The theoretical instability strip of V777 Her white dwarfs

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Pulsations in DB white dwarfs

Pulsating DB white dwarfs

Empirical V777 Her instability strip (2011 view)

● Observed pulsator ; ○ non-variable DB white dwarf

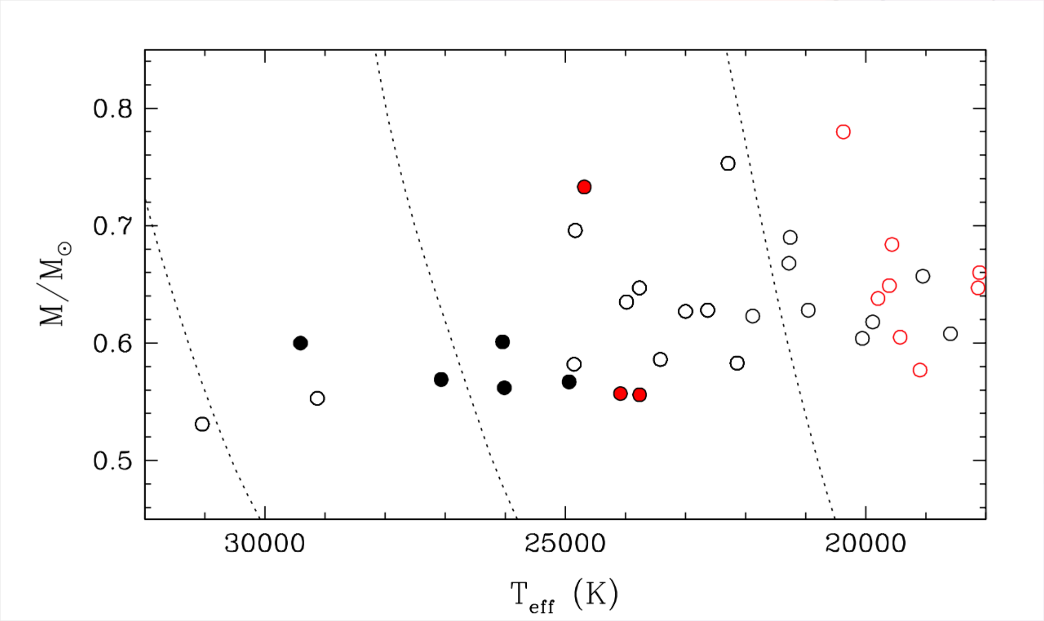


Figure from Bergeron et al. (2011)

- Black: DB (pure He atmosphere)
- Red: DBA (traces of H)

- Reliable atmospheric parameters: work of Bergeron et al. (2011), including strong constraints on H abundance (H-alpha line)

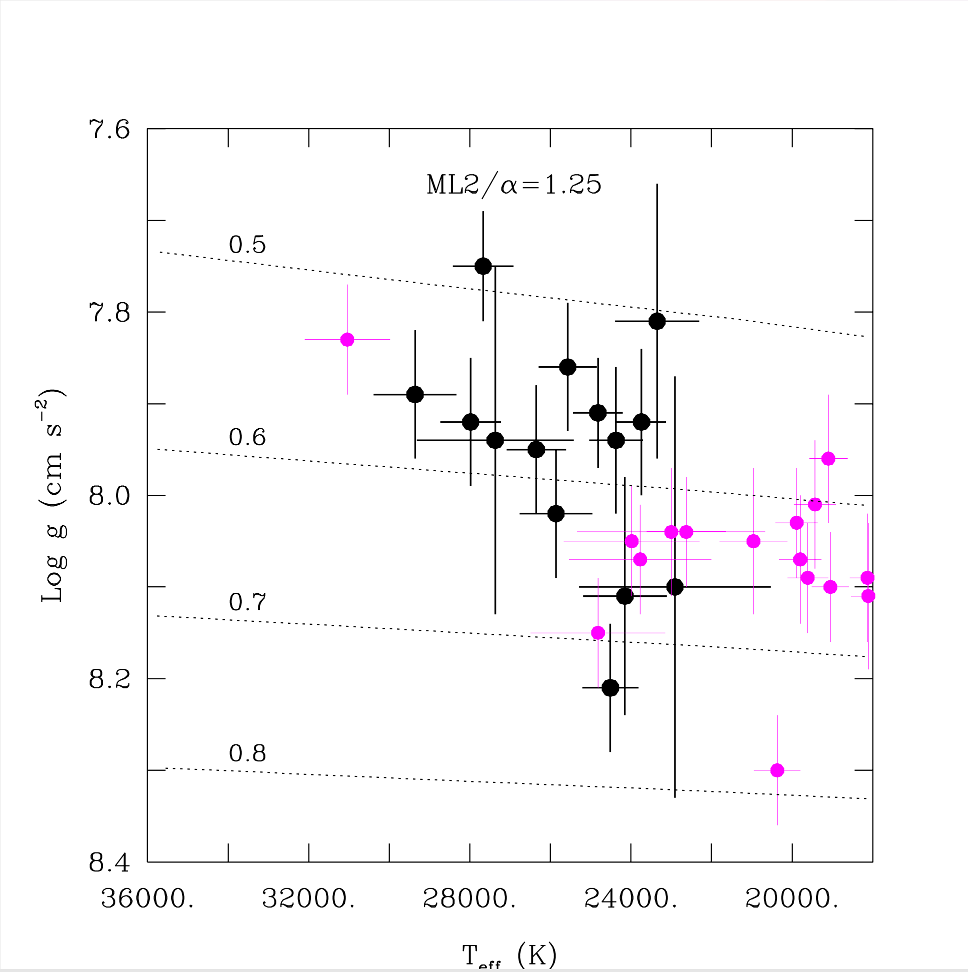
- with ML2/α=1.25

- Bergeron et al. (2011) suggests two shifted (DB and DBA), pure instability strips

Pulsating DB white dwarfs

Empirical V777 Her instability strip (2016 view)

● non variable (<10mmag); ● pulsator



Fontaine et al., in prep.

