11th meeting on hot subdwarfs and related objects,
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Feige 48: a modern view

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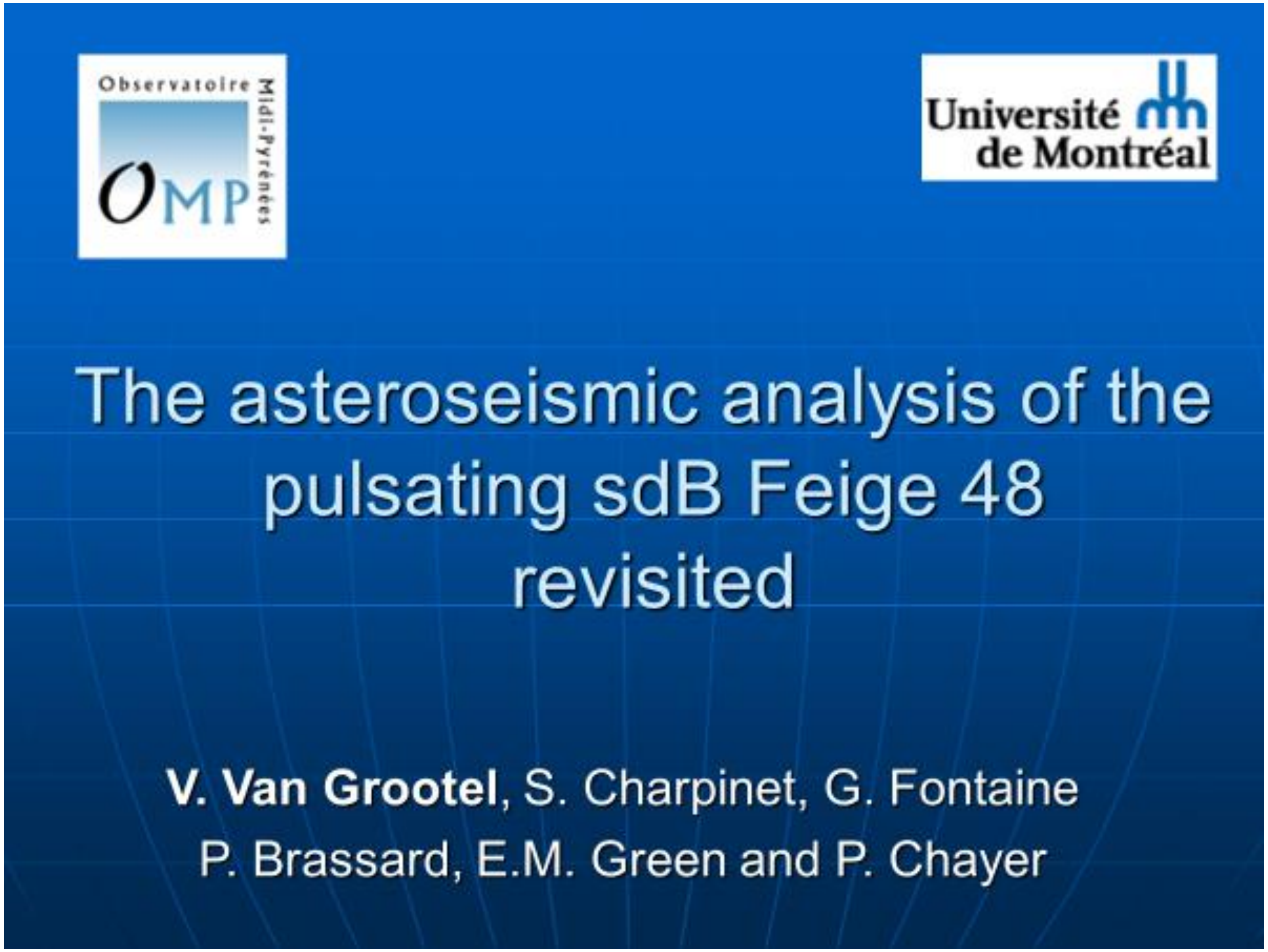
(5) University of Arizona, Tucson, USA
(6) FAU Erlangen-Nürnberg, Germany

July 2007, sdOB3, Bamberg…



Feige 48: a modern view

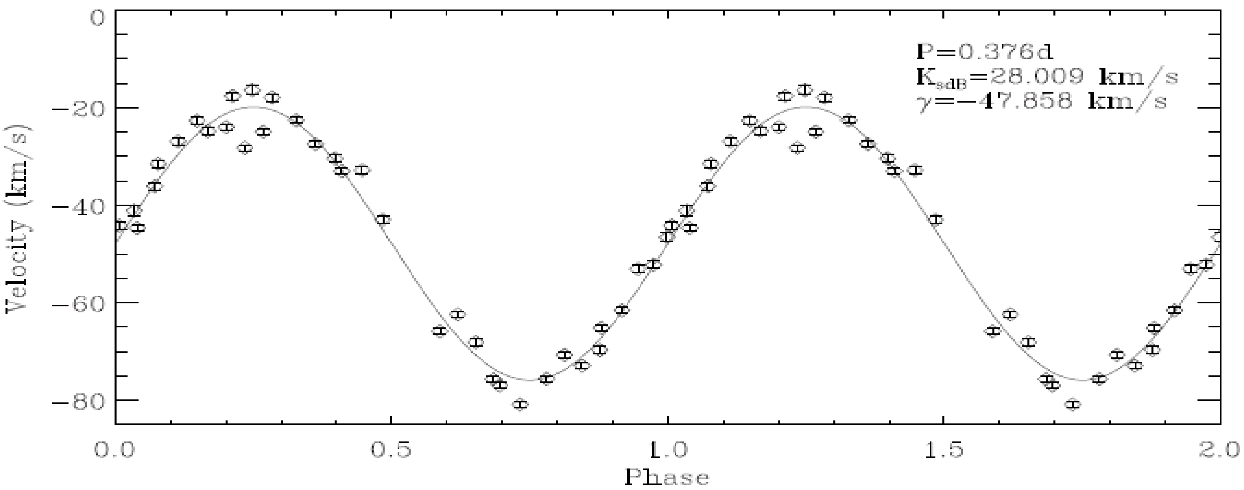
- What we know (and thought to know)…
- New observations:
  - Radial Velocities
  - Mt Bigelow/Mont4K photometric campaign
  - TESS data
- SED fitting
- New seismic analysis
- About the rotation of the sdB star
- What now…

Feige 48: what we know (and thought to know)

A bona-fide sdB star, reference atmospheric parameters (Latour et al. 2014b):
T_{eff}=29,850 ± 300 K, log g=5.46 ±0.05, log N(He)/N(H)=-2.88 ± 0.02

Revealed to be a pulsator by Koen et al. (1998), 340-380s (p-modes)

Member of a close binary system, O'Toole et al. 2004



Orbital period of 0.376 ± 0.003 d (⇔ 9.024 ± 0.072h)
The unseen companion is a white dwarf with ≥ 0.46 M_s
Orbital inclination *i* ≤ 11.4°

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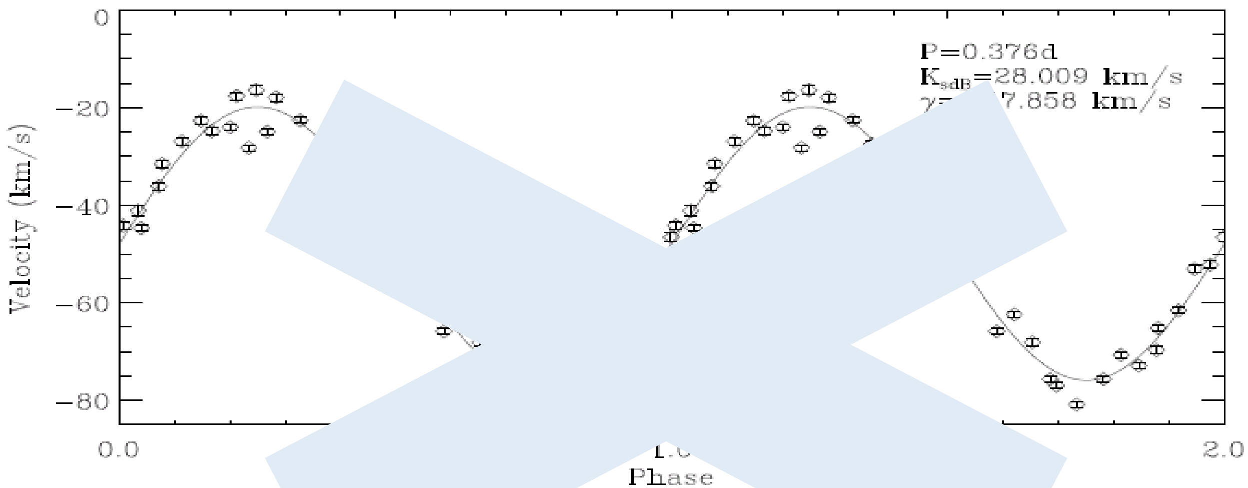


Orbital p... 0.376 ± 0.003 d (⇔ ... ± 0.072h)
The unse... companion is a white dwarf w... ≥ 0.46 M_s
Orbital inclination i ≤ 11.4°

Feige 48: what we know (and thought to know)

CFHT photometric campaign in 1998 (6 nights), Charpinet et al. 2005

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	2.83728	352.450	0.116	...
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

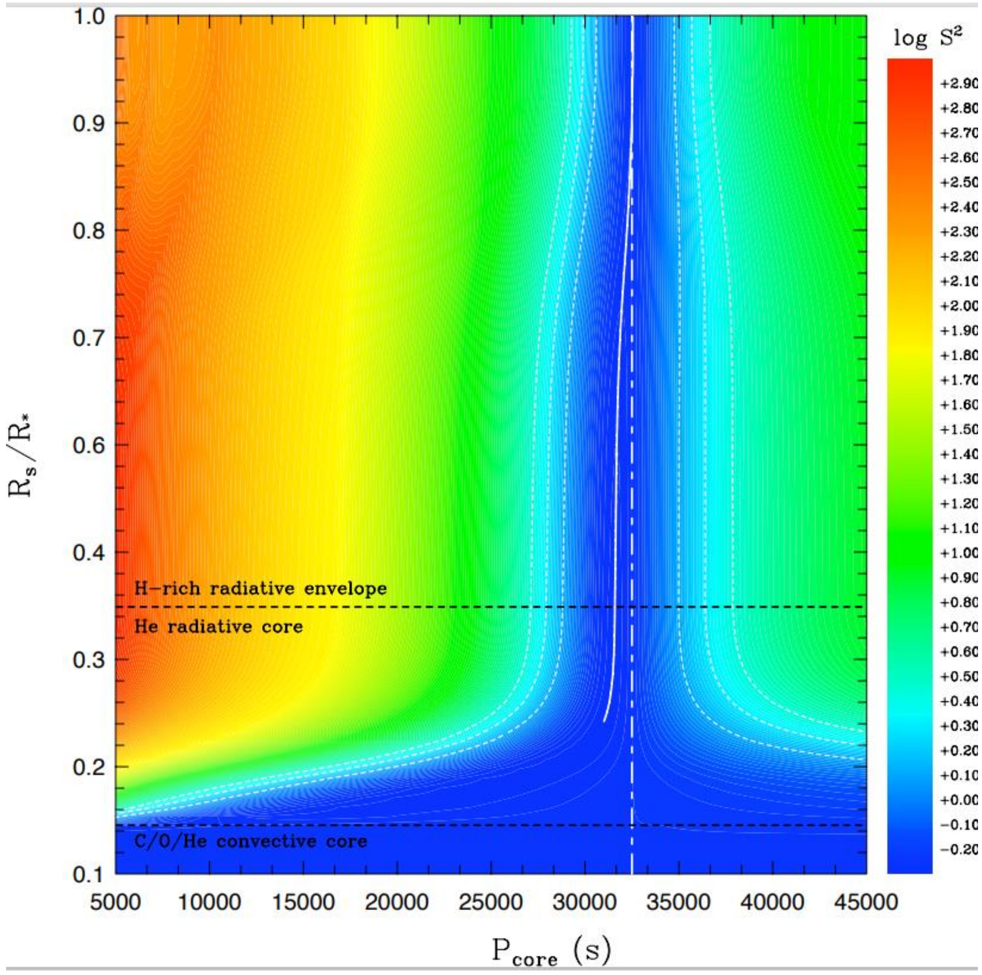
9 pulsation periods, 343-382s, in 4 groups (mean spacing: $<\Delta\nu>$ ~ 28.2 μHz, resolution of 2.2 μHz)

