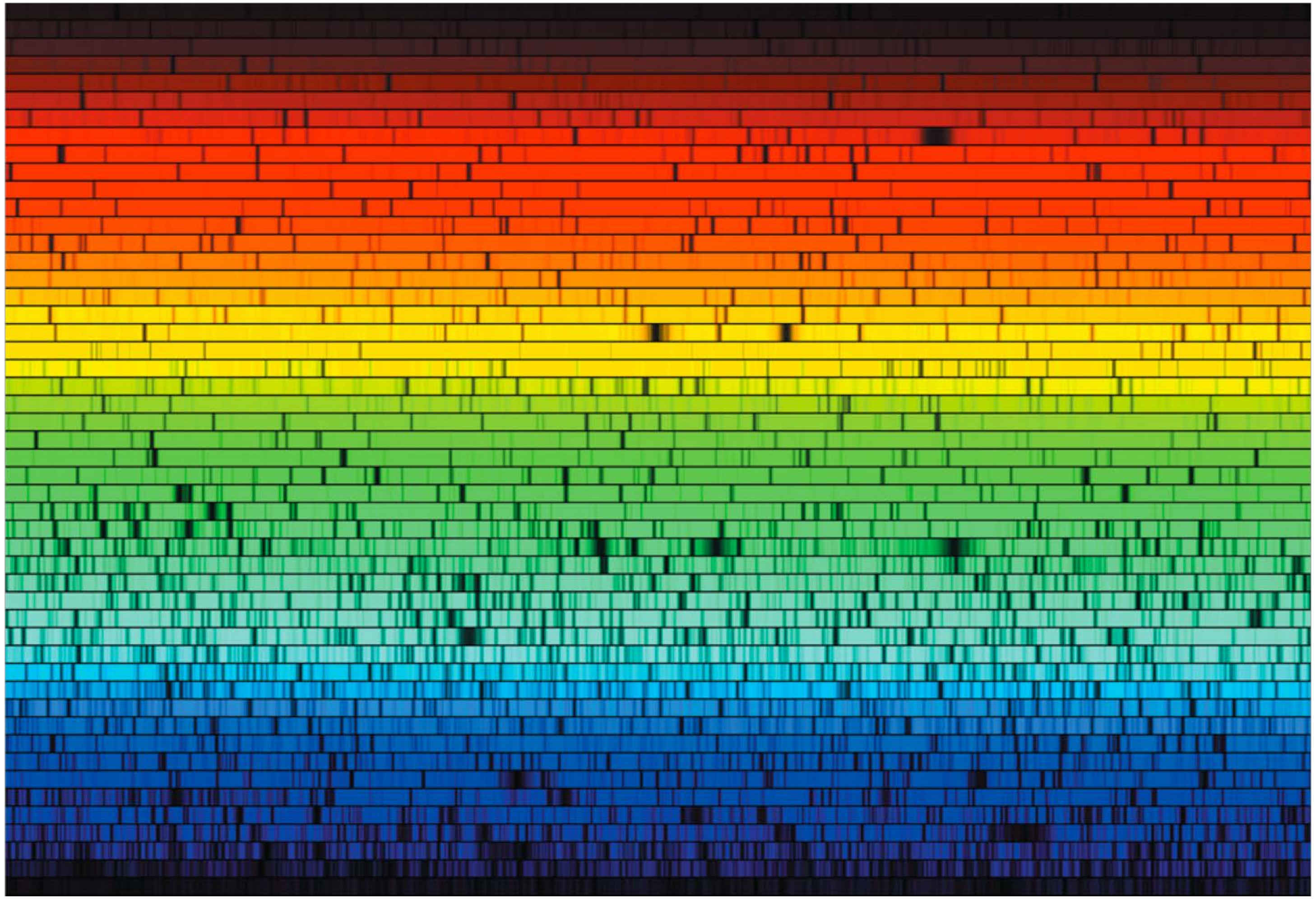
Chapter 4:
Spectroscopy

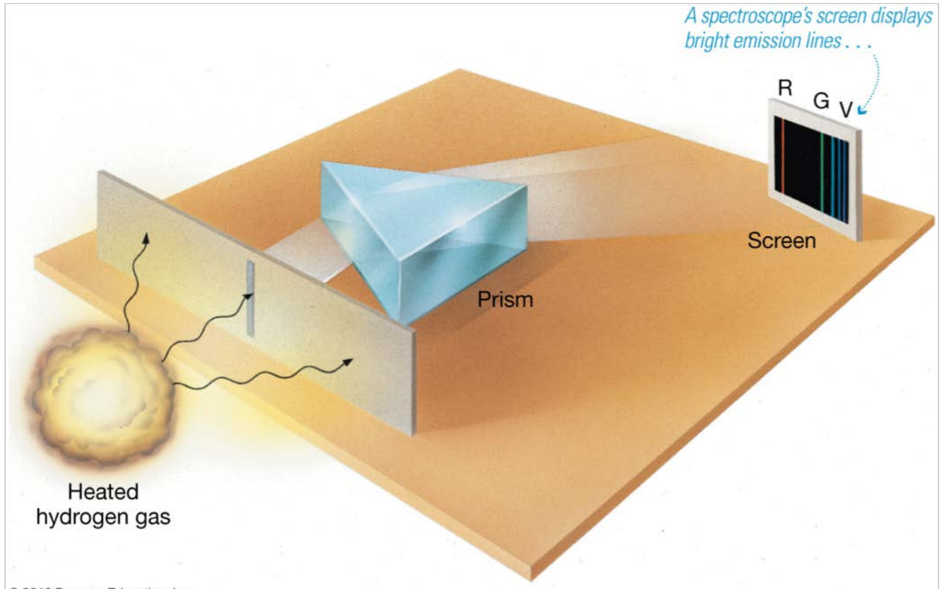
Prof. Douglas Laurence

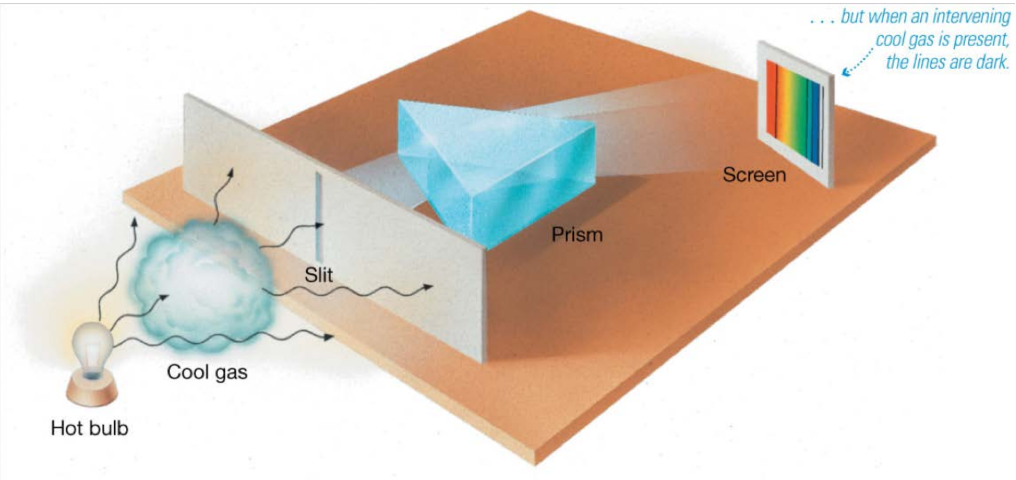
AST 1004

Atomic and Molecular Spectra



Spectroscopy

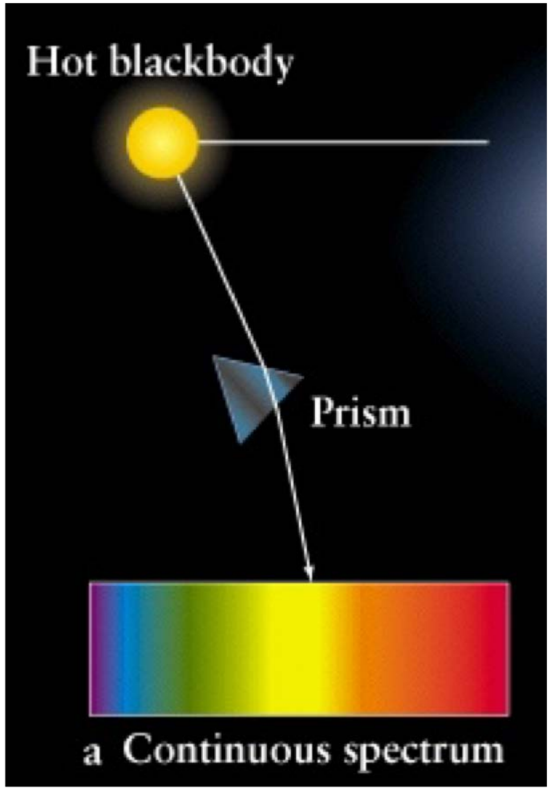




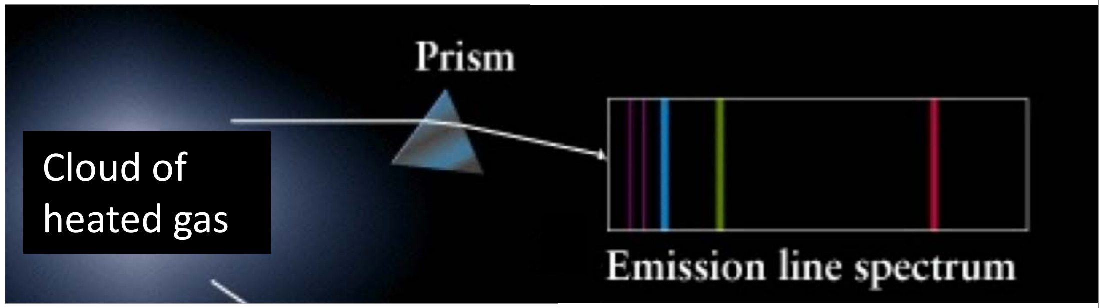
(a)

Kirchhoff's Laws of Spectroscopy

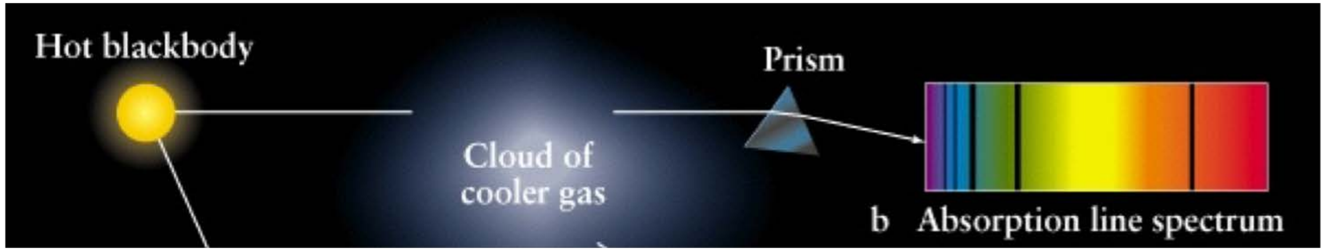
