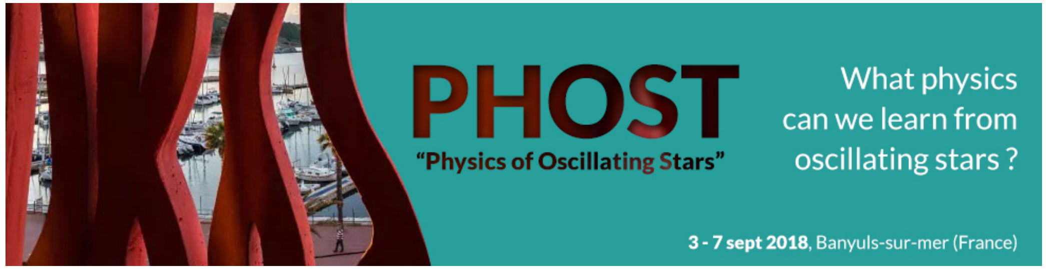


# PB 8783: the first sdO star suitable for asteroseismic modeling?

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# Plan

1. What are subdwarf B (sdB) and subdwarf O (sdO) stars?
2. Asteroseismology of sdB and sdO stars: state-of-the-art
3. Non-adiabatic asteroseismology of sdB/sdO stars
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# 1. Introduction to sdB and sdO stars

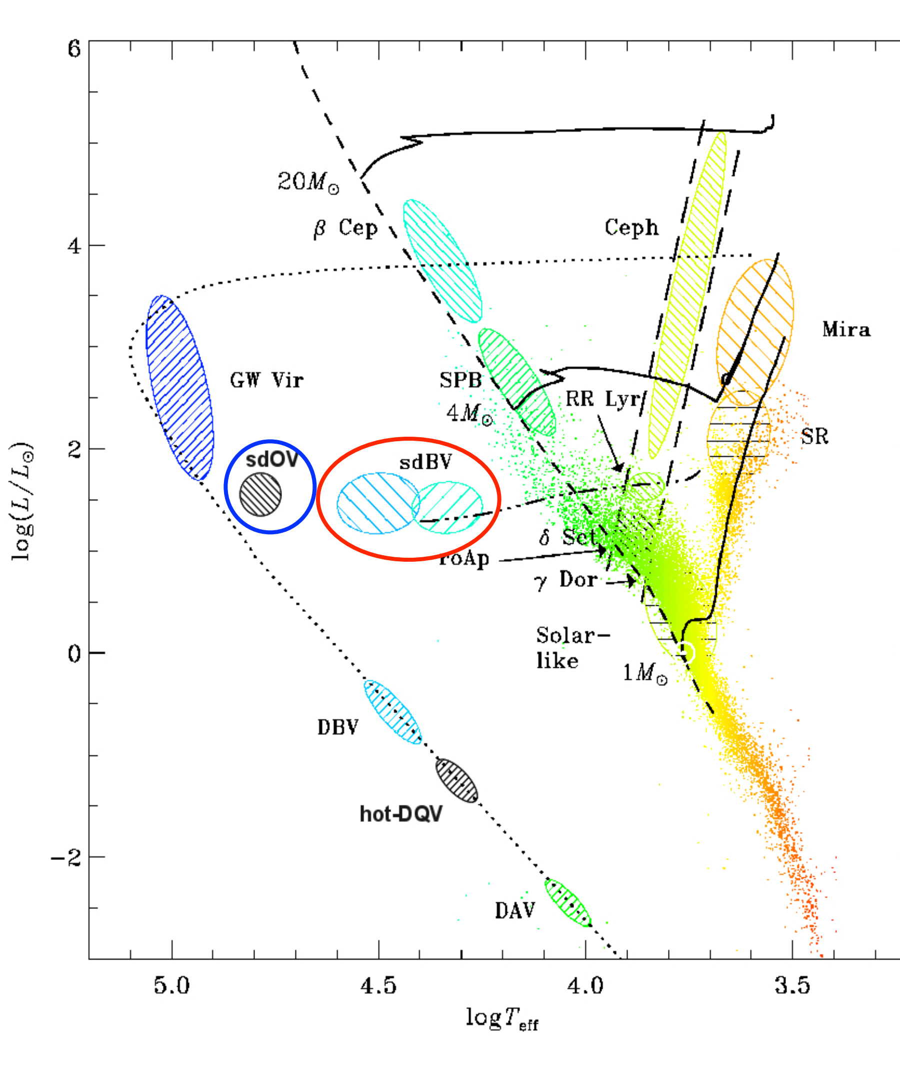
Evolved, hot ($T_{eff}$ = 20 000 - 70 000 K) and compact (log g = 5.2 - 6.2) stars

## sdB stars

- Extreme Horizontal Branch stars, core He-burning, extremely thin H-rich envelope
- p-mode and g-mode pulsators, κ-mechanism due to Fe-like elements ionization
- About 100 pulsators known in the galactic field, none in globular clusters (GCs)

## sdO stars

- Mixture of sdB progeny (post-EHB) and post-AGB stars
- 2 pulsators known in the field, 12 in GCs
- Short-period (80-140s), p-mode pulsations



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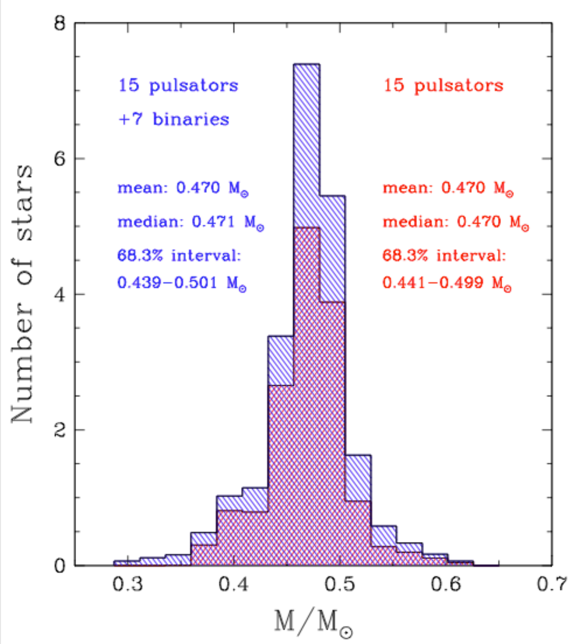
# 2. Asteroseismology of sdB and sdO stars

- To date: 15 sdB pulsators modeled by asteroseismology

Mass distribution of sdB stars




Fontaine et al. (2012)

- Access to global and structural parameters ($M_*$, logg, $R_*$, $M_{env}$, $M_{core}$, core composition, etc.)
- Help to clarify the question of **origin** of sdB stars (post-RBG stars having lost most of their H-envelope through binary interaction: stellar, sub-stellar and planet)

- Asteroseismic modeling of sdO pulsators:
  - in GCs: no hope to have good enough photometry for seismology
  - in the field: faint (V~15-18) + difficulties to get accurate Teff (almost all metal lines in UV at these Teff)

