Physics of Late Helium Flashes

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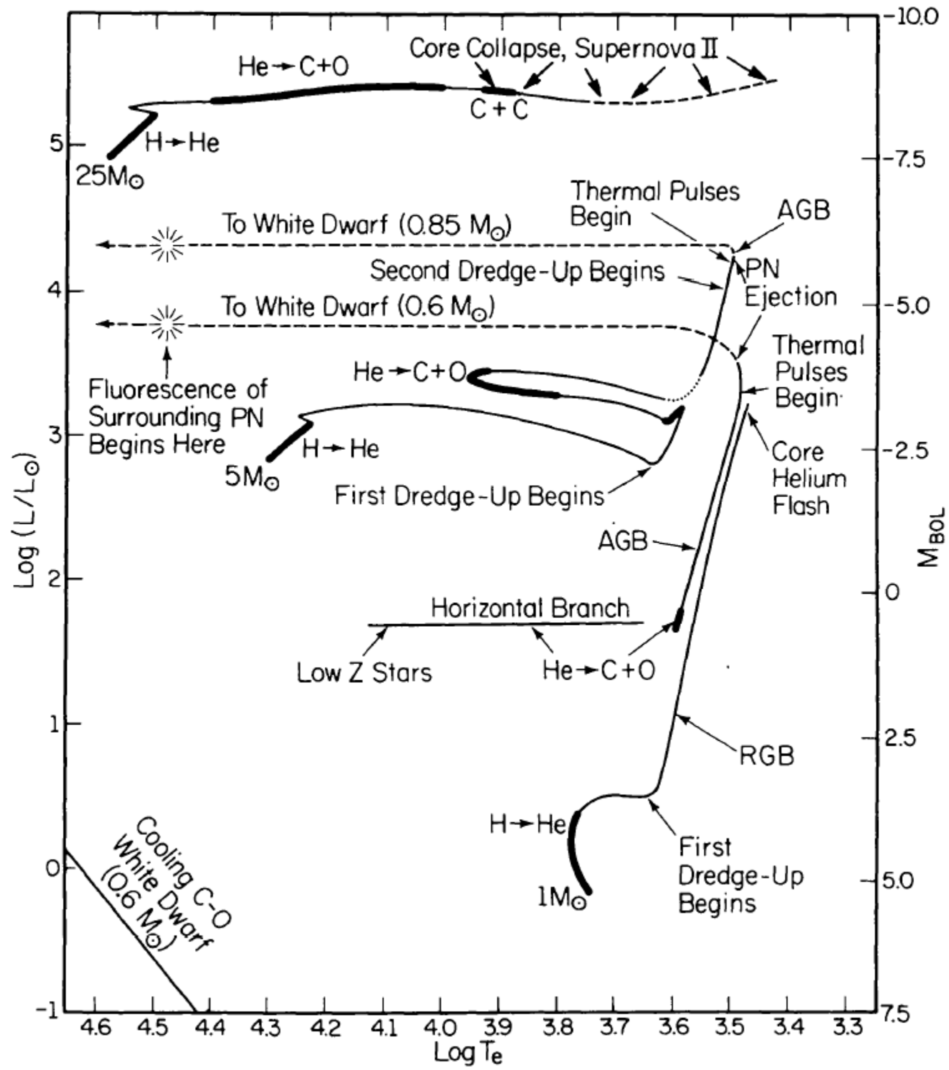
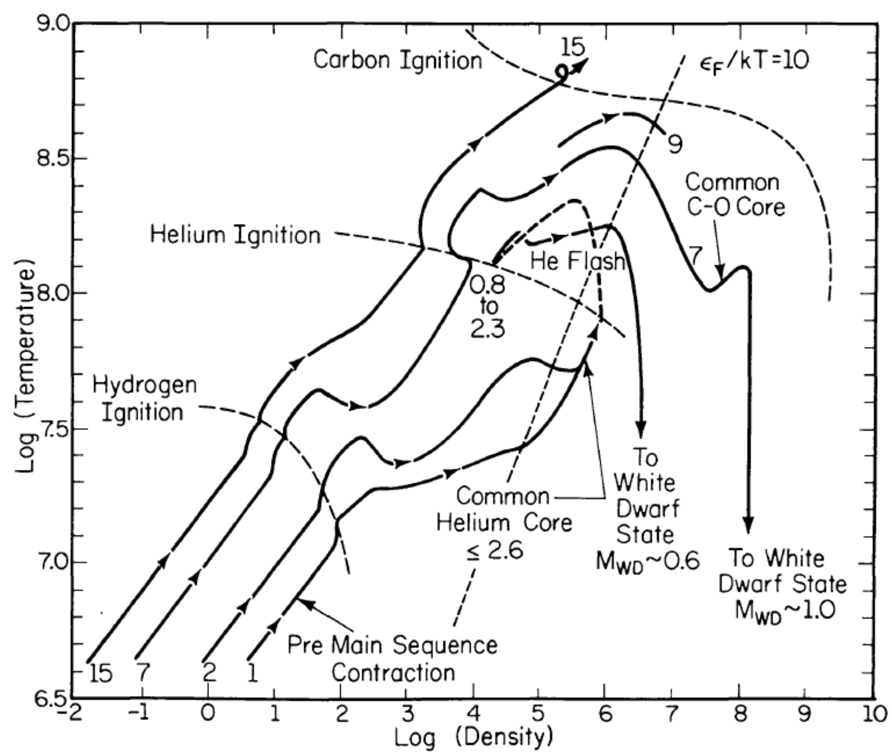
Extragalactic Transients Dec 4, 2007

