سانتا باربرا
2011

TDC on solar-like stars

A. Grigahcène, M.-A. Dupret,
M. Gabriel, R. Scuflaire
and R. Garrido

A long outstanding problem

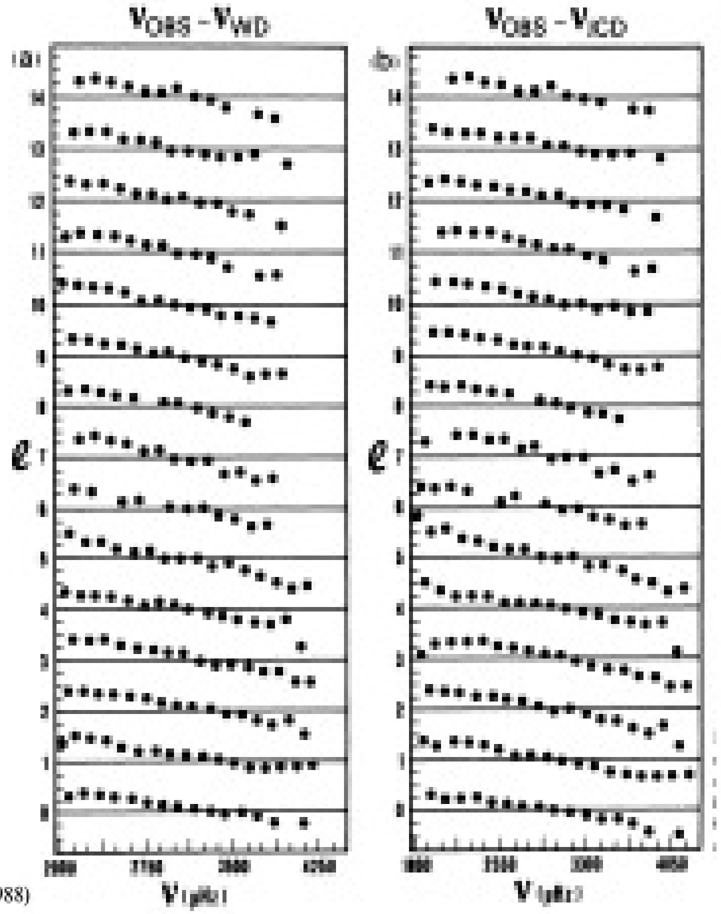
………

Astron. Astrophys. 130, 389–396 (1984)

The first comparisons of these observations with the theoretical predictions (see Christensen-Dalsgaard and Gough, 1980, 1981; Ulrich and Rhodes, 1982, 1983; Shibahashi and Osaki, 1981; Shibahashi et al., 1983; Scuflaire et al., 1981, 1982; Gabriel et al., 1982) show a fairly good agreement, better than 1%, but also a significant discrepancy. We first thought that improvements in the physics could reduce the small gap between theory and observations. Models computed by Shibahashi et al. (1983) taking the

Influence of the equation of state on the solar five-minute oscillation

A. Noels, R. Scuflaire, and M. Gabriel



Astron. Astrophys. 200, 213–217 (1988)

How comparison between observed and calculated *p*-mode eigenfrequencies can give information on the internal structure of the Sun

W.A. Dziembowski[1,*], L. Paternó[2,3], and R. Ventura[3]

Model and Modal Effects

Model effects

- EOS: Mihalas et al. 1990; Rogers, Swenson, & Iglesias 1996
- Turbulen pressure:

Demarque et al. 2000, Straka et al. 2006

- ....

Modal effects

Balmforth et al. 1992

Rosenthal et al., 1999

Gabriel, M. 1996, 2000

Nordlund and Stein, Solar Oscillations and Convection. I. Formalism for Radial Oscillations

Reference:

Pijpers, F. P., Christensen-Dalsgaard, J., & Rosenthal, C. S., eds. 1997, SCORe '96: Solar Convection, Oscillations and their Relationship (Dordrecht: Kluwer)

- Near-surface effects correction

Kjeldsen et al. 2008

Time-Dependent Convection

Used formalism: Gabriel, 1996, Grigahcene et al. 2005
Applications:
Delta Scuti red edge
Gamma Doradus excitation mechanism
Dupret et al. 2004-2005, Grigahcene et al. 2005

Effects on Low order modes frequency

ℓ (1)	n (2)	f_{ad} (3)	Δf_{fc} (4)	$\Delta f_{\delta F_c}$ (5)	$\Delta f_{\delta p_t}$ (6)	$\Delta f_{\delta(p_t,e_2)}$ (7)	$\Im(\omega_{fc})$ (8)	$\Im(\omega_{\delta F_c})$ (9)	$\Im(\omega_{\delta p_t})$ (10)	$\Im(\omega_{\delta(p_t,e_2)})$ (11)
					δ Sct: Model 7 of Table 1, t_{dyn} = 3460 s					
0	1	1.631E+02	2.322E–02	2.321E–02	2.324E–02	2.322E–02	–6.449E–07	–7.699E–07	–9.807E–07	–8.291E–07
	4	3.125E+02	1.214E–02	–6.325E–03	–7.519E–04	–3.993E–03	–9.658E–05	–3.475E–05	–1.192E–04	–3.061E–05
1	–2	1.197E+02	2.765E–02	2.765E–02	2.765E–02	2.765E–02	–1.170E–09	–9.845E–10	–6.680E–10	–6.906E–10
	3	2.723E+02	9.861E–03	4.281E–03	6.390E–03	5.196E–03	–3.894E–05	–2.907E–05	–6.623E–05	–3.432E–05
2	–4	1.081E+02	1.372E–02	1.372E–02	1.372E–02	1.372E–02	–1.021E–09	–7.092E–10	–1.555E–10	–2.415E–10
	2	3.005E+02	7.918E–03	–4.078E–03	–1.708E–04	–2.358E–03	–6.793E–05	–3.305E–05	–8.948E–05	–2.932E–05
3	–5	1.205E+02	1.919E–02	1.919E–02	1.919E–02	1.919E–02	–2.942E–09	–2.611E–09	–1.329E–09	–1.364E–09
	2	3.172E+02	5.659E–03	–1.603E–02	–9.262E–03	–1.296E–02	–1.106E–04	–3.456E–05	–1.137E–04	–1.155E–05

Dupret et al. 2005

Time-Dependent Convection

Effects on High-order modes frequency: application to solar-like stars

Beta Hydri

- **Beta Hydri** (β Hyi, β Hydri) is a star in the constellation Hydrus.
- It is about 24.4 light years away from Earth. It is larger and slightly more massive than the Sun.
- At around 150 BC, this star was two degrees away from the southern celestial pole. It is currently the nearest relatively bright star to the southern pole.
- In 2002 Endl et al. inferred the possible presence of an unseen companion orbiting Beta Hydri as hinted by radial velocity linear trend with a periodicity exceeding 20 years. A substellar object with minimum mass of 4 Jupiter masses and orbital separation of roughly 8 AUs could explain the observed trend. If confirmed, it would be a true Jupiter-analogue, though 4 times more massive. So far no planetary/substellar object has been certainly detected.

Wikipedia

Global properties of beta Hyi

Table 1. Global parameters of β Hyi.

T_{eff}(K)	log g	log ($L/L_{\odot}$)	[Fe/H]	$R/R_{\odot}$	v sin i (km/s)	Ω(μHz)	*i*(deg)	θ_{LD}	π_p	Ref.
–	–	–	–	–	–	–	–	–	153 ± 7	(1)
5730	3.80	–	-0.33	–	–	–	–	–	–	(2)
5880 ± 100	4.5	–	-0.1	–	–	–	–	–	–	(3)
5830	4.3	–	-0.1	–	–	–	–	–	–	(4)
5727	3.8	–	-0.28	–	–	–	–	–	–	(5)
5750	3.75	–	-0.10	–	–	–	–	–	–	(6)
5860	4.0	–	0.0	–	–	–	–	–	–	(7)
5740	4.4	–	–	–	–	–	–	–	–	(8)
–	–	–	–	–	2 ± 1	–	–	–	–	(9)
5800 ± 100	–	–	-0.2	–	2 ± 1	≈ 45 days	–	–	–	(10)
–	–	–	–	–	–	–	–	–	133.78 ± 0.51	(11)
5775	–	–	-0.12 ± 0.04	–	–	–	–	–	–	(12)
–	–	–	–	–	–	–	–	–	–	(1)
5710 ± 29	–	–	–	–	–	–	–	–	–	(13)
5774 ± 52	–	–	–	–	–	–	–	–	–	(14)
5860 ± 70	4.05 ± 0.30	–	-0.11 ± 0.07	–	–	–	–	–	–	(15)
	–	0.603 0.54 ±	–	–	–	–	–	–	–	(16)
5772 ± 118	3.999 ± 0.098	–	7.43	–	–	–	–	–	–	(17)
5964 ± 70	4.02 ± 0.04	–	-0.03 ± 0.05	1.69 ± 0.05	–	–	–	–	–	(18)
5872 ± 44	3.952 ± 0.005	0.54 ± 0.01	-0.2	1.814 ± 0.017	3.3 ± 0.3	–	–	2.257 ± 0.019	–	(19)
–	–	–	–	–	–	65 days	$68^{\circ}{}^{+17^{\circ}}_{-52^{\circ}}$	–	–	(20)
–	–	–	–	1.809 ± 0.015	–	–	–	–	–	(21)
–	–	–	–	–	4.3	3.6 – 5.5	38° – 72°	–	–	(22)
5790 ± 80	3.843 ± 0.081	0.55 ± 0.02	-0.10 ± 0.07	1.89 ± 0.06	2.7 ± 0.6	–	–	–	–	(23)
5860 ± 63	4.04 ± 0.10	–	-0.07 ± 0.05	–	–	–	–	–	–	(24)

