Chapter 17 – Measuring Stellar Properties & the H-R Diagram

Chapter Preview

- What makes a star tick?
- How are they born? How do they die?
- Why do stars have different properties?

Astronomers must put stars "under the telescope" and measure properties, such as mass, size, and color.

Astronomers usually make correlations graphically, using the powerful method pioneered in the early 20th century, the Hertzsprung-Russell diagram.

Key Physical Concepts to Understand:

- *the measurement of the distance, luminosity, temperature, diameter, and mass of stars,*
- *the Stefan-Boltzmann relation,*
- *the H-R diagram,*
- *estimation of a stars lifetime from its mass and luminosity*

I. Introduction

Stars are born, live according to their physical properties, and die.

How can astronomers learn of the origin and evolution of objects that are so far away that it takes years if not centuries for their light to arrive at the Earth, so small that they appear only as pinpoints of light, and so slow to age that they can live for 10s of billions of years?

The basic properties of stars that can be measured:

1. distance,
2. luminosity,
3. temperature,
4. mass,
5. composition,
6. diameter,
7. and age. (estimated using computer models of stellar evolution.)

Other important that can be measured from the Earth include magnetic field strength, rotation, velocity, and turbulence.

II. Distance

What units of distance do we use when measuring how far away stars are? the light-year and the parsec.

The **light-year** is a measure of distance, not time. It is the distance that light travels in one year, approximately 6 trillion miles.

The Sun is 8 light-minutes from Earth. Proxima Centauri, the 2nd nearest star to the Earth, is 4.3 light years away or 4×10^{13} kilometers. The North Star, Polaris, is 650 light years distant.

How do astronomers know these distances? Astronomers use measurements of stellar **parallax** (Figure 1).

As the Earth orbits the Sun nearby stars appear to move back and forth against the background sky in inverse proportion to their distance. Parallax is the same method that we all unconsciously use to judge the distances to objects when driving, playing sports, or in any other human endeavor that depends on distance estimation. Since most people have two functioning eyes they have binocular (literally "two eyes") vision. Binocular vision allows for distance estimation by parallax for nearby objects. You can explore this yourself in several ways. Hold a pencil at arm's length. Look at it with your left eye closed and then your right. Compare the position of the pencil with respect to background objects and see how the position of the pencil shifts with respect to its background as you alternate the eye with which you view it.

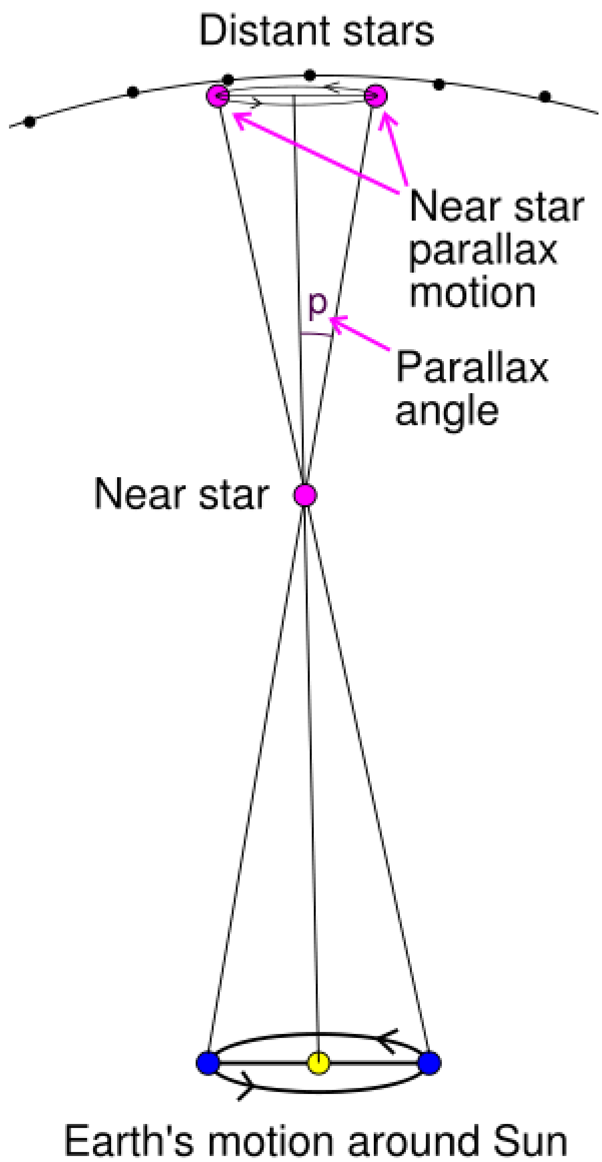


Figure 1. Stellar parallax. As the Earth orbits the Sun, nearby stars appear to shift their positions relative to distant background stars. The parallax angle P, is one-half of the maximum annual angular shift as a result of the Earth’s revolution. **FMW 365-18.3.**

The distance of an object, whether a star or a pencil, is proportional to 1/parallax angle.

If the parallax angle is 1 arcsecond (1/3600 of a degree), then by definition the distance is 1 parsec (close to the typical distance between stars in our Milky Way galaxy).

The parallax of Proxima Centauri is 0.77 arcsecond? So we can calculate its distance using the following equation:

Equation 17.1: distance in parsecs = 1 / (parallax angle in arcseconds)

or distance = 1/0.77 parsecs = 1.30 parsecs. This is comparable to a dime viewed at a distance of a mile.

Parallax measurements are only useful out to distances of 100 parsecs. Outside this distance parallax is smaller than the blur of a star caused by the Earth’s atmosphere. To overcome this limitation, the European Space Agency launched the satellite Hipparcos (named after the early Greek Astronomer Hipparchus) in 1989 to measure the parallax of the 20,000 stars within 500 parsecs of the Sun.

III. Stellar Brightness

Magnitudes. When Hipparchus catalogued 1,000 stars in 130 BC by eye, he ranked their **apparent magnitude** or **brightness** on a scale of 1 to 6, with "1st magnitude" stars the brightest and "6th magnitude" the faintest. A difference of 5 magnitudes is now defined as a factor of 100 in brightness. *Any given star is about 2.5 times brighter than a star of the next fainter magnitude. The apparent brightness of a star depends not only on its intrinsic brightness but also on its distance from us, just as the apparent brightness of a candle depends on its distance from us.*

More precisely, if a one magnitude difference in brightness between two stars corresponds to a 2.512 ratio in brightness. It follows that a 5 magnitude difference in brightness corresponds to a brightness ratio of 2.512^5 = 2.512 x 2.512 x 2.512 x 2.512 x 2.512 = 100.

Visual brightness of stars, planets and other astronomical objects is based on the visual magnitude scale (V_o). Every integer increase in magnitude represents a 2.5 increase in brightness. So the Sun is 6 trillion times brighter than a 6th magnitude star, which in turn is 4 billion times brighter than a 30th magnitude star - the limit of the Hubble Space Telescope.

Magnitude	Object or Limit
-27	the Sun
-20	brightest meteors
-13	Full Moon
-4	Venus (brightest planet)
-1	Sirius (brightest star)
+6	naked-eye limit
+9	binoculars limit
+13	8" backyard telescope limit
+18	large telescope limit (visual)
+23	large telescope limit (photograpic)
+27	large telescope limit (CCD imaging)
+30	Hubble Space Telescope limit

Figure 2. The apparent magnitude scale. There is a difference of more than 50 magnitudes in apparent magnitude between the Sun and the faintest objects

seen by the largest telescopes. This corresponds to a factor of approximately 10^{20} in brightness. **FMW 329-16.2.**

A small number of stars in the sky, some of the planets, the Moon, and the Sun are brighter than 1st magnitude. For this reason, the magnitude scale was extended to include negative magnitudes for extremely bright objects. The Sun has an apparent magnitude of -26.8. For stars that cannot be seen with the unaided eye, but can be detected telescopically, we use postive magnitudes greater than 6. The Hubble Space Telescope can detect stars nearly as faint as 30th magnitude.

How does brightness change with distance?

The brightness of an object changes according to the inverse square law for light (Chapter 5, Section VI). If we view two stars of equal intrinsic brightness, but Star A is twice as distant as Star B, Star A will appear $(1/2)^2$ as bright, or ¼ as bright, by the inverse square law.

Although the Sun is a star of average energy output and size, it overwhelms the other stars in the sky in its apparent brightness to the inhabitants of Earth simply because it is the closest star to us. It follows that apparent magnitude is not any intrinsic proper of stars, but depends mainly on their distance from us.

In order to compare the total energy output of stars, we need to compare their apparent magnitude as if they were all moved to the same distance from us.

- **If we move all the stars in the galaxy to an equal distance we can see the more fundamental differences in their total energy output per unit time or luminosity.**
- **Astronomers measure luminosity in units of solar luminosity, where the luminosity of the Sun is 4×10^{26} watts.**
- **Another way of describing the luminosity of a star is by using absolute magnitude. Absolute magnitude is the magnitude a star would have if moved to a distance of 10 parsecs.**
- **Magnitudes depend on the color to which the measurements refer (usually the color sensitivity of the human eye – or visual magnitude).**

One can measure magnitude in filters of differing color: blue magnitude, red magnitude, yellow magnitude, etc.

IV. Temperature

One of the most fundamental properties of a star is its temperature.

A star cannot be characterized by a single temperature.

Since we see near-blackbody emission from the photosphere when we view a star, we commonly use the photospheric temperature of a star to characterize it.

The Sun's photosphere is approximately 5800 K.

The photospheric temperature of a star can be measured from its color and its spectrum.

Colors

We observe stars to have different colors. The Sun appears yellow, Rigel is blue, and Betelgeuse is red.

The color of a star follows Wien’s law for blackbodies, the hotter the body the bluer it is.

