Stellar Evolution : The Life - History of Stars

Problem :

Human life span insignificant compared to the milestones in a star's life.

Solution :

Observe many stars. There will always be some star at each epoch (stage) in a star's evolution.
Observe stars in clusters. Presumably they formed at the same time.
Use statistical arguments : 90% of the stars are main sequence stars implies that stars spend 90% of their lives on the main sequence.
Use theoretical models : see what happens when the chemical composition and mass change. Compare with observations.

Birth of stars

Molecular clouds

clouds containing (atoms + molecules) + dust
cold, T = 100°k
dense, 10^4 x average density of interstellar medium, [density of cloud = 10^{-20} gm/cm3]
massive, M = 10^{37}gm [~$5 \times 10^3 M_\odot$]

Collapse triggered by

i) supernova explosion
ii) density wave

Gravitational collapse of interstellar cloud :

Collapse proceeds most rapidly at the center, where the density grows most quickly. Core is cool due to escape of radiation (infrared photons).

Slow contraction of core :

When core density is high enough the cloud is opaque to infrared radiation. Heat is trapped, temperature and pressure in the core rise. Core contracts slowly for a while.

Infall :

Material from the outer layers fall in creating heat and shock waves. The molecules in the core disassociate due to additional heating. The breakup of molecules takes up heat, thereby reduces pressure and a new collapse phase occurs.

Final contraction :

After the second collapse, the internal pressure again rises to balance gravity and the central condensation enters a new phase of very slow contraction. The protostar is surrounded by gas and dust and is observed as an infrared source.

Nuclear ignition :

The protostar heats gradually as the contraction goes on. When the core becomes hot enough nuclear fusion starts. Contraction stops since the internal energy source provides presure to balance gravity. It is still associated with gas and dust and may undergo a T-Tauri phase.

Pre-main sequence phase is a small fraction of a star's life.

Stellar Mass	Pre Main - Sequence Phase
1 $M_\odot$	5×10^7 yrs
5 $M_\odot$	10^6 yrs
15 $M_\odot$	10^5 yrs

More massive stars evolve faster through their pre Main Sequence phase.

If the mass of the prototstar < 0.08 $M_\odot$ it will shine for a short time as an infrared source. The source of its energy for radiation is the conversion of gravitiational potential energy to thermal energy. Brown dwarfs eventually fade out.

Examples of Pre-main sequence objects

i) Bok globules - dense clouds of dust and gas

ii) Infrared stars - R Mon, Orion star forming region

iii) T Tauri stars

Strong stellar wind : 50 - 200 km/s

~0.4 $M_\odot$ blown away

Mass streams away in two jets along the polar axis (Bipolar jets).

Main sequence phase extremely stable. Star self-regulates its structure. If the energy production decreases the core contracts. Presssure and temperature increases and thereby the energy production increases. Hydrostatic equlibrium is maintained.

Post Main Sequence Evolution of 1 $M_\odot$ Star.

Development of degenerate core and evolution to red giant phase :

When H in the core contracts until it is degenerate. H burns in a shell outside the core. Energy production increases causing the outer layers to expand and cool. The star moves from the M-S to the red giant region.

Helium Flash :

The core eventually gets hot enough (~10^{8}°K) for He to be fused to C by the 3-α process.