29 Stars notes 2019/11/11 - Mon - He core flash, He core burning

ask what day is best as mesa workday (wed or fri)

29.1 Helium Core flash ($M \leq 2M_{\odot}$)

For these stars, the He core increses in mass as H shell burning adds material so the star goes up the red giant branch. Refer the the bottom two figures below. The mass at which the helium core ignites. consider low mass stars first, for these He core ignites at $M = 0.45M_{\odot}$. When these ignite, the core is degenerate! This leads to a thermal runaway because the core doesn't change at all until you've put in enough energy to get to the Fermi energy.

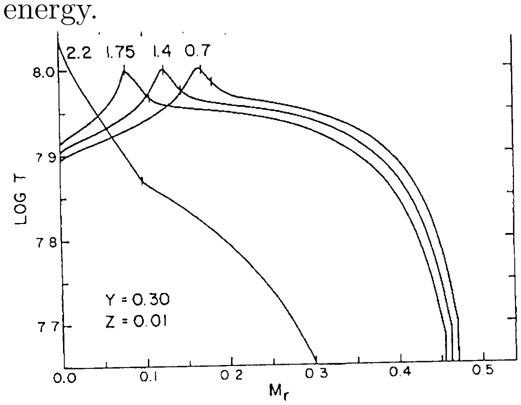


FIG. 6.—Temperature distribution within the core at the onset of the helium-core flash for red giant sequences with $(Y, Z, F_r) = (0.30, 0.01, 1.0)$. Each curve is labeled by its value of the mass M. The results shown in this figure correspond to the evolutionary phase when $L_{He} \approx 100\, L_{\odot}$. The tick marks along each curve denote the edges of the convective zone produced by the flash. In the 2.20 $M_{\odot}$ case a convective core has formed. The curves for 0.70, 1.40, and 1.75 $M_{\odot}$ extend out to the hydrogen-burning shell. M_r is in units of $M_{\odot}$.

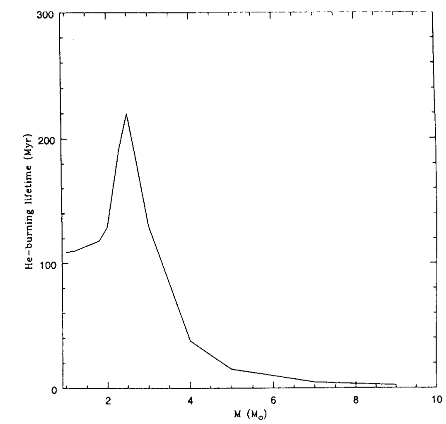
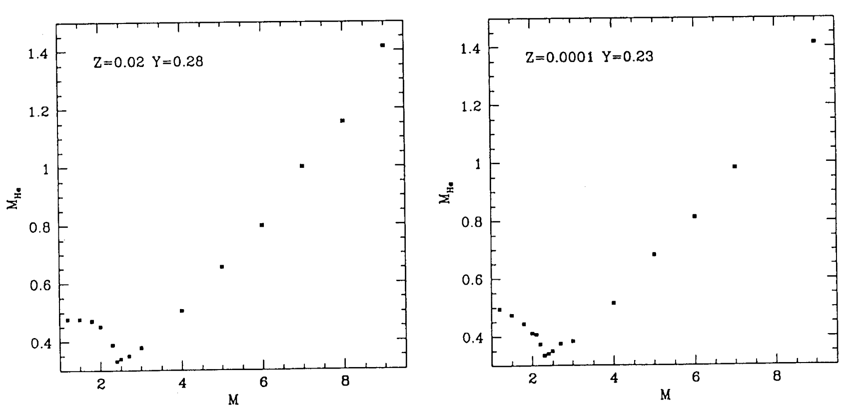


FIG. 14.—He-burning lifetime vs. the stellar mass for $Z = 0.02$ and $Y = 0.28$.

