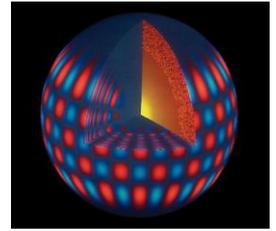# Wroclaw Helas Workshop 2008

Internal dynamics from asteroseismology for two sdB pulsators residing in close binary systems

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1. The problem of synchronization in binary systems

Long-term effects of tidal forces in a binary system

> Alignment (rotation axis perpendicular to orbital motion)

> Circularization (e = 0)

> Synchronization ($P_{rot} = P_{orb}$), <u>from surface to center</u>

Theories for calculating the synchronization times

> Zahn (e.g. 1977; radiative damping and turbulent viscosity)

> Tassoul & Tassoul (e.g. 1992; large scale hydrodynamical currents)

can differ by orders of magnitude, especially in hot stars
with radiative envelopes (such as sdB stars)

The traditional observations only deals with surface layers

Asteroseismology offers the unique opportunity to test the synchronization
*<u>with depth</u>*

2.   Introduction to sdB stars

Hot ($T_{eff} = $ 20 000 - 40 000 K) and compact (log g $= $ 5.2 - 6.2) stars belonging to Extreme Horizontal Branch

- convective He-burning core (I), radiative He mantle (II) and very thin H-rich envelope (III)
- lifetime of ~ 10^8 yr (100 Myr) on EHB, then evolve as low-mass white dwarfs
- At least 50% of sdB stars reside in binary systems, generally in close orbit ($P_{orb} \leq$ 10 days)

Two classes of multi-periodic sdB pulsators (sdBV)

> short-periods (P ~ 80 - 600 s), A $\leq$ 1%, mainly p-modes
> long-periods (P ~ 45 min - 2 h), A $\leq$ 0.1%, g-modes
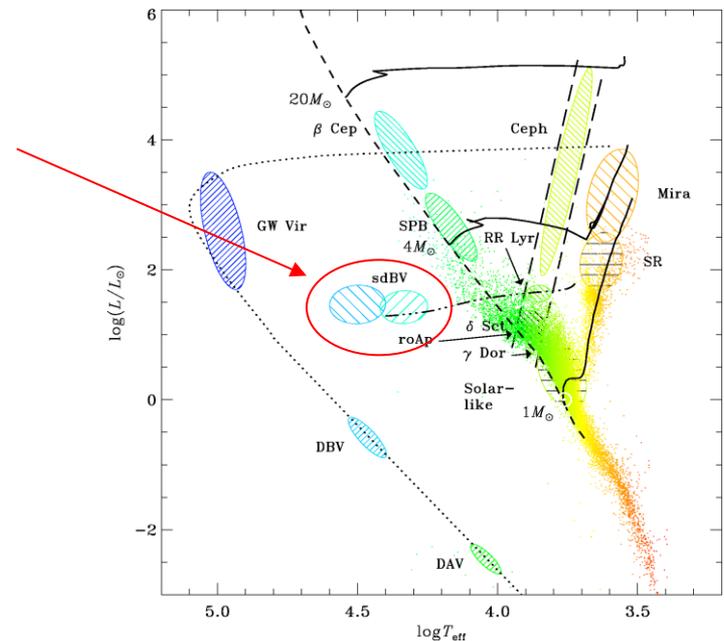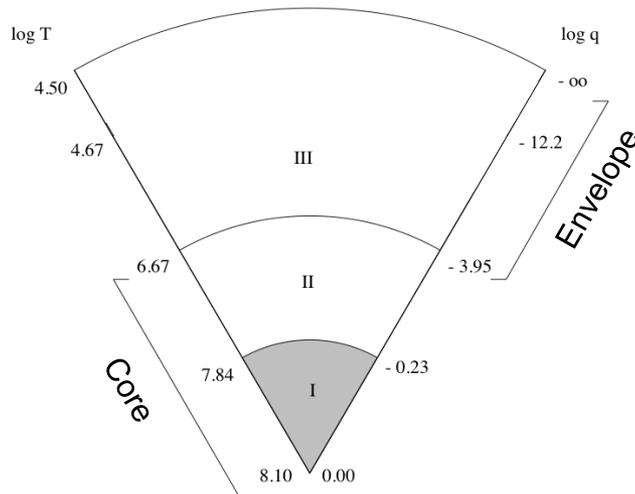
3. The forward modeling approach for asteroseismology

