Backward evolutionary calculations to model double white dwarf systems

Outline:

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Outline of the talk

Introduction

Observed double white dwarfs

Previous work by Gijs Nelemans

Backward calculation scheme

Second mass transfer phase

Possible first mass transfer phases

Future work

Astrophysical context

Possibly progenitors of Supernova type Ia

Sources of low-frequency gravitational waves

Binary evolution theory

White dwarf cooling theory

Population synthesis

Observed double white dwarfs

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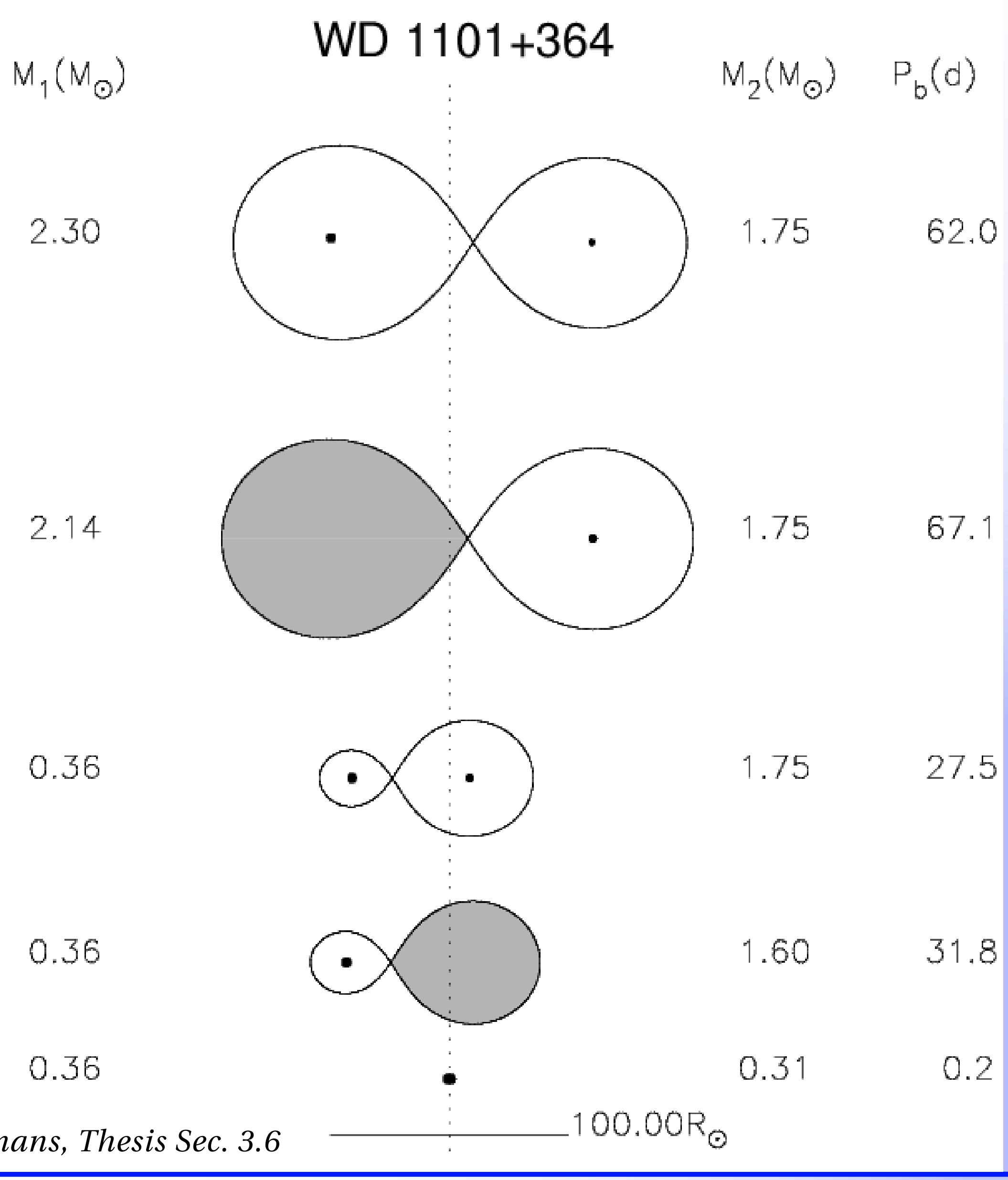
Double white dwarf systems of which both masses are known:

Name	M_1 ($M_\odot$)	M_2 ($M_\odot$)	q	P (d)	a ($R_\odot$)
WD 0136+768	0.34	0.44	0.77	1.407	4.86
WD 0957-666	0.32	0.37	0.86	0.061	0.58
WD 1101+364	0.36	0.31	1.16	0.145	1.02
WD 0135-052	0.52	0.47	1.11	1.556	5.63
WD 1204+450	0.51	0.51	1.00	1.603	5.80
WD 1704+481A	0.56	0.39	1.44	0.145	1.14
He 1414-0848	0.71	0.55	1.29	0.518	2.93
He 1047-0436	> 0.44	0.47	> 0.94	1.213	> 4.64
KPD 0422+5421	0.53	0.51	1.04	0.09	0.86
KPD 1930+2752	0.97	0.5	1.94	0.095	1.00
Average:	0.52 (0.07)	0.45 (0.07)	1.16 (0.34)	0.68 (0.67)	2.85 (2.17)

Backward evolutionary calculations to model double white dwarf systems



G. Nelemans, Thesis Sec. 3.6

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Backward calculations

Outline:

Observed system, WD + WD:
M_{wd1}, M_{wd2}, final period P_f

↓

Second mass transfer phase

↓

Intermediate system, WD + giant:
M_{wd1}, M_{g2}, intermediate period P_m
Range of M_{g2}'s → range of P_m's

↓

First mass transfer phase

↓

Initial system, MS + MS:
M_1, M_2, initial period P_i

Ranges of solutions for each possible intermediate system !

Second Mass Transfer Phase

Average orbital separation: 3 $R_\odot$

Second mass transfer phase must have been a Common Envelope:

Mass transfer is unstable, because the donor is expanded and has a deep convective envelope

Mass transfer time scale ~ 1 kyr

Primary will be engulfed by secondary envelope, hence *Common Envelope*

The Common Envelope phase lasts very short, so that the primary white dwarf will not accrete and the secondary core will not evolve

Common Envelope

Friction causes spiral in of the primary
and heating of the envelope

Idea of treating CE:

Orbital energy difference is used to expell
the envelope to infinity

Use this to calculate the progenitor systems
of the three observed double white dwarf systems,
assuming a common envelope

Calculate Common Envelope

Equate giant envelope binding energy to orbital energy difference:

$$U_{\rm bind} = \alpha_{\rm CE} \left(\frac{G M_{\rm wd1} M_{\rm wd2}}{2 a_{\rm f}} - \frac{G M_{\rm wd1} M_{\rm g2}}{2 a_{\rm m}} \right)$$

We get $U_{\rm bind}$ from our stellar models

We can calculate $a_{\rm m}$ as a function of $M_{\rm g2}$, if we know α_{CE}

Problem:

We haven't got a clue, except that α_{CE} lies in the range of 0.1 - 10

Calculate Common Envelope

However, there is a second constraint:

At the moment the Common Envelope started,
the giant secondary had to fill its Roche Lobe

The Roche Lobe radius is an indication of
the orbital separation or orbital period,
for known M_{wd1} and assumed M_{g2}

The giant radius can be calculated using our stellar models

This gives us a second method to calculate
the orbital period before the CE phase

Calculate Common Envelope

So:

We know	We don't know
Mass transfer mechanism	α_{CE}
Primary WD mass (M_{wd1})	Orbital separation or period before CE (a_m, P_m)
Giant secondary core mass, at the start of the CE = secondary WD mass (M_{wd2})	Giant secondary mass (M_{g2})
Final orbital separation or period (a_f, P_f)	

Using our stellar models, we can calculate α_{CE} and a_m (or P_m) as a function of M_{g2}, since we have the two conditions of binding energy and radius

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Stellar Models

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Since all WDs in the three systems are He-WDs, we need stellar evolutionary models upto core helium ignition