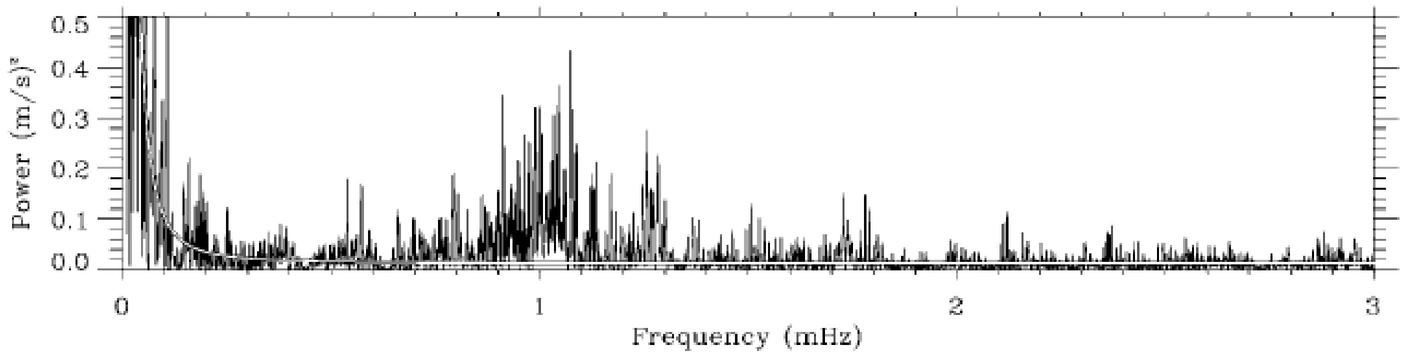
References: (1) Jenkins (1952) (2) Hearnshaw (1972); (3) Gehren (1981); (4) Andersen et al. (1984)
(5) Francois (1986) (6) Gratton & Ortolani (1986); (7) Proust & Foy (1988); (8) Abia et al. (1988);
(9) Dravins & Nordlund (1990); (10?) Dravins et al. (1993); (11?) Perryman & ESA (1997); (12) Favata et al. (1997);
(13) Blackwell & Lynas-Gray (1998); (14) di Benedetto (1998); (15) Castro et al. (1999); (16) Di Mauro et al. (2003);
(17) Allende Prieto et al. (2004); (18) da Silva et al. (2006); (19) North et al. (2007); (20) Karoff et al. (2007);
(21) Kjeldsen et al. (2008); (22) Hekker & Aerts (2010); (23) Bruntt et al. (2010); (24) Grigahcene et al. 2011

Solar-like pulsations

The Astrophysical Journal, 549:L105–L108, 2001 March 1

EVIDENCE FOR SOLAR-LIKE OSCILLATIONS IN β HYDRI

Timothy R. Bedding,[1] R. Paul Butler,[2] Hans Kjeldsen,[3] Ivan K. Baldry,[4] Simon J. O'Toole,[1] Christopher G. Tinney,[4] Geoffrey W. Marcy,[5] Francesco Kienzle,[6] and Fabien Carrier[6]



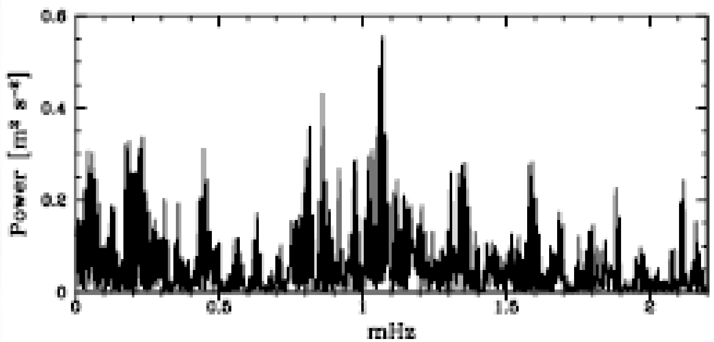
A&A 378, 142–145 (2001)
DOI: 10.1051/0004-6361:20011131

Astronomy & Astrophysics

Research Note

Solar-like oscillations in β Hydri: Confirmation of a stellar origin for the excess power⋆

F. Carrier[1], F. Bouchy[1], F. Kienzle[1], T. R. Bedding[2], H. Kjeldsen[3], R. P. Butler[4], I. K. Baldry[5], S. J. O'Toole[2], C. G. Tinney[5], and G. W. Marcy[6,7]



Asteroseismic modelling of the solar-type subgiant star β Hydri

I. M. Brandão*[1,2], G. Doğan*[3], J. Christensen-Dalsgaard[3], M. S. Cunha[1], T. R. Bedding[4], T. S. Metcalfe[5], H. Kjeldsen[3], H. Bruntt[3,6], T. Arentoft[3]

$l = 0$	$l = 1$	$l = 2$	$l = 3$
660.74 ± 2.43	...	...	...
716.68 ± 3.00	...	711.24 ± 2.13	...
774.79 ± 2.20	802.74 ± 1.69	769.97 ± 0.99	791.66 ± 1.35
831.86 ± 2.43	857.32 ± 0.86	825.86 ± 1.18	...
889.15 ± 1.23	912.91 ± 0.86	883.35 ± 0.89	...
946.11 ± 0.91	959.98 ± 0.89	939.97 ± 0.97	...
...	987.08 ± 0.87	...	...
1004.32 ± 0.86	1032.99 ± 0.86	999.40 ± 0.91	...
1061.66 ± 0.95	1089.87 ± 0.88	1057.00 ± 0.86	...
1118.67 ± 0.88	1147.35 ± 0.91	1115.20 ± 1.06	...
1177.76 ± 0.97	1203.54 ± 1.01	1172.98 ± 0.86	1198.16 ± 1.23
1235.31 ± 1.09	...	...	...
...	1320.42 ± 0.94	...	...
...	1378.92 ± 1.39	...	...

Table 3. Unidentified observed peaks with S/N ≥ 3.5.

ν (μHz)		
753.12 ± 1.57	1013.42 ± 1.50	1130.36 ± 1.30
828.70 ± 1.83	1025.80 ± 1.68	1134.32 ± 1.63
845.02 ± 1.61	1037.90 ± 1.63	1167.62 ± 1.10
868.60 ± 1.13	1065.12 ± 1.59	1256.78 ± 1.60
911.88 ± 1.76	1070.00 ± 1.43	1383.20 ± 1.75
1010.20 ± 1.91	1084.20 ± 1.57	1462.62 ± 1.92

Modeling

- Position on the HRD

Age (Gyr)	Method	Reference
8	Isochrones fitt	Hearnshaw(1972, 1973)
10	Models	Perrin(1977)
9	Models fitt	Cayrel de Strobel(1981)
9.5 ± 0.8	Models, ground base parallax	Dravins 1993
6.7	Models, Hipparcos parallax	Dravins 1998

Modeling

- Asteroseismology
  - DiMauro et al. 2003: 1.07 – 1.20 Mo
    5.2 – 6.1 Gyr
    2 Ro
  - Fernandes and Monteiro 2003: Y=0.25 – 0.30
    1.03 – 1.14 Mo
    0.87 – 1.31 Mo
    6.4 – 7.1 Gyr
  - Brandao et al. 2010: 1.03 – 1.11 Mo
    5.94 – 6.96 Gyr
    1.791 – 1.831 Ro
  - Quirion et al. 2010: 1.16 +- 0.02 Mo
    1.87 +- 0.01 Ro
    5.41 +- 0.89 Gy

Selecting the best model

- Initial grid of models: 0.75 ≤ M ≤ 2.5 Mo
  1.0 ≤ α≤ 2.5
  0.0 ≤ oversh ≤ 2.5

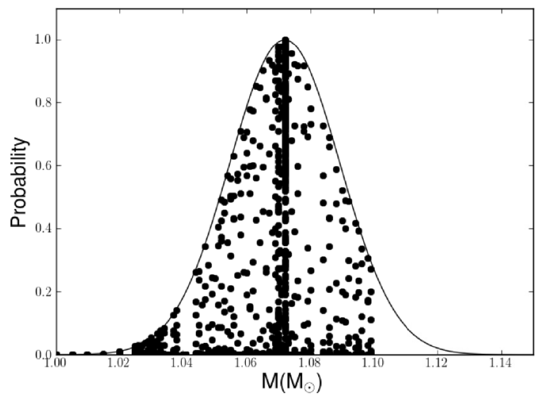
- Likelihood:

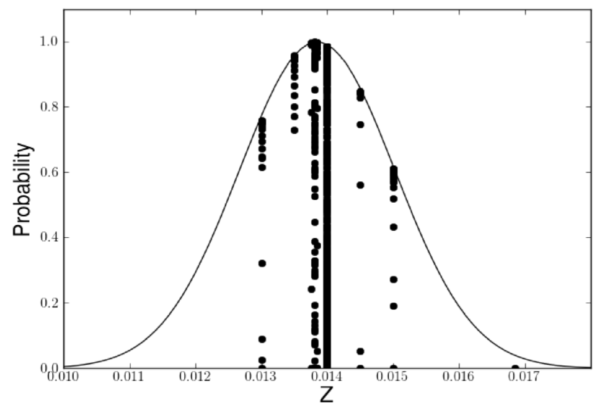
$$\mathcal{L} = \left(\prod_{i=1}^{N} \frac{1}{\sqrt{2\pi}\sigma_i}\right) \times \exp(-\chi^2/2),$$

