Physics 121.
Lecture 08.

Relative velocity at work in Hong Kong.

Physics 121.
Lecture 08.

- Topics:
  - Course announcements
  - Quiz (all answers are correct)
  - Gravitation:
    - Review
    - Orbital Motion
    - Kepler's Laws

Physics 121
Course Announcements

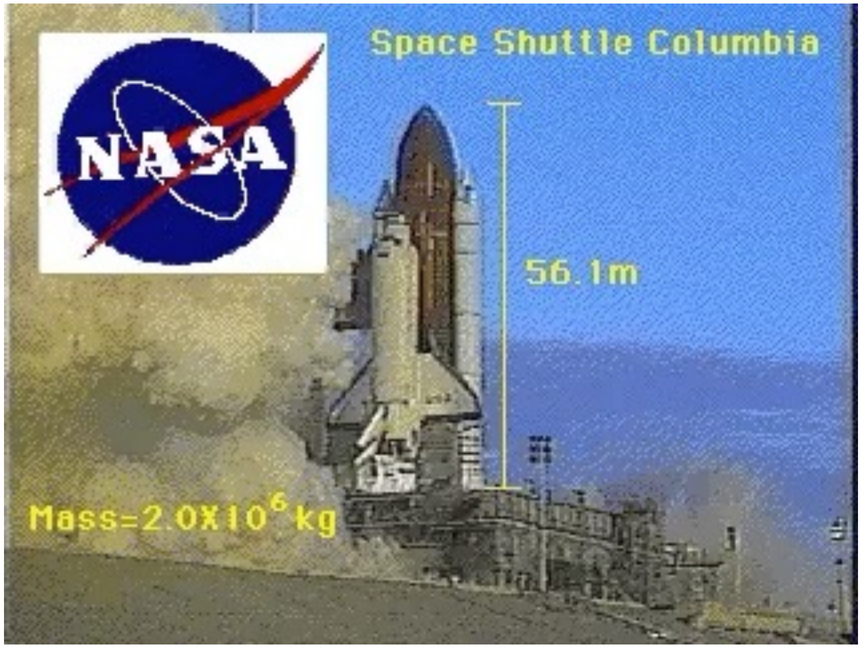
- There will be no workshops and office hours on Tuesday, Wednesday, Thursday, and Friday.

- Homework set # 4 is now available on the WEB and will be due next week on Saturday morning, February 28, at 8.30 am.

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

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 question are:
  - what is the 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.



Quiz.

- Let's practice what we learned (and read).

Food for thought.

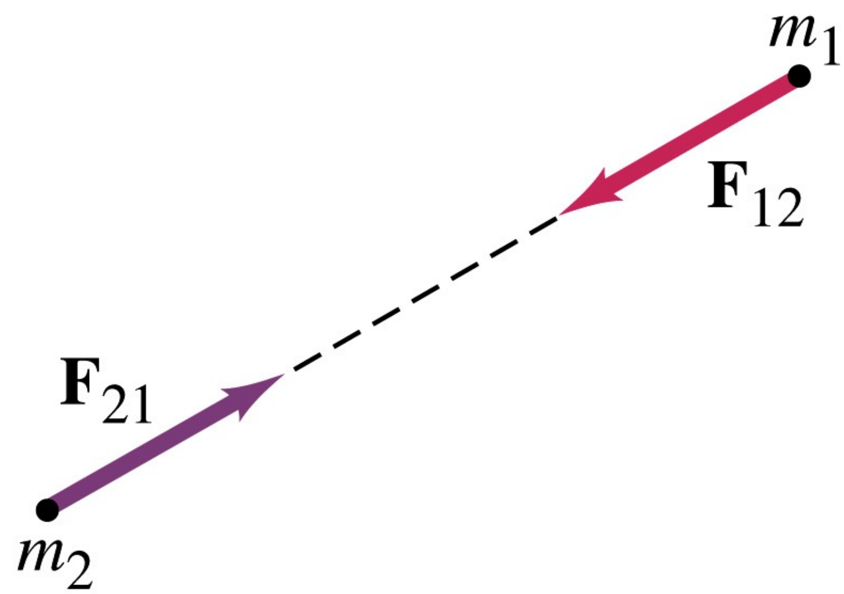
- Q: Who needs engineers?
- Q: Who needs physicists?
- A: We all do!

A quick review.
The gravitational force.