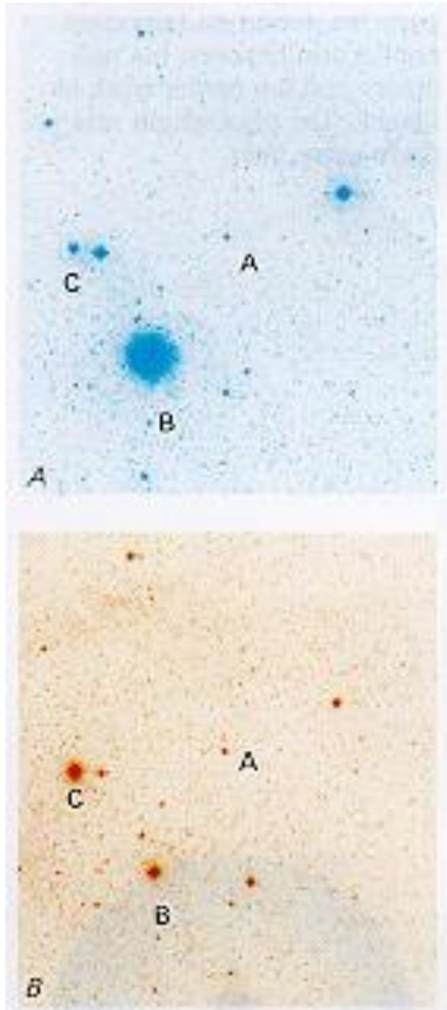


Figure 3. Filter photometry can be used to measure the photospheric temperature of a star. The upper image is a photograph of a star field taken through a blue filter. The lower image was taken with a red filter. Star A appears to have roughly the same brightness in both colors. Star B appears brighter in blue light than in red light, indicating that it is hotter than Star A. Conversely, star C appears brighter in red light than in blue light, indicating that it is cooler than Star A or Star B.

The color of a star can be used to estimate its photospheric temperature.

Blue stars are 10,000 to 25,000 K, yellow stars about 6,000 K, and red stars 2,000 to 5,000 K.

This is essentially the same method used by metallurgists to estimate the temperature of molten metal in a blast furnace.

Astronomers can make a more precise measurement with **filter photometry**.

Photoelectric photometry is a precise way of measuring the brightness of an object such as a star.

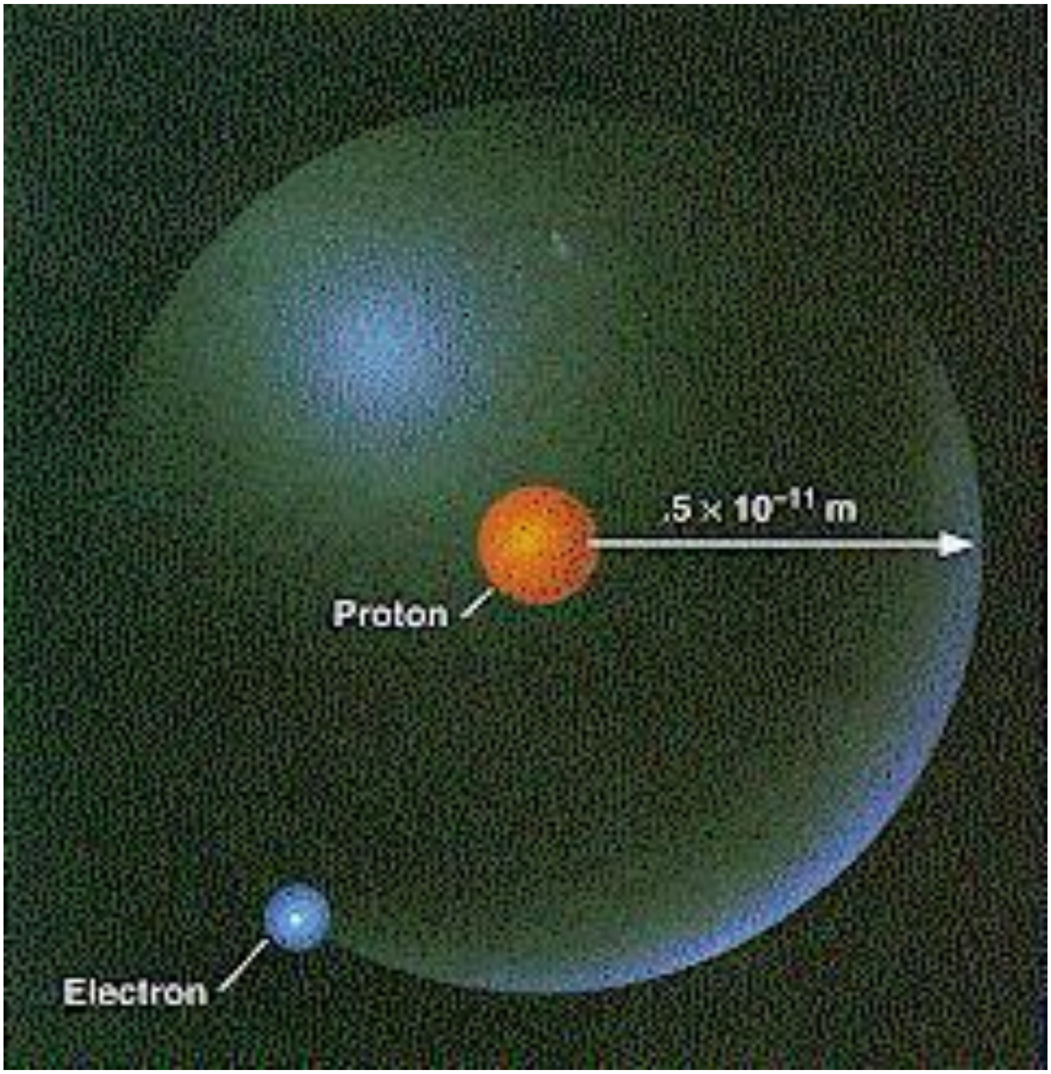
A photometer is an electronic instrument that measures the brightness of light by converting photons to an electric current. One way of performing photoelectric photometry is to use the photoelectric photocell (Chapter 14, Section II) and measuring the current that flows through the photocell circuit when light falls on the photocell.

This current is in direct proportion to the brightness of the light falling on it.

When used with a telescope, the photoelectric photometer, with filters, enables an astronomer to precisely measure the apparent brightness (or magnitude) of a star.

When filters are inserted in front of the photometer, one at a time, the color of a star can be precisely quantified. By comparison with the colors of blackbody spectra representing different temperatures, the measured star color can be used to determine its photospheric temperature.

Spectra



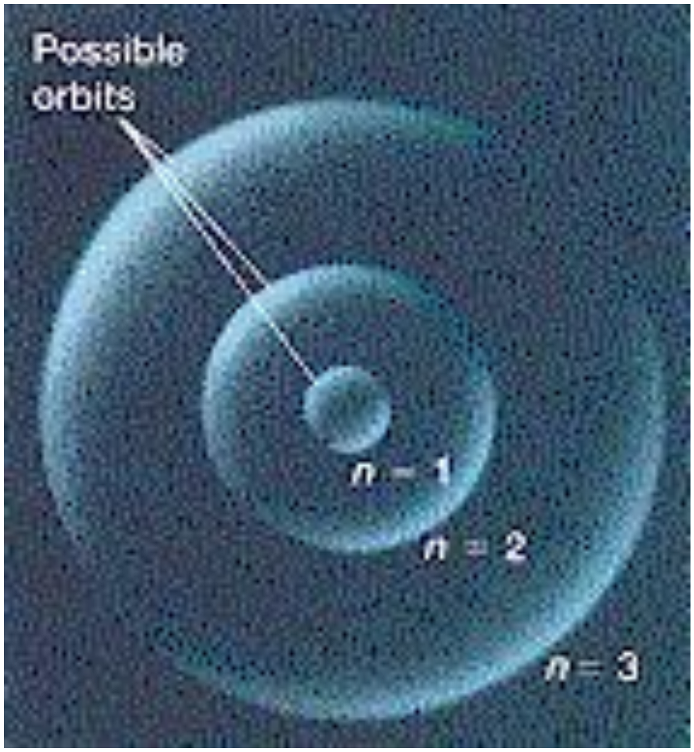
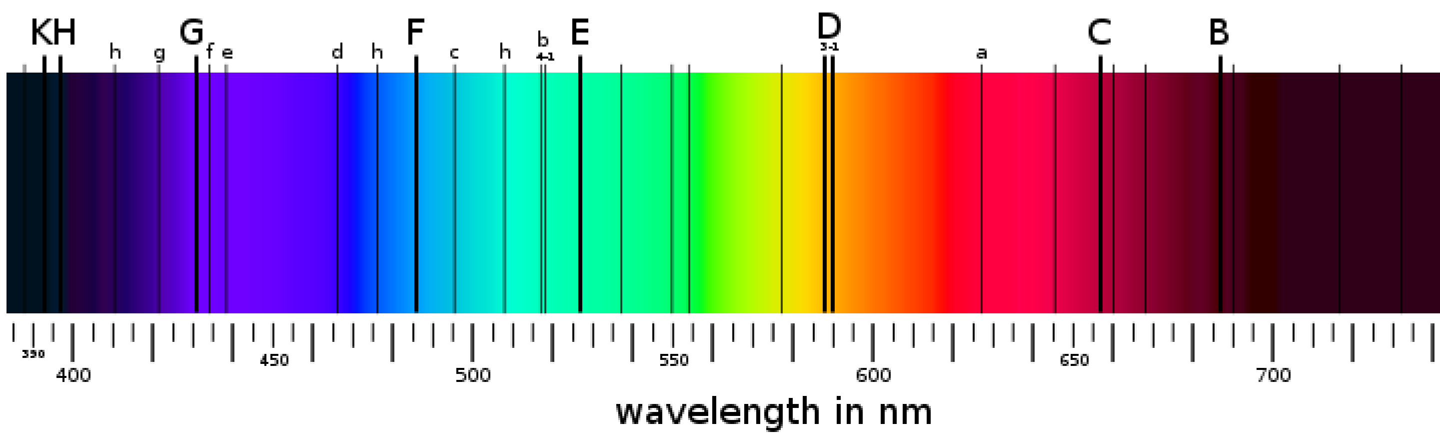


Figure 9. The Bohr model of the atom correctly predicts the behavior of light interacting with atoms in a gas.