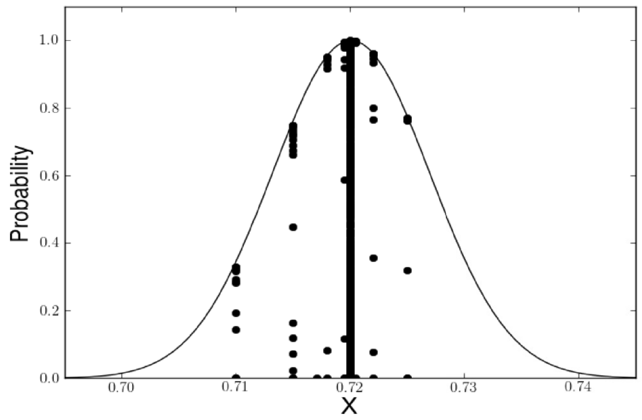
$$\chi^2 = \chi_\nu^2 + \chi_O^2$$

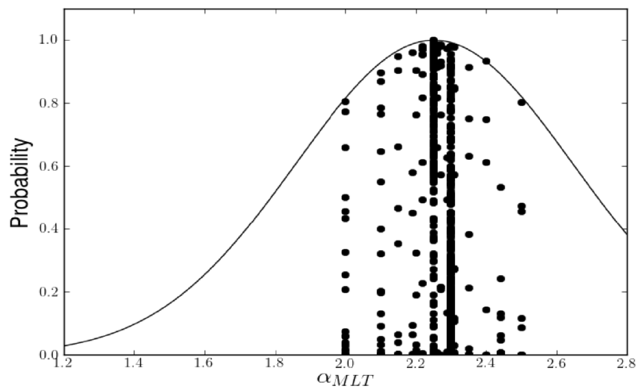
$$= \frac{1}{N_\nu}\sum_{i=1}^{N_\nu}\left(\frac{\nu_i^{theo} - \nu_i^{obs}}{\sigma_i^\nu}\right)^2 + \frac{1}{N_O}\sum_{j=1}^{N_O}\left(\frac{O_j^{theo} - O_j^{obs}}{\sigma_j^O}\right)^2$$

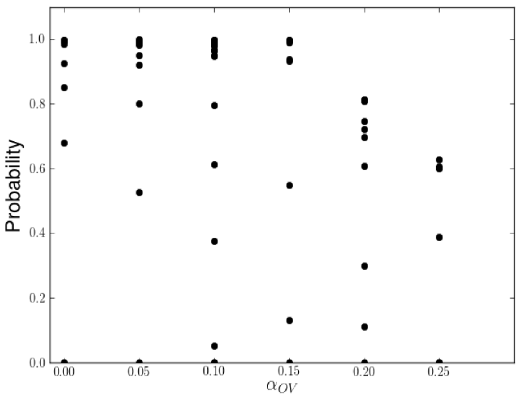
Results

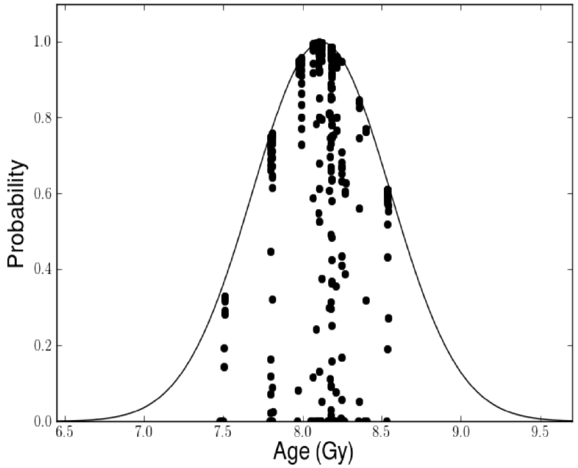

Probability
M(M$_\odot$)

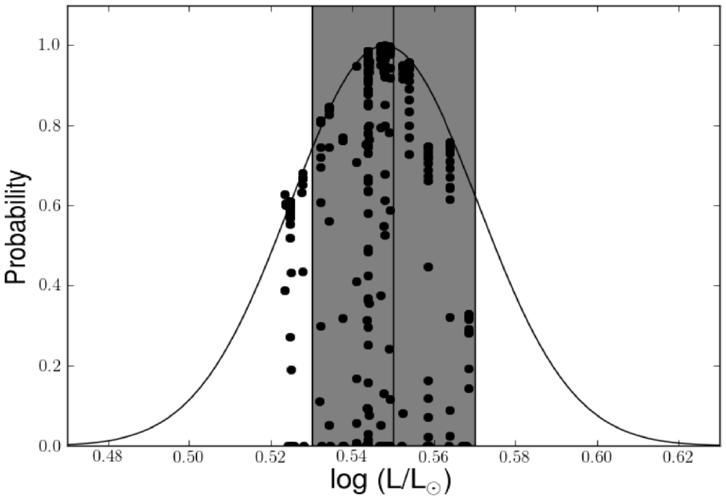

Probability
Z

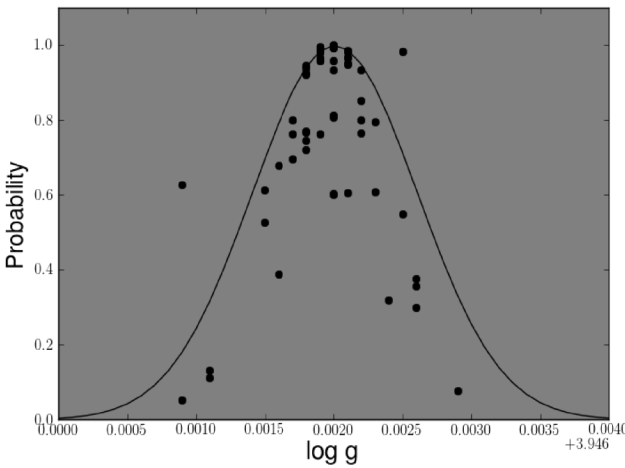

Probability
X


Probability
α_{MLT}

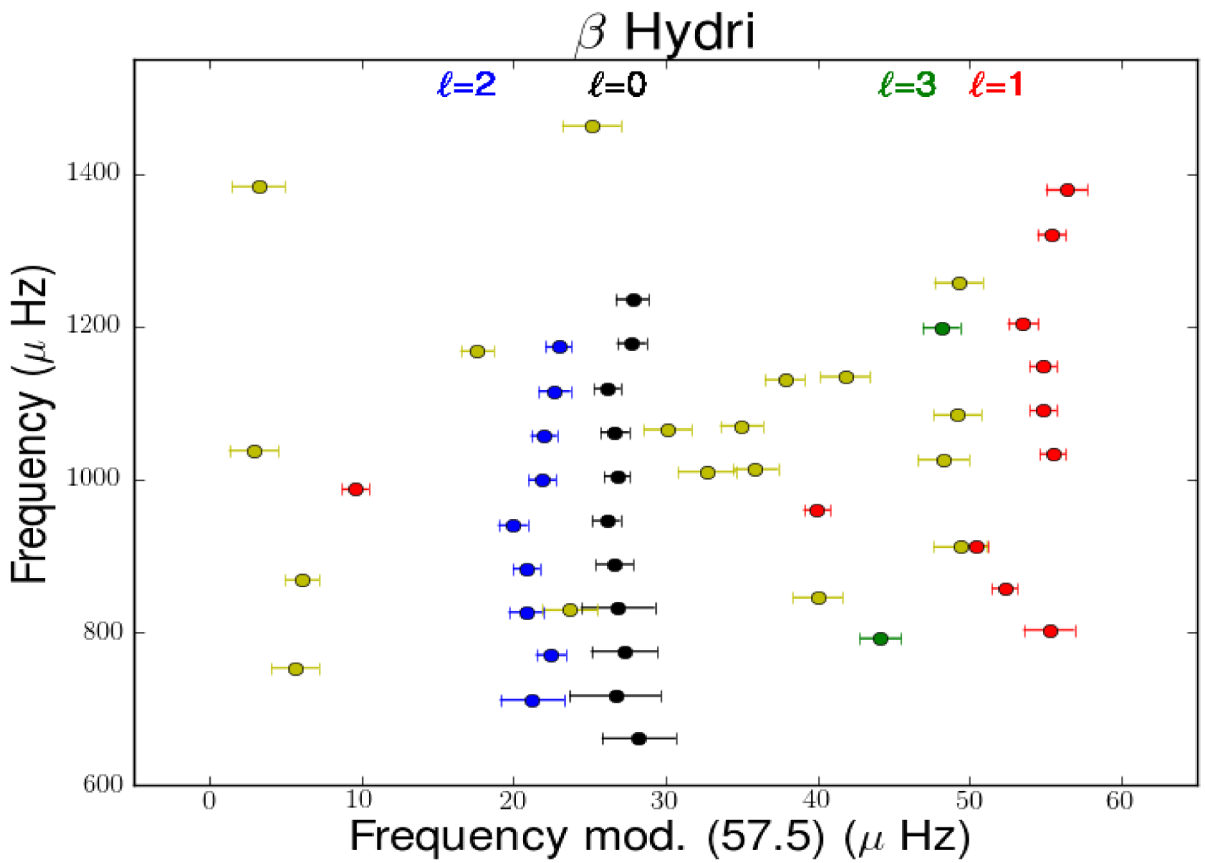

Probability
1.0
0.8
0.6
0.4
0.2
0.0
0.00 0.05 0.10 0.15 0.20 0.25
α_{OV}


Probability
1.0
0.8
0.6
0.4
0.2
0.0
6.5 7.0 7.5 8.0 8.5 9.0 9.5
Age (Gy)