Asteroseismology: splitting $\Delta\nu \sim 1/P_{rot}$, close here if we assume $P_{rot} = P_{orb}$

=> seismic modeling including rotational splittings, Van Grootel et al. 2008

Feige 48: what we know (and thought to know)

Van Grootel et al. 2008: Feige 48 is synchronized, aka $P_{rot} = P_{orb} = 9.024$h, at least down to 0.22 R_*



Feige 48: what we know (and thought to know)

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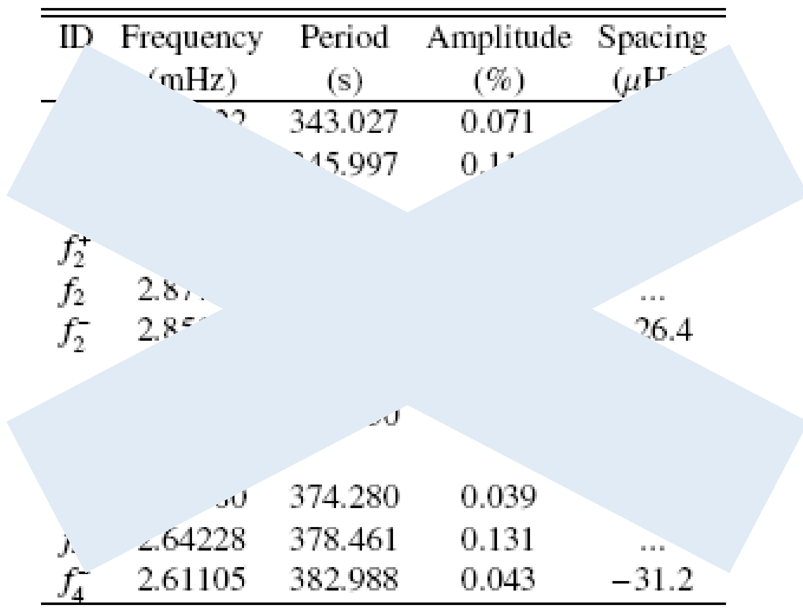

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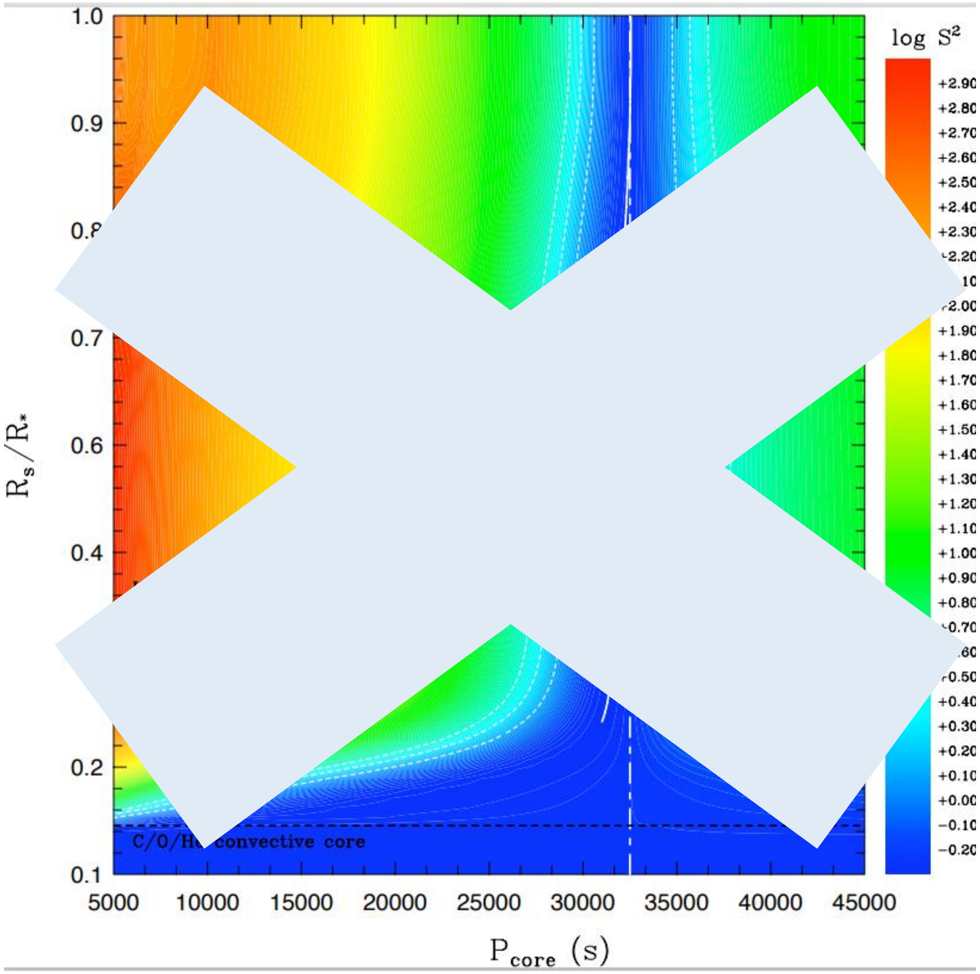
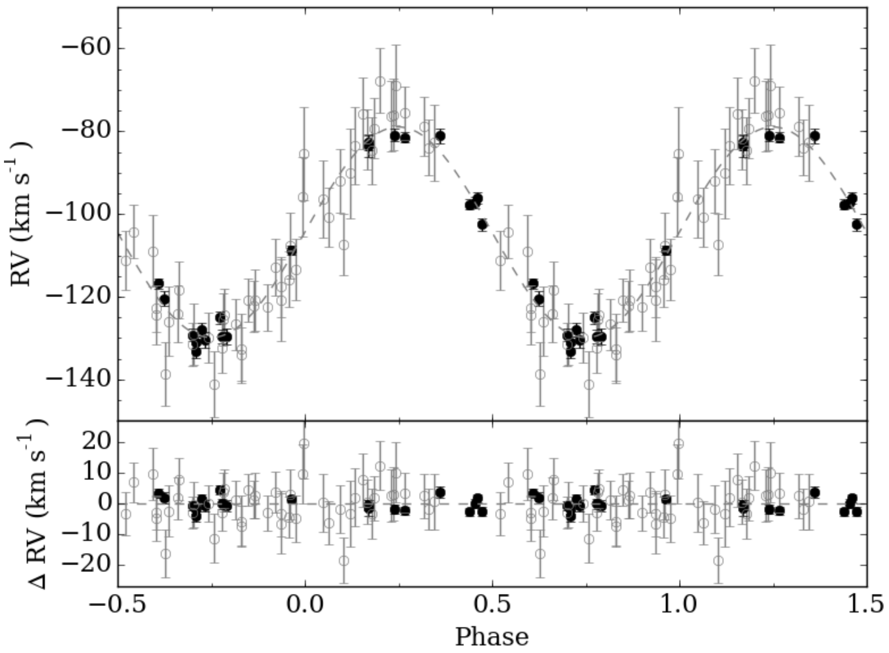
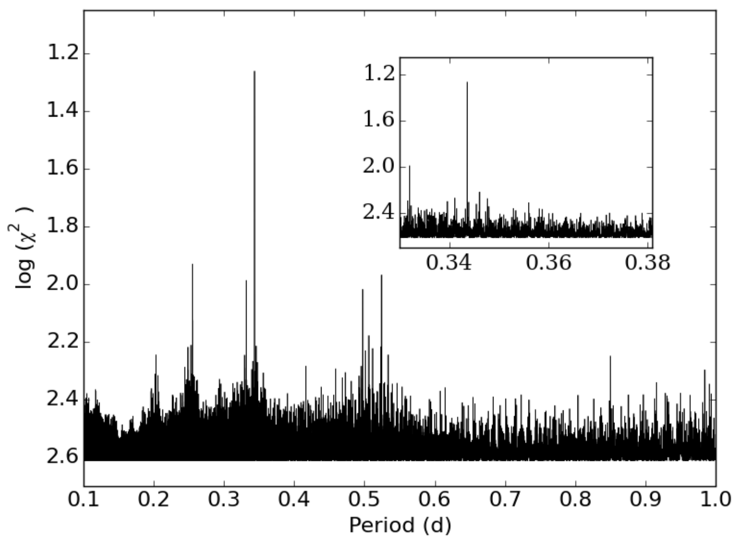


Feige 48: more recent observations

Radial Velocities

70 MMT and Bok spectra gathered by B. Green





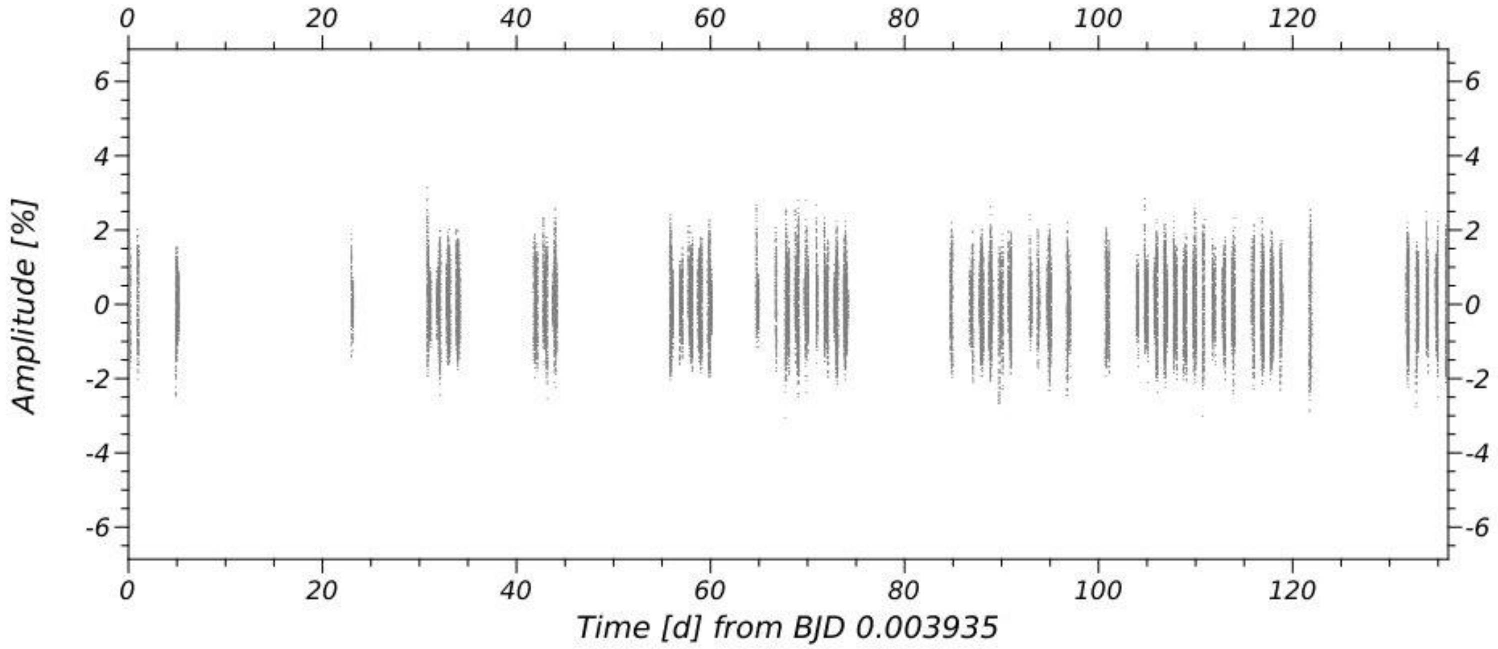
Analysis by M. Latour: P_{orb} = 0.3436091 ±2.e-7 d (8.2466h)

