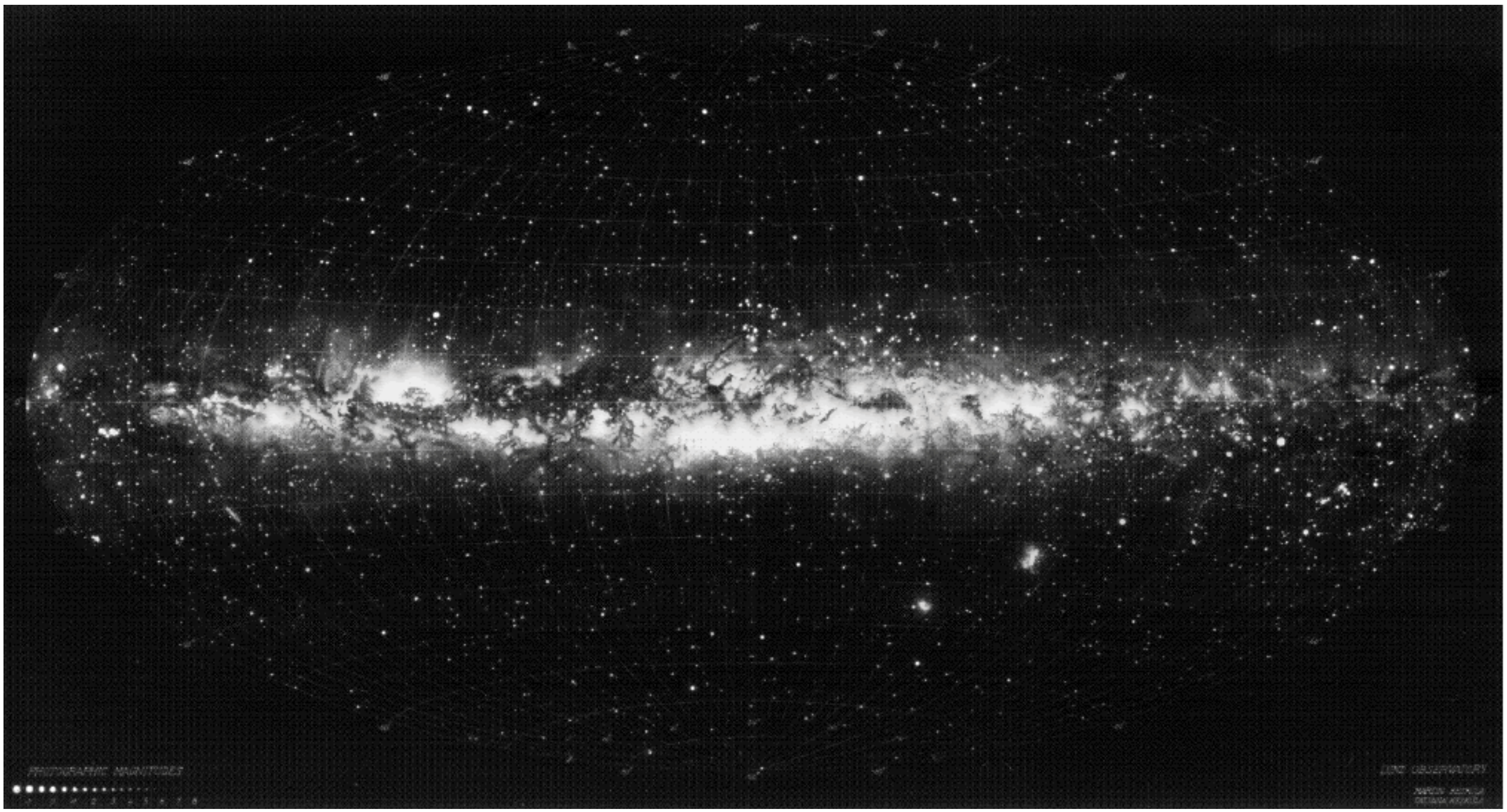
**Q**

There is a situation ~~etc~~ (several in fact) where measuring the color of a star will give us an erroneous value for its temperature, making it seem cooler than it really is.
What might cause this?