Homogeneous spectroscopic analysis by G. Fontaine

- Model atmospheres of P. Bergeron (incl. for the 16 non-variable DB/DBA)
- New spectra from Bergeron, Kilkenny (2009 & 2016), SDSS (Nitta+2009), Kepler telescope (J1929):

  14 DBV with reliable atmospheric parameters

- J1929 is the most contaminated DBA pulsator **and** the hottest V777 Her
- Still consistent with a pure strip

Pulsating DA white dwarfs

Excitation mechanism of V777 Her stars (general picture)

- Don Winget (1982):

He recombination around T_{eff}~30,000 K

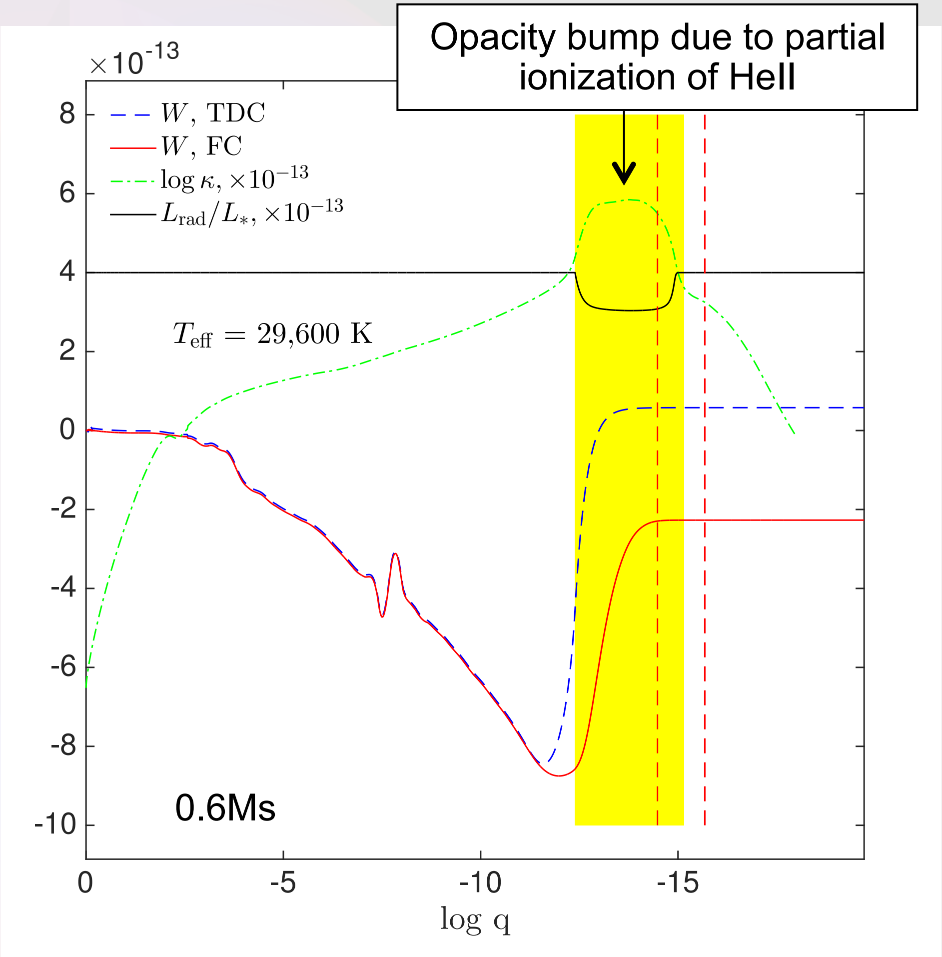
$\Rightarrow$ envelope opacity increase

$\Rightarrow$ strangle the flow of radiation

$\Rightarrow$ modes instabilities

- Pulsations are destabilized at the base of the convection zone

“convective driving”


Opacity bump due to partial ionization of HeII

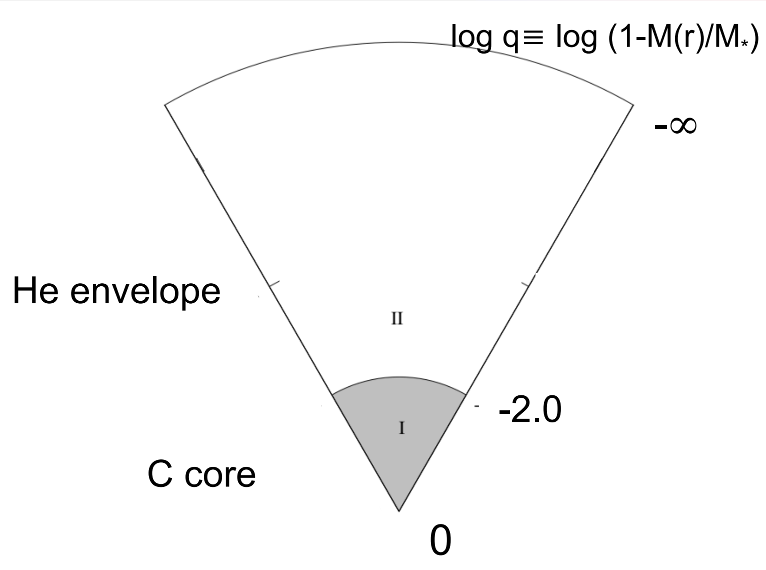
Pulsations are driven when the convection zone is sufficiently deep and developed

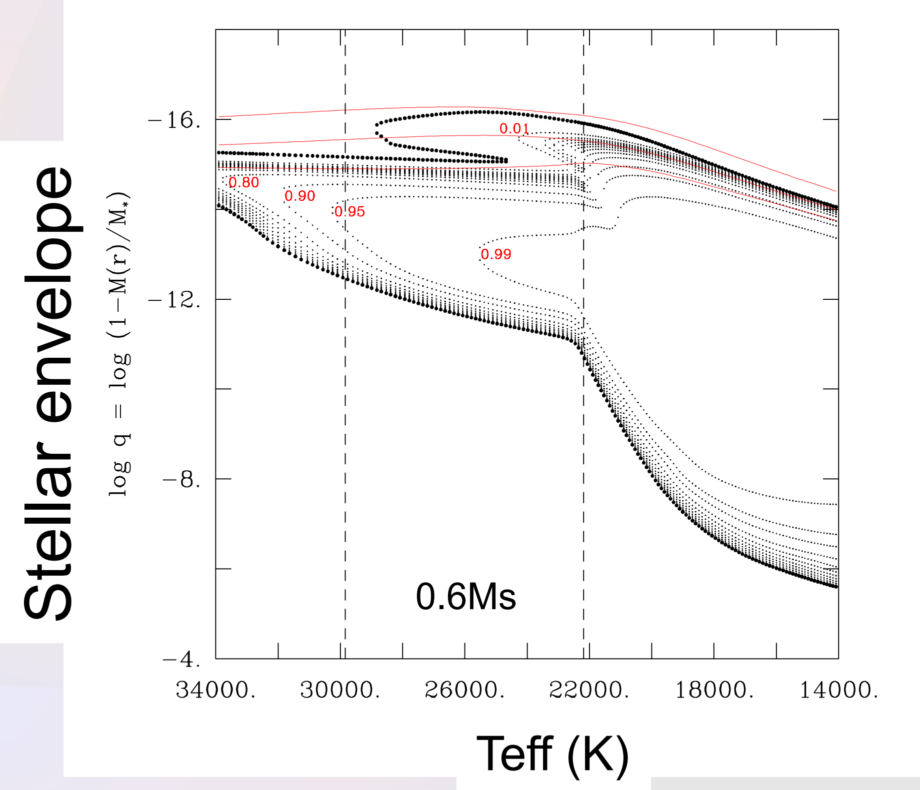
The theoretical instability strip

- Cooling DB White Dwarf Models

Evolutionary DB models

- Simplified DB white dwarf cooling models with detailed He envelopes





- Cooling tracks computed for $0.5M_s$ to $0.8M_s$ ($0.1M_s$ step)
- Tracks of DB and DBA with *N*(H)/*N*(He)=0.001 (i.e. X(H)=0.0025)
- with ML2 version (a=1,b=2,c=16); α = 1.25
- “convective feedback” on the global atmosphere structure (same T gradients as complete 1D model atmospheres – non grey atmospheres)

The theoretical instability strip

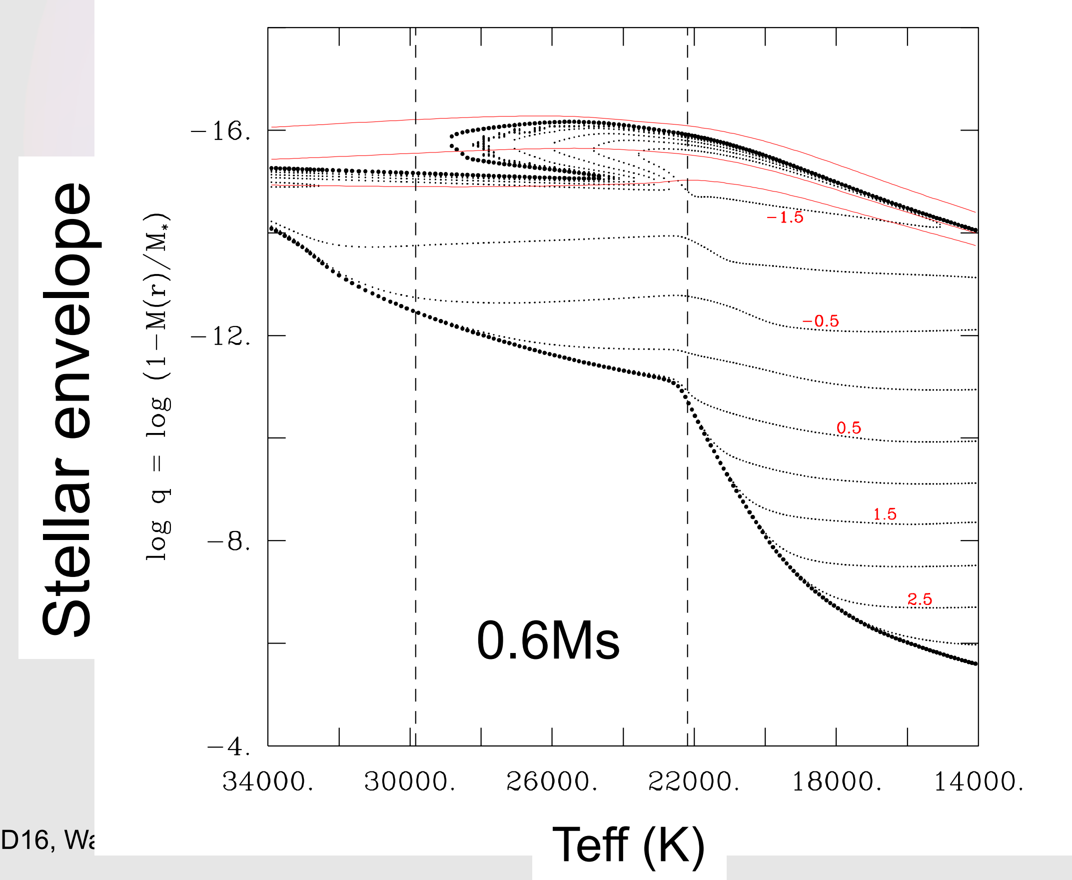
- Cooling DB White Dwarf Models
- Stability analysis tools
  - Time-Dependent Convection (TDC) Approach
  - Energy leakage argument

Why a Time-Dependent Convection approach ?

- Typical observed periods in V777 Her stars: 150-1100 s (log: 2.17-3.04)
- Frozen convection (FC), i.e. $\tau_{conv} >> \sigma$: not justified in the V777 Her T_{eff} regime

(FC is the usual assumption to study the theoretical instability strip)

- For V777 Her stars: instantaneous adaptation of convection (blue edge; $\tau_{conv} << \sigma$) and full TDC (red edge; $\tau_{conv} <\sim \sigma$)



The Time-Dependent Convection theory

- The Liege nonadiabatic pulsation code **MAD** (Dupret 2002) is the only one to implement convenient TDC treatment
- Full development in Grigahcène et al. (2005), following the theory of M. Gabriel (1974,1996)

- The timescales of pulsations and convection are **both** taken into account. Perturbation of the convective flux:

$$\delta F_C = \overline{F_C}\left(\frac{\delta\rho}{\overline{\rho}} + \frac{\delta T}{\overline{T}}\right) + \overline{\rho}\,\overline{T}\left(\overline{\delta\Delta s V} + \overline{\Delta s\,\delta V}\right)$$

- Built within the mixing-length theory (MLT), with the adopted perturbation of the mixing-length:

$$\frac{\delta l}{l} = \frac{1}{1+(\sigma\tau_c)^2}\,\frac{\delta H_p}{H_p}$$

if $\sigma \gg \tau_{\mathrm{conv}}$ (instantaneous adaption): $\delta l/l \rightarrow \delta H_p/H_p$

if $\sigma \ll \tau_{\mathrm{conv}}$ (frozen convection): $\delta l/l \rightarrow 0$

Energy leakage argument

- For the red edge (long-standing problem):