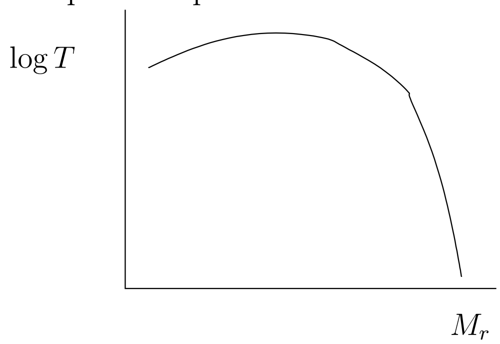


Consider why this is scary. A pure helium ball with $M_c = 0.45M_{\odot}$ and $R = 10^9$ cm. then the binding energy is $E_{GR} = 3 \times 10^{49}$ ergs. per gram this gives 3×10^{16} erg/gr. Burning

$^4He \rightarrow ^{12}C$ gives 7.6MeV/$12m_p = 8 \times 10^{17}$ erg/gr. So burning only 1/20 of the He quickly will unbind the core.

Note that for type Ia supernovae, you have a similar situation with a C+O core, and you have to burn 1/2 (not 1/20) of the mass to unbind. and those DO blow up! Differences are in the transition from a *global* thermal runaway, compared to a *local* thermal runaway. The supernova Ia case makes this transition (gets hot enough) but the He case does not. This actually has some to do with differences between triple-α and C+C burning, the size of the WD ($0.45M_\odot$ vs. $1.4M_\odot$), and the location of the ignition (off-center vs. center).

Temperature profile:

