GD1212

KIC11911480: Probing deep into the interior of a pulsating white dwarf star

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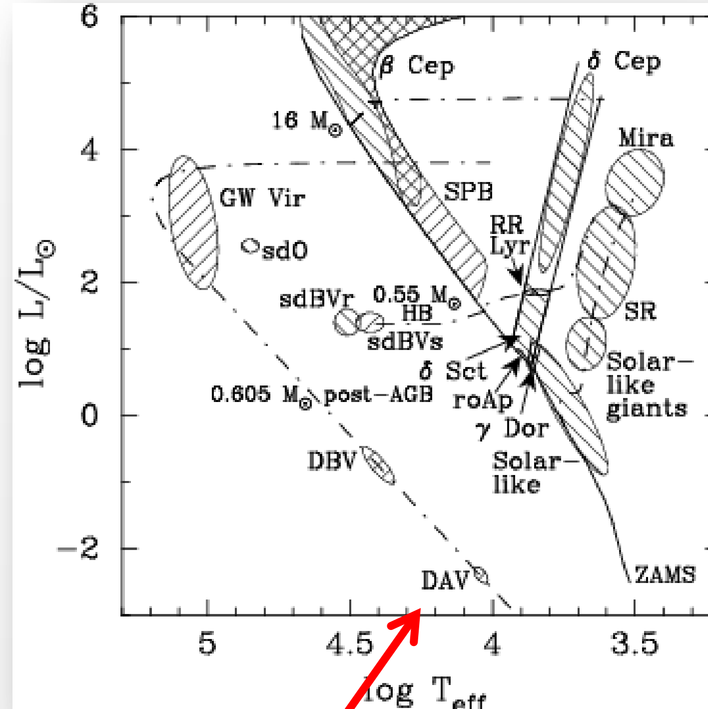
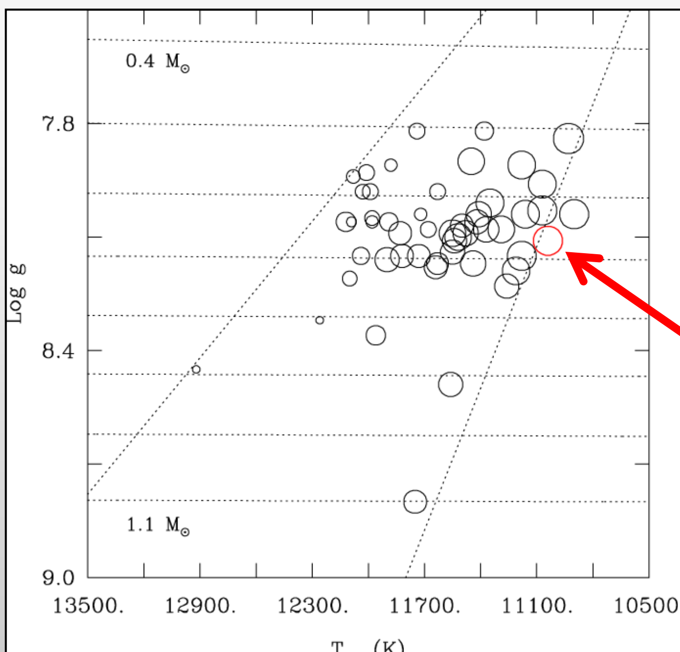
ZZCeti Instability strip

- Why GD1212?
  - We have data
  - Simplest of the “complicated” DAVs



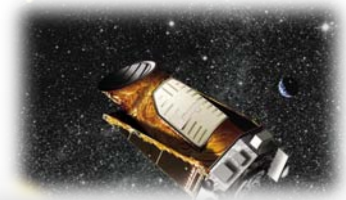
Handler et al.(2008)

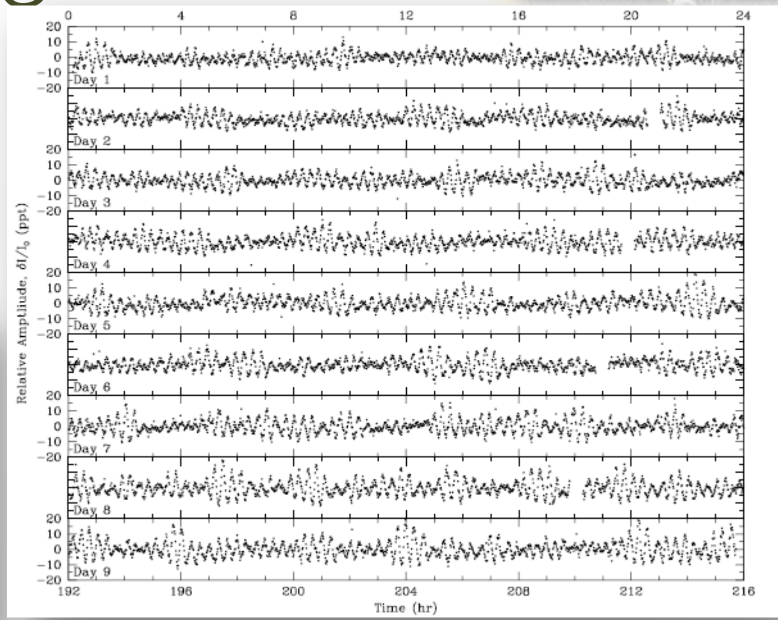


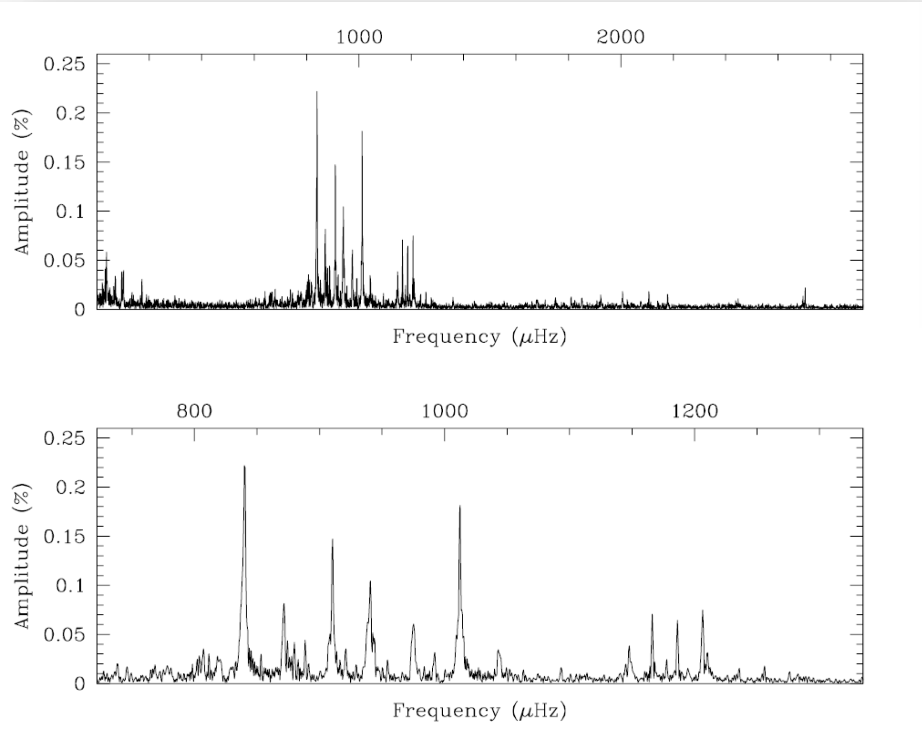
Fontaine et al.(2008)

