Physics 121.
Thursday, February 14, 2008.

Relative velocity at work in Hong Kong.

Frank L. H. Wolfs
Department of Physics and Astronomy, University of Rochester

Physics 121.
Tuesday, February 14, 2008.

- Topics:
  - Course announcements
  - Quiz
  - Gravitation:
    - Review
    - Orbital Motion
    - Kepler’s Laws

Physics 121
Course Announcements

- Homework set # 4 is now available on the WEB and will be due next week on Saturday morning, February 23, at 8.30 am.

- Homework set # 4 will have two components:
  - The regular WeBWorK component - 75%.
  - A video analysis component (will be demonstrated in a moment) - 25%.

- The first midterm exam in Physics 121 will take place two weeks from now. It will cover the material that has been discussed up to now (chapter 1 - 6) but no error analysis!

Preview of homework set # 4.

Frank Wolfs — **Physics 121, Spring 2008**
Homework Set 04 — **Due date: 02/23/2008 at 08:30am EST**

This assignment will be counted toward your final grade. You can attempt each problem 15 times; once you exceed this number of attempts, your solutions will not be recorded anymore. You may need to give 4 or 5 significant digits for some (floating point) numerical answers in order to have them accepted by the computer. Note: to use scientific notion, use a notion like xxE+yy. It is important that you use a capital E; answers with a lower case e will be evaluated differently

Gravitational force.

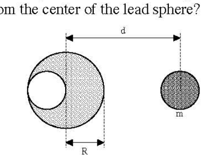
1. (20 pts) library/type29/prob05.pg
M_1 is a spherical mass (35.4 kg) at the origin. M_2 is also a spherical mass (14.5 kg) and is located on the x-axis at x = 78.0 m. At what value of x would a 20.0-kg mass experience no net gravitational force due to M_1 and M_2? __________

Gravitational force.

2. (20 pts) library/type29/prob14.pg
Some believe that the positions of the planets at the time of birth influence the newborn. Others deride this and say that the gravitational force exerted on a baby by the obstetrician is greater than that exerted by the planets. To check this claim, first calculate the gravitational force exerted on a 4.4 kg baby by a 52.3 kg doctor who is 0.7 m away. __________
Calculate the gravitational force exerted on the baby by the planet Jupiter m = 1.9E+27 kg) at its closest approach to the earth (= 6.0E+11 m). __________
Calculate the gravitational force exerted on the baby by Jupiter at its greatest distance from the earth (= 9.0E+11 m). __________

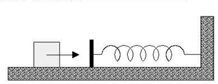
Gravitational force + principle of super position.

3. (20 pts) library/type29/prob19.pg
A spherical hollow is made in a sphere of radius R = 28.3 cm such that its surface touches the outside surface of a lead sphere and passes through its center (see Figure). The mass of the sphere before hollowing was M = 95.0 kg. What is the magnitude of the gravitational force between the hollowed-out lead sphere and a small sphere of mass m = 2.5 kg, located a distance d = 0.55 m from the center of the lead sphere? __________



Non-conservative forces.

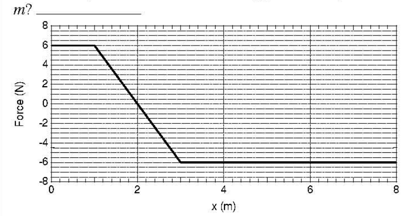
4. (20 pts) library/type12/prob16.pg
A moving 1.1 kg block collides with a horizontal spring whose spring constant is 395 N/m (see figure). The block compresses the spring a maximum distance of 10.0 cm from its rest position. The coefficient of kinetic friction between the block and the horizontal surface is 0.24. What is the work done by the spring in bringing the block to rest? __________



How much mechanical energy is being dissipated by the force of friction while the block is being brought to rest by the spring? __________
What is the speed of the block when it hits the spring? __________

Work-energy theorem.

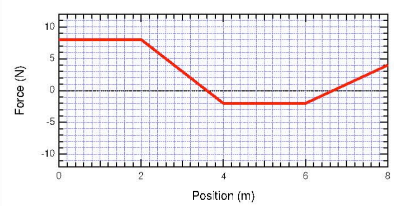
5. (20 pts) library/type12/prob06.pg
The only force acting on a 4.0 kg body as it moves along the x axis varies as shown in the Figure. The velocity of the body at x = 0 is 6.1 m/s. What is the kinetic energy of the body at x = 7.3 m? __________



At what value of x will the body have a kinetic energy of 66.0 J? __________
What is the maximum kinetic energy attained by the body between x = 0 and x = 8 m? __________

Work-energy theorem.

6. (20 pts) library/type12/prob08.pg
A block of mass 8.08 kg moves in a straight line on a horizontal frictionless surface under the influence of a force that varies with position as shown in the figure. How much work is done by the force as the block moves from the origin to 8.0 m? __________

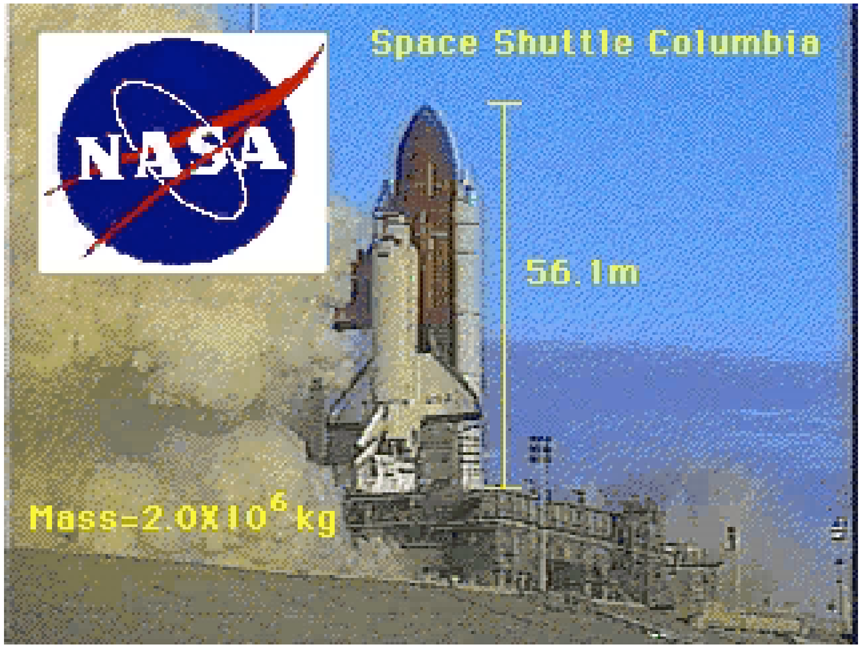


If the block has a velocity of 3.7 m/s at the origin, what is the velocity of the block at +8.0 m? __________

