

The Birth Of Stars

- **Goals:**
 - **How do stars form from the interstellar medium**
 - **Where does star formation take place**
 - **How do we induce star formation**
- **Interstellar Medium**
 - **Gas and dust between stars is the interstellar medium (ISM)**
 - **The composition is similar to the Sun.**
 - **90% of atoms are Hydrogen (70% mass).**
 - **10% are Helium (28% by mass).**
 - **<0.2% are heavier elements (metals).**
 - **Average density of the ISM is ~ 1 atom cm^{-3} (air has 10^{19} atoms cm^{-3}).**
 - **Mass of the ISM is about 10-15% of the mass of stars in our galaxy**

- **Typical Regions of the ISM**

- **Hot Gas**

- Believed to arise from supernova explosions heating ISM (ionized - HII).
- Density: $0.001 \text{ atoms cm}^{-3}$.
- $T = 10^6 \text{K}$ (note temperature not heat) .

- **HII regions**

- Hydrogen is ionized (electron stripped from the atom) by nearby luminous and massive stars (O and B type).
- Emission comes from the recombination of the electrons with the protons.
- Spectrum is dominated by Hydrogen emission lines (electrons cascade down).
- Density: $100\text{-}10^4 \text{ atoms cm}^{-3}$.
- $T = 10^4 \text{ K}$.

- **HI regions**

- Intermediate temperature and density.
- Hydrogen is not ionized it is neutral (HI)
- Density: $0.3 \text{ atoms cm}^{-3}$.
- $T = 3000\text{-}6000 \text{ K}$.
- HI absorption if cloud is in front of a star.
- HI emits at 21cm (from hyperfine transition). Mapped by radio telescopes.

- **Distribution of Gas and Dust**

Figure 20-2

- **Nebulae**

- ISM is far from uniform the distribution of gas and dust has a wide range of densities and temperatures.
- Clouds of hot (low density) material form nebulae (also known as HII region).
- $M=100-10,000 M_{\odot}$.
- Orion nebulae is the most famous.

- **Reflection Nebulae**

- Dust within the nebulae can absorb and reflect light of nearby stars.
- Spectrum resembles that of the stars reflected.

- **Dark Nebulae**

- Absorption by dust extinguish light from stars within or behind the nebulae.
- Extinction can be 20 magnitudes or greater in the visible (10^{-8} of the light gets through).

– Molecular Clouds

- **Cool regions of the ISM.**
- **Low temperature (few collisions) means molecules and dust can form.**
- **Density of 50 atoms cm^{-3} .**
- **$T=100$ K (very cool radiates in mid-infrared $29 \mu\text{m}$).**
- **Small clouds are more common than large clouds.**
- **Giant clouds can extend over 100 pc and have masses $10^5 M_{\odot}$.**
- **Believed to be the “nurseries” of stars.**
- **Small clouds are believed to merge into larger clouds.**
- **Observations of the molecular spectrum (e.g. CO) can reveal structure, dynamics and composition of these clouds.**

- **Interstellar Extinction**

- **Dust in the ISM**

- Dust in nebulae and distributed throughout the plane of the Galaxy can extinguish (extinct) light.
 - Dimming can reduce the brightness of stars or remove them from our view.
 - Two important processes the scattering and absorption of light.

- **Scattering of Light**

- Light from a star can be starred from our line of sight (photons are not destroyed by scattering).

- **Absorption of Light**

- Light can be absorbed by dust (the photon is destroyed). The dust particle is heated by the photon and will eventually reradiate this energy as the infrared light.

– Wavelength dependence of extinction

- Because of the size of dust particles extinction occurs more at shorter wavelengths.
- This effect is known as reddening.

$$A_{\lambda} \propto \frac{1}{\lambda}$$

- **A**: extinction (dimming)
 λ : wavelength (m)
- Extinction at 300nm (Ultraviolet) is 3.3x that at 1 μm (Infrared)
- We can see further into clouds by observing in the infrared.

– The effect of extinction

- Extinction changes our view of the Galaxy and Universe.
- We see preferentially brighter sources.
- Stars appear less luminous and are harder to detect.
- The distribution of stars and galaxies on the sky can be masked by the extinction.

Star Formation

- **From Gas to Stars**

Figure 20-16

- **Stars form from contracting clouds of gas and dust. Most of the matter in these clouds is hydrogen (about 70% by mass).**
- **Population II Stars**
 - **First stars to form in the galaxy.**
 - **Formed before the heavy elements (metals) were produced.**
- **Populations I stars**
 - **Formed after the first burst of star formation.**
 - **Formed from gas that has been enriched with metals from supernovae explosions.**
- **We can observe the formation of stars**

- **How does a star form?**
 - **Initial Collapse**
 - Initially a cloud of a few hundred M_{\odot} (or more) starts to collapse due to the inward force of gravity. Cloud is generally cold (less than 100K) and not very dense (less than 1000 particles cm^{-3}). Called dark nebulae (Bok globules).
 - **Collapse of the cloud is governed by**
Figure 20-24
 - Mass
 - Temperature
 - Strength of Magnetic field
 - Rotation rate (Angular Momentum)
 - Collapse may be due to Gravitation instability, or triggered (eg a nearby Supernova, or HII regions). As collapse proceeds, cloud fragments into smaller pieces, forming group or groups (clusters) of stars of lower mass.
 - A fragment destined to form a star like the Sun will contain 1 to 2 M_{\odot} of matter.

- Fragments initially 100 times larger than solar system. Collapse due to force of gravity proceeds, central density rises. This collapse is slowed by the inner regions becoming opaque (they trap radiation). The central temperature (and hence the pressure) increases.
- **~1 M_{\odot} star is forming per year in our galaxy.**
- **Protostar to Main Sequence Star**
 - The force of gravity is still strong, and causes the star to contract even further. It is now a true protostar.
 - At this time, its luminosity may be 1000x its Main Sequence value. (While its temperature is low, radius is very large).
 - The high luminosity is supplied by the energy released through gravitational contraction (Kelvin-Helmholtz contraction).

- Temperature and pressure in the protostar center increase. Nuclear reactions start in its core. These generate energy → temperature and pressure increase further.
 - Eventually gravity is balanced by the outward pressure forces.
 - The star is then in hydrostatic equilibrium and in its Main Sequence phase.
 - A protostar $<0.08 M_{\odot}$ never reaches the main sequence as it never gets sufficiently hot and dense for Hydrogen burning. Such an object becomes a Brown Dwarf.
- **Massive stars form the fastest.**
- Massive O and B types form in about 10,000 years. Young groups of stars at the top of the main sequence in HR diagram are called O and B Associations.
 - A $1 M_{\odot}$ mass star takes about 10^6 yrs.
 - Least massive stars take $>10^8$ yrs to form.
 - Low mass stars are formed more often than high mass stars.
 - In all cases, the formation time is much much less than the time the star will spend burning hydrogen on the main sequence.

– **Rotation**

- **During the process of star formation and collapse, the protostar begins to rotate faster and faster (just like skaters spin faster and faster when they bring their arms closer to their body).**
- **The faster rotation is the result of conservation of angular momentum, but the angular momentum must eventually be lost by the protostar. If it was not, stars could not form!**

– **Stars lose angular momentum by**

- **Ejecting material which carries off angular momentum, or**
- **Forming planetary systems, or by**
- **Forming binary star systems.**