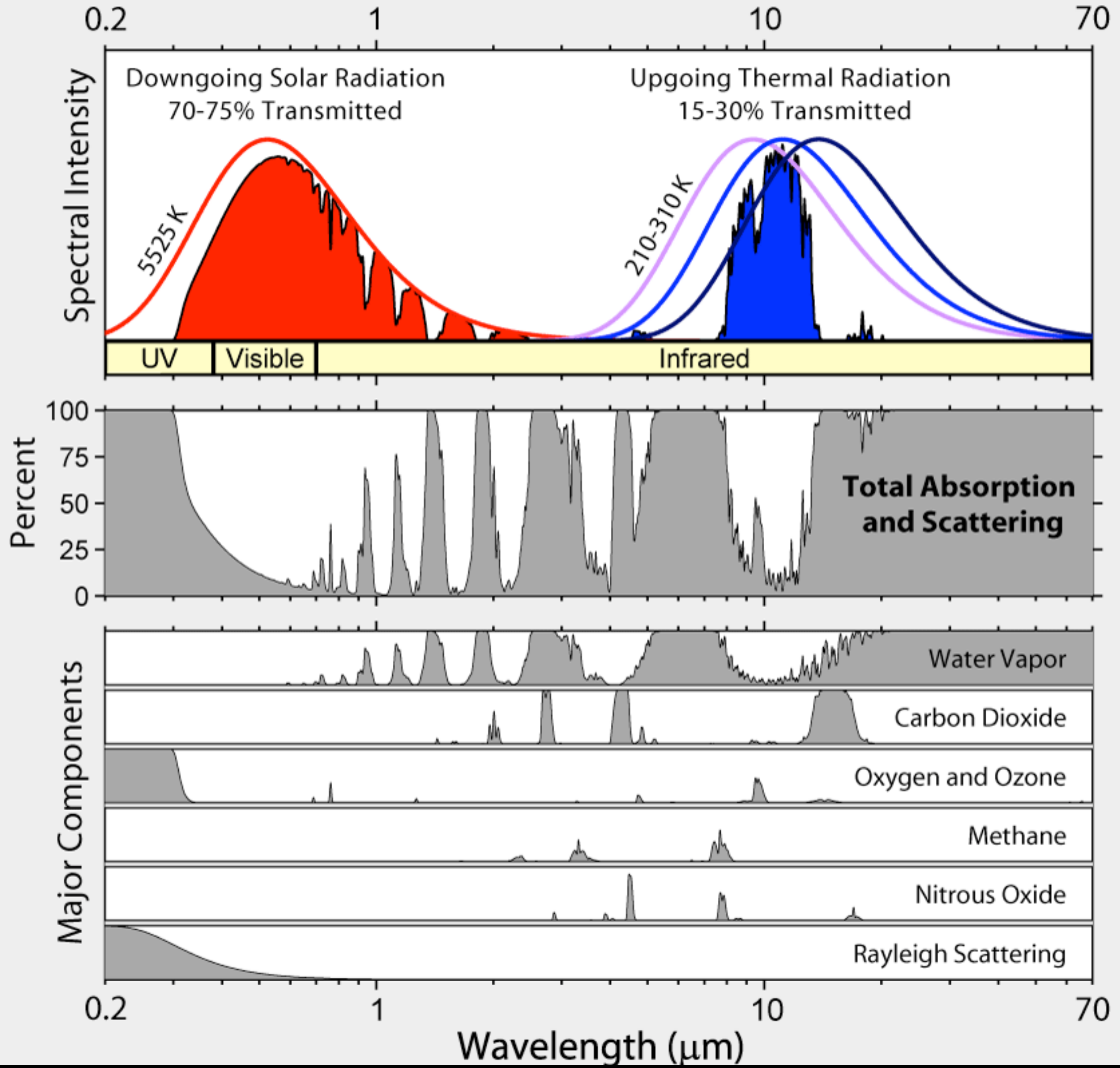
Thermal Structure: Greenhouse Effect

- Atmosphere is more or less transparent to radiation (photons) depending on wavelength – opacity
- Opacity is low at visible wavelengths, high at infrared wavelengths due to absorbers like water vapor, CO_2
- Incoming light (visible) passes through atmosphere with little absorption
- Outgoing light is infrared (since the surface temperature is lower) and is absorbed by atmosphere
- So atmosphere heats up
- Venus suffered from a *runaway* greenhouse effect – surface temperature got so high that water was unstable, so no CO_2 could dissolve and form carbonates as on Earth