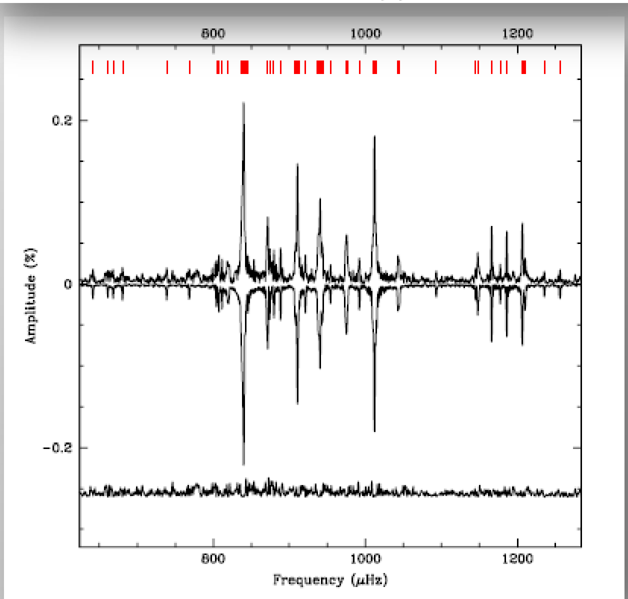
Light curve processing

- Kepler K2 test run
  - 9 days









See also Hermes et al. 2014 and poster 65

Table 3: Final list of significant frequencies above 4σ for the 9d run. Bracketted frequencies may be unsure.

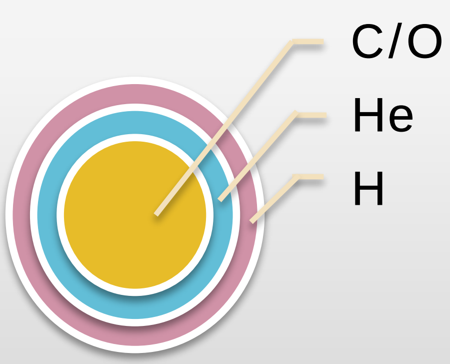
Id.	Frequency (μHz)	σ_f (μHz)	Period (s)	σ_P (s)	Amplitude (%)	σ_A (%)	Phase (s)	σ_{Ph} (s)	S/N	Comments
f_{048}	20.6931	0.1402	48325.2773	327.3270	0.0301	0.0059	0.2202	0.0270	5.1	f1-f21
f_{054}	25.1616	0.1624	39743.1002	256.5863	0.0259	0.0059	0.5367	0.0313	4.4	f42-f21
f_{032}	32.4511	0.1046	30815.5820	99.2811	0.0402	0.0059	0.5069	0.0200	6.8	f7-f3
f_{015}	36.4081	0.0654	27466.4281	49.3249	0.0641	0.0059	0.5414	0.0063	10.9	
[f_{027}]	[38.1695]	[0.0965]	[26198.9033]	[66.2164]	[0.0433]	[0.0059]	[0.9670]	[0.0095]	[7.4]	f2-f10?; blend with f15
[f_{046}]	[40.1084]	[0.1342]	[24932.4336]	[83.4495]	[0.0310]	[0.0059]	[0.1985]	[0.0259]	[5.3]	f4-f7?; blend with f15
f_{057}	64.7091	0.1666	15453.7724	39.7892	0.0238	0.0056	0.4011	0.0335	4.3	f4-f6 ?
f_{049}	69.8447	0.1361	14317.4751	27.8906	0.0292	0.0056	0.6677	0.0139	5.2	f2-f5 ?
f_{053}	71.4853	0.1494	13988.8825	29.2276	0.0265	0.0056	0.6006	0.0152	4.8	f4-f1 ?
f_{036}	94.5555	0.1028	10575.8013	11.5015	0.0371	0.0054	0.5161	0.0213	6.9	f2-f31 ?
[f_{047}]	[100.2178]	[0.1265]	[9978.2649]	[12.5987]	[0.0303]	[0.0054]	[0.4270]	[0.0130]	[5.6]	f5-f1?; blend with f33
f_{033}	101.6019	0.1006	9842.3383	9.7465	0.0382	0.0054	0.5418	0.0103	7.1	f31-f21 ?
f_{044}	171.8924	0.1091	5817.5941	3.6936	0.0325	0.0050	0.7269	0.0241	6.5	f2-f1 ?
f_{069}	641.6091	0.1575	1558.5814	0.3826	0.0181	0.0040	0.0048	0.0433	4.5	
[f_{073}]	[661.4700]	[0.1769]	[1511.7843]	[0.4043]	[0.0172]	[0.0043]	[0.4423]	[0.0460]	[4.0]	several weak peaks around
[f_{072}]	[668.5275]	[0.1724]	[1495.8247]	[0.3858]	[0.0179]	[0.0043]	[0.3825]	[0.0442]	[4.1]	*; several weak peaks around
f_{065}	680.2633	0.1554	1470.0190	0.3358	0.0199	0.0044	0.0097	0.0395	4.6	
f_{064}	738.4715	0.1696	1354.1484	0.3110	0.0202	0.0048	0.8138	0.0390	4.2	
f_{061}	768.4389	0.1692	1301.3396	0.2866	0.0222	0.0053	0.9265	0.0354	4.2	*
f_{051}	803.9796	0.1447	1243.8127	0.2239	0.0272	0.0055	0.8632	0.0311	4.9	*
f_{035}	807.1185	0.1049	1238.9754	0.1611	0.0375	0.0055	0.1074	0.0233	6.8	*
f_{062}	811.5749	0.1788	1232.1722	0.2714	0.0220	0.0055	0.9186	0.0373	4.0	*
f_{021}	819.9788	...	1219.5437	...	0.0536	...	0.6406	...	9.6	
f_{001}	840.2108	...	1190.1774	...	0.2477	...	0.9957	...	43.4	
[f_{042}]	[844.8180]	[0.1201]	[1183.6868]	[0.1683]	[0.0333]	[0.0056]	[0.1009]	[0.0243]	[5.9]	*; may be linked to f1
f_{007}	871.6296	...	1147.2763	...	0.0866	...	0.7558	...	15.3	
f_{030}	874.0884	0.0992	1144.0491	0.1298	0.0406	0.0057	0.8393	0.0209	7.2	*
f_{023}	879.8627	0.0827	1136.5410	0.1068	0.0486	0.0057	0.0691	0.0166	8.6	
f_{029}	888.5756	0.0946	1125.3967	0.1198	0.0416	0.0055	0.7081	0.0191	7.5	
f_{004}	910.4287	...	1098.3837	...	0.1513	...	0.2721	...	28.7	
f_{031}	921.1198	0.0936	1085.6351	0.1103	0.0402	0.0053	0.6656	0.0197	7.6	
f_{005}	940.7330	...	1063.0009	...	0.1099	...	0.1926	...	21.1	
f_{060}	954.4381	0.1667	1047.7369	0.1829	0.0223	0.0052	0.4139	0.0354	4.3	*
f_{010}	975.3833	...	1025.2379	...	0.0740	...	0.5623	...	14.1	
f_{039}	992.3267	0.1021	1007.7326	0.1037	0.0358	0.0052	0.1987	0.0220	7.0	
f_{002}	1012.3867	...	987.7648	...	0.1846	...	0.5738	...	37.0	
f_{040}	1043.7635	...	958.0714	...	0.0348	...	0.6009	...	7.1	*
f_{076}	*1093.3840*	*0.1962*	*914.5918*	*0.1641*	*0.0162*	*0.0045*	*0.2470*	*0.0485*	*3.6*	probably higher S/N
[f_{071}]	[1145.0845]	[0.1522]	[873.2980]	[0.1161]	[0.0180]	[0.0039]	[0.9228]	[0.0453]	[4.7]	*; may be linked to f34
f_{034}	1147.7071	...	871.3025	...	0.0380	...	0.1785	...	9.9	
f_{011}	1166.2026	0.0367	857.4839	0.0270	0.0722	0.0037	0.7412	0.0109	19.3	
f_{059}	1177.7694	0.1146	849.0626	0.0826	0.0226	0.0036	0.2073	0.0350	6.2	*
f_{014}	1186.3756	0.0394	842.9034	0.0280	0.0643	0.0036	0.9827	0.0123	18.0	
f_{012}	1206.6583	...	828.7351	...	0.0715	...	0.7307	...	21.5	
[illegible]	1210.3198		826.2279		0.0329		0.4581		9.9	
f_{084}	2447.9299	0.1386	408.5084	0.0231	0.0111	0.0022	0.1256	0.0706	5.1	
f_{079}	2695.3338	0.1034	371.0116	0.0142	0.0136	0.0020	0.0507	0.0577	6.9	
f_{063}	2703.8441	0.0647	369.8438	0.0089	0.0217	0.0020	0.9544	0.0363	11.0	