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

$$\vec{F}_{grav} = G\frac{m_1 m_2}{r^2}\hat{r}$$

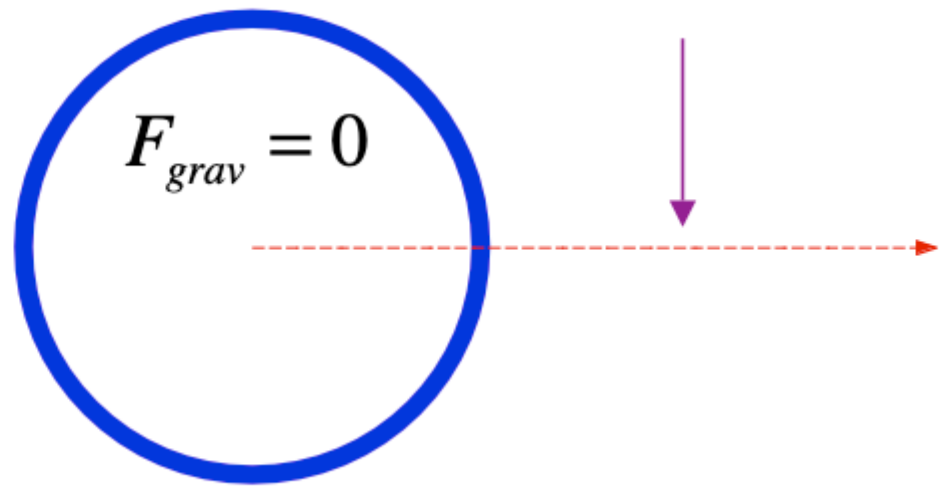
- The constant G is the gravitational constant which is equal to 6.67 x 10^{-11} N m^2/kg^2.



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

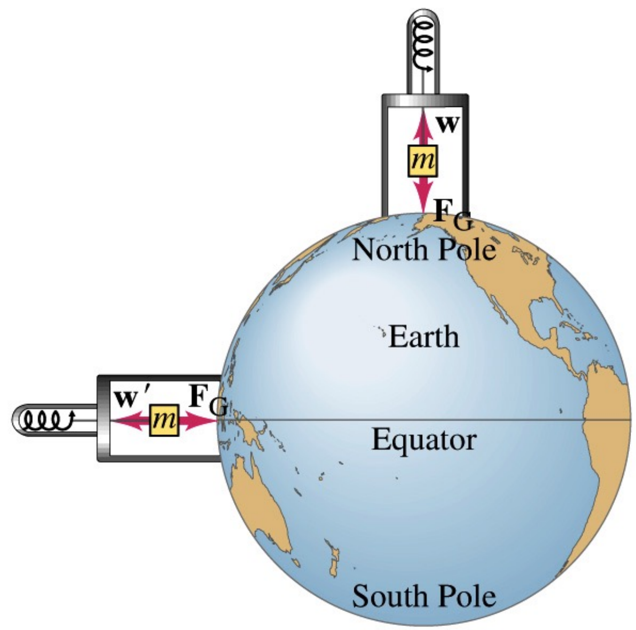
- Consider a shell of material of mass m_1 and radius R.
- In the region outside the shell, the gravitational force will be identical to what it would have been if all the mass of the shell was located at its center.
- In the region inside the shell, the gravitational force on a point mass m_2 is equal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

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



A quick review.
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).

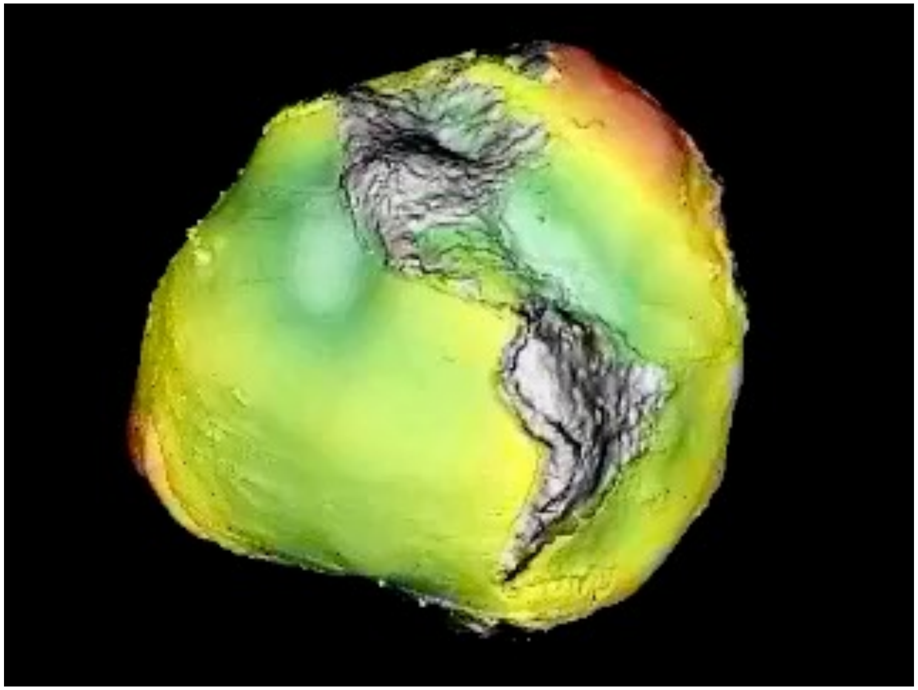


The gravitational force and the gravitational acceleration.

- Close to the surface of the earth, the gravitational force is equal to the product of the mass of the object and the gravitational acceleration g.

$$\vec{F}_{grav} = G\frac{M_E}{R^2}m\hat{r} = m\vec{g}$$

- By measuring $\vec{g}$ we can determine for example the mass of the earth (assuming we know G).



http://www.csr.utexas.edu/grace/

Changes in the gravitational acceleration.

