Stellar Evolution

Stellar evolution is driven by gravity.

Because of the large mass of the star, gravity continually wants to make the star contract.

Nuclear fusion temporarily halts the contraction by providing energy to generate high pressures which can counterbalance gravity.

When the central nuclear fuel runs out, central pressures fall, and the star core begins to collapse again.

Collapse continues until a nuclear fusion cycle begins, or some other “pressure” force halts the collapse.

For the most massive stars, nothing can halt the final collapse and a black hole is formed.

THE BIRTH OF STARS

THE INTERSTELLAR MEDIUM (ISM)

The gas and dust between the stars is called the interstellar medium **(ISM)**, and has a similar composition to the Sun. If all the gas and dust were broken down then

90% of the atoms are Hydrogen (**70%** by mass)

10% of the atoms are Helium (**28%** by mass)

Less than 0.2% of the atoms are heavier elements

The average density of the ISM in the disk is about 1 atom per cubic cm (cc or cm^3). (Almost a perfect vacuum --- compare with air which has a density of 10^{19} atoms per cubic cm)

The mass of the ISM is about 10% to 15% of the mass of the visible stars in our galaxy.

The ISM is far from uniform. Different regions have, for example, different temperatures and densities. The physical conditions in the gas and dust which make up the ISM dictate how astronomers classify the regions.

Typical Regions of the ISM

Hot gas

Thought to arise from gas heated by supernovae explosions. Hydrogen is ionized.

Typical density = 0.001 atoms per cubic cm.

Typical temperature =10^6 Kelvin.

HII regions

In these regions hydrogen is ionized (ie the electron has been stripped from the original hydrogen atom). Hydrogen emission lines are generated by electrons recombining with the ionized hydrogen ions.

HII regions are generally associated with hot (i.e. O type) stars.

Typical density = 100 to 10^4 atoms per cubic cm.

Typical temperature =10^4 Kelvin.

In the optical, HII regions show a distinct emission line spectrum.

Supernovae remnants and Planetary nebula also contain ionized gas. They are not, however, generally referred to as HII regions.

HI regions

Regions of intermediate temperature and density. HI is the designation for neutral (ie NOT ionized) hydrogen.

Typical density = 0.3 atoms per cubic cm.

Typical temperature =3000 to 6000 Kelvin.

If a HI region lies between us and a star, it will produce absorption lines in the stars spectrum.

Reflection Nebulae.

Objects which contain dust that **reflects** the light of nearby stars. A spectrum of a reflection nebula looks like the spectrum of the starlight it is reflecting.

Dark Nebulae.

Objects which contain dust that hinders our view of background stars. Thus, a dark nebula might look like a blank region of the sky where few or no stars are seen (except for foreground stars).

Molecular clouds

Cool and “dense” regions containing dust and molecules.

Hydrogen is generally in the form of molecular hydrogen --- a diatomic molecule composed of 2 hydrogen atoms (H_2)

Typical density = 50 atoms per cubic cm.

Typical temperature =100 Kelvin.

Small clouds are more common than large clouds.

Giant molecular clouds may have a mass 10^5 times that of the Sun (and a radius of 100 parsecs) and are believed to provide the nurseries for star formation. Small clouds are believed to coalesce into larger clouds.

Observations of molecular spectra (e.g. CO) reveal the structure, composition, and dynamics of these clouds.

Interstellar extinction

In the plane of the Milky Way we see regions that are apparently devoid of stars. This apparent deficit of stars is **not real,** but is due to **EXTINCTION** of the starlight by dust. Interstellar Extinction refers to the dimming of starlight by dust between us and the star.

The extinction takes 2 forms.

1. **Scattering**

   Light from the star is scattered out of our sight line by dust. The light (or photons) is **NOT** destroyed by the scattering.

2. **Absorption**

   Light is absorbed by the dust particle, and hence the **photon is destroyed**. When a dust particle absorbs a photon its temperature increases (the amount of increase depends on the size of the particle). The particle eventually re-emits the energy but at longer wavelengths (in the infrared spectral region).

For the dust in the interstellar medium, absorption and scattering are both important.

Because of the size of the dust particles, **the extinction is largest at shortest wavelengths**. As a consequence, stars appear redder than they would normally. Hence **interstellar extinction** is also referred to as **Interstellar reddening.**

Interstellar extinction has a significant influence on most optical, and ultra-violet (and X-ray) astronomy. Many published results have later turned out to be invalid because of bad corrections for interstellar extinction.

Measuring and overcoming the effects of Interstellar extinction.

1. **Since interstellar extinction is less at longer wavelengths, observations at long wavelengths (eg infrared) are less prone to errors.** In some regions of the sky, the extinction is so large that the objects are only visible at infrared (or radio) wavelengths.