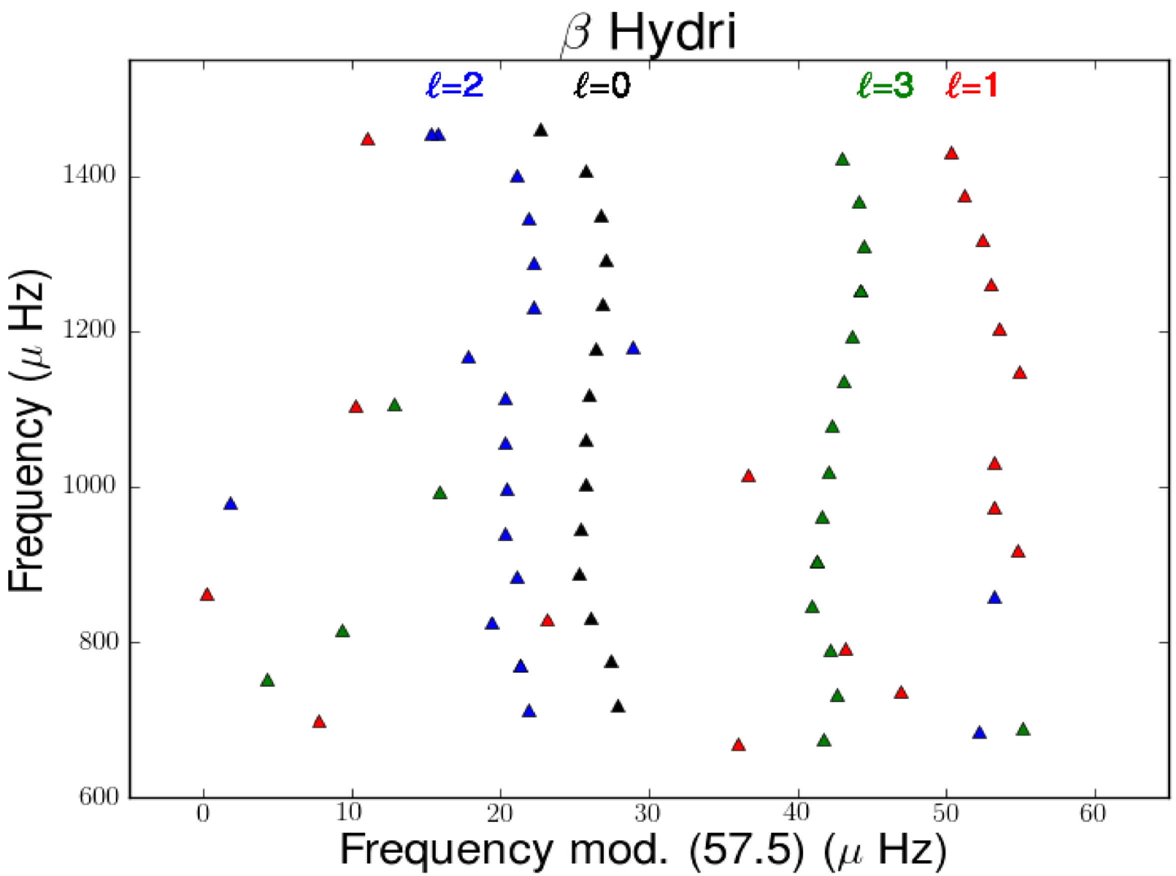

Probability
1.0
0.8
0.6
0.4
0.2
0.0
0.48 0.50 0.52 0.54 0.56 0.58 0.60 0.62
log (L/L$_\odot$)


Probability
1.0
0.8
0.6
0.4
0.2
0.0
0.0000 0.0005 0.0010 0.0015 0.0020 0.0025 0.0030 0.0035 0.0040
+3.946
log g

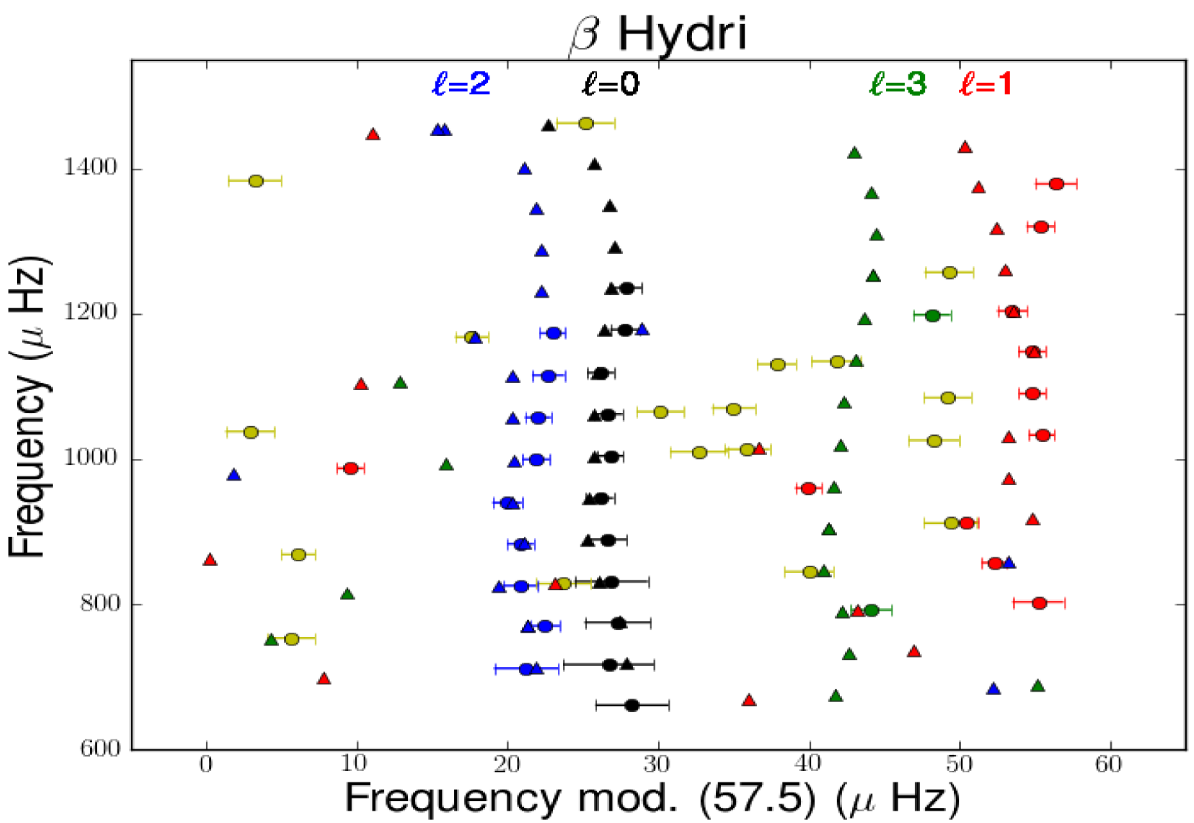
Echelle Diagram: obs.



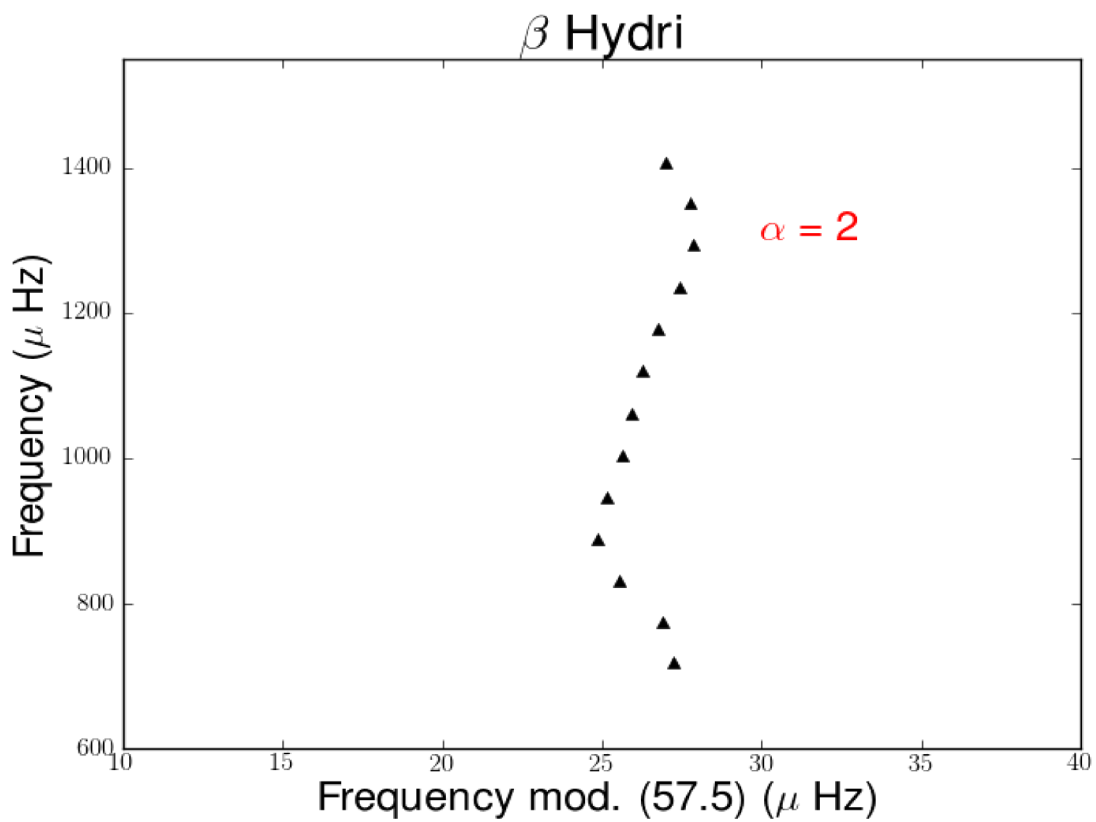
Echelle Diagram: Theor.



