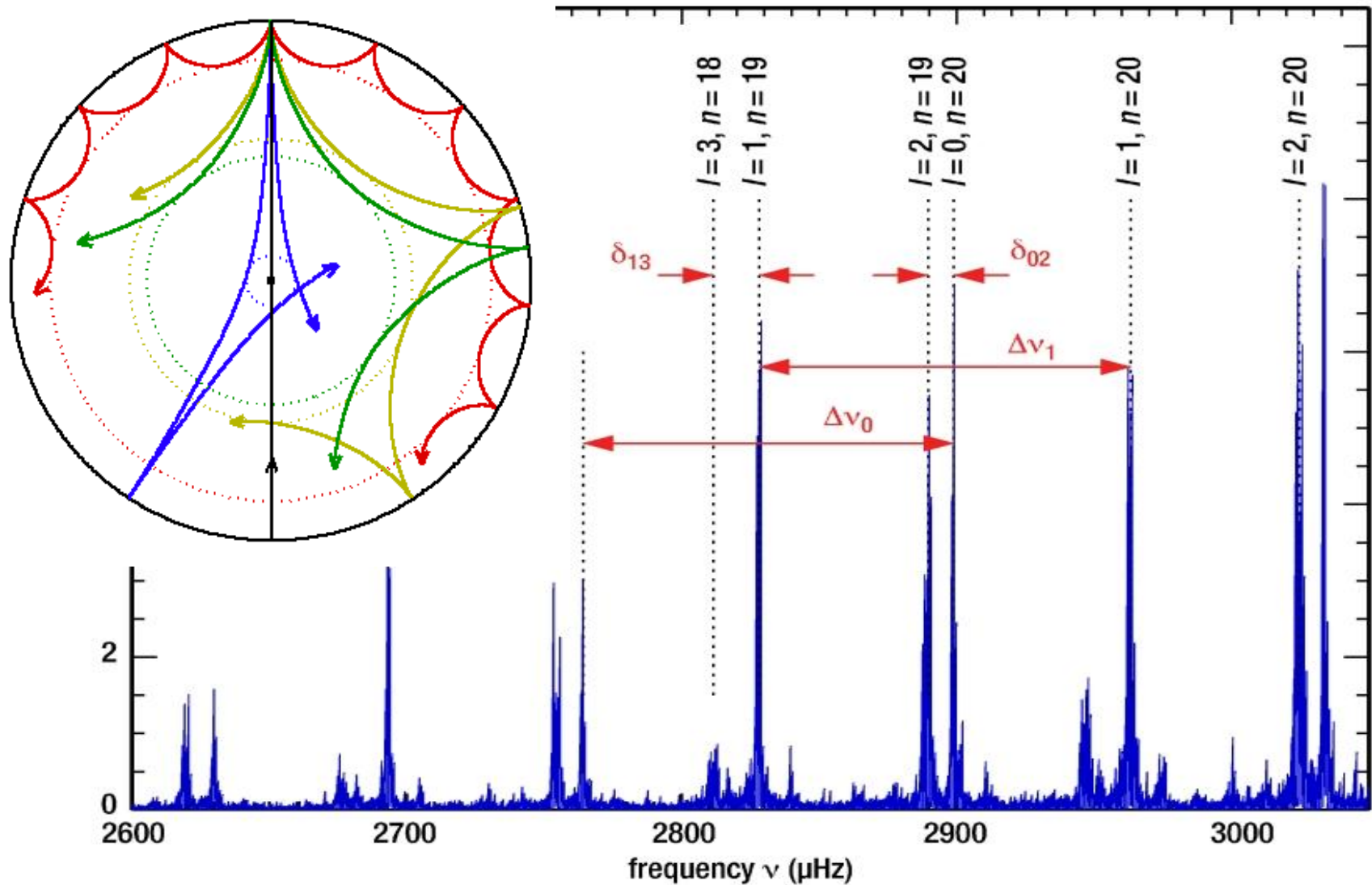


Asteroseismic modeling of solar-like oscillations