**A**

Reddening due to dust along the line of sight to the star, whether in the atmosphere, between the Earth & the star, or surrounding the star.

# Lund observatory panorama of Milky Way



Dust comes in all ~~sorts of~~ both dense clouds (easy to see in Milky Way) but also in smoother, more diffuse form.

It both absorbs light, so we need to say

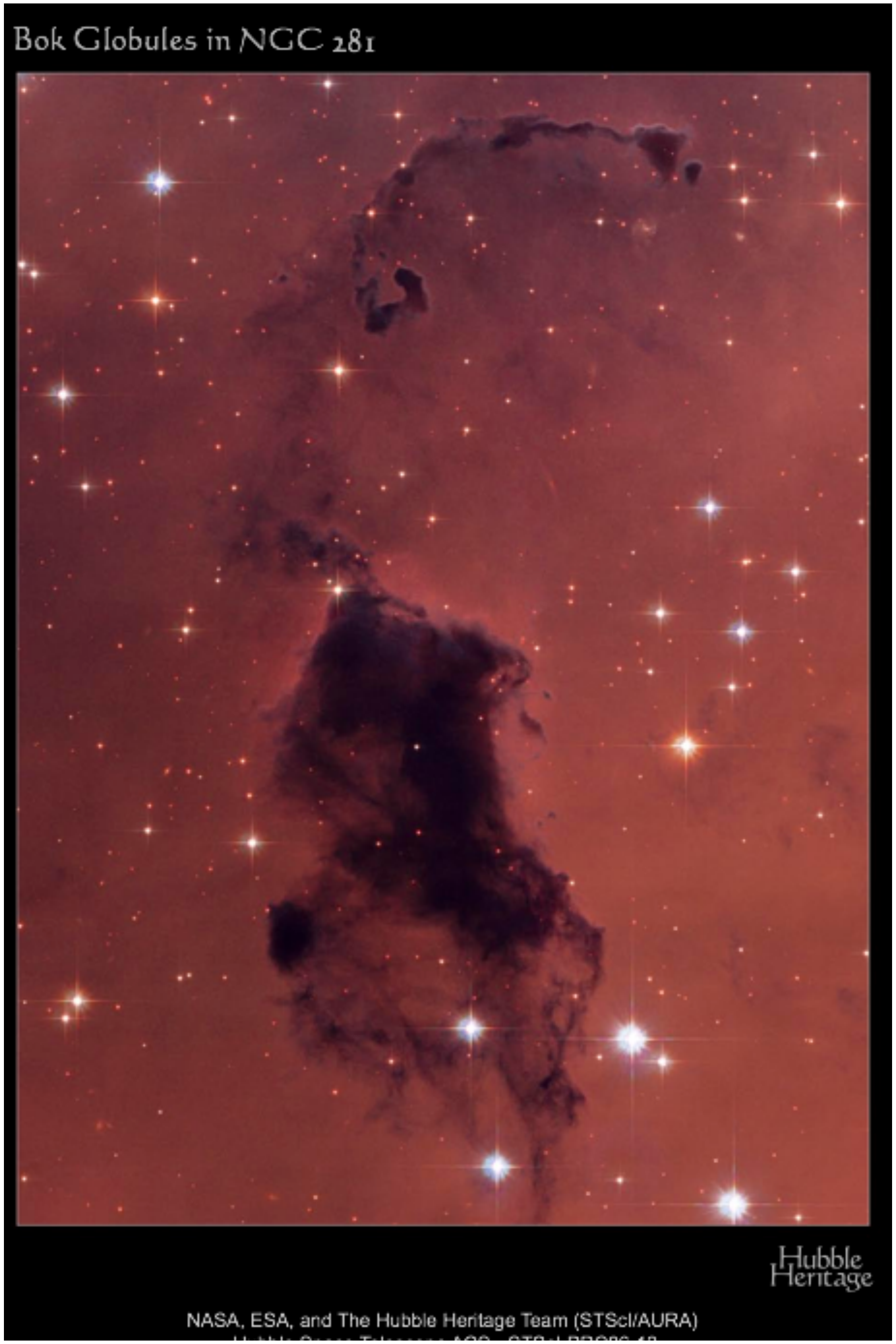
$$m - M = 5\log d - 5 + A$$

↑ extinction due to dust

And also scatters light.

