

Evolution of massive stars (~8-150 M_sun)

- High luminosity – nuclear reactions go fast, so lifetimes short
- Stellar cores (with nuclear reactions) are now convective, outer regions radiative
- First stages of evolution: CNO burning of H to He
- He burning starts without flash (core is not degenerate)



Introduction in the world of isotopes

The periodic table of the elements

A standard periodic table of elements is shown, organized into groups by atomic number. The table highlights different blocks of elements:

- s block:** Elements 1 through 2 (H) are in the first column. Groups 13 through 18 (III-VIII) are also highlighted in yellow.
- p block:** Elements 3 through 10 (He) are in the second column. Groups 13 through 18 (III-VIII) are also highlighted in yellow.
- d block:** Elements 11 through 36 (Kr) are in the third column. Groups 13 through 17 (III-VII) are highlighted in orange.
- f block:** Elements 57 through 103 (Lr) are in the fourth column. Groups 13 through 17 (III-VII) are highlighted in purple.

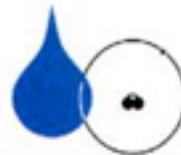
Below the table, a legend identifies the color coding for each block:

- s block: Blue
- p block: Yellow
- d block: Orange
- f block: Purple

92 elements



over 1000 isotopes



Isotopes

A X N

$A = Z + N$

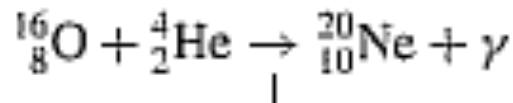
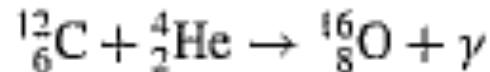
16											S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40			
15		Stable isotope								P27	P28	P29	P30	P31	P32	P33	P34	P35	P36	P37	P38	P39			
14		Long-lived radioisotope								Si25	Si26	Si27	Si28	Si29	Si30	Si31	Si32	Si33	Si34	Si35	Si36				
13		Short-lived radioisotope								Al23	Al24	Al25	Al26	Al27	Al28	Al29	Al30	Al31	Al32	Al33	Al34				
12						Mg20	Mg21	Mg22	Mg23	Mg24	Mg25	Mg26	Mg27	Mg28	Mg29	Mg30	Mg31	Mg32							
11						Na19	Na20	Na21	Na22	Na23	Na24	Na25	Na26	Na27	Na28	Na29	Na30	Na31	Na32	Na33					
10						Ne17	Ne18	Ne19	Ne20	Ne21	Ne22	Ne23	Ne24	Ne25	Ne26	Ne27									
9						F16	F17	F18	F19	F20	F21	F22	F23	F24	F25										
8					O13	O14	O15	O16	O17	O18	O19	O20	O21	O22	O23	O24									
7					N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	N21										
6					C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19									
5					B8	B9	B10	B11	B12	B13	B14	B15		B17											
4					Be6	Be7	Be8	Be9	Be10	Be11	Be12		Be14												
3					Li5	Li6	Li7	Li8	Li9		Li11														
2					He3	He4	He5	He6		He8															
1	H	D	T																						
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

Amount of neutrons (N)

<http://www2.bnl.gov/CoN/>

Later stages of nucleosynthesis

- Carbon burning core, He burning shell, H burning shell



- At this stage the star is in the red-giant region of the HR diagram

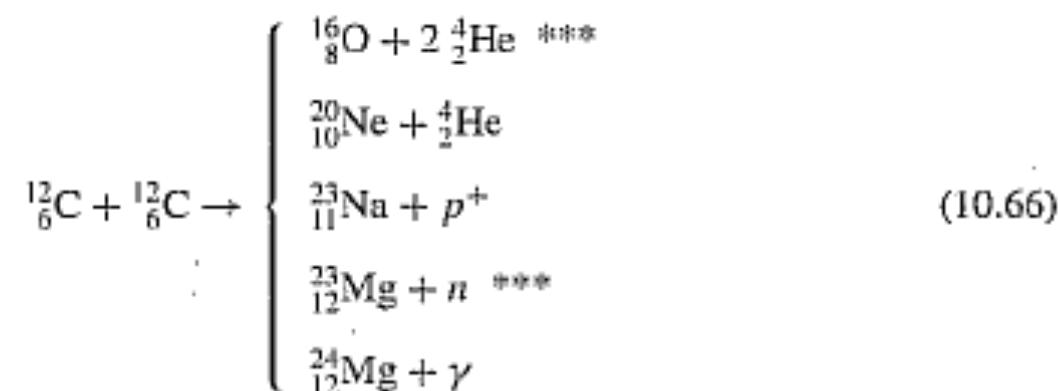
Energy loss via neutrinos: speeds up evolution

After helium burning the core contracts and the temperature rises. The most abundant fuel with the lowest charge is carbon (^{12}C). In order to get two carbons to fuse, a temperature of almost a billion K is required (actually 0.8 billion).

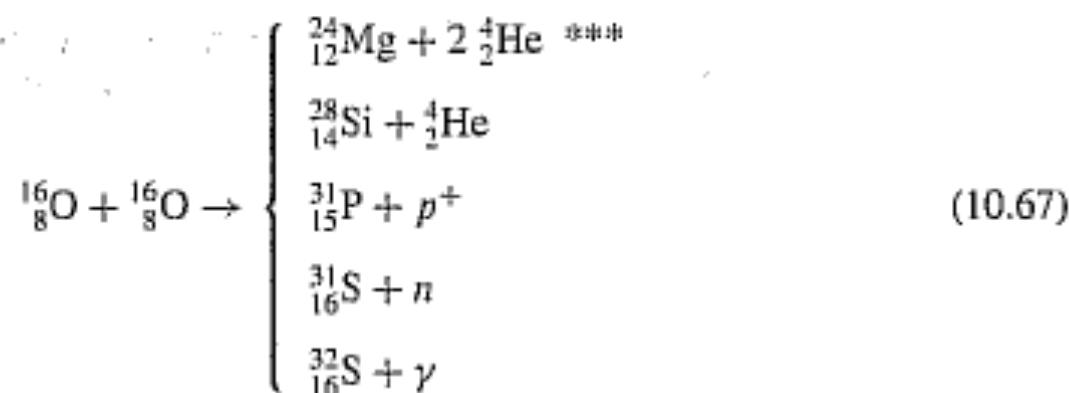
At such high temperatures, a new energy loss mechanism comes into play.



If a star is sufficiently massive, still higher central temperatures can be obtained and many other nuclear products become possible. Examples of available reactions include carbon burning reactions near 6×10^8 K,



and oxygen burning reactions near 10^9 K,

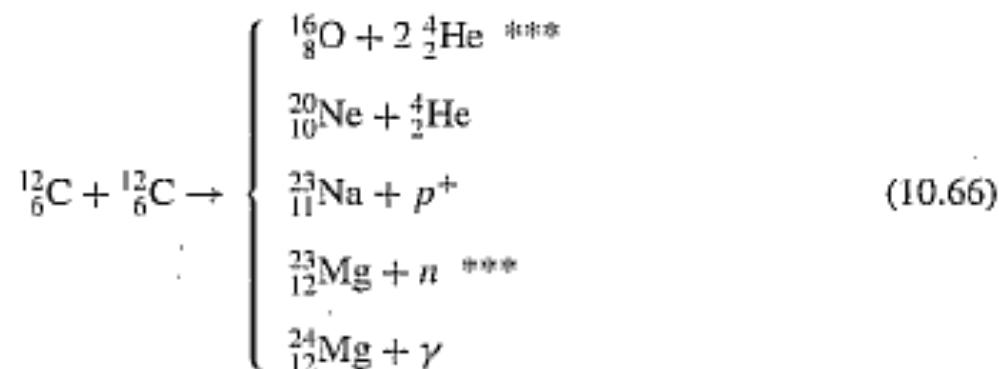


More nucleosynthesis

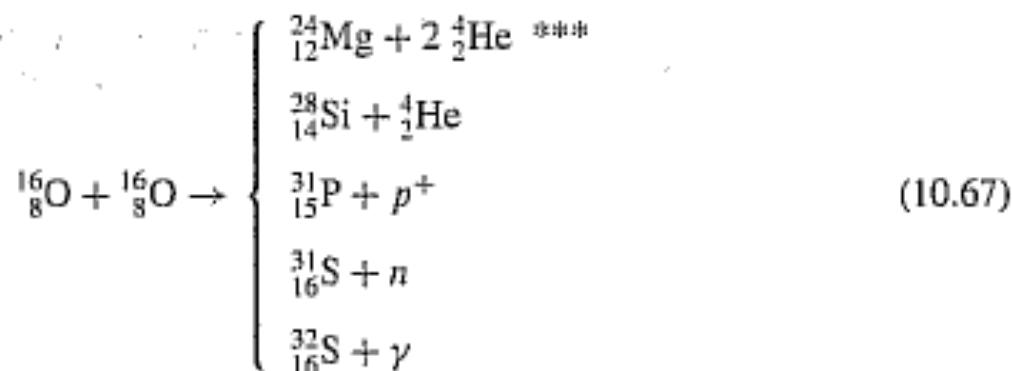
Then the star's core goes through successive stages of burning heavier and heavier elements : neon, oxygen, silicon, etc

(also have reactions that produce magnesium, sulfur, etc)

If a star is sufficiently massive, still higher central temperatures can be obtained and many other nuclear products become possible. Examples of available reactions include carbon burning reactions near 6×10^8 K,



and oxygen burning reactions near 10^9 K,



SUMMARY

Advanced Nuclear Burning Stages (e.g., 20 solar masses)

Fuel	Main Product	Secondary Products	Temp (10 ⁹ K)	Time (yr)
H	He	¹⁴ N	0.04	10 ⁷
He	C,O	¹⁸ O, ²² Ne s- process	0.2	10 ⁶
C	Ne, Mg	Na	0.8	10 ³
Ne	O, Mg	Al, P	1.5	3
O	Si, S	Cl, Ar K, Ca	2.0	0.8
Si	Fe	Ti, V, Cr Mn, Co, Ni	3.5	1 week

Why stop at Fe?

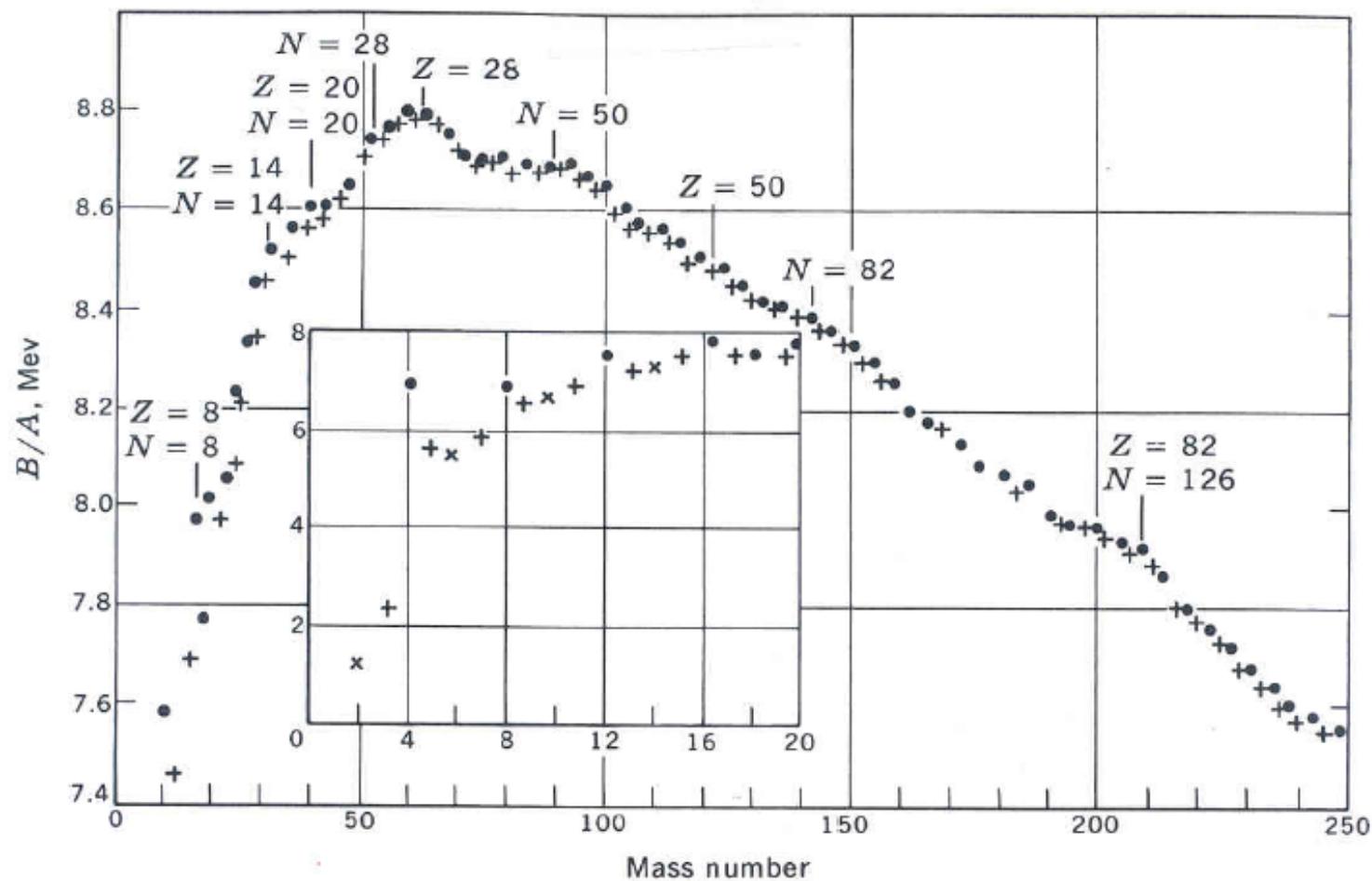
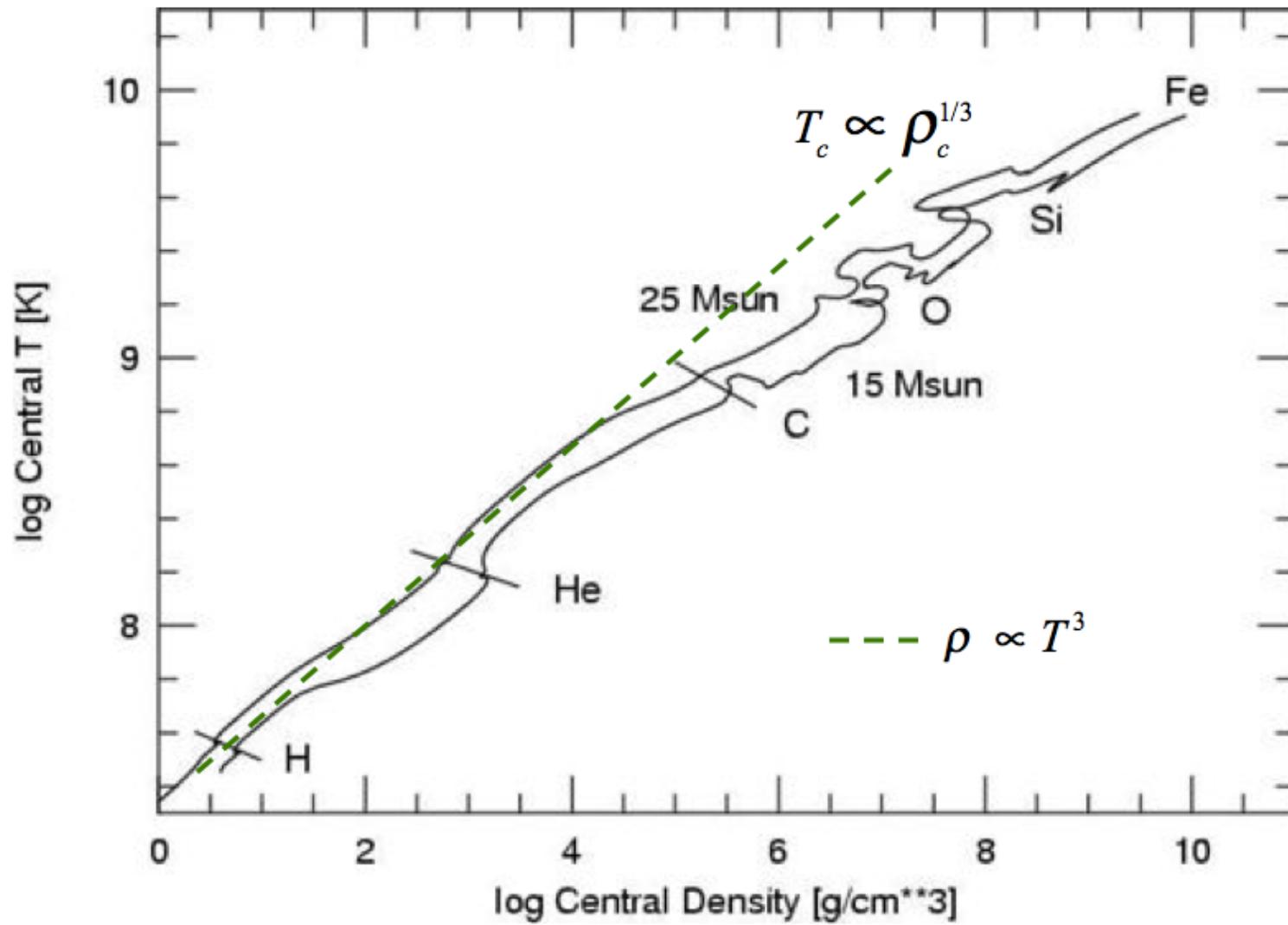


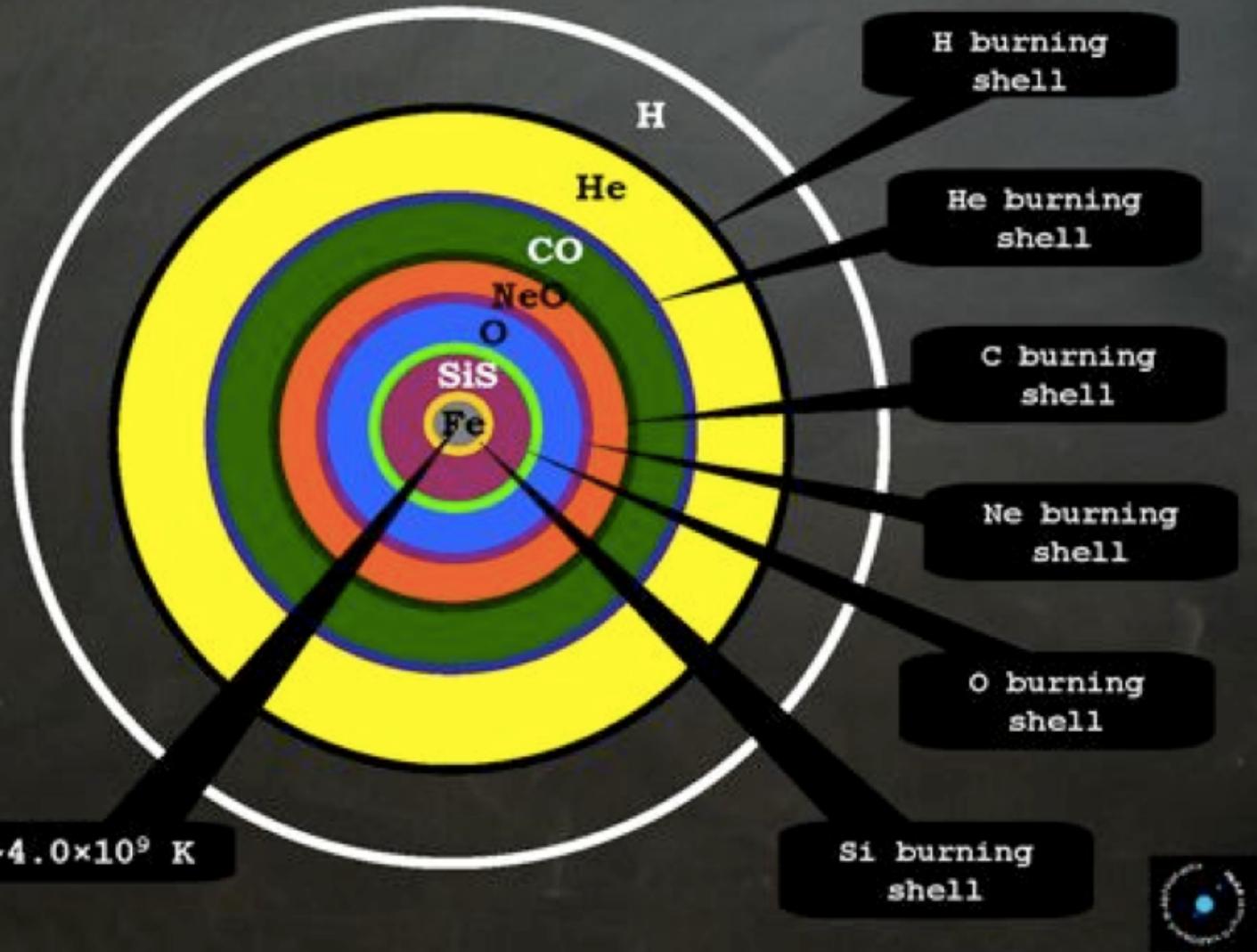
Fig. 7-1 The binding energy per nucleon of the most stable isobar of atomic weight A . The