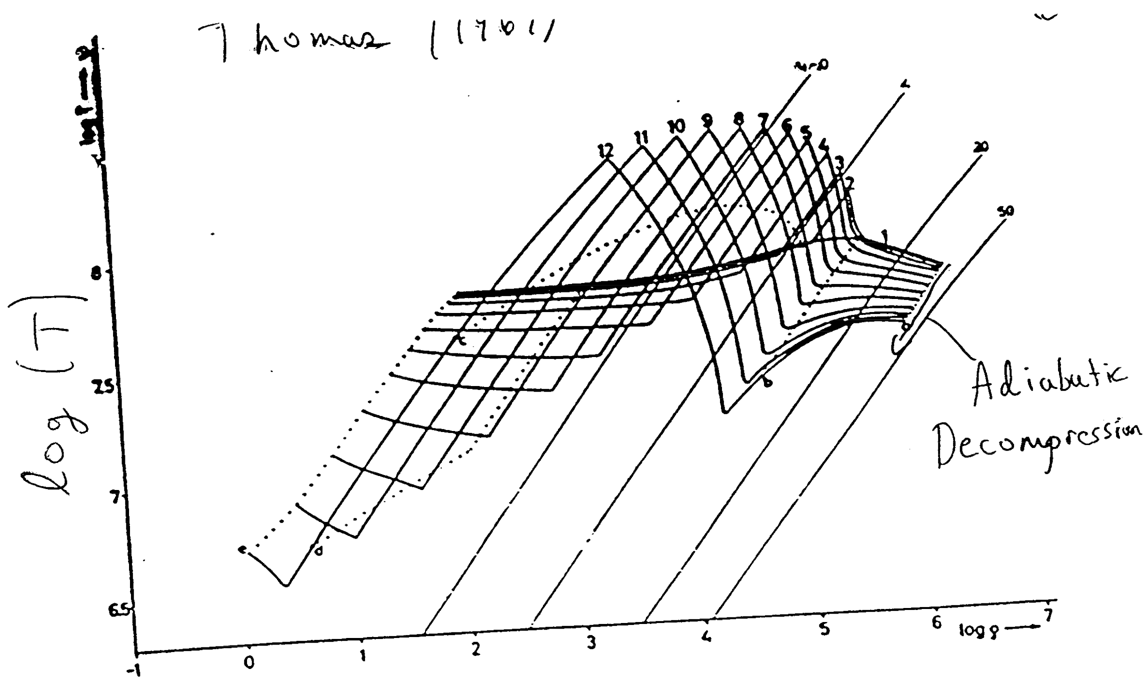


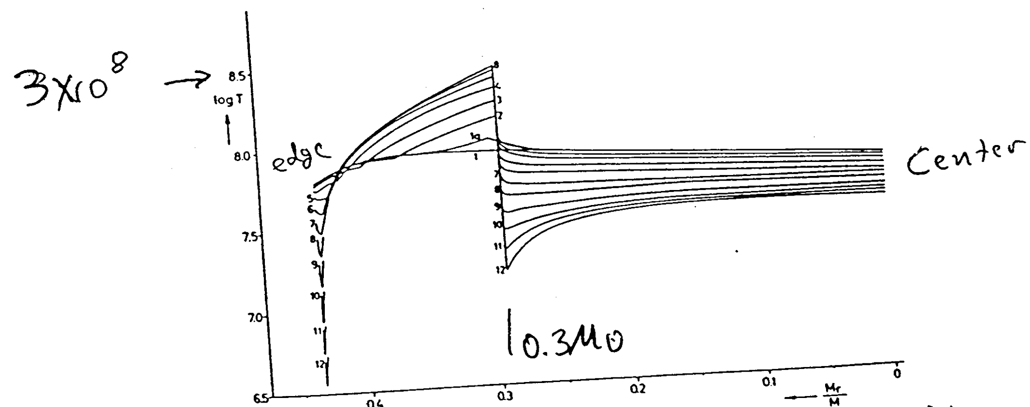
Reference to upper left figure below, which shows the ignition points for different masses, these are off-center because neutrino cooling cools the center a bit.

Helium ignites in a shell that is very degenerate, as burning proceeds the energy put into plasma goes to increasing T. This is a runaway, though not necessarily a violent one.

Below shows the progession in time of the interior. The core adiabatically decompresses. eventually you will get a non-degenerate core. Note that this is only the first of several flashes.

Showed this evolution in MESA, using the helium flash that happens in the 1 $M_\odot$ pre-MS-to-WD evolution in homework 3.

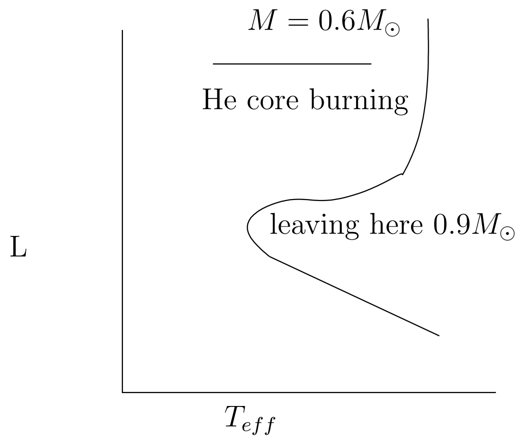




The radiative time ↓ as the convective envelope expands. At peak of $\varepsilon_{3\alpha}$, $t_{diff} \approx 5000$ yrs, $t_{nuc} = 10^4$ se

29.2 After the He flash - core He burning phase

One way we know stars make it through the He flash is because they are still there – there is a horizontal branch.



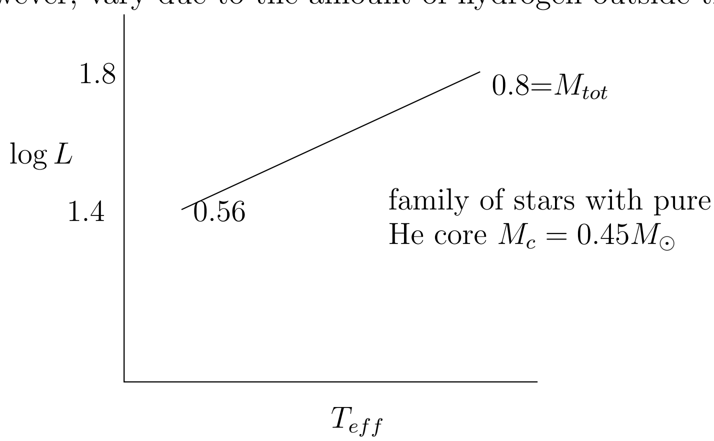
Between leaving the main sequence and reaching Horizontal branch about 0.1 to $0.3M_\odot$ is lost. two options

1. Winds on red giant branch? tough to observe, lots of uncertainty
2. During He core flash, some mass goes to infinity?

> "Since the HB progeny of the RGB stars abound in the sky, those models (of He core flash) which completely distrupt are obviously inappropriate" Iben and Renzini

Reference to the top right plot in figure before last: The helium burning lifetimes are actually pretty short.