FINDINGS

Before the '04 Tsunami, an Earthquake So Violent It Even Shook Gravity

The giant earthquake that set off a devastating tsunami across the Indian Ocean in December 2004 disrupted the earth enough to change gravity and to deflect satellites passing hundreds of miles above.

Two identical satellites, collectively known as the Gravity Recovery and Climate Experiment, or Grace, travel one behind the other in a polar orbit separated by about 130 miles.

By recording small changes in the distance between them when their orbits are deflected, the satellites provide data used to calculate variations in the earth's gravitational field.

In a report in the current issue of the journal Science, scientists at Ohio State University and the University of California, Santa Barbara, report that in the aftermath of the magnitude 9.1 earthquake, the largest in four decades, Grace recorded a sudden drop in gravity near the quake's epicenter off Sumatra.

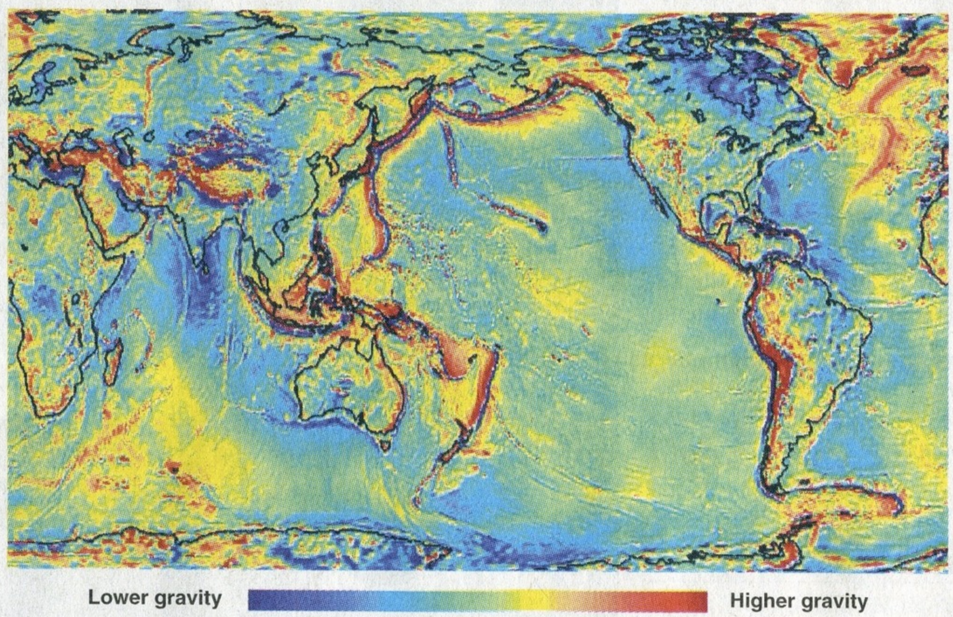
The rupture raised thousands of square miles of the seafloor, reducing the density of rocks in the earth's crust and diluting their gravitational pull. The data, combined with models of the earth's interior, indicate that the density changes extend hundreds of miles.

"It really gives an insight of the earth's interior down to the mantle area," said Shin-Chan Han, an Ohio State research scientist and an author of the Science paper. It was the first time that the gravitational effect of an earthquake had been observed.

The gravity at the earth's surface decreased by as much as about 0.0000015 percent, meaning that a 150-pound person would experience a weight loss of about one-25,000th of an ounce. In other places, where the force of the earthquake compressed rocks, gravity increased by a similar amount.

The force of gravity is changing in other areas of the earth, too. In Hudson Bay, Canada, which was crushed downward by the weight of ice during the last ice age, the ground is still rebounding upward. That change adds about one-400,000th of an ounce to the weight of a 150-pound person every year. *KENNETH CHANG*

Gravity's Rainbow Fluctuations in gravity occur across the planet. The map below shows variances (less than one-thousandth percent of the Earth's total gravity) detected by Grace.



New York Times, August 2006

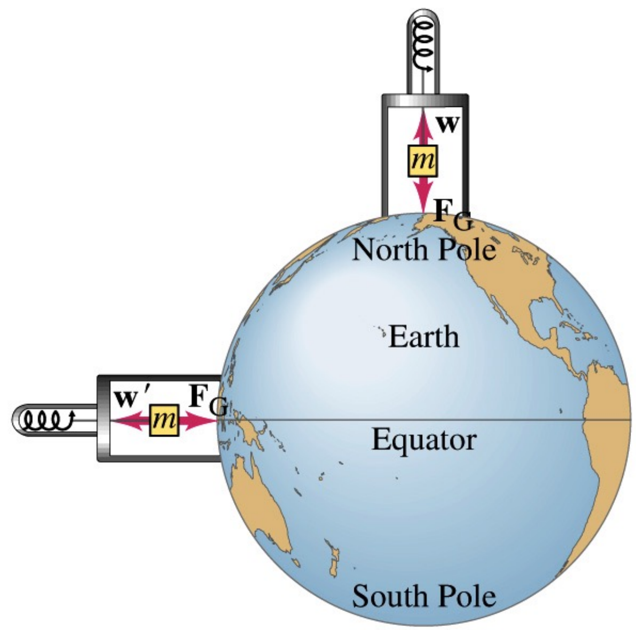
The gravitational force.
Variations in the gravitational force.