1

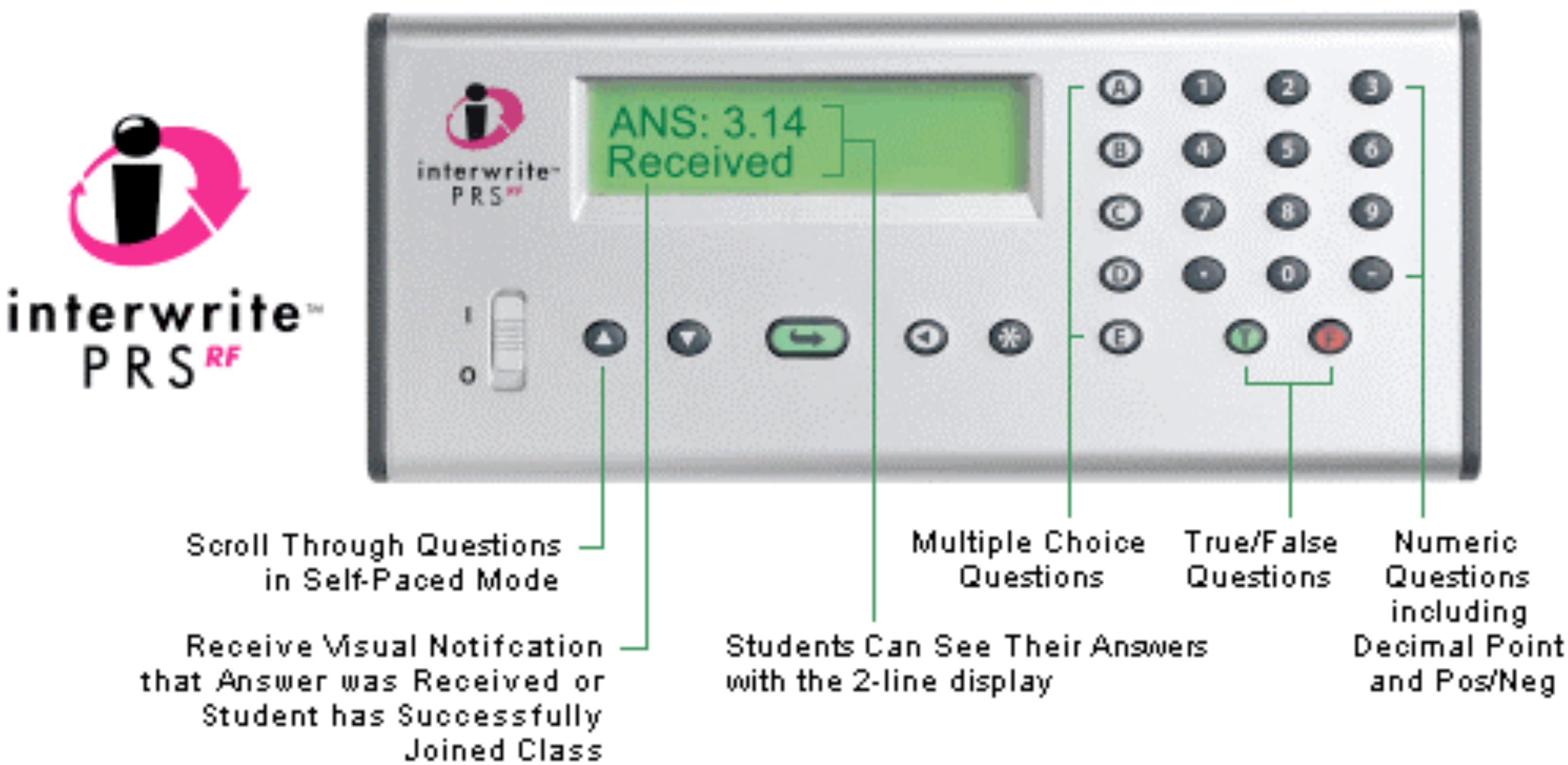
Preview of homework set # 4.

- On set # 4 you will be asked to carry out our first video analysis.
- You will study the launch of the space shuttle. The main questions are:
  - What is the vertical acceleration of the space shuttle?
  - What is the force generated by the engines?
- You will need to use loggerPro for this analysis. You can download the software from the Physics 121 website.
- Let's demonstrate how to use loggerPro.



Physics 121.
Quiz lecture 8.

- The quiz today will have 3 questions.

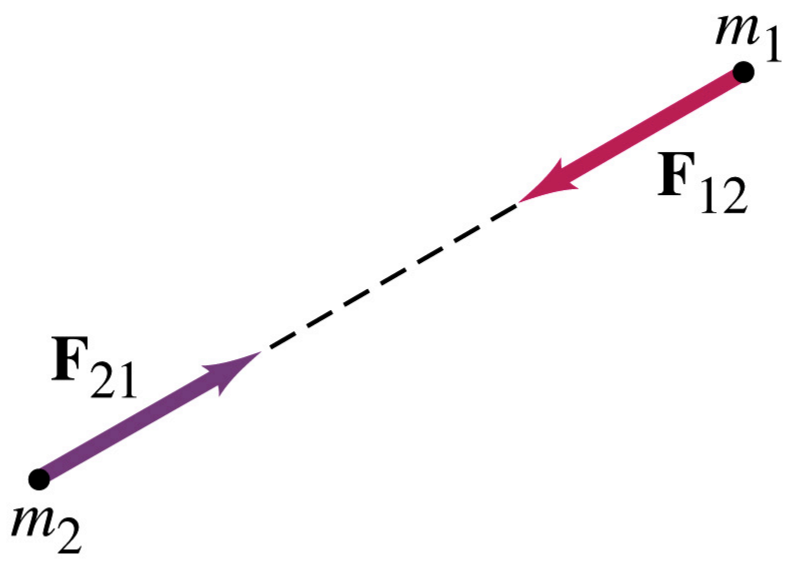


A quick review. The gravitational force.

- The magnitude of the gravitational force is given by the following relation:

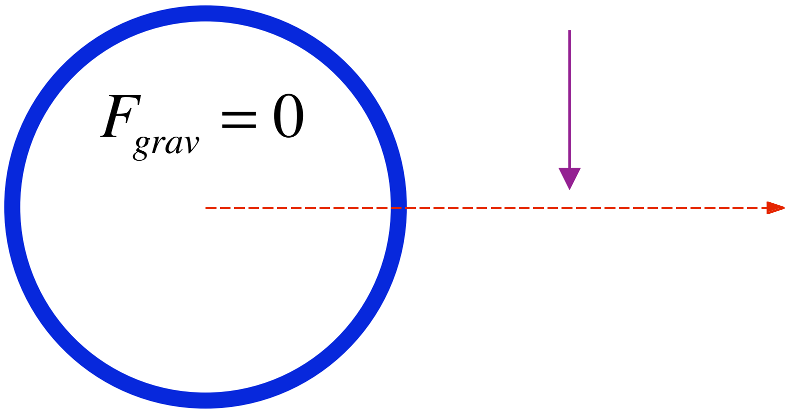
$$F_{grav} = G\frac{m_1 m_2}{r^2}$$

- The constant G is the gravitational constant which is equal to 6.67 x 10^{-11} N m^2/kg^2.