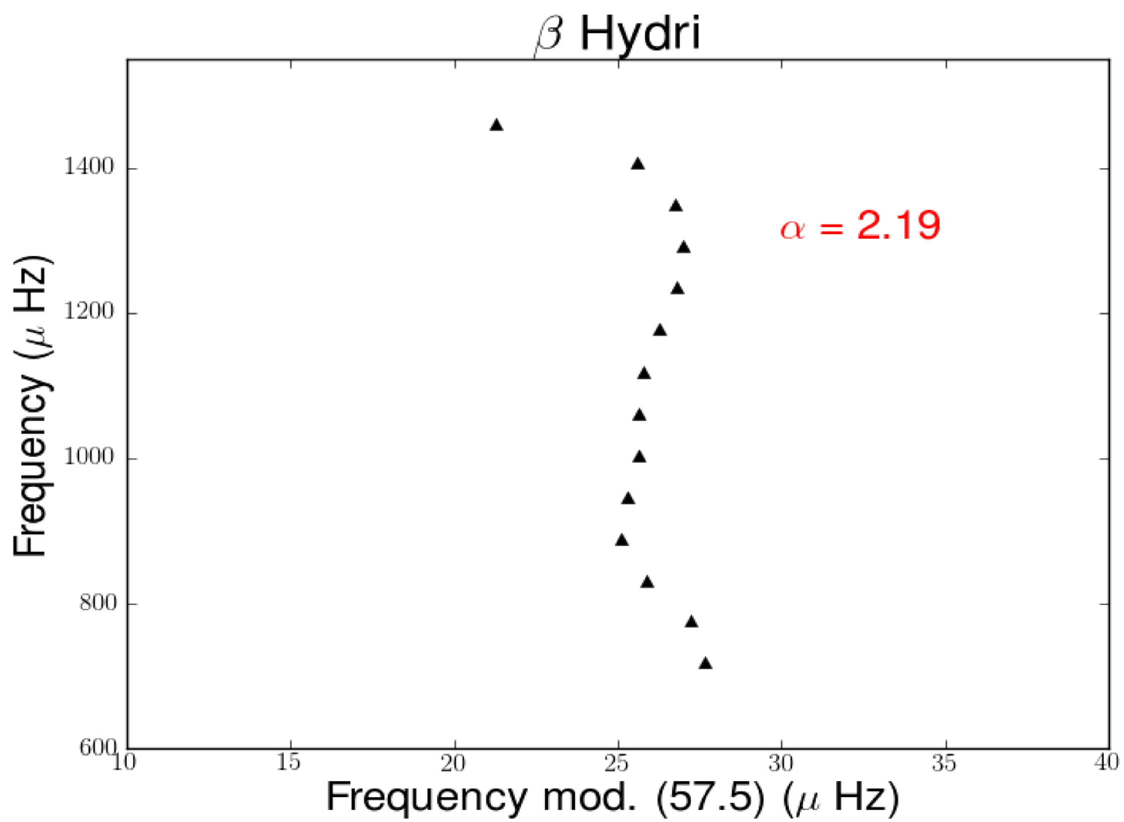
Echelle Diagram: Theor. + Obs.



