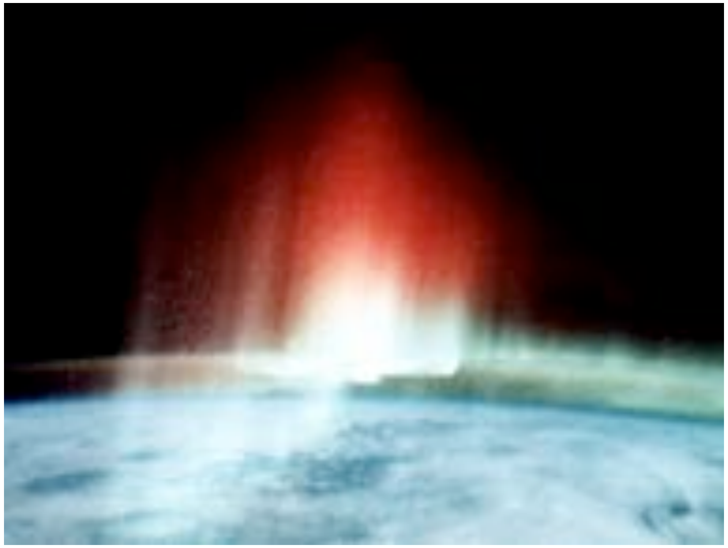
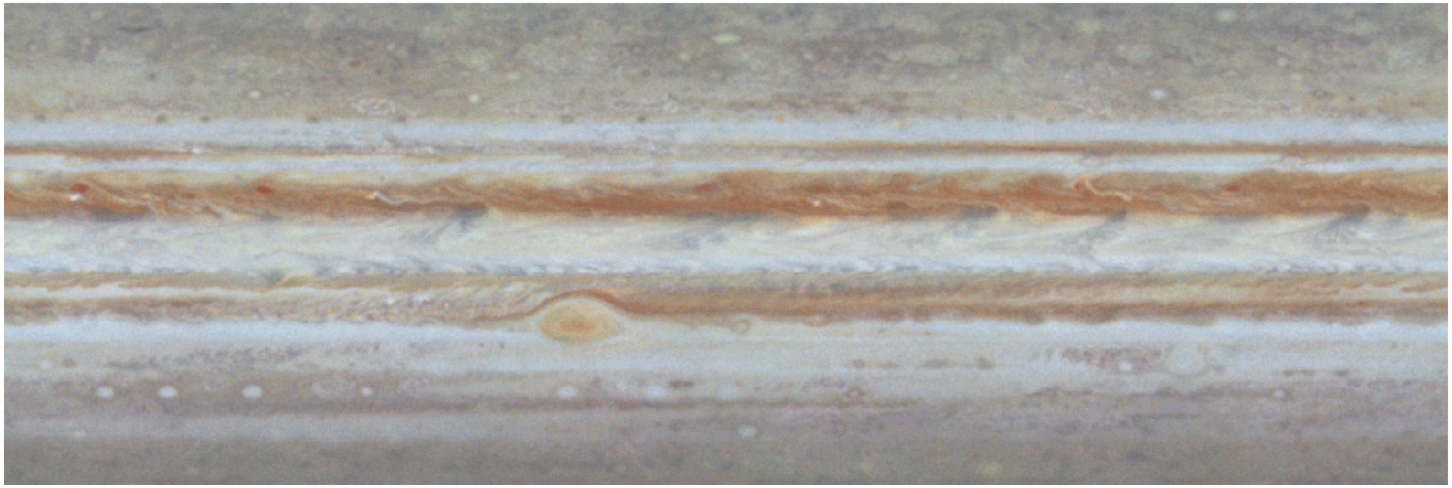
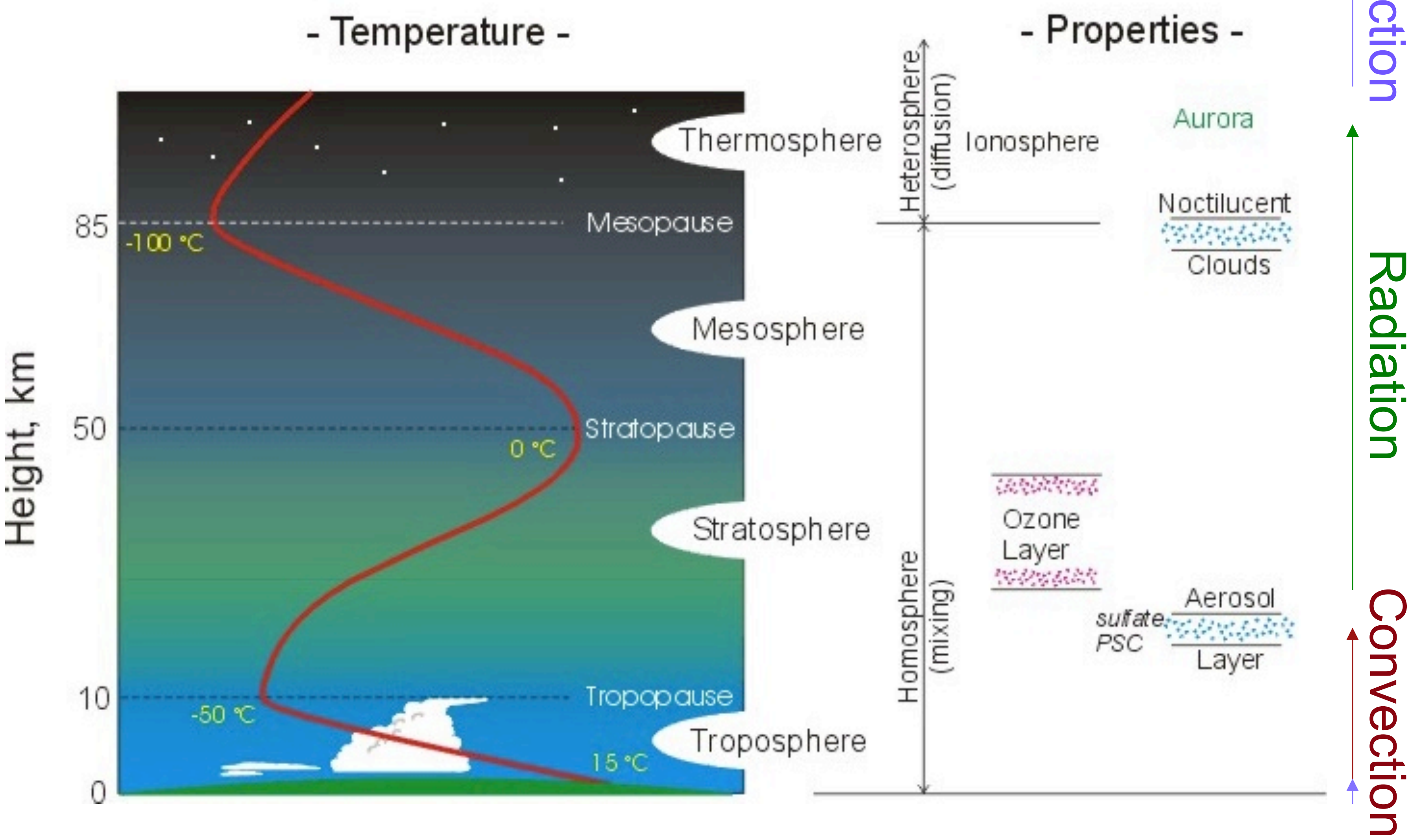
Planetary Atmospheres