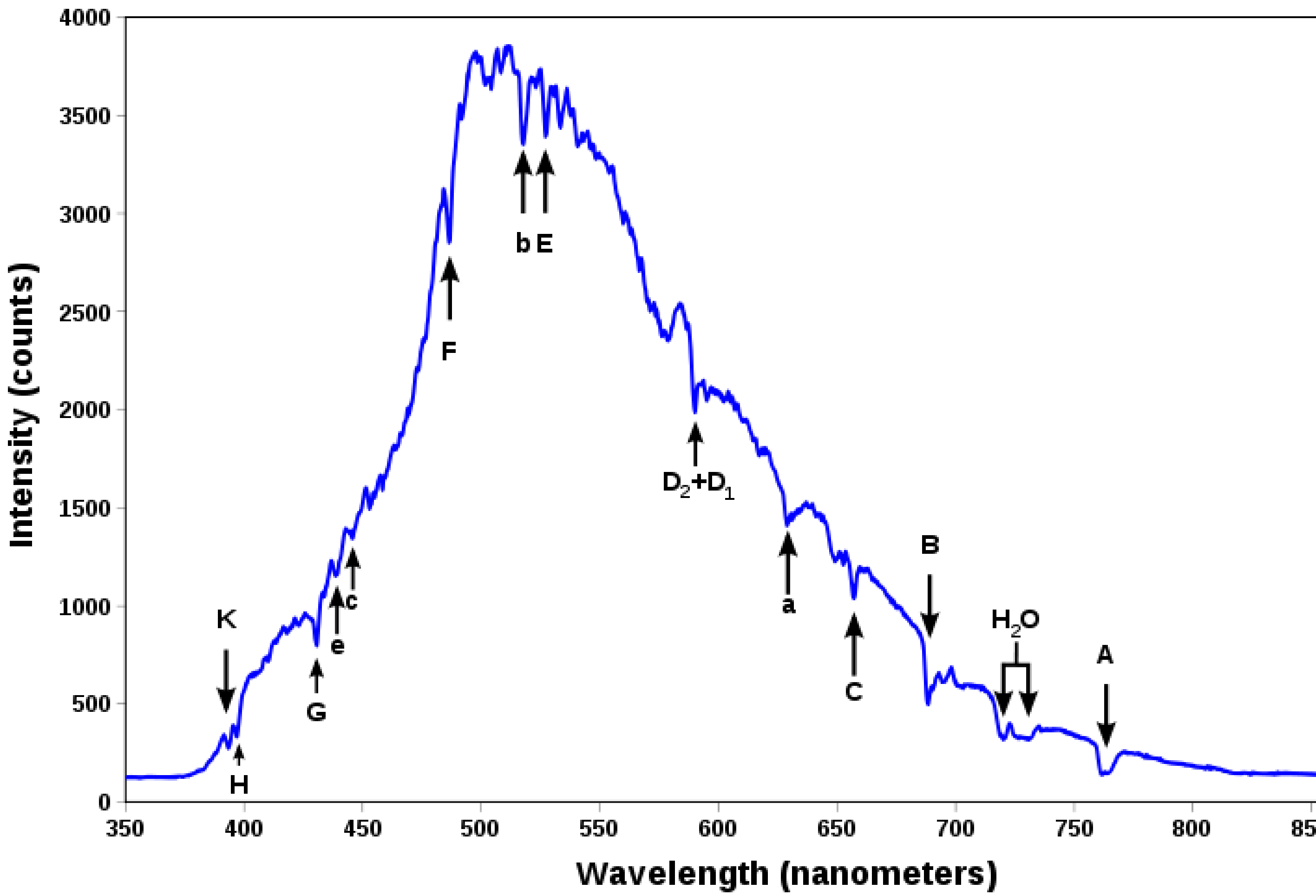


Figure 10 shows the spectrum of visible light from the Sun.

In 1815 the German physicist Joseph Fraunhofer discovered that a forest of absorption lines breaks up the white light spectrum of the Sun; these absorption lines are frequencies in the spectrum where the light intensity is relatively low.

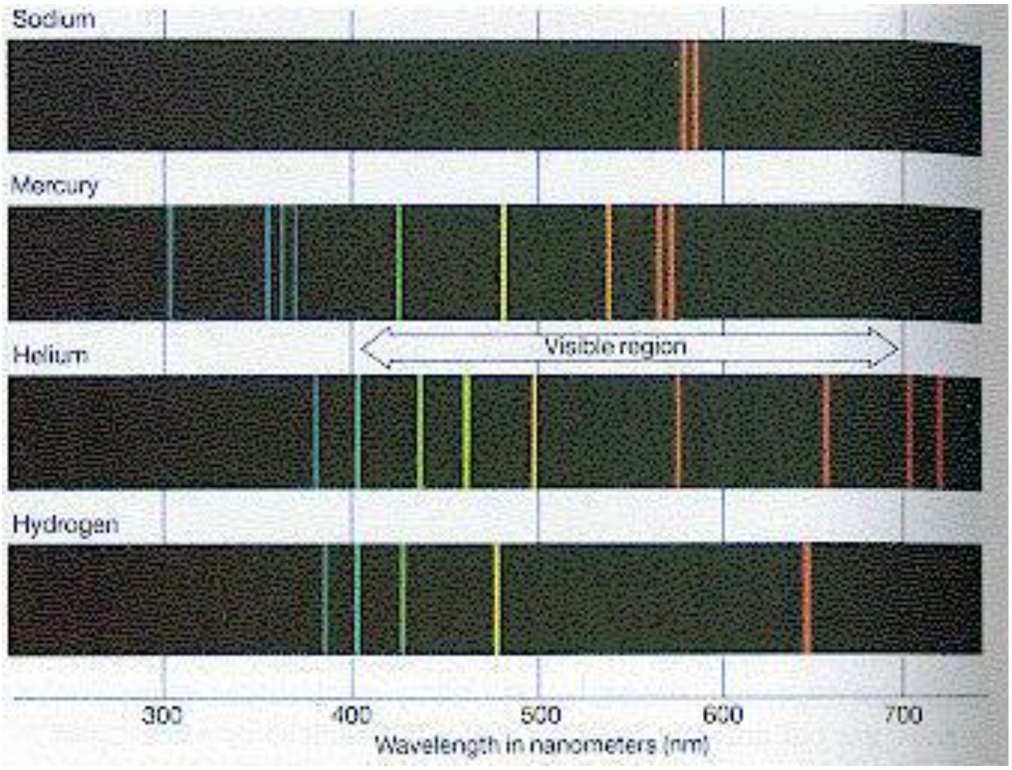


Figure 11 shows the *emission* from hydrogen, argon, and xenon gas lamps.

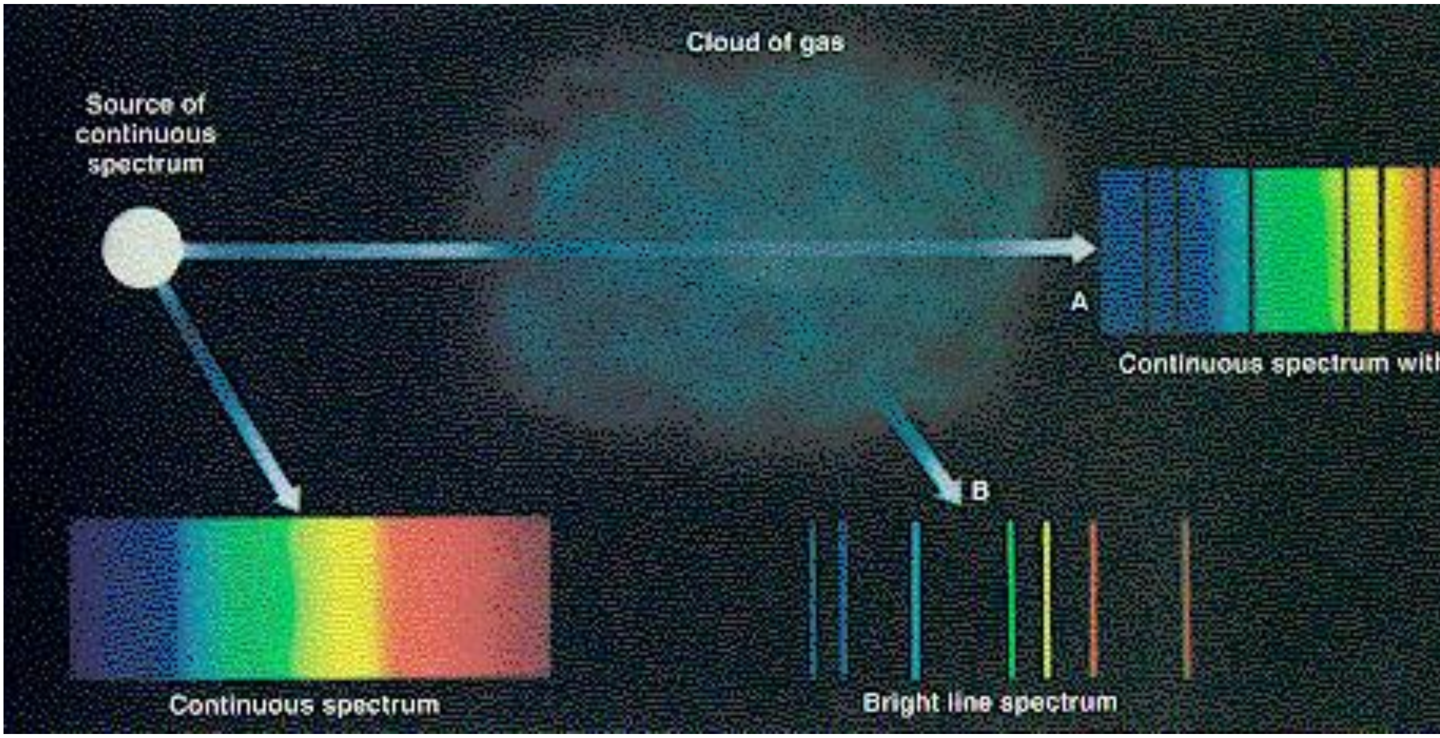
The nucleus of each element is characterized by a different number of protons, giving rise to different electrical forces imparted to its electrons and different electron energy levels.