based on the idea of Hansen, Winget & Kawaler (1985): red edge arises when

$$\tau_{th} \sim P_{crit} \quad \alpha \ (l(l+1))^{-0.5}$$

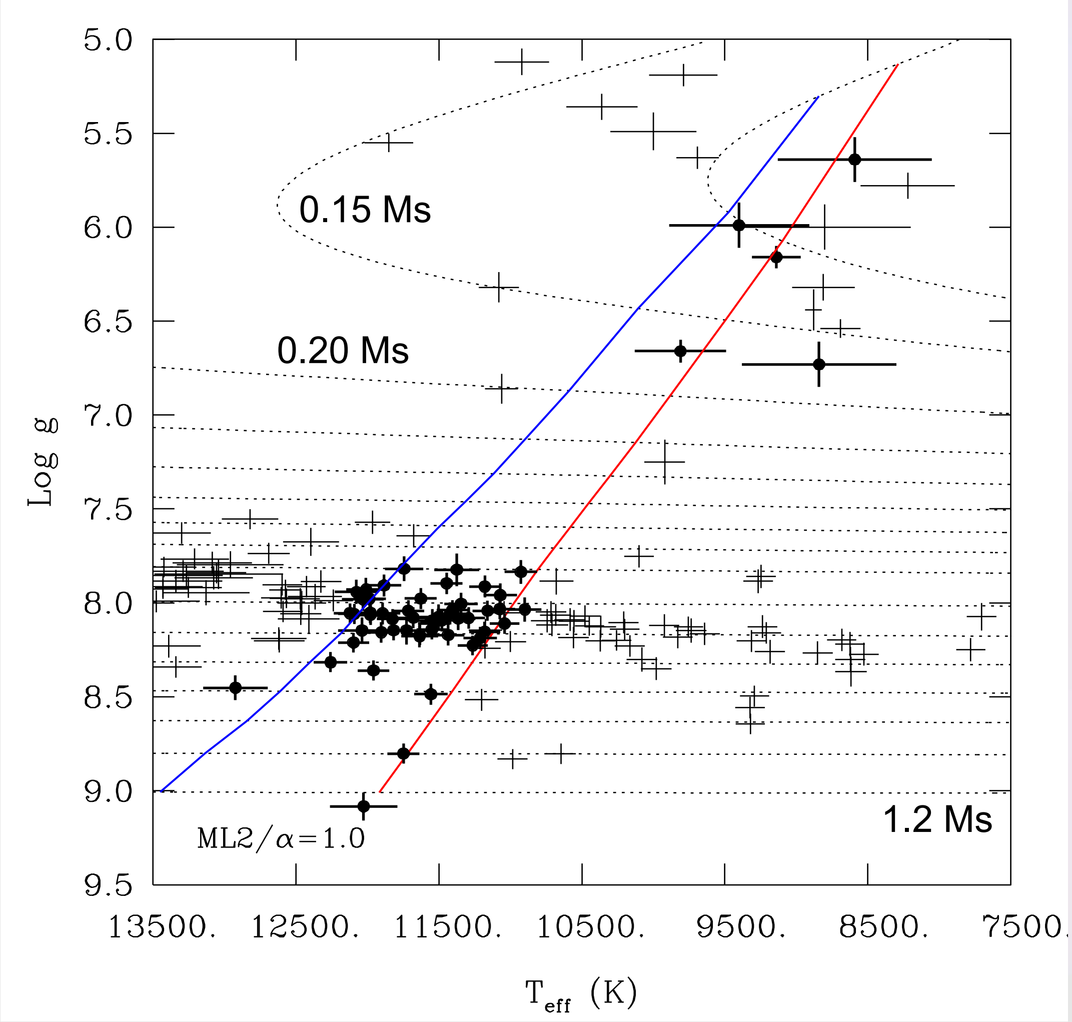
(τ_{th} : thermal timescale at the base of the convection zone),

which means the mode is no longer reflected back by star's atmosphere

- For ZZ Ceti pulsators: accounts remarkably well for the empirical red edge (Van Grootel et al. 2013)

Theoretical instability strip (g-modes l=1)

┼ non variable (<10mmag); ─●─ pulsator



Van Grootel et al. (2013)

— TDC blue edge

— Red edge (energy leakage)

Homogeneous atmospheric parameters (here ML2/α = 0.6)

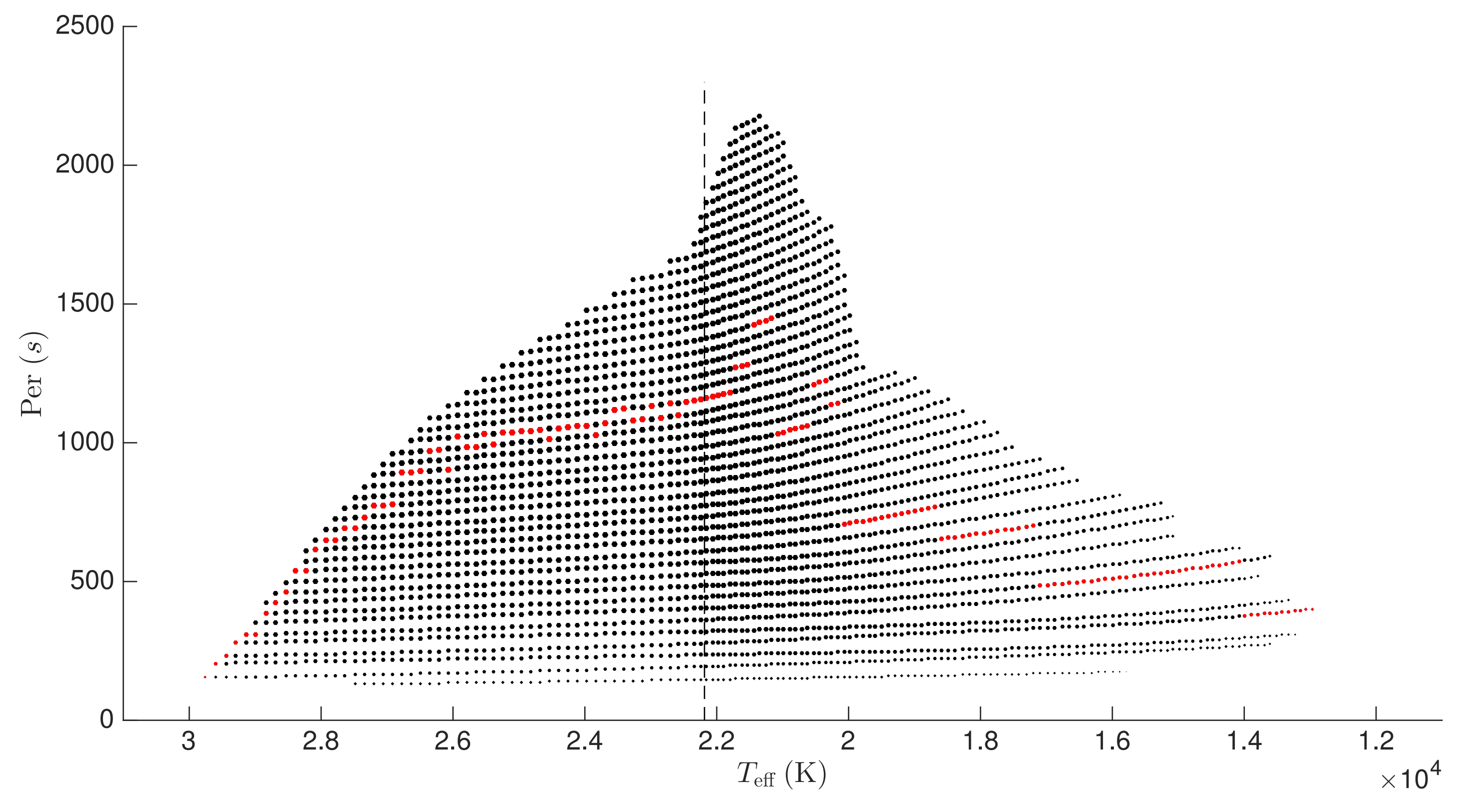
Structure and atmospheric MLT calibrations <u>are</u> dependent

