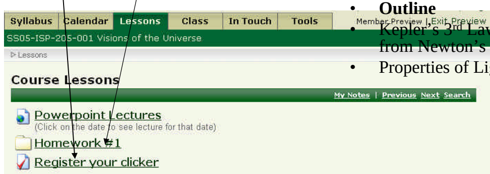
Light–January 24

- First homework
  - http://angel.msu.edu
    - Open "lessons" folder.
  - Must finish by 3:00 am, Wed, 26th, (Tues night).
- Register your clicker number.
- Forget your clicker or your clicker doesn't work?
  - You may turn in clicker answers on paper after class.
  - You may do this at most two times during the entire term.



- How to study for 1st exam
  - Be able to explain the clicker questions to a fellow student
  - **Class is about important topics**
    - **Find a way to think about what was covered. Argue with someone.**
    - **You must read book for details**
  - **Do the quizzes on** www.astronomyplace.com **Skip questions that we have not covered.**
- **Outline**
- Kepler's 3rd Law can be derived from Newton's laws of motion
- Properties of Light

Newton Implies Kepler's 3rd Law

- Easier derivation: Assume orbit is a circle. Ignore numerical constants such as π or 2.
  - Newton's Law of Gravity: Force between sun and planet
    Force = G $mass_{Sun}$ $mass_{Planet}$/$Distance^2$; $F = G\,M\,m/R^2$
  - Newton's 2nd Law
    Force = $mass_{Planet}$ acceleration; $F = m\,a$
  - $G\,M\,m/R^2 = m\,a$; mass of planet cancels out.
  - Velocity is approximately R/P, where P is period. (It is exactly $2\pi R/P$.)
  - Acceleration, change in velocity/time, is approximately (R/P)/P.
  - $G\,M/R^2 = a = R/P^2$
  - $P^2 = R^3/(G\,M)$
- What did Newton learn about Kepler's 3rd law that Kepler did not know?
- Q1 Does $P^2 = R^3$, where P is the period in years and R is semi-major axis in AU apply to a planet in orbit around another star?
  a. Yes. Physical laws are universal.
  b. Yes. Gravity causes the velocity of any planet to change.
  c. No. Years apply only to earth.
  d. No. The other star may have a different mass.

Kepler's 3rd Law

- $P^2 = R^3/(G\,M)$
- How can you use Kepler's 3rd law to weigh Jupiter?
- This is how we weigh planets, stars, and galaxies.
- Accurate derivation

constant = $4\pi^2/G = 2\times10^{30}$ kg yr^2/au^3

$$P^2 = 4\,\pi^2/G \;\; R^3/(M_{sun}+m_{planet})$$

- Mass is total mass = $M_{Sun} + m_{planet}$

Kepler's Law of Equal Areas

- Law of equal areas is *conservation of angular momentum* in Sun-planet system
  m v r = constant
  - smaller r ➔ larger v
  - Skater speeds up by bringing arms in
  - Planet speeds up when closer to sun
- Emmy Noether (about 1910) showed
  - Laws of physics are the same regardless of direction implies conservation of angular momentum

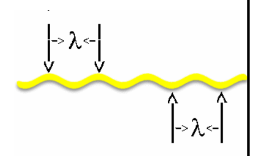
Kepler2 simulation

Light

- Almost all we about astronomy comes from analyzing light.
- What do you notice about the light of the globular cluster M10?
  - Color: Red stars are brighter than blue stars ⇒ Red stars are giants, about the size of the earth's orbit.
  - Spectra show M10 has much less oxygen (and other elements heavier than Li) than sun ⇒ M10 is very old, one of the first systems to have formed
  - Spectra shows the speed of M10 is very fast compared to that of stars near the sun ⇒ orbits of globular clusters are long & thin, whereas sun's is almost circular

Globular Cluster M10

Wavelength, Frequency and Energy



- Wavelength λ = distance between successive crests.

  m   meter

  nm   nanometer (10^{-9}m)

  Å   angstrom (10^{-10}m)
- Wave moves at speed of light c.
- Frequency is rate at which crests pass.
  - f = c/λ
  - Cycles/second; Hertz
- Photon is the smallest amount of light.
- Energy of a photon

  E = hf = hc/λ   (h = Planck's constant)

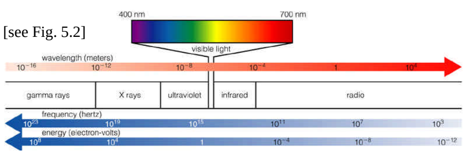
[Appendix B]

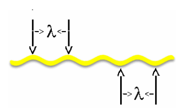
The E-M wave in action link

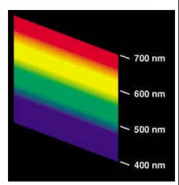
The Electromagnetic Spectrum

- Light is given different names according to its wavelength λ

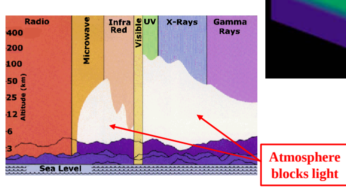
[see Fig. 5.2]







- In visible passband, different λ = different color.
  - Blue = smaller λ
  - Red = larger λ
- Only visible light and radio waves pass freely through Earth's atmosphere.



Thermal Radiation

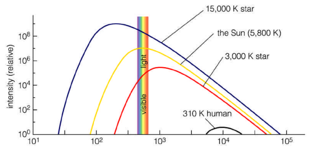
(Blackbody Radiation)

- Heat up hot plate
  - It glows more brightly as it gets hotter
  - It changes color as it gets hotter

	Temperature °K	°C	°F	Color
Completely cold.	0	-273	-459	Does not emit light
Body temperature.	310	37	99	Infrared
Blowtorch.	4000	3727	6740	Red-hot
Blast furnace.	6000	5727	10,340	White-hot
Hotter still.	7500	7227	13,040	Blue-hot

Black-Body Spectrum

[Fig. 5.10]



Wavelength [nm] →

← Energy

- Peak wavelength given by Wien's Law.
  - l_{max} = 0.0027m-K / T
  - hotter objects have peak at smaller λ.
- Total energy emitted per s *per unit surface area* is given by Steffan-Boltzmann Law:
  - $E = \sigma T^4$
  - Increase with temperature is very steep: factor of 2 for a factor of 1.2 in temperature
- Intensity distribution depends only on
  - Temperature
  - Emissivity=Light absorbed/Light incident
    - Mirror: e=0
    - Black: e=1
- Characteristic shape
  - Sharp drop towards higher energy.
  - Slow drop towards lower energy.
- Star is an approximate black body.
  - Sun is an approximate 5800-K black body.
- The Big Bang is an exact 2.7-K black body.

interactive Wien's law

Thermal Infrared Light

- Wavelength is 8,000-12,000 nm ($8\text{-}12\times10^{-6}$m)
- An object with a temperature of 300K emits most of its light in the thermal infrared.
- Does infrared light show the same thing as visible light?