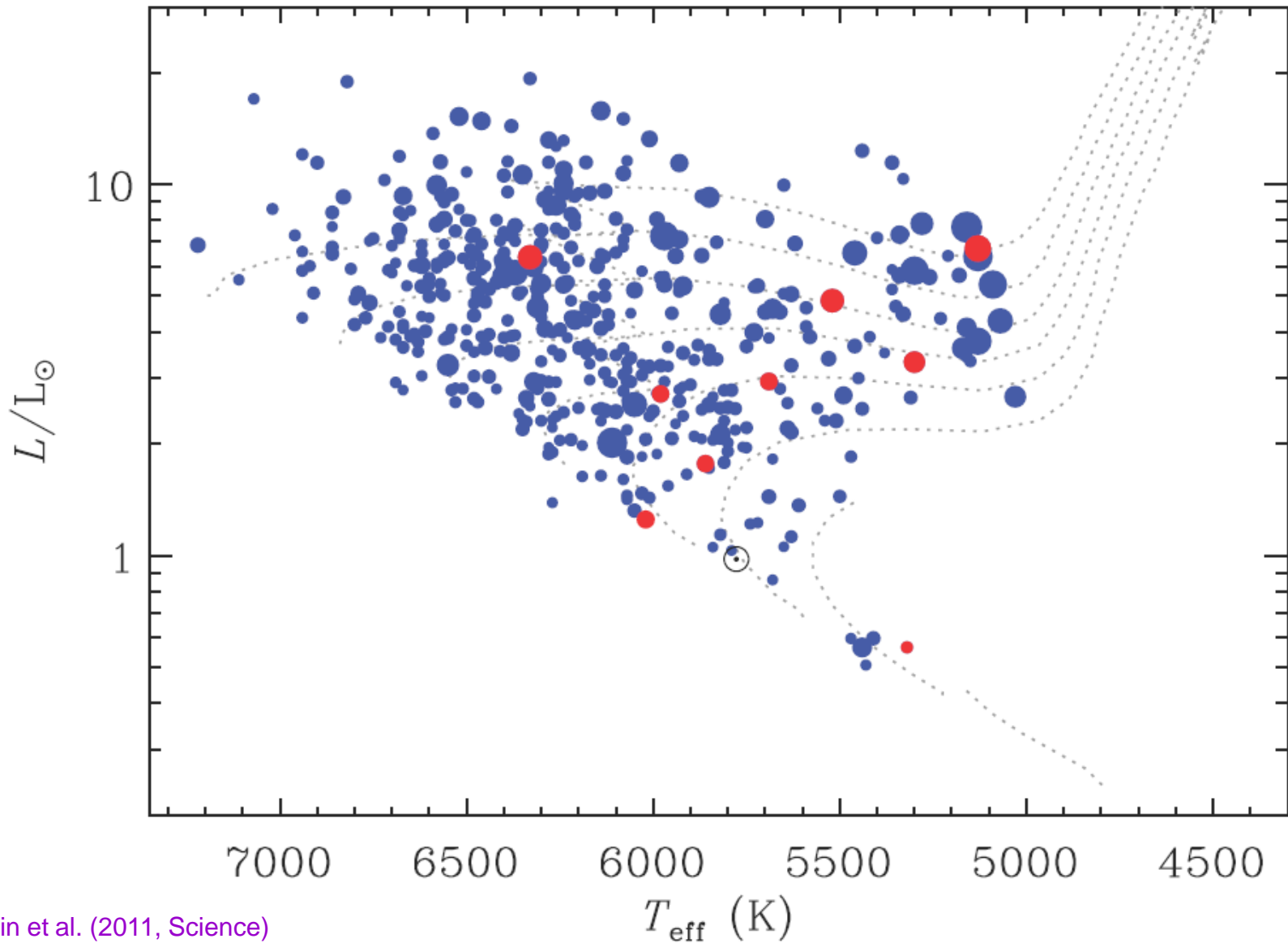
Travis Metcalfe



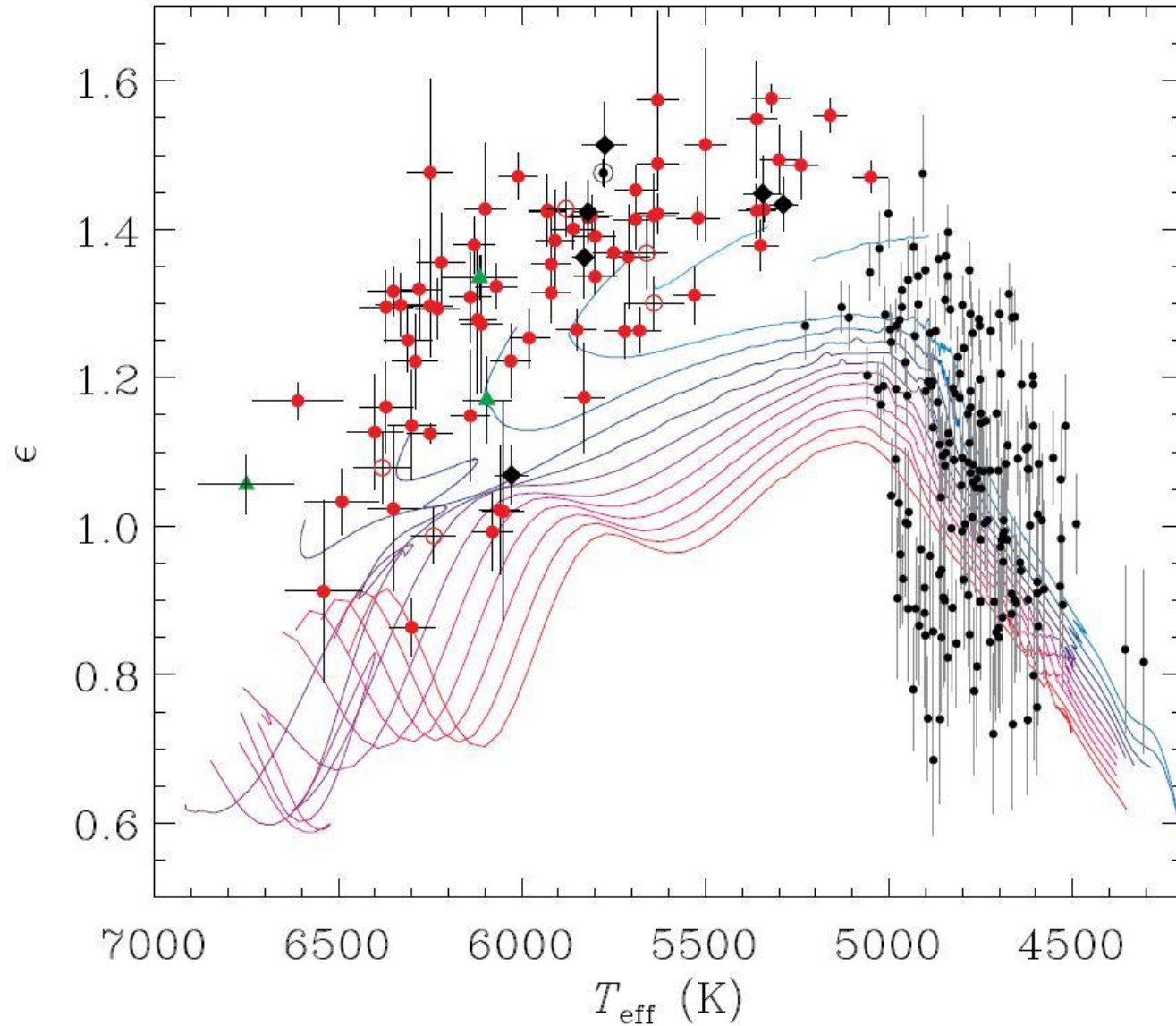
Global oscillation properties



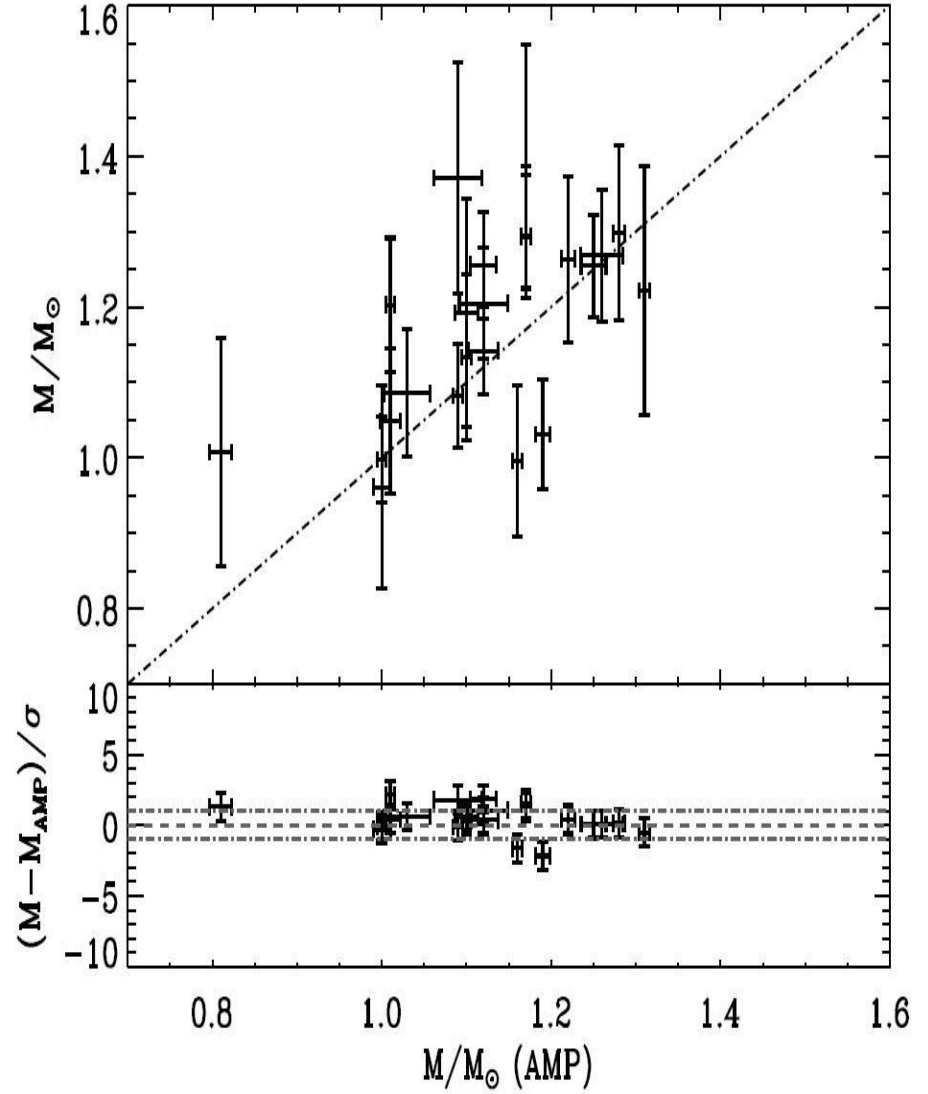
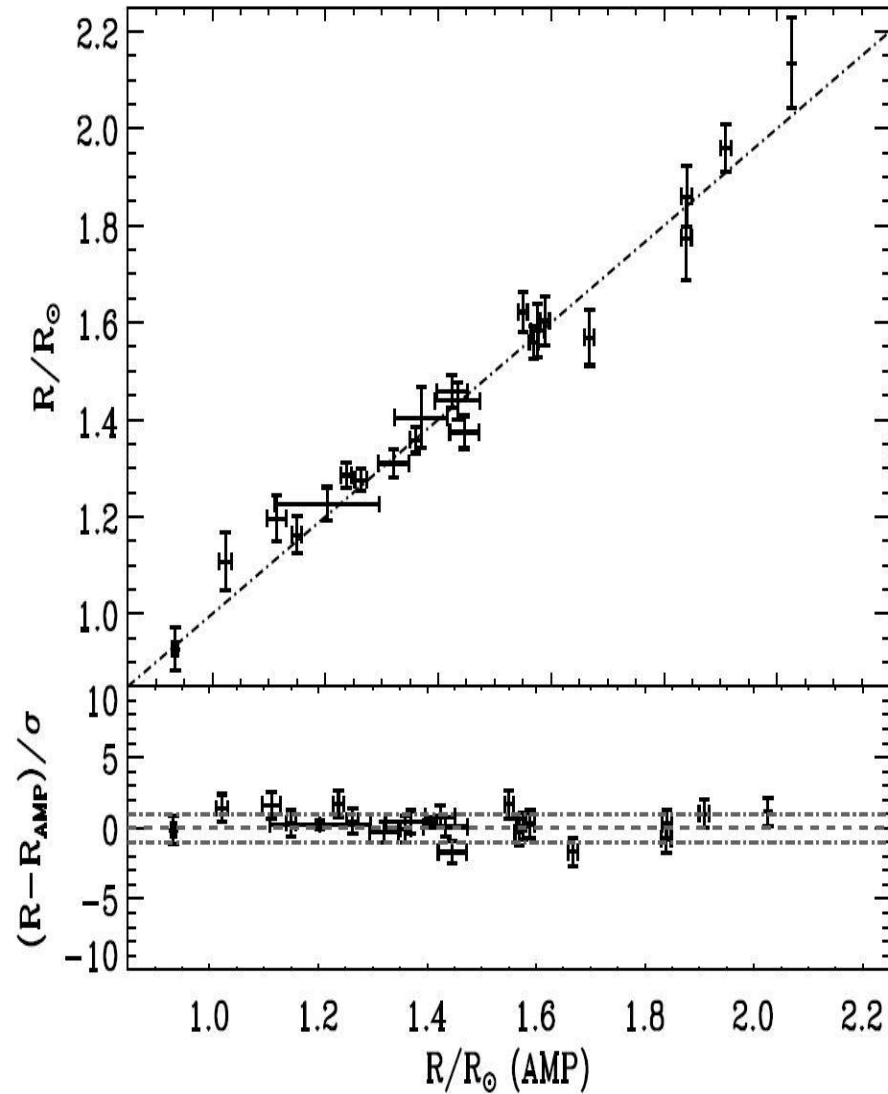
Kepler asteroseismic survey



