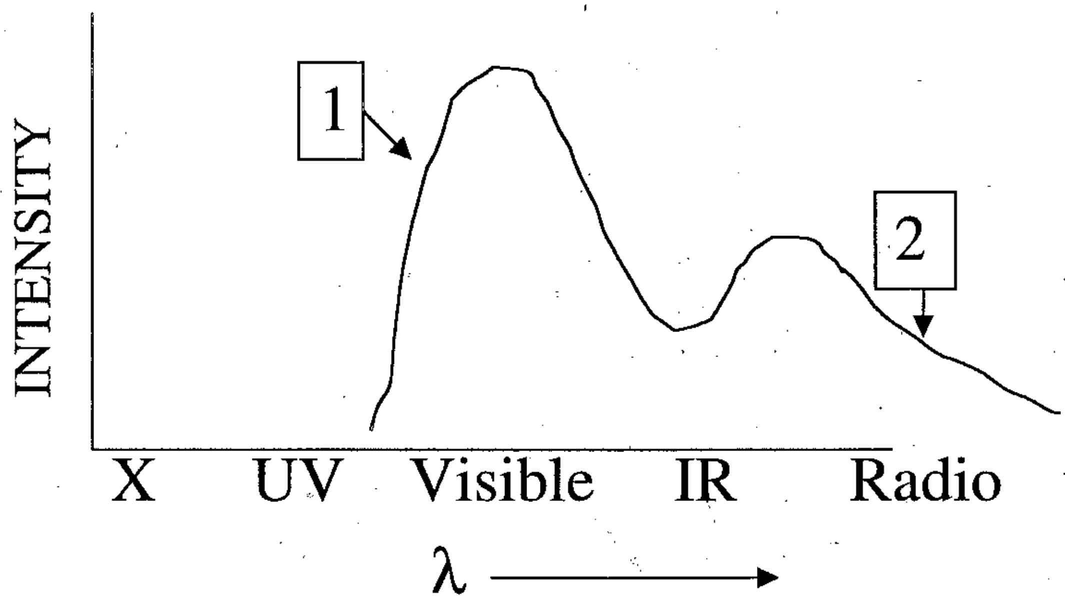
BB LAWS AND PLANETS

- Planets are not fair approximation to BB:
  ——— Lots of sunlight reflected
- Spectrum

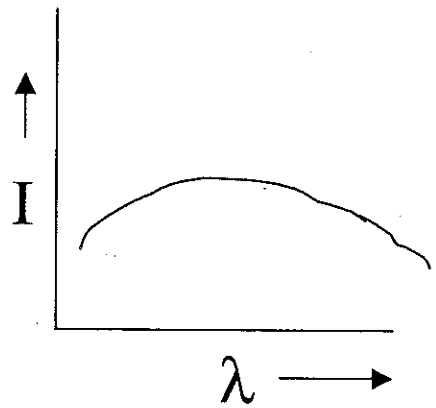


- Component 1 is reflected sunlight
- Component 2 is em radiation emitted by a planet's surface/atmosphere and may approximate a BB spectrum

WHY IS THE TEMPERATURE OF 1 ABOUT 6000K?

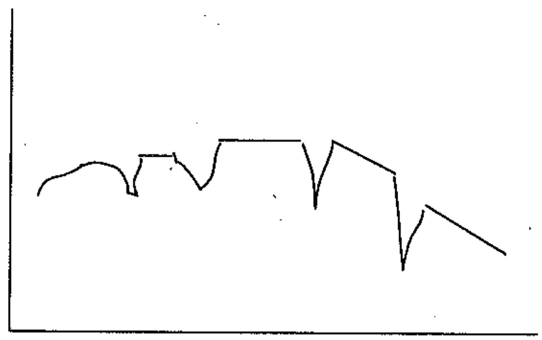
WHY IS THE TEMPERATURE OF 2 ONLY A FEW HUNDRE DEGREES KELVIN?

