Astro 350

Lecture 7

February 2, 2022

Announcements:

- **Discussion Question 2** posted on Canvas
  due next Wednesday
- **Homework 2** due Friday

Last time:

Newton's universal law of gravitation

- *Q: qualitative features? quantitative?*

Cosmic crisis! Uranus' orbit discrepancy

- *Q: what was the problem? What was the resolution?*
- *Q: implications?*

Copernican Revolution: Post Newton

Newtons laws of motion and gravity were astonishingly successful
- explained Kepler's laws
- *predicted* the existence of Neptune!

a spectacular start for modern science

other successes: `www: binary stars, exoplanets`

Newton also resoundingly confirmed Copernican heliocentric view
- the Earth is a typical planet
- one among many that orbit the Sun
- not the center of the solar system

...only the first of many such revolutions!

also: the idea of an rational, orderly "clockwork universe"
was influential far beyond cosmology

Cosmology: Progress Report after Newton

Recall: Cosmology is a mystery story

Based on evidence we can observe, want to understand:

- structure of Universe: how big? map of contents across space?
- contents of Universe: what ingredients is it made of?
- origin & evolution of U.: birth? past? future?
- rules of the game: what makes the Universe this way?

Cosmological progress so far:

Kepler precisely described planet motion

Newton explained planet motion, agrees with observation!

Lesson from Newtonian success: insight into rules of the game

- powerful laws exist explaining *all* motion due to forces
- planet motion is due to force of gravity

gravity determines behavior of the cosmos!

Geocentric vs Heliocentric: Last Thoughts

For me, a big lesson is **Humility!**
naive to think: "Greeks = dumb, us = smart"
rather a sobering reminder: sometimes, same observations can be explained in radically different ways

also: we can have *bias* not even aware of
shapes how view world, seems reasonable to everyone
humbling! examples to come – quantum mechanics, relativity

what's more...probably going on still today!
remember: all astronomy, all science ultimately tentative
In this course: my guess: $\sim 70\%$ (!) will stand test of time
but don't know which 30% is wrong...so have to learn it all!

that said, not everything up for grabs or matter of taste...
confidence/uncertainty varies tremendously
My Wagers

Stars and the Sun

Copernican "philosophy" – don't assume we are unusual applies to the planets–what about the Sun?

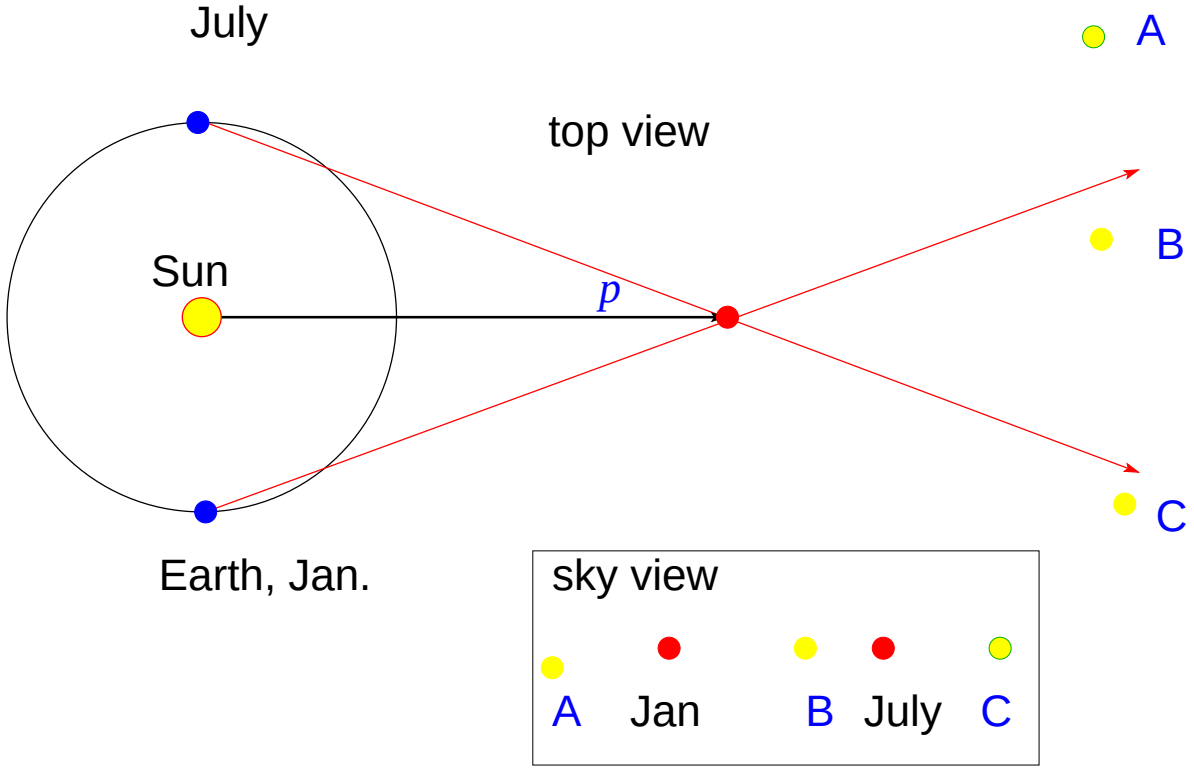
a few heliocentric Greeks guessed that the stars are like the Sun, only far away

