Frequency and amplitude variations of oscillation modes in the hot B subdwarf star KIC 10139564

First evidence of resonant mode couplings in sdB star?

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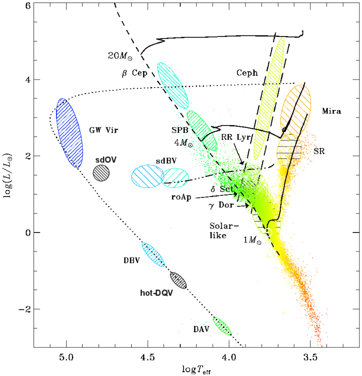
Overview



Hot B subdwarf stars (Heber, 2009)

Evolved helium core burning stars
hot: $T_{eff} \sim 22\,000 - 40\,000$K
compact: $\log g \sim 5.2 - 6.2$
low mass: ≈0.47 $M_\odot$ and a thin envelop (Fontaine et al. 2012).

Two types of sdB pulsator:
1, V361 Hya: short period *p*-mode oscillations, several minutes (Kilkenny et al. 1997);
2, V1093 Her: about 1−4 hours, *g*-mode oscillations (Green et al. 2003);
and some are **hybrid stars** with pulsating both in *p*- and *g*-mode (Schuh et al. 2006).

Introduction → frequency splitting by sdB pulsators' rotation

The frequencies split are computed up to 2nd orders with,

$$\nu_m = \nu_0 + m\Delta\nu + 0.5m^2\delta\nu. \tag{1}$$

The first order $\Delta\nu$ is calculated as,

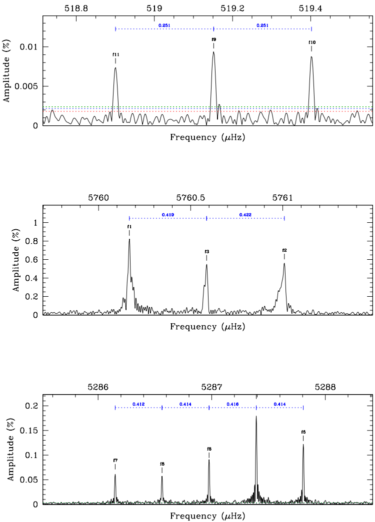
$$\Delta\nu = (1 - C)\overline{\Omega}, \tag{2}$$

and the second order splits $\delta\nu$ are approximated (Goupil et al. 1998),

$$\delta\nu = 4C\left(\frac{\overline{\Omega}}{\nu_0}\right)^2 \nu_0. \tag{3}$$

For the observed frequencies, the second order splits $\delta\nu_{obs}$ are calculated as,

$$\delta\nu_{obs} = \nu_+ + \nu_- - 2\nu_0. \tag{4}$$



Resonant mode coupling for $l = 1$ triplet modes

For $l = 1$ triplet modes, the amplitude equation (Buchler et al. 1995, 1997):

$$\frac{dA_-}{dt} = \kappa_- A_- + R_- A_0^2 A_+ \cos(\Phi - \delta_-) - A_-(q_{11} A_-^2 + q_{12} A_0^2 + q_{13} A_+^2) \quad (5a)$$

$$\frac{dA_0}{dt} = \kappa_0 A_0 + R_0 A_0 A_+ A_- \cos(\Phi + \delta_0) - A_0(q_{21} A_-^2 + q_{22} A_0^2 + q_{23} A_+^2) \quad (5b)$$

$$\frac{dA_+}{dt} = \kappa_+ A_+ + R_+ A_0^2 A_- \cos(\Phi - \delta_+) - A_+(q_{31} A_-^2 + q_{32} A_0^2 + q_{33} A_+^2) \quad (5c)$$

$$\frac{d\Phi}{dt} = \delta\nu - 2R_0 A_- A_+ \sin(\Phi - \delta_0) + A_0\left(R_- \frac{A_+}{A_-} \sin(\Phi - \delta_-) + R_+ \frac{A_-}{A_+} \sin(\Phi - \delta_+)\right) \quad (5d)$$

Three regimes

- **Frequency lock (RMC1)**: amplitude A_+, A_0 and A_- are constant, most case with $A_+/A_- \neq 1$. Frequencies in triplet are equally spaced, e.g. $\nu_+ + \nu_- = 2\nu_0$.
- **Intermediate regime (RMC2)**: The oscillation modes undergo periodic (irregular, even chaostic) amplitude and frequency modulations. $P_{mod} \sim 1/\delta\nu$.
- **Nonresonant regime (RMC3)**: Far away from resonance, no (tiny) interaction between components in the triplet.

