Common-envelope ejection efficiencies for the formation of sdB binaries

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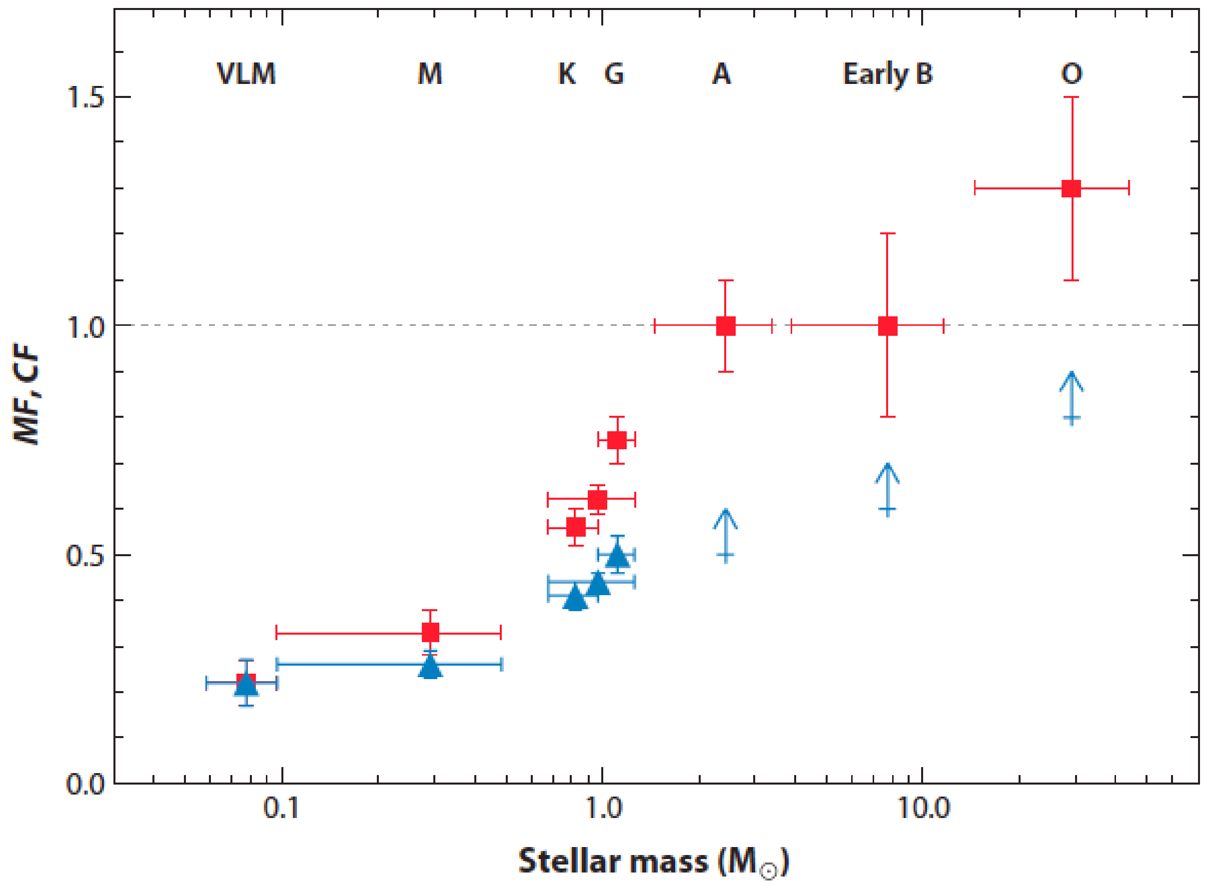
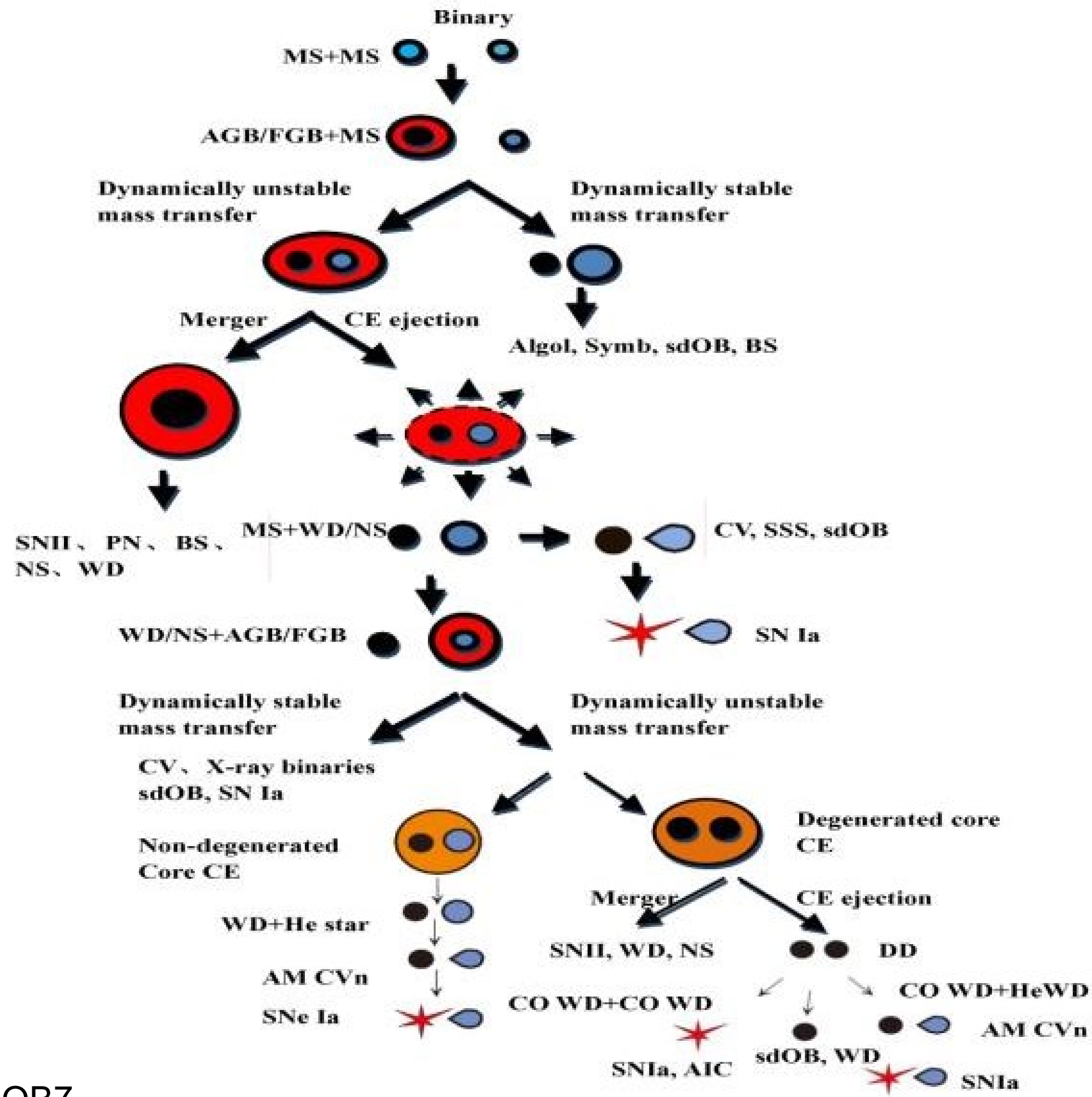
Binaries are common:

Duchêne & Kraus (2013) showed the dependency of CF (companion frequency; red squares) and MF (multiplicity frequency; blue triangles) with primary mass for main-sequence stars and field very low-mass (VLM) objects.