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

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

- The rotational multiplets (lifting $(2l+1)$-fold degeneracy) are calculated by 1st order perturbative approach :

$$\sigma_{klm} = \sigma_{kl} - m \int_0^R \Omega(r) K_{kl}(r)\, dr \quad ; \quad K_{kl}(r) = \frac{\xi_r^2 - [l(l+1) - 1]\xi_h^2 - 2\xi_r \xi_h}{\int_0^R [\xi_r^2 + l(l+1)\xi_h^2]\rho r^2 dr} \rho r^2$$

- Efficient optimization algorithms are used to explore the vast model parameter space in order to find the minima of S^2 i.e. the potential asteroseismic solutions
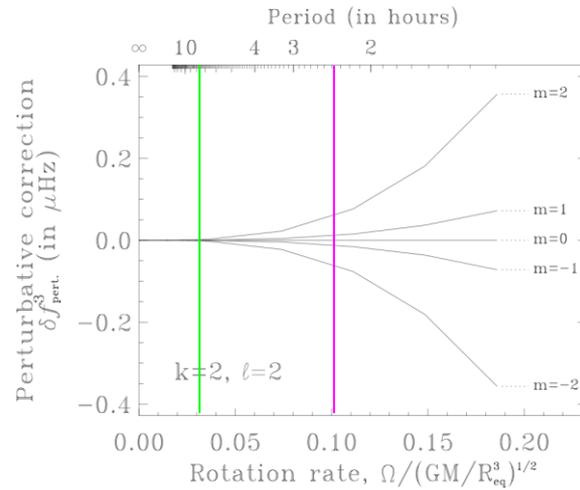
Results :
- Structural parameters of the star (T_{eff}, log g, M_*, envelope thickness, etc.)
- Identification (k,l,m) of pulsation modes
- Internal dynamics $\Omega(r)$

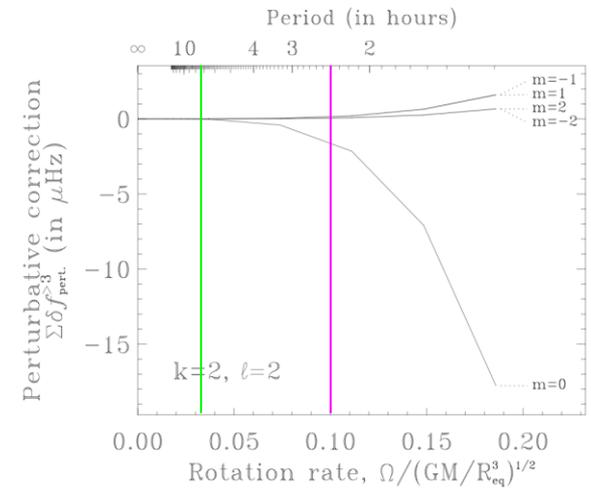# Validity of the 1st order perturbative approach

Evaluation of higher orders effects from polytropic ($N=3$) model of sdB star, with full treatment of rotation (work of D. Reese & F. Lignières)
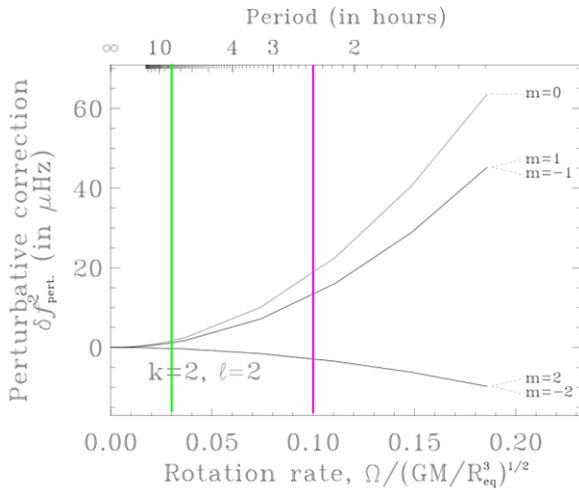
2nd order   3rd order   higher orders