- 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

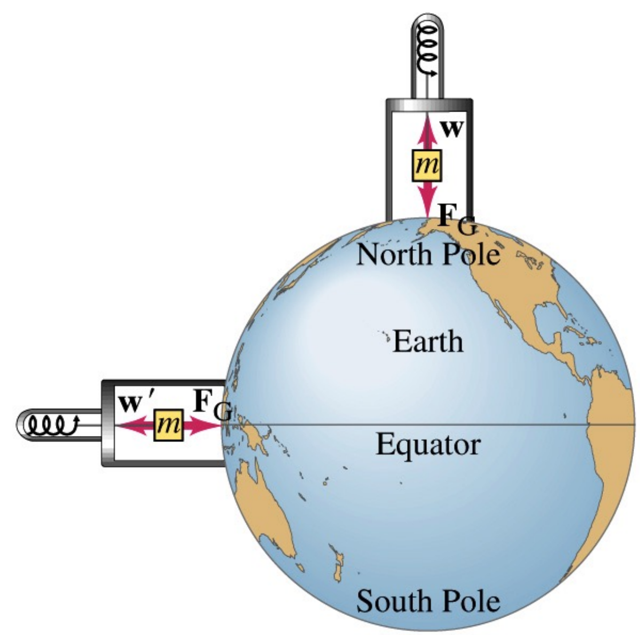
$$a = \frac{v^2}{R_e} = \frac{\left(\frac{2\pi R_e}{T}\right)^2}{R} = \frac{4\pi^2 R_e}{T^2}$$



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

$$F = mg_0 - W' = ma_c = \frac{4m\pi^2 R_e}{t^2}$$



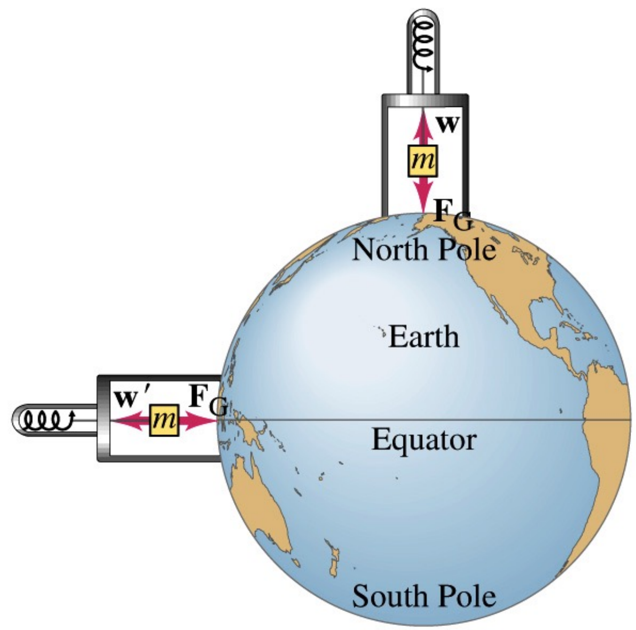
The Gravitational Force
Variations in the gravitational force

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

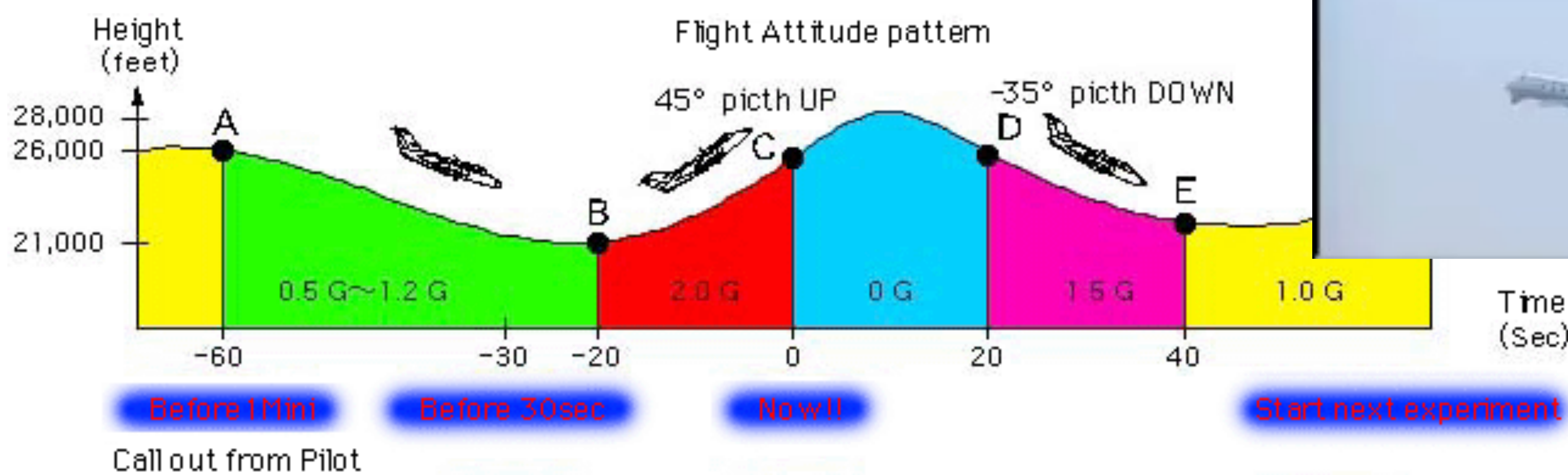
$$g = \frac{W'}{m} = g_0 - \frac{4m\pi^2 R_e}{t^2}$$