The result is that each element has its own characteristic spectrum, hence each element has its own unique spectrum, its fingerprint.

Helium (from the Greek word *helios* for Sun) was discovered in 1868, not from its detection on Earth, but from its appearance as an unidentified element in the solar spectrum.

This is just one illustration of the importance of the use ***spectroscopy*** *in astronomy, for the detection of elements and their abundances in stars.*

When does one see emission lines and when does one detect absorption lines? *An empirical set of rules for the manner in which light interacts with matter was developed in 1860 by the German physicist Gustav Kirchoff, and are called*



Kirchoff's laws (Figure 12):

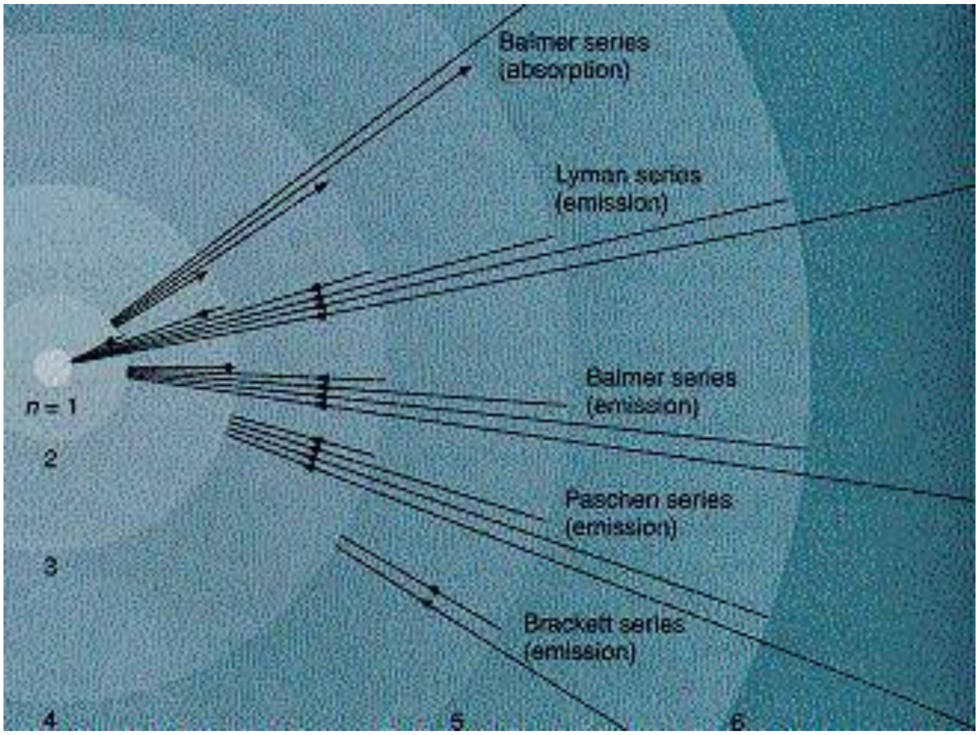
1. A hot tenuous gas gives off an emission line spectrum.
2. A hot solid, liquid, or dense gas emits a continuous spectrum with no lines (nearly a

blackbody spectrum in the case of a solid or liquid, which are close to being ideal radiators). (Chapter 5, Section VII).)

3. A continuous spectrum that passes through a relatively cool gas results in an absorption spectrum superimposed on the continuous spectrum.

Stellar **spectroscopy** is the technique of determining stellar composition and photospheric temperature, among other things, using a telescope to collect light, and optics, such as a prism, to separate light into a rainbow of its component colors, prior to the spectrum being recorded by film or a video camera.

Stellar spectra show absorption lines of hydrogen, as well as calcium, iron, and various molecules. **Spectra are related to both stellar composition and temperature.**



1. In cooler stars, like the Sun, most of the hydrogen electrons are in their lowest energy state. This means that absorption, when it occurs, occurs in the Lyman (energy level 1) series from the lowest energy state of the hydrogen atom. Since the electrons have a long way to go to be lifted to higher energy states, the Lyman series only absorbs high-energy photons from ultraviolet (UV) part of the

spectrum, blocked by the Earth’s UV-absorbing atmosphere.

2. Balmer series (energy level 2) lines are not seen because of the low temperature of the solar photosphere. Hotter stars (~10,000 K) show Blamer lines, because the hotter photospheric temperature raises electrons from energy level 1 to energy level 2. Visible light can be absorbed by energy level 2 electrons, because this energy level is closer to the higher energy levels than energy level 1 is, and therefore requires photons of less energy for absorption. Balmer lines are seen in the visible part of the spectrum in stars of moderate temperature (4,000 to 10,000 K).
3. At higher temperatures (11,000 – 25,000 K) hydrogen is stripped of

electrons (ionized) and the most prominent lines are formed from helium, a more tightly bound atom. Balmer lines and Lyman lines are weaker in stars in this temperature range.

4. At very high temperatures (greater than 25,000 K) the photosphere is almost completely ionized and the spectrum is basically continuous.
5. At low temperatures (less than 3,000 K) molecules can form in the atmosphere and can be detected from their absorption lines.

V. Diameter

Almost all stars are too far away to directly measure their diameter. The Sun is a prime exception.

How can one determine the diameter of a distant star? A star's diameter can be calculated from the Stefan-Boltzmann relation:

Equation 17.2: $L = A\sigma T^4$,

Or rearranging, **$A = L/\sigma T^4$.**

Where L is the luminosity or total energy output from a star, A is its surface area, σ is the Stefan-Boltzmann constant of proportionality, and T is the star's photospheric temperature.

1. A star’s luminosity is determined from its measured brightness and its distance.
2. If the apparent magnitude or brightness of a star has been measured by photoelectric photometry and its distance has been determined from stellar parallax, its luminosity can be calculated from the inverse square law. That gives us L.
3. The colors of a star can also be measured using photoelectric photometry (with filters), allowing the astronomer to calculate the T, the photospheric temperature.
4. Now, the surface area, A of the star can be calculated from **Equation 17.2**.
5. But the surface area of a sphere is $4\pi R^3$, where R is its radius. Knowing A, the astronomer now also knows R.

VI. Stellar Mass and Binary Stars

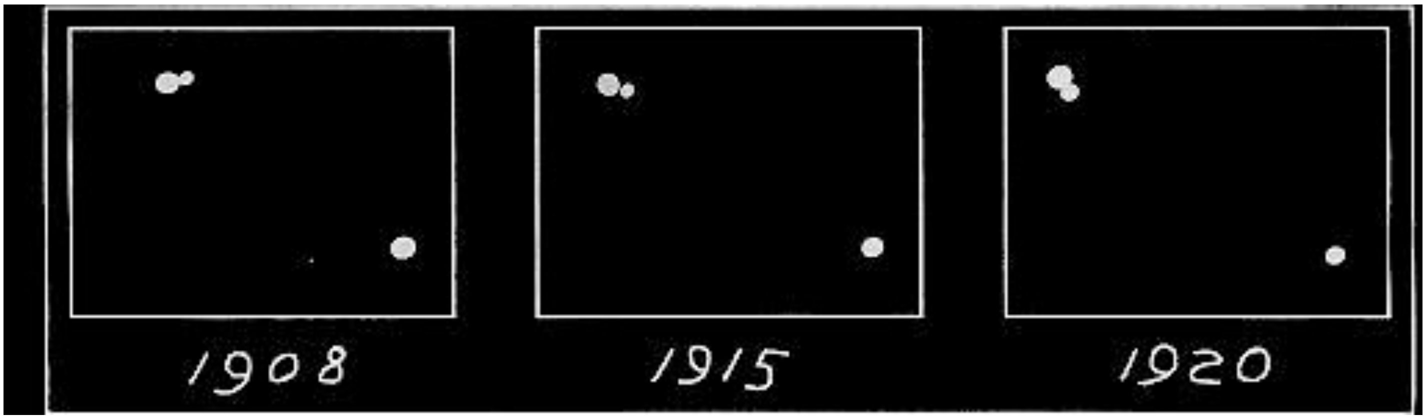


Figure 12. Kruger 60, a nearby true binary system. Three images taken from 1908 to 1920 show the revolution of both stars about their center of mass. **FMW 345-17.4.**

We can’t directly measure the mass of any star from the Earth. However, using Newtonian mechanics it is possible to derive the masses of stars from the period that a satellite takes to orbit a star. From Newtonian mechanics, a relationship akin to Kepler’s laws can be derived:

The sum of the masses of a star and its satellite times the square of the orbital period = cube of the semi-major axis.

- There are stars being orbited by companion stars that are easily seen from Earth with the aid of a telescope.
- By measuring the changing separation between one star and its companion over time, it is possible to calculate the sum of the masses of the star and its companion.
- For binaries with companions having masses much lower than the central star, it is really the mass of the central star that is being calculated.

1. Two-thirds of nearby stars are members of **multiple star systems**, stars that are seen to be close to each other on the sky.

2. One-half of the stars in the sky are thought to be **binary stars**.
3. Some of these **double stars** are **optical doubles**, two stars that appear to be close together on the sky, by are widely separated in three dimensions, so that they are not gravitational bound.
4. Others are **true binaries**, with both stars orbiting a common center of mass.

- In **visual binaries** the stars can be spatially resolved, that is, their separation can be seen and measured.
- By tracking the separation of a visual binary over time (Figure 12), the masses of the stars can be determined.
- Measurements of binaries yield a range in stellar masses from 1/10th solar mass to 100 solar masses.

IIX. The H-R diagram

What makes stars tick?

How can we determine the structure of stars, how they formed, and how their properties change as they age from studying their fundamental properties?

Table 17.1: *Normal Range of Stellar Properties*

Property	Range of Values
Luminosity	10^{-4} L to 10^{4} L
Photospheric Temperature	2000 K to 20,000 K
Radius	0.01 R to 500 R
Mass	0.1 M to 50 M

Why do luminosity and radius vary so much in stars, while photospheric temperature and mass stay in a relatively narrow range? If we examine the luminosity, photospheric temperature, radius, and masses of a random sample of stars will we see patterns that tell us something about the way stars behave?

