Exploring stellar evolution models of sdB stars using MESA

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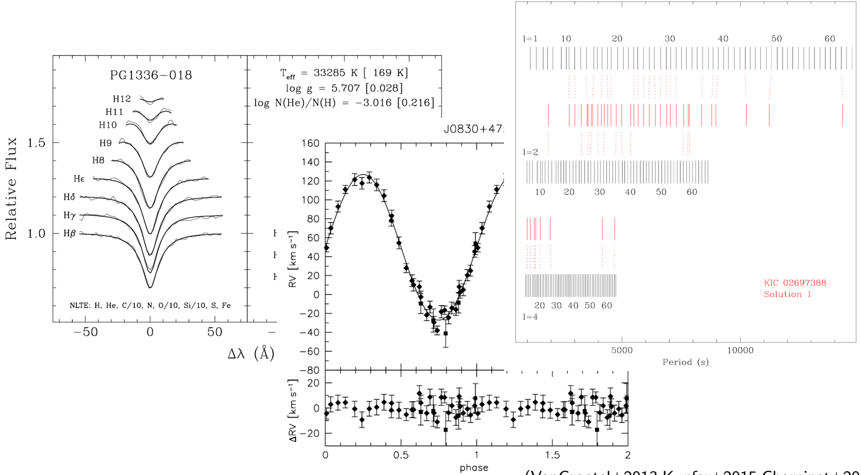
Jan-Torge Schindler
jtschindler@email.arizona.edu
Betsy Green, David Arnett

Department of Astronomy/Steward Observatory, University of Arizona

Subdwarf B stars



(VanGrootel+2013,Kupfer+2015,Charpinet+2011)

Question?

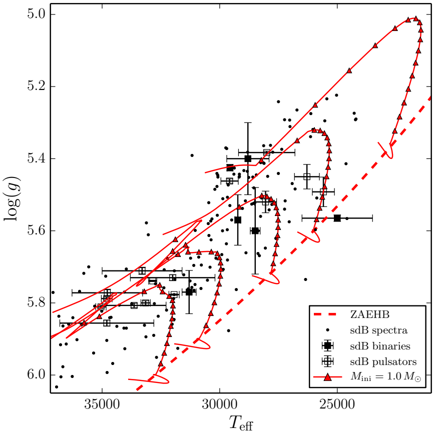
Can we **evolve** stars to fit the **structure** and constraints provided ?

Our MESA stellar evolution calculations

Progenitor model ($M_{\rm ini}$) $\xrightarrow{\text{removing the envelope } (M_{\rm relax})}$ sdB model

Standard sdB model

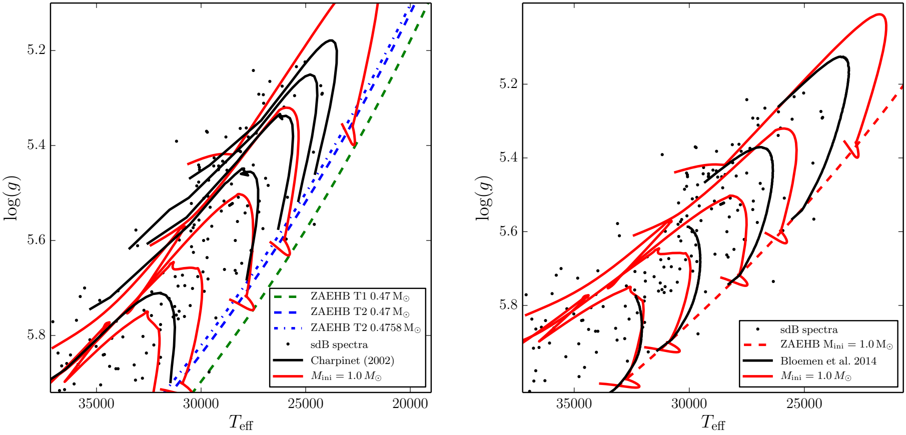
$M_{\rm ini}$ $M_{\rm relax}$	1.0-2.5 $M_\odot$ 0.475-0.485 $M_\odot$
Initial composition	$Z = 0.02$, $Y = 0.30, X = 0.68$
Opacity	**OPAL type II**, electron conduction
MLT	$\alpha_{\rm MLT}$=2
Convection criterion	**Schwarzschild**
Diffusion options	**Atomic diffusion**
RGB wind scheme	$\eta_{\rm Reimers} = 0.5$
Diffusive Overshoot	$f_{\rm ov}$