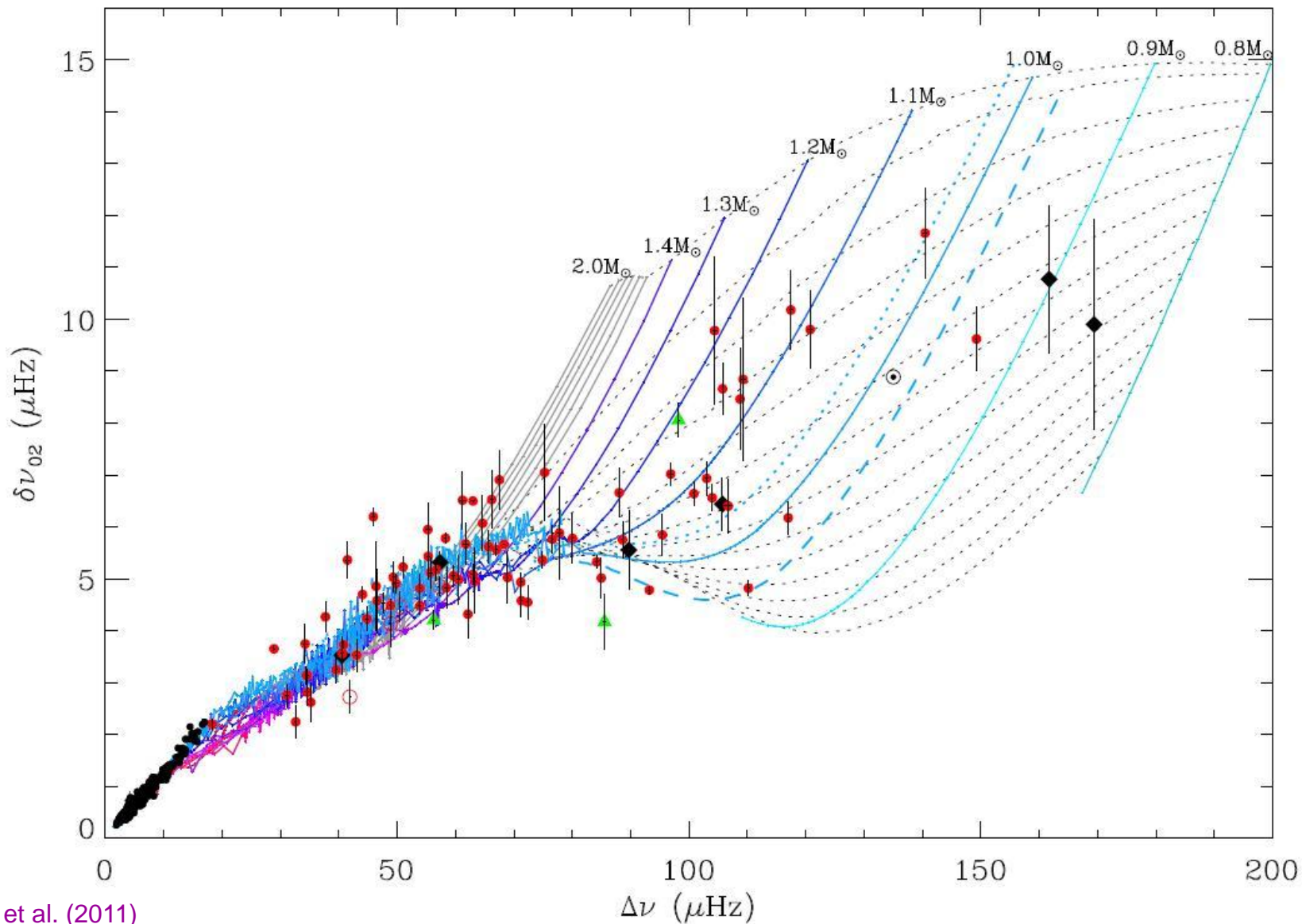
Échelle diagram



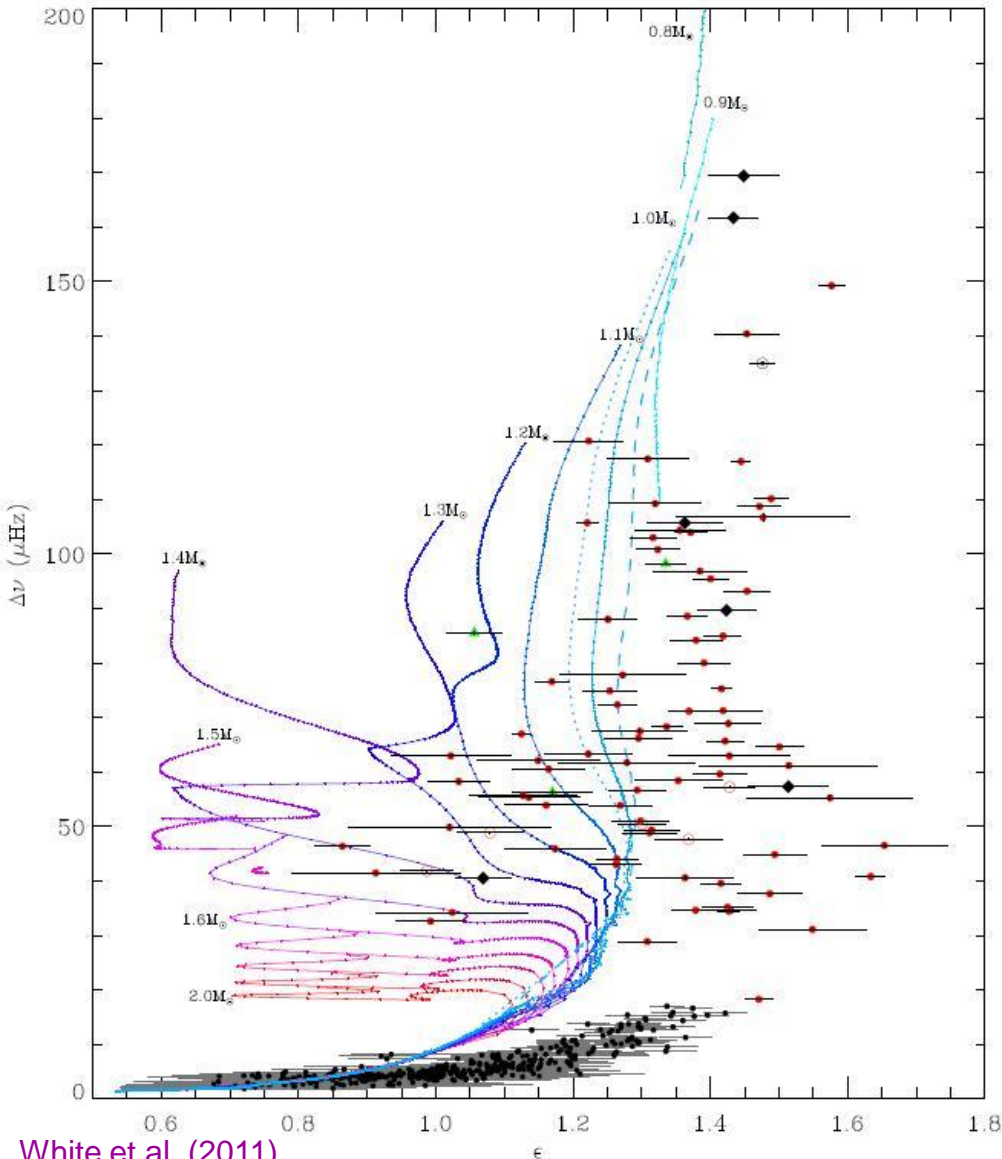
