X3

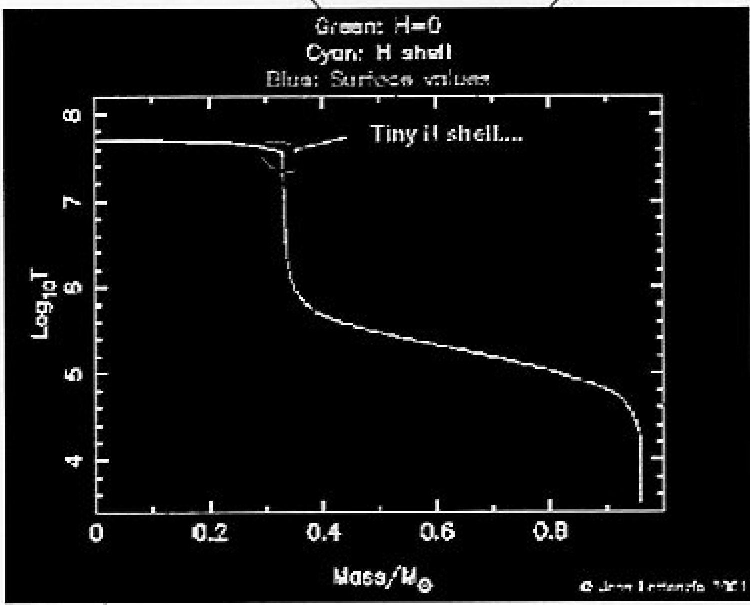
Core He Flash

– notes X3

See www for description & movies

3. As the star's radius swells, the material is less tightly bound gravitationally to the star. Also, the increased luminosity increases the linkage between grains in the envelope and the gas comprising the star. Hence the mass-loss rate increases. Here we used a Reimers mass-loss formula, and the resulting decrease in mass is shown here (horizontal or vertical).

4. The next movies colour coding to illustrate certain features of the star. Wherever all the H has been burned we draw the line in green. Where the H still has the surface value we draw the line in dark blue. In between, where the H abundance is somewhere between zero and the surface we draw the line in cyan. this indicates the position of the H-shell, or the regions of variable H abundance. An example of such a frame is shown below, where we plot temperature vs mass. You can see the isothermal H-exhausted core (in green) very clearly. The H shell is indicated in cyan, and this figure shows how narrow is the H-shell (in mass).



5. The next movie shows the H profiles along the HR evolutionary track (horizontal or vertical). Note that the outer edge of the graph moves inward, reflecting the decrease in the total mass of the star.

6. Here we show the temperature profiles during the H-burning evolution. Watch the formation of the isothermal core, once H is exhausted in the centre. Look also at how quickly the H shell thins to a tiny cyan dot!)

7. This movie shows the density profiles. Again, we clearly see the formation of the He-core and the very thin H-shell.

6. The Core Helium Flash (M=1 Msun, Z=0.02)

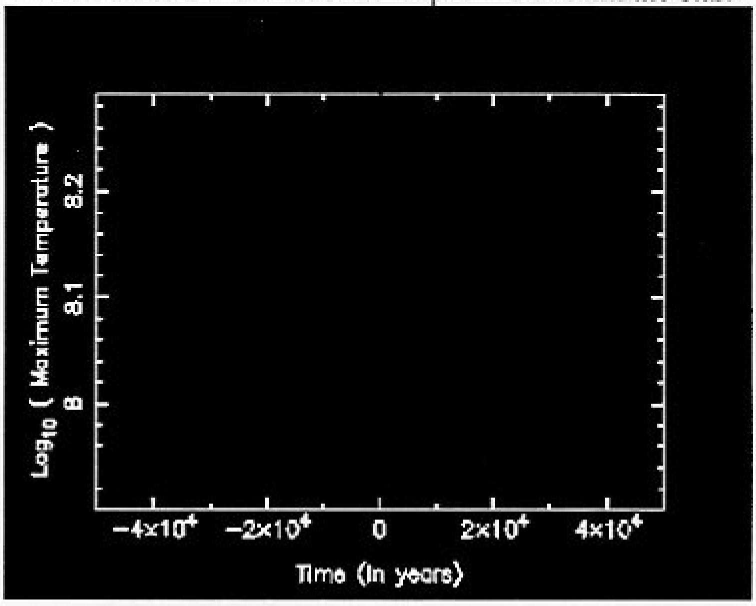
1. We resume the evolution as the star ascends the giant branch. The He core is contracting and gradually heating, but it is also getting denser and more degenerate. A completely degenerate gas has a polytropic equation of state, which means that the pressure is given by

P = K rho^gamma

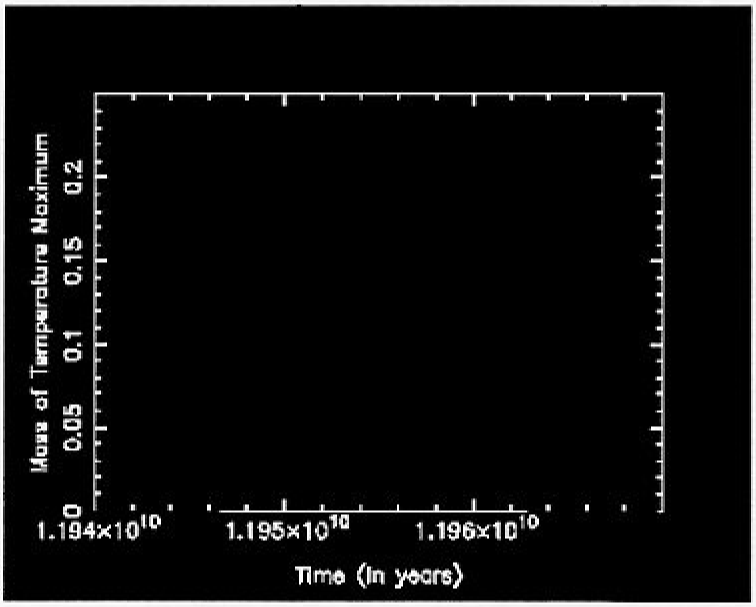
and has no temperature dependence. Now a normal gas will respond to a temperature increase by expanding (ie decreasing rho, to keep P constant). That does not happen in a degenerate gas (at least, not to the same extent, and not at all for a completely degenerate gas). Hence when the temperature finally reaches enough for the ignition of the He burning (via triple-alpha reactions; about 100 million degrees) the extra energy released does not go into expansion, but rather increases the local temperature. Due to the degeneracy, this simply causes the burning rate to further increase, and w3e have a runaway! This is called the core helium flash.

2. There is another complication too. The high density of the core enables various neutrino processes to remove energy from the core. Since these processes depend mostly on density, they are more efficient in the very centre. Hence this region cools more than zones just outside the centre. The result is that the maximum temperature in the star moves away from the centre, and slightly outward in mass. The helium flash is ignited at the point of maximum temperature, of course. Hence the flash begins in a shell (in this spherically symmetric calculation!) somewhat displaced from the centre.

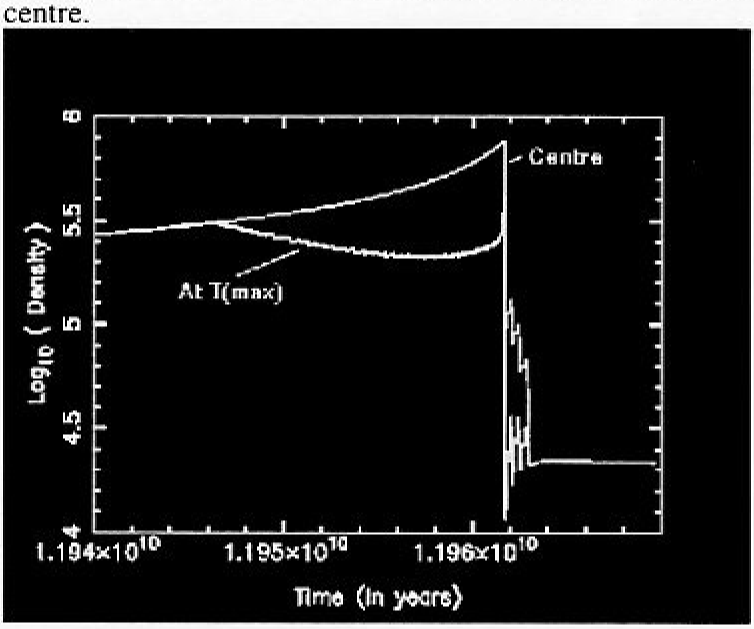
   Here we show the maximum temperature within the star.



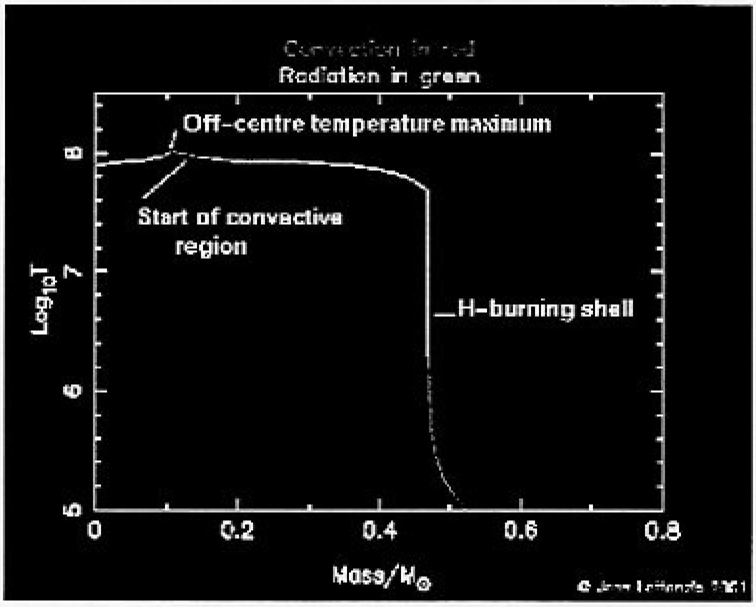
   And below we see the mass where this maximum temperature occurs. Note that it is initially in the centre, but finally moves somewhat away from the centre.



Here we show the central density and the density at the point of maximum temperature. Note that they start to differ when the point of maximum temperature moves away from the centre.



3. Here we see the temperature profiles during the ignition of the flash. This shows that the huge energy deposition drives a convective zone which reaches almost all the way to the H shell.

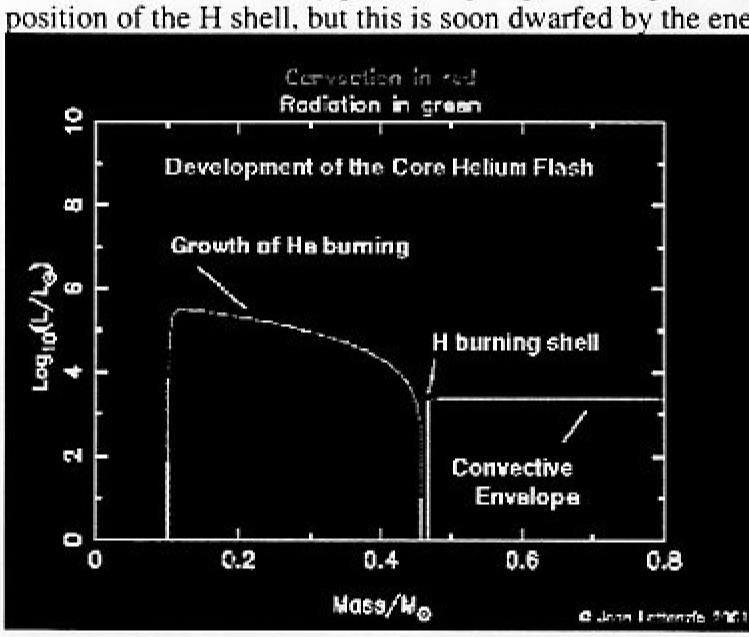


Note how the temperature of the whole core region decreases: this is because the energy released by the flash is mostly used in changing the equation of state of the core: it "lifts" the degeneracy and restores a more nearly perfect-gas equation of state.

4. A similar story is revealed in the density profiles: the core expands dramatically as a result of the energy input from the helium burning.

5. The radius profiles also show the expansion of the core. Note that this is a log plot!

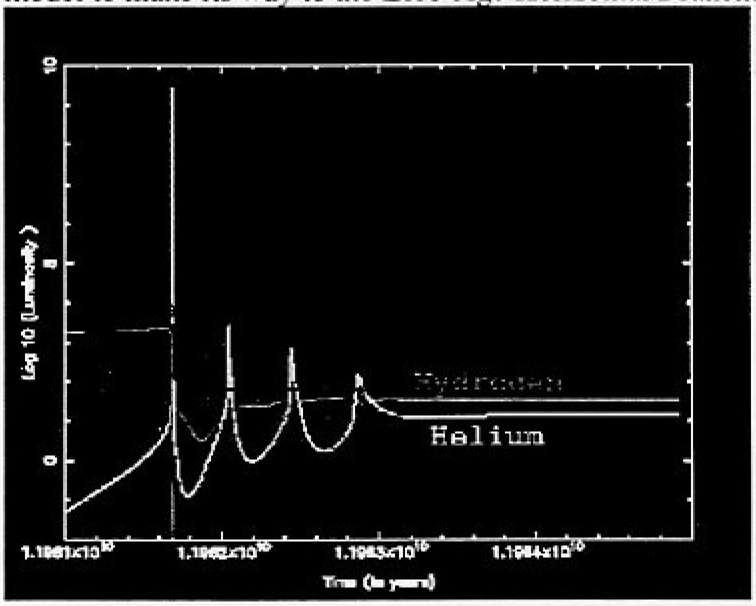
6. Of course, the luminosity profile is going to be impressive! There is a small jump in L at the position of the H shell, but this is soon dwarfed by the energy produced by the He flash.



Of course, the flash does not last long, as shown in the movie.

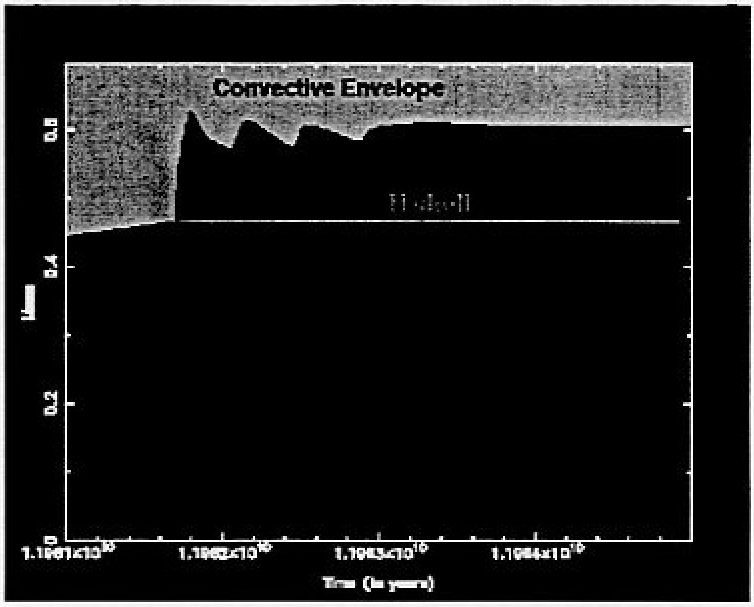
7. The He burning produces C-12. And the convection mixes the C-12 throughout the convective region. The C-12 profiles show this, but we must remember a couple of assumptions that are unlikely to be true: that we can ignore dynamic terms in the equation of motion, and that the mixing is instantaneous. Certainly for the time-steps required during this calculation, these approximations are not valid! But nevertheless we see stars in the next phase which look very much like the models. This is encouraging, but we must remind ourselves that these models must have limitations that we cannot yet determine.

8. But it takes more than one of these flashes to remove the degeneracy on the core, and for the model to make its way to the Zero-Age Horizontal Branch.



Note that the He luminosity reaches almost to 10^10 Lsun, but that the surface value changes very little! Also see that the H luminosity drops to zero: the expansion causes the H shell to be pushed outward and cool so much that the H burning stops. The subsequent flashes are much weaker.

Below we show the convective regions in the star. There are a couple of mini-flashes, but they also drive convective zones, Note that each successive flash occurs closer to the centre than the one before it. Eventually the convective zone of the flash settles down to being the



steadily burning helium core.

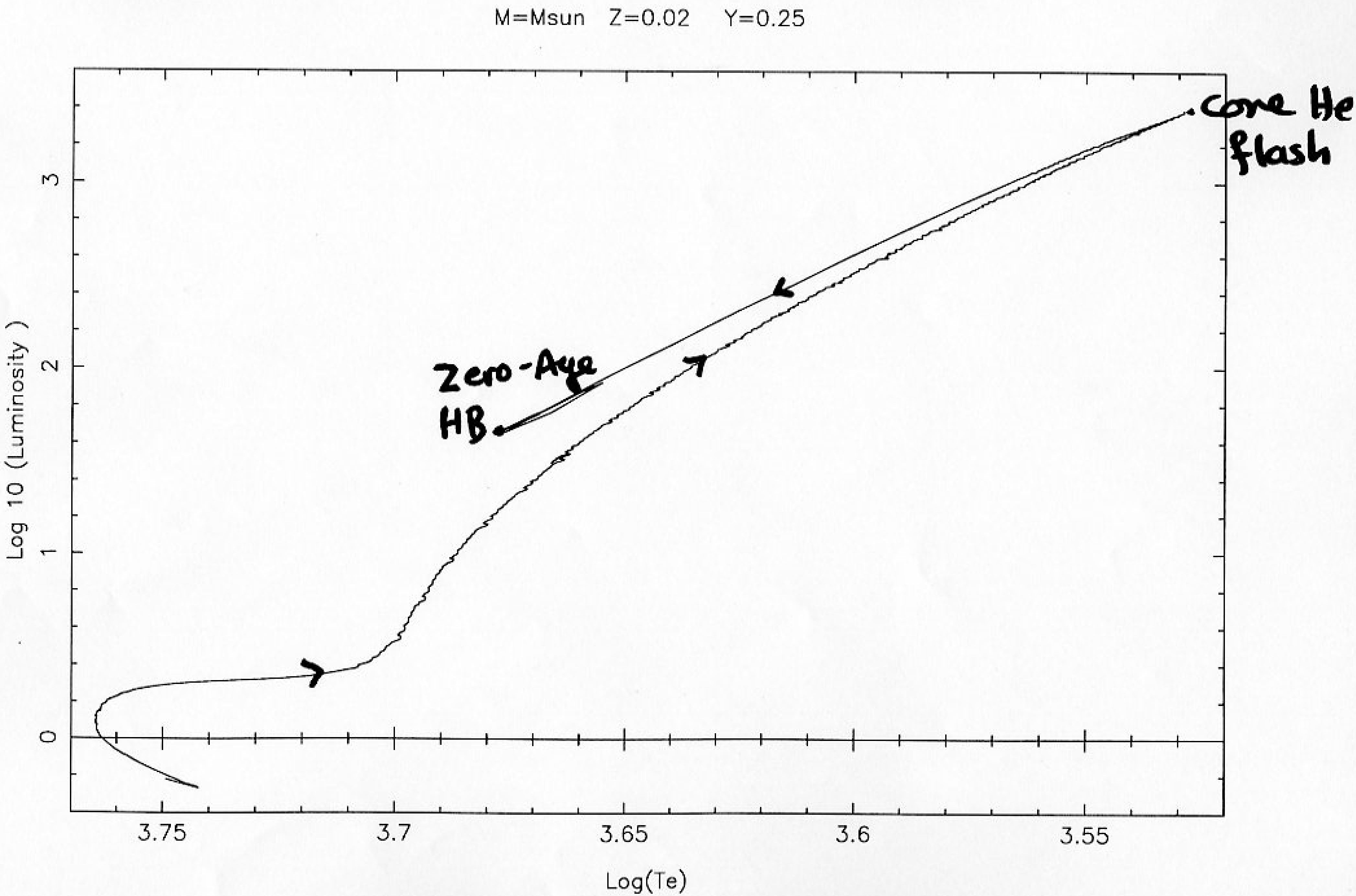
7. Core Helium Burning (M=1 Msun, Z=0.02)

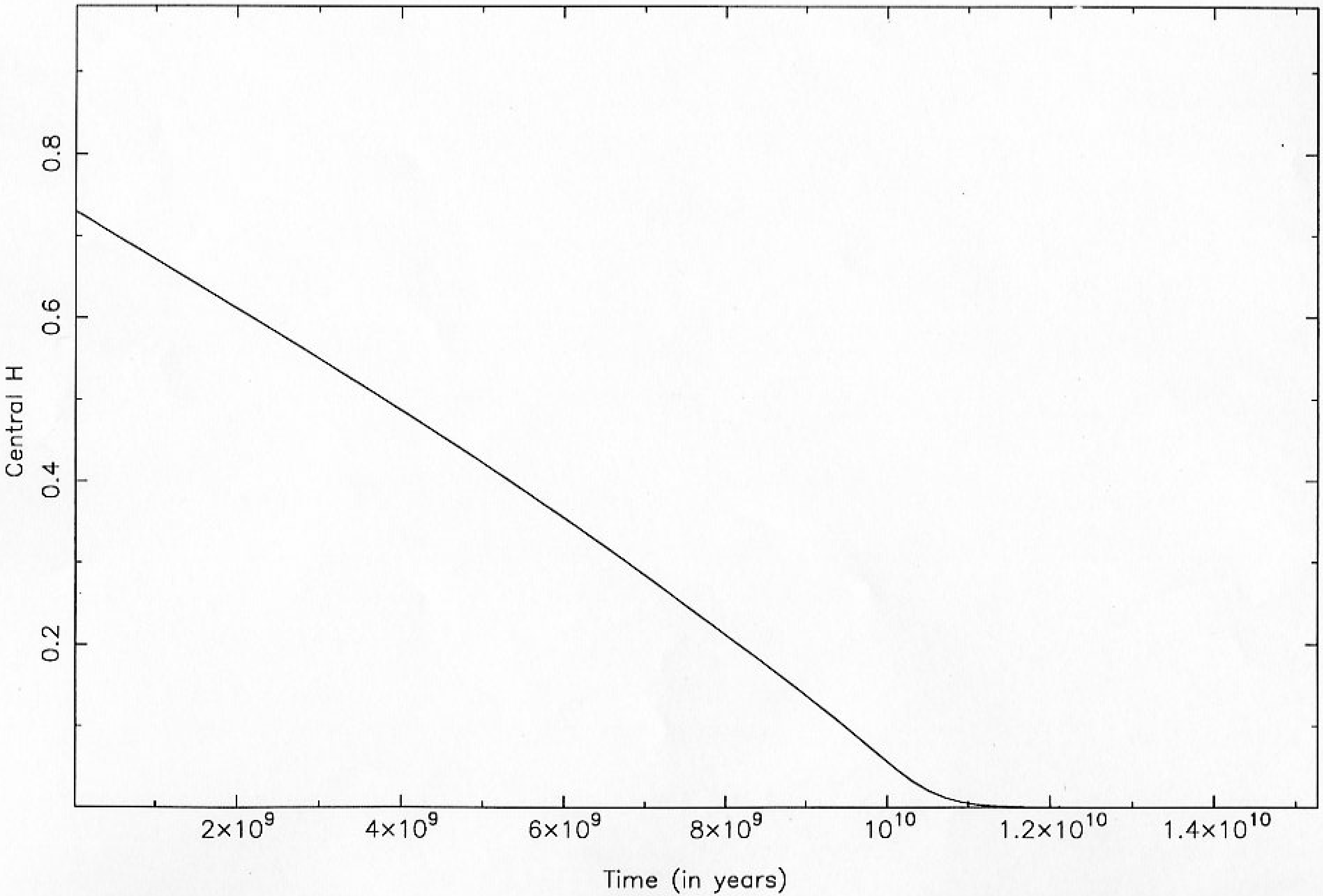
1. The star now begins evolution with two energy sources: a He-burning core and a H-burning shell. This movie (horizontal or vertical) shows the interior profiles of He as the star proceeds through the HR diagram. Note that we have colour-coded the He profiles here according to the H and He abundances

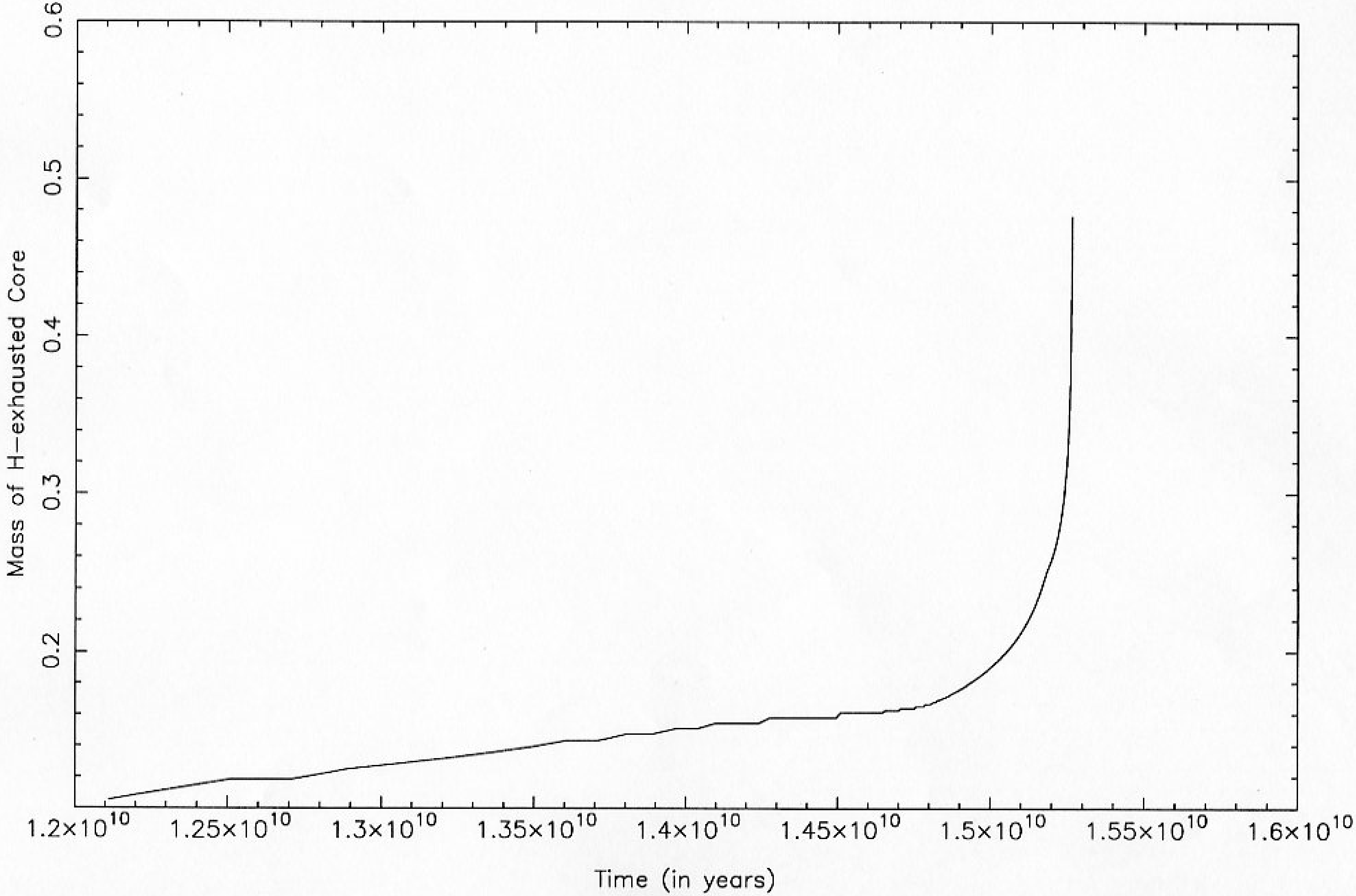
2. Semiconvection: now comes the fun bit!

3. It is not our aim here to go through all the details of semi-convection. Rather, as with the rest of this page, we use results to illustrate the principles. You are referred to the Castellani, Giannone and Renzini papers from 1970 for an excellent discussion. But here we show the latter stages of the core helium burning evolution of out M=1 Z=0.02 model.

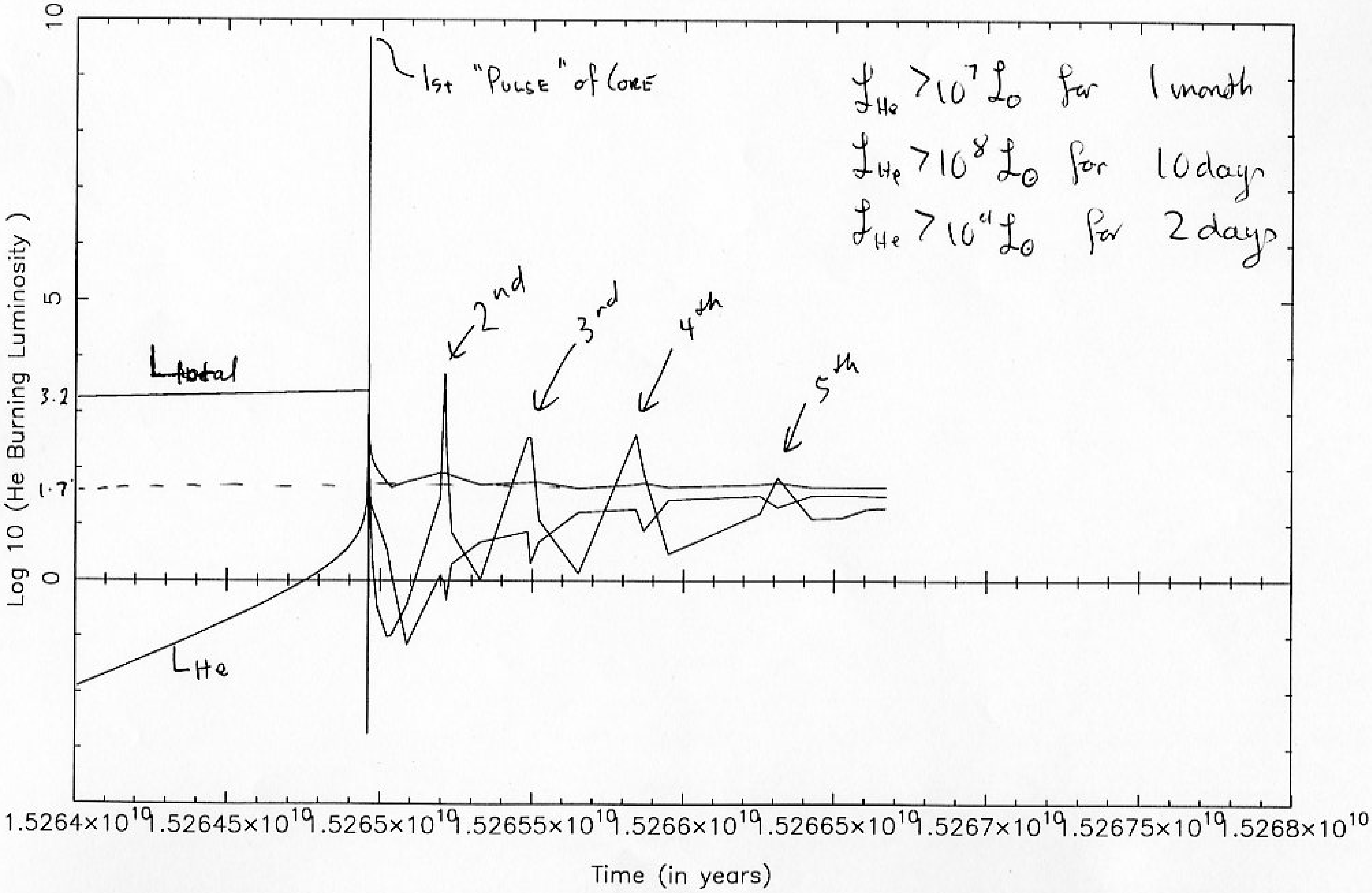
4. Initially the burning of He into C-12 increases the opacity in the core. Hence the radiative gradient increases, and hence the ratio of the gradients increases. But on the other side of the convective border there is no change in the composition (recall that the burning is happening in the very centre, but convection covers a much larger mass than the burning zone, so that there is a discontinuity in the composition at the edge of the convective core: just outside is a radiative region where there is no nuclear burning). SO we have a discontinuity in the composition and also the ratio of the radiative to adiabatic temperature gradients, as shown below.


M=Msun Z=0.02 Y=0.25
Core He flash
Zero-Age HB
Log 10 (Luminosity)
Log(Te)
3.75
3.7
3.65
3.6
3.55
0
1
2
3

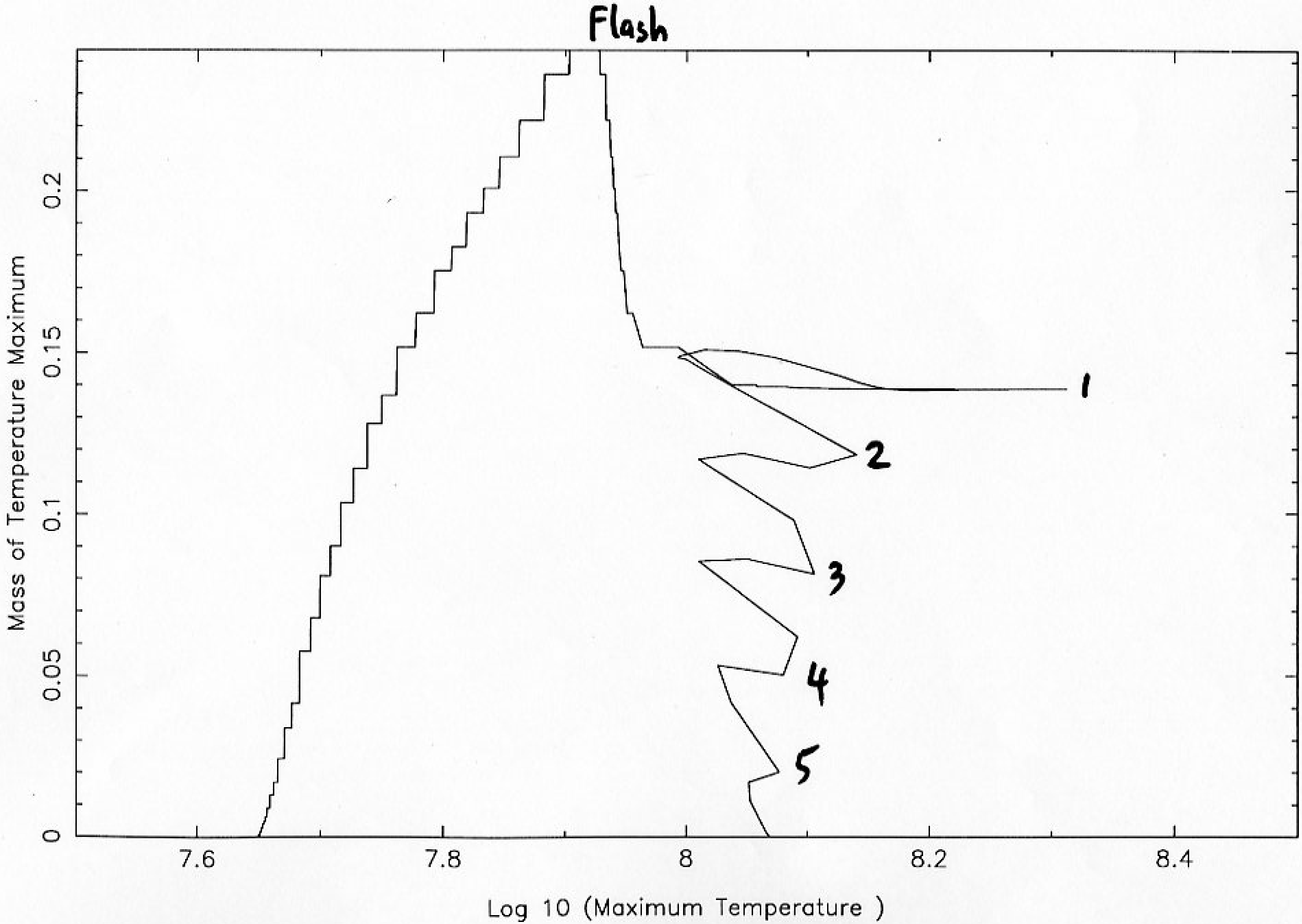

Central H
0.2
0.4
0.6
0.8
2×10^9
4×10^9
6×10^9
8×10^9
10^10
1.2×10^10
1.4×10^10
Time (in years)