TYPES OF SPECTRA



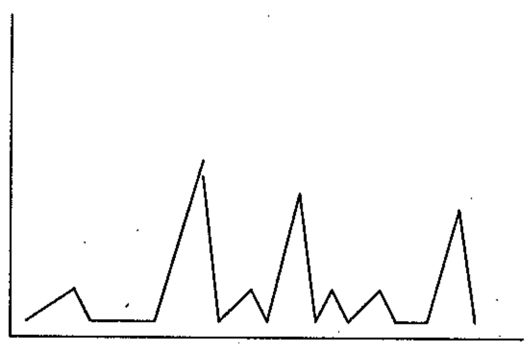
CONTINUOUS

Black body, star



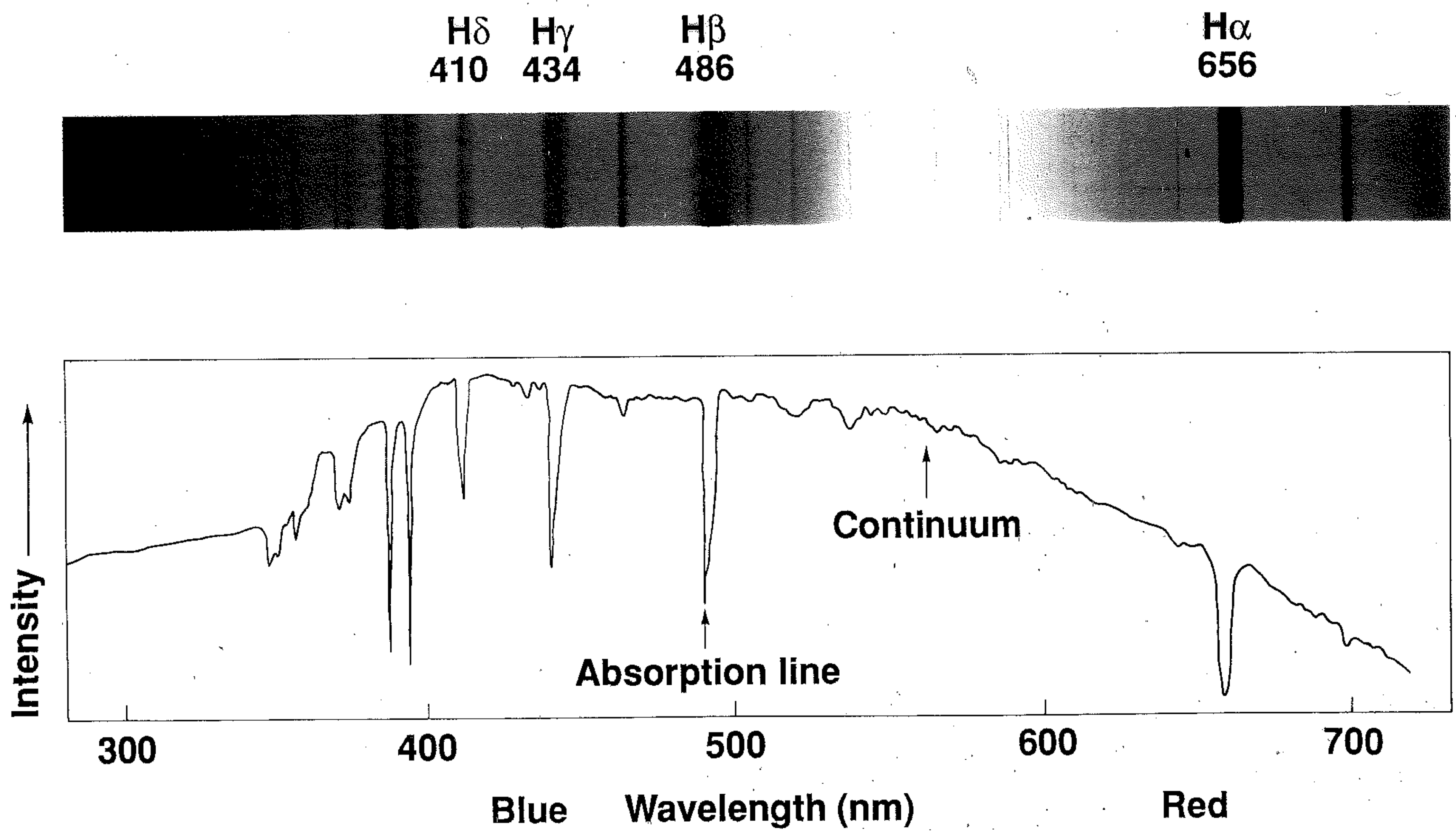
ABSORPTION-LINE

Stars



EMISSION LINES

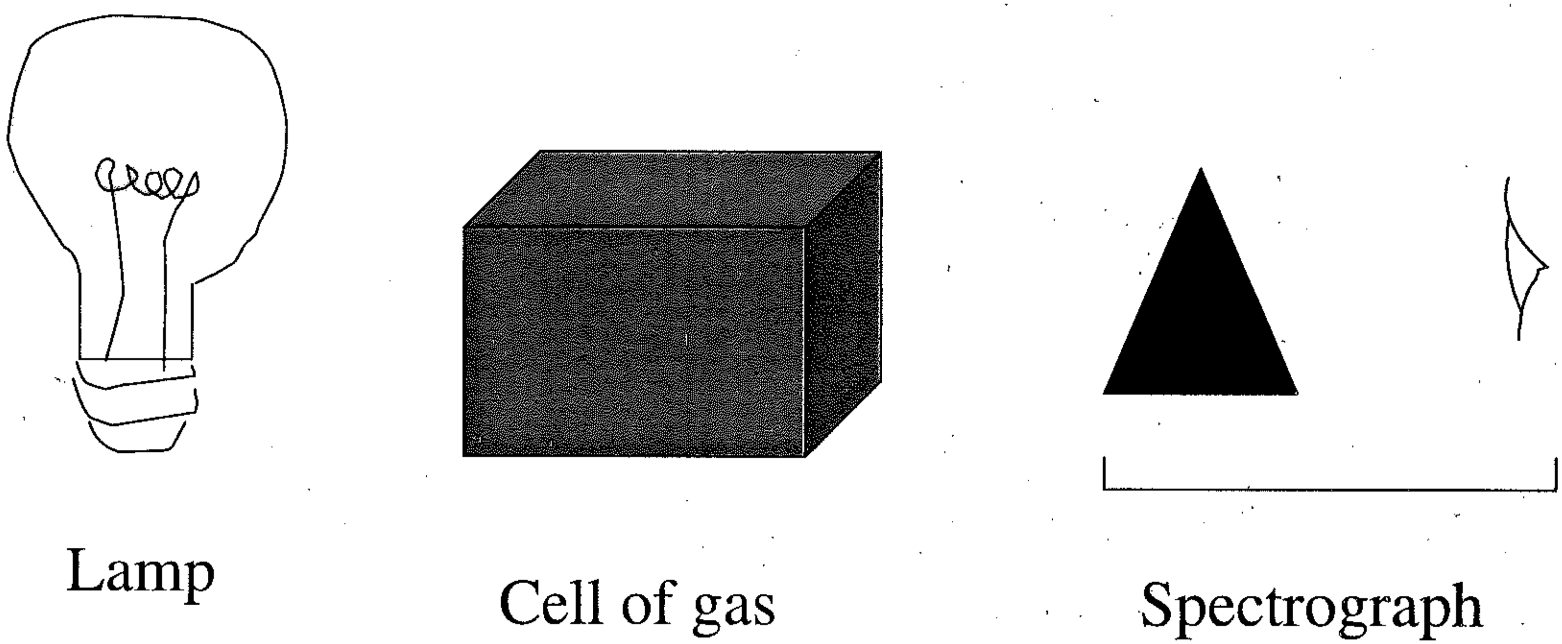
Hot gas



Visual portion of stellar spectrogram

Hartmann/Impey: The Cosmic Journey, 5th ed., Fig. 16–6; Hartmann: The Cosmic Voyage, 1992 ed., Fig. 16–3

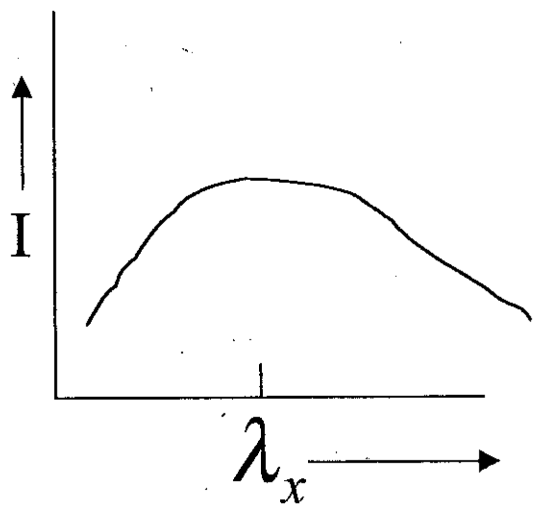
Formation of absorption lines by a stellar atmosphere



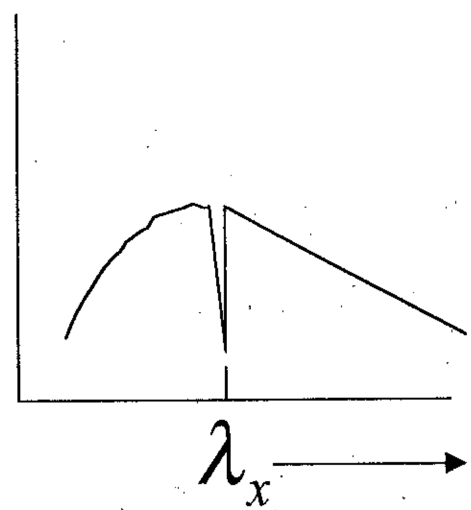
- Lamp observed without gas cell gives a continuous spectrum (approx. a blackbody spectrum)