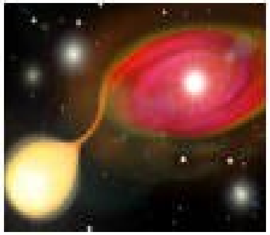
Binary Evolution Flow Chart



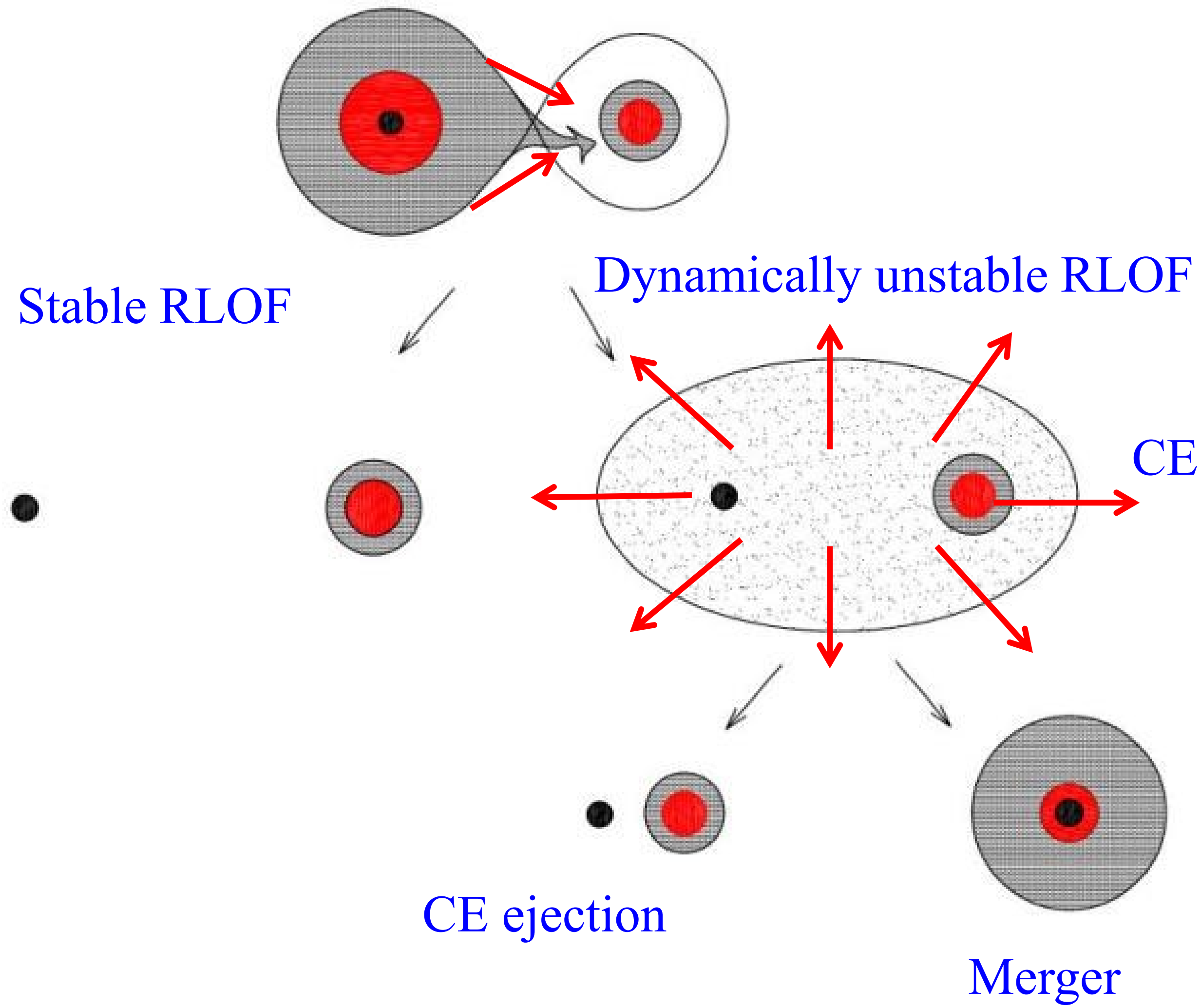
Binary evolution leads to the formation of many important objects:

- Cataclysmic variables
- Low/High mass X-ray binaries
- Millisecond pulsars
- Double degenerates
- Supernovae (including SNe Ia)
- Planetary nebulae
- Barium/CH stars
- Subdwarf B stars
- ……



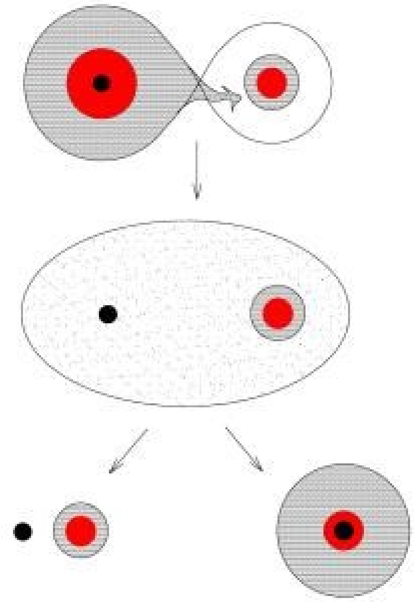

Binary Evolution



Common Envelope Ejection Criterion

$$\Delta E_{\rm orb} \simeq \frac{GM_{\rm c}M_2}{2a_{\rm f}} - \frac{G(M_{\rm c}+M_{\rm e})M_2}{2a_{\rm i}}$$

$$\alpha_{\rm CE}\Delta E_{\rm orb} \geq E_{\rm bind} = E_{\rm gr} - \alpha_{\rm th}E_{\rm th}$$



$E_{\rm gr}$ and $E_{\rm th}$ are integrated for the envelope, as we did since 1995.

No λ

How is the CE ejection efficiency ?

Is internal energy (including recombinational) necessary ?

Does the efficiency depends on companion’s type ?
(Expectation: a dM would be more efficient than a WD in ejecting a CE ?)

The observations of sdB binaries provide an opportunity to answer such questions.