A quick review.
The shell theorem (Appendix D).

- Consider a shell of material of mass m_1 and radius R.
- In the region outside the shell, the gravitational force will be identical to what it would have been if all the mass of the shell was located at its center.
- In the region inside the shell, the gravitational force on a point mass m_2 is equal to 0 N.

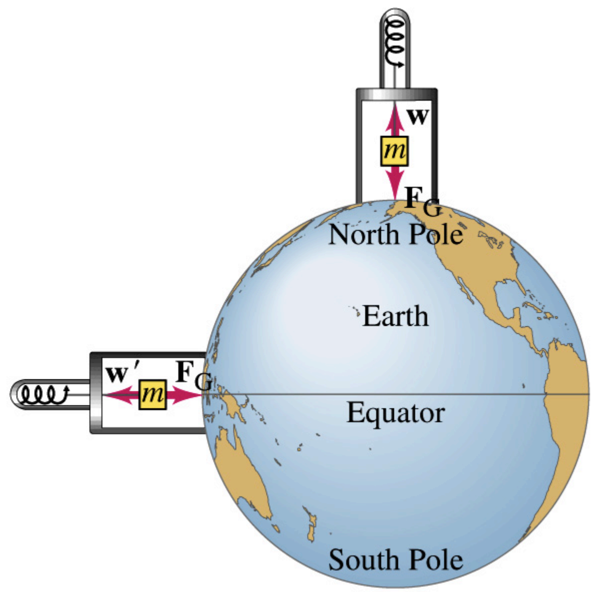


$$F_{grav} = G\frac{m_1 m_2}{r^2}$$

$$F_{grav} = 0$$

The gravitational force. Variations in the gravitational force.

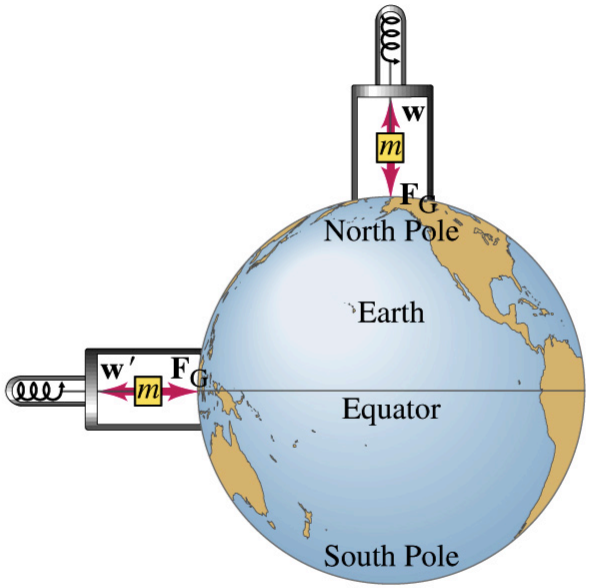
- The gravitational force on the surface of the earth is not uniform for a number of different reasons:
  - The effect of the rotation of the earth.
  - The earth is not a perfect sphere.
  - The mass is not distributed uniformly, and significant variations in density can be found (in fact using variations in the gravitational force is one way to discover oil fields).



Frank L. H. Wolfs
Department of Physics and Astronomy, University of Rochester

The gravitational force. Variations in the gravitational force.

- Let us examine the effect of the rotation of the earth in more detail.
- For an object located on the North pole we expect to find its weight to be equal to the gravitational force: $W = mg_0$.
- An object located on the equator will carry out circular motion with a period of 24 hours.
- The net acceleration of this object will be

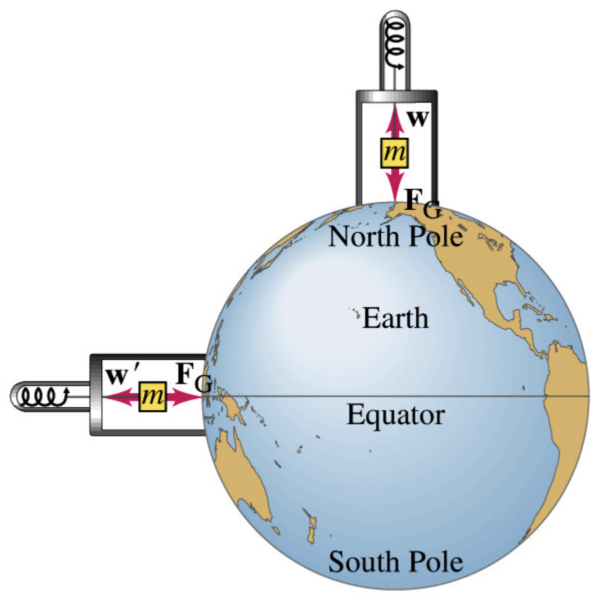


$$a = v^2/R_e = (2\pi R_e/T)^2/R_e == 4\pi^2 R_e/T^2$$

The gravitational force.
Variations in the gravitational force.

- In order to carry out the circular motion, there must be a net force acting on the object, directed towards the center of the earth.
- Thus, the weight *W'* must be less than the gravitational force (and *W*).
- The net force on the object is equal to

$$F = mg_0 - W' = ma_c = 4m\pi^2 R_e/T^2$$



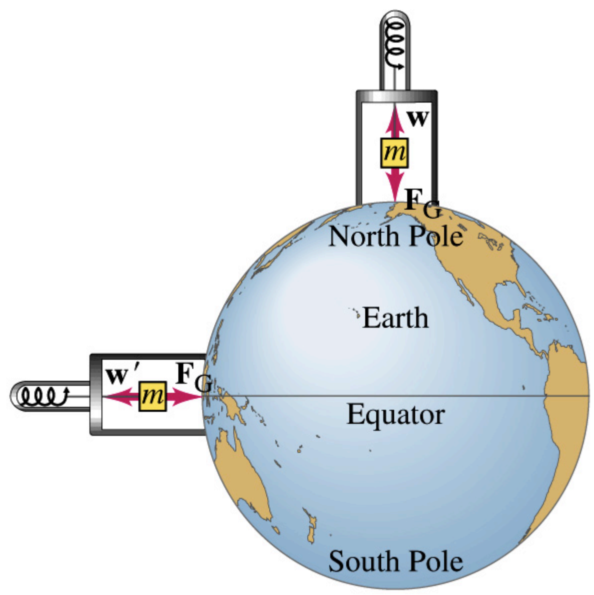
The Gravitational Force
Variations in the gravitational force

