

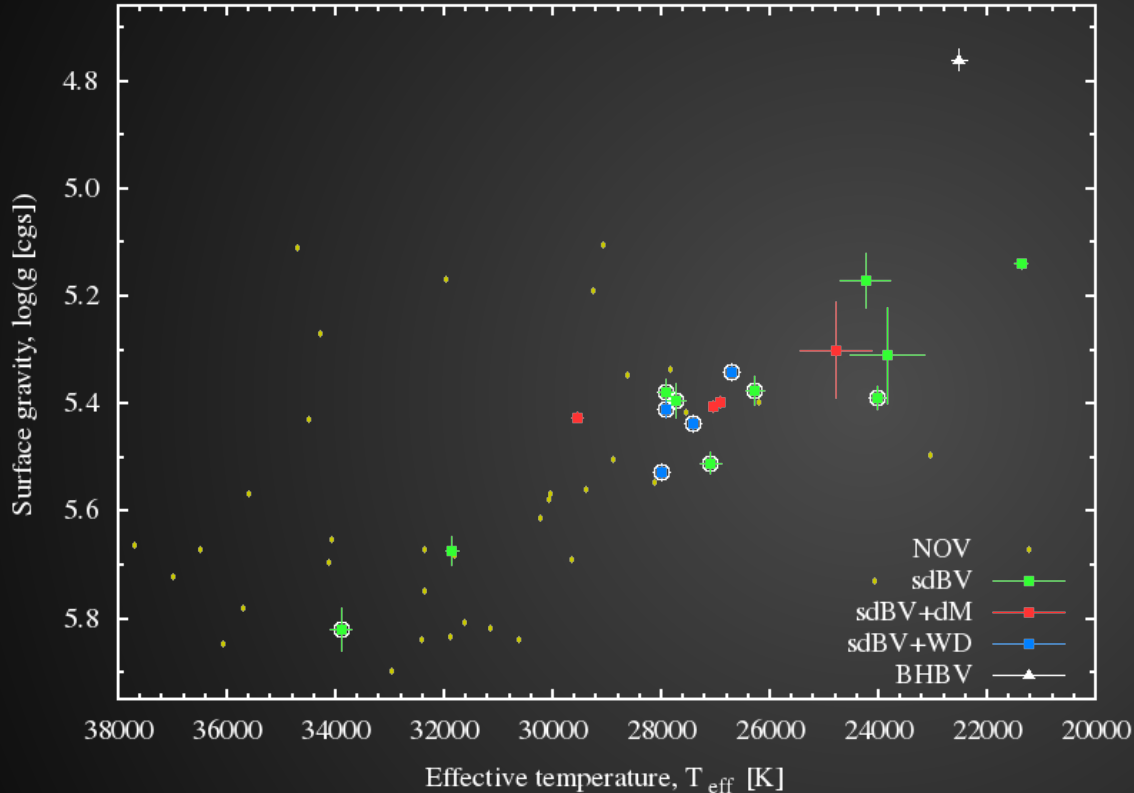
Kepler observations of sdB pulsators

New diagnostics for asteroseismology

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The sdB pulsators from K1



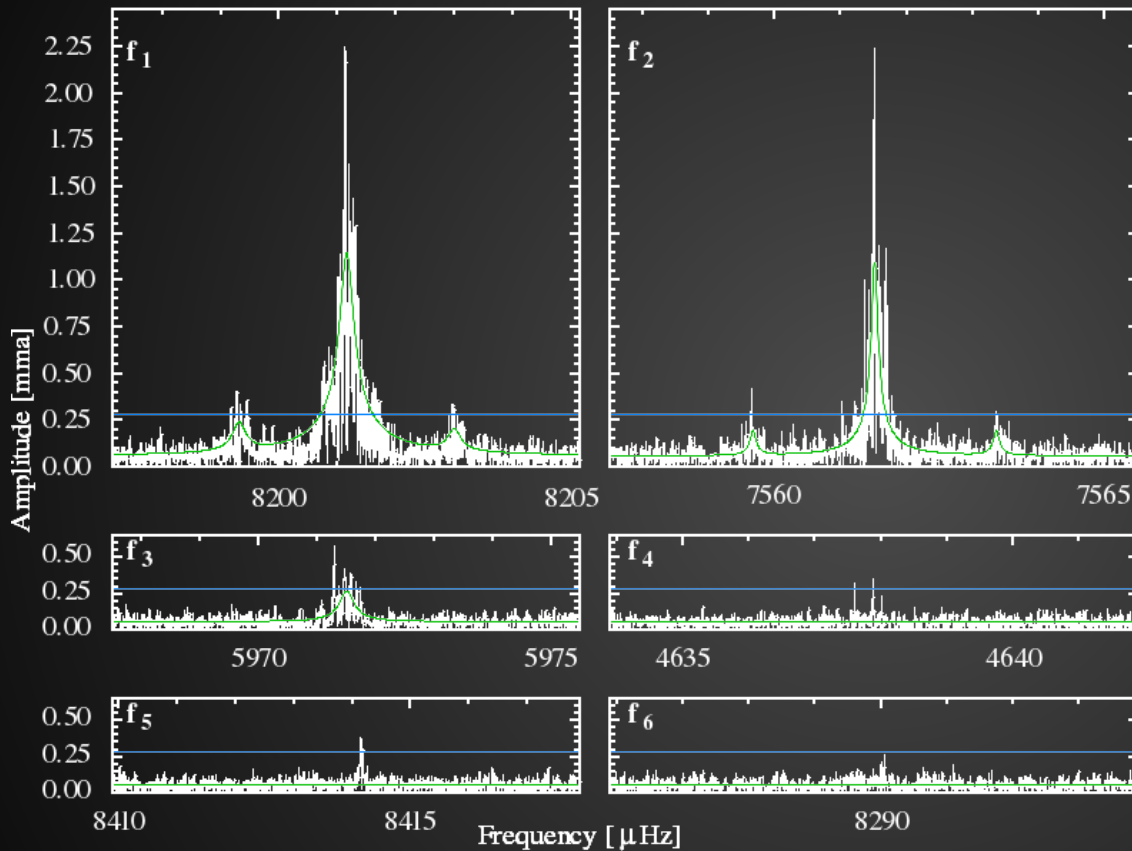
K1 found 19 pulsators:

- 2 with p-modes
- 1 BHB variable
- 3 in NGC 6791
- 3 with dM companions
- 4 with WD companions
- several with planets

And also several binaries with non-pulsating sdB companions

I will review 10 pulsators (as circled on the plot) with a particular focus on stochastic behaviour

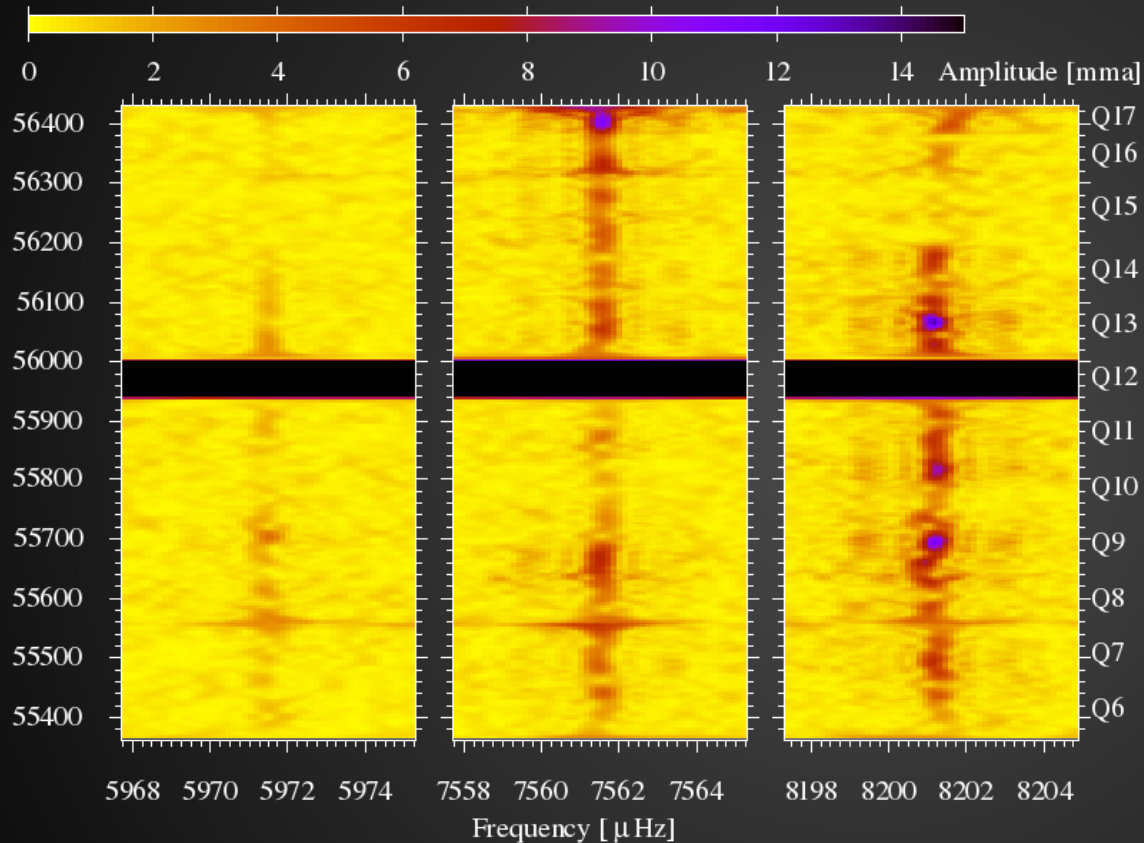
Frodo = KIC 2991276



Frodo is a p -mode pulsator with modes that show strongly stochastic behaviour

Østensen et al. (2014; A&A 564; L14)

Frodo = KIC 2991276

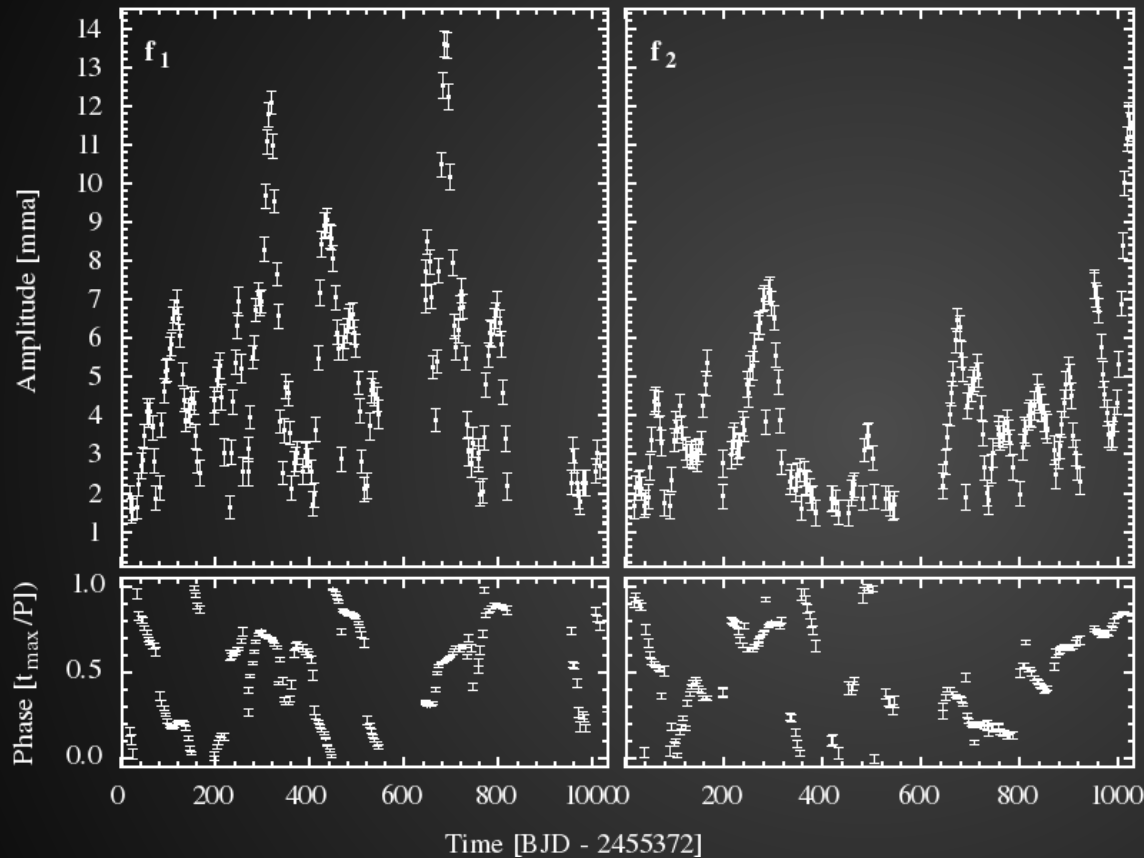


Sliding FT shows amplitudes going from 0 to 14 ppt on timescales of weeks

Sidebands seems to be correlated in amplitude: binary?

Østensen et al. (2014; A&A 564; L14)

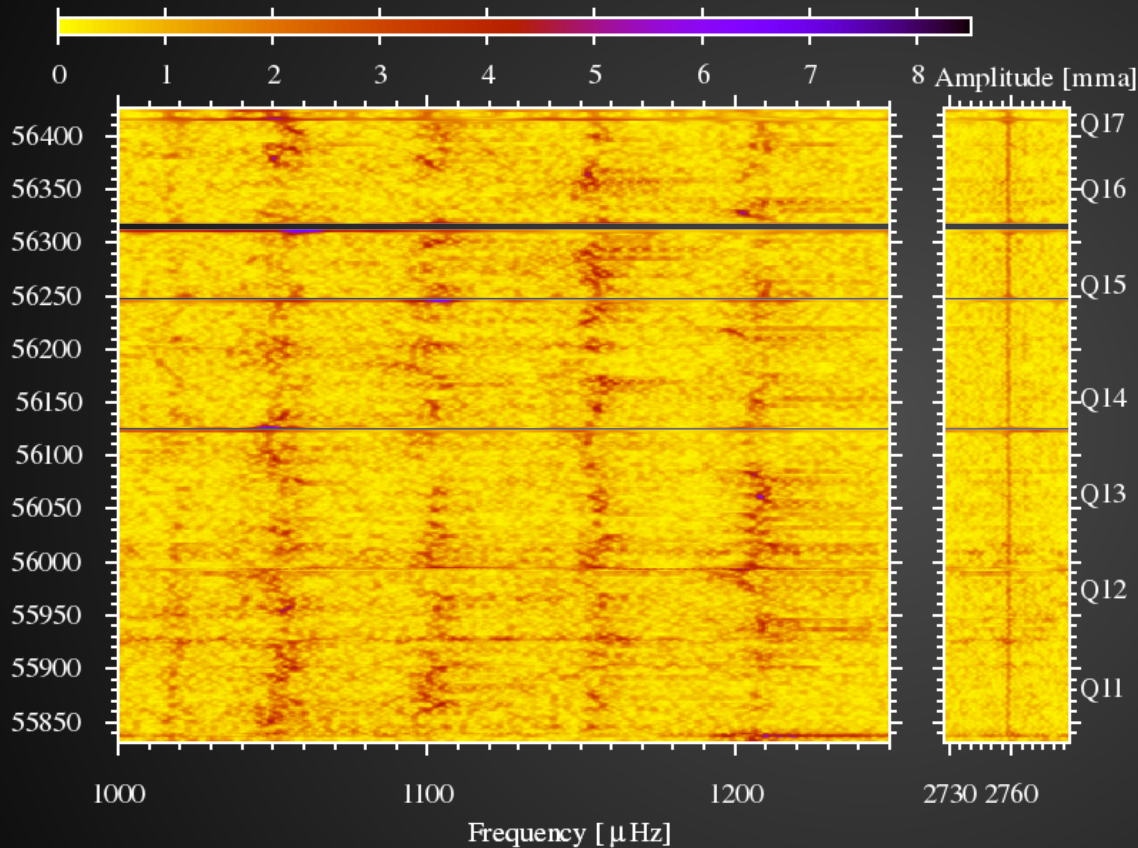
Frodo = KIC 2991276



Not just amplitude modulations, phase/frequency is really stochastic as well.

