Environmental Science Institute
THE UNIVERSITY OF TEXAS AT AUSTIN

1 University Station C9000
Austin, TX 78712
(512) 471-5847
www.esi.utexas.edu

Colossal Cosmos

Lesson plan for grades 9-12
Length of lesson: 2 Class periods (Approx 150 minutes total)
Authored: Jesús Aguilar-Landaverde, Environmental Science Institute, February 7, 2012

SOURCES AND RESOURCES:

- *The Known Universe* by AMNH
  http://www.amnh.org/news/2009/12/the-known-universe/
- Link to download the above movie file
  http://www.amnh.org/news/use-of-videos-on-this-site/
- Ask an Astrophysicist – Intro to Astronomical Distances
  http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/980226c.html
- Hyperphysics – Summary of Basic Rotational Quantities
  http://hyperphysics.phy-astr.gsu.edu/hbase/rotq.html

POTENTIAL CONCEPTS TEKS ADDRESSED THROUGH THIS LESSON:

§112.33.c Astronomy, Grade 11-12: 6A, 6B, 6C, 6E, 13B
§112.38.c Physics, Grade 9-10: 4A
§112.39.c Physics, Grade 9-12: 4A

PERFORMANCE OBJECTIVES:

Students will be able to:

- Explain how the size of the universe is related to its age, using knowledge about the speed of light
- Report the definition of astronomical terms such as light-year and astronomical unit
- Calculate the distances to the Moon, the Sun, the center of the Milky Way, and the visible universe from the Earth
- Apply concepts of kinematics to astronomical problems
- Compare and contrast the distances in space with the fastest speeds achieved by spacecraft

MATERIALS (per group of four):

- Paper
- Pencils
- Calculator (non-graphing will suffice)

1 University Station C9000
Austin, TX 78712
(512) 471-5847
www.esi.utexas.edu

CONCEPTS:

A convenient measure of astronomical length is the **light-year**, or the distance that light travels in one year (approx. 6 trillion miles). Another that results from a geometric technique of measuring distances is called a **parsec**. One parsec is approximately 3.26 light-years.

In physics, the **average speed** of a body is equal to the distance traversed divided by the time taken to traverse this distance. The **average acceleration** of a body is equal to the ratio its change in velocity over a given time interval. This value can be positive or negative. An object with a negative acceleration is said to **decelerate.**

In rotational mechanics, the **angular speed** is a dimensionless measure of rotation rate. It is proportional to another quantity known as the **frequency,** measured in revolutions per second (or cycles/second or, simply, Hz). The **period** of rotation is simply the reciprocal of the frequency.

The **gravitational force** is one of the known four fundamental forces. Two objects are said to **gravitate** when they exert a central force on one another by virtue of their **masses** and their **separation.** The Earth, stars, and even galaxies interact with matter gravitationally.

BACKGROUND:

The **distance scales** used to chart the cosmos are so large they often escape the human imagination. Astronomers and cosmologists make great use of the finite **speed of light** as postulated by Einstein's theory of special relativity; from this they have succeeded in accurately mapping massive distances to stars, galaxies, and even the edge of the visible universe. This lesson is both a quantitative introduction to astronomy and an introduction to kinematics in physics. The student will, by calculation, realize how vast cosmic distances are and how rapidly the Earth is in motion relative to the Sun and the center of the galaxy.

PREPARATION:

The instructor should download the video file from the American Museum of Natural History website (free) prior to class. This will serve as part of the lesson.

Period 1: This portion of the lesson will introduce students to astronomical definitions and will mostly focus on basic kinematics. This is to build a foundation for discussion in the second period.

ENGAGE: (20 minutes)

The purpose of this section is to get students thinking big: *very big*. Every day experiences often do not provide a framework to appreciate the astronomical quantities that astronomers deal with; the following questions might help lead into the discussion by drawing on pre-existing knowledge or experiences.

1 University Station C9000
Austin, TX 78712
(512) 471-5847
www.esi.utexas.edu

Ask:

[Distances]

One possible approach is to draw upon the students' experiences traveling; begin asking questions starting from city to state to country levels to see the furthest the students have traveled:

About how large (in miles or km) is…

- A city?
- A state?
- A country?
- What about the Earth's circumference? Radius?
  - Circumference: 40,000 km
  - Radius: 6,374 km
- The distance from the Earth to the Sun?
  - Ans: 149,598,000 km or 93,000,000 mi or 1 **Astronomical Unit**
- The distance from Earth to the nearest star that is *not* the Sun?
  - 4.2 light-years
- Can you name any larger distances?