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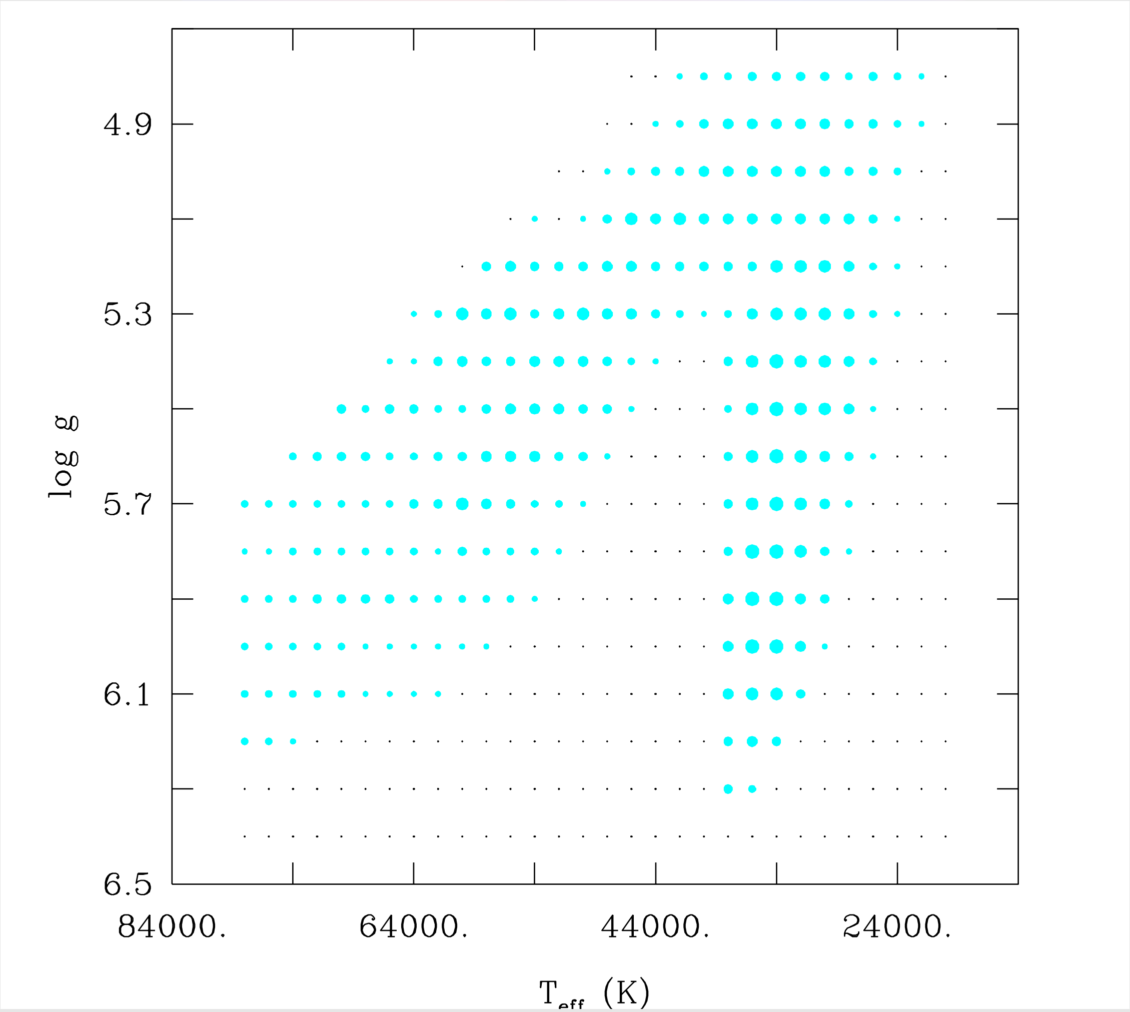
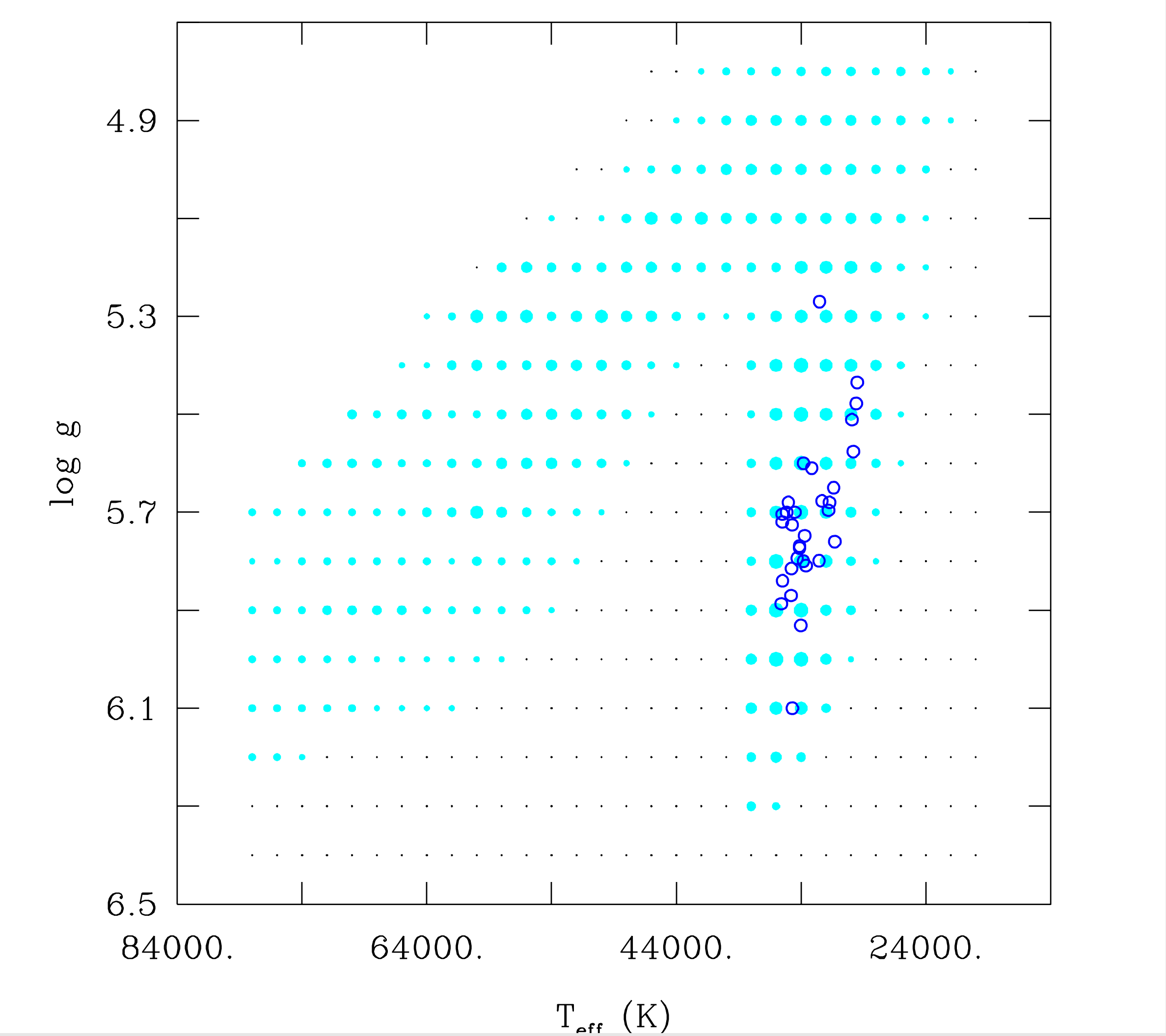
# 3. Non-adiabatic asteroseismology of sdB and sdO stars

- Static envelope models with non-uniform Fe abundances (gravitational settling+ radiative levitation): l=1 excited pulsations predicted by Cpulse and MAD



# 3. Non-adiabatic asteroseismology of sdB and sdO stars

- Static envelope models with excited pulsations (Cpulse and MAD)
- Short-period (p-mode) sdB pulsators, i.e. sdBV_r



