Formation of low-mass He WD binaries
&
Constraints to binary and stellar evolution

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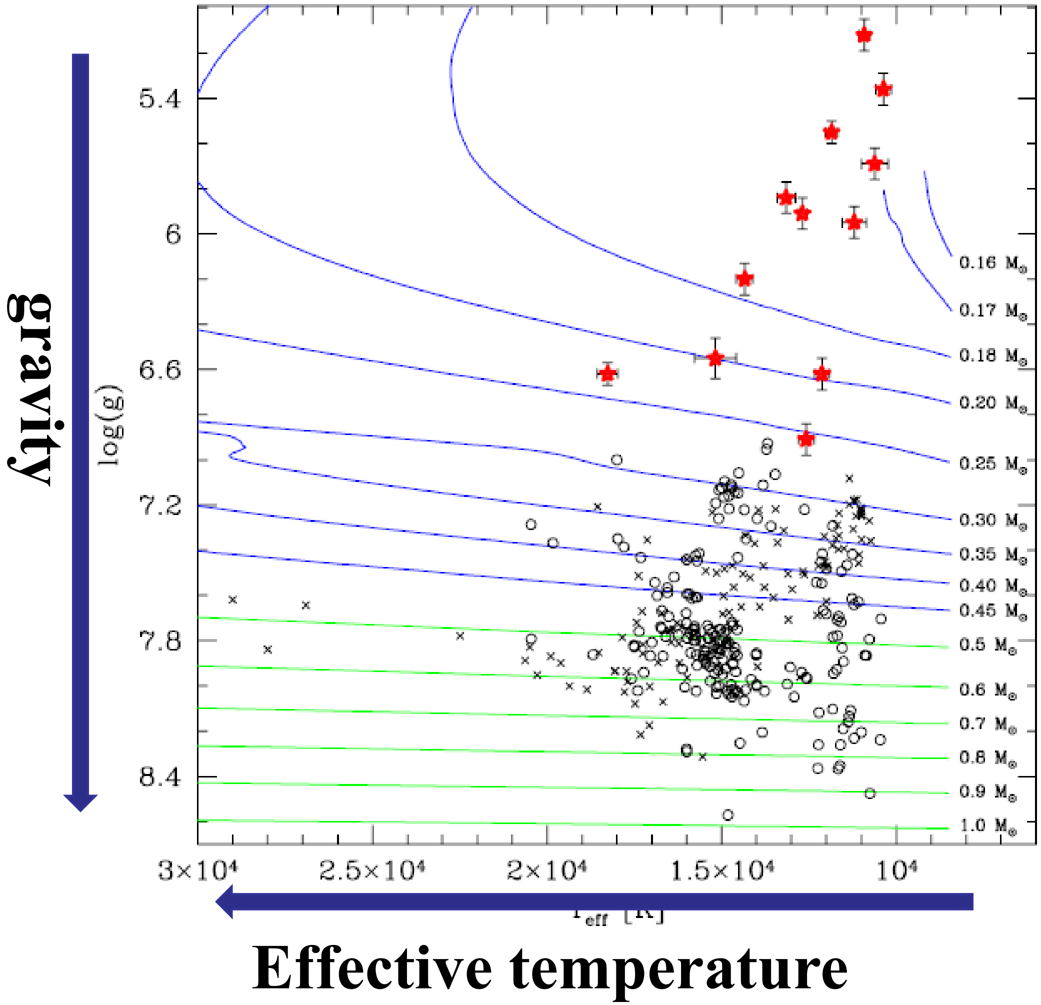
Outline

- Introduction
- Formation of ELM WDs
- EL CVn-type Binaries
- ELM WDs in DDs
- Summary

ELM WDs : Extremely low-mass white dwarfs

Brown+, 2010, ApJ



5< log *g* < 7

8000 K < *T*eff <22000 K

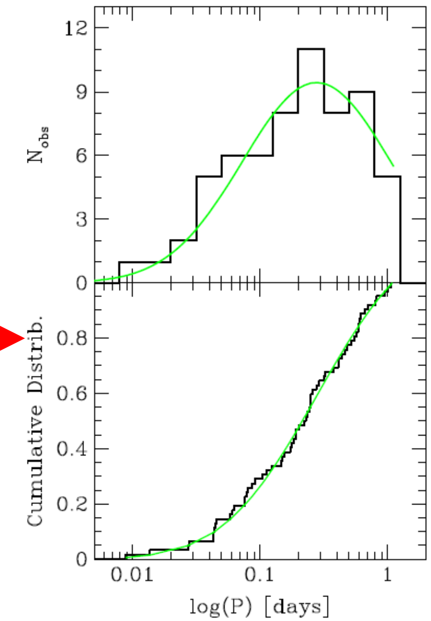
***M* < 0.25-0.3 M$_\odot$**

Observations

I.The ELM Survey (Kilic, Brown, et al. 2009--, SAO, 6.5 m MMT)

- **88 ELM WDs, of which 76 being in binaries**
- **Half of the observed binaries will merge in less than 6Gyr**

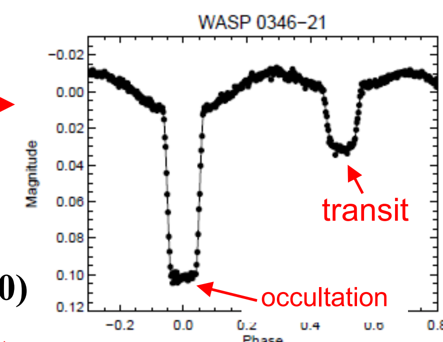
Period distribution



Brown et al. 2016, ApJ

II. The WASP Project Maxted et al.

- **The 1st sample: 1SWASP J024743.37-251549.2 (2011 MNRAS)**
- **Multiple-period pulsations (2013, Nature)**
- **17 EL CVn-type binaries (2014, MNRAS)**

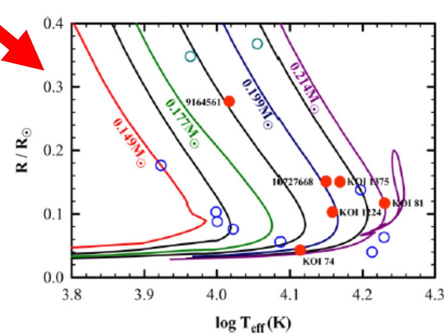


III.Kepler

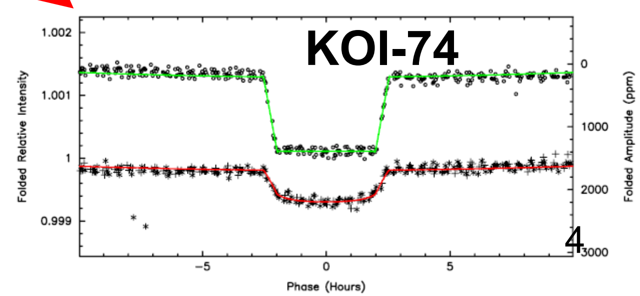
- **The first two: KOI-74, KOI-81 (van Kerkwijk+,2010)**
- **7 objects in total (Rappaport+,2015, Guo+, 2017)**