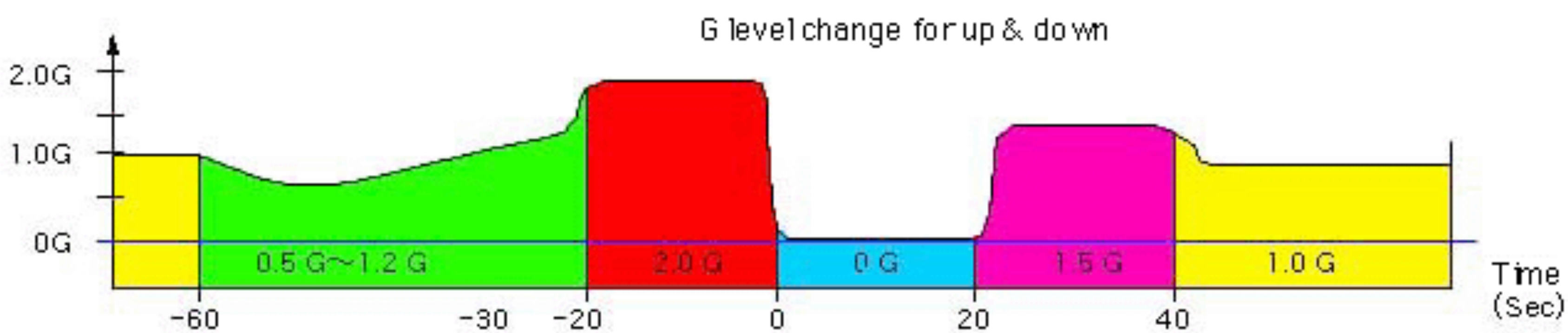
- The difference is equal to

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



Mini-gravity.
Diamond Air Service.





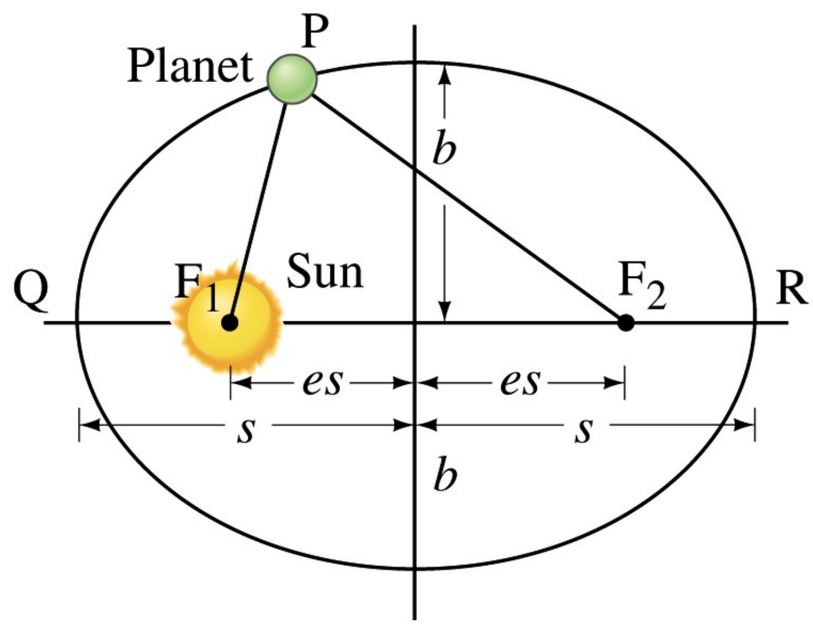
4 Minute 3 Second Intermission

- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 4 minute 3 second intermission.

- You can:
  - Stretch out.
  - Talk to your neighbors.
  - Ask me a quick question.
  - Enjoy the fantastic music.
  - Solve a WeBWork problem.
  - Go asleep, as long as you wake up in 4 minutes and 3 second.

