Announcements

- Class is now active on ICON.
- The first homework is available on ICON. It is due at noon on Wednesday, Jan 28.
- We will do i-Clicker registration now and before/after next few classes.

Today's lecture

- Scientific method
- Powers of ten
- Distances and astronomical objects

To understand the universe, scientists use the "**Scientific Method**"

- **Observe** - Observe something. Write down the observations and make sure that other people can repeat them on their own.

- **Hypothesize/Model** - Make a statement about how that something happens. The statement has to be in the form of an explanation that can be used in other contexts. The statement must help to make predictions about other observations.

- **Test and Criticize** - Observe similar things to see if the statement is correct or needs to be modified.

- **Repeat** - until you get it right.

Hypothesis/Model

- One or more ideas to explain an observation or set of observations.

- Must be useful in making predictions about other observations

- Must be testable

- Must be falsifiable.

Other words are "Theory" (e.g. Einstein's Theory of Gravity) and "Law" (e.g. Newton's Law's of Motion).

Which is not a valid scientific hypotheses?

A. Any two objects dropped from the same height above the surface of the moon will hit the lunar surface at the same time.

B. Our universe is surrounded by another, larger universe, with which we can have absolutely no contact or interaction.

C. All horses are brown.

D. Unicorns exist.

Science, religion, and pseudo-science

- **Scientific theories** are *experimentally verifiable (or falsifiable) and predictive*. They address **how** questions (e.g. How do stars form? How is a lunar eclipse caused? How did the Universe evolve?)

- **Religious and ethical statements** are (generally) not verifiable. They address **why** questions (e.g. Why does the Universe exist? What kind of life is worth living?). These are not intrinsically less worthwhile than scientific inquiries, they are simply addressing different questions. Religion and science come into conflict when religion supplies answers for questions that can now be addressed by science, i.e. evolution of humans, age of the Universe.

- **Pseudo-science theories** pretend to be scientific but are either not falsifiable (e.g. séances,) or supporters or use anecdotal evidence to support claims (e.g. astrology, 'creation' science).

Skepticism and Truth

- Role of skepticism. An essential part of the scientific method. Scientists always question the basis for an scientific assertion. This is often considered 'impolite' behavior in social settings, but is *not* impolite in scientific discussion.

- **'What is truth?'** - Scientific theories are *not* statements of *truth*. They are the best available explanation for observed facts, but are subject to revision or falsification.

- Scientists must be able to admit that they are wrong.

Occam's Razor

- What if two or more competing hypotheses both pass some initial tests - how do you choose between them?

- If the hypotheses generate different predictions it will be a simple matter to pick the best one - as long as it is feasible to carry out the experimental tests. What if the competing hypotheses don't give distinguishable, feasible predictions? Enter "Occam's Razor".

- William of Occam was a medieval scholar and logician, and, in modern form, the principle that has come to be known as Occam's Razor says:

  If two hypotheses can't be distinguished experimentally, choose the simpler one.

What is a scientific model?

A. An approximation of a real system that omits all but the most essential variables of the system. (Wikitionary)
B. A scientific model is a representation of an object or system. An example of a scientific model would be a diagram of a cell or a map ... even a model rocket! (WikiAnswers)
C. A really good looking scientist.
D. None of the above.

Hypothesis/Model

- **Must be useful in making predictions about other observations and be testable/falsifiable.**

- Does not consider the full complexity of the system or object being examined – only "essential variables".

- Often uses math, but can be anything that allows one to make predictions.

Hypothesis/Model

- Is our scale model of the solar system a scientific model? A = Yes, B = No

- Does it make predictions? It falsifiable?