VI. ELM in MSPs (>10)

Istrate+, 2014, 2016



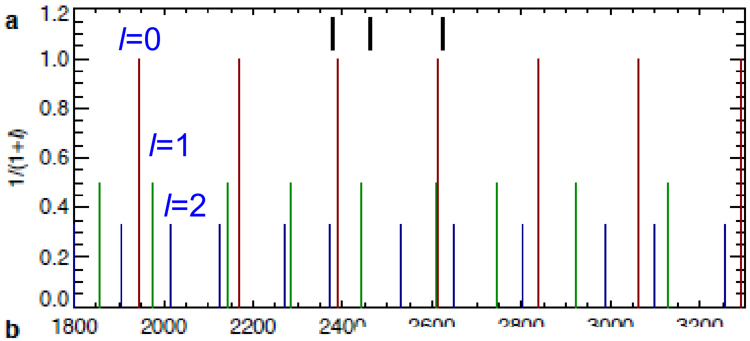
Light Curve



The pre-ELM WD instability stripe

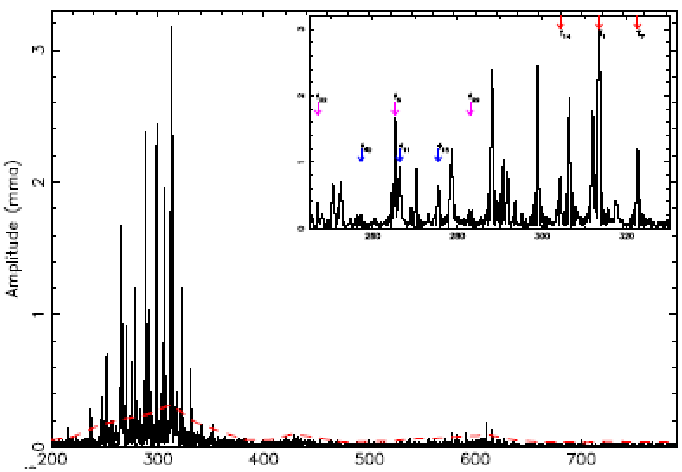
Diven by He++,He+, H+

1SWASP J024743.37-251549.2

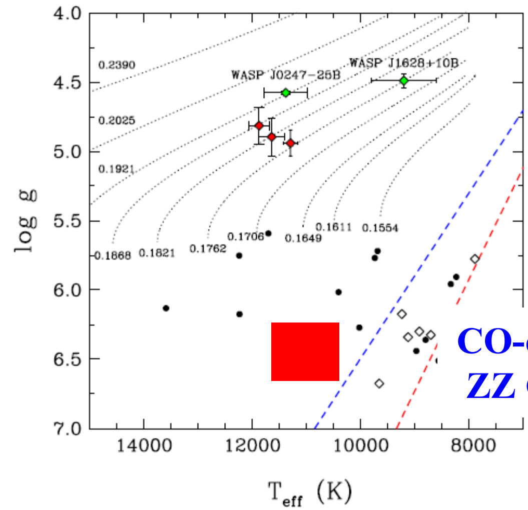


Maxted+, 2013, Nature

KIC 9164561

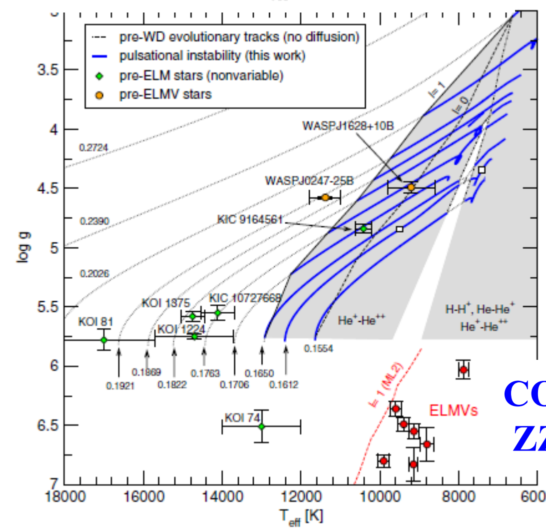


Zhang,X.+, 2016, ApJ



Gianninas+, 2016, ApJ

CO-core ZZ Ceti stars



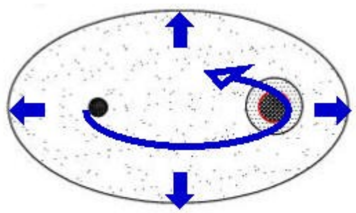
Corsico+, 2016, A&A

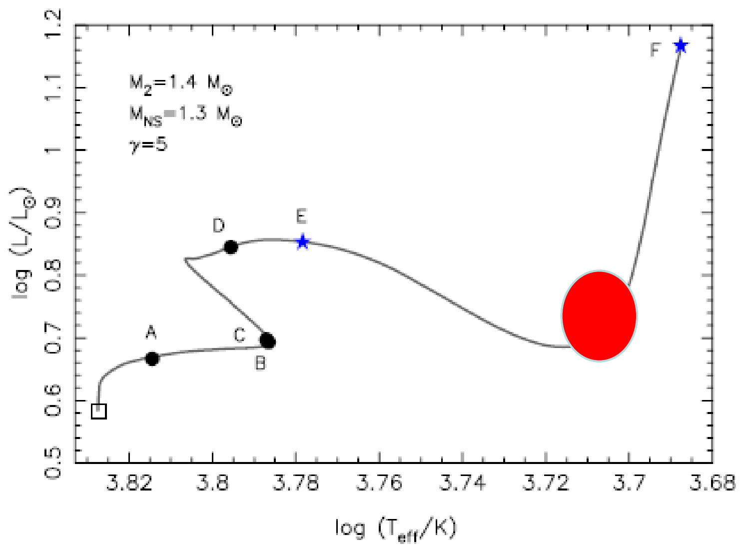
CO-core ZZ Ceti stars

Formation of extremely low-mass WDs

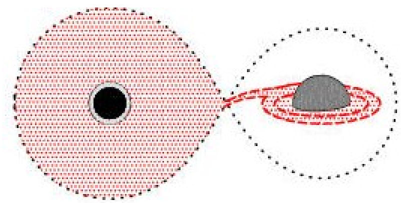
Binary Evolution

