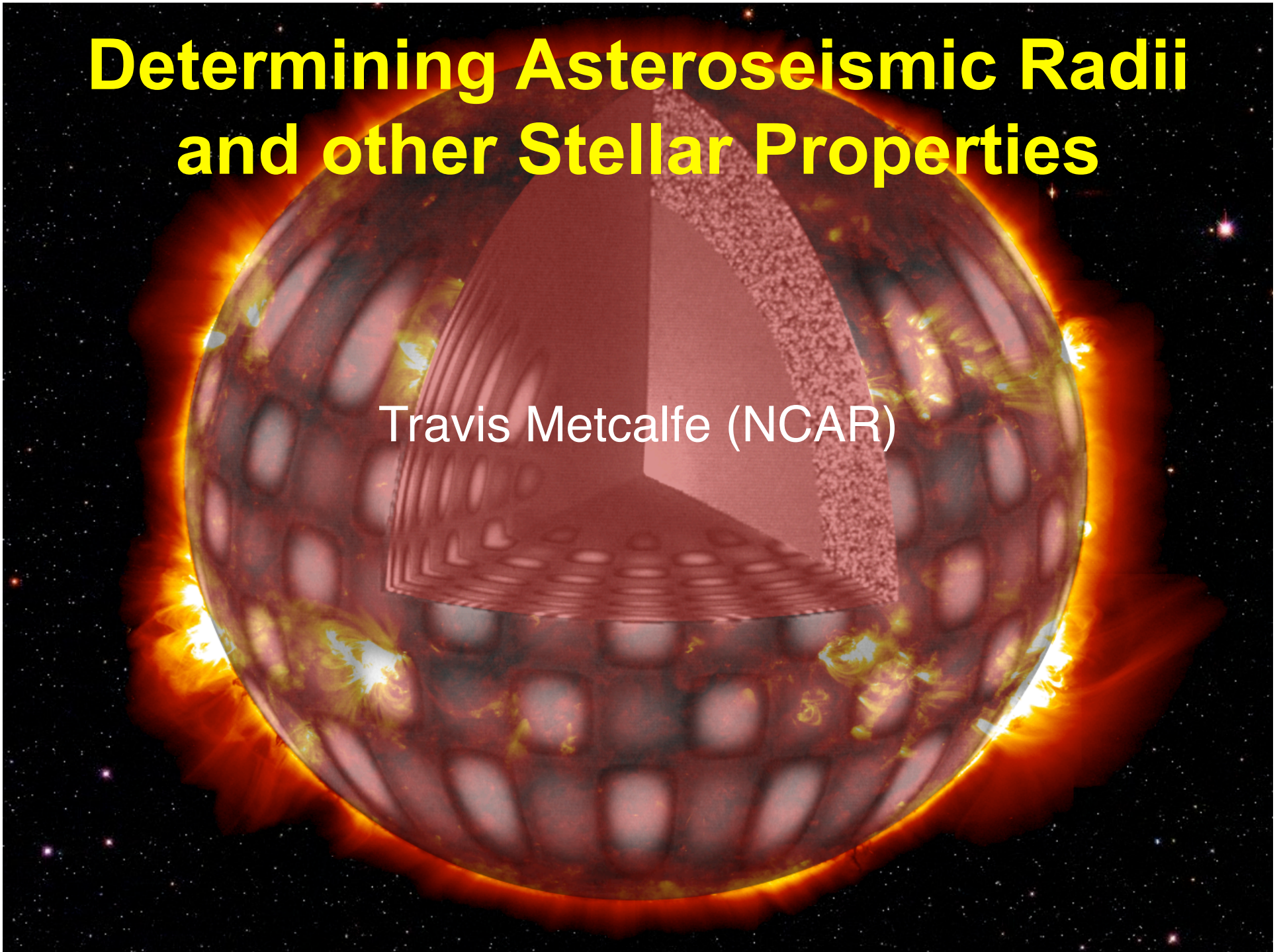
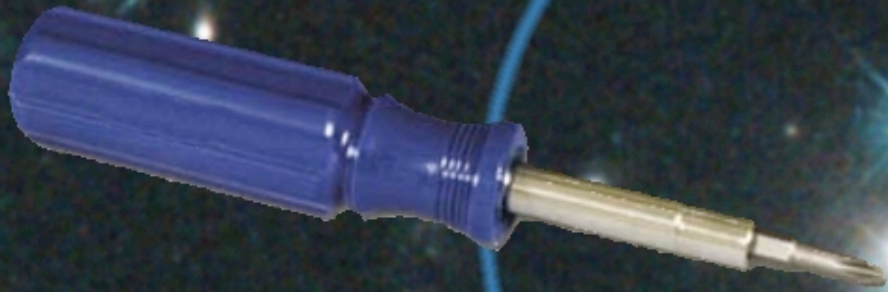