Stellar Evolution for <6 Solar Masses

Iben 1991, ApJS, 75, 55

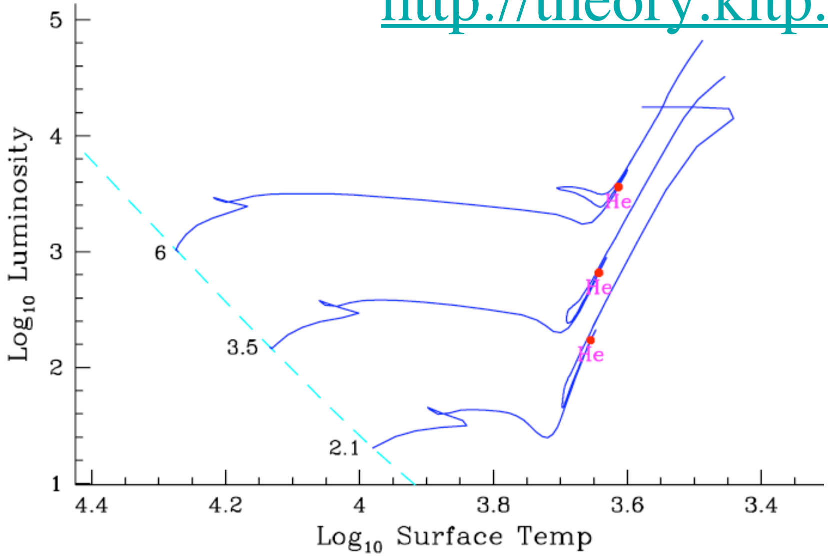
- M<2.2, He Core becomes degenerate prior to ignition
- M~ 6-8 .. ..carbon ignites. O/Ne WD.
- M > 8-10, 1D Supernovae-IIP (Kitaura et al 2006, A&A, 450, 345)



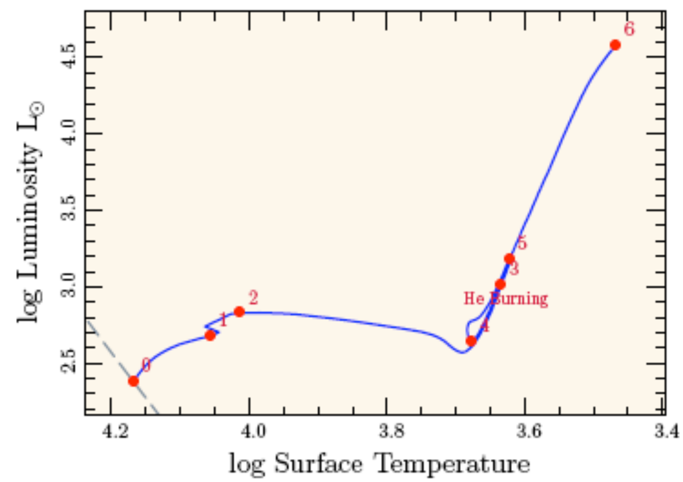


EZ: Bill Paxton's Code

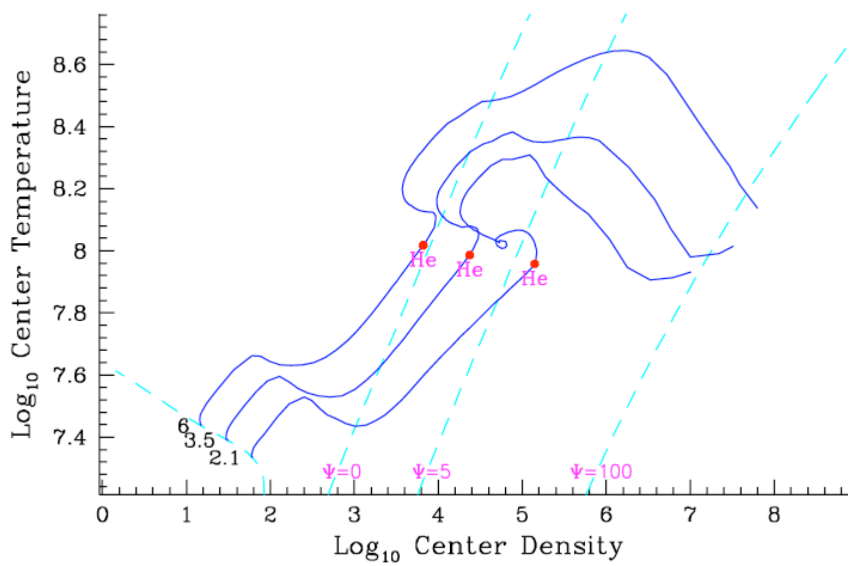
http://theory.kitp.ucsb.edu/~paxton/figs.html

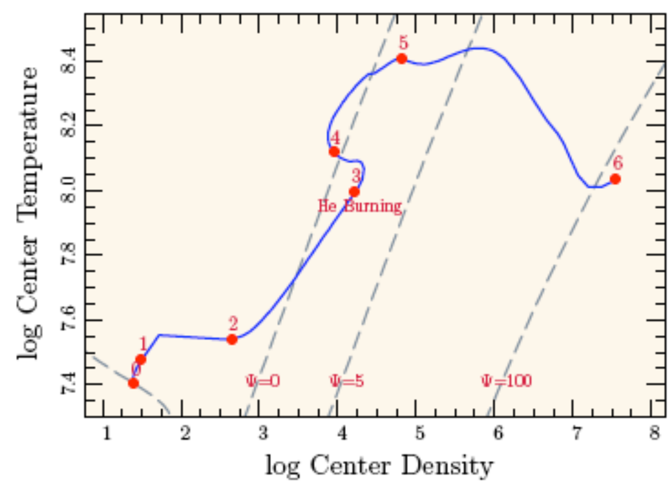


4 Solar Mass Model



	Age	Mass
0	0.00	4.000
1	161.94	3.991
2	171.55	3.989
3	172.90	3.988
4	179.61	3.977
5	206.31	3.951
6	207.82	3.391





Thermal Helium Shell Pulses on AGB

The steady Hydrogen burning shell is thin (in mass, about 1e-4) and stably burning, constantly supplying Helium that accumulates and flashes unstably. Most of the sudden He burning luminosity goes into building a large convective region.

