HYDROGEN-RICH AM CVn STARS AND THEIR COUSINS

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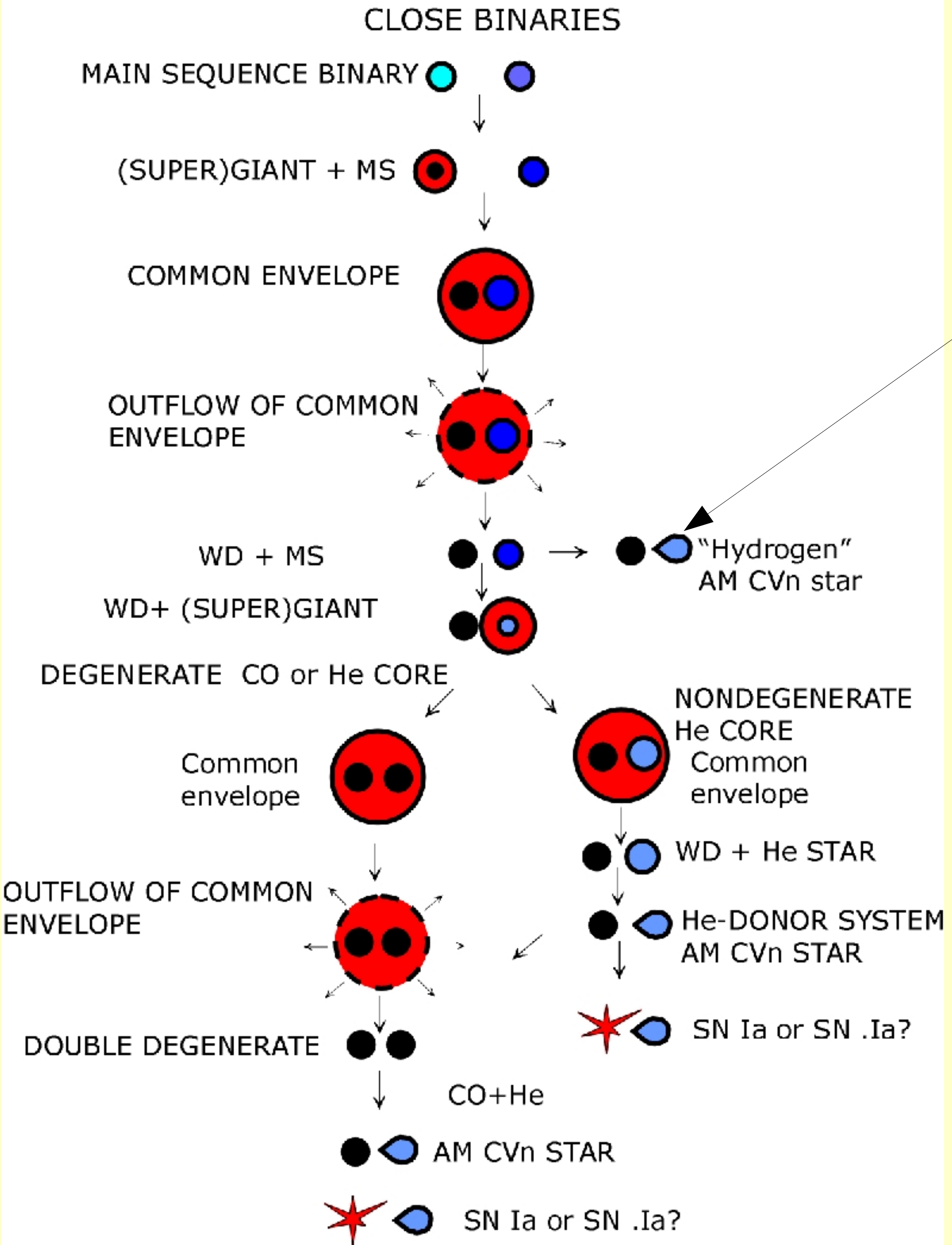
OUTLINE

1. Evolutionary computations for “evolved donors” channel of formation of ultracompact CV

2. Abundances of H in the donors of ultracompact CV

3. Stars with “hydrogen-deficient” donors above conventional P_{min} for cataclysmic variables - “cousins”

4. The number of ultracompact semidetached binaries with the deficit of hydrogen in the envelopes



Evolved donor channel – donors almost exhausted X in the centers at the instant of RLOF

Candidate(s):

<u>Almost certain candidate</u>

HM Cnc (P_{orb} = 5.4 min)

0.1 ≤ He/H ≤ 0.3 (Steiper et al. 2004), "hints" (Roelofs et al. 2010)

<u>Very doubtful candidate</u>

CP Eri (P_{orb} = 28.73 min)

He/H ≈ 1000 from "best-fit" disk model (Sion et al. 2006)

A bit of history

1984, Acta Astronomica, almost overlooked paper (8 references in 28 yr)

The Minimum Period of Hydrogen-deficient Cataclysmic Binaries

by

R. Sienkiewicz

Homogeneous isentropic models

Table 1

Minimum orbital periods (in minutes) of cataclysmic binary models

X	M_T		
	0.6	1.4	3.0
0.7	71	77.5	84
0.5	69	75	82
0.3	63	69	75
0.1	54	59	64
0.01	~40	~43	~47

Mentioned GP Com as an example of such systems

1985

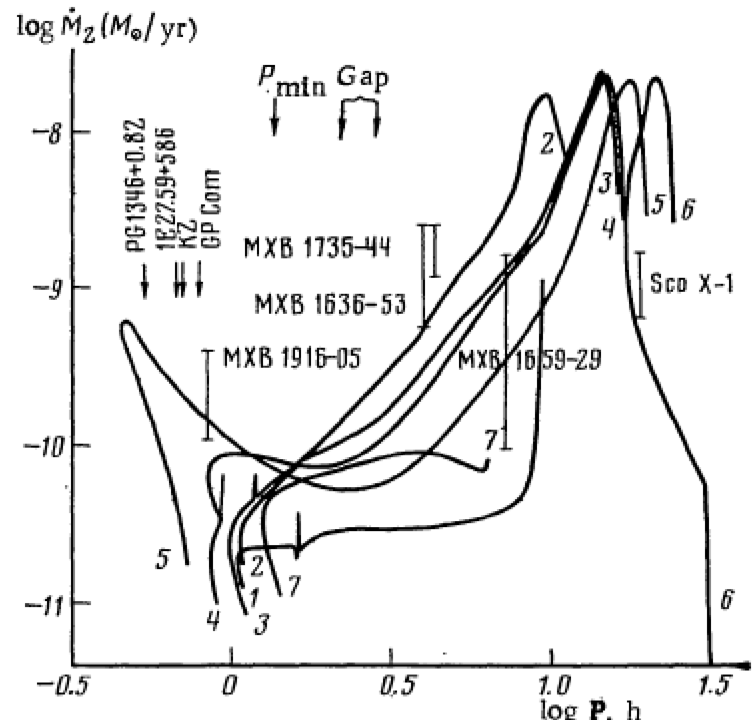
Evolution of low-mass close binaries: the minimum orbital period

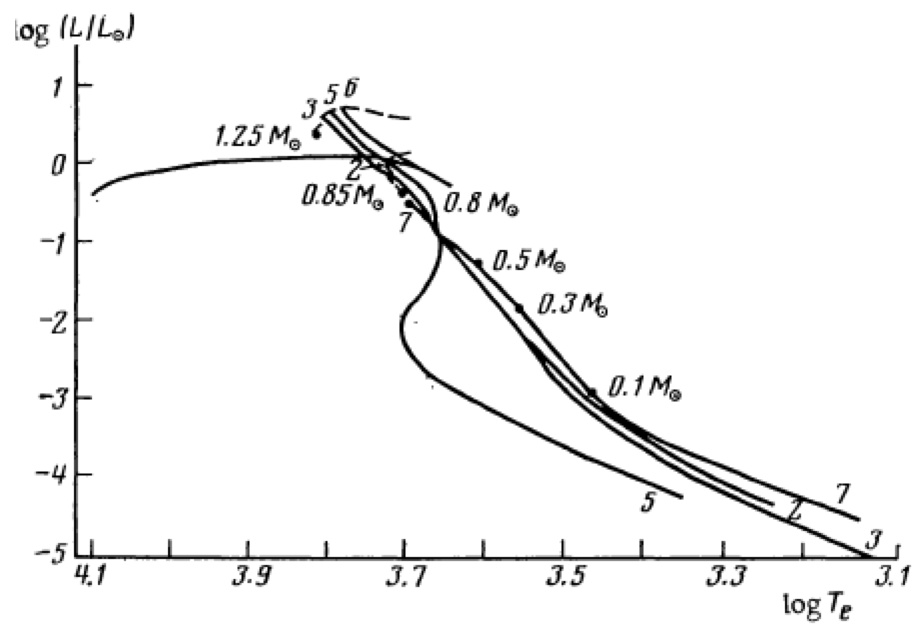
A. V. Tutukov, A. V. Fëdorova, E. V. Ergma, and L. R. Yungel'son

Astronomical Council, USSR Academy of Sciences, Moscow

(Submitted September 27, 1984)

Pis'ma Astron. Zh. 11, 123–132 (February 1985)





Full-fledged computations with Henyey-type code.

If at RLOF X_c ~ several % or M_{He}~0.01M⊙, P_{min} may be < 10 min because mixing occurs in stars << 0.3M⊙. Steep X-gradient delays mixing.

AM Cvn stars in the plot: PG1346-082=CR Boo, GP Com

1987

The evolutionary status of MXB 1820-30 and other short-period low-mass x-ray sources

A. V. Tutukov, A. V. Fedorova, E. V. Ergma, and L. R. Yungel'son

Astronomical Council, Academy of Sciences of the USSR, Moscow

(Submitted March 20, 1987)

Pis'ma Astron. Zh. 13, 780–788 (September 1987)