~~[illegible]~~, Shorter wavelengths are scattered more than longer ones, altho' exact relation between $\lambda$ & scattering depends on size of dust particles

(cf Rayleigh scattering in atmosphere $\propto \lambda^{-4}$)




- Bok globules are small, very dense globules of gas in star forming regions

Hubble Space telescope; NASA

We see the scattered light directly in blue reflection nebulae

We describle the reddening caused by dust by the change in color it produces

eg $E(B-V) = B-V - (B-V)_0$

($B-V$ ↑ observed; $(B-V)_0$ ↑ intrinsic)

(or $E(V-I)$, $E(U-B)$, etc)

We can measure the relation between $A_V$ and $E(B-V)$:

$$A_V = 3.2\,E(B-V)$$

($A_V$: extinction; $E(B-V)$: reddening)

Q

What can we learn from spectra that we can't get just as easily from colors & brightnesses of stars?

# Classifying stars by spectra

Around 1900, large efforts made to classify stars by their spectra

(Taxonomy only)

Stars classified as type A, B, C, .... etc

Some classes were more common than others and are still in use today

It was found that stars of a given spectral type had similar colours:

O and B stars very blue

⋮

G stars (like Sun) yellow

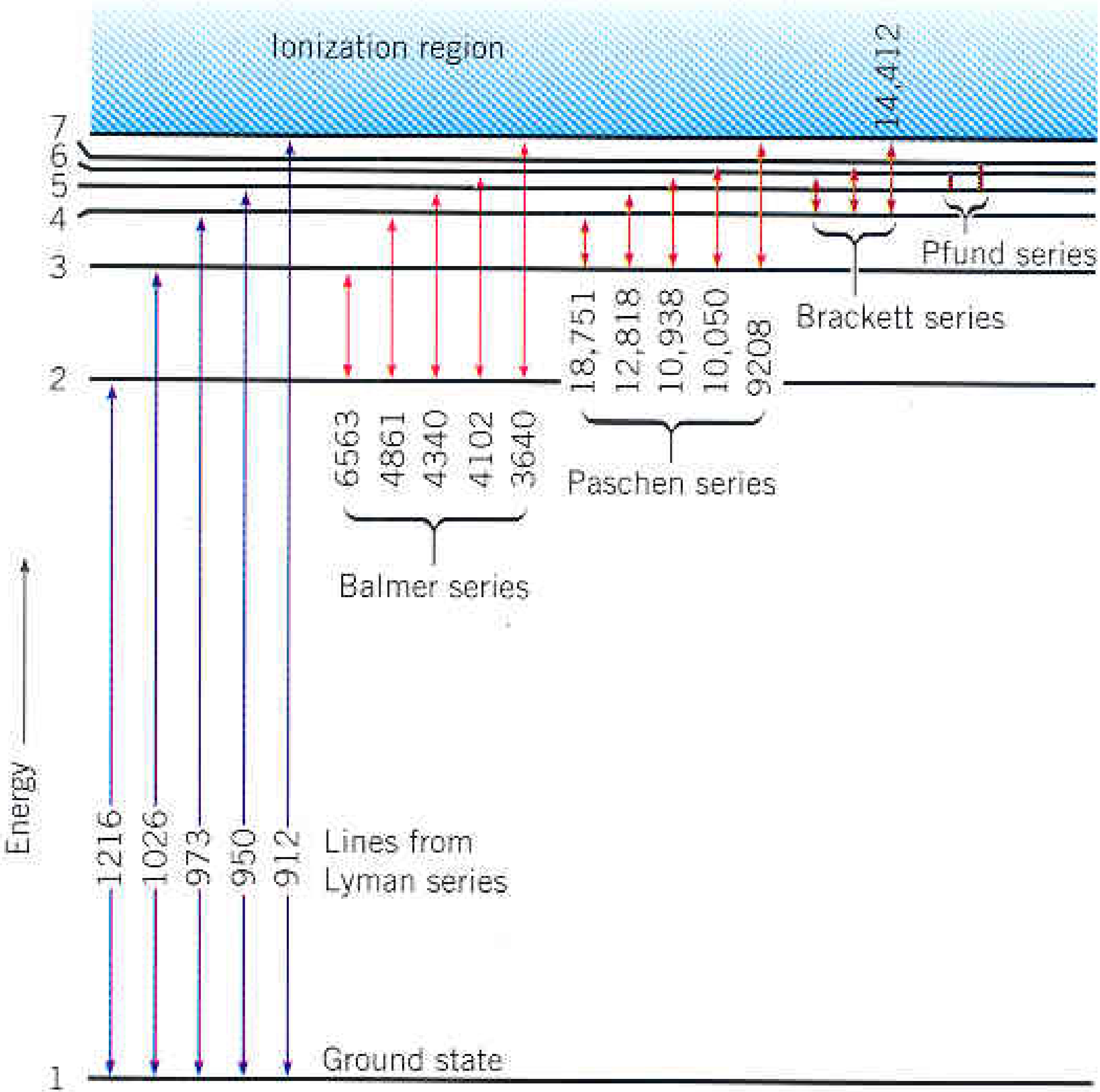
⋮

M stars very red

So, the star's temperature not only affects its color, but also what lines are seen in its spectrum

## Review question

What do we need to produce the Balmer lines from a hydrogen atom ?