- What "essential variables" does it describe?
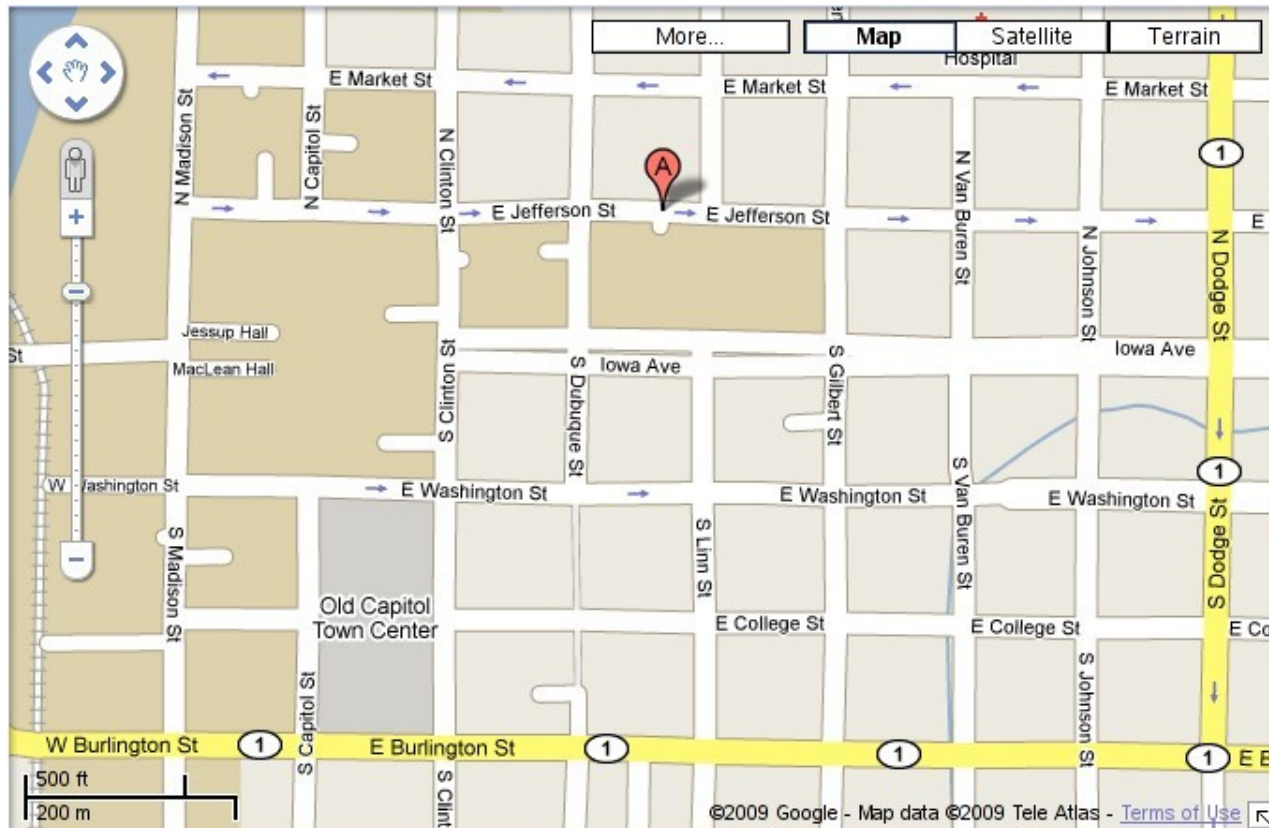
Hypothesis/Model

- Is this a scientific model? A = Yes, B = No

- What "essential variables" does it describe?