- When gas cell is put in the light path, an absorption spectrum is obtained

•Photons of wavelength greater and smaller than λ_x pass through the cell without being scattered. WHY?

SPECTRUM (no cell)



SPECTRUM (gas cell)



WHY?

- Suppose atoms in gas cell absorb photons at wavelength λ_x because such photons cause an electron in orbit around the atom's nucleus to jump from an inner Bohr orbit to an outer orbit

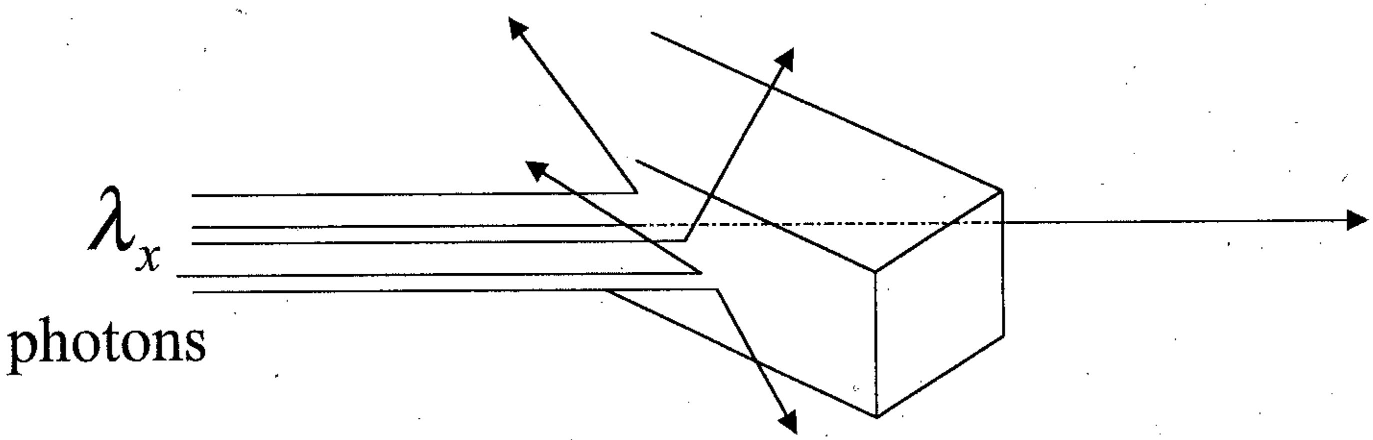
$$E_x = \frac{hc}{\lambda x} = E_{outer} - E_{inner}$$