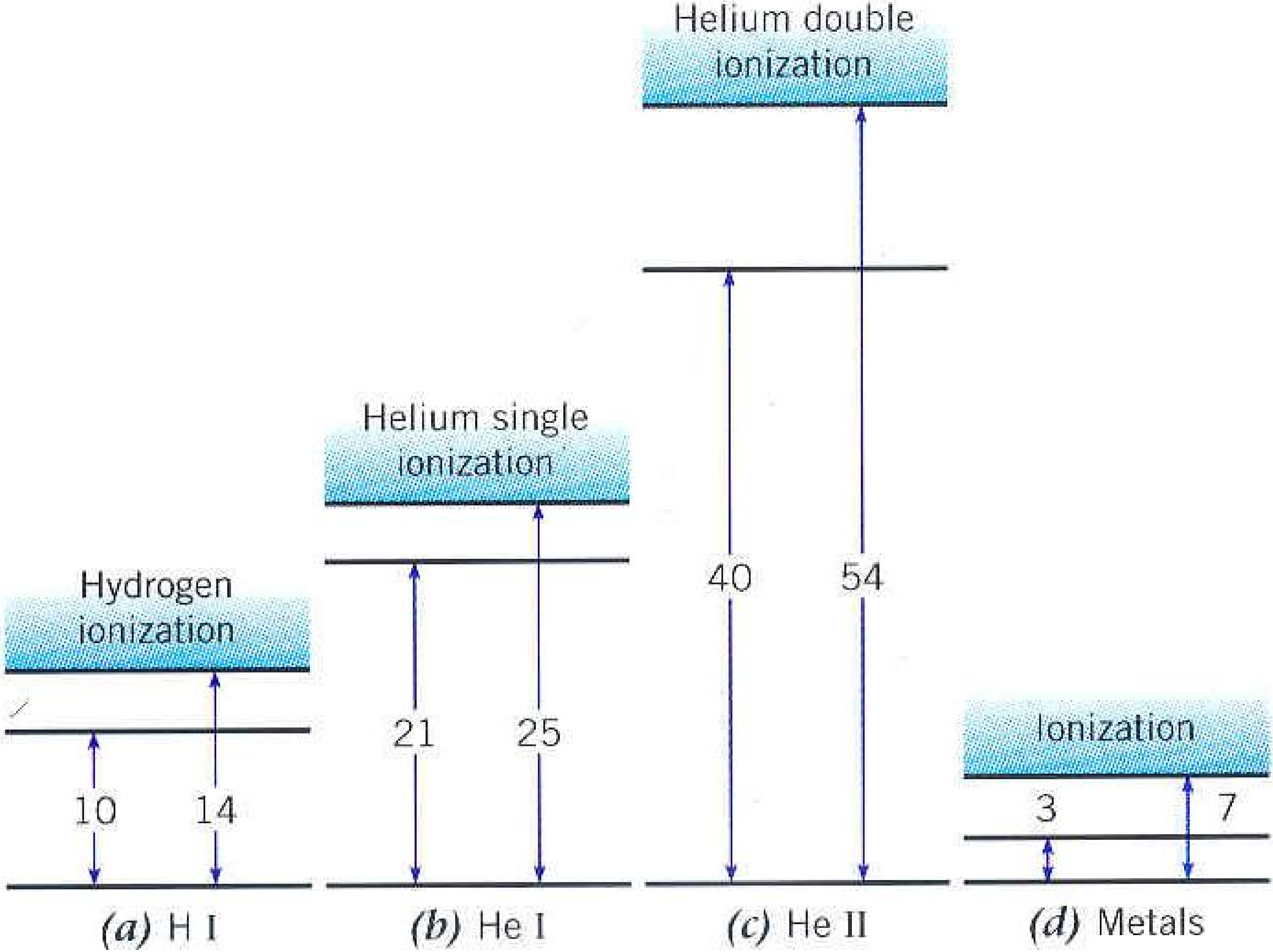


Ionization region
7
6
5
4
3
2
1
Energy
14,412
Pfund series
Brackett series
18,751
12,818
10,938
10,050
9208
Paschen series
6563
4861
4340