(partial analysis based on 18 spectra presented in Latour et al. 2014a, sdOB6 proceedings)

Feige 48: more recent observations

Mt Bigelow/Mont4K photometric campaign

January 1 – May 17, 2009

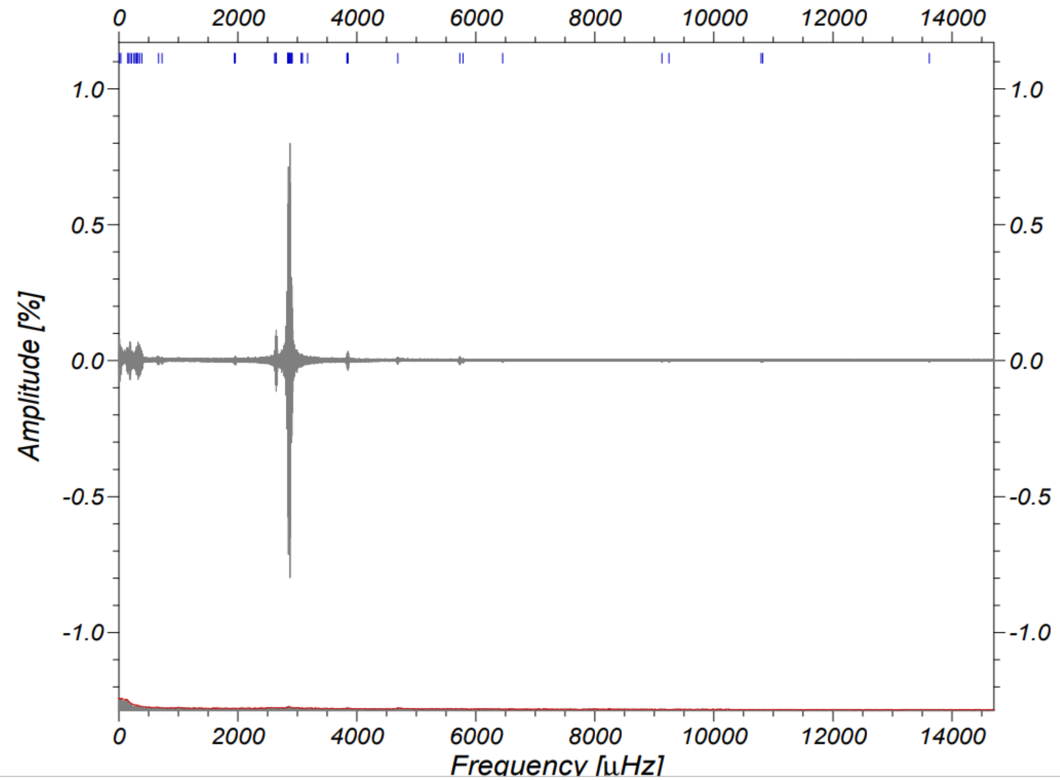


399.1h of data over 136 days, 12.2% duty cycle

0.085 µHz resolution, median noise level 70 ppm

Feige 48: more recent observations

Mt Bigelow/Mont4K photometric campaign

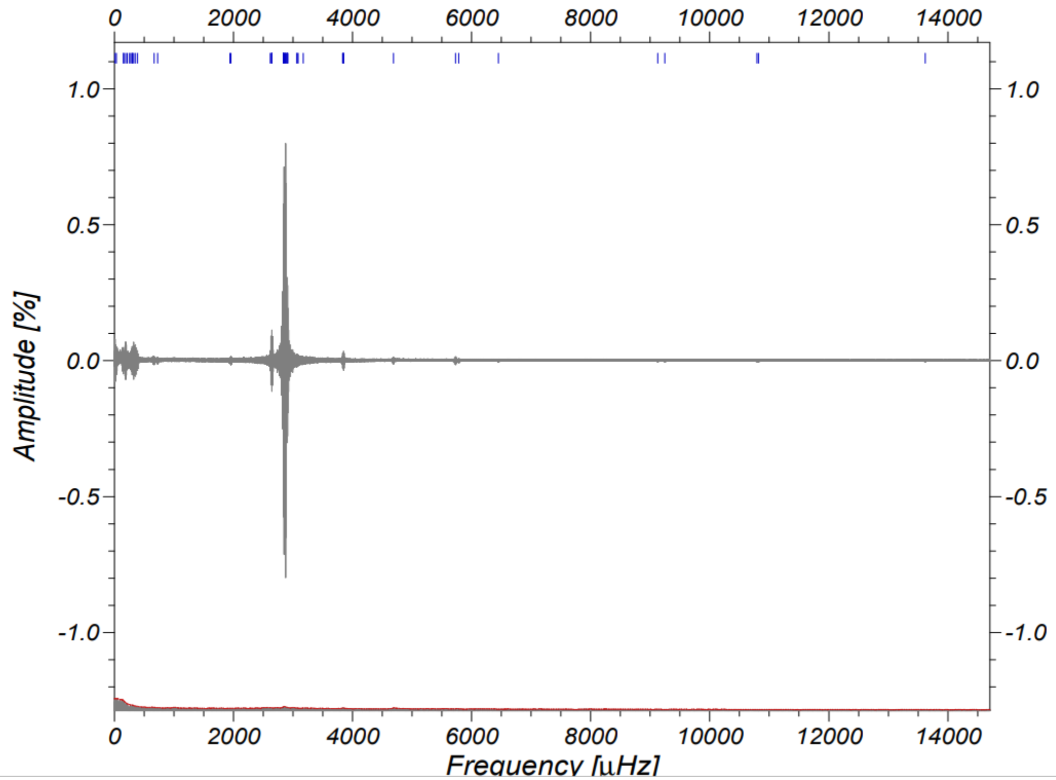


29 p-modes around ~2900 μHz + 11 g-modes ~300 μHz

=> Feige 48 is a hybrid pulsator

Feige 48: more recent observations

Mt Bigelow/Mont4K photometric campaign



+ very small peak at 33.67 μHz (SNR=4.1), which is equal to P_{orb}

=> Feige 48 is a reflection effect binary

(hence not a WD, rather a dM companion)

Feige 48: more recent observations

Mt Bigelow/Mont4K photometric campaign

A zoom on p-modes

Id.	Frequency (μHz)	σ_f (μHz)	Period (s)	σ_P (s)	Amplitude (%)	σ_A (%)	Phase (s)	σ_{Ph} (s)	S/N	Comments
f_{40}	1942.802	0.010	514.7204	0.0027	0.0108	0.0024	0.240	0.070	4.6	
f_{35}	1956.690	0.0083	511.0671	0.0022	0.0132	0.0023	0.863	0.056	5.7	
f_{32}	2618.074	0.0087	381.9601	0.0013	0.0154	0.0029	0.149	0.059	5.4	
f_{18}	2637.417	0.0041	379.15880	0.00058	0.0321	0.0028	0.678	0.028	11.6	
f_{26}	2639.709	0.0056	378.82957	0.00081	0.0235	0.0028	0.467	0.038	8.3	
f_5	2641.987	0.0012	378.50293	0.00017	0.1113	0.0028	0.5542	0.0080	40.0	f_4 in VVG2008
f_{13}	2646.495	0.0029	377.85825	0.00041	0.0441	0.0027	0.035	0.020	16.2	
f_4	2837.510	0.0011	352.42162	0.00014	0.1517	0.0037	0.7725	0.0078	41.0	f_3 in VVG2008
f_{24}	2839.3979	0.0068	352.18734	0.00084	0.0261	0.0038	0.764	0.046	6.9	
f_{27}	2840.7369	0.0091	352.0213	0.0011	0.0197	0.0038	0.333	0.062	5.1	
f_{25}	2843.0180	0.0075	351.73890	0.00093	0.0238	0.0038	0.707	0.051	6.2	
f_2	2850.82917	0.00027	350.775140	0.000033	0.7133	0.0040	0.4411	0.0018	176.4	f_2^+ in VVG2008
f_{22}	2874.3435	0.0064	347.90553	0.00078	0.0280	0.0038	0.666	0.044	7.3	
f_1	2877.15918	0.00022	347.565059	0.000026	0.8045	0.0037	0.1891	0.0015	215.6	f_2 in VVG2008
f_8	2878.6531	0.0026	347.38469	0.00031	0.0666	0.0037	0.249	0.017	18.2	
f_{21}	2903.5948	0.0051	344.40068	0.00061	0.0287	0.0031	0.201	0.035	9.2	
f_3	2906.27255	0.00056	344.083351	0.000067	0.2586	0.0031	0.3172	0.0038	83.3	f_2^- in VVG2008
f_{20}	2908.5472	0.0047	343.81426	0.00055	0.0308	0.0031	0.678	0.032	10.0	
f_{29}	2910.3685	0.0075	343.59910	0.00089	0.0191	0.0031	0.028	0.051	6.2	
f_{31}	3070.5242	0.0075	325.67729	0.00080	0.0160	0.0026	0.243	0.051	6.2	
f_{28}	3084.6677	0.0060	324.18402	0.00063	0.0196	0.0025	0.800	0.041	7.8	
f_{39}	3172.079	0.012	315.2506	0.0011	0.0111	0.0027	0.732	0.078	4.1	
f_{34}	3833.0444	0.0085	260.88923	0.00058	0.0145	0.0026	0.891	0.058	5.5	
f_{38}	3845.237	0.010	260.06202	0.00068	0.0125	0.0027	0.593	0.068	4.7	
f_{36}	3846.0415	0.0098	260.00759	0.00066	0.0127	0.0027	0.793	0.067	4.8	
f_{19}	3846.3693	0.0039	259.98543	0.00026	0.0319	0.0027	0.034	0.027	12.0	
f_{37}	4687.395	0.010	213.33810	0.00047	0.0126	0.0028	0.046	0.070	4.5	

Feige 48: more recent observations

Mt Bigelow/Mont4K photometric campaign

We have close multiplets, often asymmetric

Id.	Frequency (μHz)	σ_f (μHz)	Period (s)	σ_P (s)	Amplitude (%)	σ_A (%)	Phase (s)	σ_{Ph} (s)	S/N	Comments
378s: 4 close modes, $\Delta\nu$ ~ 2.3 μHz										
f_{18}	2637.417	0.0041	379.15880	0.00058	0.0321	0.0028	0.678	0.028	11.6	
f_{26}	2639.709	0.0056	378.82957	0.00081	0.0235	0.0028	0.467	0.038	8.3	
f_5	2641.987	0.0012	378.50293	0.00017	0.1113	0.0028	0.5542	0.0080	40.0	f_4 in VVG2008
f_{13}	2646.495	0.0029	377.85825	0.00041	0.0441	0.0027	0.035	0.020	16.2	
352s: 4 close modes, $\Delta\nu$ ~ 1.9, 1.3 and 2.3 μHz										
f_4	2837.510	0.0011	352.42162	0.00014	0.1517	0.0037	0.7725	0.0078	41.0	f_3 in VVG2008
f_{24}	2839.3979	0.0068	352.18734	0.00084	0.0261	0.0038	0.764	0.046	6.9	
f_{27}	2840.7369	0.0091	352.0213	0.0011	0.0197	0.0038	0.333	0.062	5.1	
f_{25}	2843.0180	0.0075	351.73890	0.00093	0.0238	0.0038	0.707	0.051	6.2	
347s: triplet, $\Delta\nu$ ~ 2.8 and 1.5 μHz										
f_{22}	2874.3435	0.0064	347.90553	0.00078	0.0280	0.0038	0.666	0.044	7.3	
f_1	2877.15918	0.00022	347.565059	0.000026	0.8045	0.0037	0.1891	0.0015	215.6	f_2 in VVG2008
f_8	2878.6531	0.0026	347.38469	0.00031	0.0666	0.0037	0.249	0.017	18.2	
344s: 4 close modes, $\Delta\nu$ ~ 2.7, 2.3 and 1.8 μHz										
f_{21}	2903.5948	0.0051	344.40068	0.00061	0.0287	0.0031	0.201	0.035	9.2	
f_3	2906.27255	0.00056	344.083351	0.000067	0.2586	0.0031	0.3172	0.0038	83.3	f_2^- in VVG2008
f_{20}	2908.5472	0.0047	343.81426	0.00055	0.0308	0.0031	0.678	0.032	10.0	
f_{29}	2910.3685	0.0075	343.59910	0.00089	0.0191	0.0031	0.028	0.051	6.2	