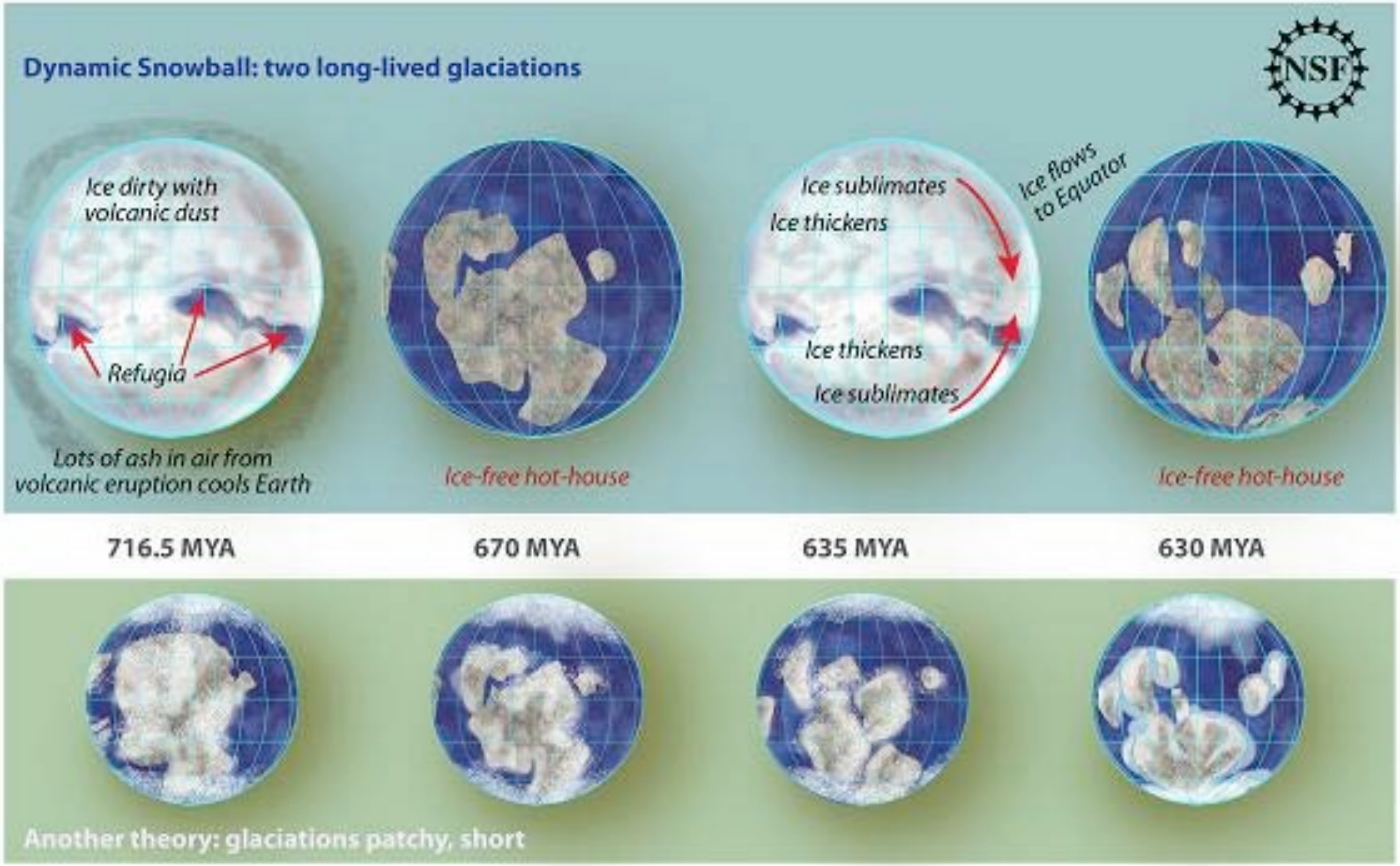
Radiation Transmitted by the Atmosphere



Thermal Structure: Albedo Effects

- Fraction of energy reflected (not absorbed) by surface is given by the albedo A ($0<A<1$)
- Coal dust has a low albedo, ice a high one
- The albedo can have an important effect on surface temperature
- E.g. ice caps grow, albedo increases, more heat is reflected, surface temperature drops, ice caps grow further . . . runaway effect!
- This mechanism is thought to have led to the Proterozoic Snowball Earth
- How might clouds affect planetary albedo?

Recurring Snowball Earth?



Atmospheric Thermal Structure

The atmospheric temperature profile is governed by the efficiency of energy transport, which largely depends on optical depth, τ_ν . Remember that heating by solar radiation is a 'top-down' process.

Optical depth (or transparency) is determined by physical and chemical processes in the atmosphere and can change in time and in altitude.

Atmospheric Thermal Structure

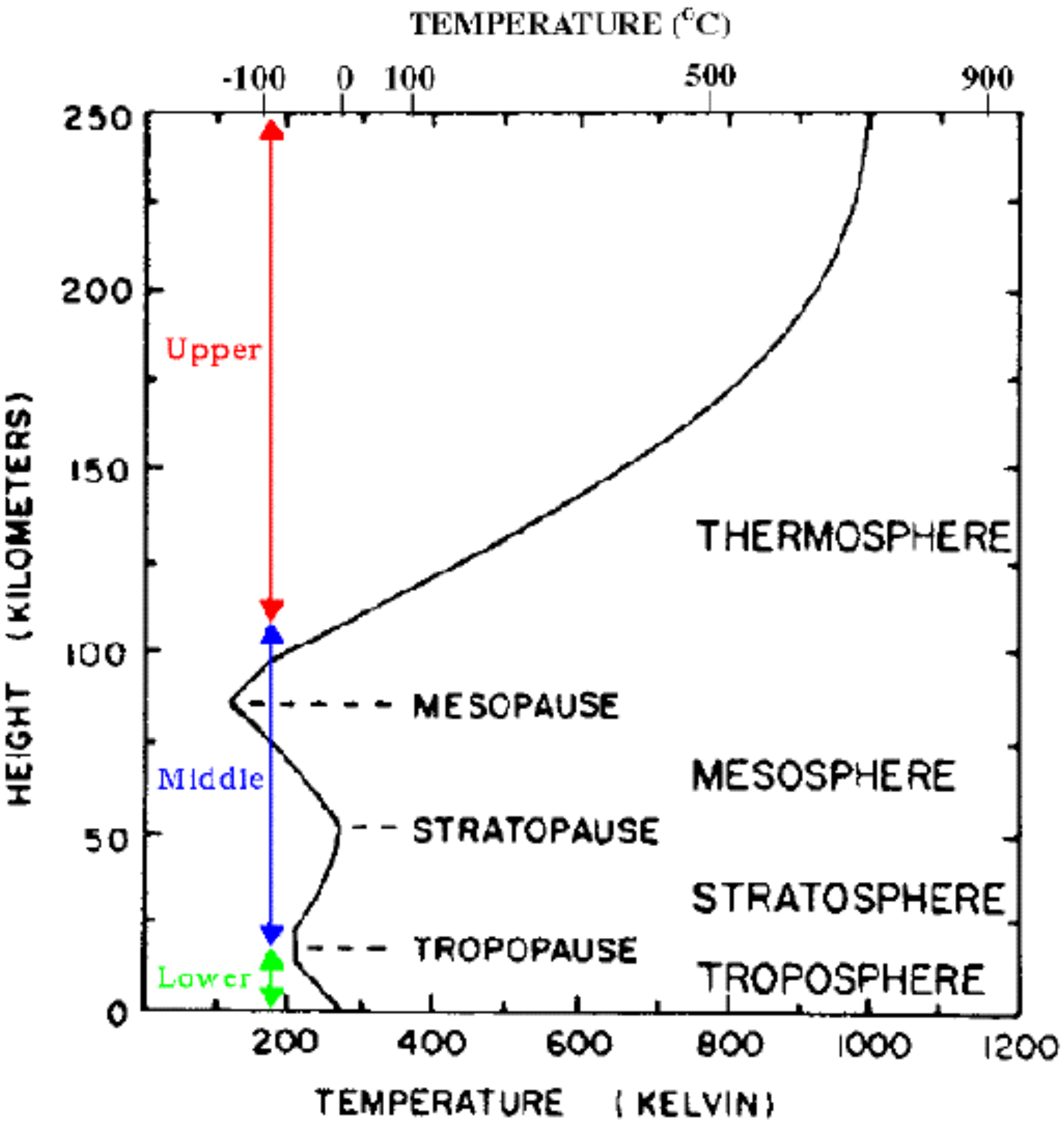
Other factors to consider:

Clouds can change the albedo, the optical depth, and the local temperature (via release/ absorption of latent heat).

Surface variations/composition can affect albedo and surface temperatures depend on the thermal properties of materials and their chemical interactions with the atmosphere

Geologic processes such as volcanism can greatly impact the composition, as well as chemistry and albedo (via dust grains and aerosols) of the atmosphere.

Atmospheric Thermal Structure



Troposphere: Where condensable gases form clouds. dT/dz < 0

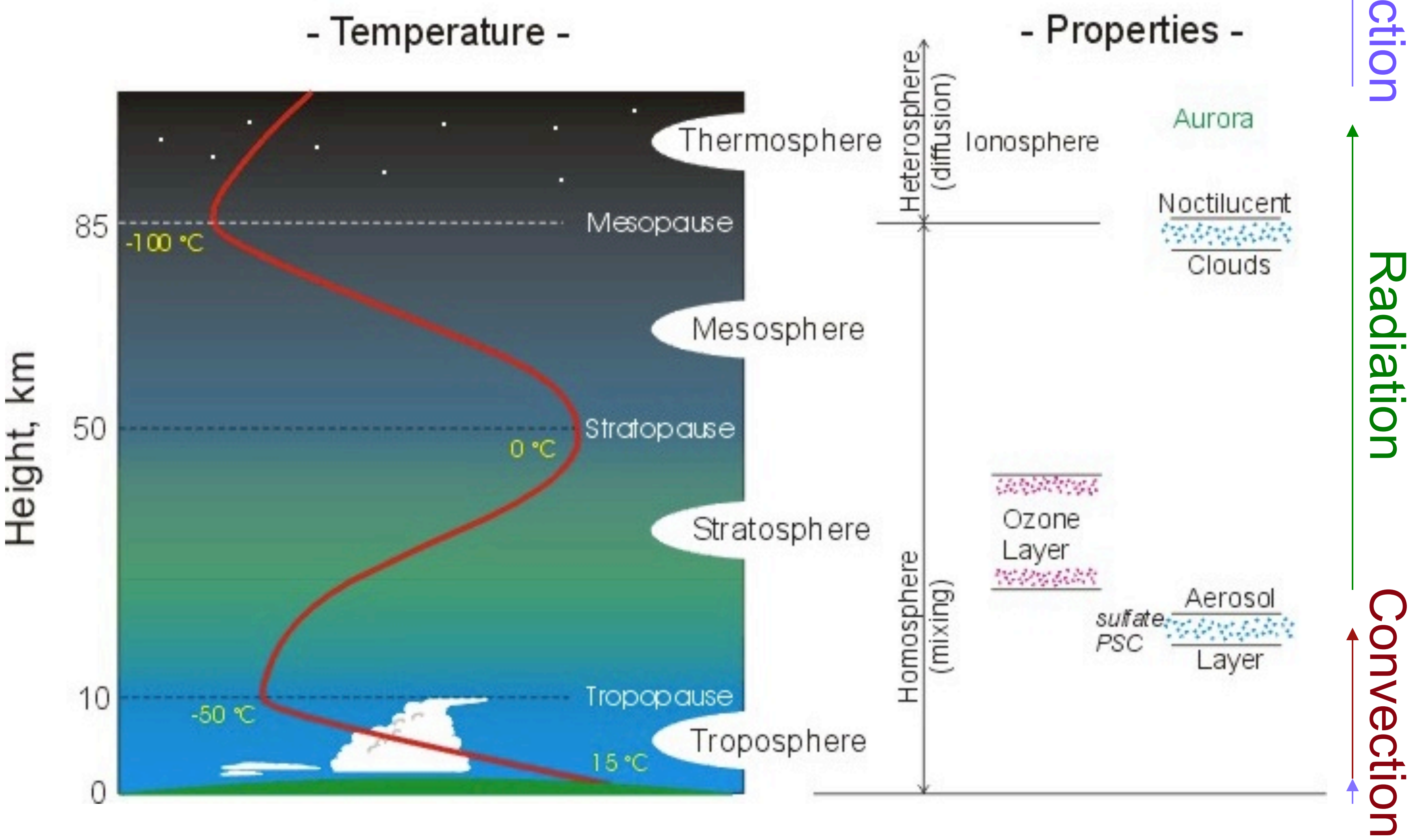
Stratosphere: dT/dz > 0

Mesosphere: dT/dz < 0

Thermosphere: dT/dz > 0

Exosphere: Roughly Isothermal

Atmospheric Thermal Structure

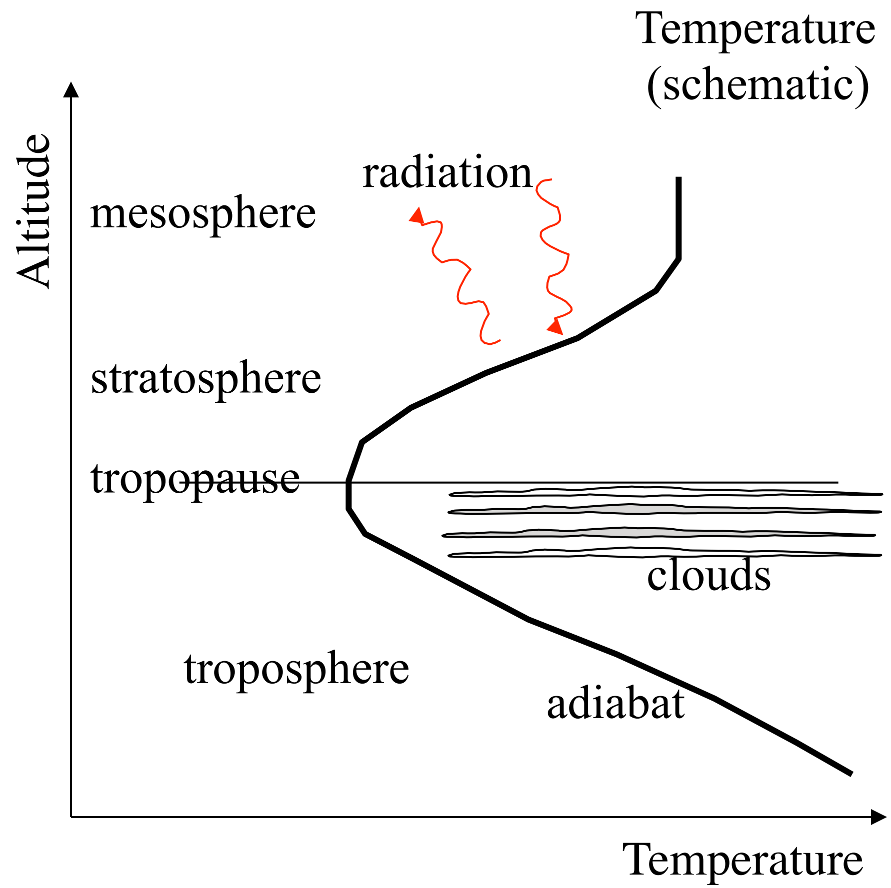


Atmospheric Thermal Structure

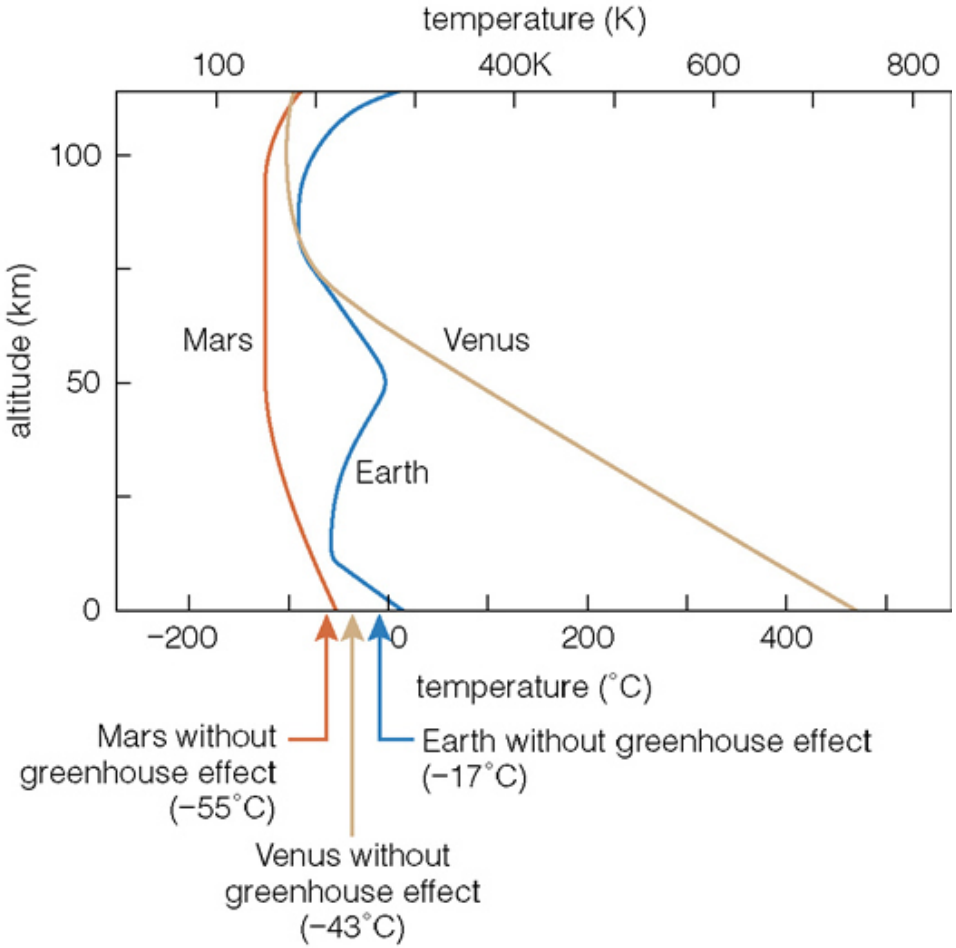
Lower atmosphere (opaque) is dominantly heated from below and will be conductive or convective (adiabatic)