13 independent modes extracted (for structure)

19 components of rotationally split multiplets (for rotation)

The forward method

- Comparison:
  - observed frequencies
  - Theoretical frequencies from static, parameterized models



T_{eff}	Effective temp.
log g	Surface gravity
q_H	H layer mass
q_{He}	He layer mass
Core comp.	Homogeneous C-O mix
Pf_1	Parameterized param. for the chemical profile at H/He transition
Pf_2	Parameterized param. for the chemical profile at He/C-O transition
Conv.	Convective efficiency (MLT)

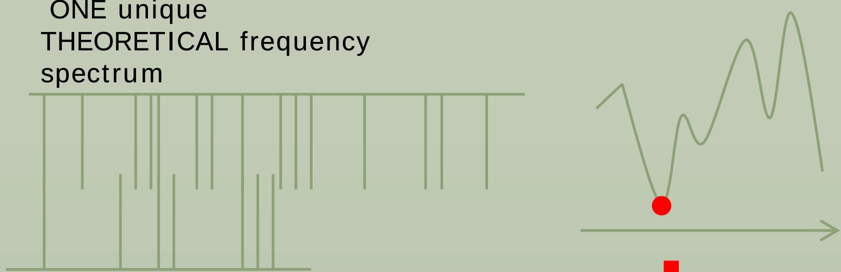
TECHNIQUE: DOUBLE-SCHEME OPTIMISATION

T_{eff}, log g, q_H, q_{He}, core comp., Pf_1, Pf_2,...

Using a multimodal optimizer based on a genetic algorithm

ONE unique THEORETICAL model

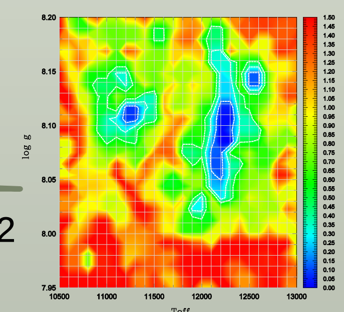
ONE unique THEORETICAL frequency spectrum



The OBSERVED frequency spectrum

Mode Id.

- **An optimal model:** *T_{eff}, log g, q_H, q_{He}, core comp., Pf_1, Pf_2*



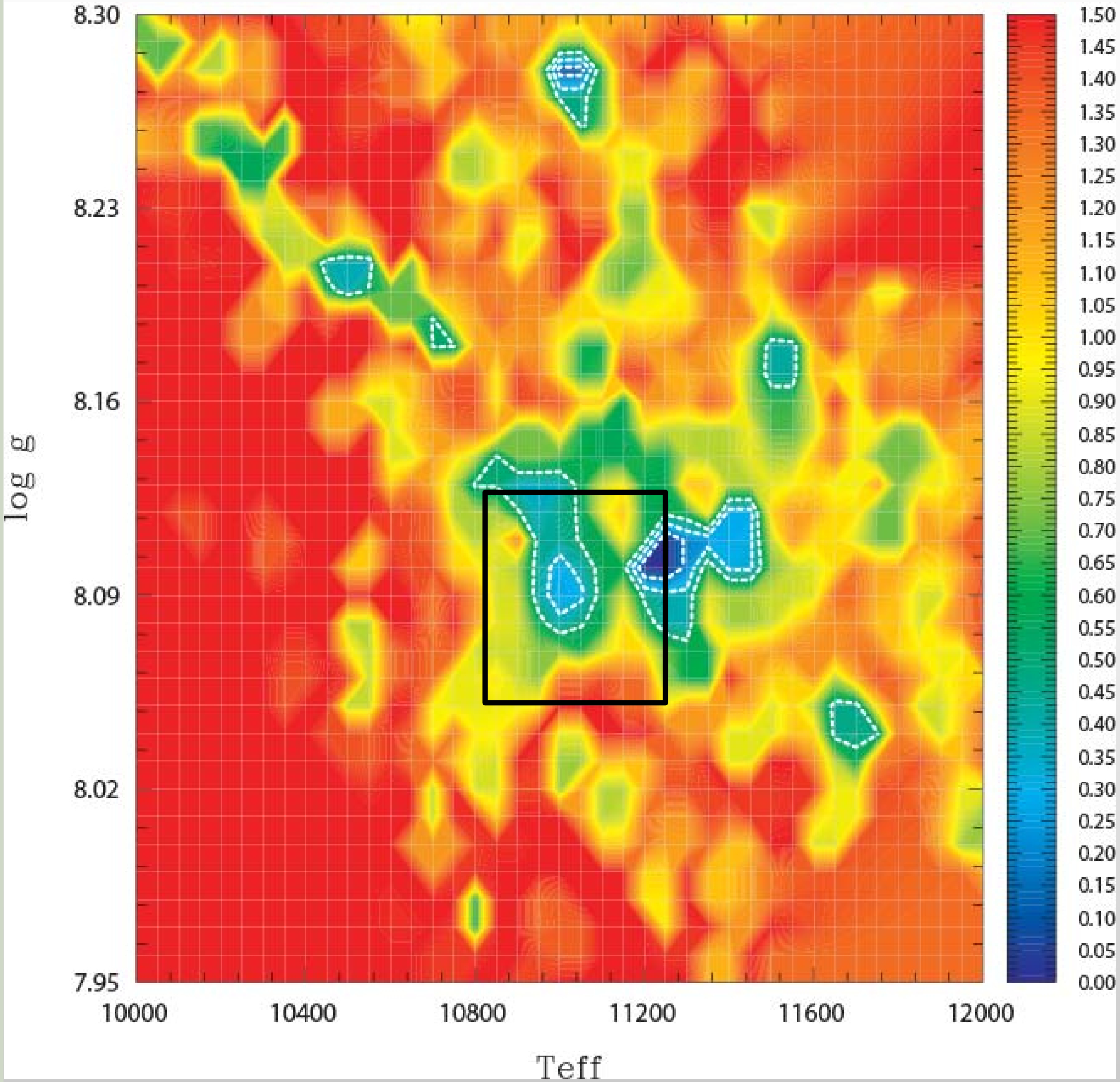
Merit function S^2

What can we infer?

