PHY100 — The Nature of the Physical World

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Lecture 1
Nature of Science,
Scales in the Universe

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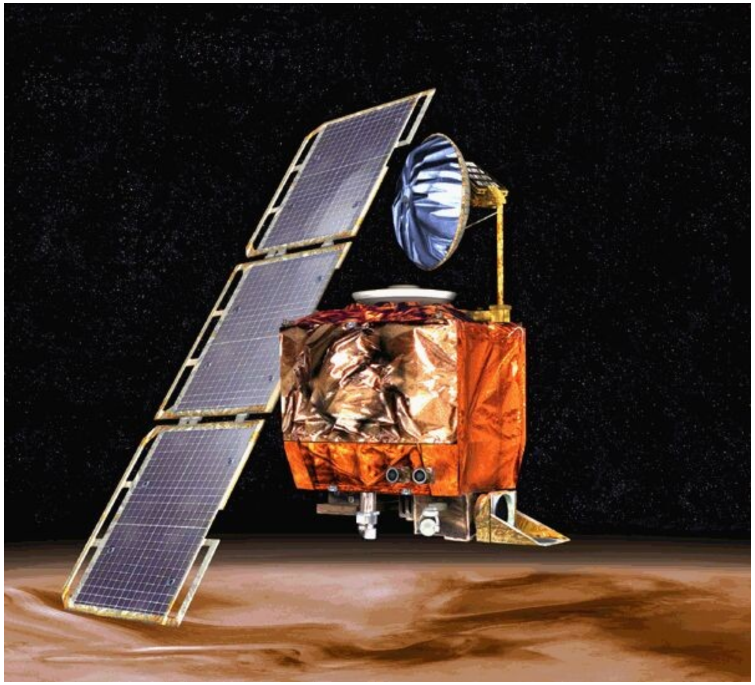
Observations

- The human experience is very limited:
  - **Size:** 1/10 millimeters – 10,000 kilometers
  - **Time:** millisecond (1/1000 sec) – 75 years
  - **Mass:** 1/10 gram – 1000 kg
- We will be using SI units (m, kg, s)



Mars Climate Orbiter (1999)... moments before crashing

1 km = 0.62 mi	1 mi = 1.6 km
1 m = 3.3 ft = 39 in	1 ft = 0.30 m
1 cm = 0.39 in	1 in = 2.5 cm
1 kg = 2.2 lb	1 lb = 0.45 kg

A little math recap

- Scientific notation:

$$\frac{1}{10}\,\text{millimeter} = \frac{1}{10}\,\frac{1}{1000}\,\text{m} = \frac{1}{10000}\,\text{m} = 0.0001\,\text{m} = 10^{-4}\,\text{m}$$

$$10000\,\text{km} = (10000)(1000)\,\text{m} = 10{,}000{,}000\,\text{m} = 10^{7}\,\text{m}$$

$$\ldots \quad 10^{-1} = 0.1 \qquad 10^{0} = 1 \qquad 10^{1} = 10 \quad \ldots$$

Physical scales in the Universe

FSU "Powers of ten" applet:
http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/index.html

Distance	**Length (m)**
Radius to visible Universe	2×10^{26}
To Andromeda Galaxy	2×10^{22}
To nearest star	4×10^{16}
Earth to Sun	1.5×10^{11}
Radius of Earth	6.4×10^{6}
Sears Tower	4.5×10^{2}
Football field	1×10^{2}
Tall person	2×10^{0}
Thickness of paper	1×10^{-4}
Wavelength of blue light	4×10^{-7}
Diameter of Hydrogen atom	1×10^{-10}
Diameter of proton	1×10^{-15}

Interval	**Time (s)**
Age of universe	5×10^{17}
Age of Grand Canyon	3×10^{14}
32 years	1×10^{9}
One year	3.2×10^{7}
One hour	3.6×10^{3}
Light travel from earth to moon	1.3×10^{0}
One cycle of guitar A string	2×10^{-3}
One cycle of FM radio wave	6×10^{-8}
Lifetime of neutral pi meson	1×10^{-16}
Lifetime of top quark	4×10^{-25}

Physical scales in the Universe

Object	Mass (kg)
Milky Way Galaxy	4×10^{41}
Sun	2×10^{30}
Earth	6×10^{24}
Boeing 747	4×10^{5}
Car	1×10^{3}
Student	7×10^{1}
Dust particle	1×10^{-9}
Top quark	3×10^{-25}
Proton	2×10^{-27}
Electron	9×10^{-31}
Neutrino	1×10^{-38}

- Our senses/normal experience is a tiny fraction of the world out there!

Does this bias our opinions about what's possible and not in our view of the Universe?...

You bet!

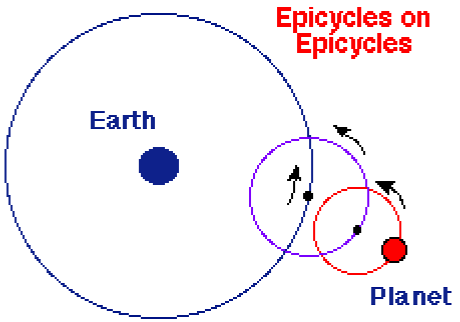
- Case example: **early astronomy**
- One of the most important early “physics” investigations was the night sky... across civilizations (Egyptians, Mayas, India, China)
- Our human experience/bias makes us put **Earth at the center of the Universe**
- With the Sun and stars moving around us
  - How do you tell a planet from a star in the sky?
- But the problem is that this model (hypothesis) is not backed up by experiment (even though many humans didn't like that!)
  - Retrograde motion of Mars: link

Pythagoras 500BC

Search for new ideas

- Retrograde motion of the planets cannot be explained by simple spheres around the Earth

  - Ptolemy's model (100AD) using epicycles and many other refinements, accommodated the retrograde motion and was able to survive 15 centuries!



