The Nature of Stars

In this class, we shall attempt to understand how we can determine the nature of stars, i.e. their **physical properties**.

Historically, most of this occurred in the second half of the 19th century and the early 20th century due to advances in telescopes, photography, and instruments to measure spectra (spectrometers) and brightness (photometers).

- Stars are so incredibly far away **(LC)** compared to the planets in our Solar System that even the largest telescopes can't resolve them, i.e. they appear as points of light.* *(we'll learn today how we to determine the distance to some stars.)*

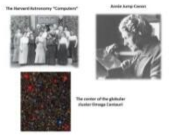
- A few stars are about 5 ly away; most are even more distant.
  Since they're so far away, you might wonder how we can determine anything about their properties. **Today we'll see how to determine for a star:**

  - **Surface Temperature**
  - **Luminosity (Brightness)**
  - **Distance**
  - **Radius**
  - **Mass**
  - **Chemical composition**

*in 2010 this changed when the red supergiant Betelgeuse was imaged using IR interferometry.

<u>Spectral Type and Surface Temperature</u>

In the 1890’s, a group of female astronomers at the Harvard Observatory were classifying stars by color and features in their absorption spectra into different classes. *They examined the spectra of 350,00 – 400,00 stars!* The final scheme is credited to **Annie Jump Canon** who devised the **Stellar Classification Scheme based on absorption lines**:



O B A F G K M

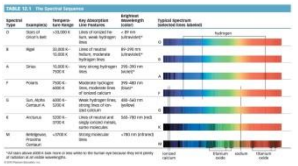
(How do you remember this? **O**h, **B**e **A F**ine **G**irl (. . . or **G**uy), **K**iss **M**e)

Canon also added 10 subdivisions for each type in this scheme, e.g:

. . . F9, G0, G1, G2, G3, . . ., G8, G9, K0 . . .

Sun

It was not known at the time, but **this classification scheme is a representation of Surface Temperature** where type **O** is hot and Type **M** is cool.



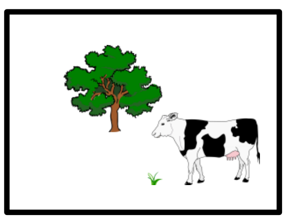
So, determining a star’s <u>Spectral Class</u> uniquely determines its <u>Surface Temperature</u>.

The Distances to Stars

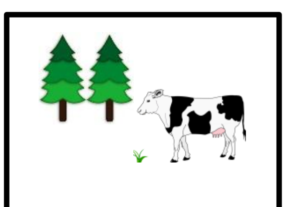
- The problem of determining the distance to an object is probably the oldest problem in astronomy and is still one of the most difficult and controversial.
- An object can be intrinsically bright (i.e. high luminosity) but appear faint if it is far away; likewise an intrinsically faint object (low luminosity) can appear bright if it is nearby.
- We will talk about many ways to determine distance to astronomical objects, not all of them work for all objects.

