Class 13
The Doppler effect;
and an introduction to telescopes

- The Doppler effect; redshifts and blueshifts
- Basic principles of astronomical telescopes
  - Atmospheric transmittance
  - The diffraction limit
  - Optical telescopes
  - Telescopes at other wavebands

I : The Doppler shift

![Optical Spectra of Seyfert Galaxies](image)
Wave crest 1: emitted when light source was at $S_1$

Wave crest 2: emitted when light source was at $S_2$

Wave crests 3 and 4: emitted when light source was at $S_3$ and $S_4$, respectively

This observer sees blue shift

Motion of light source

This observer sees red shift
The Doppler effect
- The wavelength of light is affected by the motion of the source relative to the observer
- Source moving towards observer...
  - Light waves compressed
  - Spectrum of object shifted to shorter wavelength
  - **Blueshift**
- Source moving away from observer
  - Light waves stretched
  - Spectrum of object shifted to longer wavelength
  - **Redshift**

Quantitatively... if wavelength \( \lambda \) is shifted by an amount \( \Delta \lambda \) then velocity is given by
\[
\frac{v}{c} = \frac{\Delta \lambda}{\lambda}
\]

This assumes \( v \ll c \)

II : Telescopes & atmospheric transmittance
- Modern astronomers study the Universe utilizing the full electromagnetic spectrum...
- But...many part of the spectrum are severely attenuated (or even completely blocked) by Earth’s atmosphere
  - Long wavelength radio waves... reflected by the Earth’s ionosphere
  - mid-infrared to microwaves... absorbed by various molecules in the atmosphere
  - Ultraviolet to X-rays... absorbed by various atoms in the atmosphere
  - Gamma-rays... absorbed through interactions with atomic nuclei in the atmosphere

*Atacama desert (Chili)*
III : Resolution and diffraction limit

- Definition: The **angular resolution** of a telescope is the smallest angular separation $\theta$ for which the two point-like objects (e.g. stars) are still individually distinguishable.

- The resolution of any telescope is limited by the **diffraction limit**...
  - If the telescope has an aperture size $D$ and is observing radiation with wavelength $\lambda$, the diffraction limit is
    \[ \theta \approx \frac{\lambda}{D} \]

- In practice, real telescopes may not reach the diffraction limit due to...
  - Inability to make focusing system (e.g., $\gamma$-rays)
  - Imperfections in lensing system (e.g., X-rays)
  - Atmospheric effects (e.g., many ground-based optical)
IV : Optical telescopes

- Is what way is a telescope better than the human eye?
  - Larger aperture ⇒ gathers more light
  - Larger aperture ⇒ better resolution
  - More sensitive detectors (+spectrometers, detectors that work outside optical band etc.)
  - oh yeah... and it magnifies

- Two main types of optical telescope
  - Refractor... uses lenses to focus incoming light
    - Tend to have a long “focal length”
    - Length of telescope + weight of lenses makes it hard to build a really big refracting telescope (largest has 1m aperture)
  - Reflector... uses mirrors to focus incoming light
    - All large telescopes are reflectors... easier to build large mirrors and can fold optical path (largest has 10m aperture)
(a) A large objective mirror
V : Telescopes and observatories outside of the visible band

- Current astronomical observatories operate from long wavelength radio waves ($\lambda=4 \text{m}$) to very high-energy gamma-rays ($\lambda=10^{-18} \text{m}$)
- The challenges...
  - Each part of the e/m spectrum presents its own challenges when it comes to building a focusing system (some wavelengths cannot yet be focused!)
  - Each part of e/m spectrum presents challenges in terms of building detectors
  - Many parts of the e/m spectrum require going to space (or very special places on the Earth)
  - We then need to understand the results...
Parkes Very Large Array (New Mexico)
CARMA (Combined Array for Millimeter Astronomy)

James Webb Space Telescope

Spitzer
Hubble Space Telescope (near-IR, optical, and near-UV)

(b) XMM-Newton