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f_1	2877.15918	0.00022	347.565059	0.000026	0.8045	0.0037	0.1891	0.0015	215.6	f_2 in VVG2008
f_8	2878.6531	0.0026	347.38469	0.00031	0.0666	0.0037	0.249	0.017	18.2	
344s: 4 close modes, $\Delta\nu$ ~ 2.7, 2.3 and 1.8 μHz										
f_{21}	2903.5948	0.0051	344.40068	0.00061	0.0287	0.0031	0.201	0.035	9.2	
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f_{29}	2910.3685	0.0075	343.59910	0.00089	0.0191	0.0031	0.028	0.051	6.2	

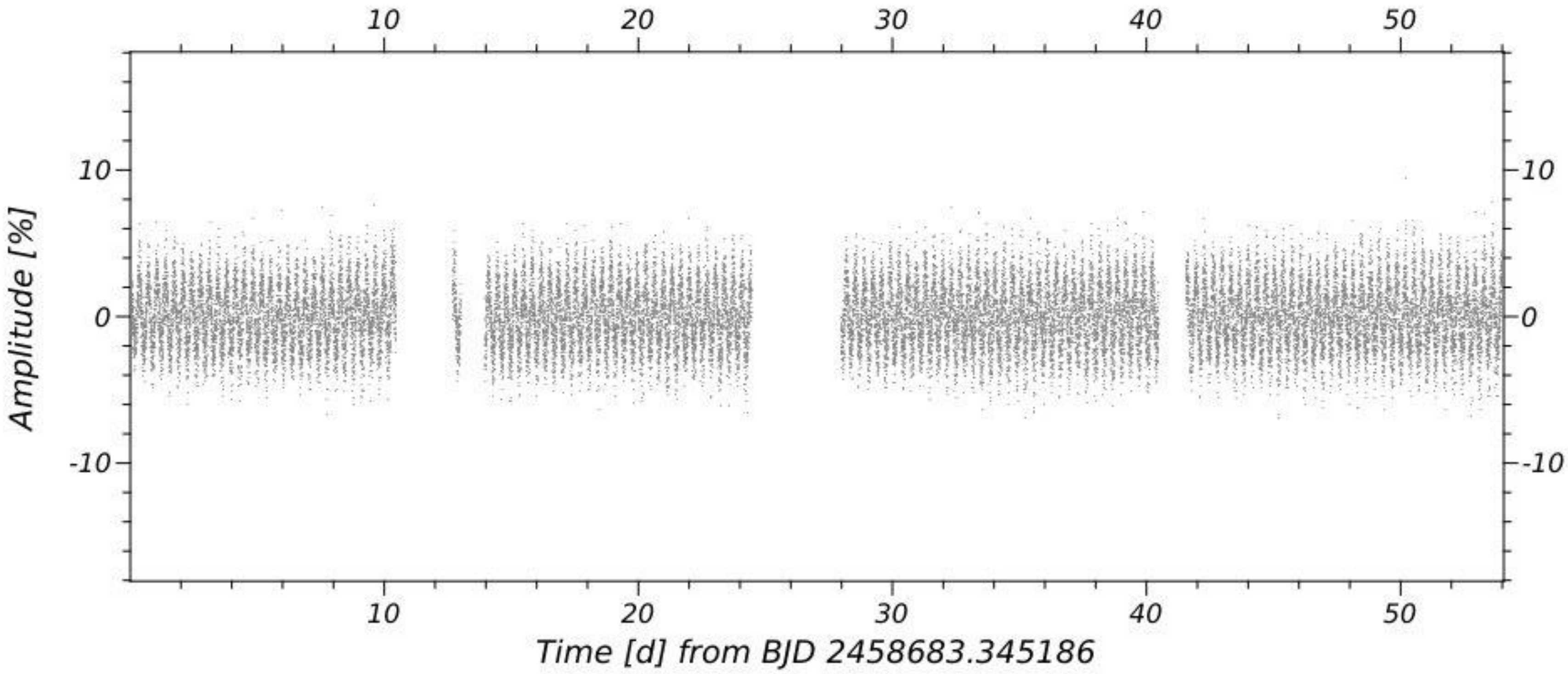
So…slow rotator ? But why asymmetric multiplets ???

Feige 48: more recent observations

TESS: sectors 14, 15, 21, 41 and 48

2-min cadence + 20s cadence for S41 and S48

S14+S15



Feige 48: more recent observations

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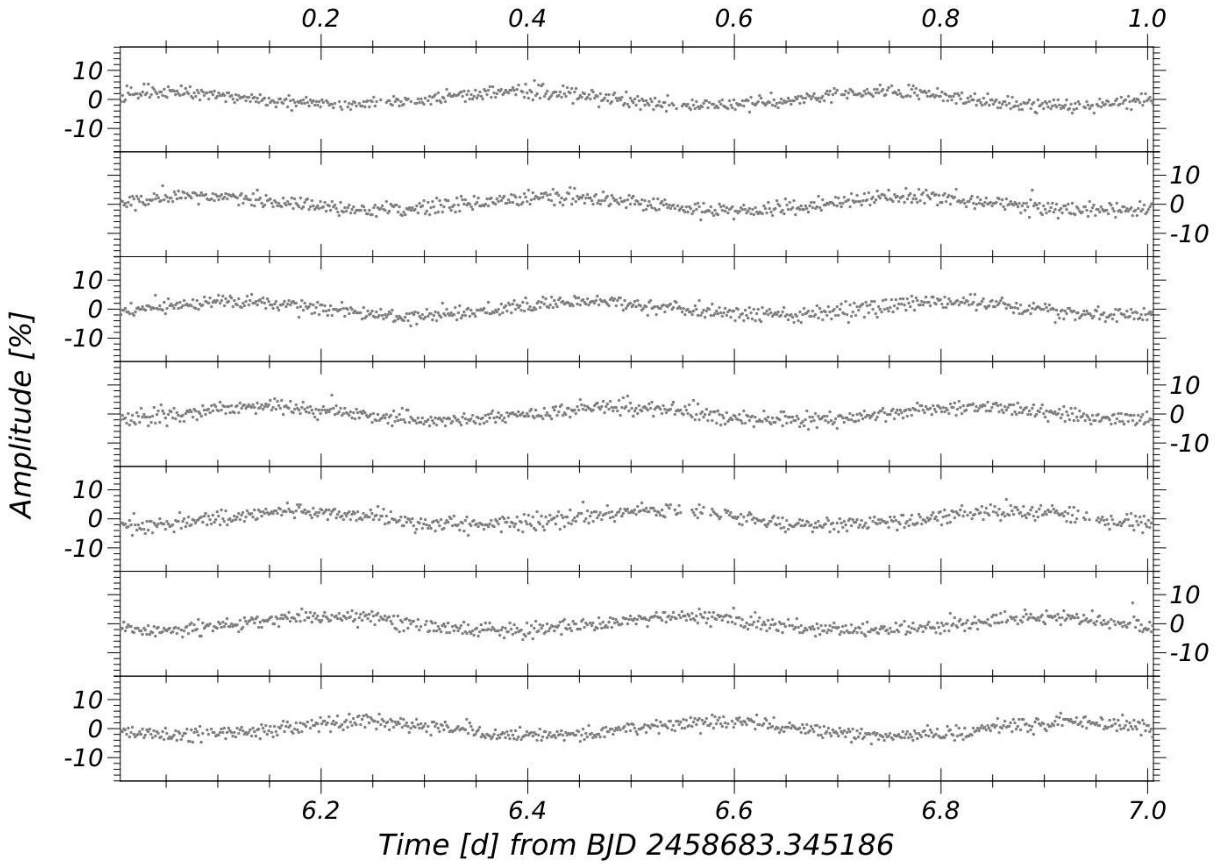
Zoom (7 days in S14)



Reflection effect prominent (2.3%)

=> Schaffenroth et al. 2023: M* and R* of the dM star, i° of the system

Feige 48: more recent observations

TESS: sectors 14, 15, 21, 41 and 48

Pulsation frequency extraction

Id.	Frequency (μHz)	σ_f (μHz)	Period (s)	σ_P (s)	Amplitude (%)	σ_A (%)	Phase (s)	σ_{Ph} (s)	S/N	Comments
					Sectors 14+15+21					
$F_{\rm orb}$	33.68396	0.00013	29687.72	0.11	2.3174	0.0099	0.8370	0.0014	235.0	$P_{\rm orb}$, reflection effect
$2^*F_{\rm orb}$	67.3676	0.0018	14843.92	0.40	0.1563	0.0096	0.665	0.019	16.3	$P_{\rm orb}/2$
F_9	129.9612	0.0049	7694.60	0.29	0.0534	0.0087	0.951	0.052	6.1	
F_7	187.7474	0.0039	5326.31	0.11	0.0650	0.0086	0.846	0.042	7.6	
F_{17}	241.7001	0.0031	4137.36	0.22	0.0330	0.0065	0.675	0.063	5.1	
F_{13}	274.6410	0.0064	3641.12	0.085	0.0411	0.0089	0.253	0.069	4.6	
F_{14}	295.6396	0.0063	3382.50	0.072	0.0401	0.0085	0.924	0.067	4.7	
F_{10}	322.5736	0.0047	3100.07	0.045	0.0533	0.0085	0.382	0.051	6.3	
F_8	351.6237	0.0042	2843.95	0.034	0.0604	0.0085	0.215	0.045	7.1	
F_{16}	385.5092	0.0031	2593.97	0.034	0.0345	0.0068	0.939	0.068	5.0	
F_6	2641.9856	0.0031	378.503	0.00044	0.0874	0.0091	0.201	0.033	9.6	
F_{12}	2646.4887	0.0061	377.859	0.00087	0.0437	0.0090	0.934	0.065	4.9	
F_4	2837.5030	0.0025	352.422	0.00031	0.1049	0.0087	0.956	0.026	12.0	
F_2	2850.83242	0.00057	350.775	0.000071	0.4495	0.0087	0.8518	0.0061	51.8	
F_{11}	2874.3172	0.0059	347.909	0.00071	0.0460	0.0091	0.995	0.063	5.1	
F_1	2877.16001	0.00029	347.565	0.000035	0.9267	0.0091	0.7967	0.0031	101.6	
F_5	2878.6746	0.0030	347.382	0.00037	0.0899	0.0092	0.281	0.032	9.8	
F_{15}	2903.5430	0.0064	344.407	0.00075	0.0394	0.0084	0.861	0.068	4.7	
F_3	2906.2733	0.0023	344.083	0.00027	0.1086	0.0084	0.757	0.025	12.9	

8 g-modes + 9 p-modes, all in direct correspondence with Mt Bigelow peaks

Feige 48: more recent observations

What about CFHT data and ~28 µHz splittings ?

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	...
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f_4	2.64228	378.461	0.131	...
f_4^-	2.61105	382.988	0.043	−31.2

1-day alias: 344.4s
1-day alias: 347.4s, $\Delta\nu$ ~ 24.9 µHz

Now 29.1 µHz
Now 26.3 µHz
=> asymmetric

Now 4 close peaks

?
Now 4 close peaks
?