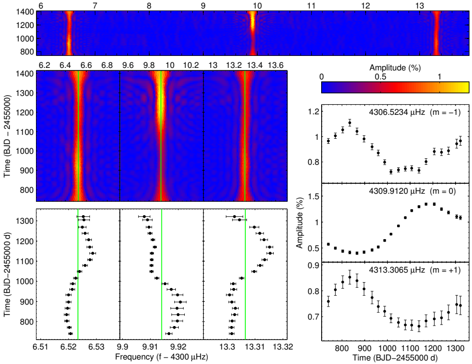
Groud-based observations

✓ White dwarf GD 358 (Goupil et al. 1998)

✓ PG 0122+200 (Vauclair et al. 2011).

Kepler observations

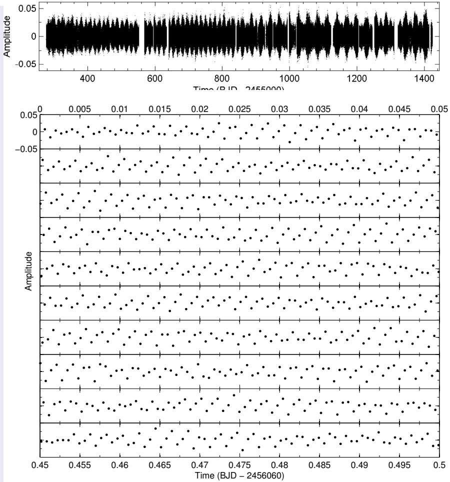
- **DBV KIC 08626021**: near two-year-observation without interruption (Zong et al. 2015).



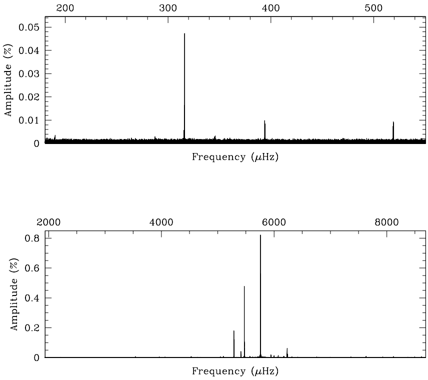
Kepler: **18sdB pulsators** → most are *g*-mode dominated and 1 is *p*-mode dominated. (Østensen et al. 2014 and references therein)

SdB star KIC10139564

- Discovered in Q2.1 and continuously observed for 38-month
- V361 Hya type with additional one low-amplitude *g*-mode oscillation (Kawaler et al. 2010)
- 57 perodicities and several multiplets (Baran et al. 2012)
- Common spacing multiplets → rotating period of 25.6±1.8 d

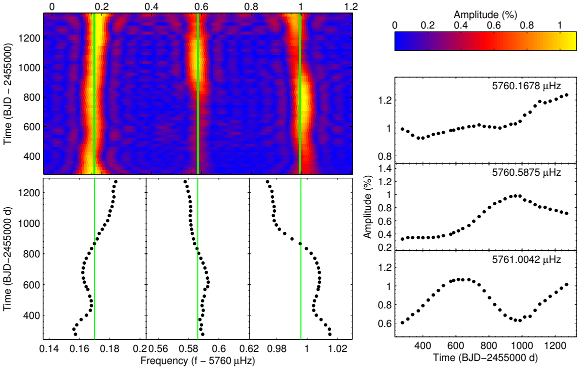


Frequency content of KIC 10139564



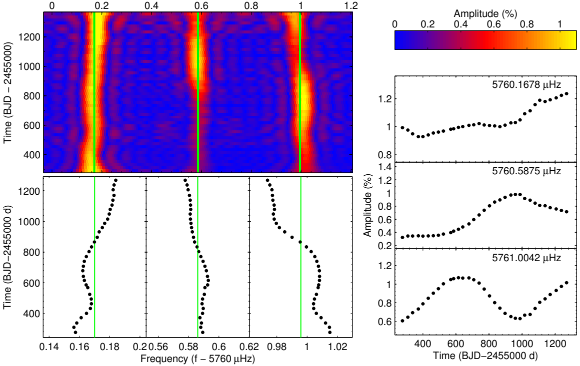
Prewhitening frequencies by Program Felix (Charpinet et al. 2010)

- ✓ new detection threshold of 5.6 σ level
- ➔ multiplets: pay particular attention
- ➔ independend frequencies
- ➔ frequency group (Baran et al. 2012)