Østensen et al. (2014; A&A 564; L14)

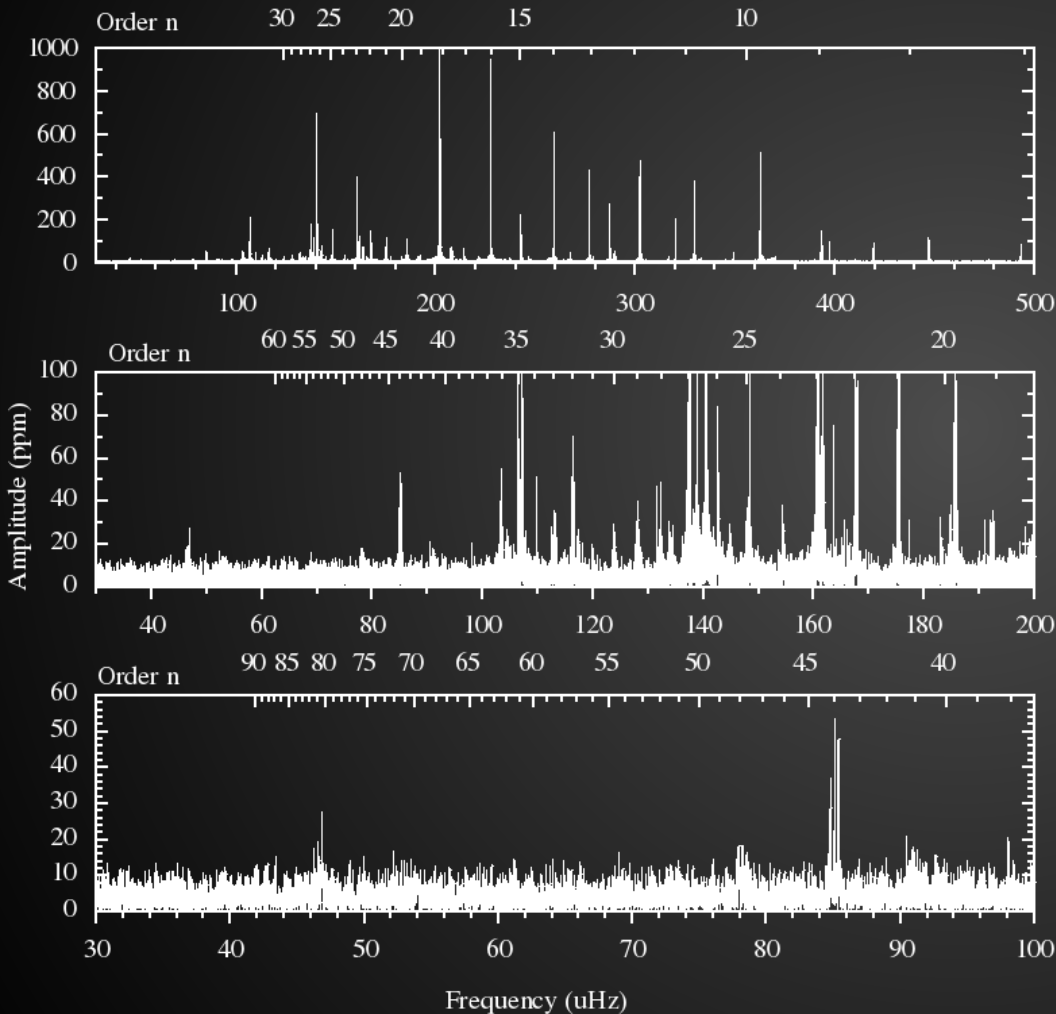
Dwalin = KIC 4552982 (DAV)



Dwalin is a DAV at the cool end of the instability strip and shows extremely stochastic pulsations around 1000 μHz and a perfectly stable mode at 2760 μHz .

Bell et al. (2015; ApJ, in press)

Hamfast = KIC 10553698

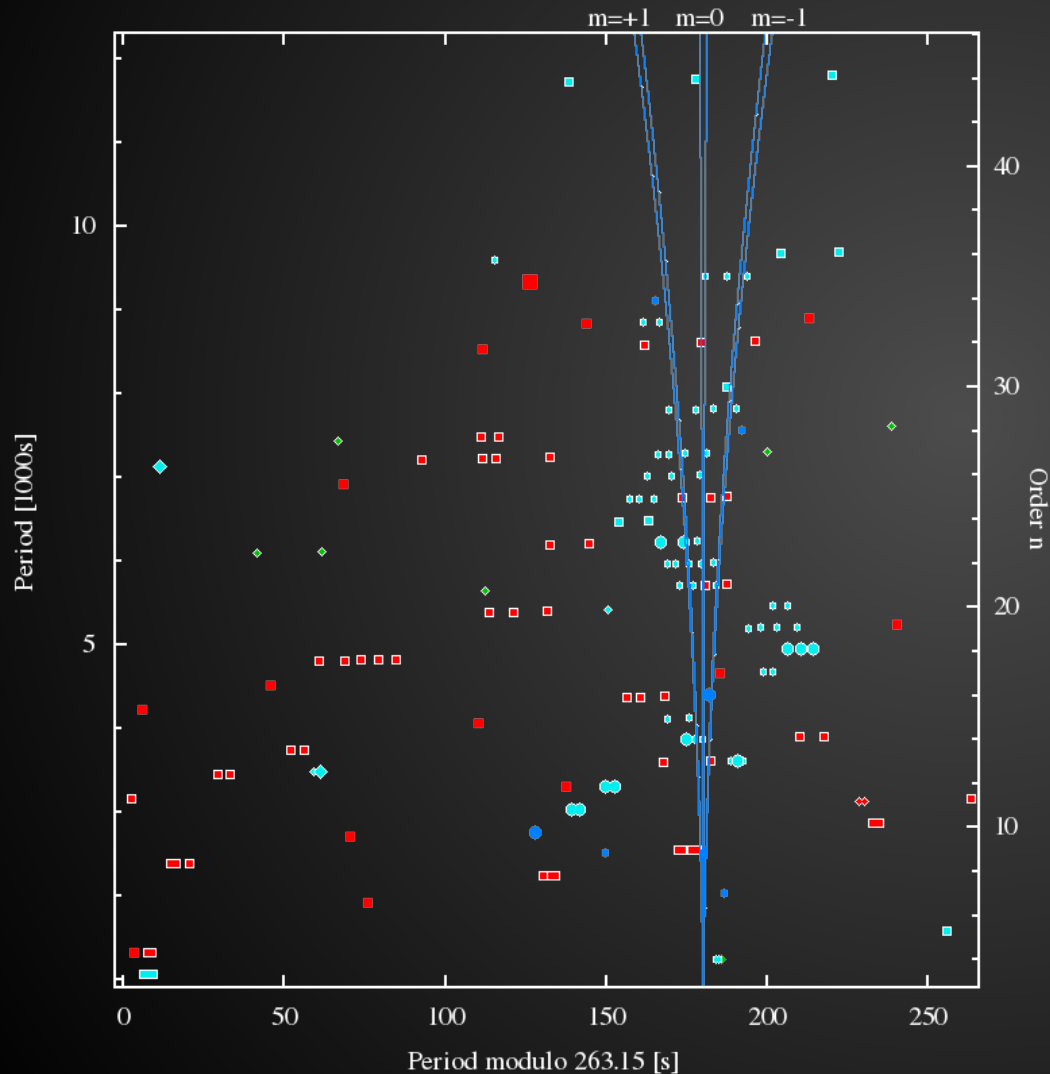


Hamfast is a g-mode pulsator in a binary with a period of 3.4 d.

Rich pulsation spectrum, with only a few modes far away from the main modes showing slightly stochastic behaviour.

Østensen et al.
(2014; A&A 569 A15)

Hamfast = KIC 10553698

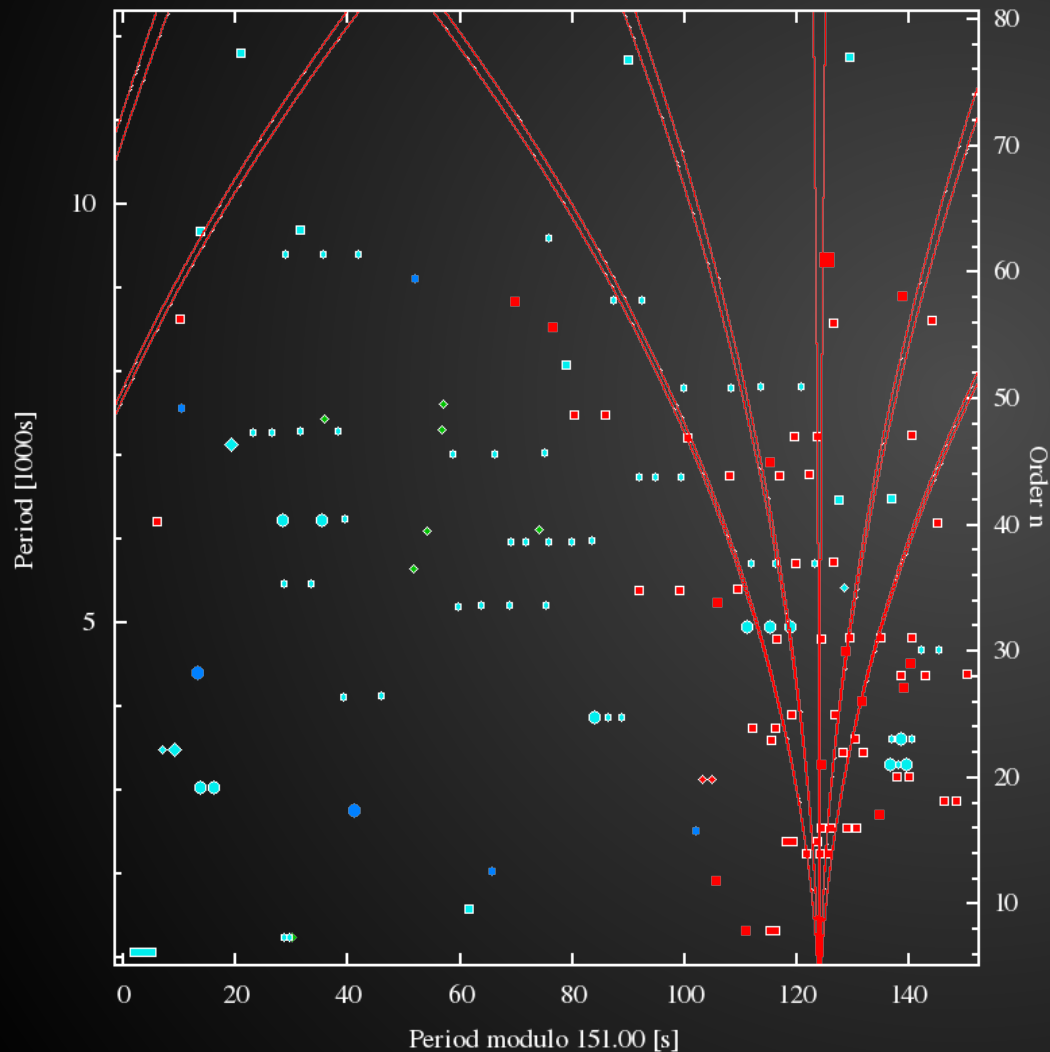


The echelle diagram reveals an almost complete sequence of multiplets

Symbols:

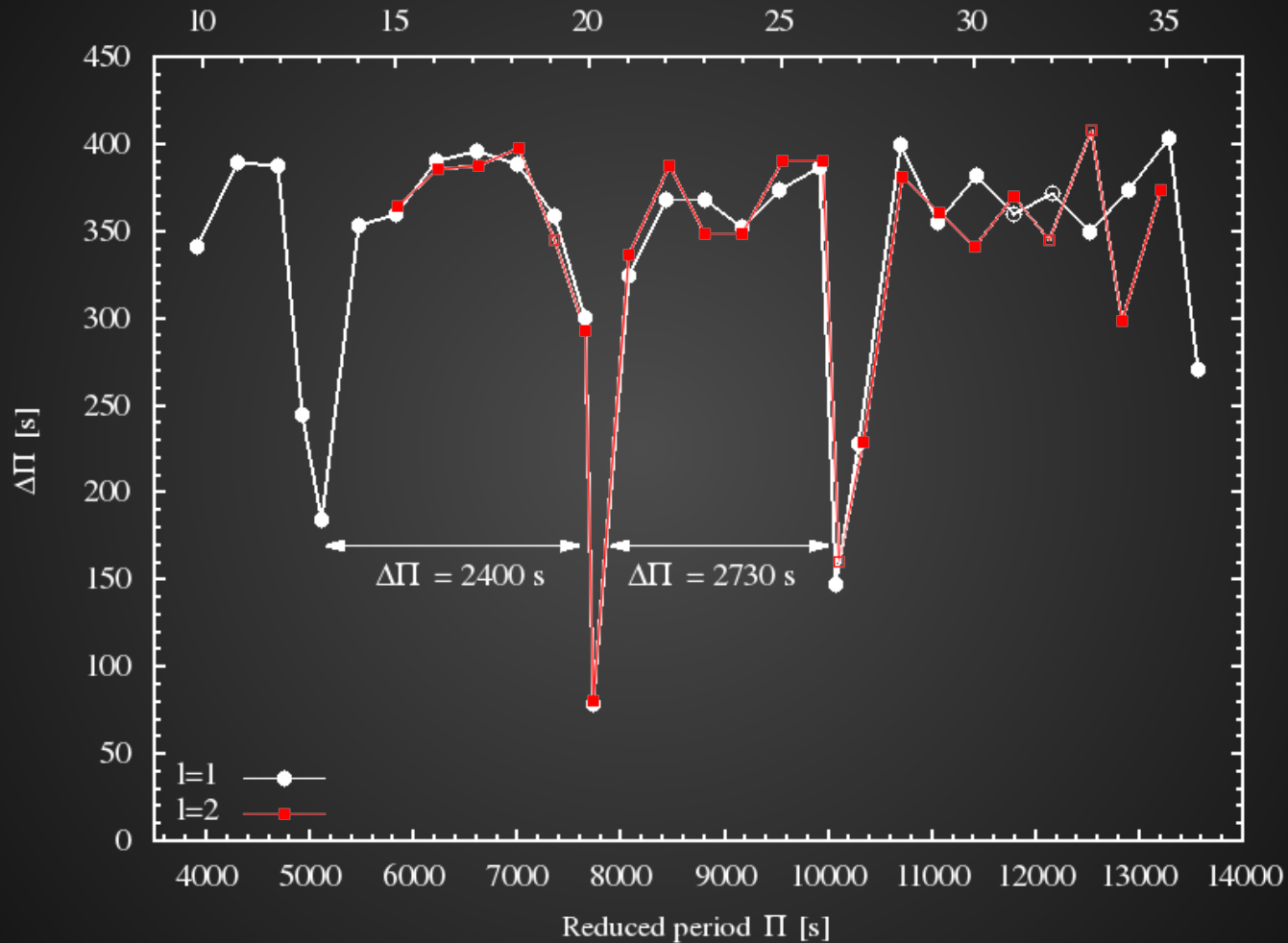
- Blue circles: $l=1$
- Red squares: $l=2$
- Blue diamonds: trapped modes
- Green diamonds: unidentified low-amplitude modes
- Outlined symbols: multiplets
- Large symbols mark the highest amplitude modes

Hamfast = KIC 10553698



The sequence for $l=2$ is also fairly complete.

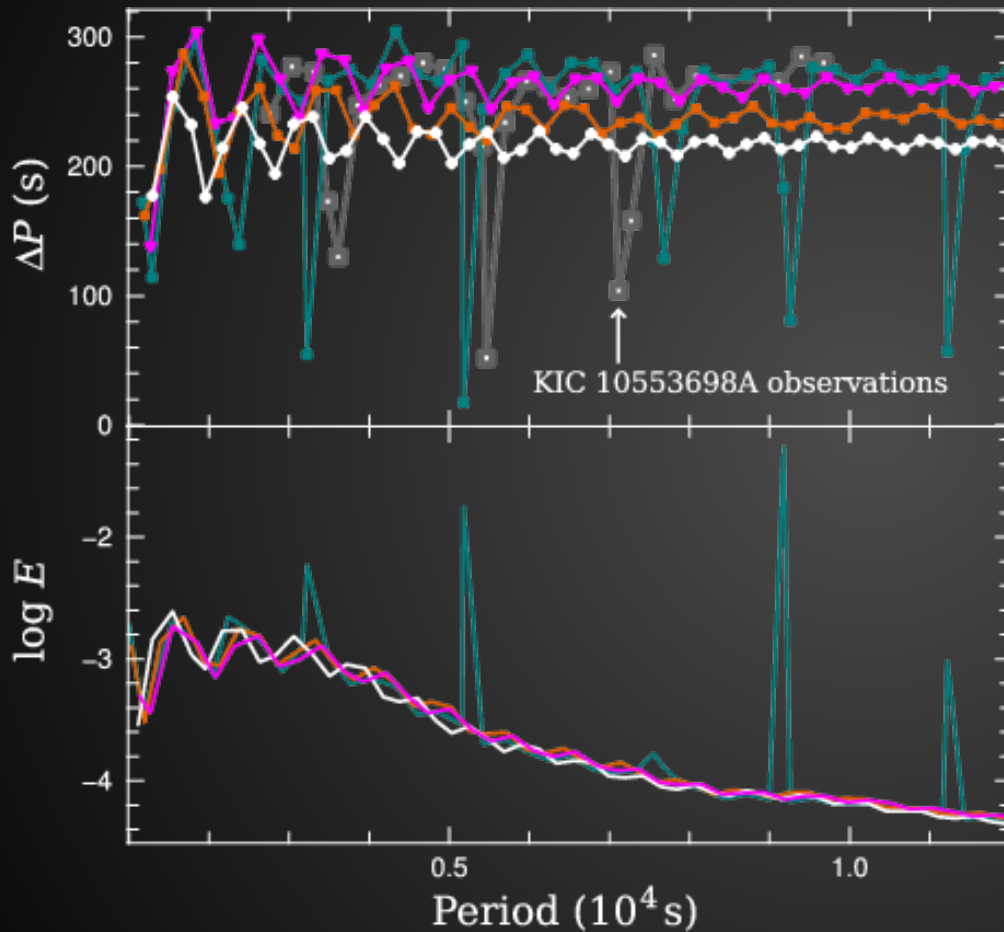
Hamfast = KIC 10553698



Reduced period diagram: $\Pi = P \sqrt{\ell(\ell+1)}$

Clearly shows $l=1$ and $l=2$ modes overlapping also for trapped modes.

Hamfast = KIC 10553698

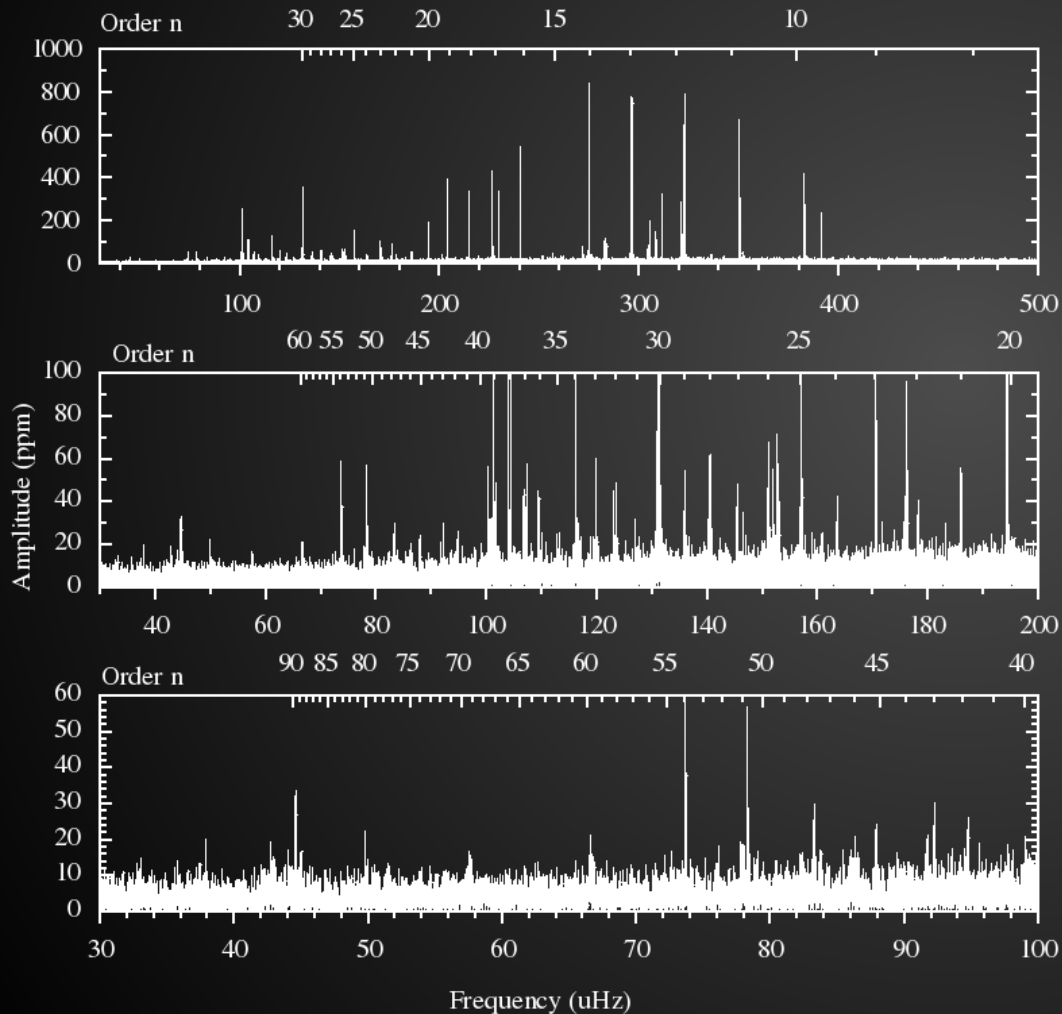


The completeness of the period spacing sequence is ideal for testing against models.

Current evolutionary models struggle with reproducing the He-core size implied by Kepler observations.

Figure from Constantino et al. (2015; MNRAS 452, 123)

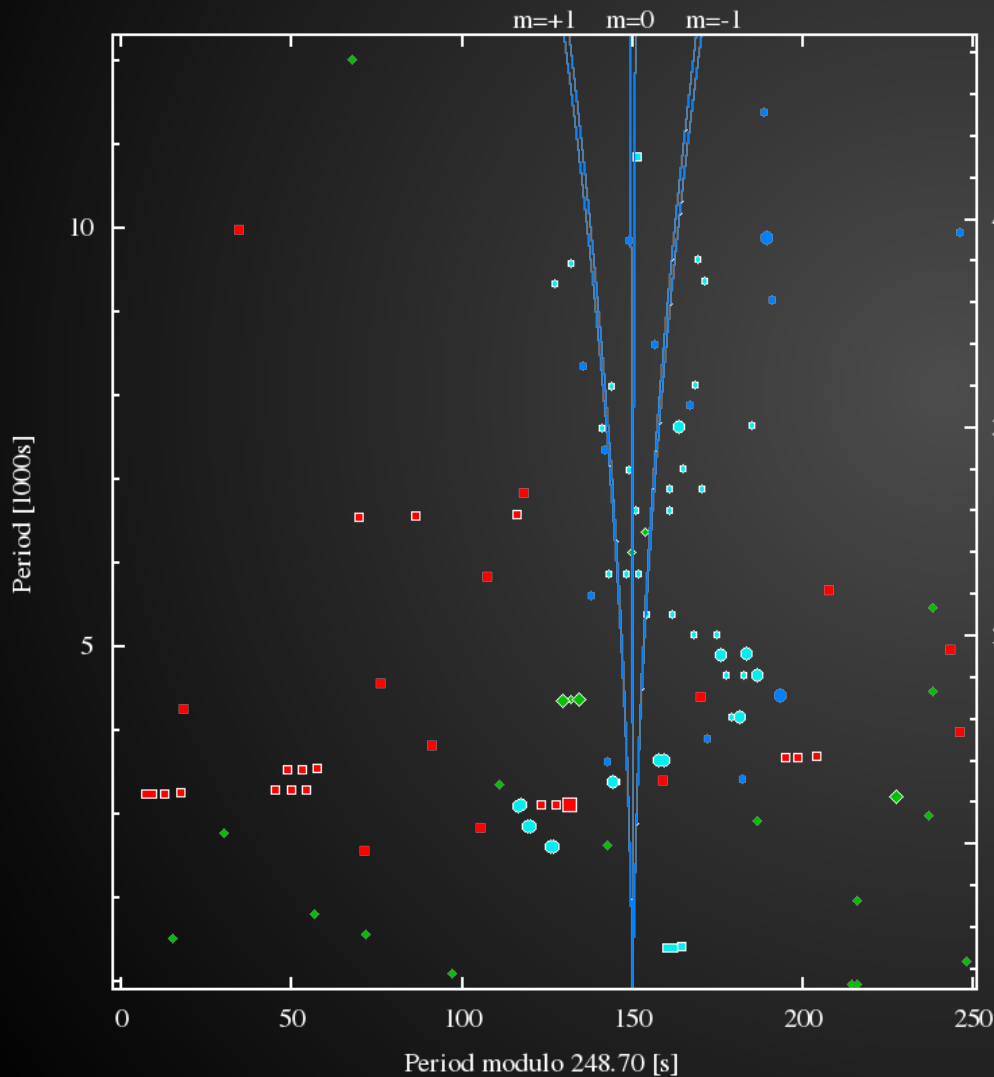
Mungo = KIC 11558725



Mungo is the first pulsating sdB+WD from the Kepler mission, as originally published by Telting et al. (2012, A&A 544 A1), where the orbital signal was analysed from RV, beaming and Rømer effects.