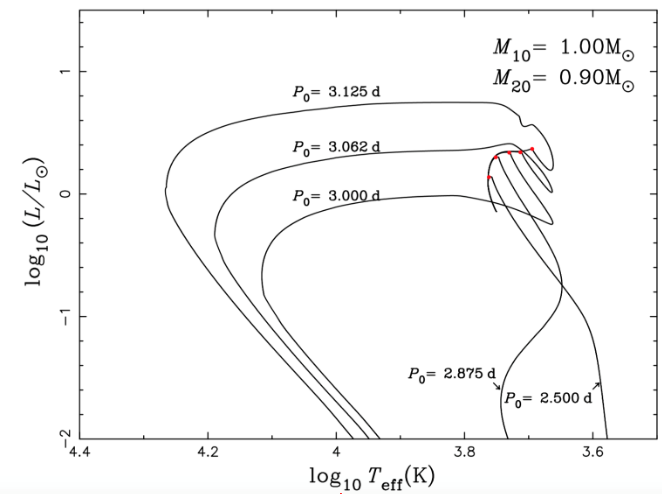
common envelope ejection





stable mass transfer

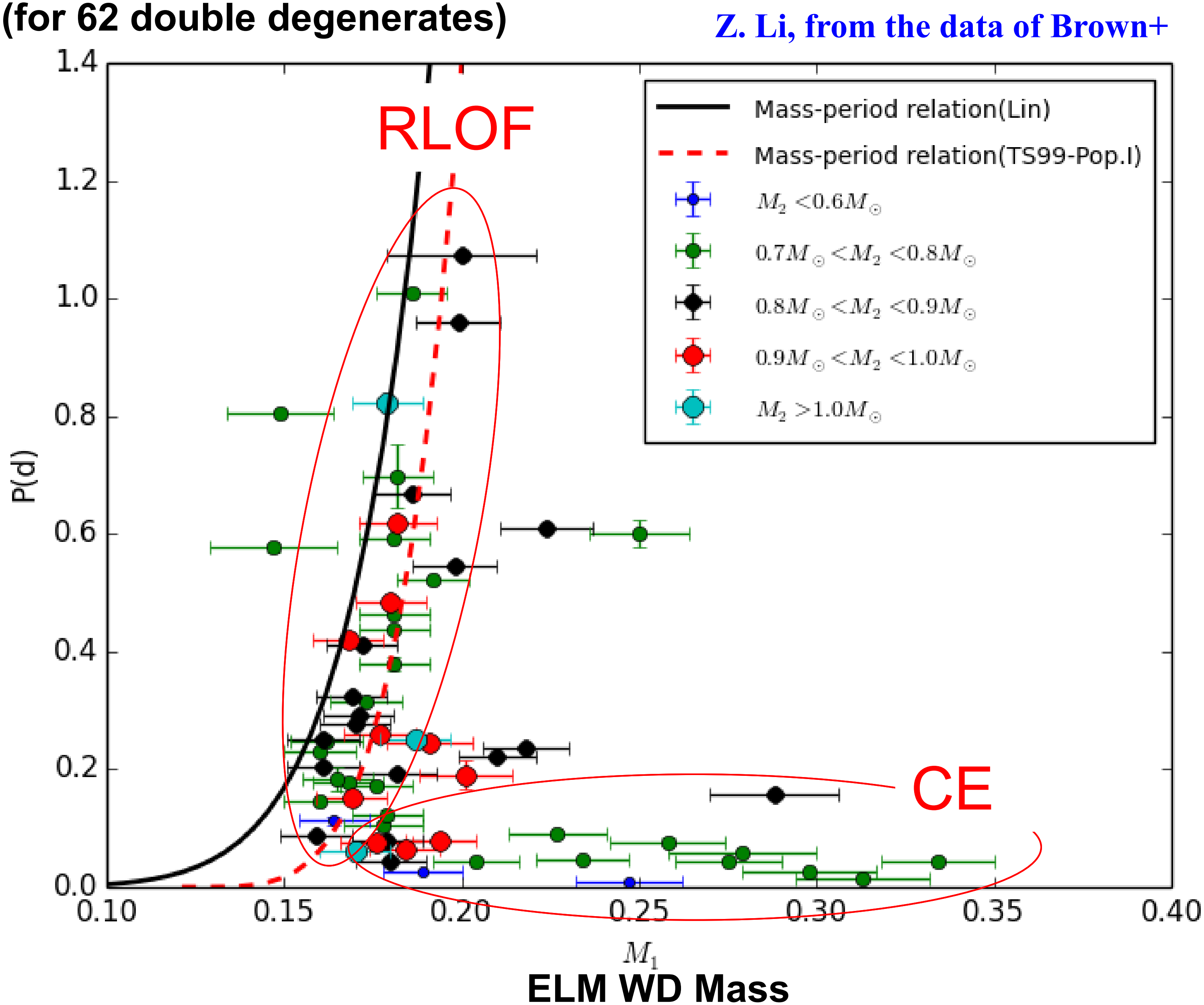




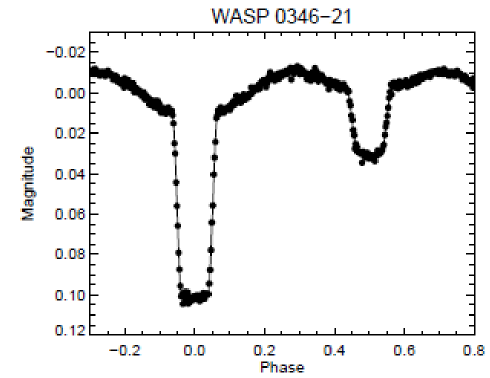
Beyond but very close to the bifurcation period

ELM WD mass VS orbital period

(for 62 double degenerates)



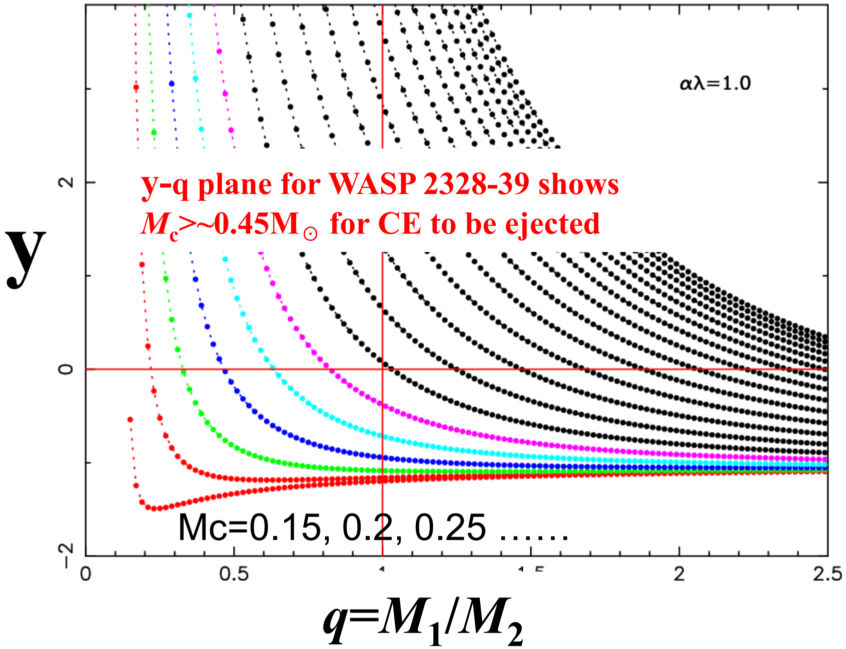
EL CVn-type Binaries



$$\alpha\left[\frac{GM_cM_{2i}}{2a_f} - \frac{G(M_c+M_e)M_{2i}}{2a_i}\right] \geq \frac{G(M_c+M_e)M_e}{\lambda R_{1i}}$$

$$y = \frac{\alpha\lambda}{2(q_i-q_f)}\left[\frac{q_f}{q_i}\left(\frac{1+q_i}{1+q_f}\right)^{1/3}\left(\frac{P_i}{P_f}\right)^{2/3}-1\right]\left(\frac{R_{1i}}{a_i}\right)-1 \geq 0.$$

$q=M_1/M_2$ **should be >1**



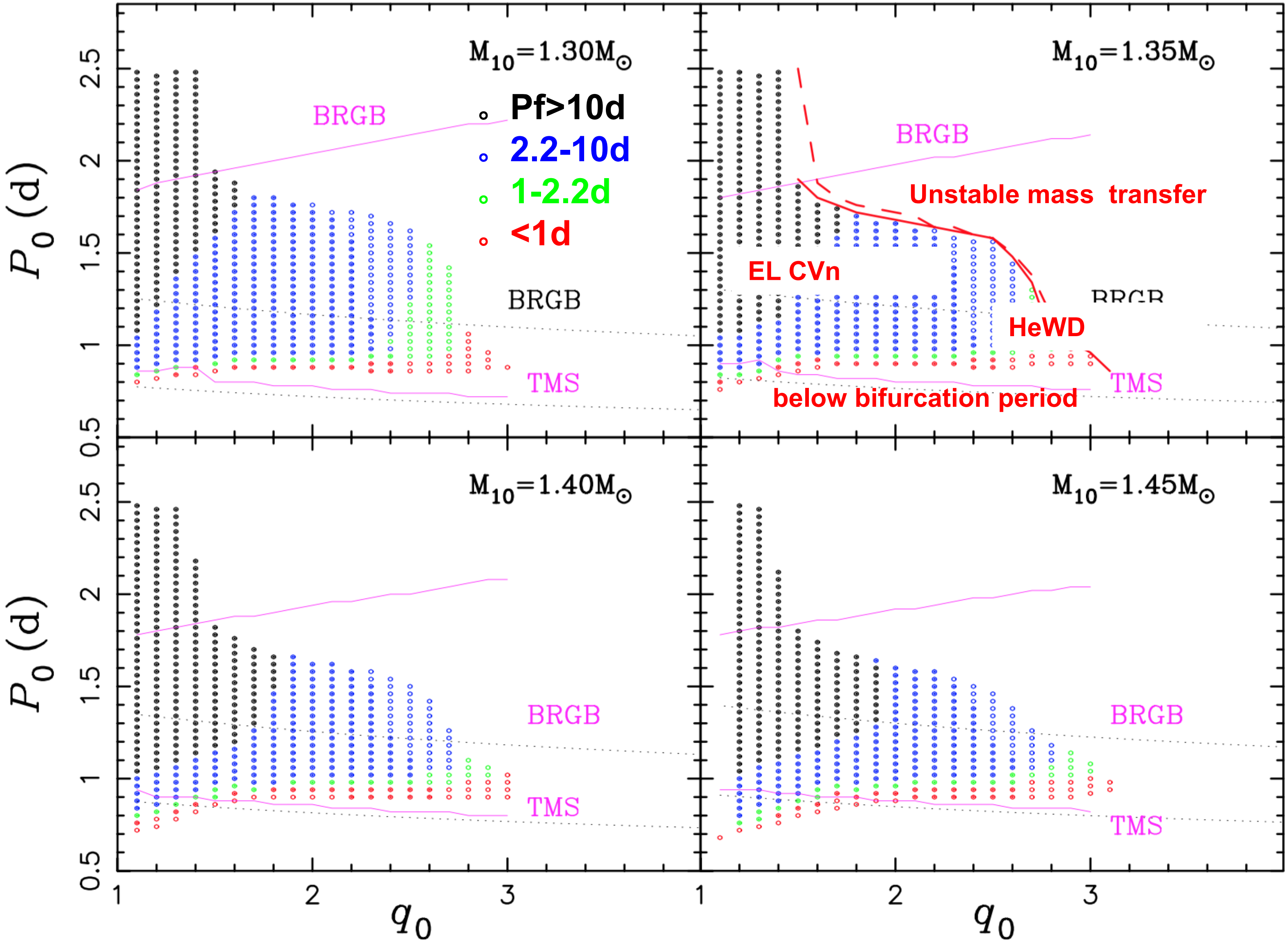
For all 17 samples, y-q analysis shows

M_c>~0.3M⊙ for CE ejection

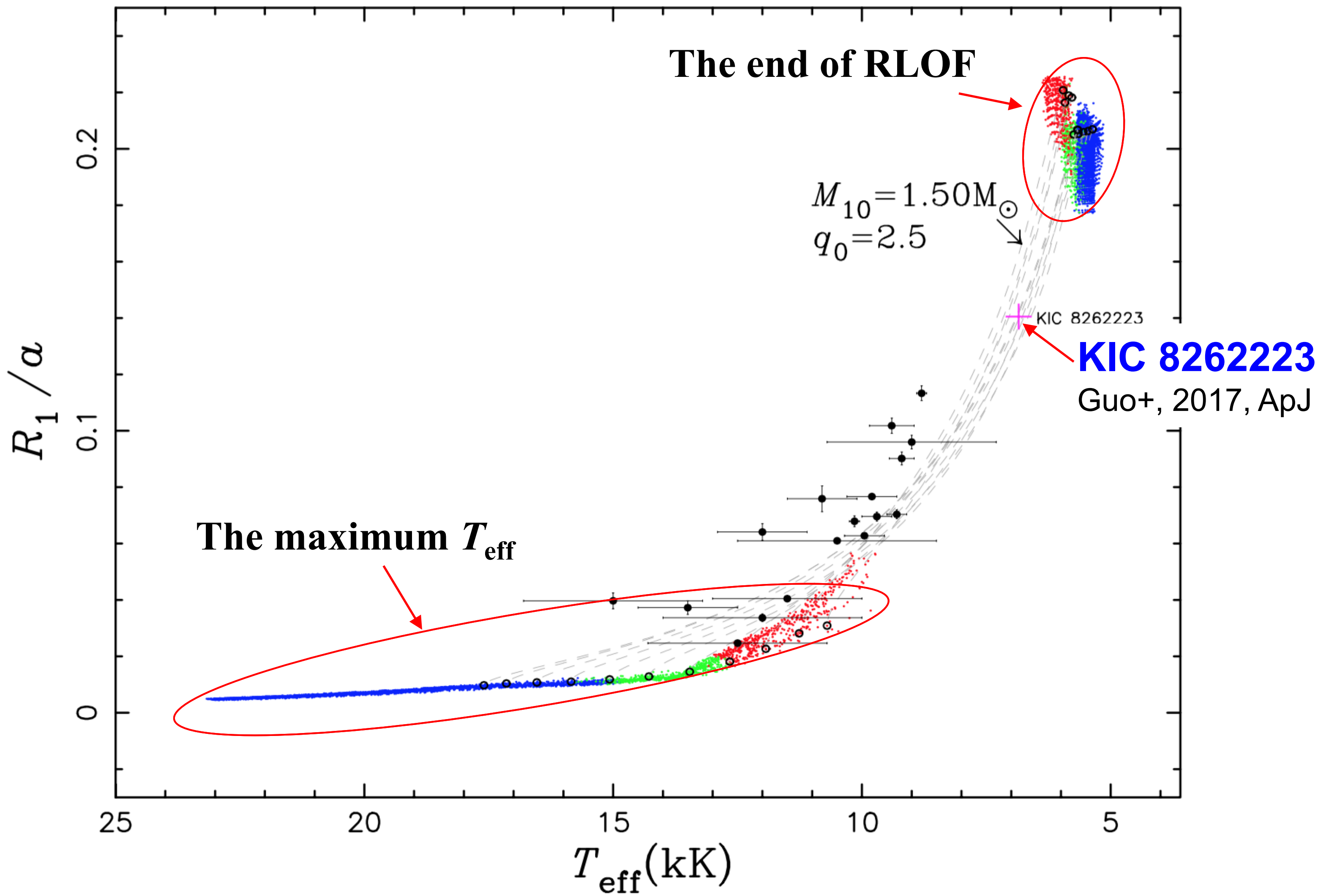
CEE is impossible!

Chen+, 2017, MNRAS

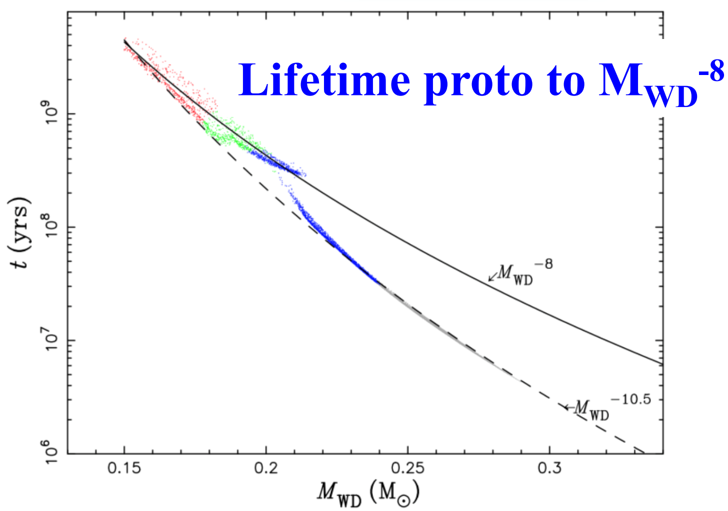
Parameter space for EL CVn-type binaries (model grid calculations)

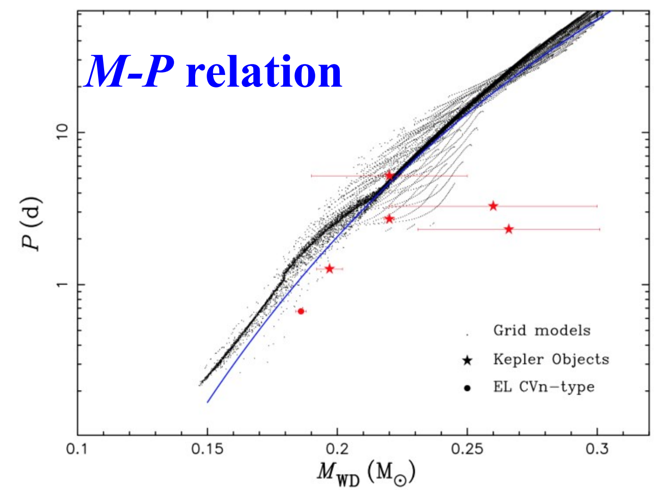


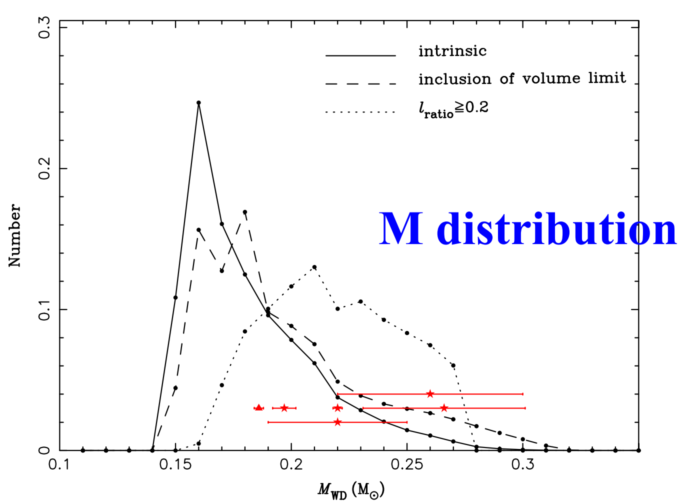
Evolutionary tracks of the proto-He WD components

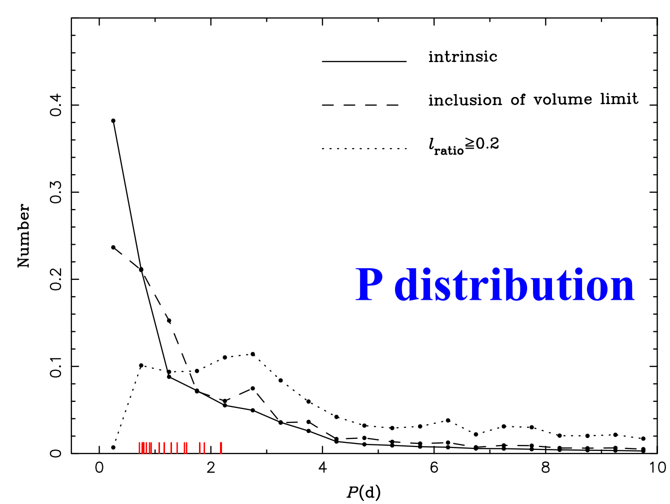


Properties of the proto-He WD components



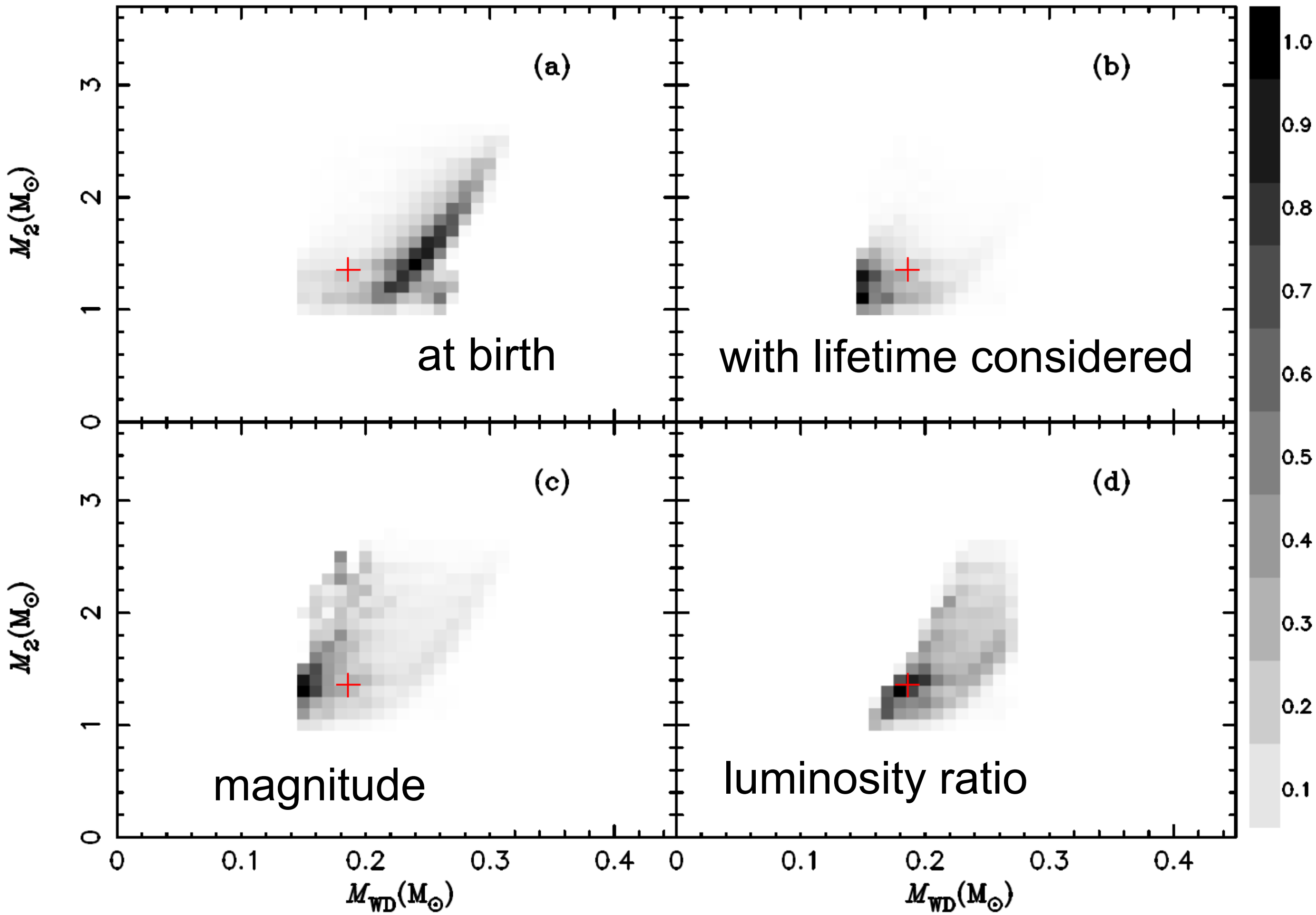






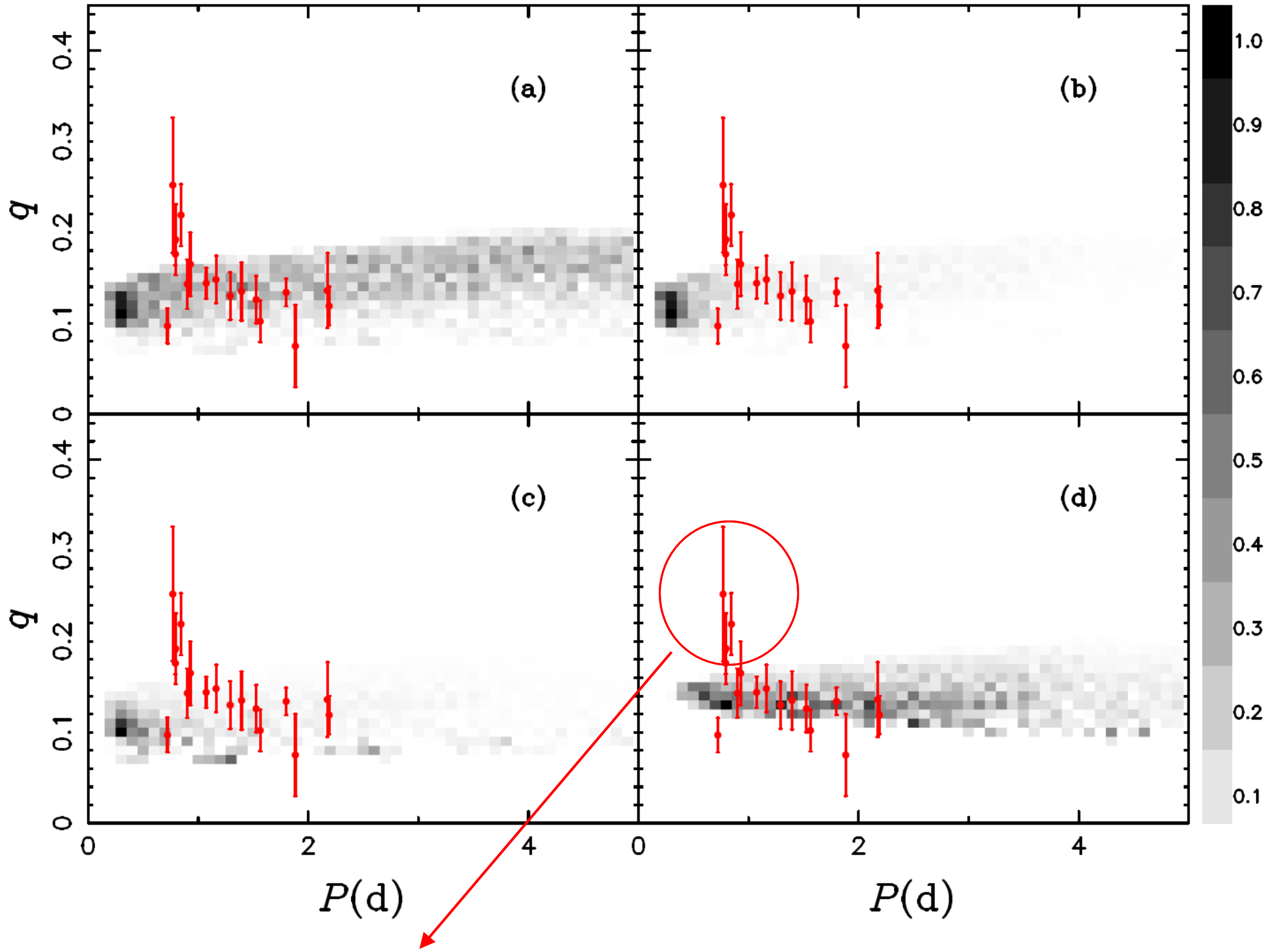
Constraint 1:
The minimum He WD mass ?

Component Masses



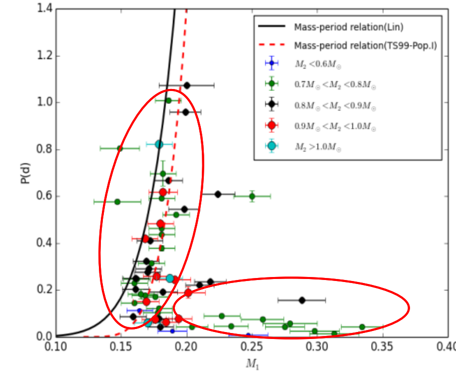
Period vs Mass ratio

Our model: mass transfer efficiency beta=0.5



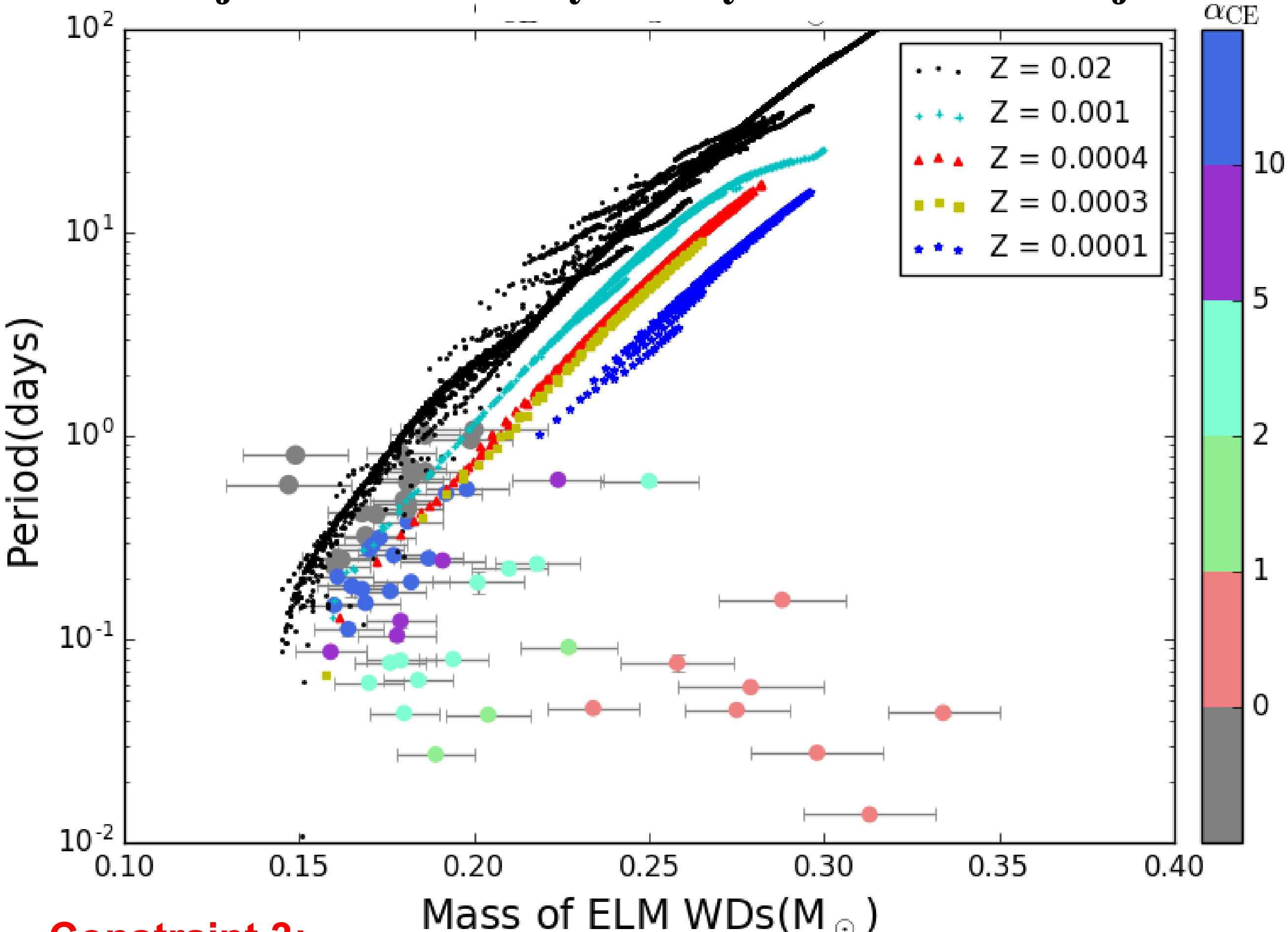
Constraint 2:
Less conservative than assumed

ELM WDs in DDs



Q: How to distinguish the the two groups ?

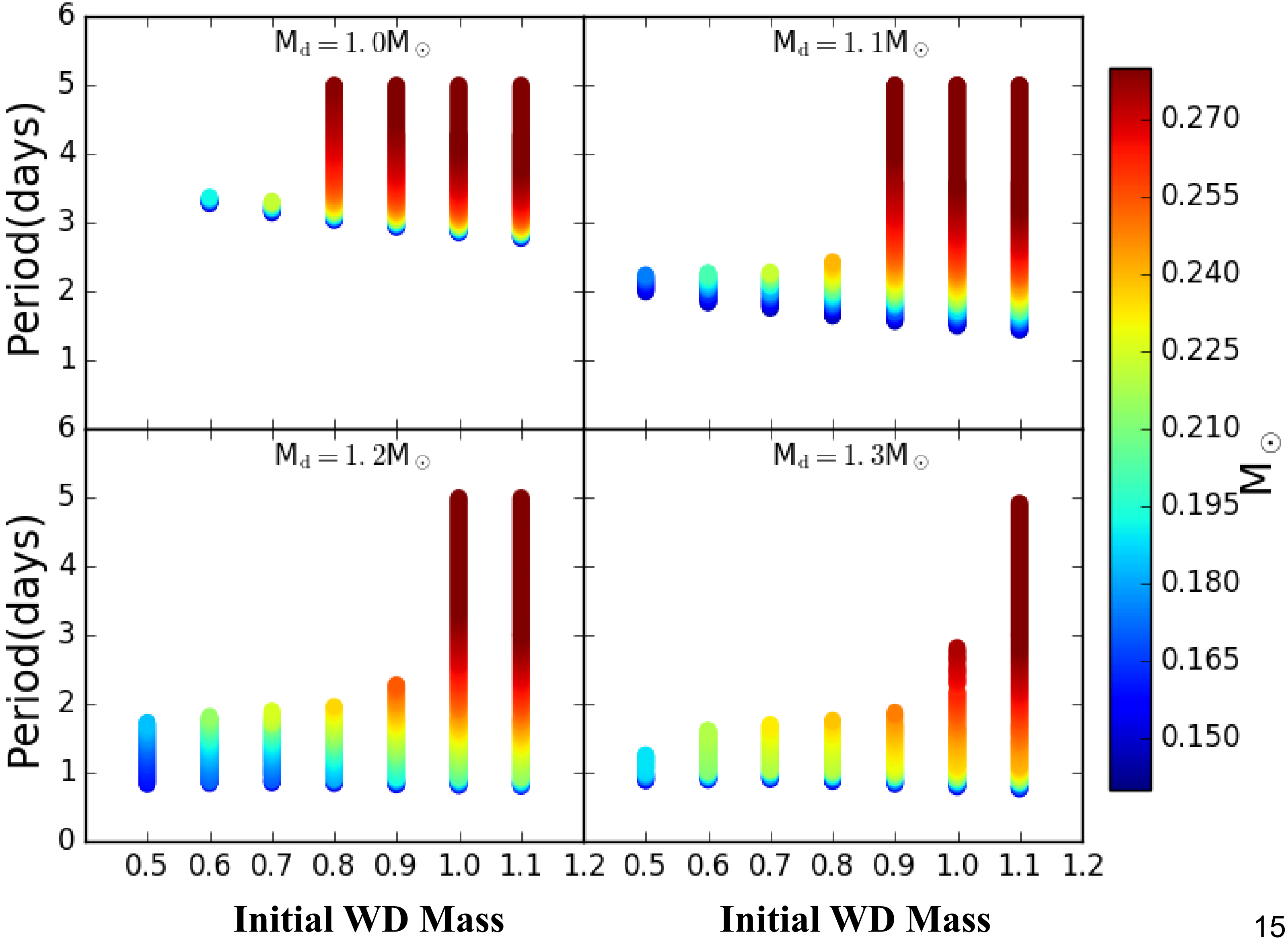
CE ejection efficiency if they were from CE ejection