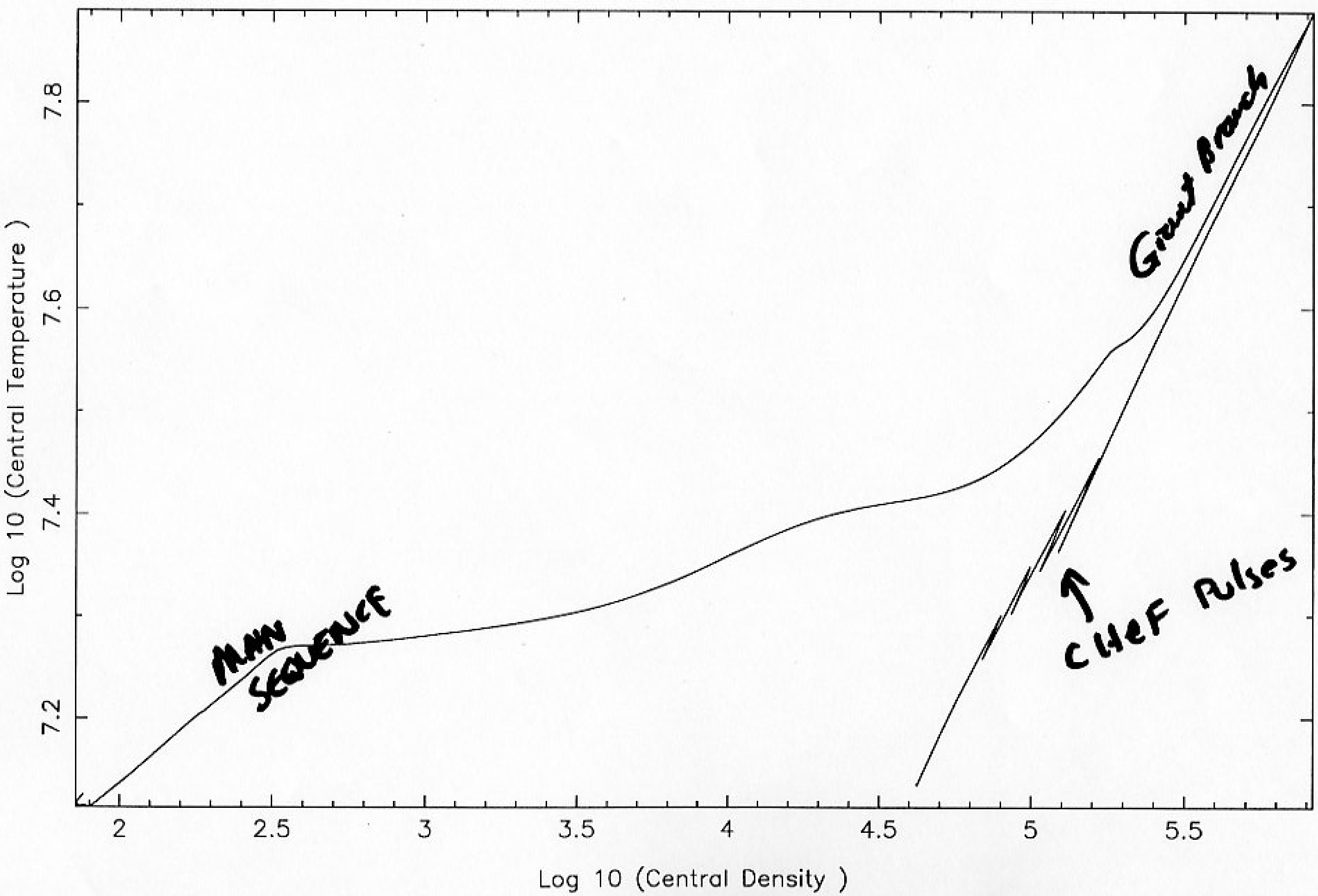


0.6
0.5
0.4
0.3
0.2
Mass of H–exhausted Core
1.2×10^10
1.25×10^10
1.3×10^10
1.35×10^10
1.4×10^10
1.45×10^10
1.5×10^10
1.55×10^10
1.6×10^10
Time (in years)

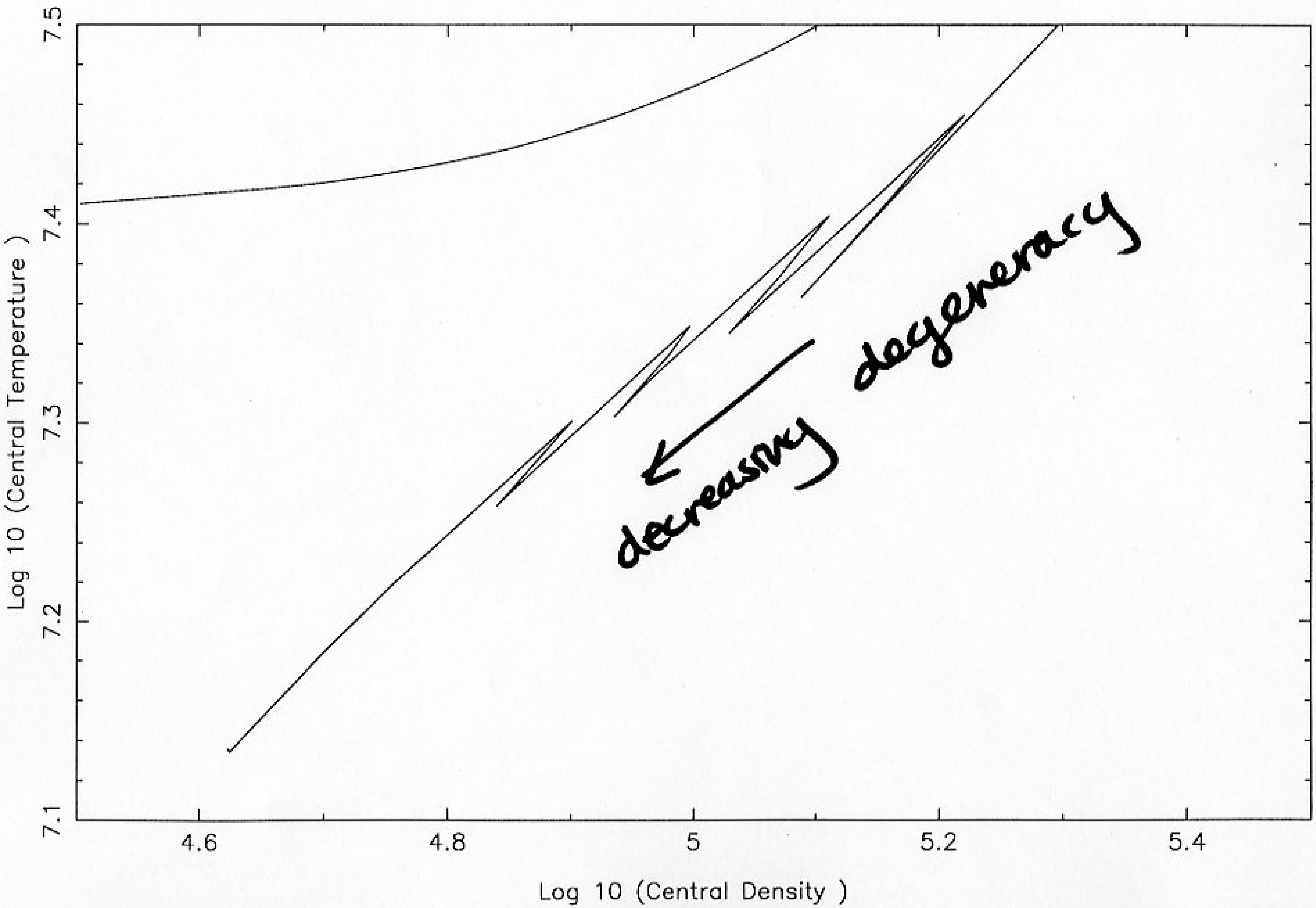


1st "Pulse" of Core
$L_{He} > 10^7 L_\odot$ for 1 month
$L_{He} > 10^8 L_\odot$ for 10 days
$L_{He} > 10^9 L_\odot$ for 2 days
2nd
3rd
4th
5th
L total
L He
10
5
3.2
1.7
0
Log 10 (He Burning Luminosity)
1.5264×10^10
1.52645×10^10
1.5265×10^10
1.52655×10^10
1.5266×10^10
1.52665×10^10
1.5267×10^10
1.52675×10^10
1.5268×10^10
Time (in years)

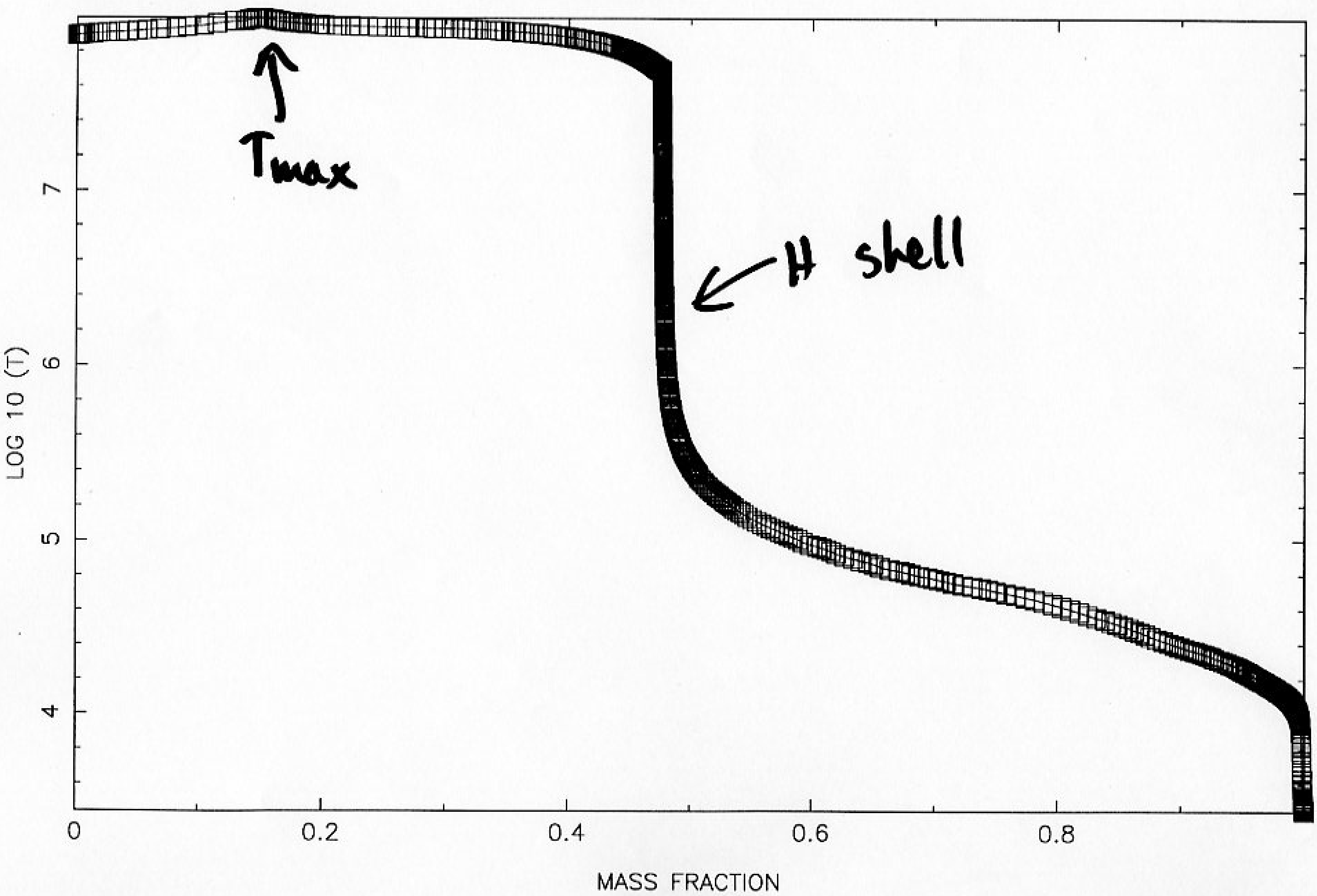

Flash
1
2
3
4
5
0
0.05
0.1
0.15
0.2
Mass of Temperature Maximum
7.6
7.8
8
8.2
8.4
Log 10 (Maximum Temperature)

