MODELS OF HELIUM STAR DONORS IN AM CVn SYSTEMS

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HELIUM SUBDWARFS AS PROGENITORS OF AM CVn STARS

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OUTLINE

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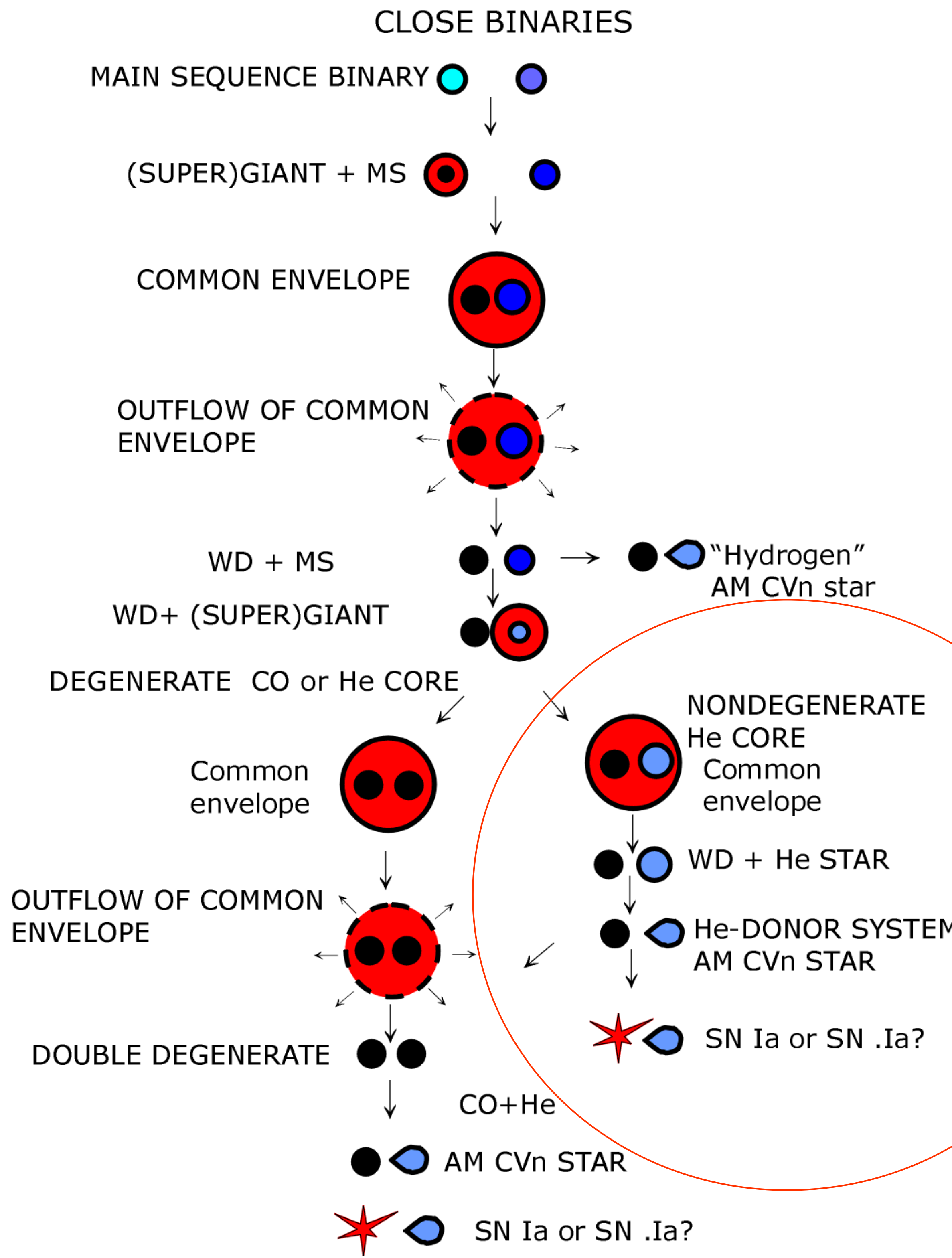
- Origin of AM Cvn's
- Possibility to discriminate between formation channels
- Some facts about He-stars
- Evolution of He-star donors in AM CVn’s
- Masses of donors in AM CVn’s
- Chemical composition of transferred matter
- Conclusion


CLOSE BINARIES
MAIN SEQUENCE BINARY
(SUPER)GIANT + MS
COMMON ENVELOPE
OUTFLOW OF COMMON ENVELOPE
WD + MS
"Hydrogen" AM CVn star
WD+ (SUPER)GIANT
DEGENERATE CO or He CORE
NONDEGENERATE He CORE
Common envelope
Common envelope
WD + He STAR
OUTFLOW OF COMMON ENVELOPE
He-DONOR SYSTEM AM CVn STAR
SN Ia or SN .Ia?
DOUBLE DEGENERATE
CO+He
AM CVn STAR
SN Ia or SN .Ia?

Formation channel	birth rate (10^{-3} yr^{-1})	total number (10^7)
double white dwarfs	1.3	2.3
helium stars	0.27	1.1
total	1.6	3.4

Present day birth rates and total number of AM CVn systems for the different formation channels (Nelemans et al. 2004)

$$\frac{a_f}{a_i} \propto \alpha\lambda \frac{M_f M_2}{M_1^2} \text{ for } M_1 \gg M_2, \;\; M_f \ll M_1$$

$$\left(\frac{\dot{J}}{J}\right)_{\rm GWR} = -\frac{32}{5}\frac{G^3}{c^5}\frac{M_{\rm He}\, M_{\rm wd}(M_{\rm He} + M_{\rm wd})}{a^4}$$

$$t_{\rm He} \approx 10^{6.95}\, M_{\rm He}^{-4.1}(1 + M_{\rm He}^{3.74})\; yr$$

$$R_{\rm He} \approx 0.2 M_{\rm He}^{0.8}$$

$$t_{\rm wd} \lesssim 13\; Gyr$$

$$R_{\rm wd} \approx 0.01 M_{\rm wd}^{-1/3}$$

$$a_f \sim R_\odot$$

Extremely fine tuning of all parameters is needed for obtaining an AM CVn system in any channel. Existing population synthesis models may be too crude in predictions of absolute numbers of systems and relative significance or even existence of certain formation channels. Possible progenitors of both WD+WD and He-star+ WD systems were not detected as yet.

Nelemans & Tout (2003): chemical composition of transferred matter may identify formation channel

CONSTRAINTS ON AM CVN FORMATION CHANNELS FROM MODELLING THE COMPOSITION OF THEIR DISCS

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Abstract. We present preliminary results of a study in which we determine the chemical composition of the transferred material in AM CVn systems as a function of the formation channel and progenitor metallicity. Using a detailed stellar evolution code we simulate the formation of the donor star in AM CVn systems and its evolution during the mass transfer. The chemical composition of the outer layers of the donor, and thus of the accretion disc, can used as input for accretion disc models, and subsequently compared to

What to expect?

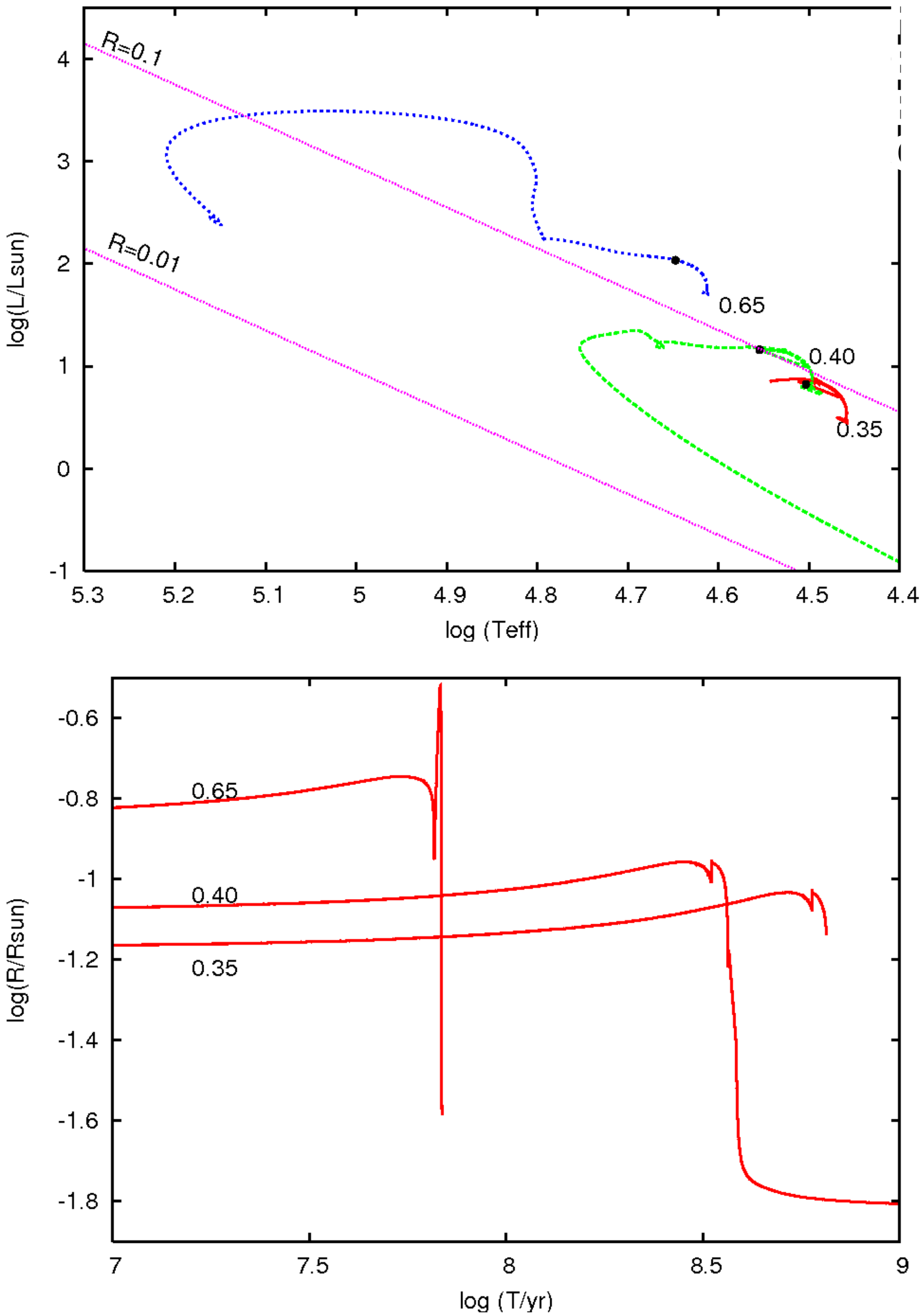
WD-channel: He, CNO-cycle products.
Abundances do not change after RLOF