- Is it falsifiable?
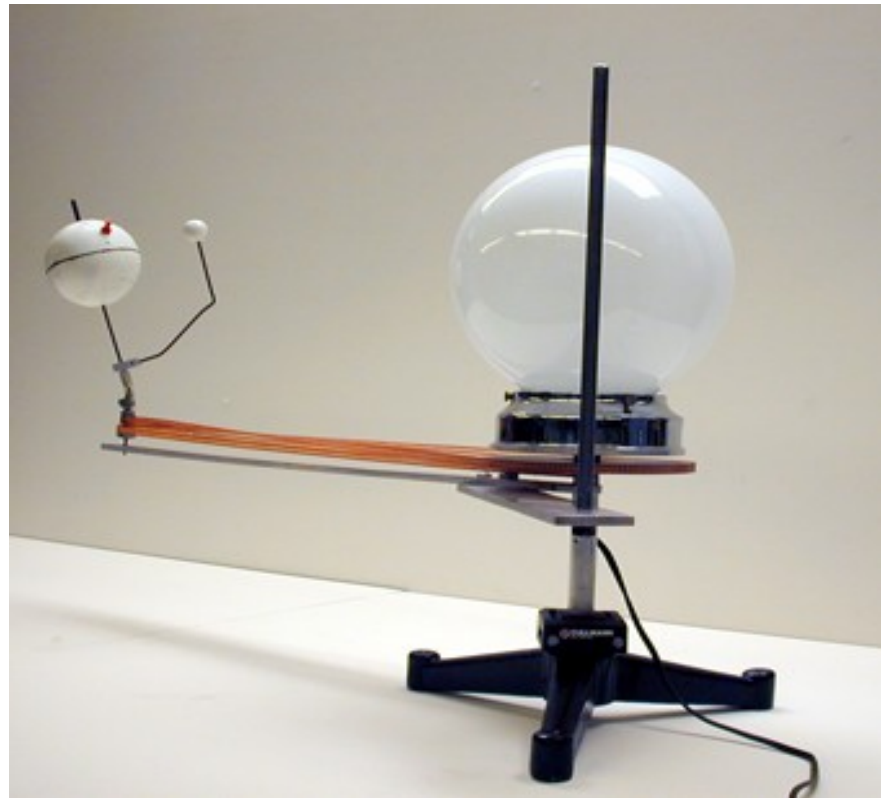
Earth, Moon, Sun 8A10.32

Hypothesis/Model

- Is this map a scientific model? A = Yes, B = No

- What "essential variables" does it describe?

- Does it make predictions? It falsifiable?

Hypothesis/Model

- Is the following statement a scientific hypothesis?

Women can stand on one foot longer than men.

A = Yes, B = No

- Does it make predictions? It falsifiable?
- What "essential variables" does it describe?
- How could the hypothesis be generalized?

Powers of ten are shorthand for writing very large numbers

$10^0 = 1$	One
$10^1 = 10$	Ten (deca)
$10^2 = 100$	Hundred (centa)
$10^3 = 1,000$	Thousand (kilo)
$10^6 = 1,000,000$	Million (mega)
$10^9 = 1,000,000,000$	Billion (giga)
$10^{12} = 1,000,000,000,000$	Trillion (tera)
$10^{15} = \ldots$	Quadrillion (peta)
$10^{54} = \ldots$	Septendecillion

They also work for very small numbers

$10^0 = 1$	One
$10^{-1} = 0.1$	One tenth (deci)
$10^{-2} = 0.01$	One hundredth (centi)
$10^{-3} = 0.001$	One thousandth (milli)
$10^{-6} = 0.000,001$	One millionth (micro)
$10^{-9} = 0.000,000,001$	One billionth (nano)
$10^{-12} = 0.000,000,000,001$	One trillionth (pico)
$10^{-15} = \ldots$	One quadrillionth (femto)
$10^{-54} = \ldots$	One septendecillionth

Scientific notation

- How to multiply:

$$10^4 \times 10^8 = 10^{12}$$

$$2.1 \times 10^4 \times 3.0 \times 10^8 = 2.1 \times 3.0 \times 10^{12}$$

$$= 6.2 \times 10^{12}$$

- How to divide:

$$10^4 \div 10^8 = 10^{-4}$$

Back to the solar system

Volume of solar system taken up by "stuff"

= (volume of Sun) / (volume of solar system)