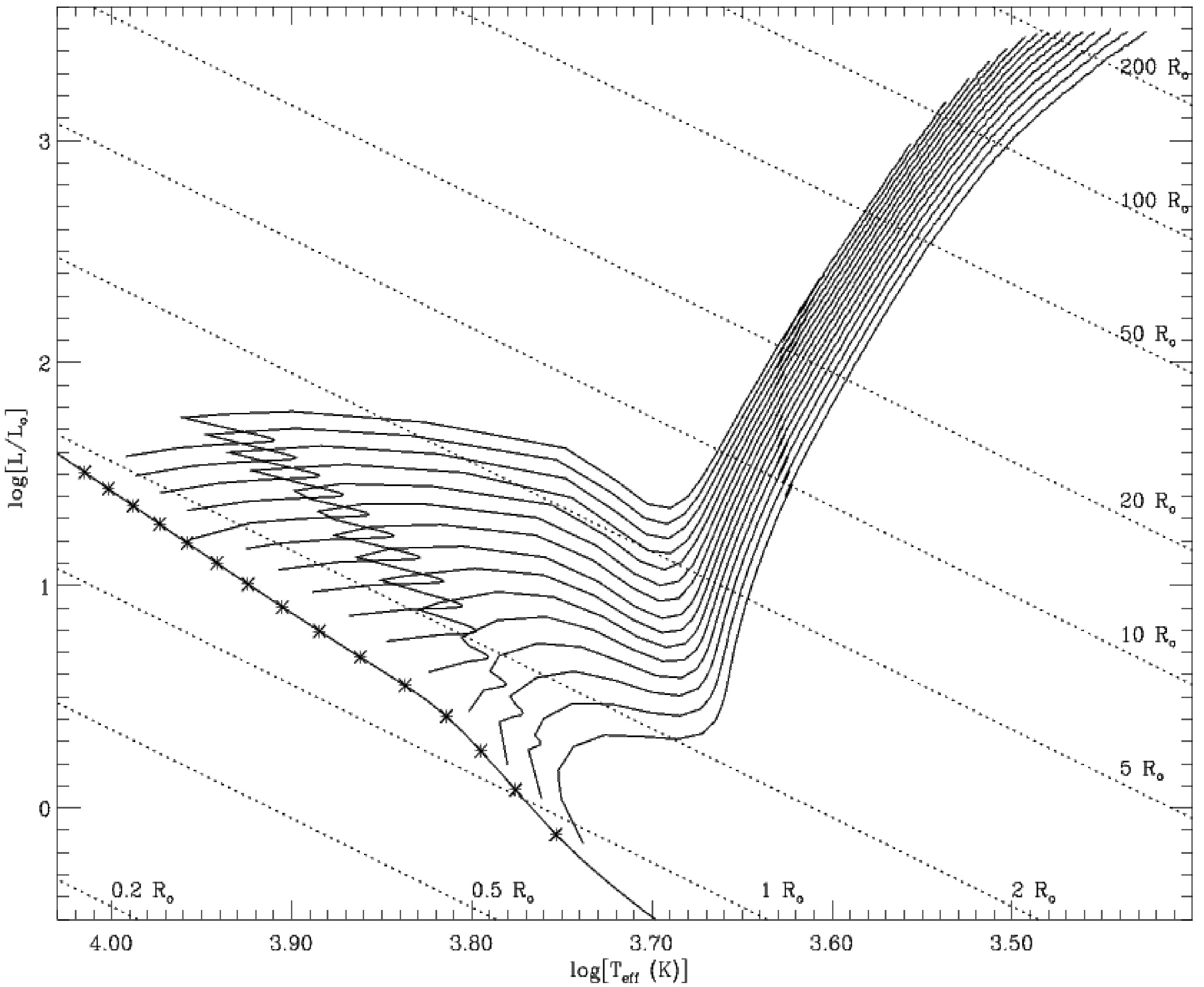
We calculated single star models from ZAMS to the tip of the giant branch, with masses between 1.0 and 2.4 M_o

After the main sequence, the core mass M_{cor} of the star can be used as a 'time coordinate'

For each mass, the radius of the star and the binding energy of the envelope at the 'time' $M_{cor} = M_{wd2}$ is needed