[Speeds]

What is the fastest vehicle you've traveled in? A car? A train? A commercial jet (ranges from approx. 500 – 650 mph)?

Possible supplement: How fast is the speed of sound? (approx. 770 mph). Has anyone (in the class) ever traveled at supersonic speeds?

Who are some of the fastest runners/cyclists on Earth? What are some of the fastest creatures on Earth? What about fastest vehicles (cars, trains, space shuttles, etc)?

Note to teachers:

It is very likely that some students may mention light years during this opening discussion; ask the student(s) to define a light-year in his/her own words. Depending on the mathematical level of the students, the class could calculate the speed of light in mph using dimensional analysis.

Also, a student or two may bring up the topic of the speed of light as a limit to speeds. Encourage this by asking just how fast the speed of light is; depending on the level of the students, it might be a good exercise for students to use dimensional analysis to convert between different units. *The commonly cited value for c is 3e8 meters/second.*

1 University Station C9000
Austin, TX 78712
(512) 471-5847
www.esi.utexas.edu

If these are not mentioned, then it is perfectly okay to save these definitions for later in the lesson.

EXPLORE: (55 minutes)

In this section, the instructor provides the students with a few constants, and the students will work, either in pairs or in groups of three, to calculate some real distances in the universe.

1. On an overhead or white board, provide the students with the following prompt and question in bold (feel free to modify):
    a. **On average, the moon is approximately 1.3 *light seconds* away from the Earth.**
    b. **What is this distance in kilometers? In miles?**
    c. For this problem, the students will need the value of the speed of light (preferably in meters/second) and the conversion factor between kilometers and miles (approx. 1 mi=1.61 km)
    d. The purpose of this exercise is to exercise students' knowledge of the definitions of speed and attention to units. If students have trouble, it may help to write the definition of speed on the board as well or to work this first example as a class [Ans: ~390,000 km; ~242,000 mi]
    e. If this problem is too simple, then the following question may be added:
    f. **Space shuttles have attained speeds of up to 17,500 mph upon re-entry. How long would it take to reach the moon assuming you could travel at this constant speed? [**Ans: approx. 14 hours!]
2. Now the fun begins. With the students now refreshed on the concepts of speed, you may wish to leave the students to work on some or all of the following questions in bold:
3. **The sun is (on average) 149,598,000 km from the Earth. This quantity is the average distance between the sun and the Earth over the course of a year and is called an Astronomical Unit (AU).**
    a. **How long would it take you to reach the sun traveling at the afterschool school zone speed?**
    b. **How long would it take you to reach the sun traveling even at *the speed of light?***
        i. The photons and thermal radiation that reach us from the sun must travel over 8 minutes from the moment they leave the photosphere of the sun to reach us
4. (Rotational Mechanics) **The *angular speed* of the *solar system* around the black hole at the center of the Milky Way galaxy is approximately 8.55e-16 radians/second, and the *orbital speed* is about 220 km/s.**
    a. **Taking the galactic center as the origin, what is the radius of the solar system's orbit in light years? In *kilo*parsecs?**
        i. 1 ly ~ 9.46e12 km
        ii. 1 pc ~ 3.26 ly
        iii. 1 kpc = 1000 pc

ESI Environmental Science Institute
THE UNIVERSITY OF TEXAS AT AUSTIN

1 University Station C9000
Austin, TX 78712
(512) 471-5847
www.esi.utexas.edu

   iv. This is drawing upon concepts from orbital motion or simple harmonic motion in physics. The angular speed (ω), the orbital speed (v), and the radius (r) are all related by the equation, $v=\omega r$. [Ans: approx. 27,200 ly, 7.6 kpc]
   v. For comparison, the nearest star outside of the solar system is a "mere" 4 ly away

b. **How long would it take a space shuttle traveling at max speed 17,500 mph to travel the distance from part a?**
   i. Answer: approx. 15 **trillion** years!!! This result is useful for the following section.

<u>**Period 2 (75 min)**</u>

This portion of the lesson will build upon the students' experiences with astronomical quantities to elaborate on just how vast space is. It will culminate in the visualization of the distances they have calculated using the AMNH video.

