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

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

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)



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 surverys

L stars:

Temperatures ~1300-2500K Strong lines of metal hydrides & neutral metals <u>T dwarfs</u> Strong Methane (CH₄) bands, like Jupiter Most likely failed stars ("Brown Dwarfs")

Cecilia Payne Gaposhkin

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 <u>Pressure-sensitive:</u> Lines get <u>broader</u> as the pressure <u>increases</u>. Larger stars are puffier, which means lower pressure, so that <u>Larger Stars</u> have <u>Narrower Lines</u>

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.