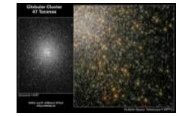
Stellar Evolution 1



- Last class, we covered how we can determine the physical properties of stars, e.g. temperature, distance, brightness, composition, mass, and radius. With the discovery of nuclear fusion in the early 20th century, theorist began to piece together the story of stars: **i.e.** **Stellar Evolution.**

- **The word Evolution might cause some confusion here.**
  In biology, evolution refers to changes in a species where the change is over many generations. The individual organism does not change or evolve.

- In astronomy, Stellar Evolution means: **The life history of an individual star from birth, to middle-age, to death.**
  Often we talk about *"The Eternal Stars",* but modern astronomy has revealed that while most stars are long-lived, they are far from eternal.

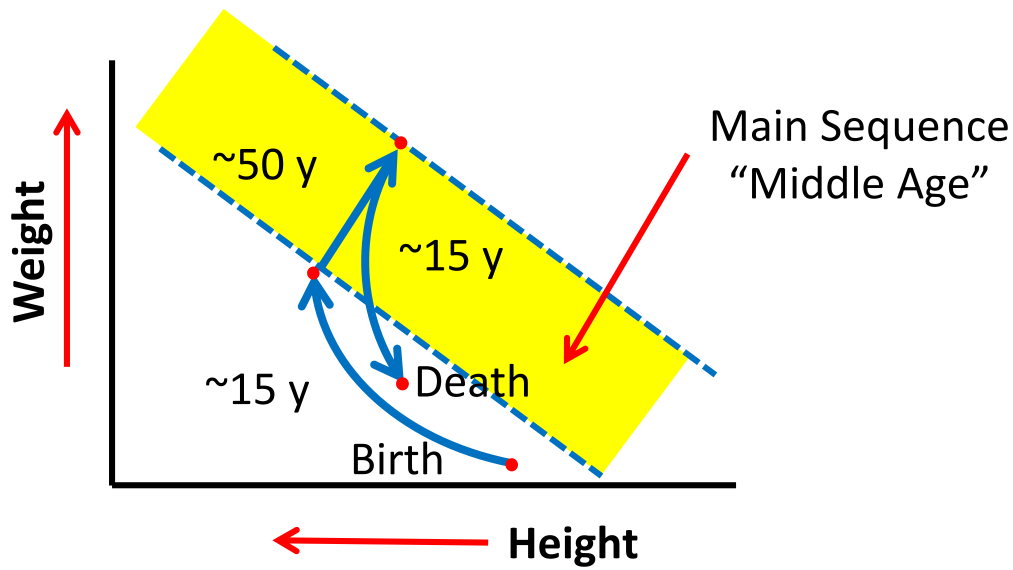
- The **main difficulty** in studying stellar evolution is the simple fact that
  stars live a long time, and we don't.
  How can we observe a star evolving? *(like we could for a squirrel.)*

- We observe different stars in different stages (*like a snapshot of people in a park*), and then piece the details together.

Stellar Evolution 1

- **One of the principal tools that is used to study stellar evolution is the HR Diagram**. As a star evolves, its luminosity and surface temperature change, and *it "moves" on the HR diagram*.

- For example, consider our analogy of the **"People HR Diagram"** from the last class. We could trace out the evolutionary track for an individual on this diagram:



- What determines a person's track on this "HR Diagram"? All kinds of things.
- **What stellar property determines a star's evolutionary track on the stellar HR diagram? (LC)**

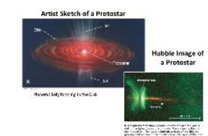
The star's mass *(with a small dependence on chemistry.)*

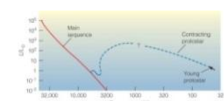
Star Formation

- **Stars form in large** (many ly across) **cool clouds of gas** (mostly molecular Hydrogen and Helium) **and dust** (mostly Carbon) known as the interstellar medium. **How do we observe this?**

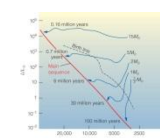
- **How does it happen?**
  Most clouds are in hydrostatic equilibrium, and require a trigger to initiate the gravitational collapse, e.g. a shock wave from a nearby supernova or passing through a galactic density wave (more on this later).

- A single cloud can form many protostars which are clouds 100's of AU in size. At its center, the protostar contracts, heats, and gives off radiation. The surface of the protostar is still cool and radiates in IR.





- When the temperature and density at the core reaches fusion conditions, Hydrogen to Helium fusion begins, hydrostatic equilibrium is achieved, the star arrives at the Main Sequence, and the actual star is born.



- Like everything about stellar evolution, the time of the protostar stage and the final location on the Main Sequence is determined by the Mass.

An excellent summary of stellar formation

Main Sequence Lifetime of a Star

- How long will a star stay on the main sequence? But first, what condition **marks the end of the star's Main Sequence Lifetime (MSLT)? (LC)**
  Ans: The star will stay on the main sequence until all of the hydrogen in the core is fused into helium.

- The Main Sequence Lifetime (MSLT) is determined by two factors:
  1. **The amount of hydrogen the star had to start with**
  2. **The temperature of the core – which is higher for higher mass stars and the fusion rate depends sensitively on the temperature.**

- Item 2 above dominates over item 1, so higher mass stars actually have very short MSLT's. **For a star of mass M:**

$$\text{MSLT} \approx [10 \text{ billion years}] \left(\frac{M_{\text{sun}}}{M}\right)^{2.5}$$

So:

$$\text{For } M = 1.0 M_{\text{sun}} \rightarrow MSLT \approx 10 \text{ billion years}$$

$$\text{For } M = 0.5 M_{\text{sun}} \rightarrow MSLT \approx 30 \text{ billion years}$$

$$\text{For } M = 20 M_{\text{sun}} \rightarrow MSLT \approx 10 \ \textbf{million} \text{ years}$$

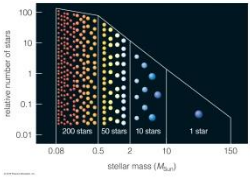
Star Formation: Observations

- Now that we have Infrared telescopes (e.g. Spitzer) in space, star formation has has become a very active area for observers.
  For example, M42, the Orion Nebula. (and Webb will do even more)

- But, this a bit misleading. **The observations are a snapshot at one instant of time**. Here's a simulation that shows how dynamic a star forming region is. The simulation spans about 250 thousand years.

- Here's the same simulation (~250 ky) at better resolution that runs without the breaks. *Each bright dot is a newly formed star. There's a lot going on inside these clouds! And remember, planets are likely forming in disks around the newly formed stars.*

- In a star forming region, what sizes of stars are formed?
  (This distribution of stellar masses is know as the **"Initial Mass Function"**)



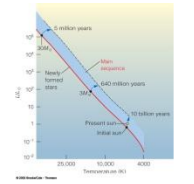
Low mass stars form in the greatest number with very few high mass stars.

Stars on the Main Sequence

- Once steady H to He fusion begins in the core of the star, it has reached the Main Sequence – **Stellar Middle Age**.

- **Why are most of the stars that we see on the Main Sequence? (LC)**
  That's where stars spend most of their lives (~90%), so it is more likely that we find them there.

- Stars do change slightly while on the Main Sequence. As helium builds up in the core, the fusion rate slowly changes which causes the surface temperature and luminosity to slowly change, and the star slowly moves on the HR diagram. **So the Main Sequence is a band not a line.**



- Compare the times on this HR diagram to the formula we had before:

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