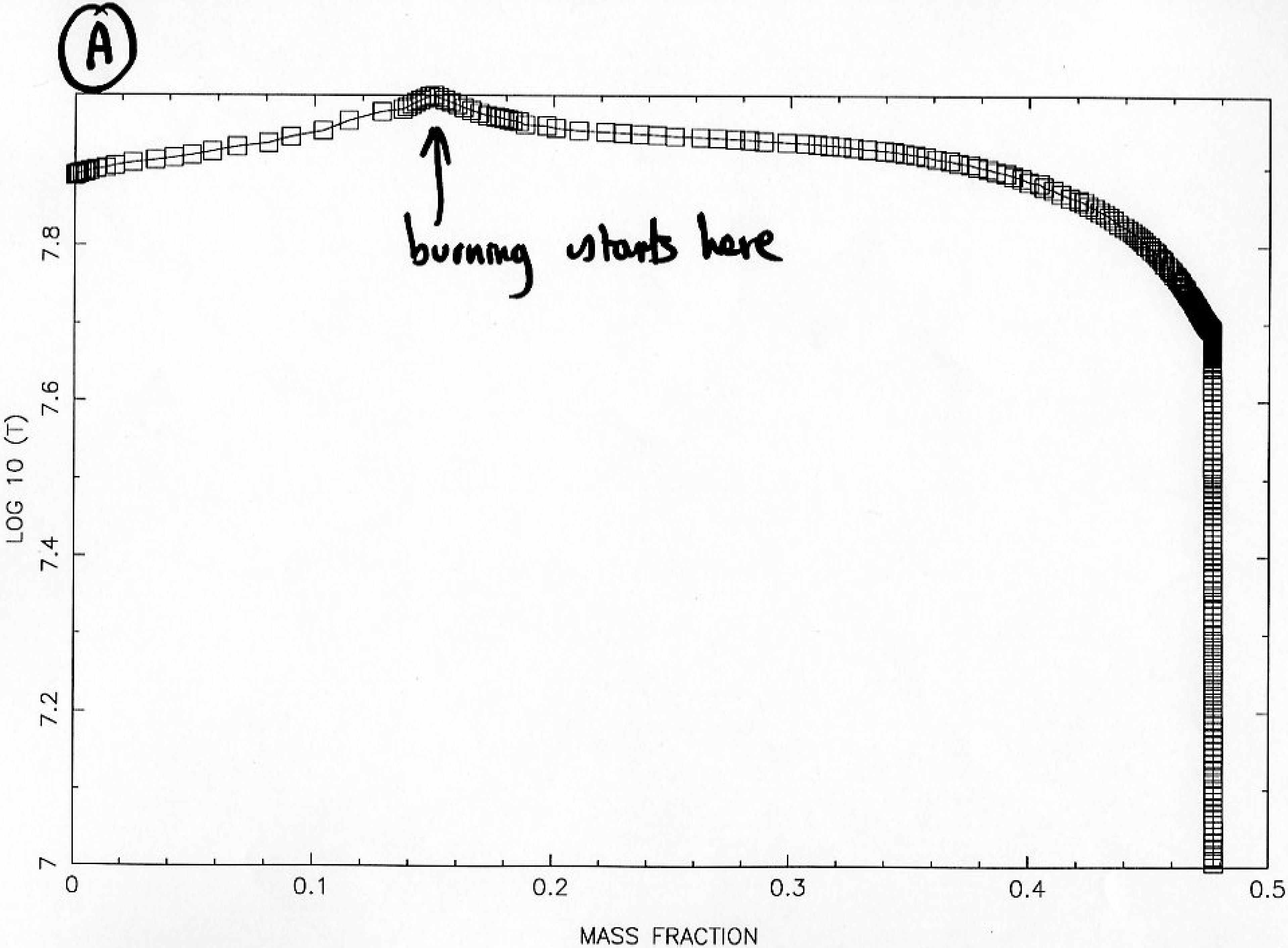


Log 10 (Central Temperature)
7.2
7.4
7.6
7.8
2
2.5
3
3.5
4
4.5
5
5.5
Log 10 (Central Density)
MAIN SEQUENCE
Giant Branch
CHeF Pulses

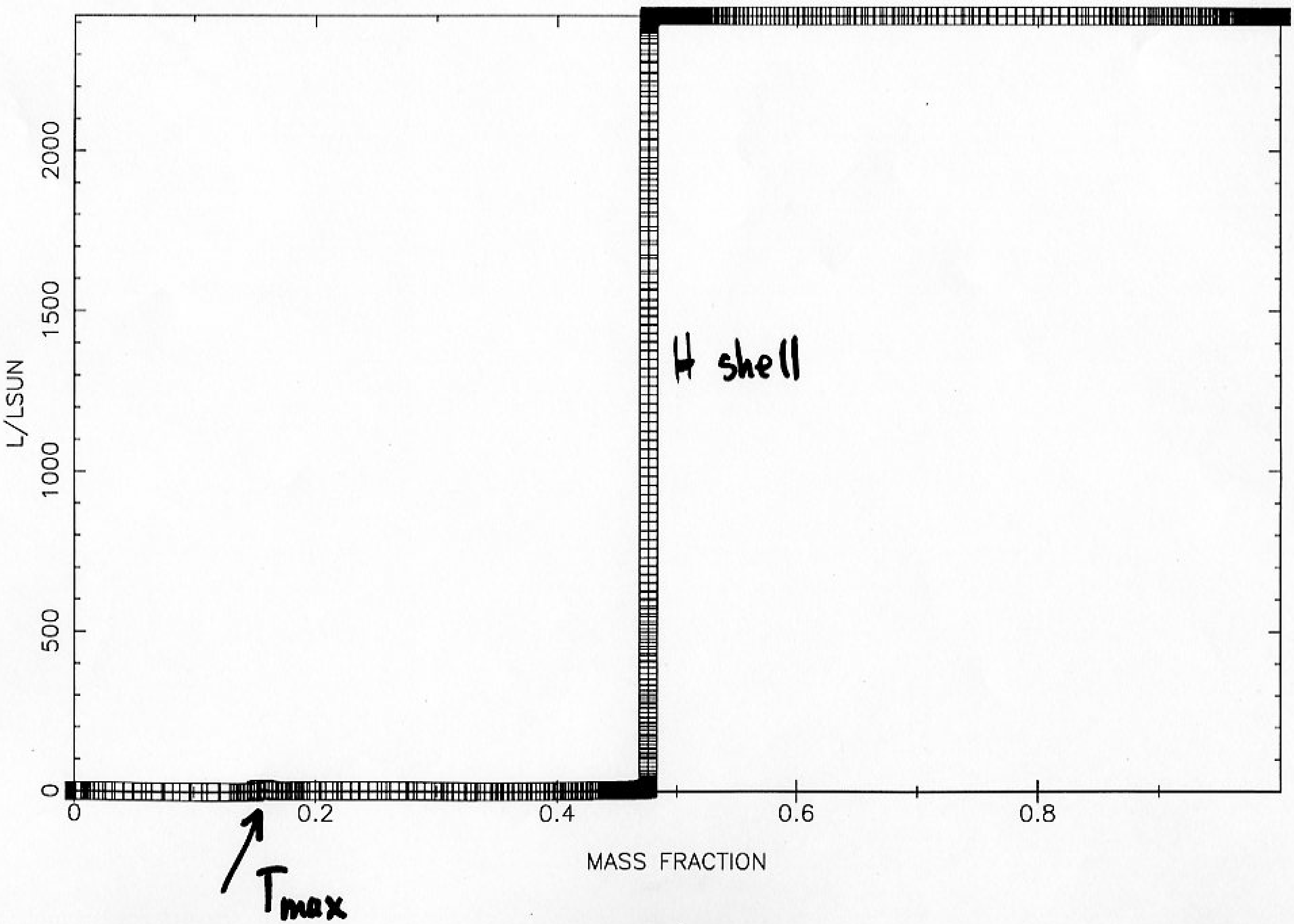

7.5
7.4
7.3
7.2
7.1
Log 10 (Central Temperature)
4.6
4.8
5
5.2
5.4
Log 10 (Central Density)
decreasing degeneracy

MODEL A (#12000)

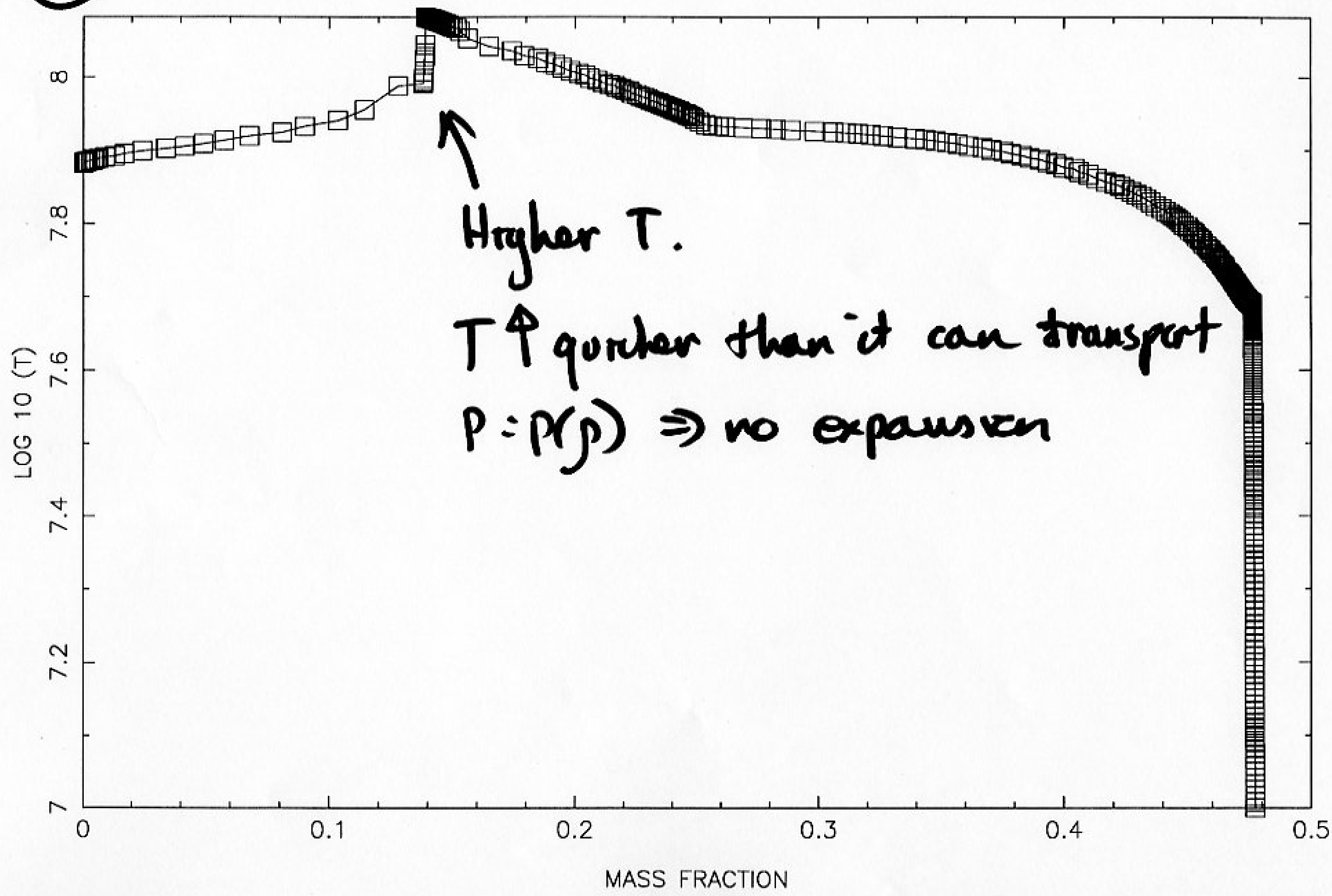


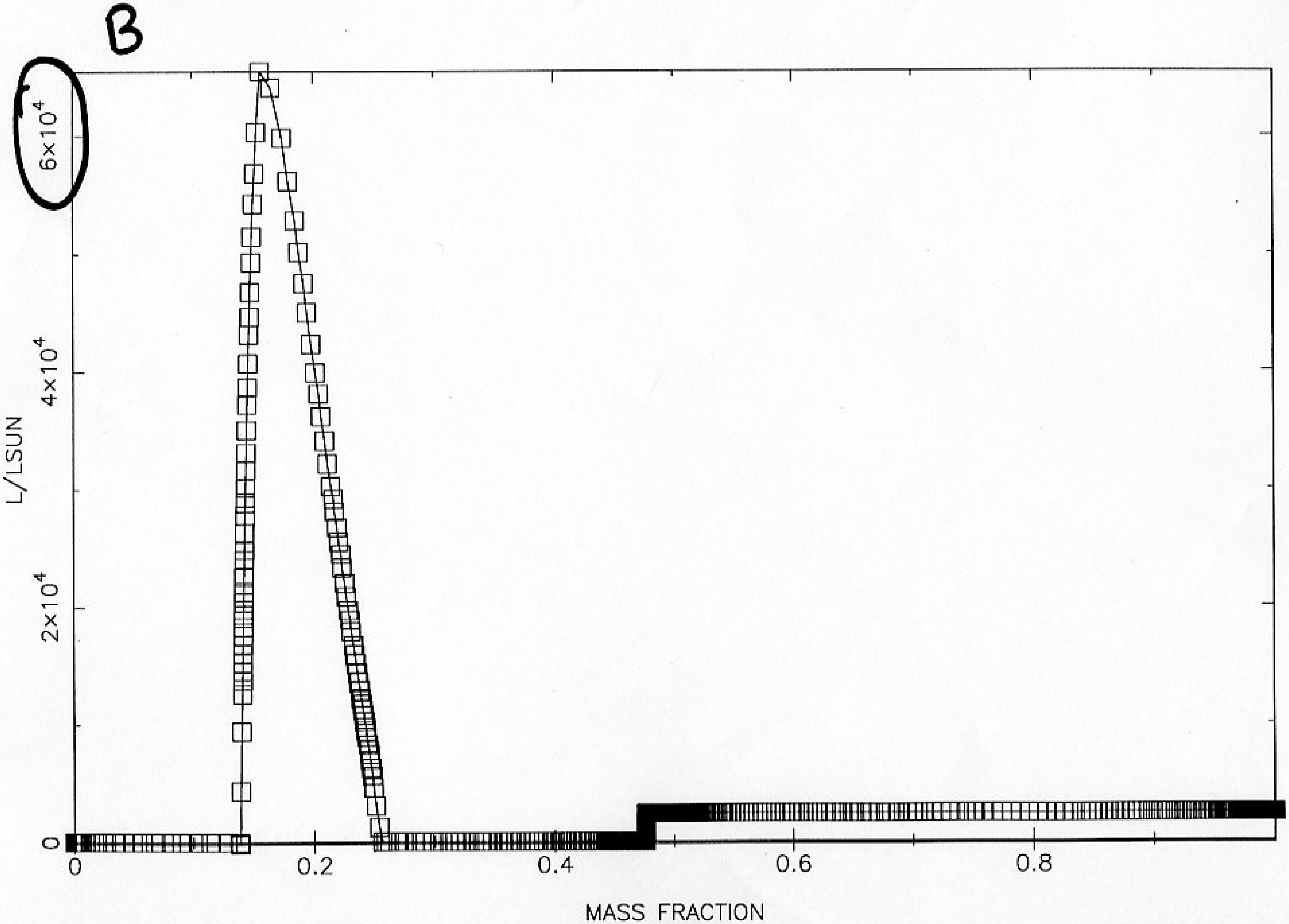

A
burning starts here
LOG 10 (T)
7
7.2
7.4
7.6
7.8
0
0.1
0.2
0.3
0.4
0.5
MASS FRACTION

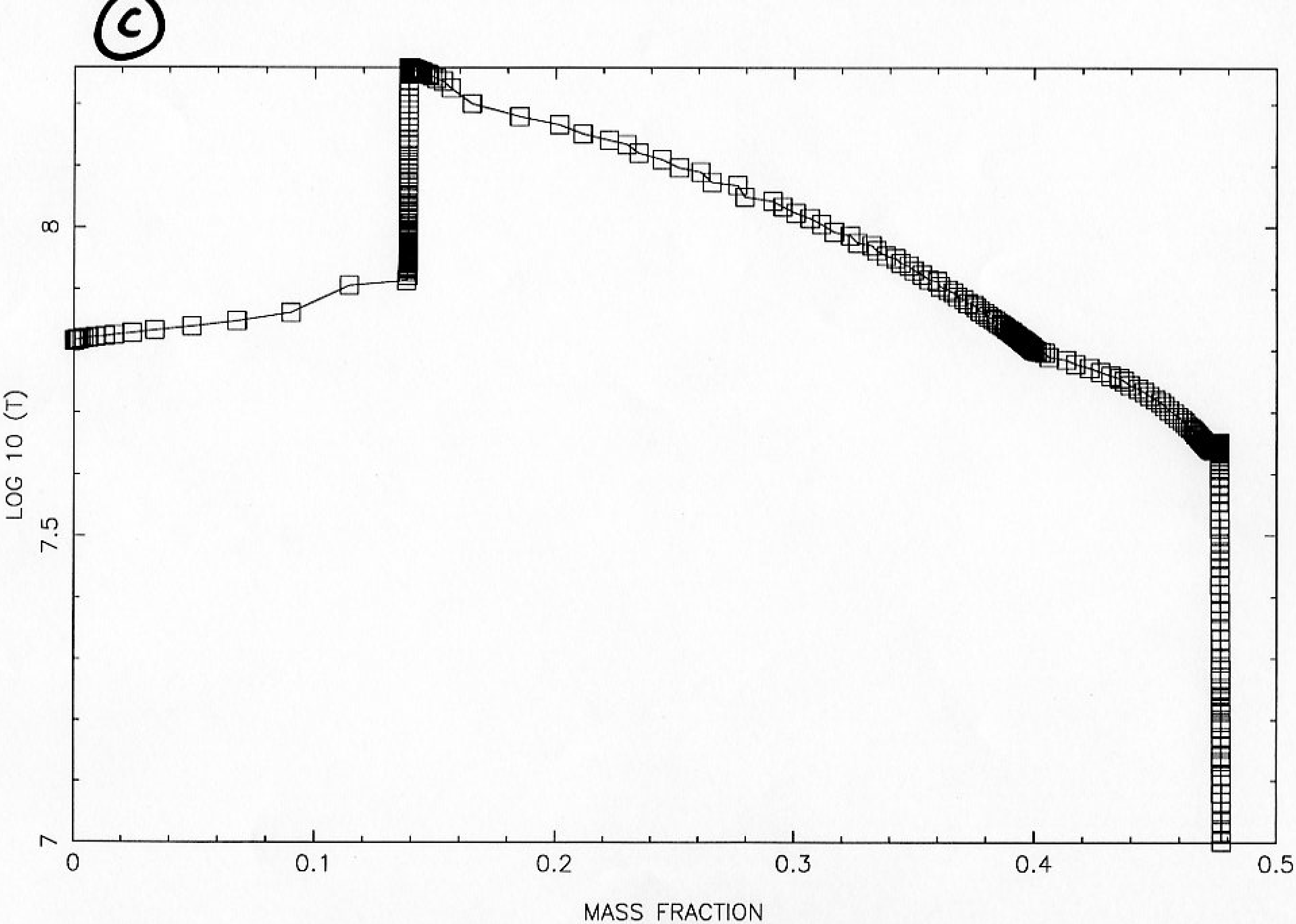
MODEL A (=12000)