The HB stars have helium cores, and so are bright. Also they have a fairly narrow range of luminosities since the have similar cores due to core convergence. Their temperatures, however, vary due to the amount of hydrogen outside the He core.



So stars on the horizontal branch decrease with mass to the left. The bluer ones are lowest mass.

29.3 Completion of Evolution for $M < 6M_\odot$

What's special about 6? $6M_\odot$ stars or less never get interiors hot enough to ignite carbon. The endpoint we want to get to is a C/O white dwarf. Punchline: These have masses ranging from $0.6M_\odot$ up to $1.1M_\odot$. So there is a lot of mass loss.

All stars with $M < 2M_\odot$ ignite the helium degenerately in the core, this led to a thermally unstable "explosion". The Helium ignition lifts the degeneracy in the core, and the star "reappears" on the Horizontal branch. (Many didn't actually calculate the evelution from the flash to the next stage.) Reference to bottom figure (HR diag) the horizontal branch is there. The top plot is also from HK showing the Helium flash. The back lists some lifetimes.

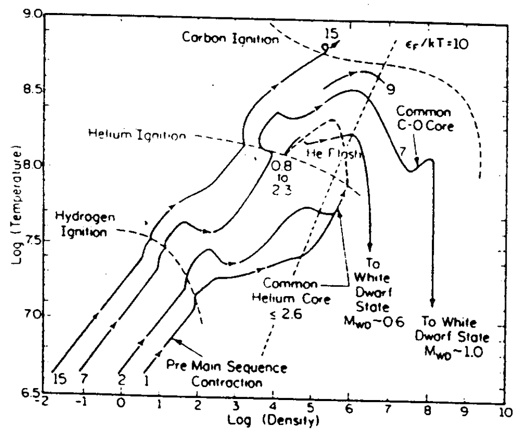


FIGURE 2.7. Central density versus central temperature for evolving stellar mod-els. Reproduced, with permission, from I. Iben Jr. 1985, "The Life and Times of an Intermediate Mass Star," in *Quarterly Journal of the Royal Astronomical Society*, Volume 26, published by Blackwell Scientific Publications.

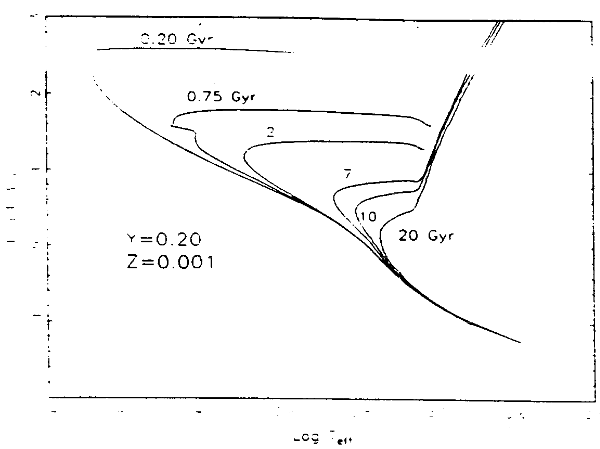


FIGURE 2.9. Representative theoretical isochrones for clusters of the indicated ages. Adapted from the *Revised Yale Isochrones*, Green et al. (1987). Note that times are in Gyr (10^9 year).

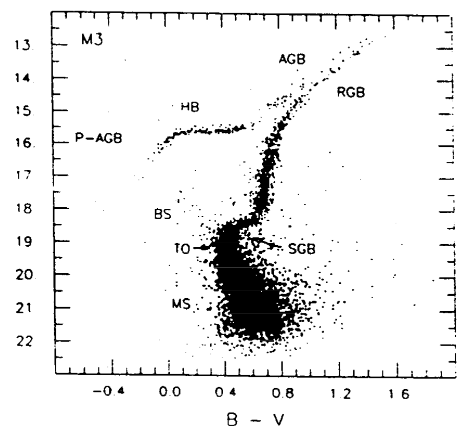


FIGURE 2.10. The observational Hertzsprung–Russell diagram for the globu-lar cluster M3. The turnoff point is labeled TO. Reproduced, with permission, from Renzini and Pecci (1988) Annual Review of Astronomy and Astrophysics

TABLE 44.