1st Law: A hot solid, liquid, or dense gas will emit a continuous, blackbody spectrum.



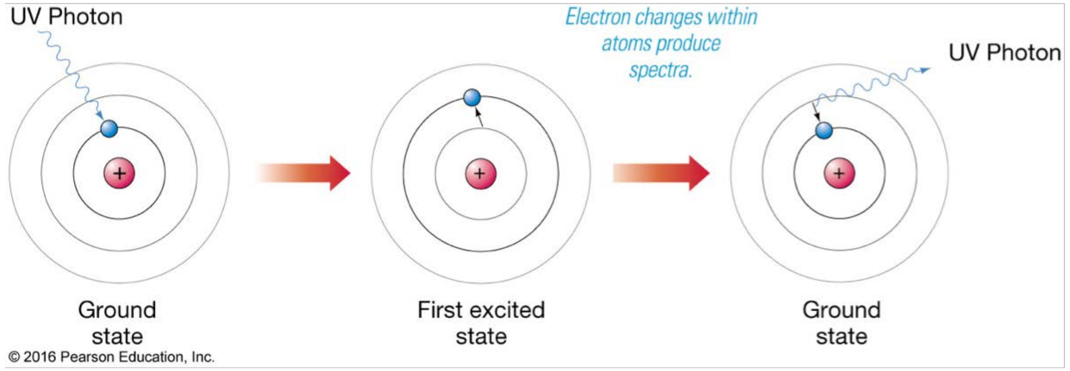
2nd Law: A heated, low density gas will emit light at specific wavelengths.

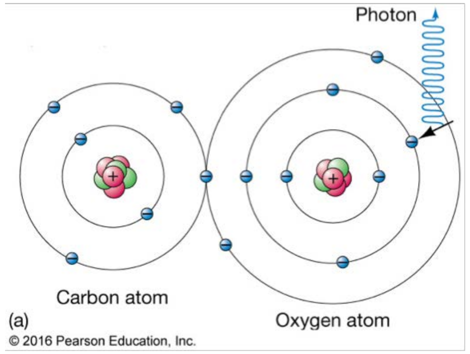


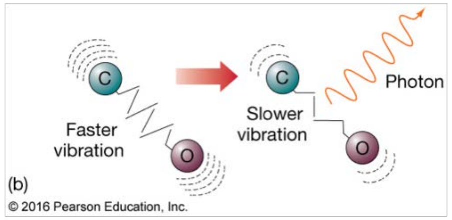
3rd Law: Light of a continuous spectrum passing through a cold, low density gas will cause specific wavelengths of light to be absorbed.