$$= hf$$

$\lambda f = c$

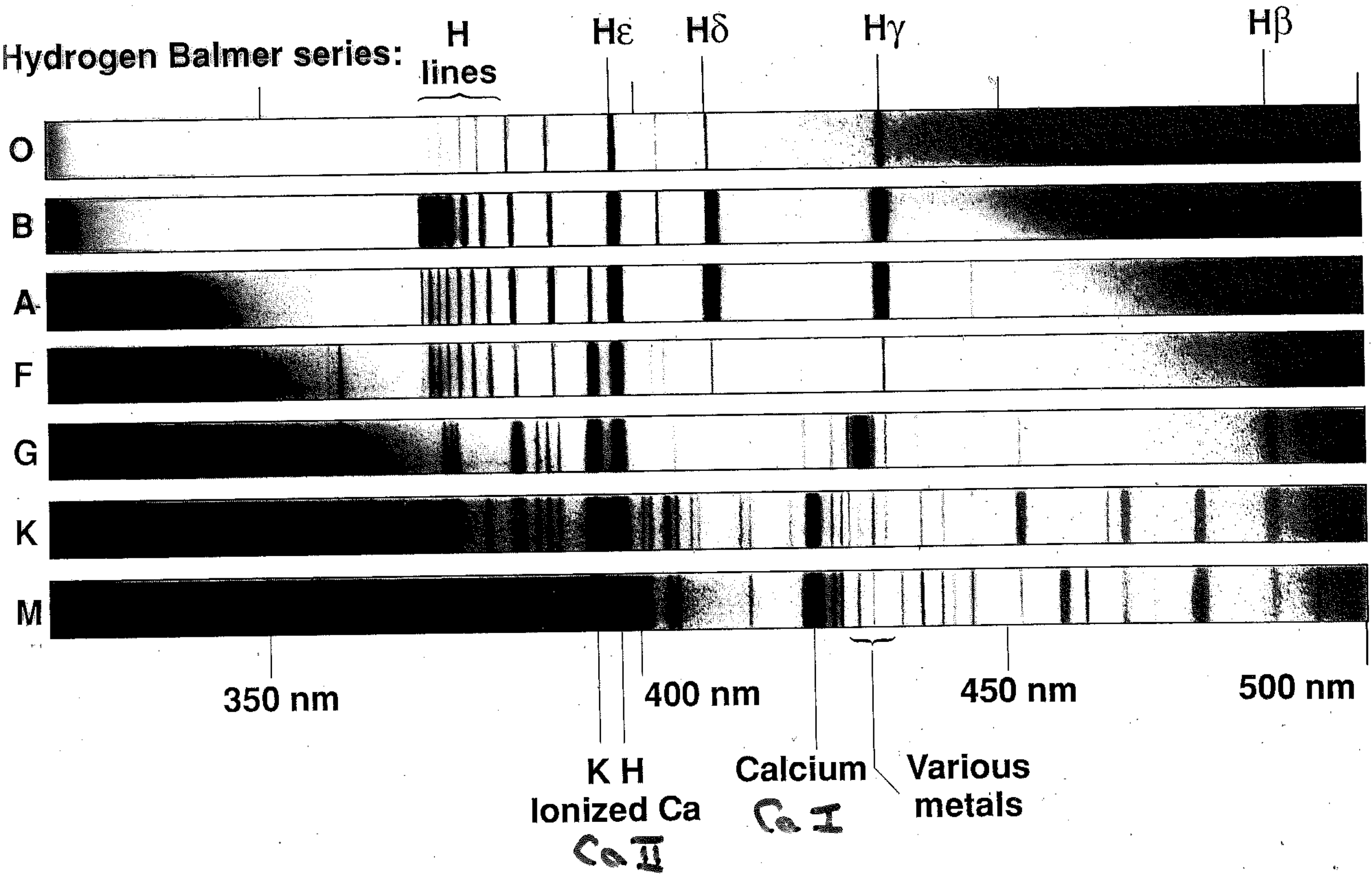
- Often, the electron in the outer orbit will quickly lose energy and emit a photon of wavelength λ_x

  But this photon will be emitted in a random direction, i.e., scattered out of the beam.
- Net result is a loss of photons of wavelength λ_x from the light passing through the cell



- Stars are spheres of hot gas, often primarily composed of hydrogen and helium
- Light from the interior of a star does not escape directly; interior not visible from the outside. (Hot fog).
- Starlight comes from a thin outer skin or atmosphere.
  - Sun of radius about 500,000 km has an atmosphere about 200 km thick

- Betelgeuse (red supergiant) has an atmosphere that is 500,000 km thick but the radius of this star is about 200 x the Sun's radius.
- Atmosphere is not a layer sharply bounded top and bottom. It may extend outwards to great distances as a wind blown off a star.



Spectra of stars

Hartmann/Impey: The Cosmic Journey, 5th ed., Fig. 16–7; Hartmann: The Cosmic Voyage, 1992 ed., Fig. 16–4

What's behind spectral classification?