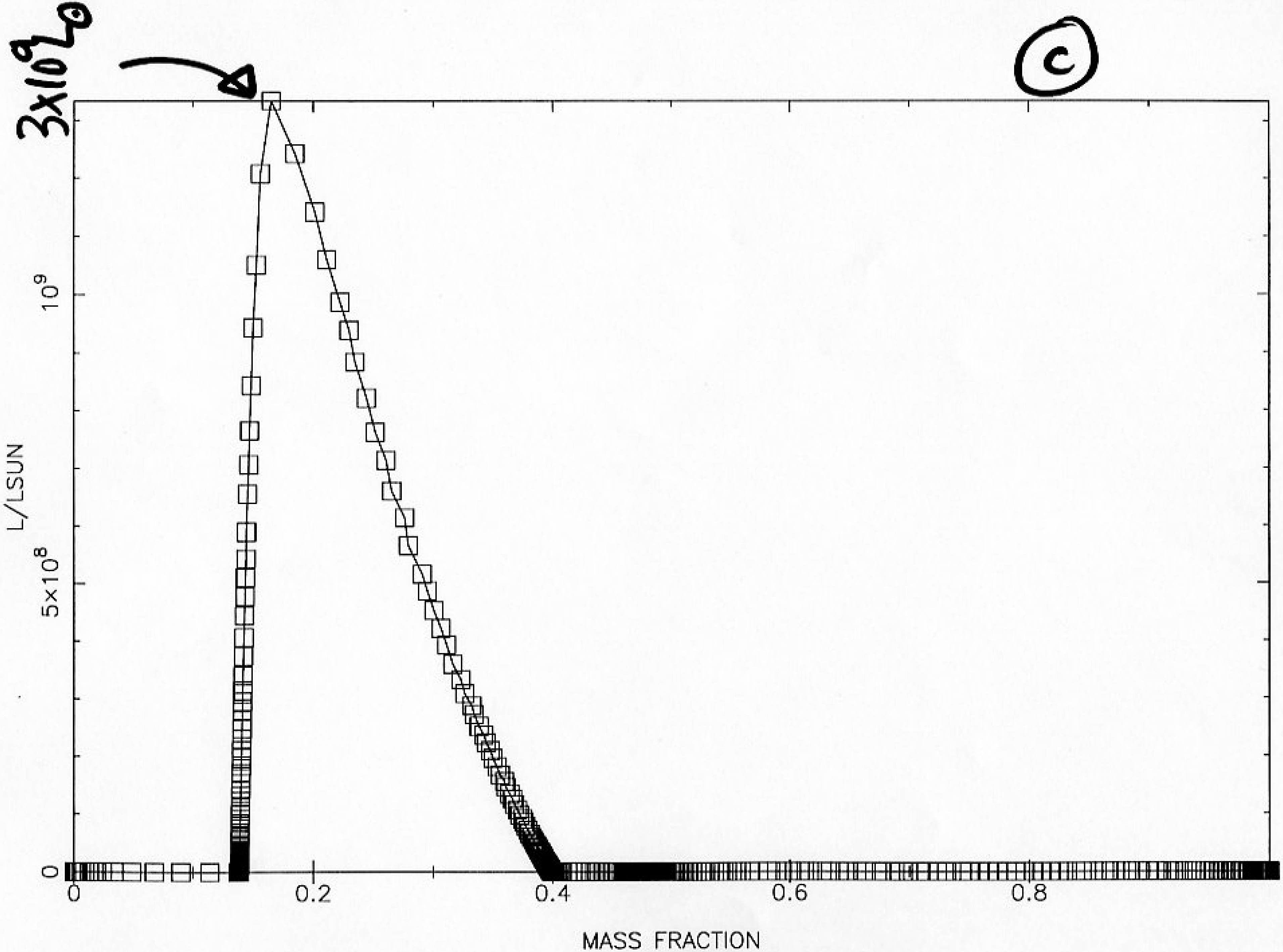


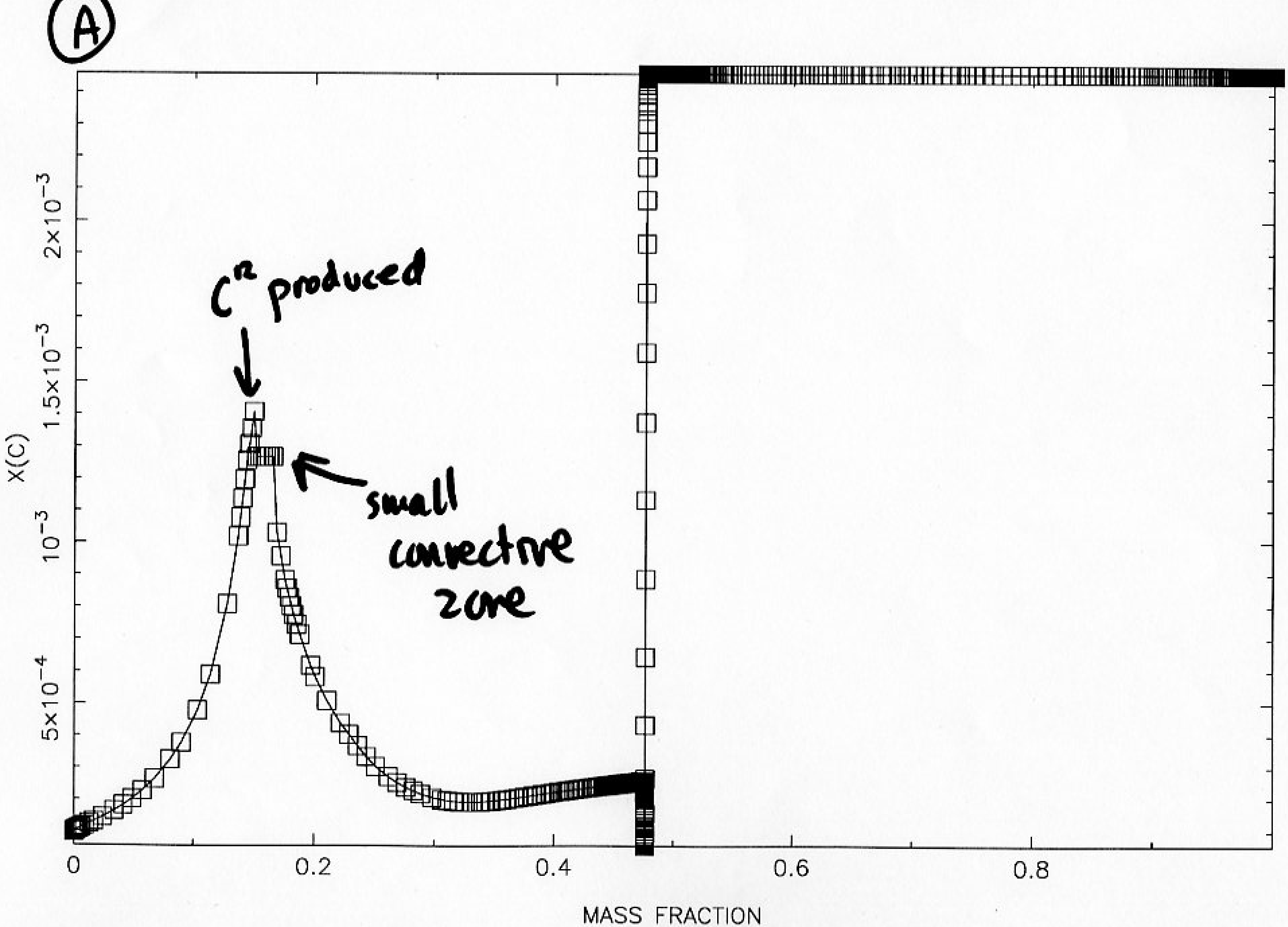
(3)

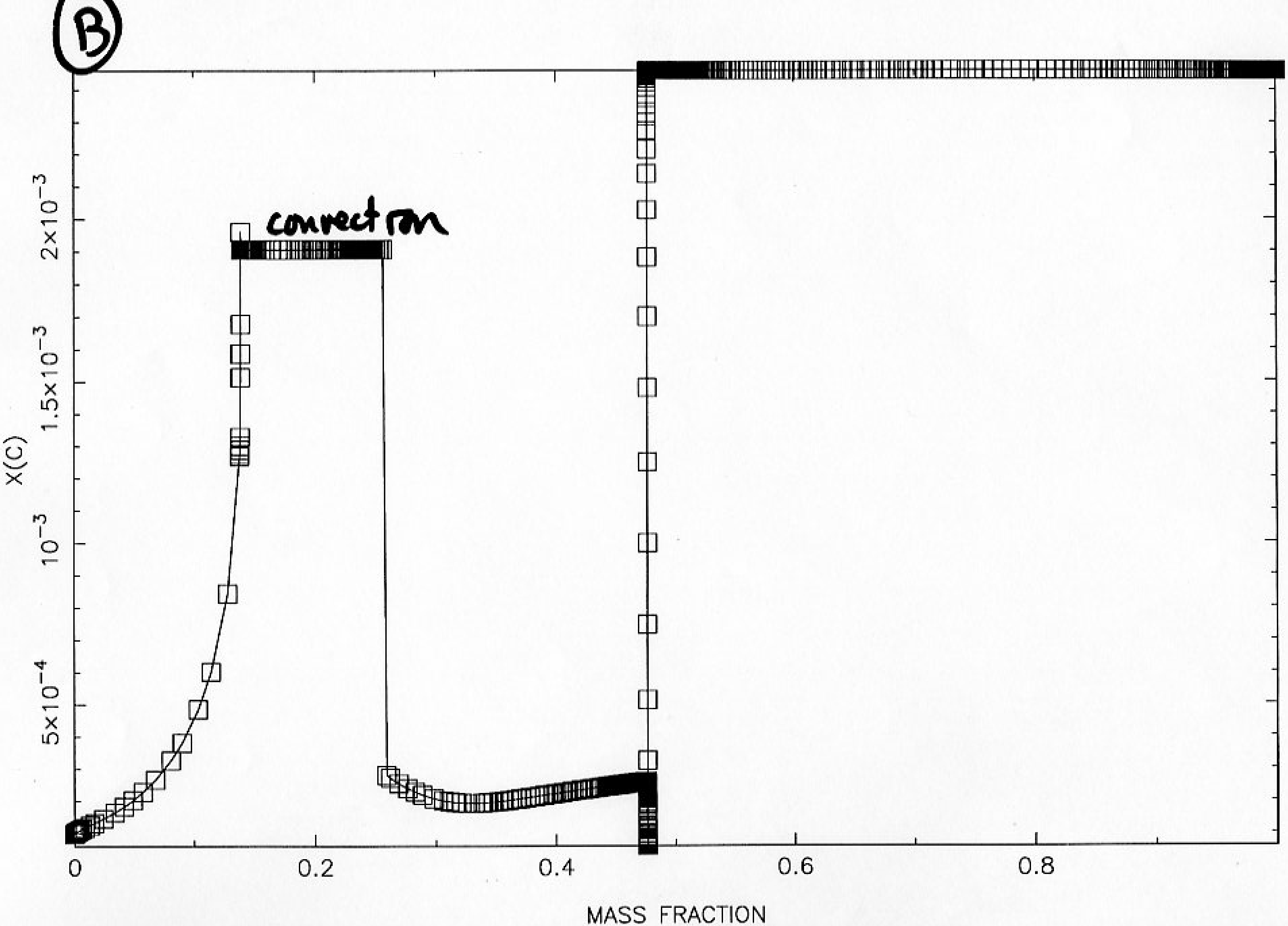

Higher T.
T↑ quicker than it can transport
P = P(ρ) ⇒ no expansion
LOG 10 (T)
8
7.8
7.6
7.4
7.2
7
0
0.1
0.2
0.3
0.4
0.5
MASS FRACTION