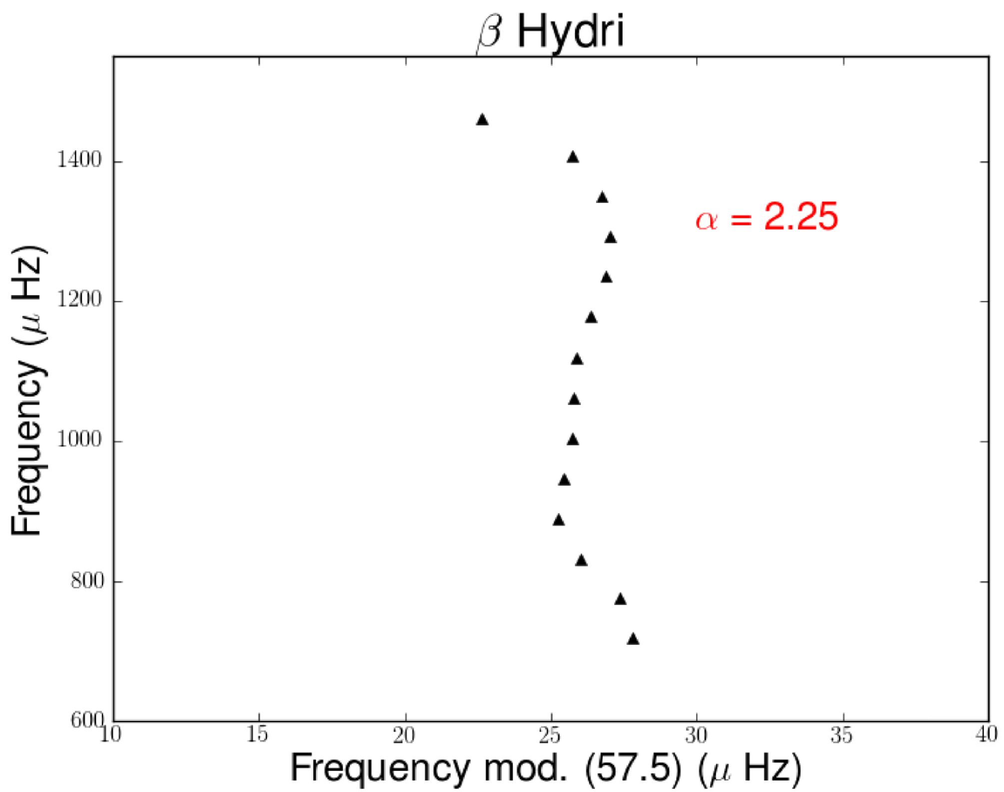
Effects of varying alpha



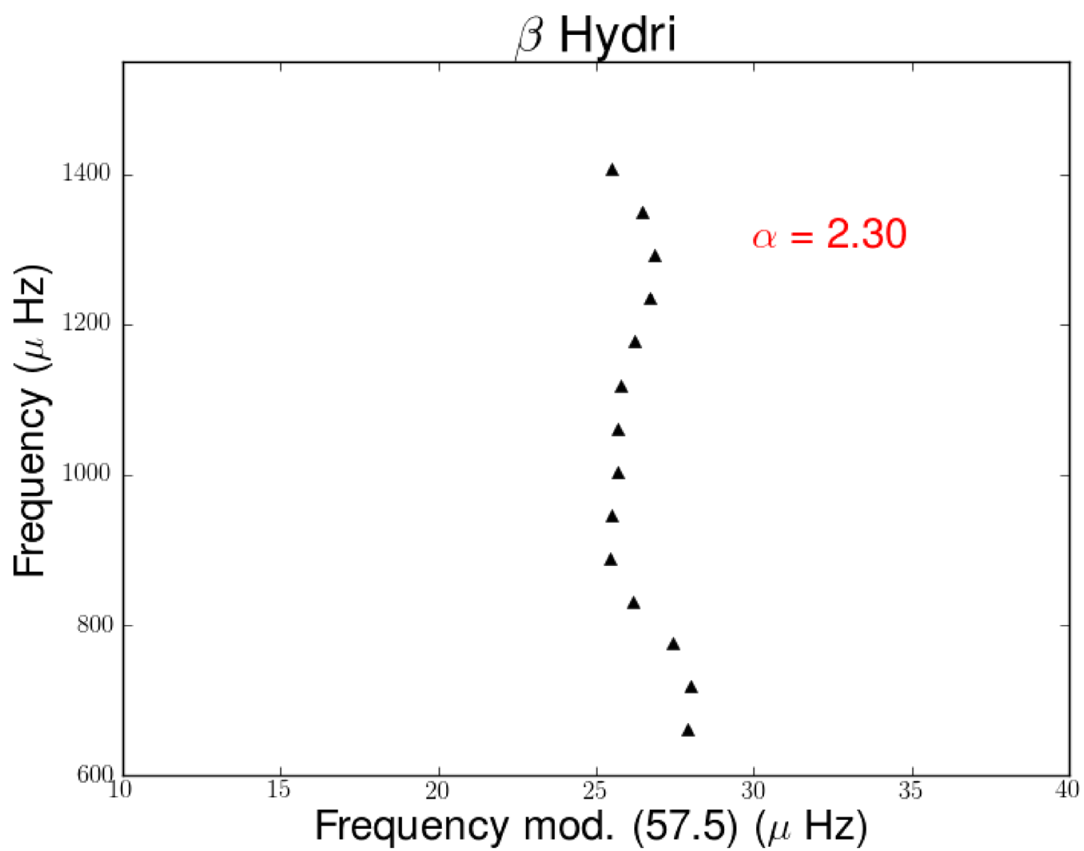
Effects of varying alpha



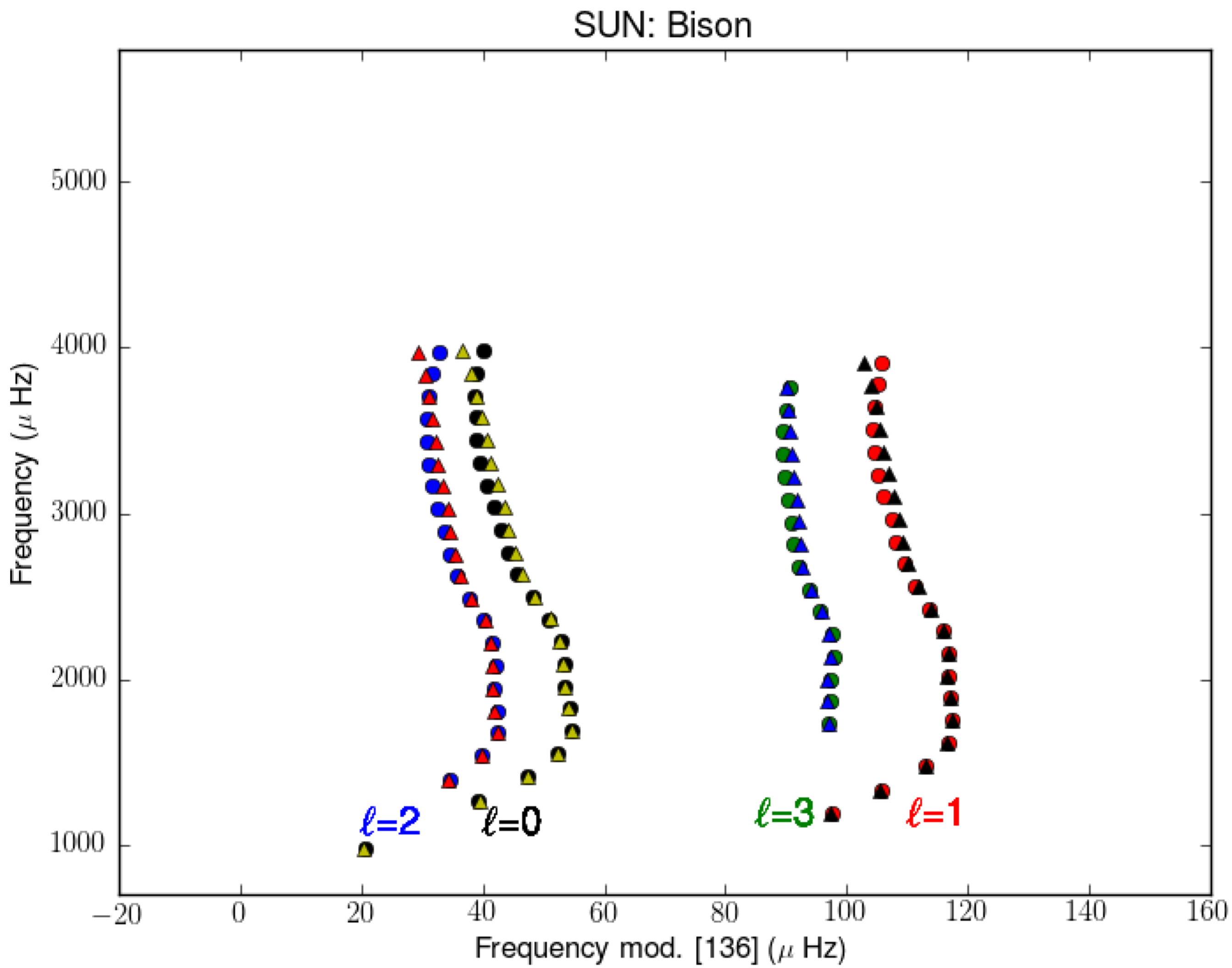
Effects of varying alpha



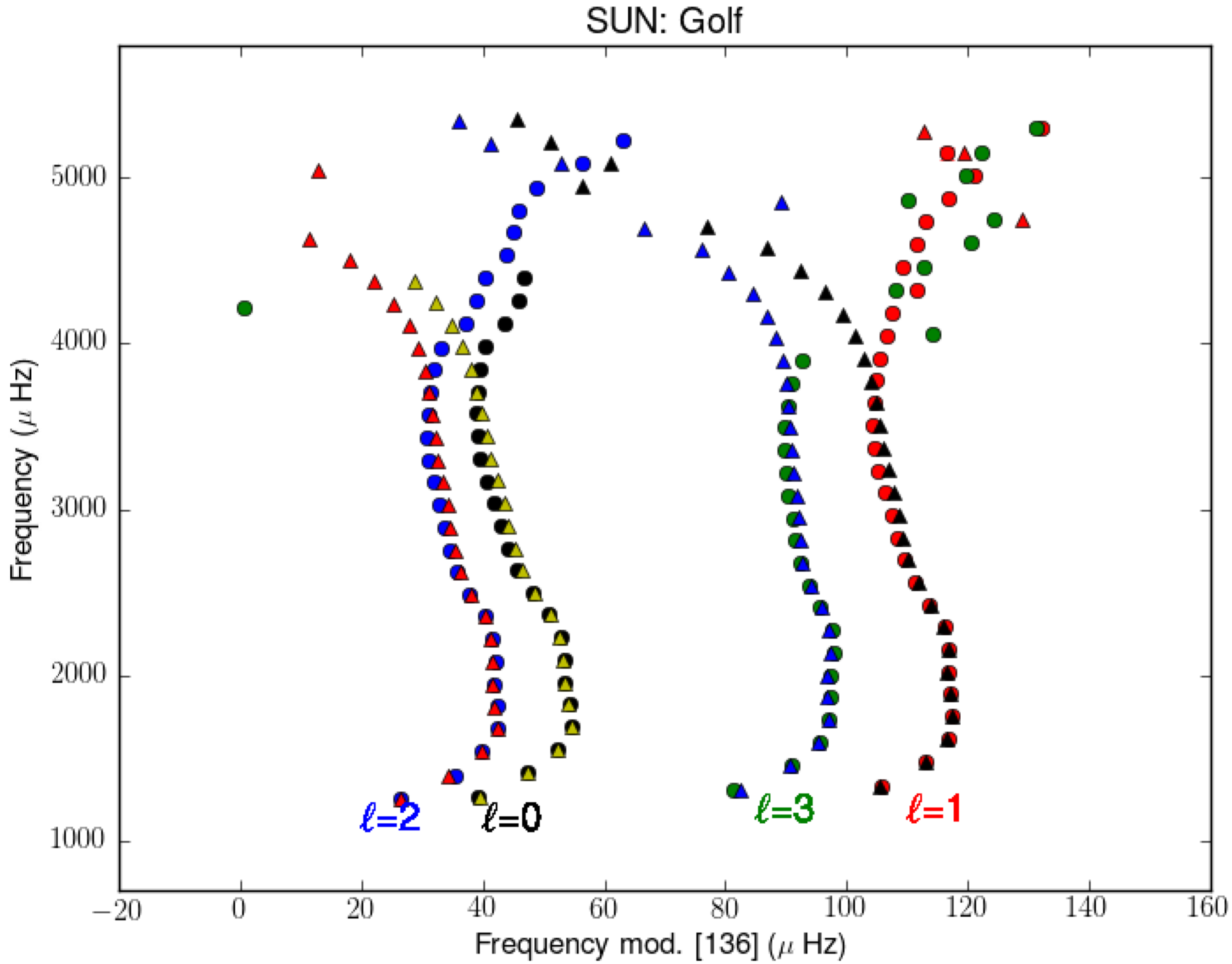
Effects of varying alpha

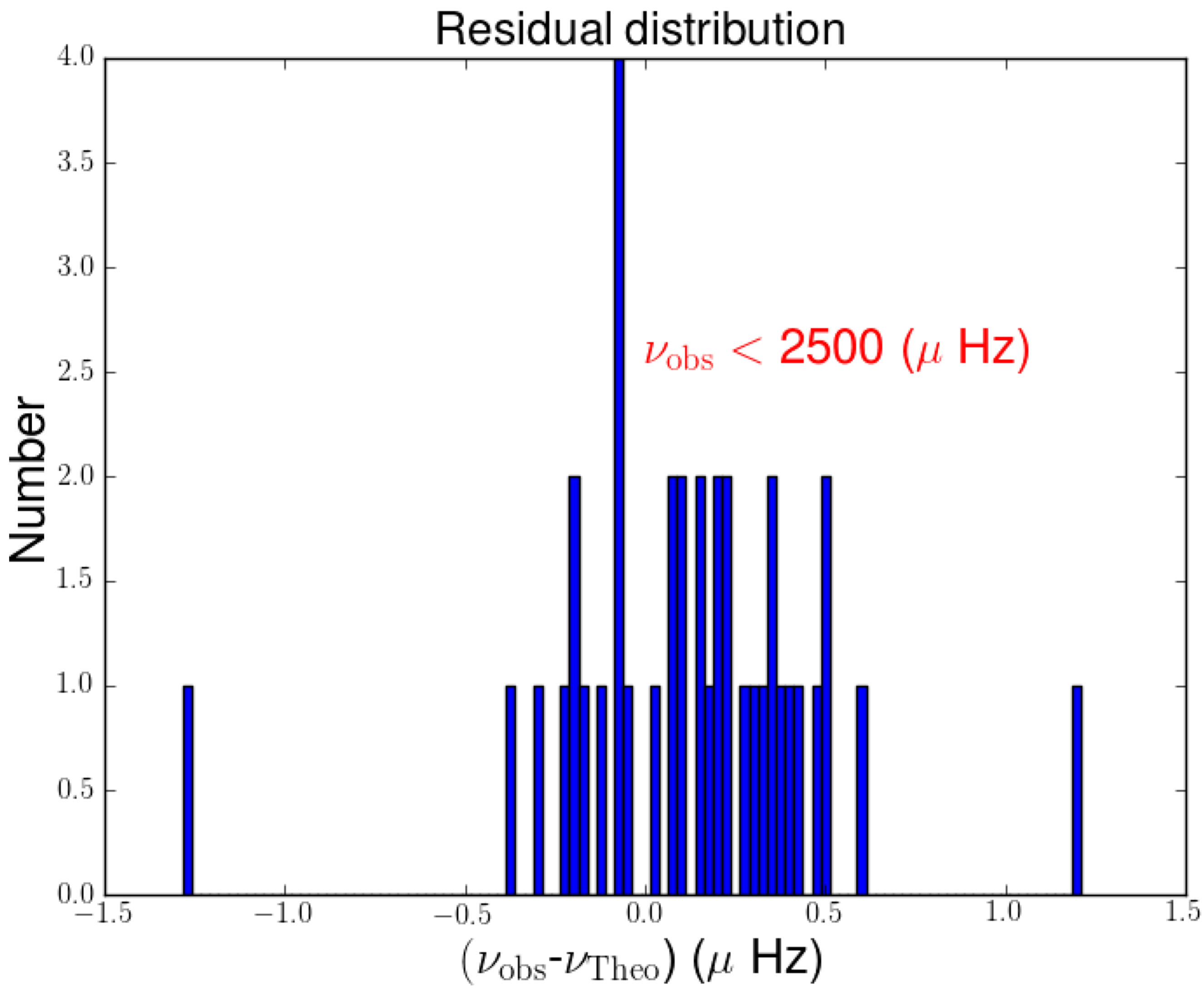


The SUN