- Two principal factors
  - atmospheric temperatures
  - atmospheric pressures

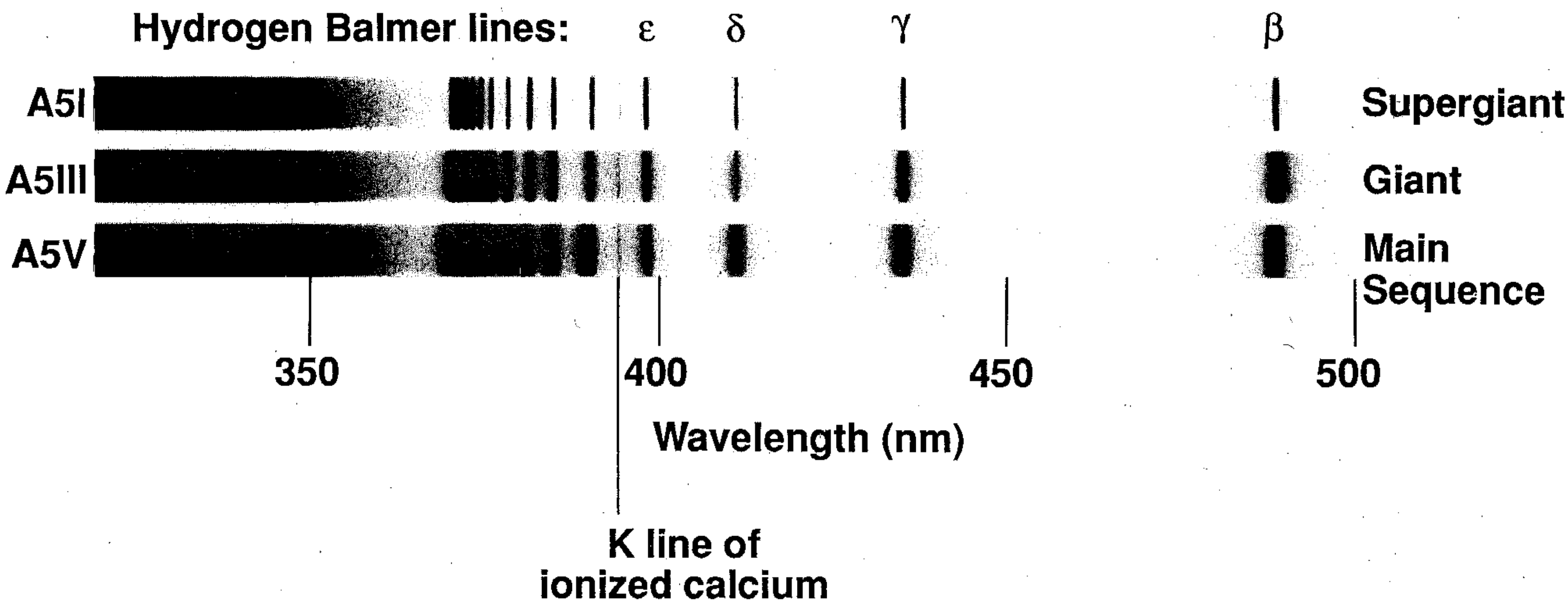
    or; equivalently, the surface gravity
- CHEMICAL COMPOSITION

Spectral Classes

Spectral Class	Approx. Temp. (K)	Hydrogen Balmer Lines	Other Special Features
O	40,000	Weak	Ionized helium
B	20,000	Medium	Neutral helium
A	10,000	Strong	Ionized calcium weak
F	7,500	Medium	Ionized calcium weak
G	5,500	Weak	Ionized calcium medium
K	4,500	Very weak	Ionized calcium strong
M	3,000	Very weak	TiO strong

Luminosity Classes

V	Main Sequence	[Dwarfs]
IV	Subgiants	
III	Giants	
II		
I	Supergiants	



Spectra of giant, supergiant, main-sequence stars

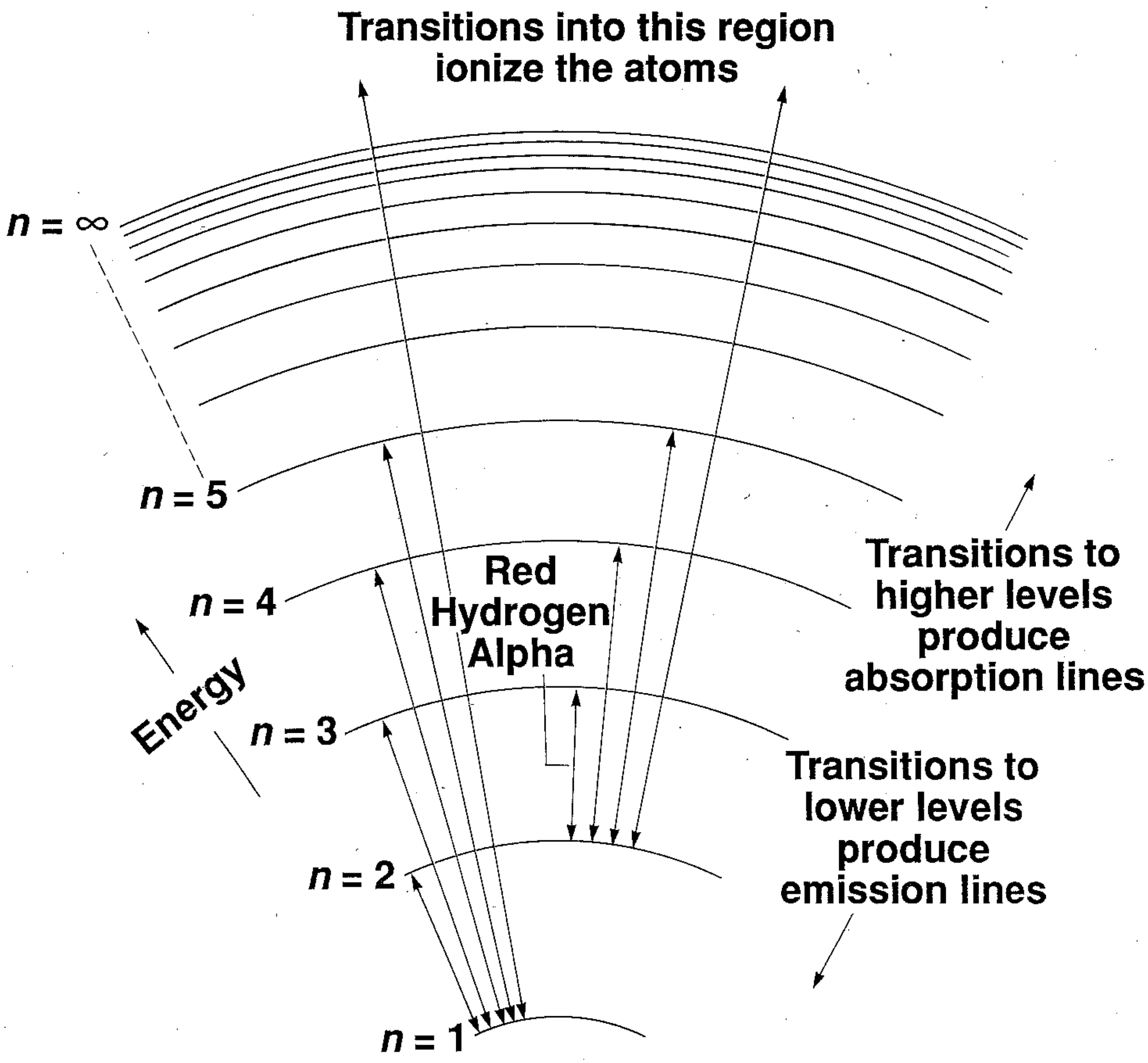
Hartmann/Impey: The Cosmic Journey, 5th ed., Fig. 16–13; Hartmann: The Cosmic Voyage, 1992 ed. Fig. 16–8