Fundamental Properties of People: Height and Weight

In this section we will graphically examine two of the fundamental physical properties of people, their height and weight, to see if they can tell us something fundamental about the structure of the human body. Subsequently, we will use the same technique to examine the fundamental properties of stars to see what

they say about stellar structure and evolution.

We can use this same graphical method for the analysis of the fundamental properties of stars, to see what we can learn about them, their sub-populations, and to separate the typical from the atypical.

Fundamental Properties of Stars: Temperature and Luminosity

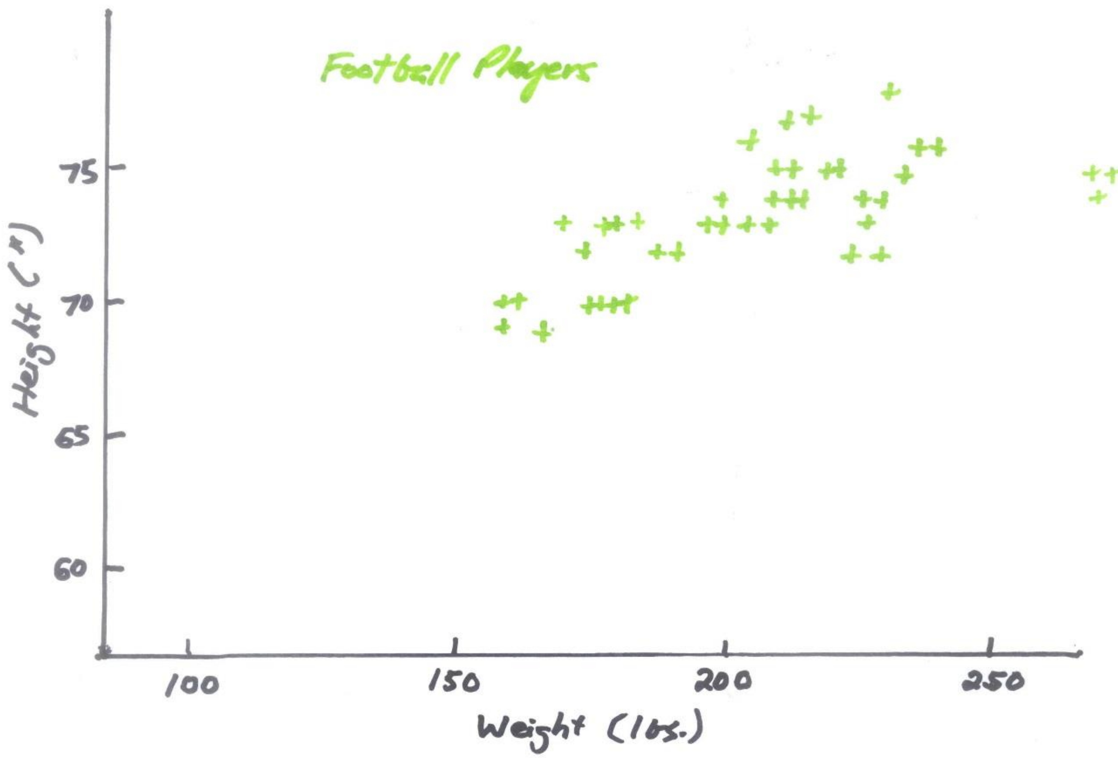


Figure 13. *Heights and weights of the 1985 Chicago Bears football team.* ***Original.***

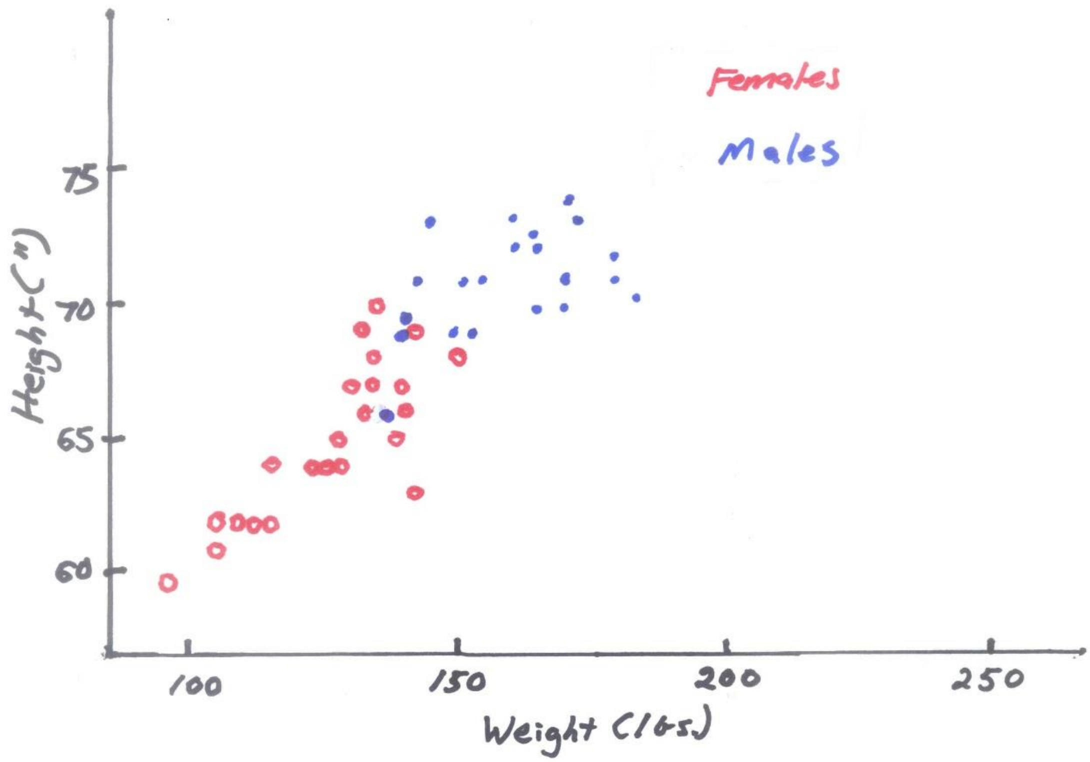


Figure 14. *Heights and weights of college students. Notice that men and women fall along the same trend line.* ***Original.***

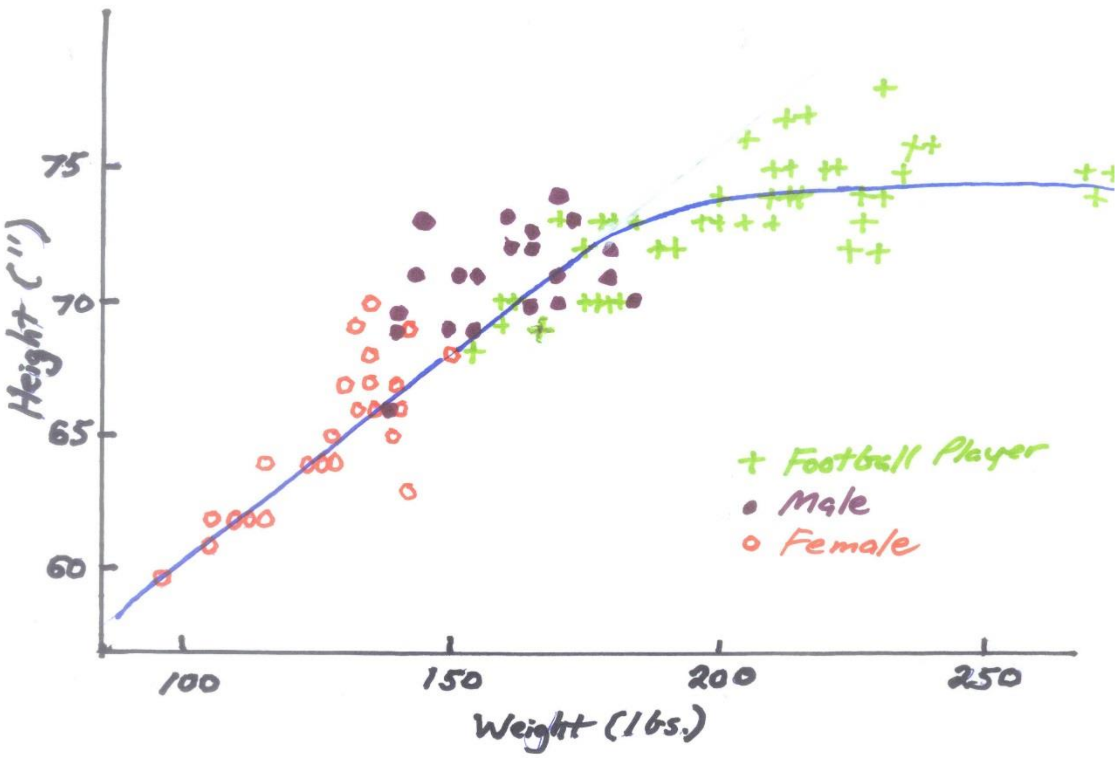


Figure 15. *Heights and weights of college students and football players combined. The solid blue line represents a suggested trend line drawn through the data.* ***Original.***

The Nearest Stars

In 1911, the Danish astronomer Ejnar Hertzsprung was the first to plot such a diagram. In 1913, the American astronomer Henry Norris Russell independently made a similar analysis. We call these diagrams Hertzsprung-Russell diagrams or H-R diagrams. Today they are one of the most powerful tools in astronomy and astrophysics. *For historical reasons the temperature scale on an H-R diagram is always plotted backwards, from high photospheric temperature on the left to low photospheric temperature on the right.*

Notice that all of the nearest 37 stars to the Sun in Figure 17, except for Sirius B (the binary companion to Sirius A), fall on a trend line, which astronomers call the main sequence. *Sirius B has nearly the same temperature as Sirius A but is more than 10,000 times less luminous. This main sequence trend is not exact, but it does show a basic relationship between a star's luminosity and its photospheric temperature. Notice that of the 37 nearest stars to the Sun only five are more luminous than the Sun. A typical solar neighborhood star is less luminous than the Sun; many are less than 1% of the Sun's luminosity.*