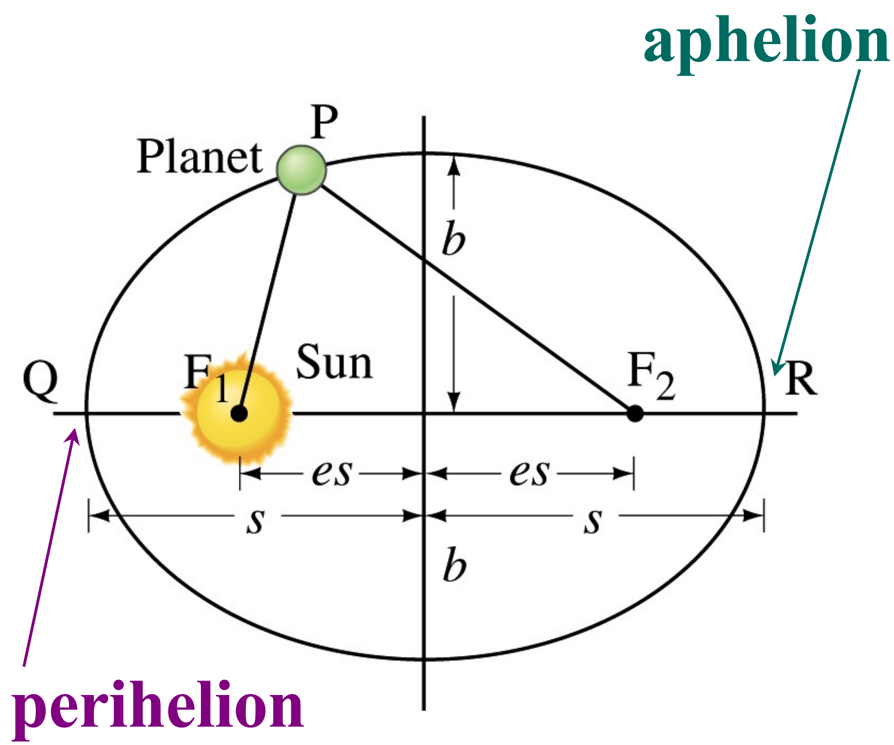
Planetary motion.
Orbital shapes.

- 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 semiminor 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.



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**.



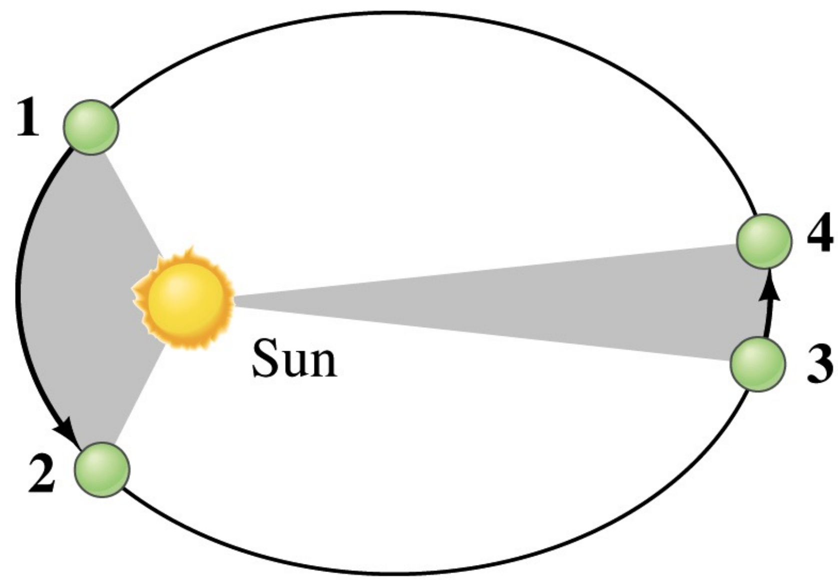
s = semi-major axis
b = semi-minor axis

Kepler's second law.

- Kepler's Second Law states:

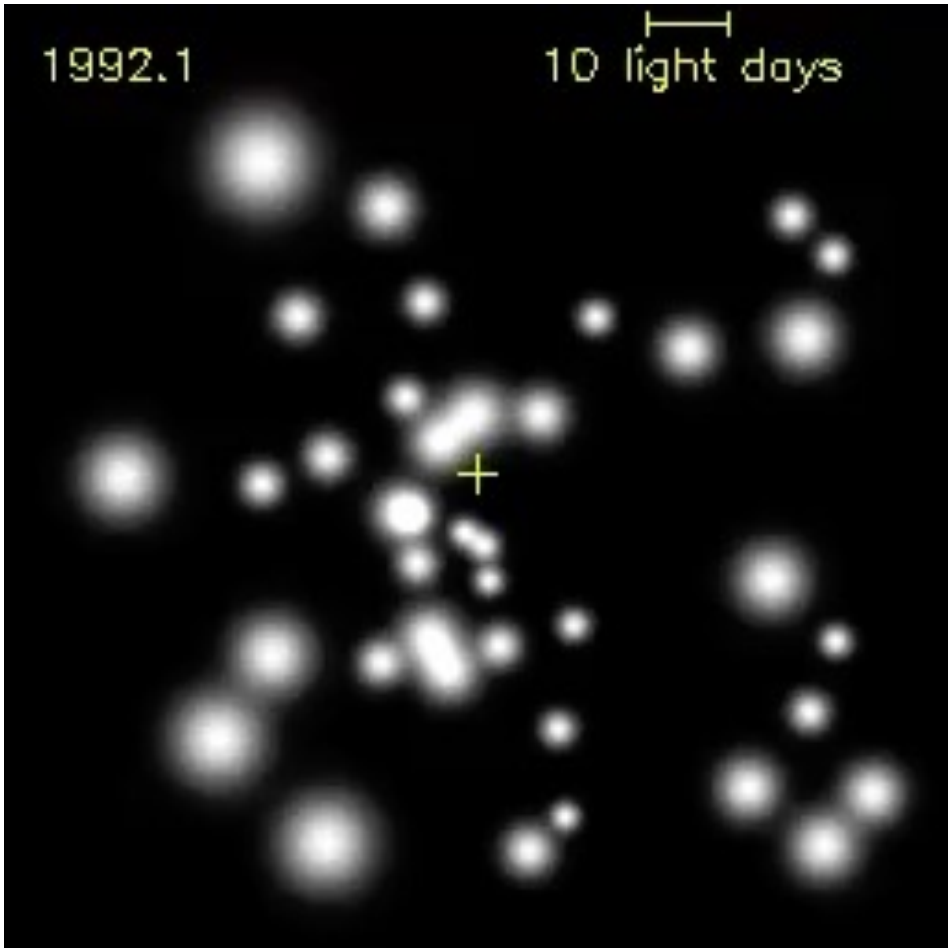
  "Each planet moves so that an imaginary line drawn from the Sun to the planet sweeps out equal areas in equal periods of time."