Important Results

- Presence of an absorption line due to species X, shows that element X is present in stellar atmosphere.
- To determine the concentration of X, temperature and other properties of the atmosphere must be known.
- Absence of lines due to an element does NOT always mean that the element is not present in the atmosphere.

Hydrogen Atom

- **1 electron around a proton**
- **Orbits labelled by a QUANTUM NUMBER, n**
- **Radius of orbit** $R = \frac{n^2}{2}$ in Å
- **Energy of orbit** $E \propto -\frac{1}{n^2}$


Transitions into this region
ionize the atoms
n = ∞
n = 5
n = 4
n = 3
n = 2
n = 1
Energy
Red
Hydrogen
Alpha
Transitions to
higher levels
produce
absorption lines
Transitions to
lower levels
produce
emission lines

Hydrogen Balmer Lines

- Recall Balmer absorption lines involve electron jumps from $n=2$ to $n \geq 3$ [not $n=1$]
- Electron must be in $n=2$ to absorb a Balmer photon
- But electron in $n=2$ is <u>very</u> likely to jump $n=2 \longrightarrow n=1$ in a flash of a second

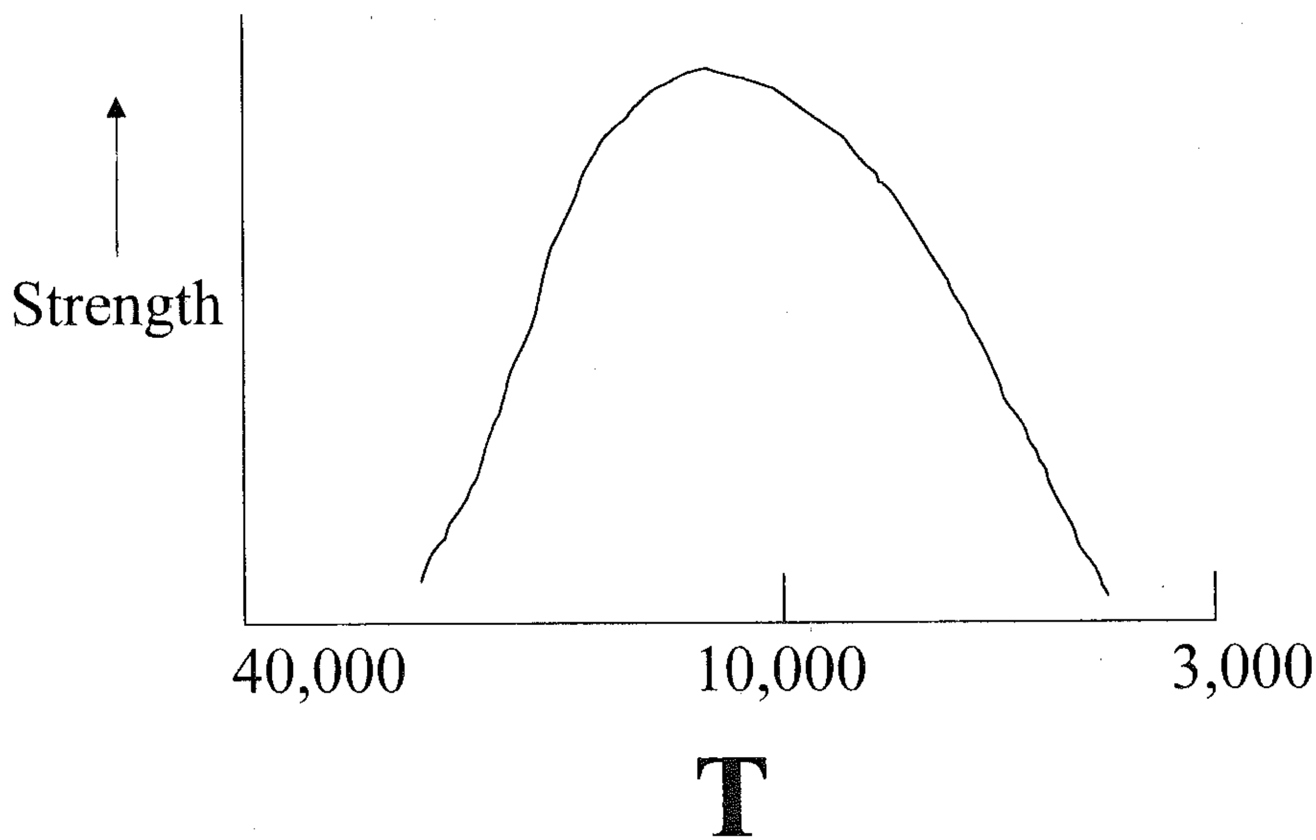
- Electrons in $n=1$ have to be forced back to $n=2$ by energetic photons or particles.
- Since the $1 \rightarrow 2$ jumps occur at a much lower rate than the spontaneous $2 \rightarrow 1$ jumps, the number of H atoms with an electron in $n=2$. is much less than $n=1$.
- The proportion in $n=2$ increases with increasing temperature.
- [WHY?]

