# [04] Star Clusters and Star Birth (2/6/18)

## Upcoming Items

1. Read Ch. 17.1–17.2 for next class and do the self-study quizzes.
2. Homework #1 due in one week.  I hope you've already started!

## APOD 2/7/17: Lobster Nebula

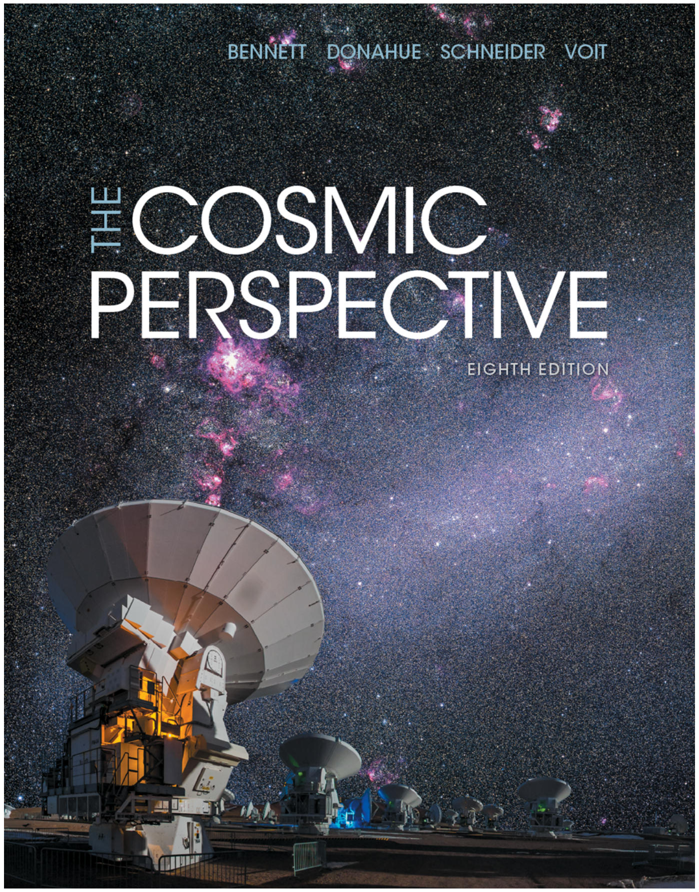
# LEARNING GOALS

Ch. 15.3, 16

*For this class, you should be able to…*

… *use the main-sequence turnoff points on H-R diagrams to estimate the relative ages of star clusters;*

… *predict whether a gas cloud in the interstellar medium will collapse to form stars based on its mass, temperature, and density;*



# Any astro questions?

# Star Birth

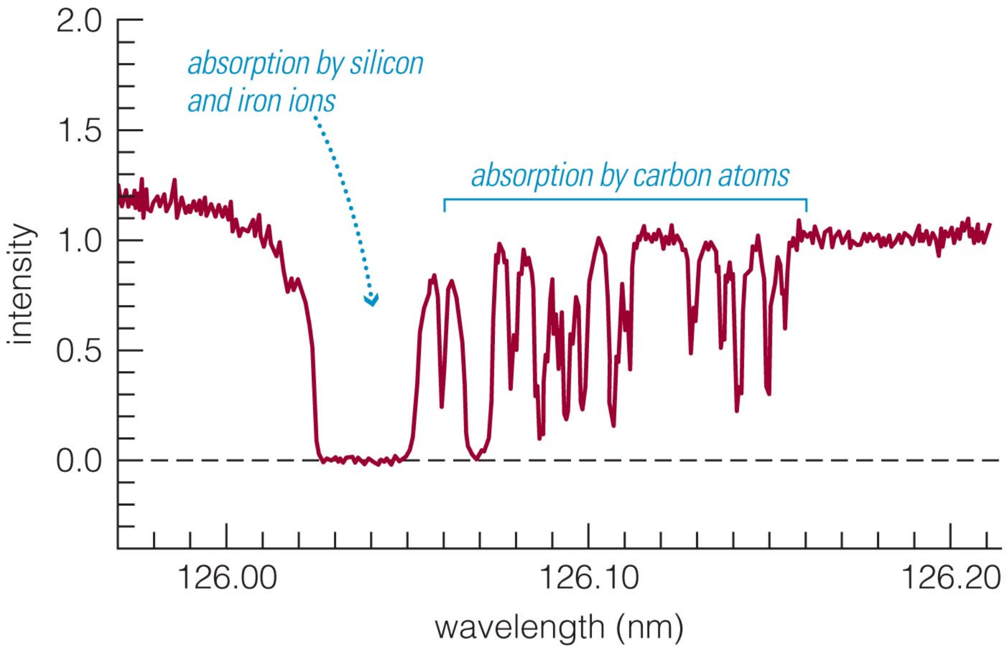
- Stars form from cold, dense clouds of gas and dust in the interstellar medium.
  - How do we know? O & B stars are found close to such clouds.
  - Coldest clouds are molecular clouds (mostly $H_2$, some CO, etc.).
- A cloud collapses if gravity overcomes thermal pressure.
  - The critical mass is called the Jeans mass.
  - As the gas cloud heats up from contraction, it becomes a protostar.
  - Lack of molecular cooling means first stars very massive (maybe?).
- A star stops collapsing and joins the main sequence when its core becomes hot and dense enough for H fusion.
  - Too little mass: no H fusion, degeneracy pressure halts collapse.
  - Too much mass: excess heat and strong winds stop star formation.
    - But the actual limit is unclear...

The Lagoon Nebula

# Star-forming Clouds

- Stars form in dark clouds of dusty gas in interstellar space.
- The gas and dust between the stars is called the **interstellar medium**.

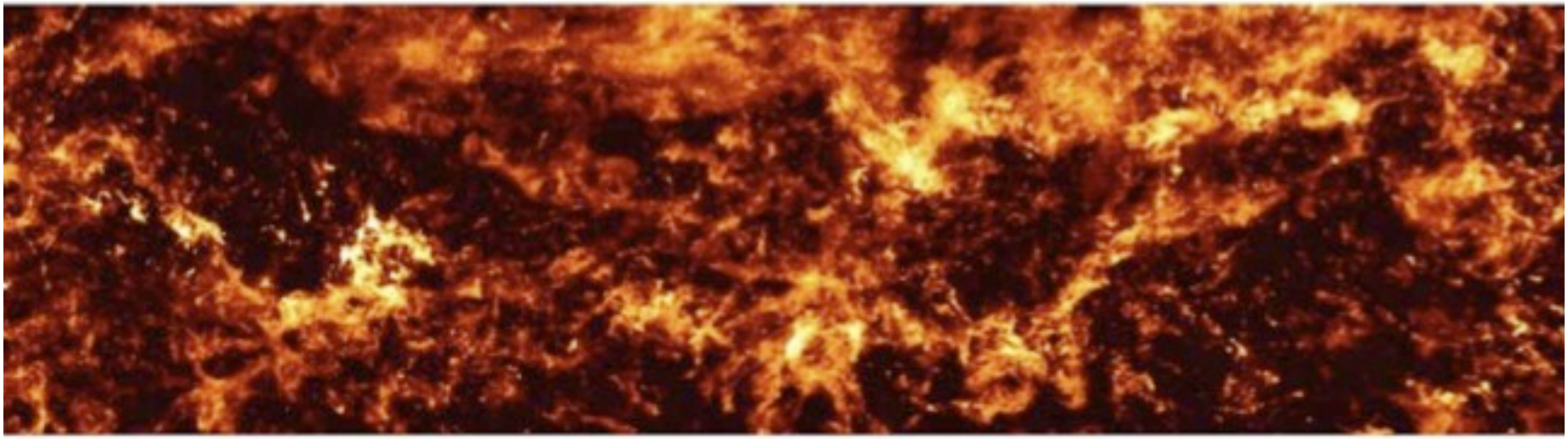
# Composition of Clouds




- We can determine the composition of interstellar gas from its absorption lines in the spectra of stars.

- 70% H, 28% He, 2% heavier elements in our region of Milky Way.

# Molecular Clouds



- Most of the matter in star-forming clouds is in the form of molecules ($H_2$, CO, etc.).
- These **molecular clouds** have temperatures of 10–100 K and densities of ~$10^2$-$10^8$ molecules per cubic centimeter.

# Interstellar Dust

- Tiny solid particles of **interstellar dust** block our view of stars on the other side of a cloud.
- Particles are < 1 µm in size and made of elements like C, O, Si, and Fe.

# Gravity Versus Pressure

- Gravity can create stars only if it can overcome the force of thermal pressure in a cloud.
- Gravity within a contracting gas cloud becomes stronger as the gas becomes denser.

# Gravitational Collapse & the Jeans Mass

- A gas cloud of mass density $\rho$ and temperature *T* collapses if its mass is above a critical value (the constant factors depend on specific assumptions):

$$M_J = \left(\frac{5k_B T}{G m_p}\right)^{3/2} \left(\frac{3}{4\pi\rho}\right)^{1/2}.$$

- This is called the *Jeans mass*. ($m_p$ is mean particle mass.)
- Here is a group question for you (I'd like to ask that when you're done discussing the question, all group members briefly raise their hands so I'll know):
  If a cloud begins to collapse, what happens to $\rho$? To *T*? Is it guaranteed that the collapse will continue? If not, what is necessary?

# Gravitational Collapse & the Jeans Mass

$$M_J = \left(\frac{5k_B T}{Gm_p}\right)^{3/2} \left(\frac{3}{4\pi\rho}\right)^{1/2}.$$

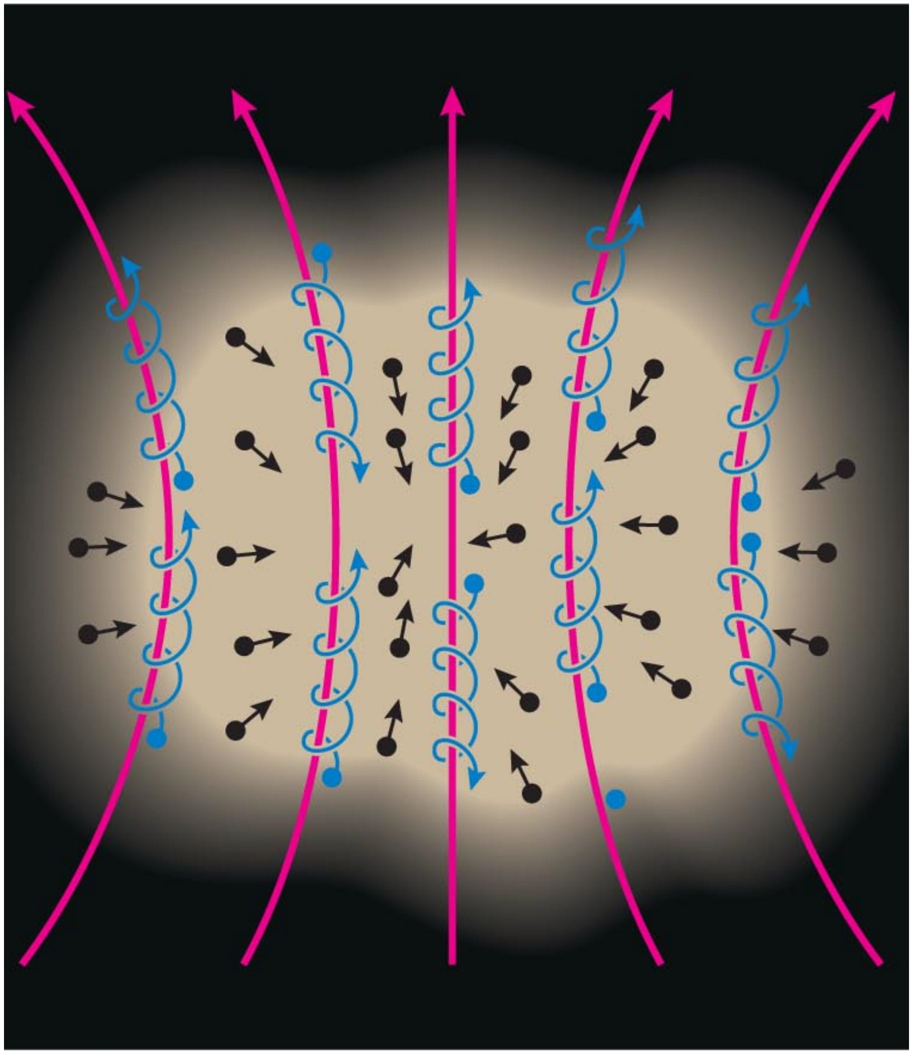
- As a gas cloud collapses and increases in density, the Jeans mass decreases *if the temperature remains low*: the gas fragments into yet smaller pieces, each of which may go on to form a star.
- What processes cause cooling? Implications for early universe? What about for dark matter?
  Please read "virial.pdf" in Files->derivations (virial theorem)
  Recommend you read the statement of the theorem first, then the applications (near the end)
  For the derivation, might group with people who are comfortable with calculus

# Mass of a Star-forming Cloud

- A typical molecular cloud must contain a few hundred solar masses for gravity to overcome force initially.
  - Temperature ~10-100 K, particle number density ~$10^2$-$10^8$ particles/$cm^3$.

- Collapse continues so long as most of the thermal energy from contraction is radiated away.
  - How does cooling actually work?
  - Emission lines from molecules in a cloud can prevent a pressure buildup by converting thermal energy into infrared and radio photons that escape the cloud.

# Resistance to Gravity



- A cloud must have even more mass to begin contracting if there are additional forces opposing gravity.
- Both magnetic fields and turbulent gas motions increase resistance to gravity.
- How would that work?

# Star Clusters

- Your book says that there are two basic types of star cluster: **open clusters** (up to thousands of stars, loosely grouped, in galactic disk) and **globular clusters** (up to millions of stars, self-gravitating, orbiting the galaxy)
- In our galaxy, that's close to true
- But as a broader perspective, seen over many galaxies, it's more of a continuum than two discrete classes
  Colliding galaxies have a lot of star formation [Why?]
- If we assume (reasonably!) that all stars in a cluster were born at roughly the same time, the brightest surviving main-sequence star gives us the age of the cluster. Why?
  - Open clusters are young and usually dissolve after a few Myr.
  - Globular clusters are very old and likely pre-date the galaxy.

Clusters are ~few pc across, so at distances >100 pc, all stars in a cluster are at about the same distance from us
Critical for analyzing standard candles, such as Cepheid variables!

Which star cluster is the oldest?

A. A cluster with all spectral types represented, and no giants or white dwarfs.
B. A cluster with F, G, K, and M main-sequence stars, lots of giants, and some white dwarfs.
C. A cluster with no O or B stars, and some giants.
D. A cluster with only K and M main-sequence stars, a few giants, and lots of white dwarfs.

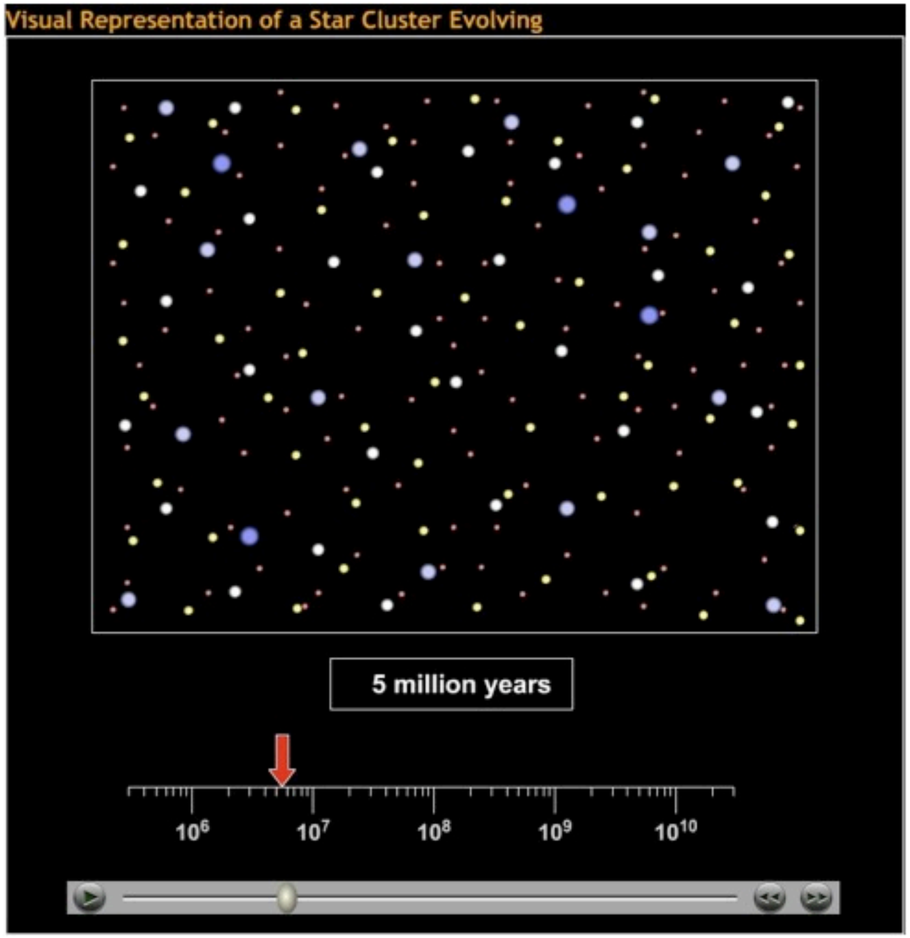
# Star Clusters

***Open cluster:*** A few thousand loosely packed stars.

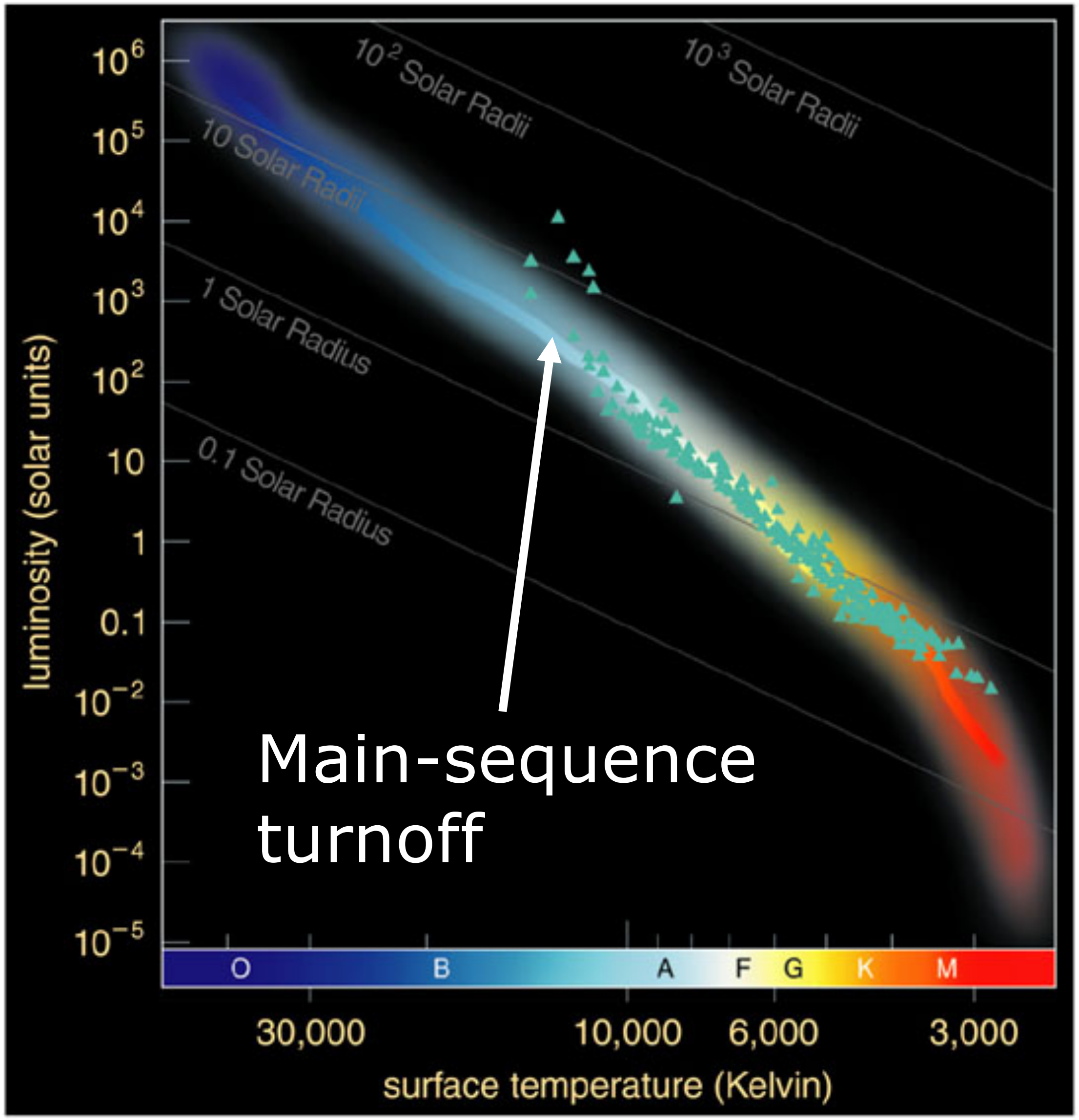
# Star Clusters

***Globular cluster:*** Up to a million