Each combination of M_{g2} and M_{cor} gives unique values for R and U_{bind}

Stellar Models



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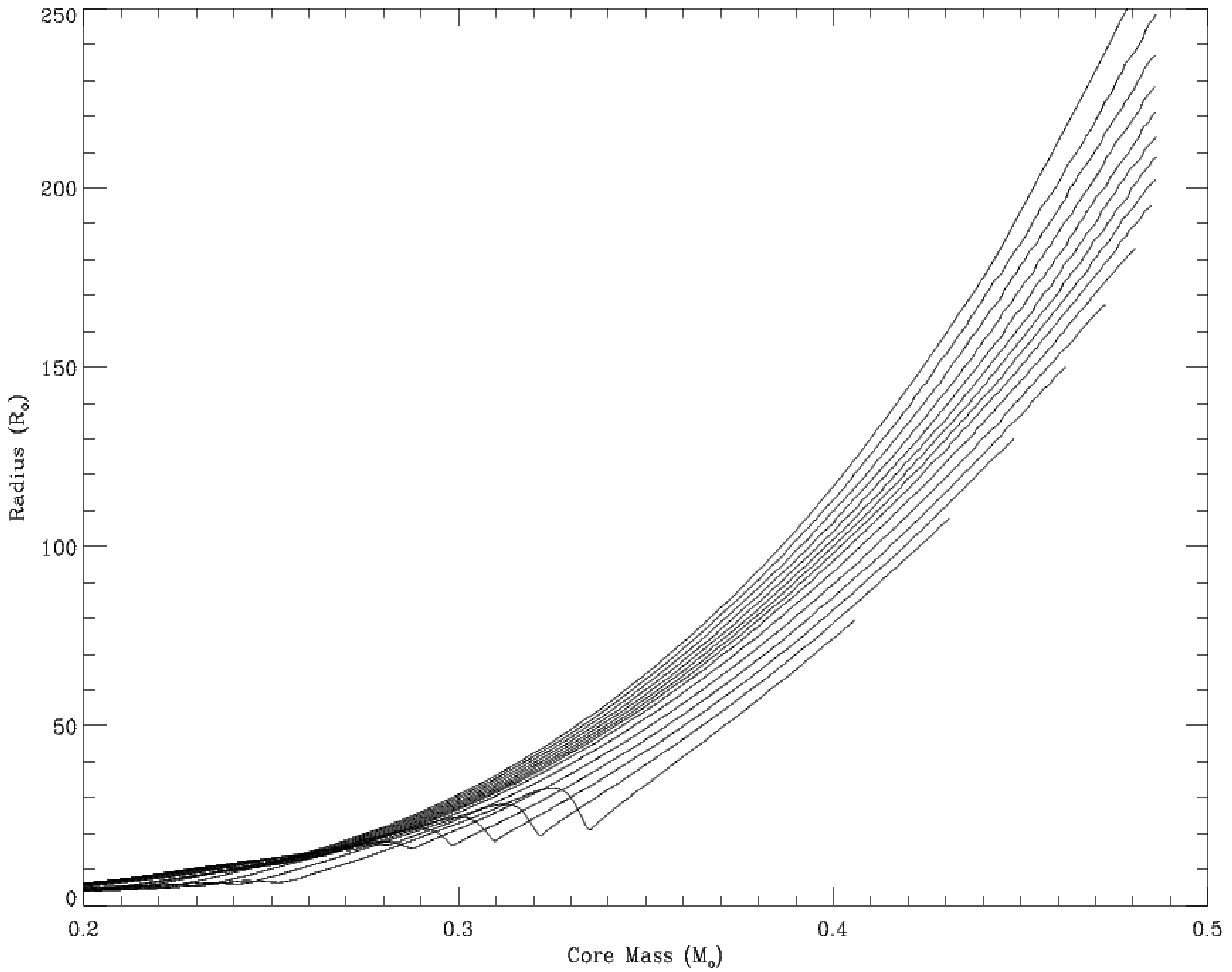
Core mass – Radius



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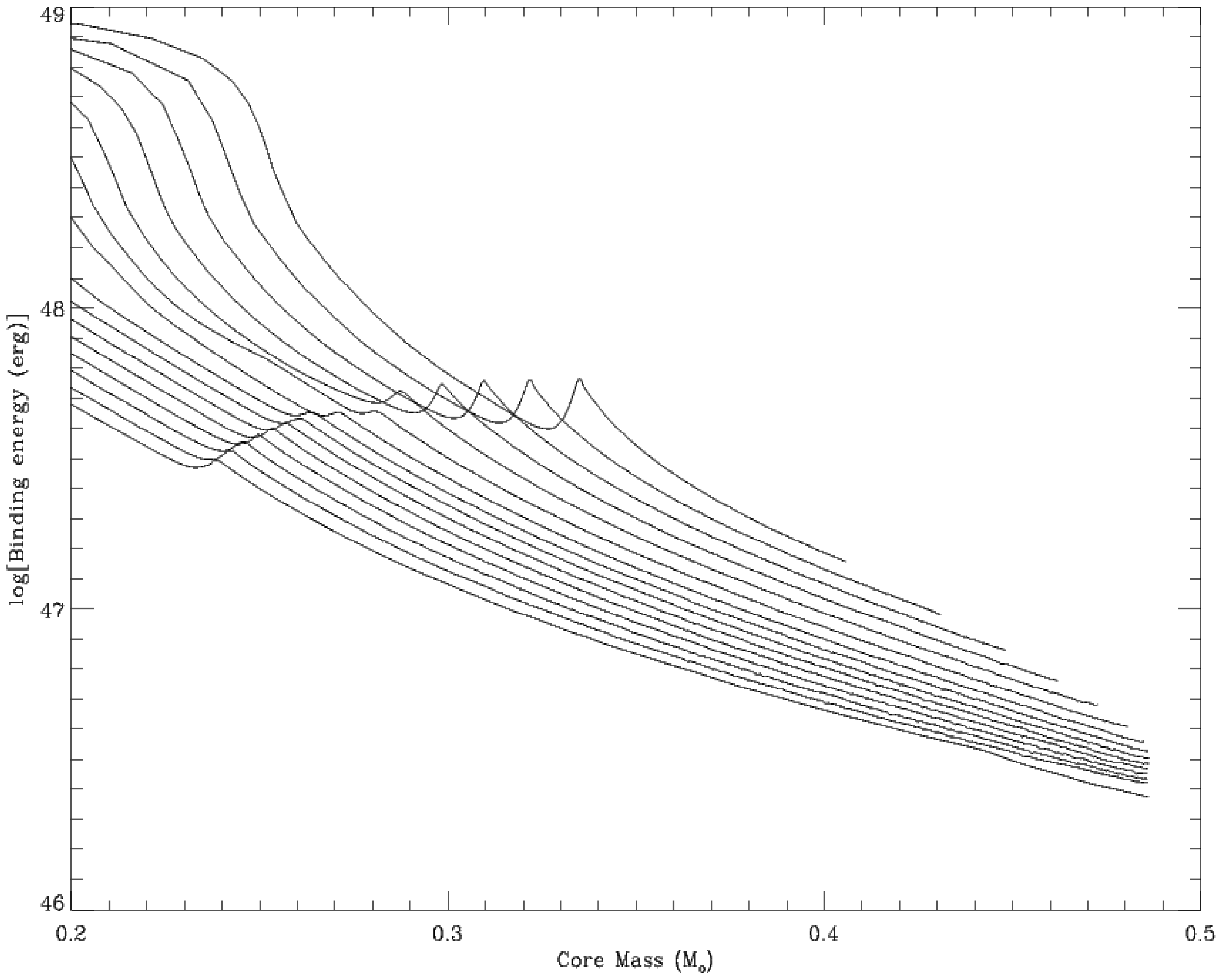
Core mass - Binding energy