Determining Asteroseismic Radii and other Stellar Properties

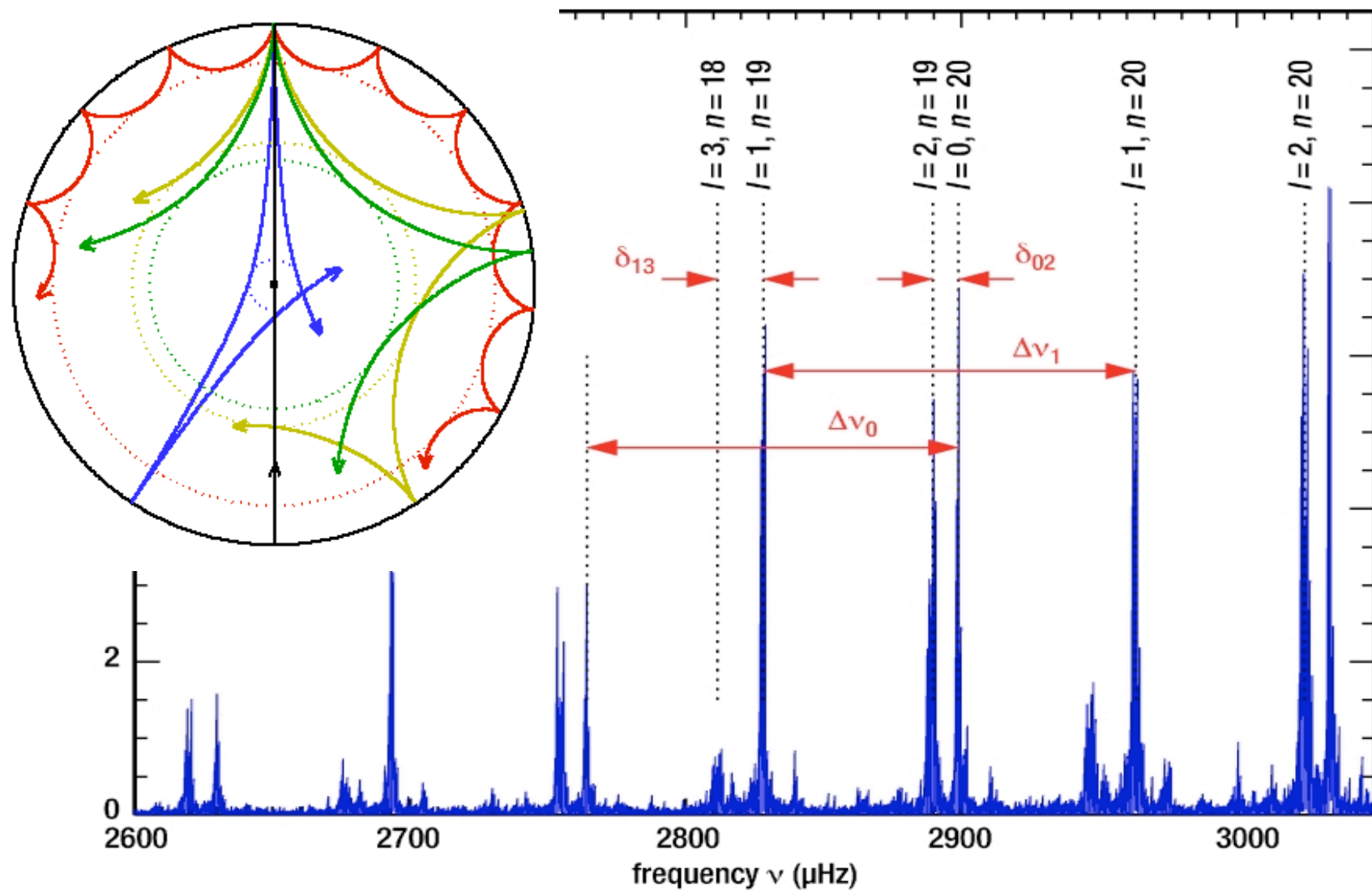
Travis Metcalfe (NCAR)



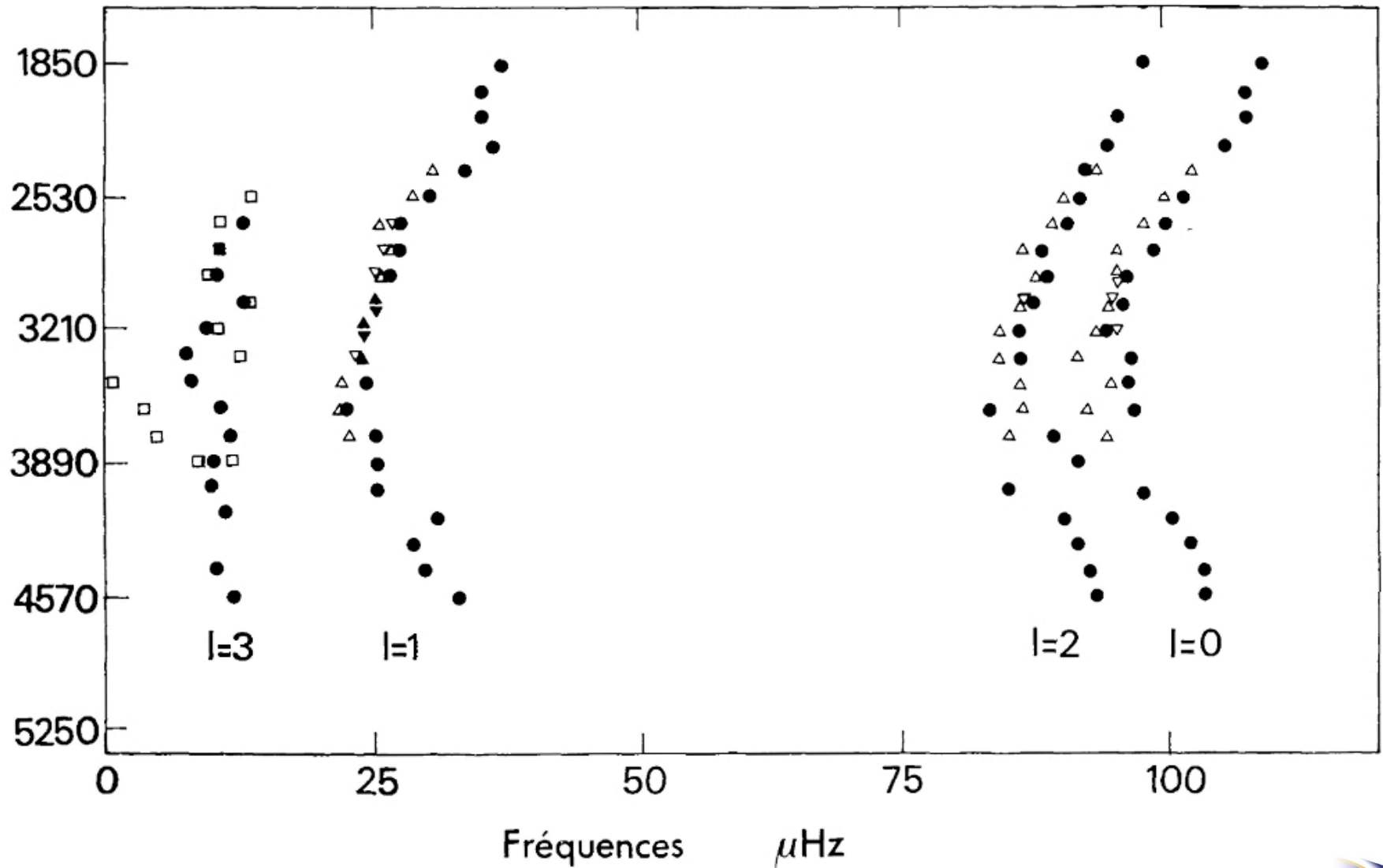
Wampler's screwdriver



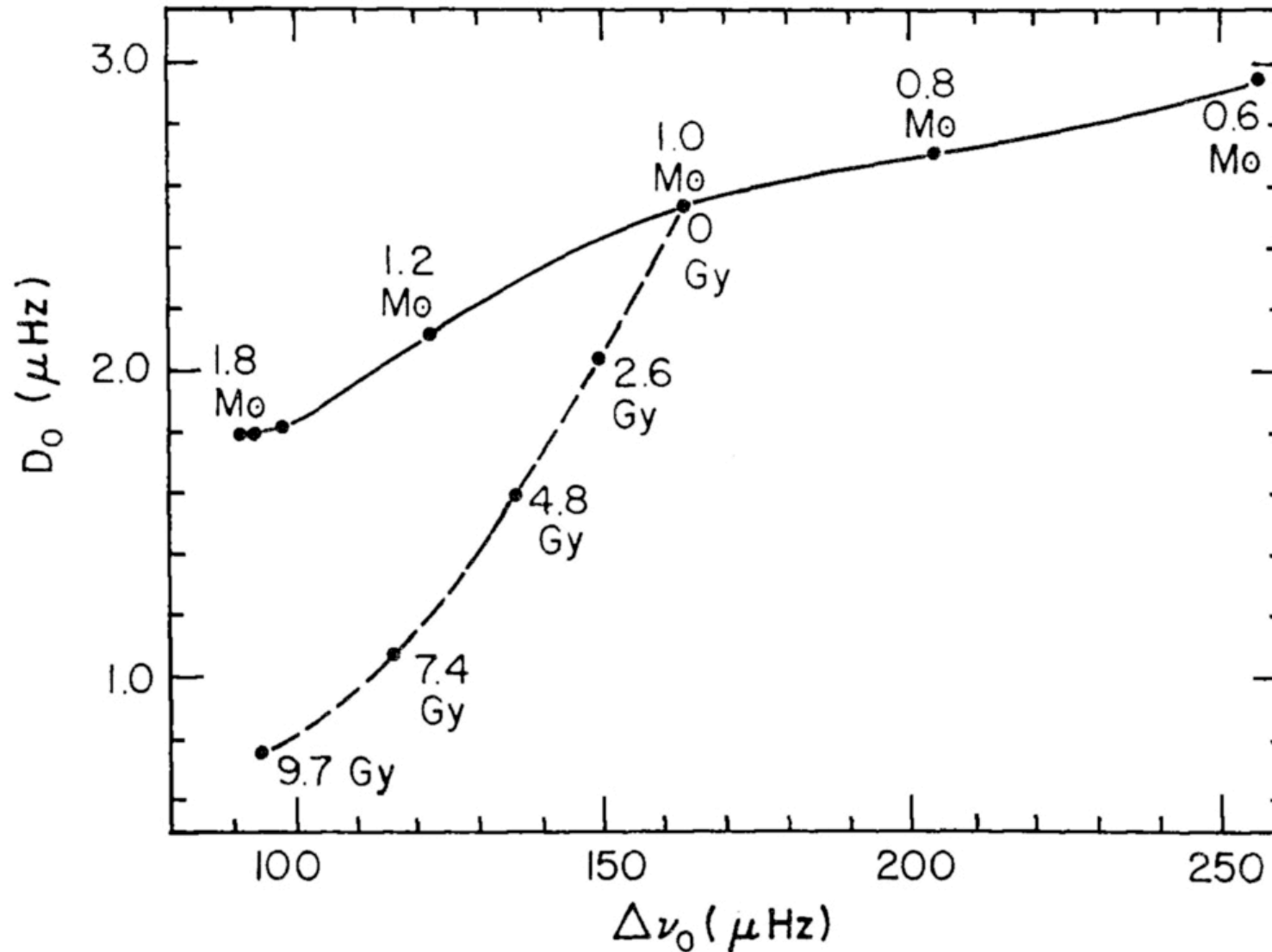
Frequency spacings



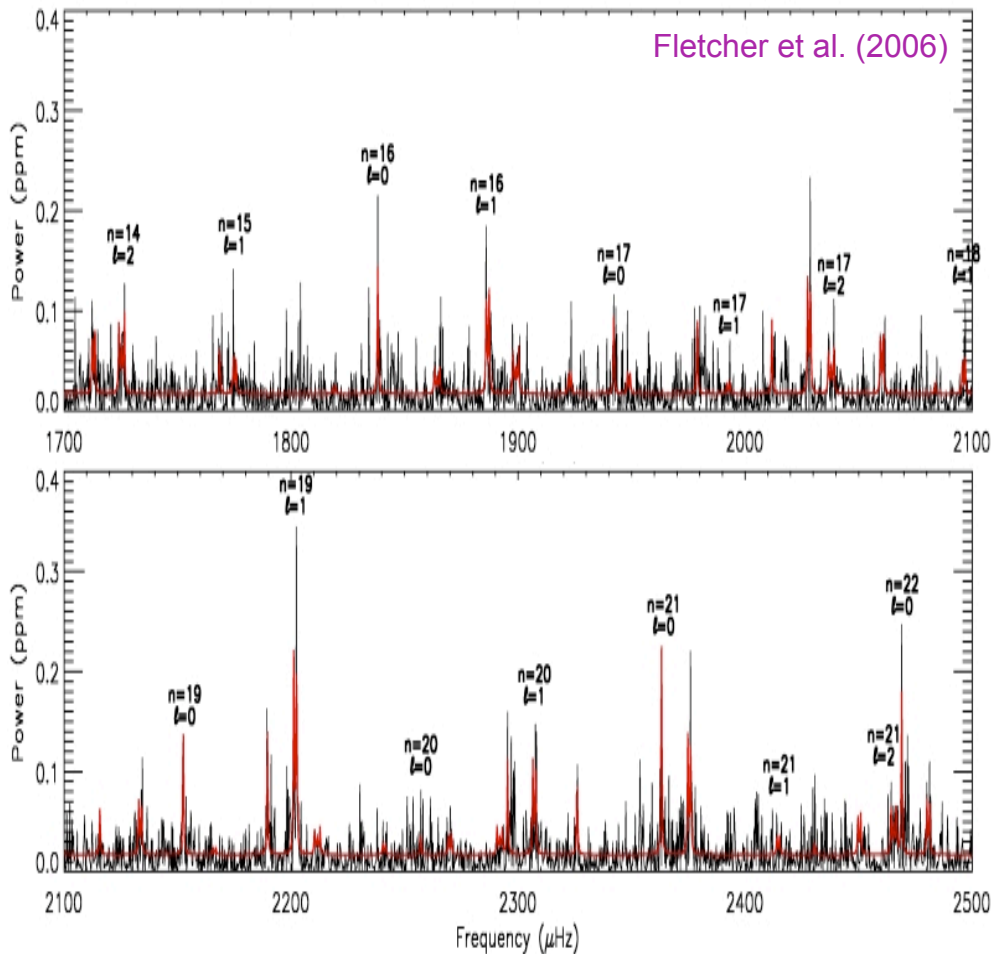
Échelle diagram



Asteroseismic H-R diagram

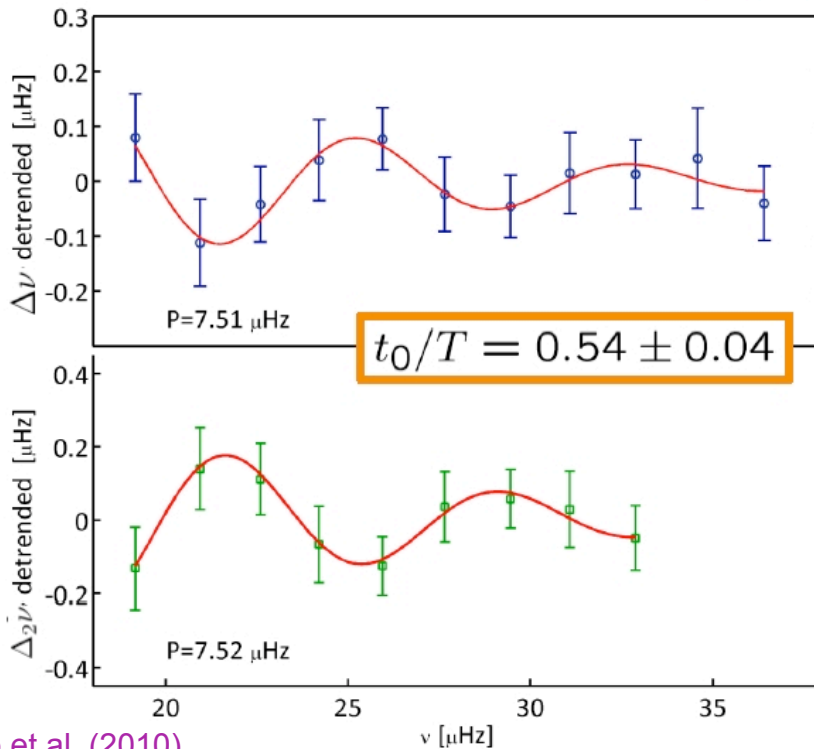
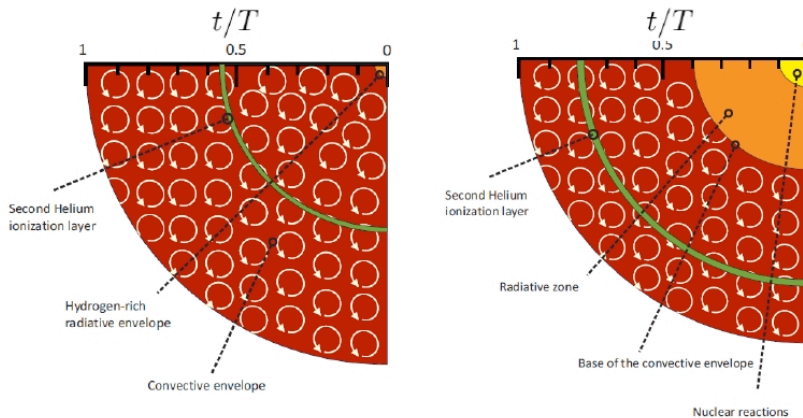


Differential rotation



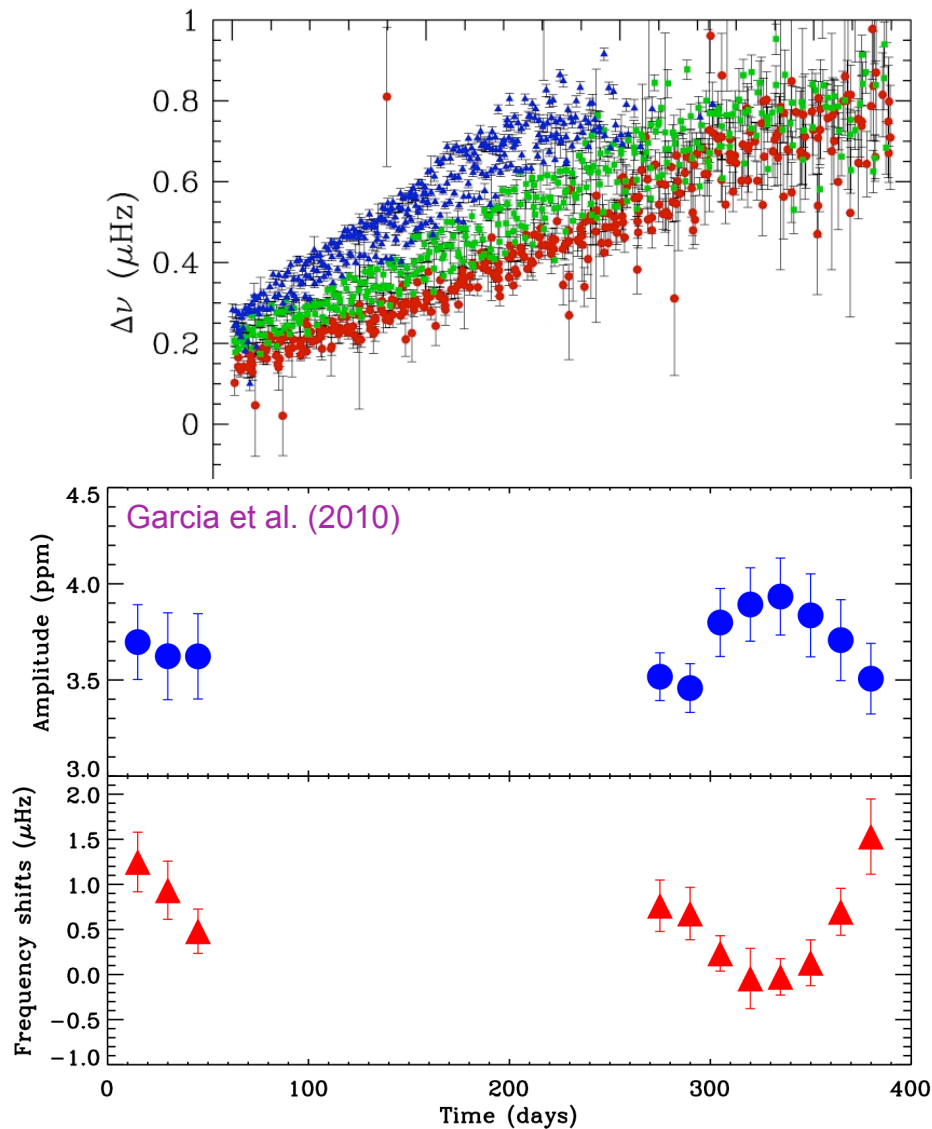
- Three seasons of precise MOST photometry for the solar-type star κ^1 Ceti
- Latitudinal differential rotation pattern has same functional form as Sun
- Asteroseismic splitting as a function of n can probe radial differential rotation