$T =$	3000K	6000K	10,000K
$\frac{N(n=2)}{N(n=1)}$	10^{-17}	10^{-9}	10^{-5}

- It is the number in n=2 that controls the strength of a Balmer line

  Strength increases from 3000K to 10,000K
- At temperatures of 10,000K and higher, the increasing numbers of energetic photons and particles remove H's electron (H is ionized) and reduces the number of H atoms

- Then, Balmer line strengths decrease for T ≥ 10,000K



Calcium

- Neutral Ca atoms easily ionized
- Ca^{+} ions fairly easily ionized
- Absorption lines from "first" Bohr orbit of Ca and Ca^{+} fall in visible spectrum.
- Lines of Ca^{++} not present in visible spectrum.

- COOL Stars

  Ca atoms more abundant than Ca^{+} ions

- WARM Stars

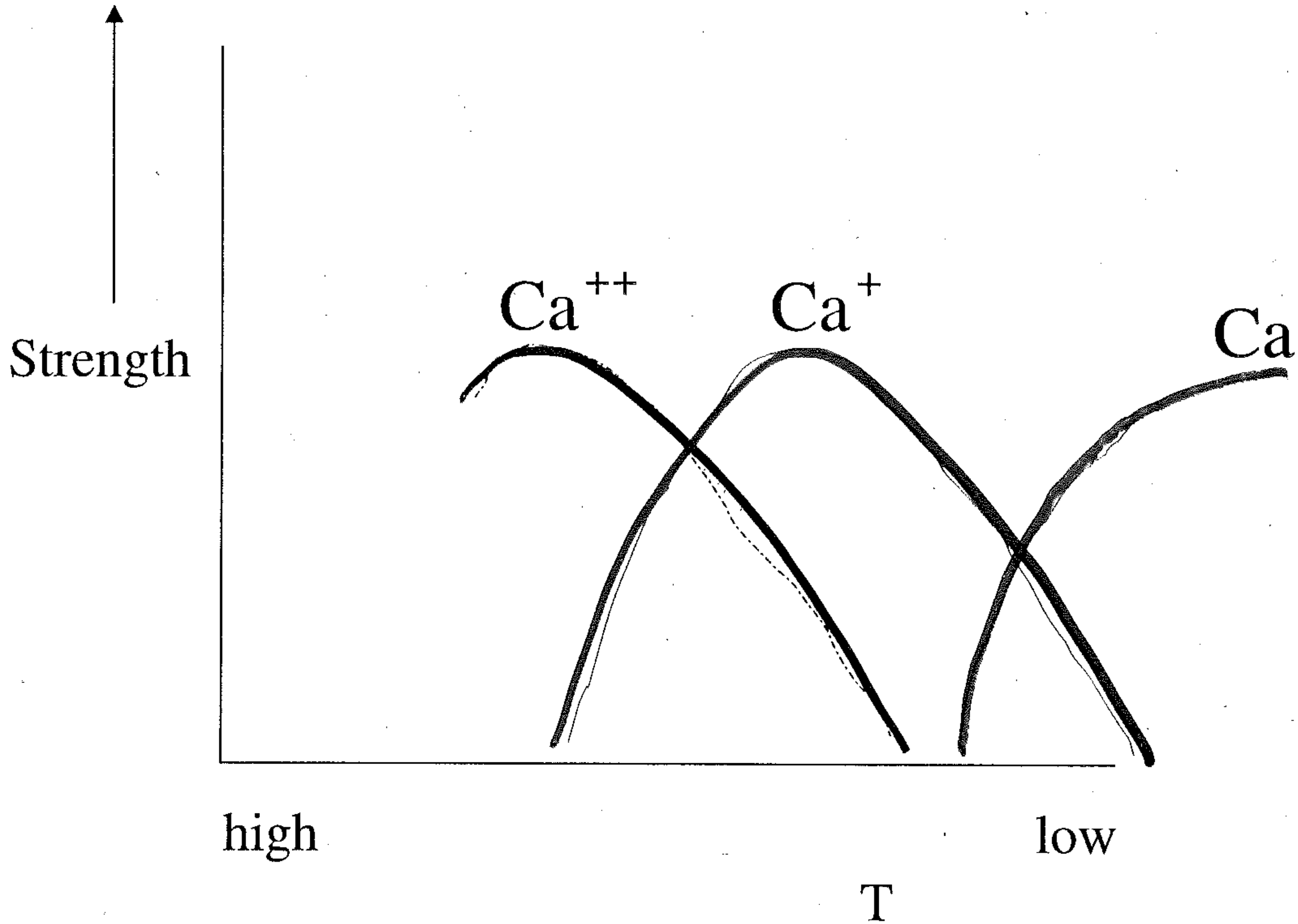
  Ca atoms and Ca^{+} ions are roughly equally abundant