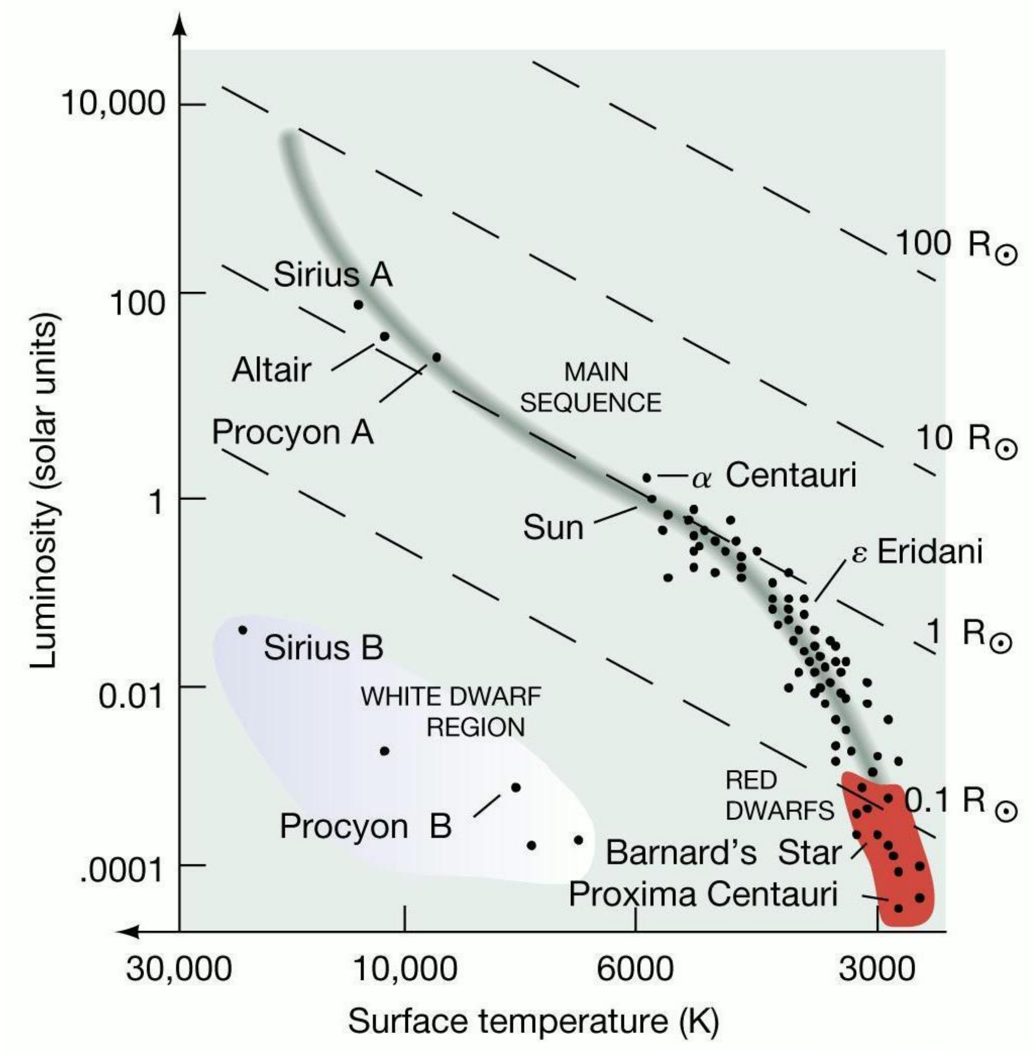


Figure 17. The H-R diagram of the 85 nearest stars. The H-R diagram for the 85 nearest stars is drawn with lines of constant stellar radius. Main sequence stars are generally smaller than one solar radius in size**. Chaisson.**

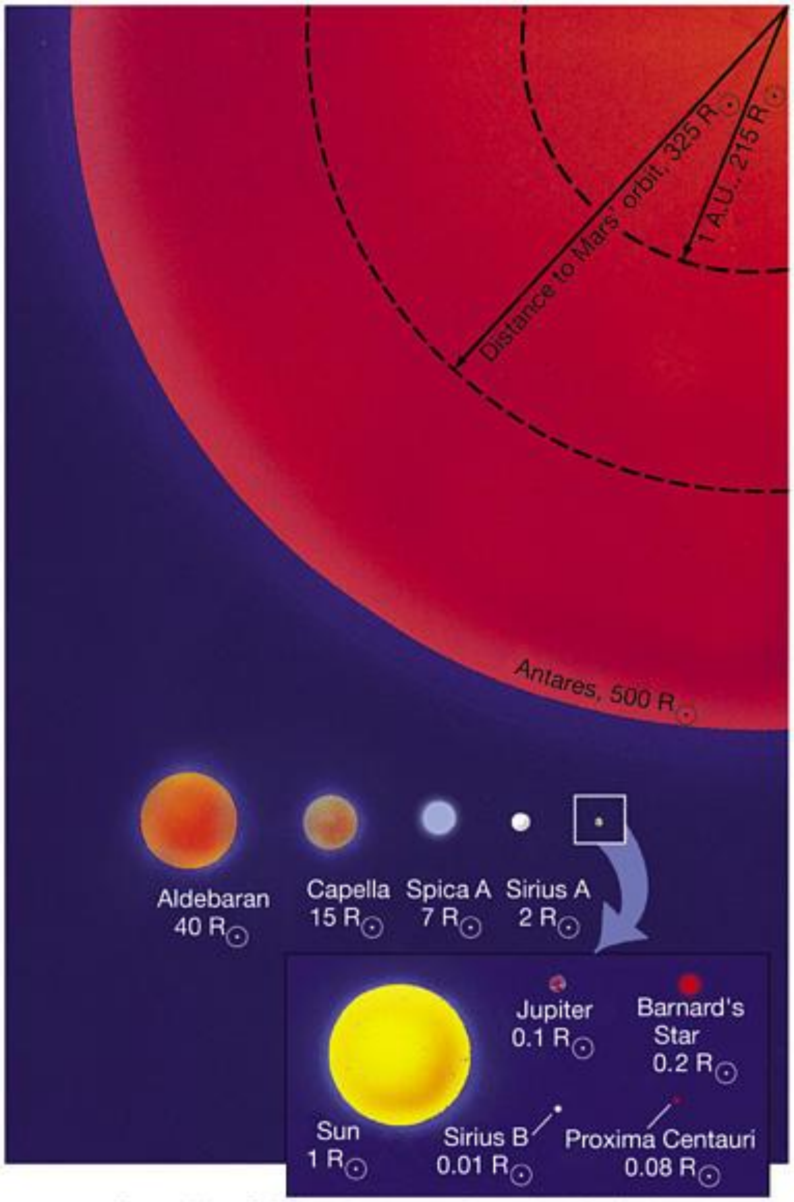


Figure 18. *The relative sizes of stars representing a selction of the brightest and nearest stars to the Sun. Radii range from 500 solar radii (Antares) to Proxima Centauri (0.08 solar radii).* ***Chaisson.***

Each point on the H-R diagram represents the luminosity and photospheric temperature of an individual star.

There is a relationship between stellar luminosity, photospheric temperature and stellar radius given by Equation 17.2, which can be written as:

Equation 17.3: $L = 4\pi R^2 T^4$.

Given the photospheric temperature and luminosity for each point in the H-R diagram, we can determine its stellar radius.

Figure 19 shows the H-R diagram for the 100 nearest stars with lines of equal radius.

The main sequence trend follows a trend of nearly constant stellar radius. The main sequence have nearly the same size, differences in their luminosity are a result of differences in photospheric temperature.

The Brightest Stars

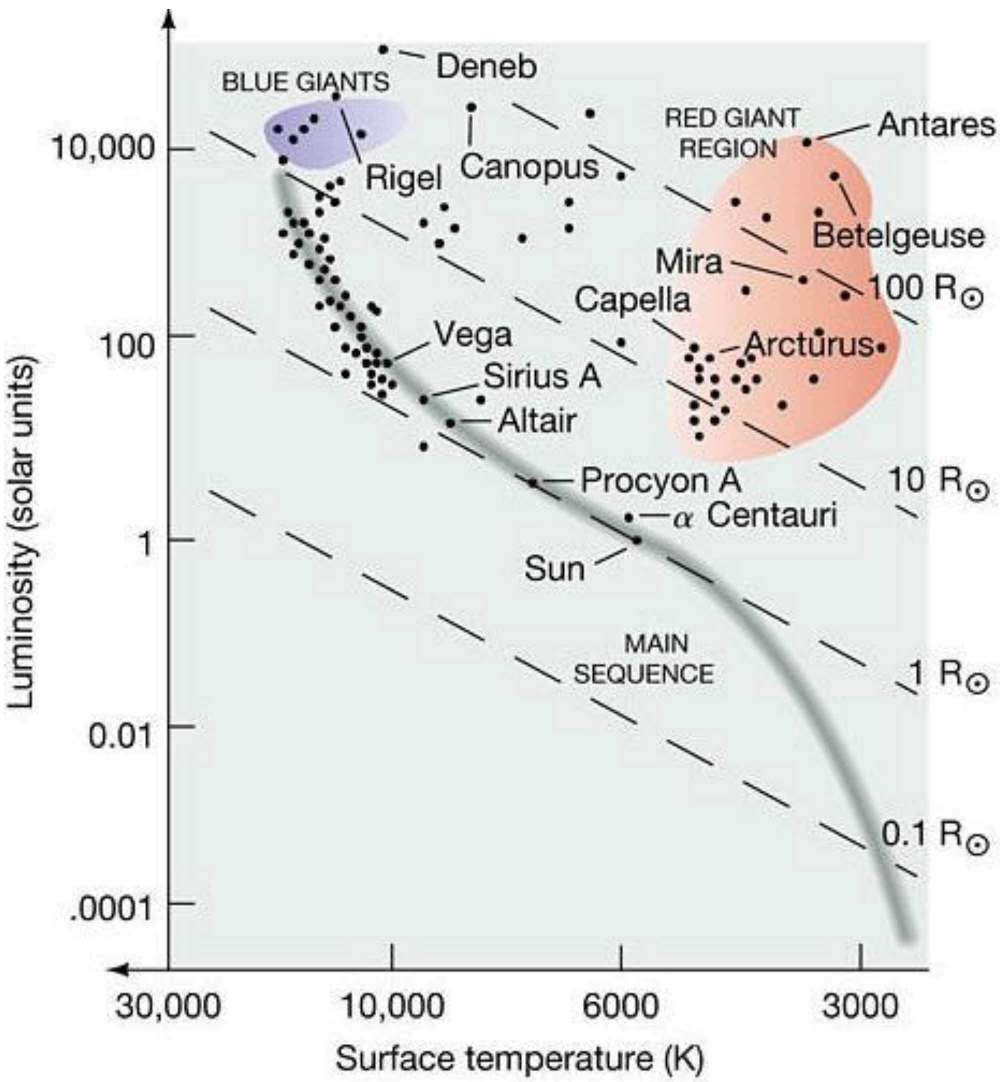


Figure 19. *The H-R diagram of the 100 stars in the sky with the greatest apparent brightness. This H-R diagram is drawn with lines of constant stellar radius. All of the brightest stars have a luminosity at least as great as the Sun.* ***Chaisson.***