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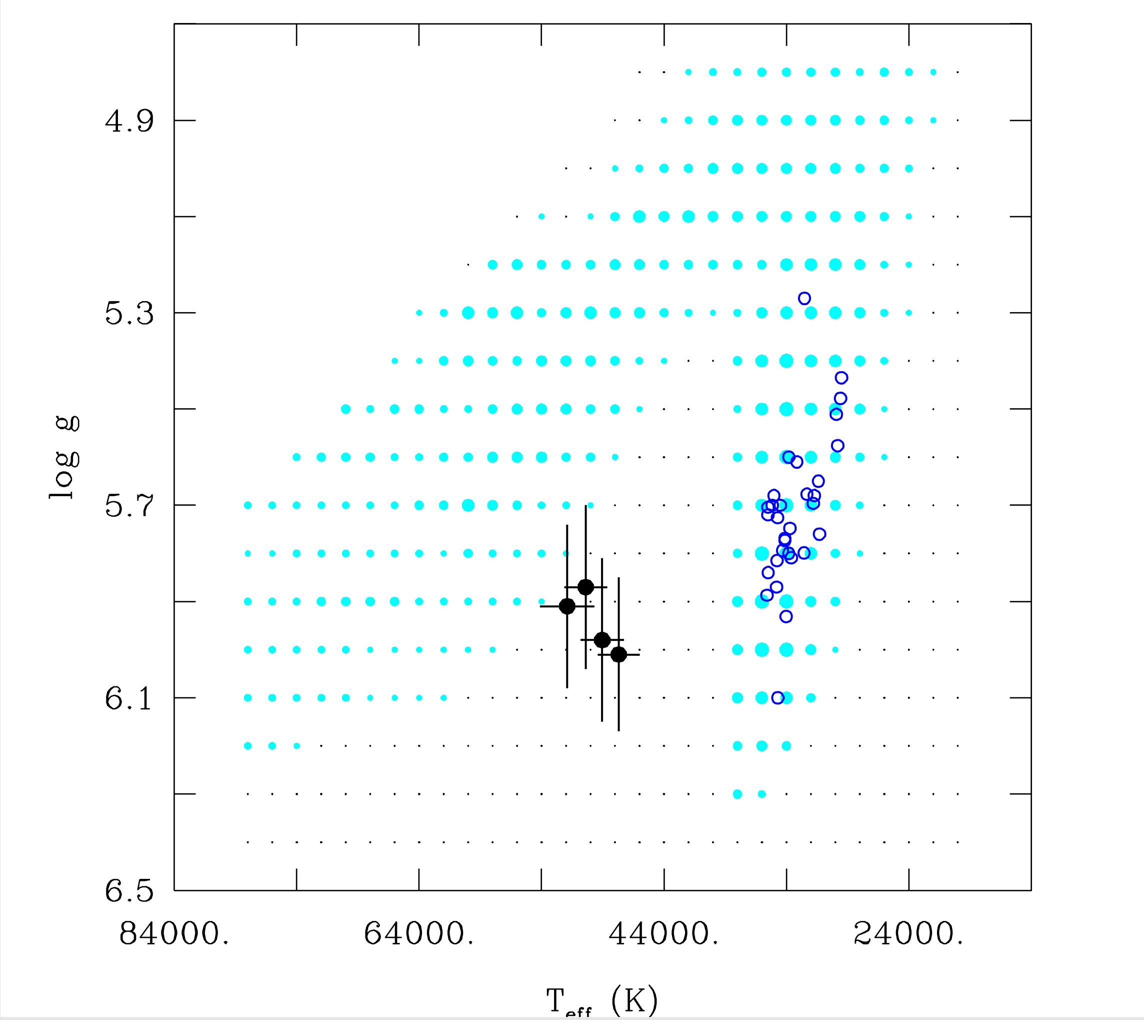
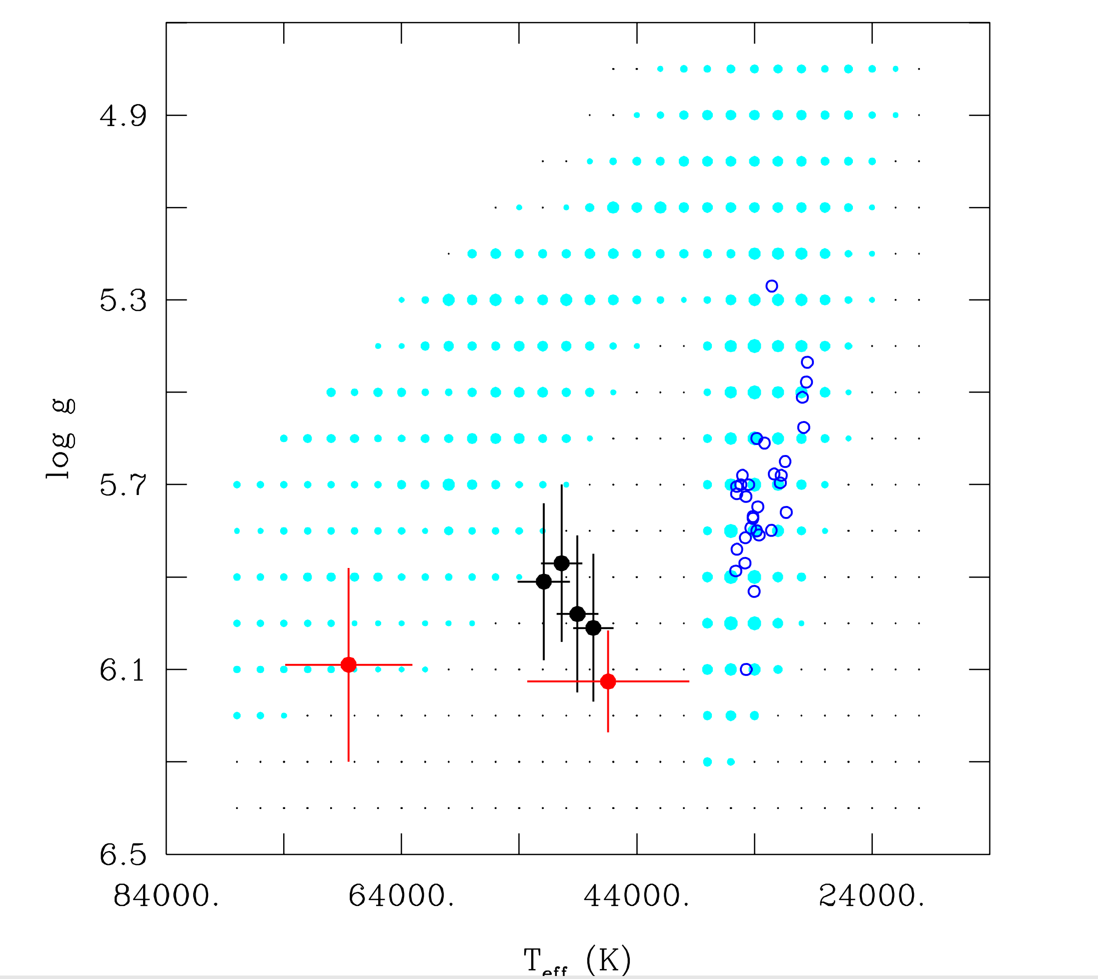