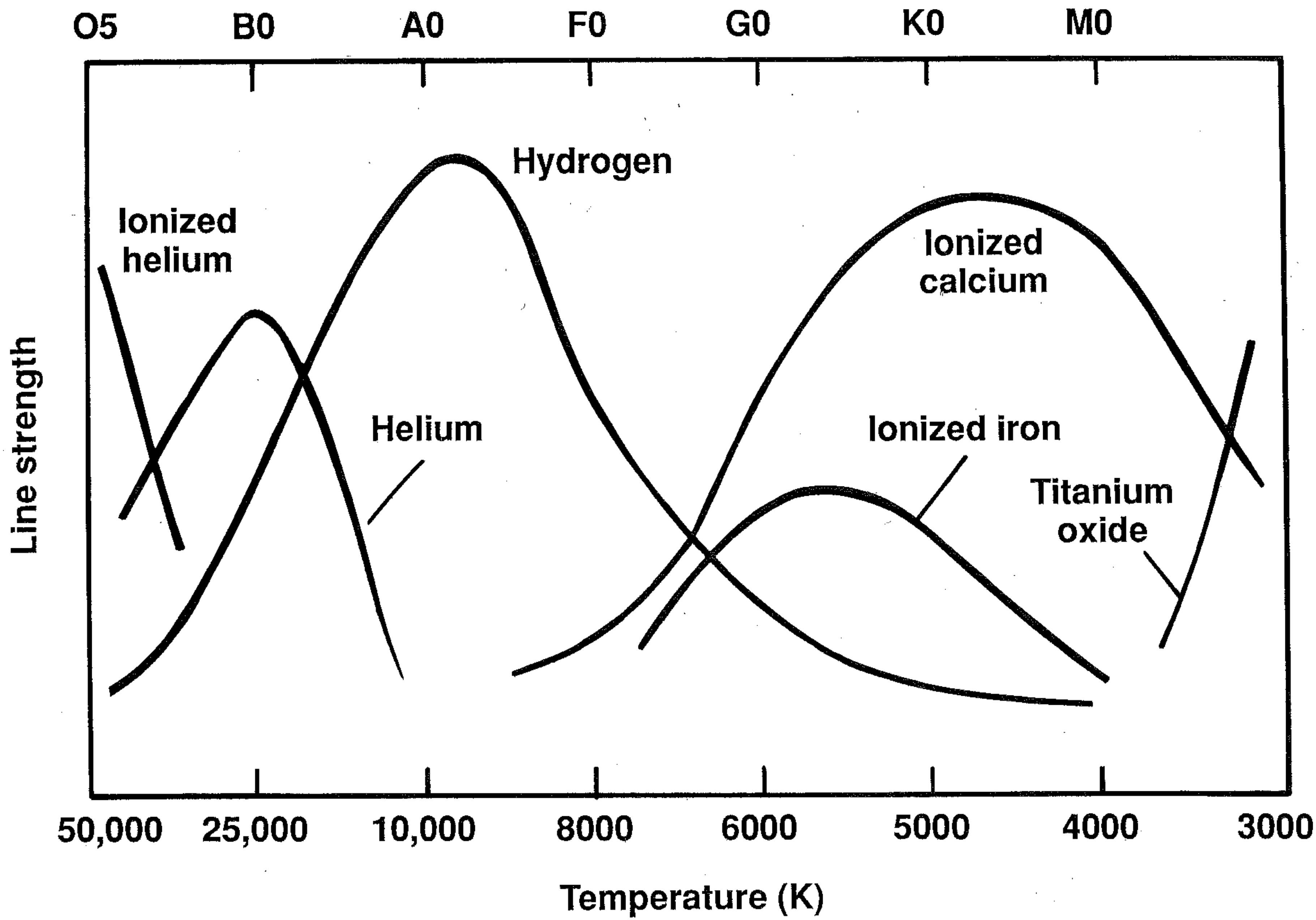
- VERY WARM Stars

  Ca^{+} ions abundant with some Ca^{++} ions and a few Ca atoms

- HOT Stars

  Ca^{++} ions most abundant


Strength
Ca++
Ca+
Ca
high
low
T



Strengths of spectral lines in stars of various temperatures

Seeds: Horizons, 1995 ed., Fig. 6–17; Foundations of Astronomy, 1994 ed., Fig. 7–16

Molecules

- Examples: TiO, CH, CO, H_2O
- Molecules are fragile and rather easily broken up by energetic photons and particles

  ★ Molecules reside only in cool stellar atmospheres.
- Strength of molecule's absorption lines DECREASES with INCREASING temperature, e.g.

  TiO strong in M stars, weak in K stars, and undetectable in G and hotter stars.