Scaling relations



C-D diagram

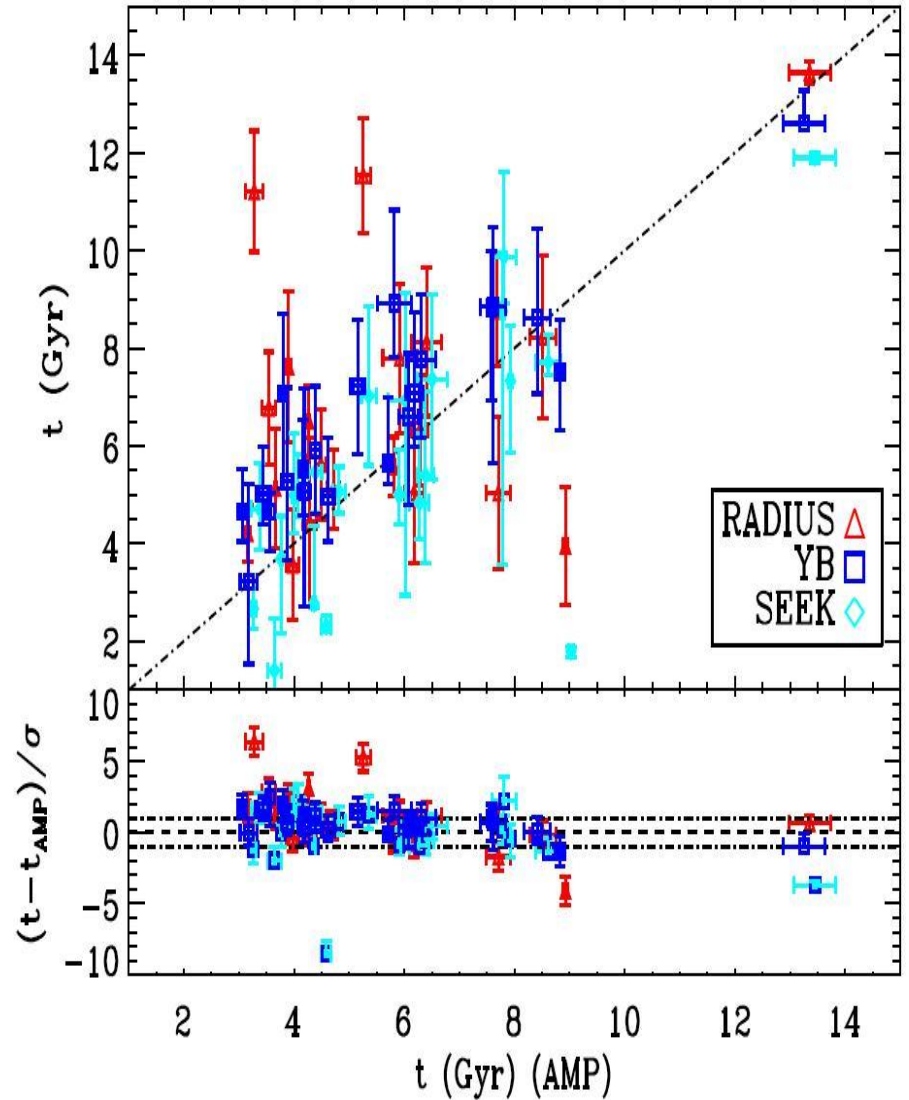
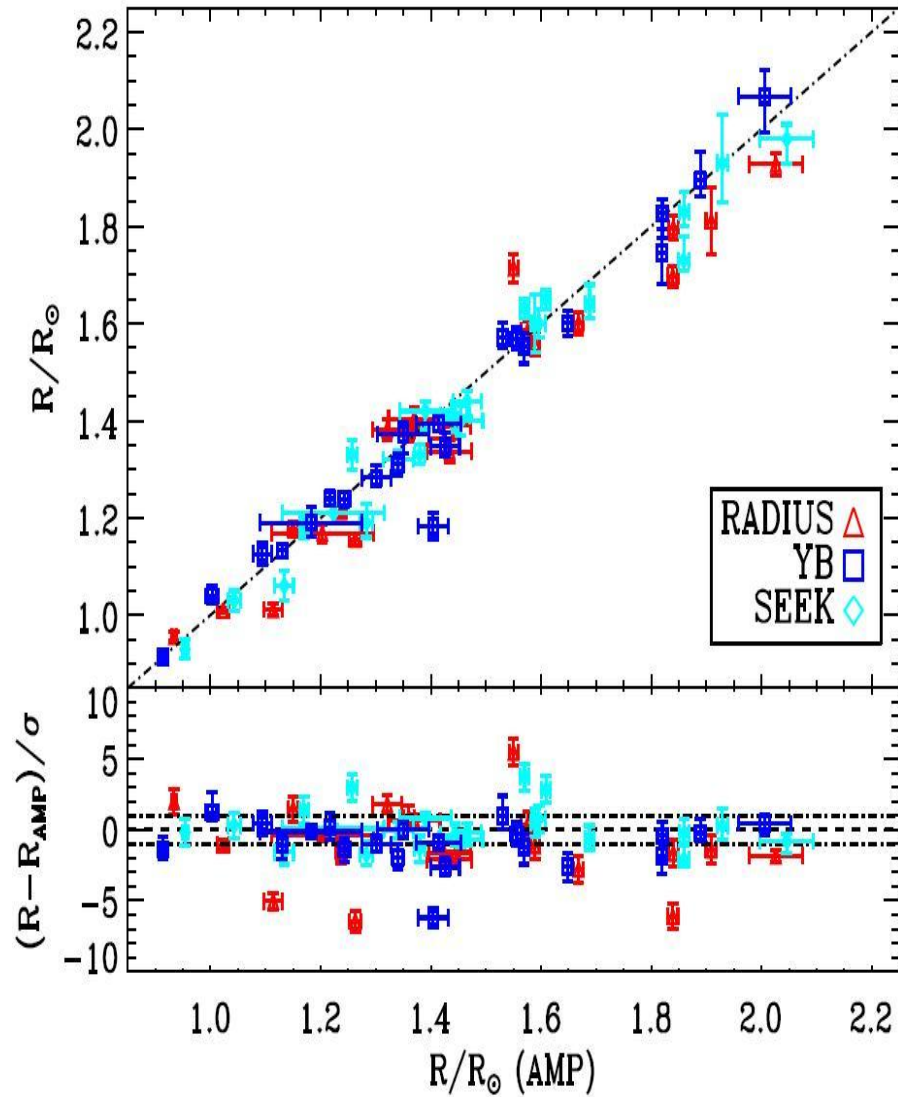