- Independent measure of:
  - Surface gravity (Mass),
  - Temperature,
  - Layering: D(H), D(He)

- Extra:
  - Bulk core composition
  - Internal rotation profile

Solution: Projection log g –T_{eff} plane



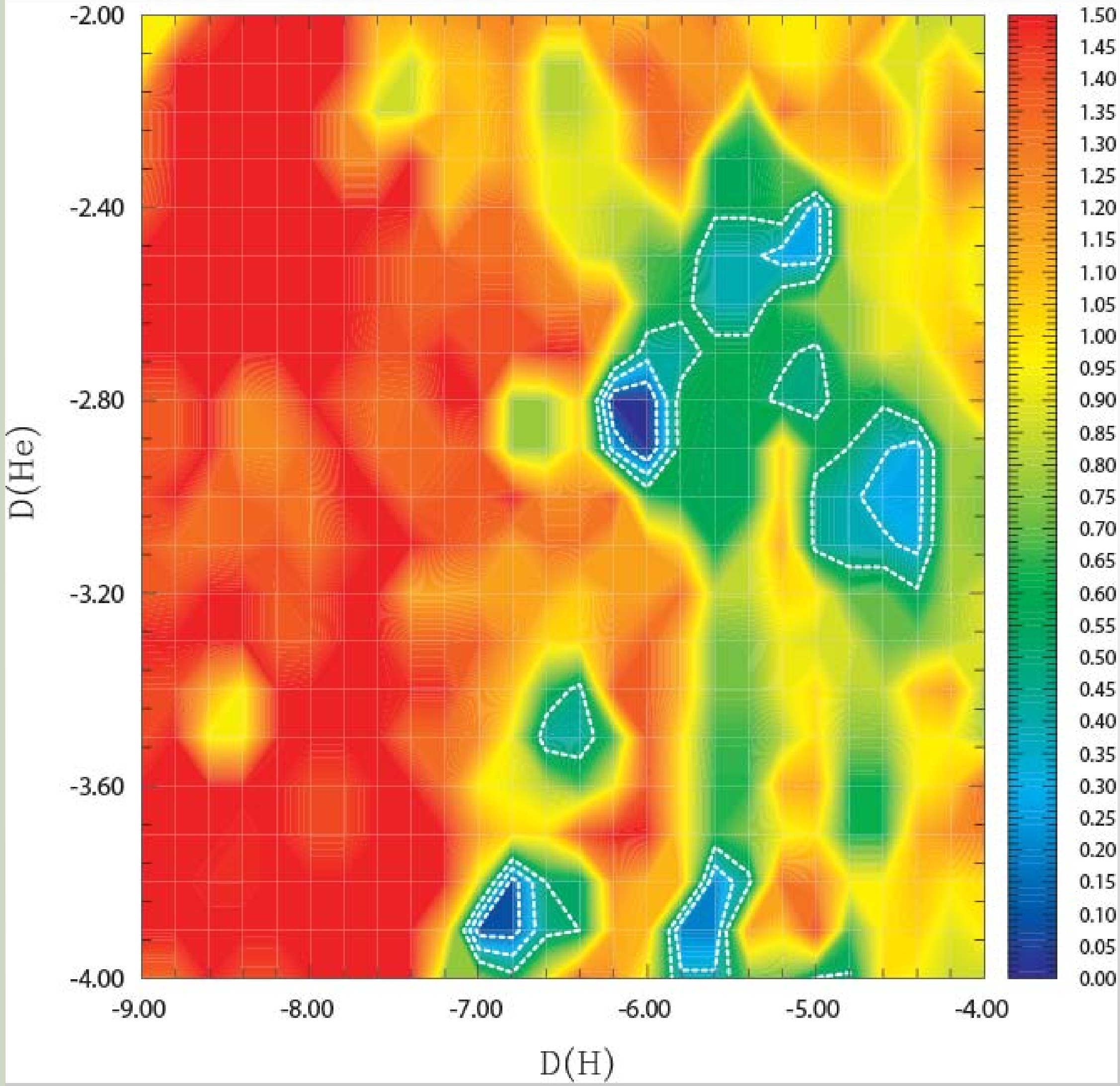
Spectroscopic solution:
T_{eff} = 11,035 ± 194 K
Log g = 8.08 ± 0.05

Sismic solution:
T_{eff} = 11,244 K
Log g = 8.10 (0.65 $M_{\odot}$)

Error estimate:
200 K
0.01 dex

Color scale -> log S^2

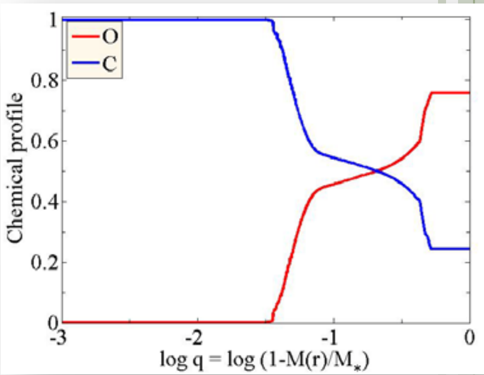
SOLUTION: PROJECTION D(H) – D(HE) PLANE



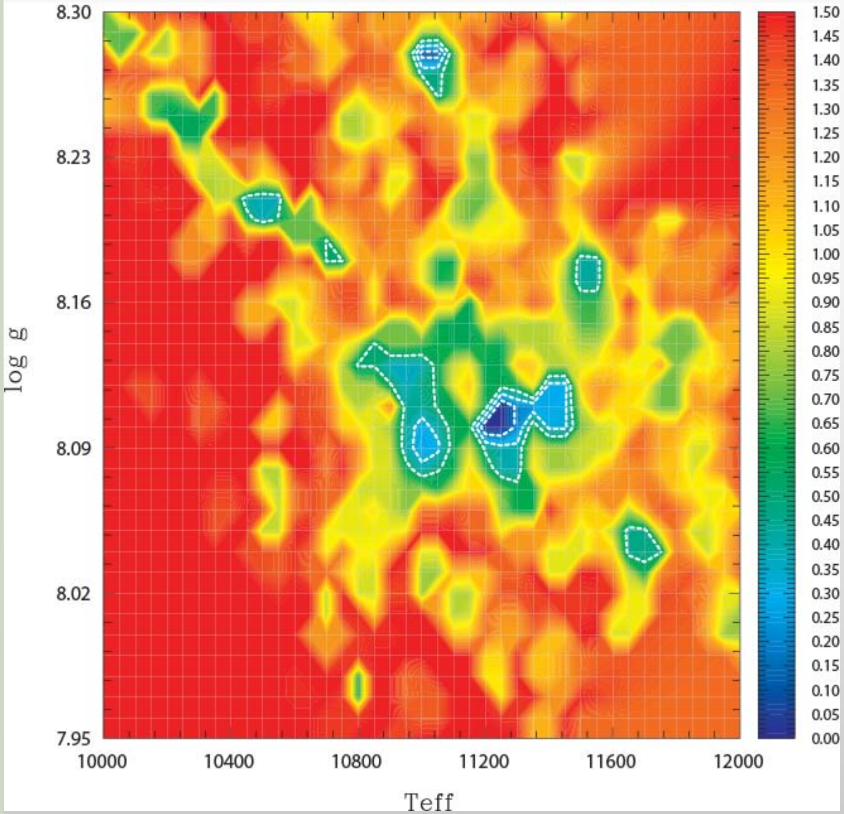
Sismic solution:
D(H) = -6.04
D(He) = -2.82