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DOI: 10.1051/0004-6361/201425213

Astronomy & Astrophysics

Hot subdwarf binaries from the MUCHFUSS project

Analysis of 12 new systems and a study of the short-period binary population★

T. Kupfer[1], S. Geier[2], U. Heber[3], R. H. Østensen[4], B. N. Barlow[5], P. F. L. Maxted[6], C. Heuser[3], V. Schaffenroth[3,7], and B. T. Gänsicke[8]

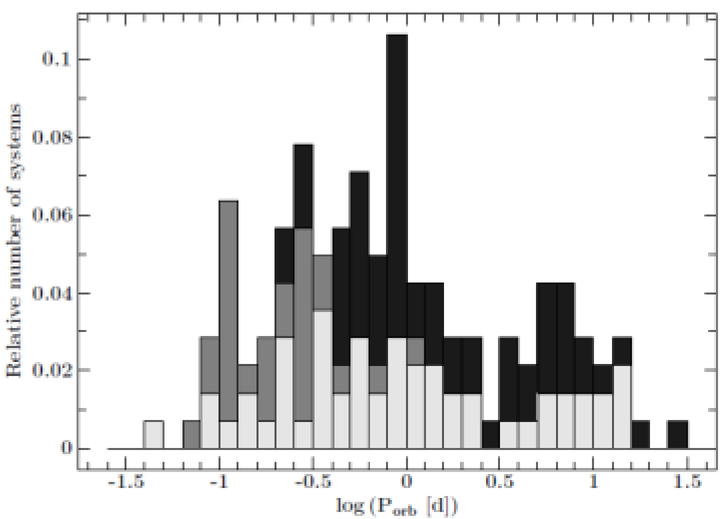
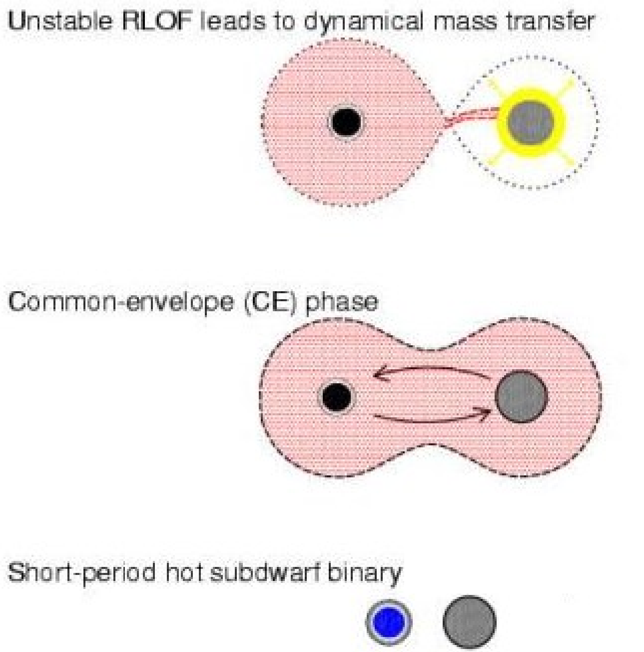


Fig. 7. Period histogram of the full sample. Light grey: WD companions, grey: dM companion, dark grey: unknown companion type.

A detailed BPS study is necessary!

Here we just show our preliminary analysis.

Short-period sdB binaries are from CE ejection channel



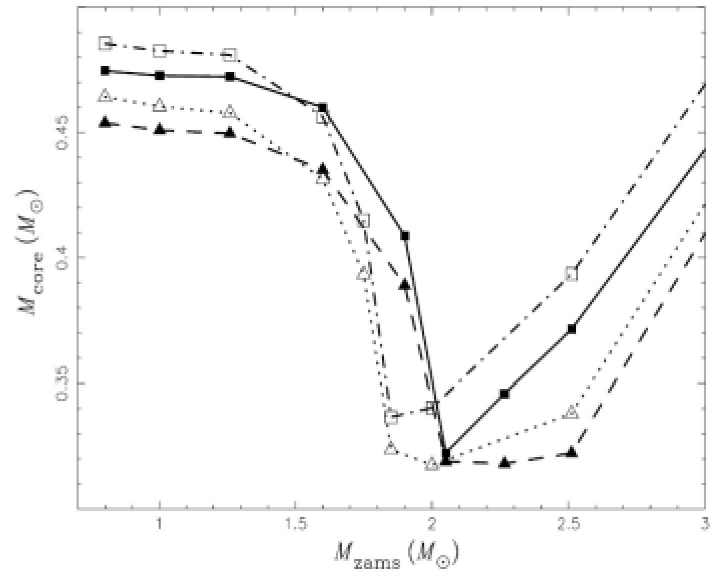


Figure 1. Range of core masses for the occurrence of a He flash (or non-degenerate helium ignition) as a function of initial mass for $Z = 0.02$ (dashed and solid curves) and $Z = 0.004$ (dotted and dot-dashed curves). The lower curve for each set gives the minimum core mass above which a star burns helium, and the upper curve gives the core mass at the normal tip of the first giant branch (FGB).

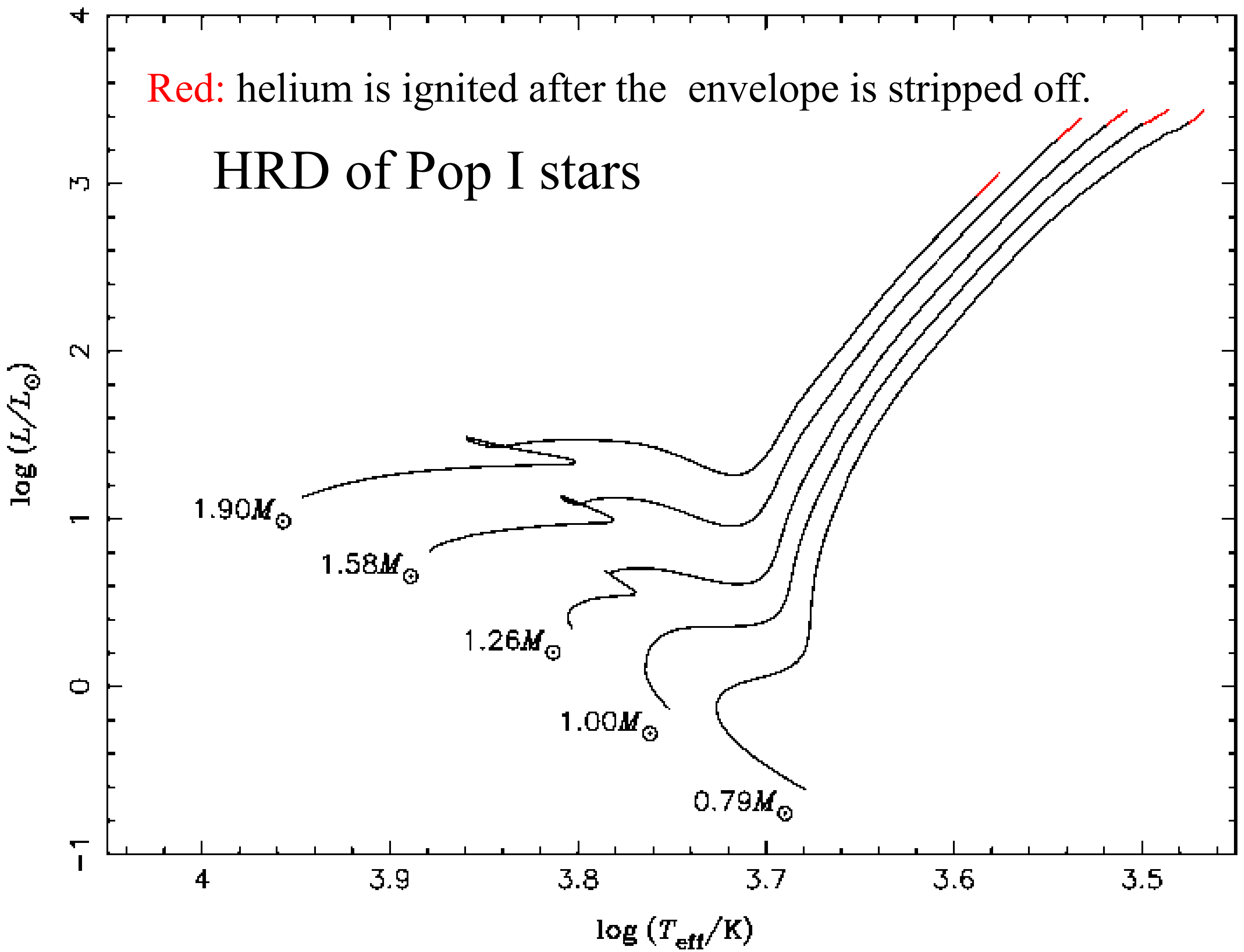
Han Z., Podsiadlowski Ph., Maxted P., Marsh T., Ivanova N., 2002, MNRAS, 336, 449