STELLAR MODEL : 0.8 M , Z = 0.001

NB	AGE QCC	MASS MDOT	LOGL RHOC	LOGTE LOGTC	X	Y	C12	C13	N14	O16	O17	O18	NE20	NE22
1	1.1407569E+08	0.8000	-.309	3.768	0.756000	0.243000	0.000224	0.000004	0.000070	0.000531	0.000000	0.000001	0.000071	0.000006
	0.0185	0.000	1.972	7.087	0.750387	0.248515	0.000078	0.000032	0.000209	0.000531	0.000000	0.000001	0.000071	0.000006
2	2.3581760E+09	0.8000	-.276	3.771	0.756000	0.243000	0.000224	0.000004	0.000070	0.000531	0.000000	0.000001	0.000071	0.000006
	0.0000	.0.000	2.048	7.098	0.620215	0.378726	0.000001	0.000000	0.000334	0.000531	0.000001	0.000000	0.000071	0.000006
3	3.7209620E+09	0.8000	-.246	3.774	0.756000	0.243000	0.000224	0.000004	0.000070	0.000531	0.000000	0.000001	0.000071	0.000006
	0.0000	0.000	2.104	7.111	0.540551	0.458409	0.000001	0.000000	0.000334	0.000530	0.000001	0.000000	0.000071	0.000006
4	5.0837478E+09	0.8000	-.212	3.778	0.756000	0.243000	0.000224	0.000004	0.000070	0.000531	0.000000	0.000001	0.000071	0.000006
	0.0000	0.000	2.167	7.126	0.460535	0.538441	0.000001	0.000000	0.000334	0.000529	0.000003	0.000000	0.000071	0.000006
5	6.4465341E+09	0.8000	-.173	3.782	0.756000	0.243000	0.000224	0.000004	0.000070	0.000531	0.000000	0.000001	0.000071	0.000006
	0.0000	0.000	2.238	7.143	0.379802	0.619186	0.000001	0.000000	0.000334	0.000527	0.000005	0.000000	0.000071	0.000006
6	7.7752504E+09	0.8000	-.130	3.785	0.756000	0.243000	0.000224	0.000004	0.000070	0.000531	0.000000	0.000001	0.000071	0.000006
	0.0000	0.000	2.317	7.163	0.300273	0.698723	0.000001	0.000000	0.000333	0.000520	0.000012	0.000000	0.000071	0.000006
7	9.1380357E+09	0.8000	-.079	3.790	0.756000	0.243000	0.000224	0.000004	0.000070	0.000531	0.000000	0.000001	0.000071	0.000006
	0.0000	0.000	2.413	7.186	0.219056	0.779946	0.000001	0.000000	0.000334	0.000504	0.000029	0.000000	0.000071	0.000006
8	1.0194195E+10	0.8000	-.035	3.793	0.756000	0.243000	0.000224	0.000004	0.000070	0.000531	0.000000	0.000001	0.000071	0.000006
	0.0000	0.000	2.500	7.205	0.159935	0.839069	0.000001	0.000000	0.000341	0.000471	0.000055	0.000000	0.000071	0.000006
9	1.1504173E+10	0.8000	0.030	3.796	0.756000	0.243000	0.000224	0.000004	0.000070	0.000531	0.000000	0.000001	0.000071	0.000006
	0.0000	0.000	2.629	7.231	0.099241	0.899769	0.000002	0.000001	0.000391	0.000376	0.000093	0.000000	0.000071	0.000006
10	1.2570646E+10	0.8000	0.094	3.799	0.756000	0.243000	0.000224	0.000004	0.000070	0.000531	0.000000	0.000001	0.000071	0.000006
	0.0000	0.000	2.754	7.257	0.060559	0.938473	0.000003	0.000001	0.000533	0.000230	0.000075	0.000000	0.000071	0.000006
11	1.3369600E+10	0.8000	0.149	3.801	0.756000	0.243000	0.000224	0.000004	0.000070	0.000531	0.000000	0.000001	0.000071	0.000006
	0.0000	0.000	2.855	7.288	0.030834	0.968224	0.000004	0.000001	0.000684	0.000103	0.000025	0.000000	0.000071	0.000006
12	1.4277941E+10	0.8000	0.225	3.802	0.756000	0.243000	0.000224	0.000004	0.000070	0.000531	0.000000	0.000001	0.000071	0.000006
	0.0000	0.000	3.025	7.316	0.001138	0.997929	0.000005	0.000002	0.000741	0.000053	0.000006	0.000000	0.000071	0.000006
13	1.5029531E+10	0.8000	0.311	3.799	0.756000	0.243000	0.000224	0.000004	0.000070	0.000531	0.000000	0.000001	0.000071	0.000006
	0.0000	0.000	3.274	7.324	0.000000	0.999067	0.000005	0.000002	0.000741	0.000052	0.000006	0.000000	0.000071	0.000006
14	1.5242352E+10	0.8000	0.340	3.796	0.756000	0.243000	0.000224	0.000004	0.000070	0.000531	0.000000	0.000001	0.000071	0.000006
	0.0000	0.000	3.374	7.329	0.000000	0.999068	0.000005	0.000002	0.000741	0.000052	0.000006	0.000000	0.000071	0.000006