Structure
Composition
Clouds
Photochemistry
Meteorology
Atmospheric Escape

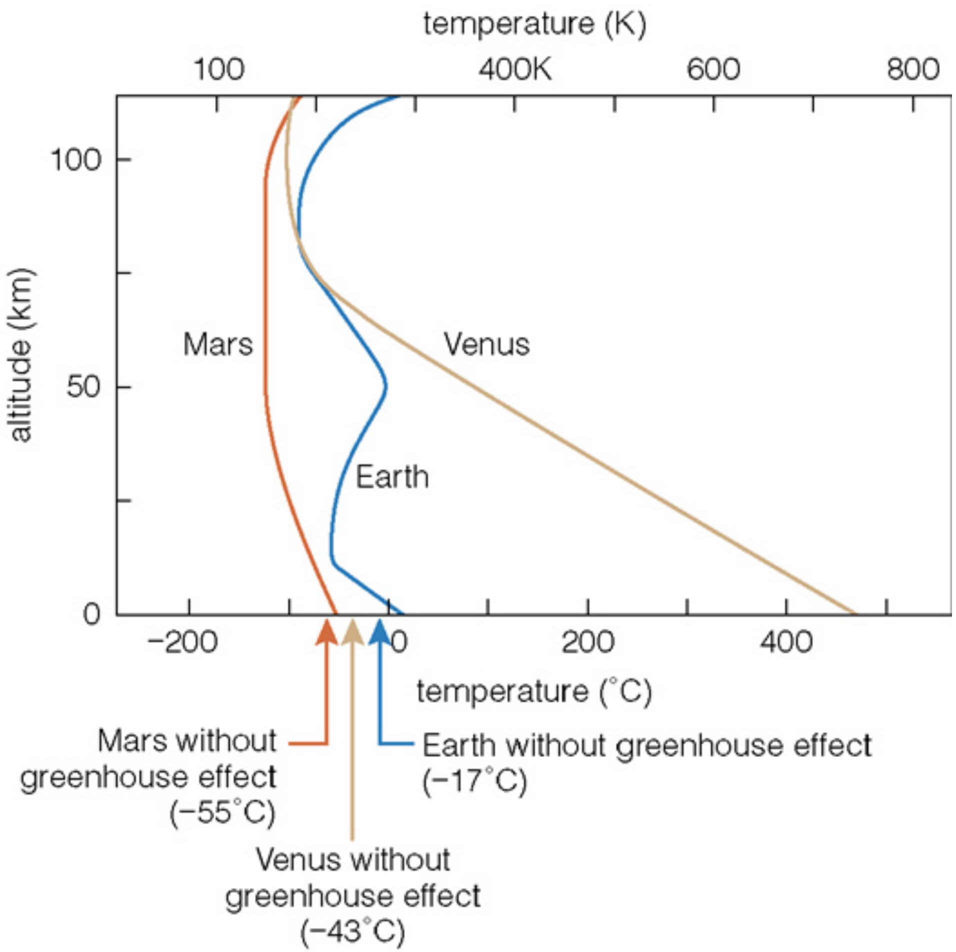




Atmospheric Thermal Structure



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

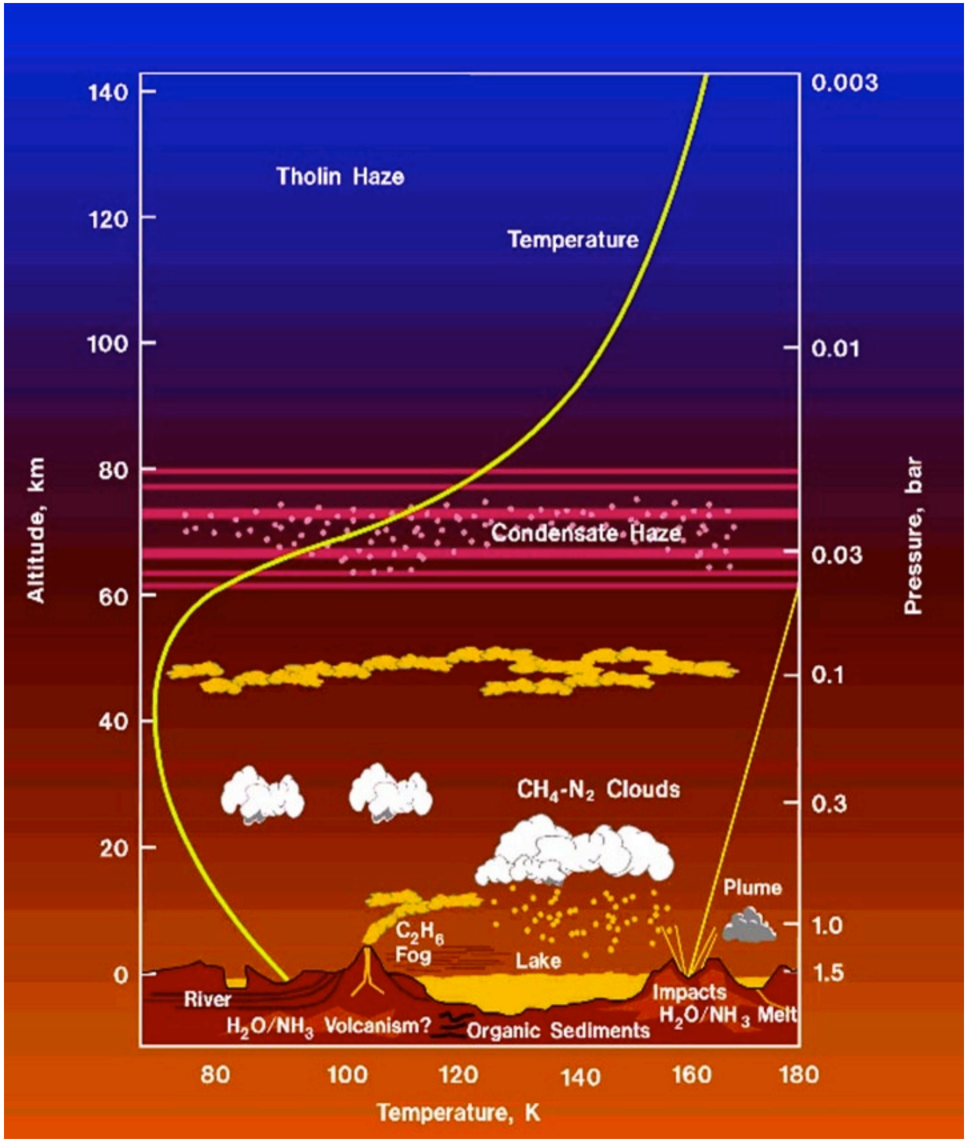
Balance between greenhouse and anti-greenhouse effects:

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

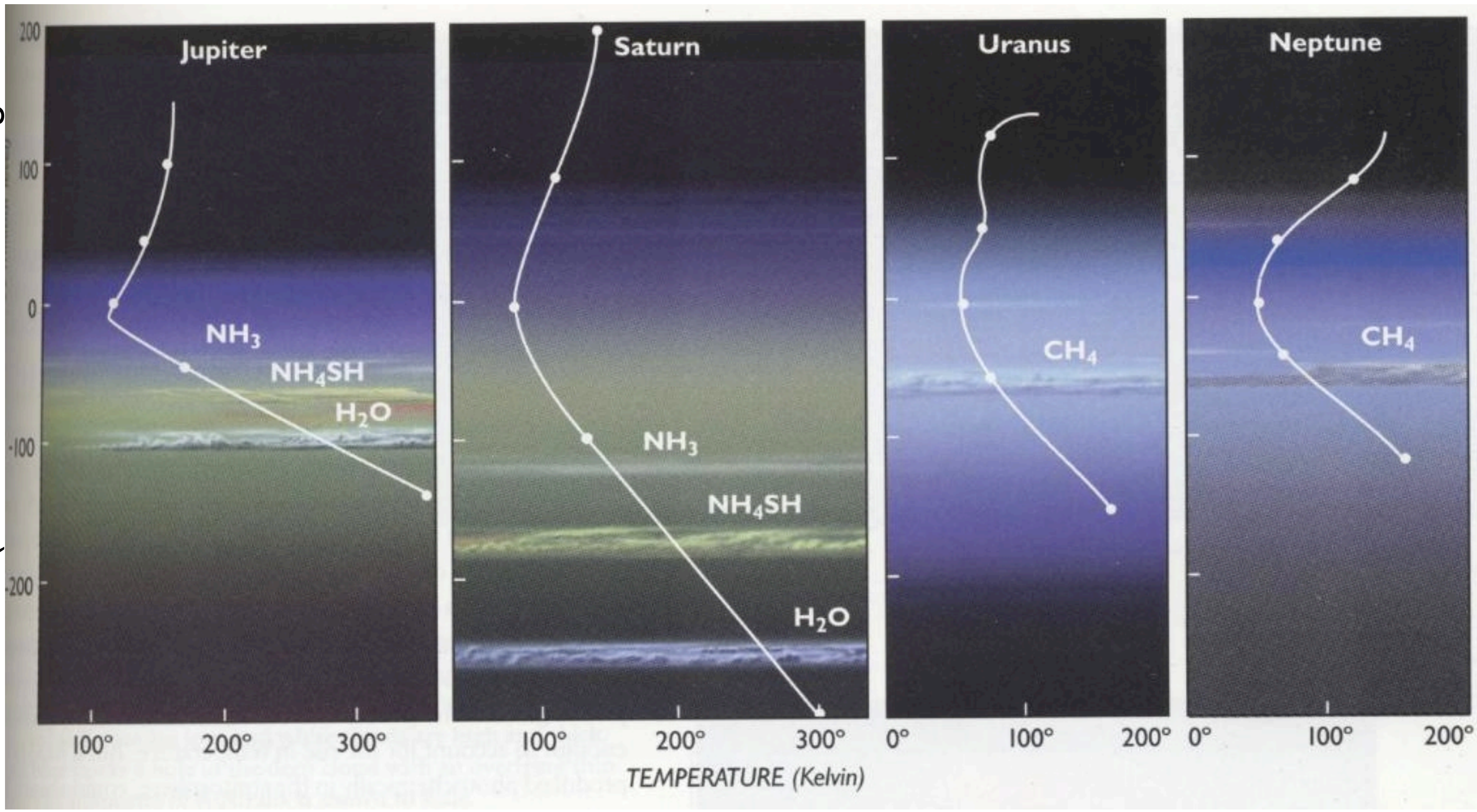
Net ~12 K increase over T_{eq}

Stratopause at ~250 km (trapped organic radiation)



Giant Planet Atmospheric Structure

Altitude (km above 100 mbar height