He-star channel: (reduced) He,
(enhanced) C,O,
(deficit or even absence of N).
Abundances depend on evolutionary state at RLOF and vary later.

CV- channel: H, He, CNO-cycle products.
Abundances do not change.

The aim of the study – systematic investigation of the evolution of He-donors depending on their mass, total mass of the system and evolutionary state at RLOF

Dots – end of "main-sequence"



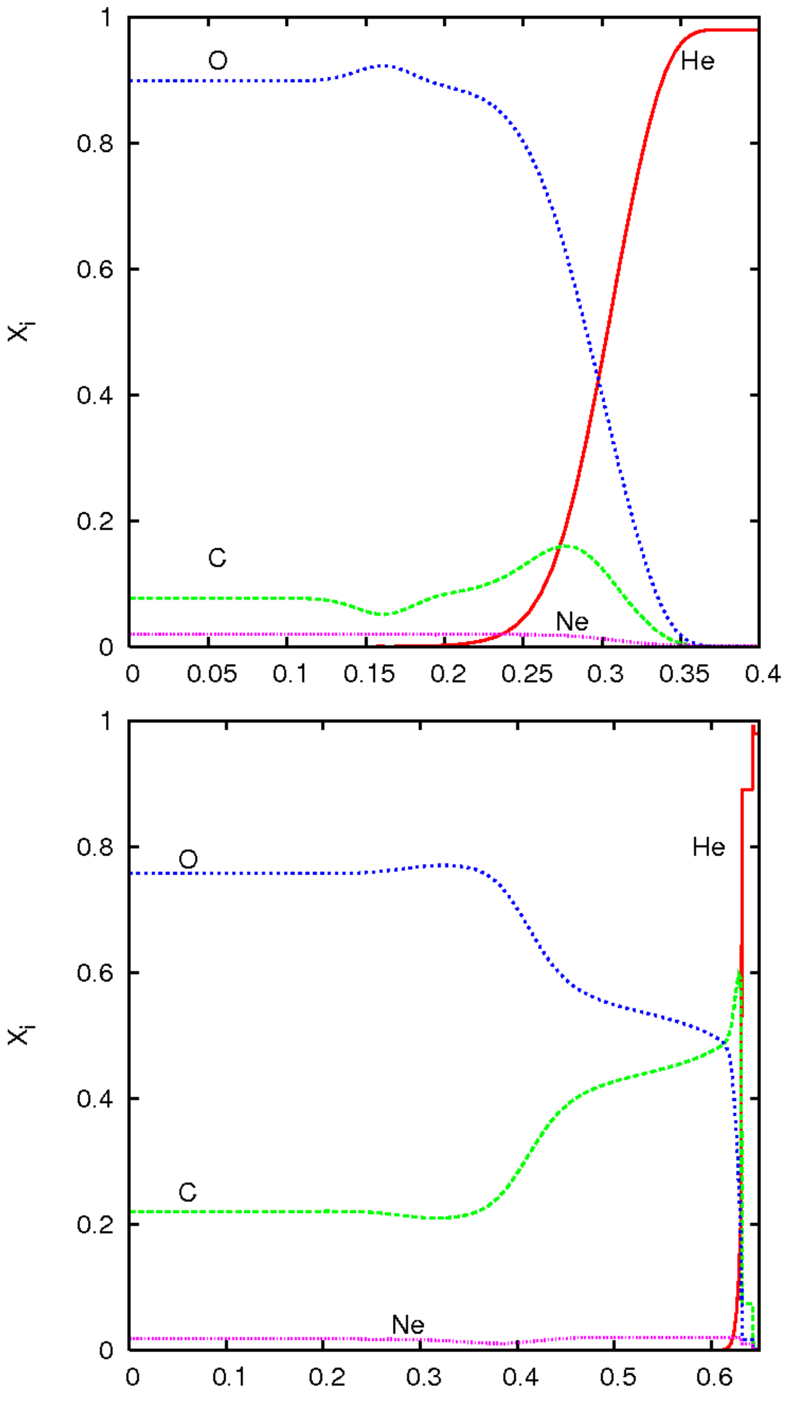
He stars almost do not

expand in the core

He-burning stage.

Possibility of RLOF

is defined by AML



Low-mass He stars turn into “hybrid” WD with a non-negligible surface He-layer.

In binaries, if He-stars finish He-burning prior to RLOF but make contact later, they may contribute to the WD-channel and produce CO-rich AM Cvn's

Previous studies of He-donors:

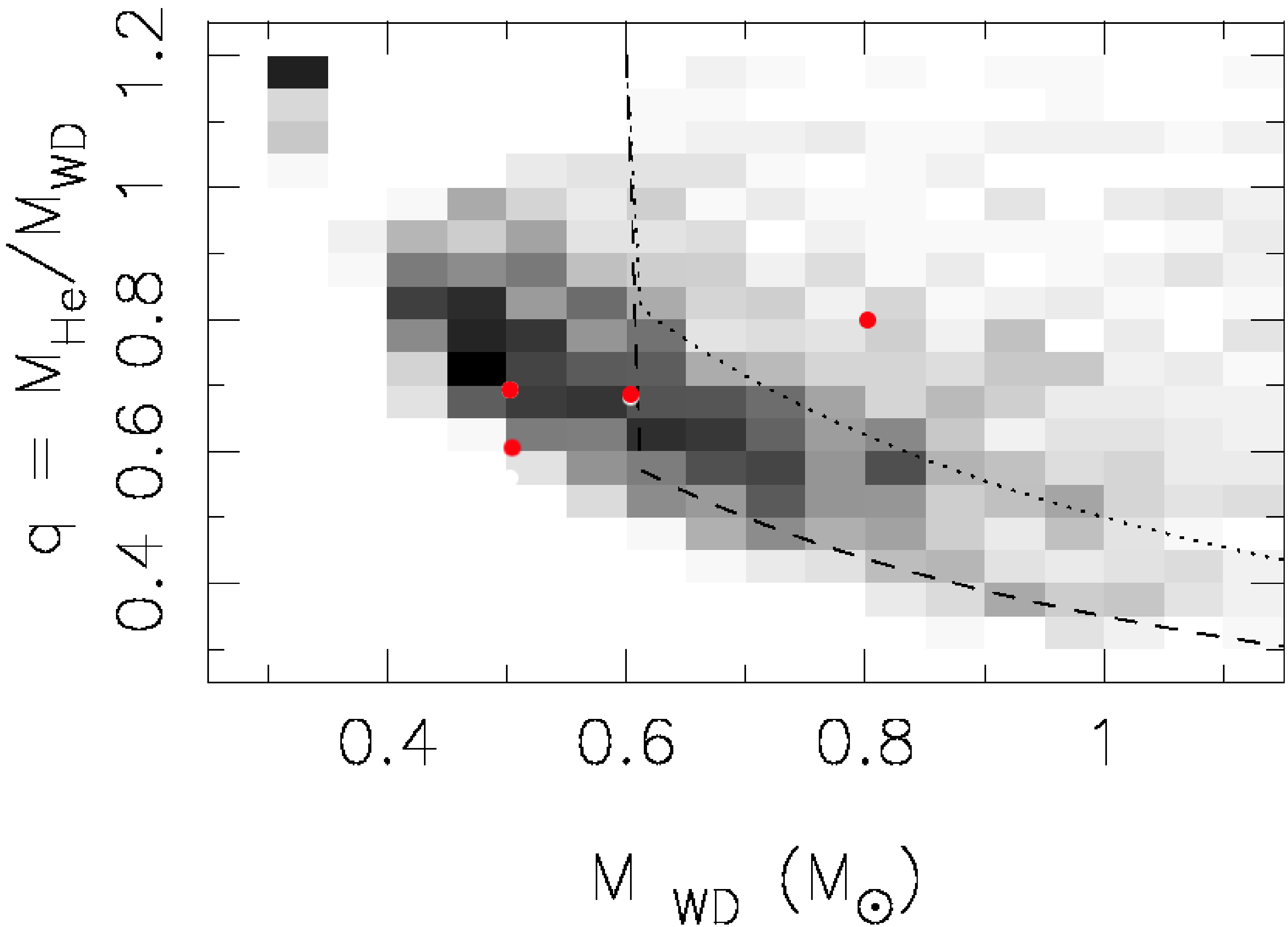
Savonije, de Kool, van den Heuvel (1986) – 0.6+1.3, P_0=37min, Y_c=0.26, aim – X-ray systems

Tutukov, Fedorova (1989); Ergma, Fedorova (1990) – a set of tracks for He star+NS, He star+WD, aim - X-ray systems, AM CVn's

Yoon, Langer (2004) - 0.6+0.8, P_0=39min, Y_c=0.39, evolution including mass/momentum loss by novae explosions

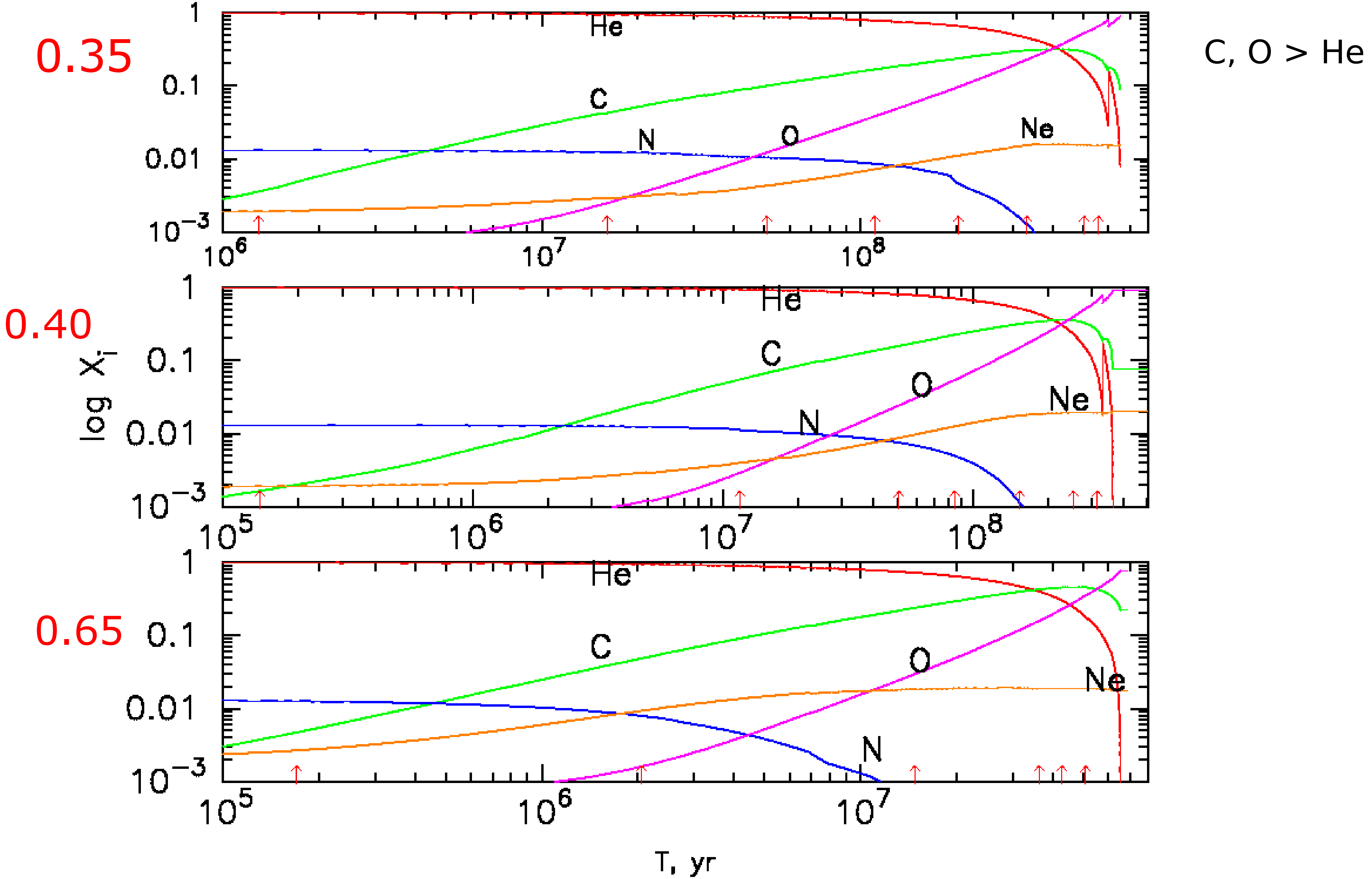
None had addressed chemical composition of transferred matter

Progenitors of He-star systems, Nelemans et al. 2001



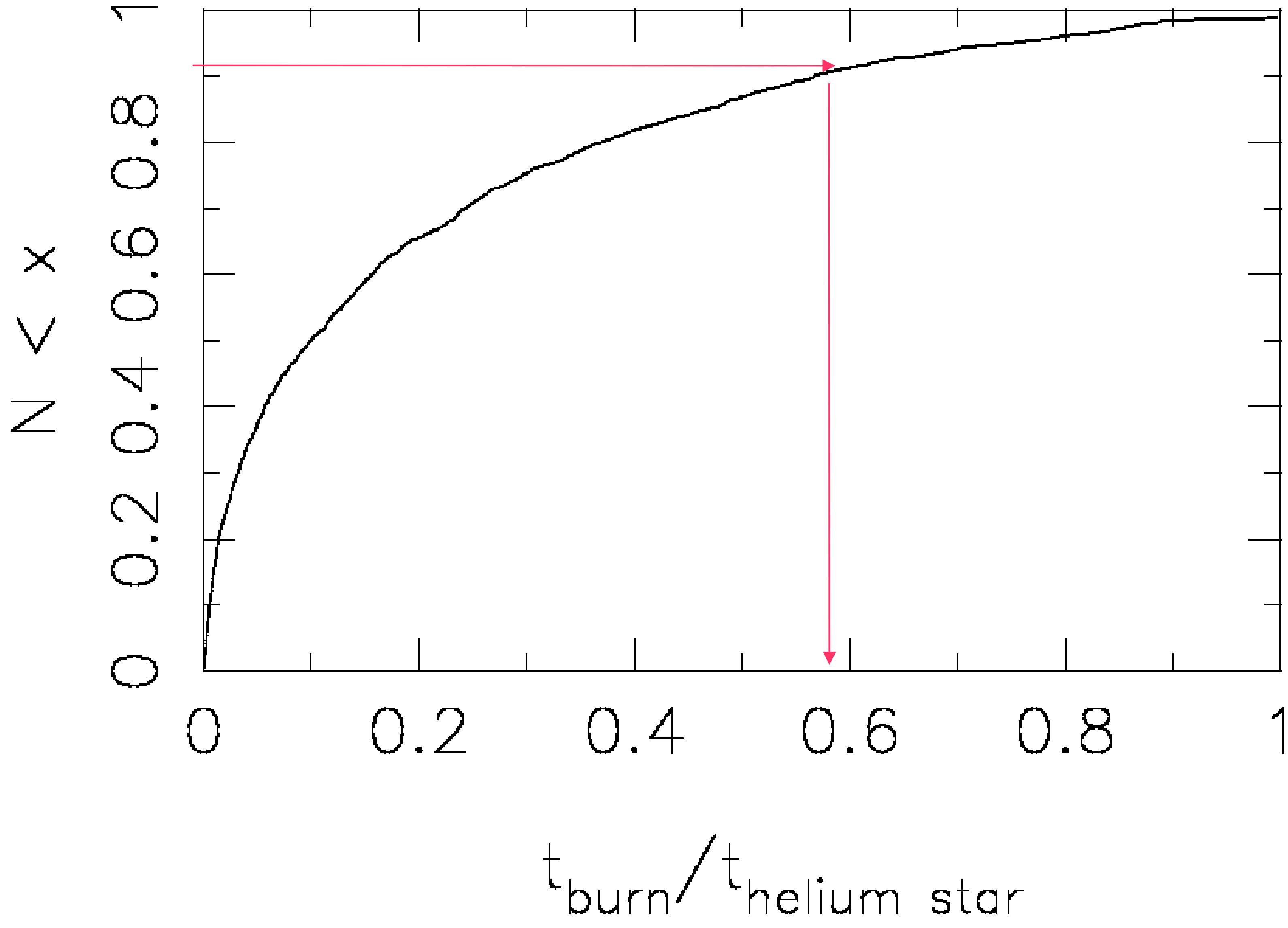
Selected pairs: 0.35+0.5, 0.4+0.6, 0.4+0.8, 0.65 +0.8

Evolution of abundances in the centers of He-star models



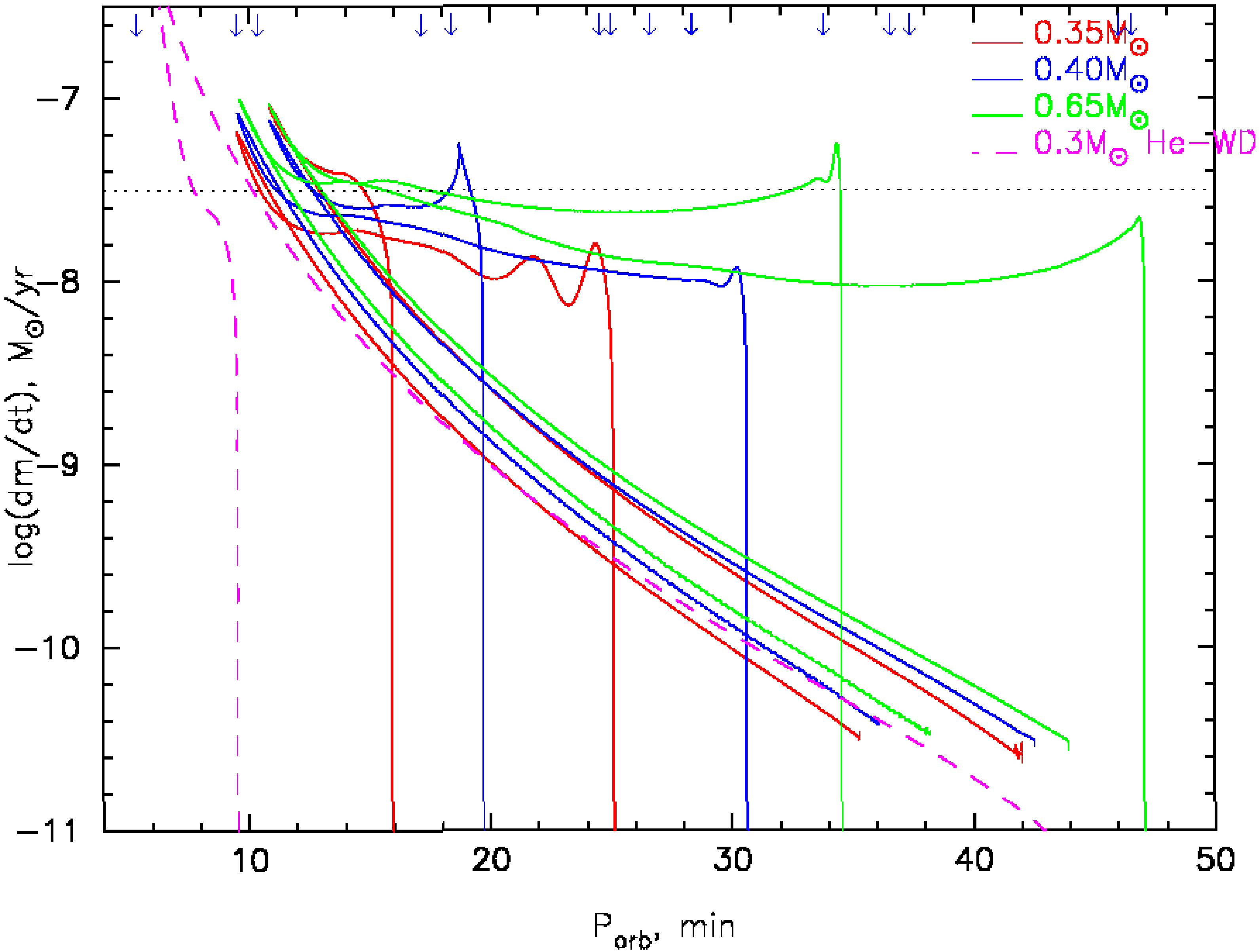
Grid of tracks with constant step (20 min) in post-CE periods up to P_0 which still allows RLOF in He-burning stage

N(x) from Nelemans et al. 2001: fraction of total He-burning time spent before contact

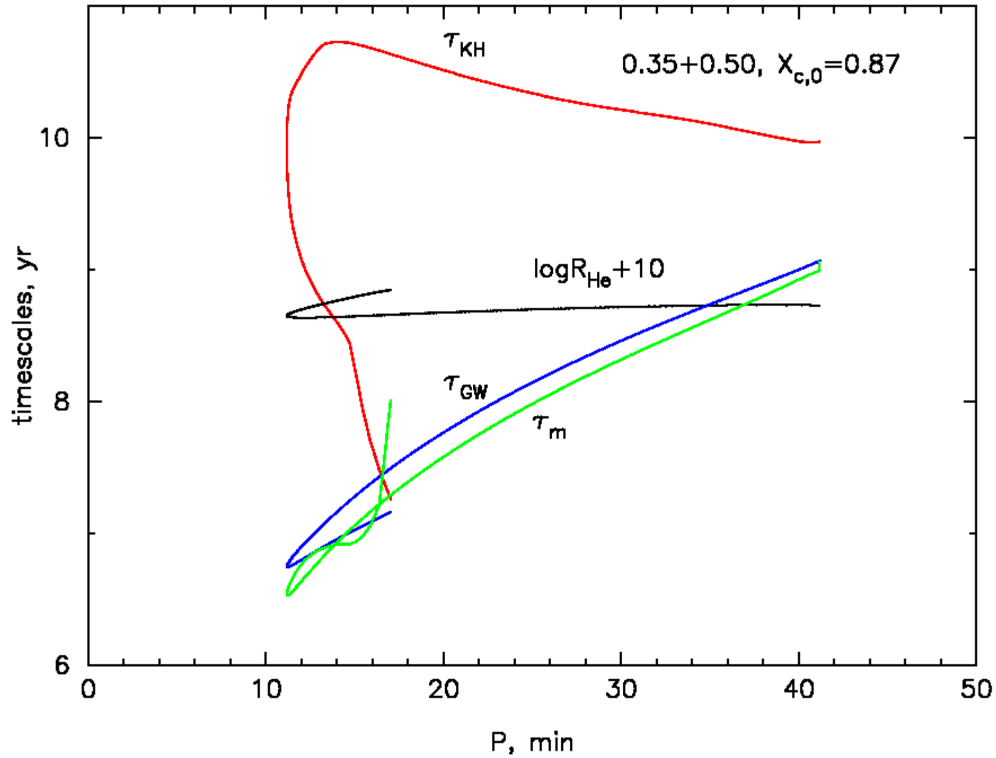


≈90% of systems evolve to contact in ≈60% of He-burning time, hence, Post-CE P_0 < (100 – 120) min, Y_c >(0.4 – 0.5), but dominance of C or O in the transferred matter is also possible (RLOF in the last 20-30% of the lifetime)

Arrows – periods of known AM CVn's



1. Small spread of Pmin and dm/dt
2. Tracks for initially most evolved He-stars overlap with the tracks for the initially least evolved WD (from Deloye et al.)
3. What happens between P(RLOF) and Pmin?

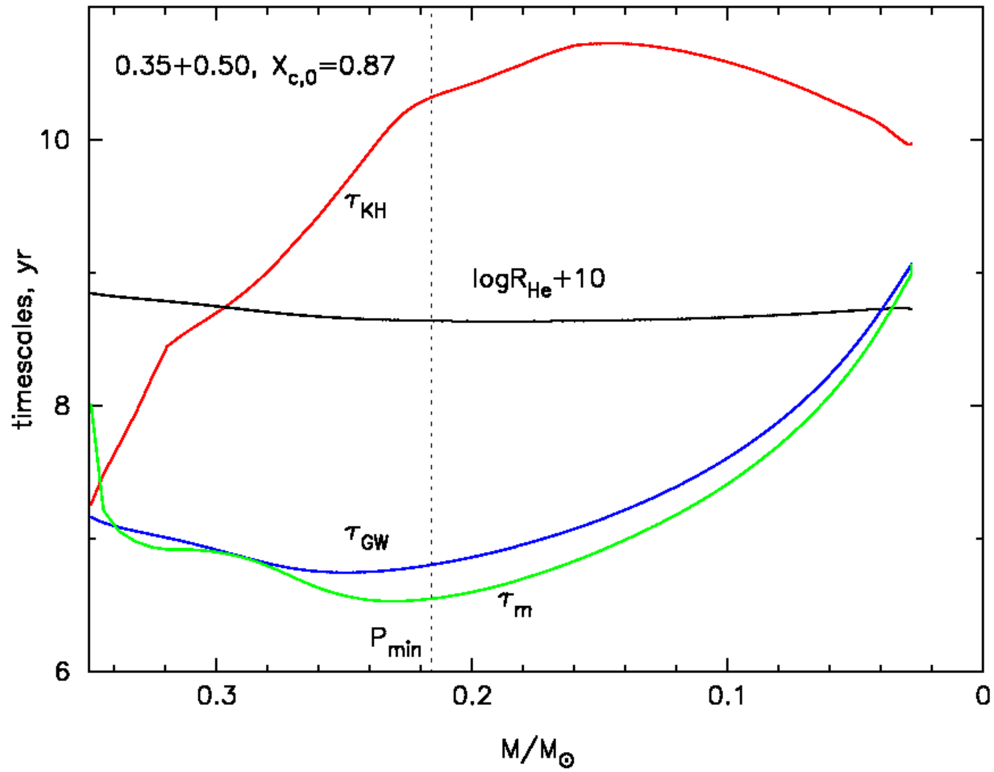


Behaviour in post RLOF stage:

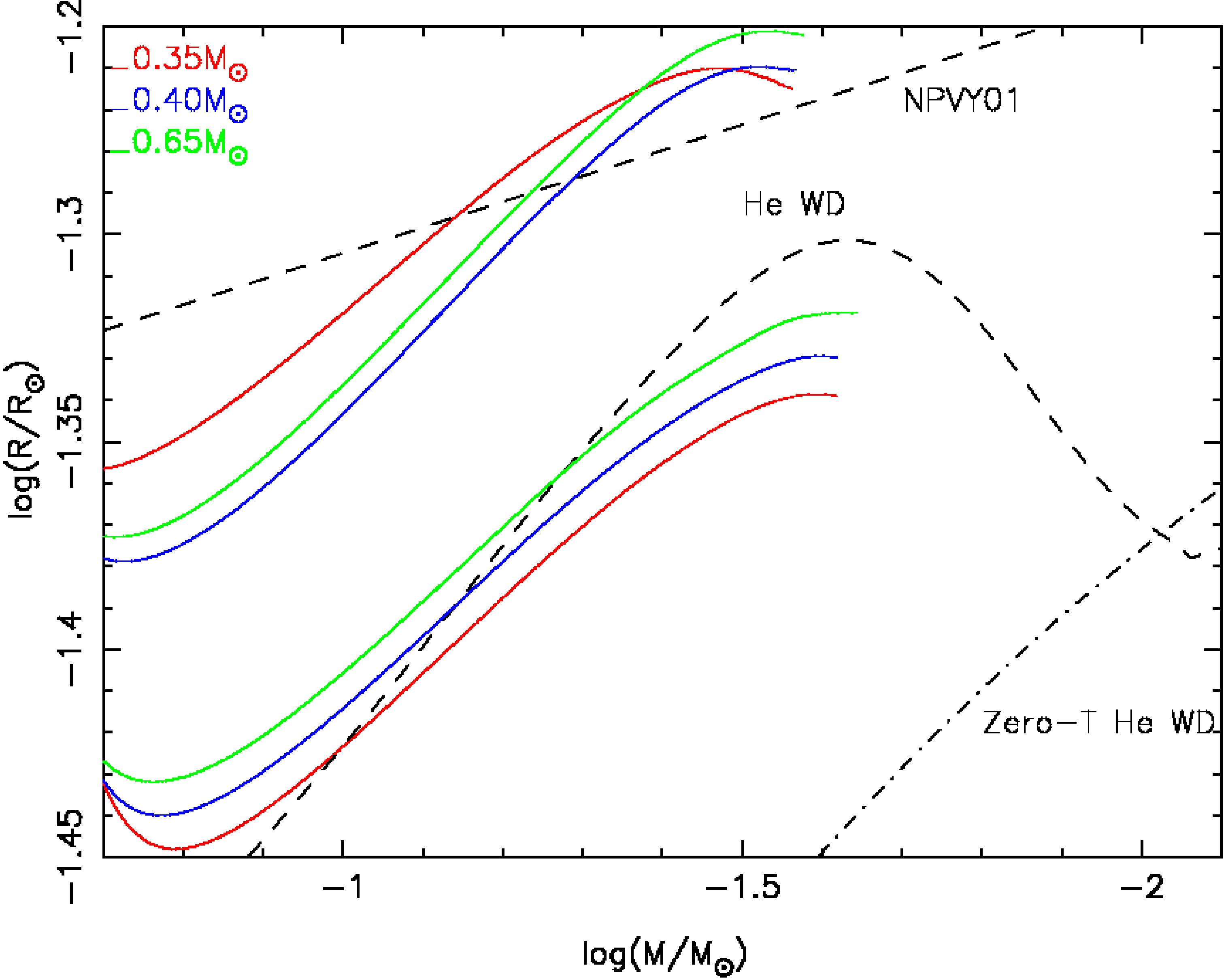
Mass loss rate is defined by AML via GWR

Stars are not in thermal equilibrium until M~0.01-0.03

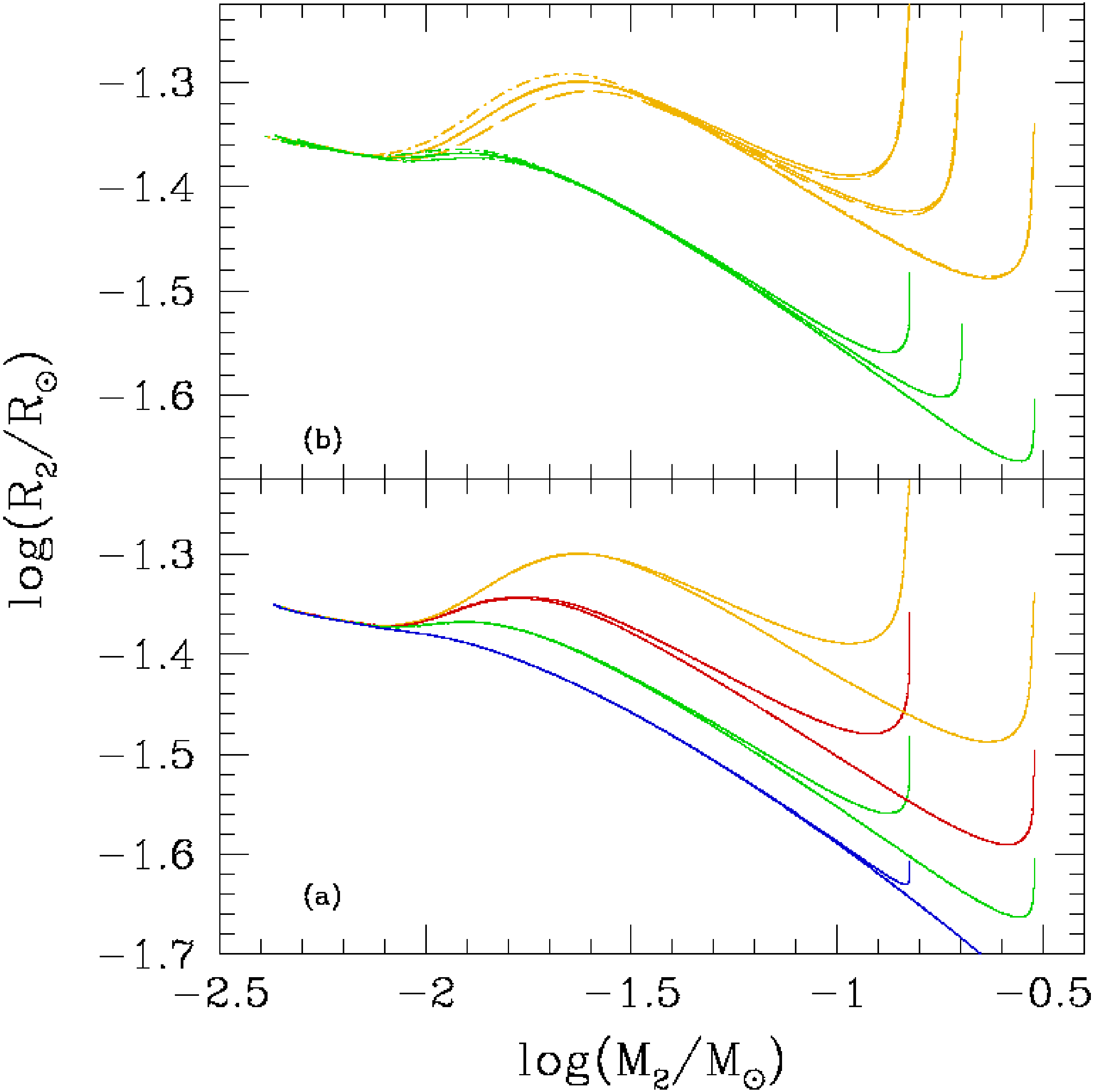
Stellar radii almost do not change



The stars become homogeneous and weakly degenerate

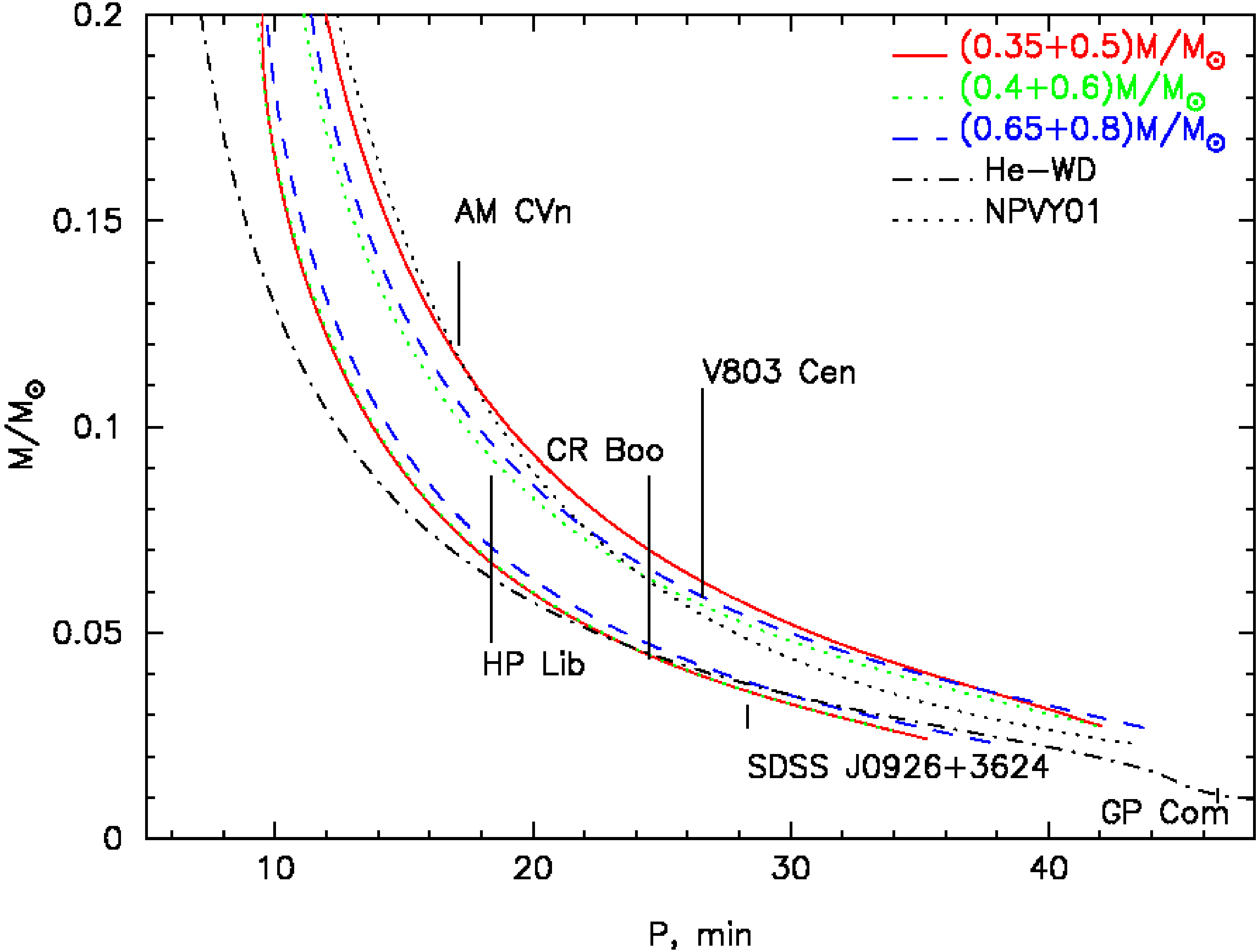


At M=0.01-0.03 thermal timescale of degenerate configuration gradually becomes < timescale of mass loss. Adiabatic stage comes to the end, the star cools and approaches M-R relation for completely degenerate configurations (Deloye et al. '07). Two 'familes' of AM CVn's merge? Transition between M-R relations has to be considered in population synthesis.



Deloye et al.'07: arbitrarily degenerate He-WD of different initial entropy in systems with different Mtotal

Remnants of He-donors are similar weakly degenerate homogeneous objects Differ only in chemical composition: C+O+He instead of pure He. They will evolve similarly and form a single family with a small offset from He-WD family due to difference in composition.



Observations:
Roelofs et al.,
2006, 2007

Marsh et al.
2007

AM Cvn, V803 Cen, CR Boo – He-star family?
SDSS.... - WD family?
HPLib, GP Com - ?

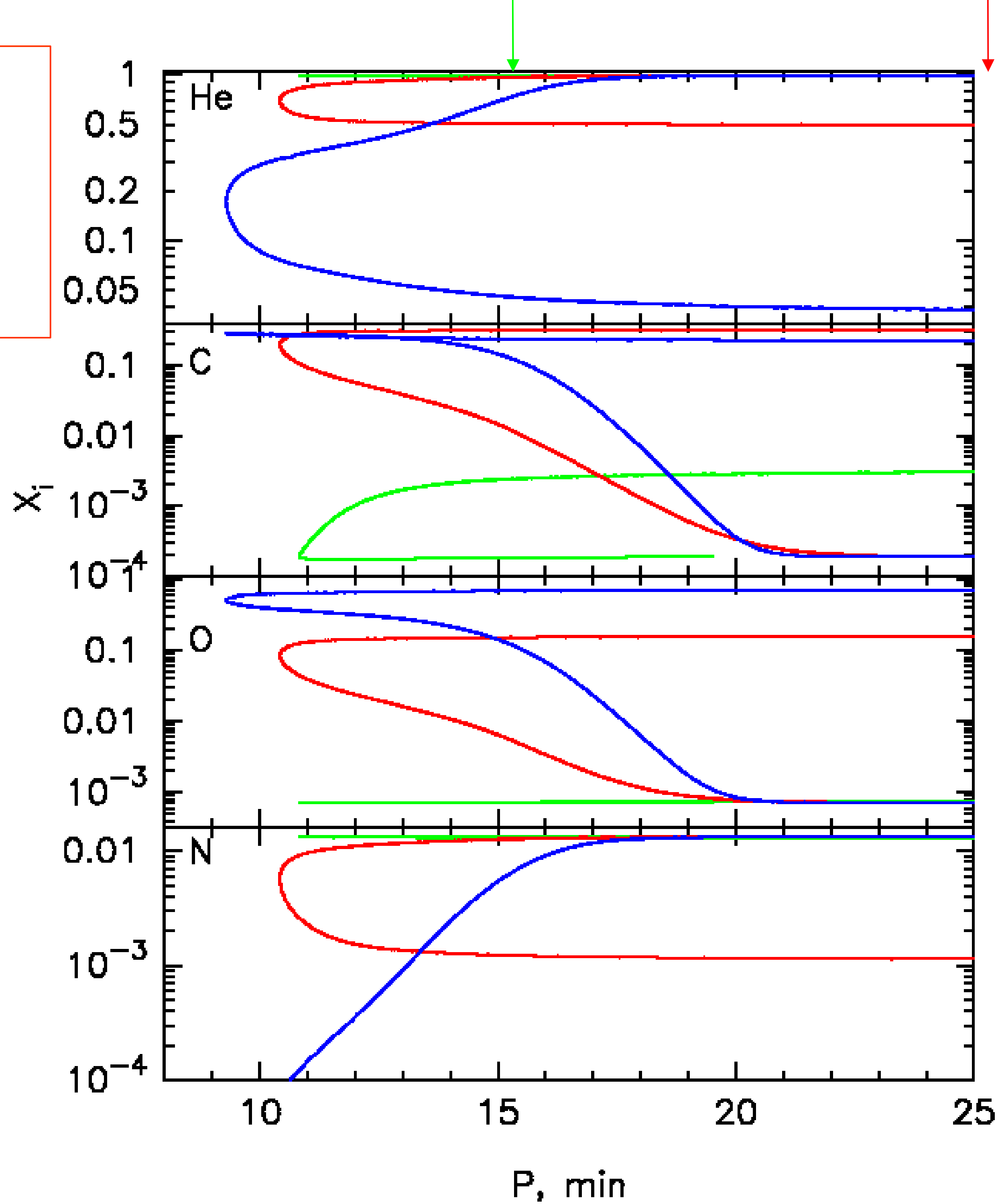
0.4+0.6 M_sun

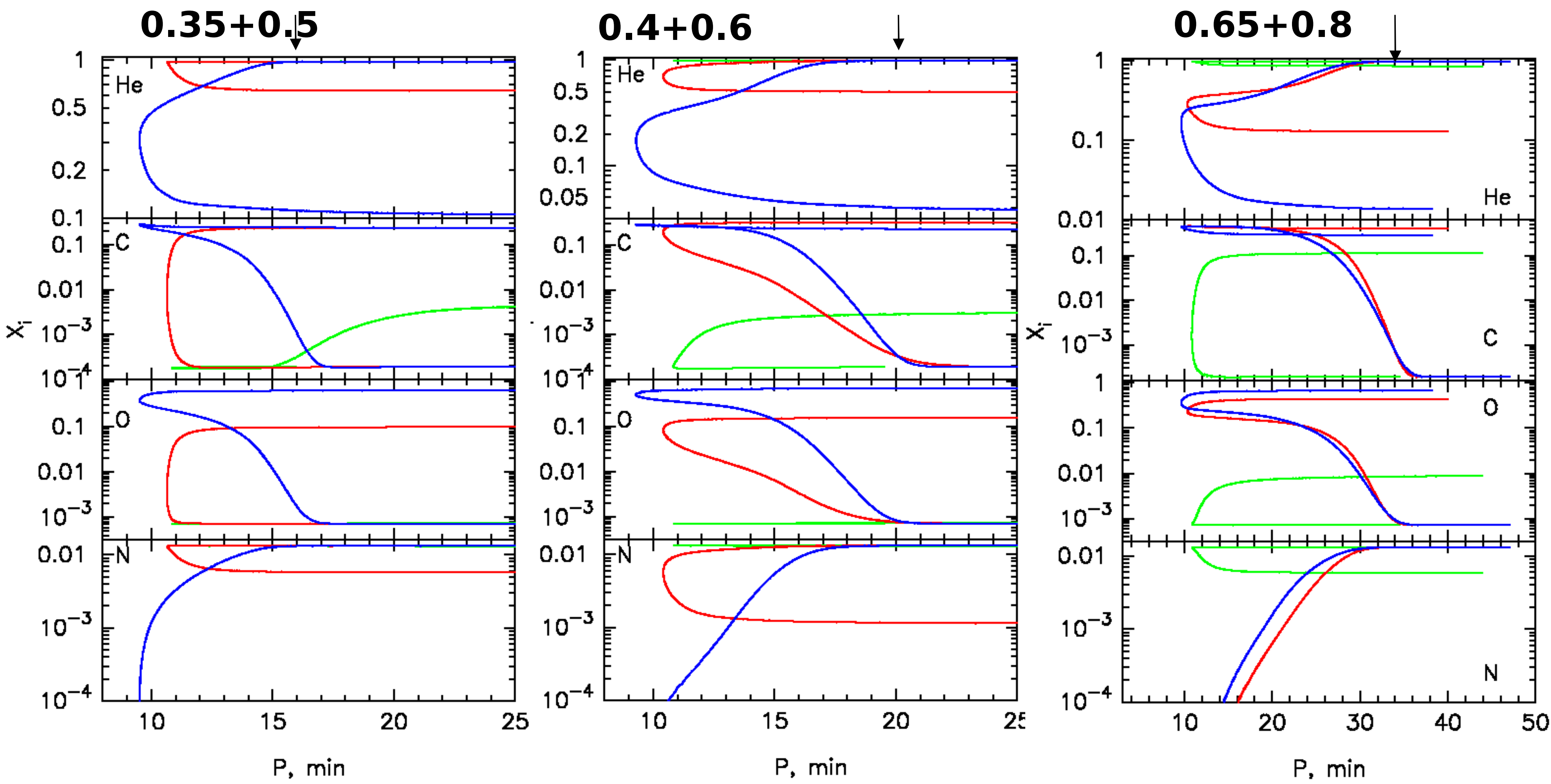
Green Y_c≈0.98
Red Y_c≈0.50
Blue Y_c≈0.07

Convective core of the model that overflowed critical lobe becomes uncovered close to P_min

Abundances in the transferred matter do not change at P > 15 min, but stars are hardly observable before because of fast evolution.

In "typical" systems abundances – in the range outlined in red





Green – unevolved donor, red – P=100 min, blue – extremely evolved donor.

Abunances in transferred matter change with P slightly differently, but it is important that they do not change at P≥15 min.

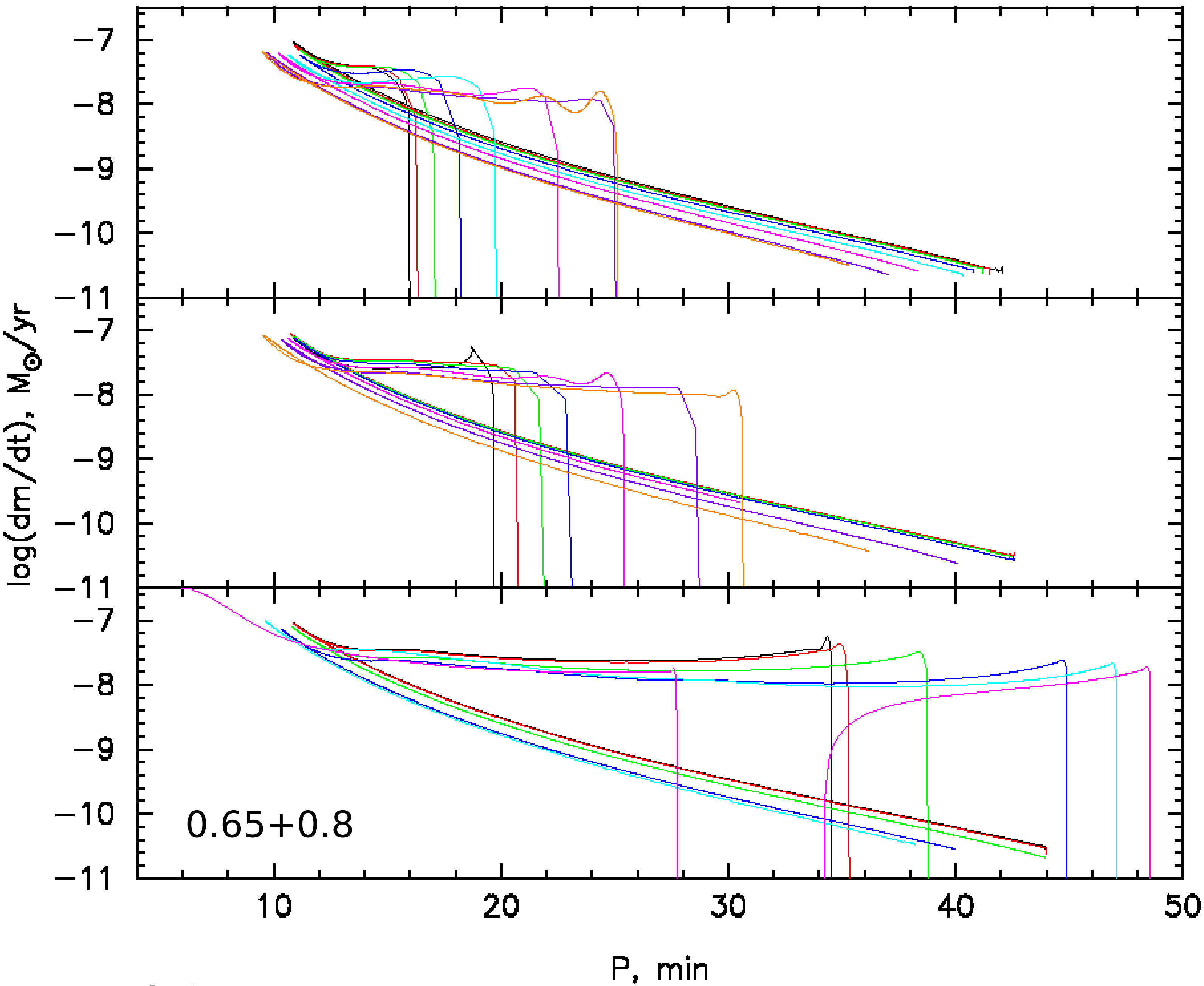
Abundances in transferred matter at $P_{orb} \gtrsim 15$ min

	He star ("typical systems")	He WD	GP Com (Strohmayer'04)
He	> 0.4	0.98	0.977 ± 0.002
C	$2 \cdot 10^{-4}$ - 0.3	$(1-6) \cdot 10^{-4}$	$< 2 \cdot 10-3$
N	$\lesssim 5 \cdot 10^{-3}$	$(1-3) \cdot 10^{-2}$	$(1.7 \pm 0.1) \cdot 10^{-2}$
O	$7 \cdot 10^{-4}$ - 0.25	$(1-2) \cdot 10^{-3}$	$(2.2 \pm 0.3) \cdot 10^{-3}$
Ne	$2 \cdot 10^{-3}$ - $2 \cdot 10^{-2}$	$\approx 2 \cdot 10^{-3}$	$(3.7 \pm 0.2) \cdot 10^{-3}$