or more stars in a dense ball bound together by gravity, e.g., Hercules (M13).

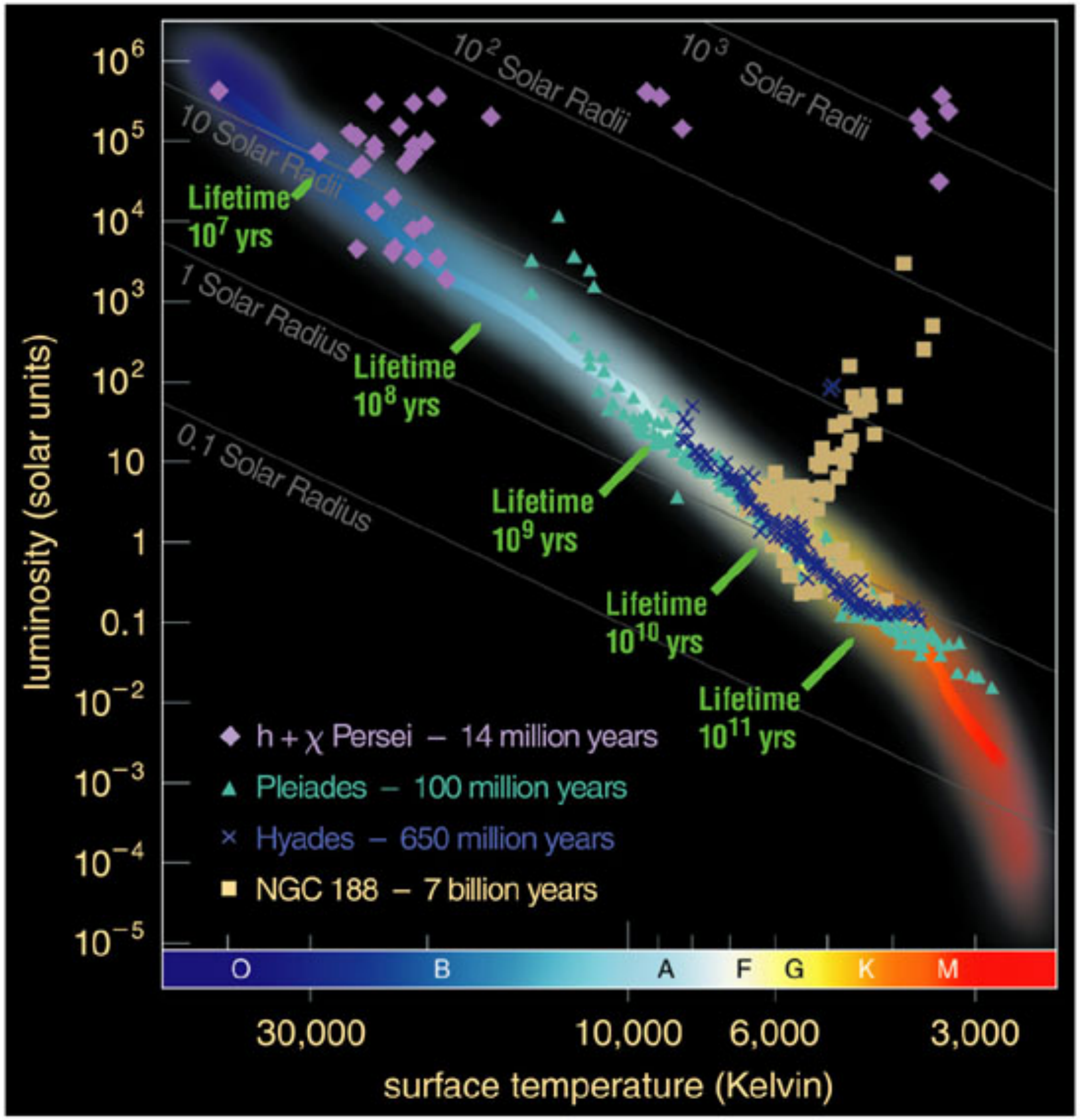
# Measuring the Age of a Star Cluster



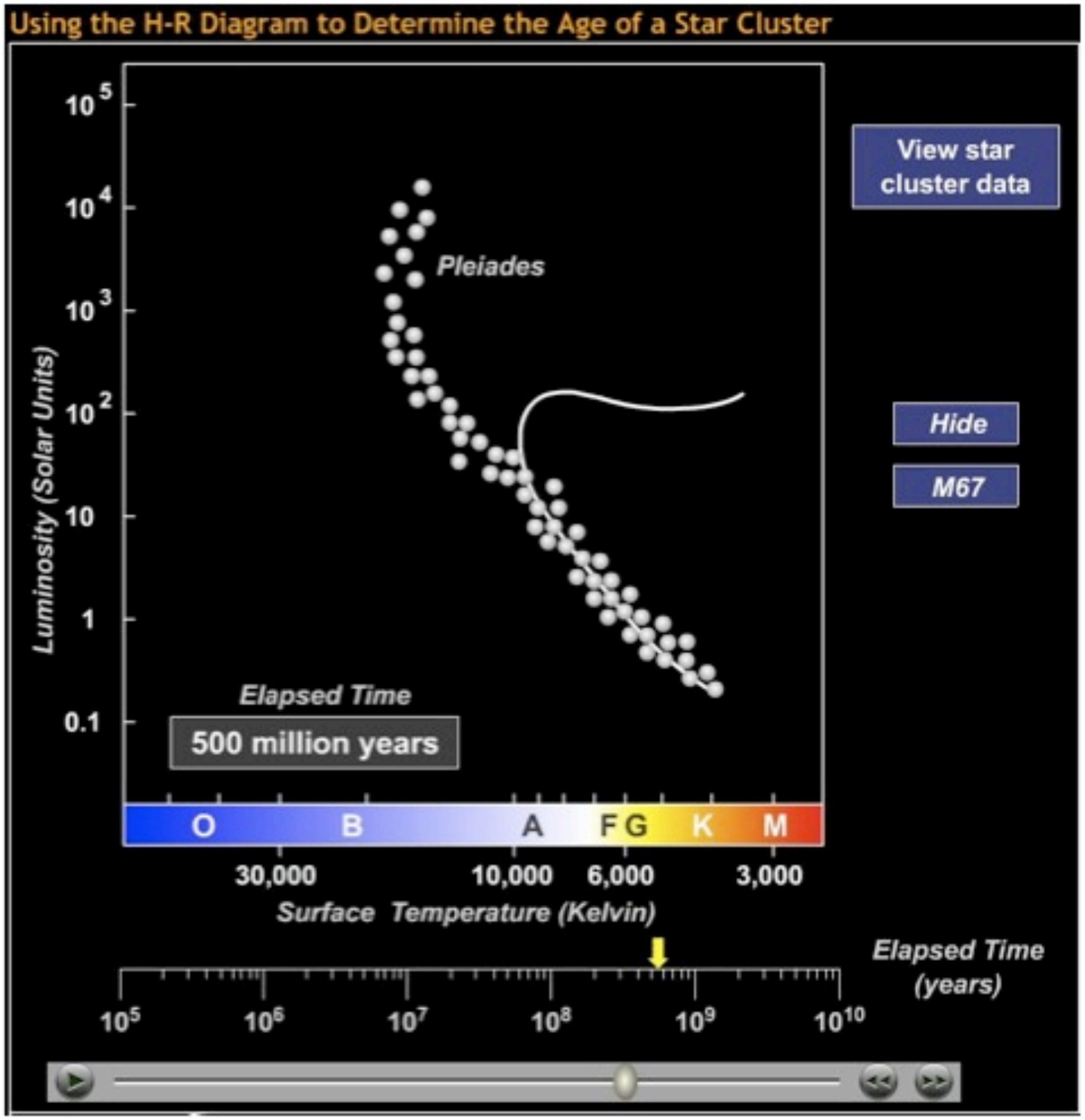

- Recall, on the main sequence, blue stars are much shorter lived than red stars.
- So in a cluster, if the stars all formed at the same time, blue stars die first, followed by white, yellow, orange, then red stars.