Newton pushed this further and showed that this is true

Q: what data is needed for comparison?

Stellar Parallax Revisited

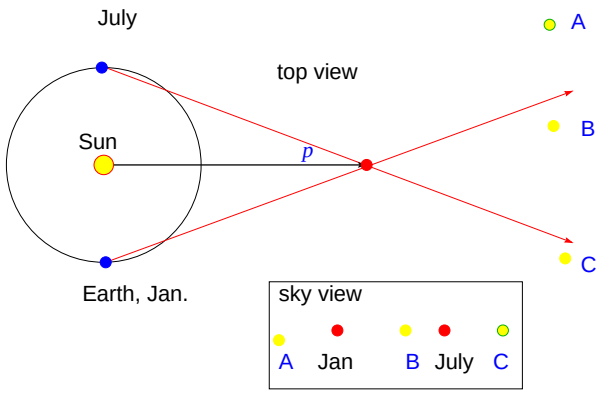
Recall: Earth orbit $\rightarrow$ shifting viewpoint/perspective on stars
$\rightarrow$ nearby stars appear to shift relative to distant stars
Demo: cover one eye, cover instructor with thumb, switch eyes
Demo: do it again with thumb held halfway



parallax angle p:
shift on sky
from midpoint

Q: how can we use parallax to find distance?

Parallax: the Gold Standard of Distances



from parallax angle p can find distance $d = 1\ \text{AU}/\tan p$ (exact formula)

but the shift very small:

parallax angle p is tiny (< 1 arc second $= 1/3600$ degree)

$\rightarrow$ "skinny triangle" law works just fine:

$\tan p \approx p_{\text{radians}}$

$$d = \frac{1\ \text{AU}}{p_{\text{radians}}} = \frac{200,000\ \text{AU}}{p_{\text{arcsec}}} = \frac{1\ \text{parsec}}{p_{\text{arcsec}}} \qquad (1)$$

where p_{arcsec} is measured in arc seconds $= 1/3600$ degree

Star Distances and Parsecs

from parallax p find distance

$$d = \frac{1 \text{ parsec}}{p_{\text{arcsec}}} \tag{2}$$

- new distance unit: 1parsec = 1 pc = 200,000 AU
- *nearest star:* $d(\alpha \text{ Cen}) = 1.3$ pc
  $\rightarrow$ 1 pc is typical star-star distance in a galaxy
- light travels 1 pc in 3 yrs: 1 pc = 3 light years (lyr)