Color scale -> log S^2

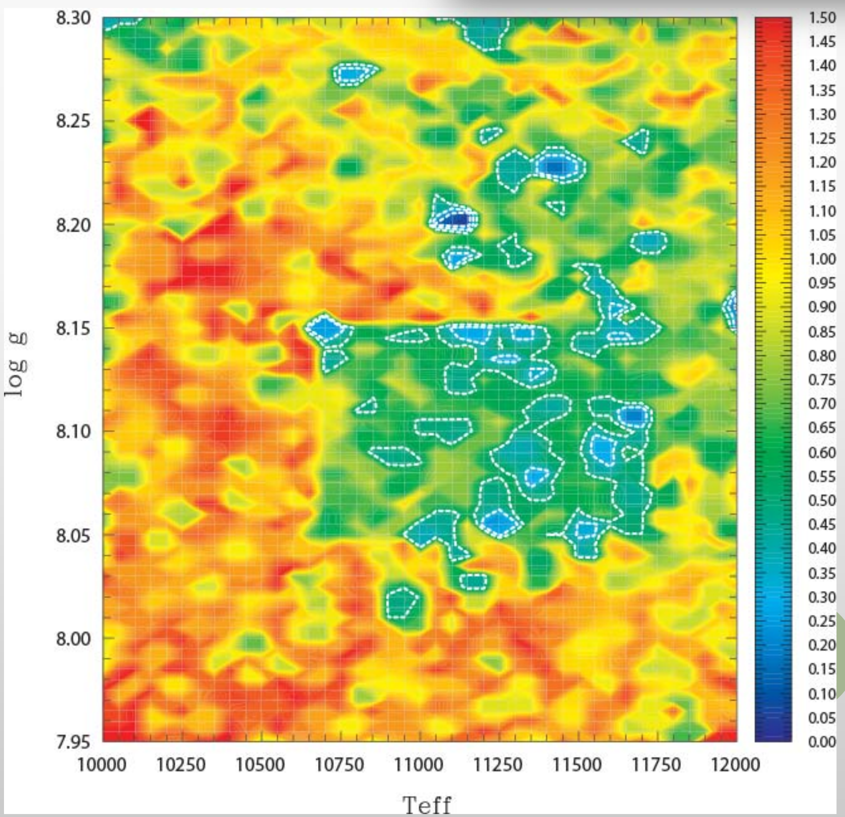
Homogeneous VS non-homogeneous core



- S^2 = 28

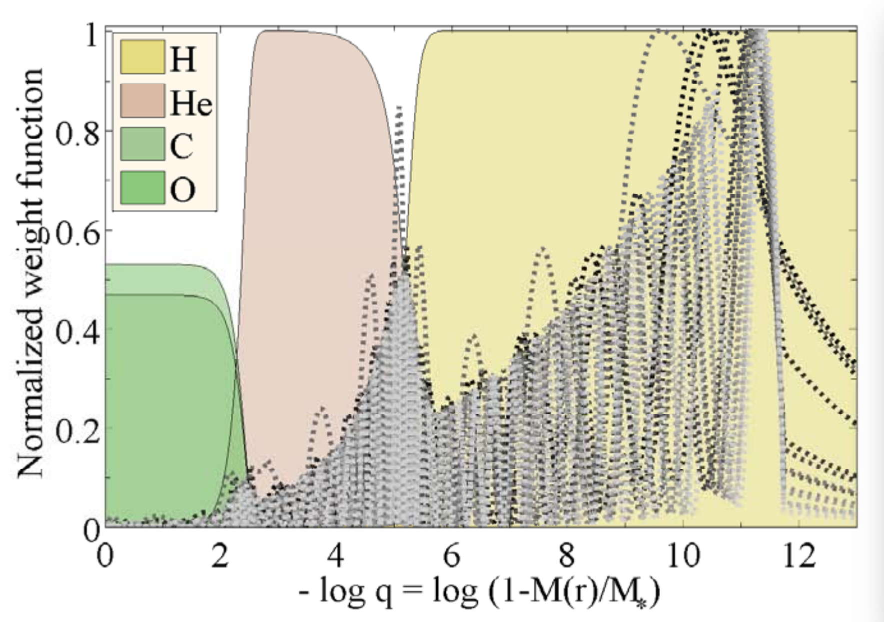


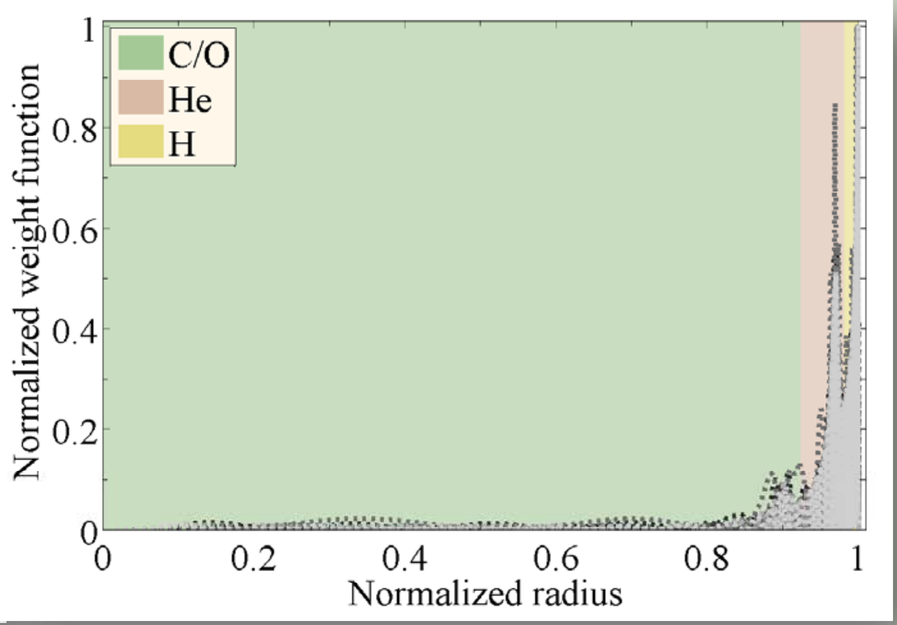
S^2= 252



WHICH PARTS OF THE STAR CONTRIBUTE THE MOST TO THE PULSATIONS?