Convection zone depth



- Second differences ($\Delta_2\nu$) measure deviations from even frequency spacing
- Base of the convection zone and He ionization create oscillatory signals
- CoRoT measured the acoustic radius of He ionization in HR 7349

Magnetic activity cycles



- Solar p-mode shifts first detected in 1990, depend on frequency and degree
- Normalizing by a simple parametrization removes most of the dependencies
- CoRoT found frequency shifts in HD49933 with 120-day cycle period

Sun-as-a-star data

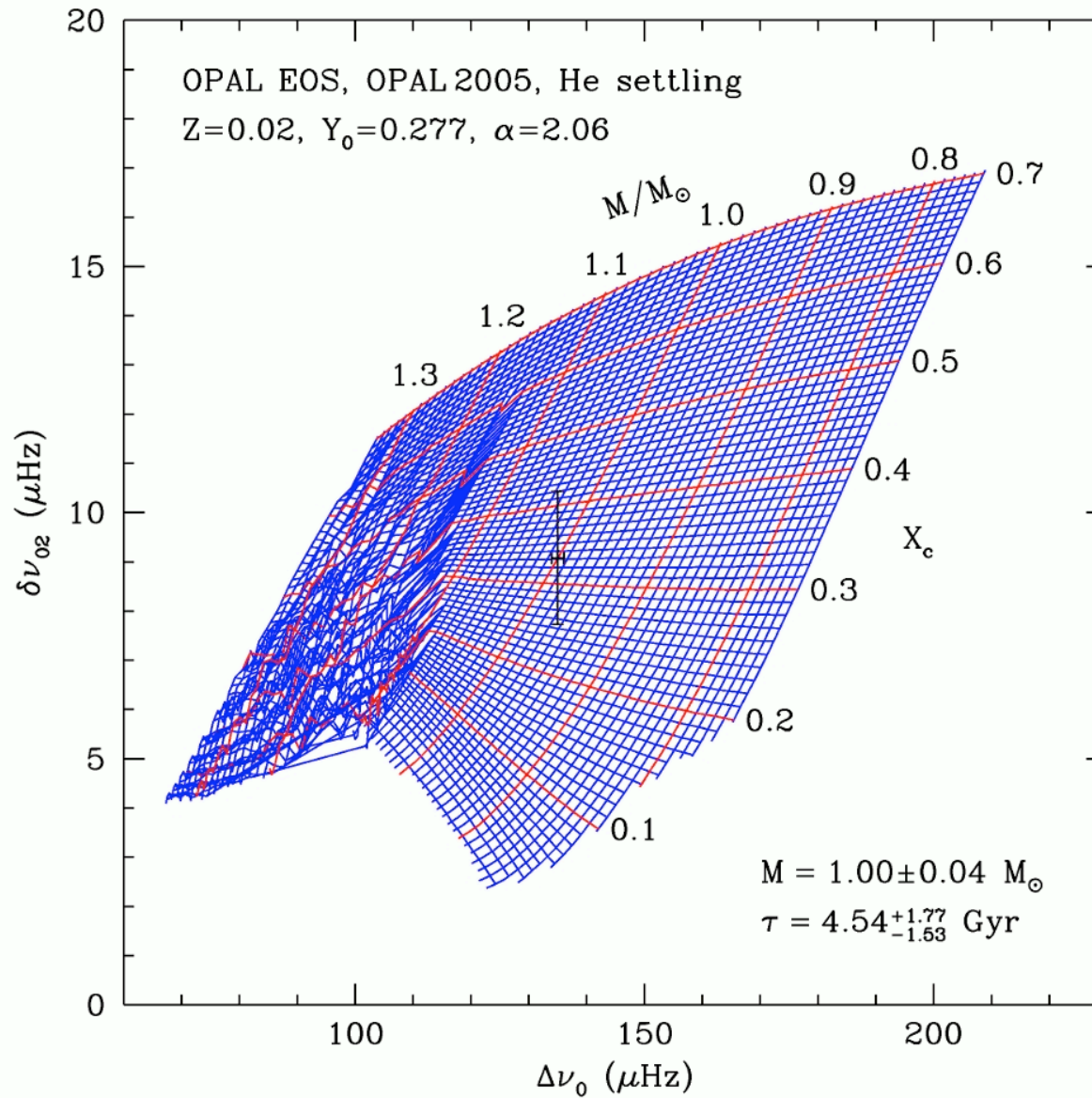
Table 1. Raw, best-fitting frequencies (in μHz) from our pseudo-global peak-bagging analysis.