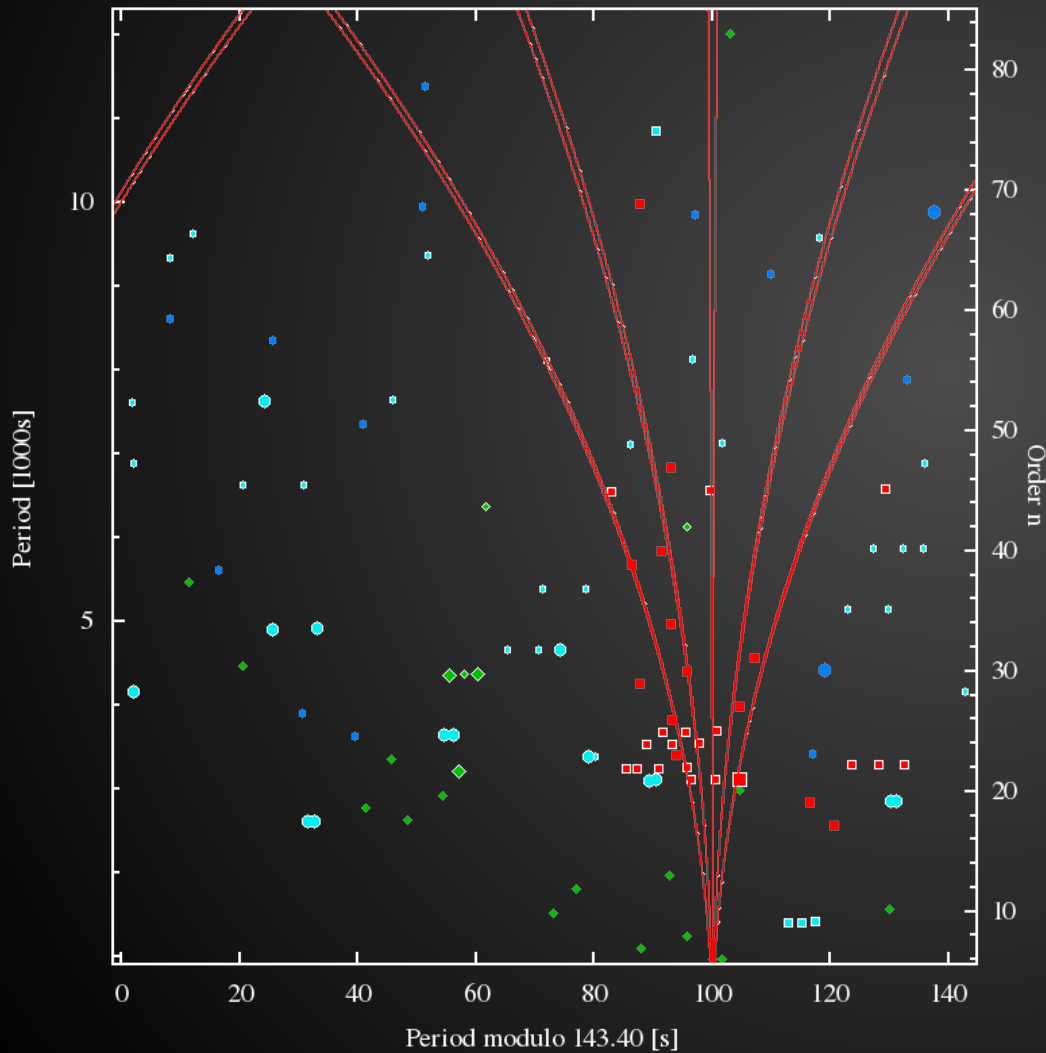
Here I've redone the pulsation analysis including all Q's.

Mungo = KIC 11558725



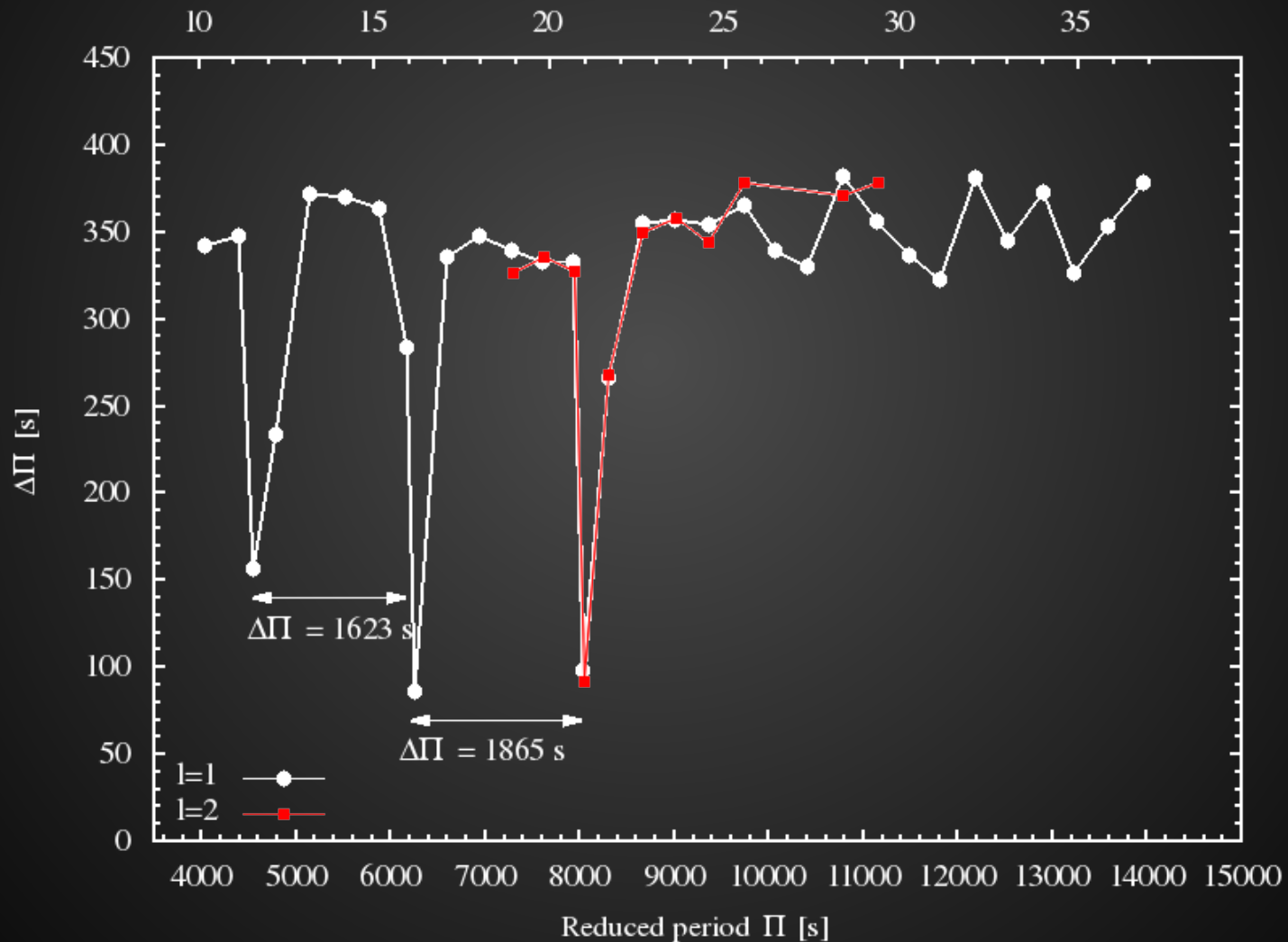
The echelle diagram reveals an almost complete sequence of multiplets for $l=1$

Mungo = KIC 11558725



The echelle diagram reveals an almost complete sequence of multiplets for $l=1$.
But $l=2$ is much more sparse.

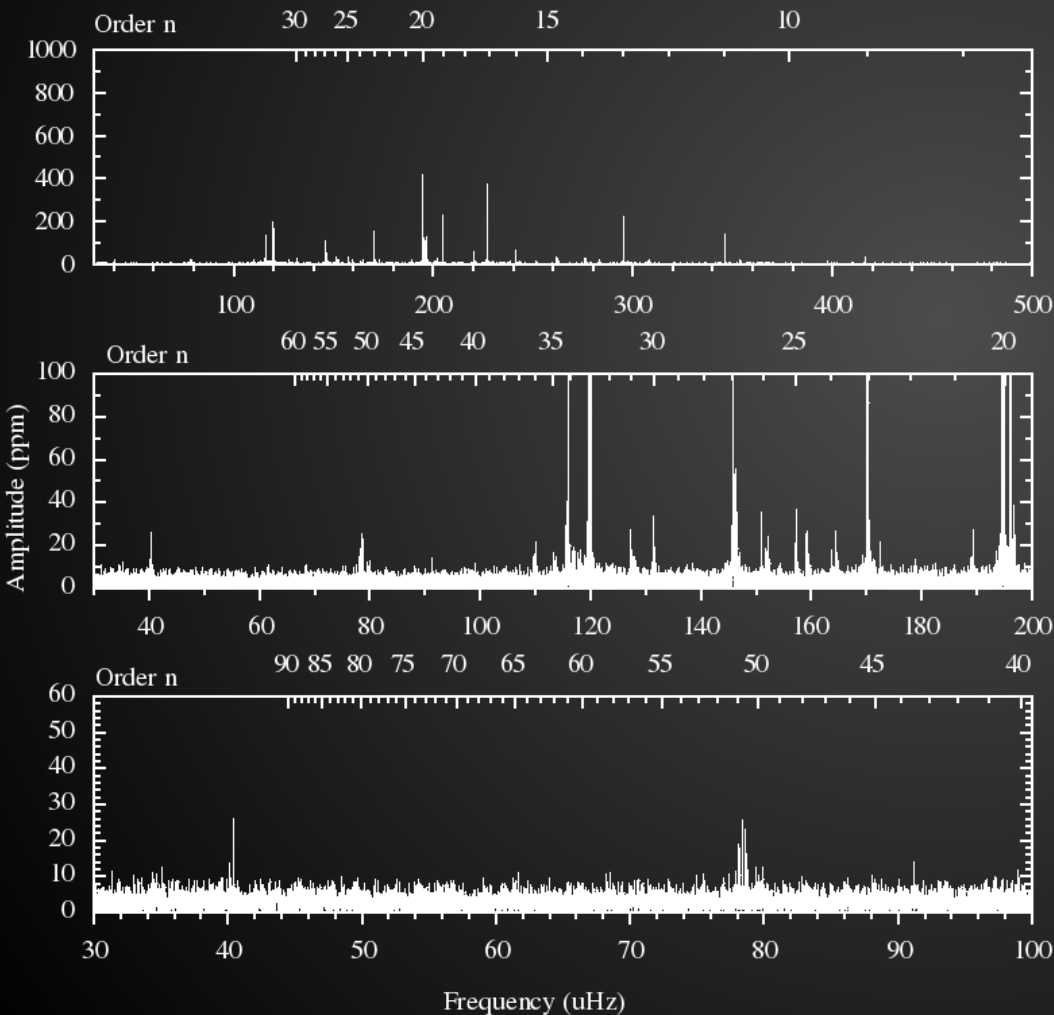
Mungo = KIC 11558725



Primula = KIC 7668647

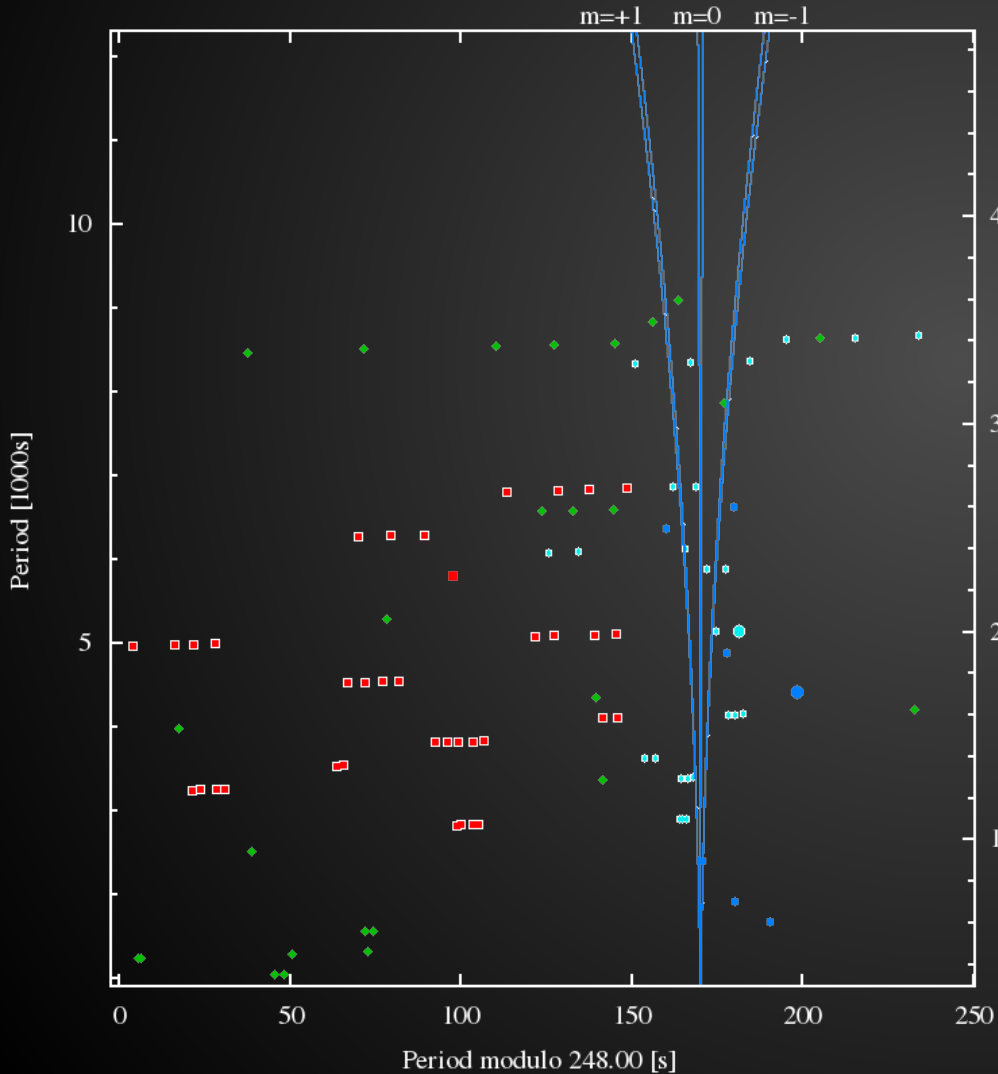
Primula is an sdB+WD with $P=14.2$ d.

It shows broad, stochastic peaks for most modes, except $l=1$ at low n .