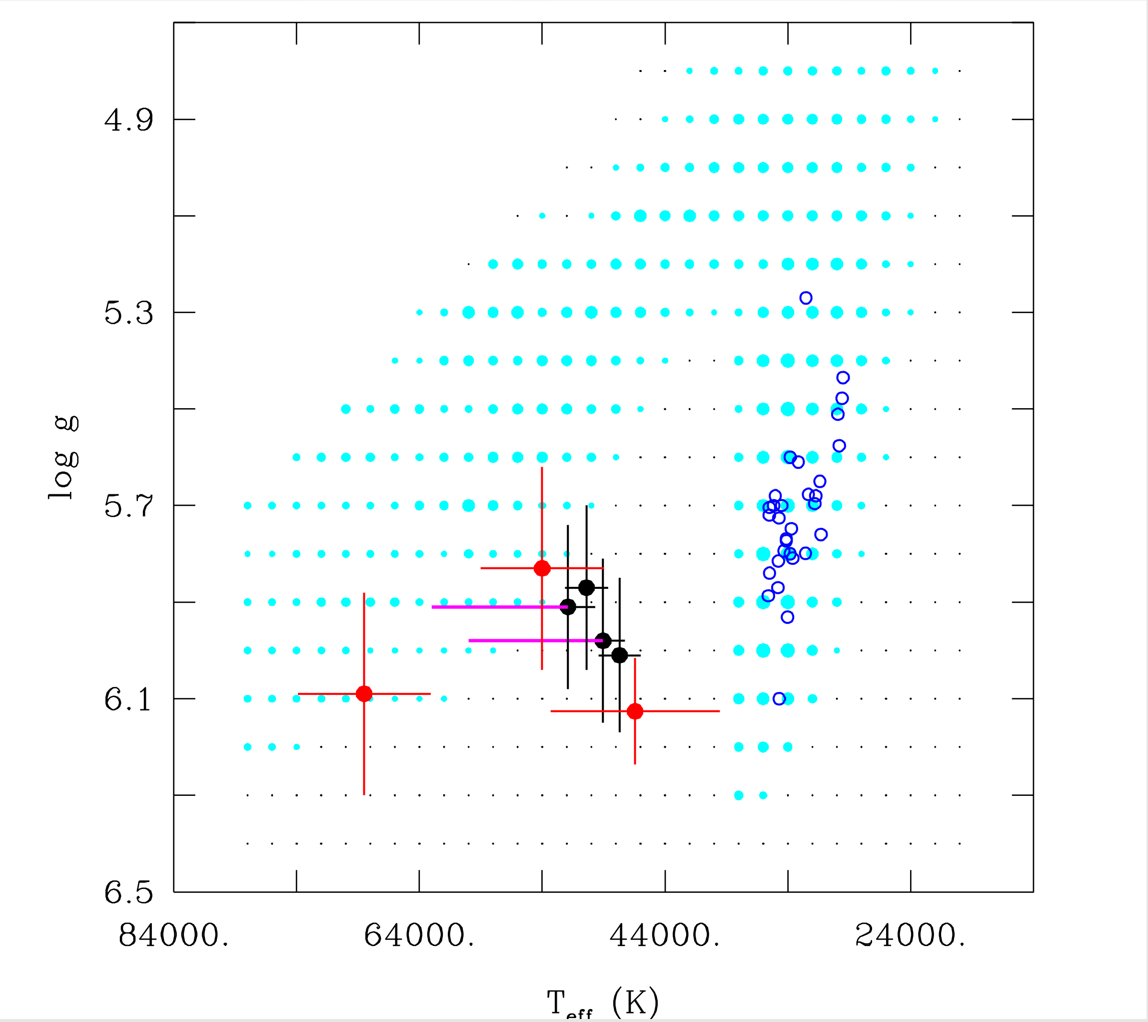
## 3. Non-adiabatic asteroseismology of sdB and sdO stars

- Static envelope models with excited pulsations (Cpulse and MAD)
- Short-period (p-mode) sdB pulsators, i.e. sdBV_r
- sdO pulsators in Omega Cen
- Field sdO pulsators



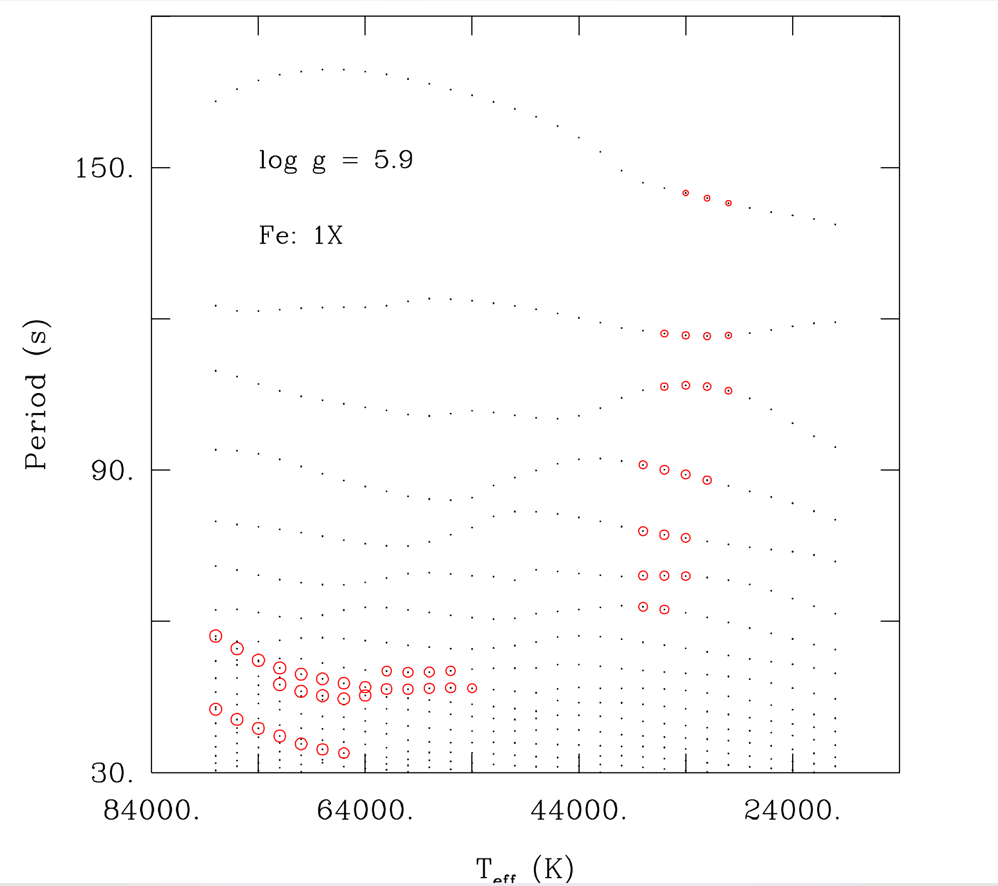
# 3. Non-adiabatic asteroseismology of sdB and sdO stars

Corrected Teff based on UV (HST/COS) spectra: **+8,000 K** (Latour et al. 2017)



# 3. Non-adiabatic asteroseismology of sdB and sdO stars

There is also a problem at the period level...



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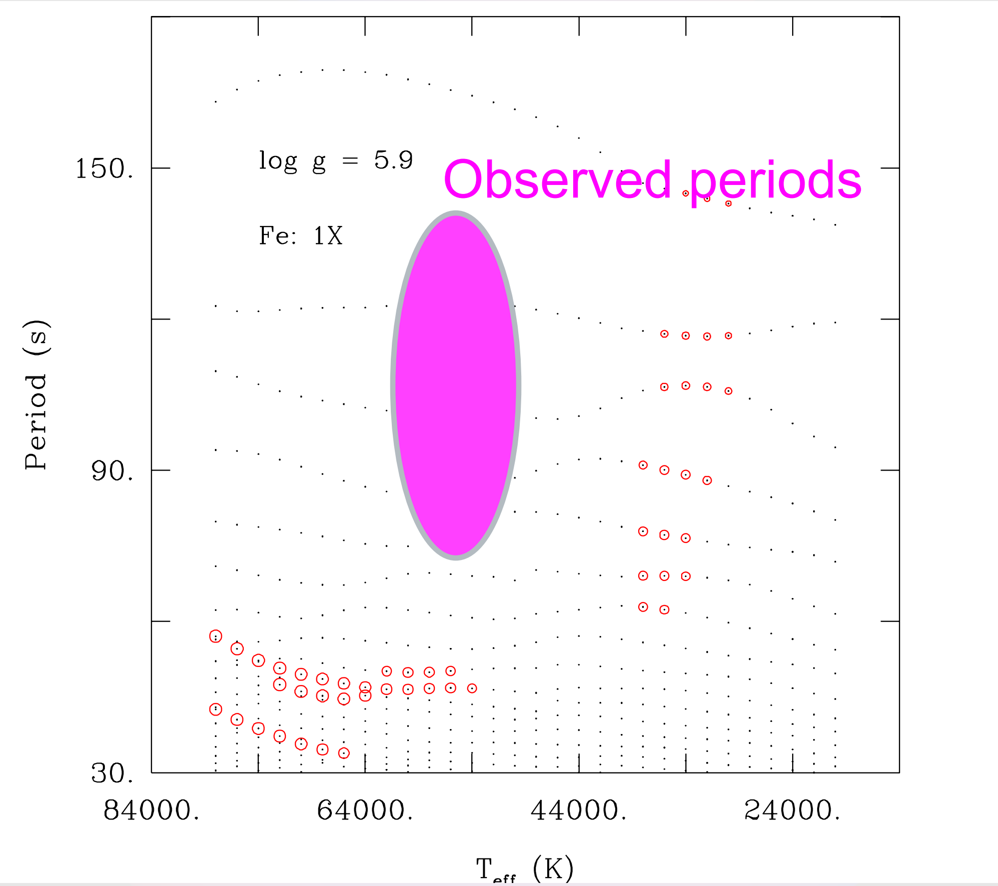