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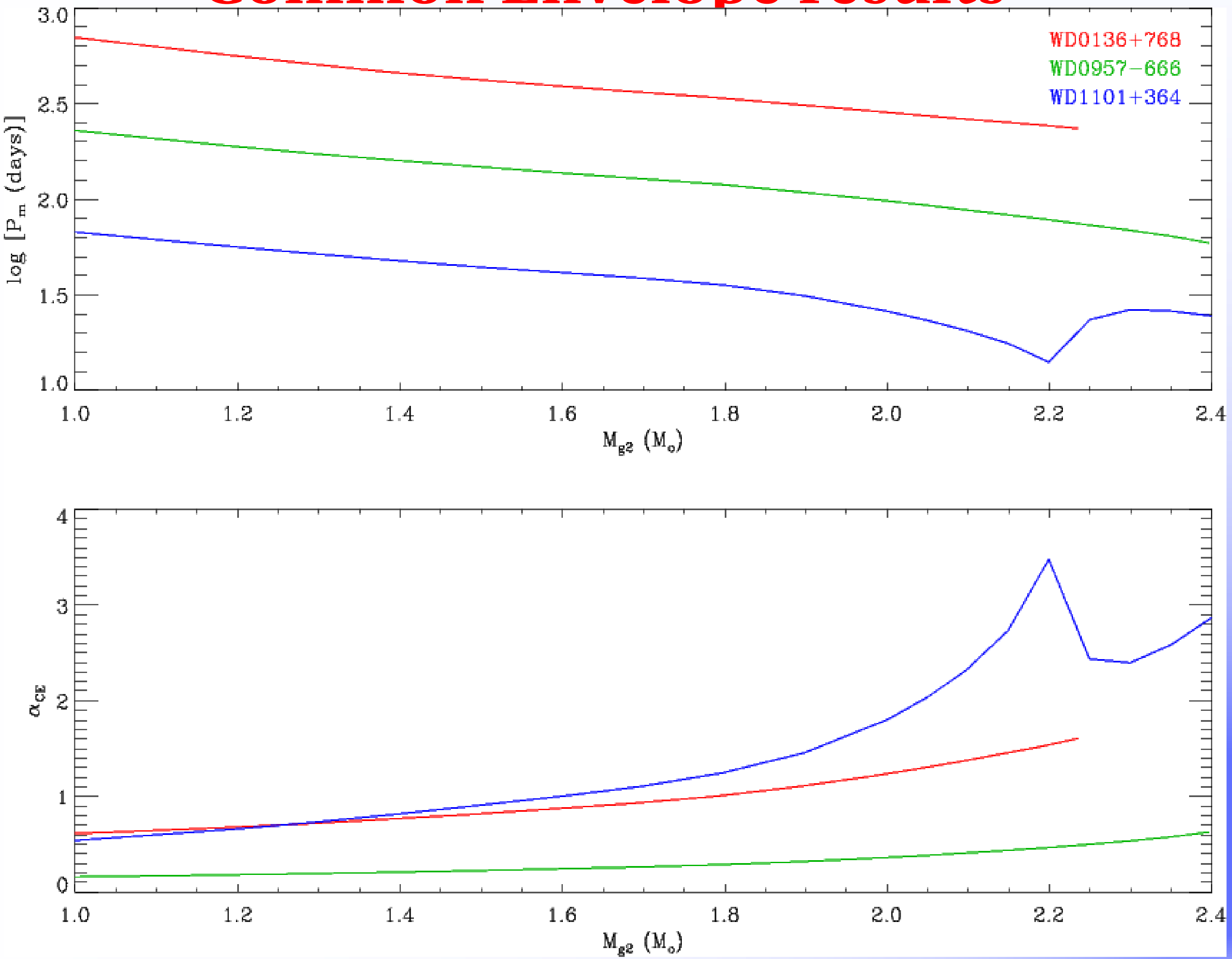
Common Envelope results