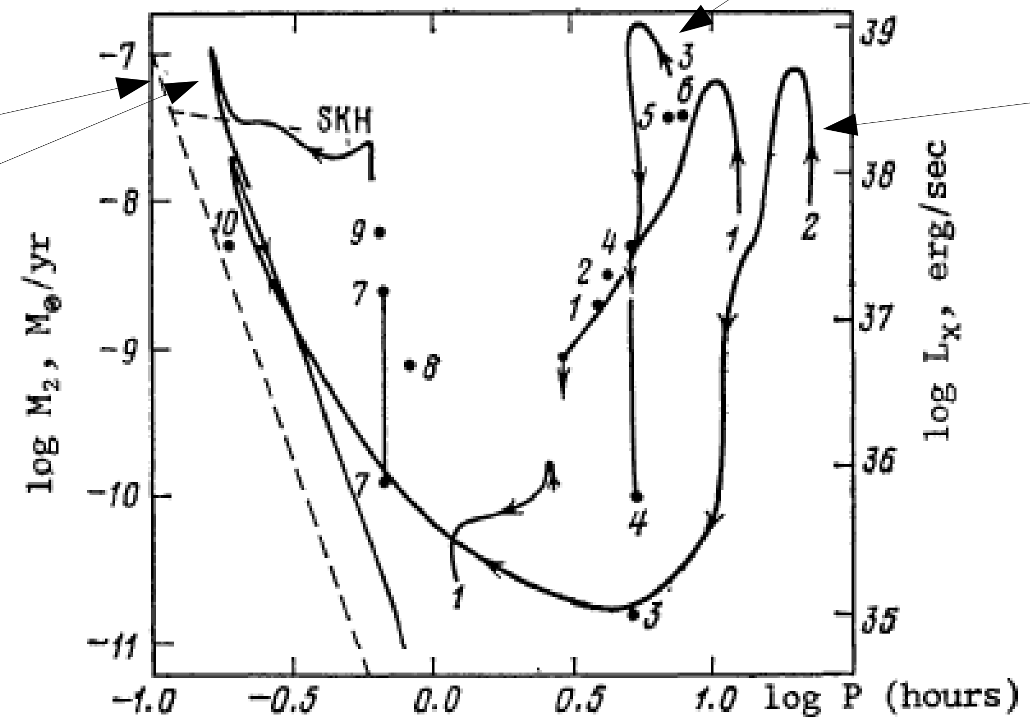
Enhanced MB

All 3 hypothetical scenarii were already known

DD

He-star

Evolved donor

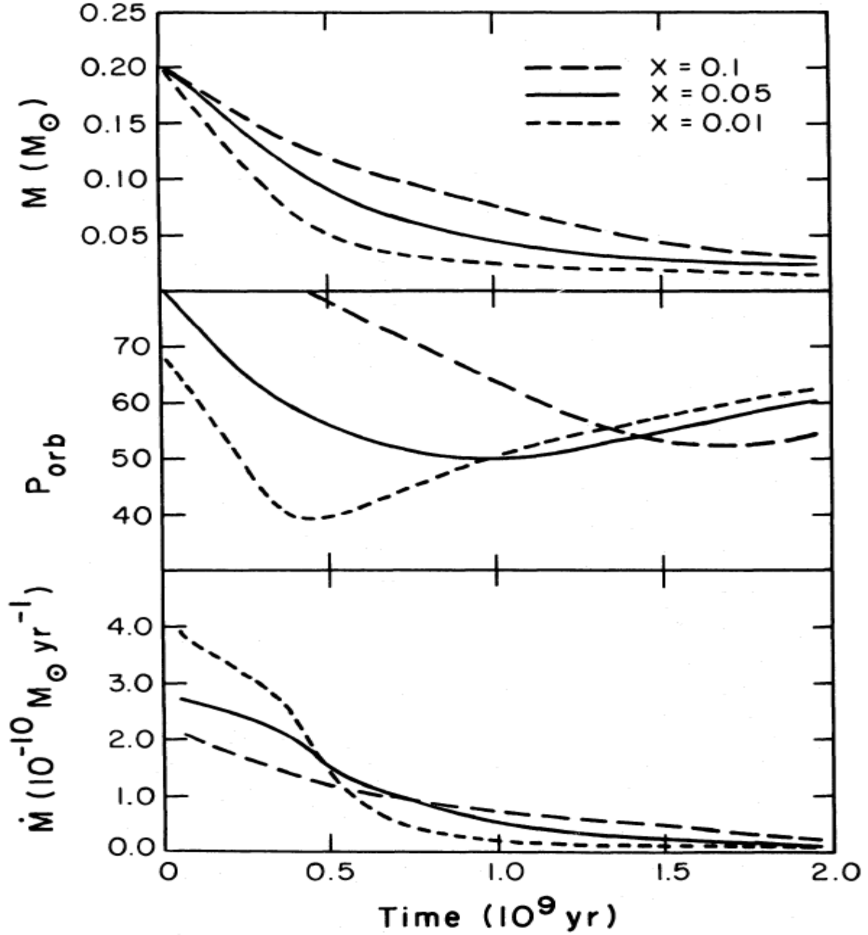


THE ASTROPHYSICAL JOURNAL, 304:231–240, 1986 May 1

THE EVOLUTION OF ULTRASHORT PERIOD BINARY SYSTEMS[1]

L. A. NELSON, S. A. RAPPAPORT, AND P. C. JOSS
Center for Theoretical Physics, Center for Space Research, and Department of Physics, Massachusetts Institute of Technology

1986, simplified 2-zone homogeneous models. In fact, confirmed Sienkiewicz's results (about 100 ref. in 26 yr)



...ution for three representative (homogeneous) hydrogen abundances, X, as indicated. The init...

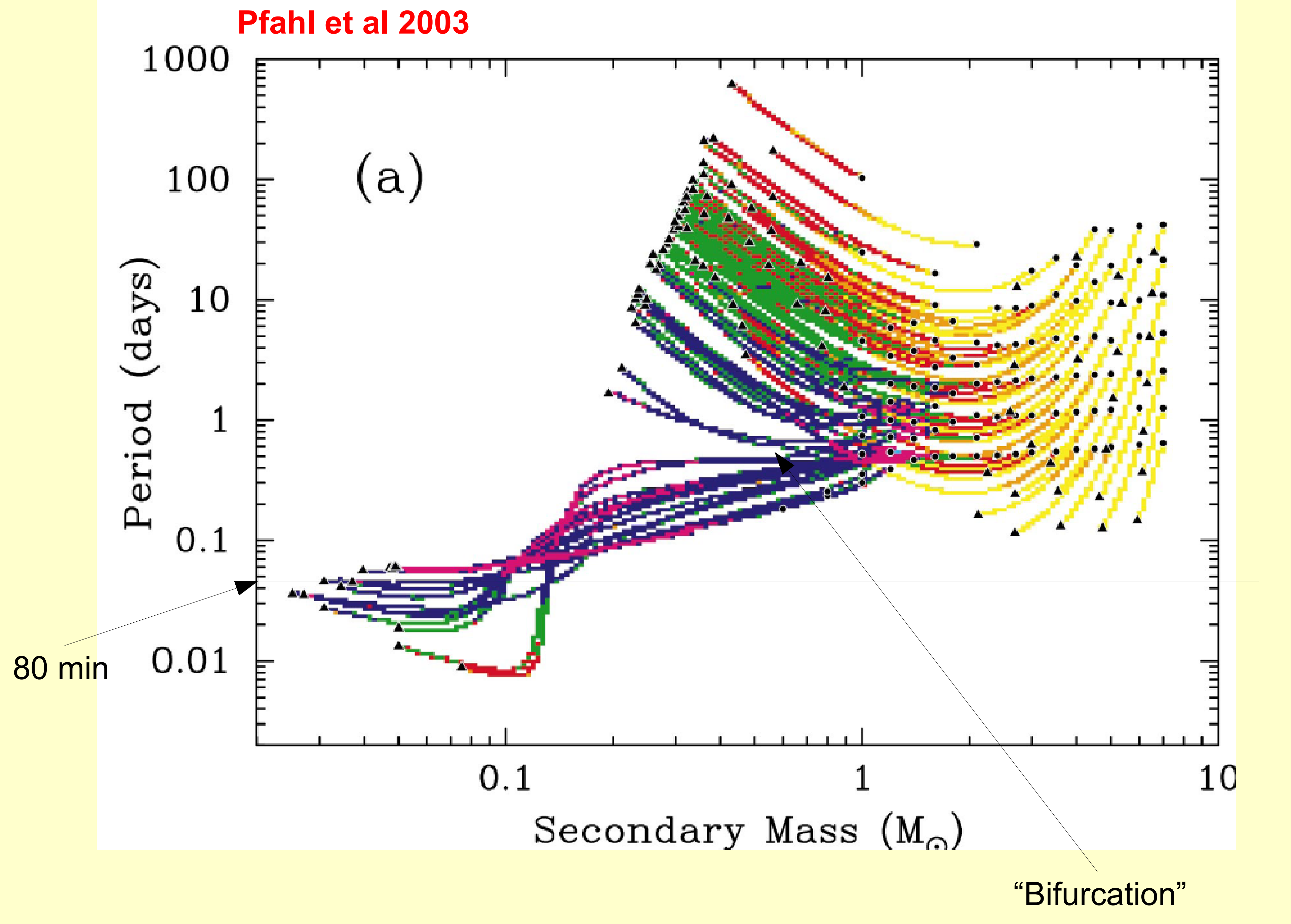
Later work – mainly on systems with NS or even BH accretors

Pylyser & Savonije 1988, 1989

Ergma & coauthors 1989, 1998

Van der Sluys & coauthors 2005a,b

Rappaport & coauthors 2003



Pfahl et al 2003
(a)
1000
100
10
1
0.1
0.01
Period (days)
0.1
1
10
Secondary Mass ($M_\odot$)
80 min
"Bifurcation"

2003: the first and still unique systematic study

Mon. Not. R. Astron. Soc. **340,** 1214–1228 (2003)

Cataclysmic variables with evolved secondaries and the progenitors of AM CVn stars

Ph. Podsiadlowski,[1★] Z. Han[2] and S. Rappaport[3]

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[2] *Yunnan Observatory, National Astronomical Observatories, The Chinese Academy of Sciences, Kunming 650011, China*
[3] *Department of Physics and Centre for Space Research, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

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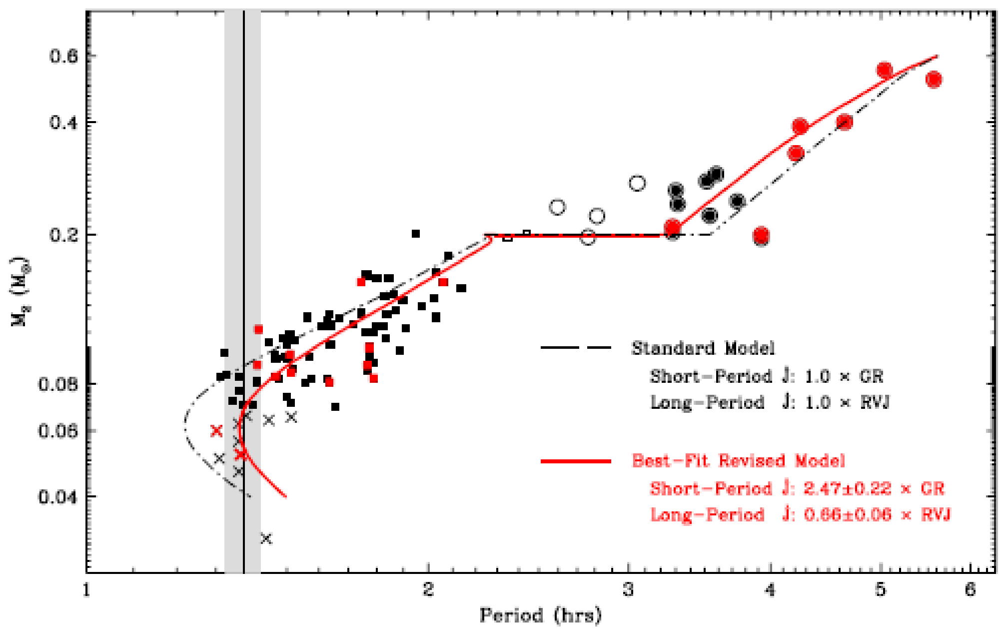
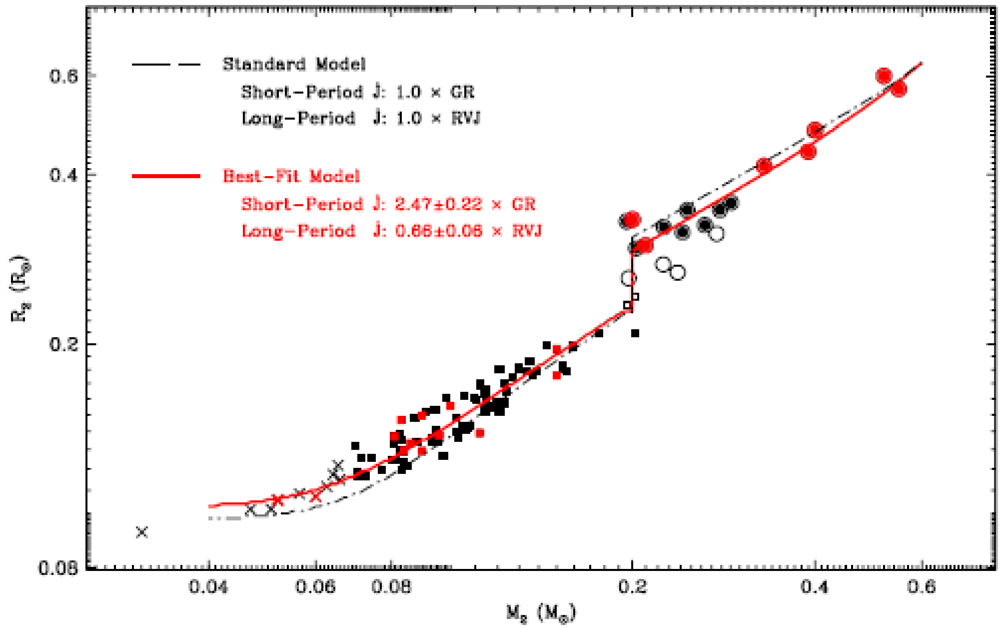
of magnetic braking. In our standard model, where CE ejection is efficient, some 10 per cent of all CVs have initially evolved secondaries (with a central hydrogen abundance $X_c < 0.4$) and ultimately become ultracompact systems (implying a Galactic birth rate for AM CVn-like stars of $\sim 10^{-3}$ yr^{-1}). While these systems do not experience a period gap between 2 and 3 h,