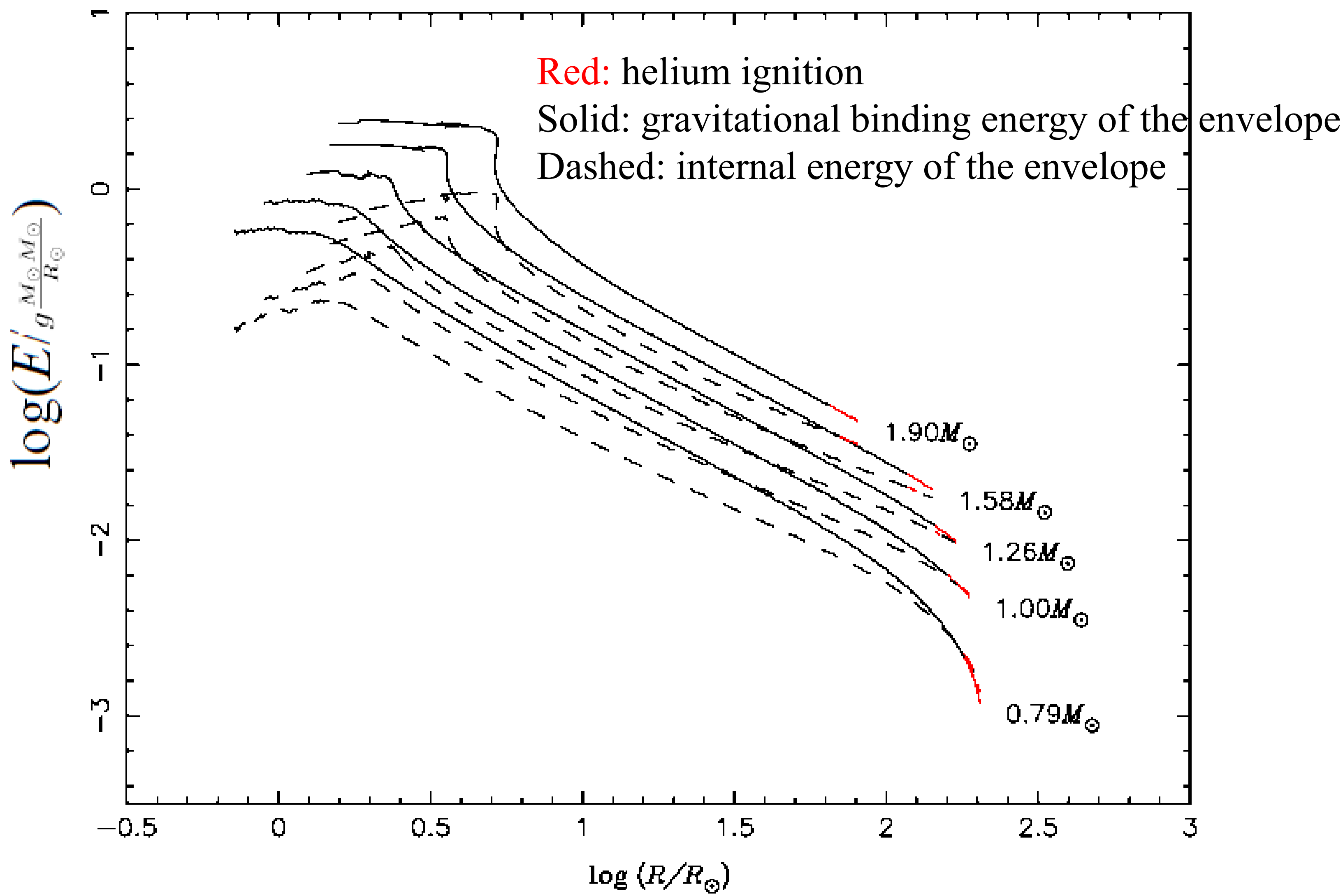
Assumptions:

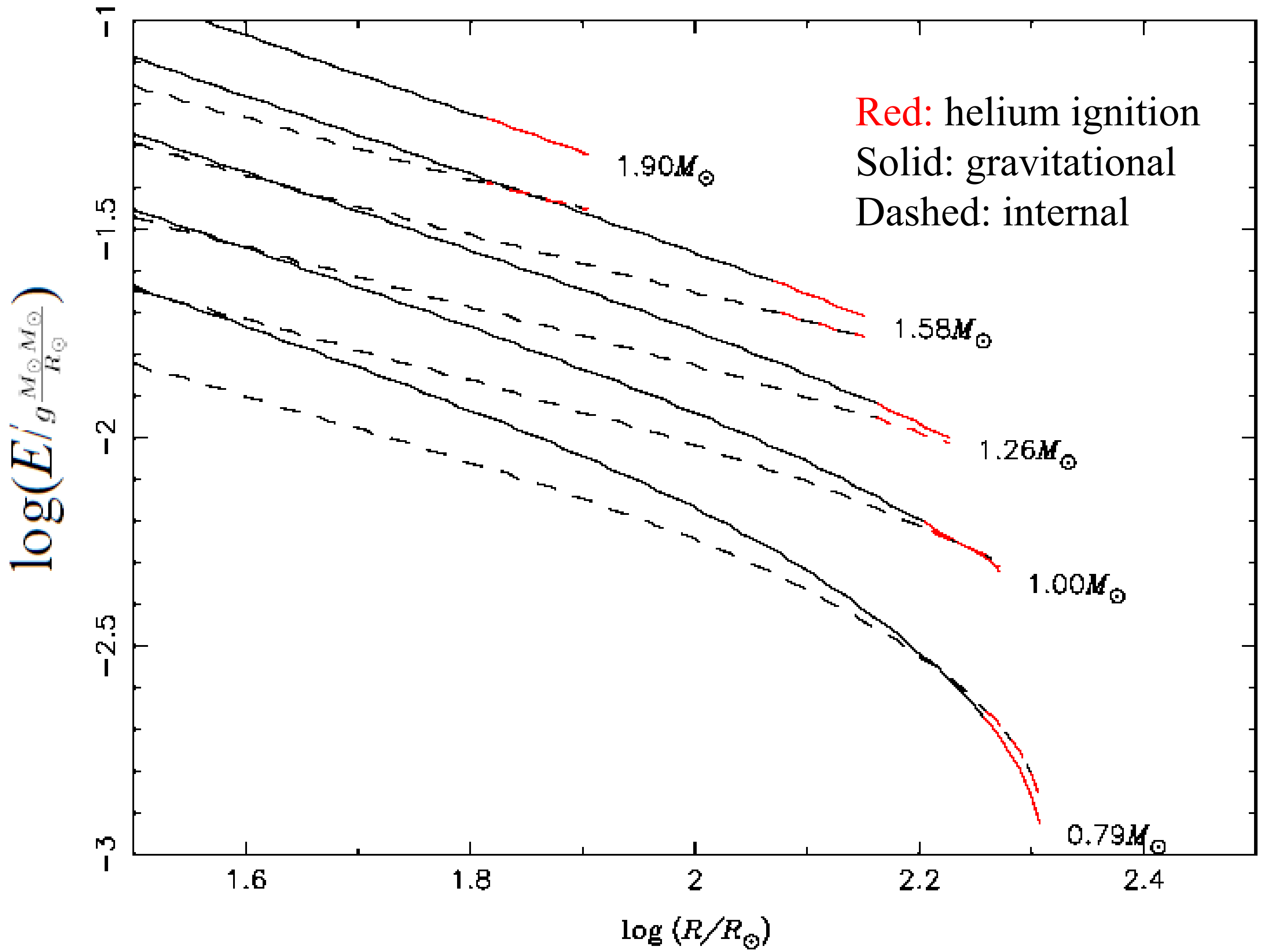
1) Short orbital periods sdB binaries are from CE ejections.
2) The mass of dM companions is taken to be 0.1Msun, and that of WD companions 0.4Msun

Stellar Models:

1) ¼ Reimers' stellar wind
2) With overshooting $\delta_{\rm ov} = 0.12$, equivalent to $0.25H_{\rm p}$
3) For Z=0.02, M=0.8, 1.0, 1.26, 1.6, 1.9Msun

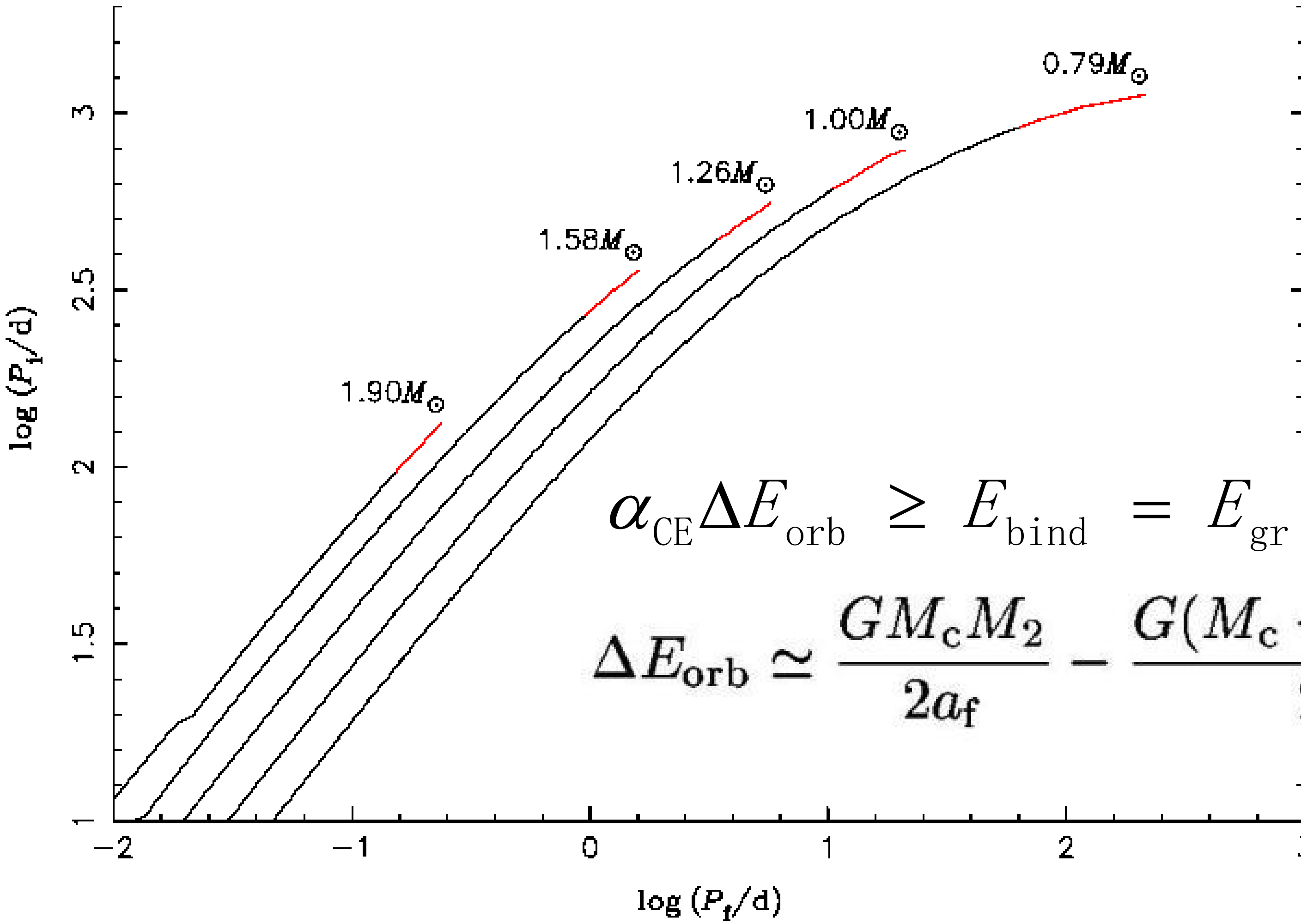

Red: helium is ignited after the envelope is stripped off.
HRD of Pop I stars
1.90$M_\odot$
1.58$M_\odot$
1.26$M_\odot$
1.00$M_\odot$
0.79$M_\odot$
log ($L/L_\odot$)
log (T_{eff}/K)
4
3.9
3.8
3.7
3.6
3.5
−1
0
1
2
3
4


Red: helium ignition
Solid: gravitational binding energy of the envelope
Dashed: internal energy of the envelope
$\log(E/g\frac{M_\odot M_\odot}{R_\odot})$
$\log(R/R_\odot)$
$1.90M_\odot$
$1.58M_\odot$
$1.26M_\odot$
$1.00M_\odot$
$0.79M_\odot$