  - And then Copernicus (1543), based on elegance and aesthetics, proposed that the **Sun was at the center of the Universe!**

But both Ptolemy and Copernicus models agreed with data!

Copernicus was trying to find a “simpler model”

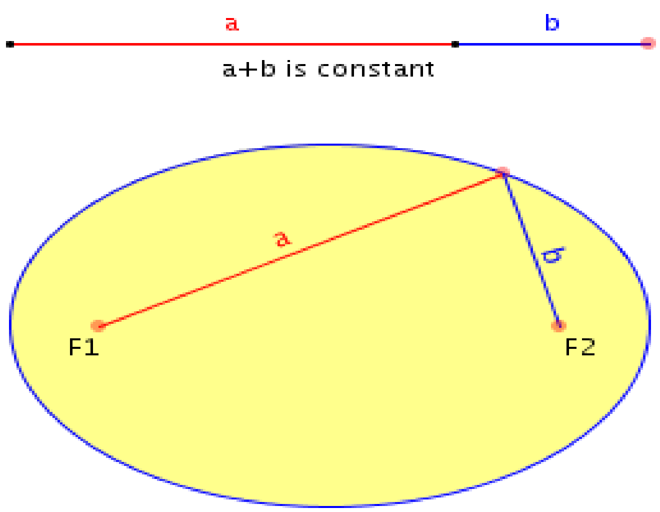
Huh?

- This Copernican model raises a whole new set of issues:
  - How does the Earth (our whole world) move?
  - Why aren't people and objects left behind?
- Tycho Brahe (~1570) performed many accurate observations with new instruments: brought the error down to 0.5-2 arcminutes (1 part in 10,000 across the sky, or 10x better than before)

Full moon ~ 30 arcminutes

- Johannes Kepler (~1600) showed that neither Copernicus nor Ptolemy fit his data, instead:

  Sun-focused ellipses actually fit the data



Newton's laws explain this motion

In summary

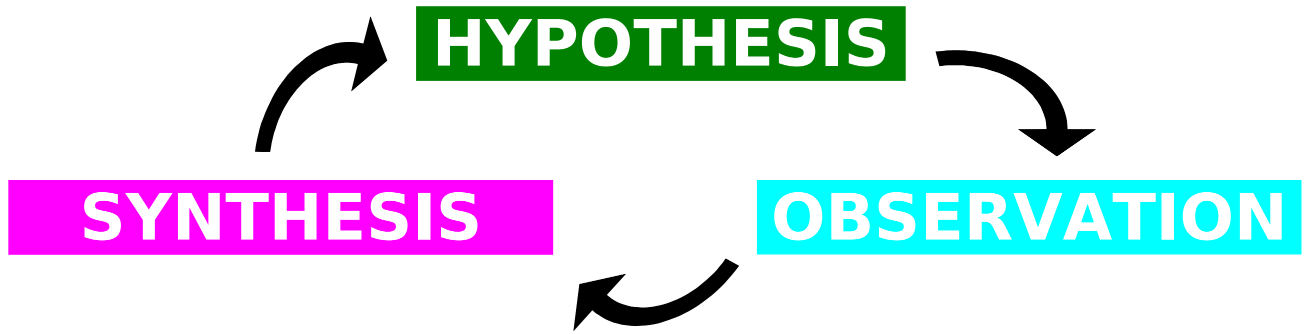
Why should nature follow our naive and arrogant expectations?

- The process of setting up a hypothesis and comparing it to observations drives our knowledge

- Better/new observations make previously accepted hypothesis wrong

The scientific method

- Science is understanding our surroundings through observation and synthesis



- A framework of scientific ideas is called a **theory**: it helps understanding and interpreting the observations
  - A good theory reduces or explains a large number of observations and consists of a **few ideas or principles**
  - Theories should be **predictive**: the theory is validated if the observations confirm the predictions
  - Theories cannot be proven. New evidence can always contradict and perhaps invalidate a theory (**falsifiable**).

Good science is always provisional: it can and many times evolve

What is science?

- Science tells how to understand the world around us
  - Same for religion …
  - Same for art …
- What's different?
  - Science bows to observation
  - Science is testable and refutable
  - Religion is irrefutable. It is a matter of faith and opinion

- **Limitations of science**
- Non-scientific theories/statements are not testable, even if they are true:
  - Undetectable aliens are living among us
  - The earth was created with apparent age
  - MJ is the greatest basketball player to have played

Scientific method revisited

- Our job as scientists is to try to unravel new limits in Nature that our theory has to explain
  - You can do this by refining old observations
  - Making new observations that were not possible before
  - Or proposing new hypothesis
  - Actually, many of us try to discover new phenomena that we know the theory cannot explain!
  - If discovered, this means a new theory is necessary
- Scientific observations must be reproducible: you have to give enough detail about the techniques, set-up, conditions of measurement and provide accurate results
- All observations are incomplete unless provided with **units** and a **measure/estimate of how good** is the observation:

observation + error estimate