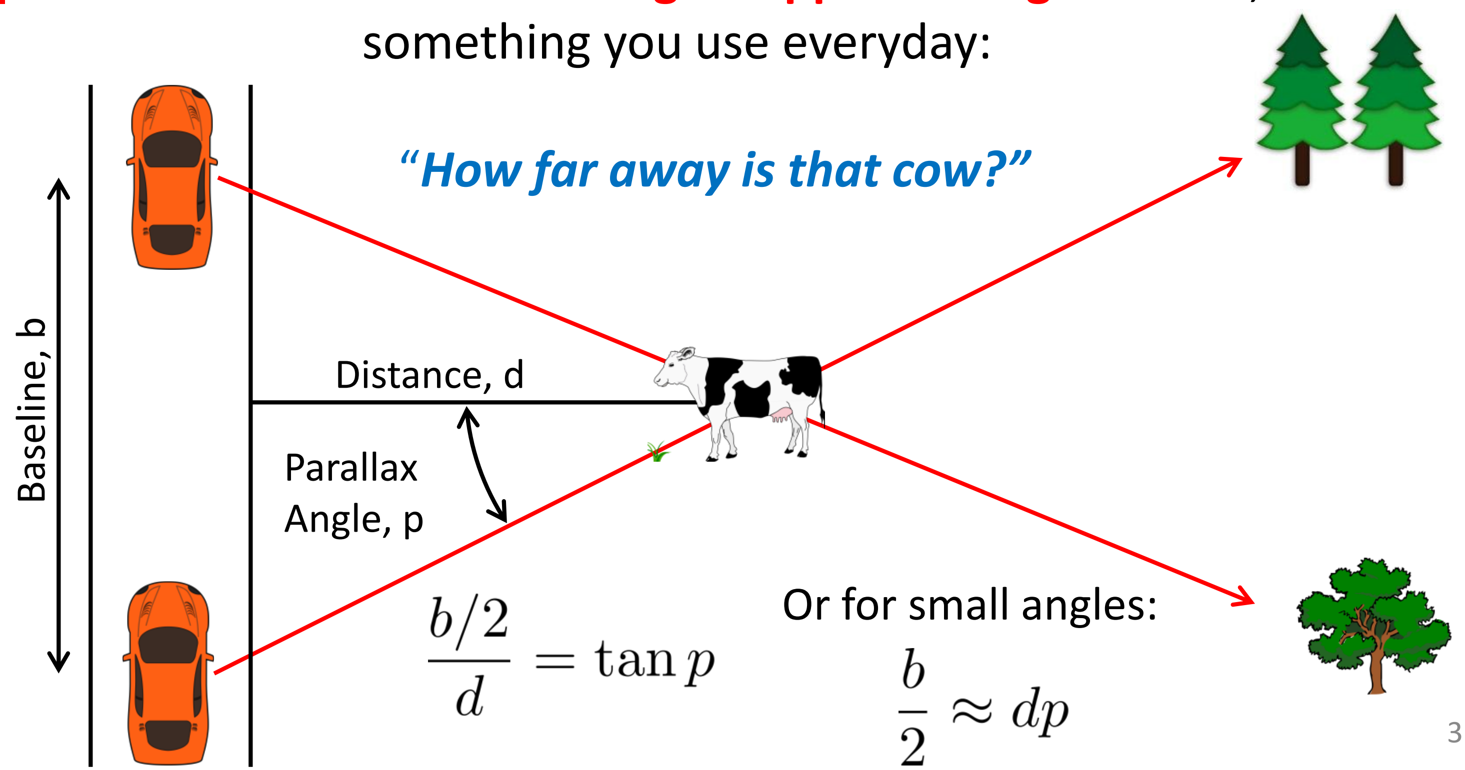
Stellar Parallax: distance measurement using an apparent angular shift, something you use everyday:

What you see



What you see

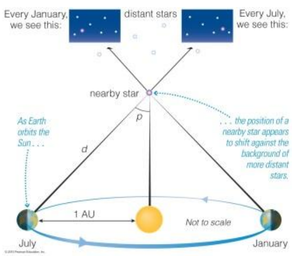




$$\frac{b/2}{d} = \tan p$$

$$\frac{b}{2} \approx dp$$

The Distances to Stars



In astronomy, parallax works the same way:

- But parallax angles of stars are all very small, less than 1 second of arc (1'') – that means they are very far away.

- When using parallax, it is convenient to define a **new unit of distance:**

1 Parsec (pc) = distance that 1 AU subtends 1'' = 3.26 light years

- This is handy when working with parallax angles in arc seconds since

distance in pc = 1/(parallax angle in arc seconds)

So, the nearest stars are about 5 ly away, what are their parallax angles? **(LC)**

(5 ly ~ 2pc; p~1/2 ~ 0.5 ''; this is why the measurements of stellar parallax weren't successful until 1838)

(What about this blooper by Han Solo in the original Star Wars?)

- **Parallax is our only <u>direct</u> way to measure the distances to stars;**

For ground-based observations, it works out to about 1500 ly (~460 pc); beyond that the parallax angles are too small to measure. *(What can the GAIA spacecraft do? Thousands of pc)*

<u>Brightness and Magnitude</u>

In astronomy, there are **two measures of brightness that are important:**

- **How bright an object appears from Earth = Apparent Brightness**
  <u>or</u> Apparent Magnitude
- **Intrinsic brightness = Luminosity <u>or</u> Absolute Magnitude**

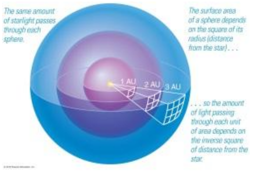
And to make things really confusing, there are **<u>two ways to measure these</u>**:

<u>AstroPhysics Way</u>:

- **Luminosity (L)** is the total energy emitted in radiation per unit time in Watts.