- The effective gravitational acceleration at the equator will thus be less than the gravitational acceleration at the poles:

$$g = W'/m = g_0 - 4\pi^2 R_e/T^2$$

- The difference is equal to

$$g_0 - g = 0.034 \text{ m/s}^2$$

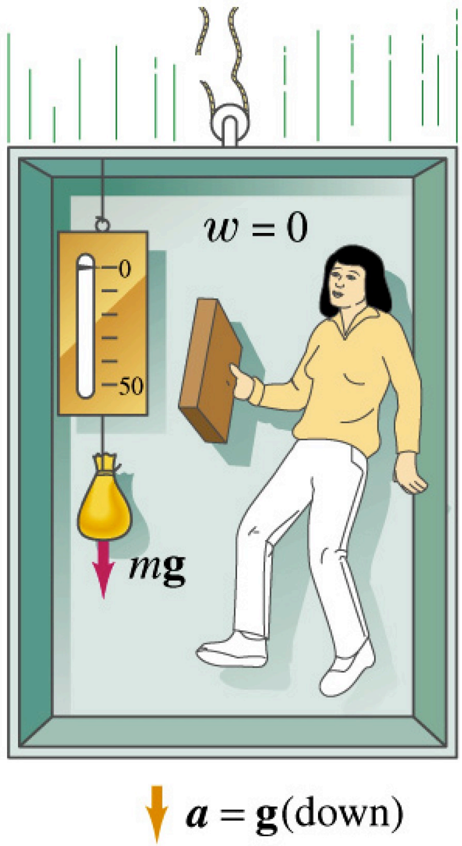


Orbital motion and weightlessness.

- One of the most confusing aspects of orbital motion is the concept of weightlessness.
- Frequently people interpret this as implying the absence of the gravitational force.
- Certainly this can not be the case since the gravitational force scales as $1/r^2$ and is thus not that different from the force we feel on the surface on the earth.

Orbital motion and weightlessness.

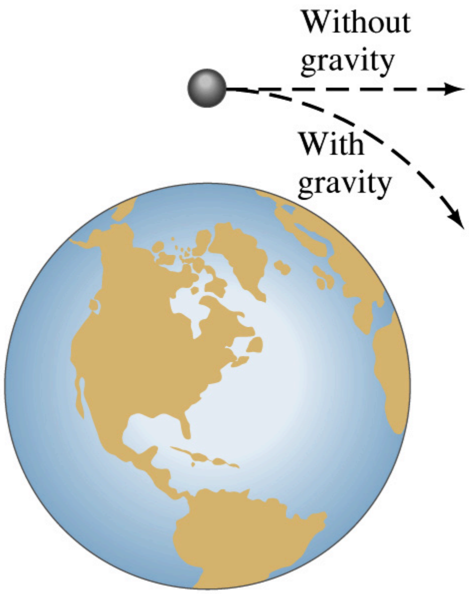
- We experience apparent weightlessness anytime we fall with the same acceleration as our surroundings.
- Consider a falling elevator. Every object in the elevator will fall with the same acceleration, and the elevator will not need to exert any additional forces, such as the normal force, on those inside it.
- It appears as if the objects in the elevator are weightless (in reality they of course are not).



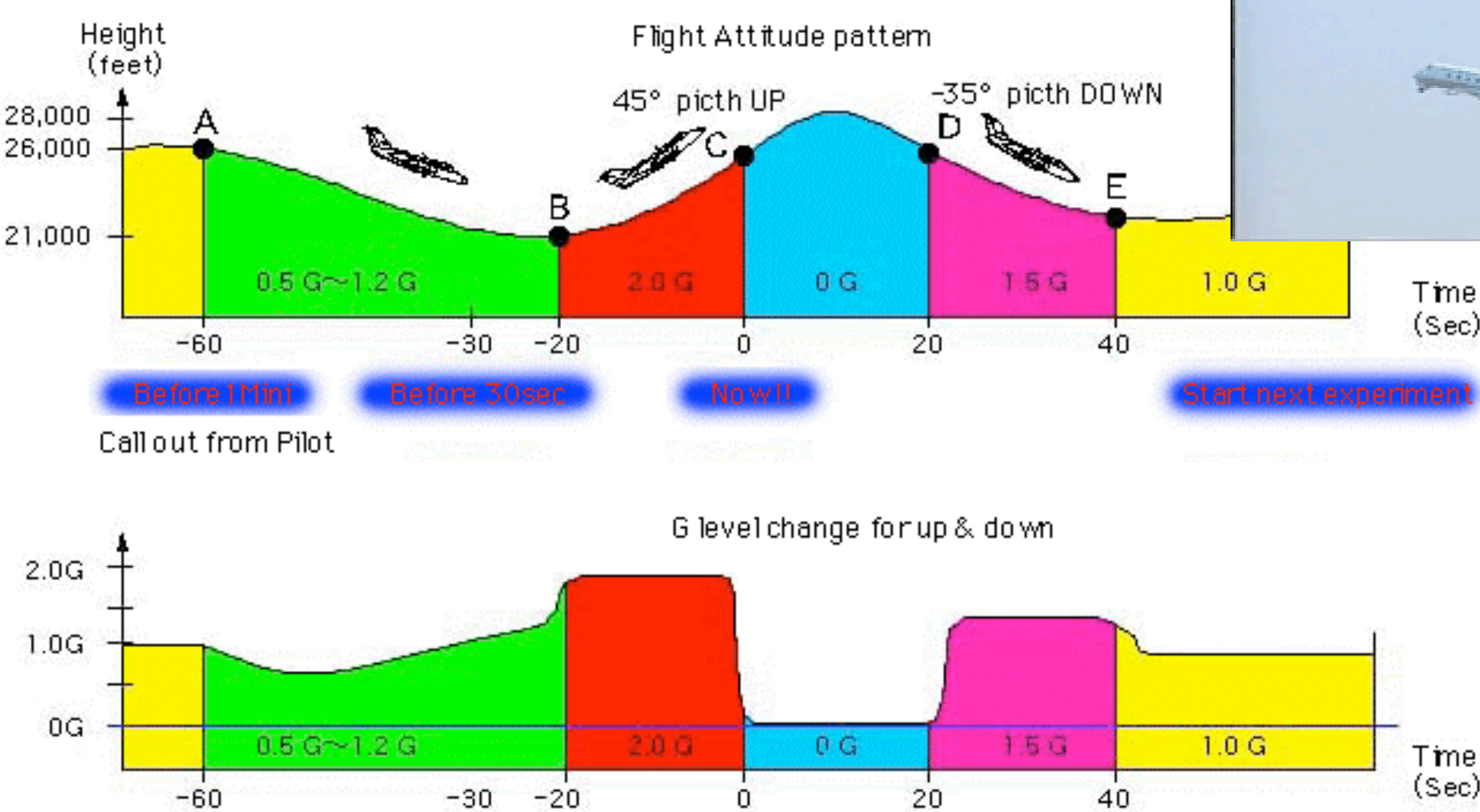
Department of Physics and Astronomy, University of Rochester

Orbital motion and weightlessness.