ε diagram

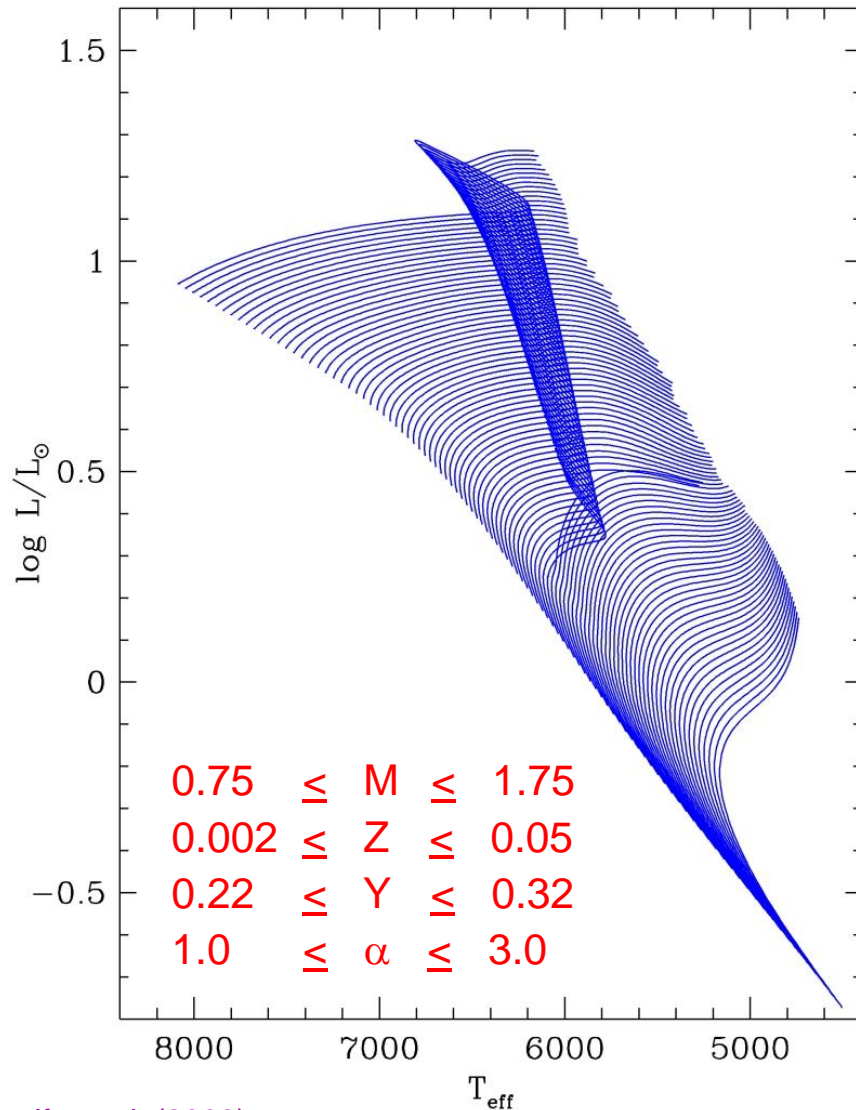


- C-D diagram for more evolved stars, plot $\Delta\nu$ against ε instead of $\delta\nu$
- Models are systematically to the left of observations due to surface effects
- Value of ε is sometimes ambiguous by ± 1 for F stars with broad ridges