Many profound consequences, e.g.,:

- *stars are much farther than the planets*
- *hence the Universe is much larger than the Solar System*
- travel to even the nearest stars takes years
- can't visit, so must learn all we can from starlight

Light

Light deeply connected to
electric charges, electric forces, and magnetic forces

Experiments show:
changing electric force generates magnetic force
changing magnetic force generates electric force

1. E&M linked: "electromagnetic force"

2. EM disturbances can travel through space:
   each regenerates the other: E $\rightarrow$ M $\rightarrow$ E $\rightarrow$ M $\rightarrow$ ...
   electromagnetic waves = "EM radiation"

Light as Electromagnetic Waves

light is an electromagnetic phenomenon:

- created by motions (in fact: acceleration) of electric charges
- that is: light must be created by charged particles
  e.g., in light bulb, hot filament drives electron motion

but light itself is *made of* electromagnetic fields

- which exert forces on charged particles
- that is: light interacts with charged particles
  e.g., in antenna, electrons driven back and forth

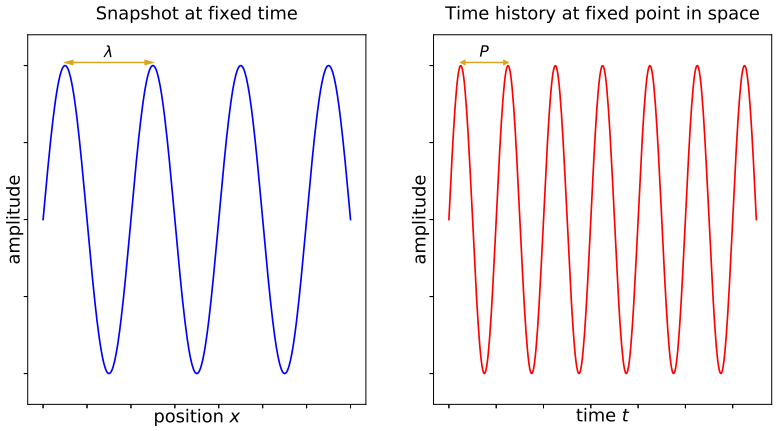
note: if an elementary particle has *zero* electric charge (neutral):

