

STAR FORMATION (Ch. 19)

The basics: **GRAVITY** vs. **PRESSURE** (heat; but also rotation and magnetic fields)

Stages (you don't have to memorize numbers of stages)

1. Interstellar cloud—cold ($T \sim 10\text{K}$), large ($\sim 1\text{-}10\text{pc}$), massive ($\sim 10^3 - 10^5 M_\odot$), so gravity wins easily over gas pressure (atomic motions—see Fig. 19.2): cloud must break up, or “fragment.”

Other inhibitors: rotation, magnetic fields (Fig.19.3).

2. Collapsing cloud fragment—still cold, size $\sim 0.1\text{-}0.01\text{pc}$. This may fragment further, so have multiple stages of fragmentation (see Fig. 19.4).

3. Fragmentation ceases—center of fragment dense enough to become *opaque* to its own radiation, so it heats up, slowing the collapse. (Previously it was transparent and so could stay cool because radiation escaped easily.)

4. Protostar—now object has a “surface” because it is opaque; this surface is the **photosphere** (the layer where the photons can finally escape into space). So a protostar is defined by when the object becomes dense enough to have a photosphere.

Protostar heats up by gravitational contraction and accretion of remaining material (from a disk). But the temperature in center is too low for nuclear reactions at this stage.

5. Continued slow contraction (getting fainter), heating. Protostar moves roughly on a vertical track in the H-R diagram (see Fig. 19.7).

6. Central temperature reaches about 10 million K, get ignition of nuclear fusion of H into He.

7. Adjustment to the “zero-age” main sequence. This is when stars can just balance gravity with pressure at all layers, and will spend about 90% of their lives in this stage.

Different stellar masses: arrive at the main sequence at different temperatures and luminosities. See Fig. 19.8.

Note: the “main sequence” is the location in the H-R diagram of all stars of different masses.

Brown dwarfs: Stars with $M < 0.1M_0$ never get hot enough to ignite H. They just cool off and fade forever. Hard to detect because so faint, but by now 100s have been discovered. (Read Discovery 19-1, p. 498).

Observations relevant to star formation

Fragments—observed mostly by molecular spectral lines (but also dust extinction)

Cocoon stars—shrouded by dust (and gas) still falling onto the protostar, so glow mainly in the IR. All seen associated with molecular clouds and their fragments.

Protostars—stars above the main sequence, presumably about to settle down to their main sequence lives. The T Tauri-type stars are the best examples.

Disks—At good resolution, most protostars show evidence of substantial disks of gas and dust (recall how crucial this is for planet formation!). Can see in visual and infrared radiation. See Figs. 19.11, 19.12.

Protostellar winds—Probably clears the star of its remaining debris (except planets); often seen as very energetic bipolar outflows (See Figs. 19.13, 19.14).

Shock waves (sec. 19.5)—from stellar winds and explosions (to be discussed later). These can compress nearby (or even fairly distant) matter, can induce *more* star formation. So star formation *propagates* like a chain reaction, and in fact can be modeled like a disease epidemic. (See possible example, Fig. 19.16 in text.)

Star Clusters (sec. 19.6)

Groups of stars all located in the same volume of space, i.e. **all at the same distance**, and so presumably **all formed at the same time**; i.e. all stars in a given cluster have the same age. Best chance to test theories of stellar evolution!

Can easily get H-R diagram using only apparent brightnesses, because effect of distance would be to just shift all the L's by the same factor (vertically in H-R diagram).

2 main types of clusters

A. Open clusters

Most have ~100-10,000 stars, size ~ 1-10 pc. Some show main sequence (MS) populated all the way to spectral type O (massive) \Rightarrow must be very young (less than ~ few million years)

Some have MS only populated up to redder (cooler, less massive) spectral types \Rightarrow most massive stars have died.

Can see that you can get ages of clusters by extent of the MS. Find that open cluster ages vary from very young (~few million yr.) to very old (~10 billion yr.) This shows that star formation has been an ongoing process in over the whole history of our galaxy. But notice that they are *all* found in the disk of the Milky Way (we'll come back to this).

B. Globular clusters

Very dense clusters, up to 10^6 stars within ~ 50 pc size. Most are very distant ($\sim 1,000$ to $100,000$ pc), and are *not* distributed in the disk of the Milky Way \Rightarrow they form a spherical “halo” around the Milky Way.

H-R diagrams: MS includes low mass stars, but NO stars with mass $>$ about 0.8 solar masses \Rightarrow all are old! Ages ~ 12 -17 billion years.

These were almost certainly the first objects to be formed in our Galaxy. Note: Abundances of all elements heavier than carbon are very small compared to the sun and most other stars (because they formed when the Galaxy was relatively “pollution free” — we’ll return to this).

Make sure you understand the H-R diagrams in Figs. 19.18-19.19.

Can you explain what determines the lifetime of a star clusters? Why do open clusters survive (on average) for a much shorter time than globular clusters? (This is actually a fairly complicated question, but a good one to consider — think of the properties of the two types of clusters and their orbits through our Galaxy.) What if the question were asked this way: What is suggested by the fact that *all* globular clusters are much older than any open cluster?