Hopefully to be solved with Fe+Ni models:

- Importance of Ni for driving (Jeffery & Saio 2006, Hu et al. 2011, Bloemen et al. 2014)
- Higher ionization T => deeper Z-bump => longer periods
- ready since April 2018 (OPAL monochromatic opacities of Ni), hurray !

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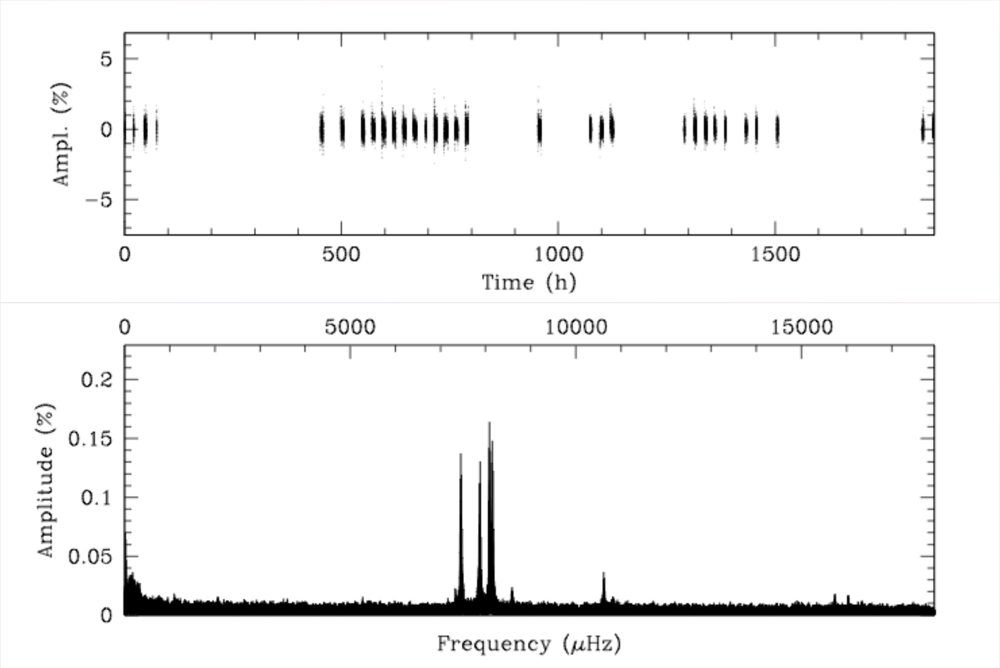
# 4. PB 8783: sdB or sdO star?

## PB 8783 = pulsating subdwarf + F companion

- The second pulsating subdwarf discovered: Koen et al. (1997)
- Frequently re-observed over the years (V=12.6):
  - O'Donoghue et al. (1998), multi-site campaign,183h data over 15 days
  - Jeffery & Pollacco (2000): pulsations from RV spectroscopy
  - Vuckovic et al. (2005) and Vuckovic et al. (2010): ULTRACAM@WHT in u'g'r'
  - This work: 78d @61"-Mont Bigelow campaign in fall 2007 (Fontaine et al. 2012)




Mt-Bigelow campaign:
- Formal resolution: 0.15μHz
- Noise level: 35 ppm

**An old friend of us, always thought to be a sdB star**

# 4. PB 8783: sdB or sdO star?

## A very stable pulsation spectrum

<>: observed multiplets structure

| DOD 1998 | Jeffery & Pollacco (2000) | Vuckovic et al. (2005) | Mont Bigelow |
|---|---|---|---|
| 94.133 | 94.118 | 94.13 | 94.165 |
| 94.454 | ... | ... | 94.452 |
| 116.418 | 116.809 | 116.42 | <116.43> |
| <122.678> | 122.835 | 122.60 | <122.680> |
| 123.578 | ... | 123.58 | <123.630> |
| 127.060 | 127.275 | 127.01 | <127.044> |
| <134.165> | 134.120 | 134.44 | <134.169> |
| 136.269 | 136.258 | ... | 136.273 |

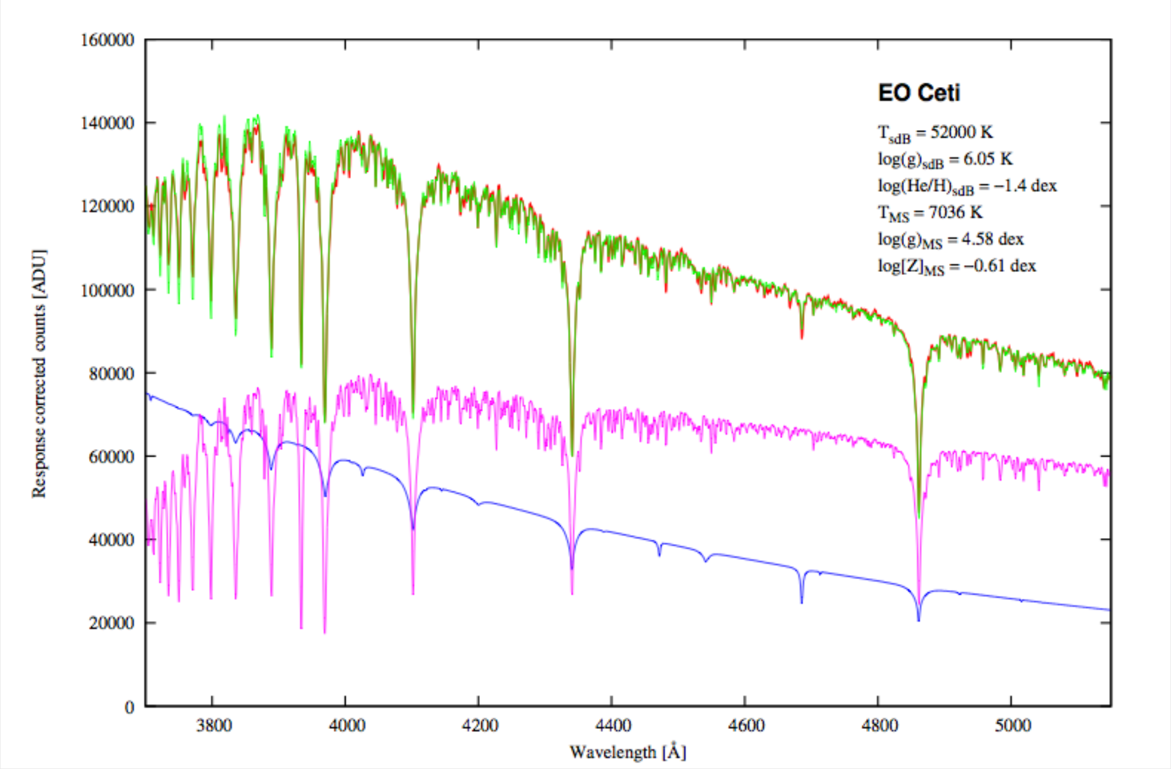
In our Mont Bigelow data (analysis with FELIX, Charpinet et al. 2010):