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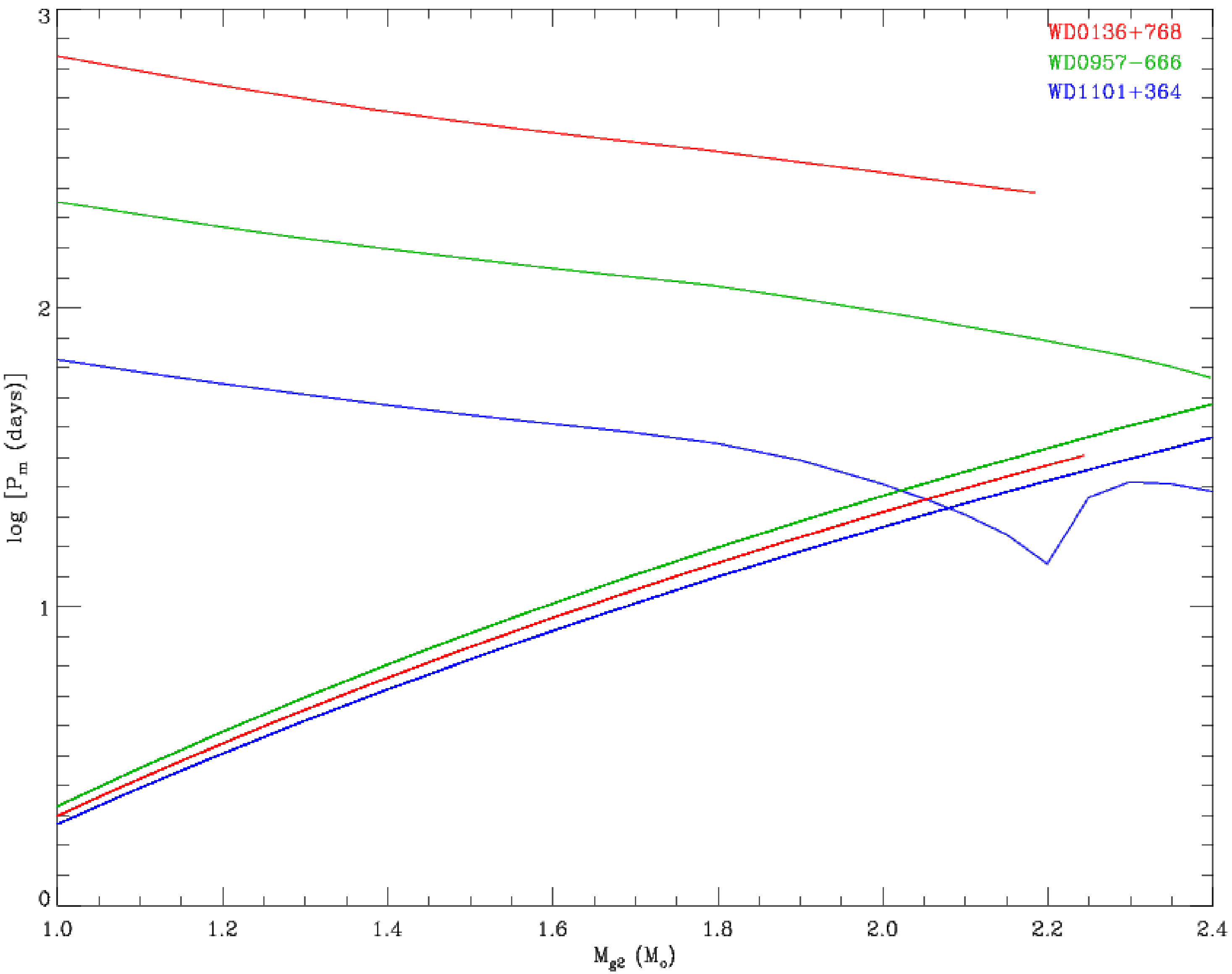
Possible first mass transfer phases