4102
3640
Balmer series
1216
1026
973
950
912
Lines from Lyman series
Ground state

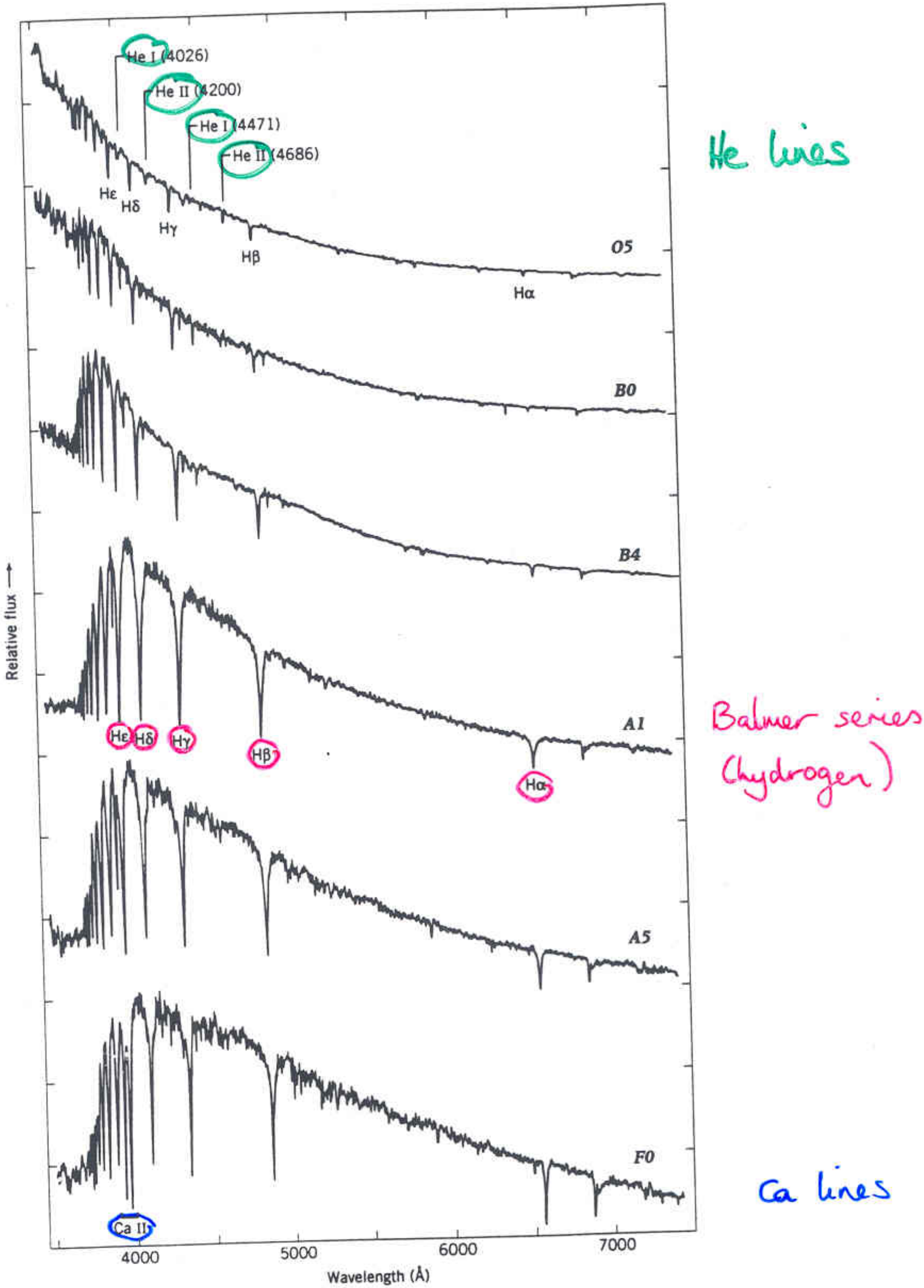
# Stars vary in temperature between ~2000K and ~50,000K