<u>Very strong statement about Xc at RLOF leading to formation of AM CVn and expected birthrate</u>

Knigge, Baraffe, Patterson (2011): AML law based on mass-radius relation for donor stars





"Standard case" — Rappaport, Verbunt, Joss (1983)

$$\left(\frac{dJ}{dt}\right)_{RVJ} = -3.810^{-30} M_2 R_2^4 \omega^3$$

Knigge et al. "best fit":

Above the gap:

$$\frac{dJ}{dt} \approx 0.66 \left(\frac{dJ}{dt}\right)_{RVJ} \left(\frac{R}{R_\odot}\right)^{-1}$$

Below the gap:

$$\frac{dJ}{dt} \approx 2.47 \left(\frac{dJ}{dt}\right)_{GWR}$$

THIS STUDY: Knigge et al. "best fit"

MB is *switched-on* if

$\Delta R_{conv} \geq \Delta R_{conv,\odot} = 0.065 R_\odot$

MB is *switched-off* if

$\Delta R_{conv}/R_{star} < 0.8$ or ΔR_{conv} becomes $< 0.065 R_\odot$

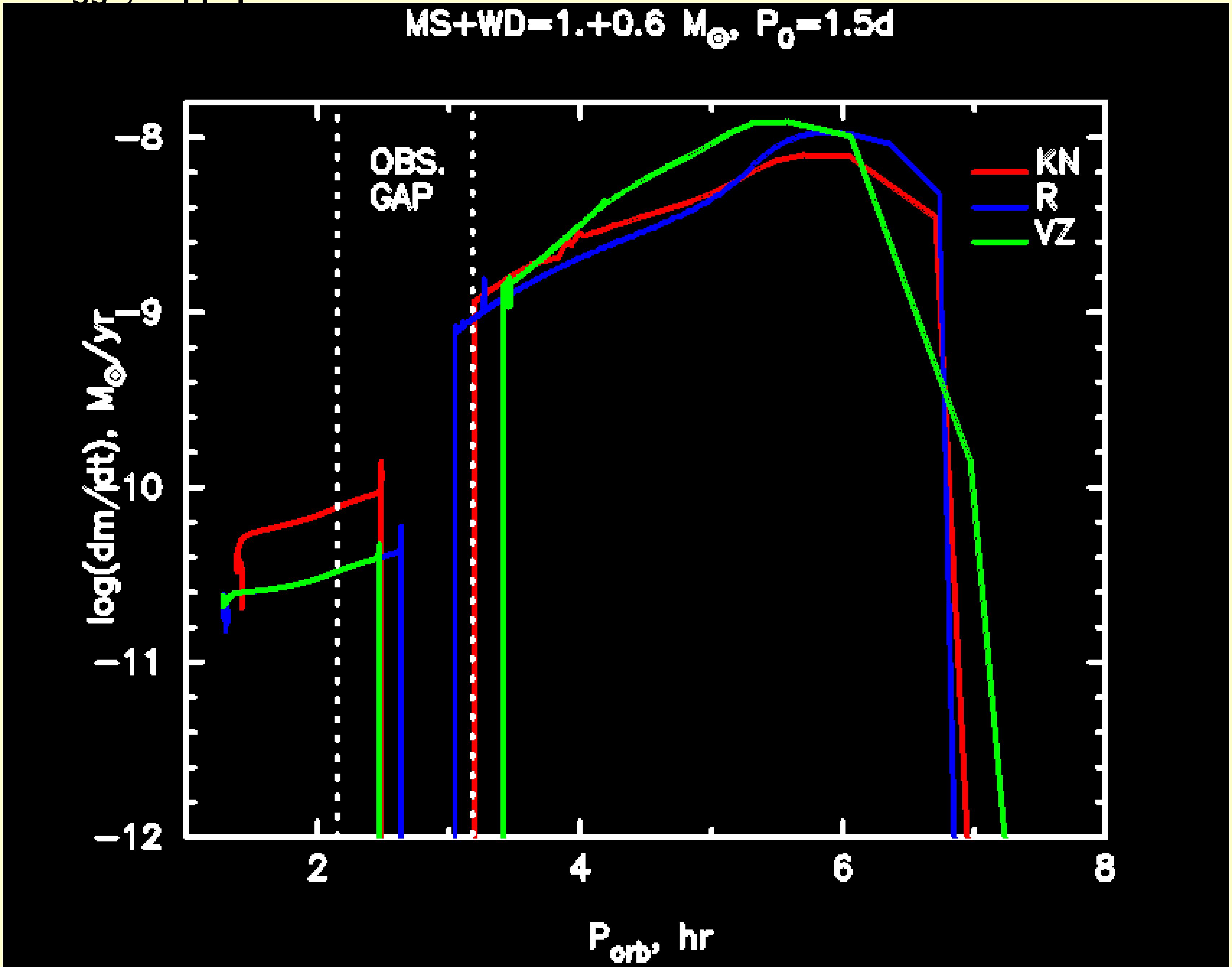
GWR is *enhanced* if MB is *switched-off*

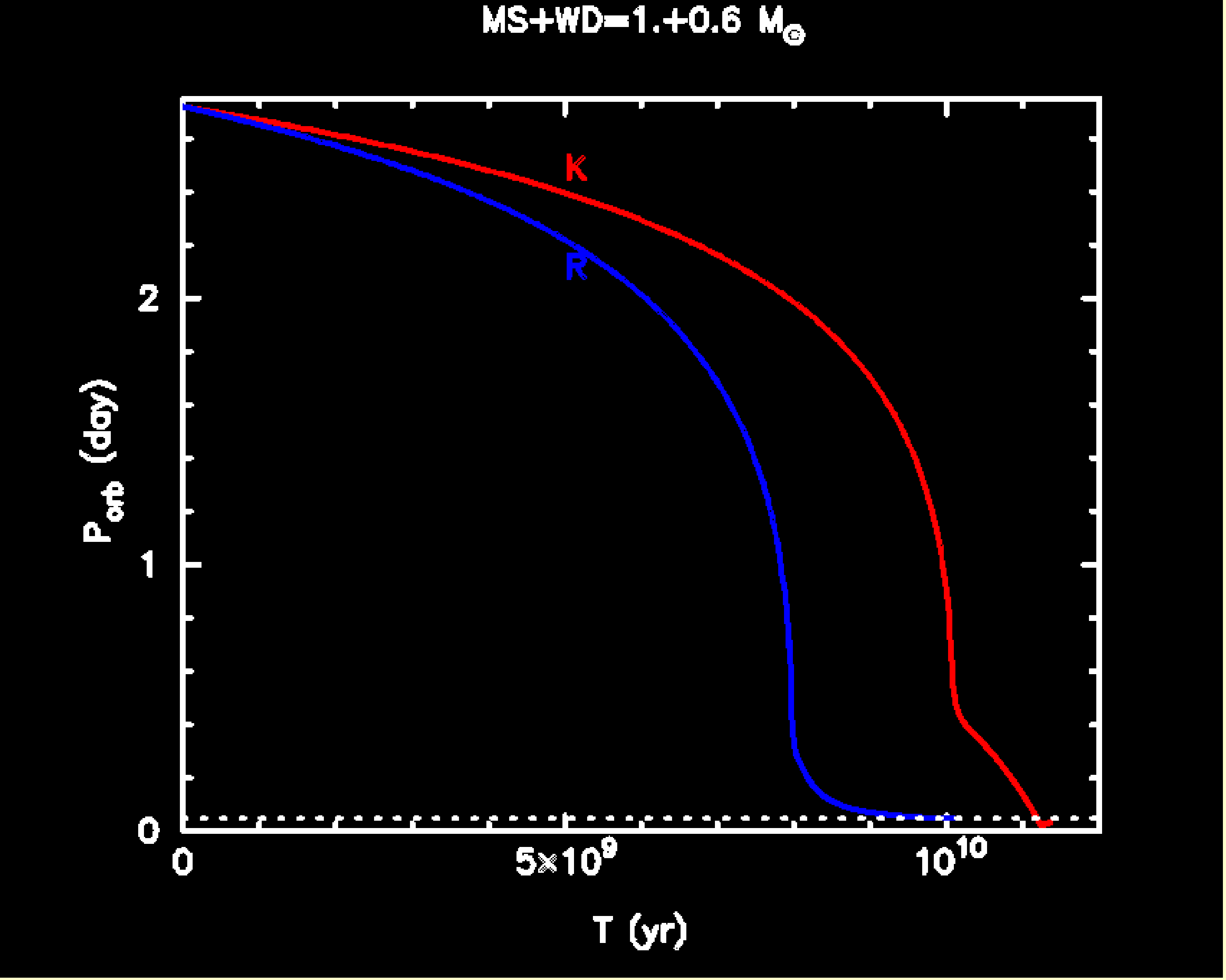
Parameters space:

$M_d = 0.6, 0.8, 0.95, 1.0, 1.1, 1.2 M_\odot$

$M_a = 0.6, 0.8, 1.0, 1.1, 1.2, 1.3 M_\odot$

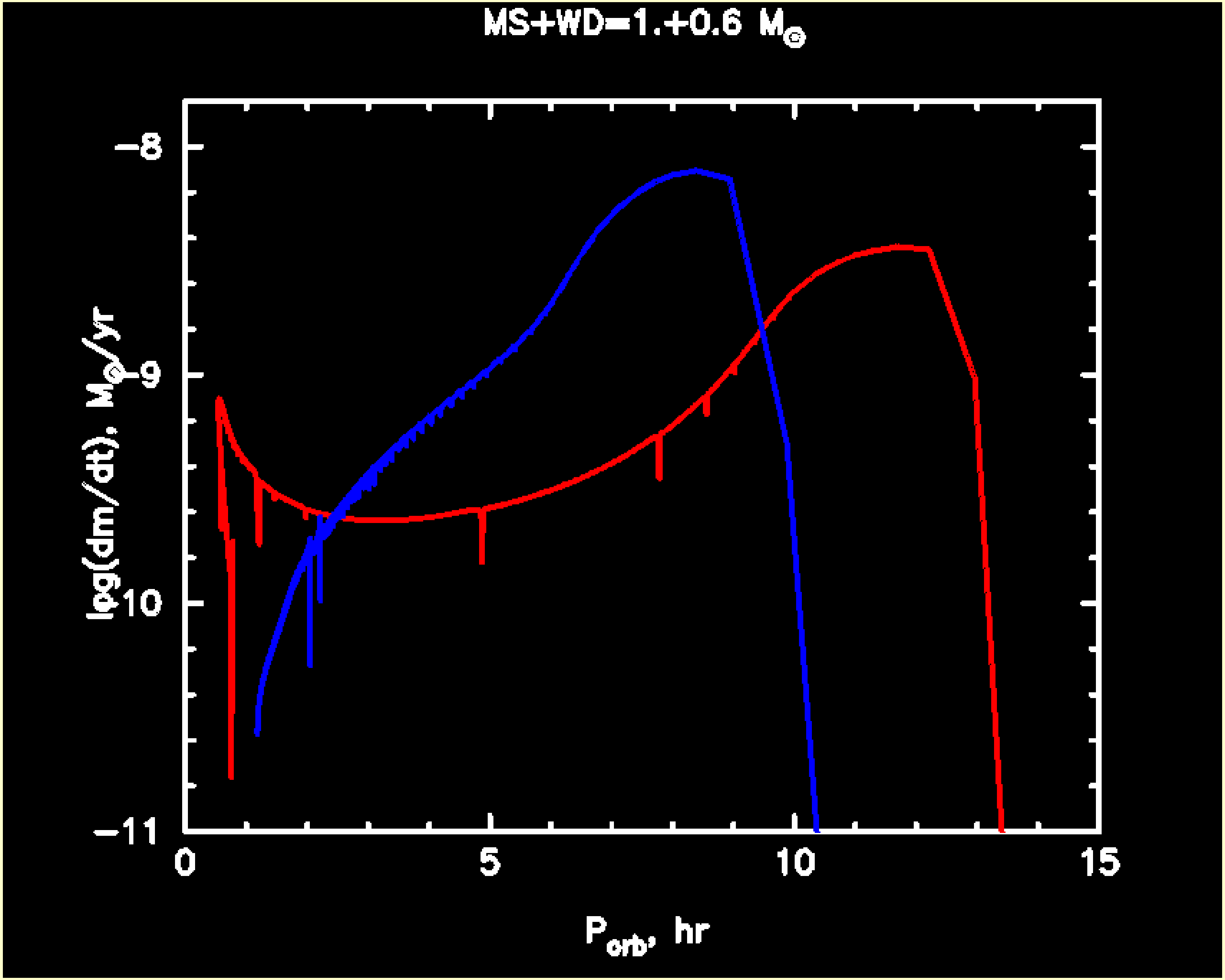
Comparison of mass-loss rates for initially almost unevolved donors for Knigge, Rappaport and Verbunt-Zwaan AML laws



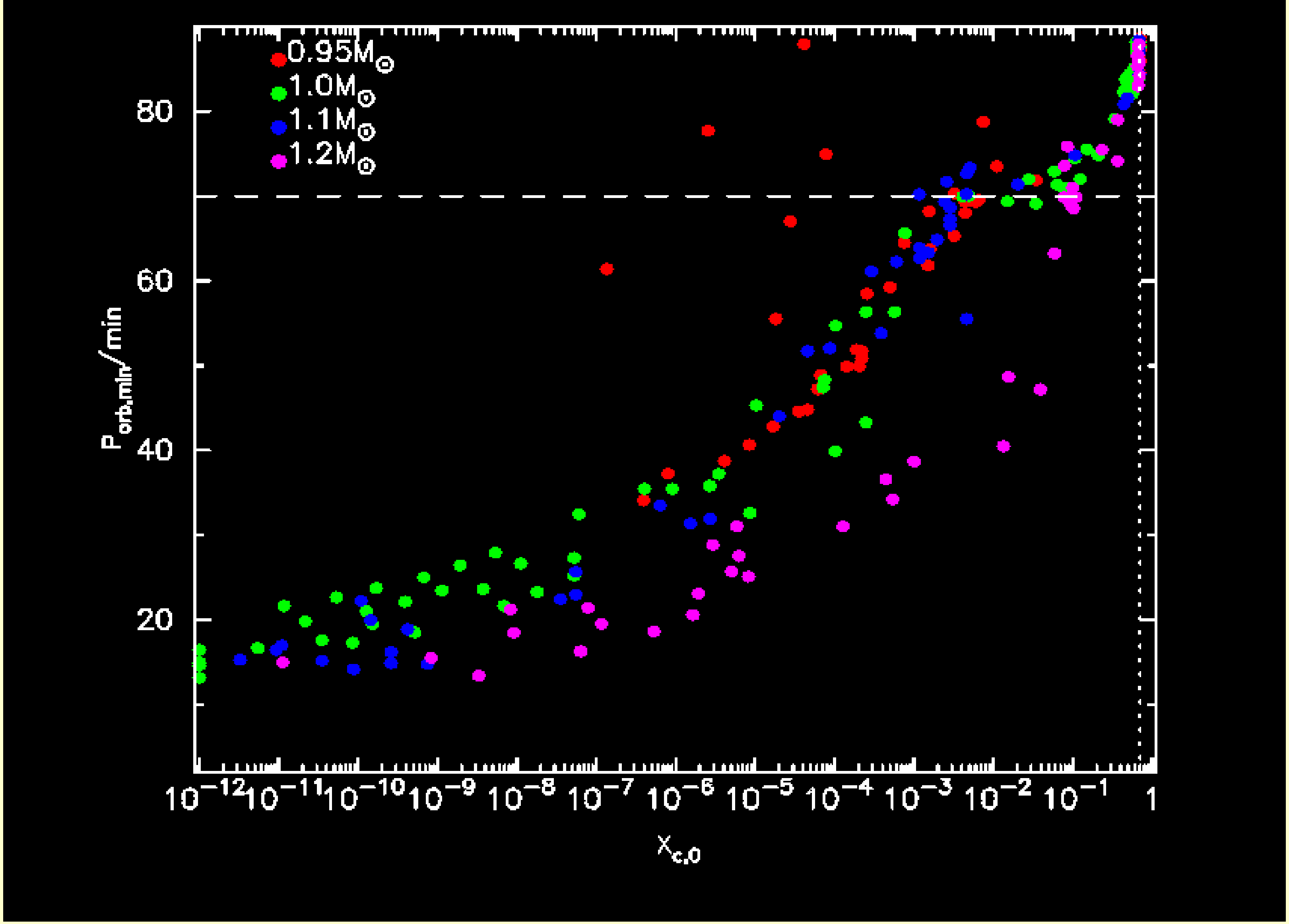


Post-CE
P_0=2.72d

At RLOF models computed with Knigge's law are “more evolved”:
K.: X_c≈1e-7 vs. R: X_c≈ 4e-2. The latter only “touch” AM Cvn range



MS+WD=1.+0.6 $M_\odot$
log(dm/dt), $M_\odot$/yr
−8
−9
−10
−11
0
5
10
15
P_{orb}, hr



Minimum orbital periods vs. X_c at RLOF. Colour coding – different initial mass of donors.

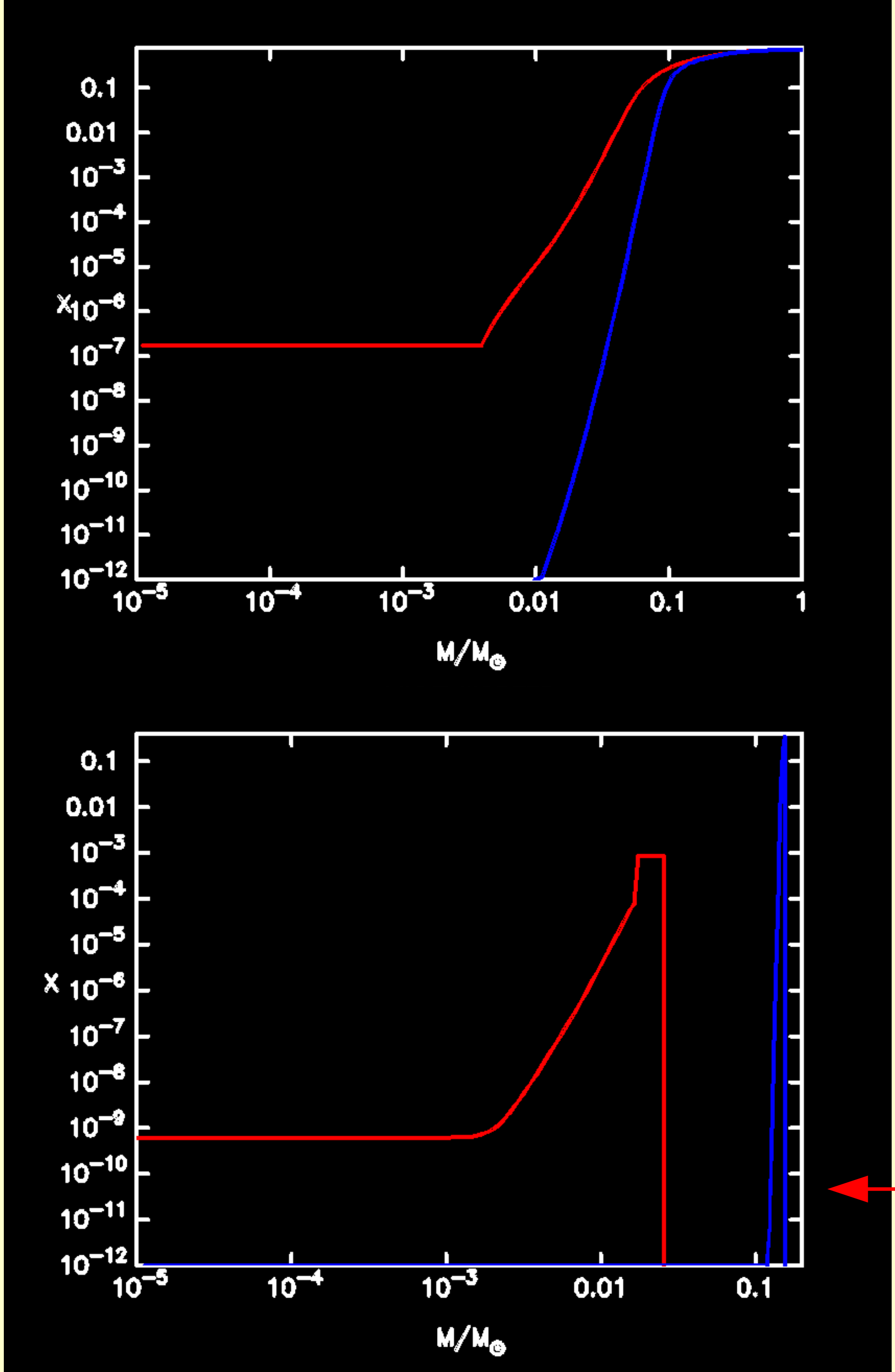
If $X_c < 0.3 – 0.4$, P_{orb} may become noticeably lower than 80 min.

For penetration of AM CVn period range Xc < several% is necessary.

Red outliers – late ME start, "heavy" M_1 – still have large mass.