- Weight functions:
  - Determination of the bulk core composition

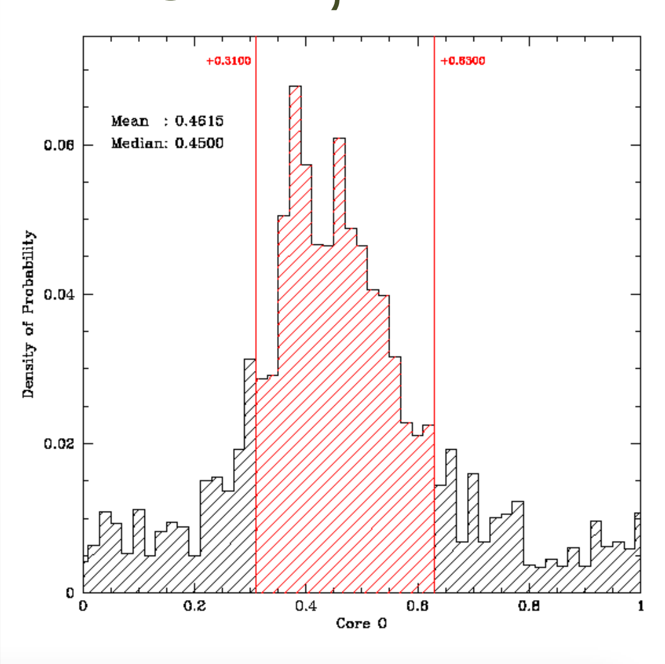


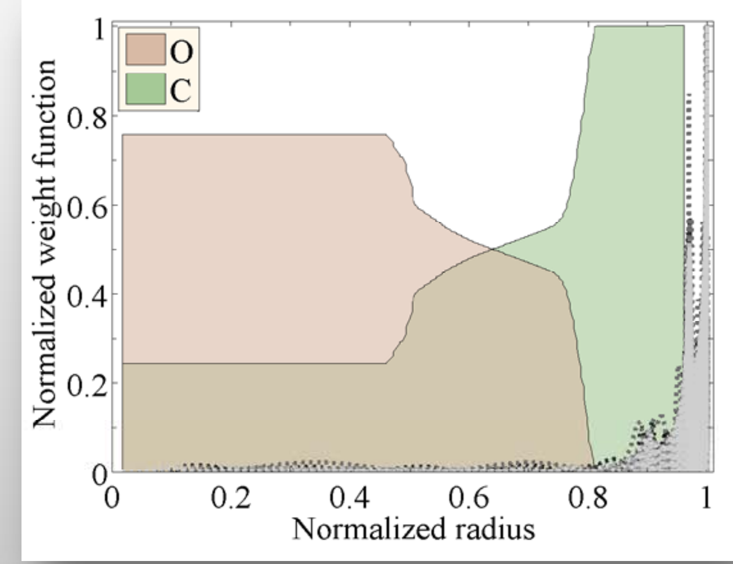


- C/O= 47-53%

Compared to evolutionary model, where do we stand?

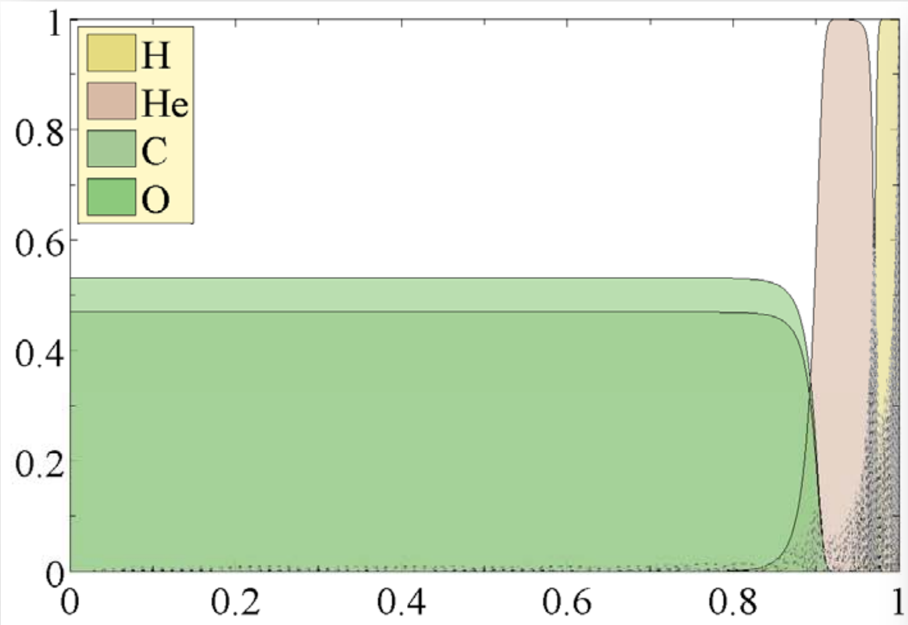
- What we find:
  - C/O= 47-53%
- Compared to profiles from Salaris et al. (2010)
  - C/O = 43-58%

