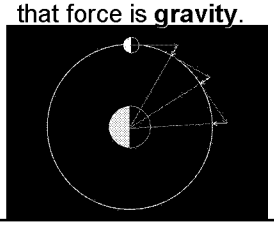
# Stars & Galaxies in Motion

Wednesday, October 14

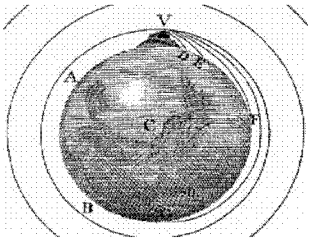
Put P.S. #2 into "in box", pick up P.S. #3

Newton Says:

- Objects move in straight lines at constant speed **unless** a force acts on them.
- The Moon moves on a **curved** path at **changing** speed.
- Therefore a **force** is acting on the Moon: that force is **gravity**.



Newton: **shape** of orbit depends on **speed** of satellite at launch.




Low speed = **closed** orbit (circle, ellipse).
High speed = **open** orbit (parabola, hyperbola).

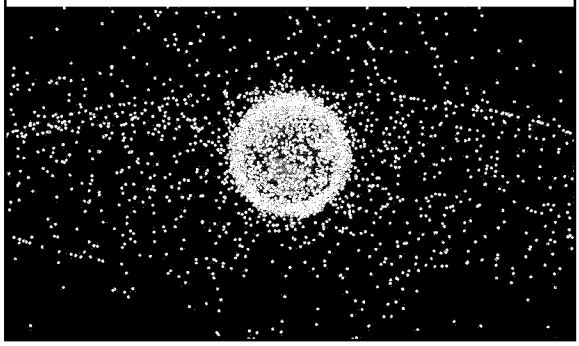
A satellite will have a circular orbit if its initial speed = **circular speed** ( $v_{circ}$ )

$$v_{circ} = \sqrt{\frac{GM}{r}}$$

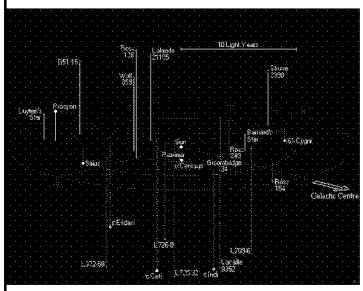
Presented without proof (life is too short).

r = radius of circular orbit
M = mass of object being orbited

To stay in low Earth orbit, a satellite must have v = $v_{circ}$= 7.9 km/sec (18,000 mph).



Gravity makes the Moon orbit the Earth.
It makes planets orbit the Sun.
**What does it do on larger scales?**

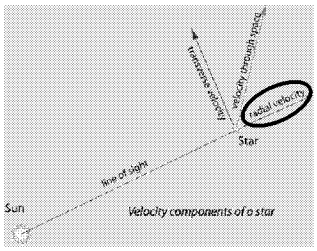



Solar Neighborhood: Stars within 13 light-years (4 parsecs) of the Sun.

The **radial velocity** of a star is found from its **Doppler shift**.

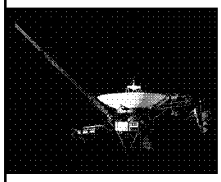
Radial velocity = how fast an object is moving toward you or away from you.

$$\frac{\Delta\lambda}{\lambda_0} = \frac{V}{c}$$




Results: nearby stars are moving toward and away from the Sun in equal numbers.

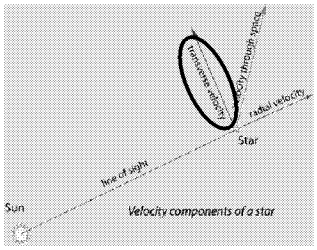
More results: nearby stars have radial velocities 20 to 30 kilometers/second.



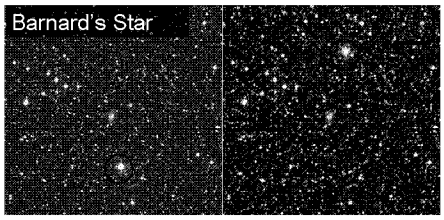
Comparison: Voyager 1 is moving away from the Sun at 17 km/sec.

The **transverse velocity** of a star is found from its **proper motion**.

Transverse velocity = how fast an object is moving from side to side.

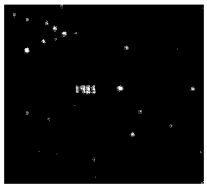


Proper motion = how fast a star is moving relative to background objects in arcseconds per year.




