Lecture 23

Star Formation;
Life on the Main Sequence

Protostars
Pre-Main Sequence Stars
Forming Star Clusters

The Story so far..

• Stellar Properties:
  – The most massive Main Sequence Stars are the biggest and most luminous
  – Off Main Sequence no obvious relationship between position on HR and mass

• What is the Main Sequence?
  – Stars that (like Sun) are supported by Perfect Gas pressure maintained by fusion of Hydrogen
  – Common because stable and lots of fuel

• What are the others?
  – Supported or fueled differently
  – Stages before or after Main Sequence
Star Conception

- Earliest formation stage found by looking inside "dark nebulae" using infrared and radio astronomy. Dust extinction very small at largest wavelengths, so you can actually see through them.
- Forming star ("protostar") is collapsing cloud of dust and gas. Is heated by matter falling on it. Dust emits infrared light. Molecules in cloud heated and glow in radio. Takes maybe few 100,000 years.
- Biggest barrier to star formation: getting rid of spin (angular momentum)

Star Birth

Current model: spinning cloud settles into hot core plus disk of material in orbit, some of which falls onto hot core.
- Core does not collapse under gravity because of pressure of gas heated temporarily by falling onto core.
- Some place actual "birth" at time it disperses dust/gas "cocoon". Then called "pre-main sequence" star. These stars are to right of main sequence (cooler, larger) since they are still contracting.
- Energy source: gravitational energy resulting from collapsing of material onto core. Not a stable stage.
Pre-Main Sequence Stars

- Lower masses: "T-Tauri" star. The Sun was one of these.
  - Some show massive gas/dust disks, with large winds and "jets" out the poles.
  - Much flare and spot activity stirred up by rapid spin.
  - Takes few million years to "settle onto" main sequence.
    Are planets (and/or binary companions?) leftovers of the disk??

- Higher masses:
  - Collapse very rapidly and reach main sequence before dispersing cocoon. See them bursting out of clouds and forming HII regions.
  - May grow by absorbing smaller forming stars
  - Principle: everything happens faster for higher mass stars

Star Cluster Formation

- Many stars are often formed at the same time in a "cluster" in a very large cloud of interstellar matter. The clouds are so cold that all the hydrogen atoms combine into H₂ molecules:
  (Also see complex hydrocarbons).
- **Giant Molecular Clouds ("GMC")**:
  - Total mass 100,000 - 2,000,000 Mₜₚ
  - Diameter 20 - 100 pc
  - Density 200 H₂ molecules/cm³
  - Temperature 10-50 K
Young Star Clusters

• Star clusters may be formed when collapse of a GMC is triggered by compression from:
  – Overall sloshing around of gas ("density waves")
  – Nearby stellar explosion

• Star clusters are very useful in study of stellar evolution:
  – All the stars are born from the same composition gas
  – All the stars have the same age
  – The only stellar differences are the mass, and how the mass affects the star's appearance at the cluster's age.

• Very young clusters can be identified by having less luminous stars to right of main sequence: they are still settling down.

Evolution after Fusion begins

• What happens after star starts core H fusion?
  – Eventually fuel runs out and gravity wins.
  – How fast and in what stages depends almost entirely on the initial mass.

• Evolving stars: Can predict how star evolves by looking in detail at interior of model (T, P at different depths), and allowing composition to change as fusion proceeds.

• Main sequence stage. Defined as "fusing H in core".
Evolution Timescale

- To estimate the duration of any stage that depends on an energy source:
  - Energy available = Mass × Efficiency
  - Rate of energy use = Luminosity (Watts)
  
  Lifetime = (Energy Available)/(Rate of Use)
  
  = Efficiency × Mass / Luminosity

- For the sun,
  - detailed models show it has 10% of its H available
  - we find M.S. lifetime = 10×10^9 yrs ("10 Gyr")

- For the rest of the main sequence, can do ratio with sun:

  M.S Lifetime/Solar M.S. Lifetime = (M/M_{sun})(L/L_{sun})

Main Sequence Lifetime

So can complete our table for main sequence stars:

<table>
<thead>
<tr>
<th>Mass ($M_{sun}$)</th>
<th>Lum ($L_{sun}$)</th>
<th>Radius ($R_{sun}$)</th>
<th>Temp (deg K)</th>
<th>MS life (yrs)</th>
<th>Spec</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>5x10^5</td>
<td>18</td>
<td>40,000</td>
<td>8 Myr</td>
<td>O5</td>
<td>Zeta Pup</td>
</tr>
<tr>
<td>3.2</td>
<td>80</td>
<td>2.5</td>
<td>9900</td>
<td>400 Myr</td>
<td>A0</td>
<td>Vega</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5800</td>
<td>10 Gyr</td>
<td>G2</td>
<td>Sun</td>
</tr>
<tr>
<td>0.1</td>
<td>8x10^{-4}</td>
<td>.13</td>
<td>2400</td>
<td>1000 Gyr</td>
<td>M7</td>
<td>Wolf 359</td>
</tr>
</tbody>
</table>

more massive stars last a much shorter time!
Orion Protostars

Low Mass Star Formation
Jet

Figure 7.8, p218, Arny

Young Star Clusters

Mar 20, 2006  Astro 100 Lecture 23

Mar 20, 2006  Astro 100 Lecture 23  Figure 7.8, p218, Arny
Pre-Main Sequence on the H-R

Figure 7.9, p219, Arny

Mar 20, 2006  Astro 100 Lecture 23  15