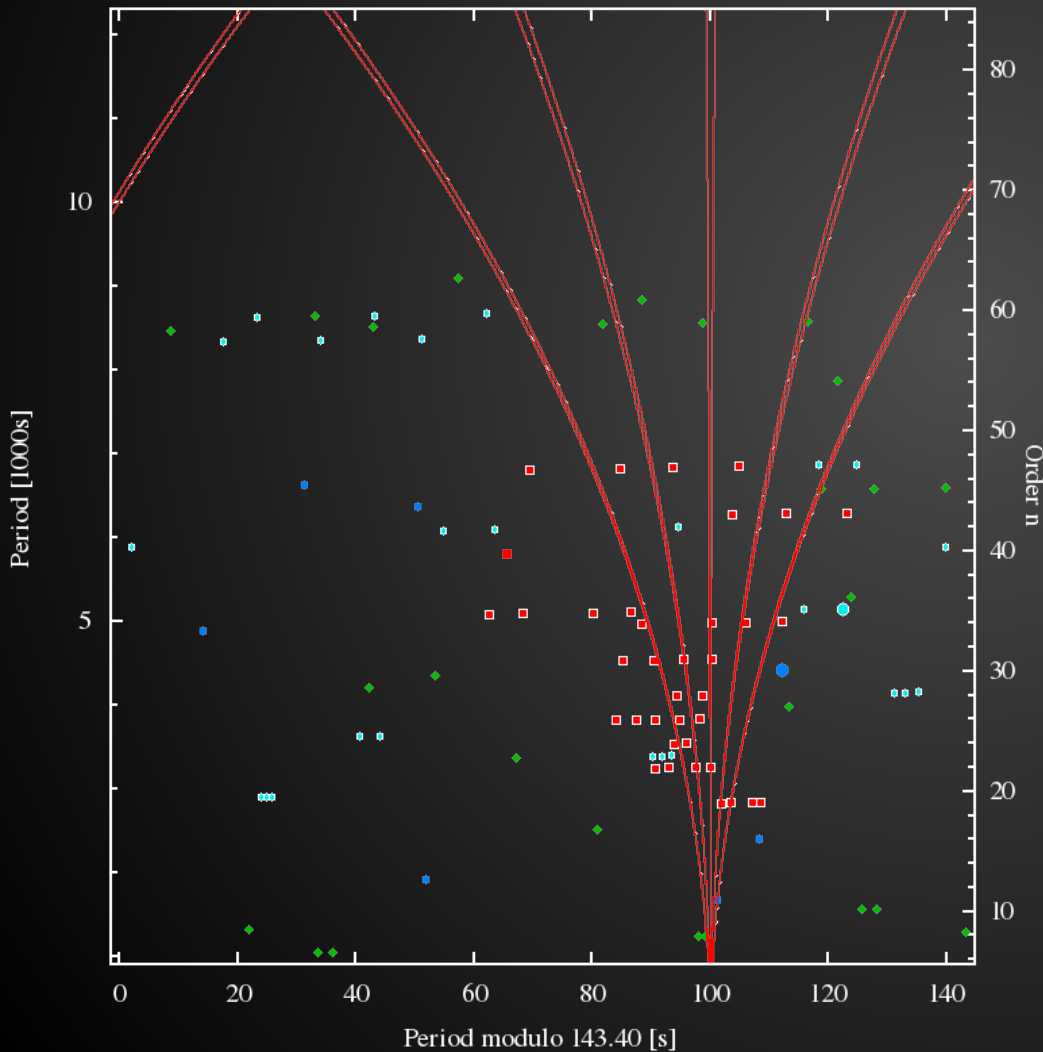
Telting et al.
(2014; A&A 570; A129)

Primula = KIC 7668647



The échelle diagram reveals incomplete sequences of $l=1$ and $l=2$, with no multiplets that can be clearly identified as trapped modes.

Primula = KIC 7668647

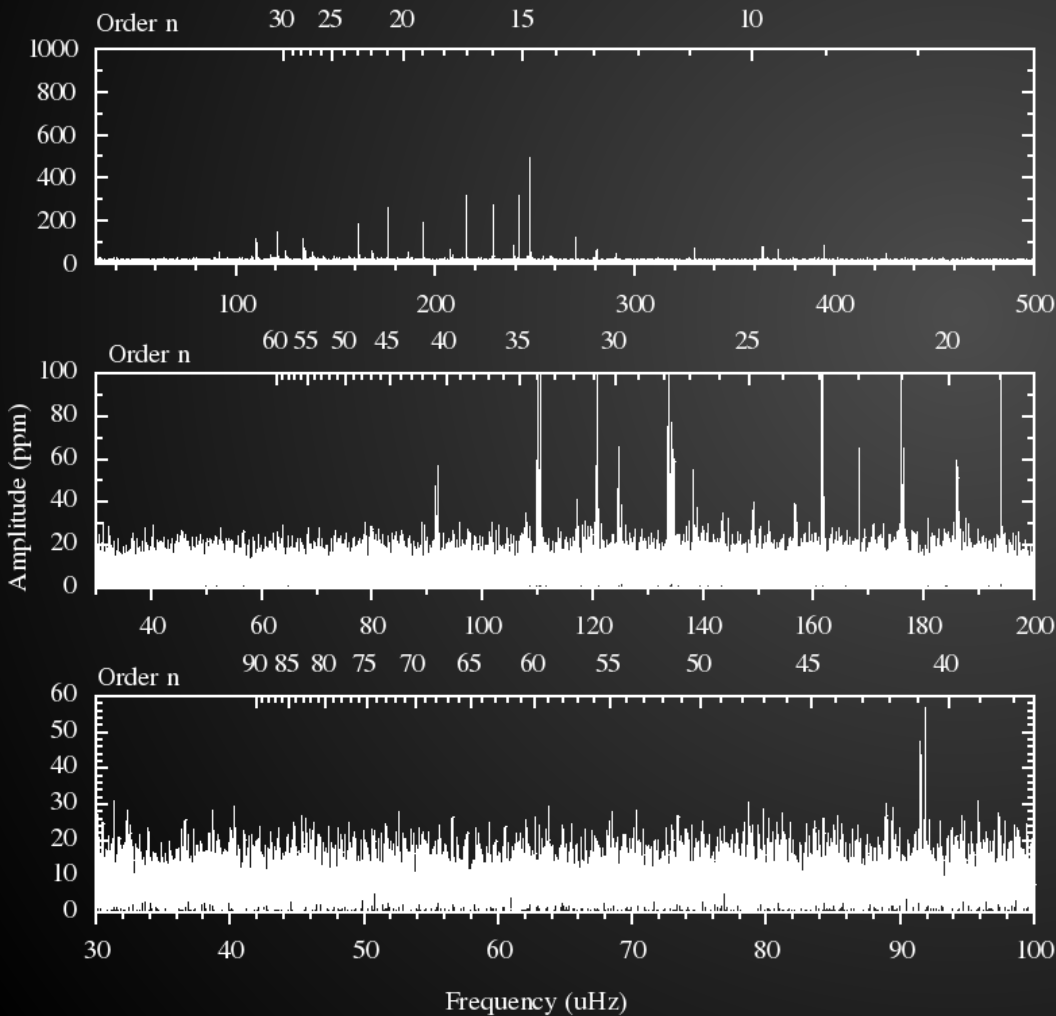


The échelle diagram reveals incomplete sequences of $l=1$ and $l=2$, with no multiplets that can be clearly identified as trapped modes.

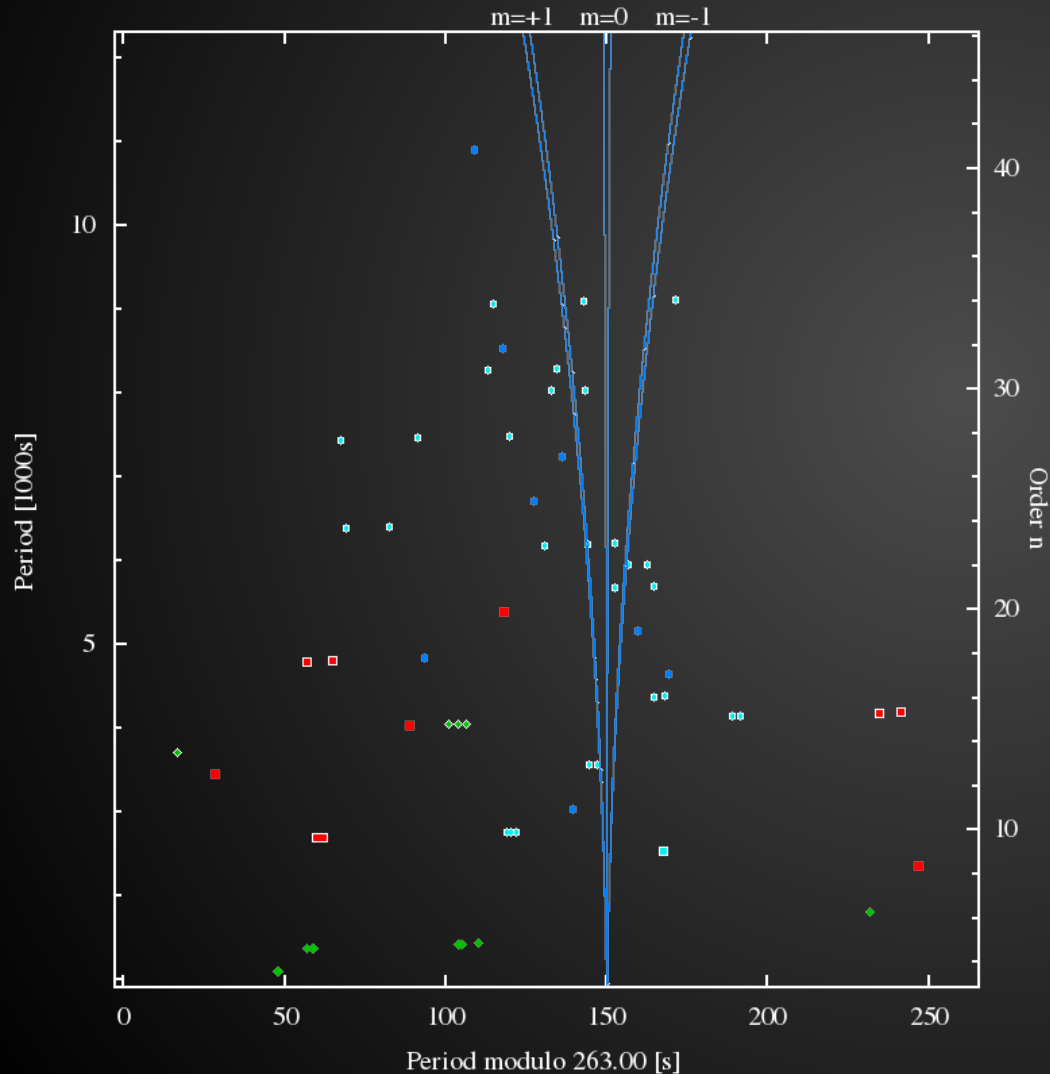
Incompleteness makes it hopeless to construct a useful reduced-period diagram.

Will = KIC 7664467

Will is another sdBV+WD binary. Details will be published by Baran et al. (2015, in prep).



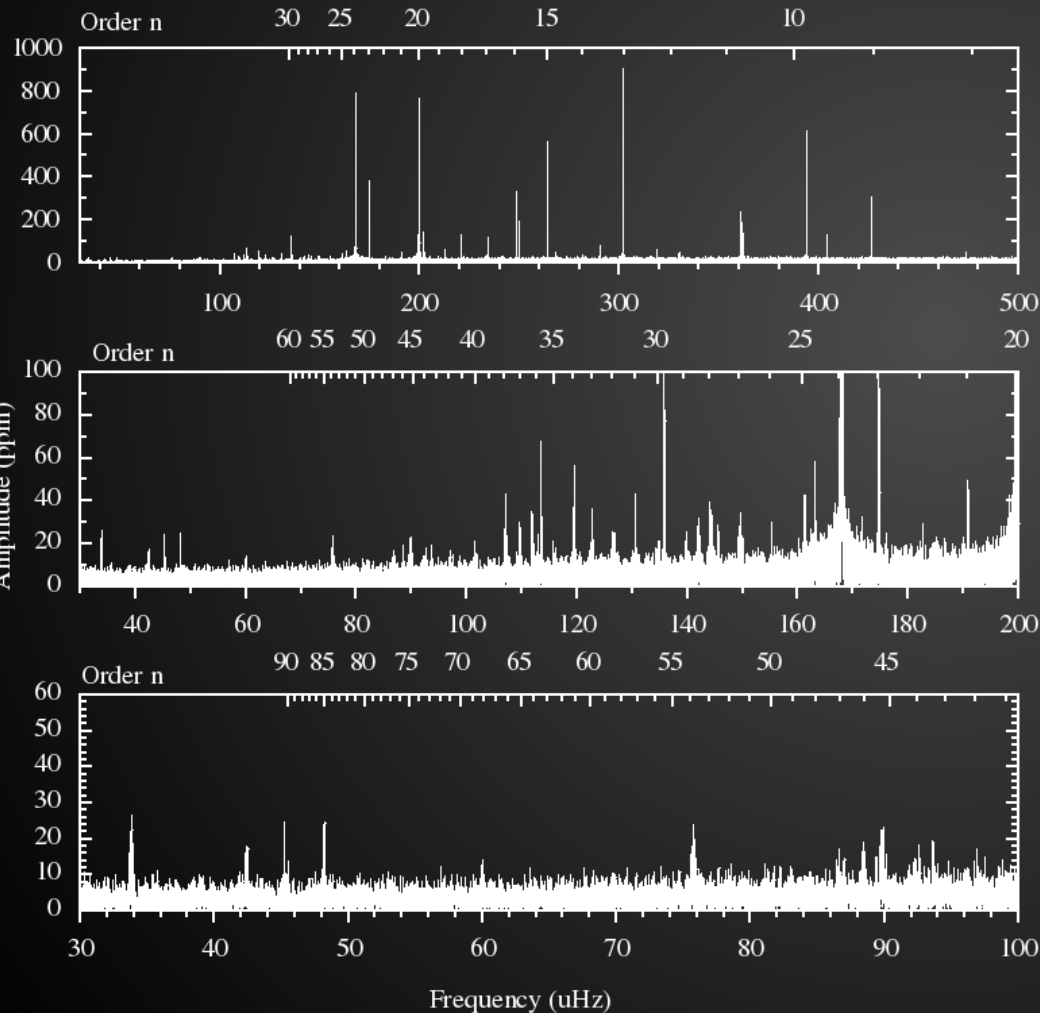
Will = KIC 7664467



The echelle diagram reveals very sparse sequences, but one triplet appears to be trapped.

Very few $l=2$ modes are seen.