- **The Apparent Brightness (in Watts/m^2)** is how bright the object appears when seen from some distance, d, which is related to the luminosity by the inverse square law for radiation:

$$\text{Apparent Brightness} = \frac{L}{4\pi d^2}$$



so an object appears fainter as the square of its distance; e.g.

(LC) **If an object is moved two times further away, how does its apparent brightness change?**

It is four times fainter.

Brightness and Magnitude

Astronomy Way (. . . *to make things really confusing*):

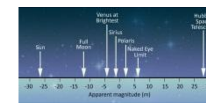
- More than two thousand years ago, the Greek astronomer Hipparchus put stars into brightness categories – as seen from the Earth:

Brightest stars
"First Magnitude"

Faintest stars
"Sixth Magnitude"

1 2 3 4 5 6

- So, **Apparent Magnitude (m)** is the brightness of a star on this magnitude scale.
- But, the scale runs backwards, and it extends to objects brighter than m = +1 and fainter than m = +6; regardless, it's widely used by astronomers.



- Today, a difference of 5 magnitudes is defined to be a factor of 100 in brightness in Watts/m^2.
- *(to make matters worse. .)* Astronomer's also use **Absolute Magnitude (M)** to measure a star's intrinsic brightness. **M is the magnitude the star would have if it were at a reference distance of 10 parsecs.**
- So, we have two different scales that measure the same things:

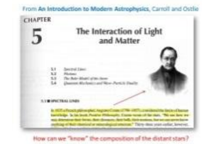
Luminosity (Watts)	⟷	**Absolute Magnitude**
Apparent Brightness (Watts/m^2)	⟷	**Apparent Magnitude**

Important Point: to know a star's Luminosity or Absolute Magnitude, you must know its distance.

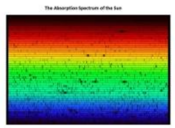
The Composition of Stars

How can we ever "know" the composition of the distant stars? **(LC)**

Answer: by analyzing their spectra!



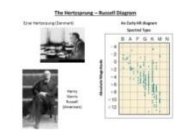
When astronomer's examined the spectra of stars, they saw absorption lines for just about every atom on the periodic table, and for some molecules in the case of lower temperature Type M stars.



- Does this mean that stars are made up of all of these chemicals?
- If they are, then the composition of stars would be similar to planets.
- **In 1925, Cecilia Payne-Gaposchkin** applied the new physics of atoms (quantum mechanics) with the also new theory of ionized gases (plasma physics) to show that:
  - **even though absorption lines of just about everything can be found in stellar spectra, the dominant chemicals by mass are hydrogen and helium.**