The theoretical instability strip

- Cooling DB White Dwarf Models
- Stability analysis tools
    - Time-Dependent Convection (TDC) Approach
    - Energy leakage argument
- **Results**

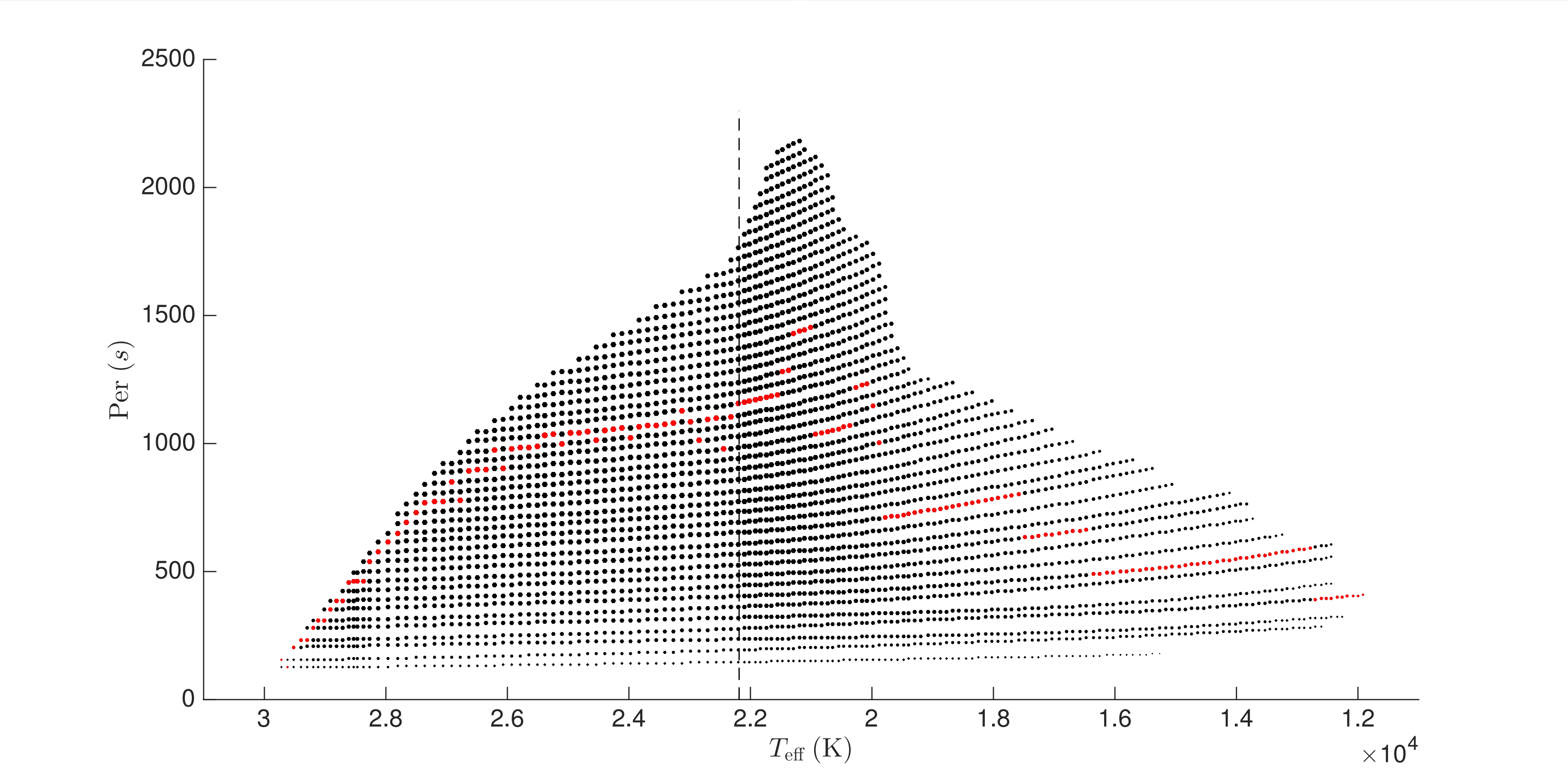
Results: computing the theoretical instability strip

0.6 Ms DB cooling sequence, ML2/α = 1.25, l=1, detailed atmosphere, TDC



Results: computing the theoretical instability strip

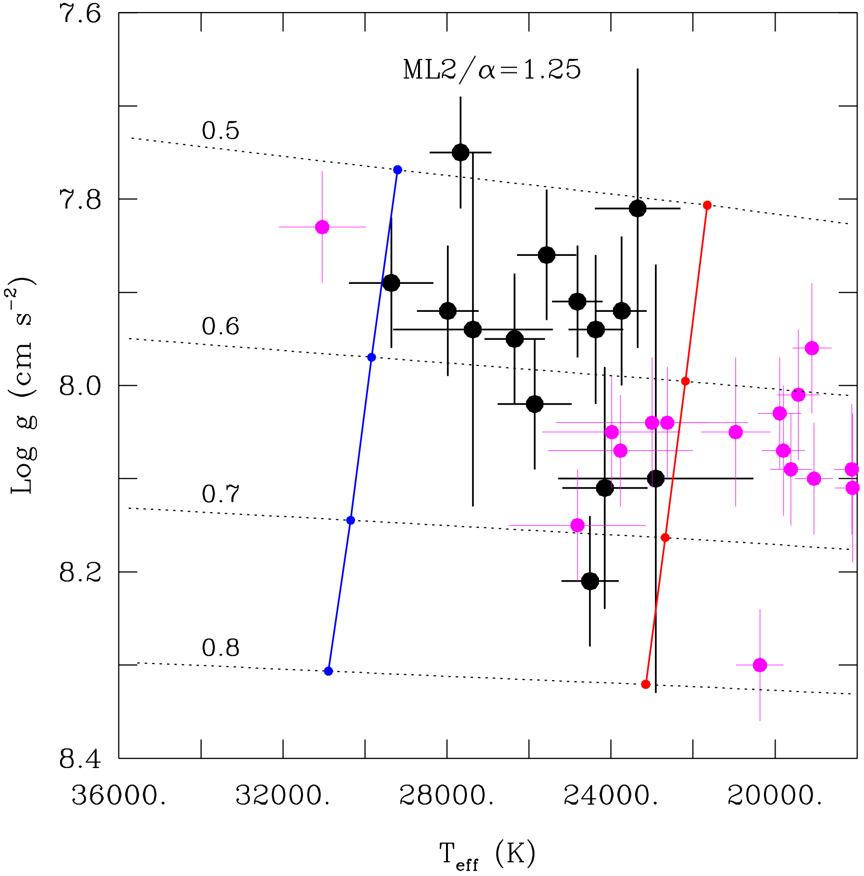
0.6 Ms DBA cooling sequence, ML2/α = 1.25, l=1, detailed atmosphere, TDC