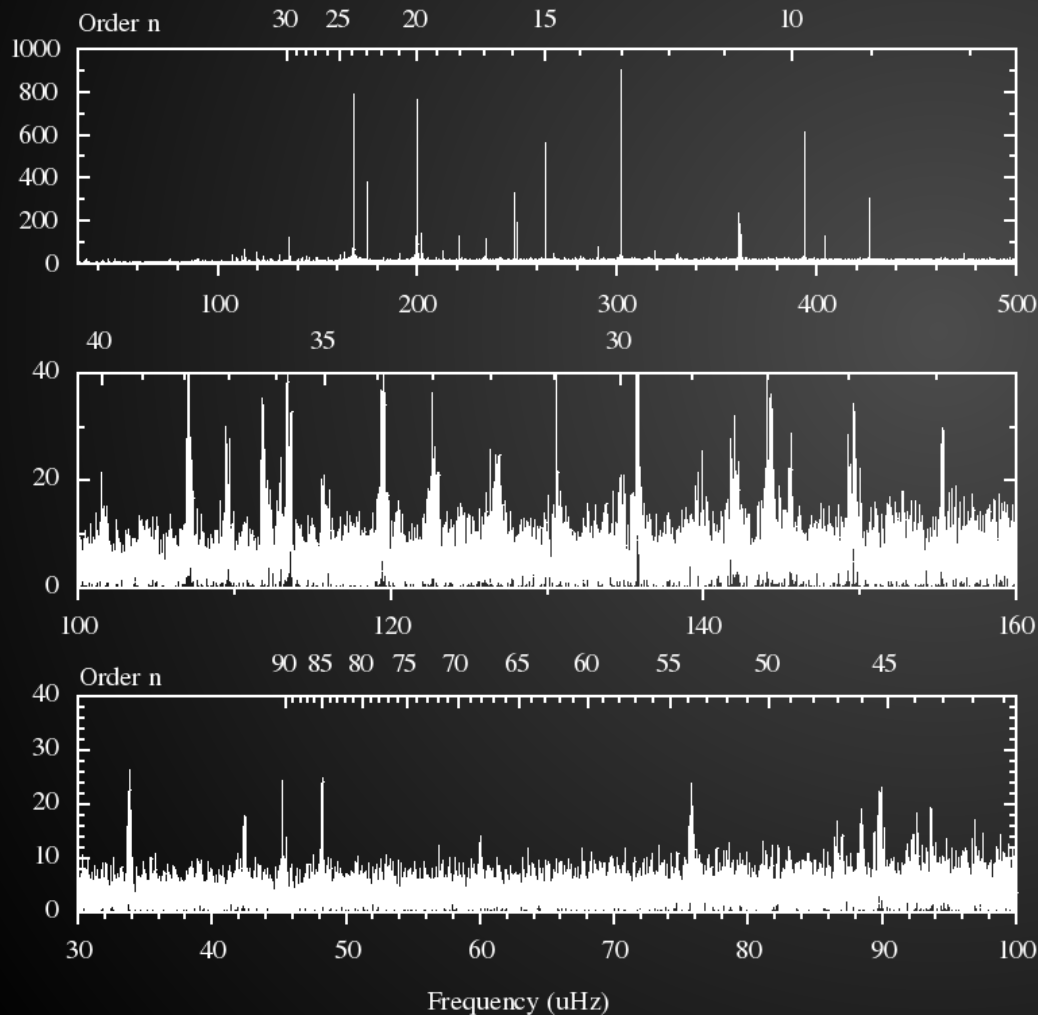
Rosie = KIC 5807616



Rosie is the single sdBV from Charpinet et al. (2011; Nature 480 p496).

It shows many very stochastic peaks across most of the g-mode pulsation range.

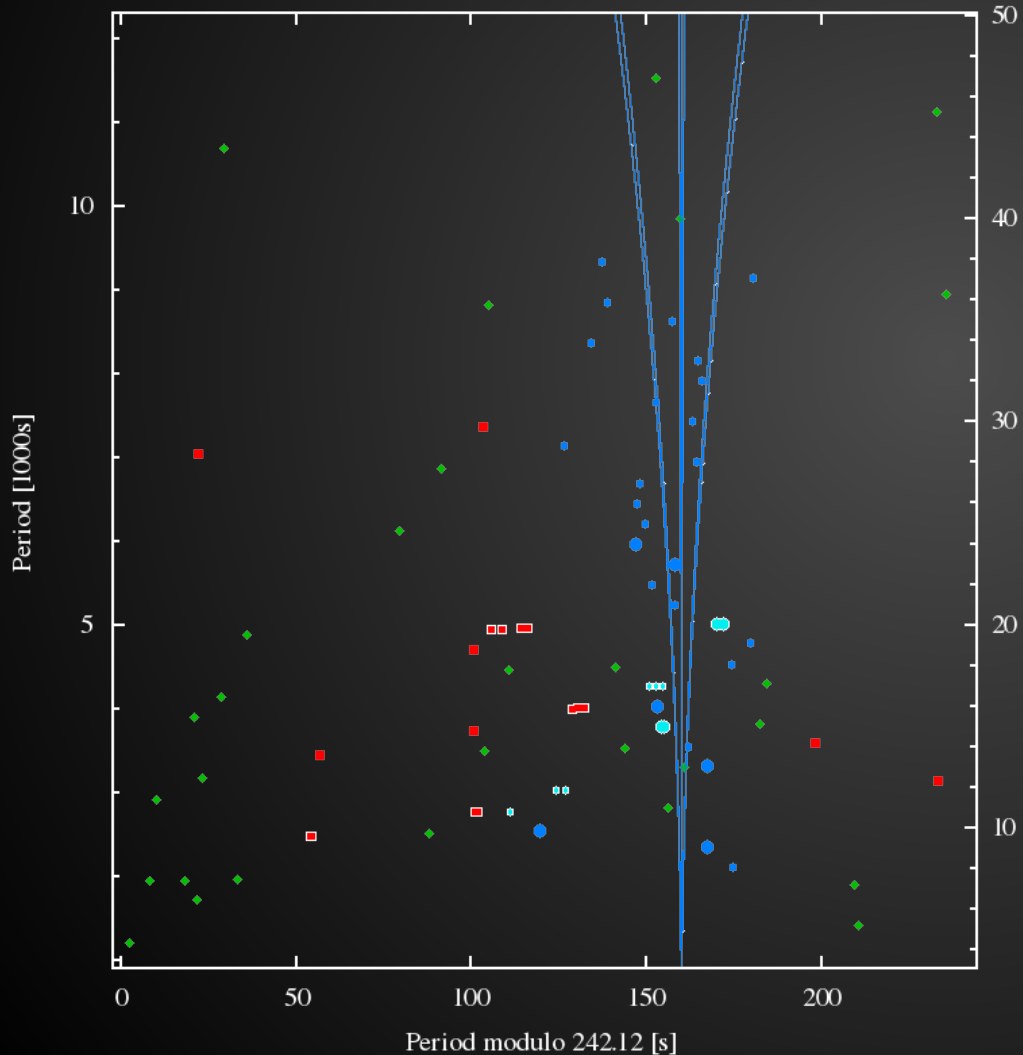
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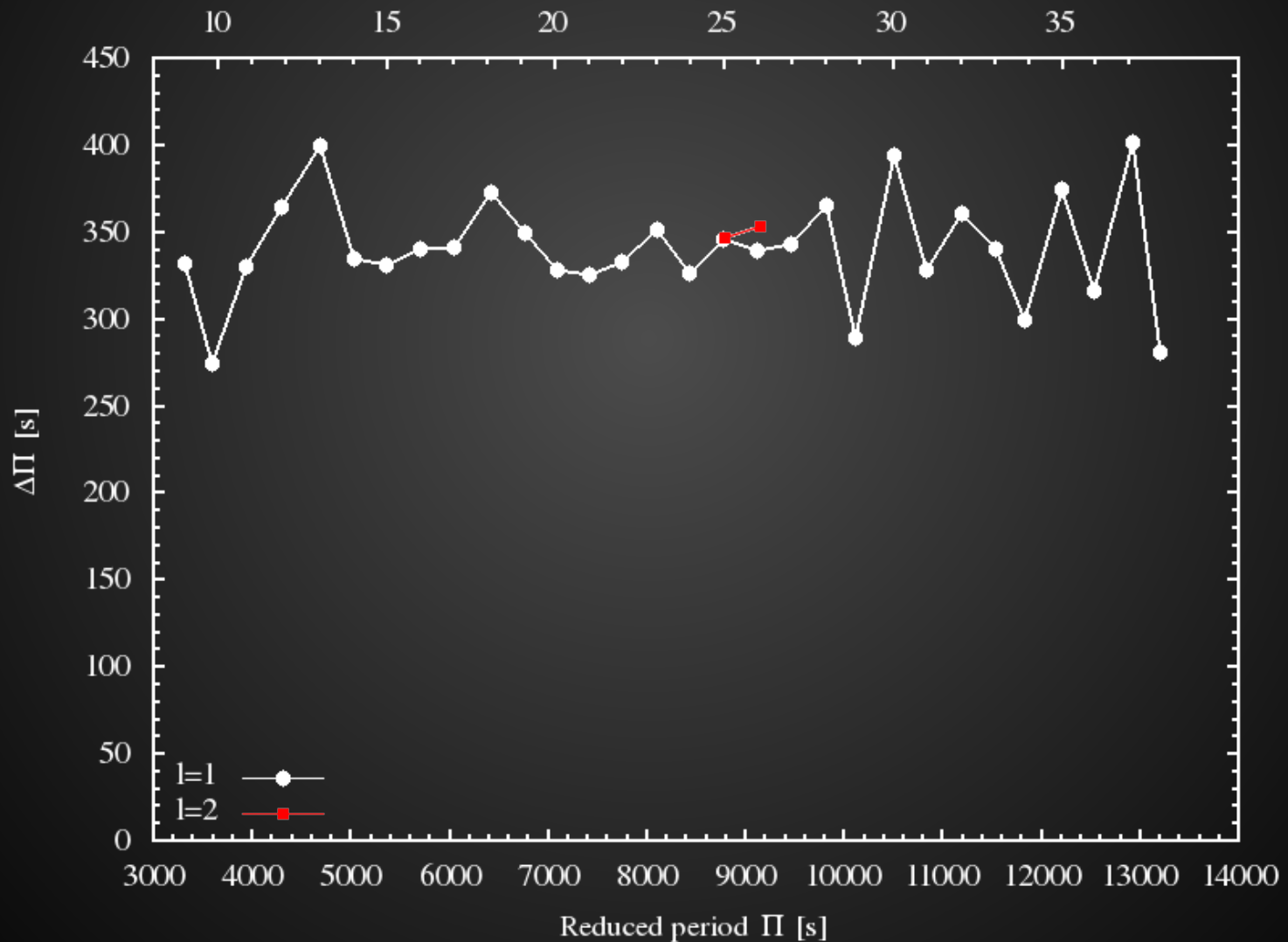


The echelle diagram reveals an almost complete sequence of $l=1$ modes

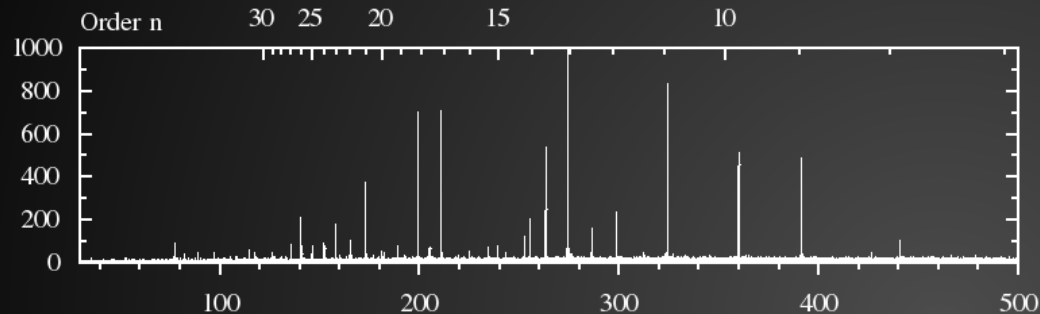
But:

- few clear multiplets
- a sparse sequence of modes that might be $l=2$
- many low-amplitude modes that cannot be identified

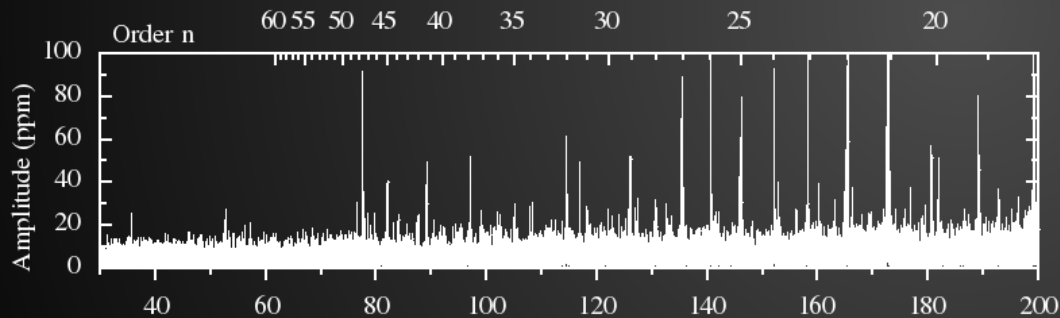
Rosie = KIC 5807616



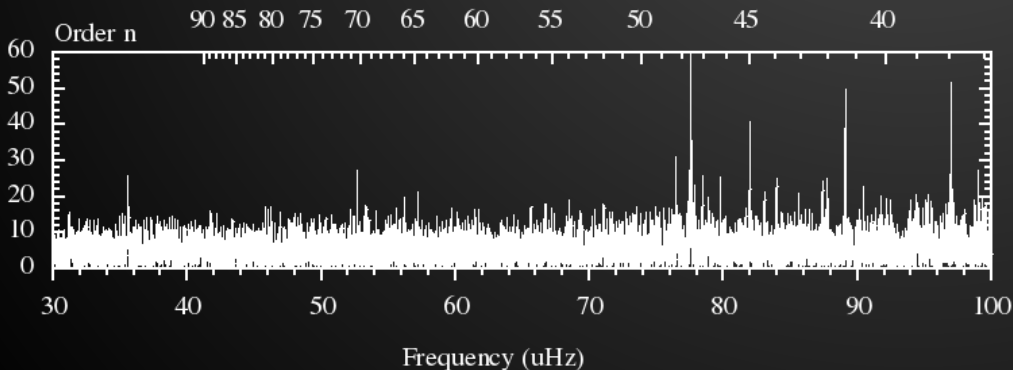
Otho = KIC 10001893



Otho is the single sdBV for which Silvotti et al. (2014; A&A A570) claimed 3 planets around.