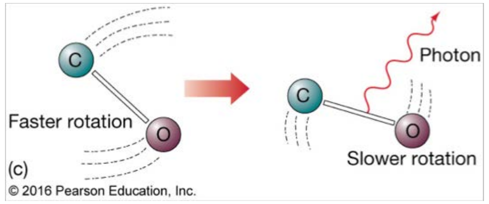


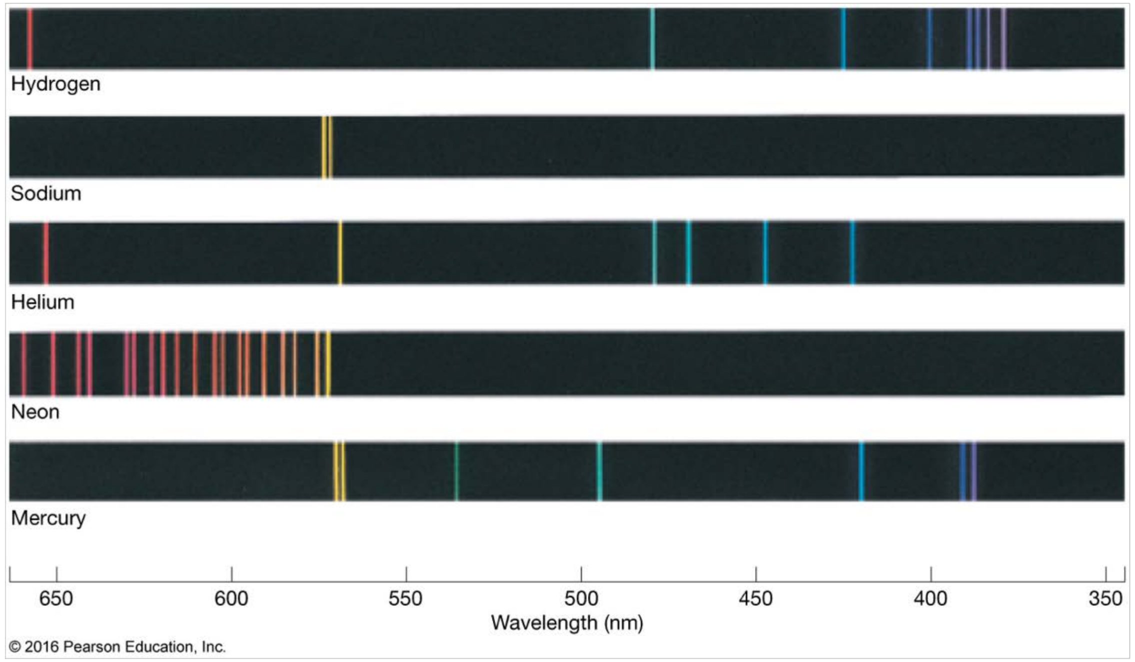
Emission and Absorption of Photons



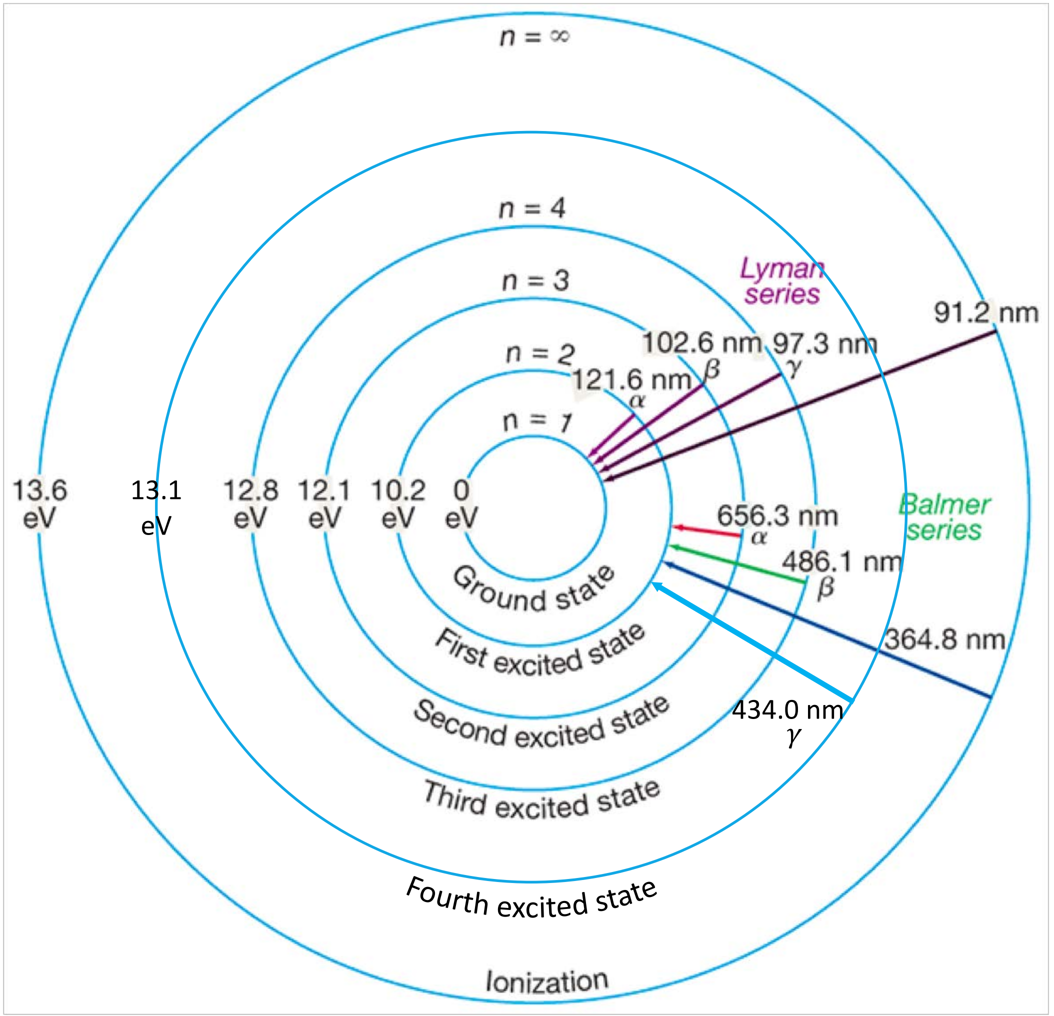








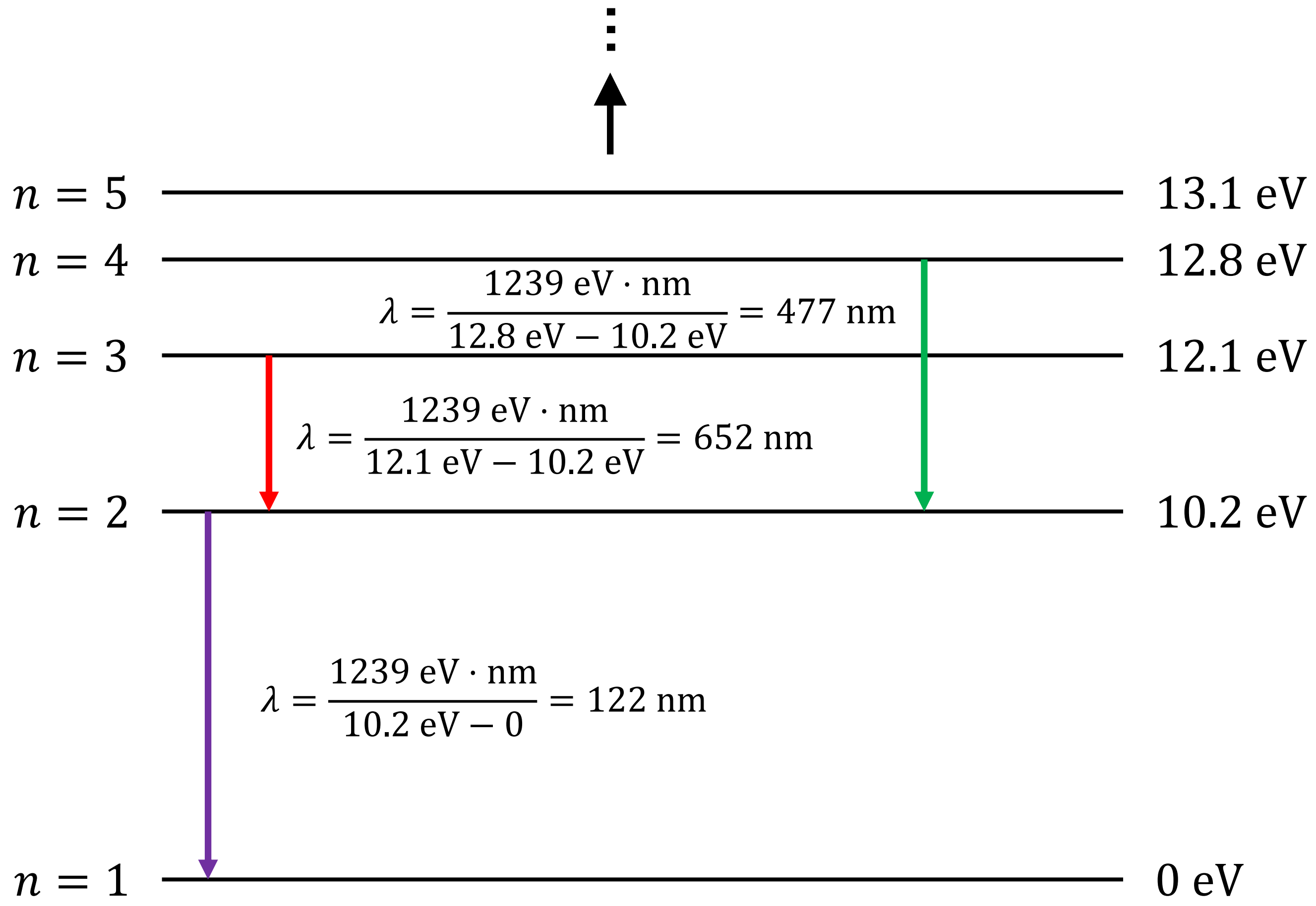
Emission Spectrum of Hydrogen



Balmer Series

Lyman Series not visible – emission is in the ultraviolet

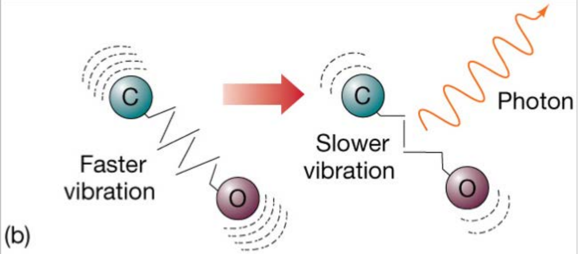
Computing Photon Emissions

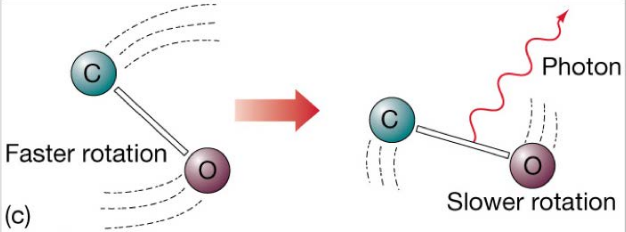