**For each of the common envelope outcomes,
multiple ranges of possibile first mass transfer phases
must be investigated:**

Different scenarios:
stable, conservative MT
stable, non-conservative MT
Common Envelope

For each scenario:
different initial mass ratios
different initial periods

Stable, conservative mass transfer



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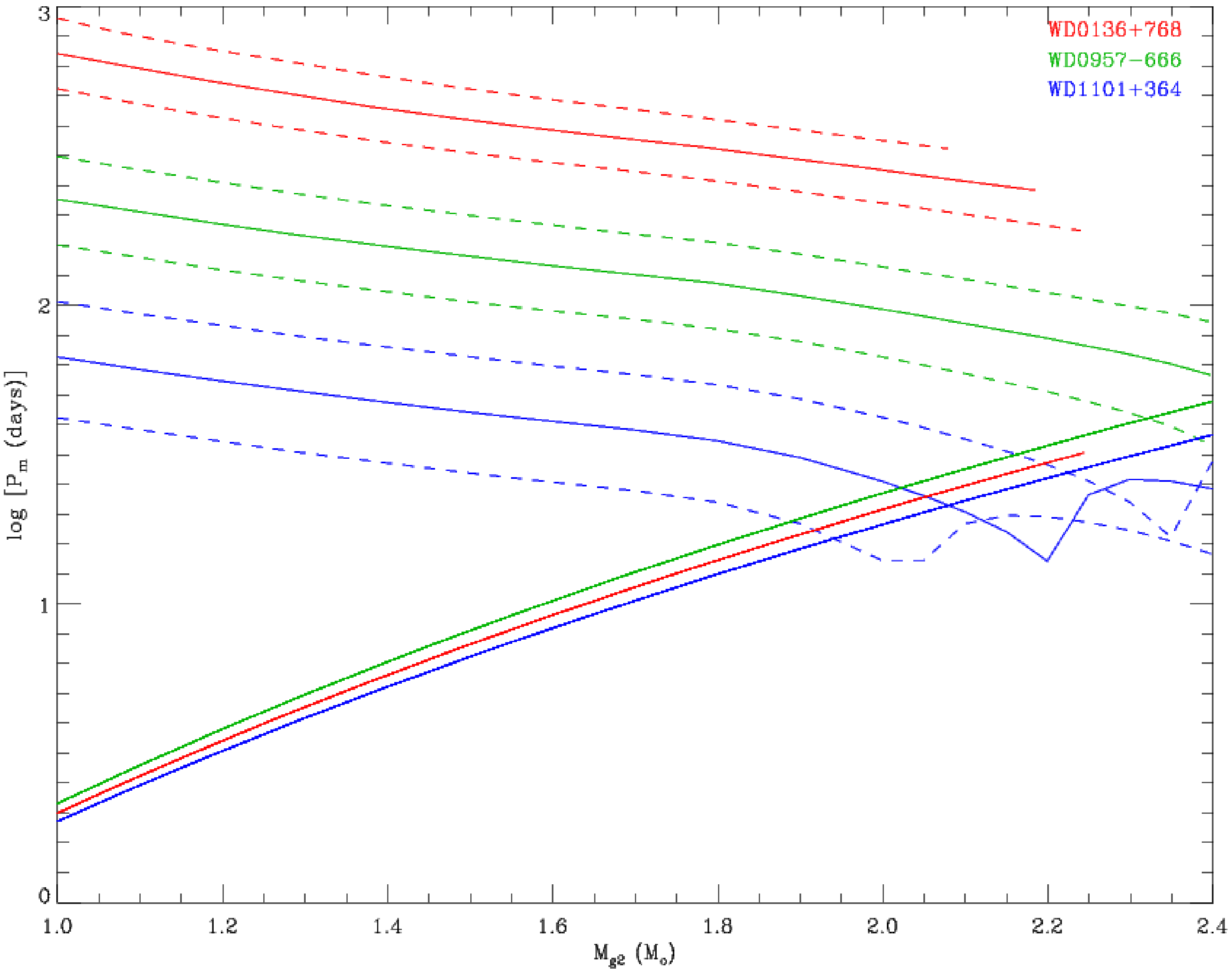
Stable, conservative mass transfer