A.D. 2000 A.D. 1950

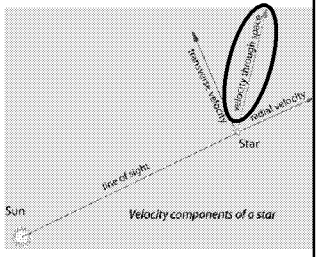
Barnard's star has the highest proper motion of any star: 10.3 arcseconds per year (1 degree every 350 years).



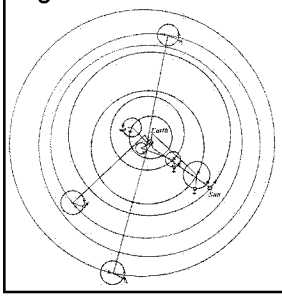
The **nearer** a star, the **higher** its proper motion. (Barnard's star is just 1.8 parsecs away.)

Stars in the solar neighborhood move randomly at speeds of about 40 km/sec **relative to the Sun**.

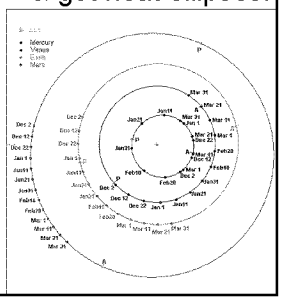
But…
Is it useful to think of stars' velocity relative to the Sun?



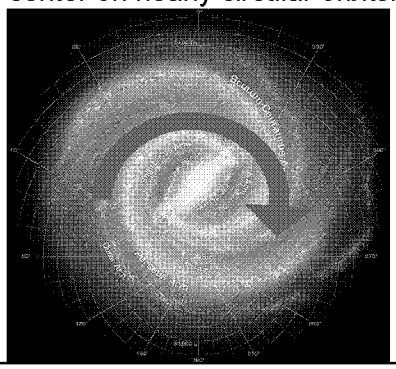
**Ptolemy** looked at planetary motions relative to the **Earth** & got a mess.



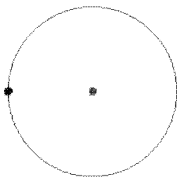

**Kepler** looked at planetary motions relative to the **Sun** & got neat ellipses.



The Milky Way Galaxy is a disk. Stars orbit the center on nearly circular orbits.



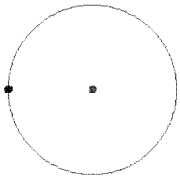
How can we measure the speed with which the Sun (& neighboring stars) move around the Galaxy's center?



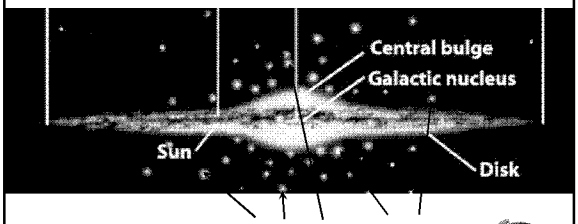
Blue dot = Sun
Red dot = Galaxy center

Distance to Galaxy center doesn't change. Therefore, no Doppler shift. Pity.

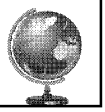
If there were distant objects at rest with respect to Galaxy's center, we could measure **their** Doppler shifts!

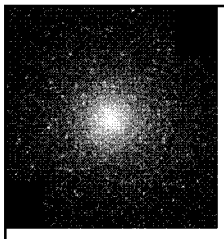


The Galaxy has an entourage of star clusters that (on average) are at rest with respect to the Galaxy's center.



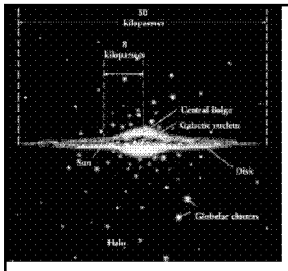

They are called "globular clusters" because of their shape.





A globular cluster contains >100,000 stars in a region <10 parsecs across.

Easy to see.
Easy to measure Doppler shifts.




Globular clusters are blueshifted in the direction of the Sun's motion; redshifted in opposite direction.

Size of Doppler shift indicates Sun is moving at **220 kilometers per second** around the Galaxy's center.