- Weightlessness in space is based on the same principle:
  - Both astronaut and spaceship "fall" with the same acceleration towards the earth.
  - Since both of them fall in the same way (gravitational acceleration only depends on the mass of the earth, not on the mass of the spaceship or the astronaut) the astronaut appears to be weightless.

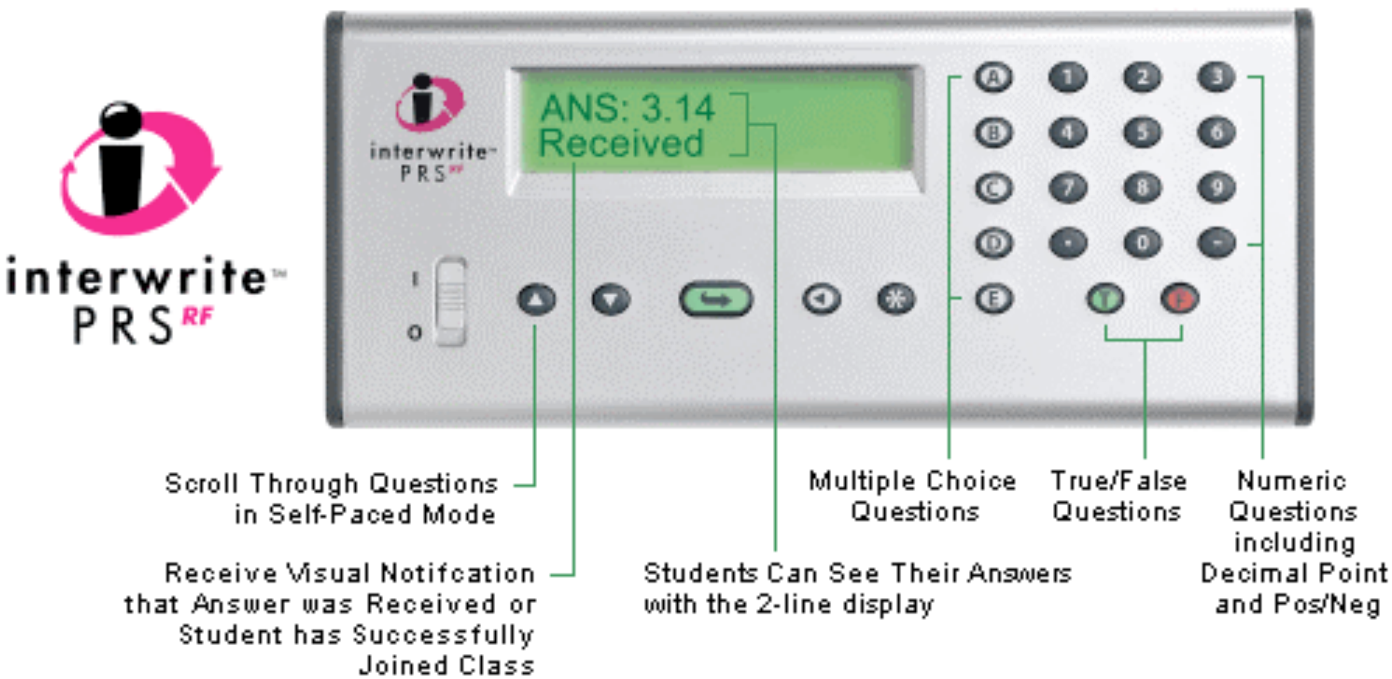


Mini-gravity.
Diamond Air Service.



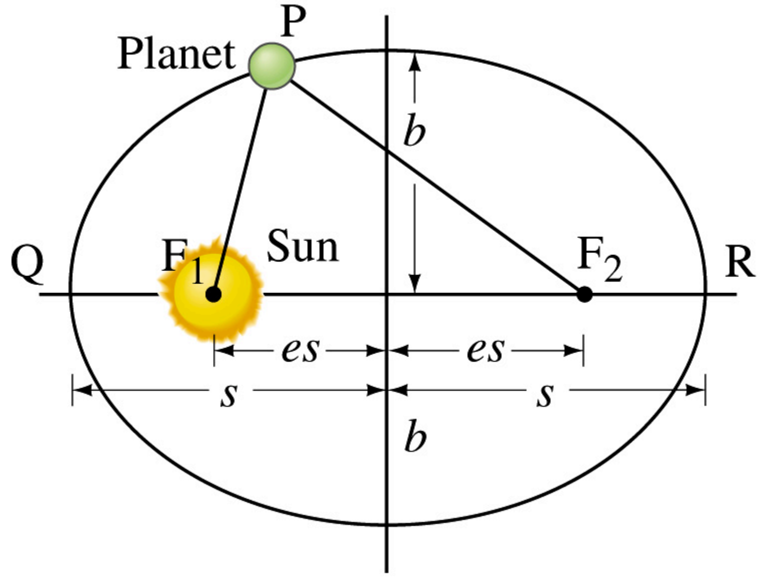
Gravity and orbital motion.

- Let's test our understanding of orbital motion by looking at the following concept questions:
  - Q7.1
  - Q7.2
  - Q7.3
  - Q7.4
  - Q7.5



Planetary motion. Orbital shapes.

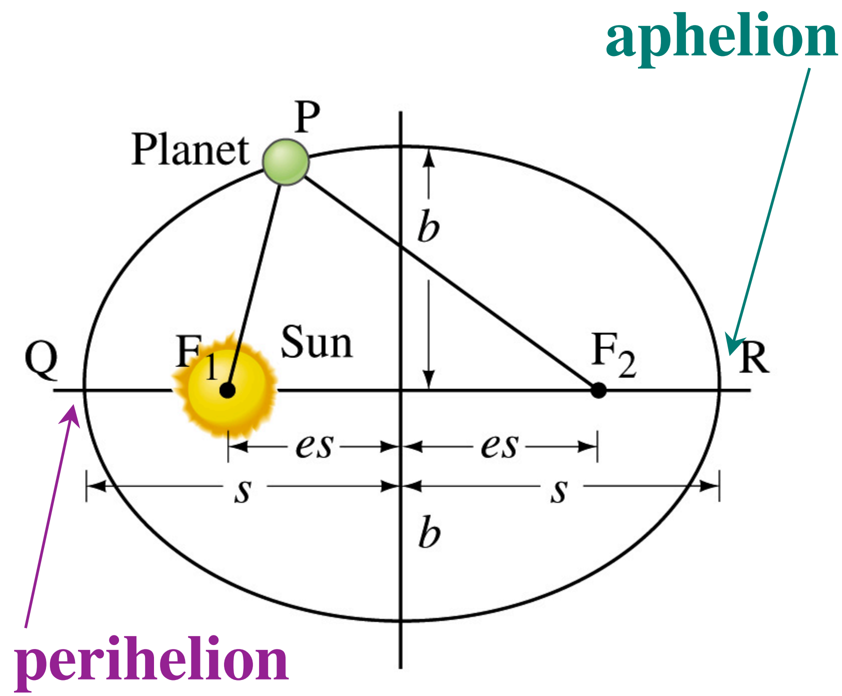
- Stable planetary motion does not require a perfect circular orbit.
- The shape of the orbit of a planet is described by an ellipse (note: a circle is a special type of ellipse). The ellipse is determined by specifying its semimajor axis s and its seminiminor axis b.
- The foci of an ellipse are special points for which the sum of the distance F_1 to P and the distance F_2 to P is the same for every point on the ellipse.