Straniero et al, 1997, ApJ, 478, 332

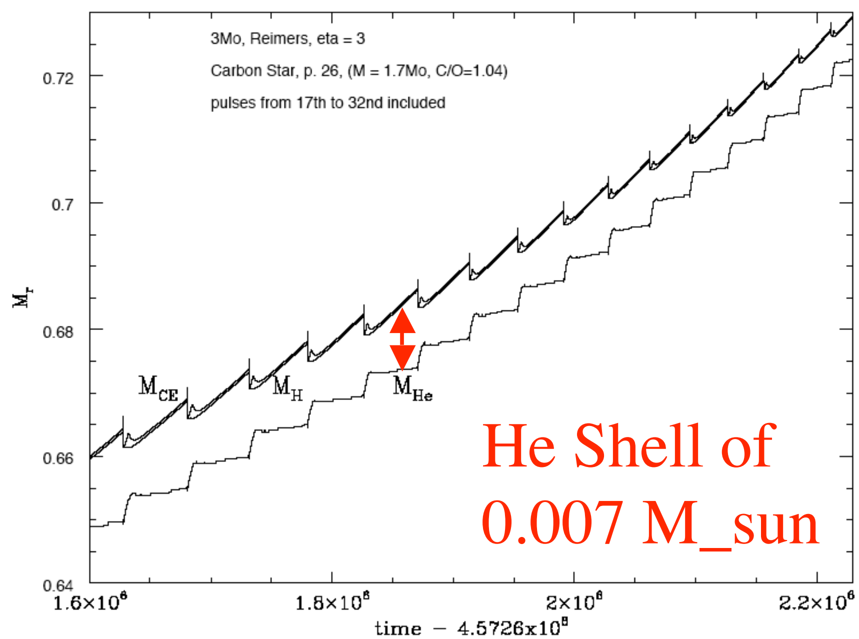


FIG. 8.—The position in mass of the H-exhausted core (M_H), the He-exhausted core (M_{He}), and the bottom limit of the convective envelope (M_{CE}) for the case of a 3 $M_\odot$ model with mass loss. The figure clearly illustrates the variation in time of the third dredge-up.

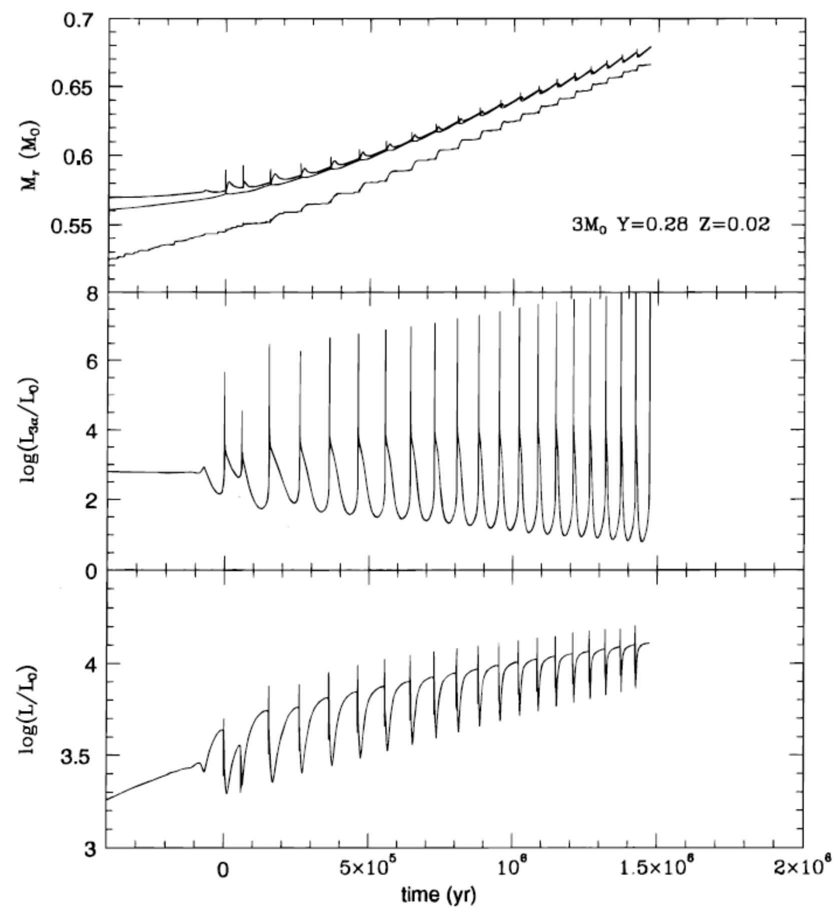
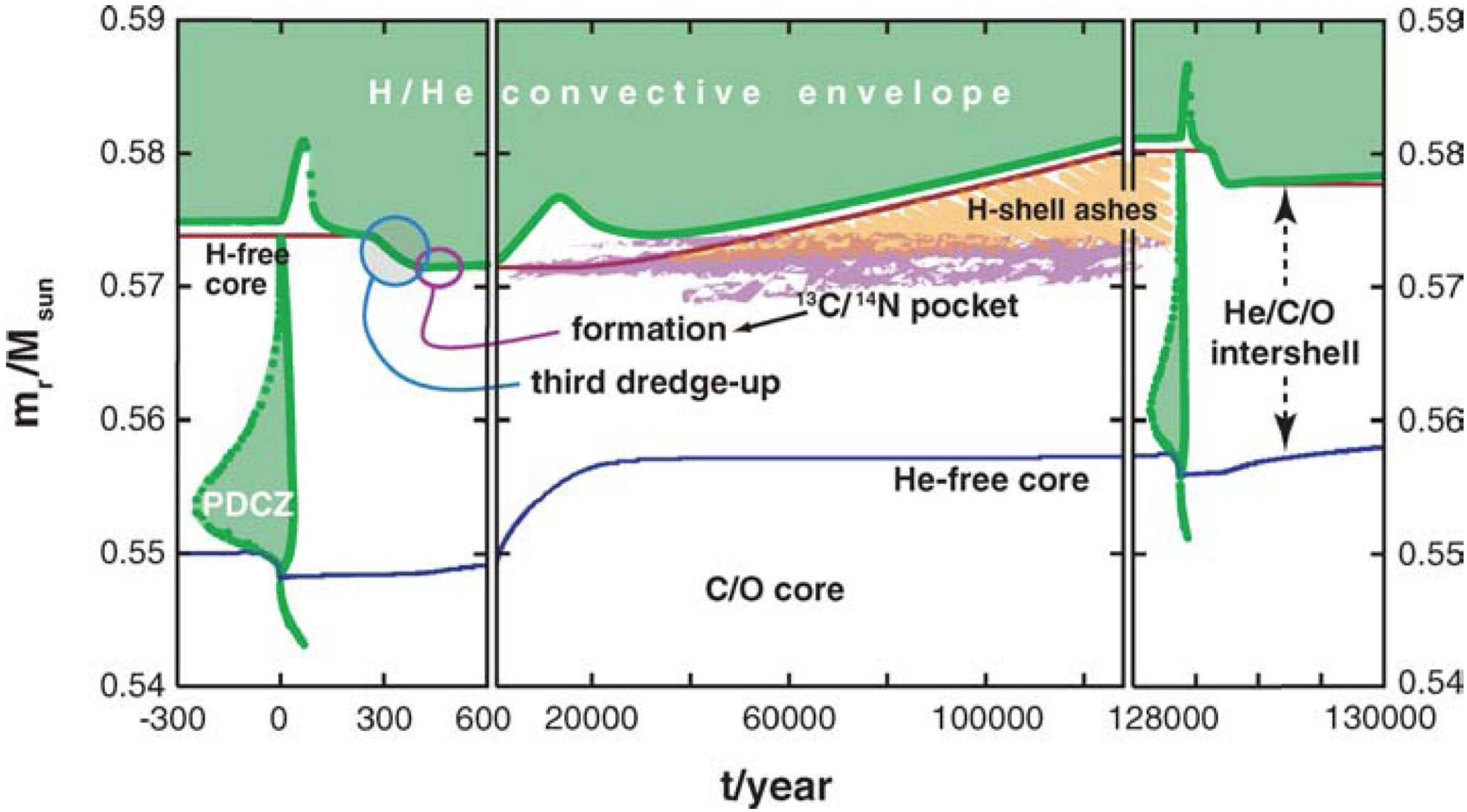