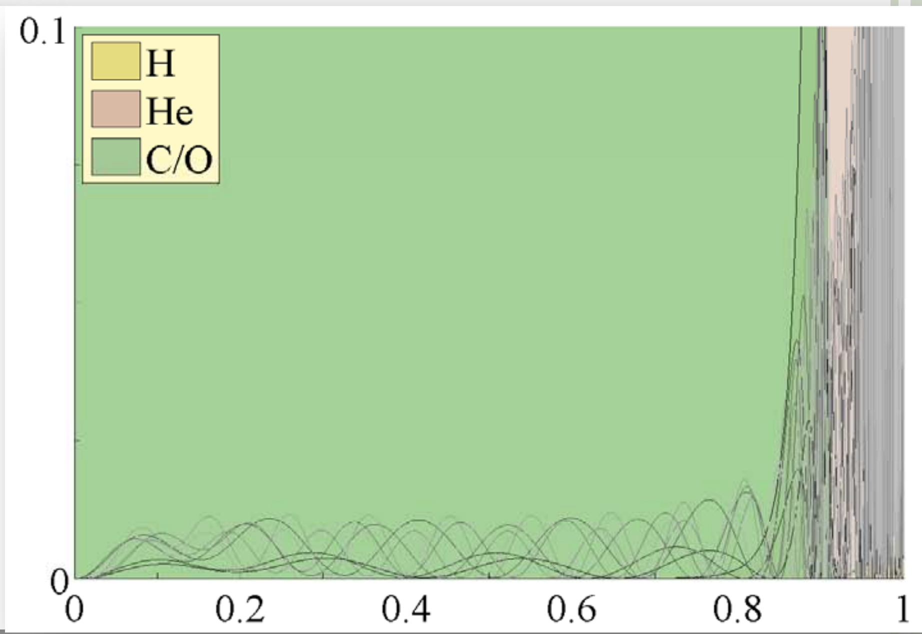




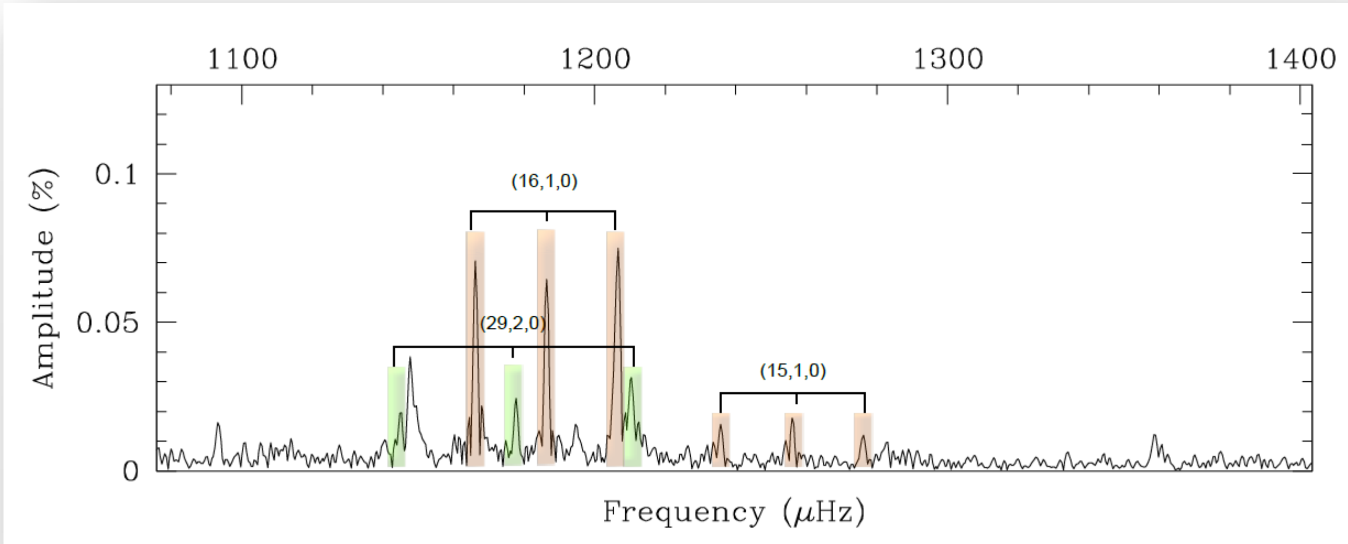
GD1212: Rotation kernels

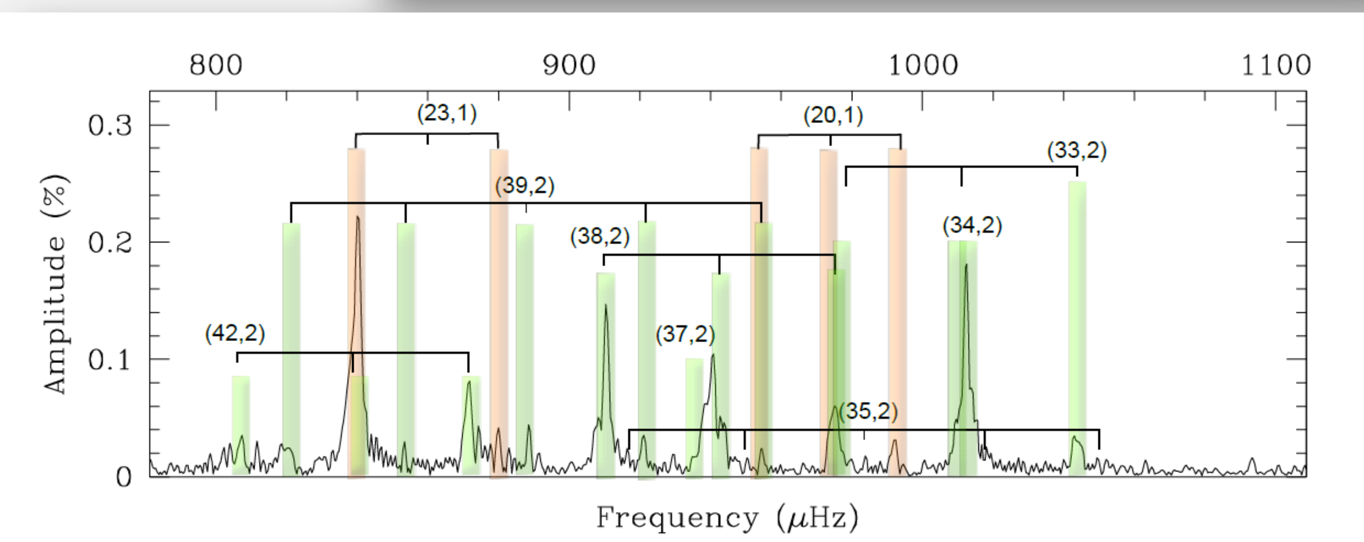
- Going deep into the interior





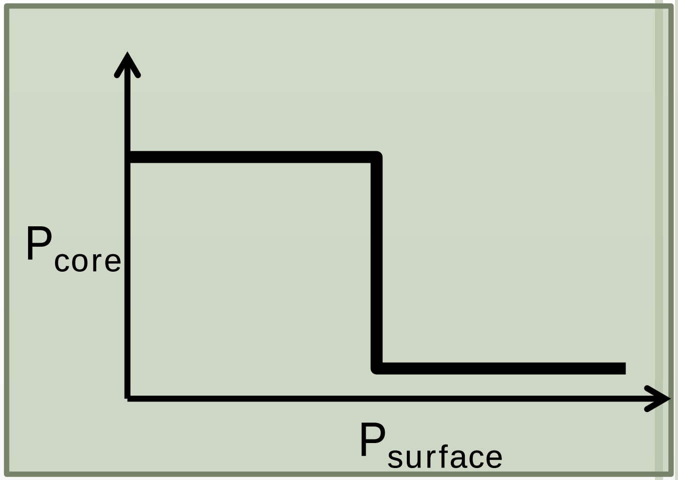
GD1212: ROTATIONAL SPLITTINGS

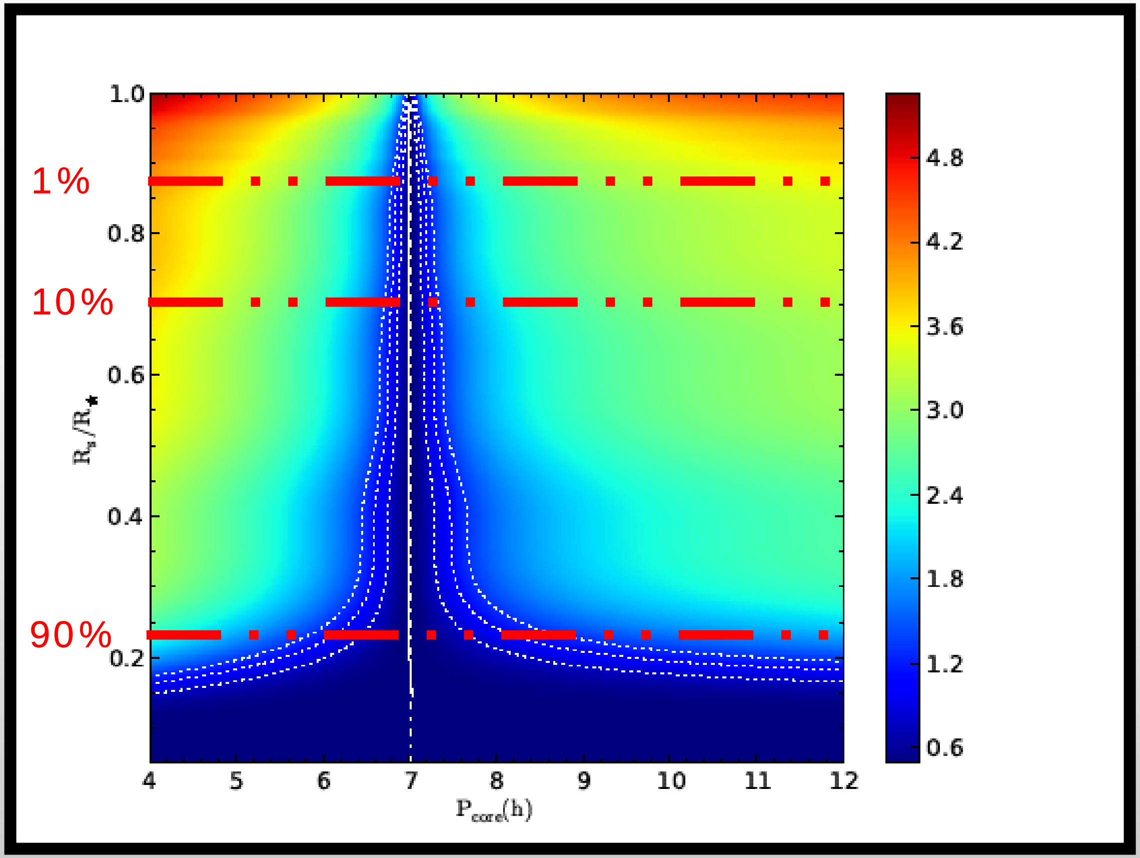


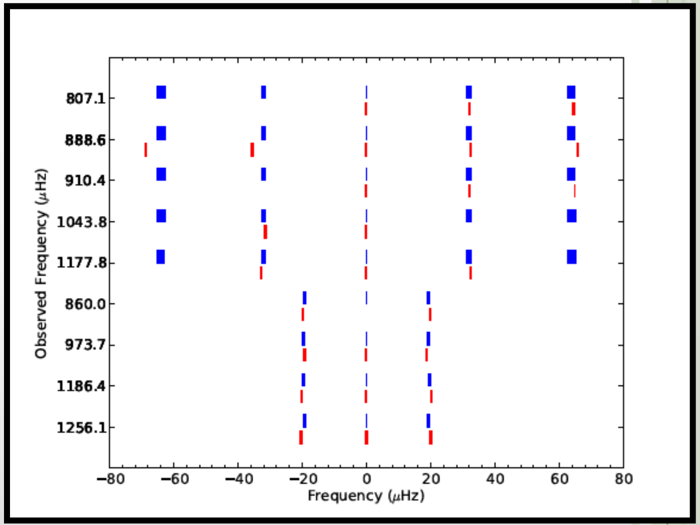


INTERNAL ROTATION PROFILE

- Solid-body rotation test

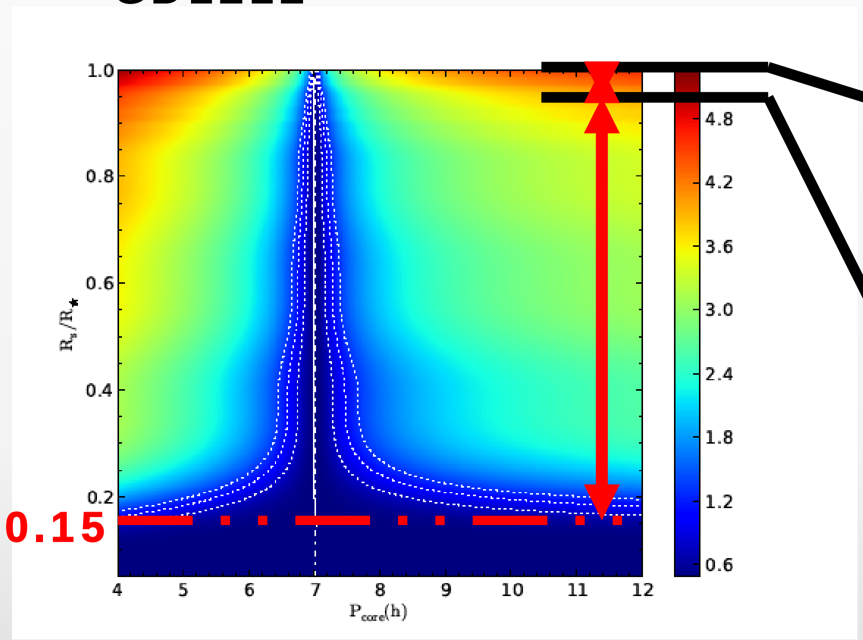




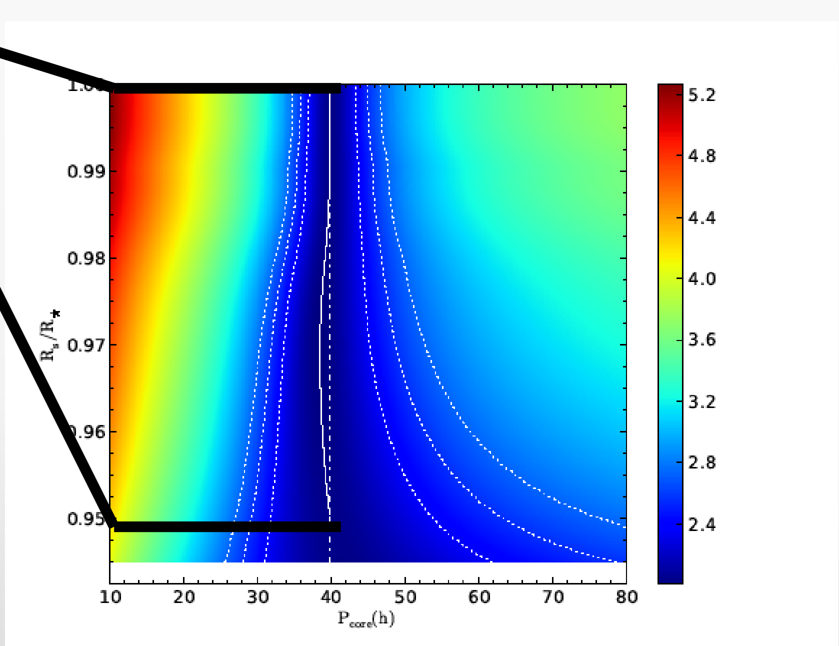