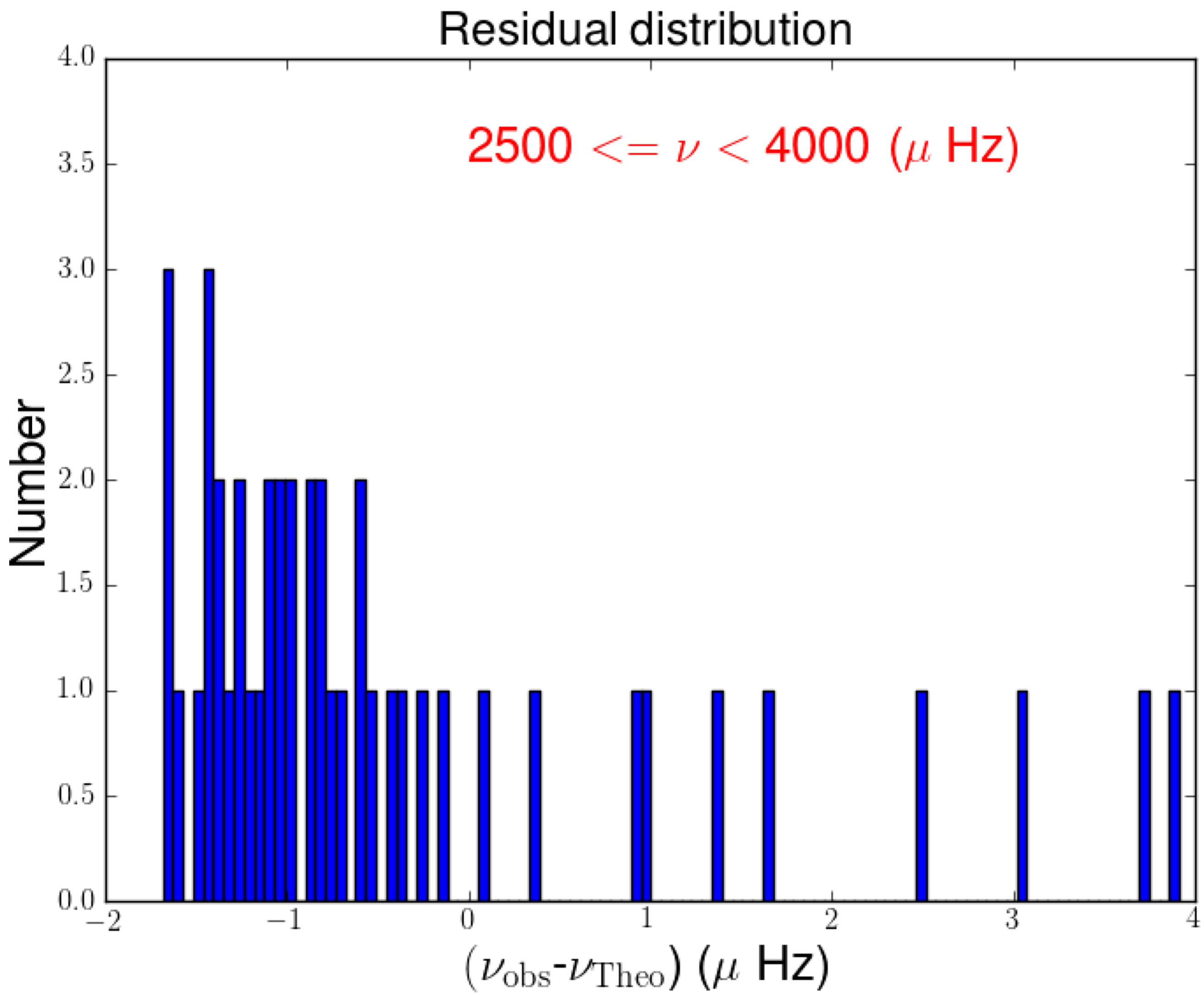

SUN: Bison
Frequency (μ Hz)
Frequency mod. [136] (μ Hz)
5000
4000
3000
2000
1000
−20
0
20
40
60
80
100
120
140
160
ℓ=2
ℓ=0
ℓ=3
ℓ=1

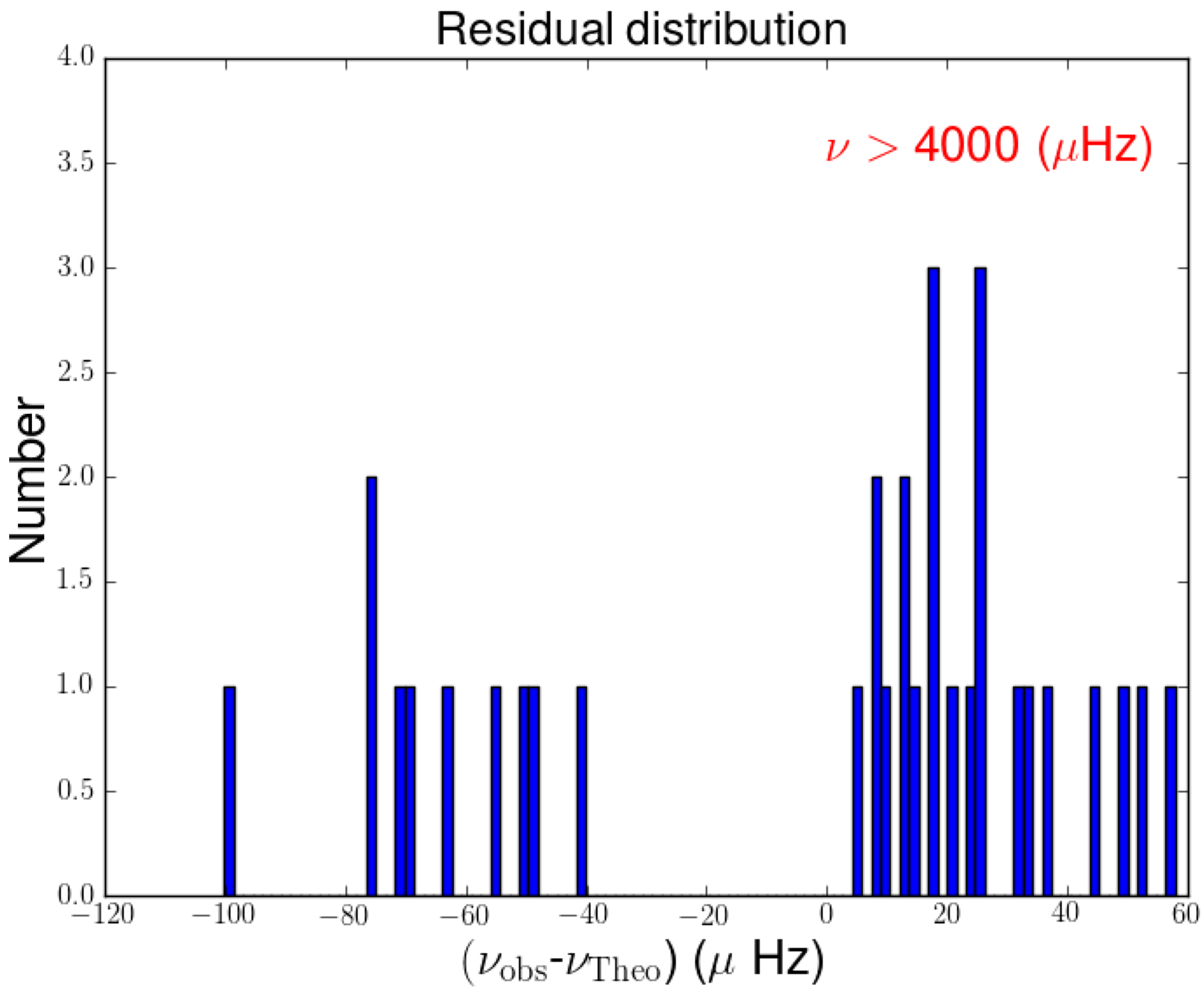
The SUN


SUN: Golf
Frequency (μ Hz)
Frequency mod. [136] (μ Hz)
ℓ=2
ℓ=0
ℓ=3
ℓ=1
5000
4000
3000
2000
1000
−20
0
20
40
60
80
100
120
140
160