Q: The most common element in the universe is hydrogen. Would you expect to see it in neutral or ionized form in stellar photospheres?

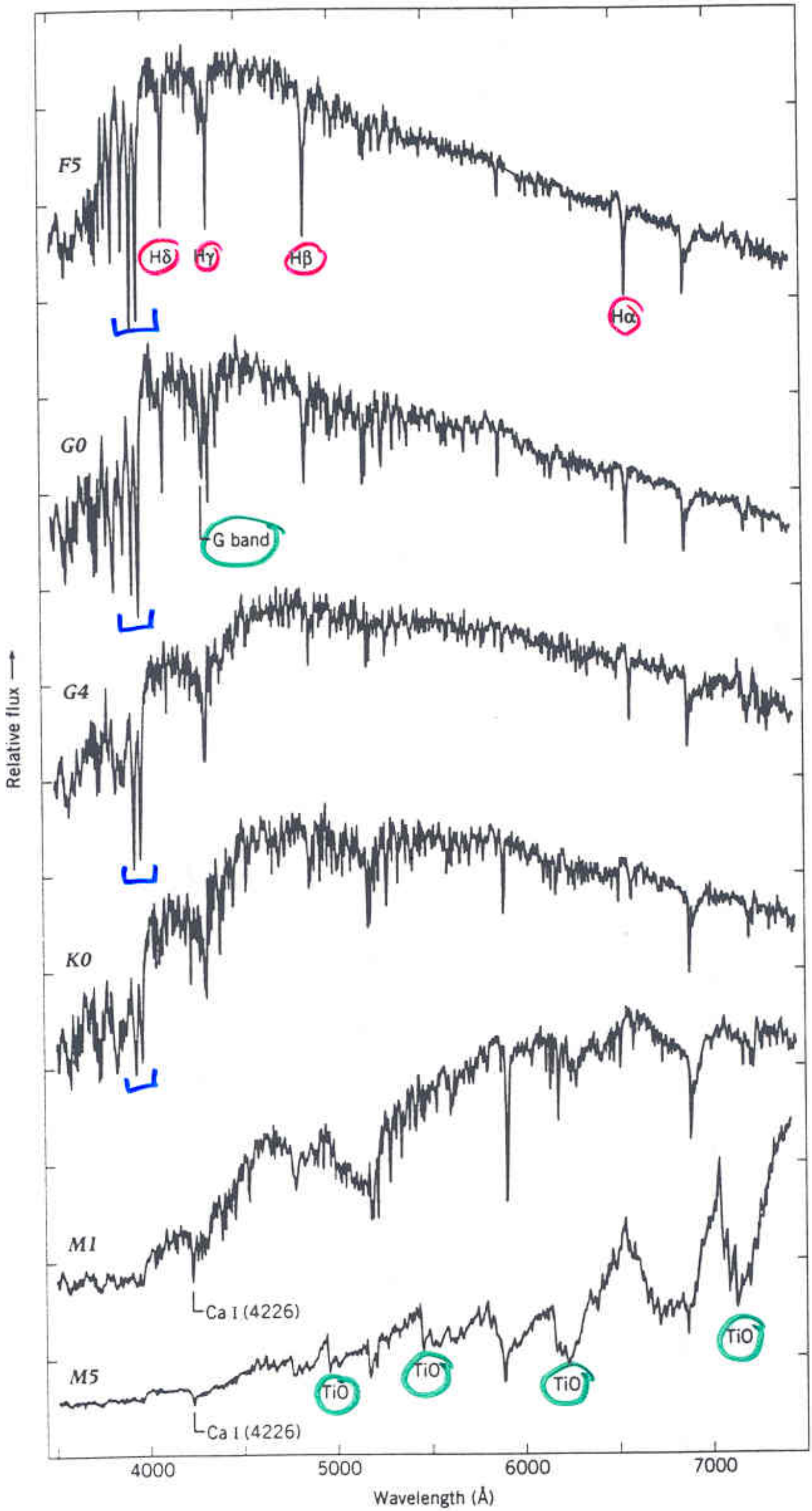
Q: The next most common element is helium. Would we see it in neutral or ionized form?