How does it compare to other ZZCeti?

GD1212



R548



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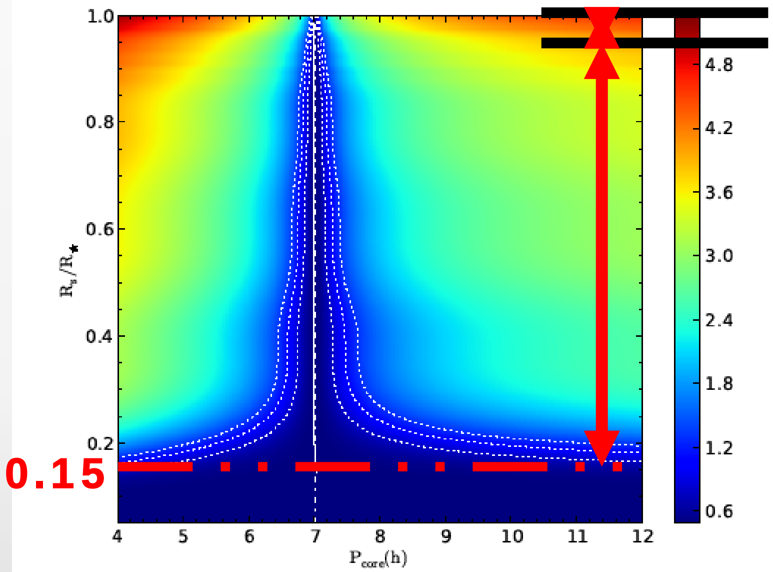
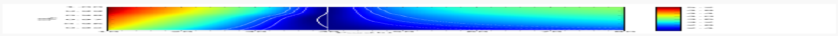
GD1212



R548



CONCLUSION

- IT WORKS!!
- We have been able to determine for GD1212:
  - Mass (Surface gravity)
  - Temperature
  - Chemical stratification: H/He layering
- Extra:
  - Bulk core composition
  - Internal rotation profile
- Future prospects:
  - Analysis of other Kepler 1-2 WDs
    (See Greiss et al. Poster 6)