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

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- Photochemistry
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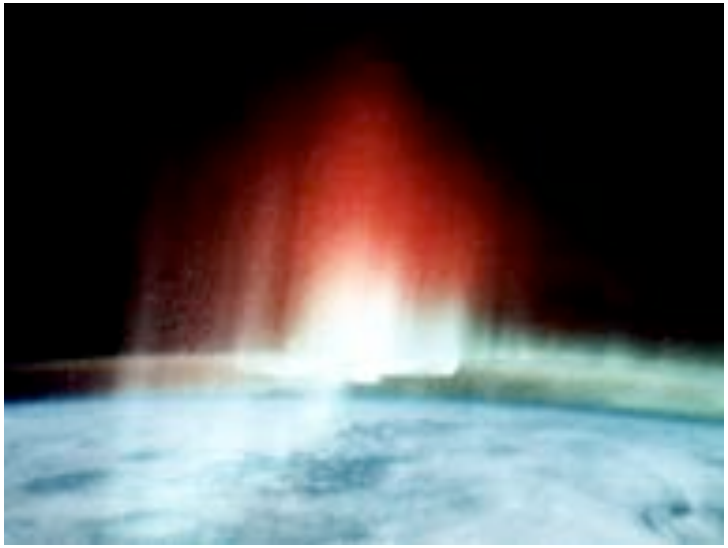
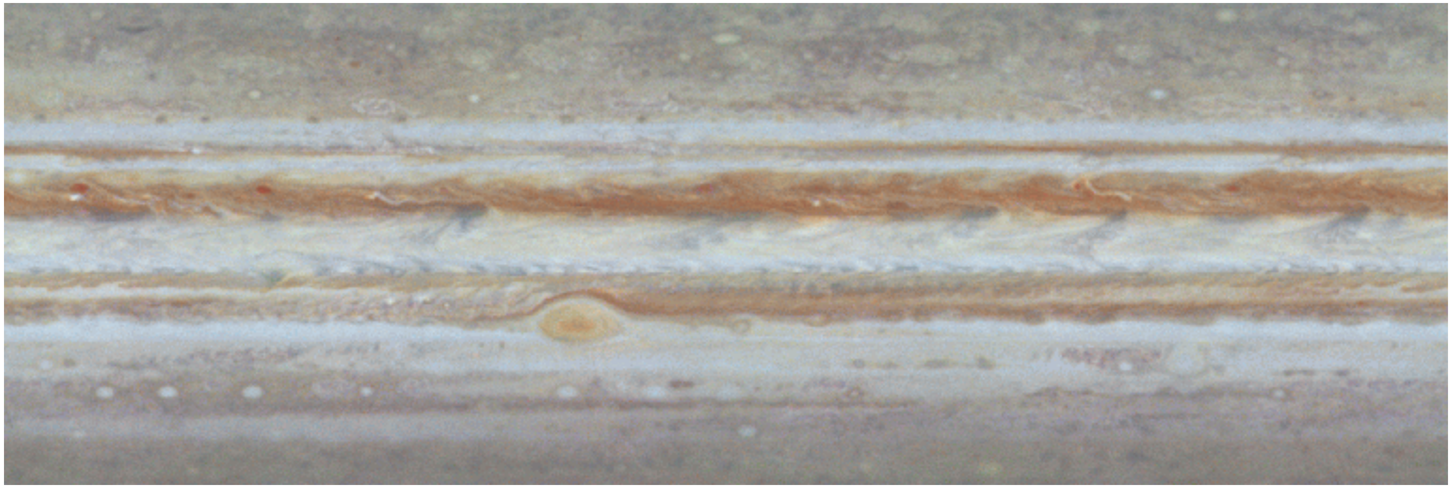
- Atmospheric Escape