$P_{min} > P_{min}$ computed by Podsiadlowski et al. because of enhanced GWR

Two different types of structures of initial and final models



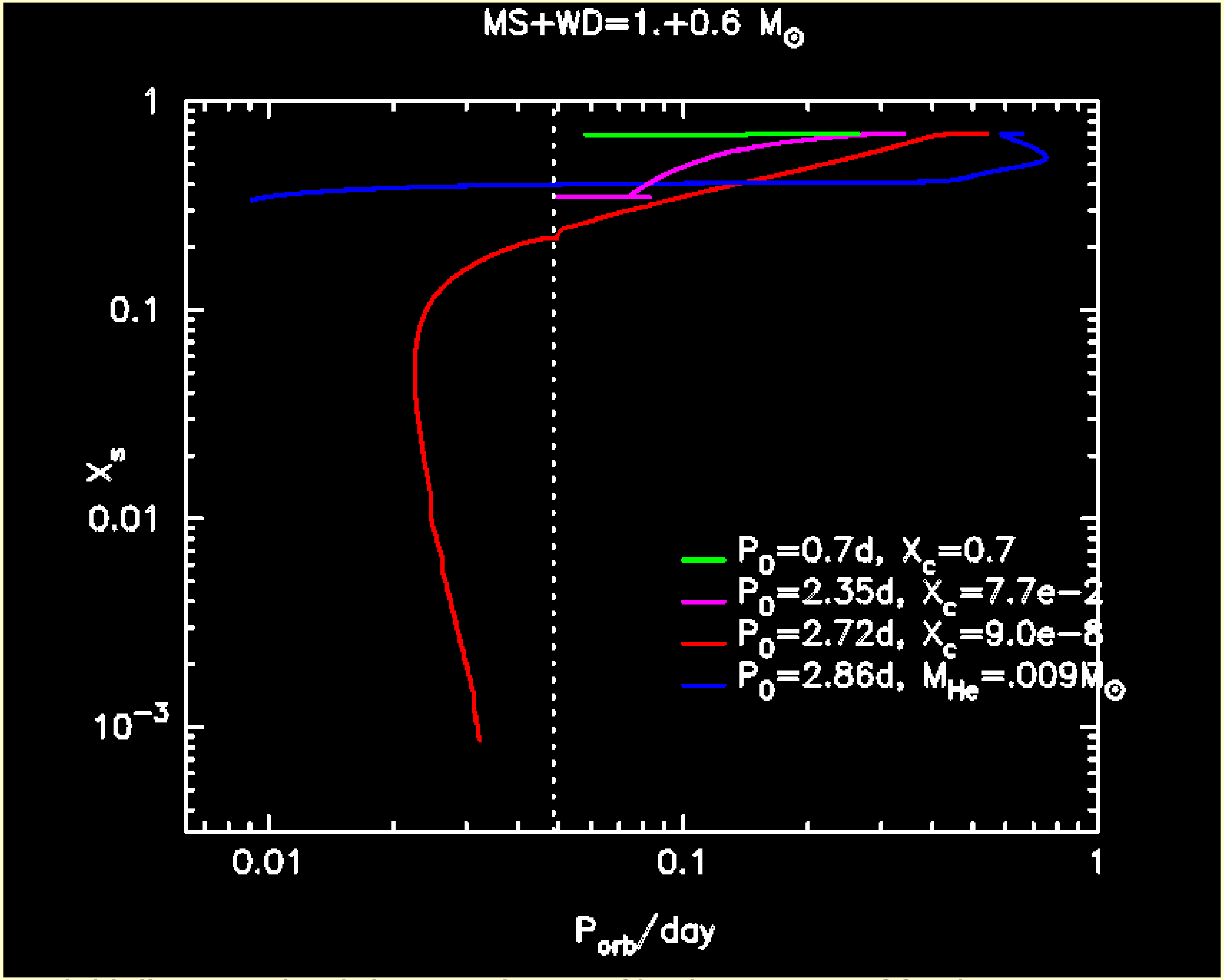
T=10.076Gyr

T=10.769Gyr

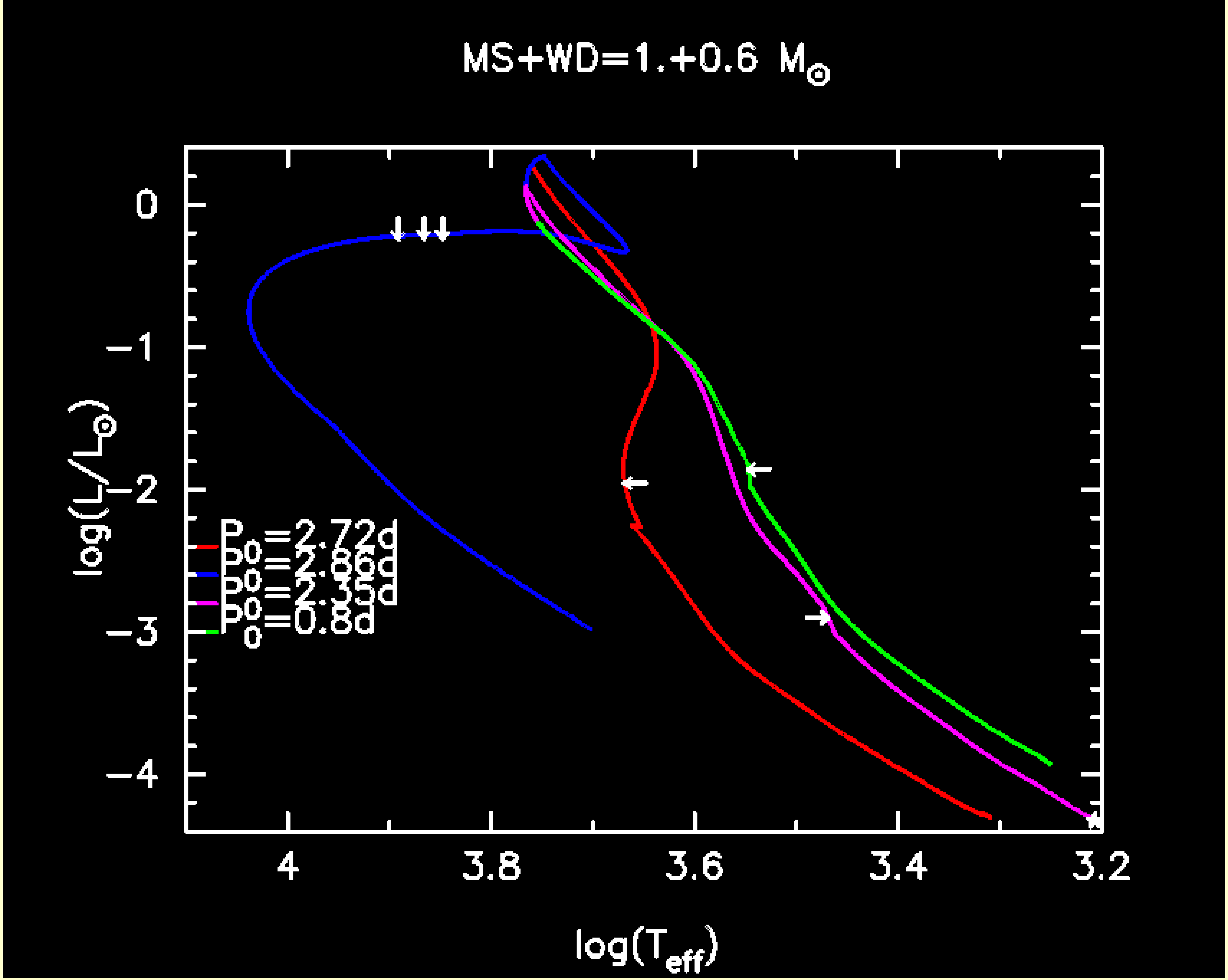
T=11.360Gyr

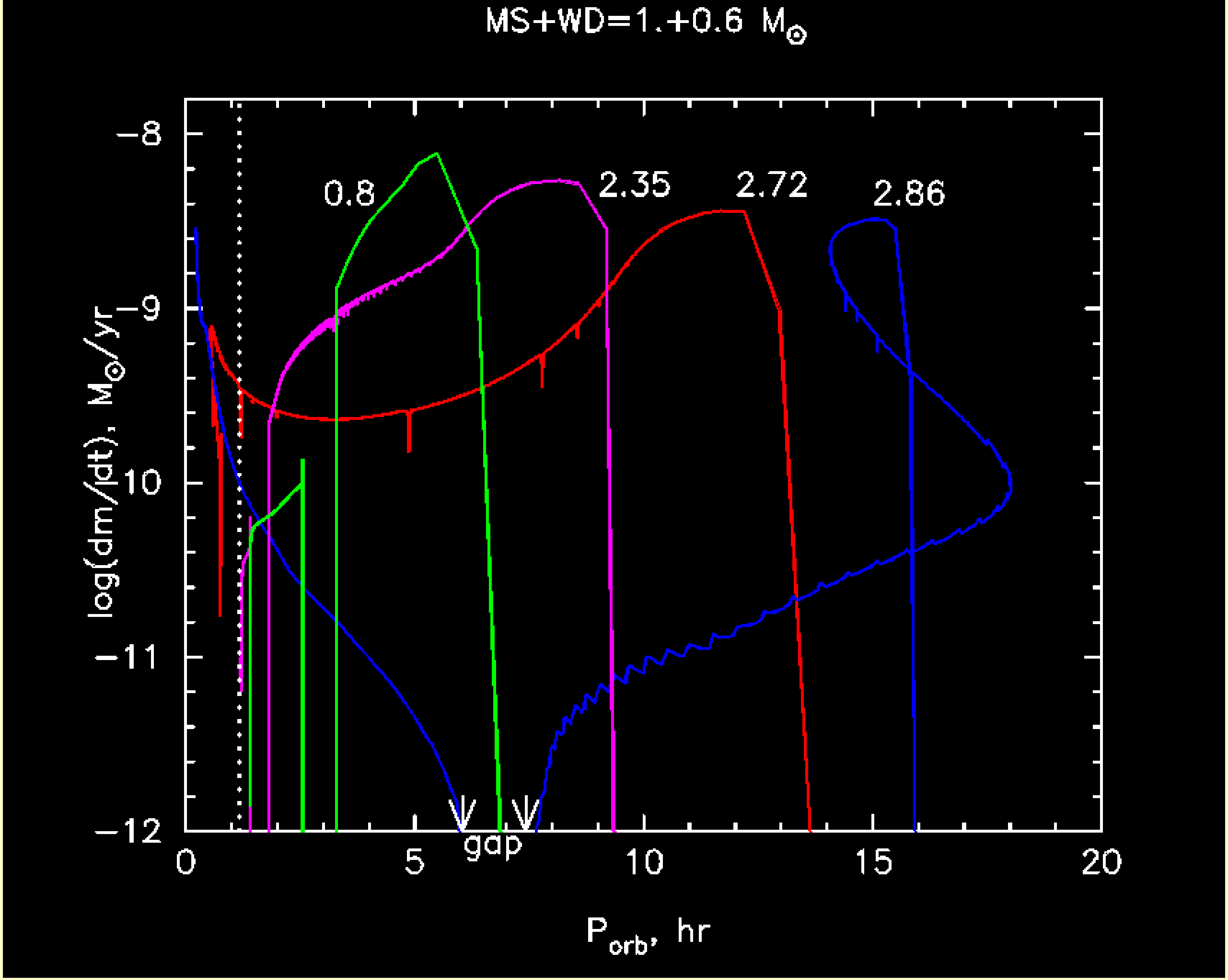
T=13.4Gyr

“Underripe” stripped giant ≈ He WD

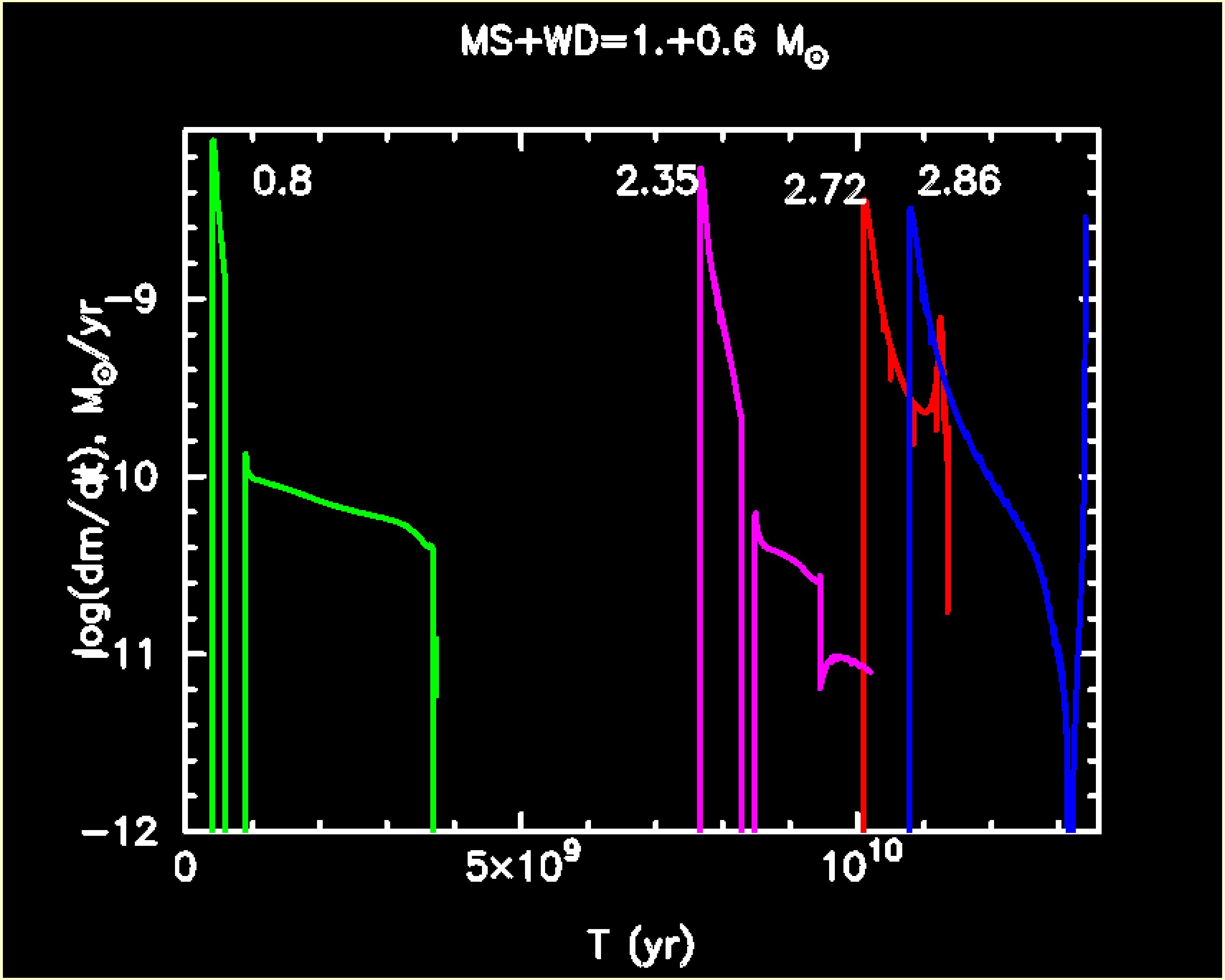


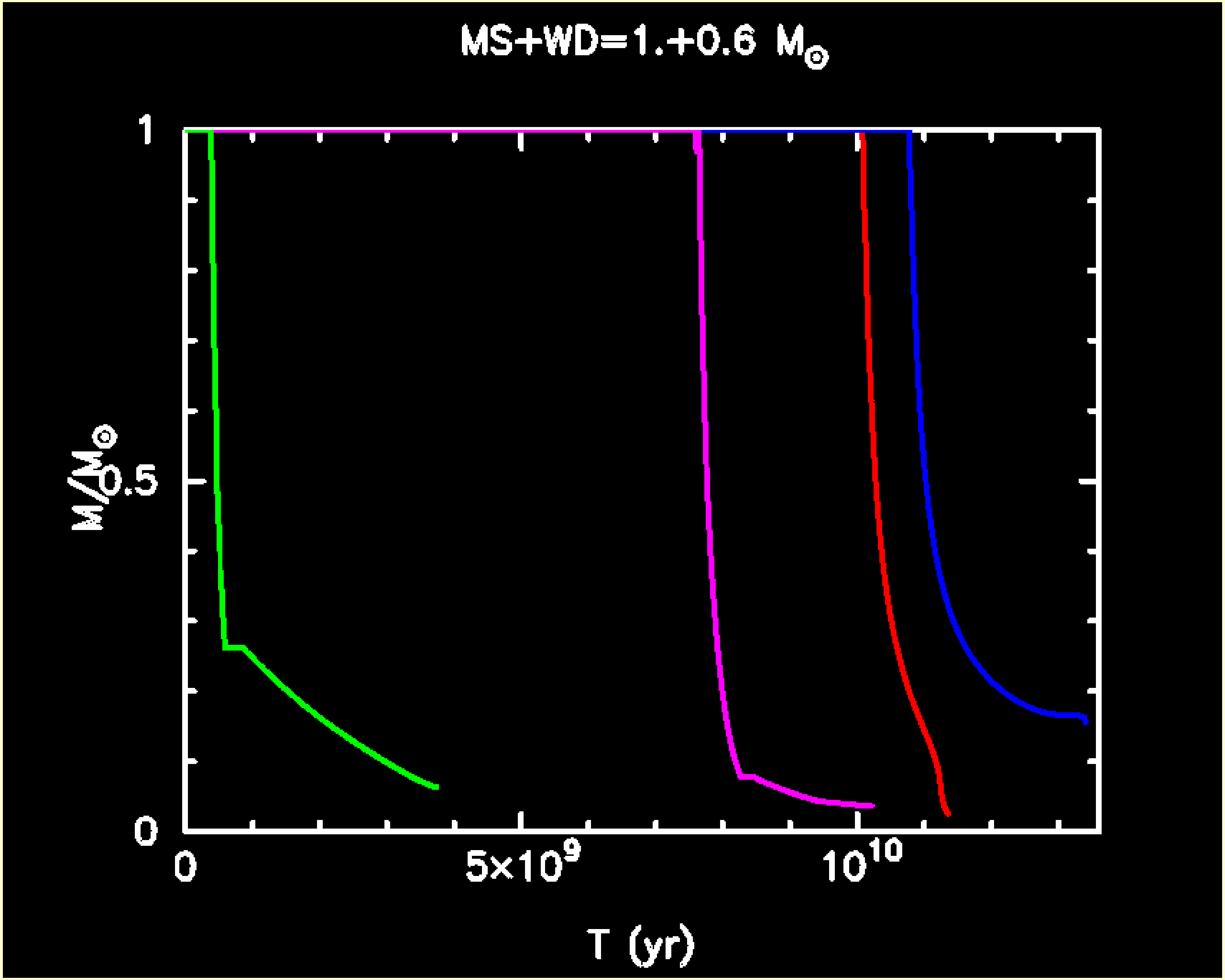
Green – initially unevolved donor, mixes at 3hr, bounces at 80 min