- Rotation period greater than ~ 9 h : 1st order completely valid
- Rotation period to ~ 2.5 h : corrections due to high orders (mainly 2nd order) have the same scale than the accuracy of asteroseismic fits (10 - 15 μHz)

Conclusion : 1st order perturbative approach valid for our purposes

4. Test of the spin-orbit synchronism in the Feige 48 system

Feige 48 system : pulsating sdB + unseen white dwarf, $P_{orb} = 9.024 \pm 0.072$ h (O'Toole et al. 2004)
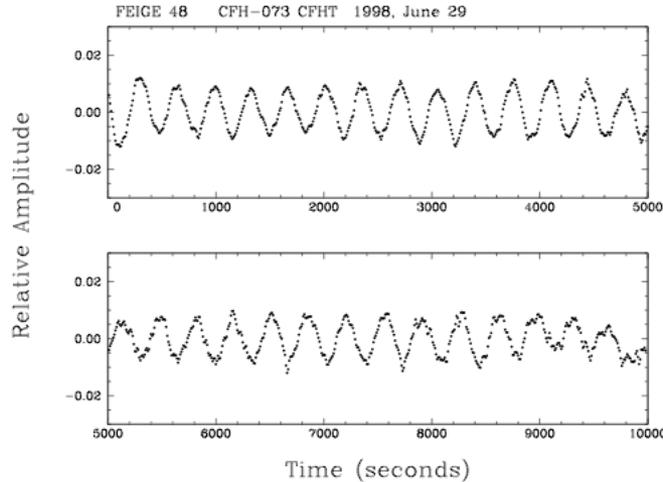
Light curve of the pulsating sdB @ CFHT
(25-30 June 1998)

Frequency analysis :
9 pulsation periods, organized in
3 multiplets with $\overline{\Delta \nu} \sim 28$ µHz
(Charpinet et al. 2005)

$\rightarrow$

| ID	Frequency (mHz)	Period (s)	Amplitude (%)	Spacing (µHz)
f_1^-	2.91522	343.027	0.071	+25.0
f_1	2.89020	345.997	0.111	...
f_2^-	2.90640	344.068	0.411	+28.9
f_2	2.87745	347.530	0.640	...
f_2^+	2.85107	350.746	0.165	−26.4
f_3 or f_1^+	2.83728	352.450	0.116	−52.9
f_4^-	2.67180	374.280	0.039	+29.5
f_4	2.64228	378.461	0.131	...
f_4^+	2.61105	382.988	0.043	−31.2

Asteroseismic analysis under the assumption of solid-body rotation (P_{rot} free parameter)
- ✓ Determination of structural parameters (surface gravity, stellar mass, H-rich envelope thickness)
- ✓ $P_{rot} = 9.028 \pm 0.48$ h. Excellent agreement with the orbital period found by RV variations !

Feige 48 : Investigating the hypothesis of synchronization

Strategy : investigate the rotation of arbitrary two layers in the star (differential rotation)