Department of Physics and Astronomy, University of Rochester

Planetary motion.
Kepler's first law.

- Note: for a circle $s = b$ and $F_1 = F_2$.
- The sun is located at one focus on the ellipse.
- The eccentricity e of the defined such that es is the distance from the center of the ellipse to either focus. Note: for a circle $e = 0$ m.
- The properties of the shape of the orbit of the planets and the location of the sun are part of what we call **Kepler's First Law**.

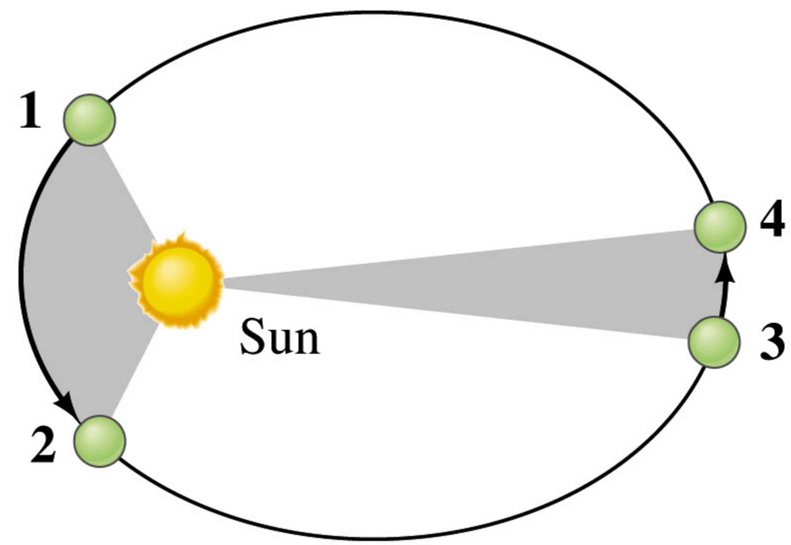


Kepler's second law.

- Kepler's Second Law states:

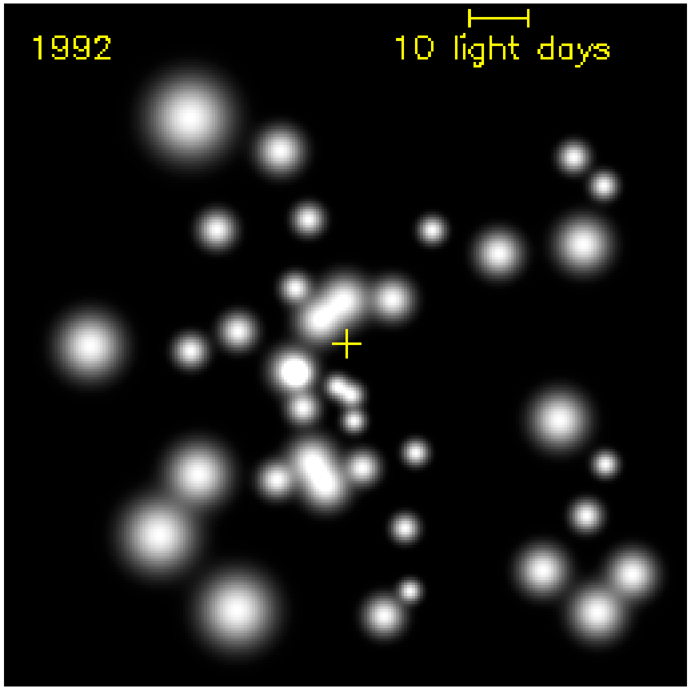
  "Each planet moves so that an imaginary line drawn from the Sun to the planet sweeps out equal areas in equal periods of time."

- Important consequences of Kepler's Second Law:
  - The velocity of the planet will increase the closer the planet is to the Sun (e.g. $v_{12} > v_{34}$).
  - The details of the orbit provide information about the mass of the sun.



Kepler's second law.

- Kepler's Second Law can also be used to describe the motion of stars around black holes.
- The study of the motion of the nearby stars can be used to determine the mass of the black hole.
- A good example is the determination of the mass of the black hole at the center of our galaxy. Based on the motion of the star S2 we have determined that the mass of the black hole is 2,600,000 times the mass of the sun.



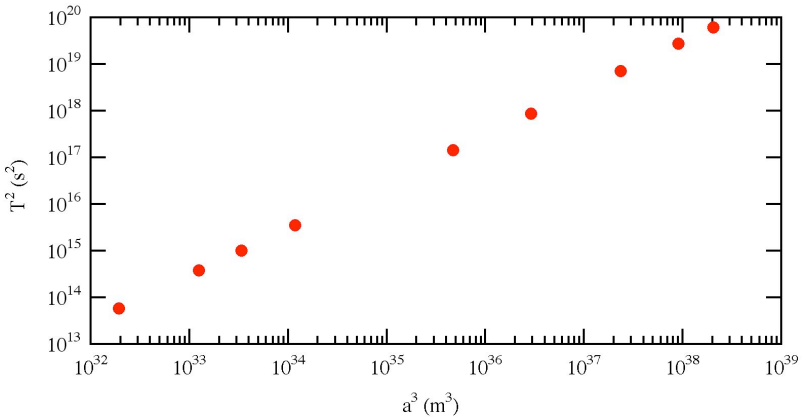
Center of the Milky Way. Credit: MPE and UCLA

Kepler's third law.

- Kepler's Third Law states:

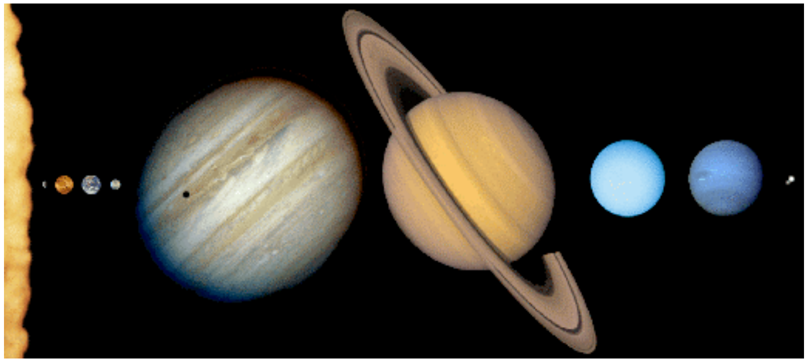
  " The ratio of the squares of the periods of any two planets revolving about the Sun is equal to the ratio of the cubes of their semimajor axes."