Hard to believe anymore on triplets with $\Delta\nu$ ~28 µHz

Feige 48: more recent observations

BUT

Id.	Frequency (μHz)	σ_f (μHz)	Period (s)	σ_P (s)	Amplitude (%)	σ_A (%)	Phase (s)	σ_{Ph} (s)	S/N	Comments
					Sectors 14+15+21					
F_6	2641.9856	0.0031	378.503	0.00044	0.0874	0.0091	0.201	0.033	9.6	
F_{12}	2646.4887	0.0061	377.859	0.00087	0.0437	0.0090	0.934	0.065	4.9	
F_4	2837.5030	0.0025	352.422	0.00031	0.1049	0.0087	0.956	0.026	12.0	
F_2	2850.83242	0.00057	350.775	0.000071	0.4495	0.0087	0.8518	0.0061	51.8	
F_{11}	2874.3172	0.0059	347.909	0.00071	0.0460	0.0091	0.995	0.063	5.1	
F_1	2877.16001	0.00029	347.565	0.000035	0.9267	0.0091	0.7967	0.0031	101.6	
F_5	2878.6746	0.0030	347.382	0.00037	0.0899	0.0092	0.281	0.032	9.8	
F_{15}	2903.5430	0.0064	344.407	0.00075	0.0394	0.0084	0.861	0.068	4.7	
F_3	2906.2733	0.0023	344.083	0.00027	0.1086	0.0084	0.757	0.025	12.9	

- F2-F5-F3 (350.7-347.382-344.083s): $\Delta\nu$ ~27.7 µHz

- Among Bigelow close multiplets:

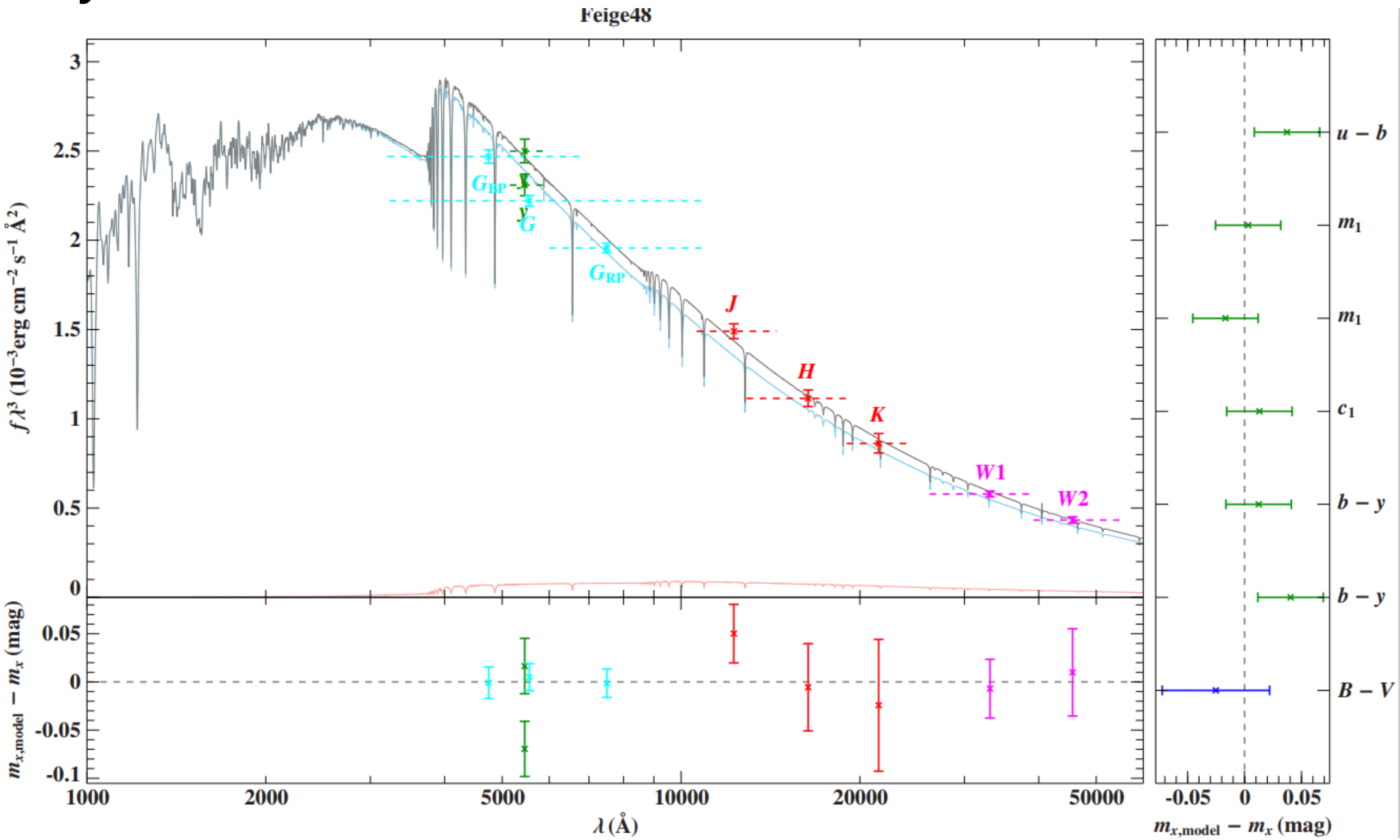
- 378s group: 2 close modes $\Delta\nu$ ~4.5 µHz
- 347s group: same 3 close modes, asymmetric, w/o F5: $\Delta\nu$ ~4.4 µHz
- 344s group: 2 close modes, $\Delta\nu$ ~2.7 µHz (if F3 not taken)

- Small *and* large splittings (non-solid body rotation) ?

PS: no obvious splitting among g-modes

Feige 48: SED fitting

Done by Uli, march 2020



No IR excess observed, reasonable fit

Feige 48: SED fitting

Done by Uli, march 2020 => Gaia DR2

Object: Feige48	68% confidence interval
Angular diameter $\log(\Theta\,(\mathrm{rad}))$	$-10.923^{+0.018}_{-0.020}$
Color excess $E(B-V)$	$0.028^{+0.019}_{-0.020}$ mag
Extinction parameter R_V (fixed)	3.1
Parallax ϖ (*Gaia*, RUWE = 1.14)	1.22 ± 0.04 mas
Component 1:	
Effective temperature T_{eff} (prescribed)	29900 ± 300 K
Surface gravity $\log(g\,(\mathrm{cm\,s^{-2}}))$ (prescribed)	5.46 ± 0.05
Microturbulence ξ (fixed)	$0\,\mathrm{km\,s^{-1}}$
Metallicity z (fixed)	0 dex
Helium abundance $\log(n(\mathrm{He}))$ (fixed)	−2.88
Surface ratio (fixed)	1
Radius $R_\star = \Theta/(2\varpi)$	$0.217^{+0.012}_{-0.013}\,R_\odot$
Mass $M = gR_\star^2/G$	$0.50 \pm 0.08\,M_\odot$
Luminosity $\log\left(\frac{L}{L_\odot}\right) = \log\left(\left(\frac{R_\star}{R_\odot}\right)^2\left(\frac{T_{\mathrm{eff}}}{5775\,\mathrm{K}}\right)^4\right)$	$1.53^{+0.05}_{-0.06}$

PS: Gaia DR3: parallax=1.2641±0.0288 mas

SED fitting by Schaffenroth et al. (2022), DR3:

$M_{sdB}=0.470^{+0.064}_{-0.059}\ M_{sun}$

$R_{sdB}=0.213\pm0.007\ R_{sun}$

Feige 48: new seismic analysis

Search the stellar model(s) whose theoretical periods best fit the observed ones, in order to minimize

$$S^2(a_1, a_2, ..., a_N) = \sum_{i=1}^{N_{\rm obs}} (P_{\rm obs}^{(i)} - P_{\rm th}^{(i)})^2$$

> **Optimization procedure**: Efficient optimization codes (based on *Genetic Algorithms*) to thoroughly explore the parameter space and find the minima of S^2

Under *external* constraints from spectroscopy with **static** models:

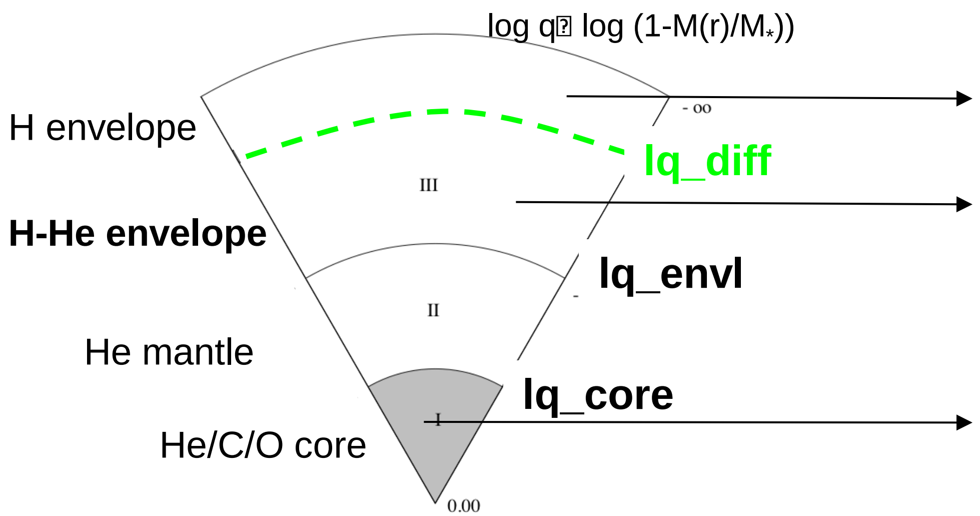
- $0.3 \leq \mathbf{M_*} \leq 0.7\ M_{sun}$ (Han et al. 2002, 2003)
- –3.0 ≤ **lq_env** ≤ –1.5
- –0.40 ≤ **lq_core** ≤ –0.10
- $0 \leq \mathbf{He_{core}} \leq 1$
- $0 \leq \mathbf{O_{core}} \leq 1$
- $\mathbf{H_{env,diff}}$: 20-100% + location of the transition **lq_diff**
- Steep to smooth profiles (pro_fac parameters: **pf_diff**, **pf_env**, and **pf_core**)

\+ T_{eff}, log g @ 1σ spectroscopy

Parameterized static models

Complete static equilibrium models, *<u>independent</u> of stellar evolution*

sdB stars



Envelope with double transition:

Pure H envelope

H/He envelope (+Fe)

($\mathbf{H_{env,diff}}$)

$\mathbf{He_{core}, O_{core}}$

$\mathbf{(He_{core}+O_{core}+C_{core}=1)}$

+ chemical transition profiles (smooth to steep): **pf_diff**, **pf_env**, **pf_core**