Magenta – significantly evolved donor, mixes at 115 min, bounces at 70 min
Red – extremely evolved donor, never mixes, bounces at 30 min
Blue – donor with small He-core, evolves into WD, track is limited by absence of adequate EOS


MS+WD=1.+0.6 $M_\odot$
0
−1
−2
−3
−4
$\log(L/L_\odot)$
4
3.8
3.6
3.4
3.2
$\log(T_{eff})$
P_0=2.72d
P_0=2.86d
P_0=2.35d
P_0=0.8d

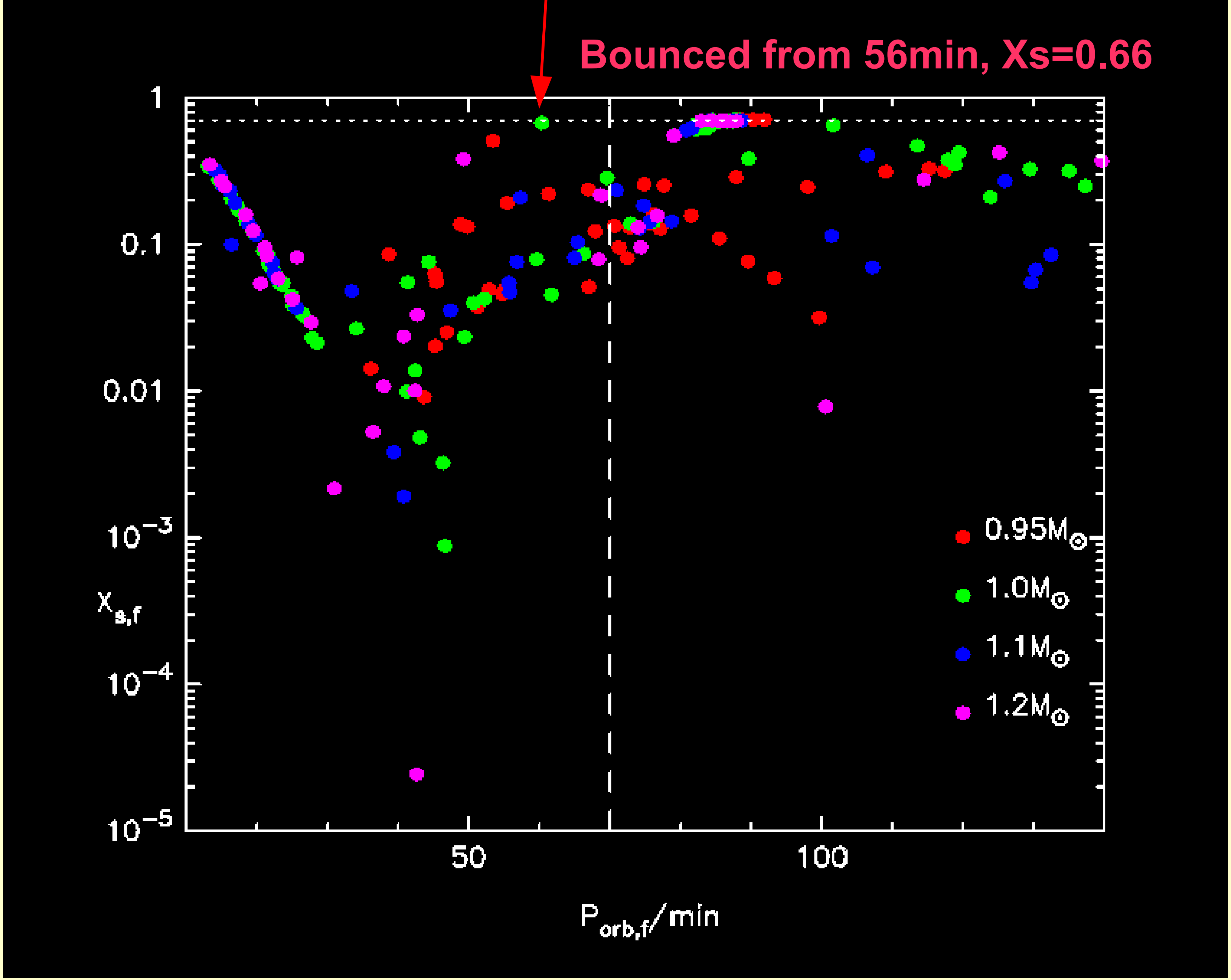


Xc≈0.7, 8e-2, 9e-8; M_{He}≈0.009Msun


MS+WD=1.+0.6 $M_\odot$
0.8
2.35
2.72
2.86
log(dm/dt), $M_\odot$/yr
−9
−10
−11
−12
0
5×10^9
10^10
T (yr)

