

Is star formation spontaneous, or does it need an external trigger?

Possible triggers for star formation:

increase in external pressure from

- nearby supernovae
- nearby massive stars with strong stellar winds (O, B stars)
- density waves associated with spiral structure

Does star formation in a galaxy spread like an infectious disease?

T Tauri stars

low-mass pre main sequence stars

Transition objects between earlier stages of collapse, ~~are~~ still shrouded in dust & only visible in IR, and main sequence stars

Unstable environment : mass loss ("P Cygni profiles"), rapid variations in luminosity, etc

These stars are found to be on the pre-mainsequence evolutionary tracks when T, L are measured.

12.3 Pre-Main-Sequence Evolution

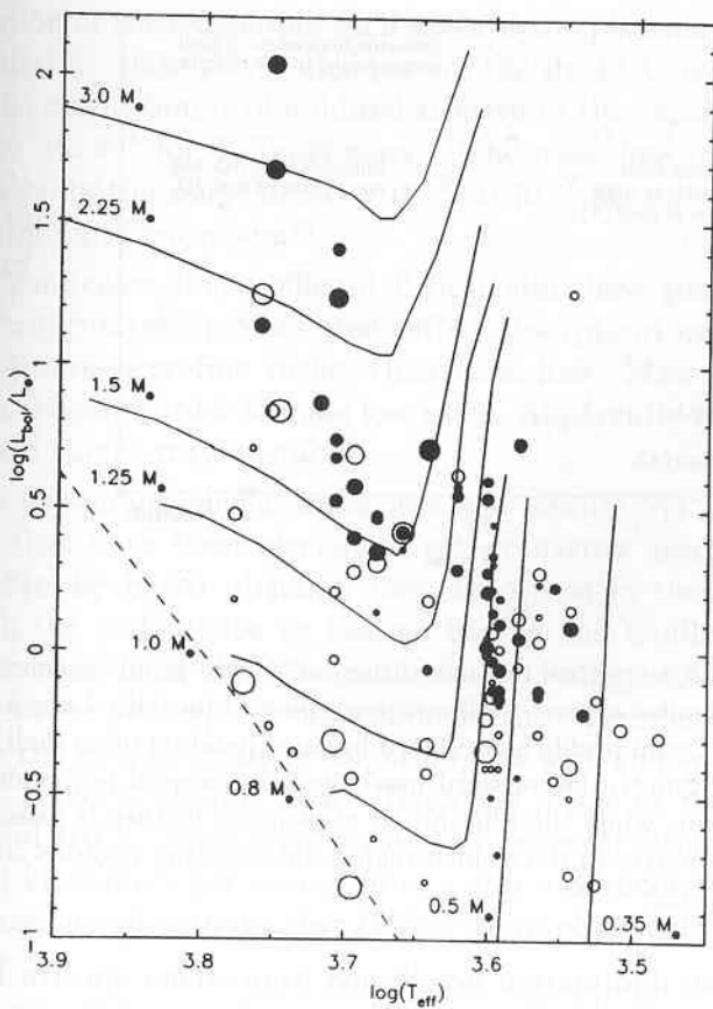


Figure 12.11 The positions of T Tauri stars on the H-R diagram. The sizes of the circles indicate the rate of rotation. Stars with strong emission lines are indicated by filled circles and weak emission line stars are represented by open circles. Theoretical pre-main-sequence evolutionary tracks are also included. (Figure from Bertout, *Annu. Rev. Astron. Astrophys.*, 27, 351, 1989. Reproduced with permission from the *Annual Review of Astronomy and Astrophysics*, Volume 27, ©1989 by Annual Reviews Inc.)

Early stages of collapse of protostar

Jeans mass : minimum mass for grav.
collapse

$$M_J \propto T^{3/2} \rho^{-1/2}$$

Early collapse is isothermal as cloud density low & it is optically thin

Q. What happens to the Jeans mass as the isothermal collapse proceeds?

$$\rho \uparrow \text{ so } M_J \downarrow$$

Smaller regions (smaller masses) become gravitationally unstable

→ FRAGMENTATION

This is why stars (particularly young ones) are found in clusters

Youngest clusters are known as O-B associations

Q It is likely that stars of all masses are formed, and ~~the~~ in fact low-mass stars are more common. Why are they called O-B assⁿ?

Many young star clusters disperse as they become older, but dense clusters or those that live away from the disk most of the time can survive

OB associations - groups of very young high mass stars (some lower mass stars too)

- not gravitationally bound; expanding & will dissolve into field.

How is it possible for a gravitationally bound cloud to give birth to a gravitationally unbound association?

Evolution after the main sequence

Once a star arrives on the main sequence, it is burning $H \rightarrow He$ in its core.

Mean molecular weight in core is slowly increasing

Recall ideal gas law

$$P = \frac{\rho k T}{\mu m_H}$$

↑
mean molecular weight



If ρ, T stay unchanged, what happens to the pressure? How will the star's structure adjust?

If pressure in core decreases, it will not be able to support overlying layers of the star.

So, the core will be compressed.

Gravitational potential energy released

Virial theorem: half energy is radiated away, half goes into increasing temperature.

Nuclear reaction rate for p-p chain goes as $\rho \times T_6^4$ (near 1.5×10^7 K)

X is mass fraction of hydrogen

T_6 is temp in units of 10^6 K.

Mass fraction of hydrogen is decreasing
as $H \rightarrow He$

BUT $\rho \uparrow$ and $T \uparrow$ and these
terms win

Reaction rate goes up and so
luminosity of star slowly increases

→ Star leaves the Zero Age Main
Sequence

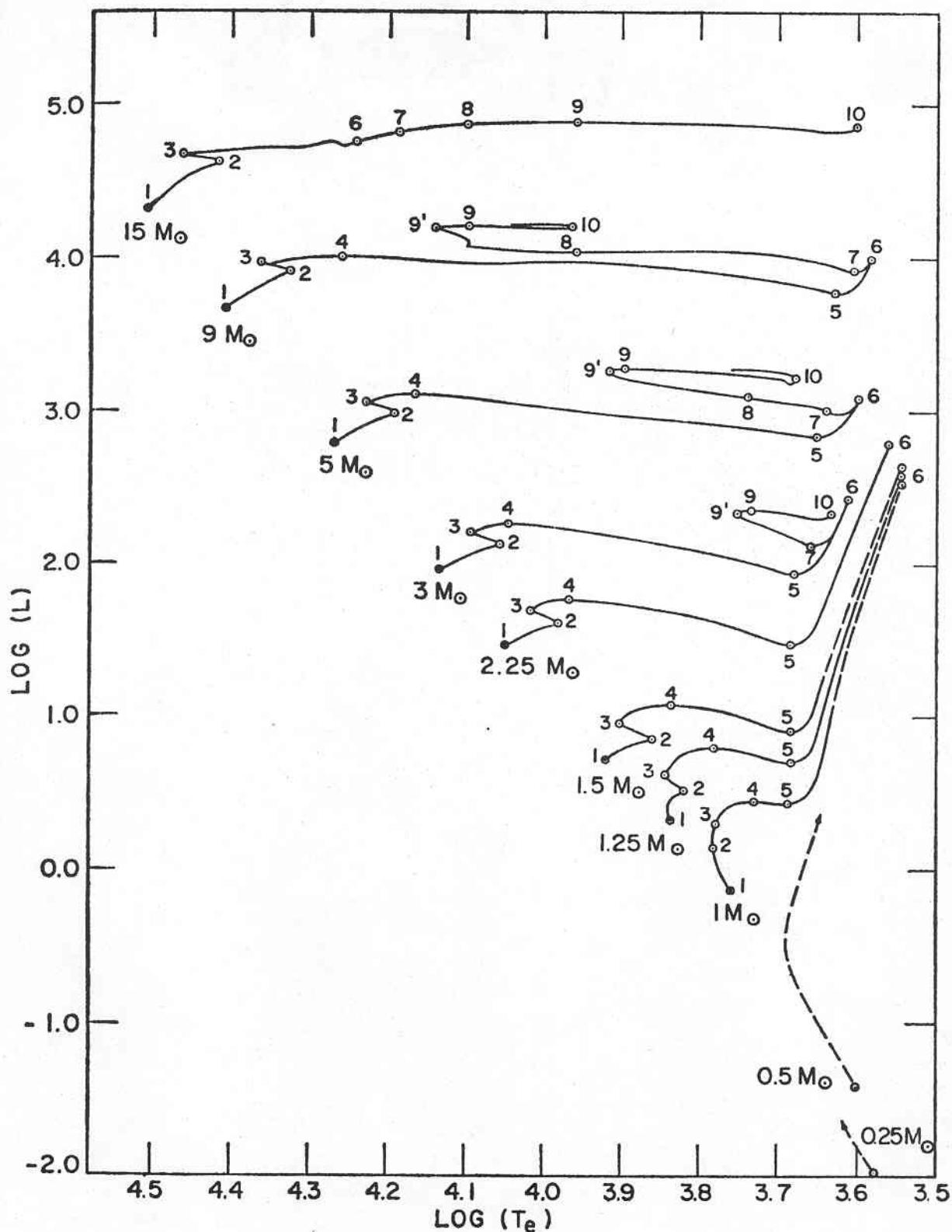


Figure 13.1 Main-sequence and post-main-sequence evolutionary tracks of stars with an initial composition of $X = 0.708$, $Y = 0.272$, and $Z = 0.020$. (Figure from Iben, *Annu. Rev. Astron. Astrophys.*, 5, 571, 1967. Reproduced with permission from the *Annual Review of Astronomy and Astrophysics*, Volume 5, ©1967 by Annual Reviews Inc.)

Why stars leave the main sequence (properly)

stable main-sequence star is in equilibrium:

inward force of gravity
balanced by

outward force of gas & radiation pressure
(caused by fusion)

But its core, where fusion is going on,
is slowly being turned from hydrogen to
helium.

- What happens when there is no hydrogen left in the core?
- Can we see the helium increase in the star's spectrum?

Fairly quickly, in a star the mass of the Sun, this gravitational heating will heat the shell of hydrogen just outside the core & start fusion there.

called hydrogen shell burning.

A star's luminosity is determined by its surface temperature & surface area. At point 3 in the diagram the star's luminosity is slightly higher but the temperature is almost unchanged. What does this imply about the star's diameter?

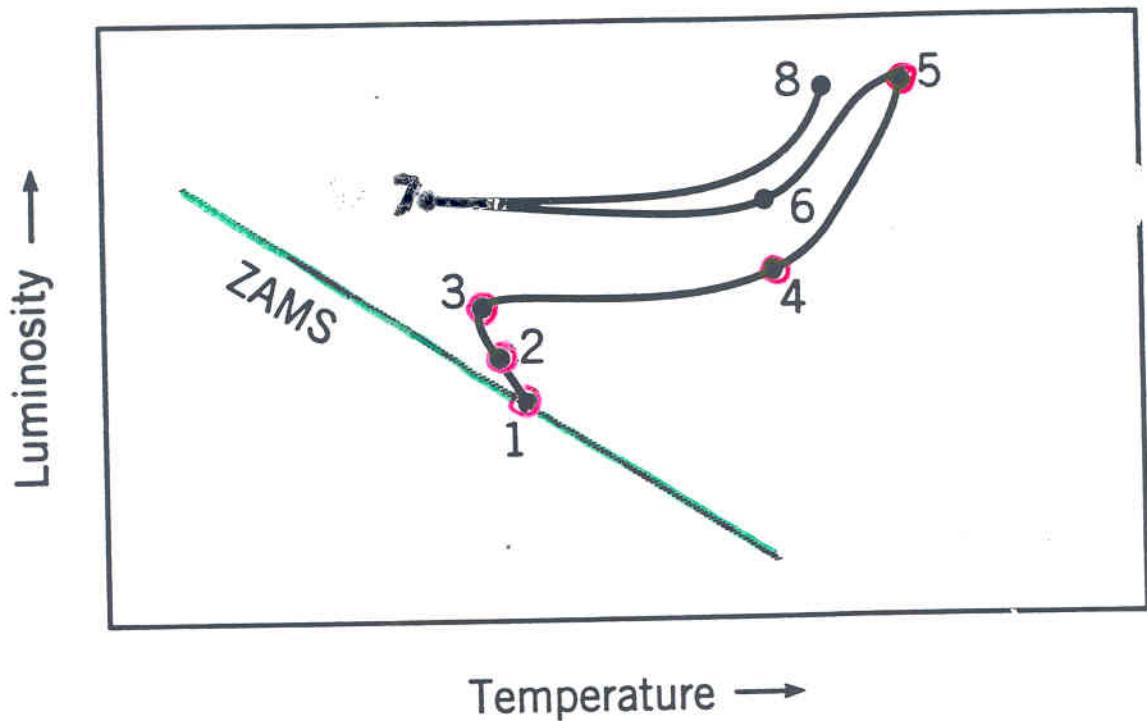


FIGURE 18–3. A schematic diagram of the evolutionary track of a star of one solar mass in the Hertzsprung-Russell diagram. The events occurring at each numbered point are discussed in the text.

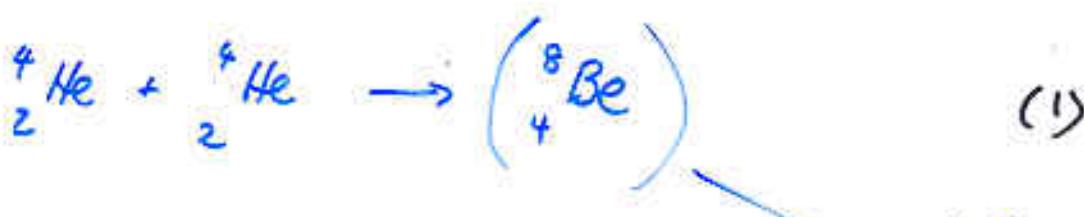
- Most of photons generated in hydrogen-burning shell do not easily escape the star, but are absorbed by outer layers & cause them to expand
- core contracts
- outer layers expand
- So as envelope expands, it cools
(just as gases expanding out of aerosol can cool)
 - So temperature of star's surface decreases
(4)
 - Then whole envelope becomes convective, energy can get out, star gets more luminous & becomes a red giant
(5)

Evolution during red giant phase is
FAST compared to main sequence
lifetime so red giants are relatively
rare

Question : there are several well-known
bright red giants in the night sky —
how can this be if red giants are
rare ?

Core continues to contract and heat until it reaches a temperature of 10^8 K - ~~ten times~~ its main sequence temperature

This is hot enough for helium nuclei to fuse to make carbon



very soon after



TRIPLE ALPHA reaction

(5)

Need high enough p, T for reaction 2 to happen before Be decays

Helium ignition can happen so quickly
that it is explosive (HELIUM FLASH)

if the core is so dense that it
becomes degenerate

In this case, increasing temperature
does not increase pressure as in
an ideal gas (normally in a star)

So star does not expand (as usual)

We call this a thermal runaway

Question What is likely to happen
when all the core He is burnt to
carbon?

Low-mass stars (cont)

Horizontal branch : core He burning
shell H burning

Asymptotic giant branch (AGB)

- + C-O core
- : shell He burning
- : shell H burning

- Stars pulsate (long-period variables) at & near tip of AGB
- Star loses remaining H envelope, puffs off shells ; seen in ^{IR &} radio (OH/IR stars) and as "planetary nebulae".
- Central star has little H left ; never gets hot enough to ignite C & O.
Becomes a white dwarf.

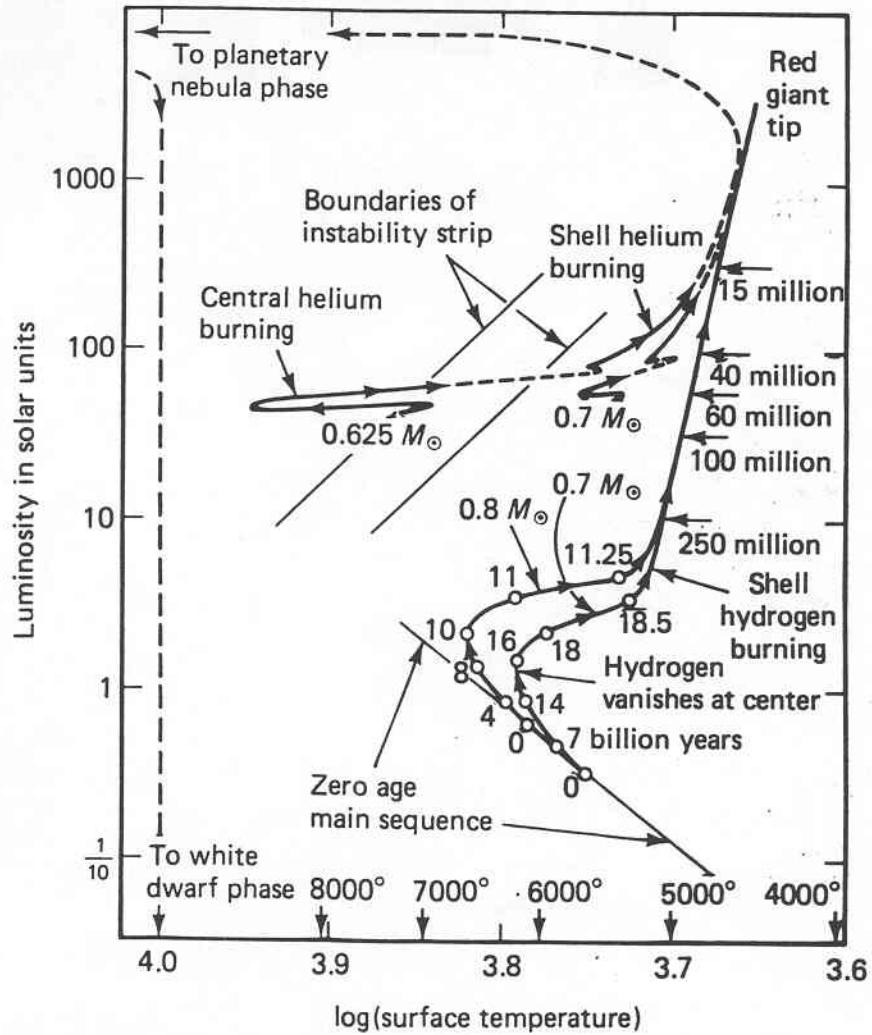


Fig. 14.11. Evolutionary tracks for population II stars with 0.7 and $0.8 M_{\odot}$. A helium abundance of $Y = 0.30$ and a heavy element abundance of $Z = 10^{-3}$ was used. On the main sequence and subgiant branches evolution times since arrival on the zero age main sequence are given in billions of years. On the red giant branch evolution times from one arrow to the next are given in millions of years. Also indicated is the instability strip, the T_{eff} , L domain in which stars start to pulsate (see Chapter 17). From the tip of the asymptotic giant branch the stars probably evolve through the planetary nebula stage to become white dwarfs as indicated by the long dashed lines. From Iben (1971).