Helium double ionization
Helium single ionization
Hydrogen ionization
10
14
21
25
40
54
Ionization
3
7
(a) H I
(b) He I
(c) He II
(d) Metals



He I (4026)
He II (4200)
He I (4471)
He II (4686)
Hε
Hδ
Hγ
Hβ
Hα
O5
B0
B4
A1
A5
F0
Ca II
Relative flux
Wavelength (Å)
4000
5000
6000
7000
He lines
Balmer series (hydrogen)
Ca lines




Balmer lines weaker

G band - not just a single line

Ca lines strong

TiO and other molecules cause bands of absorption

Main thing that determines the appearance of a star's spectrum is its (photospheric) temperature

Spectral types :

O B A F G K M

hot ↑ cool

Sun

Recall that H and He are two most abundant elements in universe

So H lines are very important

# Classification of stellar spectra

* what's important *

- most of the Universe is hydrogen, so the Balmer series (transitions of H atom in visible region) is important
  - what it looks like
  - what transitions in the atom cause it
- He lines (next most common element; very hard to get a He atom excited)
- "metal" lines from elements such as Ca, Fe
- molecules in cool stars
- the physics that causes these lines to be seen in stars @ different temperature

**Figure 3.10** The relative strength of spectral lines from important species as a function of spectral type. Each species shows the effects of excitation and ionization. For example, the increase in H line strengths from K to A stars is because the increasing temperature results in more hydrogen in the $n = 2$ levels and higher. However, the higher temperatures of the B and O stars ionize the hydrogen, and the lines get weaker.

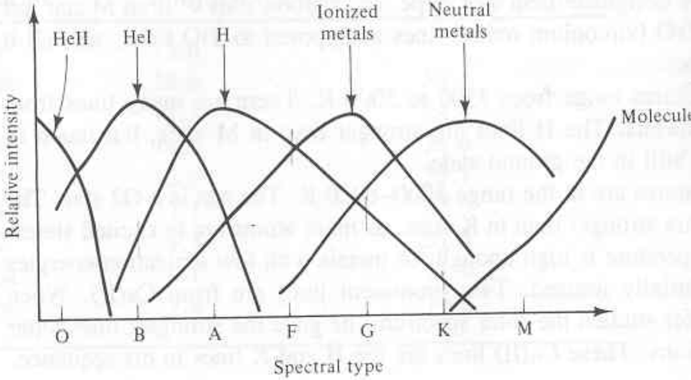


**TABLE 3.1** Ionization Energies (eV)

| Atom | Singly ionized | Doubly ionized |
|---|---|---|
| H | 13.6 | |
| He | 24.6 | 54.4 |
| C | 11.3 | 24.4 |
| N | 14.5 | 29.6 |
| O | 13.6 | 35.1 |
| Na | 5.1 | 47.3 |
| K | 4.3 | 31.8 |
| Ca | 6.1 | 11.9 |
| Fe | 7.9 | 16.2 |

O, B stars

Hottest stars are so hot that all H in photosphere fully ionized

⇒ no Balmer lines

A stars

Temperature just right for Balmer lines : significant no of electrons in 1st excited state

F, G, K, M stars

Cooler, so H in ground state

"Metal" lines stronger

Coolest ones have molecules surviving (TiO, etc)