“Look, but don’t touch.”

- Astronomers’ Motto
Light: Key Concepts

(1) Visible light is just one form of electromagnetic radiation.

(2) Light can be thought of as a wave or as a particle.

(3) Light forms a spectrum from short to long wavelengths.

(4) A hot, opaque object produces a continuous blackbody spectrum.
Visible light is just one form of electromagnetic radiation.

The universe contains electrically charged particles: electrons (−) and protons (+).

Charged particles are surrounded by electric fields and magnetic fields.

Fluctuations in these fields produce electromagnetic radiation.
Visible light is a form of electromagnetic radiation -

- but so are
  radio waves,
  microwaves,
  infrared light,
  ultraviolet light,
  X-rays, and
  gamma rays.
(2A) Light can be thought of as a wave.

Wave = a periodic fluctuation travelling through a medium.

Ocean wave = fluctuation in the height of water.

Sound wave = fluctuation in air pressure.

Electromagnetic wave = fluctuation in electric and magnetic fields.
Wave Characteristics:

(1) Wavelength, $\lambda$ (lambda): distance between wave crests (units = meter).

(2) Frequency, $\nu$ (nu): number of crests passing per second (units = 1/sec = Hertz).

(3) Amplitude, $a$: height of wave crests.
Speed of light:

Speed of wave, \( c \), equals wavelength times frequency (units = meter/sec):

\[
c = \lambda \times \nu
\]

The speed of light in a vacuum is always

\[
c = 300,000 \text{ km/s}
\]

(186,000 miles/sec).
(2B) Light can be thought of as a particle.

Light shows some properties of a wave: **diffraction** and **interference**.

It shows some properties of a particle: **the photoelectric effect**.

(In the photoelectric effect, particles of light, called **photons**, kick electrons out of atoms.)
How sound waves would travel without diffraction:

This doesn't happen

How sound waves actually travel with diffraction:

Sound waves bend

Diffraction happens for light, too!
Photons

The energy of a photon is related to the frequency of a wave:

\[ E = h\nu \]

- \( E \) = energy of photon
- \( \nu \) = frequency of light
- \( h \) = Planck’s constant (A Small Number)
(3) Light forms a spectrum from short to long wavelength.

Visible light has wavelengths from 400 to 700 nanometers. \[1 \text{ nanometer (nm)} = 10^{-9} \text{ meter}\].

Color is determined by wavelength:

- **Blue**: 480 nm
- **Green**: 530 nm
- **Red**: 660 nm
The complete spectrum of light

<table>
<thead>
<tr>
<th></th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma rays</td>
<td>![Gamma rays](lambda &lt; 0.01 nanometers)</td>
</tr>
<tr>
<td>X-rays</td>
<td>![X-rays](0.01 – 10 nm)</td>
</tr>
<tr>
<td>Ultraviolet</td>
<td>![Ultraviolet](10 – 400 nm)</td>
</tr>
<tr>
<td>Visible</td>
<td>![Visible](400 – 700 nm)</td>
</tr>
<tr>
<td>Infrared</td>
<td>![Infrared](700 nm – 1 mm)</td>
</tr>
<tr>
<td>Microwaves</td>
<td>![Microwaves](1 – 100 mm)</td>
</tr>
<tr>
<td>Radio</td>
<td>![Radio](&gt; 100 mm)</td>
</tr>
</tbody>
</table>
Visible light occupies only a tiny sliver of the full spectrum.
Earth’s atmosphere is transparent to visible light and some microwaves and radio waves. To observe efficiently at other wavelengths, we must go above atmosphere.
A hot, opaque object produces a continuous blackbody spectrum of light.

The universe is full of light of all different wavelengths. How is light made?

One way to make objects emit light is to heat them up.
An object is **hot** when the atoms of which it is made are in rapid random motion.

The **temperature** is a measure of the average speed of the atoms.

Random motions stop at **absolute zero** temperature.
Temperature Scale:

In physics and astronomy, we use the Kelvin scale, which has a zero at absolute zero.

Kelvin = Celsius + 273
Water boils: 373 Kelvin
Water freezes: 273 Kelvin
Absolute zero: 0 Kelvin
What is a “blackbody”? 

A blackbody is an object that absorbs all the light that hits it. Heat a blackbody: it emits a continuous spectrum of electromagnetic radiation. The total amount of radiation and the wavelength of radiation depend only on temperature (Max Planck).
Wavelength of maximum emission is **inversely related** to **temperature**.

\[
\lambda_{\text{max}} = \frac{2,900,000 \text{ nm}}{T}
\]

\(\lambda_{\text{max}}\) = wavelength of maximum emission

\(T\) = temperature (in Kelvins)
Blackbody curves:
Solar spectrum:
Taking the temperature of stars!

Betelgeuse: a reddish star (cooler).

Rigel: a bluish star (hotter).
Total energy radiated is STRONGLY dependent on temperature.

\[ F = \sigma T^4 \]

F = energy radiated per second per square meter
T = temperature (in Kelvins)
\( \sigma \) = a universal constant
Few closing questions:

1) Which one is hotter – a red-hot piece of metal, or white-hot piece of metal?
2) Could we have radio eyes?
3) If we double the temperature of a blackbody, how will the energy per unit area it produces change?
4) If we double the temperature of a blackbody, how will its maximum intensity shift in wavelength?
5) Are there green stars? (tricky)