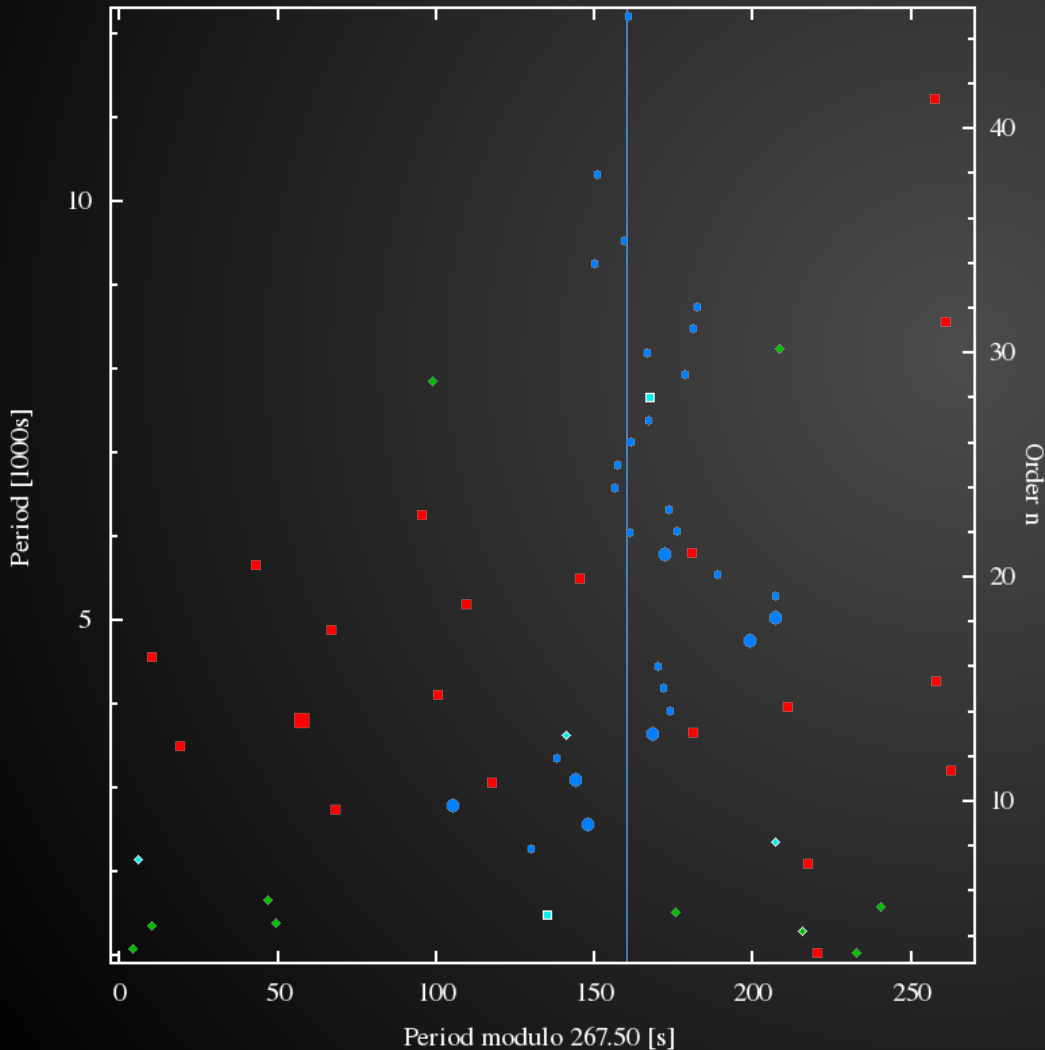


FT shows a rich pulsation spectrum with a mix of sharp and stochastic peaks.



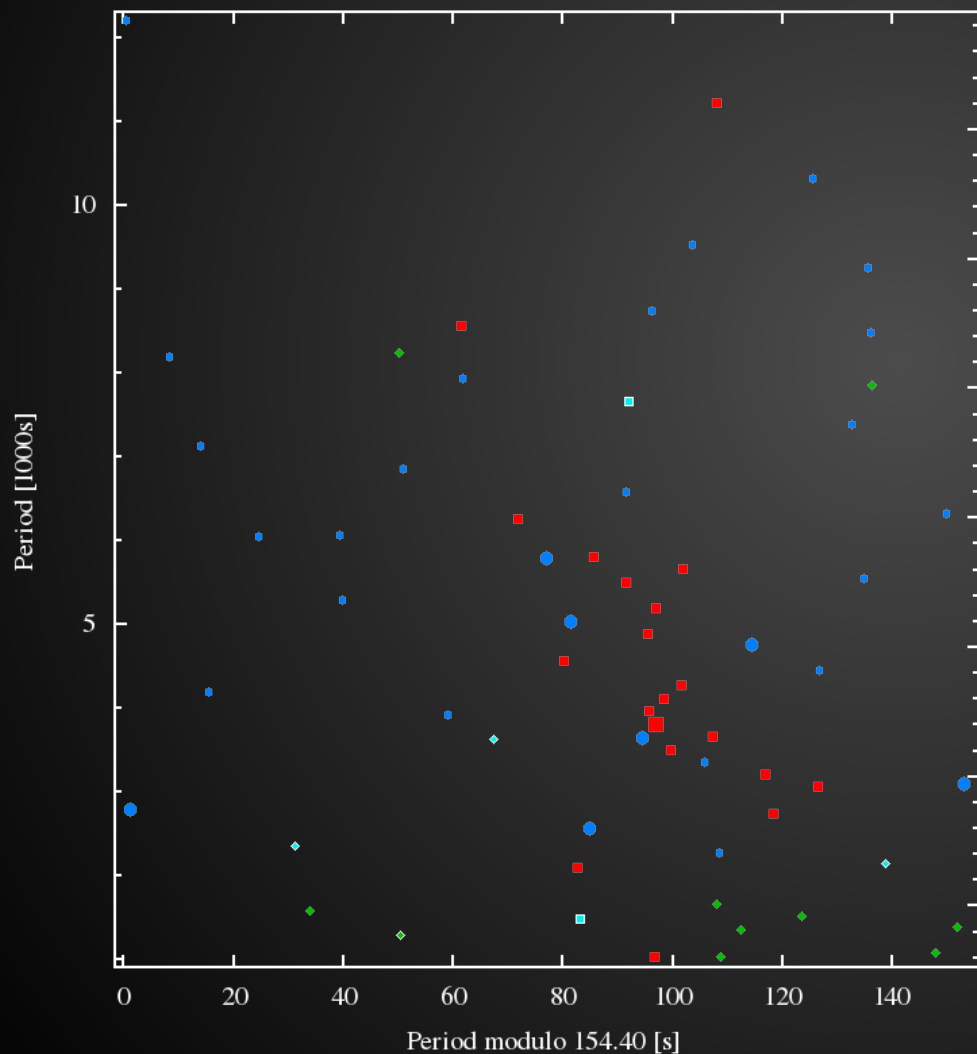
No multiplets!

Otho = KIC 10001893



The échelle diagram shows clear $l=1$ and $l=2$ sequences, but without support from mode splittings, some identifications will be ambiguous.

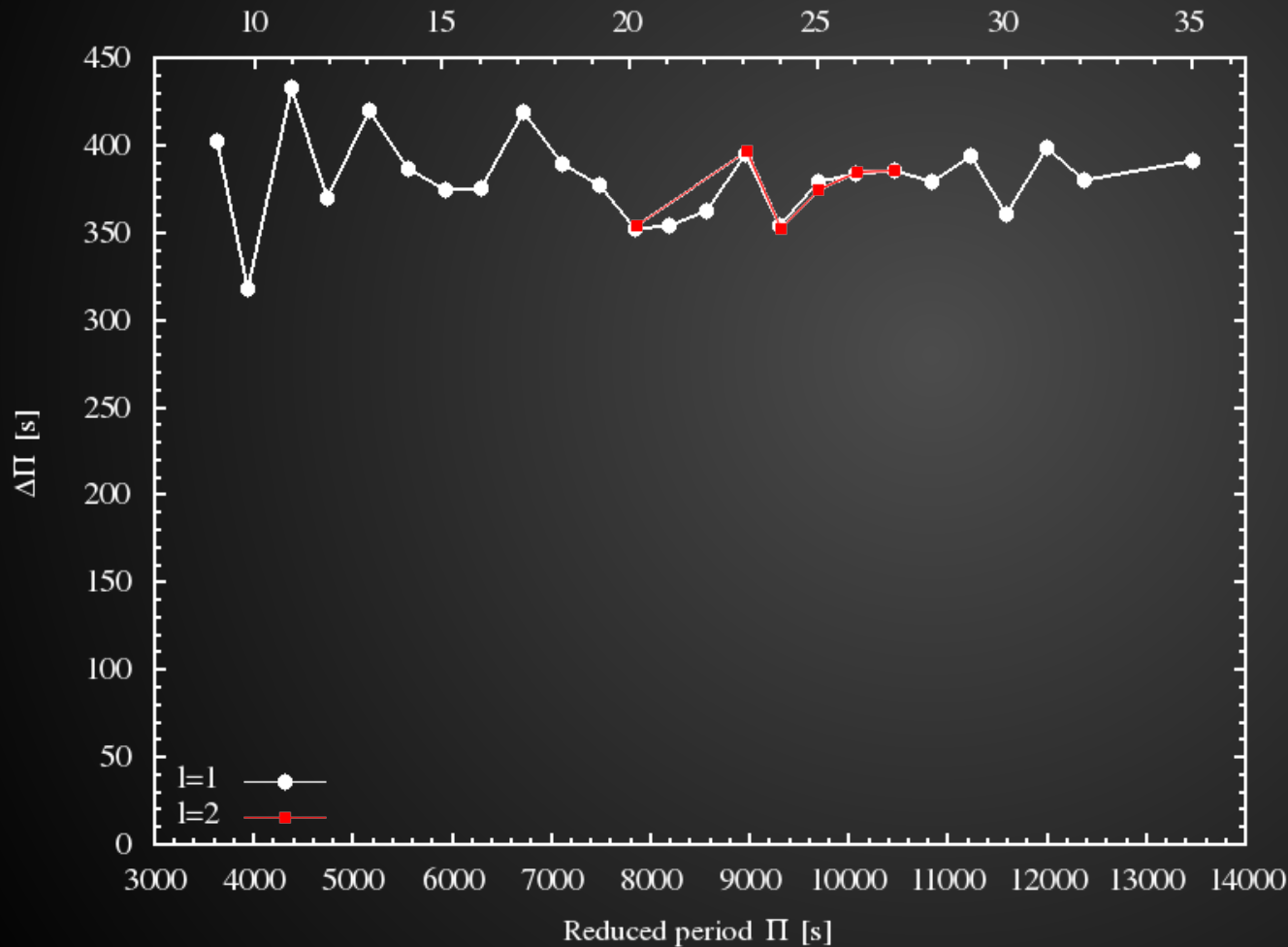
Otho = KIC 10001893



The échelle diagram shows clear $l=1$ and $l=2$ sequences, but without support from mode splittings, some identifications will be ambiguous.

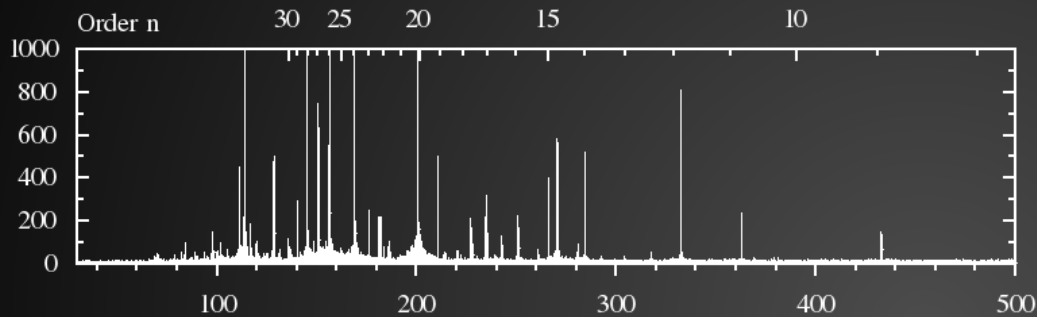
The $l=2$ sequence is not complete.

Otho = KIC 10001893



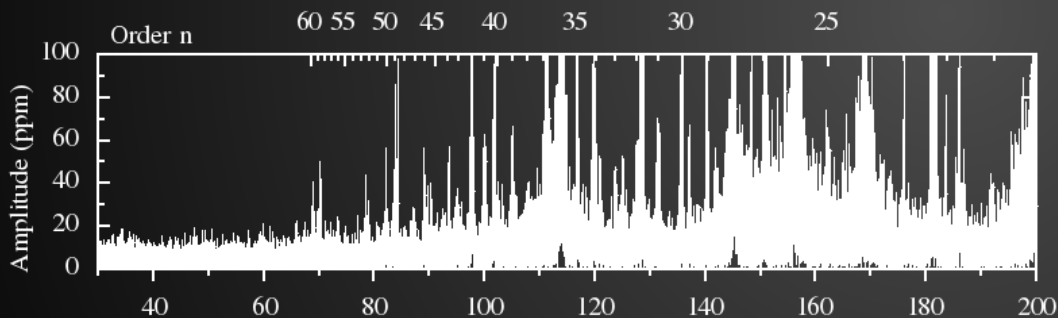
Without splittings, the few modes that could be trapped cannot be assigned an ID, and the reduced period diagram does not show much.

Pippin = KIC 2697388

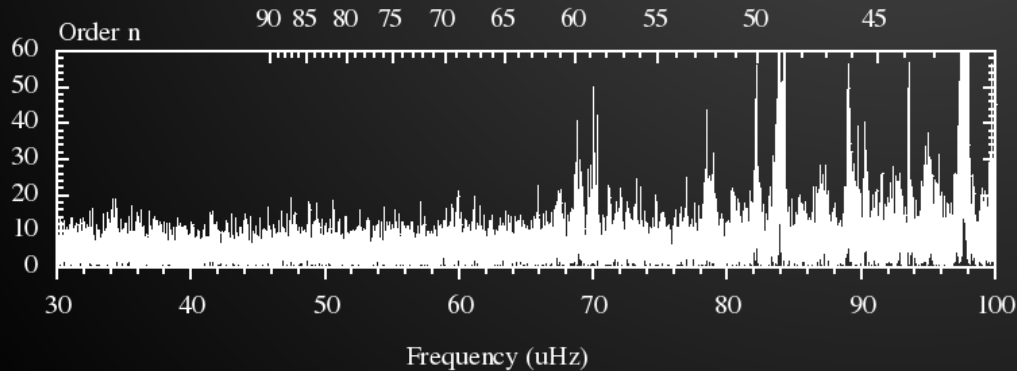


Quite rich pulsator with very stochastic modes, especially at low frequencies.

