Lec #40: 30 Nov 11 Chapter 2

TODAY: STAR FORMATION

I. Overview of Star Formation Process

II. Evolution Onto the Main Sequence

Monday: Wrap Up

Stability Against Collapse

- Gravitationally bound: satisfies Virial Theorem

  $2 * KE = -PE$
- $PE \sim -0.6\ GM_c^2 / R_c$
- $KE \sim 3/2\ NkT$; $N = M_c/\mu m_H$
- if T<-U/2, collapse; T>-U/2, expand
- *Unstable* against collapse if

  $3M_c kT/\ \mu m_H < 0.6\ GM_c^2 / R_c$
- $R_c = (3M_c/4\pi\rho)^{1/3}$ if ρ is constant
- with this, we can recast the condition as...

- minimum mass to collapse (*Jeans Mass*)

  $M_c > M_J \sim (5kT/G\mu m_H)^{3/2}\ (3/4\pi\rho)^{1/2}$
- minimum radius to collapse (*Jeans Radius*)

  $R_c > R_J \sim (15kT/4\pi G\mu m_H\rho)^{1/2}$
- but clouds must initially have expanded or contracted until they were stable, so...

1. what "triggers" the collapse beyond this point?
2. what permits them to keep collapsing (rather than just becoming stable at a smaller radius)?
3. what stops the collapse?

Fragmentation

- most molecular clouds are >> 1 solar mass
- if collapse were the whole story, all stars would be huge
- but most are less massive than the Sun
- fragmentation naturally occurs in collapsing cloud, because as density increases, Jeans length and Jeans mass decrease, so localized regions become unstable
- heirarchical process, but ...

1. What stops the fragmentation?
2. Why are there any stars at all?

The Role of Dust

- gravitational potential energy must be radiated away, or else it will go into kinetic energy (gas pressure), which will stop the free fall
- must radiate to stay "isothermal"
- at cold temperatures in these clouds, hydrogen and helium are very poor radiators
- dust grains must radiate thermally to keep collapse going
- dust also provides site for formation of complex molecules
- eventually, dust is the first step in accretion

Other Considerations

- Angular Momentum
  - collapsing cloud preserves angular momentum
  - inevitably leads to formation of DISKS
  - stars must be born spinning very rapidly
  - maybe in excess of "break up" velocity
  - most spin slowly now
  - so something must slow them down
- Magnetic field
  - hard to collapse charged particles perpendicular to field lines
  - galactic magnetic field must be overcome
  - but not totally; young stars have strong magnetic field

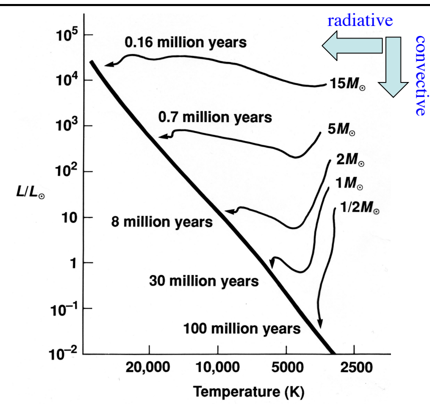
Pre-Main-Sequence Evolution

- Protostar = self-gravitating hot ball of gas, continuously being fed by accreting matter
- At first: no internal nuclear heat production
- Star cools by radiation:
  - Kelvin-Helmholz time scale
- Star contracts, central density and temperature increases (!)
- Deuterium ignites as soon as $T_c > 1x10^6$ K
  - Thermostat: too hot: star swells, T_c goes down, and deuterium burning slows
- Star becomes fully convective

- Stellar radius inflates: can reach 3...5 $R_\odot$.
- (We are now in the T-Tauri star phase)
- Star contracts slowly
  - with constant temperature for low mass stars, i.e. they move vertically downward in the HR diagram
- T_c and ρ_c increase until:
- Hydrogen ignition
  - Prolonged hydrogen burning starts
  - "Born" on ZAMS
  - Beginning of 'adult' life of the star

How Do These Steps Depend on Mass?

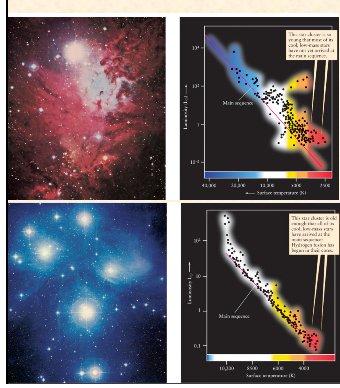
- There are many more low-mass than high-mass stars. How much of this is due to the formation process?
  - what determines the size of cloud fragments?
  - do different "triggers" produce different distributions of mass?
- More massive stars contract to main sequence much faster than less massive stars
- Upper mass limit: ? 100 - 200 M_{sun}
- Lower mass limit: ~ 0.08 M_{sun}



Determining Stellar Ages

- In general, it is NOT possible to measure "age"
- For young stars, activity ~ $t^{-1/2}$ (e.g. f_x)
  - rotating rapidly; spin down on this timescale
  - eventually no disk to produce drag, so spindown stops
- HR diagram fits to theoretical models
- Clusters:
  - assume all stars born at same time
  - position in HR diagram depends on mass AND time
  - main sequence "turn off" gives age of cluster
  - clusters tend to disperse (become unbound)
  - some clusters don't stand out (e.g. moving groups)

Cluster HR Diagrams



If all stars started forming at once, the high-mass stars get to main sequence before the low-mass stars.

If cluster is old enough, high-mass stars already evolve off the main sequence before low-mass stars even arrive!

Examples of young clusters...

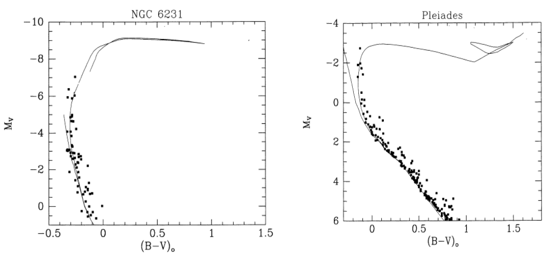


Fig. 10. Same as in Fig. 9 for NGC 6231, $m - M = 12.50$, $E(B-V) = 0.46$, log age = 6.72

Fig. 20. Same as in Fig. 9 for the Pleiades, $m - M = 5.60$, $E(B-V) = 0.04$, log age = 8.00

NGC 6231 (Open Cluster)
Age ~ 6Myr

Pleiades (Open Cluster)
Age ~ 100Myr

Examples of old clusters...

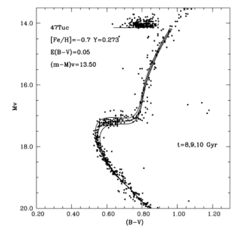
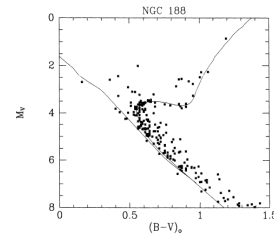


Fig. 1. Isochrones of 8-10 Gyr for the composition $(Y, Z) = (0.273, 0.008)$ (α-enhanced) applied to 47 Tuc. The data are from Hesser et al. (1987)



in Fig. 36 for NGC 188, $m - M = 11.35$, $E(B-V) = 0.12$, log age = 9.82. Same comments as fo

47 Tuc (Globular
Cluster) Age = 8-10 GYr

NGC188 (Open Cluster)
Age = 7 GYr