TABLE 45. *Lifetimes in nuclear phases (in unit of* 10^6 yr) *for* $Z = 0.02$.

Initial mass	H-burning phase	He-burning phase	C-burning phase	$\frac{t_{He}}{t_H}$
$120M_\odot$	2.5614	0.4145	0.009498	0.1618
85	2.8228	0.3923	0.006734	0.1390
60	3.4469	0.4233	0.009144	0.1228
40	4.3032	0.4648	0.008947	0.1080
25	6.4077	0.6297	0.009385	0.09827
20	8.1409	0.7885	0.01418	0.09686
15	11.5842	1.1160	0.02793	0.09634
12	16.0176	1.5689	0.04931	0.09795
9	26.3886	2.6233	0.11706	0.09941
7	43.1880	4.7260	—	0.1094
5	94.4591	12.4288	—	0.1316
4	164.734	26.1720	—	0.1589
3	352.503	86.1926	—	0.2445
2.5	584.916	145.365	—	0.2485
2	1115.94	240.930	—	0.2159
1.7	1827.31	—	—	—
1.5	2694.65	—	—	—
1.25 $\alpha = 0.2$	4912.63	—	—	—
1.25 $\alpha = 0.0$	3948.16	—	—	—
1	9961.73	—	—	—
0.9	15500.30	—	—	
0.8	25027.88	—	—	

TABLE 46. *Lifetimes in nuclear phases (in unit of* 10^6 yr) *for* $Z = 0.01$.

Initial mass	H-burning phase	He-burning phase	C-burning phase	$\frac{t_{He}}{t_H}$
$120M_\odot$	2.7798	0.2836	0.002900	0.1020
85	3.0630	0.3124	0.003365	0.1020
60	3.7148	0.3602	—	0.09697
40	4.8909	0.4372	0.005251	0.08938
25	7.1905	0.6433	0.009786	0.08947
20	9.3841	0.8350	0.01401	0.08899
15	13.2674	1.1979	0.02551	0.09029
12	18.1163	1.6049	0.04286	0.08859
9	28.7514	2.7045	0.08833	0.09406
7	45.0533	4.6874	—	0.1040
5	88.2763	10.9212	—	0.1237
4	144.068	19.7350	—	0.1370
3	290.798	45.2332	—	0.1555
2.5	482.332	79.0886	—	0.1640
2	855.634	140.594	—	0.1643
1.7	1331.80	—	—	—
1.5	1842.74	—	—	—
1.25 $\alpha = 0.2$	3209.57	—	—	—
1.25 $\alpha = 0.0$	2668.77	—	—	—
1	6263.59	—	—	—
0.9	9452.35	—	—	—
0.8	15029.5	—	—	—

TABLE 47. *Lifetimes in nuclear phases (in unit of* 10^6 yr) *for* $2 \times \dot{M}$ *and* $Z = 0.02$.