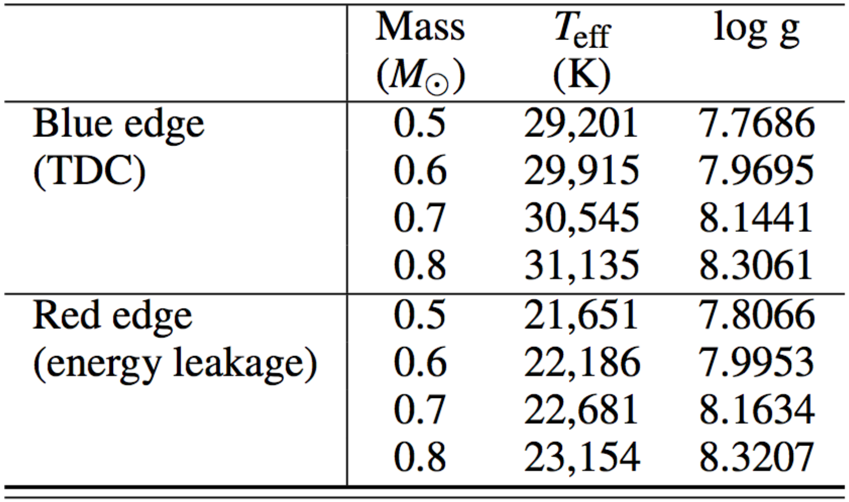


- Only few differences, way cooler compared to the empirical red edge
- TDC red edge too cool compared to the empirical one (// ZZ Ceti)

Results: computing the theoretical instability strip

Red edge by energy leakage argument





	Mass ($M_\odot$)	$T_{\rm eff}$ (K)	log g
Blue edge (TDC)	0.5	29,201	7.7686
	0.6	29,915	7.9695
	0.7	30,545	8.1441
	0.8	31,135	8.3061
Red edge (energy leakage)	0.5	21,651	7.8066
	0.6	22,186	7.9953
	0.7	22,681	8.1634
	0.8	23,154	8.3207

NB: negligible offset (~100K) for DBA sequence

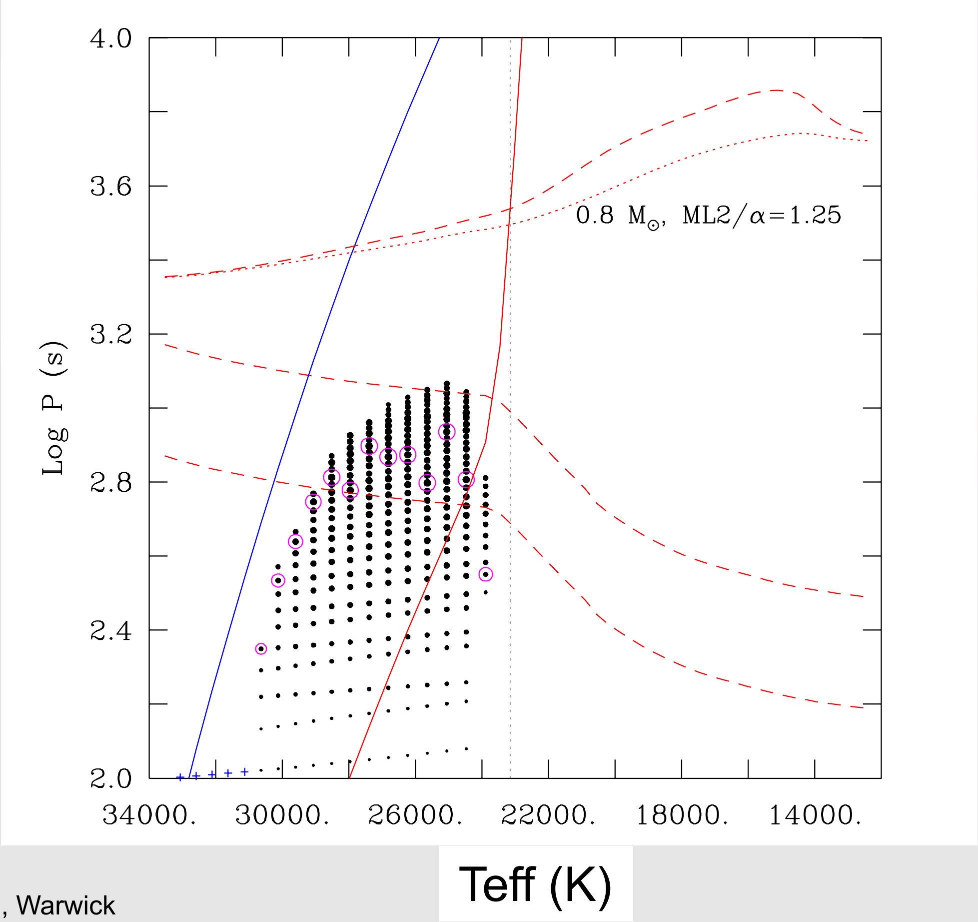
Red edge leakage
slightly too cool (?)

Results: computing the theoretical instability strip

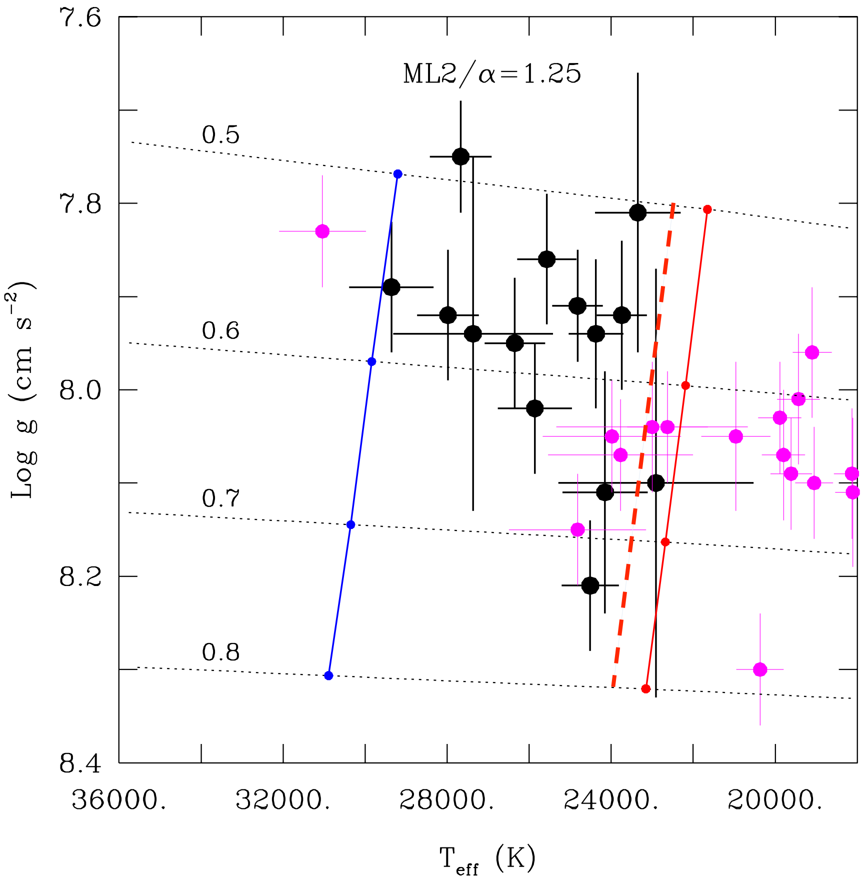
- TDC **with** turbulent pressure perturbations