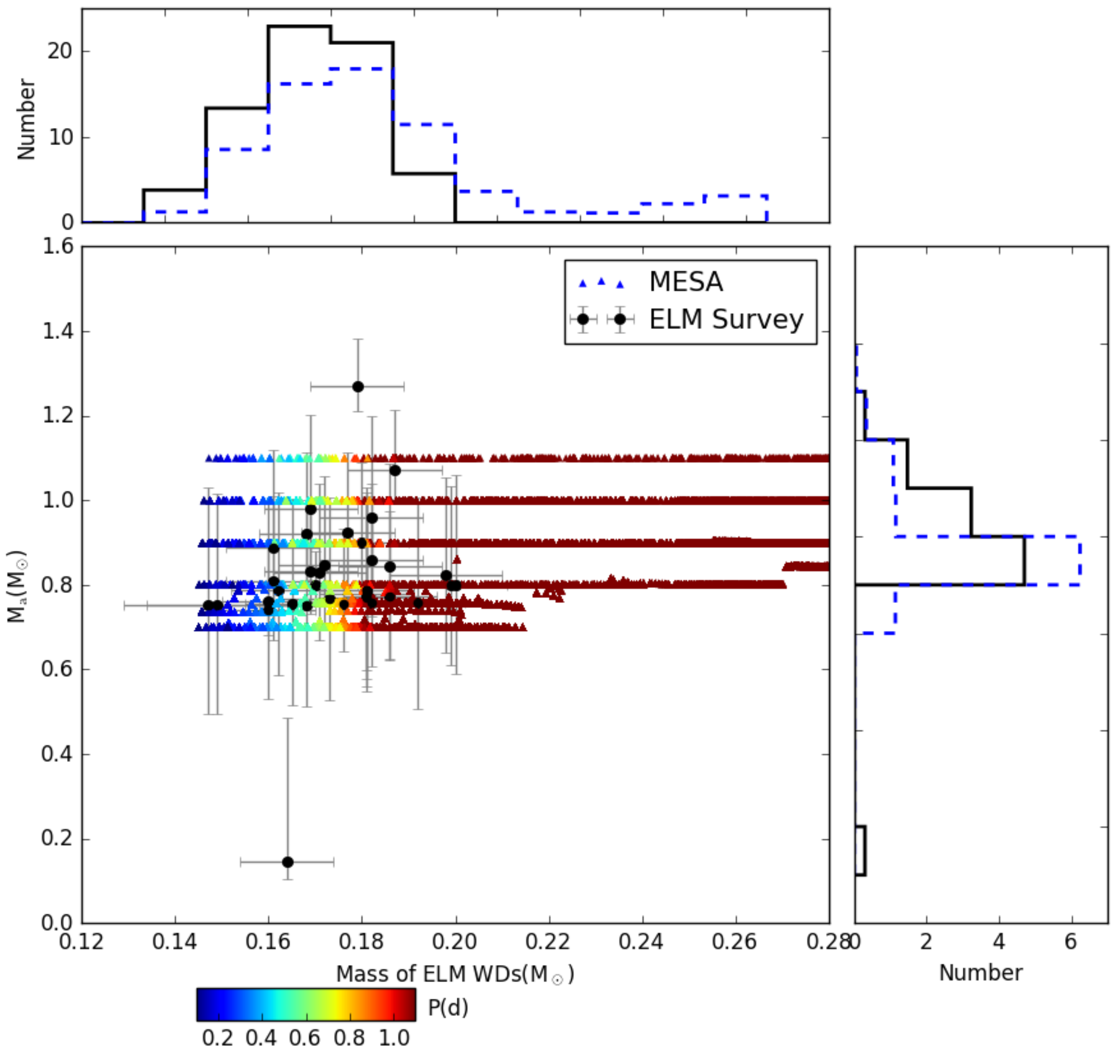
Constraint 3:

The minimum He WD mass for various metallicities

Parameter Space for ELM WD in DDs (stable RLOF)



Component masses in DDs

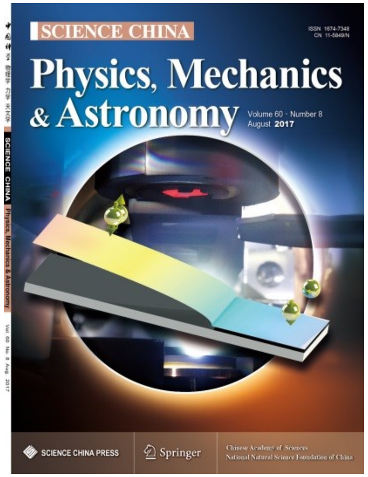


Summary

- ELM WDs can be produced by binary evolution either from stable mass transfer or common envelope ejection, but the observed **EL CVn-type binaries and ELM WDs in MSPs (need to be recycled) could be only produced by stable mass transfer.**
- **The lifetime of proto-He WD strongly depends on the ELM WD mass, proto to M_{WD}^{-8}**, leading to an intrinsic mass peak close to the minimum He WD mass (~0.16$M_{\odot}$ for pop I). For EL CVn-type binaries, the mass peak is 0.17-0.21$M_{\odot}$ after the selection effects are included. Preliminary results for DDs show a similar mass distribution.
- **The minimum He WD mass is around ~0.15$M_{\odot}$** for Pop I,which is determined by stellar EOS,not by the mass transfer process. It varies with metallicity.
- The assumption of 50 percent mass lost by the primary being accreted by the secondary gives the results generally consistent with the observations of EL CVn-type binaries,while mass transfer is likely less conservative in binaries with large mass ratio.

Thank You!

Sci. China-Phys. Mech. Astron.



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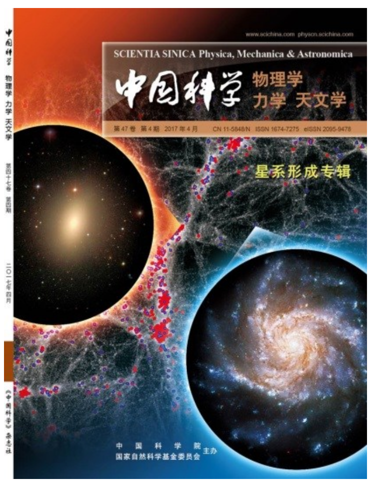

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