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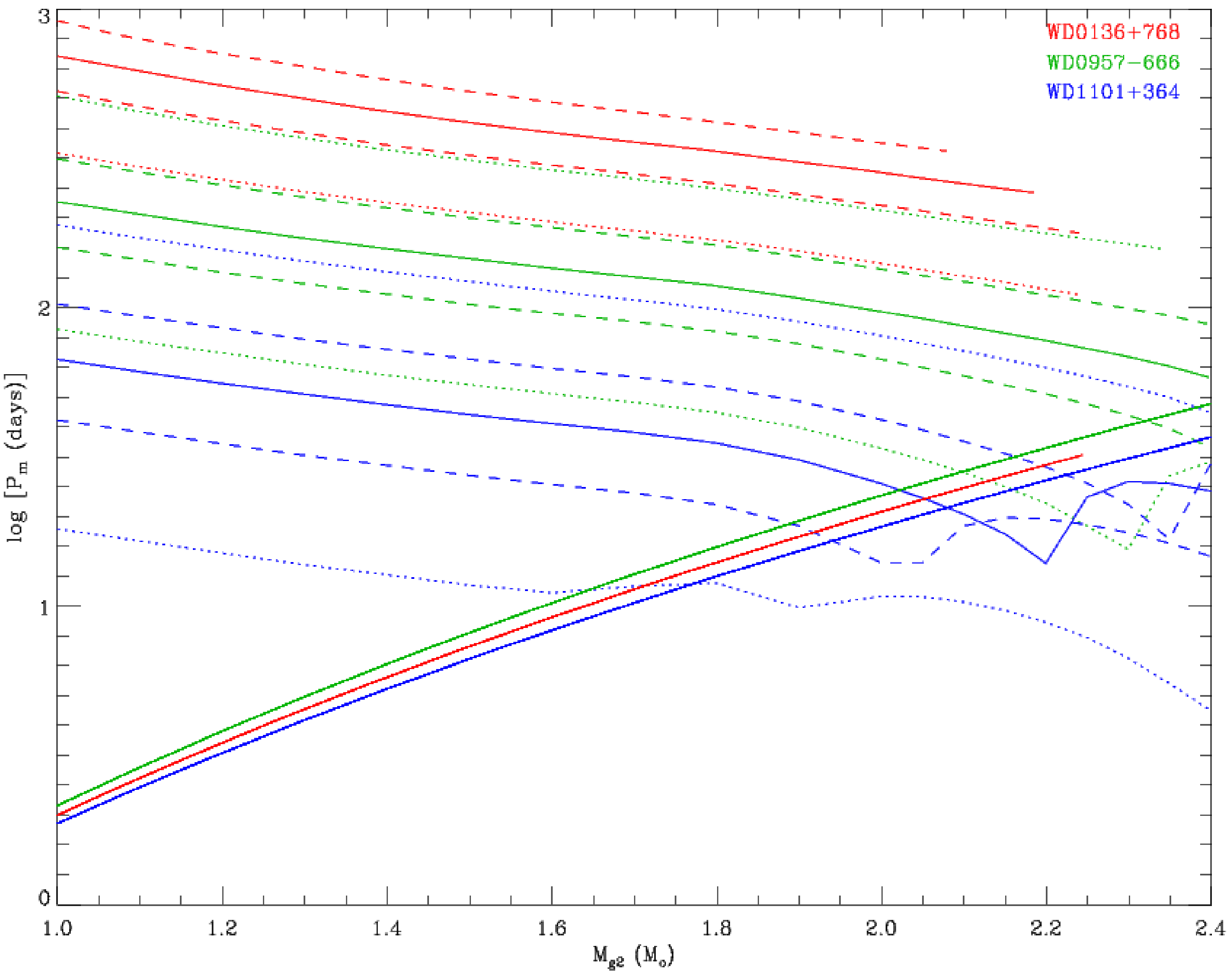
Stable, conservative mass transfer



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Stable, conservative mass transfer

Problems sofar:

Mass transfer in possible progenitor systems is unstable

or

Mass transfer rate is too high:
Primary core mass doesn't grow enough
during mass transfer phase

Possible solutions:

Shorter, but not too short, initial period

Include rotation in models,
non-conservative mass transfer

Future work

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Find a better criterion for stable mass transfer

**Do forward binary evolution calculations
to confirm the outcome of
the first mass transfer phase**

**Consider partially conservative mass transfer
to explain WD0136+768**

Include the non-helium WDs in the sample

Include WD cooling age constraints