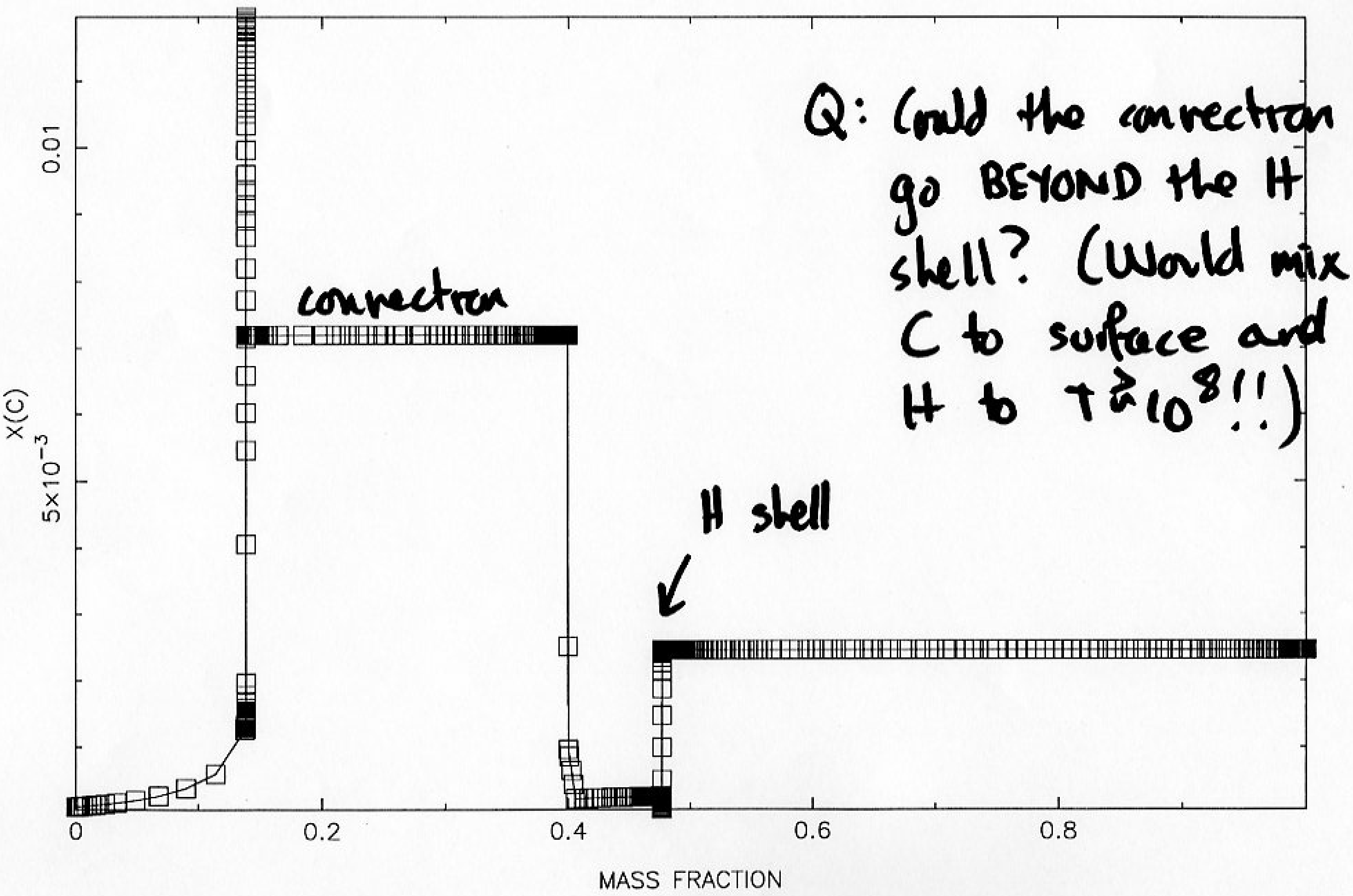

B
L/LSUN
6×10^4
4×10^4
2×10^4
0
0
0.2
0.4
0.6
0.8
MASS FRACTION


c
LOG 10 (T)
8
7.5
7
0
0.1
0.2
0.3
0.4
0.5
MASS FRACTION

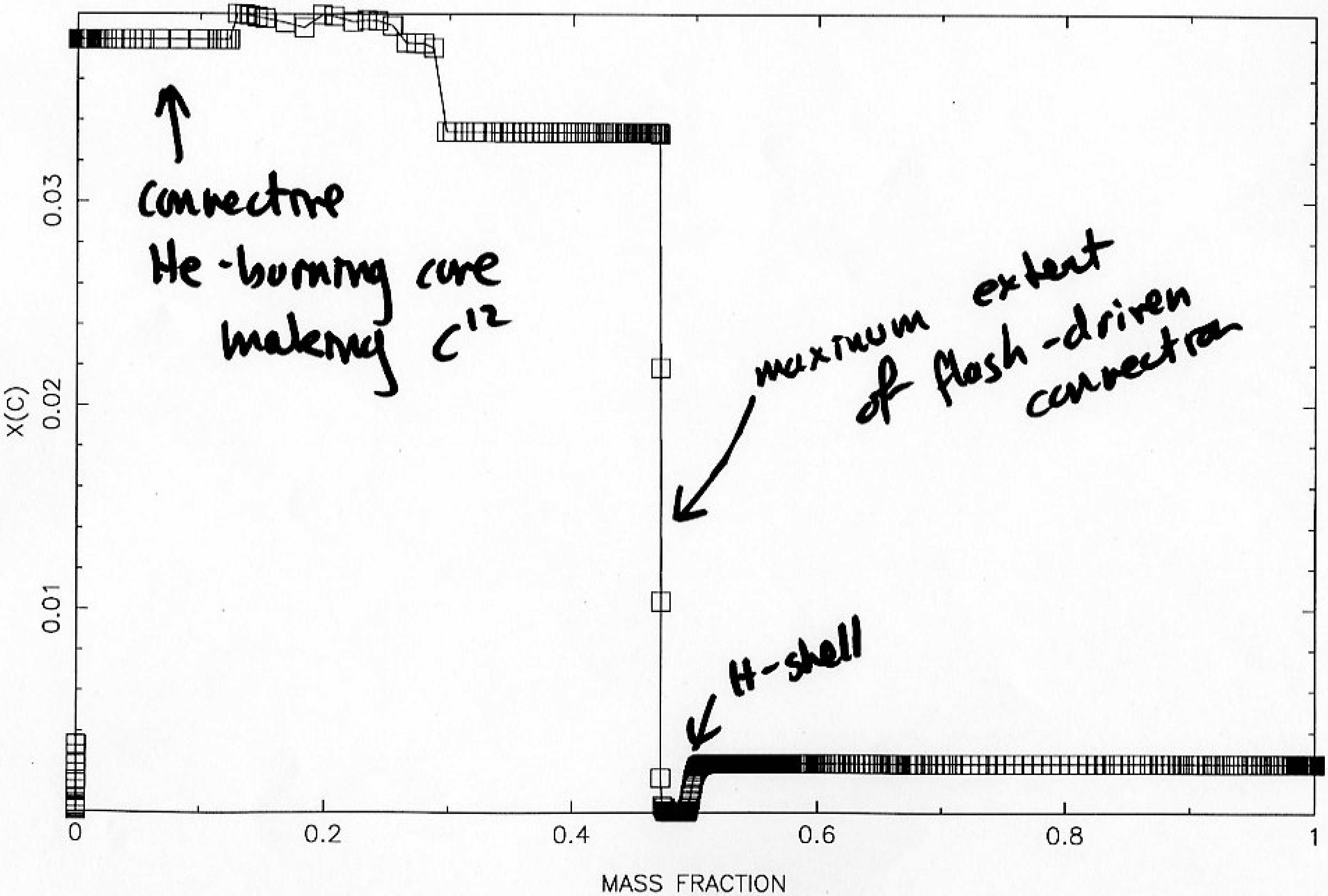

(c)
3x10^9 L☉
L/LSUN
10^9
5×10^8
0
0
0.2
0.4
0.6
0.8
MASS FRACTION

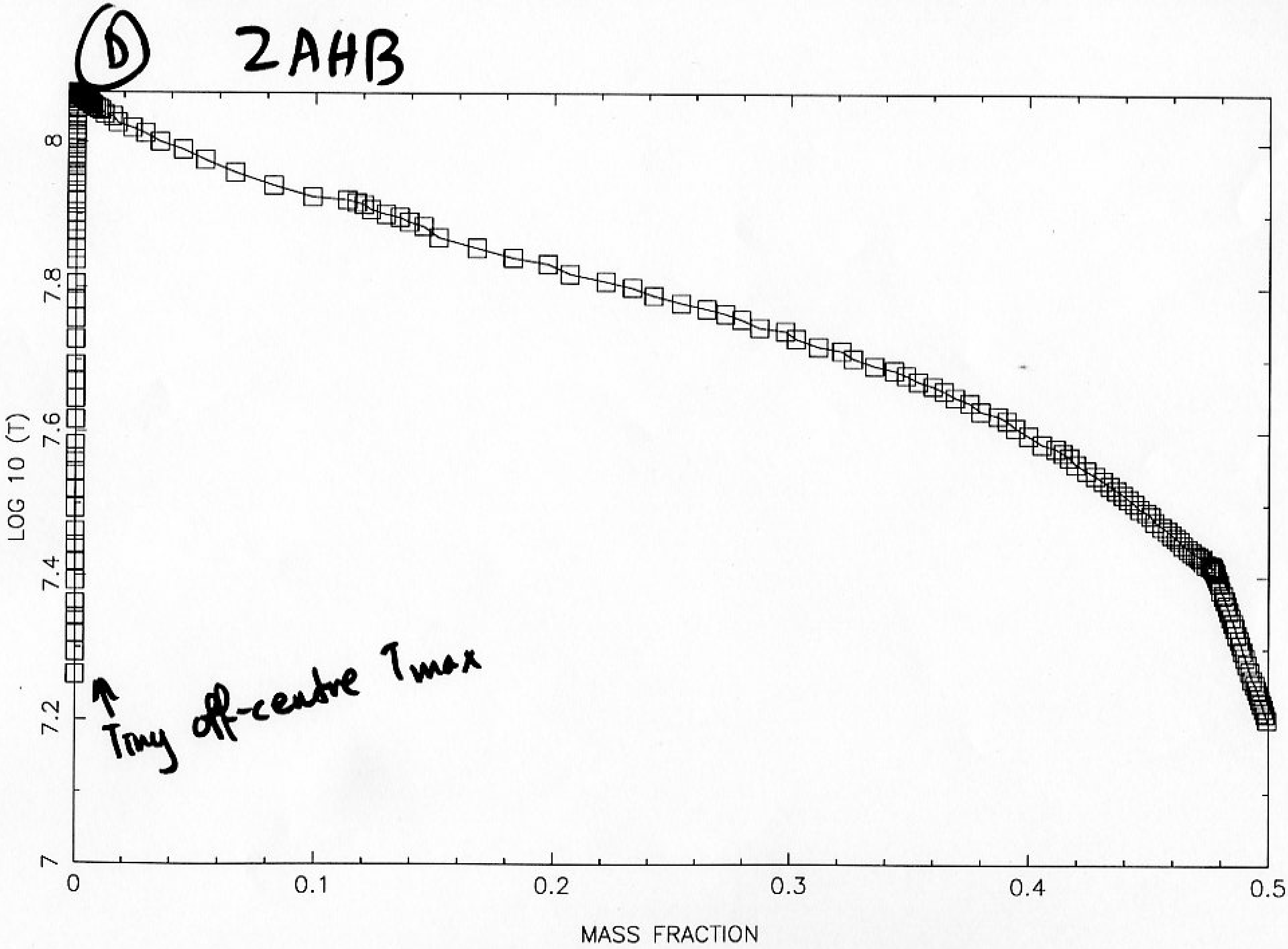

A
X(C)
2x10^-3
1.5x10^-3
10^-3
5x10^-4
0
0.2
0.4
0.6
0.8
MASS FRACTION
C^12 produced
small convective zone

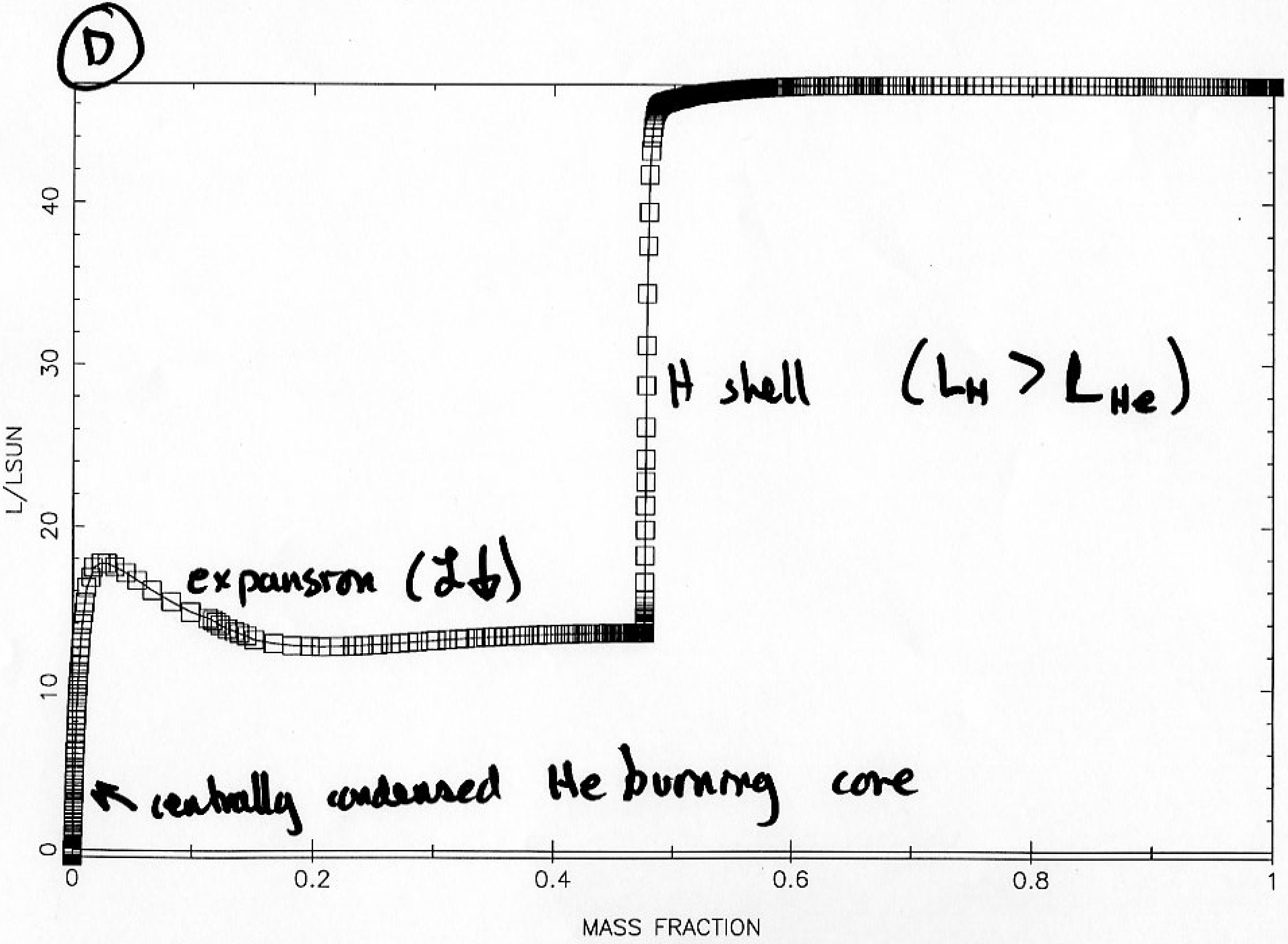

B
convection
X(C)
2x10^-3
1.5x10^-3
10^-3
5x10^-4
0
0.2
0.4
0.6
0.8
MASS FRACTION



Q: Could the convection go BEYOND the H shell? (Would mix C to surface and H to T ≳ 10^8!!)
convection
H shell
X(C)
0.01
5×10^−3
0
0.2
0.4
0.6
0.8
MASS FRACTION


X(C)
0.01
0.02
0.03
0
0.2
0.4
0.6
0.8
1
MASS FRACTION
convective
He-burning core
making C^{12}
maximum extent
of flash-driven
convection
H-shell


D
2AHB
LOG 10 (T)
8
7.8
7.6
7.4
7.2
7
0
0.1
0.2
0.3
0.4
0.5
MASS FRACTION
Tiny off-centre Tmax



D
L/LSUN
0
10
20
30
40
0
0.2
0.4
0.6
0.8
1
MASS FRACTION
H shell
$(L_H > L_{He})$
expansion
centrally condensed He burning core