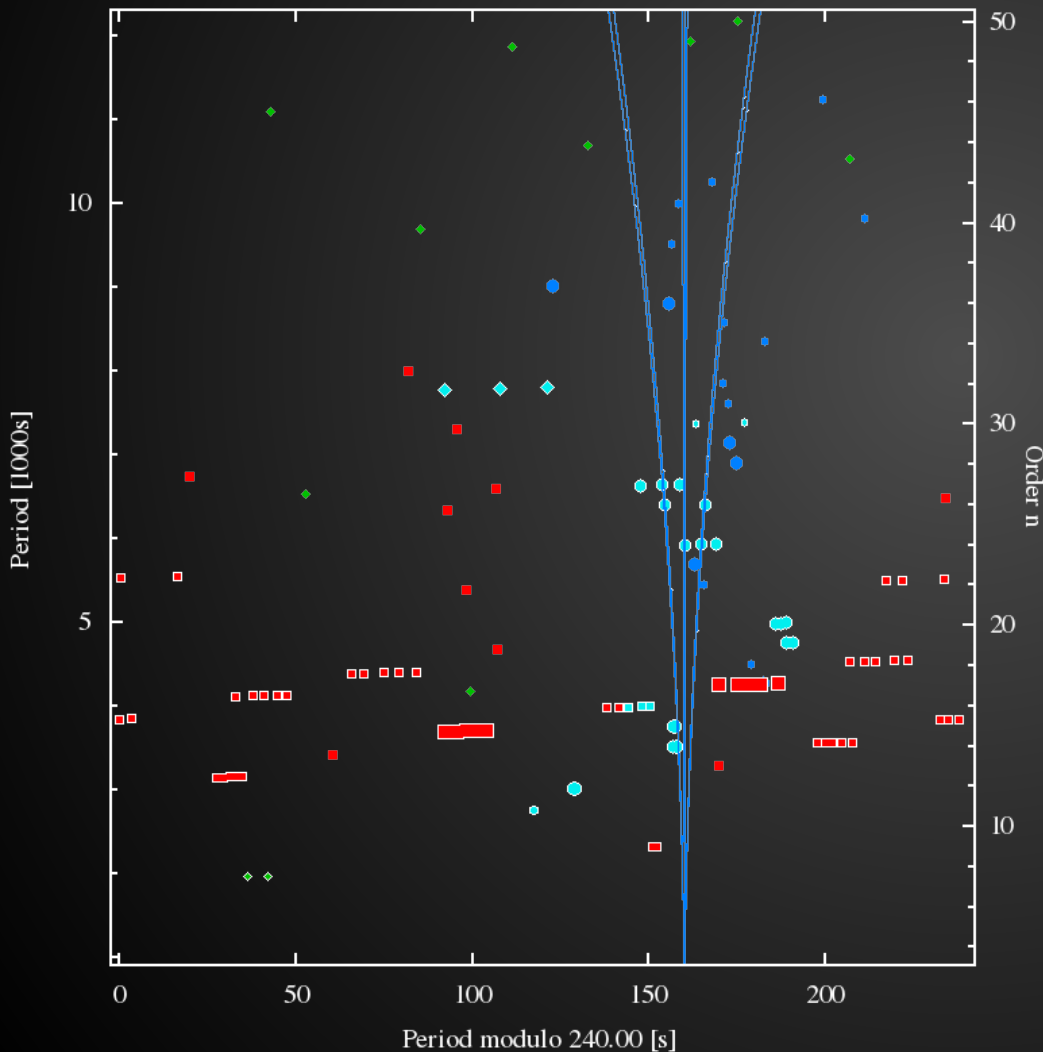
Poster by Kern et al.



Pippin was given an asteroseismic analysis by Charpinet et al. (2011) based on early data.



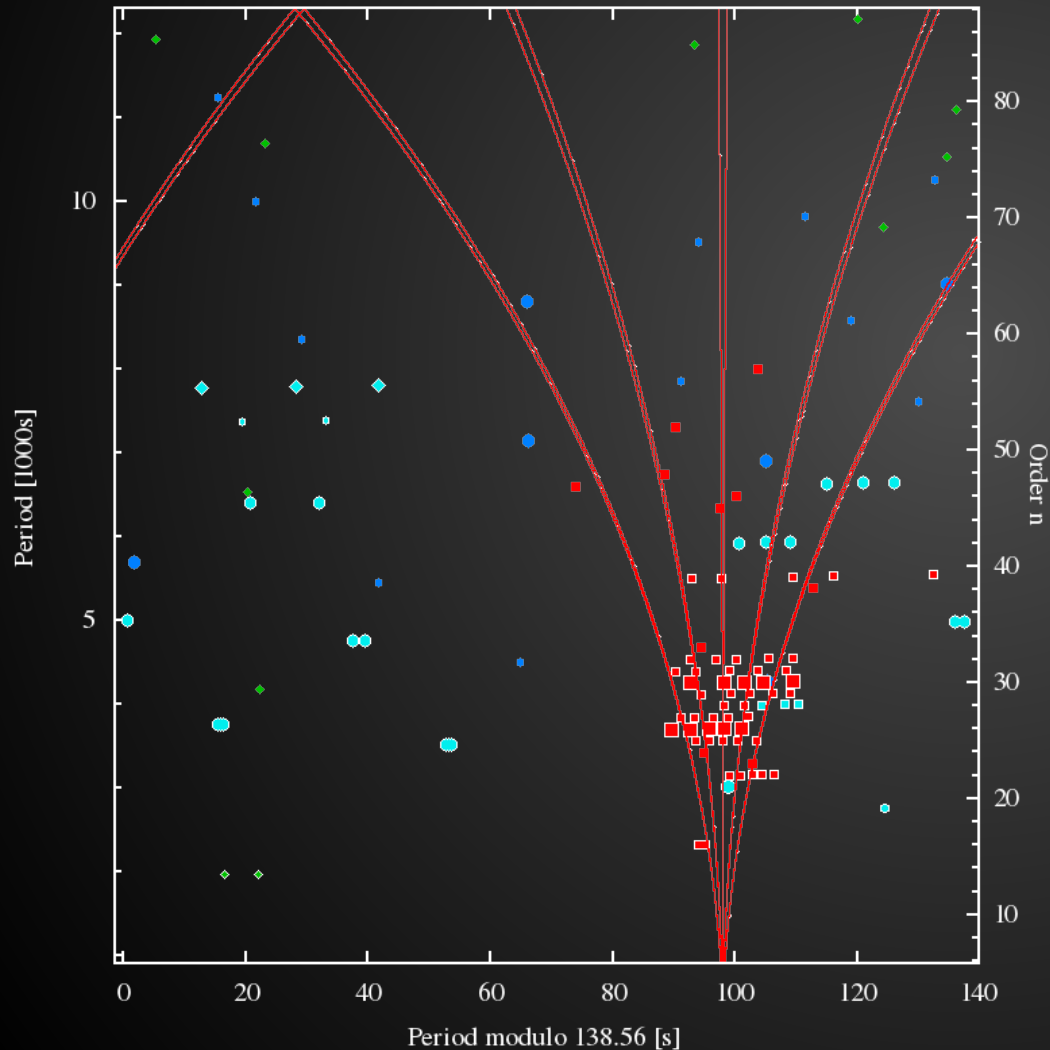
Pippin = KIC 2697388



The échelle diagram reveals almost complete sequences of $l=1$, and $l=2$ modes, with some possibly trapped modes.

The stochasticity makes the FT often hard to interpret, with forests of peaks. Better results may be achieved by comparing subsets of data or sliding FT's as in the Kern poster.

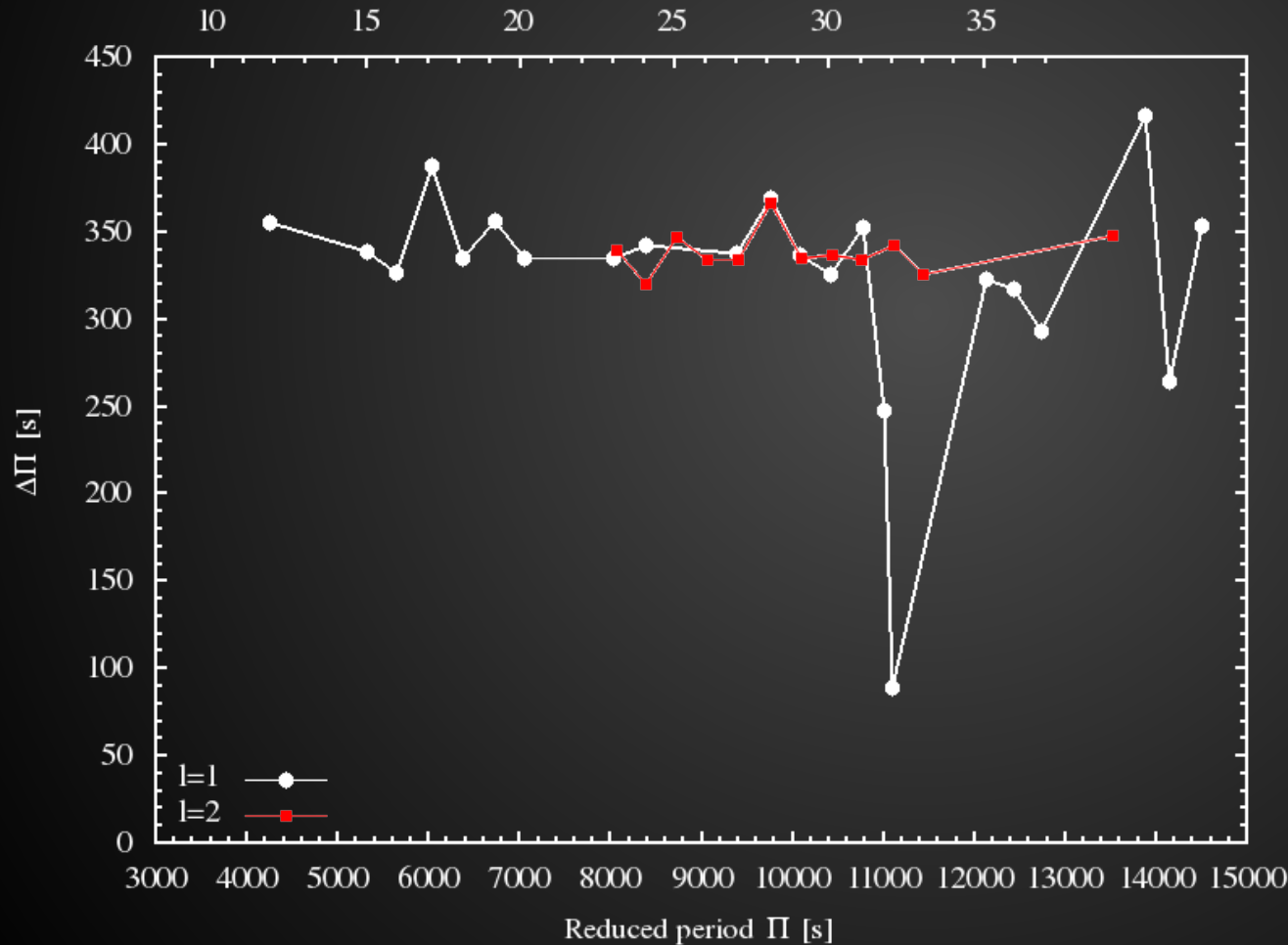
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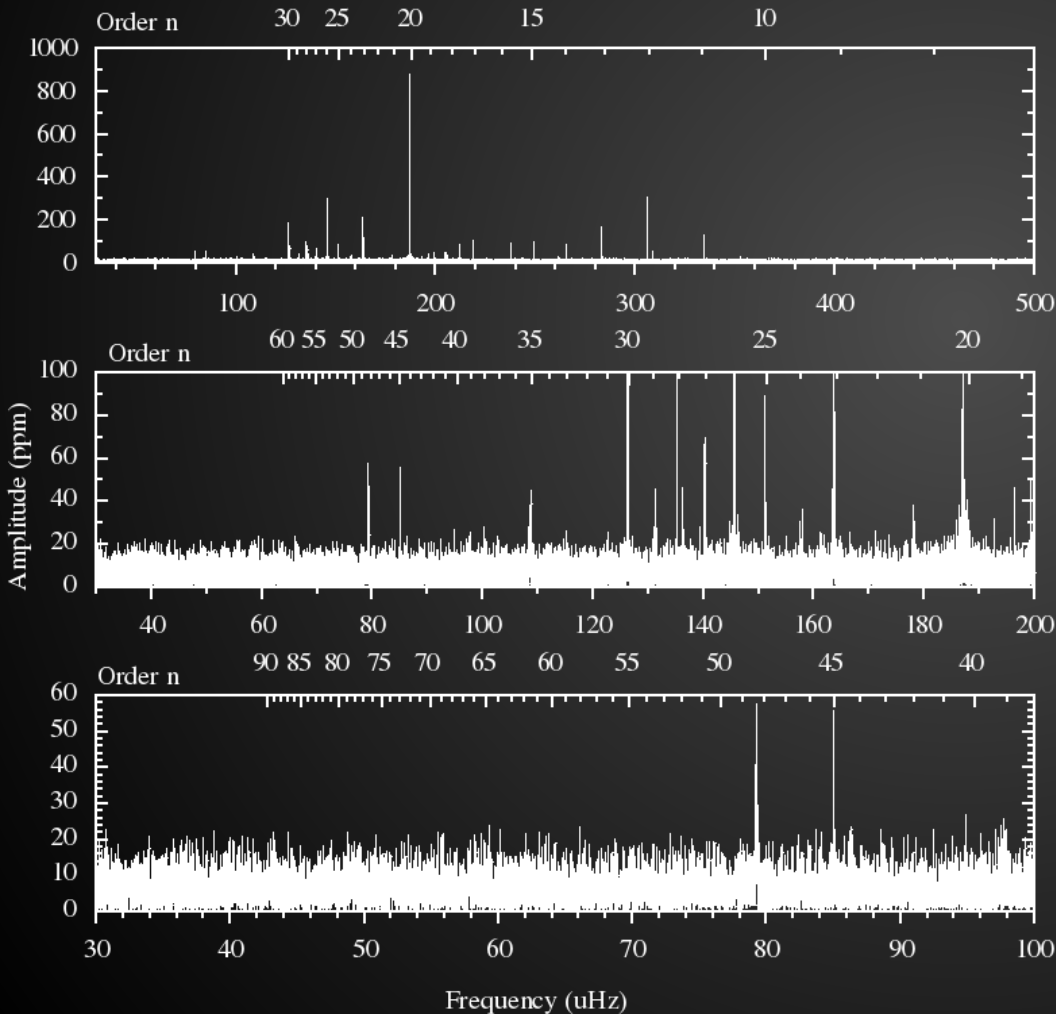


The reduced period diagram indicates a trapped $l=1$ at high n , but no supporting $l=2$ mode has been found.

Difficult case...

Paladin = KIC 8302197

Rather sparse pulsator with no more than 30 modes and no multiplets.



Paladin was analysed by Baran et al (2014; A&A 573 A52)

Nine g-mode pulsators

Name	KIC	Orbit	'Planets'	Stochastic	$\Delta\pi_1$	Ω	Trapped modes
Hamfast	10553698	3.4 d	yes: 1	Mostly not	263.2	43 d	Yes
Mungo	11558725	10.1 d	yes: lots	Mostly not	248.7	45 d	Yes
Primula	7668647	14.2 d	yes: 1	Quite	248.0	47 d	No clear ones
Will	7664467	1.6 d	no	Mostly not	263.0	35 d	Yes
Rosie	5807616	–	yes: 2–5	Very	242.1	48 d	No
Otho	10001893	–	yes: 3	Quite	267.5	∞	No
Pippin	2697388	–	no	Very	240.0	42 d	Maybe
Paladin	8302197	–	no	Quite	257.7	∞	Too sparse
Samwise	3527751	–	no	Quite	266.0	43 d	?