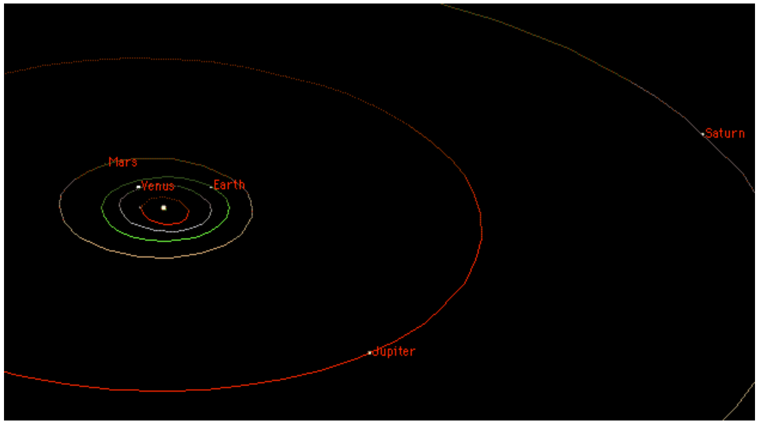
- The derivation of Kepler's Third Law assumes that the only force on each planet is the gravitational force between the planet and the sun.

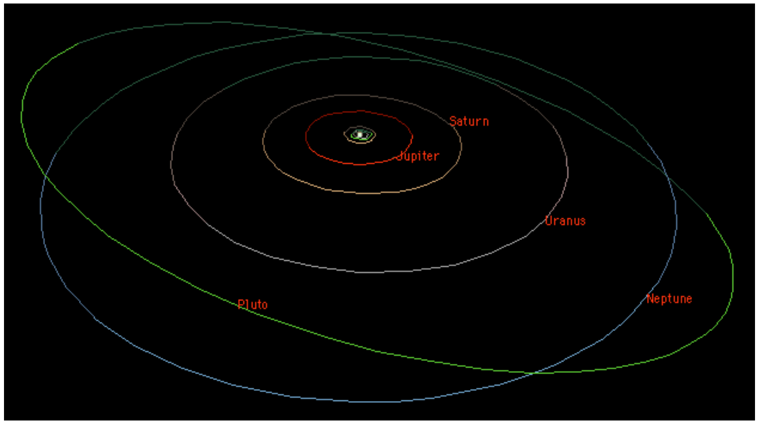


The solar system.

- The perturbation from pure elliptical orbits were a result of the gravitational attraction between the planets.
- Detailed measurements of these perturbations led to the discovery of e.g. Neptune and Pluto.