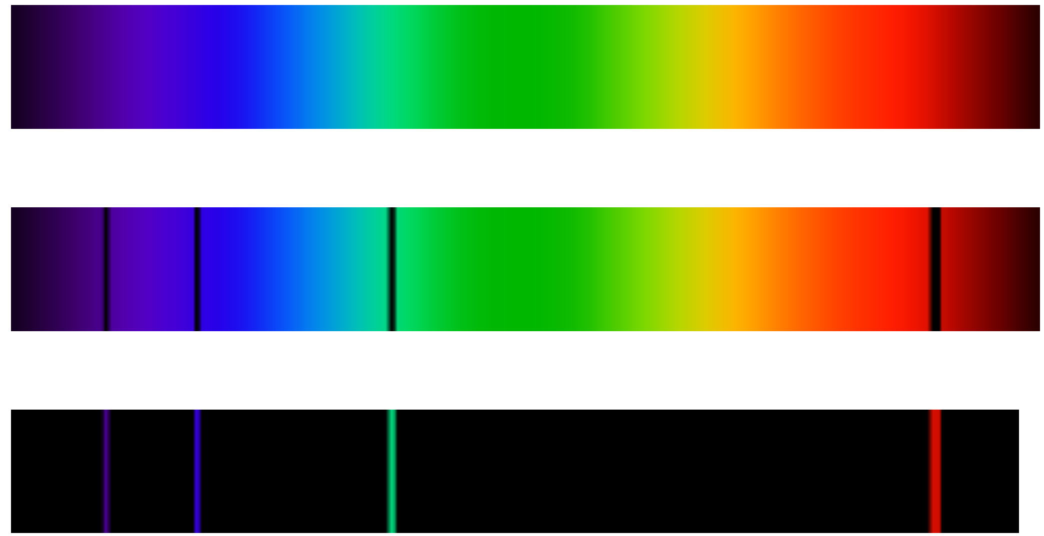


Spectra: Observing the Atmosphere

Continuous Spectrum

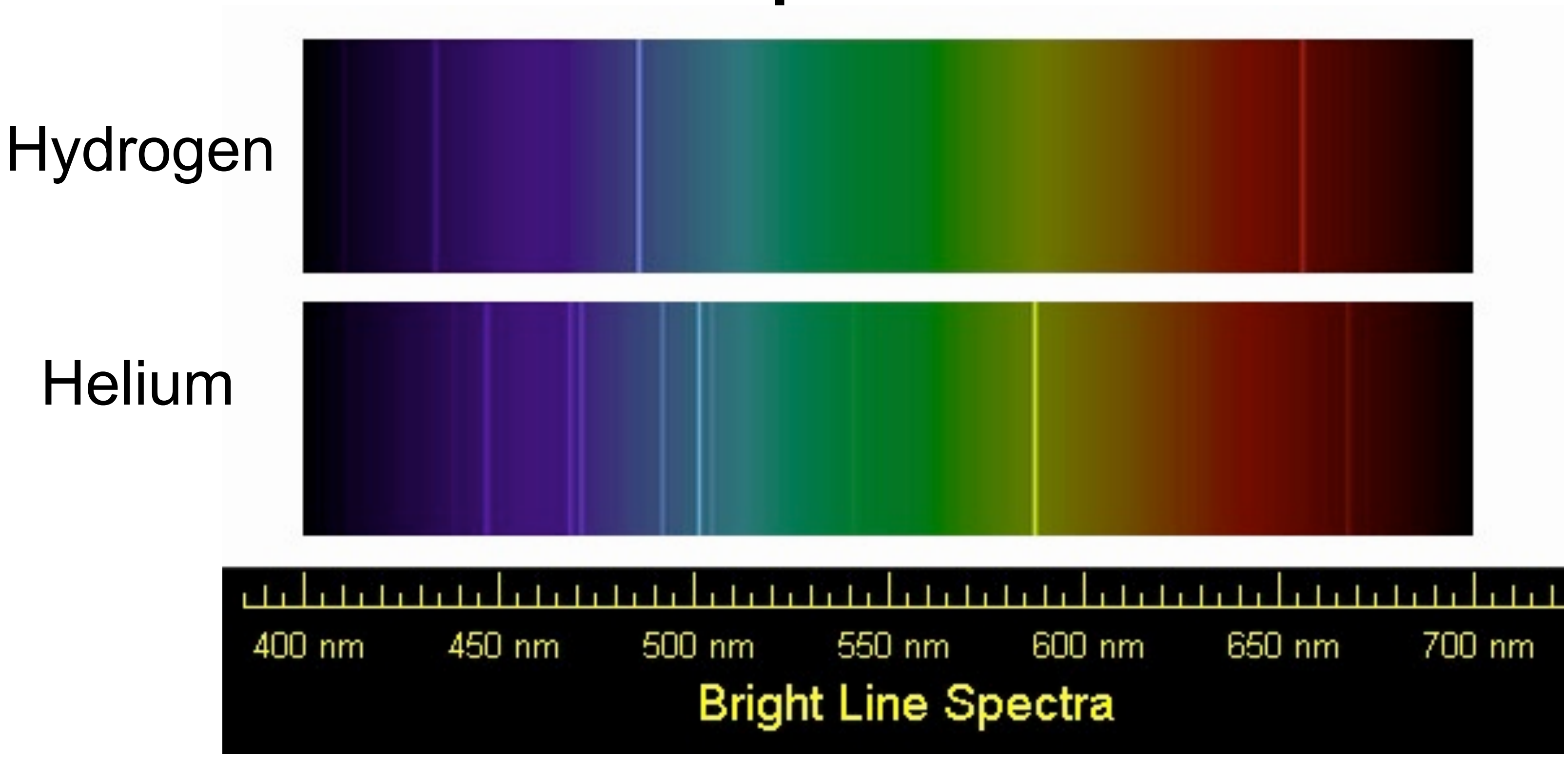
Absorption Spectrum

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.

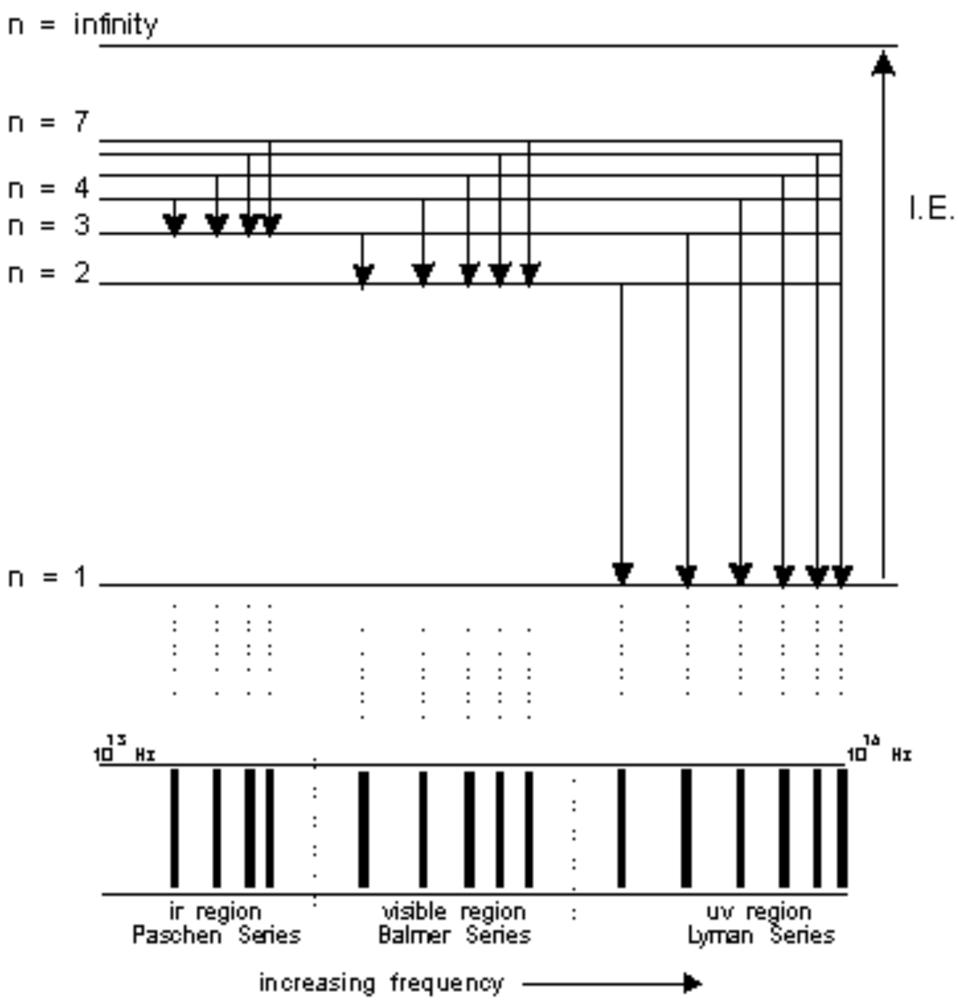
Spectra



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.

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

Spectra: Sources

In observing spectral emission/absorption features in a planetary atmosphere, one must consider the primary sources of the continuum spectra.