Intermediate regime of RMC

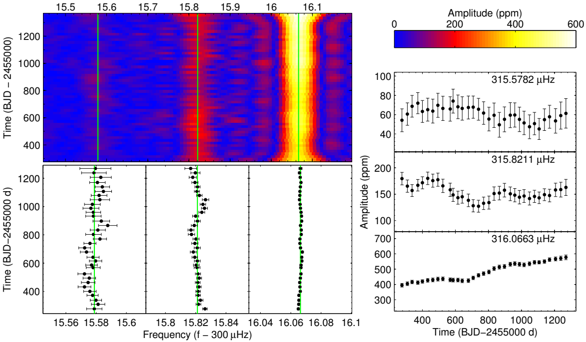
- Coherent frequency variations
- Amplitude modulations



Intermediate regime of RMC

- Coherent frequency variations
- Amplitude modulations

Frequency and amplitude variations of the triplet $T2$ near 316 μHz

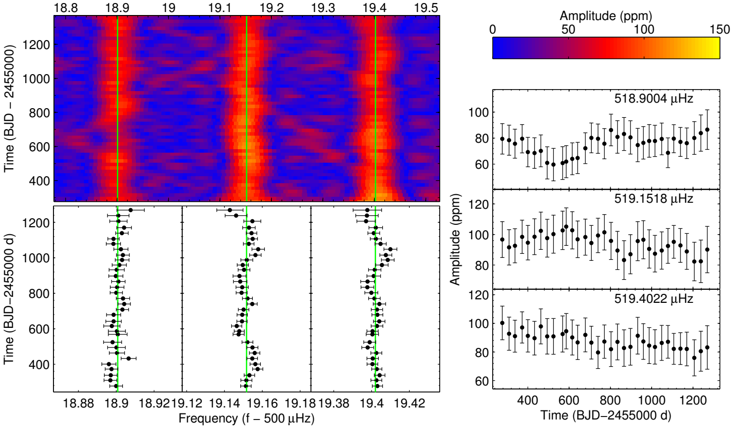


Narrow hysteresis regime of RMC?

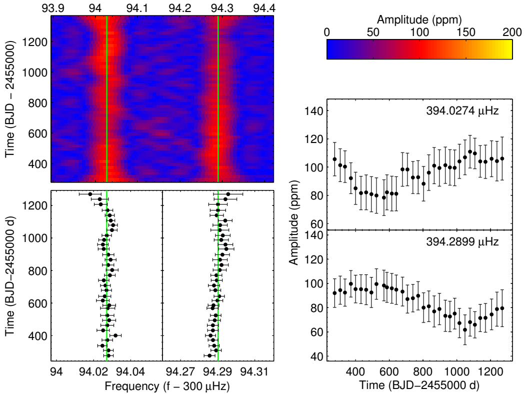
- One component shows amplitude increasing
- Constant frequency

Frequency lock of RMC

Amplitude and frequency of the 3 components are stable during the 38-month *Kepler* observations.



Frequency and amplitude variations of the doublet $D1$ near 394 μHz



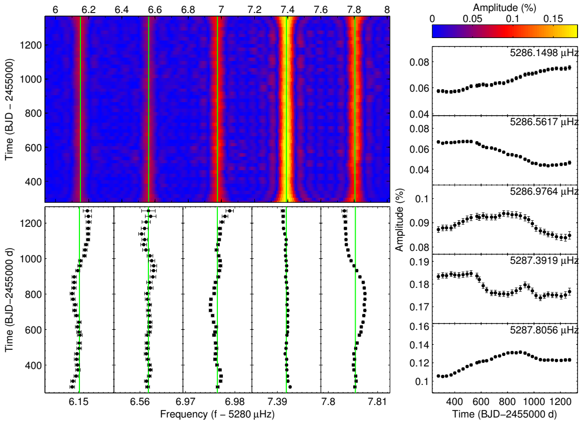
Intermediate regime of RMC

No numerical solutions for two components with one is the central one in the incomplete triplet

- Amplitude varying
- Frequency constant

Intermediate regime of RMC

Amplitude and frequency modulations (no existing numerical exploration for $l = 2$ quintuplet).



Summary

Frequency and amplitude variations in sdB KIC 10139564

We found frequency and amplitude modulations in sdB star KIC10139564, thanks to the high quality and long duration data obtained from *Kepler* spacecraft.

The first evidence of resonant mode coupling in sdB star

Those frequency and amplitude modulations suggest that one sees the 3 different regimes of nonlinear resonant mode coupling mechanism.

Intermediate regime in sdB star KIC 10139564

The intermediate regime occuring on a timescale of several years may pave the way to new diagnosis of the first measure of the growth rate of the oscillation modes in sdB stars.

Further work

- Seismic models on sdB star KIC 10139564
- Searching for other resonant coupling like: $\nu_1 \sim \nu_2 + \nu_3$

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Thank you!