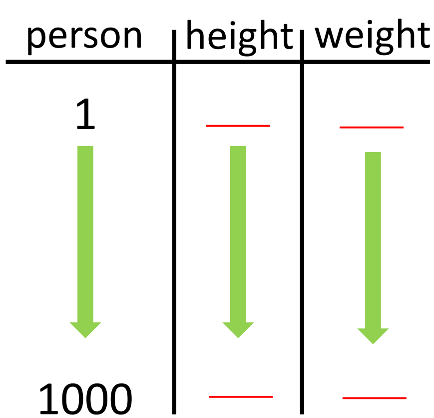
The Hertzsprung-Russell (HR) Diagram

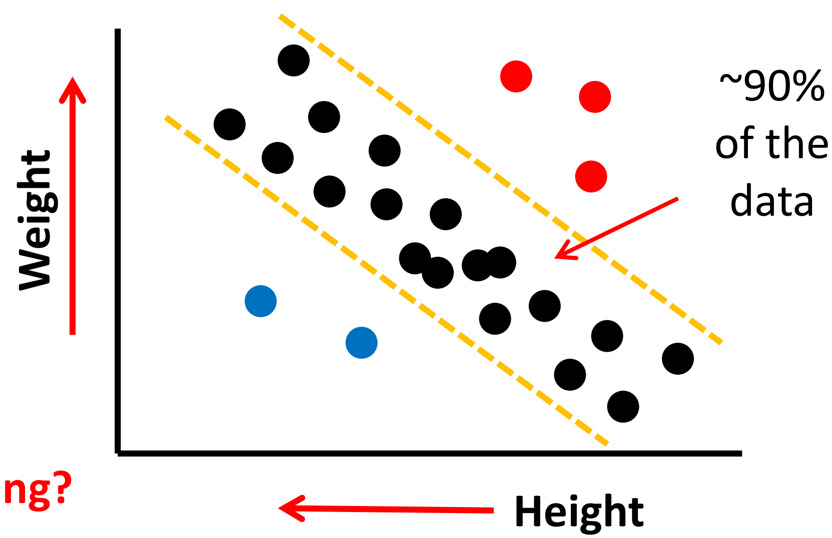
- In the early 1900's, a Danish astronomer (**Hertzsprung**) and an American (**Russell**) independently began to place stars on diagrams showing their spectral type and absolute magnitude.
- These diagrams are now called **Hertsprung-Russell Diagrams**, . . . *and thank goodness everyone just calls them* ***HR Diagrams****.*
- **What is an HR diagram?**



Consider an Analogy:

- Suppose you randomly select 1000 people and measure their height and weight.
- You might then put your data in a table.
- Then you might make a plot of your data.





What is this graph saying?

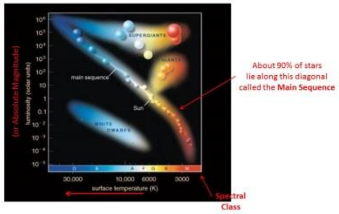
For most cases (~90%): tall people weigh more and short people weigh less.

The HR Diagram for Stars

Take a sample of stars for which we can measure a distance, and determine:

- **The Surface Temperature or Spectral Class**
- **The Luminosity or Absolute Magnitude**
- **Make a plot**

The Basic HR Diagram



What is this plot saying?

- **Most stars (~90%) are on the diagonal band called The Main Sequence; for these stars:**

  Hot stars are brighter (more luminous), and
  Cool stars are fainter (less luminous).

- Some stars (Giants, Supergiants, and White Dwarfs) are above and below the Main Sequence – we'll have to explain these.

We'll see that the HR diagram is an extremely useful tool for studying the life histories of stars – i.e. Stellar Evolution.

The Sizes of Stars

- For any star that we can see in a telescope, **we can always determine**:
  1. **The Apparent Brightness or Apparent Magnitude**
  2. **The Spectral Type or Surface Temperature (T)**

- If the star is within about 1500 ly, **we can determine its distance, d, by parallax**.

- If we know the apparent brightness or magnitude and the distance d, **we can determine the Luminosity (L) by the inverse square law**.

- Finally, if we know the **luminosity (L)** and the **temperature (T)**, **what can we calculate for the star? (LC)**

  The radius (R) of the star. . . ***How the hell do we do that?***

Assume the star radiates as a black body:

$$L = (\text{surface area}) \times \sigma T^4 = 4\pi R^2 \sigma T^4$$

$$R = \sqrt{\frac{L}{4\pi\sigma T^4}}$$

Binary Stars and Stellar Mass

- **Binary stars are two stars bound by gravity that orbit their common center of mass**

PhET

- There are types of binaries that are named by how they are detected: **visual, astrometric, spectroscopic, and eclipsing**, **but they're all the same thing: two stars orbiting each other. The ways to detect binary stars is exactly the same as how we detect extrasolar planets – only much easier.**

- **The important thing about Binary Stars is that measuring the properties of the orbits allows us to:**

Determine Stellar Masses

As of now, this is our only way of measuring masses of stars, and, as we'll see, the mass of a star is its most important property.

Luminosity Class and Patterns

- Besides Spectral Class, astronomers use **Luminosity Class to denote where a star is on the HR Diagram** (it's actually based on the density of gas at the surface of the star):

TABLE 12.2 Stellar Luminosity Classes

Class	Description
I	Supergiants
II	Bright giants
III	Giants
IV	Subgiants
V	Main-sequence stars

- Now, when we compare stars, we begin to see patterns.

- **And when we put all of these properties on an HR Diagram**, the patterns really become evident. *(By the way, this is about the nicest HR Diagram that I've ever seen! We'll talk about the Main Sequence Lifetimes in the next class.)*