= $(4/3)\pi$(radius of Sun)^3 / $(4/3)\pi$(radius of Neptune's orbit)^3

= (radius of Sun)^3 / (radius of Neptune's orbit)^3
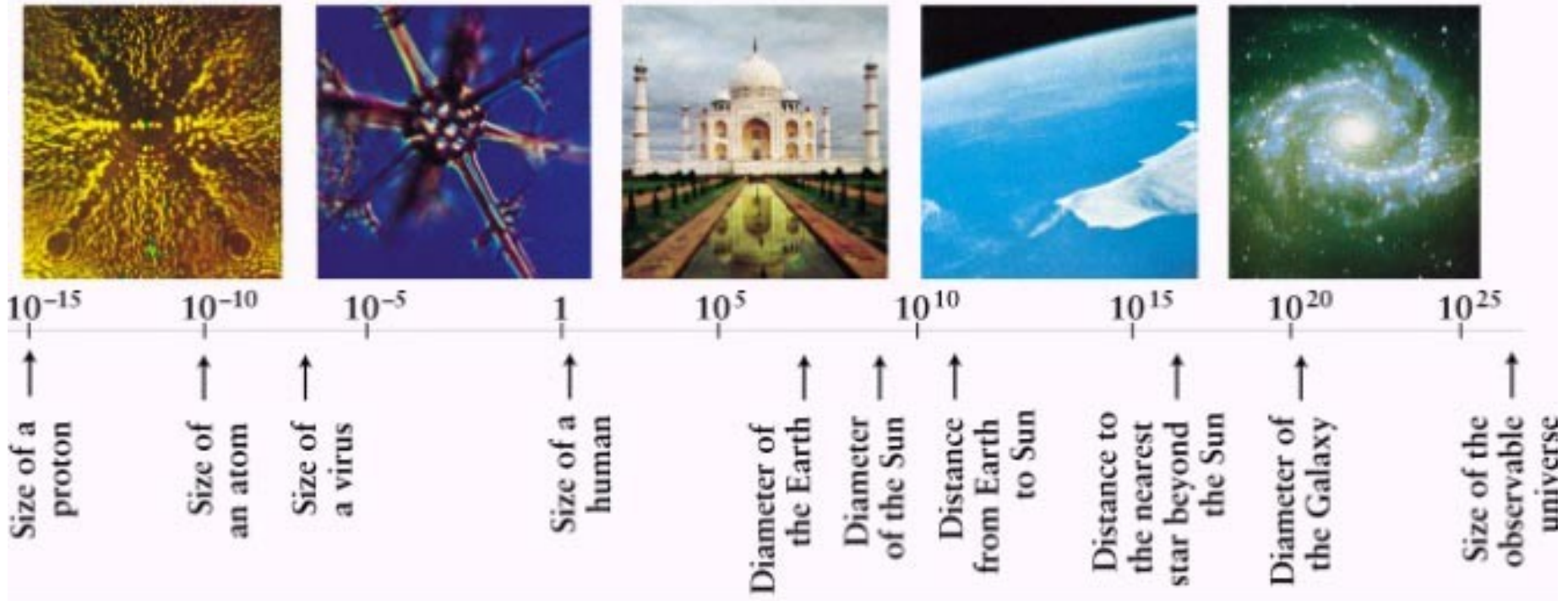
= $(7\times10^8)^3$ / $(4.5\times10^{12})^3$

= $(7^3\times10^{8\times3})$ / $(4.5^3\times10^{12\times3})$

= $(7/4.5)^3\times(10^{8\times3-12\times3})$

= 3.8×10^{-12} = a few millionths of a millionth

Volume of a sphere = $(4/3)\pi R^3$

| 10^{-15} | 10^{-10} | 10^{-5} | 1 | 10^5 | 10^{10} | 10^{15} | 10^{20} | 10^{25} |