2. We can correct for the interstellar extinction. Crudely we assume that interstellar extinction behaves the same in all directions. **We can observe stars of the same spectral type to deduce the behavior of the extinction.** We can then correct our observations for the "Interstellar extinction".

The exact composition of the dust in the interstellar medium is still uncertain. Much of it is probably in the from of silicate grains surrounded by a layer of water ice or hydrogen. Some of the dust may also be in the form of graphite. Dust grains are generally small:

0.5 nm (0.0005×10^{-6} m, somewhat larger than complex molecules) **to**

250 nm (c.f. visible light: 500 nm)

NB: Our view of the Galaxy, and its contents, is profoundly influenced by the way we view it.

Examples:

1. We preferentially see the brightest sources, since they can be seen at the largest distances. Some objects may be very common, but we see few of them because they are faint.

   e.g. Brown dwarfs are extremely difficult to detect. They are very faint, and give off most of their energy in the infrared spectral region.

2. The dust in the interstellar medium absorbs light from distant stars. This makes the stars appear less luminous, and makes them more difficult to detect.

3. At X-ray wavelengths absorption by both interstellar gas and dust is important. This absorption can, depending on its strength, strongly modify the observed spectrum.

Star Formation

Stars form from contracting clouds of gas and dust. Most of the matter in these clouds is hydrogen (about 70% by mass).

The first generation of stars **(Population II stars)** formed from material that was deficient in heavy elements.

Later generations of stars **(Population I stars)** formed from material that was enriched with heavy elements by supernovae explosions in massive, fast evolving stars. The heavy elements ejected into interstellar gas and dust clouds by supernovae were synthesized in the interiors of these stars during the nuclear energy generation process.

Astronomers can observe protostars (stars in the process of formation) in the Milky Way Galaxy by looking for luminous objects in regions filled with dense clouds of gas and dust. Infrared astronomy is a major means of observing protostars, **since the stars are cool, and may be hidden by dus**t.

Protostars occupy the low temperature region (right hand side) of the HR diagram above the main sequence. They generally occur in clusters.

How Does a Star Form?

Initially a cloud of a few hundred M_{sun} (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 per cubic centimeter).

The collapse of the cloud is governed by

(a) Mass

(b) Temperature

(c) Strength of Magnetic field

(d) Rotation rate (Angular Momentum)

Collapse of cloud may be due to a Gravitation instability, or may be triggered by an external event (eg a nearby Supernova, or nearby HII regions). As the collapse proceeds, it eventually fragments into smaller pieces, forming a 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_{sun} of matter. Fragment is initially 100 times larger than present solar system. As the collapse due to the inward force of gravity proceeds, the central density rises. This collapse is slowed by the inner regions becoming opaque (they trap radiation). The central temperature (and hence the pressure) increases.

About 1 solar mass star is forming each year in our galaxy.'

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 several thousand times its Main sequence value. (While its temperature is low, its radius is very large). **The high luminosity is supplied by the energy released through gravitational contraction.**

As the temperature and pressure in the center of the protostar increase, nuclear reactions will start to occur in its core. The nuclear reactions generate energy which causes the temperature and pressure to increase further.

Eventually the inward forces of gravity are balanced by the outward pressure forces and a stable star forms (it ceases its collapse). It is now in **hydrostatic equilibrium** and in its main sequence phase of evolution (the prime of its life).

A protostar less massive than **0.08 M_{sun}** never reaches the main sequence since its central regions never become sufficiently hot and dense for nuclear burning of H to occur. Such an object becomes a **Brown Dwarf.**

The most massive stars form the fastest.

e.g.

Massive O and B types form in about 10,000 years. Young groups of stars at the top of the main sequence in the HR diagram are called O and B Associations.

A star of one Solar mass takes about 10 million years to form.

The least massive stars take hundreds of millions of years to form.

Low mass stars are formed much 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!

It is thought that stars lose angular momentum by

(1) ejecting material which carries off angular momentum, or

(1) by forming planetary systems, or by

(2) forming binary star systems.

T Tauri Stars

A very young star (final stage of protostar). Named after the prototype star T Tauri. They fall above the main sequence.

T Tauri stars vary their luminosity irregularly by up to a factor of 10. They are more “active” than the Sun --- i.e. show more magnetic activity.

They emit broad, very intense emission lines, and sometimes x-ray and radio emission. The emission lines are broad because of Doppler shifts, indicating rapid motions of the mass of the outer parts of the star. **They are ejecting matter in a strong stellar wind.**

They show evidence that they have a disk of material around them --- material left over from the stars formation.

Herbig-Haro objects result from gas ejected from T Tauri stars.

Masers

In some star forming regions conditions are such that a particular molecule “masers”. Maser refers to **microwave amplification by stimulated emission of radiation.** (Laser = light amplification ...).