<u>**EXPLAIN : (20)**</u>

Now that the students have had some exposure to the magnitudes involved in astronomy, a good question to ask is: **how big *is* the universe?** Understanding the answer to this question is very important, for our calculations are determined (and limited) by the speed of light – we cannot see past a certain point in space – the horizon beyond which light from our universe has not yet travelled. This point in space is the direct link between the universe's size…and *the universe's age*. You may ask the students the following question in bold:

- **How old is the universe?**
  - [Ans: about 13.7 **billion** years old]
  - This is a perfect chance to re-visit the question from 4b) above: a space shuttle at peak speed would take over a thousand times the age of the universe to reach the center of the Milky Way!
- Based on what we have calculated, our own galaxy is at least tens of thousands of light years across. **Are there still larger structures out there?**
  - Students may mention other galaxies; ask for their feedback about their thoughts on the distances to these galaxies
    - Exempli gratia: Would you say these galaxies are thousands, hundreds of thousands, millions, etc of light years away?
      - For reference, our nearest neighbor, the Andromeda Galaxy is about 2.6 million ly away
      - Quasars (*quasi-stellar radio sources)*, among the most distant objects we can see, are observed at distances of 10 billion ly and beyond
    - How many galaxies are in the universe?

Environmental Science Institute
THE UNIVERSITY OF TEXAS AT AUSTIN

1 University Station C9000
Austin, TX 78712
(512) 471-5847
www.esi.utexas.edu

ELABORATE: (25 minutes)

- **Is there a maximum size or distance across the universe out there?**
  - Again, this answer is tricky, but the question here is hinting at the fact that if we have a universe with a finite age **and** a finite speed of light, there must be **some** point beyond which light has not yet had time to reach us. [See Learning Module for more details]
  - It may be helpful to have students work in pairs for this section; try to probe the students with these two constants, the age of the universe and the speed of light, to see if they can deduce the existence of this *Cosmic Horizon.*
  - At the end of the section, have students share their thoughts about the significance of this "maximum distance"
    - How does it compare with all of the previous distances?
    - If light travels at a finite speed, then what is significant about the light that we see from 13.7 billion light years ago?
    - How might this remarkable artifact help us understand more about the universe?
  - If time allows, the instructor may wish to mention the *Cosmic Microwave Background* radiation [Also in Learning Module]
  - One great result from cosmology and astronomy is that the students can quantitatively understand the size of the *observable universe* (this is **not** to be confused with the size of the universe itself!). That is, in every direction, there is a limit beyond we cannot physically observe or collect information, and this point is at 13.7 billion light years in any direction. This is not only a horizon in space, but also in *time.* **

  **Note: When astronomers look through telescopes at distant stars, they are in essence looking back in time. For, the stars, galaxies, and other structures appear to us as they did thousands, millions, or even billions of years ago. The video at the end of the lesson does make a mention of this horizon as having this dual nature.

EVALUATE: (30 minutes)

At long last! During this section, play the video, *The Known Universe,* for the students. This is to really put into perspective and underscore all of the calculations done throughout the lesson. The students will get a real (and hopefully rewarding) picture of the vastness of the universe, as we know it. I supply these two questions for either discussion or homework based on the video as time allows.

- At the end of the video, a large colored map encircles the visible universe. What is this "light from an earlier universe"? How far away is it? How has this discovery impacted our understanding of the history of the universe?
  - This question prompts the student to do a bit of research on the CMB and its role in the corroboration of the Big Bang model of the universe. The light from the CMB, according to modern cosmology, was emitted approximately 400,000 years after the Big Bang as the universe continued to expand. There are many other facts the student may provide.

1 University Station C9000
Austin, TX 78712
(512) 471-5847
www.esi.utexas.edu

- As the video zoomed out, there came a point where all of the known galaxies formed an "hourglass" shape with darkness everywhere else. What makes these "areas we have yet to map"? If data one day revealed these empty patches to be identical to the rest of the sky we have mapped, what would this say about the universe as a whole?
    - This is due to the dusty plane of our own Milky Way galaxy. The thick dust in the spiral arms of the galaxy make it difficult to observe in many wavelengths of light, including the optical. One of the great assumptions of cosmology is that the universe, on the largest scales, is relatively homogenous and isotropic (radiation in all directions is the same). If the "missing" galaxies were filled in and looked just like what we can already see, this would be another great support for the cosmological model of the universe.