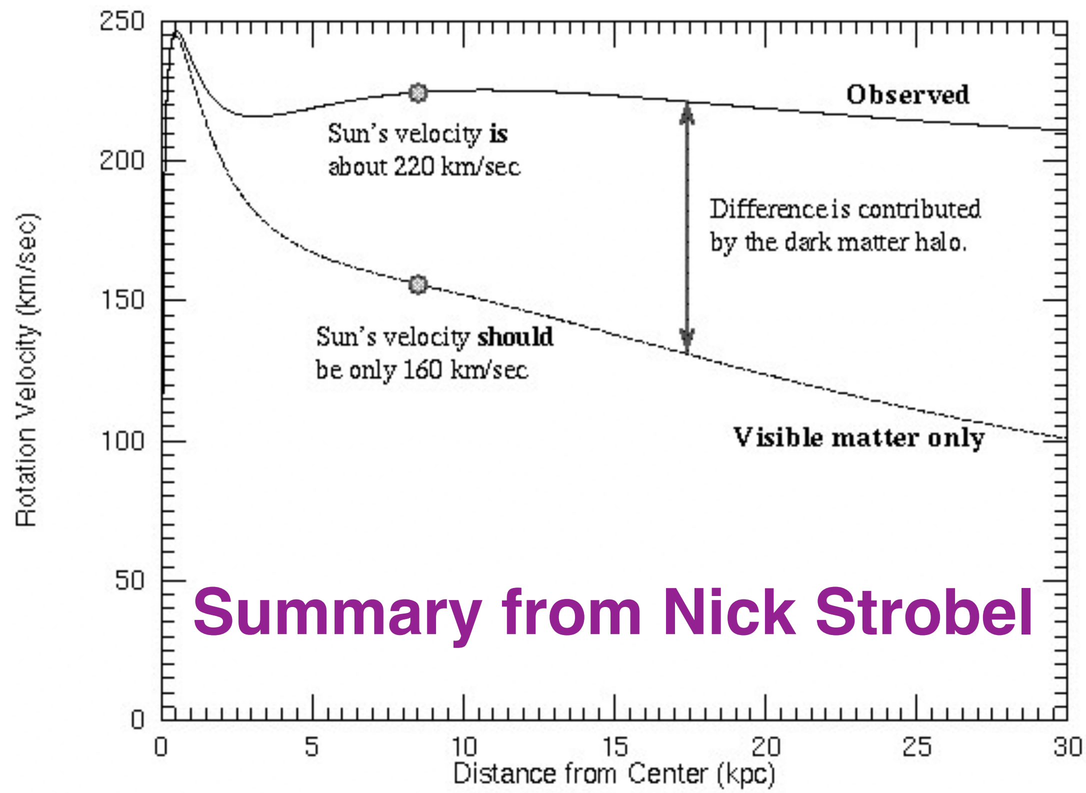




Bill Arnett, http://seds.lpl.arizona.edu/nineplanets/arnett.html

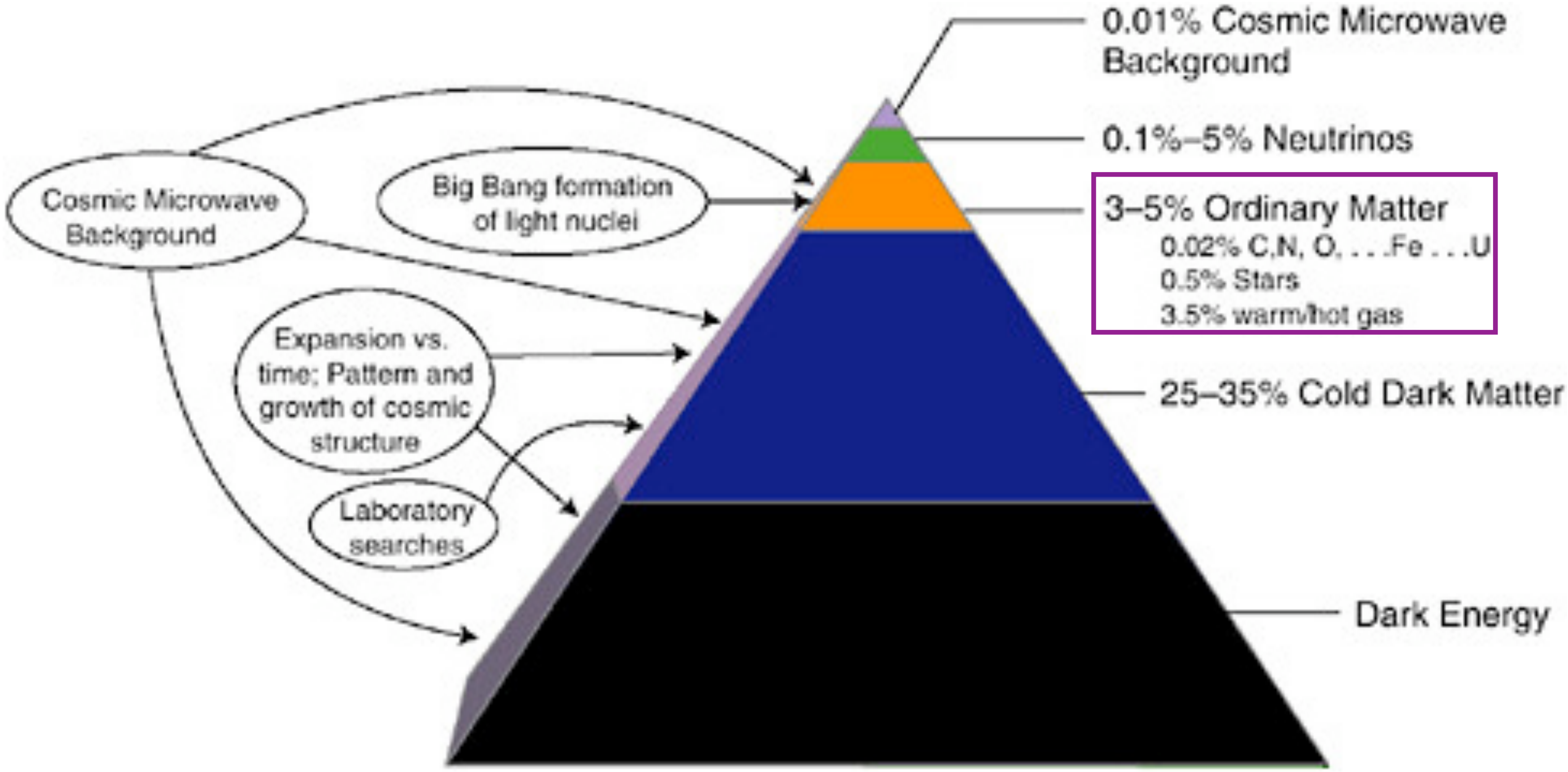
Evidence for dark matter: Galactic rotation curves.

Milky Way Illustrated.
Illustration Credit & Copyright: Mark Garlick (Space Art)



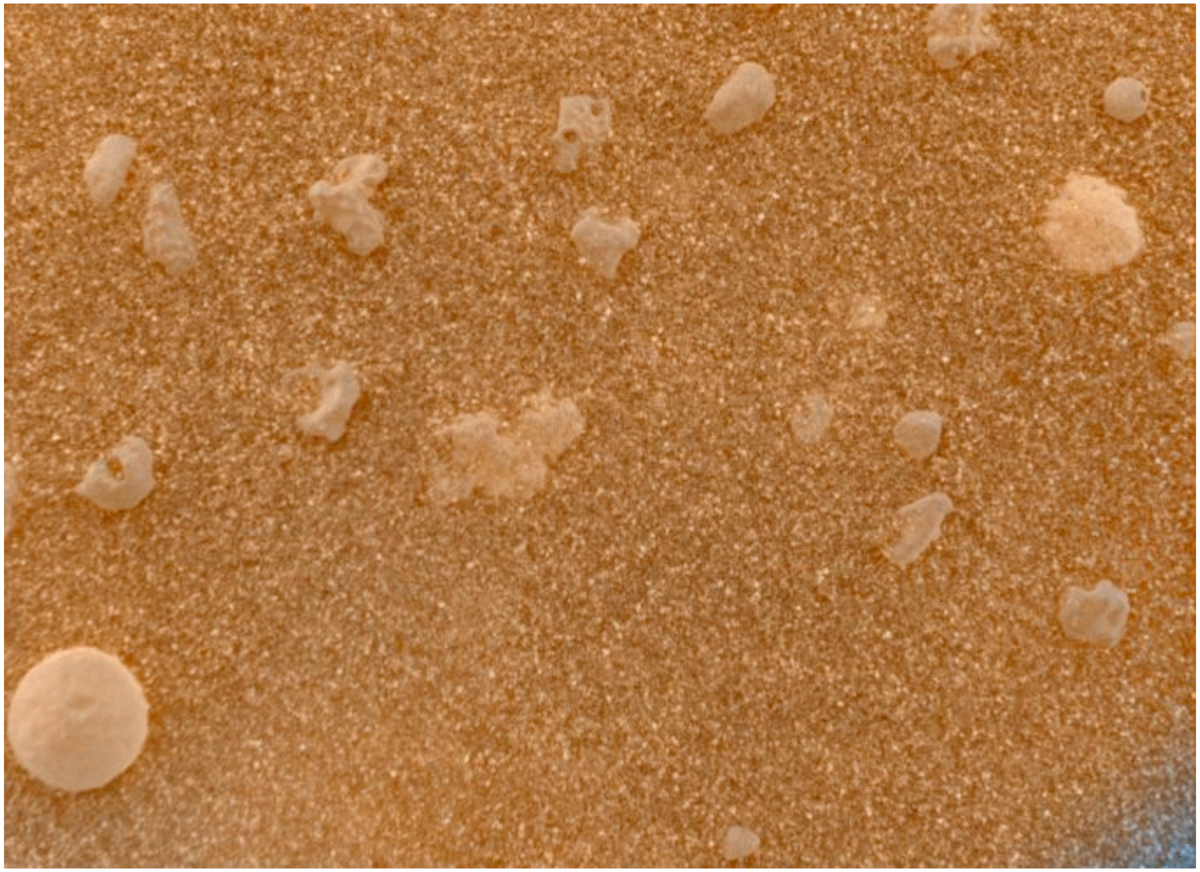
The gravity of the visible matter in the Galaxy is not enough to explain the high orbital speeds of stars in the Galaxy. For example, the Sun is moving about 60 km/sec too fast. The part of the rotation curve contributed by the visible matter only is the bottom curve. The discrepancy between the two curves is evidence for a **dark matter halo.**

Mass/energy balance in our Universe.



Source: *Connecting Quarks with the Cosmos*, The National Academies Press, p.86.

That's all!
Next week: Work and Energy.



Magnified Mars
Credit: Mars Exploration Rover Mission, JPL, USGS, NASA