n	$\ell = 0$	$\ell = 1$	$\ell = 2$	$\ell = 3$	$\ell = 4$
6	972.613 \pm 0.002				
7		1185.592 \pm 0.004			
8	1263.162 \pm 0.012	1329.629 \pm 0.004	1394.680 \pm 0.011		
9	1407.481 \pm 0.006	1472.836 \pm 0.005	1535.861 \pm 0.008	1591.575 \pm 0.014	
10	1548.336 \pm 0.007	1612.723 \pm 0.007	1674.540 \pm 0.008	1729.092 \pm 0.016	
11	1686.601 \pm 0.011	1749.285 \pm 0.007	1810.314 \pm 0.009	1865.307 \pm 0.019	
12	1822.203 \pm 0.011	1885.091 \pm 0.009	1945.816 \pm 0.013	2001.265 \pm 0.017	
13	1957.431 \pm 0.012	2020.810 \pm 0.010	2082.131 \pm 0.015	2137.821 \pm 0.019	
14	2093.535 \pm 0.013	2156.812 \pm 0.014	2217.698 \pm 0.018	2273.563 \pm 0.026	2324.163 \pm 0.051
15	2228.774 \pm 0.014	2292.032 \pm 0.015	2352.280 \pm 0.017	2407.707 \pm 0.025	2458.716 \pm 0.076
16	2362.823 \pm 0.015	2425.650 \pm 0.014	2485.948 \pm 0.019	2541.754 \pm 0.023	2593.197 \pm 0.053
17	2496.226 \pm 0.016	2559.235 \pm 0.015	2619.761 \pm 0.018	2676.252 \pm 0.022	2728.502 \pm 0.038
18	2629.724 \pm 0.014	2693.437 \pm 0.013	2754.551 \pm 0.016	2811.440 \pm 0.020	2864.349 \pm 0.033
19	2764.211 \pm 0.014	2828.258 \pm 0.013	2889.708 \pm 0.016	2947.075 \pm 0.018	3000.227 \pm 0.034
20	2899.101 \pm 0.012	2963.447 \pm 0.012	3024.839 \pm 0.016	3082.439 \pm 0.022	3136.105 \pm 0.032
21	3033.845 \pm 0.012	3098.287 \pm 0.013	3159.997 \pm 0.017	3217.881 \pm 0.024	3271.864 \pm 0.048
22	3168.726 \pm 0.014	3233.321 \pm 0.016	3295.275 \pm 0.021	3353.580 \pm 0.037	3408.325 \pm 0.069
23	3303.652 \pm 0.019	3368.689 \pm 0.021	3431.006 \pm 0.030	3489.699 \pm 0.049	
24	3439.152 \pm 0.027	3504.397 \pm 0.028	3567.248 \pm 0.041	3626.408 \pm 0.073	
25	3575.083 \pm 0.046	3640.791 \pm 0.036	3703.388 \pm 0.065	3762.917 \pm 0.102	
26	3710.938 \pm 0.086	3777.436 \pm 0.050	3840.118 \pm 0.143	3900.029 \pm 0.155	
27	3847.250 \pm 0.177	3913.995 \pm 0.066	3977.388 \pm 0.297		
28	3984.507 \pm 0.323				

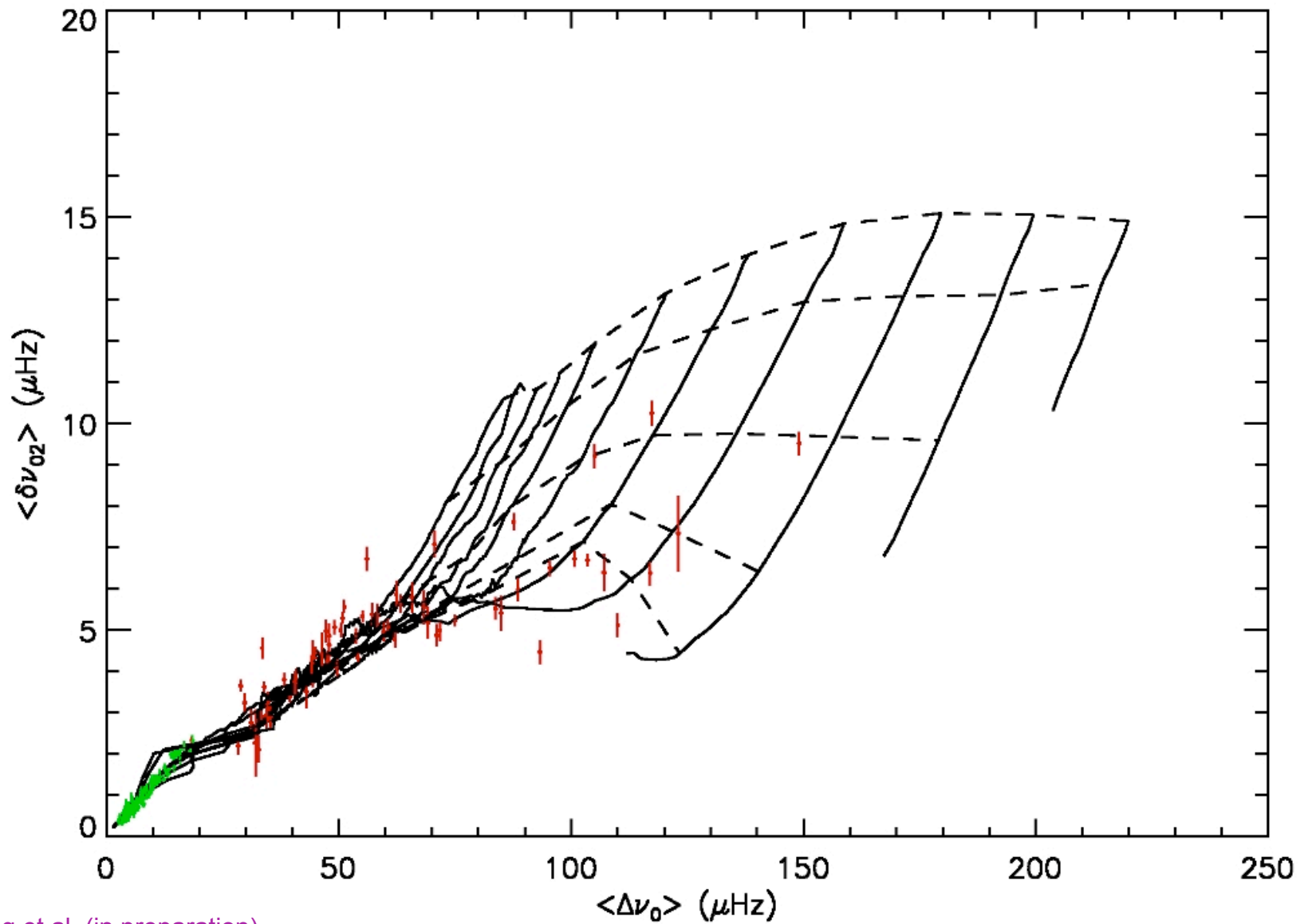
$$\langle \Delta v_0 \rangle = 135.07 \pm 1.03 \mu\text{Hz}$$