Schindler+2015

Comparison with other sdB models

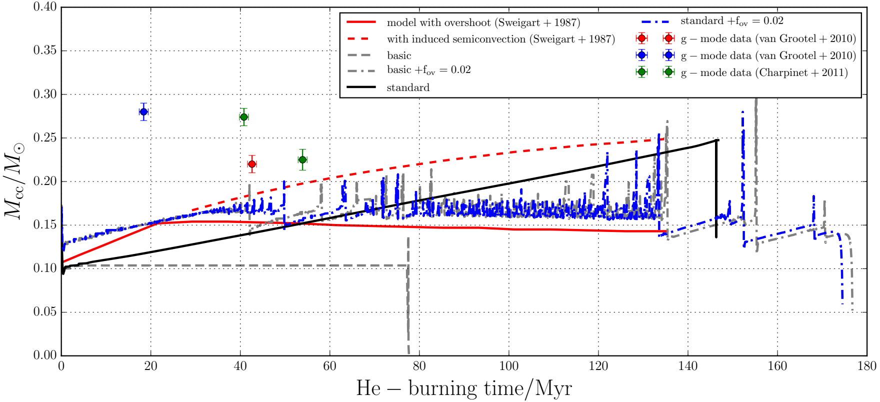
Schindler+2015



In comparison with other models we find

Generally **good agreement** of the evolution in the $\log g$-$T_{\rm eff}$-plane.

Comparison with constraints on the mixed core



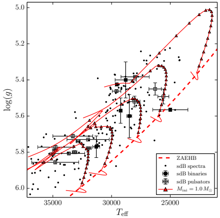
Influence of overshoot on M_{cc}

f_{ov}	no overshoot	0.01	0.02	0.04	0.08	0.10
standard $M_{cc}/M_{\odot}$	0.172	0.149	0.157	0.179	0.227	0.252
basic $M_{cc}/M_{\odot}$	0.105	0.152	0.157	0.179	0.227	0.252

In summary

$\log g$-T_{eff}-plane

- **Good agreement** with previous models
  (Bloemen+2014, Charpinet+2002)
- Models with $M_{\mathrm{ini}} \sim 0.9 - 2.0$ do **not cover the full sdB mass range**
  $M_{\mathrm{He-core,max}} \approx 0.467\,M_{\odot}$
  Is that a problem or not?



Interiors

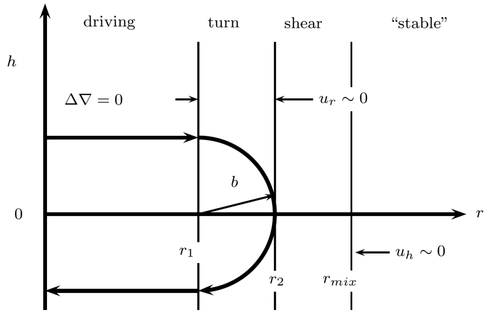
- Overshoot with $f_{\mathrm{ov}} > 0.08 \Rightarrow M_{\mathrm{cc}}$ close to asteroseismology
  $\Rightarrow$ Implausibly high parameter!
  $\Rightarrow$ Diffusive overshoot not meant for stellar interiors?
- **"Weird" wiggly behaviour** of convective boundary with active overshoot.
  $\Rightarrow$ Inadequate treatment of convective boundary?
  $\Rightarrow$ What is the connection to Partial Mixing/ Induced Semiconvection?

We find:

Current mixing algorithms cannot reproduce the inferred structure through consistent stellar evolution using plausible parameters.

321D - Beyond MLT

Arnett+2015



Driving only to buoyancy in uniform composition:

$$\mathbf{B} \approx \mathbf{g}\beta_{\mathrm{T}}\Delta\nabla$$

$$\mathbf{D} \approx \mathbf{u}l_{\mathrm{d}}/\left|u\right|$$

$$\Delta\nabla \approx \nabla - \nabla_{\mathrm{e}}$$

Additional velocity equation:

$$d\mathbf{u}/dt = \mathbf{B} - \mathbf{D} \qquad \text{or}$$

$$d(u^2/2)dt = \mathbf{ug}\beta_{\mathrm{T}}\Delta\nabla - u^2 l_{\mathrm{d}}/\left|u\right|$$

Conclusions and outlook

321D Approximation

- Calculated convective Velocity u_r
  - Braking layers and boundaries for convective flow
- Turbulent heating term in energy equation
- Ram pressure term in hydrostatic equation

$\Rightarrow$ Calibrated to resemble 3D simulations **not** to observational data.

$\Rightarrow$ No arbitrarily adjustable parameters!

However

- Going from 3D turbulent simulations to one ordinary differential equation much is missing.
- Semiconvection (in whatever form) is still regarded as an open question.

We plan to implement 321D into MESA starting this fall!