Stars in this corner of the H-R diagram are not only very luminous, but they are very large. These stars are called giants and supergiants. Very small stars occupy the lower left-hand corner of the H-R diagram; they are called white dwarfs.

The Main Sequence: a Mass Sequence

- We have used the H-R diagram to look at the correlation of the fundamental stellar properties of luminosity, photospheric temperature, and radius.
- **How does a star's mass correlate with its position on the H-R diagram?**
- In Figure 19 we see the masses of selected stars marked on the H-R diagram.
- Studying this diagram, it is easy to see that giant and supergiant stars are generally more massive than other stars; the two supergiant stars shown are both about 10 solar masses.
- The white dwarfs are both about one solar mass.
- There is a definite mass trend along the main sequence with the least luminous, smaller stars in the lower right-hand corner having the least mass, changing to more massive, larger, more luminous stars as the main sequence is followed to the upper left-hand corner of the H-R diagram. **The main sequence is a mass sequence.**

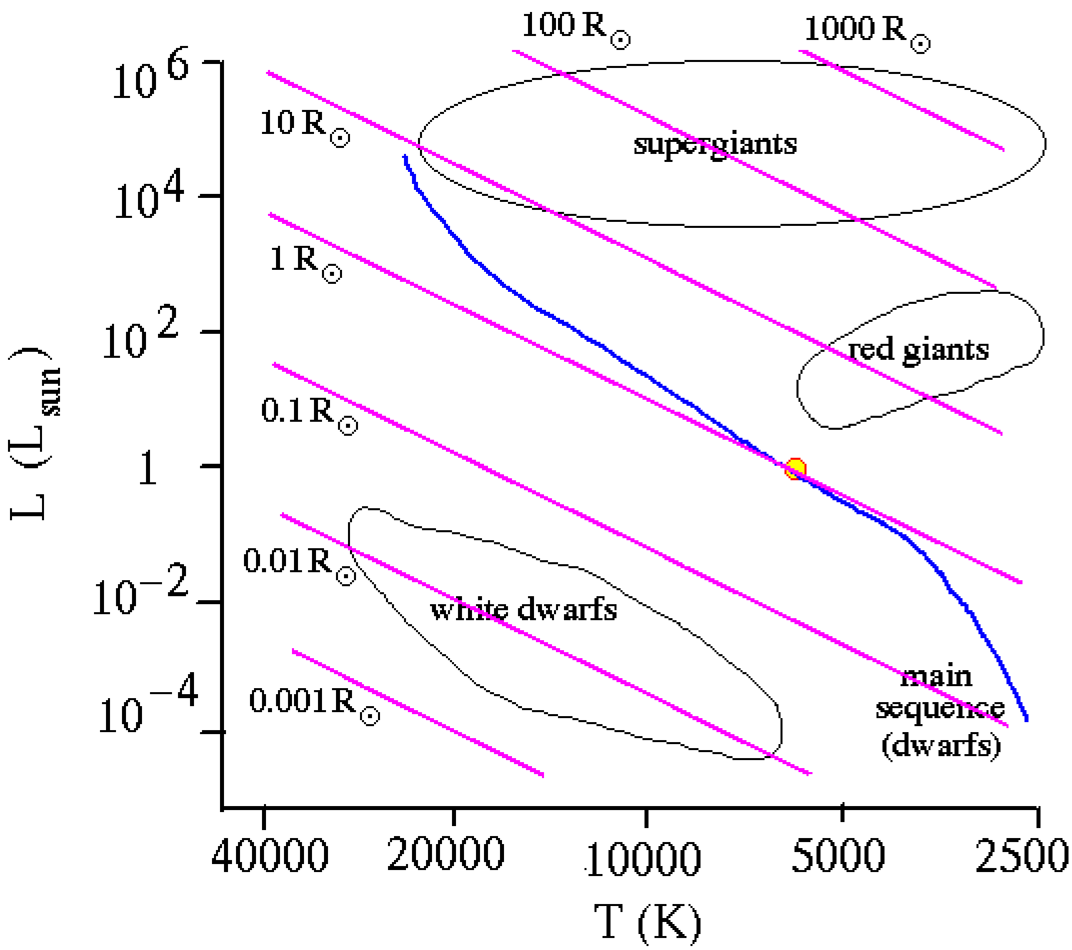


Figure 19. Panel A: A schematic H-R diagram showing the location of main sequence stars, giants, supergiants, and white dwarfs. **Modify.** *From* ***http://abyss.uoregon.edu/~js/ast122/lectures/lec11.html***

Although mass doesn’t change much over the H-R diagram (only varying between 0.1 solar mass and 10 solar masses in this diagram), stellar radii vary by a factor of one thousand, and stellar volumes vary by the stellar radius cubed (or a factor of 1000 x 1000 x 1000 = 1 billion). The result is that stellar densities (mass divided by volume) vary widely, from a supergiant with a density close to that of water to a white dwarf, one tablespoon full of which could weigh a ton.

IIX. Stellar Lifetimes

What can we say about the ages of stars from the H-R diagram?

How long can a star live?

Let's assume that stars fuse their nuclear fuel at a constant rate. The estimated longevity of a star is then the mass of the star, the amount of nuclear fuel available, divided by the rate that it burns this fuel, which is proportion to its luminosity.

Equation 17.4: lifetime = constant of proportionality x mass /luminosity,

What is the constant of proportionality? We have estimated 10 billion years for the expected lifetime of the Sun. If we **Equation 17.4** to solve for the lifetime of the Sun, and use solar mass, solar luminosity, and years for our units of mass, luminosity, and age, we obtain the following:

10 billion years = constant of proportionality x 1 solar mass / 1 solar luminosity,

or constant of proportionality = 10^{10} years x solar luminosity/solar mass,

Equation 17.5: lifetime = 10^{10} years x mass/luminosity,

where mass is in units solar mass and luminosity is in units of solar luminosity.

How long are a 10 solar mass main sequence star and a 0.1 solar mass main sequence star expected to live (i.e. fuse hydrogen into helium)?

- From Figure 19 we see that a 10 solar mass main sequence star has a luminosity of about 3000 times the luminosity of the Sun. From Equation 17.5 we have:

- Lifetime of a 10 solar mass star = 10^{10} years x 10/300 = 3 x 10^{7} years.

- From Figure 20, a 0.1 solar mass main sequence star has a luminosity of only one-thousandth of the Sun's luminosity, so:

- Lifetime of a 0.1 solar mass star = 10^{10} years x 0.1/0.001 = 10^{12} years.

These ages are summarized in Table 17.2.

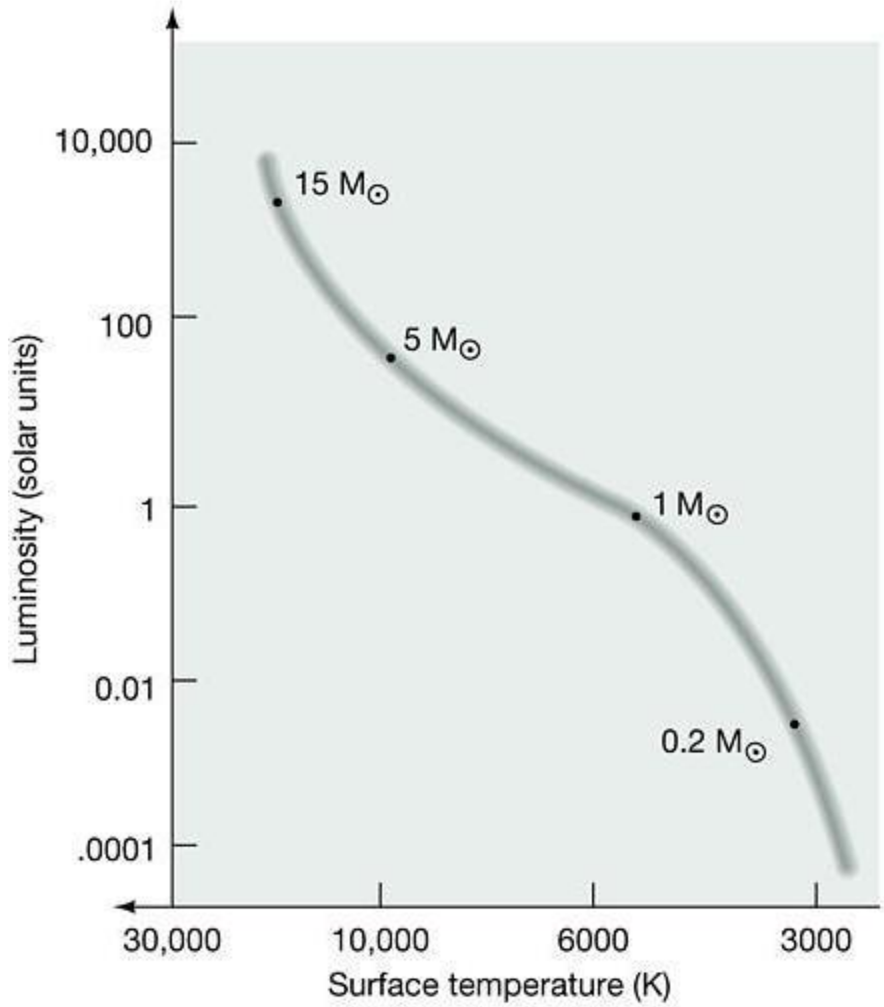


Figure 19. *Masses of stars on the main sequence. Notice that the main sequence is a mass sequence with the least massive stars the least luminous and the most massive the most luminous.* ***Chaisson. Modify to add masses of giants, supergiants and white dwarfs.***