Grid-based methods

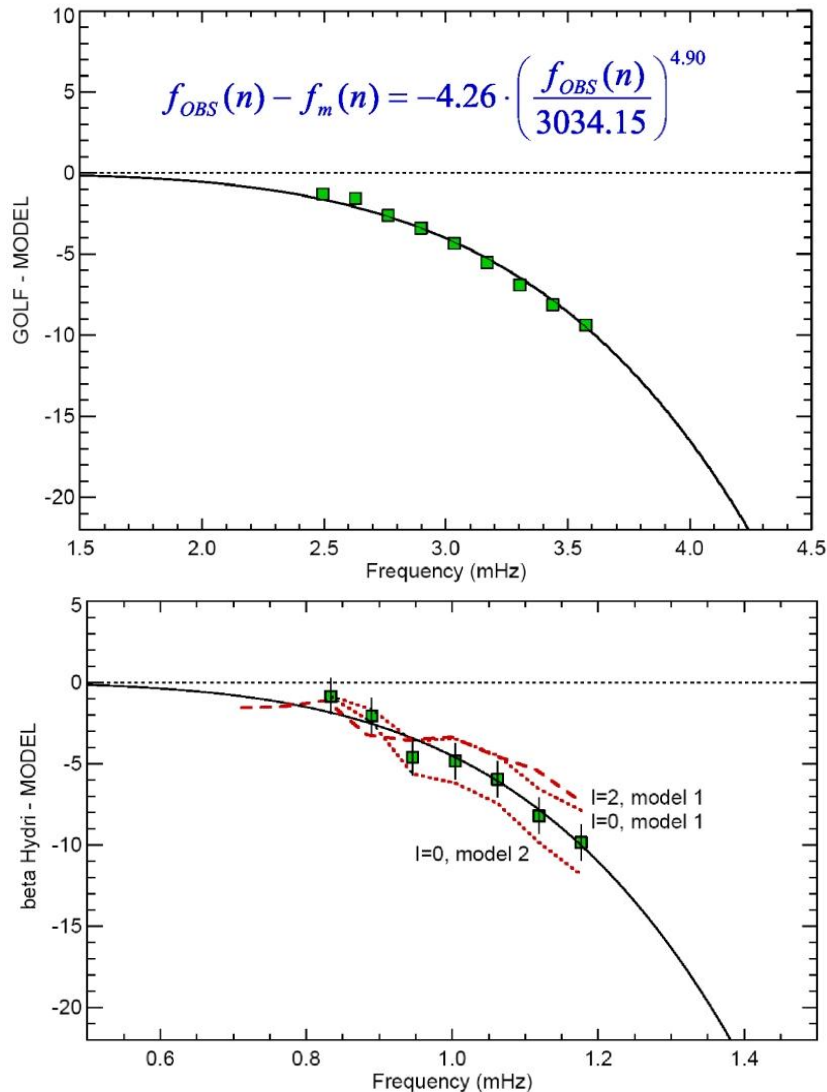


Fitting the frequencies



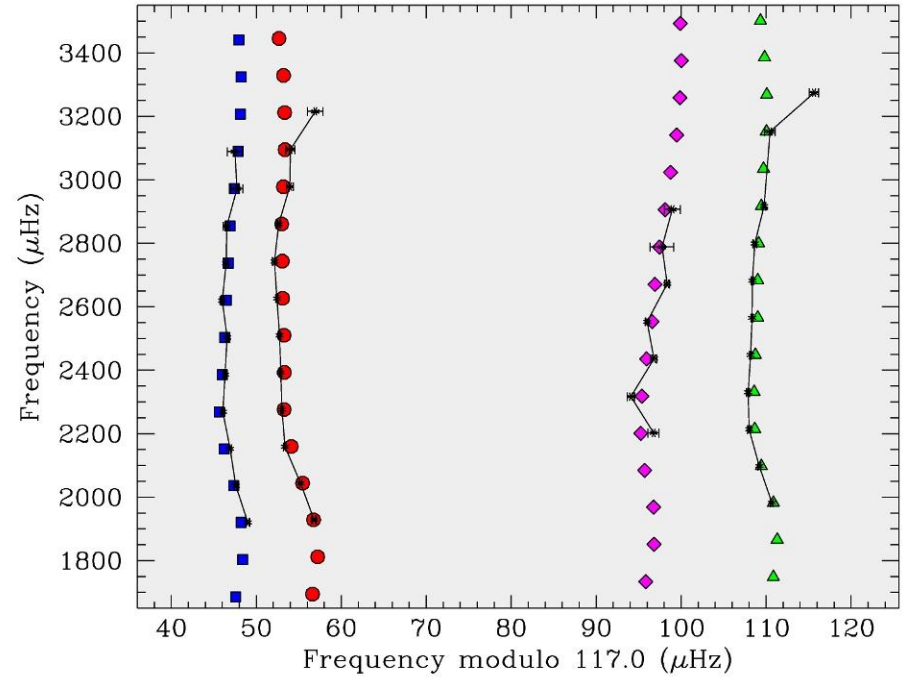
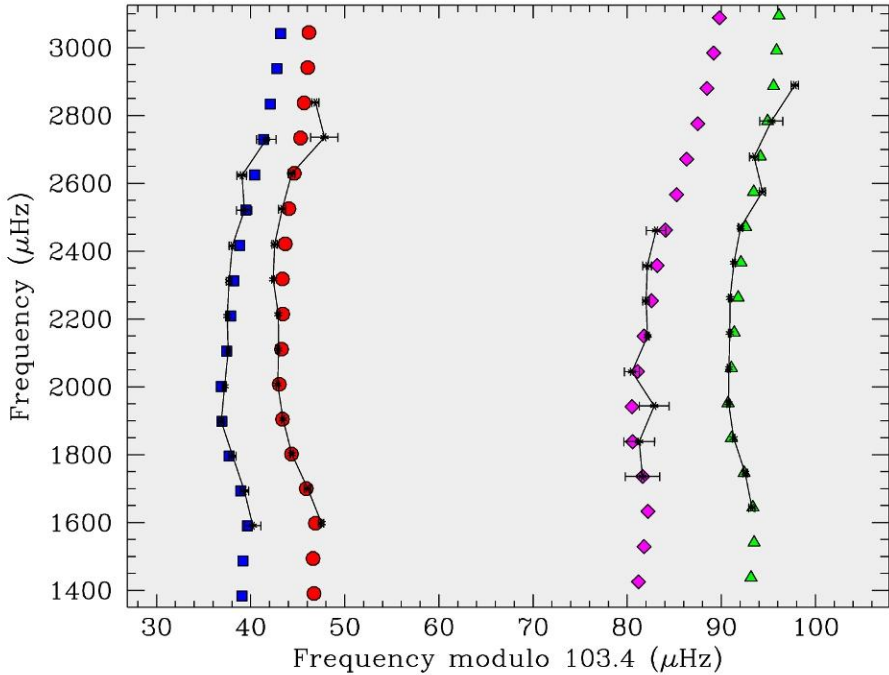
- Stellar evolution tracks from ASTEC, pulsation analysis with ADIPLS
- Parallel genetic algorithm optimizes globally, local analysis + SVD for errors
- Stellar age from match to large separation, correct surface effects empirically

Empirical surface correction



- Incomplete modeling of surface convection zone leads to systematic errors
- Parameterize the offset, calibrate with solar data, apply homology scaling
- For near-optimal models, this procedure is enough to correct β Hydri data

Example: binary system



Method	R/R _⊙	M/M _⊙	t (Gyr)	Z	Y _i	α
AMP	1.24 ± 0.03	1.10 ± 0.02	6.5 ± 0.4	0.022 ± 0.003	0.251 ± 0.025	2.06 ± 0.06
SEEK	1.23 ± 0.02	1.11 ^{+0.02} _{-0.07}	9.33 ^{+0.1} _{-0.4}	0.027 ± 0.003	0.245 ^{+0.03} _{-0.01}	2.28 ± 0.05
RADIUS	1.232 ± 0.002	1.109 ± 0.006	5.5 ± 0.1	0.028	0.272	1.8
YB	1.22 ^{+0.03} _{-0.04}	1.10 ^{+0.04} _{-0.14}	6.2 ^{+3.4} _{-1.5}	...	...	...
isochron	1.254 ± 0.016	1.25 ± 0.07	5.8 ± 0.9	...	...	...
activity	...	...	7.9	...	...	...