FIG. 4.—Same as Fig. 4, but for the 3 $M_\odot$ model without mass loss

Blowup During Helium Shell Flashes



Herwig, 2005, ARAA, 43, 435

Normal Evolution Path

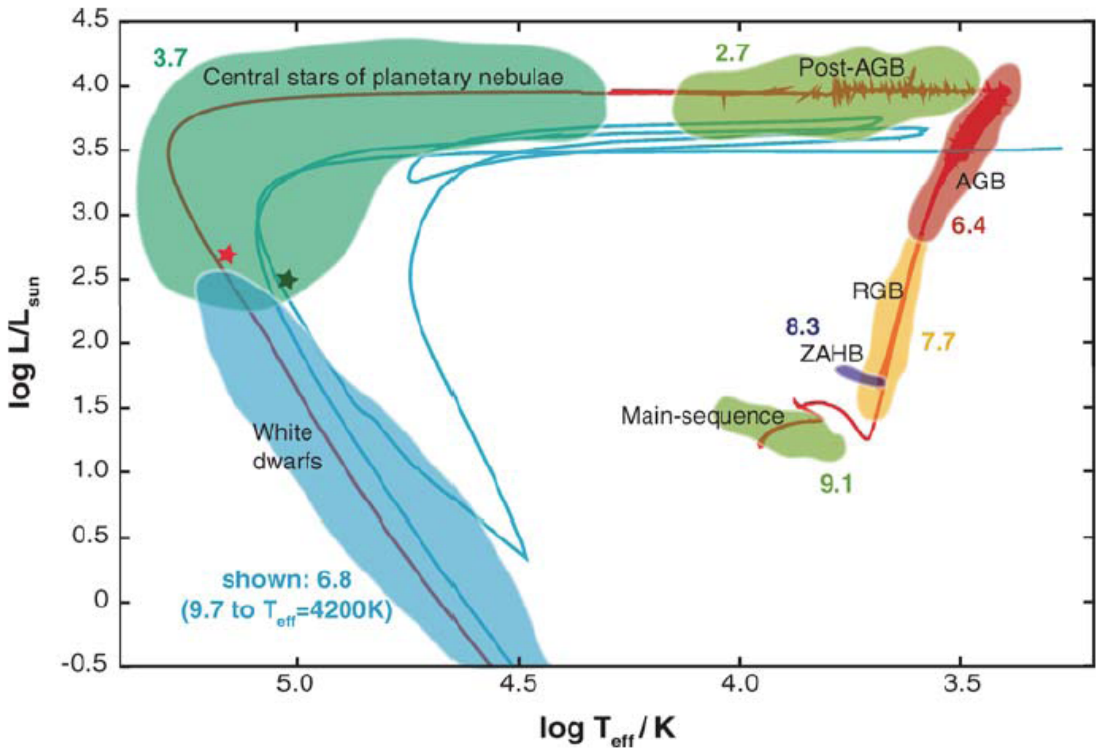


Figure 1 Hertzsprung-Russell diagram of a complete 2 $M_\odot$ evolution track for solar metallicity from the main sequence to the white dwarf evolution phase. In the cooler section of the post-AGB phase, wiggles in the track are caused by numerical convergence difficulties. The *blue* track shows a born-again evolution (triggered by a very late thermal pulse, Section 4.2) of the same mass, however, shifted by approximately $\Delta \log T_{\rm eff} = -0.2$ and $\Delta \log L/L_\odot = -0.5$ for clarity. The *red* and *green* stars mark the position of the central stars of planetary nebulae for which spectra are shown in Figure 8 (see Section 4.2). The number labels for each evolutionary phase indicates the log of the approximate duration for a 2 $M_\odot$ case. Larger or smaller mass cases would have smaller or larger evolutionary timescales, respectively.

Herwig, 2005, ARAA, 43, 435

Numbers are log (time) for a 2 solar mass star

90% of White Dwarf Formation

Iben 1991, ApJS, 75, 55

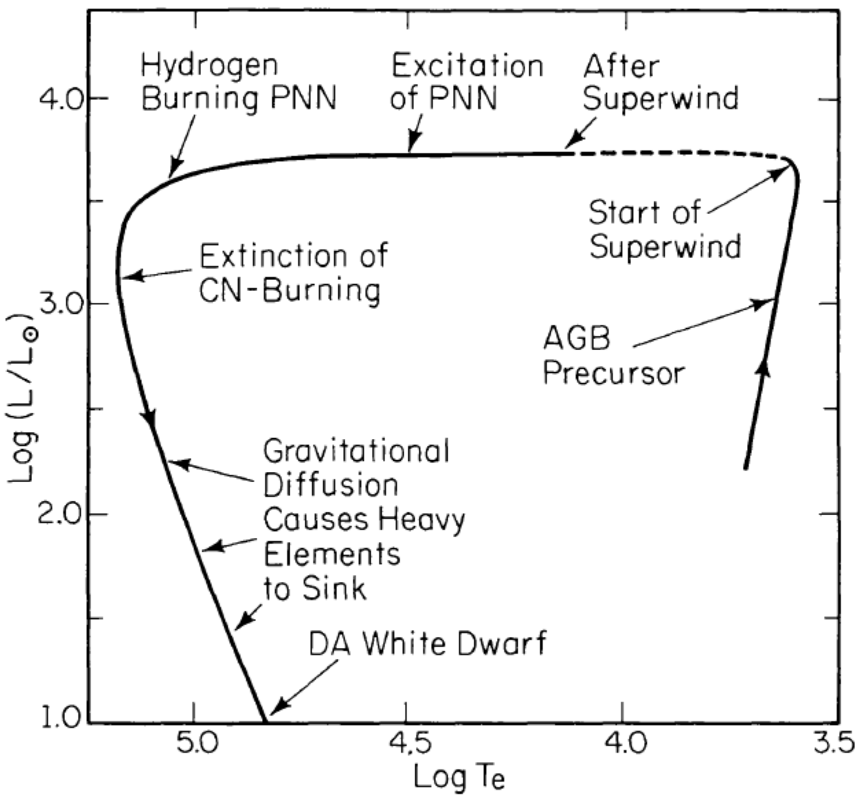
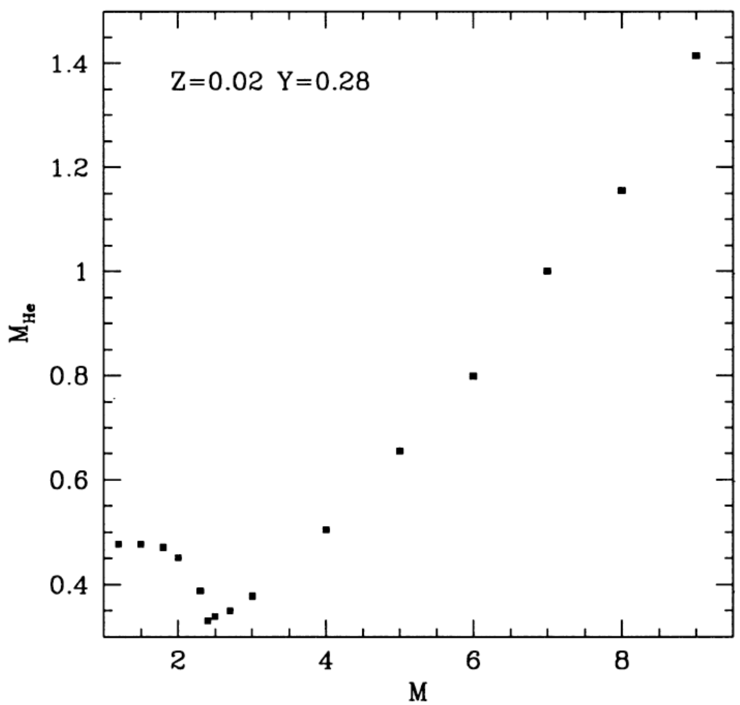


FIG. 43.—Evolutionary track of the hypothetical remnant of a nebular ejection event. The precursor AGB model of initial mass less than $\sim 2\ M_\odot$ has experienced 10 thermal pulses and ejection is assumed to occur when the precursor model is approximately halfway between the 10th pulse and (what would have been) the 11th pulse. The mass of the helium layer between the outer edge of the CO core and the base of the hydrogen-burning shell is $\sim 0.5 \times dM_H$, where dM_H is the mass processed by the hydrogen-burning shell between pulses. As mass is abstracted at a high rate from the model, it departs from the AGB branch and evolves rapidly to the blue when the mass in the remnant hydrogen-rich layer decreases below $\sim 0.01\ M_\odot$. Adapted from Iben (1984) and Iben and MacDonald (1985).

- Mass loss in the winds of the AGB star truncates the H burning shell, which eventually collapses and contracts.
- Most of the H envelope leaves in a wind, since the mass loss rate exceeds the H burning rate.
- The further evolution involves contraction and some residual H burning.
- Most often, the end result is a DA white dwarf of mass close to beginning of

C/O Masses and Final WD Masses

Dominguez et al, 1999, 524, 226



Helium Core mass at He Ignition

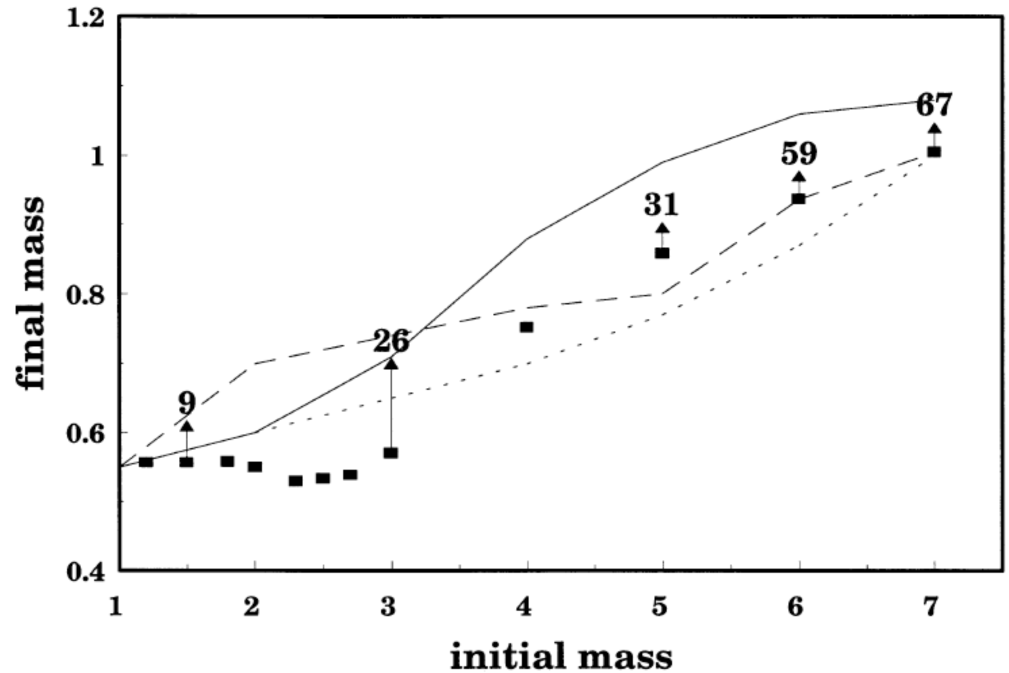
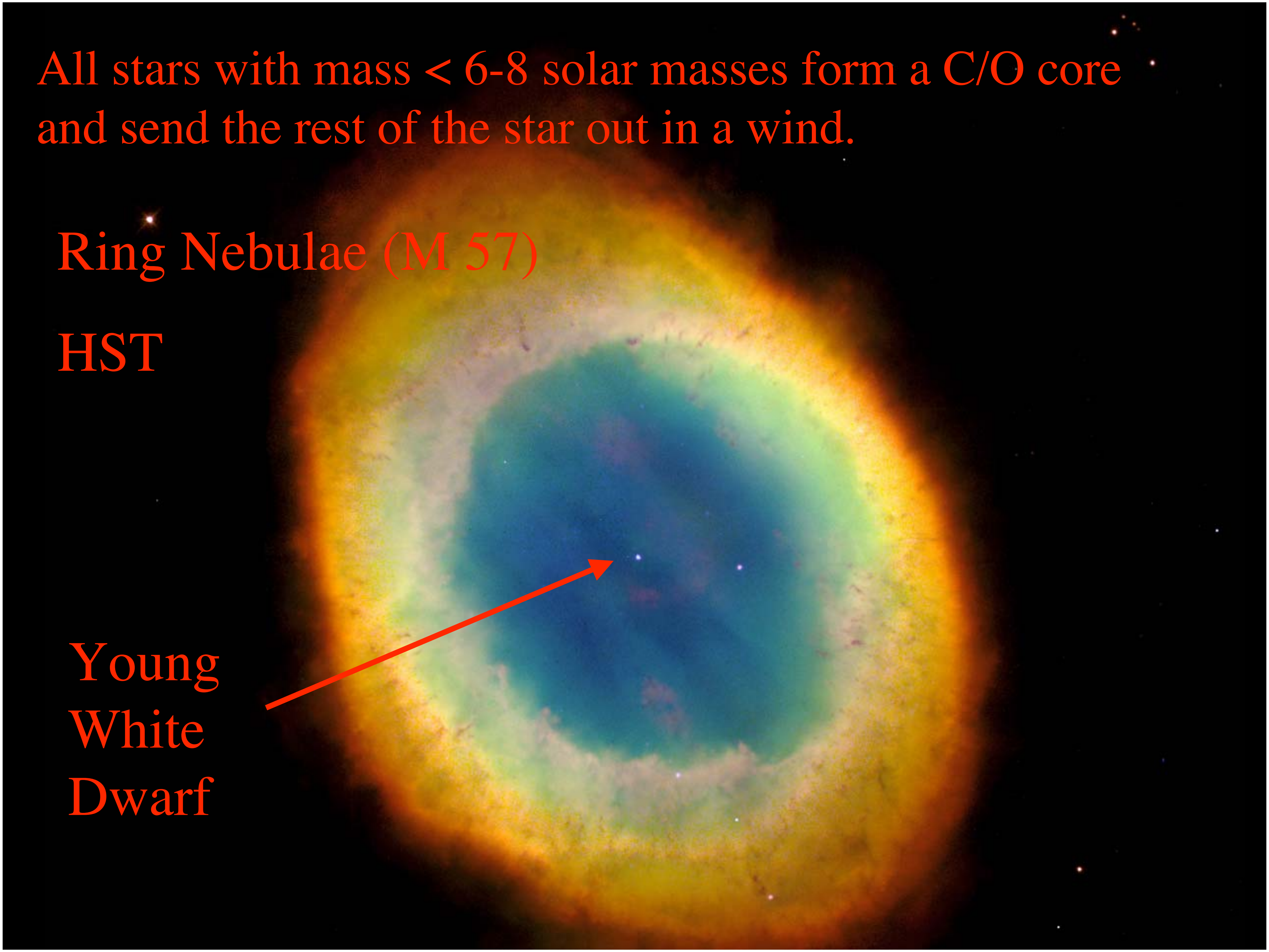


FIG. 16.—Final masses: the He core masses at the beginning of the TP-AGB phase (*squares*); the residual masses at the end of the AGB (*triangles*); initial/final mass relation by Weideman (1987) for the Galactic disk (*dotted line*) and for the Magellanic Clouds (*dashed line*); the initial/final mass relation updated by Herwig (1995) for the Galactic disk (*solid line*). The numeric labels indicate the number of thermal pulses occurring before the end of the AGB phase.


All stars with mass < 6-8 solar masses form a C/O core and send the rest of the star out in a wind.
Ring Nebulae (M 57)
HST
Young White Dwarf

Hydrogen Shell Evolution

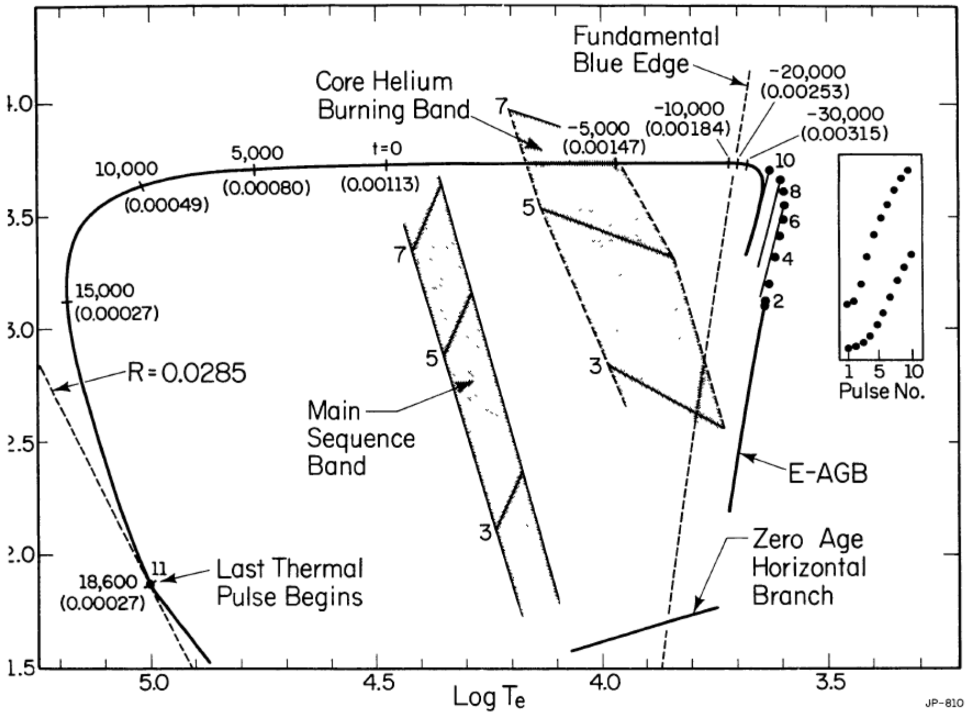


Figure 5 Evolutionary track in the H-R diagram of an AGB model of mass $0.6M_\odot$, initial composition $(Y, Z) = (0.25, 0.001)$. After burning helium in its core on the horizontal branch, the model arrives on the E-AGB to burn helium in a shell; the hydrogen-burning shell is extinguished. The E-AGB phase is terminated when hydrogen reignites and thermal pulsing begins. The location of the model at the start of each pulse is indicated by heavy dots. Excursions in the H-R diagram during the extended postflash dip and recovery period are shown for pulses 7, 9, and 10. Dots in the panel in the extreme right-hand portion of the diagram describe the excursion in luminosity during extended dips for all pulses that occur on the AGB. Evolution time ($t = 0$ when $T_e = 30{,}000$ K) and mass in the hydrogen-rich envelope (in parentheses) are shown at various points along the track leaving the AGB after the tenth pulse. Time is in yr, and M_e and R are in solar units. A line of constant radius passes through the location of the beginning of the eleventh pulse when the model has become a hot white dwarf. The dashed line is a blue edge for pulsation in the fundamental mode for a model of mass $0.6M_\odot$ and $(Y, Z) = (0.25, 0.001)$. Shown for orientation purposes are rough evolutionary tracks during core hydrogen- and core helium-burning phases for $(Y, Z) = (0.28, 0.001)$ and masses 3, 5, and $7M_\odot$.

Iben 1991, ApJS, 75, 55

This plot shows the evolution of the H burning shell during the contraction phase

(H Shell mass)

and time

Late Helium Flashes

Iben 1991, ApJS, 75, 55

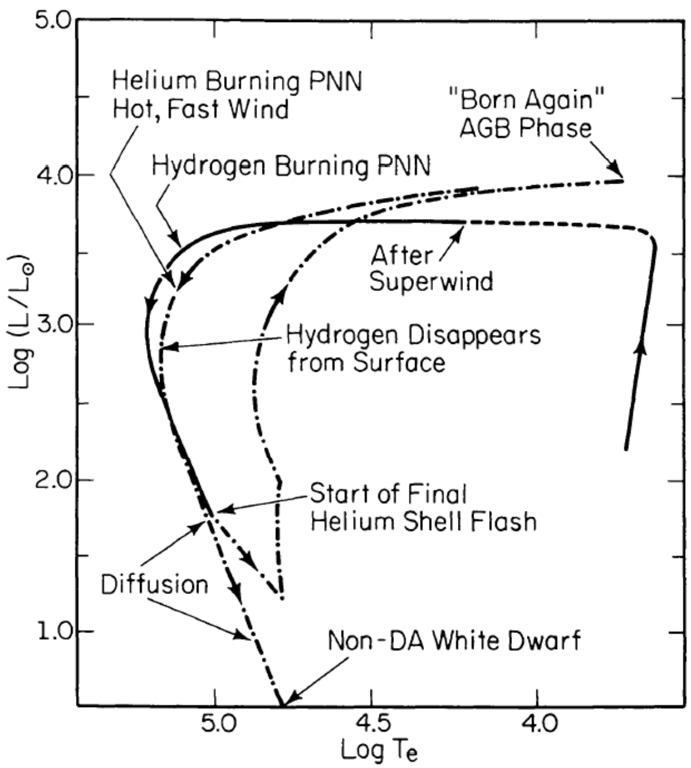


FIG. 44.—Evolutionary track of the hypothetical remnant of a nebular ejection event which occurs when the mass of the helium layer between the CO core and the base of the hydrogen-burning shell is $\sim 0.85 \times dM_H$. Other model characteristics are the same as those of the model described in Fig. 43. After hydrogen burning effectively ceases, the model envelope contracts rapidly and the conversion of gravitational potential energy into heat leads to the ignition of helium in the helium layer even though the mass of this layer is smaller than the critical mass dM_H for ignition on the AGB. In consequence of the hot, fast wind from the remnant, the remainder of the hydrogen-rich envelope is expelled, leaving only a trace of hydrogen which has escaped inward in consequence of chemical diffusion. The model adopts the characteristics of a non-Da white dwarf. Adapted from Iben *et al.* (1983) and Iben (1984).

- If the helium shell was about 80-90% of the way to the next flash, then it can ignite later (Fujimoto 1977)

- When it ignites depends on how close it was and how massive the WD is.

- Evolution after ignition is quite dramatic. . . And sketched here..

- Sometimes the slight amount of remaining H can also be

Three Events

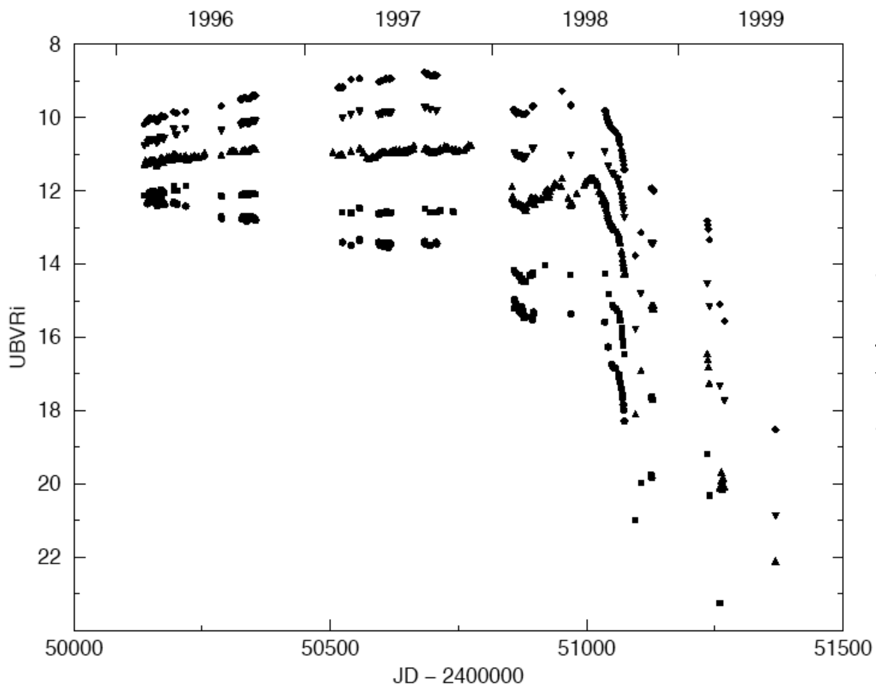


FIG. 3.—*UBVRi* light curve of V4334 Sgr. This curve includes only the observations made at the Dutch 0.91 m telescope and the Reñaca 0.2 m telescope, plus some observations at late stages made by Jacoby, Jacoby & De Marco and Benetti. *Bottom to top*: *U*, *B*, *V*, *R*, *i* light curves.

- Typically up to -5 to -8, lasts for many years, evolves to red..
- Dust is formed..

FG Sge (1894)
V605 Aql (1917) (-5)
V4334 Sgr (1992, Sakurai)

Duerbeck et al. AJ, 119, 2360 (2000)

TABLE 5

EVENTS IN THE EVOLUTION OF FG SAGITTAE, V605 AQUILAE, AND V4334 SAGITTARII

Parameter	FG Sge	V605 Aql	V4334 Sge
Brightness increase (spectrum)	1894–1975 [B–G2 I]	1917.7–1918	1994.8–1995
Time of brightness maximum in *B* (spectrum)......	1968 [A3 I]	1919.6	B 1996.3 [F0]
Spectrum at later stage................................	G–K0 I in 1980s	C2, 2 in 1921.7	C2, 2 in 1997.3
Onset of dust formation	1992	1922.6 (?)	1998.4
Dramatic decline ("disappearance").................	?	1924	1999.2

V4334 Sgr (Sakurai's Object)