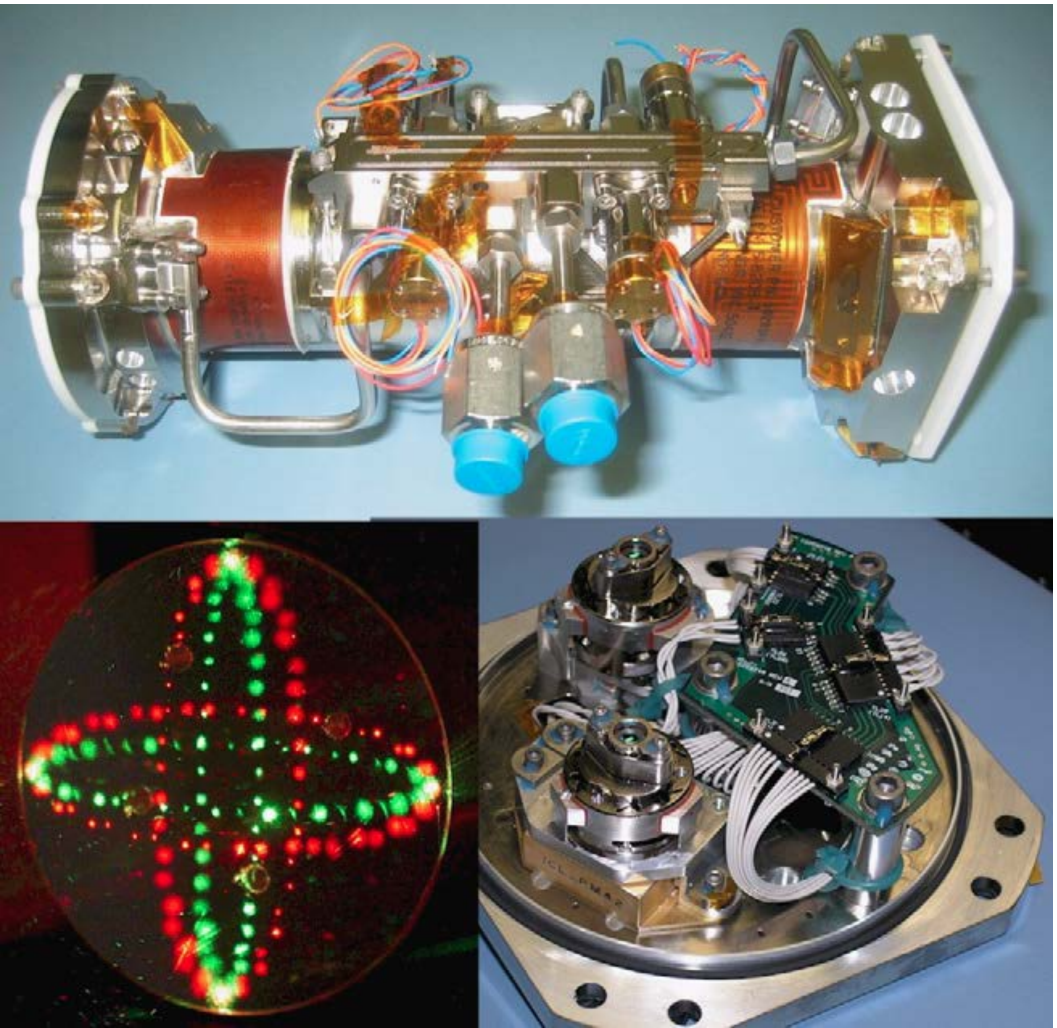
Reflected sunlight:
Generally in the UV, visible and near-infrared wavelengths

Example: Uranus and Neptune appear green/blue due to the presence of methane in their atmospheres. Methane absorbs the red part of the visible spectrum, causing mostly green/blue light to be reflected.

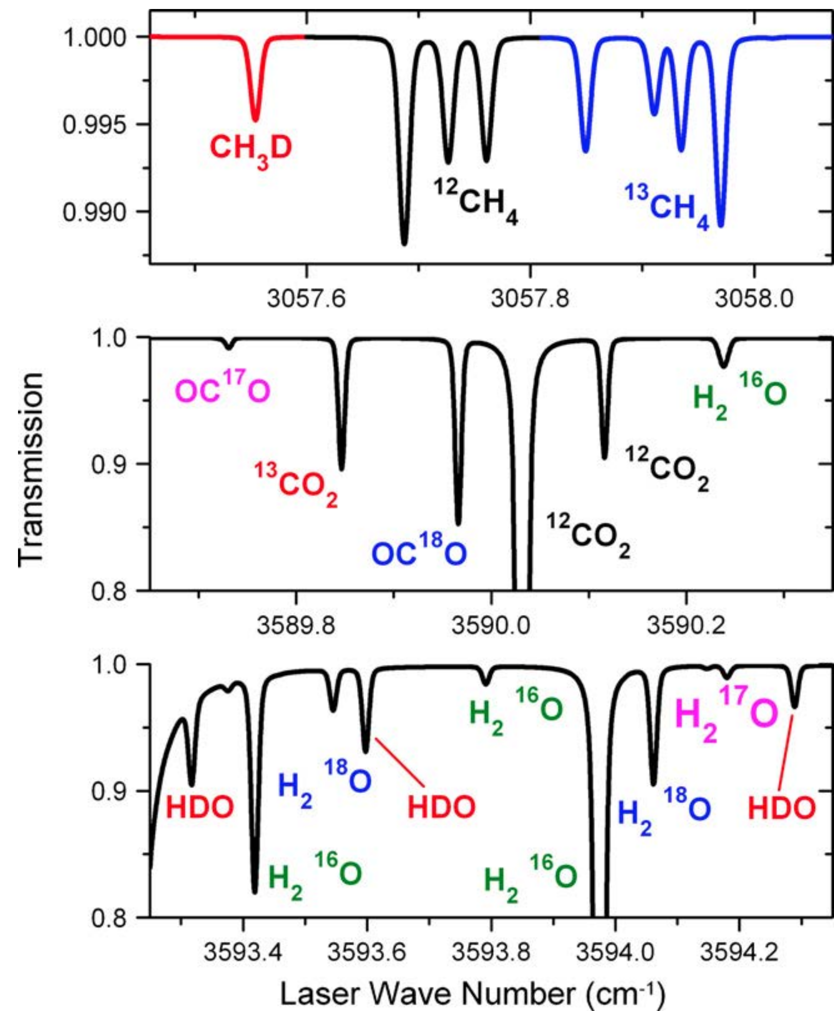
Thermal radiation:
From the ‘surface’ or deeper atmospheric layers of the planet, generally peaks in the infrared and radio wavelengths due to the temperature of the ‘surface’ generating a black body radiation curve.