After each burning stage the core contracts, heats up and ignites another fuel



Pre-SuperNova Stage

NOT TO SCALE



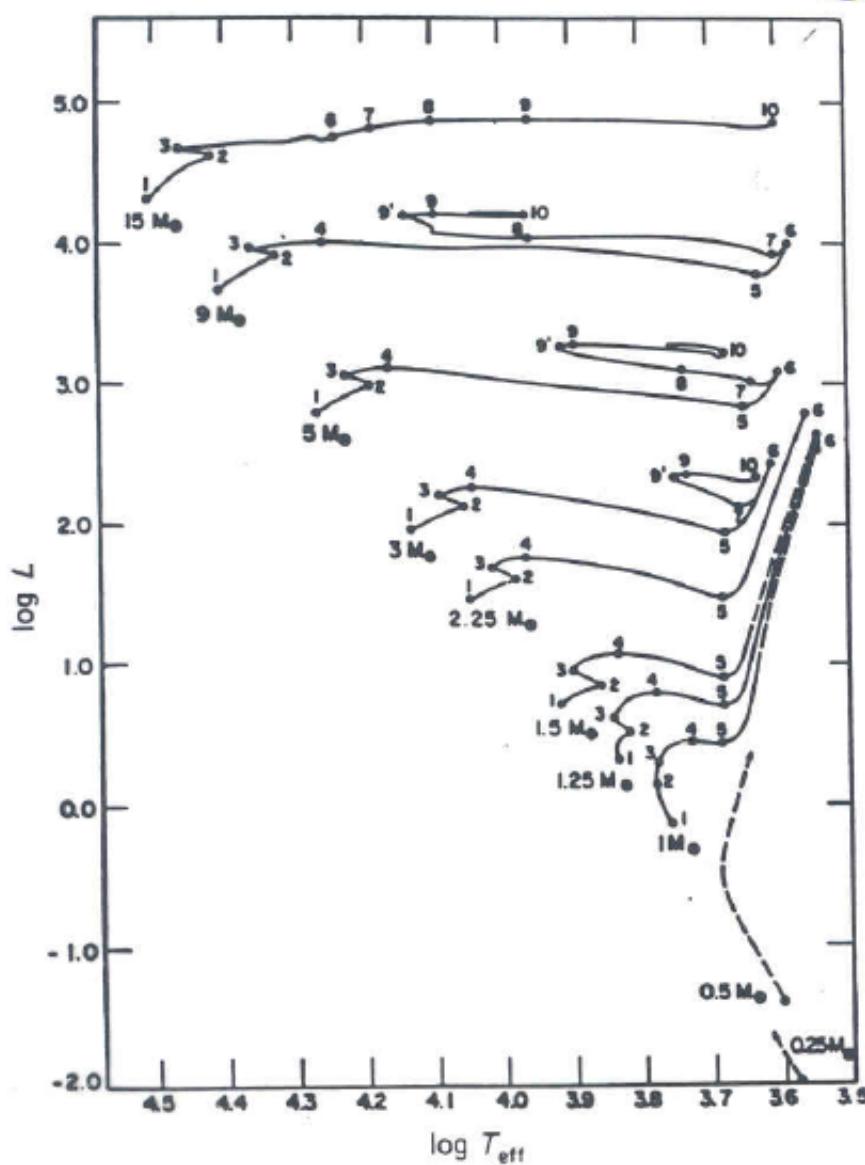


Fig. 15.1. Evolutionary tracks for stars of different masses. For more massive stars the luminosities of the red giants do not increase as much as those for lower mass stars. For the more massive stars the triple-alpha reaction starts soon after they reach the red giant region. The points with the numbers indicate the position for the onset of helium