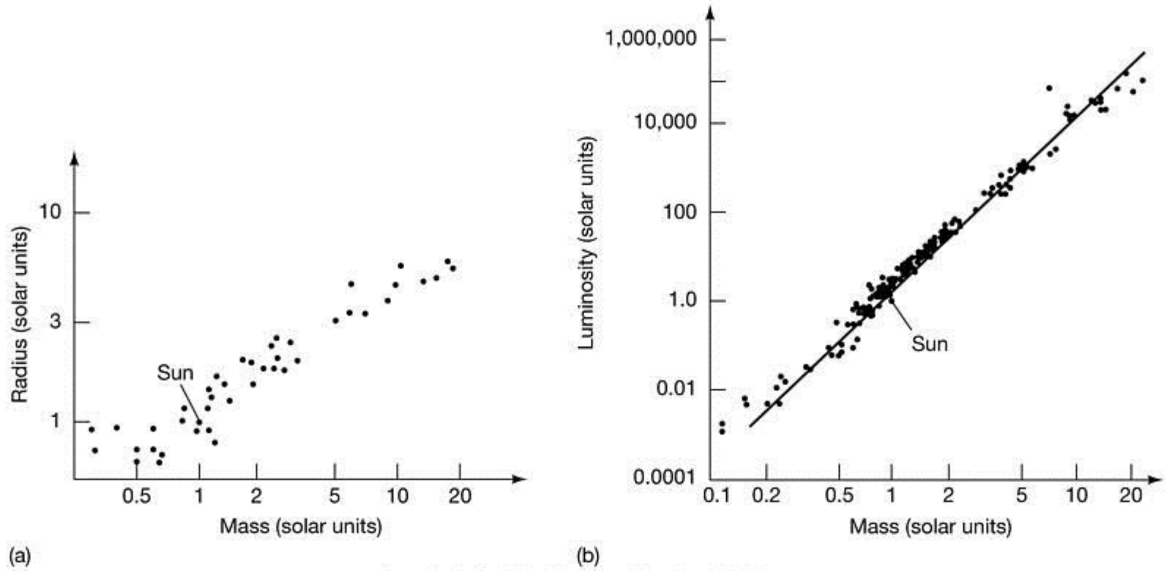


Figure 17. *The mass-luminosity and mass-radius relationship for main sequence stars.* ***Chaisson.***

Table 17.2 *Lifetimes of Stars on the Main Sequence*

Stellar Mass	Stellar Luminosity	Stellar Lifetime
10 solar masses	3000 solar luminosities	3×10^7 years
1 solar mass	1 solar luminosity	10^{10} years
0.1 solar mass	0.001 solar luminosity	10^{12} years

Stellar ages for stars on the main sequence vary by a considerable amount, mainly because high mass stars burn their fuel at an incredible rate, far out of proportion to their mass, while low mass stars have a low nuclear metabolism.

Class	Photospheric Temperature	Wavelength of Peak Emission
O	> 25,000 K	Ultraviolet
B	11,000 – 25,000 K	Ultraviolet
A	7,500 – 11,000 K	Blue
F	5,000 – 7,500 K	White to blue
G	5,000 – 6,000K	Yellow to white
K	3,500 – 5,000 K	Red to orange
M	< 3,500 K	Infrared to red

Table 18.2: *Stellar Temperature Classes*

Star Clusters

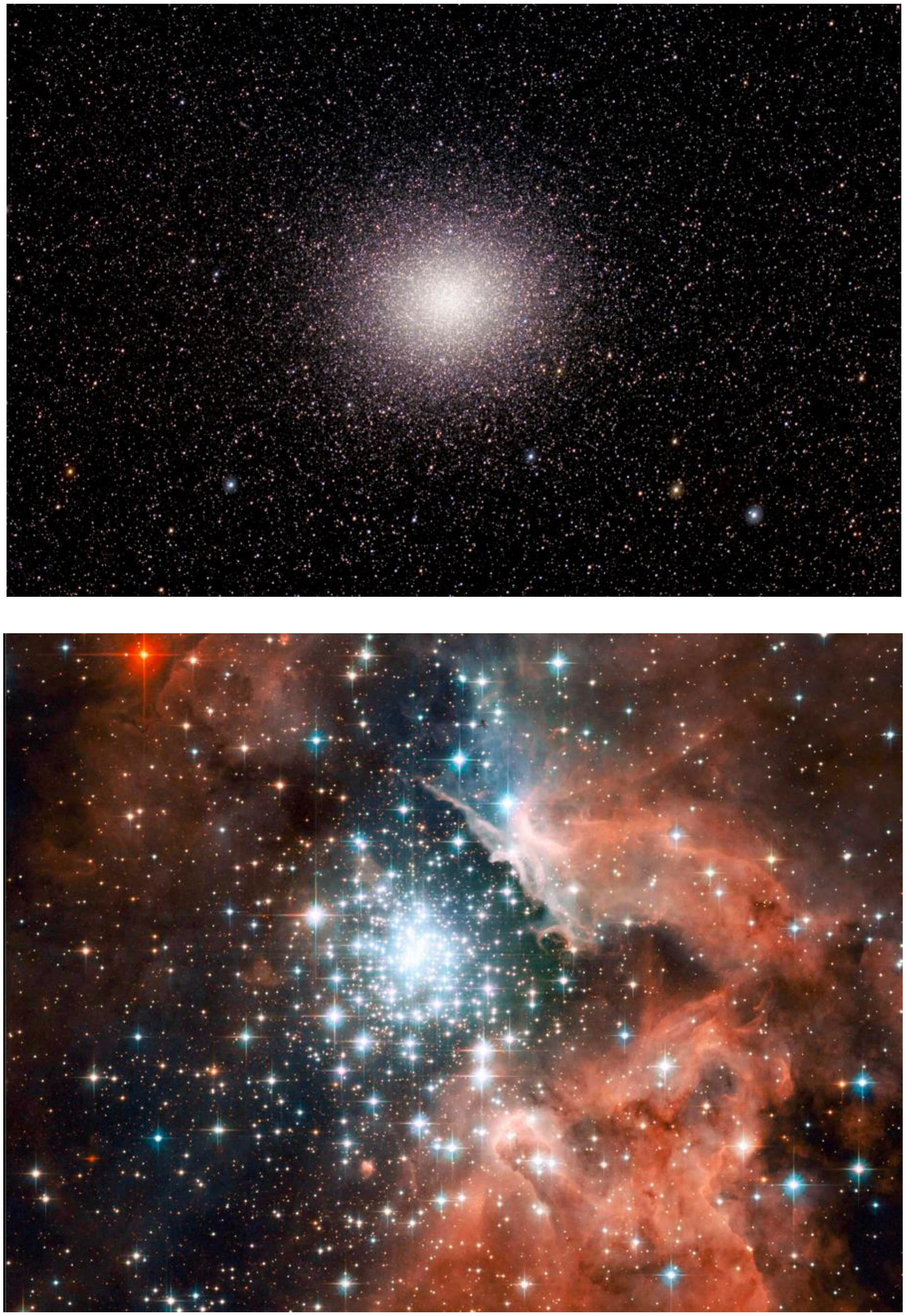


Figure 21. *Star clusters.* ***Panel A****: The largest known globular cluster, Omega Centauri. This image is approximately 90 light years across and contains roughly 10 million stars.* ***APOD, Fred Lehman. Panel B:*** *The Jewel Box, a young open star cluster approximately 8,000 light years distant.* ***NASA, HST.***

- The key in studying the evolution of stars is the comparison of H-R diagrams of star clusters.
- Star clusters are groups of stars that were born at roughly the same time and place, having gravitationally condensed out of a single cloud of gas and dust.
- Because the stars formed at the same location, they are at the same distance. This makes it easy to measure their relative luminosities.
- Because they formed at nearly the same time, this makes it easy to determine which stellar properties are not age-related.
- Studying a series of star clusters of differing ages is like studying the evolution of humans by taking year-book pictures of students from different grades, say pre-school through seniors in college, and determining which physical features change with age and which don't.

Summary

1. Some of the fundamental properties of stars are mass, diameter, photospheric temperature, distance, composition, and luminosity.
2. The distance to a nearby star can be measured from its parallax. From its apparent brightness and distance its luminosity can be determined, using the inverse-square law.
3. The photospheric temperature of a star can be measured using filter photometry and applying Wien’s law relating color and temperature.
4. Spectroscopy can also be used to determine the photospheric temperature of a star in addition to its composition.

5. Once the photospheric temperature and luminosity of a star are determined, the Stefan-Boltzmann law can be used to derive its diameter.

6. One of the most powerful methods of analyzing the structure and evolution of stars is through the Hertzsprung-Russell diagram, a plot of the luminosities and photospheric temperatures of a group of stars.
7. Most stars fall along a line in the H-R diagram called the main sequence.
8. The main sequence is a mass sequence, representing the trend that the more massive a star is, the more hot and luminous it is.
9. Stars on the main sequence are nearly the same diameter as the Sun. A star's lifetime on the main sequence is proportional to its mass divided by its luminosity.
10. Because massive stars are luminous well out of proportion to their mass, they have much shorter life spans than low mass stars.