- 11 additional periods with amplitudes between 4.5 and 6.0σ => **19 independent observed periods in total, 60-190 s**
- Many observed rotational multiplets (1 triplet, 3 quintuplets without central components, and 1 l=4 with 6 components)

**A priori an excellent target for asteroseismology**

# 4. PB 8783: sdB or sdO star?

- Highly contaminated spectrum by the F-companion -> “depollution” procedure needed. Various methods available in spectroscopy...but none is easy to apply and fully convincing here
- Østensen 2012: new medium-resolution spectroscopy @WHT and Mercator, he noticed absence of HeI, and presence of HeII, which is typical of sdO stars

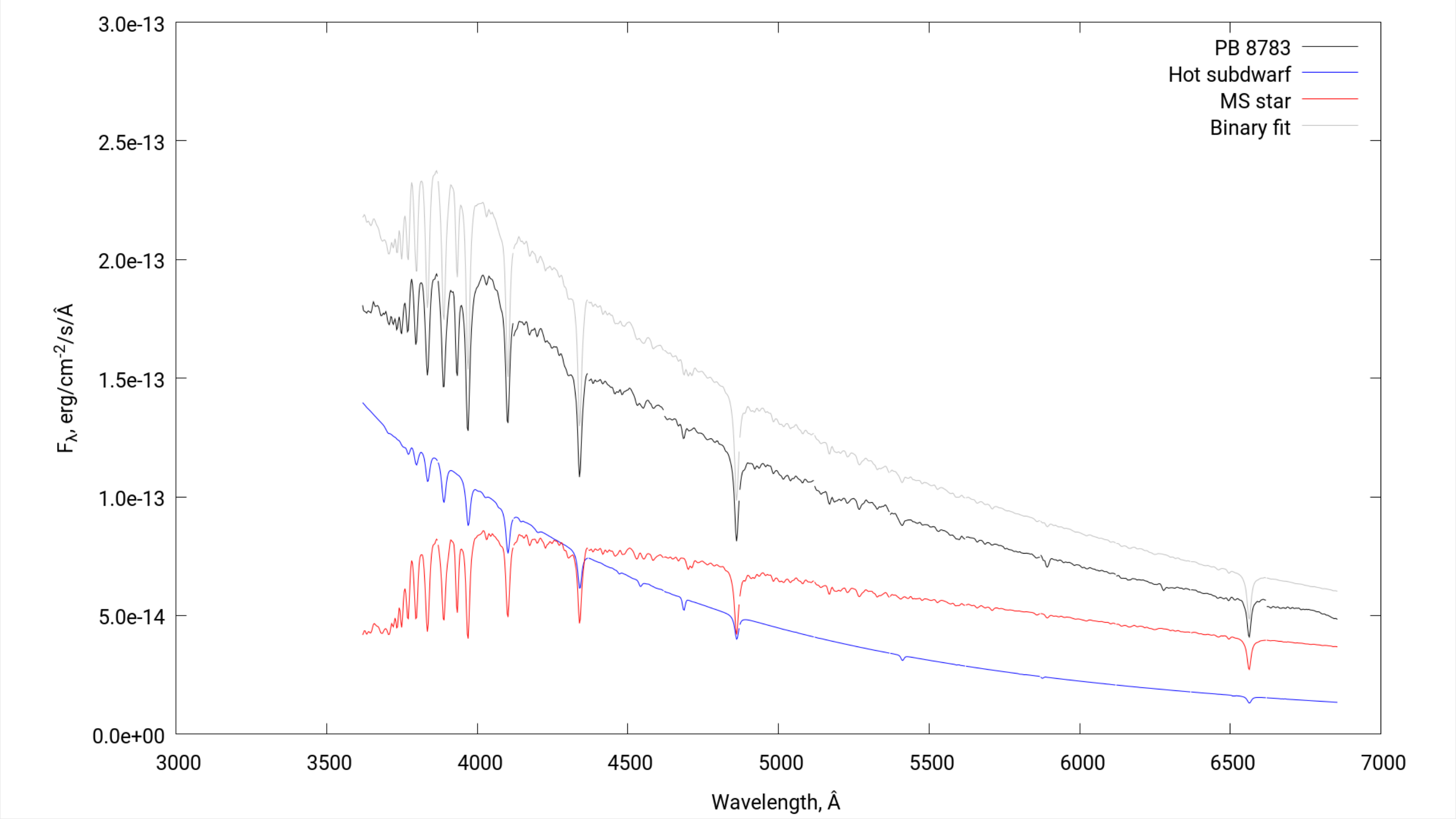



$T_{eff}$ >~ 50,000 K
log g ~ 6

Østensen 2012

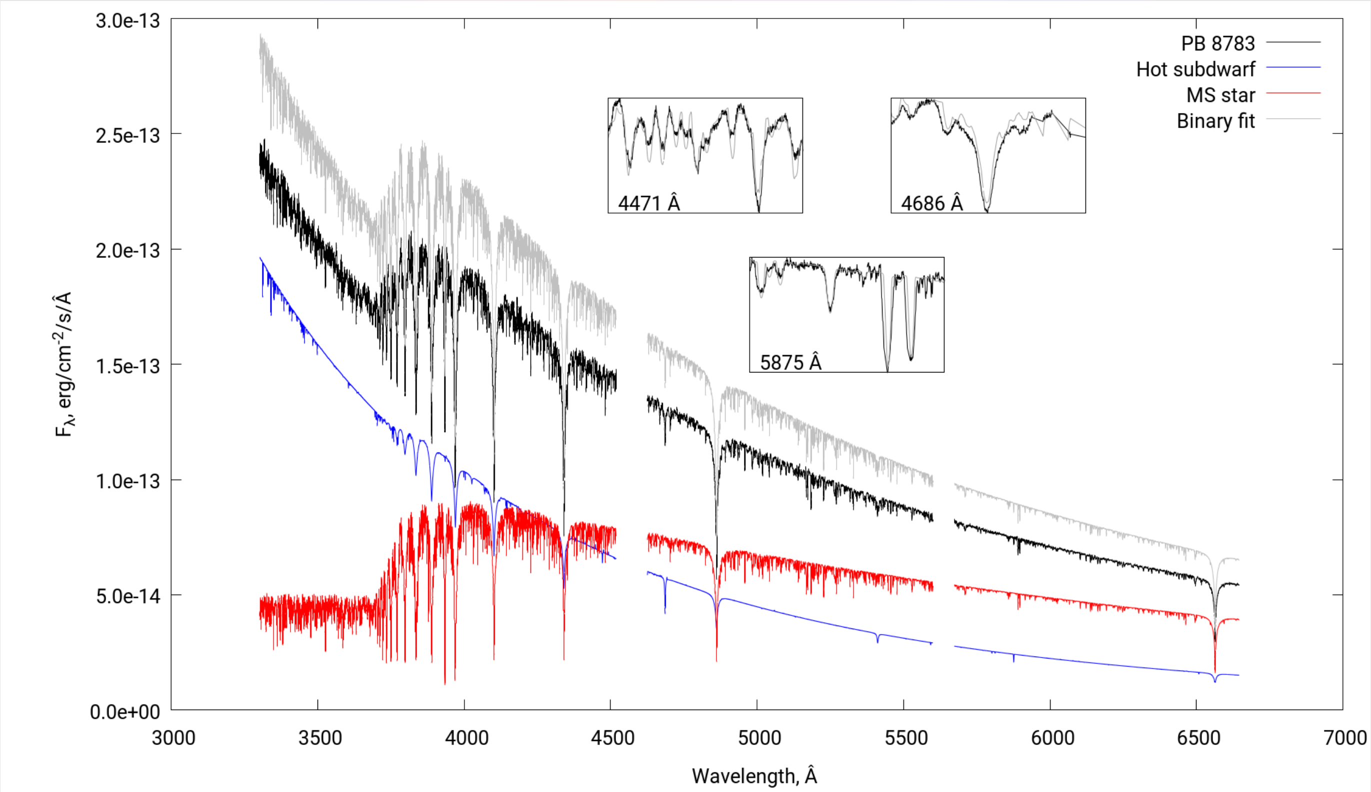
# 4. PB 8783: sdB or sdO star?