Upper atmosphere intercepts solar radiation and re-radiates it

There will be a temperature minimum where radiative cooling is most efficient (the tropopause)



Terrestrial Planets Atmospheric Thermal Structure



Mars, Venus, Earth all

- have warm tropospheres (and greenhouse gases)
- have warm thermospheres which absorb Solar X rays

Only Earth has

- a warm stratosphere
- an UV-absorbing gas (O_3)

All three planets have warmer surface temps due to greenhouse effect

Titan's Atmospheric Thermal Profile

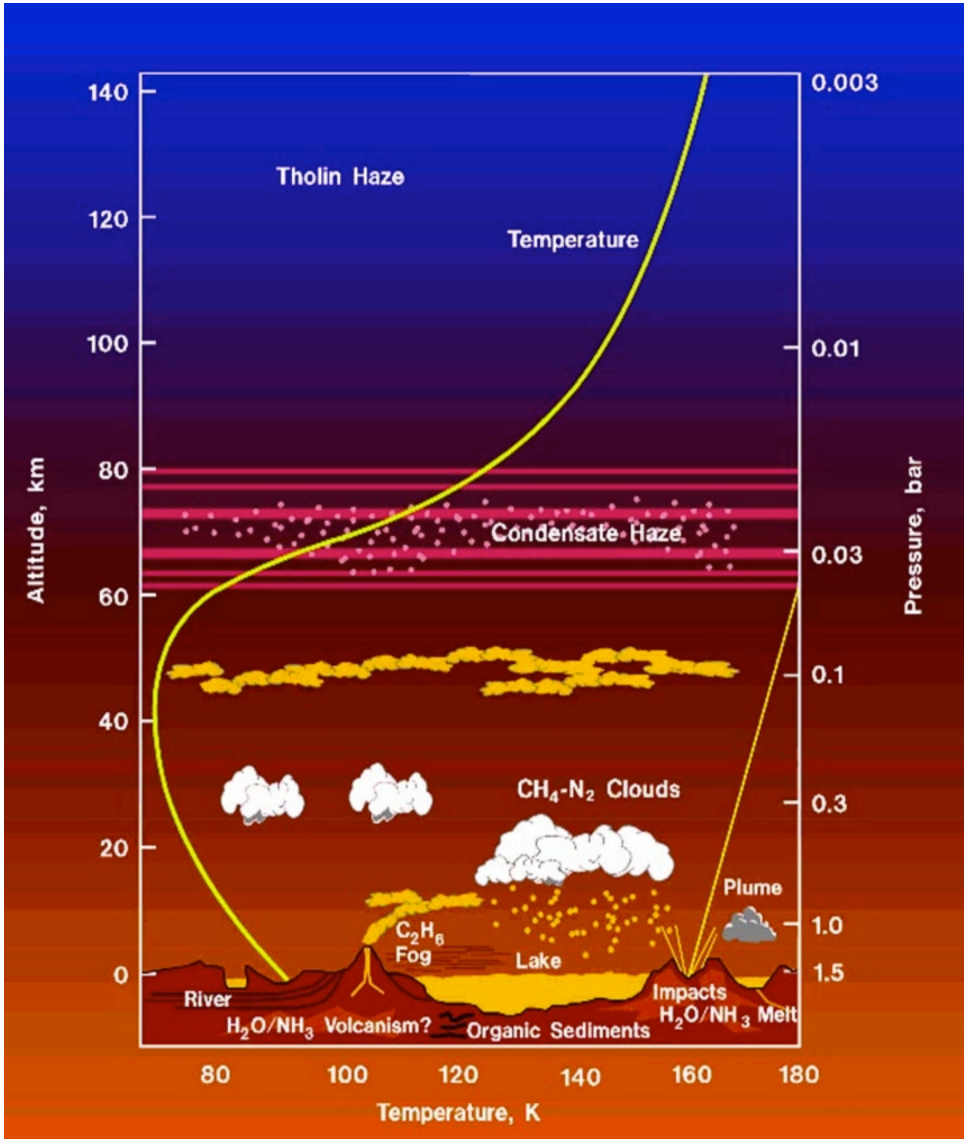
Balance between greenhouse and anti-green house effects:

Greenhouse effects cause +21 K increase in surface temperature over T_{eq}

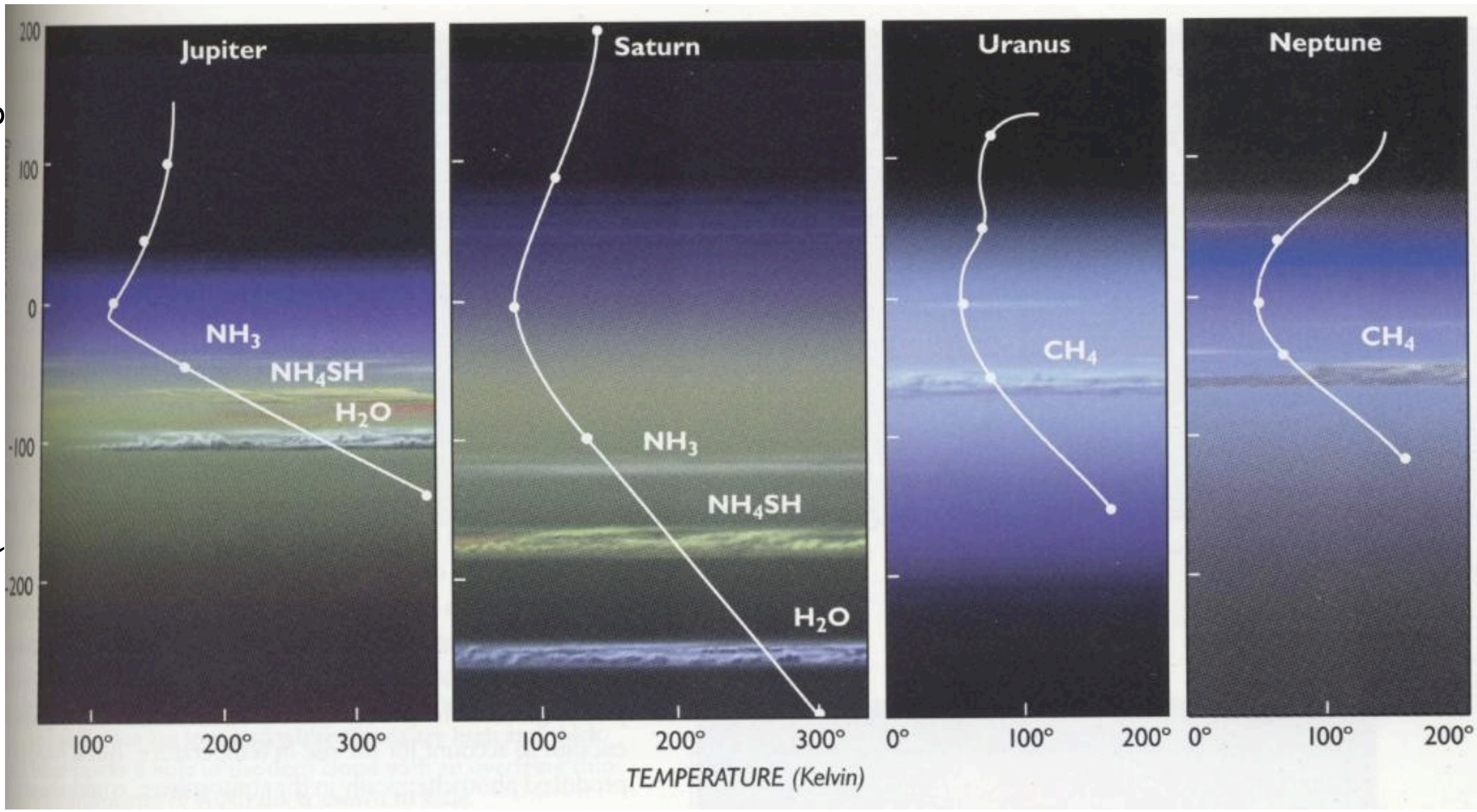
Anti-greenhouse from haze layer absorption of sunlight is responsible for -9 K difference

Net ~12 K increase over T_{eq}

Stratopause at ~250 km (organic-trapped radiation)



