Lecture 9: Stellar Spectra
Readings: Section 19-4, 19-5, and 19-8

Key Ideas

Color of a star depends on its Temperature
- Red Stars are Cooler
- Blue Stars are Hotter

Spectral Classification
- Classify stars by their spectral lines
- Spectral differences are due to Temperature

Spectral Sequence (Temperature Sequence)
  O  B  A  F  G  K  M  L  T

Luminosity Classes

Chemical Composition

Wien’s Law

Relates peak wavelength and temperature

\[ \lambda_{\text{peak}} = \frac{2,900,000 \text{ nm}}{T} \]

In words: “Hotter objects are BLUER”
  “Cooler objects are REDDER”

See Figure 19-7

Colors of Stars
Stars are hot, dense balls of gas
- Continuous spectrum from the lowest visible layers (“photosphere”)
  - Approximates a blackbody spectrum with a single temperature

From Wien’s Law, we expect:
- Hotter stars appear BLUE (T=10,000-50,000K)
- Middle stars appear YELLOW (T~6000K)
- Cool stars appear RED (T~3000K)

Spectra of Stars
Hot dense lower photosphere of a star is surrounded by thinner (but hot) atmosphere
Produces an Absorption-Line Spectrum superimposed on a Continuous Spectrum
Lines come from the elements in the stellar atmosphere
Can we use stellar spectra to distinguish among different types of stars?

We can identify lines in a stellar spectrum by comparing their wavelengths with spectra of elements we observe in the laboratory.

Spectral Classification of Stars

1866: Angelo Secchi observed the spectra of ~4000 stars
   Divided them into 4 broad classes by common spectral absorption features
1886-1897 Henry Draper Memorial Survey at Harvard
   Led by Edward Pickering
   Objective prism photograph of the sky from Harvard and Arequipa, Peru
Spectra of 220,000 stars:
   Hired women as “computers” to analyze the stellar spectra

Harvard Classification (1890)

Edward Pickering & Willamina Fleming made a first attempt to classify ~10,000 stars by their spectra.
   Sorted by Hydrogen absorption-line strength
   Spectral Type “A” = strongest Hydrogen lines
   Followed by types B,C,D, etc. (weaker)
Problem:
   The other lines didn’t fit into this sequence

Annie Jump Cannon

In 1901, Annie Jump Cannon noticed that stellar temperature was the principal distinguishing feature:
   Re-ordered the ABC types by temperature
   Many classes thrown out as redundant
Left with 7 primary classes:
O B A F G K M

Later work added the classes R, N, and S.

Stellar Spectral Sequence

See Figure 19-11 and figure below

![Spectra of Dwarf Stars (Luminosity Class V)](image)

Henry Draper Catalog of Stars

Cannon further refined the spectral classification system by dividing the classes into numbered subclasses

For example, A was divided into

A0  A1  A2  A3  ....  A9

Between 1911 and 1924, she classified about 220,000 stars, published as the Henry Draper Catalog.

New Spectral Types: L&T

Coolest stars (<2500K) discovered by recent digital all-sky surveys
L stars:
  Temperatures ~1300-2500K
  Strong lines of metal hydrides & neutral metals

T dwarfs
  Strong Methane (CH$_4$) bands, like Jupiter
  Most likely failed stars (Brown Dwarfs)

Cecilia Payne Gaposchkin

Harvard graduate student in 1920s
1925 Ph. D. dissertation was a classic

  First comprehensive theoretical interpretation of spectra
  Based on the then new atomic physics

Showed that stars are mostly Hydrogen and Helium with traces of all of the other metals.

The Spectral Sequence

O  B  A  F  G  K  M  L  T

Hottest           Coolest
50,000K ←-------------→ 1300K
Bluest          Reddest

Spectral Sequence is a **TEMPERATURE** sequence

*A Mnemonic for the Spectral Sequence:*

One Big Apple From Georgia Killed My Little Turtle

The Spectral Sequence is a Temperature Sequence
Differences among the spectral types are due to differences in **Temperature**

What lines you see depends primarily on the state of *excitation* and *ionization* of the gas.

These are determined primarily by the Temperature of the gas.

**Implications**
- Composition differences are relatively unimportant
- Differences in temperature matter the most

**Absorption Lines**

Electron absorbs a photon with *exactly* the energy needed to jump from a lower to a higher orbital.
- Only photons with the exact excitation energy are absorbed.
- All others pass through unabsorbed

**Example: Hydrogen Lines**
Visible Hydrogen absorption lines come from the first excited state of Hydrogen (n=2)

B Stars (11,000-30,000 K):
- Most of the H is ionized, so only very weak H lines in visible

A Stars (7500-11,000K)
- Ideal excitation conditions, strongest H lines in visible.

G stars (5200-5900 K)
- Too cool, little excited H, so only weak H lines in the visible

Line strengths diagram shown in Figure 19-12

**Modern Synthesis: The M-K System**

In 1943, Morgan & Keenan added the *Luminosity Class* as a second classification parameter:
Ia = Bright Supergiants
Ib = Supergiants
II = Bright Giants
III = Giants
IV = Subgiants
V = Dwarfs

Luminosity Classification

Absorption lines are *Pressure-sensitive:*  
Lines get *broader* as the pressure *increases.*
Larger stars are puffier, which means lower pressure, so that
Larger Stars have Narrower Lines

Since larger stars are *brighter* at a given temperature, this measures relative stellar luminosity for stars of the *same* temperature.

See Figure 19-15

Full Spectral + Luminosity Classification of Stars:

Sun:
G2V (“G dwarf”)

Winter Sky:
Betelgeuse: M2 Ib star (“Red Supergiant”)
Rigel: B8 Ia star (“Blue Supergiant”)
Sirius: A1V star (“A dwarf”)
Aldebaran: K5 III star (“Red Giant”)

Why is this Important?
Spectral classification provides a way to estimate the physical characteristics of stars by comparing their spectral features.
  Spectral differences primarily reflect differences in the temperatures of the stellar atmospheres.
  A star’s spectrum uniquely locates the star within the overall sequence of stellar properties.
Powerful tool for understanding the physics of stars.
Example: the Effects of Dust

There is gas and dust in between the stars. Dust particles are very small and scatter blue light more efficiently than red light.

Most stars appear to be REDDER than they really are.

A star’s color no longer tells you its tempertuare.

But the spectrum still does!

Chemical Composition

We can also determine the abundances of many elements in stars by using the “atomic fingerprints” seen in spectral absorption lines.

We first determine
   (1) the star’s temperature (spectral class)
   (2) the star’s surface density (luminosity class)

Once these are known, we can then estimate the abundance of any elements that have absorption lines in a stellar spectrum!

We find that most stars in the Galaxy have a composition very similar to that of the Sun (70% H, 28% He and 2% everything else.)
But, very interestingly, there are stars that deficient in the abundances of all elements heavier than He compared to the Sun.