$$\lambda = \frac{hc}{\Delta E}$$

$$hc = 1{,}239\ \text{eV} \cdot \text{nm}$$

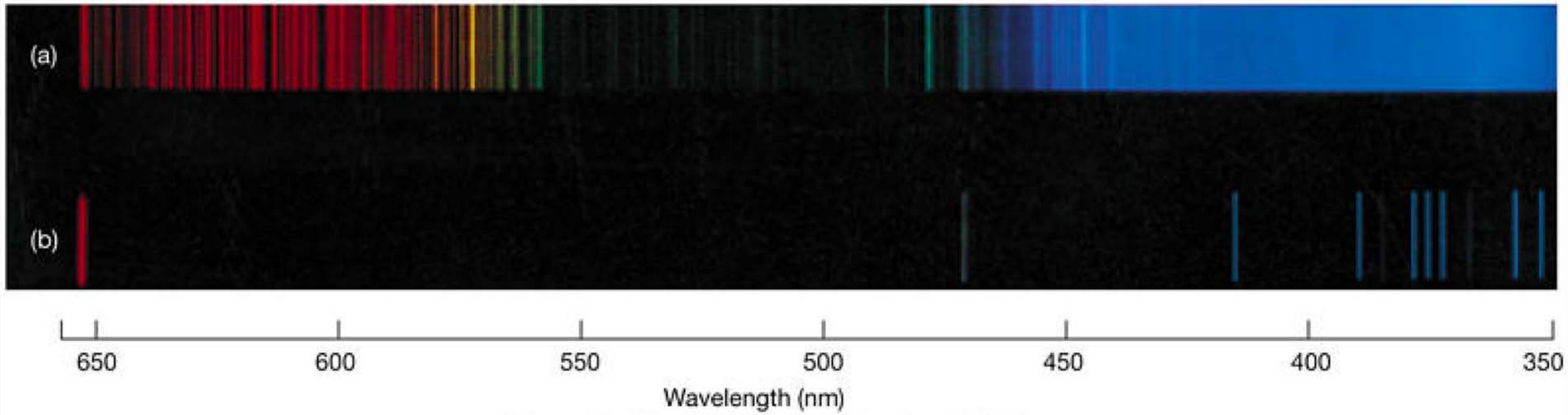
Atomic vs. Molecular Spectra



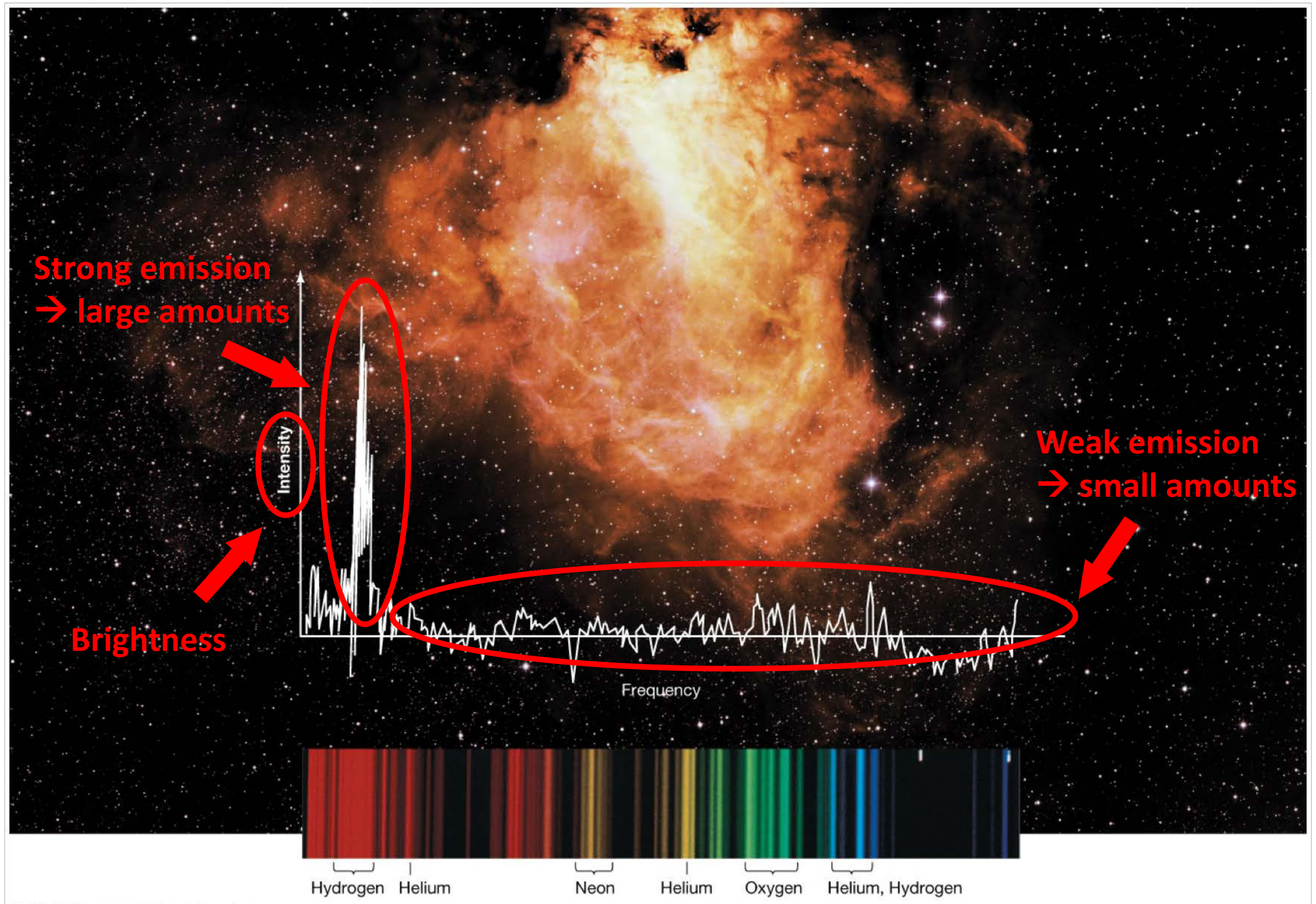


(a) Molecular hydrogen, H_2

(b) Atomic hydrogen, H

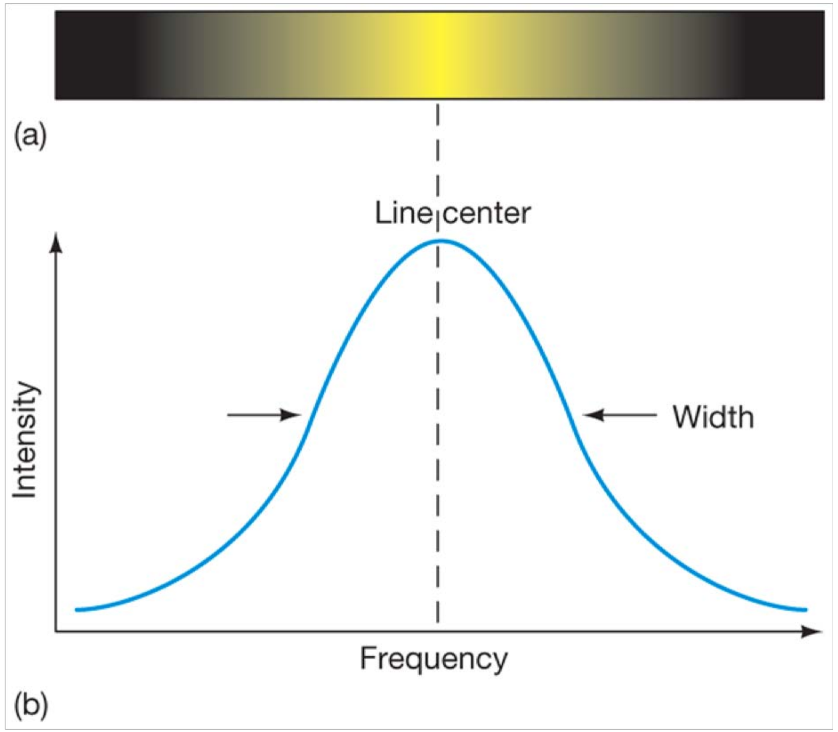


Detecting Chemical Elements

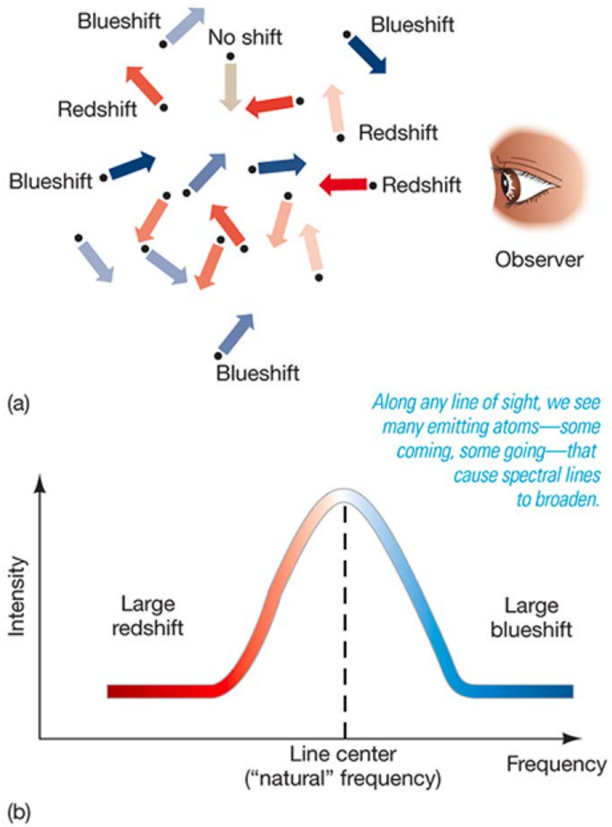


Spectral Line Features

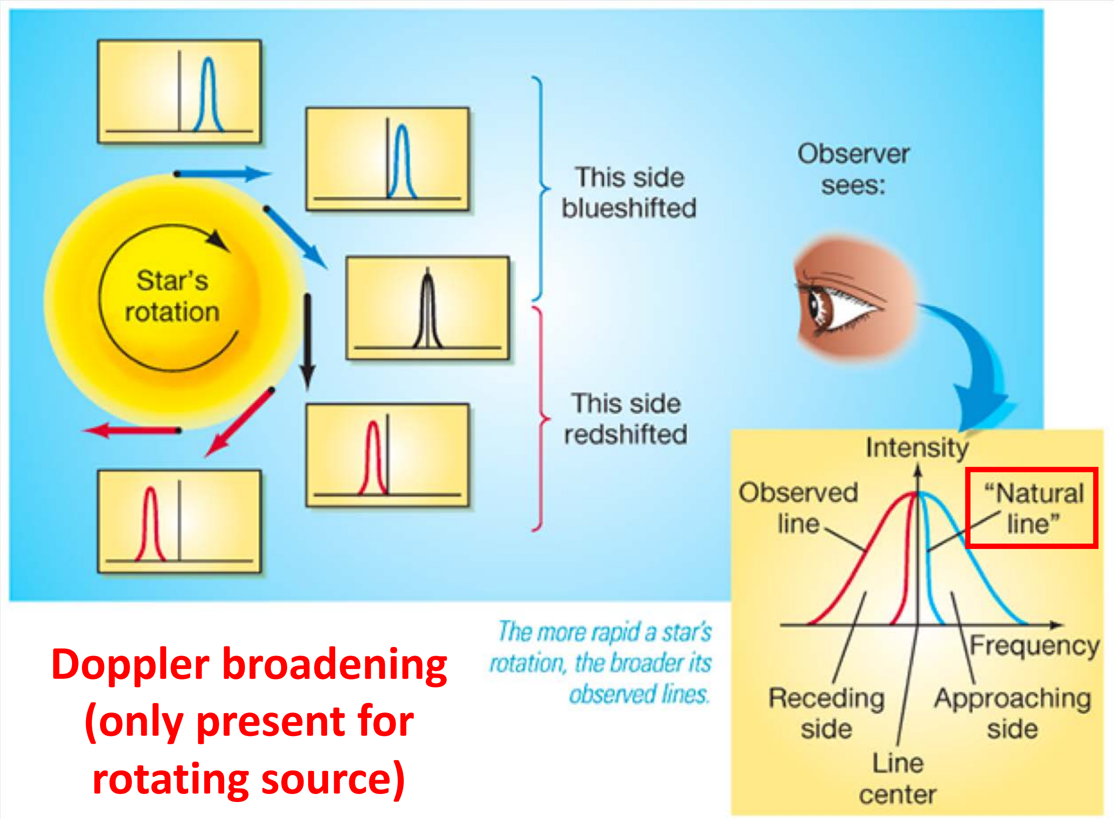
Observed Spectral Characteristic	Information Provided
Peak frequency or wavelength (continuous spectra only)	Temperature (Wien's law)
Lines present	Composition, temperature
Line intensities	Composition, temperature
Line width	Temperature, turbulence, rotation speed, density, magnetic field
Doppler shift	Line-of-sight velocity



Line Broadening



Thermal broadening (always present)



Doppler broadening (only present for rotating source)