+ total mass of the star **M***

= 4th generation (4G) models of sdB stars

Feige 48: new seismic analysis

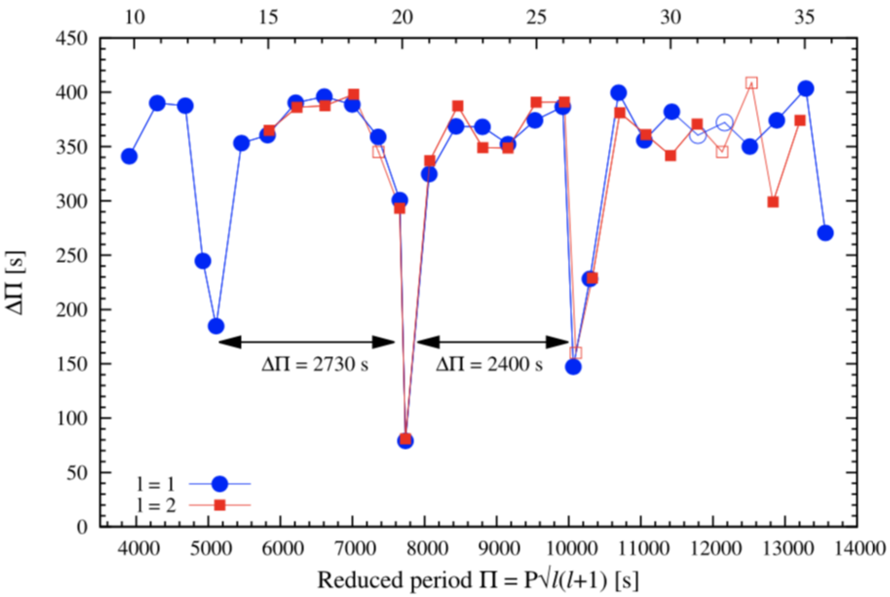
Feige 48: new seismic analysis

Hypothesis 1: slow rotation

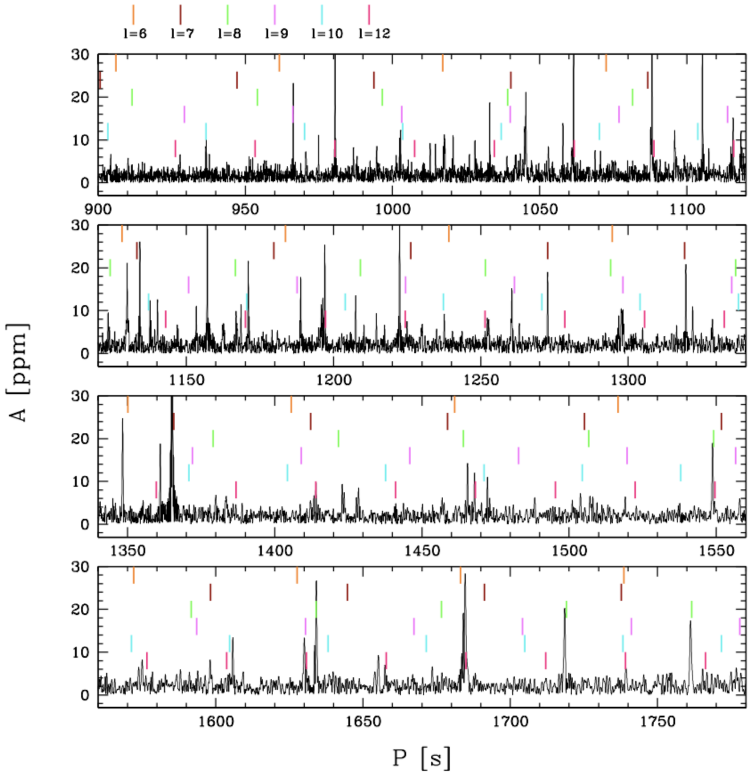
12 p-modes (ell ≤ 4) and 7 g-modes (ell ≤ 2)

Asteroseismology of sdB pulsators: Marking results

1. Observations of trapped g-modes (Østensen et al. 2014, Uzundag et al. 2017)
2. Observations of g-modes up to l=12 ! (Telting et al. 2014, Kern et al. 2018, Silvotti et al. 2019)



Østensen et al. 2014



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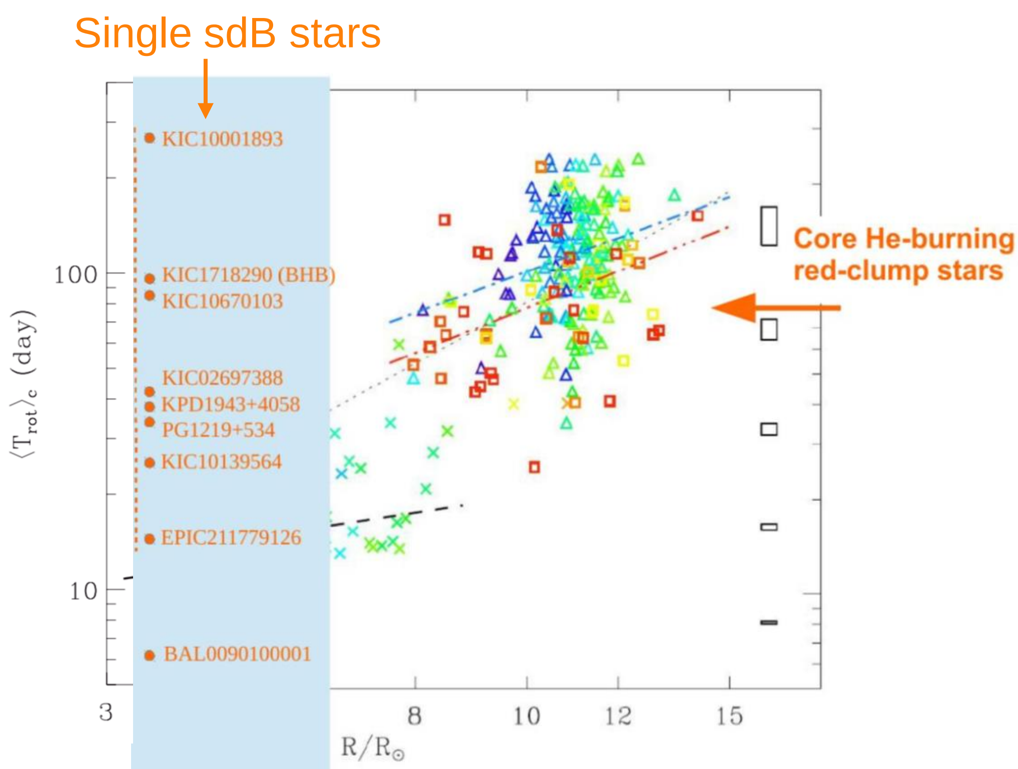
2. Observations of g-modes up to l=12 ! (Telting et al. 2014, Kern et al. 2018, Silvotti et al. 2019)
3. Single sdB stars are (almost) all slow rotators (Charpinet et al. 2018), in direct line with core rotation of Red Clump stars (Mosser et al. 2012) => indication of similar evolution (post-RGB stars)



Mosser et al. 2012
Charpinet et al. 2018

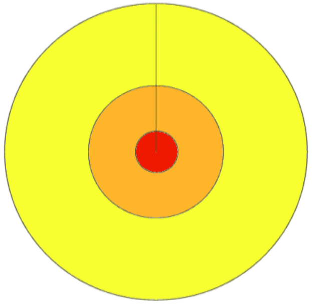
Asteroseismology of sdB pulsators: Marking results

Fontaine et al., Charpinet et al., Van Grootel et al.,…: 18 sdB stars modeled by asteroseismology (mass, radius, H-rich env. thickness, core composition,…)

Two tests of seismic results thanks to GAIA:

1. Possibility to cross-check with **distance** derived based on seismic stellar parameters
2. Combined to spectroscopy, possibility to to cross-check with **mass** derived from asteroseismology

Test 1: Method for deriving asteroseismic distances

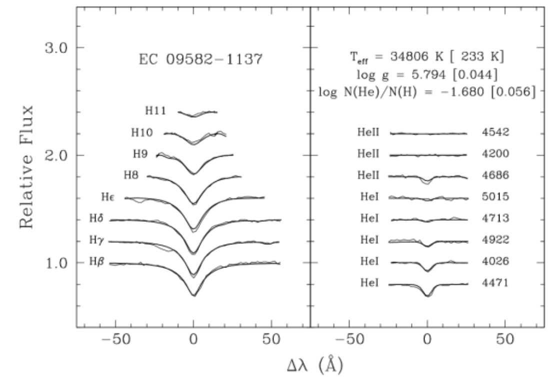


Asteroseismology

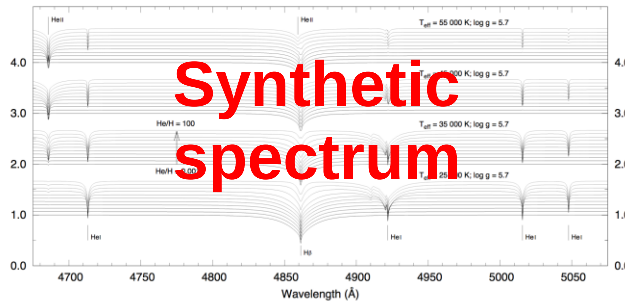
- log g
- T_{eff}
- M_*

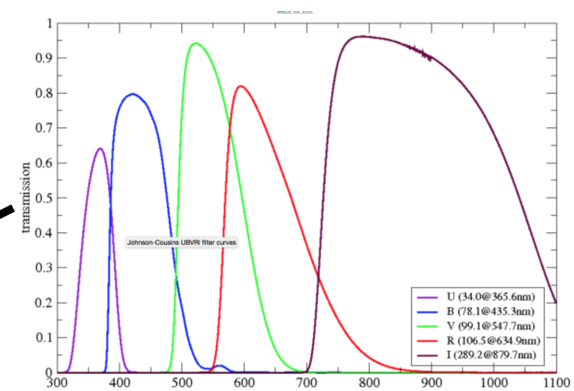
N(He)/N(H)

Spectroscopic fitting



Synthetic spectrum





Absolute magnitude M_a

Bandpass of filter a

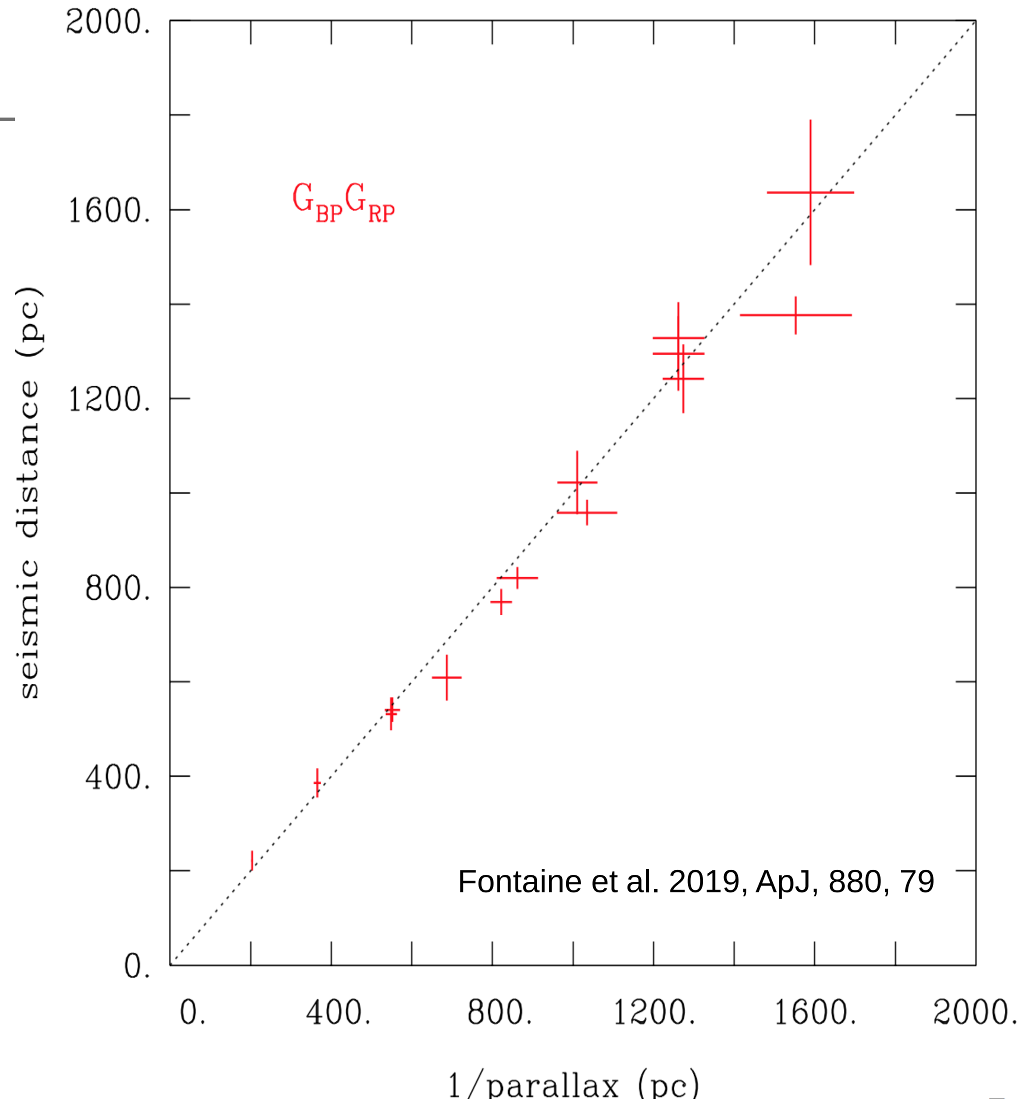
Apparent magnitude a

Asteroseismic distance

Absorption coefficient:
Bandpass+E(B-V)