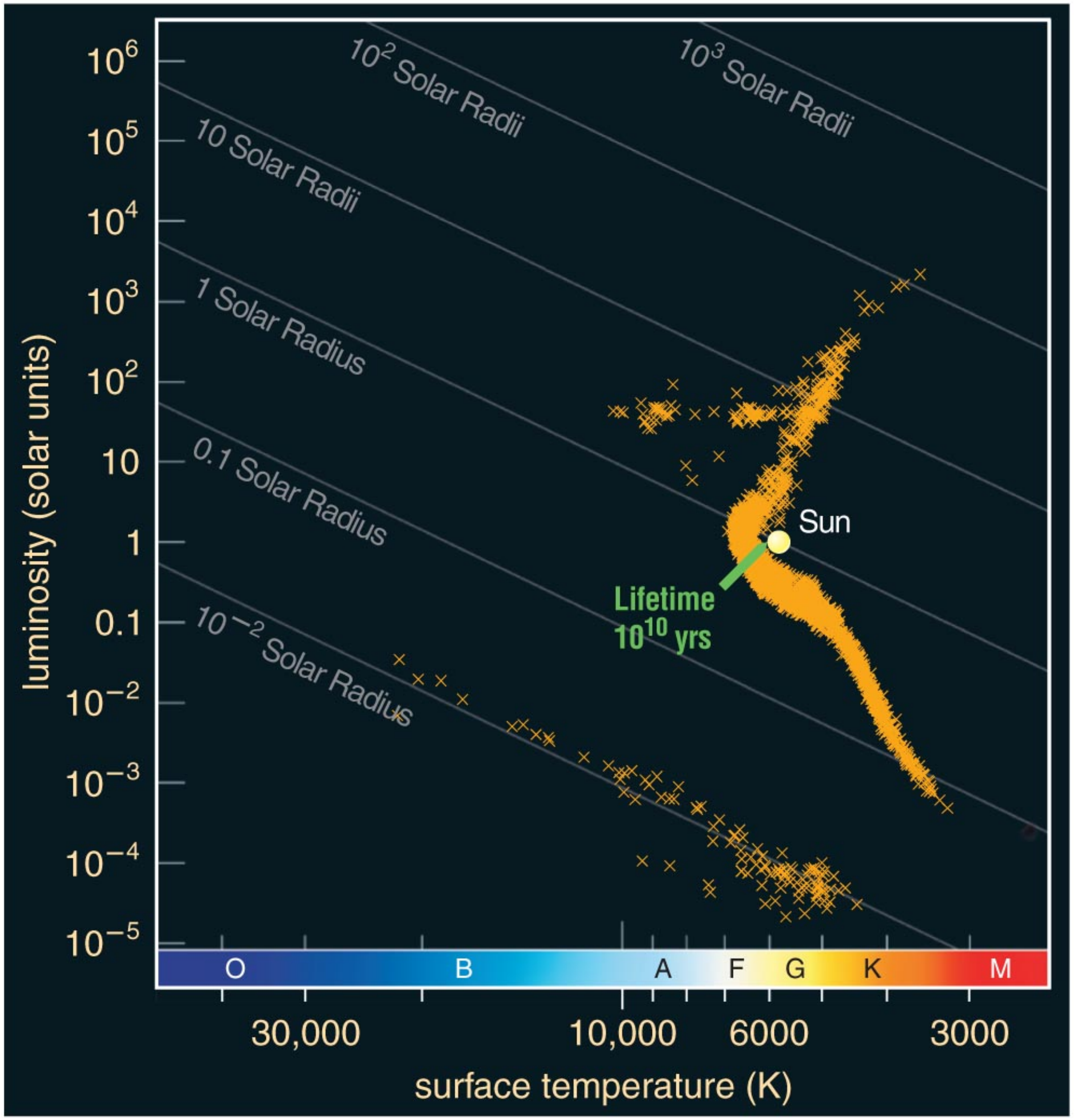

- The Pleiades cluster now has no stars with life expectancy less than around 100 million years.




- The main-sequence turnoff point of a cluster tells us its age.




- To determine accurate ages, we compare models of stellar evolution to the cluster data.




- Detailed modeling of the oldest globular clusters reveals that they are about 13 billion years old…

