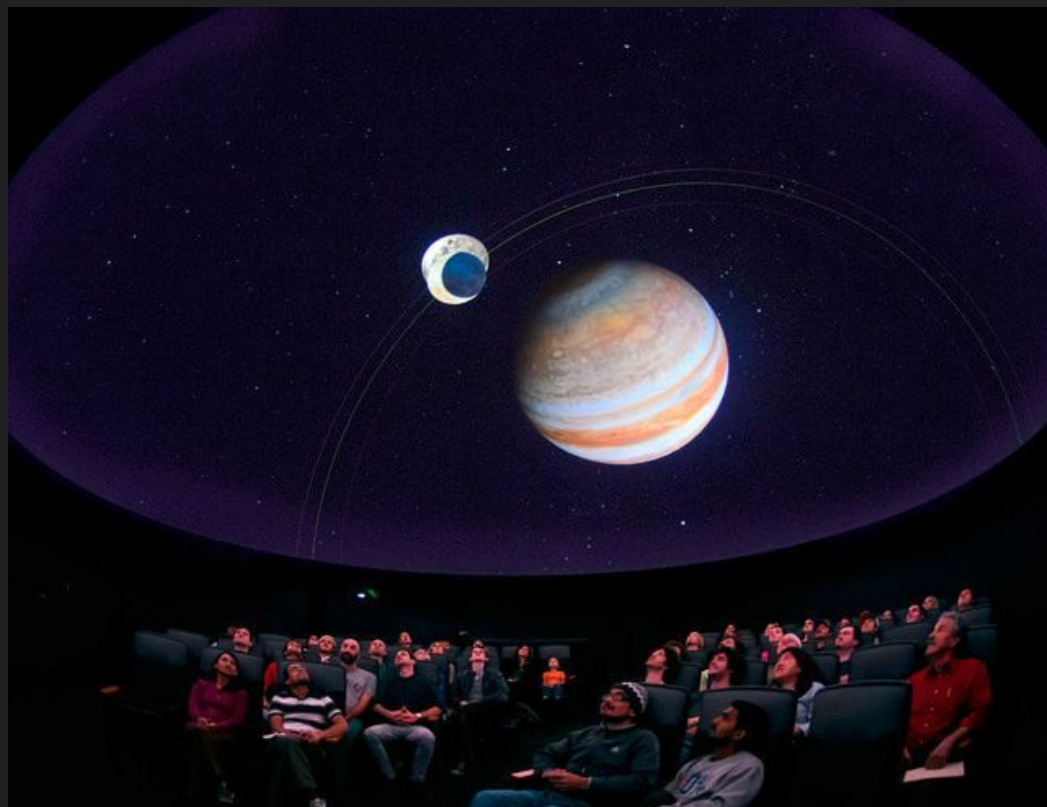
# Meet in Planetarium Next Class

---



UNIVERSITY  
OF WYOMING

College of Engineering  
and Physical Sciences  
Physics and Astronomy



# Next time

---

- Galaxies II