Results of test 1: seismic vs GAIA distances

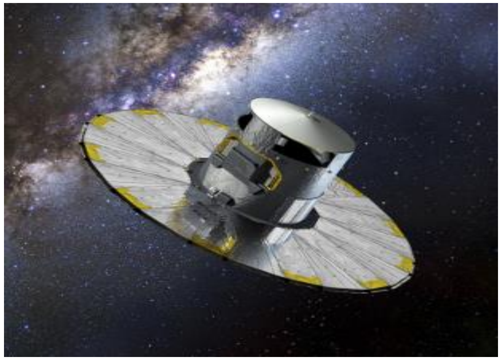
Name	d(Gaia) (pc)	$d(G_{BP}G_{RP})$ (pc)
PG 1047+003	687±37	609±49
PG 0014+067	2794±1037	1812±277
PG 1219+534	549±14	532±35
Feige 48	822±27	769±28
EC 05217−3914	1590±108	1636±154
PG 1325+102	862±51	820±23
PG 0048+091	1058±48	...
EC 20117−4014	587±13	...
PG 0911+456	1035±75	958±27
BAL 090100001	365.6±8.6	386±31
EC 09582−1137	1553±139	1376±40
KPD 1943+4058	1274±51	1242±73
KPD 0629−0016	1011±50	1022±67
KIC 02697388[b]	1262±64	1328±76
KIC 02697388[c]	1262±64	1295±79
PG 1336−018	552±19	541±26
TIC 278659026	203.7±2.1	221±21



All distances agree within 1sigma

Test 2: Method for deriving "spectroscopic" masses

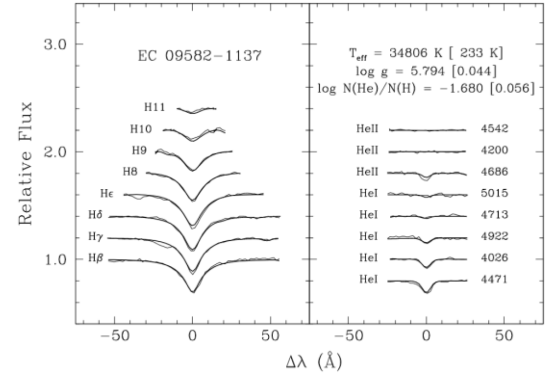
GAIA



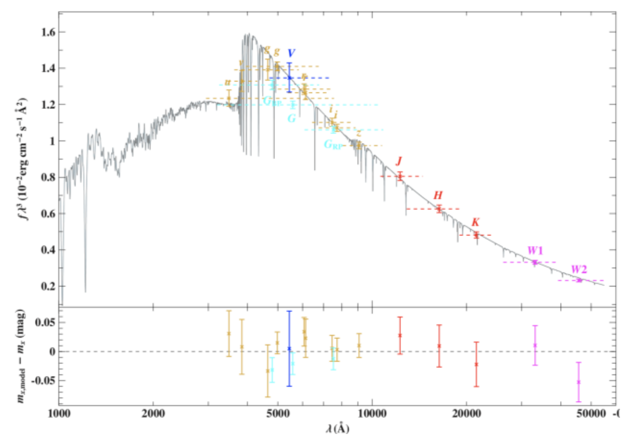
- distance d/parallax ϖ

- log g = GM/R^2
- T_{eff}

Spectroscopic fitting



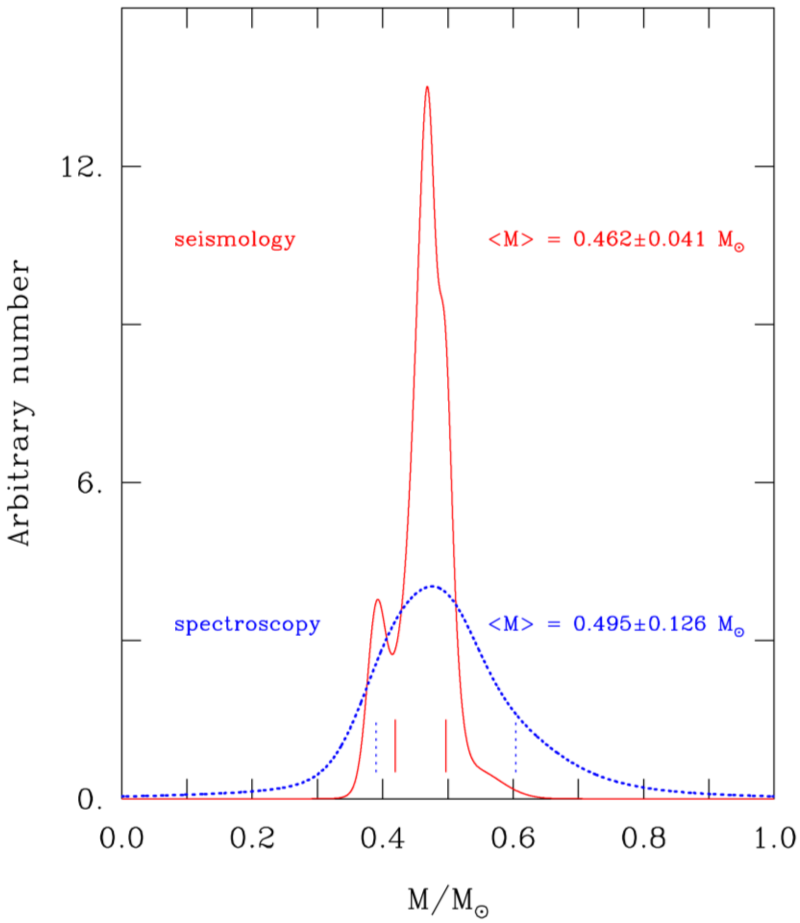
Spectral energy distribution (SED) fitting to colors (photometry)

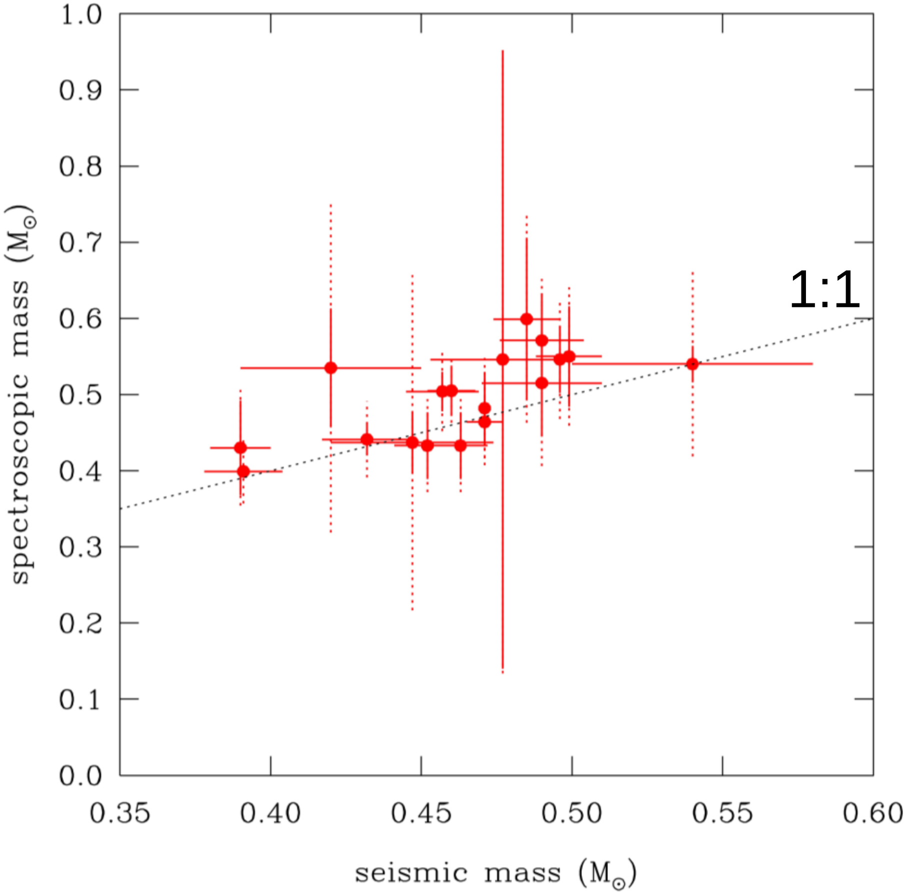


- Angular diameter $\theta \approx 2R/d$ (if θ<<1)

« Spectroscopic » mass
$$M = g\theta^2 / 4G\varpi^2$$

Results of test 2: seismic vs spectroscopic masses



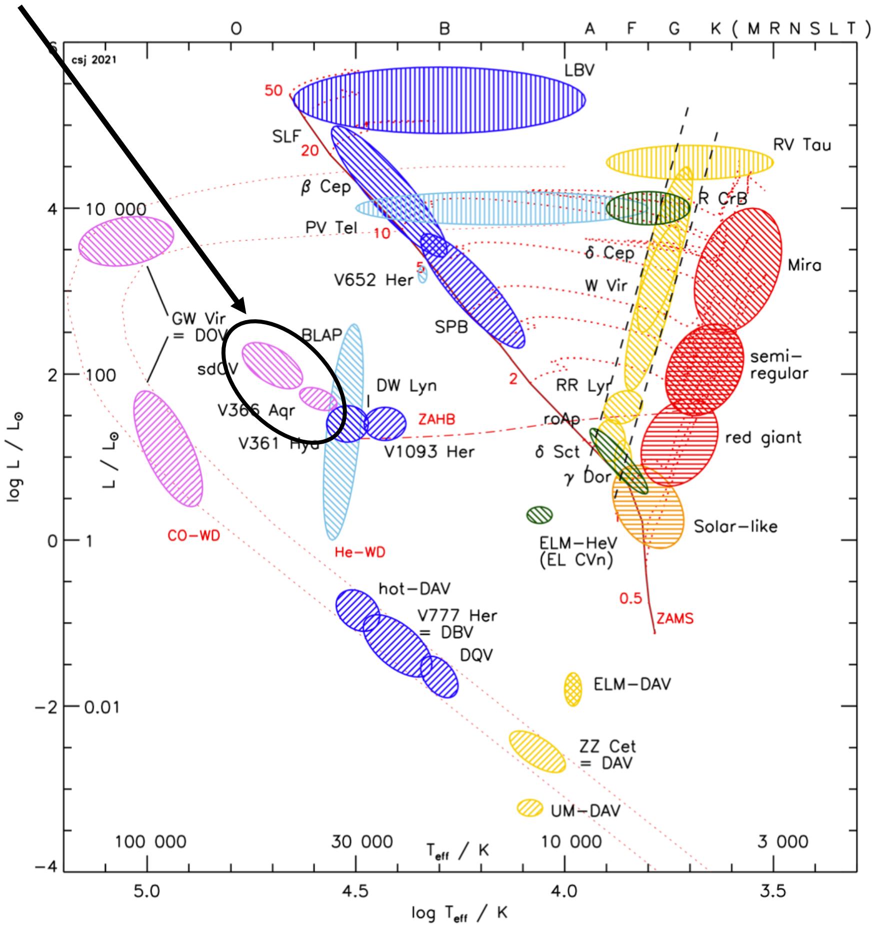


ΔM/M seismology ~ 10%

ΔM/M spectroscopy ~ 25%

Subdwarf O (sdO) stars

Hotter stars (T_{eff} ~ 40,000 – 80,000 K), wide range of log g (4.0-6.2). Some are (would be) post-EHB, some direct post-RGB, some mergers, some post-AGB



D. Kurtz/S. Jeffery

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Hotter stars (T_{eff} ~ 40,000 – 80,000 K), wide range of log g (4.0-6.2). Some are (would be) post-EHB, some direct post-RGB, some mergers, some post-AGB

> **Pulsating sdOs in the field:** 3 known (incl. PB 8783) despite extensive search (Rodriguez-Lopez et al. 2007, Johnson et al. 2014)

> A couple of sdOVs identified in **globular clusters** (Omega Cen - Randall et al. 2011, NGC 2808 - Brown et al. 2014)

Very short periods (1-2 minutes), consistent with p-modes (Fontaine et al. 2008)