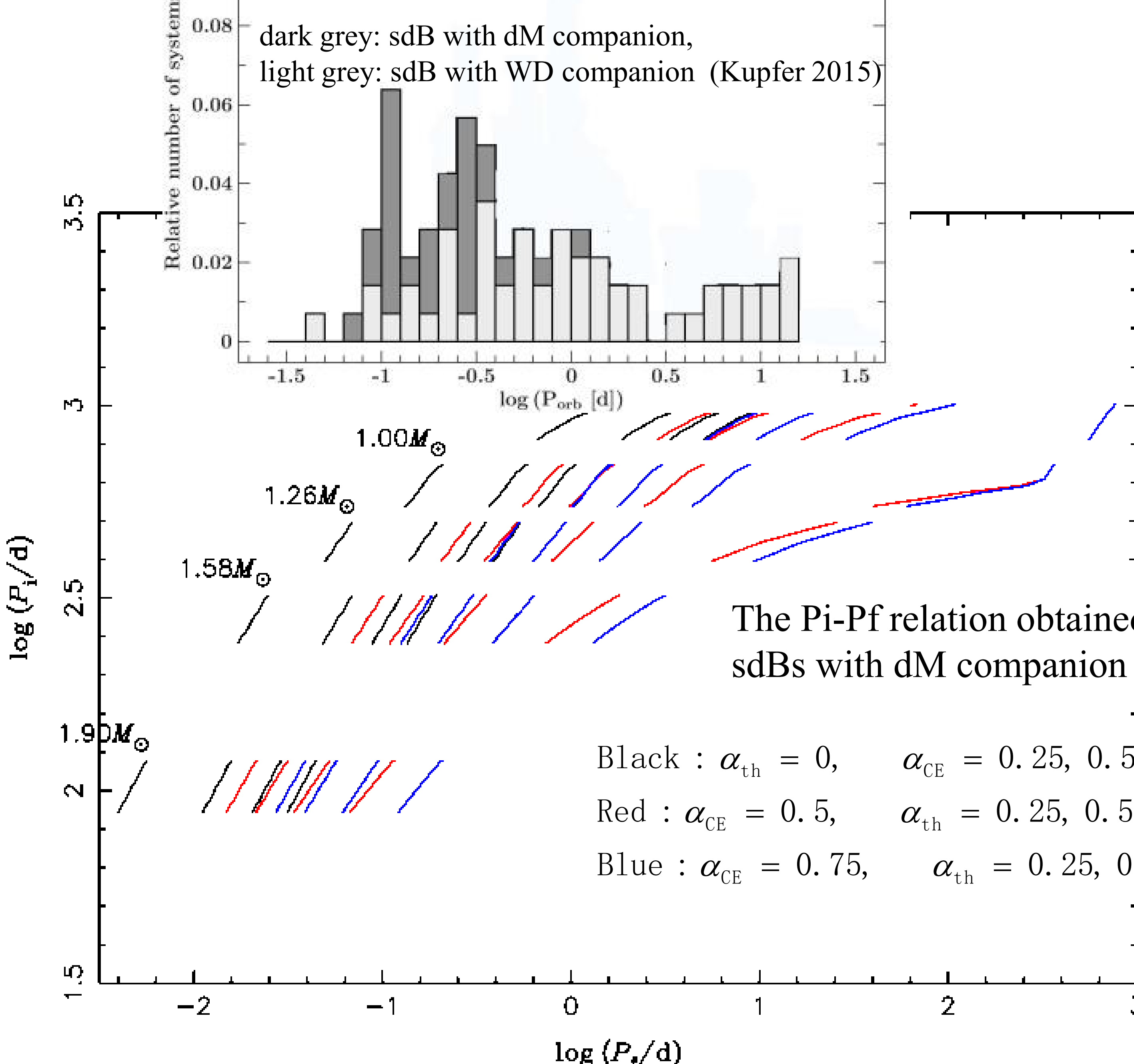
Red: helium ignition
Solid: gravitational
Dashed: internal
1.90$M_\odot$
1.58$M_\odot$
1.26$M_\odot$
1.00$M_\odot$
0.79$M_\odot$
$\log(E/g\frac{M_\odot M_\odot}{R_\odot})$
−1
−1.5
−2
−2.5
−3
1.6
1.8
2
2.2
2.4
$\log(R/R_\odot)$

Given M1, M2, R1 (Roche lobe filling), we can obtain orbital period P.
Given Ebind, alpha_CE, alpha_th, we can then obtain the relation between the initial orbital period Pi and the final orbital period Pf.



$$\alpha_{\mathrm{CE}} \Delta E_{\mathrm{orb}} \geq E_{\mathrm{bind}} = E_{\mathrm{gr}} - \alpha_{\mathrm{th}} E_{\mathrm{th}}$$

$$\Delta E_{\mathrm{orb}} \simeq \frac{G M_{\mathrm{c}} M_2}{2 a_{\mathrm{f}}} - \frac{G(M_{\mathrm{c}} + M_{\mathrm{e}}) M_2}{2 a_{\mathrm{i}}}$$

