LECTURE 3 (1/10):
COLORS, SPECTRA, AND SURFACE TEMPERATURES OF STARS

3.1 BLACKBODIES: COLOR AND TEMPERATURE

A *blackbody* is an object that absorbs all light that hits it. However, a blackbody also emits light, provided that its temperature is above absolute zero (see figure 7-2).

If two blackbodies are the same size but different temperatures, the hotter blackbody is brighter. It emits more light than the cooler blackbody at every wavelength.

A hotter blackbody also emits a larger fraction of its light at shorter wavelengths. Thus, a hotter blackbody is *bluer* and a cooler blackbody is *redder*. The wavelength of peak emission is $\lambda_{max} = 0.0029/T$ meters, where T is the temperature in degrees Kelvin.

From the color of a blackbody, or the wavelength of its peak emission, we can infer its temperature.

The spectrum of a star is approximately a blackbody spectrum, so the color of a star indicates the temperature at its surface. The sun's surface temperature is about 5,800 K (degrees Kelvin), and its spectrum is peaked at yellowish light.

3.2 SPECTRAL LINES

Superposed on a star's continuous, blackbody-like spectrum are *absorption lines*.

Absorption lines are produced by atoms and molecules in the star's photosphere (near the surface), which absorb light at specific wavelengths. Each atom acts as a tiny filter, removing light in narrow bands of wavelength.

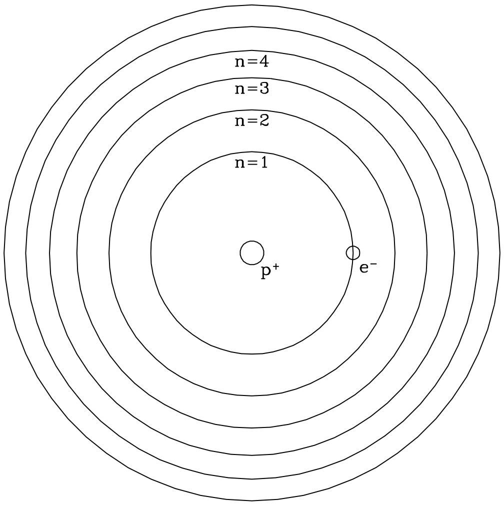
Electrons in an atom can only occupy orbits with specific, discrete energies. Energy is conserved, so an electron can move to a higher orbit by absorbing a photon with just the energy needed to move it to this orbit. An orbit above the lowest energy orbit is called an excited state.

An atom can emit light at the same frequencies that it absorbs it, a process called de-excitation or line emission, but the emitted photons generally go in a random direction, not towards the original observer.

3.3 HYDROGEN ABSORPTION

A neutral hydrogen atom contains a single electron orbiting a single proton.

A remarkable discovery of the early 20th century was that the electron in a hydrogen atom can only occupy discrete orbits with energy $E = E_0/n^2$, where E_0 is a constant and n is an integer.



A neutral hydrogen atom only absorbs photons that move an electron from one orbit to another. Such photons must have energy

$$E \;=\; E_0/n^2 - E_0/m^2 \;=\; hc/\lambda,$$

where n and m are integers (1, 2, 3, etc.).

The visible-light absorption lines of hydrogen are produced by electrons moving from the second orbit (a.k.a. the first excited state) to a higher orbit, i.e. $n = 2$ and $m > 2$.

Absorption from the first orbit (a.k.a. the ground state) occurs at ultraviolet wavelengths.

3.4 SPECTRAL CLASSES

We can identify the atoms or molecules that produce lines at particular wavelengths by comparing to laboratory experiments.

Different stars display a bewildering variety of absorption spectra. Near the turn of the century, astronomers (Pickering, Cannon, and others) began to classify stars based on their absorption lines.

Initially, classes were ordered according to the strength (darkness) of their hydrogen absorption lines:

A, B stars – strong hydrogen lines
F, G stars – strong "metal" lines
K, M stars – lines produced by molecules
O stars – helium lines

Note: Astronomers refer to all chemical elements heavier than helium as "metals"

What do the spectral classes mean physically? An important clue comes from plotting spectral class against color.

3.5 THE MEANING OF THE SPECTRAL CLASSES

It was eventually (1920's) realized that stars near the sun have similar chemical compositions, and that the spectral type of a star is determined primarily by its *surface temperature*.

From hottest to coolest, the sequence of spectral types is

O B A F G K M

Why do A stars, in the middle, have the strongest hydrogen lines?

- In hot stars, most of the hydrogen is ionized, so it cannot produce absorption lines.
- In cool stars, most of the hydrogen is in the *ground state* (first orbit), so it cannot produce absorption lines in *visible* light. This hydrogen produces absorption lines in *ultraviolet* light, which does not penetrate the earth's atmosphere.

Only hot stars (O, B) have helium in excited states, where it can produce visible absorption lines.

Molecules can only form and survive in cool (K, M) stars.

3.6 WHY MEASURE STELLAR SPECTRA?

The spectral class of a star tells us its surface temperature. But so does the color, which is much easier to measure. So why measure spectra?

Answer 1: Reddening by interstellar dust

Gas between the stars contains tiny grains of "dust" (more like smoke). These absorb some of the light from background stars, especially blue light. The observed color of a star can thus be redder than its true color.

Answer 2: Other information

While spectral class tells us primarily about temperature, we can also learn other things from a spectrum:

- line strengths $\longrightarrow$ chemical composition (if we're careful to correct for temperature)
- Doppler shifts $\longrightarrow$ radial velocity
- line widths $\longrightarrow$ density of gas $\rightarrow$ size of star

In addition to OBAFGKM spectral type, stars can be divided into *luminosity classes* (I, II, III, IV, V from brightest to faintest) on the basis of their line widths.

3.7 SUMMARY

The *continuum* spectrum of a star is similar to that of a blackbody. The hotter the star, the bluer its spectrum.

Stellar spectra also show absorption lines, produced by atoms and molecules near the surface of the star.

The *spectral class* of a star is determined primarily by its surface temperature. From hottest to coolest, the spectral sequence is OBAFGKM.

O stars are hot and have helium lines. A stars have the strongest hydrogen lines. The sun is a G star. K and M stars are cool and have molecular lines.

We can learn about the surface temperature of a star from its *continuum* spectrum (color) or from its *discrete* spectrum (absorption lines). Although the physical principles are different, both methods give similar answers.

The spectrum of a star can also tell us about its composition, its radial velocity, and its size.