Residual distribution
Number
$\nu_{\rm obs} < 2500$ (μ Hz)
($\nu_{\rm obs}$-$\nu_{\rm Theo}$) (μ Hz)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5


Residual distribution
$2500 <= \nu < 4000$ (μ Hz)
Number
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−2
−1
0
1
2
3
4
(ν_{obs}-ν_{Theo}) (μ Hz)

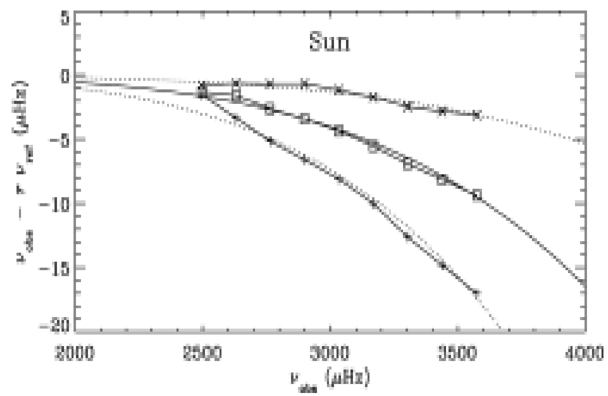

Residual distribution
$\nu > 4000$ (μHz)
Number
(ν_{obs}-ν_{Theo}) (μ Hz)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−120
−100
−80
−60
−40
−20
0
20
40
60

Near-surface Correction

$$\nu_{obs}(n) - \nu_{best}(n) = a\left[\frac{\nu_{obs}(n)}{\nu_0}\right]^b$$

$$\nu_{best}(n) = r\nu_{ref}(n).$$

$$\nu_{obs}(n) - r\nu_{ref}(n) = a\left[\frac{\nu_{obs}(n)}{\nu_0}\right]^b$$

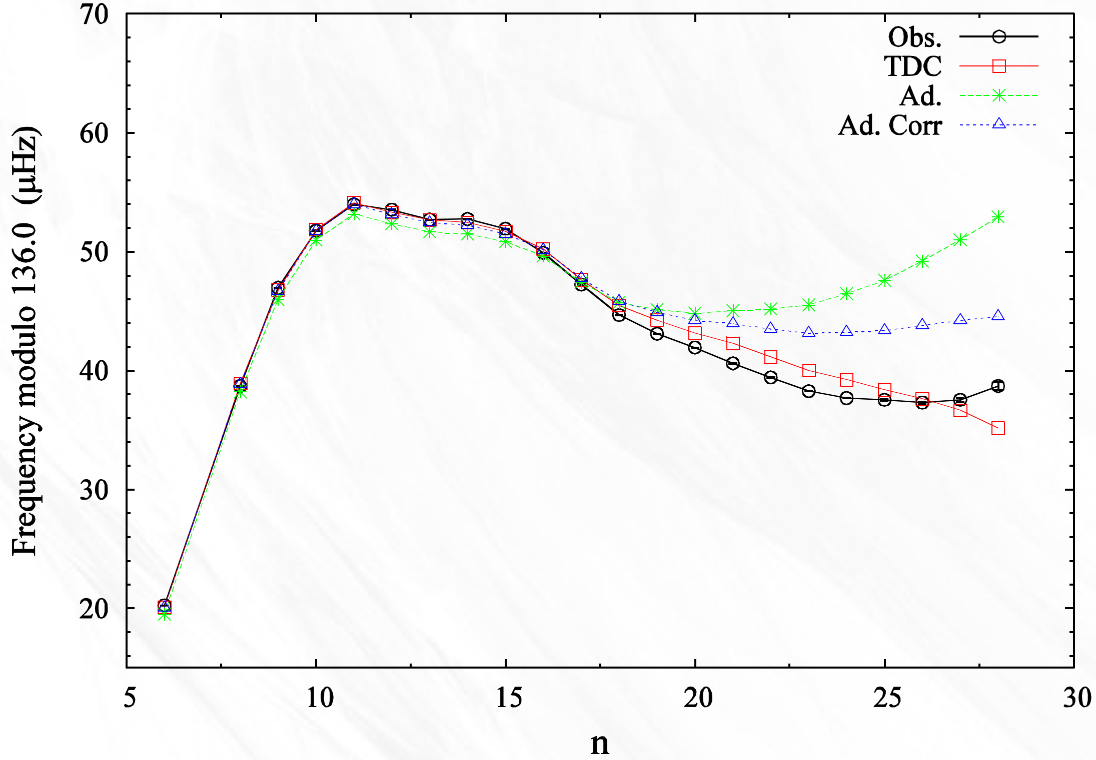


The Astrophysical Journal, 683: L175–L178, 2008 August 20

CORRECTING STELLAR OSCILLATION FREQUENCIES FOR NEAR-SURFACE EFFECTS

Hans Kjeldsen,[1] Timothy R. Bedding,[2] and Jørgen Christensen-Dalsgaard[1]

The SUN



Obs.
TDC
Ad.
Ad. Corr
Frequency modulo 136.0 (μHz)
70
60
50
40
30
20
5
10
15
20
25
30
n

Best models
obtained for some solar-like stars

Star	T_{eff} (K)	Log g	Log $(L/L_\odot)$	[Fe/H]	M ($M_\odot$)	R ($R_\odot$)	Age (Gyr)
Sun	5778 ± 10	4.44 ± 0.01	0.0	0.00 ± 0.01	1.00	1.00	4.57
α Cen A	5832 ± 62	4.33 ± 0.11	0.18 ± 0.02	0.23 ± 0.05	1.105 ± 0.007	1.224 ± 0.003	–
β Hyi	5860 ± 63	4.04 ± 0.10	0.55 ± 0.02	-0.07 ± 0.05	–	1.809 ± 0.015	–
τ Cet	5310 ± 62	4.44 ± 0.10	-0.31 ± 0.02	-0.52 ± 0.03	–	0.793 ± 0.004	–

Star	Model	M ($M_\odot$)	R ($R_\odot$)	Age (Gyr)	T_{eff} (K)	log g	log $(L/L_\odot)$	Z/X	α_{MLT}	α_{Ov}
Sun	TDC	1.00	1.00	4.5774	5779	4.4383	0.0004	0.0251	1.810	0.00
	Adiab.	1.00	1.00	4.5889	5780	4.4380	0.0008	0.0251	1.810	0.00
	Corr.	1.00	1.00	4.5774	5779	4.4383	0.0004	0.0251	1.810	0.00
α Cen A	TDC	1.1045	1.2199	5.9675	5829	4.3088	0.1879	0.0441	1.802	0.35
	Adiab.	1.1041	1.2225	6.4143	5784	4.3068	0.1762	0.0444	1.802	0.25
	Corr.	1.1041	1.2205	6.1748	5808	4.3083	0.1820	0.0438	1.802	0.30
β Hyi	TDC	1.072	1.8211	8.1957	5858	3.9478	0.5446	0.0194	2.300	0.00
	Adiab.	1.070	1.8223	8.2923	5856	3.9464	0.5445	0.0194	2.500	0.00
	Corr.	1.080	1.8207	7.8221	5856	3.9513	0.5436	0.0194	1.900	0.00
τ Cet	TDC	0.8370	0.8094	3.4594	5432	4.5447	-0.2909	0.0077	1.250	0.20
	Adiab.	0.8450	0.8130	2.9298	5454	4.5450	-0.2802	0.0077	1.250	0.20
	Corr.	0.8370	0.8091	3.4662	5431	4.5451	-0.2916	0.0077	1.250	0.21

Average lifetime associated with the oscillation modes

Star	$\nu_{max}(\mu Hz)$	$\langle\tau_{obs}\rangle$ (days)	$\langle\tau_{TDC}\rangle$ (days)	$\nu(\mu Hz)$
Sun	3034	3.16 ± 0.2	3.18	$[2200, 4000]_{\ell=0,1}$
α Cen A	2410	3.9 ± 1.4	3.64	$[1900, 2900]_{\ell=0}$
β Hyi	1000	$2.3^{+0.6}_{-0.5}$	2.28	$[900, 1200]_{\ell=0}$
τ Cet	4500	1.7 ± 0.5	1.75	$[3800, 5200]_{\ell=0}$

Observations: Chaplin et al. 2009.

Conclusions

In this work we have considered how a physically more robust representation of the mode physics near the surface can provide a better fitting of the stellar models, based on seismic data:

- Frequencies of solar-like oscillations calculated using TDC provide a significant improvement compared with the adiabatic frequencies.
- The values of the mode lifetime obtained with TDC is close to the observed values, confirming the better physical description of the mode physics near the surface provided by TDC when applied to solar-like stars.

In conclusion, TDC provides an improvement on the description of the mode physics near the surface of solar-like stars, being a more robust base for model fitting of stars with convective envelopes using precise seismic data. Consequently, it may thus be very important to use TDC models for any detailed asteroseismic study of solar-like stars and their near surface structure, including a possible calibration of convection through the mixing-length.

Thanks

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Merci

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どうもありがとうございました