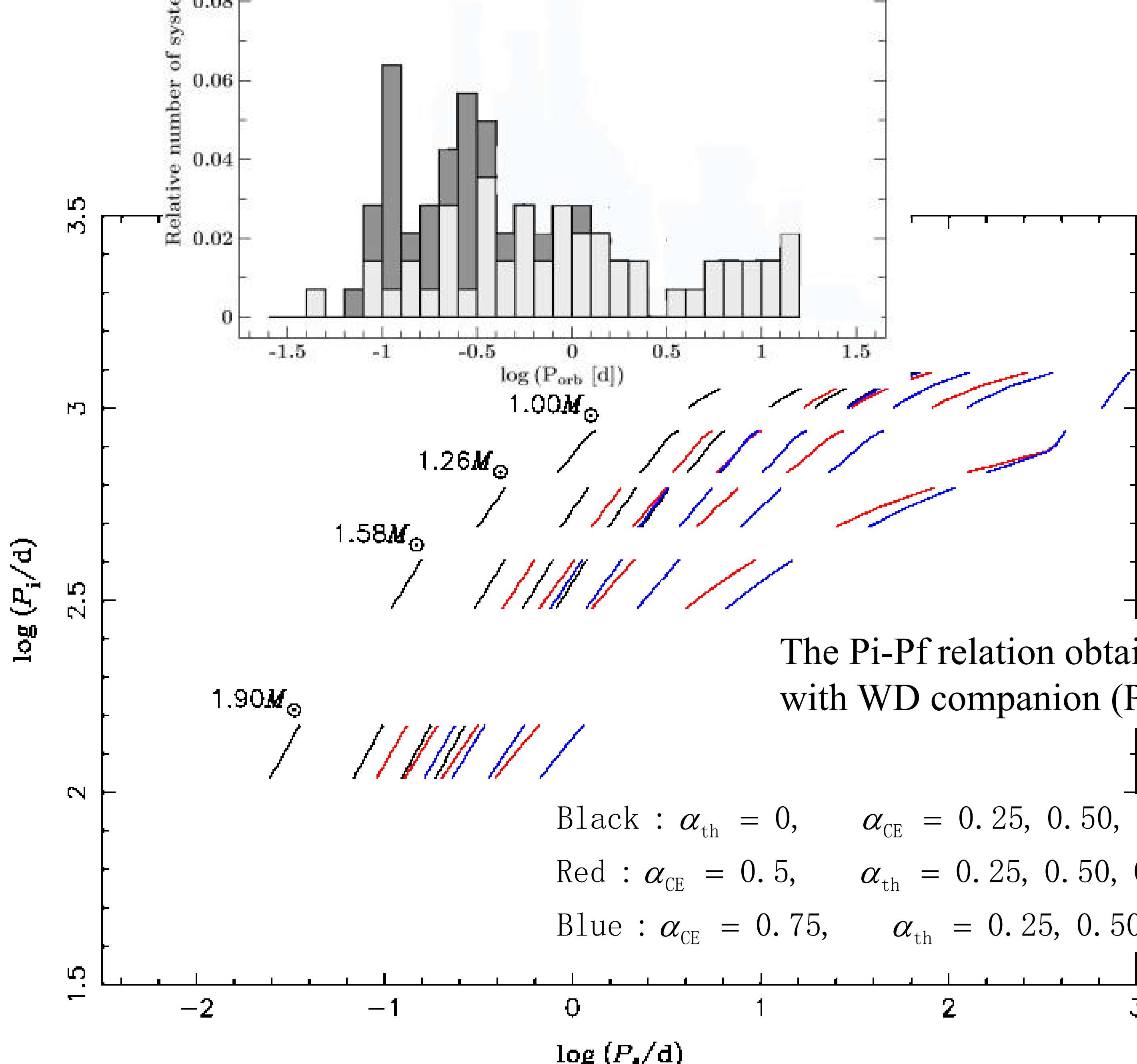


The Pi-Pf relation obtained for sdBs with dM companion (Pop I).

Black : α_{th} = 0, α_{CE} = 0. 25, 0. 50, 0. 75, 1. 0

Red : α_{CE} = 0. 5, α_{th} = 0. 25, 0. 50, 0. 75, 1. 0

Blue : α_{CE} = 0. 75, α_{th} = 0. 25, 0. 50, 0. 75, 1. 0



The Pi-Pf relation obtained for sdBs with WD companion (Pop I)