- it cannot emit light
- it cannot absorb or scatter light

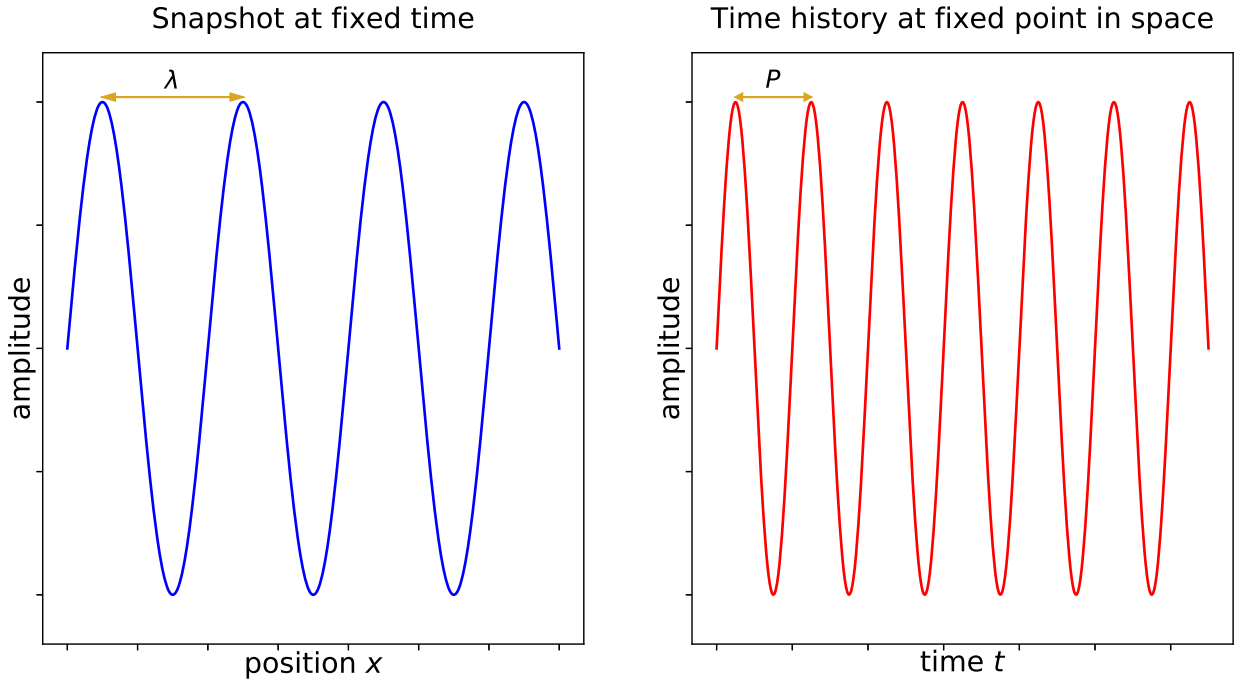
Light as Electromagnetic Waves

light is a type of **wave**:

a wave is oscillating disturbance in a medium
wave can travel, medium does not
Demo: the wave!



wavelength λ size of one cycle
$\rightarrow$ wave "ID number"
period P time for one cycle
for experts: $\lambda/P = \lambda\nu = c$



intensity I

"strength" of wave = "height of peaks"

Q: Sound waves: how do we experience λ*?* I*?*

Q: Light waves: how do we experience λ*?* I*?*

Sound:

$\lambda \leftrightarrow$ pitch

high pitch (treble): small λ

low pitch (bass): large λ

intensity = loudness

Light:

$\lambda \leftrightarrow$ color

visible light: larger λ: more red

smaller λ: more blue

intensity = apparent brightness

Note for experts: in more detail, we distinguish

- *flux* = apparent brightness of unresolved (point-like) source
  e.g., stars, distant quasars
- *intensity* = surface brightness of resolved (extended) source
  e.g., Moon, planets, nearby galaxies

The Speed of Light

Light is very fast!
So fast that it was a feat to measure the speed in lab
now known quite well

$$\begin{aligned} c &= \text{constant} = 299,792,458 \text{ m/s} \\ &= 3.0 \times 10^8 \text{ m/s} = 186,000 \text{ miles/s} = 6.7 \times 10^8 \text{ miles/hr} \end{aligned}$$

enormous–but not infinite!
$\rightarrow$ finite speed of light hugely important for astronomy
$\rightarrow$ telescopes are time machines *Q: how?*

note: light speed c is *same* for all λ
Q: what would happen if this were not true?

The Electromagnetic Spectrum

EM waves can have λ outside of visible range

`www: EM spectrum` **most** wavelengths are invisible to human eyes!

Generally, light is combination of pure waves
with different λ

distribution of intensities:
different brightness at diff. λ: **spectrum**

diagram: sketch spectrum axes
Q: spectrum of laser pointer?
Q: spectrum of white light?

Technology Tim's Terminology Tip: "Radiation"

Warning!

meaning of "radiation" in Physics, Astronomy, Cosmology
  $\neq$ "radiation" in everyday parlance!

In Physics, Astronomy, Cosmology...and more importantly...
In this course and on the exams:
radiation = movement of energy through space
  carried by particles or waves

Examples:
ordinary visible light! e.g., flashlight, sunlight, starlight, ...
  completely benign and indeed necessary for life!
but also invisible EM waves: radio, UV, X-ray...
and even non-EM particles: neutrinos...

Beware Confusion: "radiation" so defined $\neq$ radioactivity!
  more on radioactivity later...