- 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.



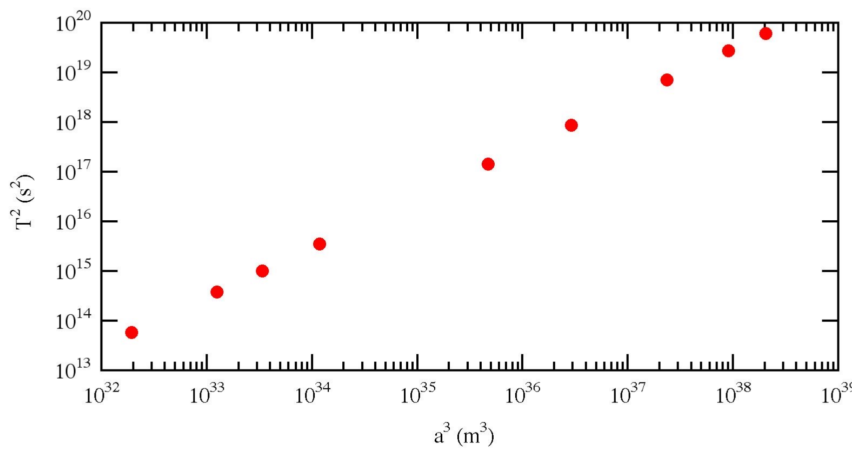
Center of the Milky Way. Credit: MPE and UCLA

Kepler’s third law.

- Kepler’s Third Law states:

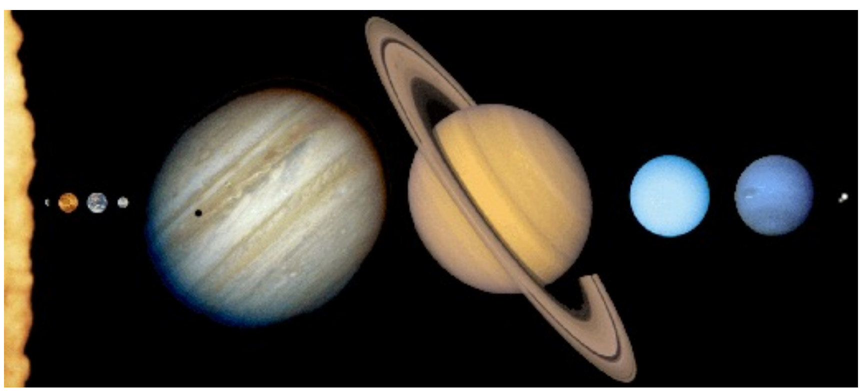
  “ The ratio of the squares of the periods of any two planets revolving about the Sun is equal to the ratio of the cubes of their semimajor axes.”

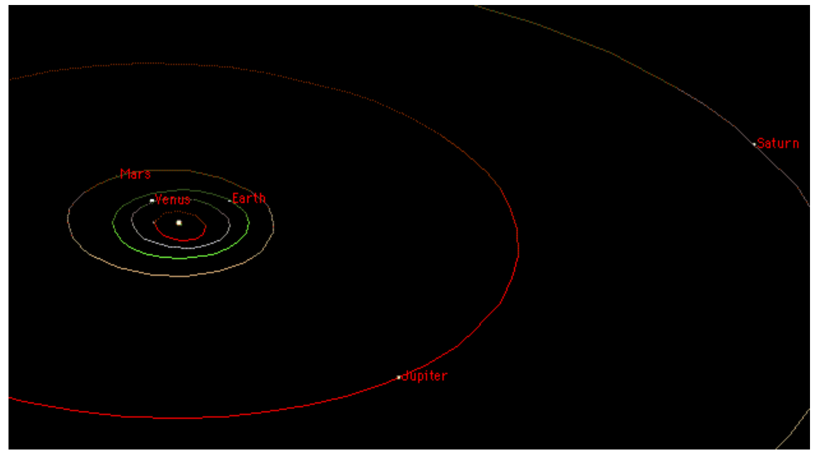
- The derivation of Kepler’s Third Law assumes that the only force on each planet is the gravitational force between the planet and the sun.

