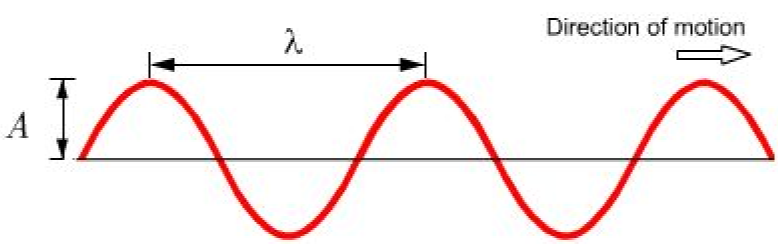
Properties of Light

- Astronomers are unable to do direct experiments
  - Objects are too far away
  - Time scale in Universe too large
  - Observe instead - which is why everything is learned through light
- Brightness diminishes with distance

Light

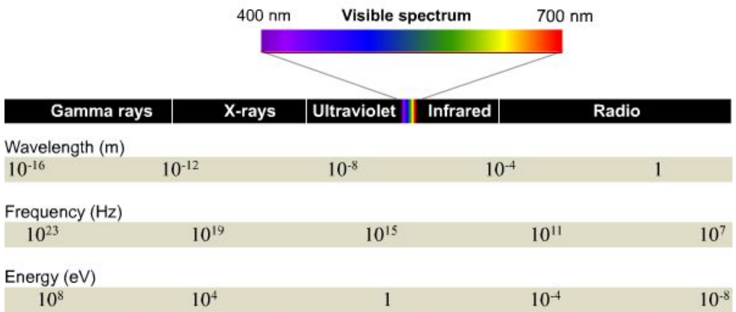
- Wavelike phenomenon that carries bundles of electromagnetic energy as “photons”
- Able to distinguish light by wavelength or frequency
  - Could also be called “colour,” but there could be confusion
    - Colour in astronomy usually means the difference in the amount of light (source brightness) at two different wavelengths

$$A = \mathrm{Amplitude}$$
$$\lambda = \mathrm{Wavelength}$$



Electromagnetic Wave

- Light is an electromagnetic wave
- In a vacuum, velocity of light = wavelength x frequency
  - $$\text{Speed of light} = \text{wavelength} \times \text{frequency}$$ $$c = \lambda f$$
- Frequency is the number of waves passing any point each second
  - All light travels at 300,000 km/s
  - $$1\,\mathrm{light\ year} = (3.15 \times 10^{7}\,\mathrm{s})(3 \times 10^{8}\,\mathrm{m/s}) = 9.46 \times 10^{15}\,\mathrm{m}$$
- Visible Spectrum: Violet -> Red, Red has long wavelength and lower frequency
  - Only a small portion of what we can see



Range of detection

- Electromagnetic radiation spans more than 10^{30} in wavelength and frequency
    - The range lets us probe a wide range of physical scale + energy

Blackbody Radiation

- Theoretical construct, impossible to actually create one
    - Things come close - some stars
    - Emission of light only depends on temp
    - Is a perfect absorber
    - Absorbs and emits light at all wavelengths
    - Does not emit the same amount of light at each wavelength
- Wavelength of emission peaks as 1/T nm.
    - At higher temps, wavelength gets shorter
    - Blue > orange > red hot
    - Total emission over all wavelengths from a blackbody is proportional to T^4
    - The shape of emission curve is given by “Plank’s Law”

Wein's Law

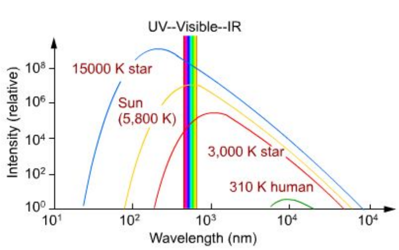
$$\lambda_{\max} = \frac{2{,}900{,}000}{T}$$