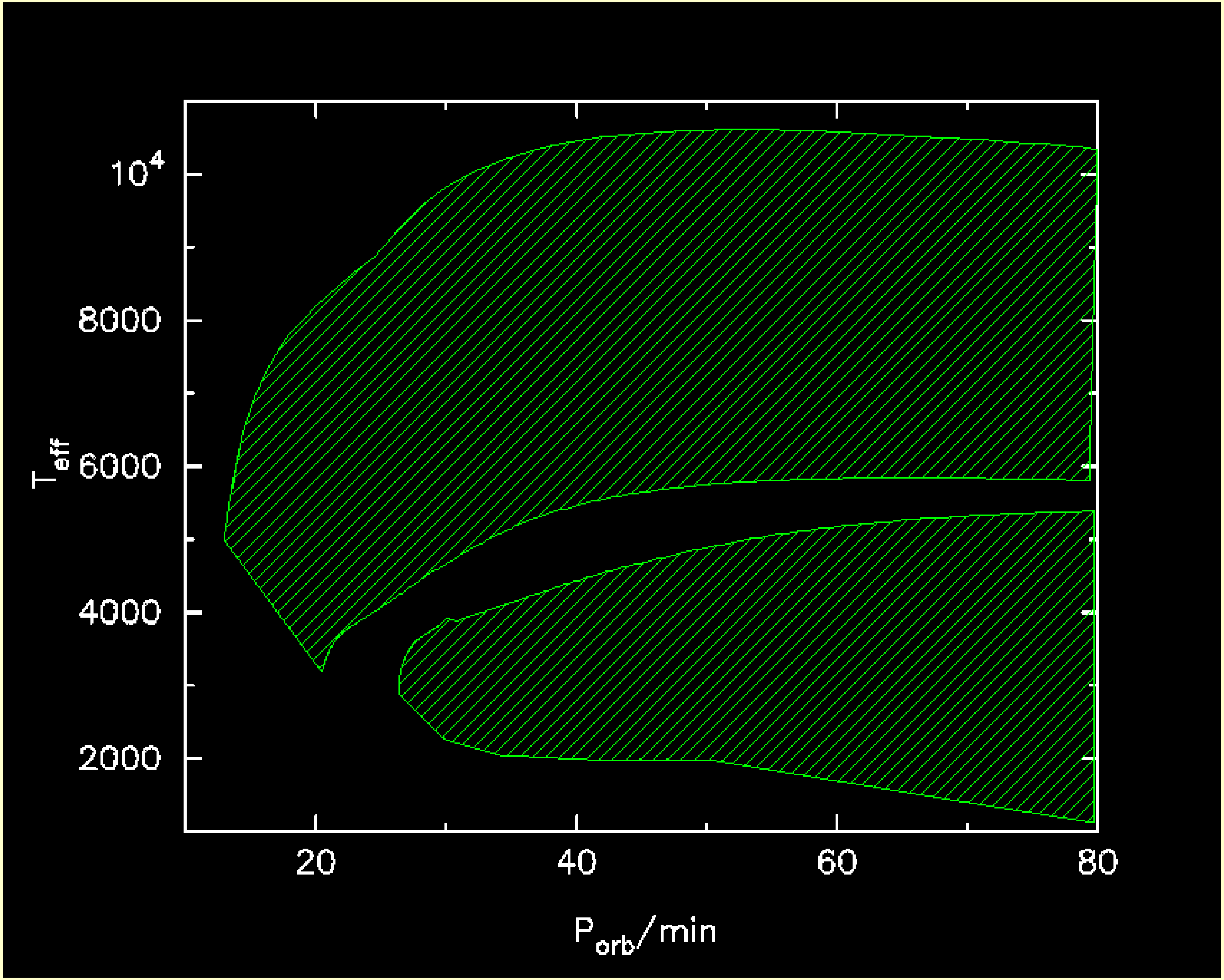


MS+WD=1.+0.6 M$_\odot$
1
0.5
0
M/M$_\odot$
0
5×10^9
10^{10}
T (yr)

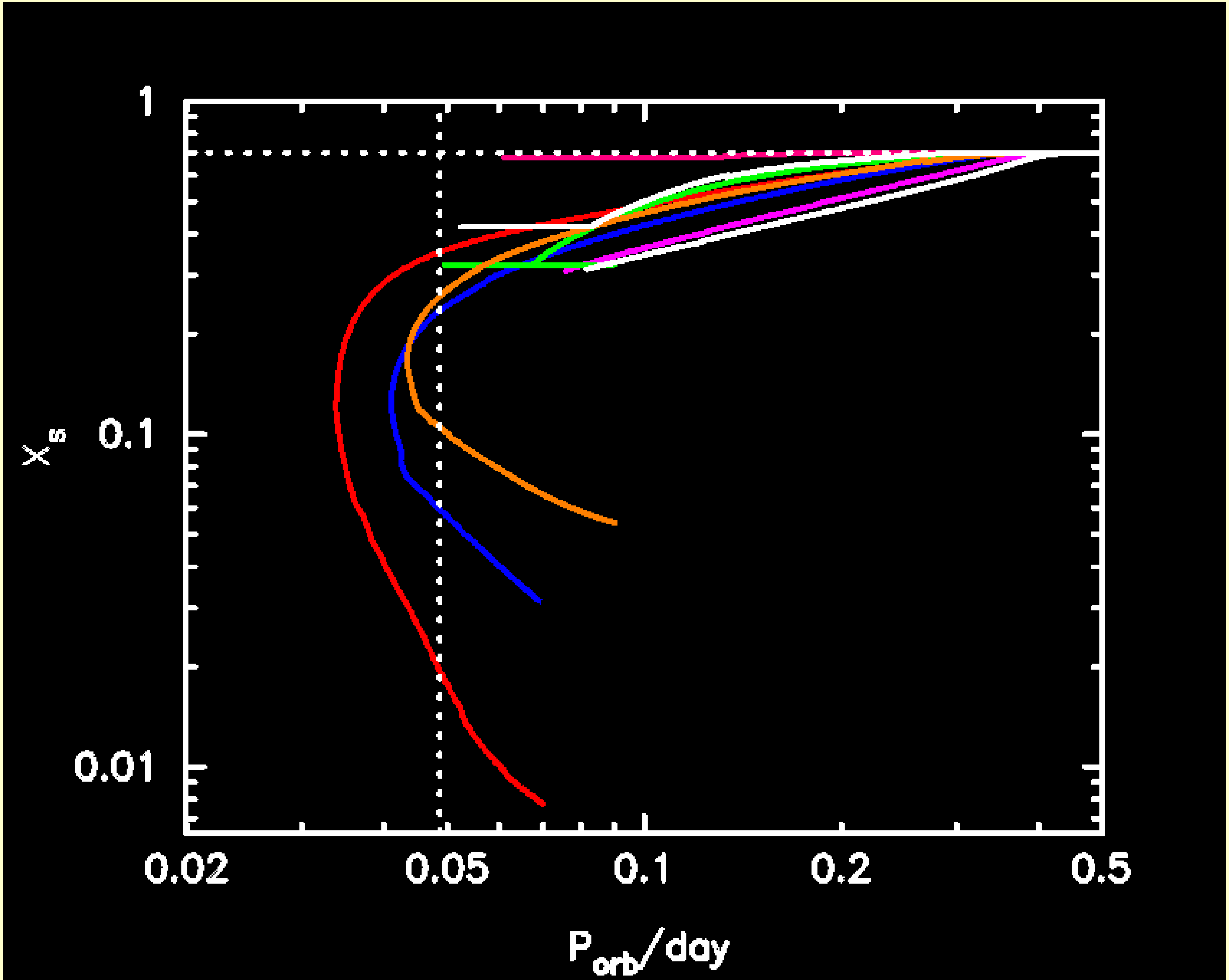


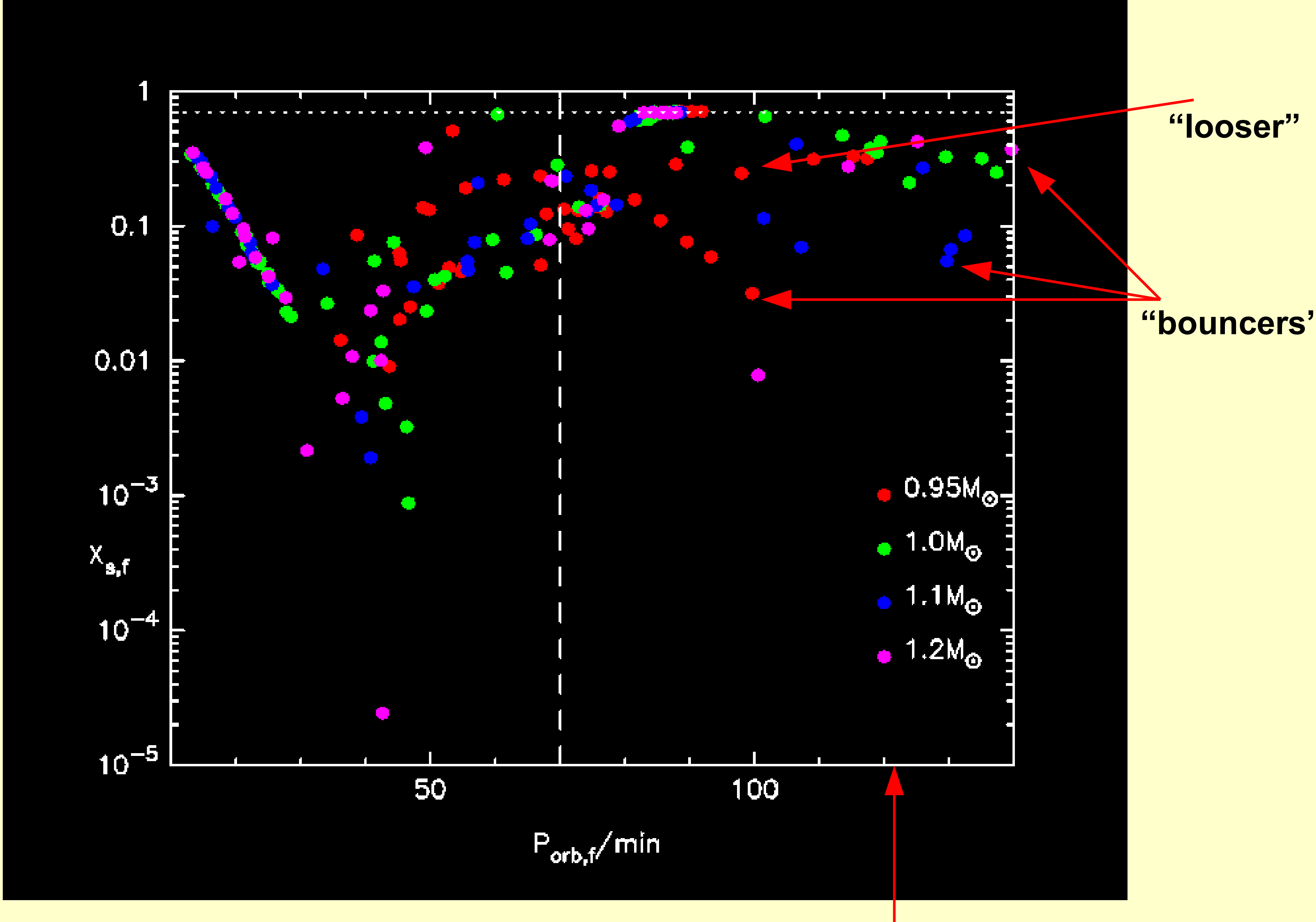
Final surface X vs. final P. A range of X at any given P.
Rising branch to the left – systems evolving into WD