- Our work: very high S/N, low-resolution (9Å) spectra (Bok telescope, AZ)
- Method: fit to a linear combination of synthetic sdO and F spectra, to minimize $\chi^2$
- The F-companion dominates: ~72% of the flux at 660 nm, still >50% at 435 nm



# 4. PB 8783: sdB or sdO star?

- Our work: in summer 2017, we obtained high S/N, very high-resolution (0.1 Å) spectroscopy @UVES/VLT
- Same analysis method: $T_{eff}$ ~ 52,000 K, log g ~ 5.85 (±3000K and 0.15, ongoing)




**We definitely have a sdO star...but to be more accurate and precise, we (desperately) need UV spectra !**

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# 5. Asteroseismic modeling of PB 8783

**Models:**

> $2^{nd}$ generation models: up to 70,000 K, adapted to sdB and sdO stars

- static envelope structures; central regions (e.g. convective core) ≡ hard ball
- include detailed envelope microscopic diffusion (nonuniform envelope Fe abundance),
- 4 input parameters : $T_{eff}$, log g, $M_*$, envelope thickness log ($M_{env}/M_*$)

> $3^{rd}$ and $4^{th}$ generation models (complete static structures):

only for subdwarf on EHB (core He-burning), not suited for sdO stars

**Method:** usual forward modeling approach

Fit directly and simultaneously all observed pulsation periods with theoretical ones calculated from sdB models, in order to minimize

$$S^2 = \sum_{i=1}^{N_{\rm obs}} \left( \frac{P^i_{\rm obs} - P^i_{\rm th}}{\sigma_i} \right)^2$$

- Efficient optimization algorithms are used to explore the model parameter space in order to find the minima of $S^2$ i.e. the potential asteroseismic solutions

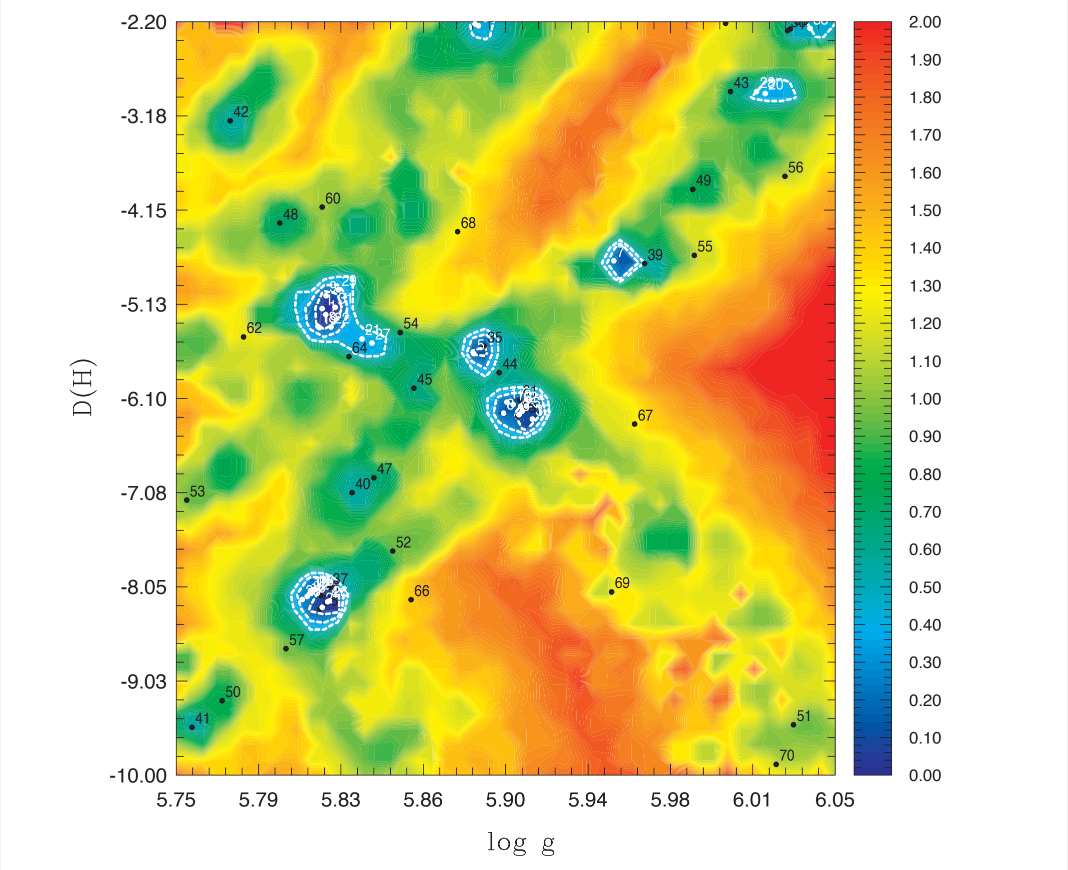
# 5. Asteroseismic modeling of PB 8783

✓ Search parameter space
- $0.3 \leq M_*/M_s \leq 0.7$ (Han et al. 2002, 2003)
- $-10.0 \leq \log (M_{env}/M_*) \leq -2.5$
- log g between 5.7 and 6.1

$T_{eff}$= 53,000 K **fixed** (p-modes are not sensitive to Teff)