a) transition fixed at 0.3 R_* (Kawaler & Hostler 2005), for several configurations where surface rotation is fixed to 32,500 s (= P_{orb}). Optimization on structural parameters.
b) transition vary from 0.1 to 1.0 R_*. Structural parameters and surface rotation fixed (to 32,500 s). Optimization on core rotation period P_{core}
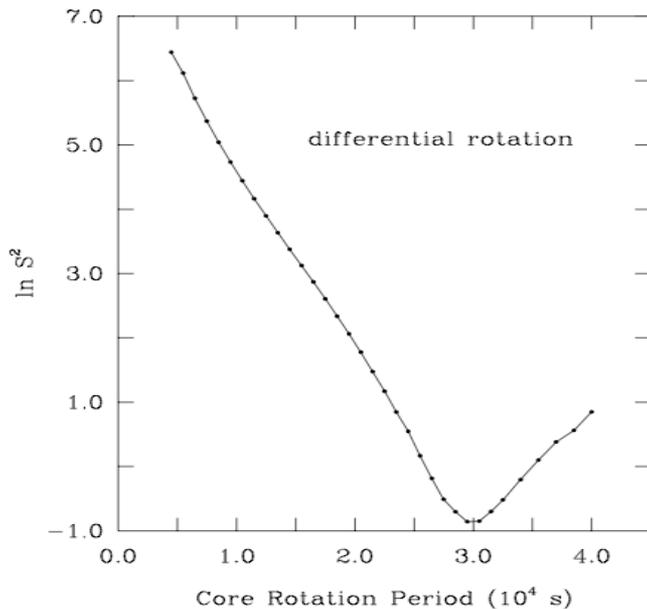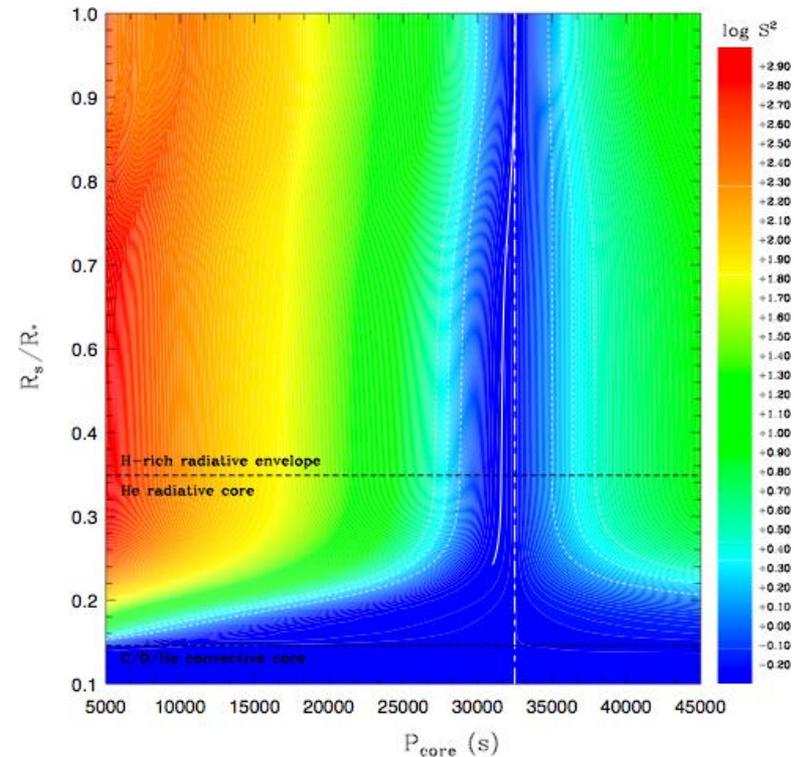
sdB is tidally locked in the Feige 48 system, from surface to ~ 0.22 R_* at least

4.2 Test of the spin-orbit synchronism in the PG 1336-018 system

PG 1336-018 system : pulsating sdB + dM star, P_{orb} = 8 728 s (Kilkenny et al. 2000)

• 25 pulsation periods $96 - 205$ s (Kilkenny et al. 2003)
• Structural parameters derived from asteroseismology in excellent agreement with those derived from orbital motion modelization (Vuckovic et al. 2007)

• Much more tight system than Feige 48 (R_{orb} ~ 1 R_{sun})$\Rightarrow$ most probably synchronized; but we cannot infer the age of the configuration (lifetime sdB ~ 100 Myr)