Size of a proton

Size of an atom

Size of a virus

Size of a human

Diameter of the Earth

Diameter of the Sun

Distance from Earth to Sun

Distance to the nearest star beyond the Sun

Diameter of the Galaxy

Size of the observable universe

Sizes are in meters

People

Height of (small) person is about 1.1 m

Earth

Radius of earth or $R_\oplus$ is 6.4×10^6 m

Sun

SOHO (NASA and ESA)

Radius of Sun or $R_{\odot}$ is 7×10^8 m

Earth to Sun

SOHO (NASA and ESA)
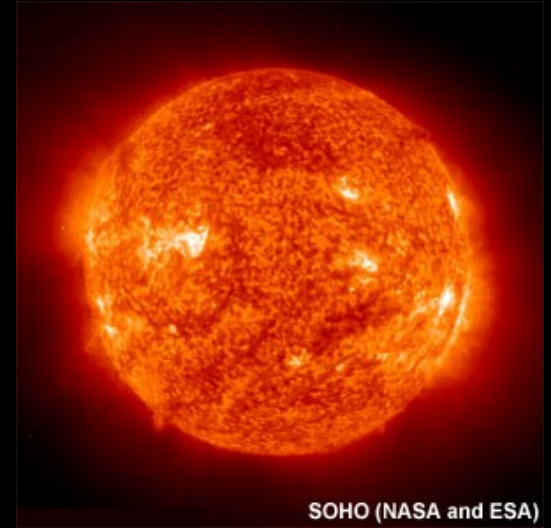
Distance from Earth to Sun is 1.5×10^{11} m

This is one "Astronomical Unit" = 1 A.U.

Sun to Nearest Star

SOHO (NASA and ESA)

SOHO (NASA and ESA)
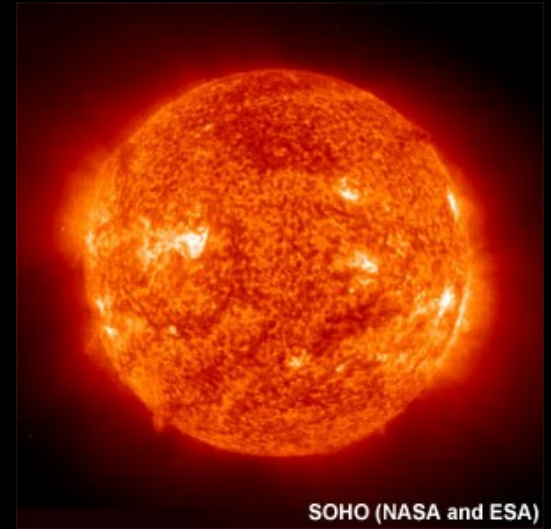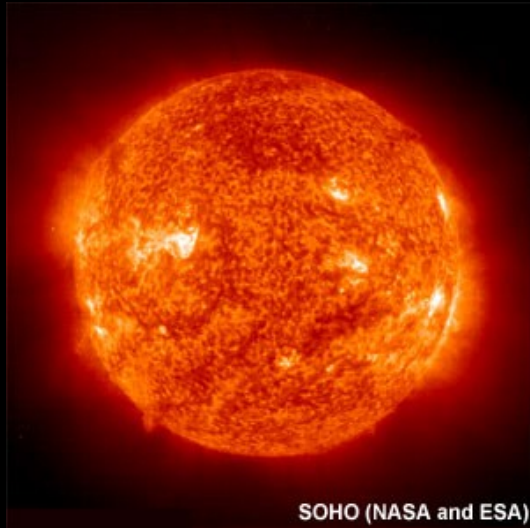
Distance from Sun to nearest star is 4.1×10^{16} m