✓ Best fit: $S^2$~3.5, i.e. <ΔP/P>~0.37%, <ΔP>=0.4 s, but non-unique solution

$M_{env}$



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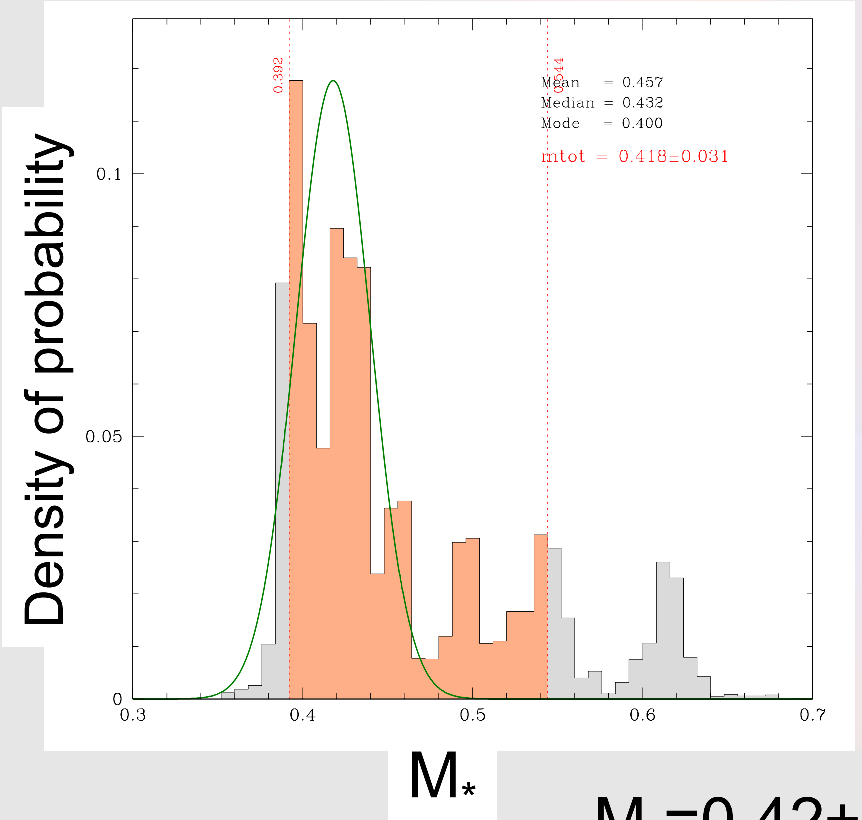
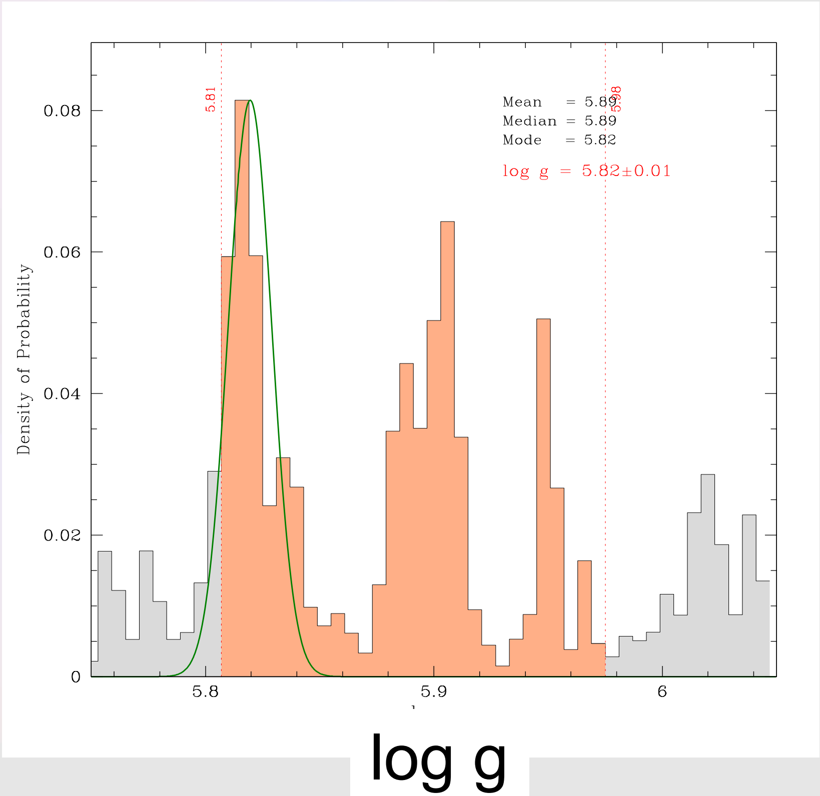
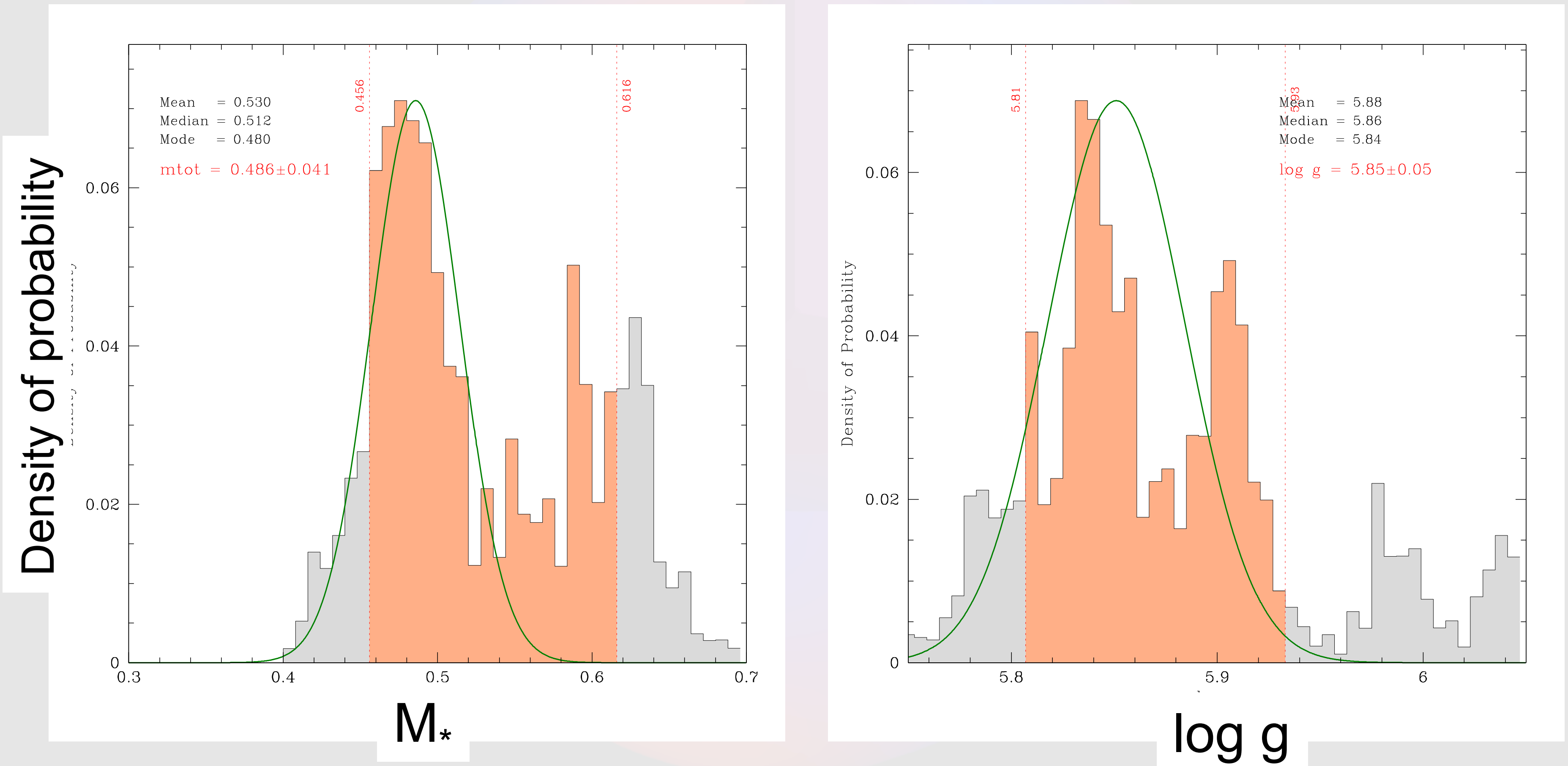



$M_*=0.42\pm0.03\ M_{sun}$

## 5. Asteroseismic modeling of PB 8783

- ✓ Same exercise, but $T_{eff}$= 60,000 K **fixed** (inspired by Latour et al. 2017)
- ✓ Best fit: $S^2$~4.3, i.e. <ΔP/P>~0.43%, <ΔP>=0.47 s, but non-unique solution




$M_* = 0.486 \pm 0.041\ M_{sun}$

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# Conclusions

Nonadiabatic seismology of sdB/sdO stars

- OK for sdBV_r stars, not for sdOs
- Under-estimation of Teff for sdO stars with optical spectroscopy
- Still a period problem: models with Fe+Ni in the envelope

PB8783

- A priori an excellent target for asteroseismology
- Definitely a sdO pulsator
- But we need UV spectra to get accurate <u>and</u> precise spectroscopic parameters
- (partly) due to this, non-unique asteroseismic solution

## Prospects:

- ✓ “Special” models for sdO, post-EHB stars (He-shell burning)
- ✓ UV spectroscopy for sdO stars
- ✓ Using the GAIA distances as constraints (PB 8783: d=911 pc)
- ✓ Exploitation of the rotational multiplets to get internal rotation profile (PB 8783)