Method	R/R _⊙	M/M _⊙	t (Gyr)	Z	Y _i	α
AMP	1.13 ± 0.03	1.07 ± 0.03	5.9 ± 0.4	0.020 ± 0.003	0.243 ± 0.035	2.00 ± 0.07
SEEK	1.11 ± 0.02	0.99 ± 0.02	6.35 ± 0.1	0.020 ± 0.003	0.300 ± 0.01	1.80 ± 0.05
RADIUS	1.113 ± 0.004	1.039 ± 0.011	6.3 ± 0.4	0.022	0.278	1.8
YB	1.11 ^{+0.02} _{-0.06}	1.051 ^{+0.002} _{-0.010}	5.6 ^{+2.0} _{-1.1}	...	...	...
isochron	1.154 ± 0.015	1.10 ± 0.06	8.0 ± 1.3	...	...	...
activity	...	...	7.4	...	...	...

Uniform analysis

Star	M/M_{\odot}	Z	Y_0	α	$t(\text{Gyr})$	L/L_{\odot}	R/R_{\odot}	T_{eff}	$\log g$	[M/H]	χ^2_{seis}	χ^2_{spec}
Sun	1.01	0.02388	0.285	2.12	4.512	0.999	1.004	5765	4.439	+0.148	1.5	0.5
α Cen A	1.11	0.02992	0.287	1.86	4.844	1.475	1.222	5759	4.309	+0.252	6.1	0.4
α Cen B	0.92	0.02992	0.287	2.00	5.044	0.513	0.865	5256	4.527	+0.251	2.4	0.1
β Hyi	1.09	0.01786	0.314	2.00	5.408	3.560	1.819	5884	3.955	+0.037	1.6	0.4
ν Ind	0.95	0.00234	0.292	1.02	5.549	5.411	2.990	5096	3.464	-0.869	2.7	11.0
τ Cet	0.79	0.01294	0.294	2.06	7.609	0.489	0.796	5417	4.534	-0.119	3.5	1.5
μ Ara	1.11	0.04130	0.316	2.12	6.659	1.894	1.365	5801	4.213	+0.418	9.1	0.6
Procyon	1.50	0.01426	0.260	1.88	1.796	7.031	2.053	6566	3.989	-0.097	4.0	0.1
HD 49933	1.20	0.00701	0.240	1.96	2.270	3.352	1.404	6597	4.222	-0.421	5.6	0.5
KIC 3632418	1.28	0.01213	0.256	1.68	3.160	4.266	1.840	6120	4.015	-0.171	5.9	0.3
KIC 3656476	1.09	0.03090	0.278	1.96	7.709	1.611	1.321	5664	4.233	+0.260	3.2	2.3
KIC 4914923	1.10	0.02032	0.267	1.90	6.177	1.974	1.370	5851	4.206	+0.065	6.1	0.7
KIC 5184732	1.25	0.04130	0.280	1.96	3.976	1.892	1.360	5811	4.268	+0.394	7.2	0.5
KIC 5512589	1.16	0.02032	0.234	1.86	7.682	2.597	1.668	5680	4.058	+0.045	4.7	0.1
KIC 6106415	1.12	0.01730	0.246	2.00	4.715	1.760	1.237	5984	4.302	-0.019	4.6	0.6
KIC 6116048	1.12	0.01337	0.220	1.94	5.256	1.842	1.263	5990	4.284	-0.148	12.5	1.9
KIC 6603624	1.01	0.02992	0.284	1.84	8.514	1.096	1.150	5513	4.321	+0.250	1.9	0.8
KIC 6933899	1.10	0.01905	0.282	1.98	6.283	2.690	1.576	5893	4.084	+0.045	3.6	1.3
KIC 7680114	1.19	0.02099	0.240	2.00	5.920	2.168	1.446	5830	4.193	+0.063	5.9	0.2
KIC 7976303	1.17	0.01000	0.225	1.66	5.806	4.161	2.026	5798	3.893	-0.274	7.7	8.9
KIC 8006161	1.00	0.03090	0.258	1.84	4.283	0.602	0.934	5268	4.497	+0.248	4.2	2.2
KIC 8228742	1.31	0.01730	0.228	1.76	4.264	4.132	1.839	6075	4.026	-0.030	9.8	1.5
KIC 8379927	1.09	0.01622	0.234	1.66	3.278	1.235	1.114	5771	4.381	-0.055	3.8	3.0
KIC 8760414	0.81	0.00345	0.220	1.82	13.35	1.074	1.023	5814	4.326	-0.742	6.5	16.0
KIC 10018963	1.17	0.01067	0.291	2.12	3.663	5.199	1.909	6314	3.944	-0.206	12.6	0.2
KIC 10273246	1.24	0.01175	0.249	1.86	4.285	5.293	2.136	5997	3.872	-0.189	10.8	1.4
KIC 10516096	1.12	0.01472	0.232	1.88	6.406	2.215	1.424	5906	4.180	-0.099	1.1	0.1
KIC 10920273	1.00	0.01067	0.296	2.04	6.739	3.314	1.779	5844	3.937	-0.203	6.5	1.9
KIC 10963065	1.03	0.01067	0.271	1.66	3.899	1.734	1.203	6046	4.290	-0.218	3.0	0.3
KIC 11026764	1.28	0.02032	0.275	2.30	4.287	4.888	2.110	5914	3.896	+0.070	10.0	4.2
KIC 11244118	1.01	0.02805	0.318	2.16	8.925	2.151	1.550	5620	4.061	+0.242	6.2	1.9
KIC 11395018	1.23	0.02312	0.301	1.94	4.461	4.402	2.158	5697	3.860	+0.144	8.1	0.5
KIC 11713510	1.00	0.01000	0.265	2.10	7.825	2.734	1.569	5930	4.046	-0.250	4.7	0.0
KIC 12009504	1.26	0.01675	0.220	1.86	3.542	2.546	1.434	6093	4.225	-0.049	4.7	0.9
KIC 12258514	1.22	0.01968	0.262	1.78	4.485	2.668	1.589	5858	4.122	+0.048	14.4	0.8



There are known knowns. These are things we know that we know. There are known unknowns. That is to say, there are things that we know now we don't know. But there are also unknown unknowns. These are things we do not know we don't know.