THE RANGE OF EXPECTED EFFECTIVE TEMPERATURES.
LIFETIME AT HIGH T IS SHORT

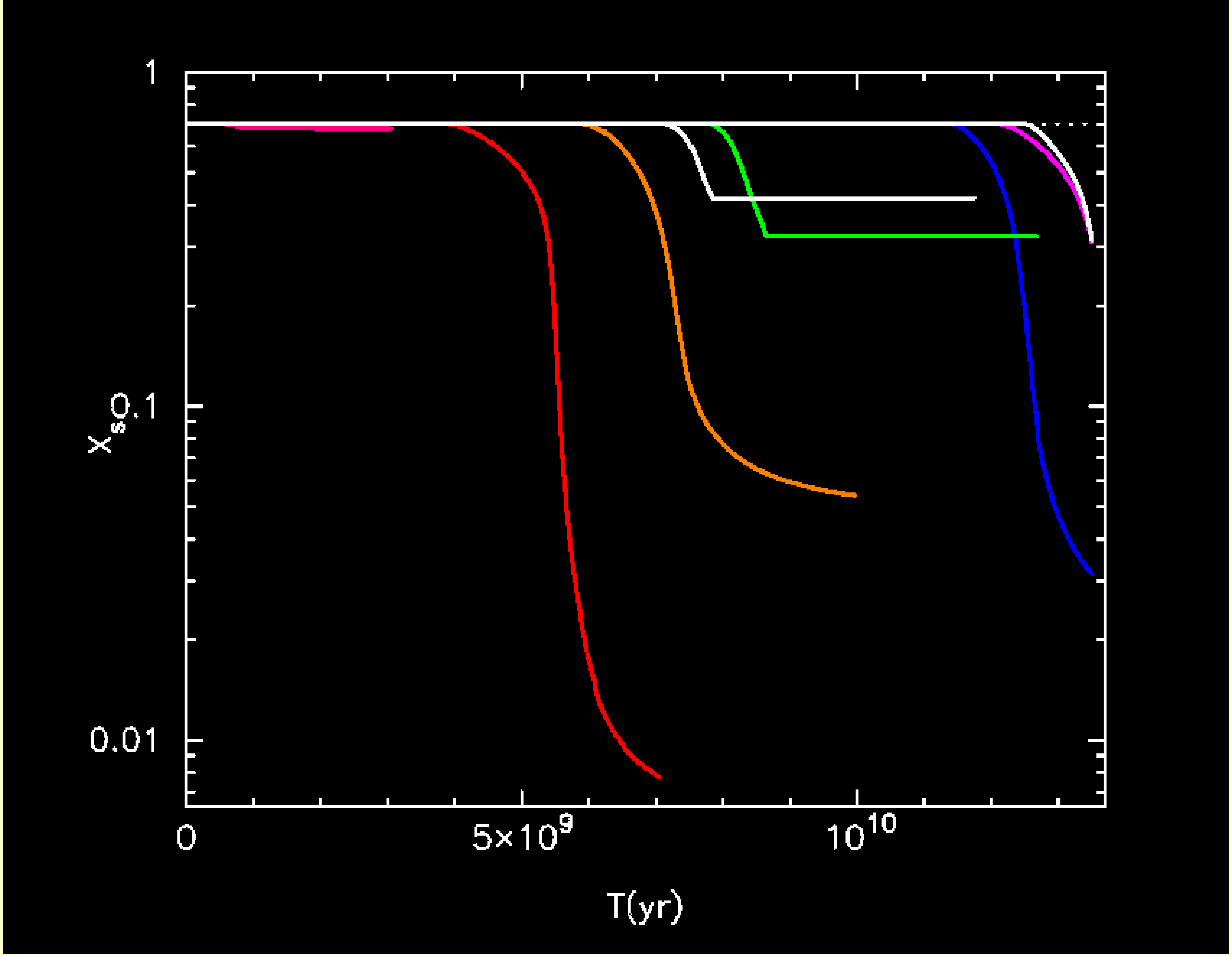


“COUSINS” - SYSTEMS THAT “BOUNCED” OR FAILED TO REACH AM CVn RANGE AND HAVE P>80 min.

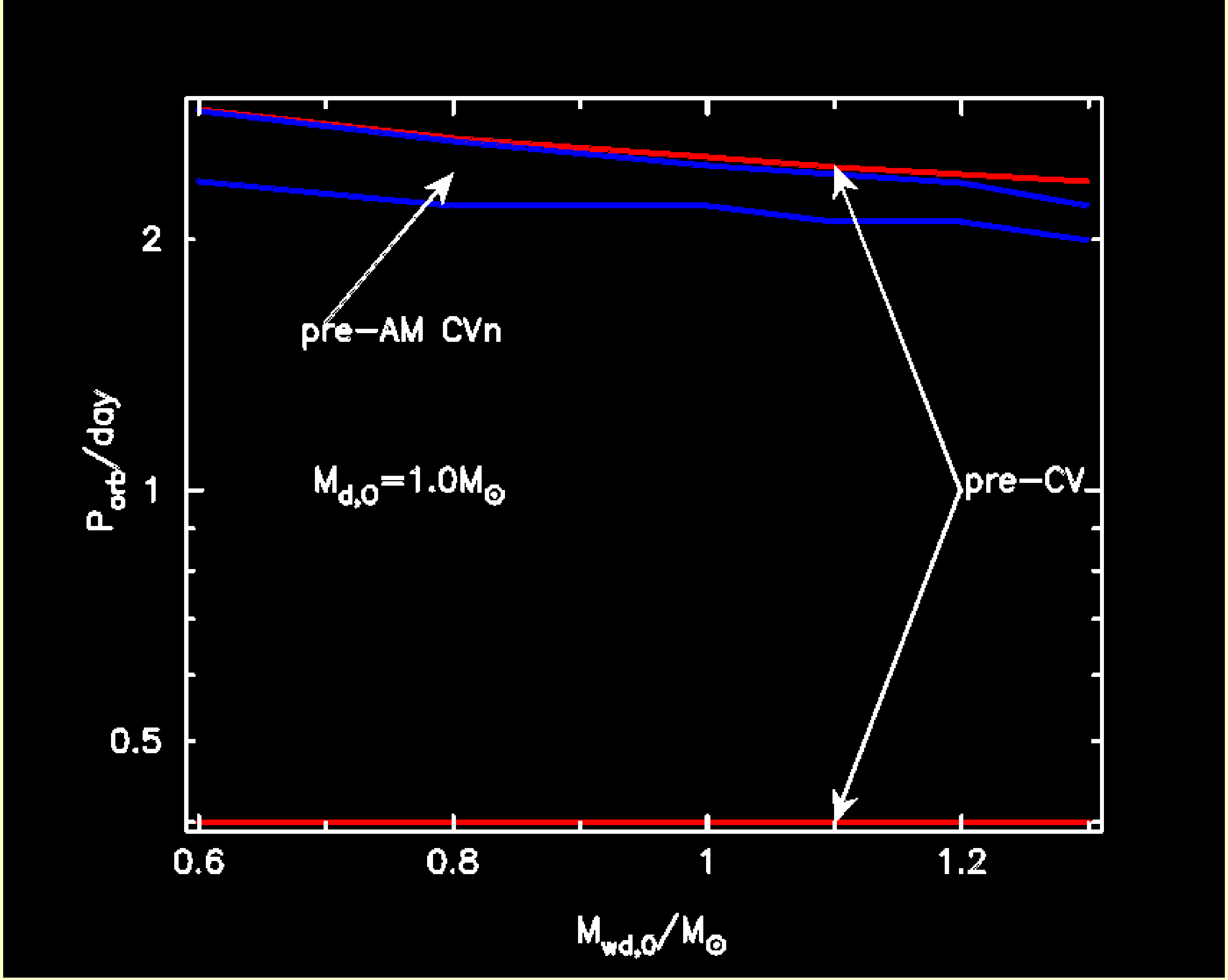




Possibility of low X_c in the period gap.



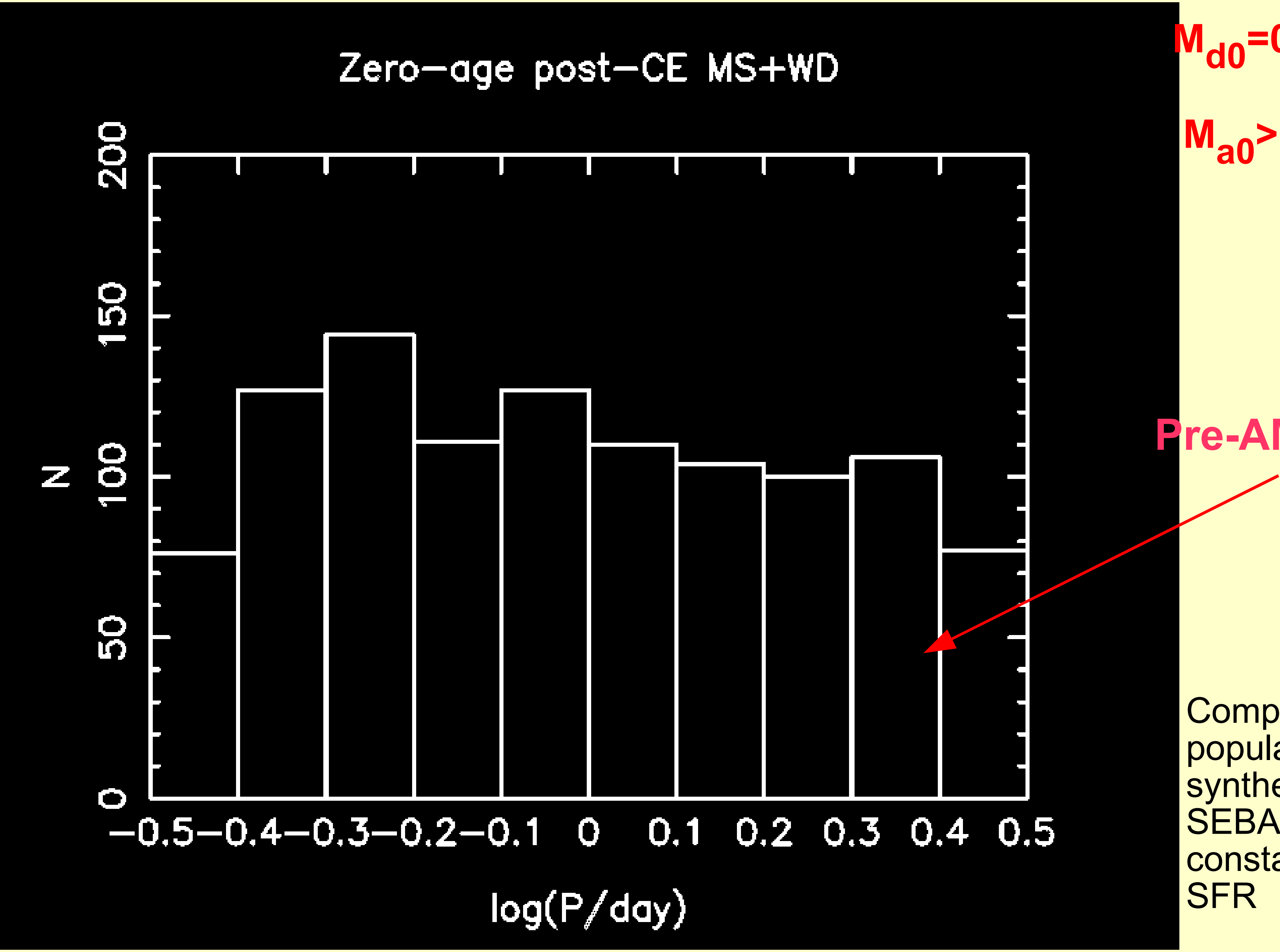
Lifetime at low X ~ Gyr



RED – limits of the total range of CV precursors including systems that diverge but have final periods below several days.
BLUE – limits of the range of precursors of AM Cvn's

M_{d0}=0.95-1.2

M_{a0}>0.6



Computed by population synthesis code SEBA for constant SFR

dN \propto dlogP (approximately), birthrate $\sim 10^{-6}$*SFR

Minimum time needed at least to "touch" AM CVn's range of periods (Gyr):

M_d	T_{min}
0.95	10.8
1.0	7.8
1.1	5.5
1.2	3.6

ESTIMATE:

Lifetime in the AM CVn's period range --- several Gyr

Number of "evolved donor" AM CVn's in the Galaxy:

1000*SFR ~ several thousand ~ several % of all AM CVn's

Conclusion

“Evolved donor” AM CVn stars are apparently even less numerous than thought before

A large scatter of H-abundances is expected for these stars

Next step:

Comparison of efficiency of different channels of production of AM CVn's

THANK YOU FOR ATTENTION AND PATIENCE !