Stefan's Law

$$E = \sigma T^4$$

$$\text{where } \sigma = 5.67 \times 10^{-8}\,\mathrm{W/m^2/K^4}$$

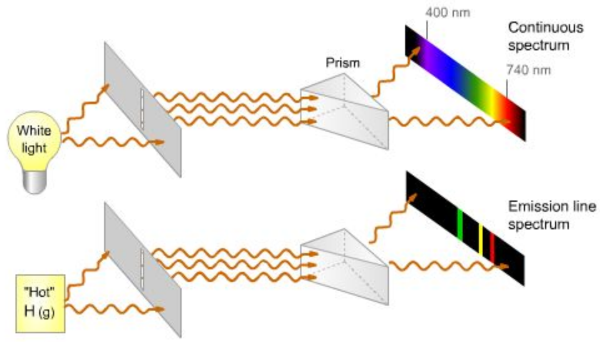
Blackbody (Planck) curves of different temperatures



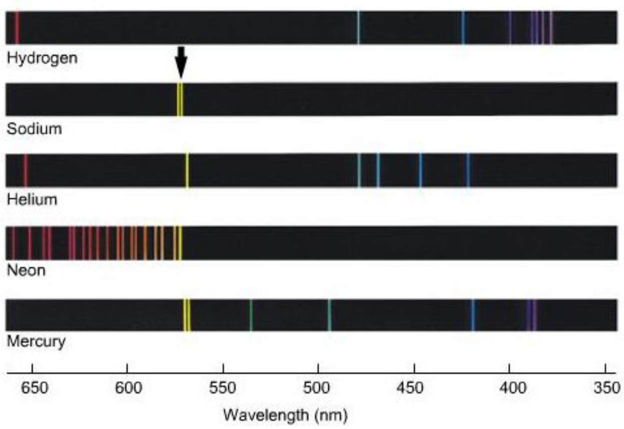
- We’re only able to see blue for the 15000K star because it's the limit of our visual range

Emission Line Spectrum

- Blackbodies are a way to produce a continuous emission - emission at all wavelengths
- Often times many things will suffice to perform similar to blackbodies
  - Most solids, or high pressure emitters of light
  - Ex: Hot lightbulb through a slit and through a prism will result in a continuous spectrum (rainbow)
  - However, for hot gas, you get a discrete spectrum - only certain colours show up
    - Called emission lines

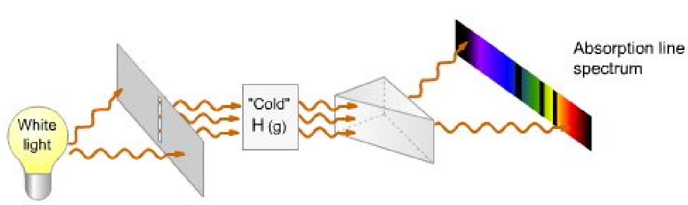


- Able to identify elements in a source by their spectral line signature



Absorption Line Spectrum

- Placing a cool gas in front of a source of a continuous spectrum will absorb the light at certain wavelengths to produce an absorption line spectrum



- Wavelength of spectral absorption or emission lines depends on the energy difference b/w initial and final levels

Photon Energy,

$$E = hf = c\frac{\Delta\lambda}{\lambda}$$

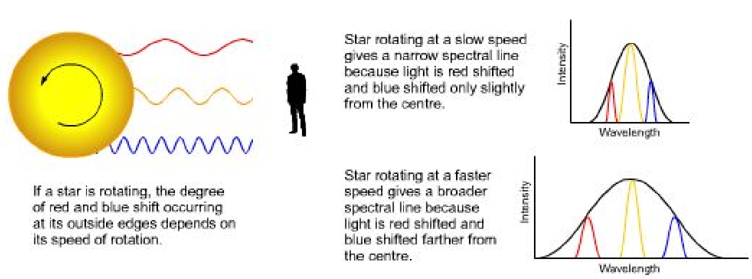
- For sodium, emission and absorption spectrum is the same
- The type of spectrum observed depends on the conditions and viewing perspective

<u>Doppler Shift</u>

- When the source of a wave is moving, or when the detector of the wave is moving, the wavelength measured at the detector side is not the same as the source side
- Change in wavelength depends on relative velocity between source and detector along direction that the wave is moving
    - Known as **Line of Sight**
- Can be used to measure radial velocity of items in Universe
- Objects moving away from the detector produce longer wavelengths
    - **“Red Shift”**
- Objects moving towards the detector produce short wavelengths
    - **“Blue Shift”**
- Ex with sound:
    - If an object emitting sound is stationary wrt observer, sound will have true wavelength and normal pitch
    - If object is moving wrt observer
        - Observer in front will hear shorter wavelength, higher pitch
        - Observer in back will hear longer wavelength, lower pitch