Black : α_{th} = 0, α_{CE} = 0.25, 0.50, 0.75, 1.0

Red : α_{CE} = 0.5, α_{th} = 0.25, 0.50, 0.75, 1.0

Blue : α_{CE} = 0.75, α_{th} = 0.25, 0.50, 0.75, 1.0

Selection effects: long orbital periods are disfavoured observationally

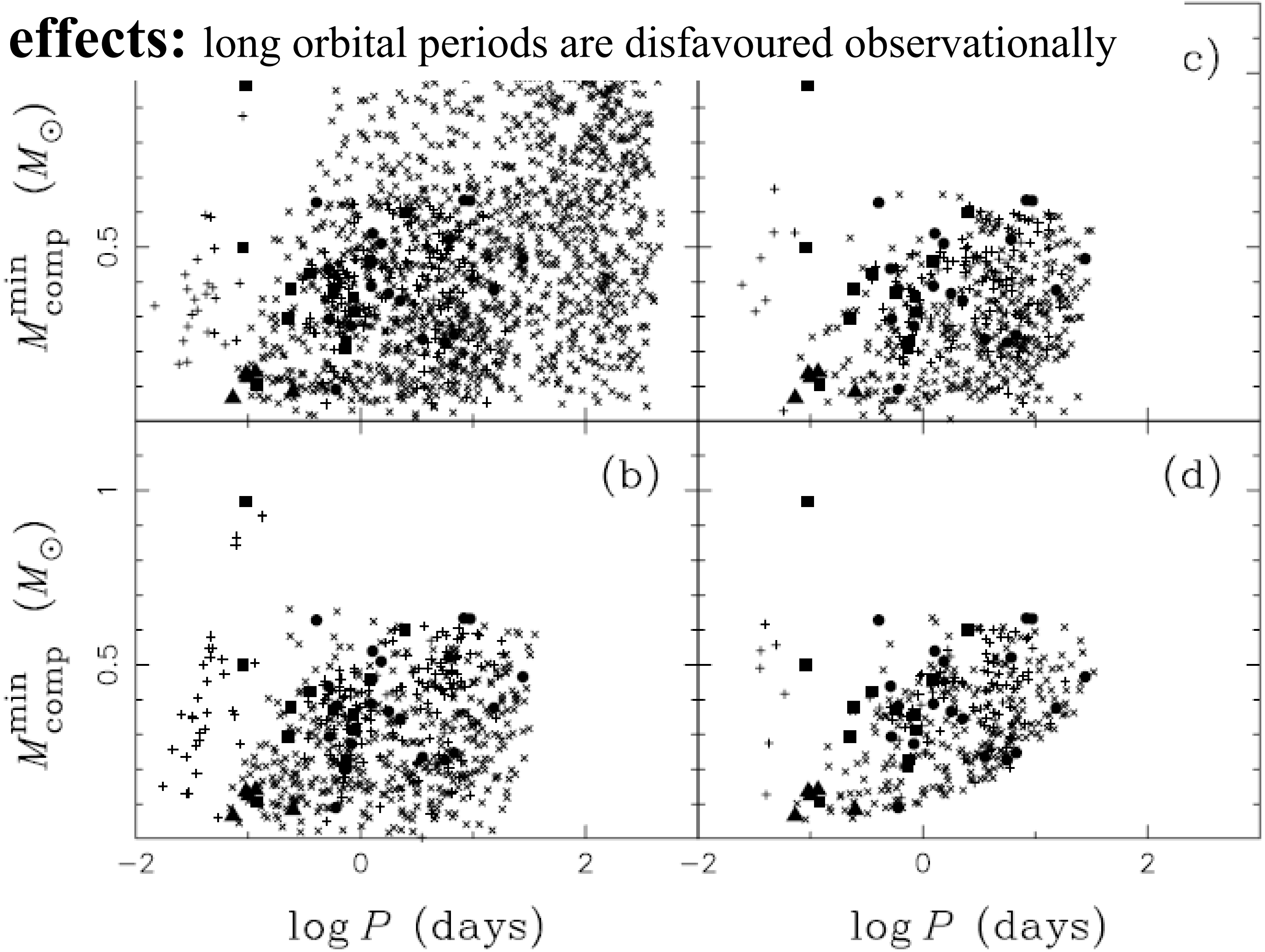


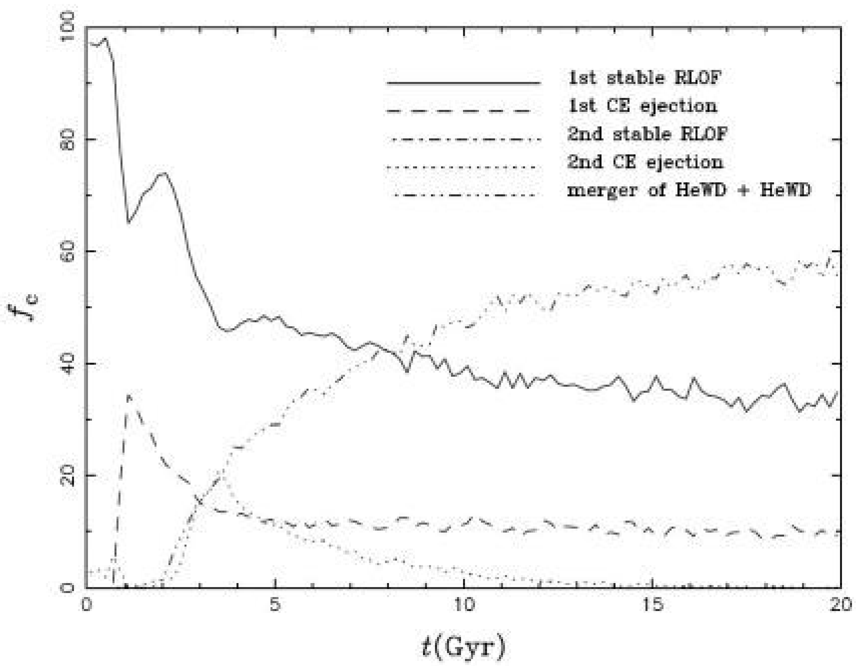
Figure 16. Similar to Fig. 13, but for sdB stars with and without selection effects from simulation set 2 (the best-fitting model): no selection effects (a), GK selection effect (b), the GK and the strip selections effects (c), the GK, the strip and the K selection effects (d).

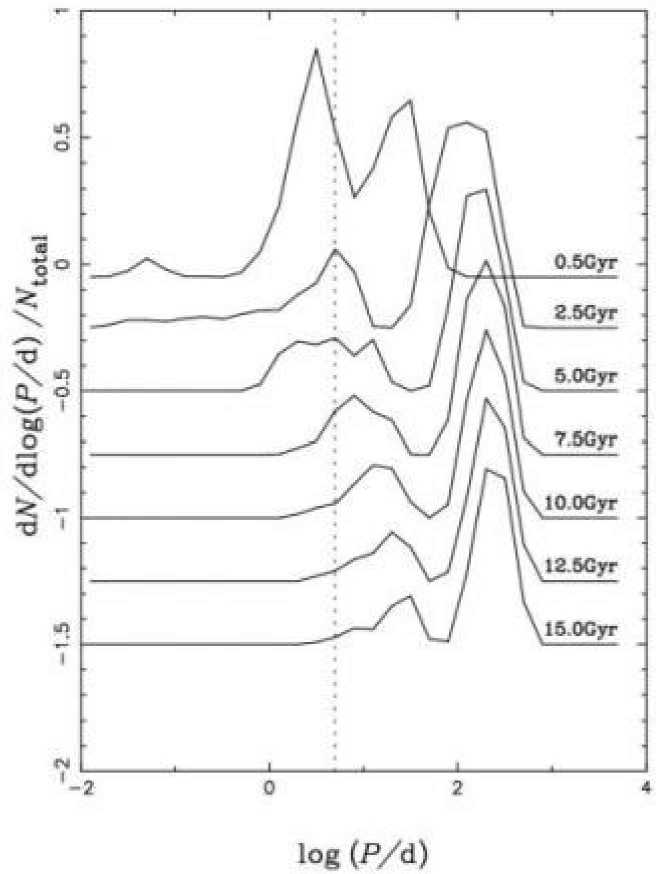
Han Z., Podsiadlowski Ph, Maxted P., Marsh T., 2003, MNRAS, 341, 669

EHB stars in globular clusters

Han, 2008, A&A, 484, L31

Lack of binarity of EHB





Merger channel dominates for old globular clusters and orbital periods of binary EHB stars are larger too.

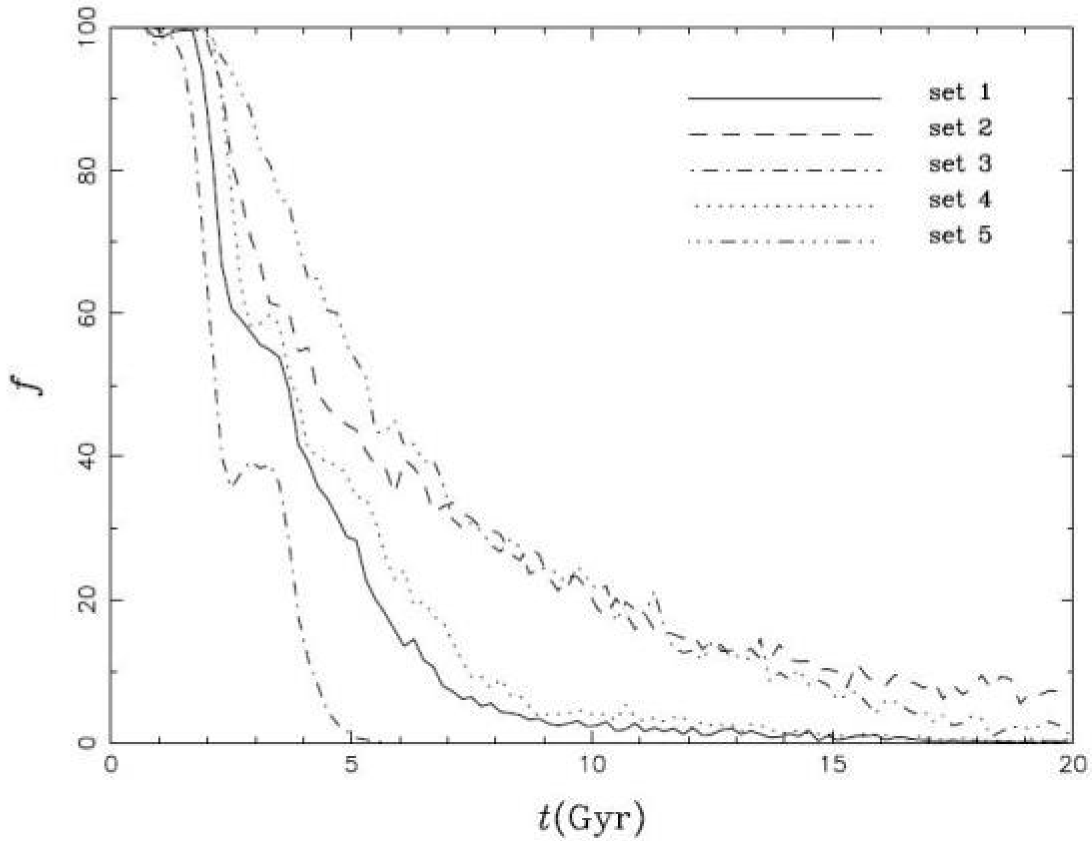


Fig. 3. The evolution of the fraction f (in percentage) of close EHB binaries (with orbital periods $P < 5\,\mathrm{d}$) among all EHB stars, including both binaries and singles. Note that the GK selection effect is applied. If the selection effect is not considered, f would be smaller due to the fact that the GK selection effect excludes wide EHB+MS binaries from the first stable RLOF channel.

Conclusions

- Internal energy (including recombinational) does play a role in CE evolution.
- Detailed BPS study with selection effects required for understanding CE ejection with WD/dM companions!
- Please: Observations of sdB binaries in GC.

Thanks !