Giant Planet Atmospheric Structure



Note position and order/composition of cloud decks

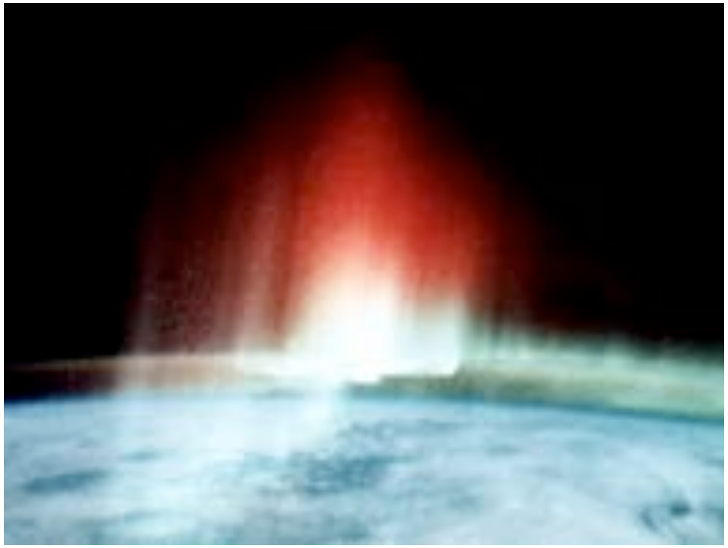
Atmospheric Thermal Structure

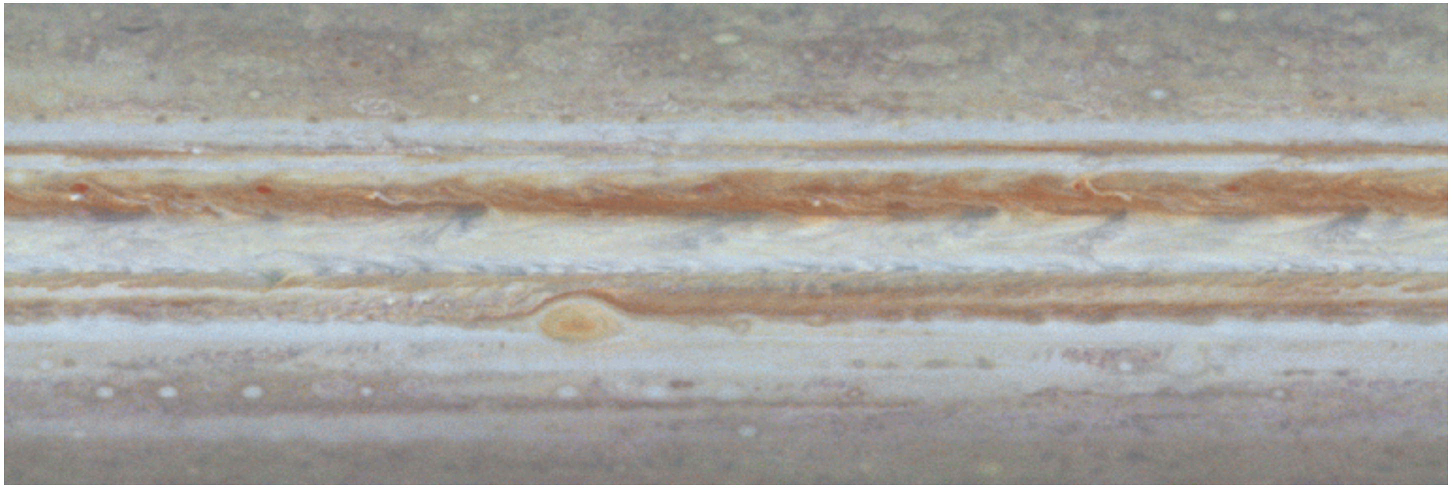
Radiation interactions are responsible for the structure we see:

- Troposphere
  - absorbs IR photons from the surface
  - temperature drops with altitude
  - hot air rises and high gas density causes storms (convection)
- Stratosphere
  - lies above the greenhouse gases (no IR absorption)
  - absorbs heat via Solar UV photons which dissociate ozone (O_3)
  - UV penetrates only top layer; hotter air is above colder air
  - no convection or weather; the atmosphere is stably stratified
- Thermosphere
  - absorbs heat via Solar X-rays which ionize all gases
  - contains ionosphere, which reflects back human radio signals
- Exosphere
  - hottest layer; gas extremely rarified; provides noticeable drag on satellites