Initial mass	H-burning phase	He-burning phase	C-burning phase	$\frac{t_{He}}{t_H}$
$120M_\odot$	2.5743	0.8728	0.06941	0.3390
85	2.8228	0.5751	0.03021	0.2037
60	3.4469	0.6760	0.04279	0.1961
40	4.3032	0.6005	0.02932	0.1395
25	6.4077	0.6360	0.009416	0.09926
20	8.1409	0.7924	0.01413	0.09734

TABLE 48. *WR lifetimes (in unit of* 10^5 yr).

Masse	t(WR)	t(WN)	t(WC)
$Z = 0.020$	($\dot{M}$ standard)		
120	7.430	4.422	3.008
85	4.008	1.776	2.232
60	4.222	1.568	2.654
40	2.575	0.724	1.851
32:	0.000	0.000	0.000
$Z = 0.020$	($\dot{M} \times 2$ in post-MS stages)		
120	12.717	3.644	9.073
85	6.072	1.132	4.940
60	7.063	0.857	6.206
40	4.980	0.682	4.298
25:	0.000	0.000	0.000
$Z = 0.001$			
120	2.772	2.772	0.000
85	0.204	0.204	0.000
80:	0.000	0.000	0.000

Horizontal branch ends when He is burned to a C/O core. This contracts until degenerate. This creates the situation where there is not only a hydrogen shell burning but also a helium shell burning.

Now M_{He} verses M, This is actually the CO core mass. Right figure "core mass at beginning of AGB" These then move up the Asymtotic giant branch.

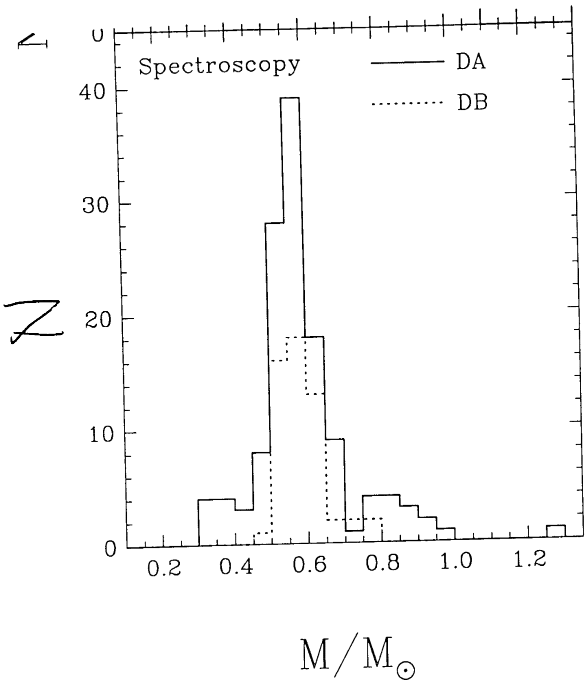
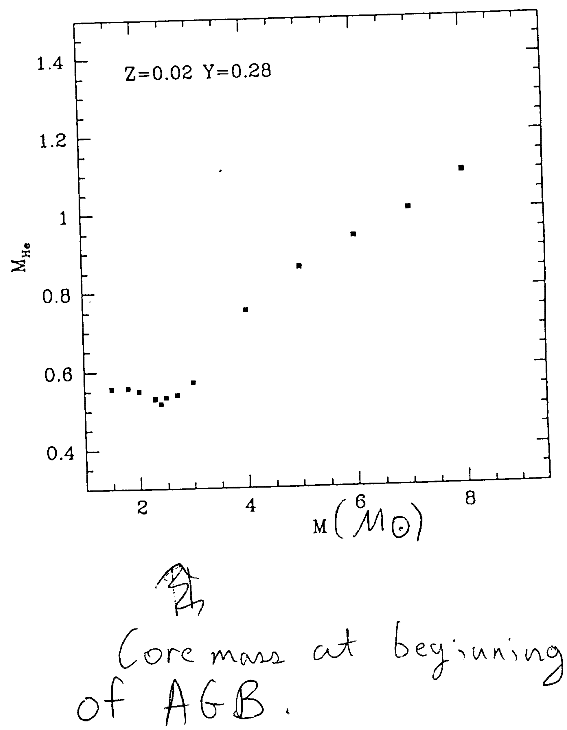
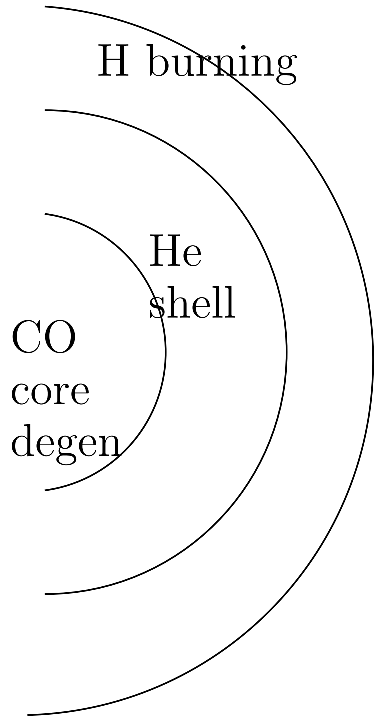