Ground-based spectra: Fraunhofer + Planetary + Telluric

…or just take your own light source and instrument to the planet!



Webster & Mahaffy (2011)

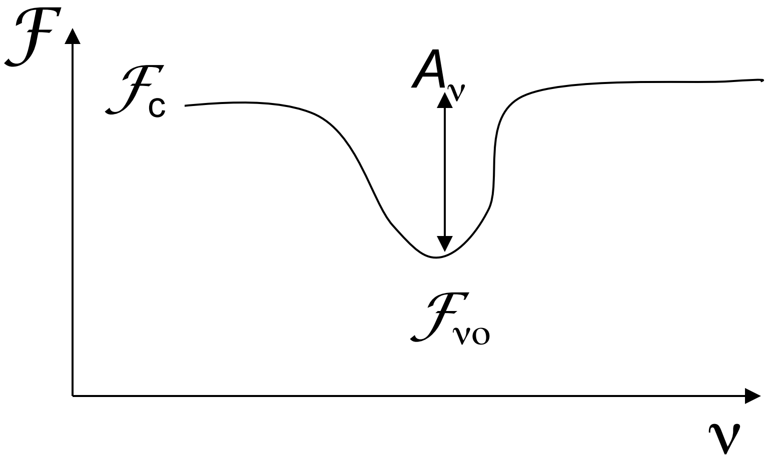


Spectra: Line Profiles

Spectral lines have a finite shape that tells about various properties in the planetary atmosphere we are observing.

Note that the absorption features are often not 'blacked out' lines in the spectrum, but decreases in intensity with a measurable depth and width.

Absorption Depth:



$$A_\nu \equiv \frac{\mathcal{F}_c - \mathcal{F}_{\nu_0}}{\mathcal{F}_c}$$

$$A_\nu = 1 - e^{-\tau_\nu}$$

Spectra: Line Profiles

Absorption Width: Equivalent Width

$$EW = \int_0^\infty A_\nu d\nu = \int_0^\infty \left(1 - e^{-\tau_\nu}\right) d\nu$$

The optical depth at the center of the line is determined by the extinction coefficient and the column density (N_c):

$$\tau_{\nu o} = \int_0^L N\alpha_{\nu o}\, dl = N_c \alpha_{\nu o}$$

Therefore, for $\tau_\nu << 1$:

$$EW \approx \int_0^\infty \tau_\nu\, d\nu = N_c \alpha_{\nu o} \int_0^\infty \Phi_\nu\, d\nu$$

Where the line shape:

$$\Phi_\nu \equiv \frac{\alpha_\nu}{\alpha_{\nu_0}}$$

Spectra: Line Profiles

Equivalent Width

$$EW \approx N_c \alpha_{\nu o} \int_0^\infty \Phi_\nu \, d\nu$$

Increases linearly with N_c while $\tau_\nu << 1$, but as τ_ν increases the line profile saturates, causing the EW to become proportional to $(N_c)^{1/2}$

If this behavior (the “curve of growth”) is understood, then the abundance of a gas can be determined from the observed EW.

Spectra: Line Profiles

What controls the line shape?

Lorentz Line Shape: Shape due to finite lifetime of excited states

Doppler Broadening: Due to relative motion along the line of sight. Can be used to infer atmospheric wind speeds as well as temperature based on the Maxwellian distribution function.

Pressure/Collisional Broadening: Due to collisions between molecules slightly perturbing the energy levels of electron states (I.e. photons with λ_{ul} +/- $\delta\lambda$ can cause excitation/de-excitation)

* Remember that τ_ν will determine what altitude you are 'probing' for a given wavelength (or frequency).

Compositions of Terrestrial Atmospheres

	Earth	Venus	Mars	Titan
Pressure	1 bar	92 bar	0.006 bar	1.5 bar
N_2	77%	3.5%	2.7%	98.4%
O_2	21%	-	-	-
H_2O	1%	0.01%	0.006%	-
Ar	0.93%	0.007%	1.6%	0.004%
CO_2	0.035%	96%	95%	~1ppb
CH_4	1.7ppm	-	?	1.6%
^{40}Ar	6.6×10^{16} kg	1.4×10^{16} kg	4.5×10^{14} kg	3.5×10^{14} kg
H/D	3000	63	1100	3600
$^{14}N/^{15}N$	272	273	170	183

Isotopes are useful for inferring outgassing and atmos. loss