Natural line thickness due to thermal broadening

Chapter 5:
Telescopes

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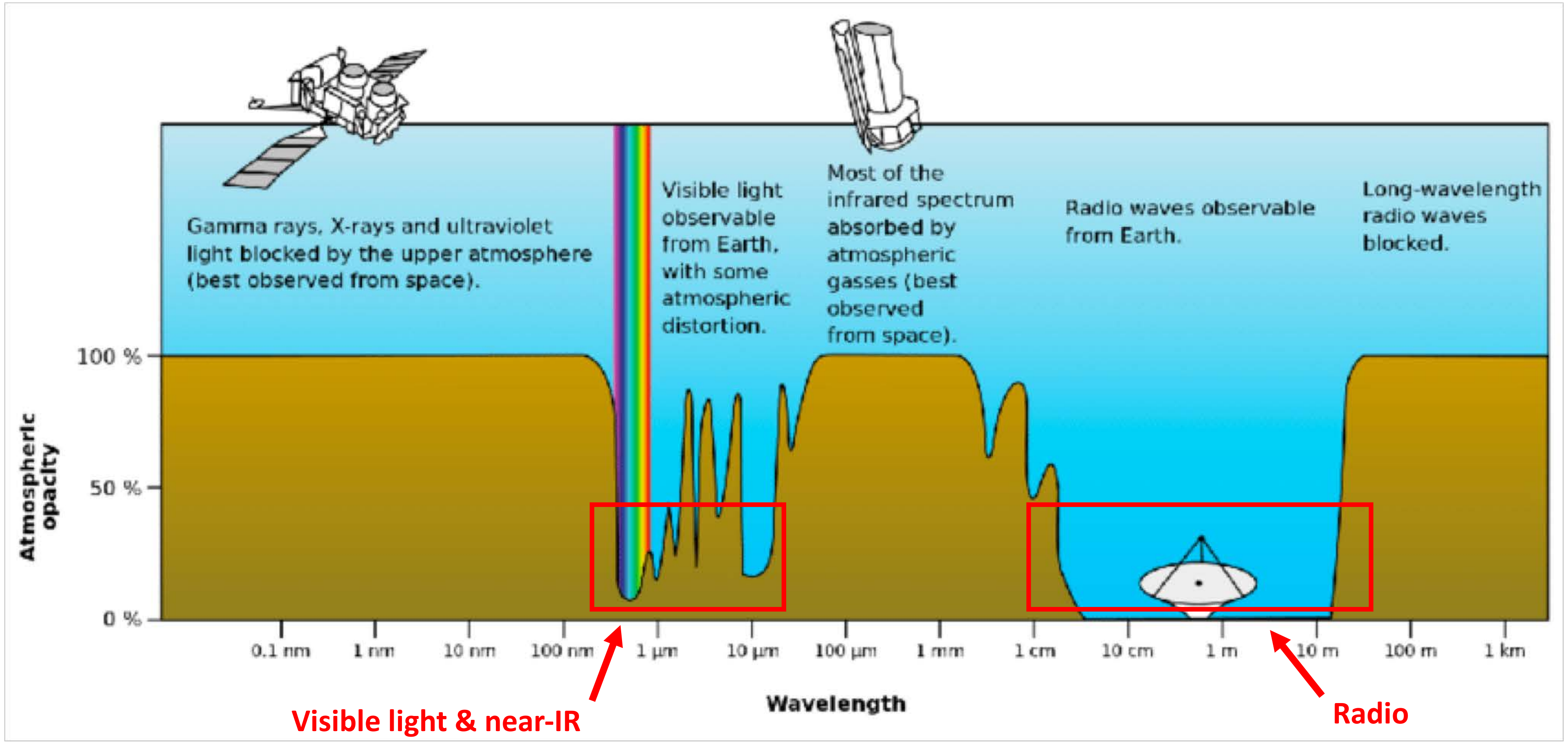
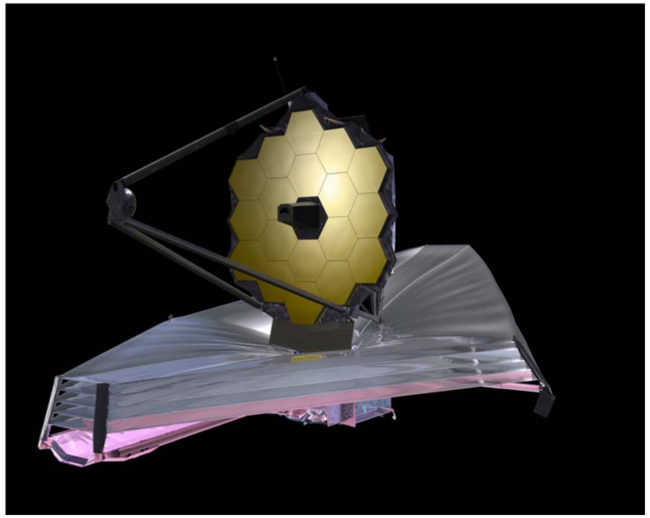
Atmospheric Absorption of Light



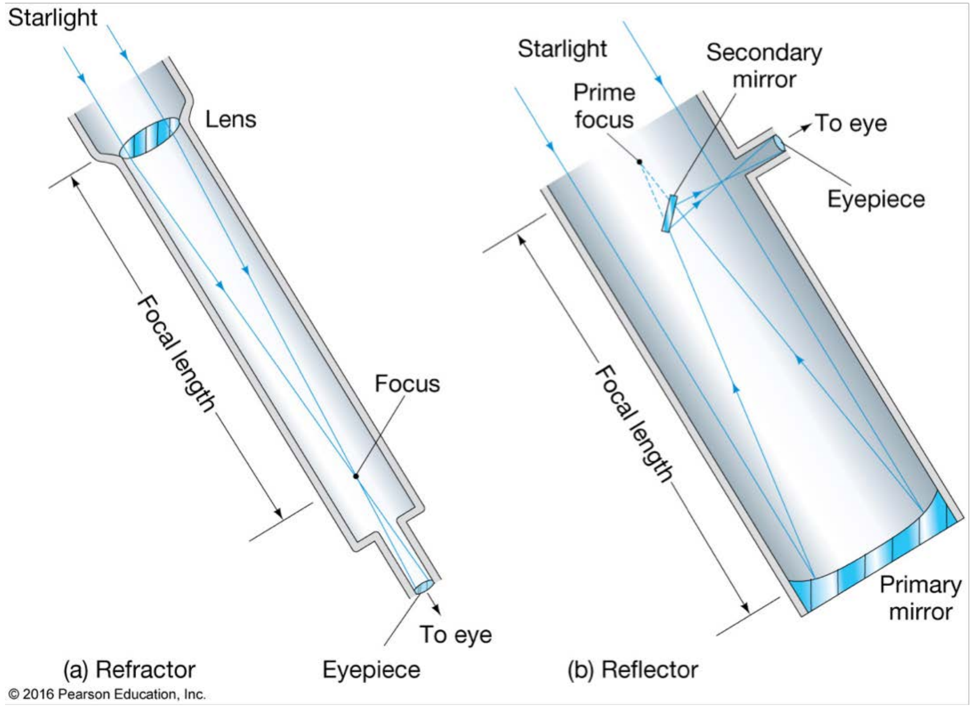
Types of Telescopes

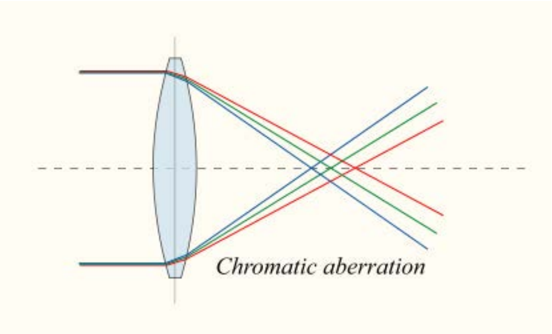
- **Earth-bound** telescopes:
    - Optical (e.g. *GTC, “Grand Canary Telescope”*)
    - Near-IR (e.g. *Keck 1*)
    - Radio (e.g. *Green Bank Telescope*)

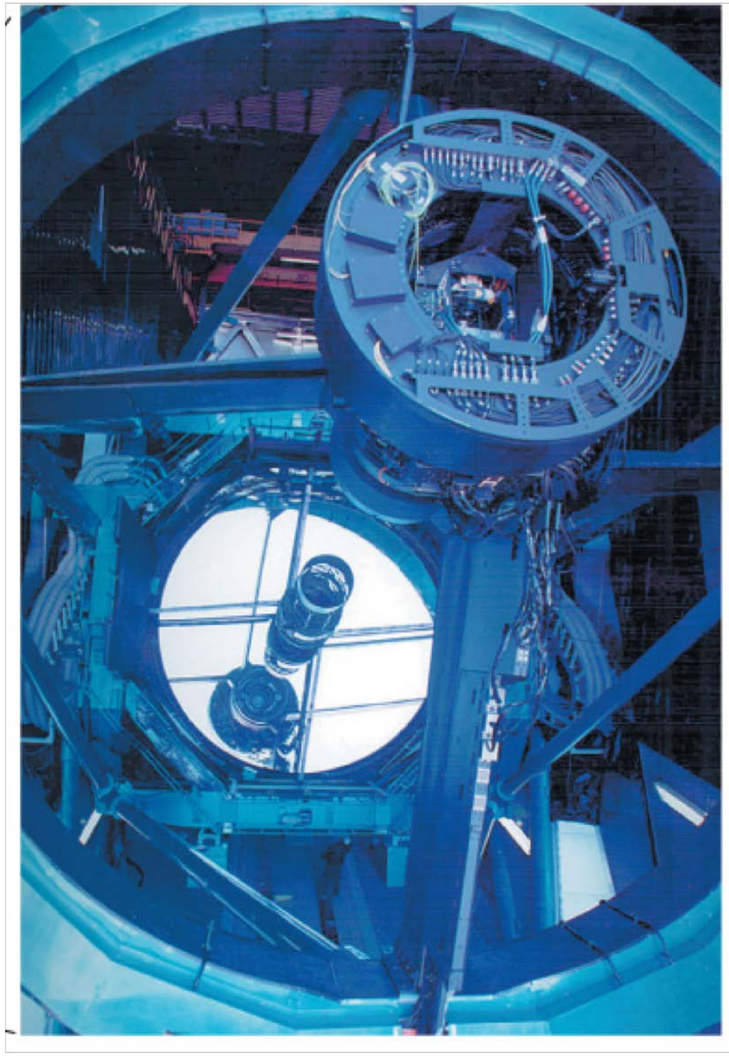
- **Space-based** telescopes:
    - Gamma-ray (e.g. *Fermi-LAT*)
    - X-ray (e.g. *SWIFT*)
    - Microwave (e.g. *Planck*)
    - Optical (e.g. *Hubble* or *JWST*)