FIG. 22.—*Top panel*: Mass distributions for the hydrogen- and helium-rich atmosphere white dwarfs in our parallax sample. The mean mass of the hydrogen-rich subsample is $\langle M \rangle = 0.61\ M_\odot$ with a dispersion of $\sigma(M) = 0.20\ M_\odot$, and the corresponding values for the helium-rich subsample are $\langle M \rangle = 0.72\ M_\odot$ and $\sigma(M) = 0.17\ M_\odot$. *Bottom panel*: Mass distributions for hotter DA and DB stars determined from spectroscopic analyses. The mean mass and dispersion for the DA stars are $\langle M \rangle = 0.59\ M_\odot$, $\sigma = 0.13\ M_\odot$, and for the DB stars $\langle M \rangle = 0.59\ M_\odot$, $\sigma = 0.06\ M_\odot$.



29.4 Asymtotic Giant branch



Schwarzschild and Harm (1965) discovered that the Helium burning was thermally unstable and occured as recurrent burning events. Thin Shell instability. Mass accumuates over a long timescale and then burns quickly. Let's get a feel for this.

Lets go back to entropy equation in the thin shell.

$$T\frac{ds}{dt} = \epsilon_{3\alpha} - \frac{1}{\rho}\vec{\nabla}\cdot\vec{F}$$

In a Thin ($H \ll R$) shell there is a critical difference for a thermal perturbation which is that the pressure does NOT change.

What about a whole star In Hydrostatic balance?

$$\frac{dP}{dr} = -\rho\frac{Gm(r)}{r^2}$$

From this the pressure goes as

$$\frac{\Delta P}{R} \simeq \frac{P_c}{R} \propto \frac{M}{R^3}\frac{M}{R^2} \Rightarrow P_c \propto \frac{M^2}{R^4}$$

also for an ideal gas star

$$T \propto \frac{M}{R}$$

so if we perturb temp we'll change the pressure.

$$P_c \propto \frac{T^4}{M^2}$$

For geometrically thin, the size of the shell is not tied to the gravitational depth. we have

$$\frac{dP}{dr} = -\rho \frac{Gm(r)}{r^2}$$

if the physical extent is $\ll r$ and $m_{shell} \ll m(r)$ this gives that

$$dP = -\frac{Gm_c}{r_c^2} \int \rho(r) dr$$

then integrating which is

$$P_{shellbase} = \frac{Gm_c}{r_c^2} \int_{r_c}^{\infty} \rho(r) dr$$

so that the pressure doesn't depend on the temperature of the shell.