Speed of Earth's rotation (at equator) =

0.5 km/second = 1000 miles/hour

Earth's orbital speed around Sun =

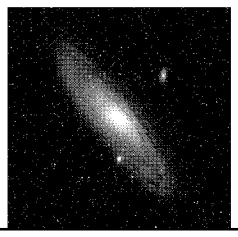
29 km/second = 65,000 miles/hour

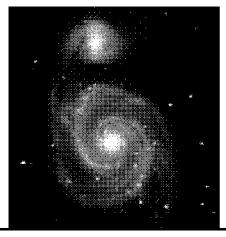
Sun's orbital speed around Galaxy center =

220 km/second = 490,000 miles/hour

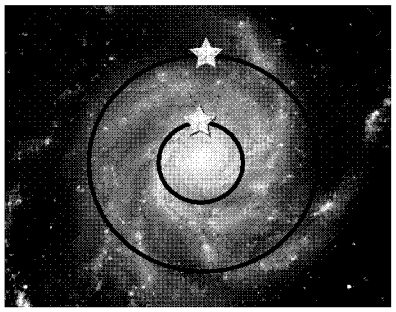
Bright galaxies tend to have one of two shapes.

1) **Spiral** galaxies, like the Andromeda Galaxy and the Whirlpool Galaxy.

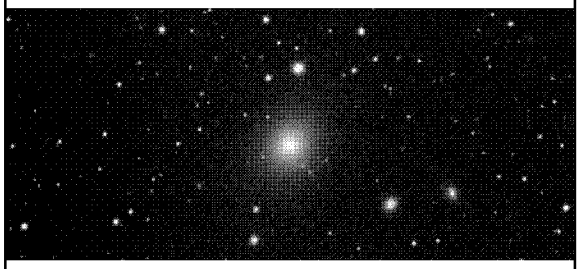




Stars in a spiral galaxy go around on neat (almost) circular orbits.

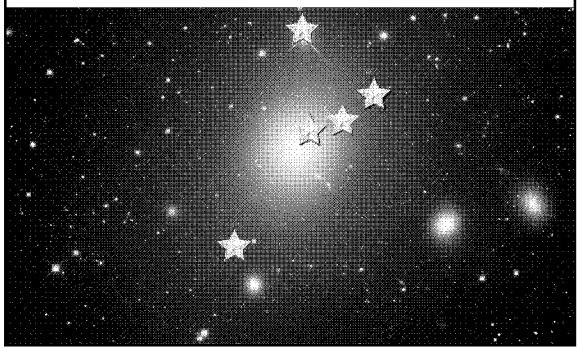


2) **Elliptical** galaxies, like the galaxy known as M87.



Spiral galaxies are more photogenic, so they appear in all the “coffee table” books.

Stars in an elliptical galaxy are on disordered, randomly oriented orbits.



**Spiral galaxy:** stars are "good citizens", traveling on orderly orbits, all moving in the same direction.

**Elliptical galaxy:** stars are "individualists", traveling on chaotic orbits, all in different directions.

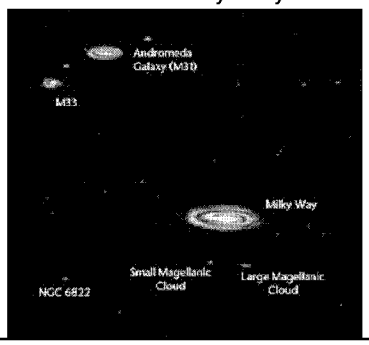
Why are some galaxies orderly (spiral) & others chaotic (elliptical)?

Milky Way Galaxy & Andromeda Galaxy are pulled toward each other.
What will happen when they collide??

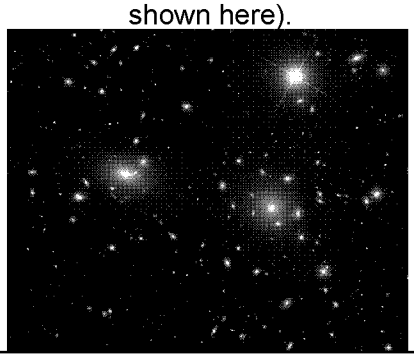
When 2 orderly spiral galaxies collide, they become a chaotic elliptical galaxy.

(When 2 orderly cars collide, they don't become an orderly truck: they become a chaotic heap of metal.)

**Spiral** galaxies are mainly in lower-density regions (like the **Local Group** which contains the Andromeda & Milky Way Galaxies).




**Elliptical** galaxies exist mainly in high-density clusters (like the Coma Cluster, shown here).



Friday's Lecture:

The Elusive **Dark Matter**

Reminders:

Have you read chapters 1 – 4 ?
Problem Set 3 is due **Wed, Oct 21**.
Planetarium shows **Oct 27 & 28.**