Optical Astronomy



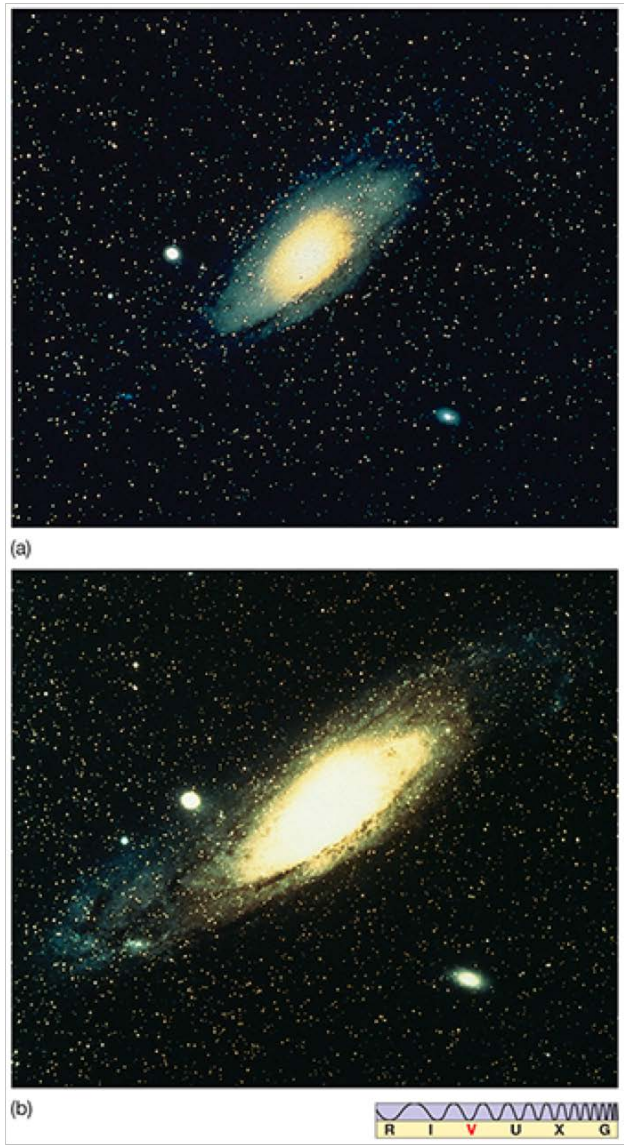




An inside look at the Subaru telescope

Light-Gathering

- Observed brightness depends on two factors:
  - **Area** of collecting surface
  - Light-gathering **time**
- Many objects of interest are very far away, and so appear very dim.
- High observed brightness is particularly important when studying spectra, since incoming light has to be split into multiple beams of light at different frequencies.



2x collecting area,
same collecting time

Resolution

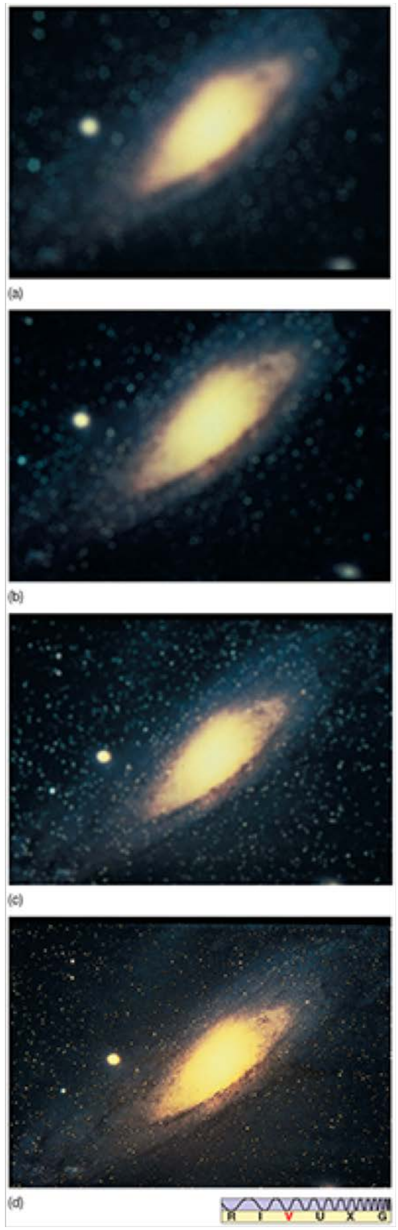
- Resolution is the ability to tell two distinct objects apart from one another.
  - Put another way, **resolution** measures the minimum distance two objects can be separated by and still be distinguished from one another.

arcseconds

wavelength

$$\text{angular resolution (“)} = 0.25\,\frac{\lambda\ (\mu\text{m})}{D\ (\text{m})}$$