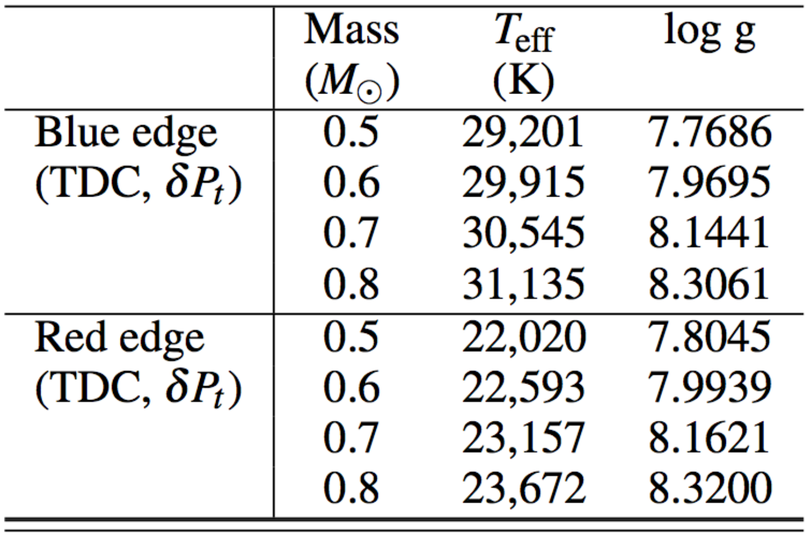
$$\frac{\delta P_t}{P_t} = \frac{\delta \rho}{\rho} + 2\frac{\overline{\delta V_r}}{V_r}$$

- Dupret et al. (2008): hotter red edge if δPt=4…but still ~3000 K too cool
- But with δPt=3:



Results: computing the theoretical instability strip





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	0.8	31,135	8.3061
Red edge (TDC, δP_t)	0.5	22,020	7.8045
	0.6	22,593	7.9939
	0.7	23,157	8.1621
	0.8	23,672	8.3200

~500 K hotter than red edge leakage

But 3δPt is not physically realistic. Mimic other components of the Reynolds stress tensor (Pt = *rr* component), i.e. **turbulent viscosity** ?

The theoretical instability strip

- Cooling DB White Dwarf Models
- Stability analysis tools
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  - Energy leakage argument
- Results
- **Conclusions**

Conclusion and Prospects

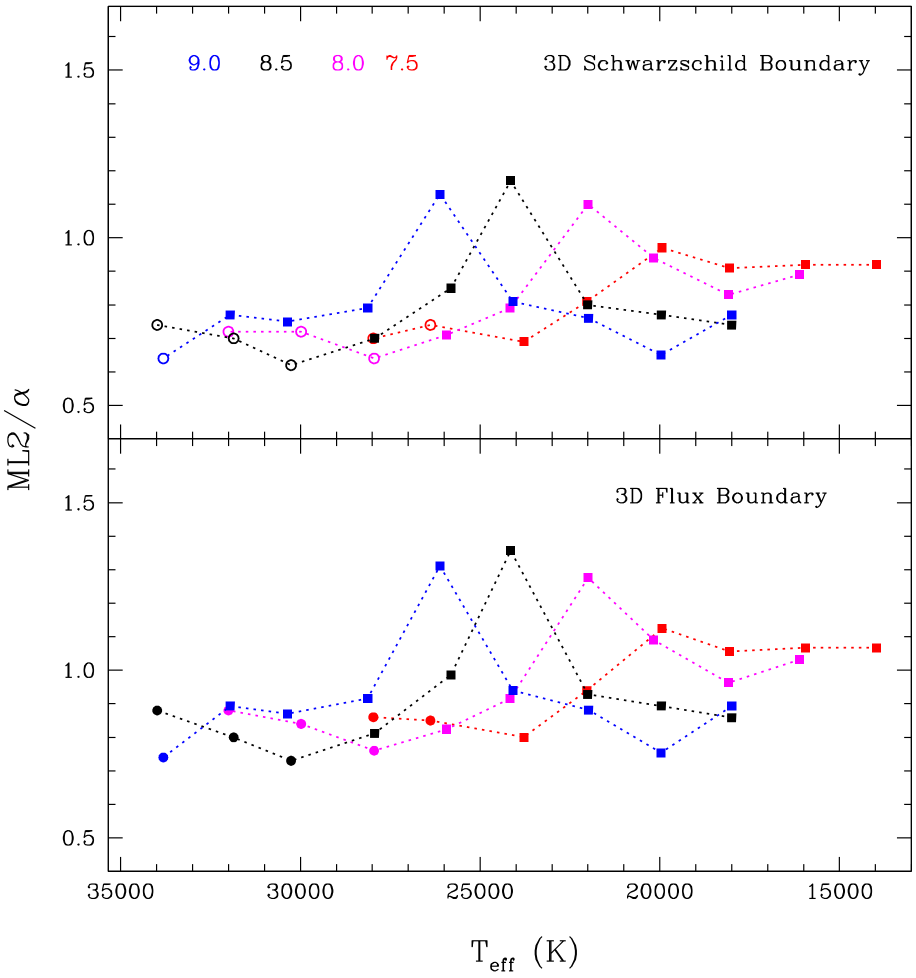
Conclusions:

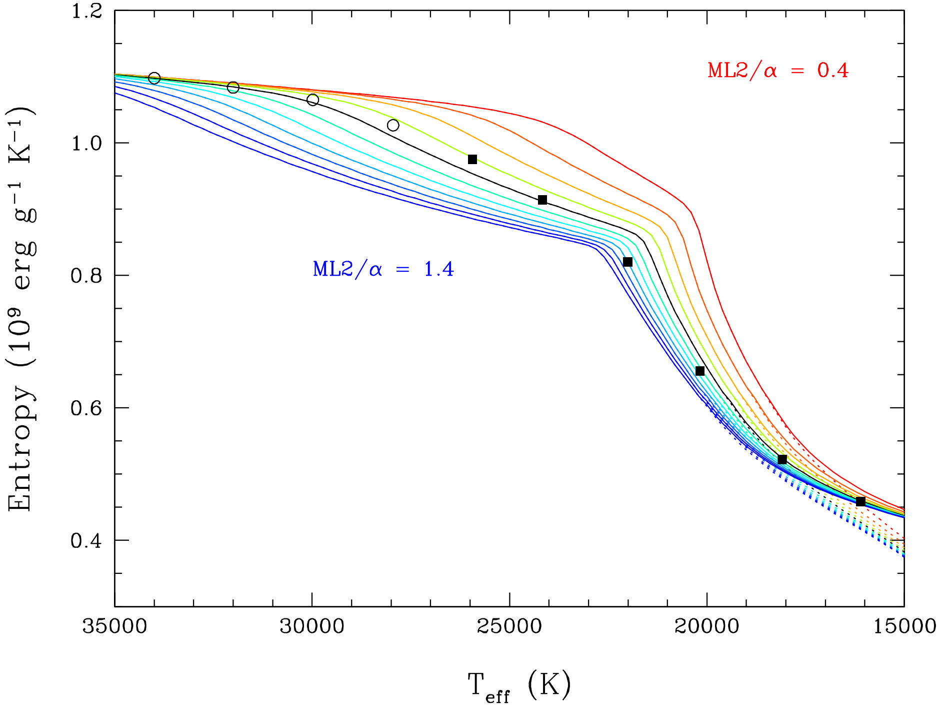
- **No fuziness** on the V777 Her instability strip due to the DB/DBA flavor
- **Our TDC treatment**
  - very well reproduced the empirical blue edge
  - produced a far too cool red edge in its standard version,
  - but satisfyingly reproduced the empirical red edge if δPt included and enhanced by a factor 3
- Energy leakage red edge appears slightly too cool
- Our results suggest **turbulent viscosity** plays a key role in the red edge emergence (// Brickhill 1990)

Prospects:

- Turbulent viscosity perturbations to include in MAD
- Variable α_{MLT} as a function of Teff/logg from 3D simulations
- Patched 1D models with nonlocal α_{MLT}
- Non-local treatment of TDC (already included in MAD)
- New V777 Her pulsators (especially close to the blue edge) needed!

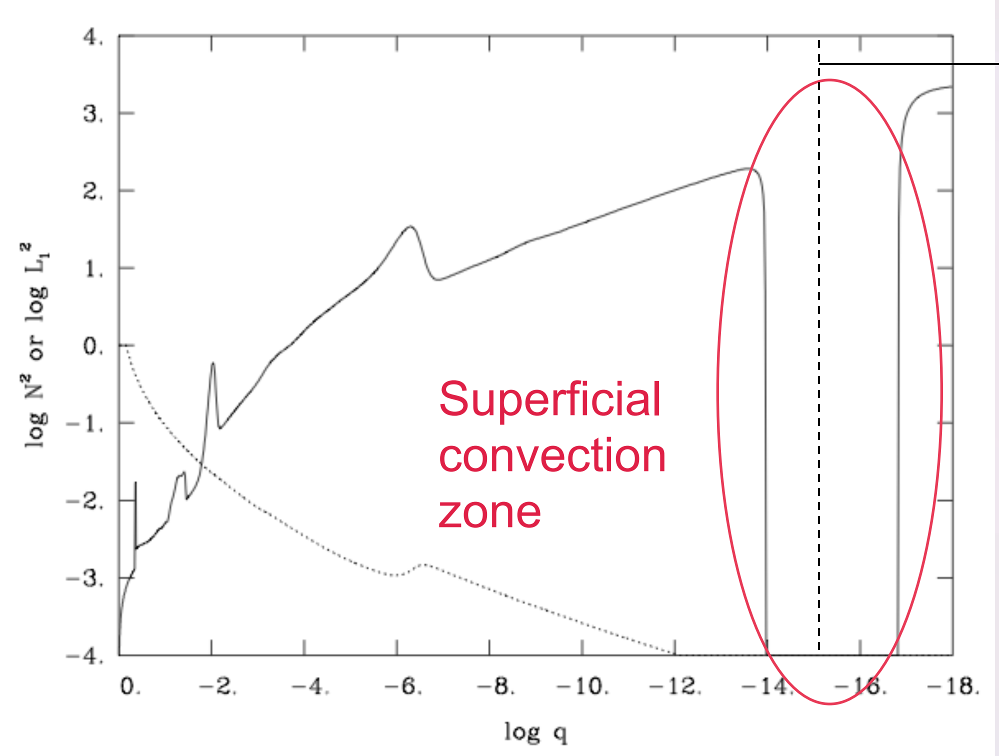
Preliminary calibrations from 3D simulations (P.E. Tremblay)





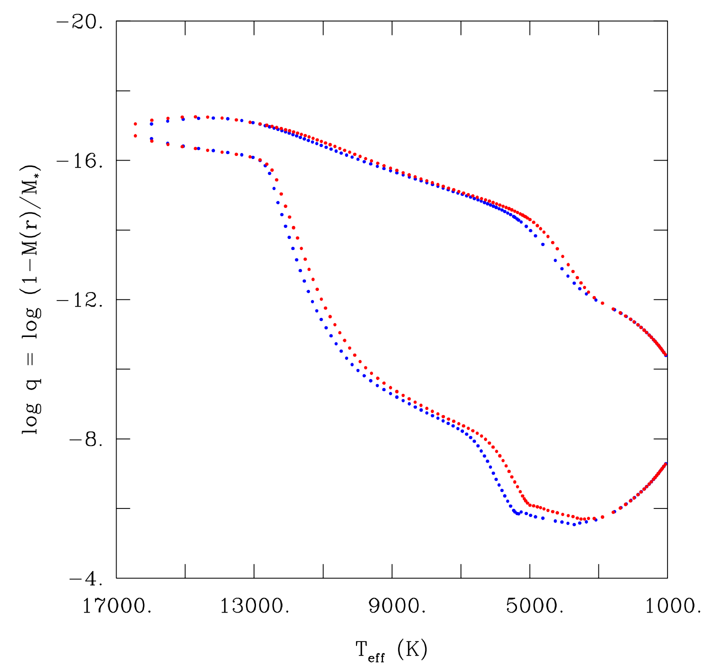
Supp. Slides

Cooling DB models



Base of the atmosphere (τ=100)

Detailed modeling of the superficial layers



- Standard grey atmosphere
- Detailed atmosphere

Our cooling models have the same T gradients as the complete (1D) model atmospheres (upper BCs)

⇒"feedback" of the convection on the global atmosphere structure

Comparison DB and DBA cooling sequences