Lecture 30 – 3  How the Stars Shine: Cosmic Furnaces  
21 March, 2012  (Read Chapter 12 as background for lecture notes.)

Note: Each of the 5 phases of stellar evolution will be discussed in detail using a similar format.

I. Timescales

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning</td>
<td>start of gravitational collapse from a rotating cloud of gas and dust</td>
</tr>
<tr>
<td>End</td>
<td>arrival on the main sequence with the start of $4\text{H} \rightarrow \text{He}$ fusion in the core</td>
</tr>
<tr>
<td>Duration</td>
<td>the protostar phase is very short (&lt;0.1%) compared to the total lifetime of the star.</td>
</tr>
</tbody>
</table>

Examples:

- $10 \text{ M}_\sun$ 
- $1 \text{ M}_\sun$ 
- $0.1 \text{ M}_\sun$ 
- $10^7$ yrs 
- $10^7$ yrs 
- $10^8$ yrs 

II. Birthsites

Giant Molecular Clouds (GMCs) -- Stars are born typically in small groups or larger clusters inside GMCs of gas and dust. Typical GMCs contain between $10^5$ to $10^6 \text{ M}_\sun$ of material composed primarily of H and He ($\sim 75\%$ H, $23\%$ He, $2\%$ all other atoms). GMCs are cold (20-40 K) and are usually opaque to visible light.

Groups and Clusters -- The majority of stars are born as part of a small group of stars (few to tens), or a cluster of stars (few hundred to few thousand). The birth of a group or cluster occurs when part of the GMC becomes unstable and collapses under its own gravitational forces; such a region is called a GMC core.

Stellar Mass Spectrum -- whether in groups or clusters, the stars formed have a range of masses, typically from a low of $\sim 0.1 \text{ M}_\sun$ up to $\sim 40 \text{ M}_\sun$. The graph that describes the relative numbers of stars of a given mass is called the stellar mass spectrum. There are many more low mass stars than high mass stars.

Singles and Pairs -- within groups and clusters, stars form either as a single star (like our Sun), or as multiple star systems of 2 or more stars that are bound together for the lifetime of the stars. The relative numbers are $\sim 50\%$ singles, $\sim 40\%$ doubles, $\sim 10\%$ triples or more

III. Early Protostar Phase

Mass-loss -- all stars begin their gravitational collapse with about twice the mass that they will eventually end up with when they reach the zero age main sequence. During their collapse they go through a phase of rapid mass loss where mass is ejected from the collapsing system in the form of bipolar jets. Such stars are commonly referred to as either T Tauri stars or Herbig-Haro (or HH) objects. Much of this phase is heavily obscured from optical view, and can most easily be detected in infrared or radio emission which can escape from the cloud relatively unhindered. What light does manage to escape is in the form of scattered radiation from the atoms of gas (mostly H, He, C, N, O, etc) surrounding the protostar, and the colorful glow from these objects is sometimes referred to as an emission nebulae or reflection nebulae.

IV. Final Protostar Phase

Zero Age main Sequence -- The end of the protostar phase occurs when the central temperature of the protostar is high enough ($> 10$ million K) to ignite the fusion of $\text{H}$ nuclei to form $\text{He}$. The energy released ($4\text{H} \rightarrow \text{He} + \text{energy release}$) from this most simple of nuclear reactions acts to halt the gravitational collapse, and the star reaches a stable size and surface temperature determined entirely by the total mass of the star.

V. H-R Diagram

The best way to keep track of the evolution of a group or cluster is to plot luminosity and surface temperature of the individual stars on an H-R diagram. 2 examples are given below for clusters of age $10^7$ yrs and $10^8$ yrs: