Unsolved Problems with Thermonuclear Runaways and Their Consequences

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With a lot of help from my friends:

Theory:

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Dave Arnett (UA)

Raph Hix (ORNL)

Christian Iliadis (UNC)

Grant Newsham (ASU)

Observations:

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Chick Woodward

Bob Gehrz

Julian Osborne

Kim Page

Greg Schwarz (AAS)

Steve Shore (Pisa)

Mark Wagner (LBTO)

(No Postdoc or Graduate student was harmed in the production of this talk)

Sumnery of Unsolved problems:

1. Latest results from Fermi/LAT: 3/12 CNe emit > 100MeV photons.
2. Are Classical, Recurrent, and Symbiotic Novae SN Ia progenitors?
3. When does the mixing occur during the TNR? How much?
4. How much mass is accreted and ejected during the CN outburst
5. THEREFORE→Are the WDs growing in mass?
6. How well do we know the ejecta abundances (and mass)?
7. CV white dwarfs (Dwarf Novae) are probably growing in mass do they show evidence for mixing?
8. If not, is there a way to prevent mixing?
9. If so, are Cataclysmic Variables Ia progenitors [not CNe]?
10. What is the evolutionary status of the secondary (mass donor)?
11. What are the effects of magnetic fields on the WD and on the secondary?
12. What is the mass of the White Dwarf?

All Types of Recurrent Novae have Recently gone into Outburst:

System	Last Outburst	Orbital Period	Secondary
RS Oph	2006	455 days	Giant
U Sco	2009	1.23 days	G3?
T Pyx	2011	0.1 days	unknown

And have been or are being studied in X-rays

Why do we care ?

Cataclysmic Variables and Symbiotic Systems may be
Progenitors of Supernovae Ia (2011fe and PTF 11X)
Classical Novae cannot be the Progenitors since they are losing mass!

Single Degenerate Scenario:
Accretion onto a CO White Dwarf
in a Close Binary System
(SN Ia 2011fe and PTF11x are members)
Suggestions: Dwarf, Recurrent, or Symbiotic Novae:
MULTIPLE CHANNELS

(and working on SN Ia is helpful in getting funding in the US)

Actually, of course, They are really, really fun to study

Latest Observational Results for SN Ia progenitors: Single Degenerate Scenario:

1. SN Ia 2011fe (M101) discovered by the Palomar Transient Factory about 11 hours after the explosion. No evidence for circumbinary material and progenitor likely a CO WD.
2. However, PTF 11kx was a SN Ia that exploded in a system with circumbinary material and they suggest that the progenitor was a Symbiotic Binary like RS Oph. But maybe not.
3. LMC: Schaefer and Pagnotta (2012) did not "find" a star in the "center" of a Ia remnant in the LMC (to stringent but not impossible limits); Edwards, Pagnotta , Schaefer (2012) find lots of stars in the center of another SN Ia remnant.

4. Zorotovic et al. (2011) find that the WDs in Cataclysmic Variables are growing in mass.
5. For example: U Gem –1.2$M_\odot$; SS Cyg – 0.8$M_\odot$; IP Peg – 1.16$M_\odot$; Z Cam – 0.99$M_\odot$

   These are the nearest and brightest CV's. [Canonical value is 0.6$M_\odot$ for single WDs]

"Conclusions"

1. SN Ia's are a mixed zoo but our Ia colleagues can "diddle" the data to make them standard candles.
2. The Single Degenerate scenario is NOT ruled out.
3. Something is probably preventing mixing in CV's as opposed to Classical Novae where the mixing must be taking place.

Two parts to this talk:

1. Solar accretion with NOVA

2. Solar accretion with MESA

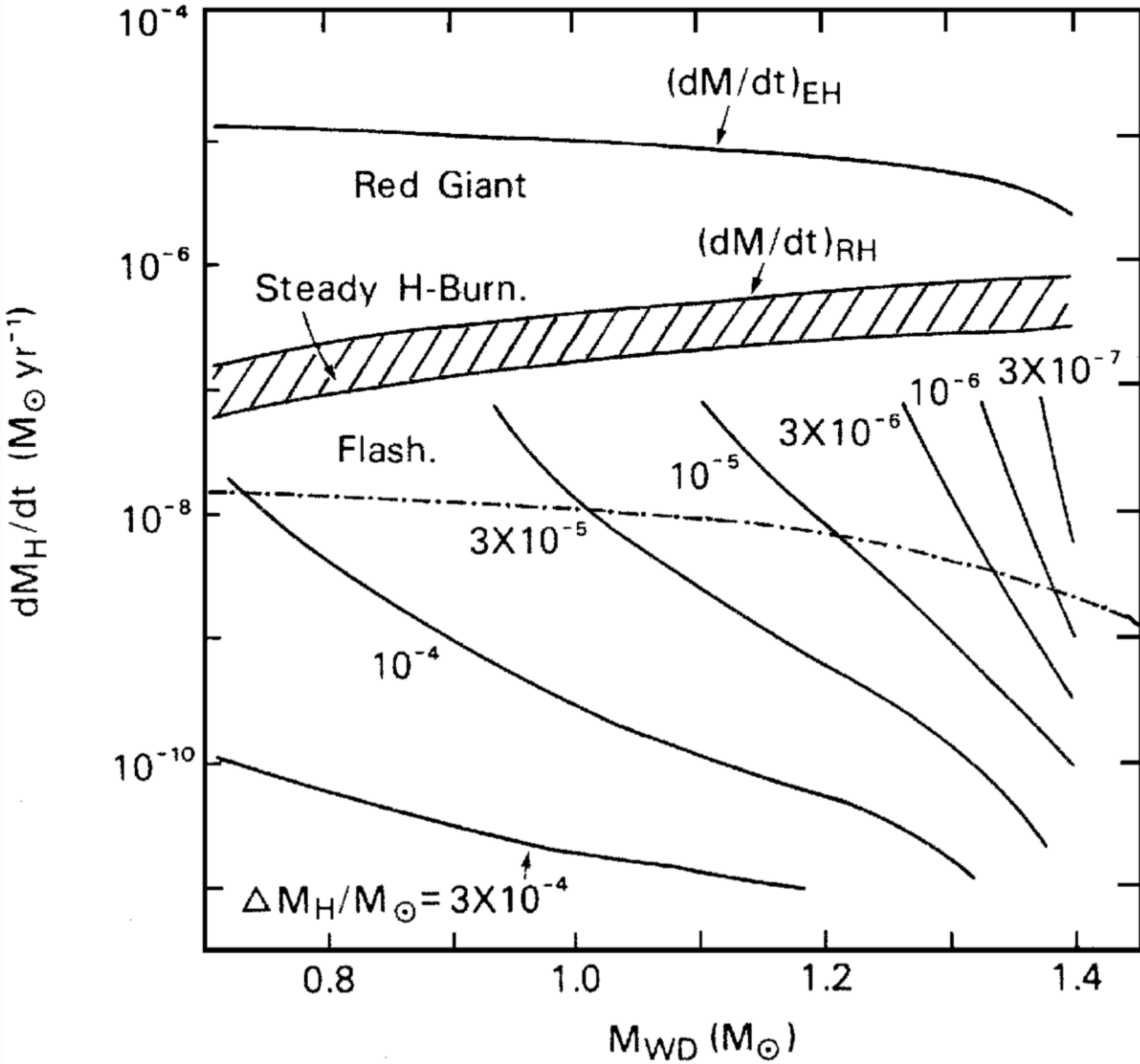
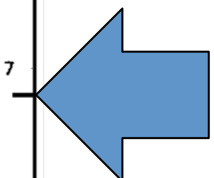


Figure 5 Regimes of steady nuclear burning, weak flashes (cyclic burning), and strong flashes (novae) in the $\dot{M}$–M_{WD} plane (cf Fujimoto 1982a,b, Nomoto 1982, DiStefano & Rappaport 1995). The ΔM_H values indicate envelope masses (for a given accretion rate) at which burning is ignited. Below the *dash-dot line*, flashes produce nova explosions.



$10^{-7} M_\odot$

This Figure is the main argument against the Single Degenerate Scenario

The calculations shown on this plot make no assumptions about:

1. Chemical Composition of accreting material

2. Chemical Composition of underlying WD and whether or not mixing has taken place

3. Thermal structure of the underlying WD and whether or not it has suffered previous outbursts

4. How many outbursts it has undergone and how they have changed the thermal and compositional structure of the underlying WD.

5. But they do assume static, steady-state envelopes (UNLIKE A REAL ACCRETING WHITE DWARF)

Therefore, I can accrete solar material, assume no mixing with the Core, and follow the “first” outburst on the WD

Simulations (NOVA):

•Accreted Solar material onto $0.4M_\odot$, $0.7M_\odot$, $1.0M_\odot$, $1.25M_\odot$, $1.35M_\odot$ White Dwarfs (no mixing with WD Core matter)

•2 initial luminosities: $4 \times 10^{-3} L_\odot$ (CWD) and $10^{-2} L_\odot$ (ENV)

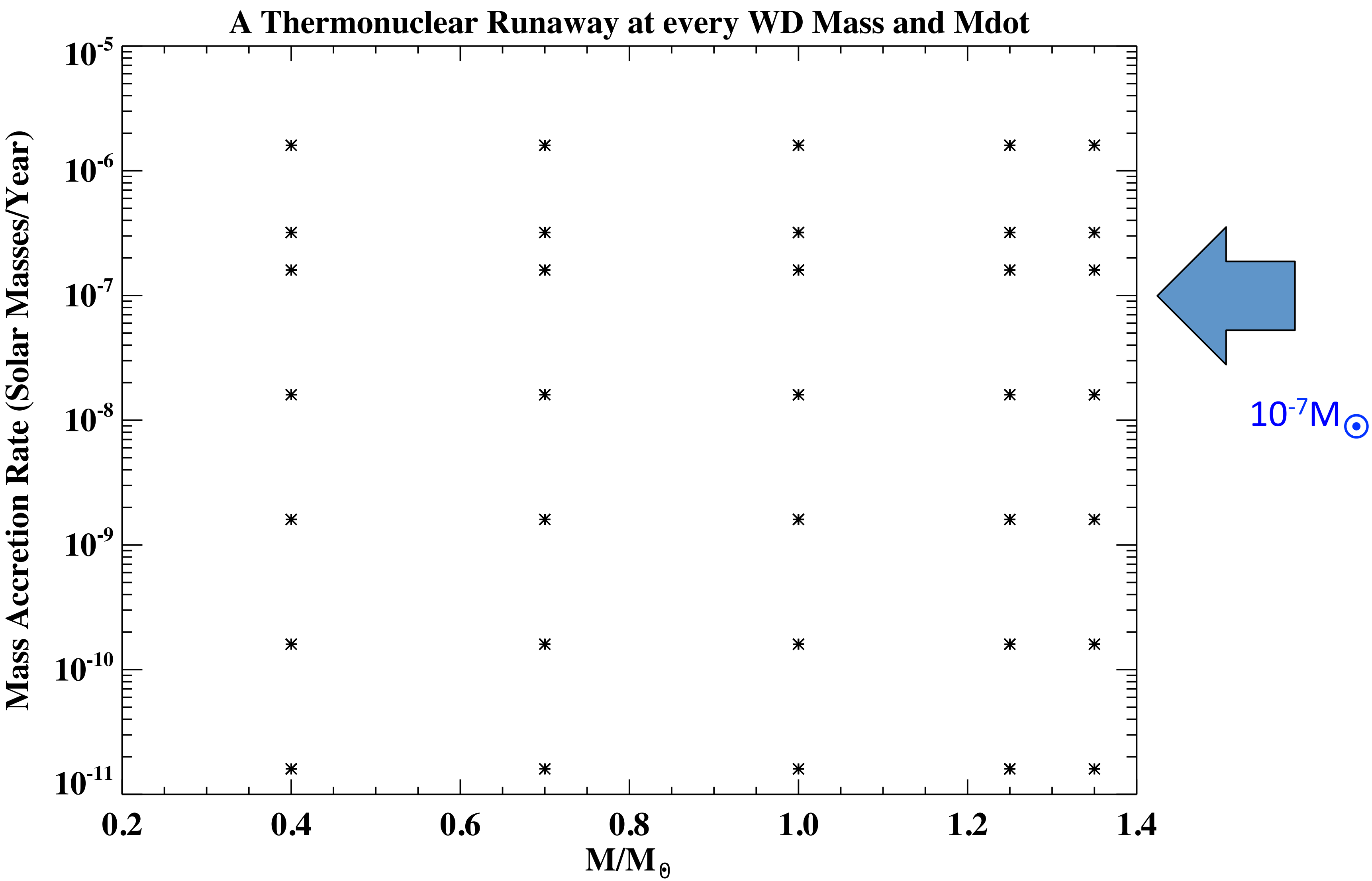
•7 Mass accretion rates from $1.6 \times 10^{-11}\ M_\odot/\mathrm{yr}$ to $1.6 \times 10^{-6}\ M_\odot/\mathrm{yr}$

(extra simulation at $3 \times 10^{-7}\ M_\odot/\mathrm{yr}$)

•150 mass zones with surface zone masses less than $10^{-9}\ M_\odot$

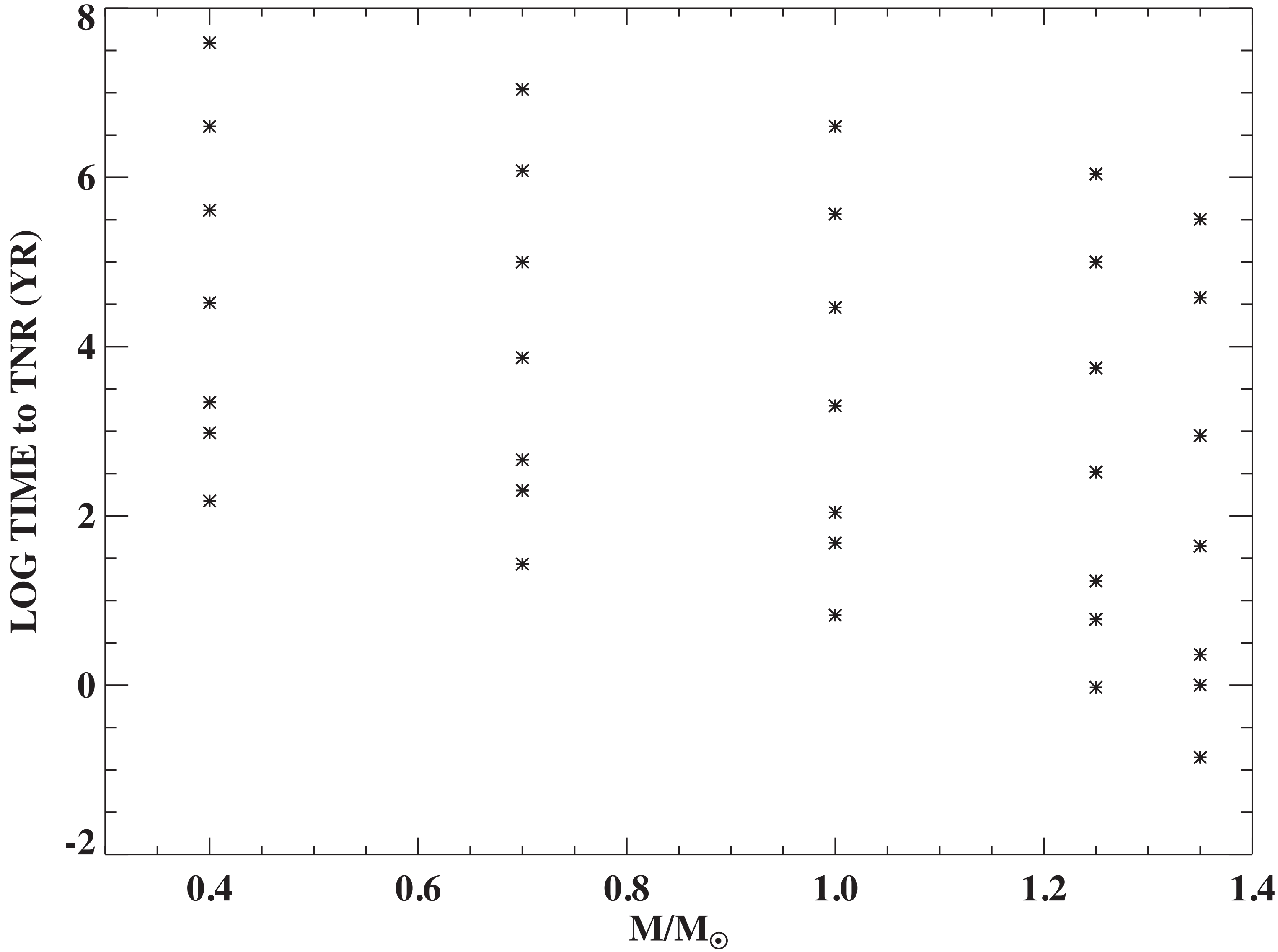
•Both Complete WDs and just Envelopes: No substantial differences in results.

•Just the first outburst on the WD (a feature of NOVA)

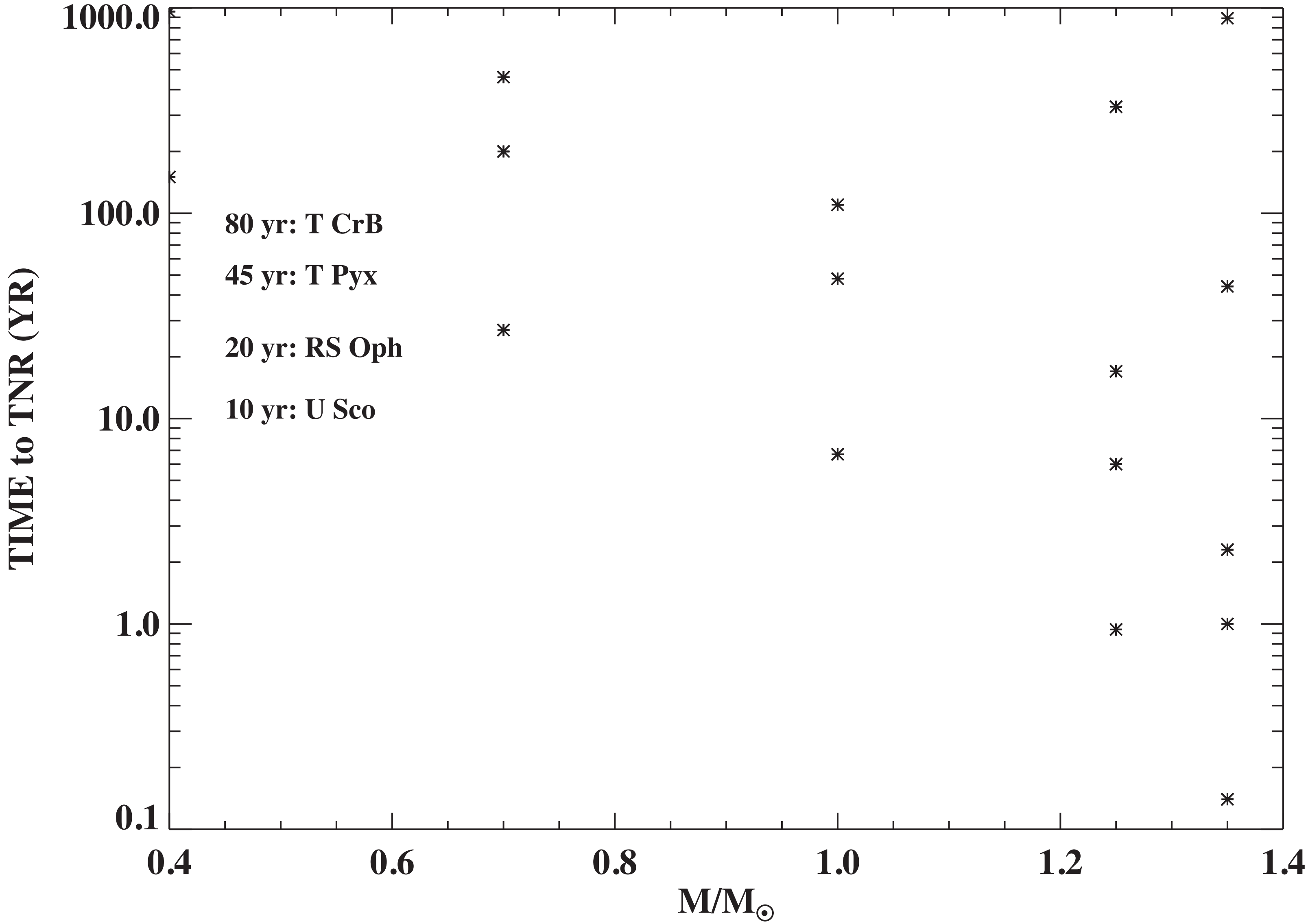


A Thermonuclear Runaway at every WD Mass and Mdot
Mass Accretion Rate (Solar Masses/Year)
10-5
10-6
10-7
10-8
10-9
10-10
10-11
0.2
0.4
0.6
0.8
1.0
1.2
1.4
M/M⊙
10-7M⊙

Accretion time to TNR as a function of White Dwarf Mass



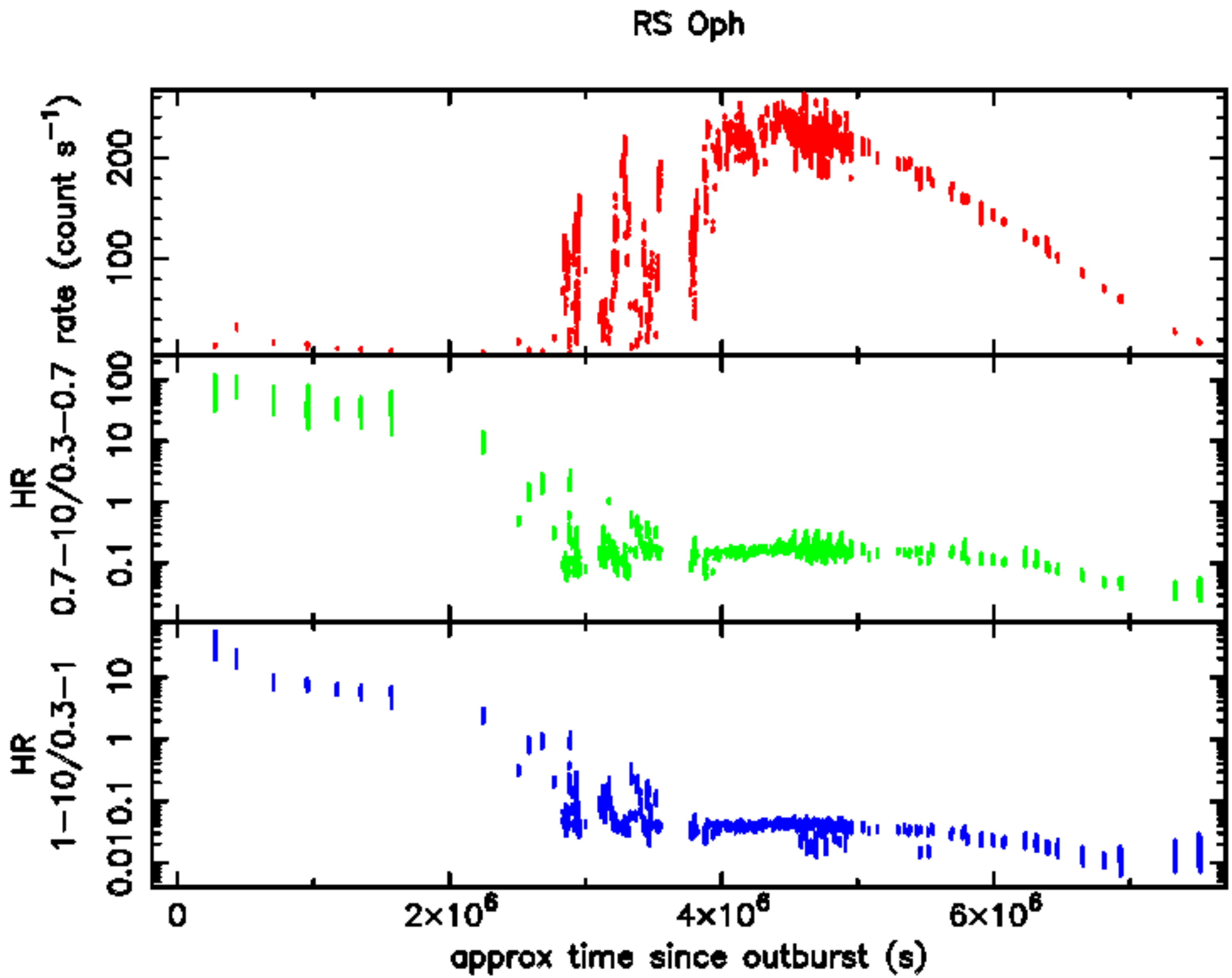
Accretion Time to TNR plus some Recurrent Novae



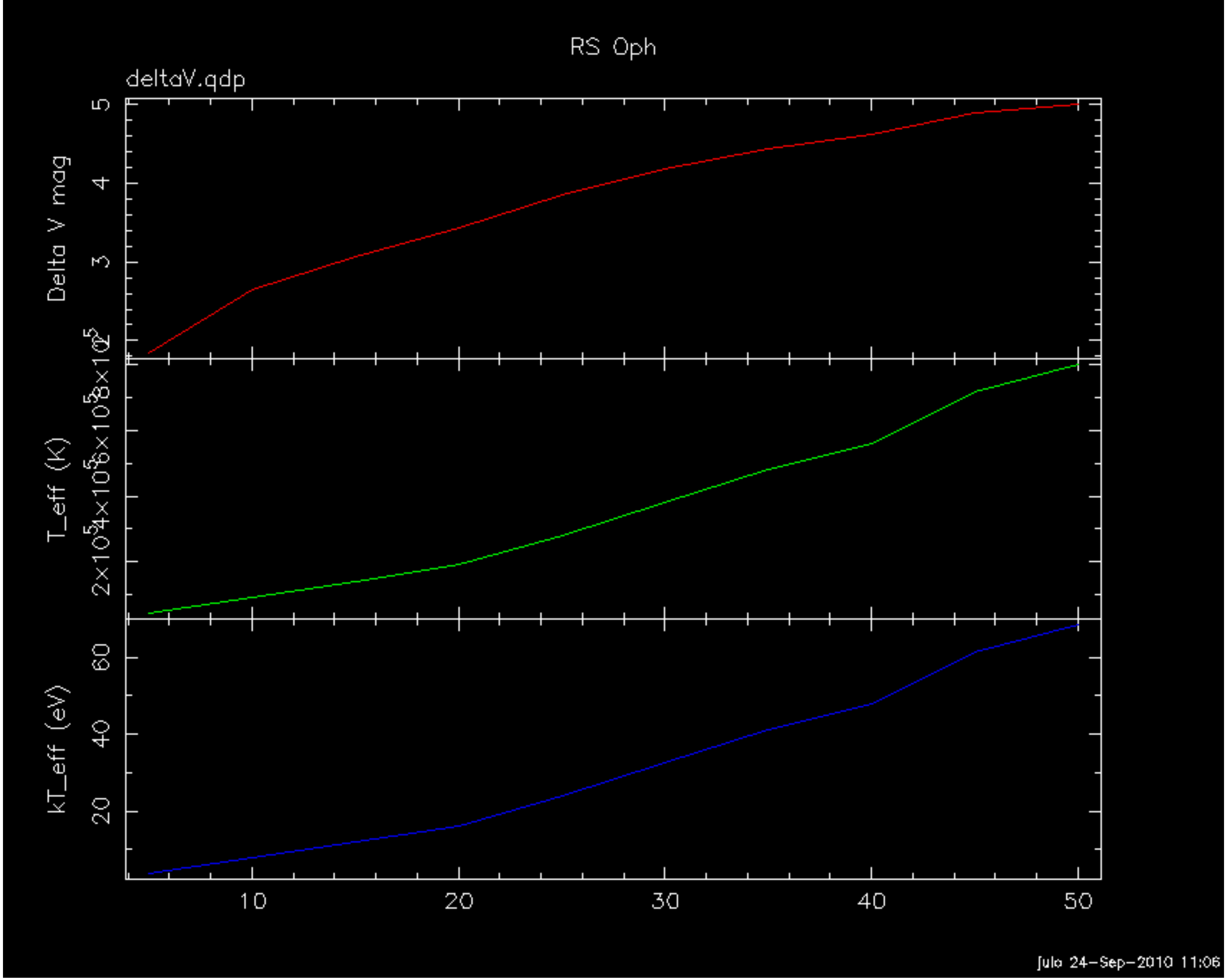
Will they be detected
in X-rays
while evolving to the

Thermonuclear
Runaway?

Swift Light Curve and Hardness Ratio for RS Oph in Outburst



---- ~30 days----



Julian Osborne: from Bath and Harkness

The Supersoft source in RS Oph did not become visible to

Swift

until about day 26 to 30 when its

temperature was about 400,000K to 500,000K

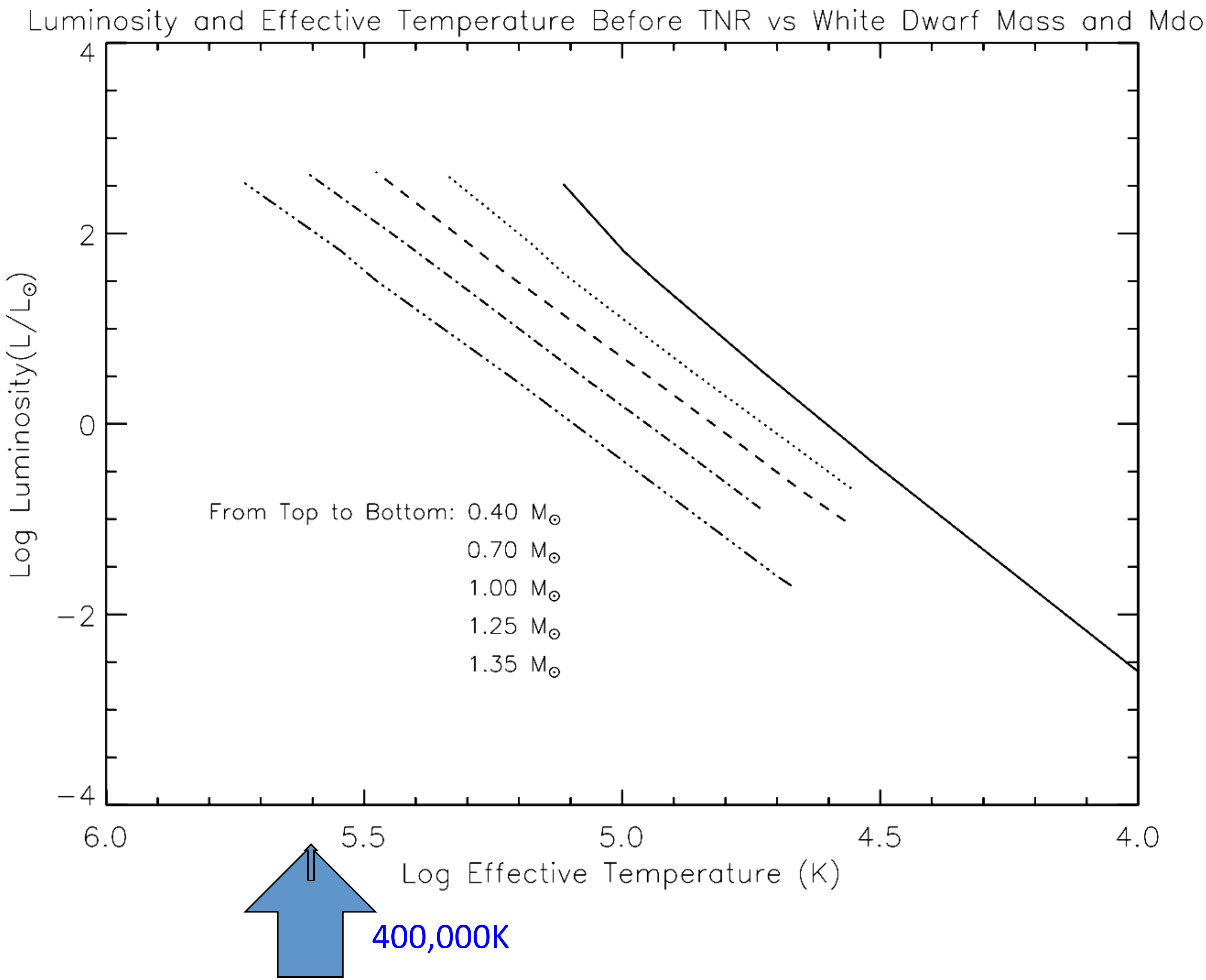
(higher if we believe the atmosphere fits).

This implies that a Super Soft Source

must be around this temperature
to be seen by Swift.

We predict:

Before the TNR

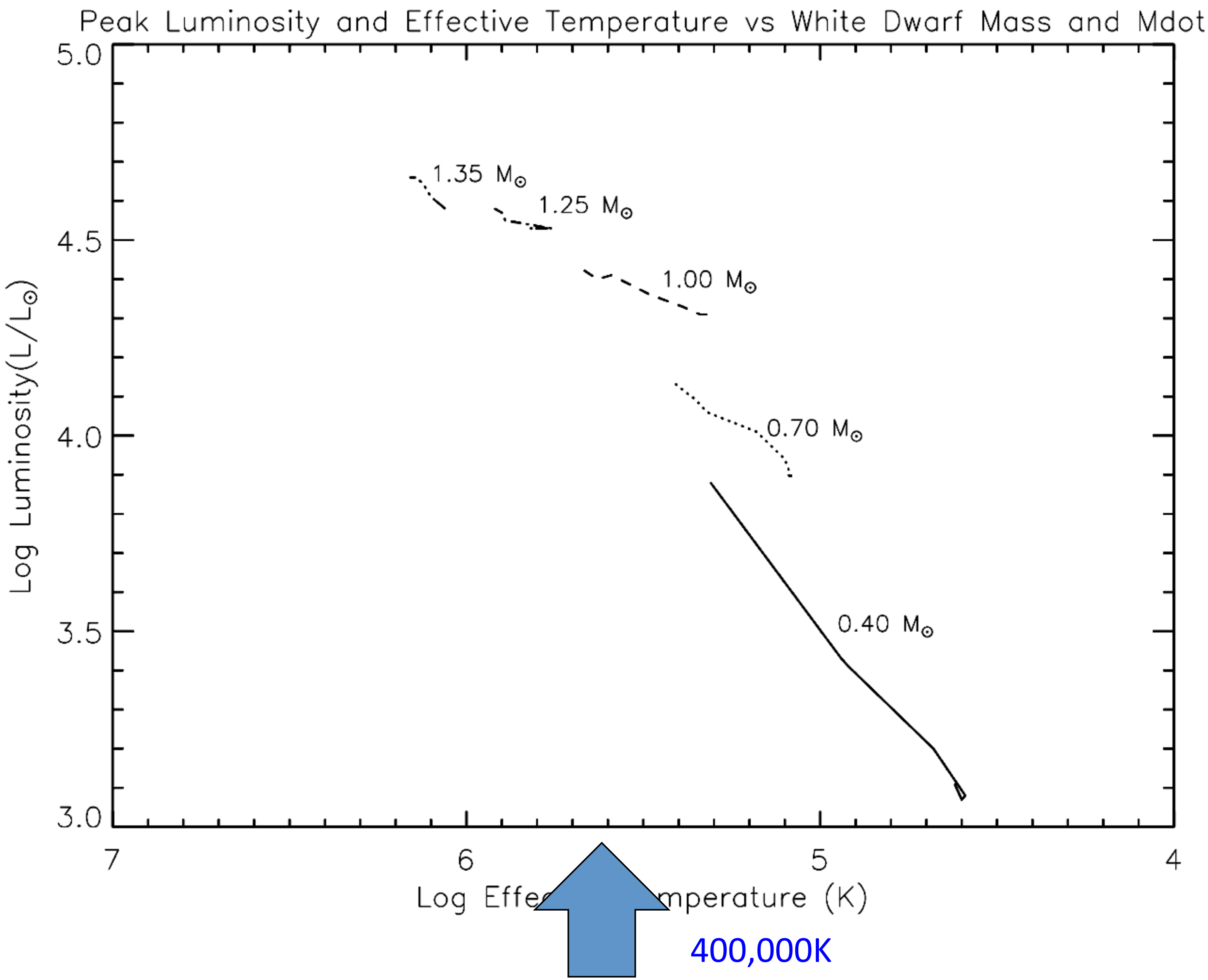


Only the most massive white dwarfs accreting at the highest rates might be detected by Swift before the TNR.

But they have the shortest "duty" cycles (accretion time to TNR).

What about at the peak of the TNR?

Peak Luminosity and effective Temperature of the TNR



At the peak of the TNR:

The sequences that are hottest and most luminous are:

Those with the highest mass accretion rate at each mass.

They are the sequences that have accreted the least amount of material and, therefore, have ejected the least amount of material.

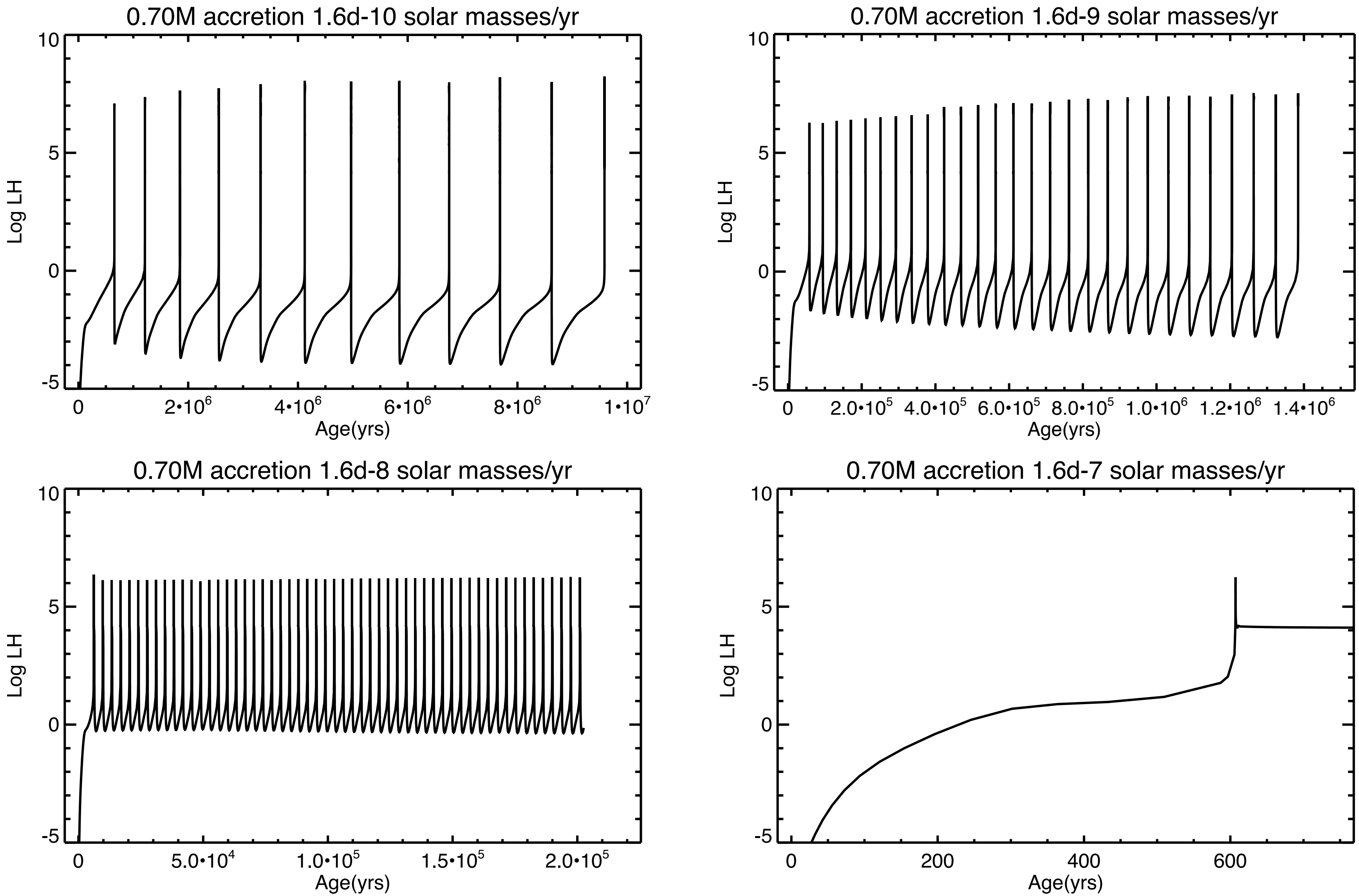
They are "bright" in X-rays for the shortest amount of time (Solar Accretion ONLY! – this is not true for either CO or ONe accretion).

Peak temperature in X-rays is probably a measure of WD mass.

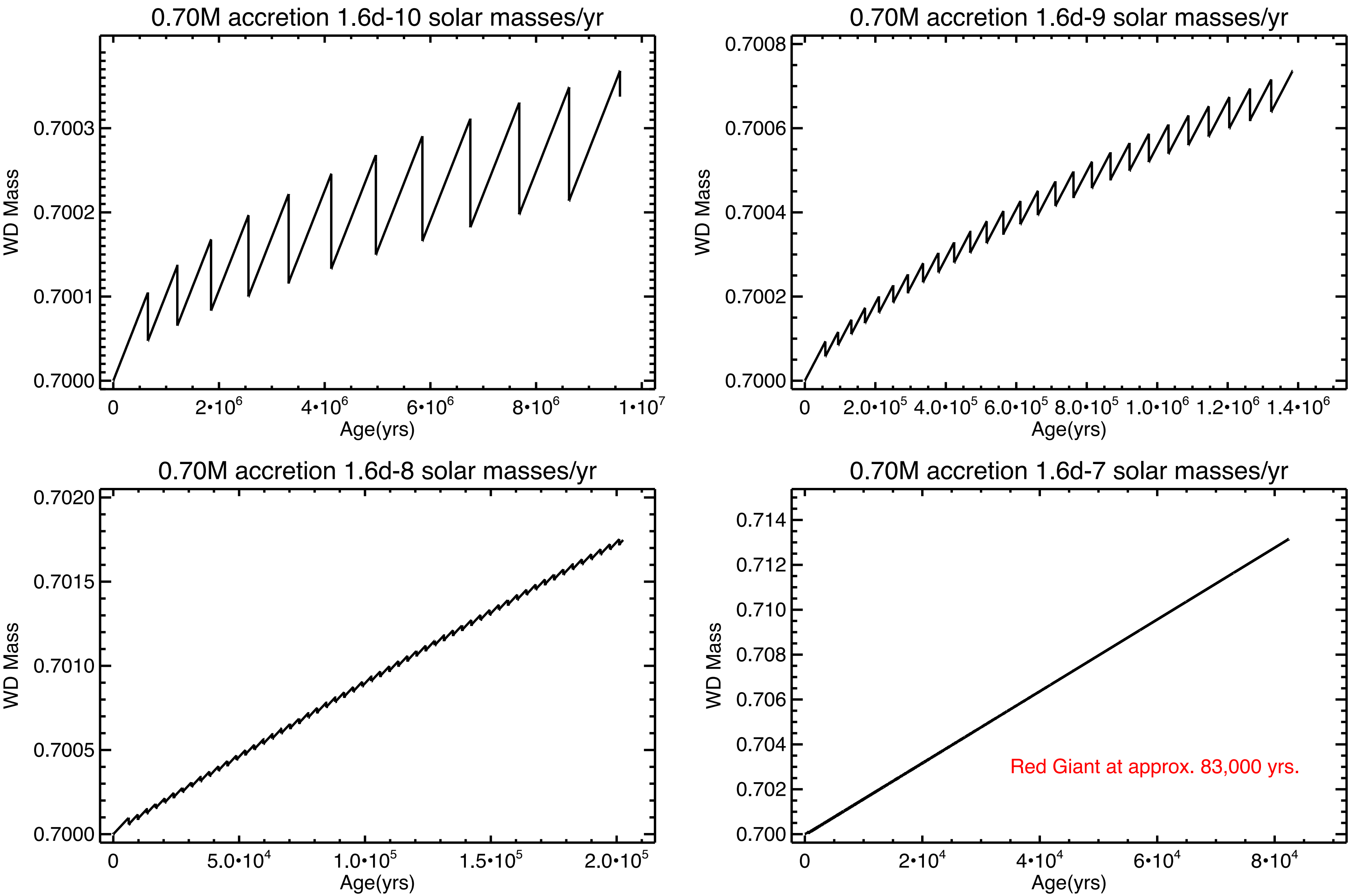
New calculations with a new code: MESA
Paxton et al. 2010, 2013

Solar accretion onto White Dwarfs
BUT
Multiple outbursts and many more zones

Hydrogen Luminosity vs. Time in Solar Units 0.7Msun

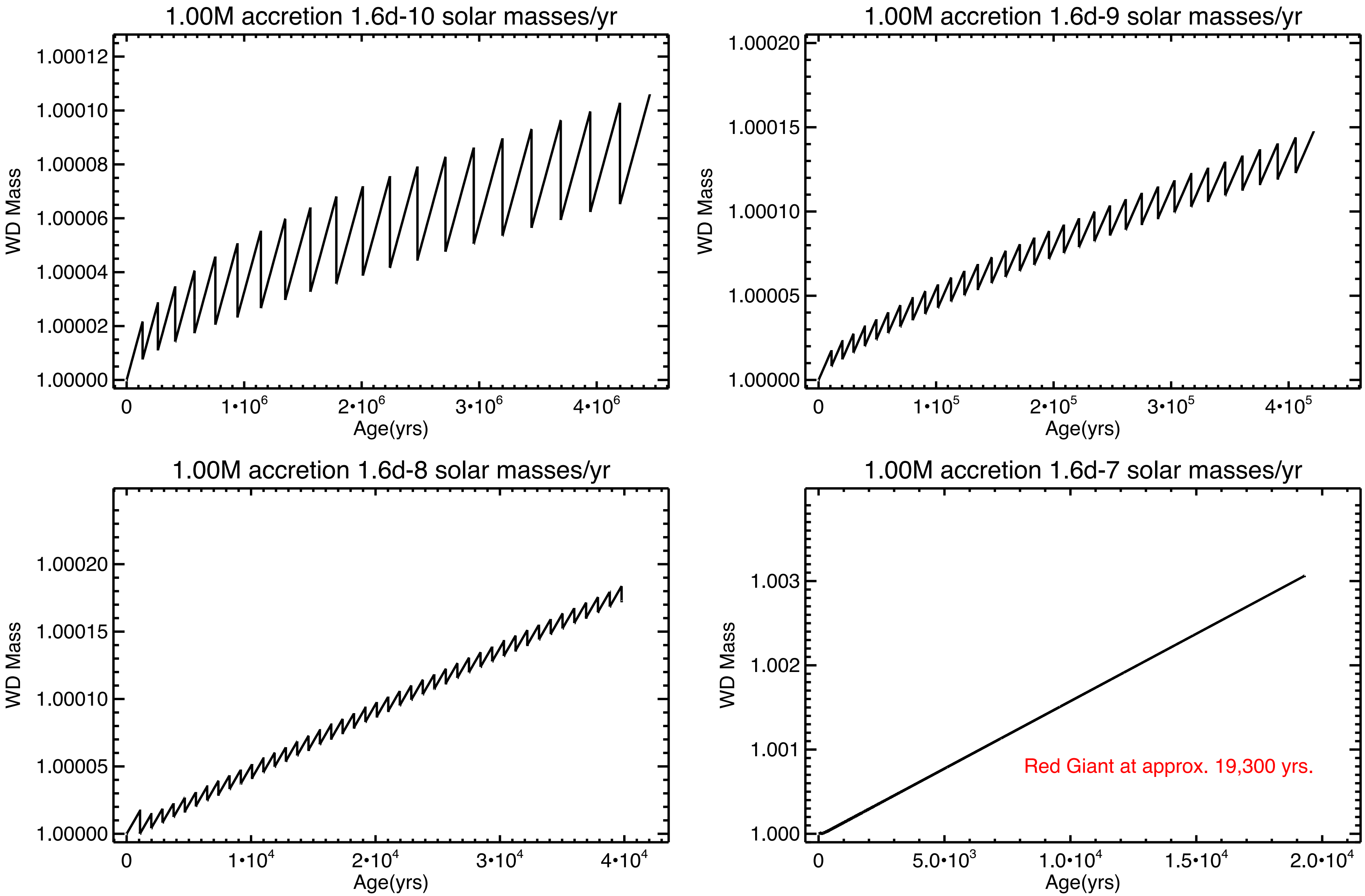


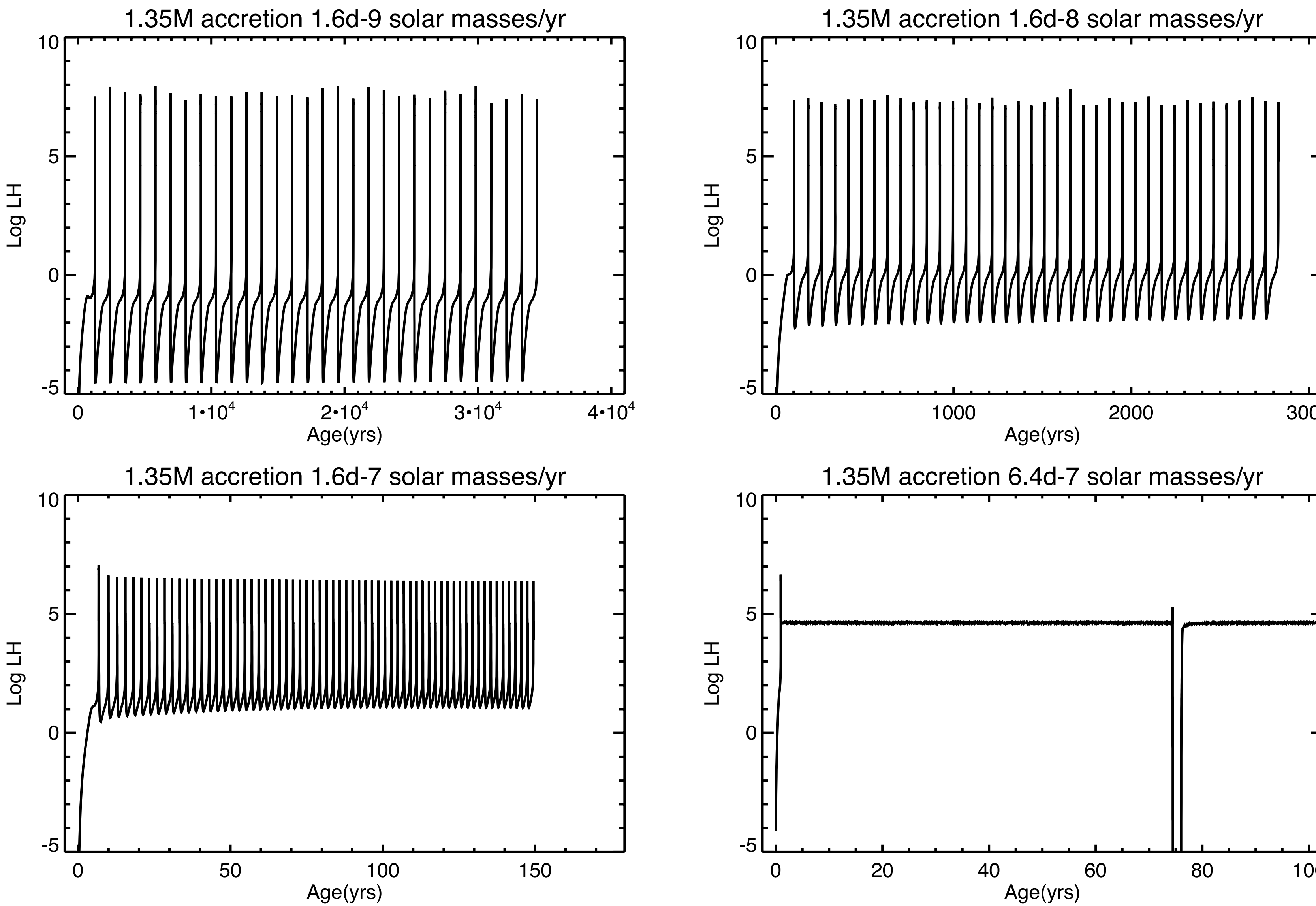
White Dwarf Mass vs Time:
Each decline in mass is caused by mass loss prior to the next TNR



White Dwarf Mass VS Time

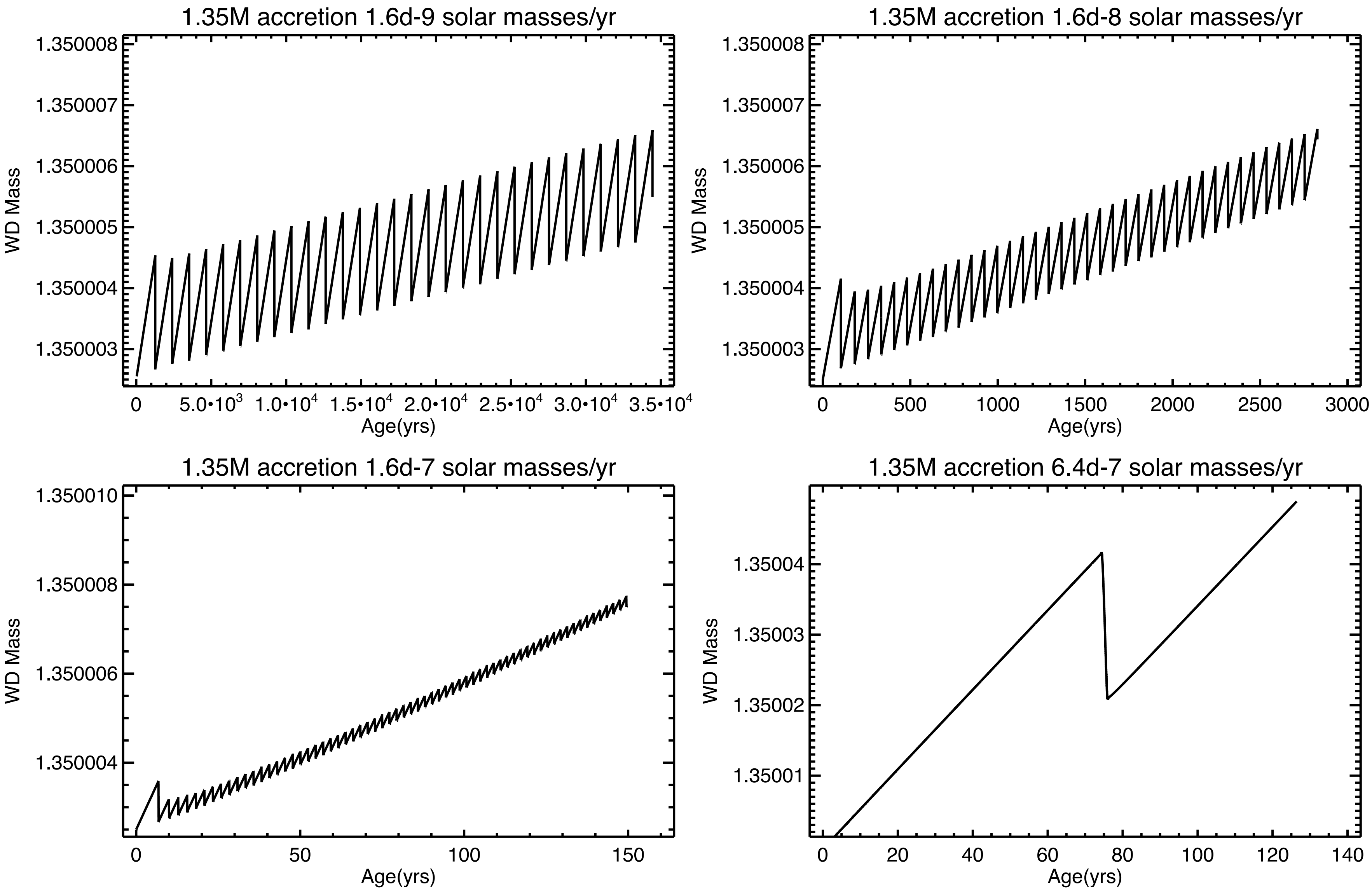
Each decline in WD mass is caused by mass loss before the next TNR

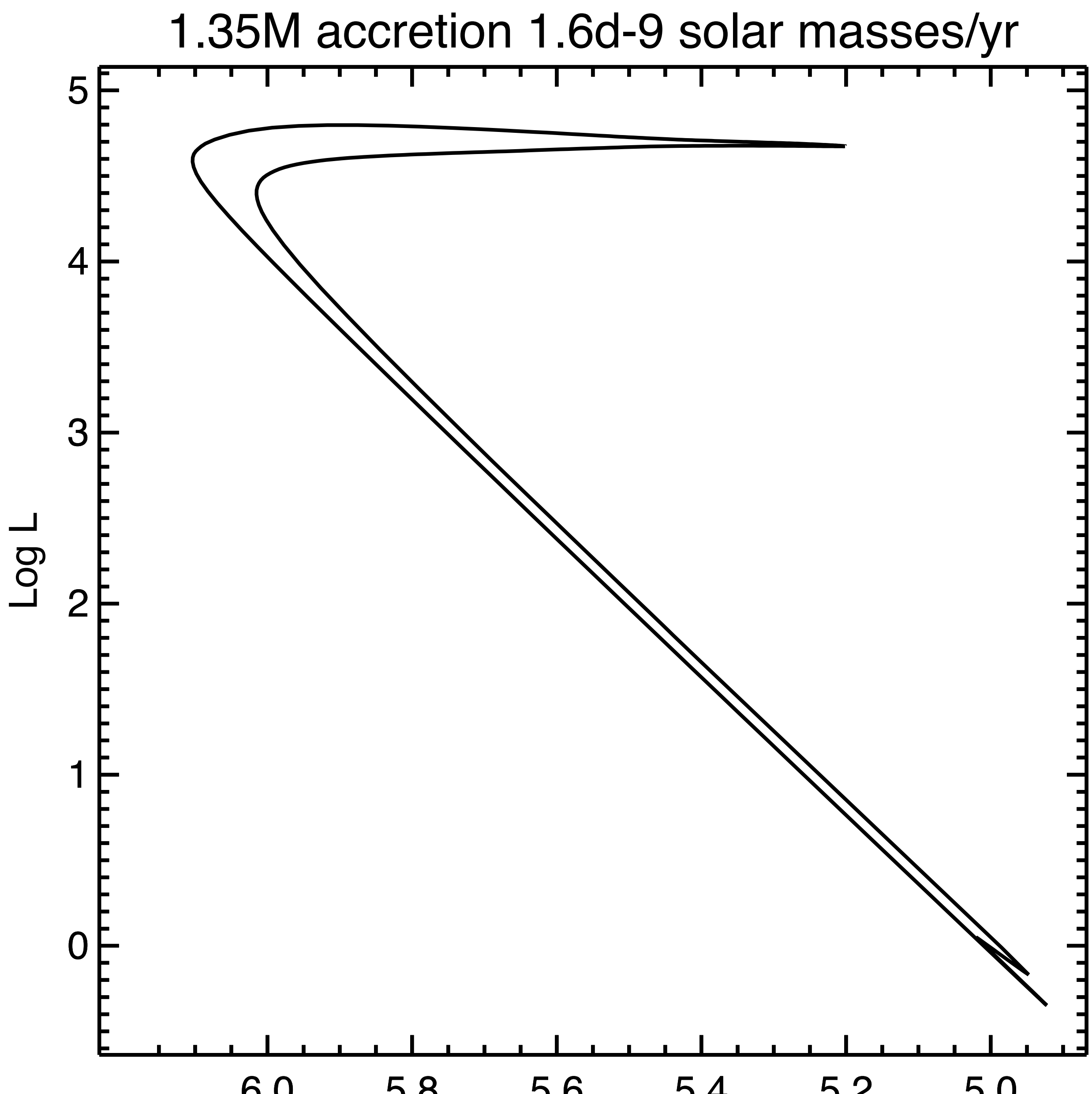




Helium Flash

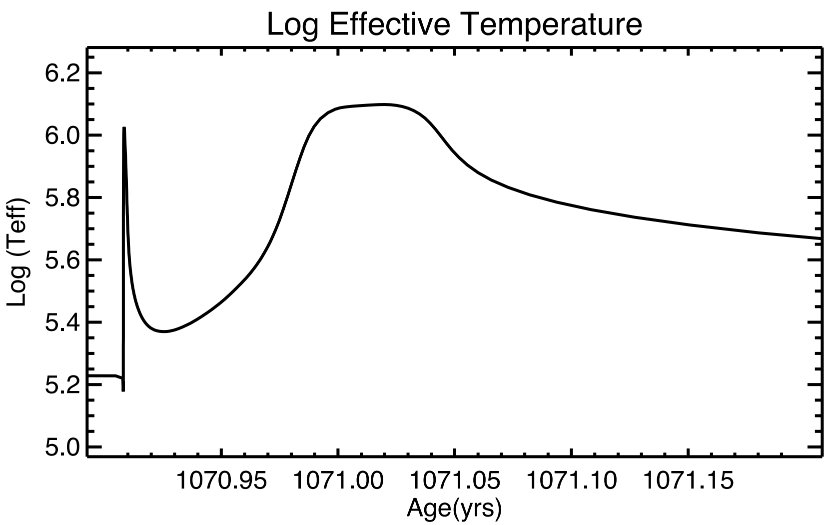
White Dwarf Mass vs Time for the 1.35$M_\odot$ Sequences

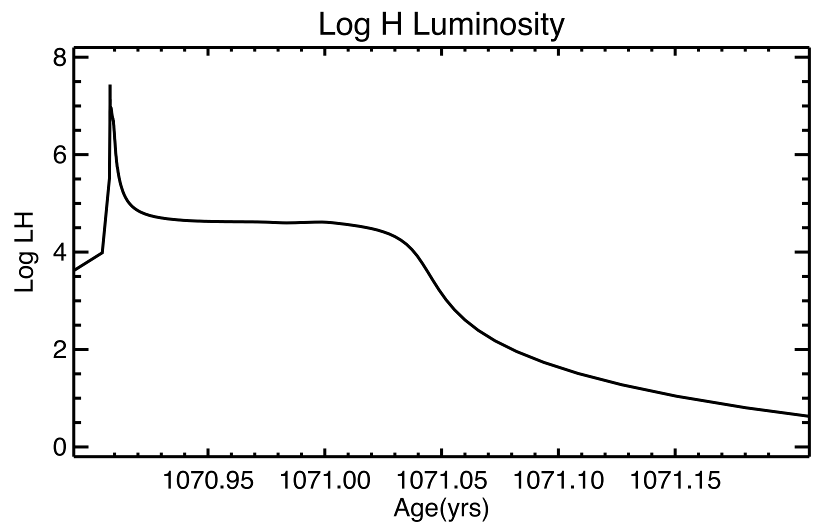


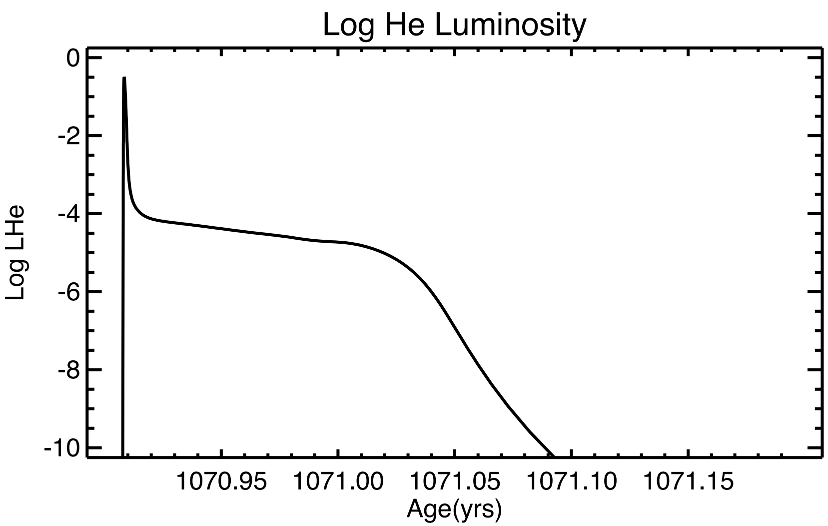

1.35M accretion 1.6d-9 solar masses/yr
Log L
Log (Teff)
5
4
3
2
1
0
6.0
5.8
5.6
5.4
5.2
5.0

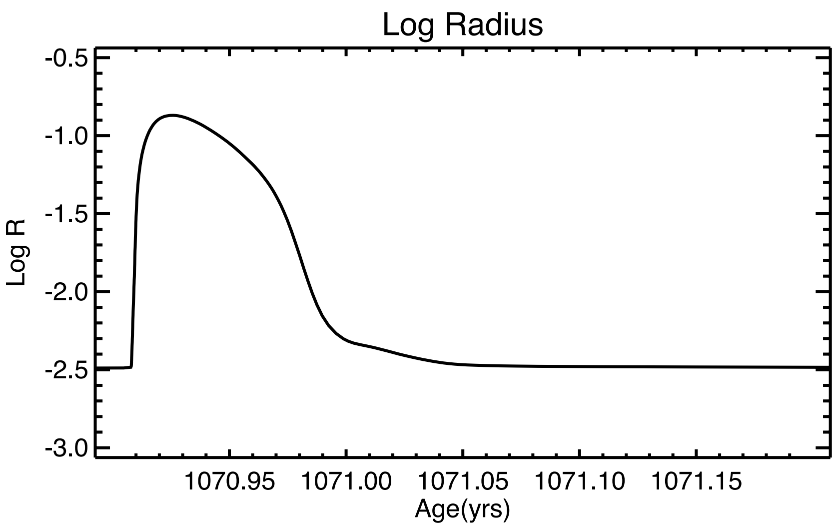
ONE FLASH

1.35M accretion 1.6d-8 solar masses/yr



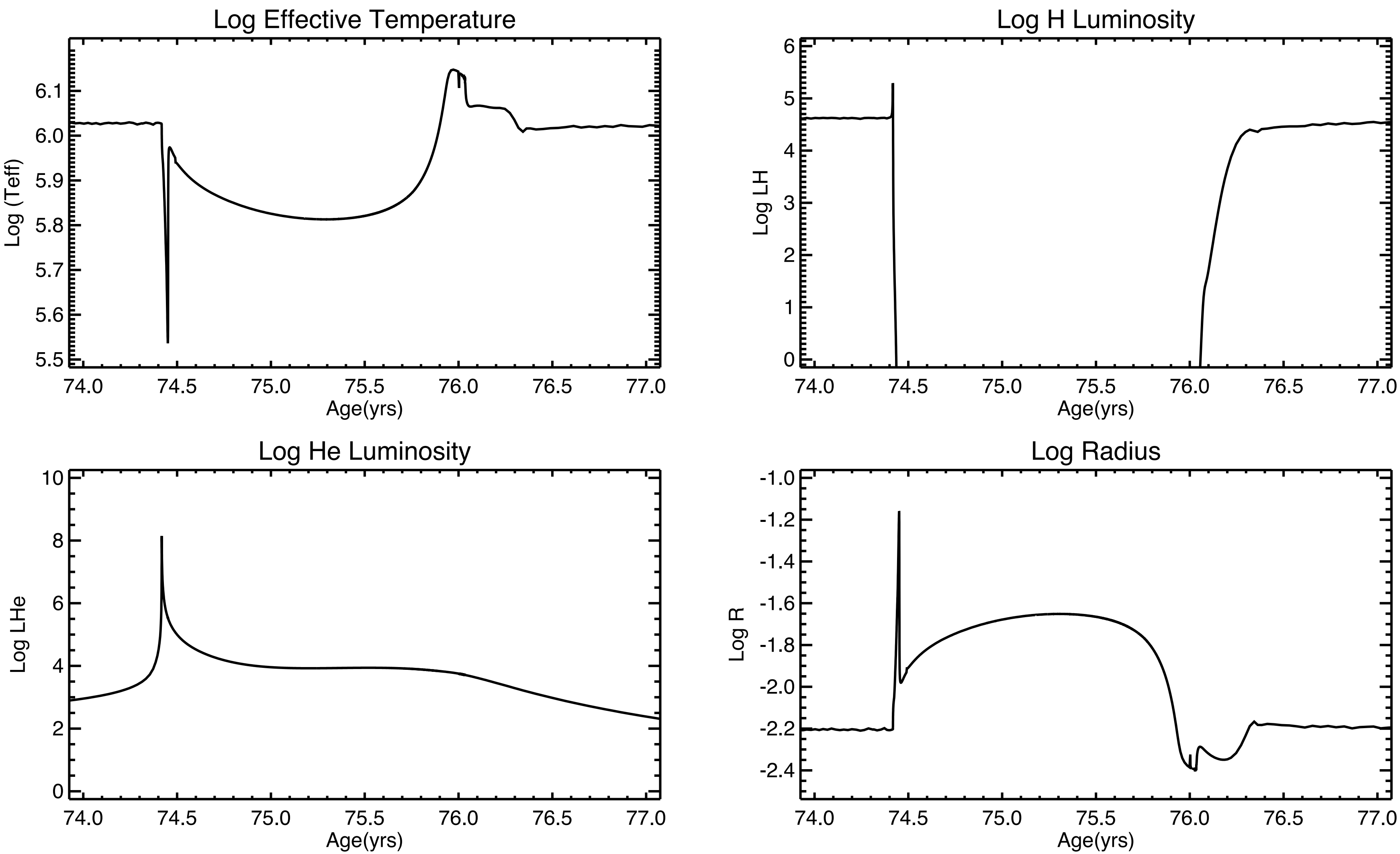


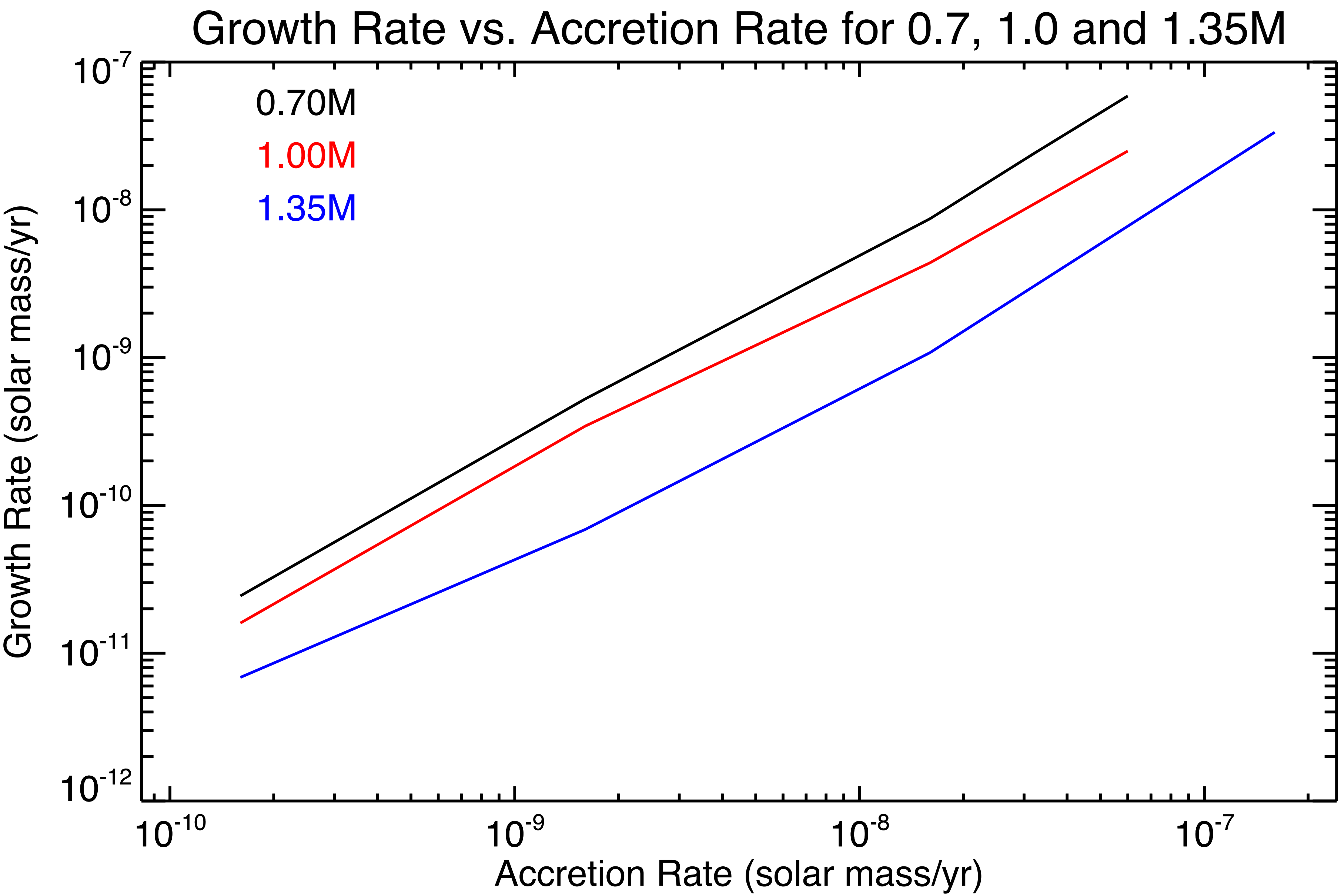




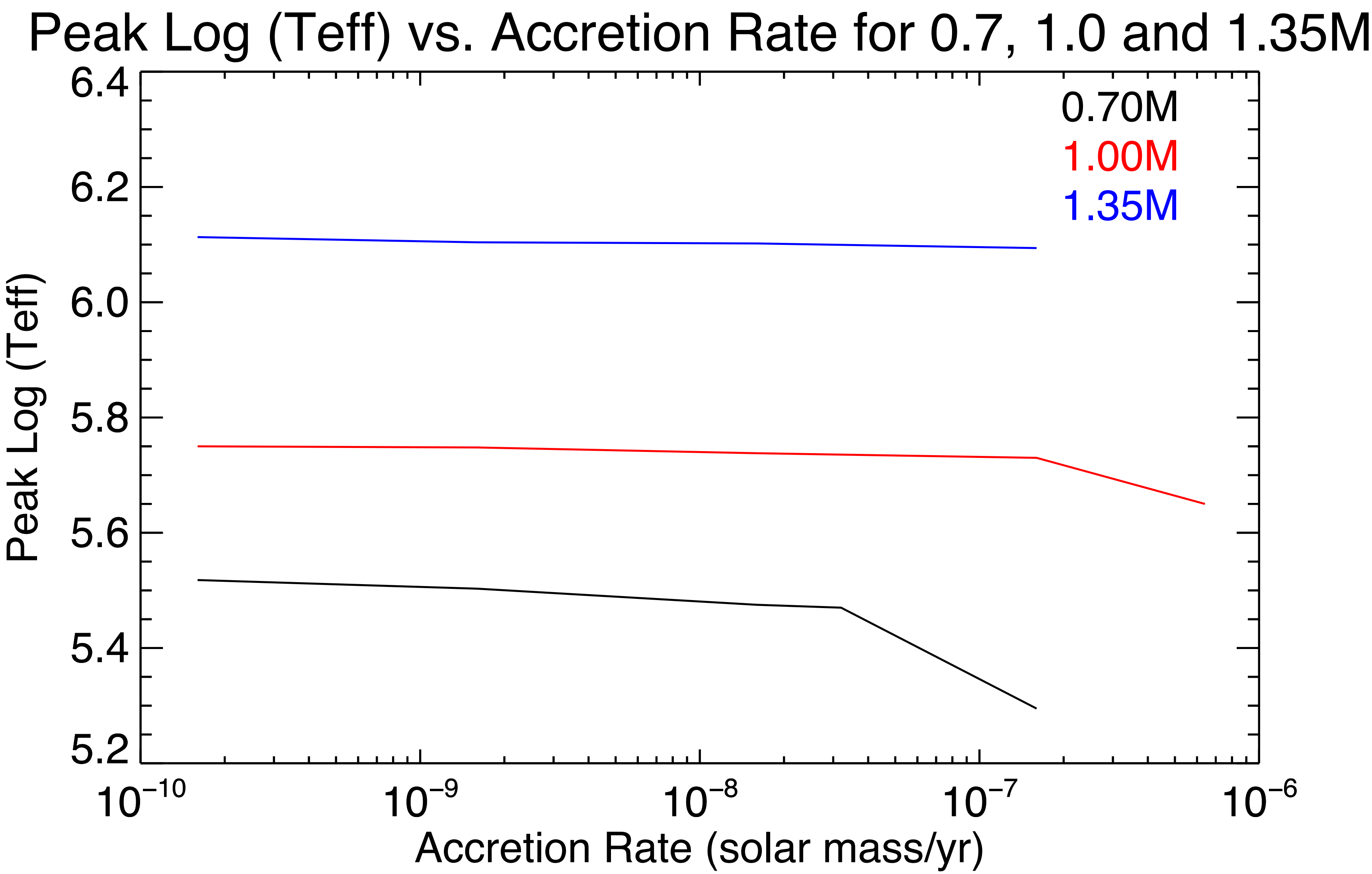
Helium Flash

1.35M accretion 6.4d-7 solar masses/yr



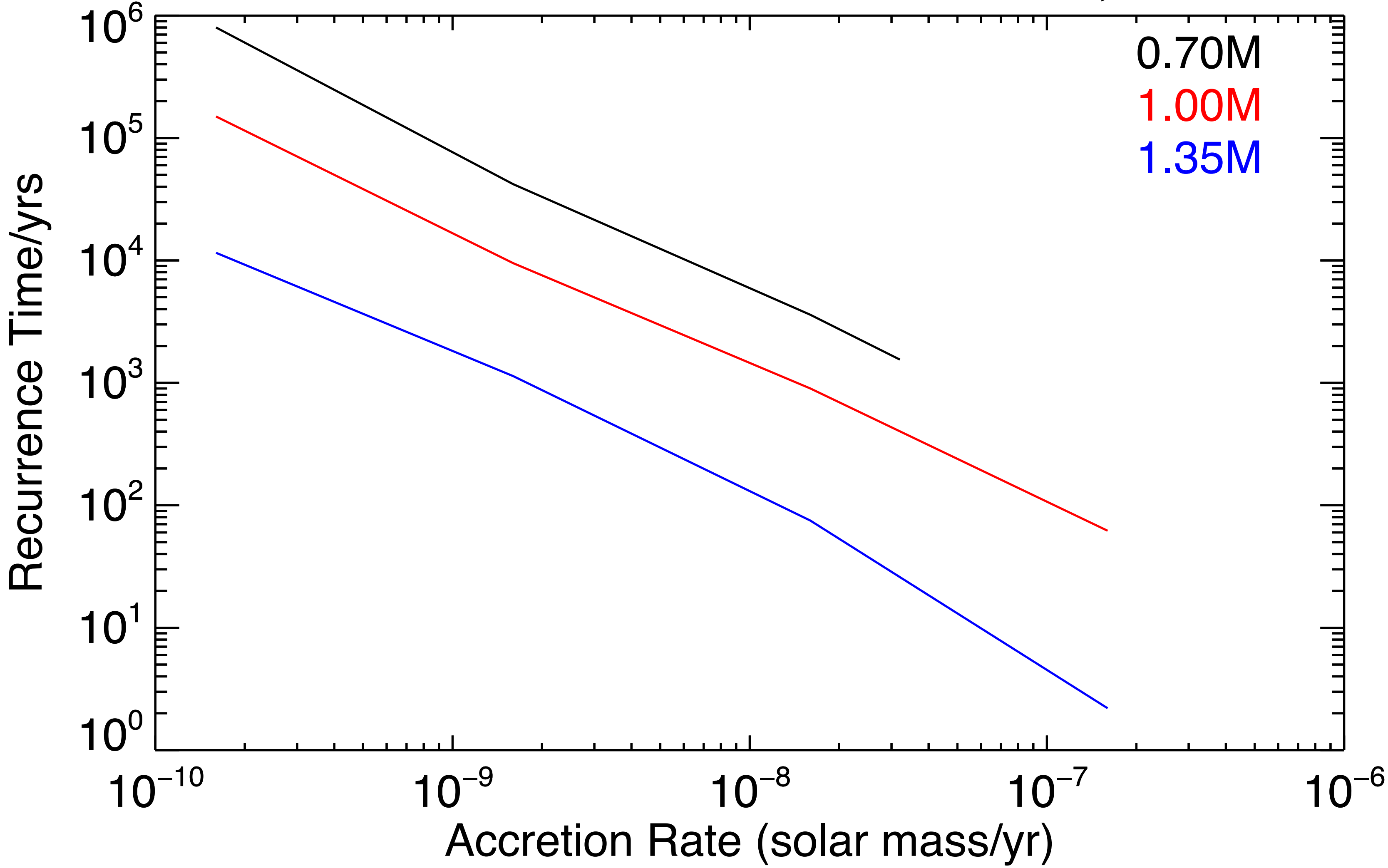


Growth Rate vs. Accretion Rate for 0.7, 1.0 and 1.35M
0.70M
1.00M
1.35M
Growth Rate (solar mass/yr)
Accretion Rate (solar mass/yr)
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^-10
10^-9
10^-8
10^-7

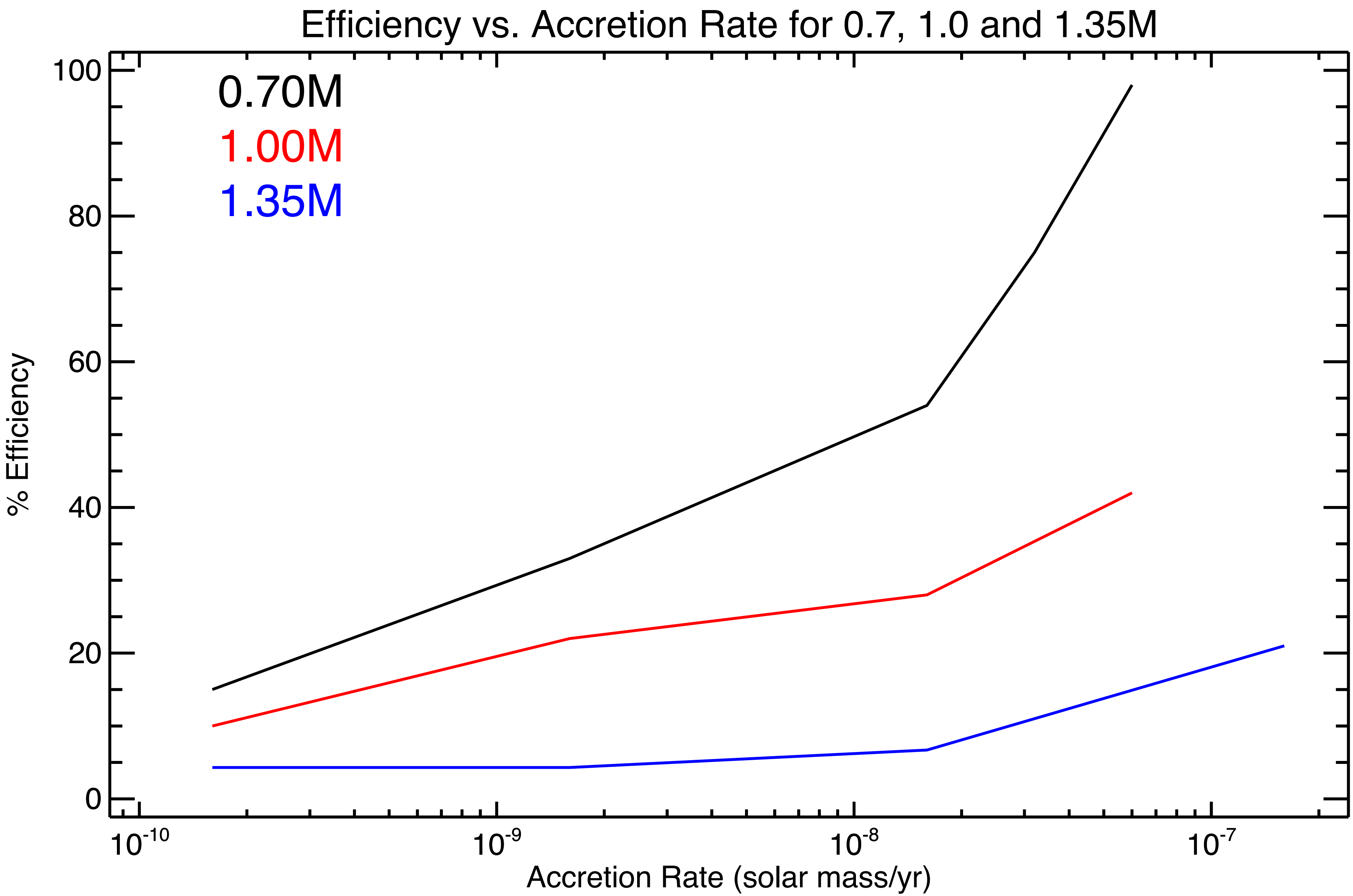


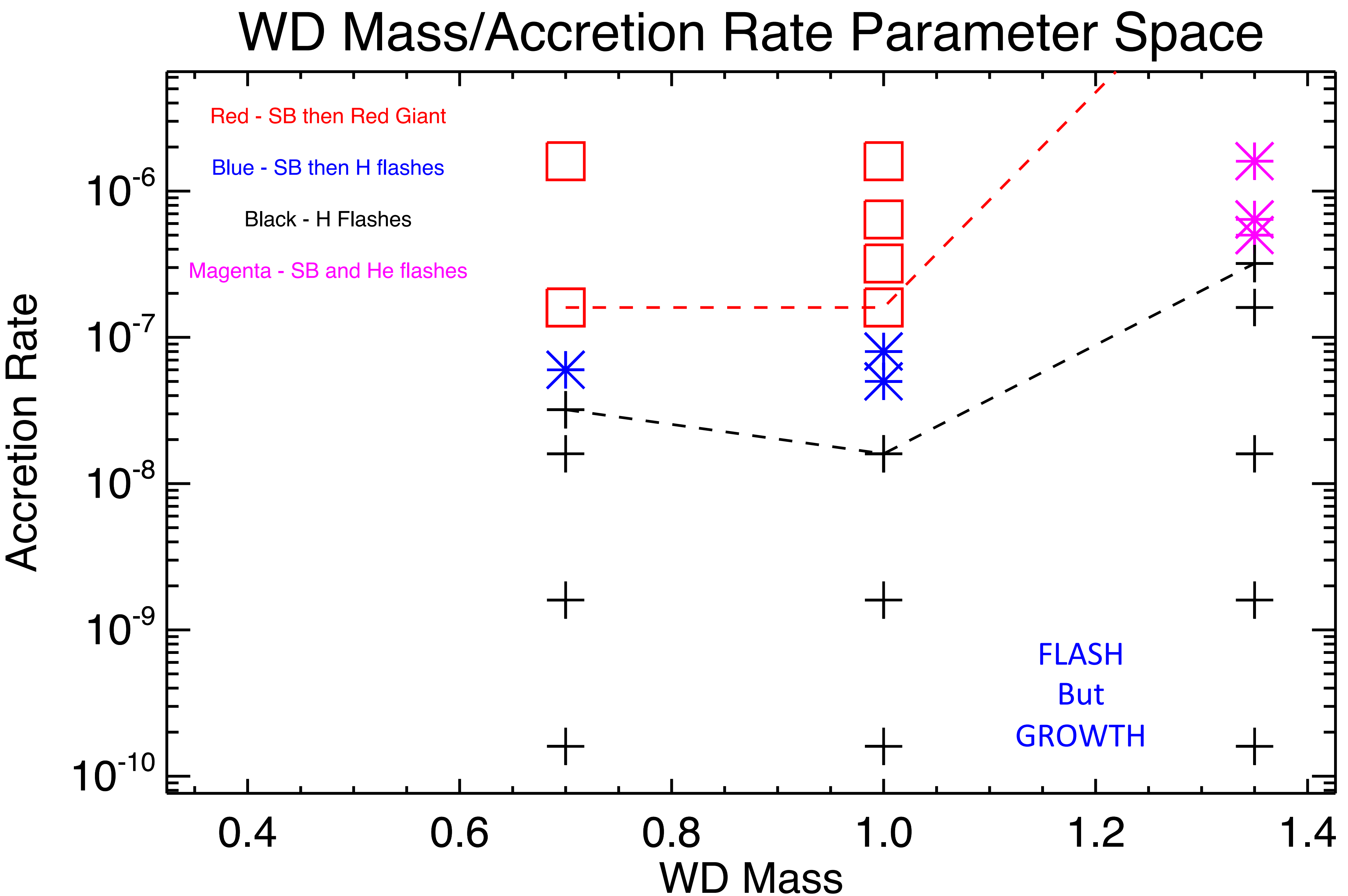
Peak Log (Teff) vs. Accretion Rate for 0.7, 1.0 and 1.35M
0.70M
1.00M
1.35M
Peak Log (Teff)
6.4
6.2
6.0
5.8
5.6
5.4
5.2
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
Accretion Rate (solar mass/yr)

Recurrence Time vs. Accretion Rate for 0.7, 1.0 and 1.35M



Efficiency: How much mass is left on the WD after the TNR





WD Mass/Accretion Rate Parameter Space
Red - SB then Red Giant
Blue - SB then H flashes
Black - H Flashes
Magenta - SB and He flashes
FLASH
But
GROWTH
Accretion Rate
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
0.4
0.6
0.8
1.0
1.2
1.4
WD Mass

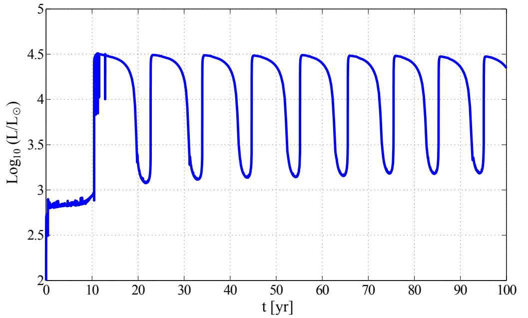
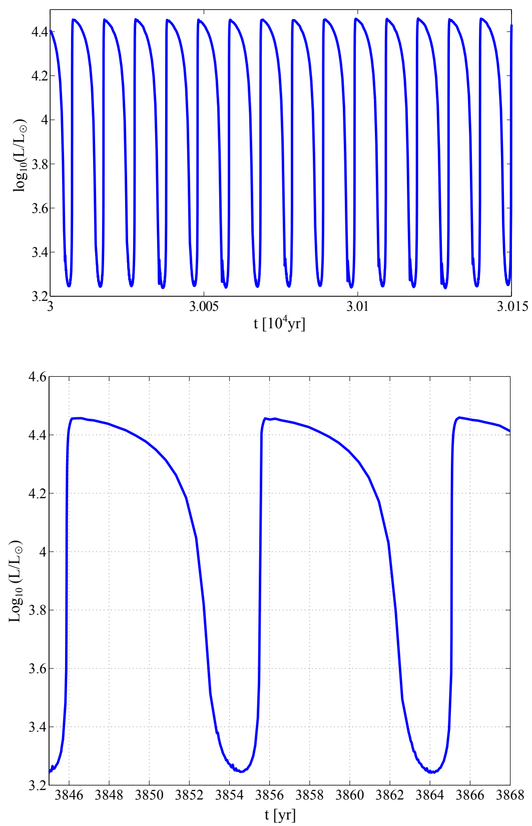


Figure 1. The first 10 outbursts for a $1.0 M_\odot$ WD with peak accretion rate of $10^{-6} M_\odot yr^{-1}$ – only the first outburst ejected mass.



A

B

Figure 2. The secular sequence of flashes for the model depicted in fig. 1, 3×10^4 years after the onset of accretion. Panel B shows one cycle in detail. Note the high similarity from cycle to cycle.

Idan, Shaviv, and Shaviv

At high rates: helium flashes

At “low” rates (10^{-7}Ms) WD grows in mass

see also Yaron et al.2005

Hernanz and Jose 2007

Iben 1982

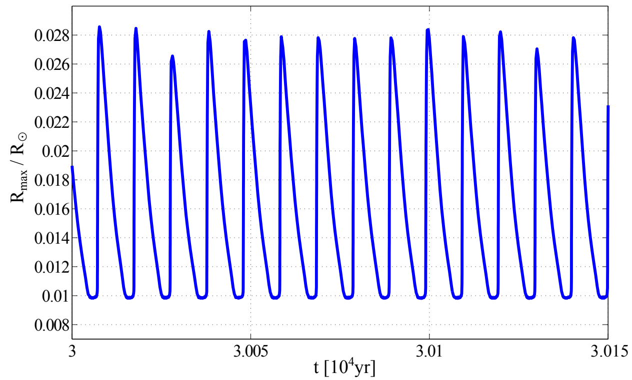


Figure 3. The maximum radius reached during outbursts, for the model depicted in fig. 1. The small variations in the maximum radius are due to the finite time step taken.

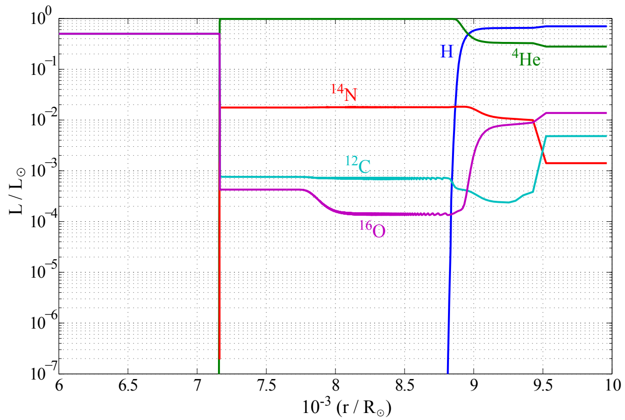


Figure 4. The abundances after 3000 cycles of small outbursts, for the model depicted in fig. 1.

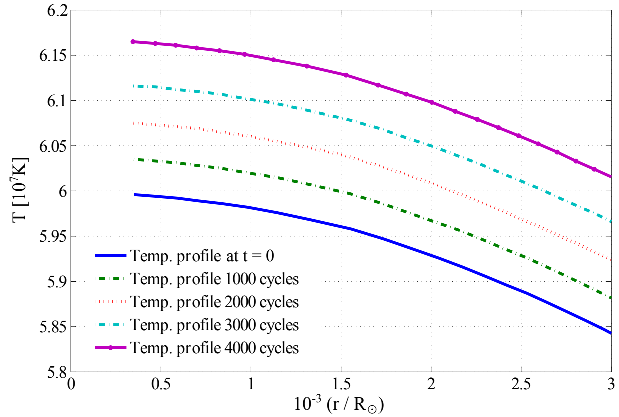


Figure 6. The temperature profile at the core, for the model depicted in fig. 1. Note that the heating is due to the adiabatic contraction of the WD associated with the additional accreted mass.

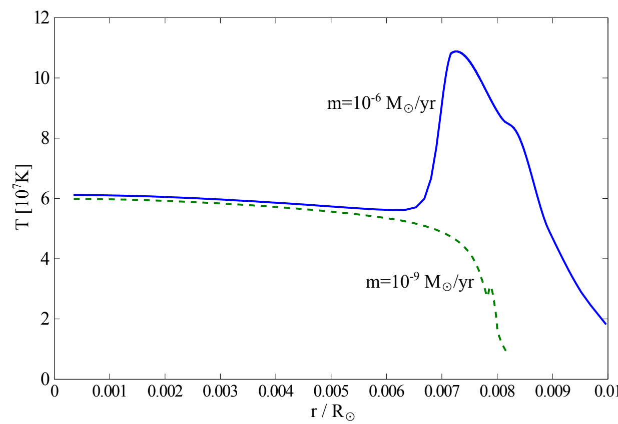


Figure 7. Comparison between the temperature profiles after 3000 outbursts of a 1 $M_{\odot}$ WD, accreting at a rate of $10^{-9} M_{\odot}/yr$ (dashed) and at a rate of $10^{-6} M_{\odot}/yr$ (solid).

The large mass of the accreted envelope, nearly $0.01 M_{\odot}$, affects the structure of the WD as well. As a consequence, the

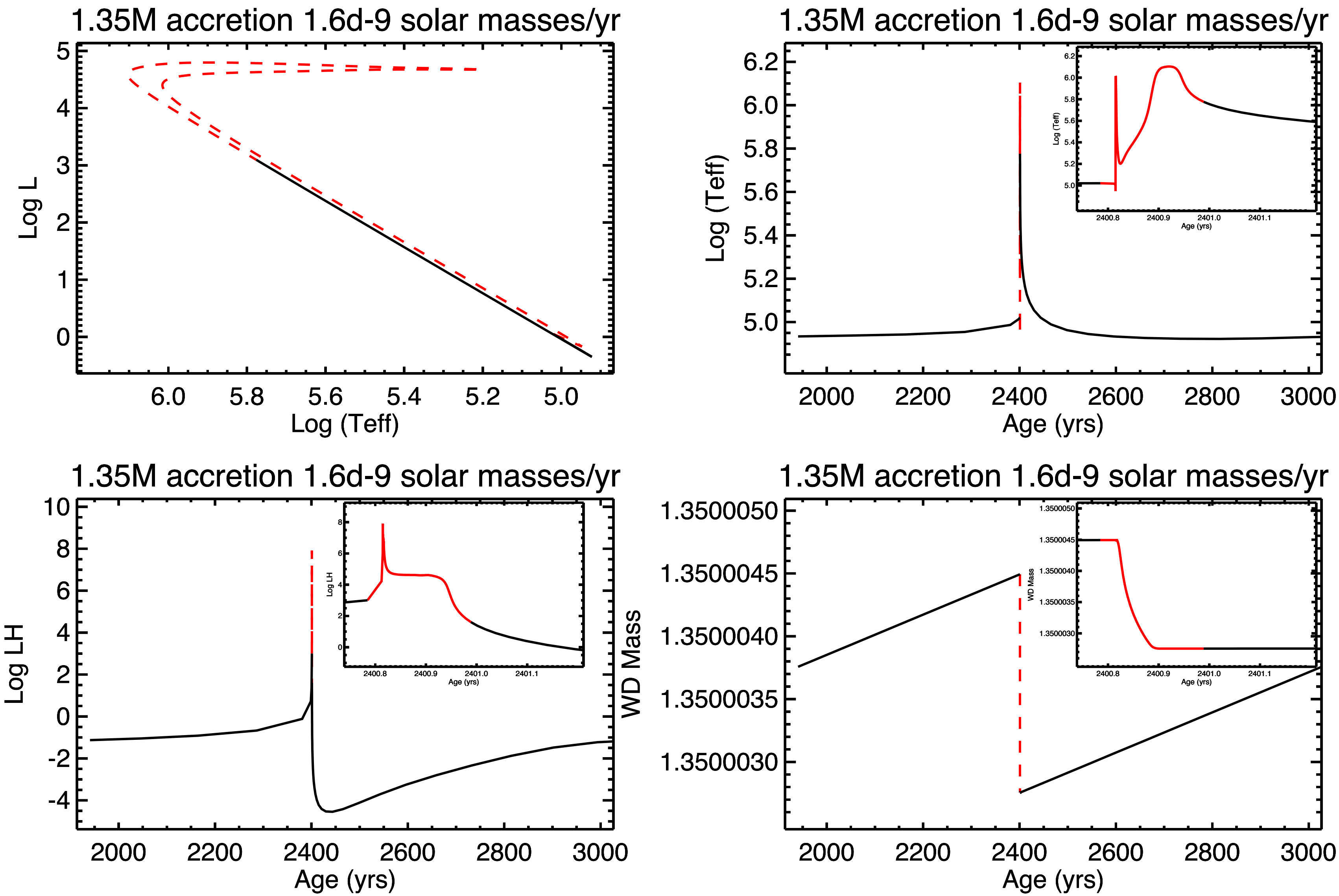
Conclusions:

The “Nomoto” Diagram is not correct.
A better discussion is in Yoon et al. 2004.
It also violates the Schwarzschild and Harm
Thin shell instability.

Therefore: The Single Degenerate Scenario Lives

BUT:
How is mixing prevented?

There are no solved problems



1.35M accretion 1.6d-9 solar masses/yr
Log L
Log (Teff)
1.35M accretion 1.6d-9 solar masses/yr
Log (Teff)
Age (yrs)
1.35M accretion 1.6d-9 solar masses/yr
Log LH
Age (yrs)
1.35M accretion 1.6d-9 solar masses/yr
WD Mass
Age (yrs)