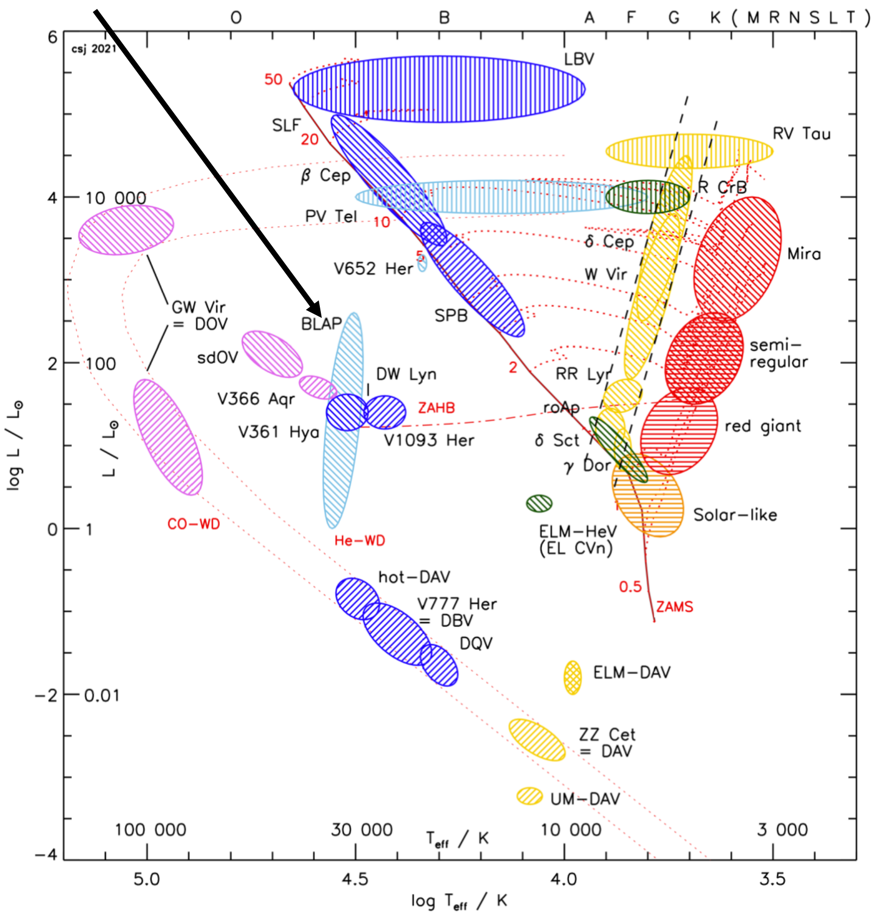
Seismic modeling of sdOVs only tentative (PB8783; Van Grootel et al. 2019)

> V366 Aqr pulsators: 3 g-modes pulsators (periods of ~30 min) in stars with T_{eff} ~ 40,000 K, all intermediate He-rich and extremely enriched in some metal elements.

BLAPs

Blue, Large Amplitude Pulsators, discovered by Pietrukowicz in 2017

- Short-period (3-40 min), radially pulsating (0.2-0.4 mag) H-deficient stars
- Evolutionary path/origin unknown (pre-ELM H-shell burning WDs ? Byrne et al. 2020, 2021) – see Pietrukowicz and Bradshaw's talks



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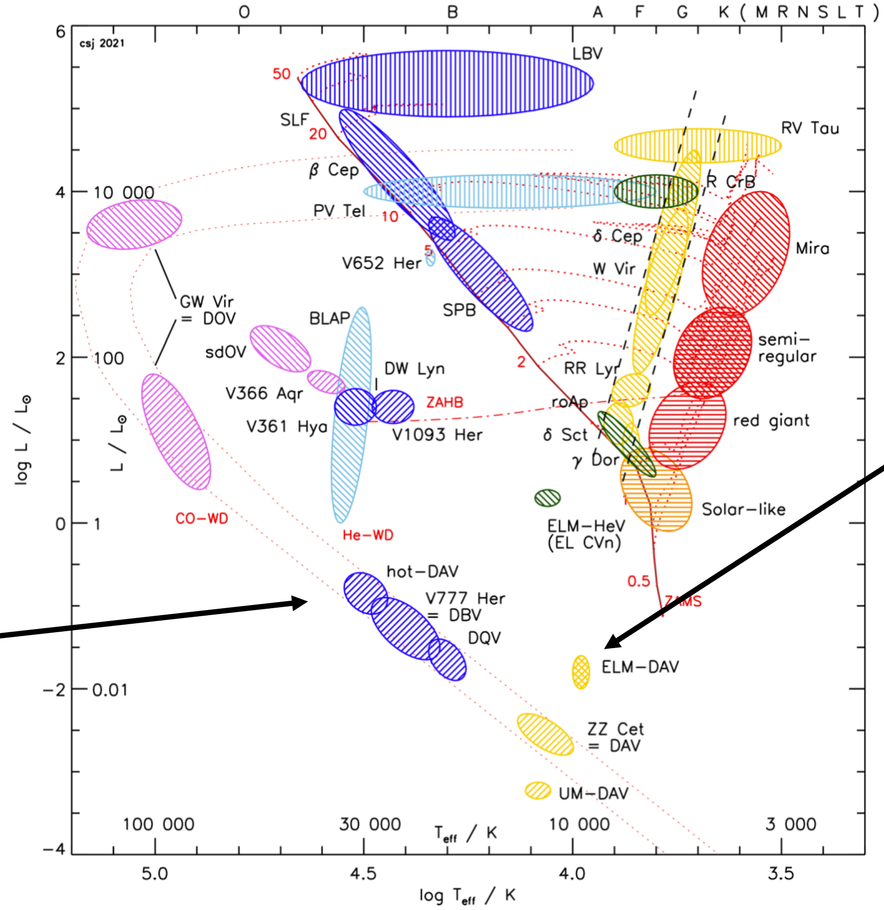
ELM-DAV white dwarfs

Extremely-low-mass (ELM) white dwarfs (He-core)
DA = H-dominant atmospheres (V=variable)

~2-100 min pulsations (g-modes), an extension of the ZZ Ceti instability strip towards low masses (Van Grootel et al. 2013)

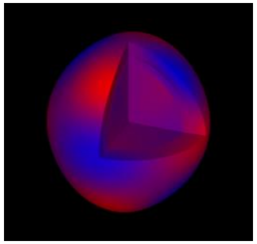
+ hot-DAV



See L. Antunes Amaral's talks

D. Kurtz/S. Jeffery

10th Meeting on Hot Subdwarfs
and Related Objects



Short-period hot subdwarf pulsators in TESS Southern hemisphere – new and old friends

Valérie Van Grootel

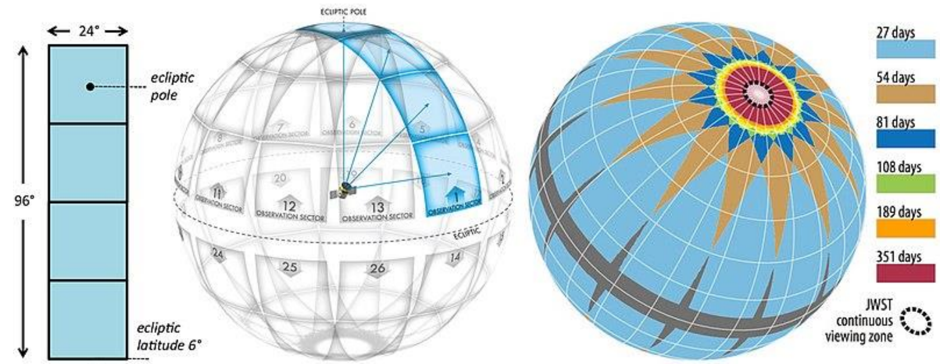
(STAR Institute, ULiège, FNRS)

A. Baran R.H. Østensen D. Kilkenny H. Worters

S. Charpinet, B. Barlow, & TASC WG8 members

The TESS space mission

4 wide-angle cameras (10cm lenses)
2:1 lunar synchronuous orbit



Primary mission (2018 - 2019)
- Cycles 1 (south) and 2 (north)
- 2-min cadence data (SC)

Extended mission (2020 - 2022)
- Cycles 3 (south) and 4 (north+ecliptic)
- 2-min and 20s (USC) cadence data

1 cycle = 13 sectors of ~27 days each (= 2 TESS orbits)

Currently in cycle 4

TASC WG8: Evolved compact stars with TESS

~1300 hot subdwarfs observed in primary mission, ~3500 at the end of Cycle 4

Searching for sdBVp in TESS data

- This work: southern hemisphere (Cycle 1+ Cycle 3 + south ecliptic of Cycle 4)

- Importance of 20s cadence data (USC) for p-modes !

- Two independent searches for sdBVp pulsators, by pre-withening technique:

- A. Baran (method: Baran & Koen 2021)
- V. Van Grootel/S. Charpinet with FELIX tool (Charpinet et al. 2010, Zong et al. 2016)

1/ automated search for variations >1500 muHz down to SNR=4.8
2/ individual check if consistent with p-modes pulsations (usually, it’s not ☺)

+ check with spectra we have well a hot subdwarf (R. Østensen, D. Kilkenny, H. Worters, P. Németh,…)

RESULTS:

40 p-mode pulsators, confirmed to be hot subdwarfs:

- 17 new detections (10 in SC and 7 in USC)
- 23 known sdBVp (1 in SC and 22 in USC)

New detections

- 7 new sdBVpg (hybrids):
  - TIC 10011123 (3 g-modes and 1 p-modes), 1-sector (S33)
  - TIC 143699381 (3 g- and 2 p-), 1 sector (S13)
  - TIC 366656123 (1 g- and 1 p-), 1 sector (S44)
  - TIC 408147637 (1 g- and 3 p-), 1 sector (S38)
  - TIC 241771689 (6 g- and 35 p-) – seismic modeling potential ! (S38)
  - TIC 273218137 (3 g- and 3 p-), 2 sectors (S10, S37)
  - TIC 169285097 (Sahoo et al. 2020), 37 g- and 6 p-modes, seismic modeling potential ! (S2, S29) (see sdOB9)

- 7 sdBV p-modes only, including 2 with seismic modeling potential (11 p-modes for TIC 295046932 (S39), 10 modes for TIC 409644971 (S13, S39)

- 1 new sdO with p-modes (TIC 387107334), S13. Adding to the three known in the field.

- 4 sdV, need better spectra to determine O/B types

Old friends

- Better data for 4:
  - HE 0230–4323 (Kilkenny et al. 2010), S3
  - EC 09582–1137 (Randall et al. 2009), S35
  - TIC 69298924 (Baran et al. 2011), S44,S45,S46
  - CS 1246 (Barlow et al. 2010, 2011), S38 – TESS detects a g-mode pulsation, so this star is likely a hybrid one.
- No significant improvement for 17:
  - PB8783, sdOV (Van Grootel et al. 2014)
  - EC 03089-6421, sdOV (Kilkenny et al. 2017, 2019);
  - PG 1047+003, TIC 60257911, PG 1315-123, V1405 Ori (K2 data, Reed et al. 2018, 2019, 2020);
  - EPIC 211779126 (K2; Baran et al. 2017)
  - EC 01541-1409 (Randall et al. 2014);
  - EC 11583-2708 (Kilkenny et al. 2006)
  - EC 21281-5010 Kilkenny et al. 2019;
  - PG 1241-084 (Baran et al. 2018);
  - TIC 322009509 (Barlow et al. 2009),
  - EC 20117-4014 (Randall et al. 2006),
  - TIC 366399746 (Boudreaux et al. 2017),
  - 2M 0415+0154 (Oreiro et al. 2009)
  - EC 11275-2504 (Kilkenny et al. 2019)
  - V1835 Ori (Baran et al. 2011)

Conclusions

- TESS is useful and efficient at finding new short-period variables, including a new sdOV.
- Many of these new variables are hybrid pulsators
- Several of these new detections have asteroseismic modeling potential, including 2 hybrid.
- Concerning old friends, 4 have more detected frequencies (but doesn’t make them seismic modeling “candidates”), and 17 have no significantly improved pulsation spectra.

Conclusions

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…back at ground-based telescopes to obtain better data on new short-period variables discovered by TESS !!!