I : The speed of light

- Light travels through a **vacuum** at a **finite** (but very fast) speed
  - First evidence obtained by Romer who was carefully timing when the moons of Jupiter entered the shadow of Jupiter
  - Found that these eclipses were 16.6mins “late” when Jupiter was on the far side of the Sun
  - Interpreted as the extra time it takes for light to cross the diameter of the Earth’s orbit

\[
\text{speed} = \frac{\text{distance}}{\text{time}} = \frac{(2.0\text{AU})(1.5 \times 10^{11} \text{m/AU})}{(16.6\text{min})(60\text{s/min})} \approx 3.0 \times 10^8 \text{m/s}
\]

- One way to obtain accurate measurement in the laboratory is to use rapidly rotating mirrors
Modern viewpoint... speed of light defined to be \( c = 299,792,458 \) m/s

When Earth is near Jupiter, we observe eclipses of Jupiter's moons earlier than expected.

When Earth is far from Jupiter, we observe eclipses of Jupiter's moons later than expected.
II : Basic nature of light

- Maxwell (1870)
  - Starting from two important experimental results (Ampere’s Law and Faraday’s law of induction), Maxwell developed a unified theory of electricity and magnetism (Maxwell’s equations).
  - Electric and magnetic fields are just facets of a unified electromagnetic field
  - Immediate prediction of Maxwell’s equation... waves of electromagnetic energy can travel through vacuum with a speed of 3.0x10⁸m/s.
  - He realized that he had just “discovered” light
  - These waves were characterized by their wavelength or frequency.

Wavelength $\lambda$ is the distance between two peaks

Speed $c$ is the speed at which a peak moves through space

Frequency $\nu$ (Greek “nu”) is the number of peaks passing a particular location per unit time

$$\nu = \frac{c}{\lambda}$$
- We already knew that light was a wave from experiments of Thomas Young (1803; the "Young’s slit" experiment)
- Wavelength determines color

(a) An experiment with light

A double slit experiment
Young’s slit formula... bright peaks are at angles given by

\[ \theta = \frac{\lambda}{D} \quad n = 0, 1, 2, \ldots \]

Maxwell’s equations put no restriction on wavelength of radiation... so e/m waves exist outside of the visible band!
The Andromeda galaxy (M31)
III : Particle-wave duality

- We have seen that light can be understood as electromagnetic waves... they undergo diffraction and produce interference patterns
- BUT, light/electromagnetic-radiation can also behave as a stream of particles...
  - Carries energy and momentum in discrete packets
  - Can create a blip on a CCD chip
- This strange double-behavior is referred to as particle-wave duality
- The “light particles” are called photons - they are quanta of the electromagnetic field

Properties of photons : Suppose that the corresponding electromagnetic wave has frequency $\nu$. Then...

- Photons have energy
  \[ E = h\nu \]
- Photon has momentum
  \[ p = \frac{h\nu}{c} \]
- Photon has angular momentum
  \[ l = \pm\frac{h}{2\pi} \]

$h$ is called “Planck’s constant”...

$h = 6.62 \times 10^{-34} \text{m}^2\text{kg/s}$