Signatures of "He-star channel": reduced He, N, enhanced C, O, Ne

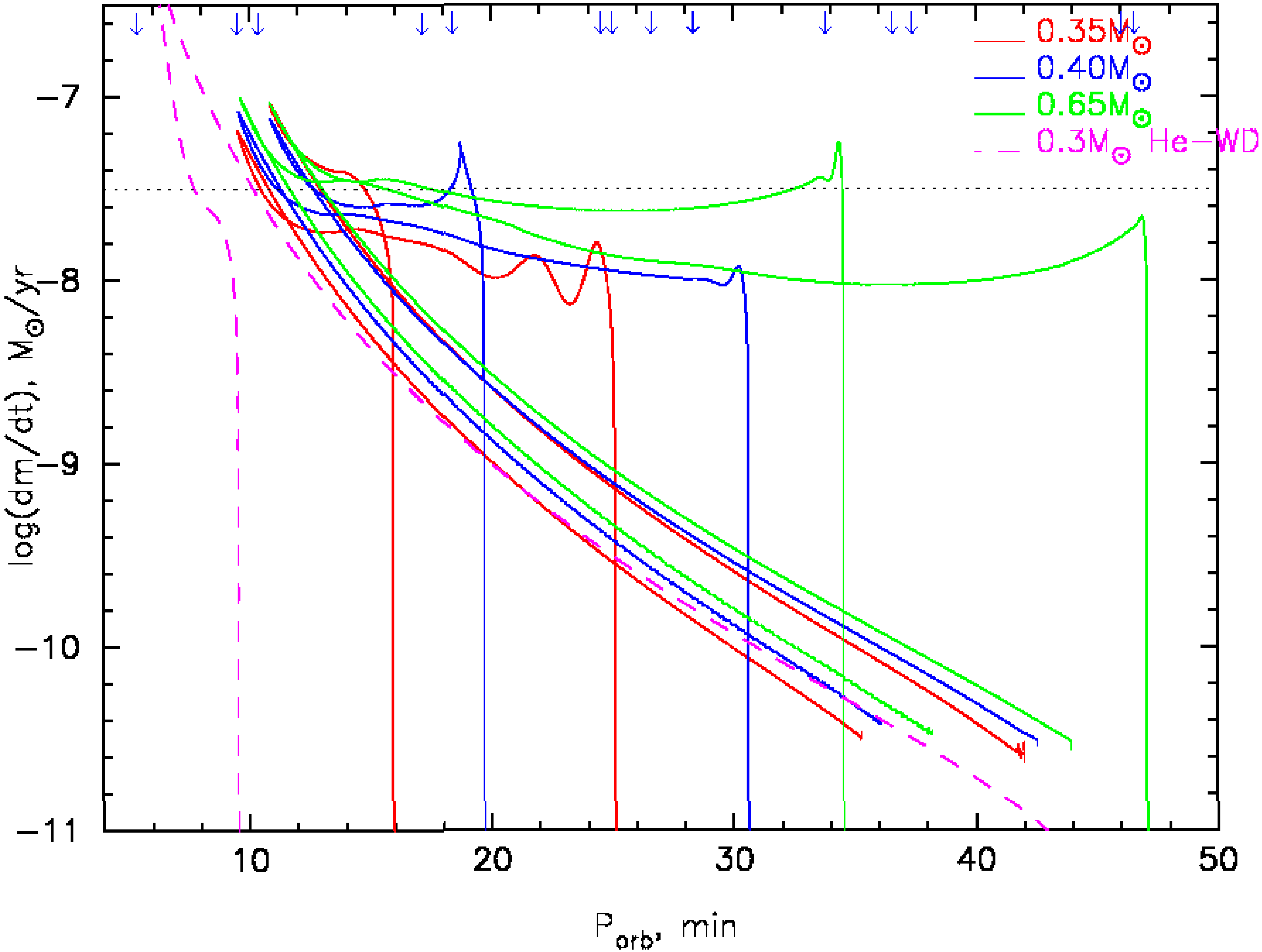
Depletion of even ~ 0.01 of He in He-star would result in
1 abundances of C, O incompatible with descent of donor
from He-dwarf

C-rich donors in AM Cvn's may be produced by initially strongly evolved He-stars

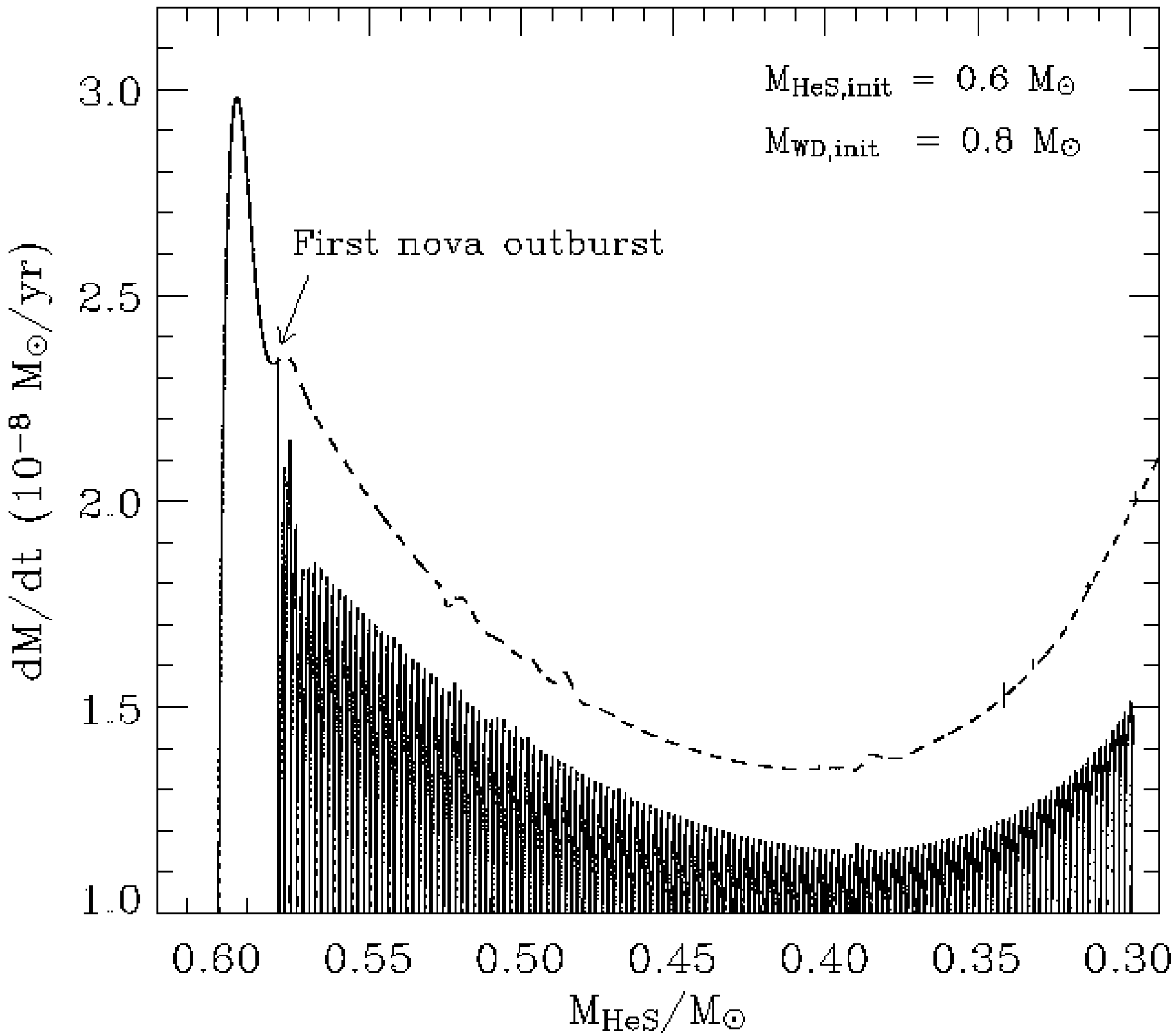


The last model: M≈0.3, X_O≈0.27, X_C≈0.71, X_Ne=0.02

Arrows – periods of known AM CVn's



How evolution of He-star systems is influenced by unstable He-burning   between P(RLOF) and P_min?



Yoon & Langer, 2004
He-novae instead of ELD
due to dissipative heating
at the base of accreted layer.

Mass and momentum are
lost.

Stellar evolution most
probably does not
produce 'naked' helium stars.
Stellar remnants have
H-rich envelopes.
He-novae may be preceded
by H-novae. Then we will
have a sequence of
explosive events:
H-novae, He-novae, SN.Ia
in the course of evolution
of the same binary!?

CONCLUSIONS

- Formation of both WD+WD and He-star+WD systems needs from the Nature very fine “tuning” of evolutionary parameters. May be our models are too crude?
- Mass loss rates and minimum P weakly depend on masses of donors, total mass of binaries and their initial evolutionary state.
- He donors turn into homogeneous He-C-O weakly degenerate objects.
- Transferred matter may be He- or C- or O-dominated.
- At M≈0.03-0.01 M-R relation changes its sign and starts to approach M-R relation for completely degenerate objects. Two families of AM CVn’s (if they really exist) merge?
- Even weak burning of He may change C, O abundances to an extent which will manifest existence of the “He-donors” family of AM CVn’s
- Possible mass and momentum loss between RLOF and P_min must be studied.
- Do we recognize all selection effects preventing discovery of AM CVn's?

THANK YOU FOR ATTENTION

AND PATIENCE!