Planetary Atmospheres

Structure
Composition
Clouds
Photochemistry
Meteorology
Atmospheric Escape



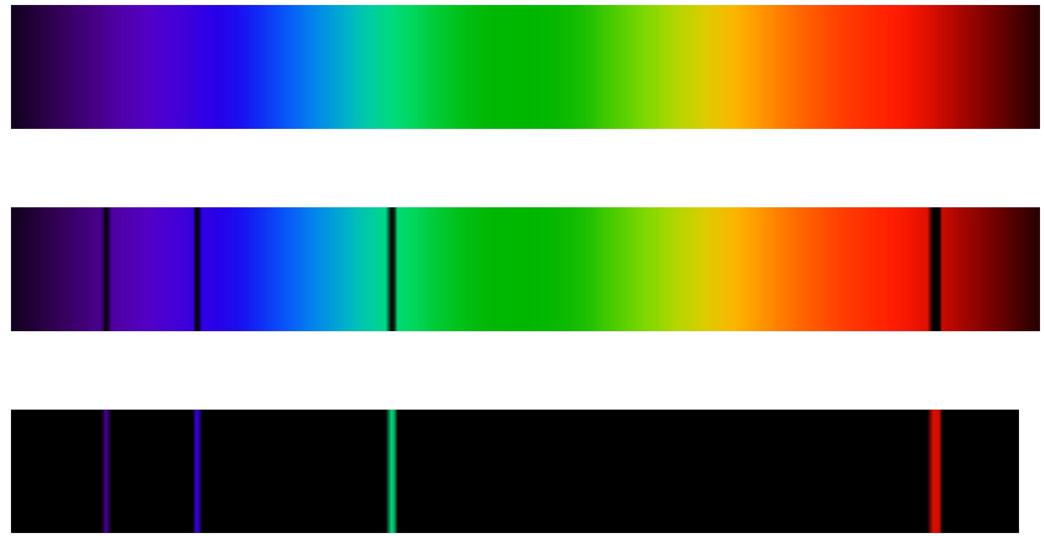


Spectra: Observing the Atmosphere

Continuous Spectrum

Absorption Spectrum

Emission Spectrum

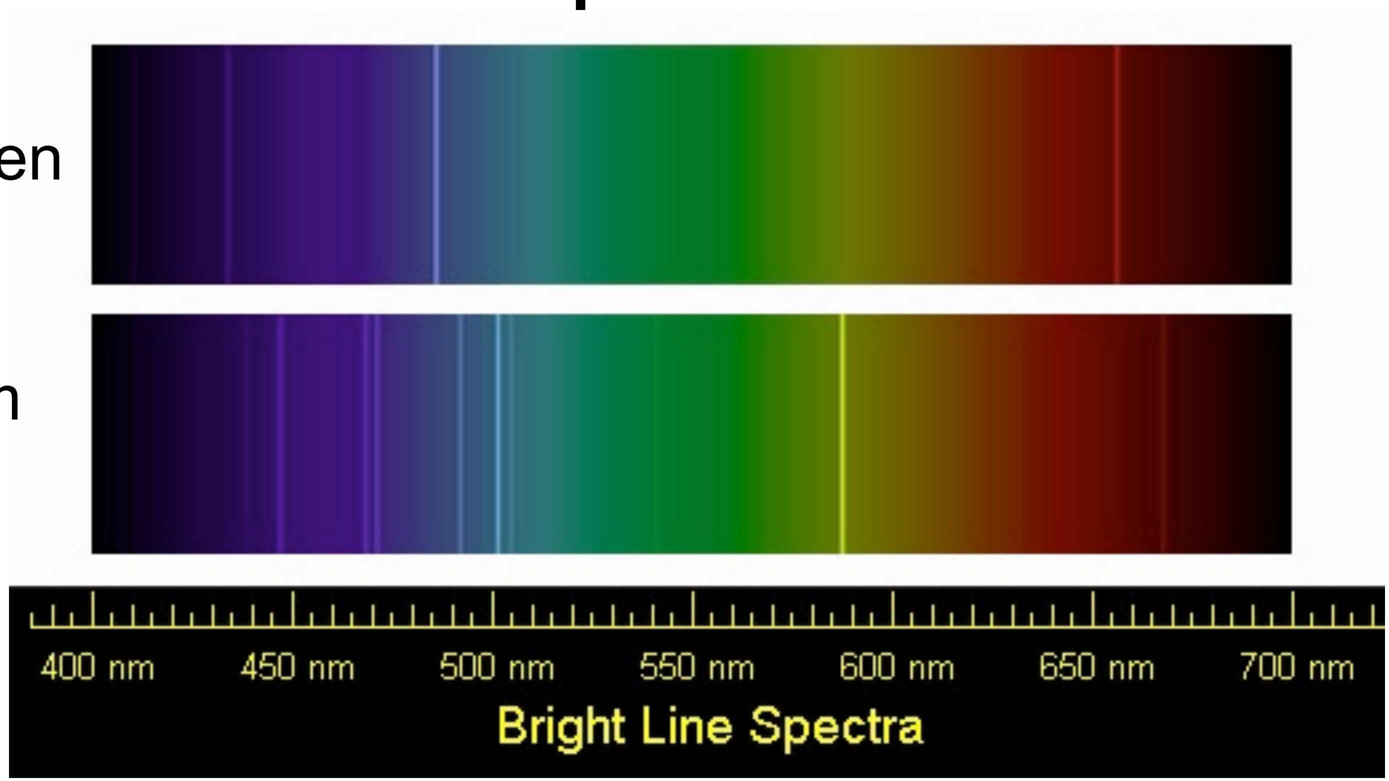


Light emitted from a perfect black body generates a continuous spectrum. However, as radiation emitted from the Sun passes through its cooler photosphere, wavelengths of light are absorbed, resulting in absorption lines or a ‘Fraunhofer absorption spectrum’ in solar radiation.

Spectra

Hydrogen

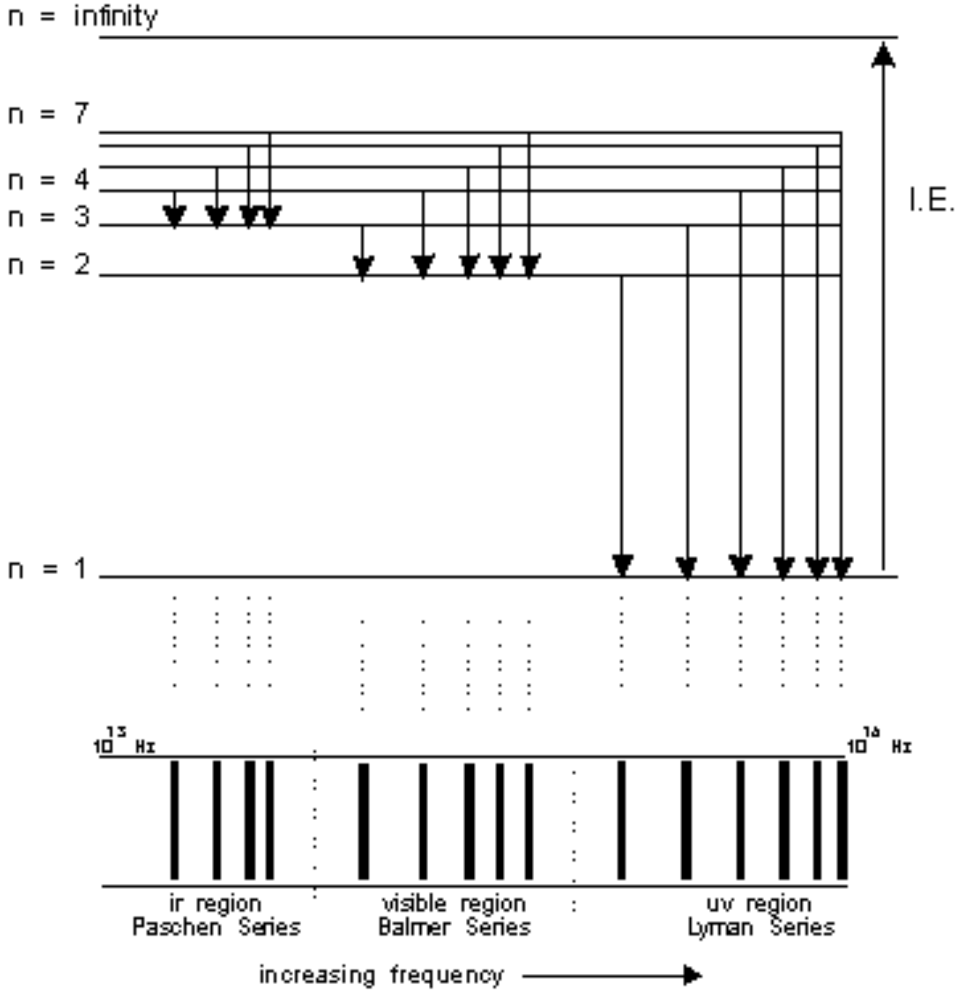
Helium



Each element/molecule has its own spectral ‘fingerprint’ that can be observed in either emission or absorption depending on its temperature relative to the light source.

Cooler $\Rightarrow$ Then wavelengths will be absorbed and appear dark in the spectrum.

Spectra



Just a reminder:
These wavelengths of emission/absorption are uniquely and directly determined by the quantized energy transitions of electrons in a given atom/ molecule.

$E_{ul} = h\nu = hc / \lambda$