• We carried out only b) approach due to time calculation

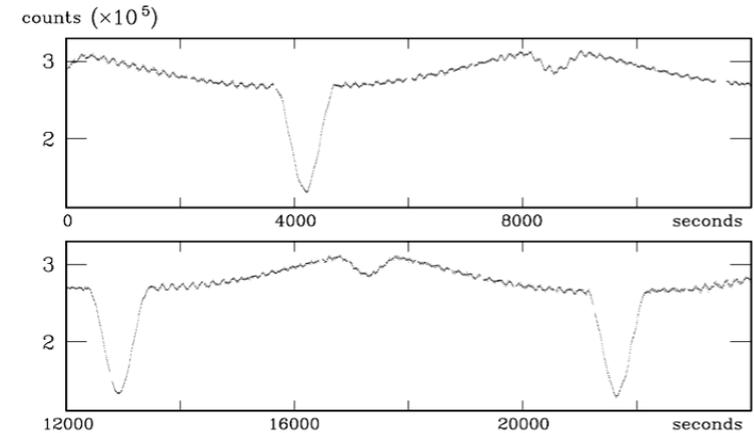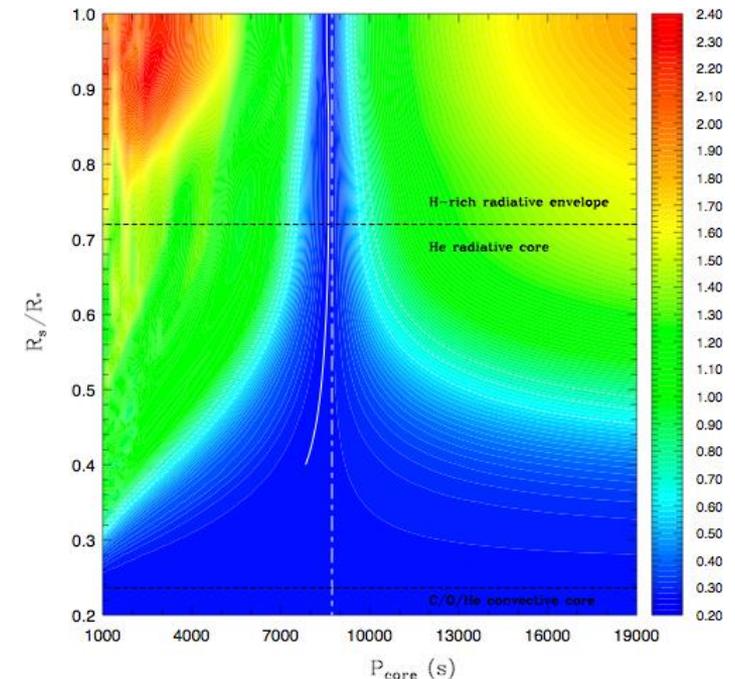sdB PG 1336-018 is tidally locked from surface to ~ 0.55 R_* at least

Figure from Kilkenny et al. (2003)

5. Conclusion and room for improvement

Conclusion :

We have demonstrated spin-orbit synchronism from asteroseismology

- from surface to 0.22 R_* at least for sdB star Feige 48 (P_{orb} = 32 486 s)
- from surface to 0.55 R_* at least for sdB star PG 1336-018 (P_{orb} = 8728 s)

In both cases, dynamics of deeper regions cannot be inferred with the type of pulsation modes in these <u>short-periods</u> sdB stars

Room for improvement :

✓ Dynamics of deep regions (to convective core) could be probed by g-modes of <u>long-periods</u> pulsating sdB stars (tools are now ready)

$\Rightarrow$ *new constraints for tidal dissipation theories ???*

✓ Improvement of the tools to study internal dynamics :
- implementation of other rotation laws like $\Omega(r,\theta)$ (e.g. cylindrical)
- division of star in more than 2 layers (physical layers ?)
- implementation of 2nd order perturbation for fastest sdB rotators.
Ideally (future) : full treatment of stellar rotation