Diameter of collecting surface

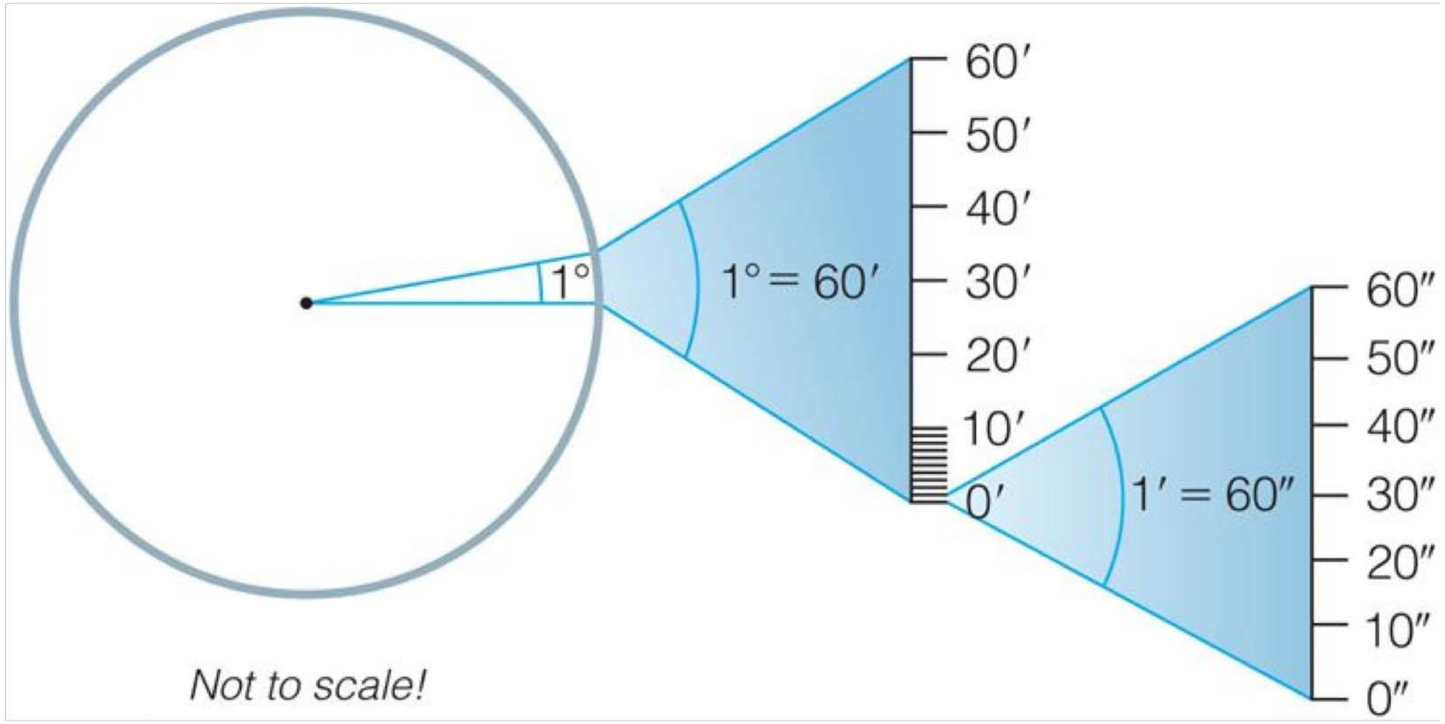


Arcminutes and Arcseconds

$$1 \text{ circle} = 360^o$$

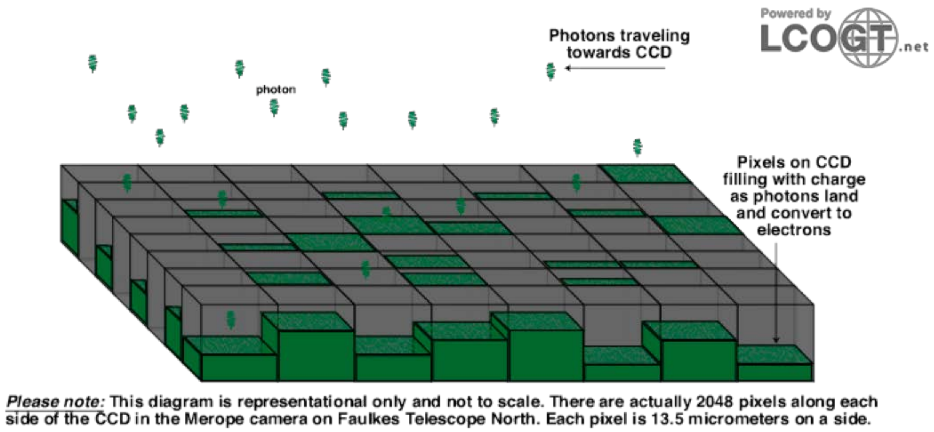
$$1^o = 60'$$

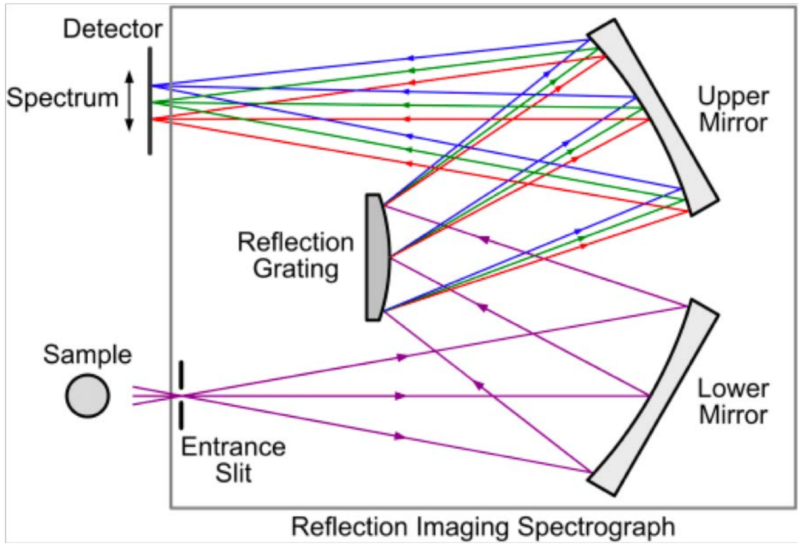
$$1' = 60''$$



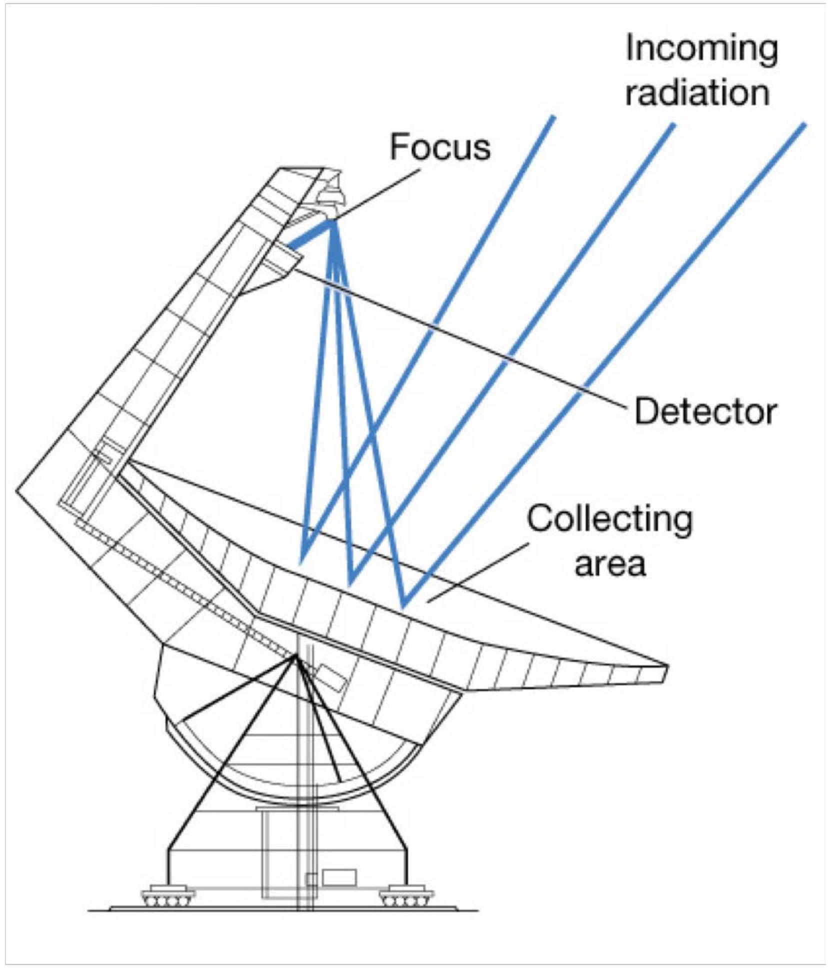
Photometry vs. Spectroscopy

- Two basic functions of a telescope: **photometry** and **spectroscopy**.
  - **Photometry** is the study of the brightness of an image at specific points on the image by analyzing each pixel on the CCD chip.
  - **Spectroscopy** is the study of the spectrum of an object, utilizing a filter, prism, or diffraction grating to split the light into constituent colors.





Radio Astronomy



Radio vs. Optical Astronomy

- Optical telescopes:
  - Are significantly smaller than radio telescopes, and thus are cheaper to build.
  - Many objects of interest are very bright in visible light.
- Radio telescopes:
  - Offer 24 hour observation, since the Sun is a weak radio emitter.
  - Allow us to observe objects that aren't very bright in visible light (often objects that are bright in visible are dim in radio, and vice-versa).
  - Radio waves have very large wavelengths, so telescopes must have very large diameters to have comparable resolutions (100m radio vs. 1m optical).
  - Can be combined into **interferometry arrays**, which allow for vastly superior resolution to even the best space-based optical telescopes.

Radio Interferometry Arrays

Acts as a giant radio telescope, allowing to see to tiny angular resolution.

Event Horizon Telescope

- A global array of radio telescopes:
  - All observing at 1.3mm
  - Has an effective diameter of ~10,000 km
  - Angular resolution ~30 μarcsec (able to read a newspaper in NYC from Paris)
- First black hole observed with EHT:
  - Black hole at center of M87
  - 42 ± 3 μarcsec across
  - No other telescope has ever achieved a small enough angular resolution to see a black hole before (April 10, 2019)