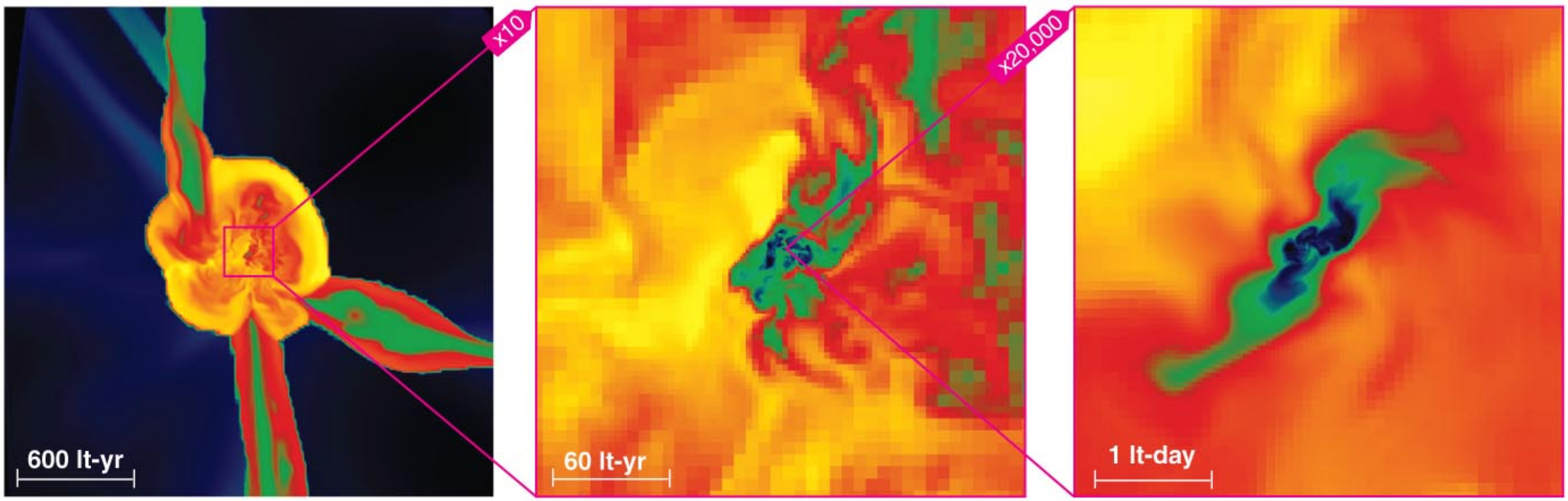
# The First Stars

- Elements like carbon and oxygen had not yet been made when the first stars formed.

- Without CO molecules to provide cooling (much more efficient than $H_2$), the clouds that formed the first stars had to be considerably warmer than today's molecular clouds.

- It is therefore plausible (but there is a lot of discussion!) that the first stars were more massive than most of today's stars, for gravity to overcome pressure.
  Why not clear? Because final lump size depends on density as well as temperature. Current stars are much less massive than the initial Jeans mass of the cloud; lots happens in between!

# Simulation of the First Stars



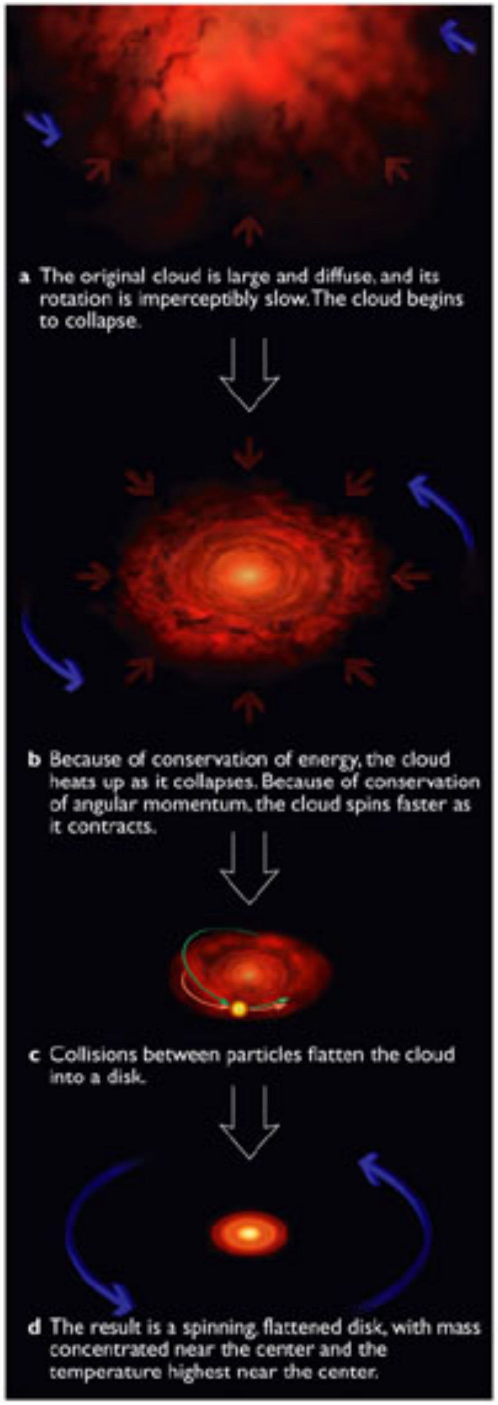

- This particular simulation of early star formation suggests the first molecular clouds never cooled below 100 K, making stars of ~100 $M_\odot$. But higher-resolution simulations suggest that the mass could be lower.

# Trapping of Thermal Energy

- As contraction packs the molecules and dust particles of a cloud fragment closer together, it becomes harder for infrared and radio photons to escape.
- Thermal energy then begins to build up inside, increasing the internal pressure.
- Contraction slows down, and the center of the cloud fragment becomes a **protostar**.

# Protostar to Main Sequence

- A protostar contracts and heats up until the core temperature is sufficient for hydrogen fusion.
- Contraction ends when gravitational equilibrium is established (energy released by core fusion balances energy radiated from the surface).
- This takes 30 million years for a star like the Sun (less time for more massive stars).




## *Summary of Star Birth*

1. Gravity causes gas cloud to shrink and fragment.
2. Core of shrinking cloud heats up (and rotates).
3. When core gets hot enough, fusion begins and stops the shrinking.
4. New star achieves long-lasting state of balance.