Define light-year = ly = 9.46×10^{15} m

Distance from Sun to nearest star is 4.3 ly

to Center of Milky Way

Distance to Center of our galaxy is 2.6×10^{20} m
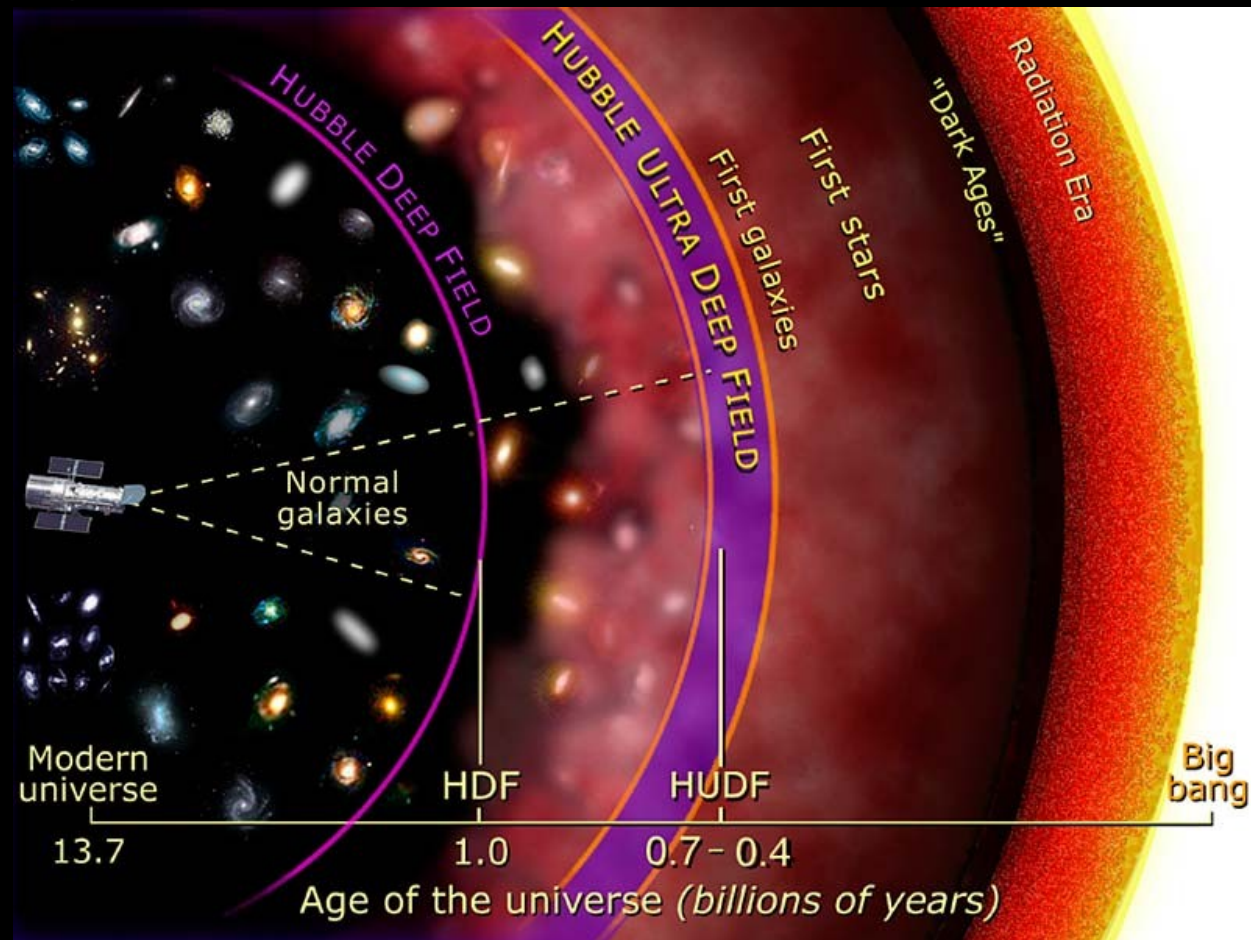
or 28,000 ly

to Nearest (big) Galaxy

Distance to nearest (big) galaxy is 2.4×10^{22} m

or 2.6×10^{6} ly

to edge of Observable Universe

Distance to edge of observable universe is
1.3×10^{26} m or 1.4×10^{10} ly