If $v << c$ then $\frac{v_{rad}}{c} = \frac{\Delta\lambda}{\lambda}$ where $\Delta\lambda = \lambda_{obs} - \lambda_{rest}$

- Shift is linear if velocity is much smaller than spd of light
- Could use Doppler Shift to look at how fast things are rotating
    - Ex: Star that’s rotating
        - Some of the light we observe is coming from the centre, some is from star coming towards us, some from star going away
            - Will be red and blue shifted



Telescopes

- Telescopes have a large collecting area
    - Detecting faint objects is thus possible
- Collecting area is proportional to **aperture diameter** squared
    - $A = \frac{1}{4}\pi d^2$ or $A = \pi r^2$
- **Resolving Power**
    - Ability to separate objects close to each other, or distinguish things in finer detail
        - Depends on diameter (to first power)
- Resolution proportional to diameter and wavelength
- Telescopes made with lenses/mirrors
- Modern astronomy uses instruments instead of human eye to detect photons collected by telescopes

Resolution of Telescopes

- Fundamental limitation of all optics (Telescopes, microscopes, eyes)
- B/c of diffraction of light
    - Depends on size and shape of aperture
    - Light spreads after going through a hole
        - Nearby images can overlap b/c of the spread
- To calculate the spread from the hole to the detector:
    - $\Theta_{limit} = \frac{1.22\lambda}{D}$, where λ is wavelength, and D is diameter.
    - Called the **airy limit** or **Raleigh diffraction limit**

Refraction: Lenses

- Made from material like glass
- Lens causes light to bend from a source to a focus, where all the light can then be detected by a device
- Disadvantages
    - Each lens requires two very accurate surfaces
    - Can't have internal imperfections
    - Diff wavelengths bend differently, no common focus for all lights
    - All lens material absorb some light, but not uniformly across all wavelengths
    - No way to get a perfectly focused image **- chromatic abberation**
    - Can only be supported around the edges
        - If you make a large lense, it will be very heavy, will bend and change focus if moved

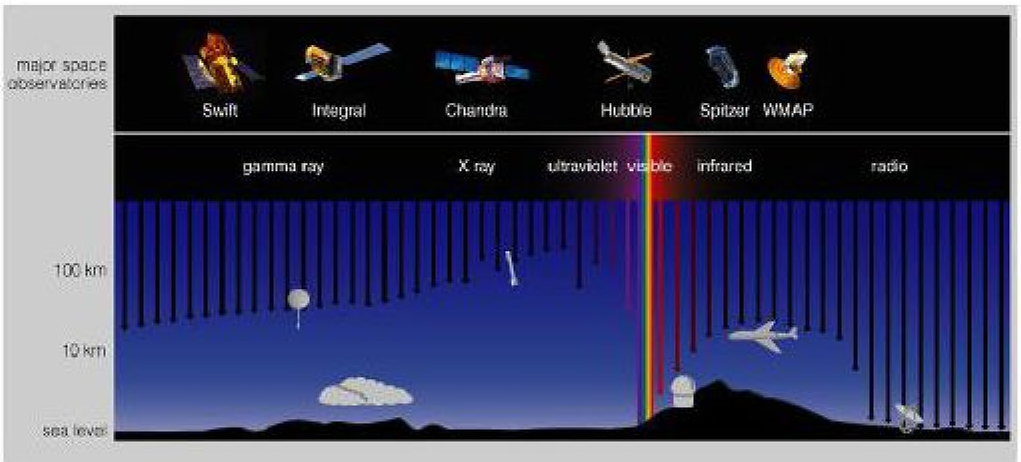
Reflection: Mirrors

- Advantages
    - Can reflect all wavelengths at the same time - all wavelengths have the same focus
    - Supported by their backside

    - Only one surface needed

<u>Observation of Non-Visible Wavelengths</u>

- Atmosphere isn't transparent to all wavelengths of light
    - Transparent to visible light, our eyes are able to see visible light - goes through atmosphere, but not true for many other wavelengths



Interferometer

- Collecting area determines how bright things appear
    - Collecting more light means we're able to see fainter things
- Resolution doesn't depend on collecting area
    - Just diameter
- Able to simulate this by having two small telescopes separated a length that a larger telescope would take instead
    - Much higher resolution