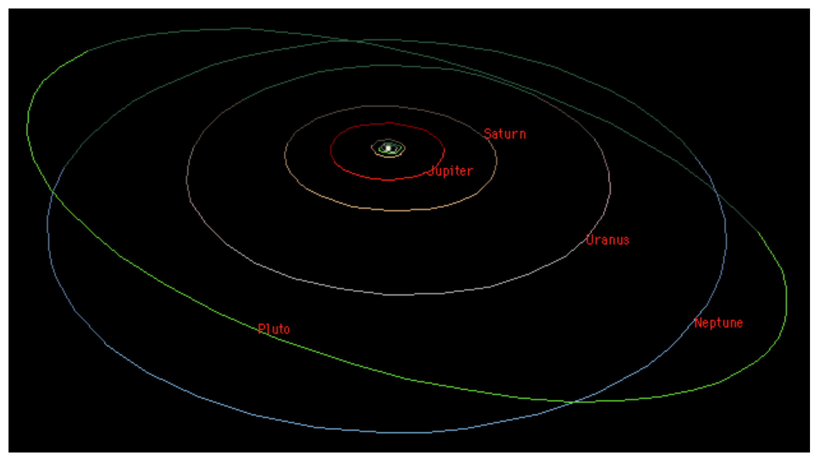


The solar system.

- 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.





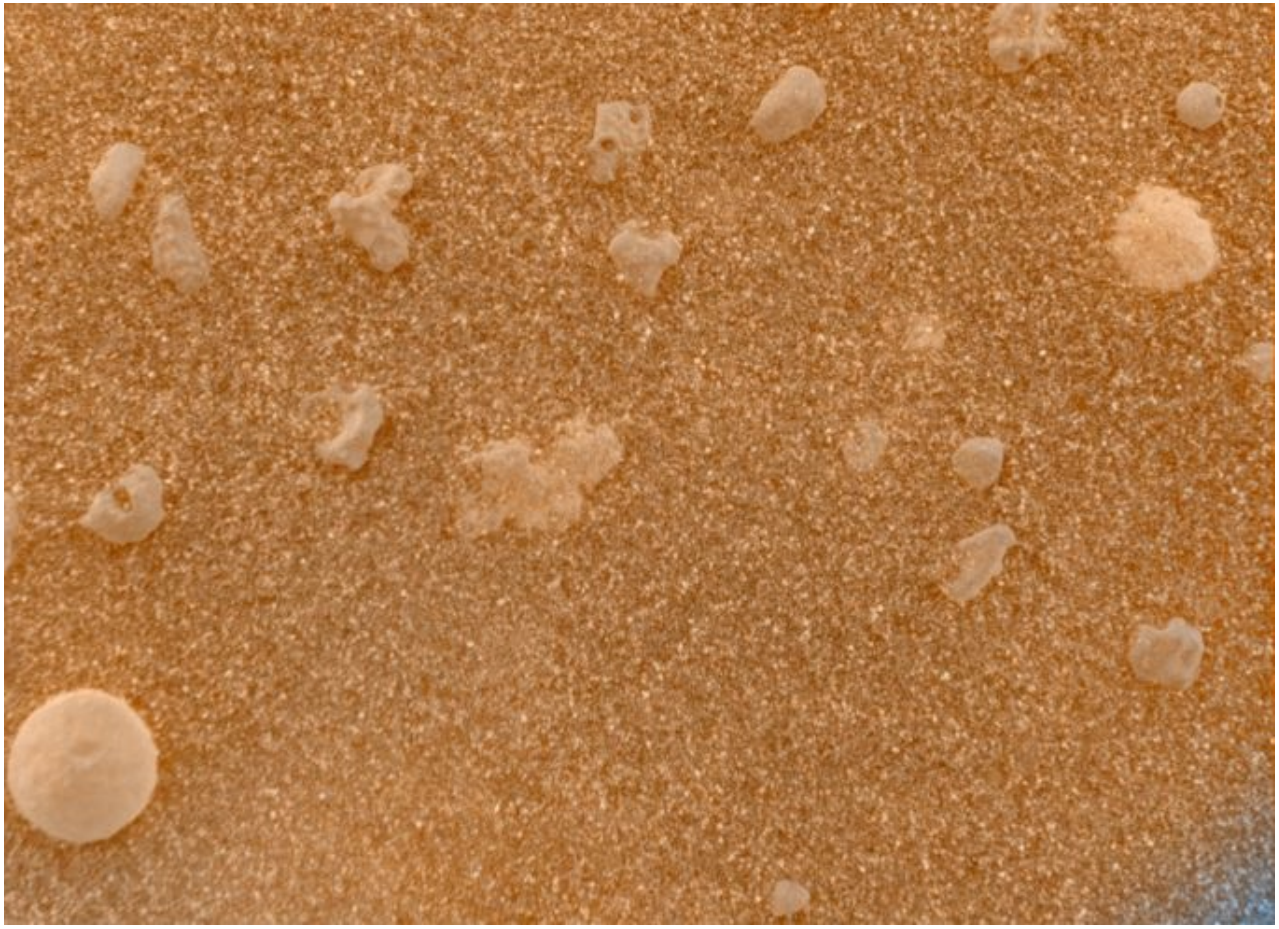


Bill Arnett, http://seds.lpl.arizona.edu/nineplanets/arnett.html

Concept Test.

- Let's practice what we learned (and read).

That's all!
On Thursday: Work and Energy.



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