$$\langle \delta v_{02} \rangle = 9.08 \pm 1.35 \mu\text{Hz}$$

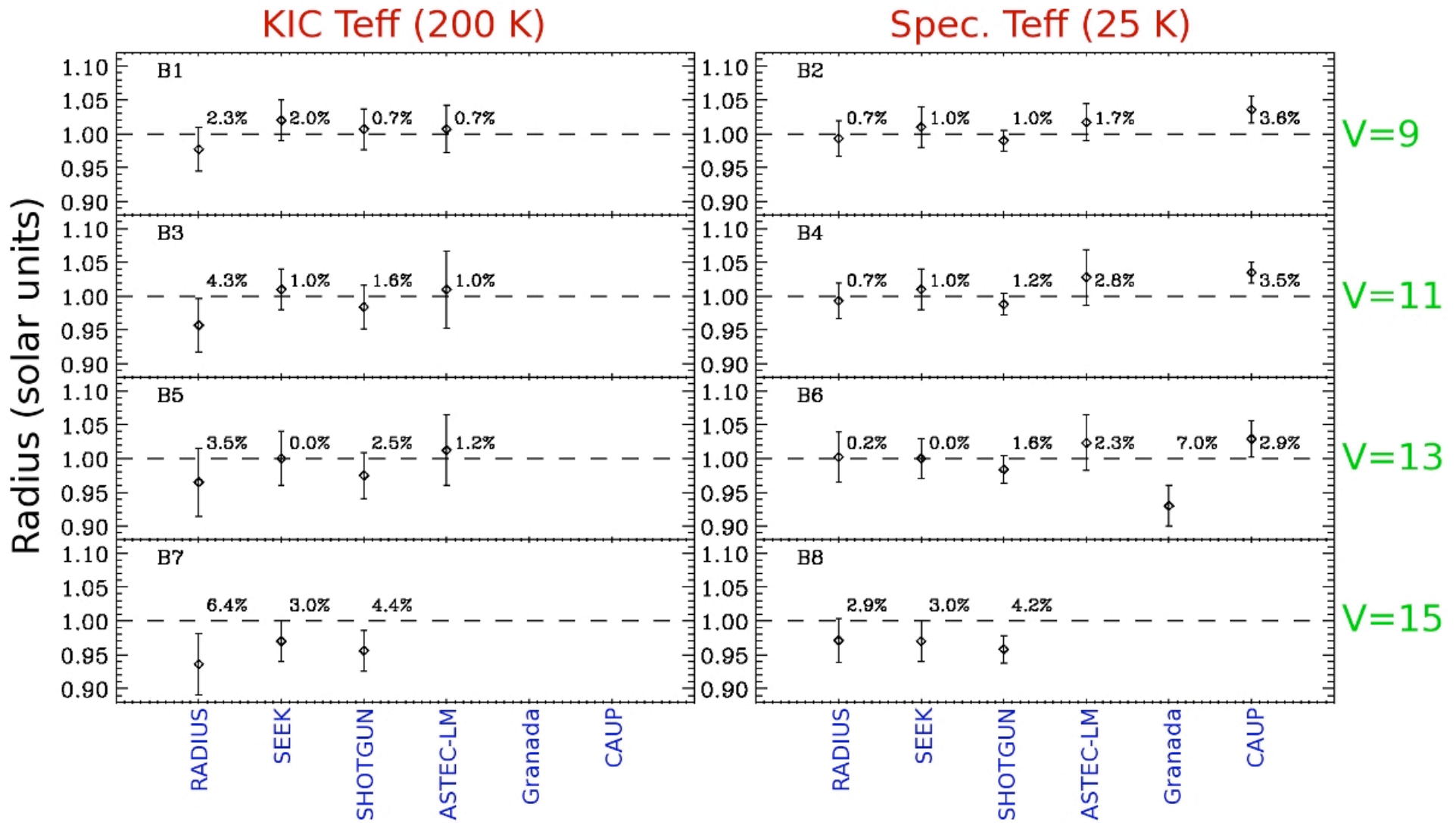
C-D diagram



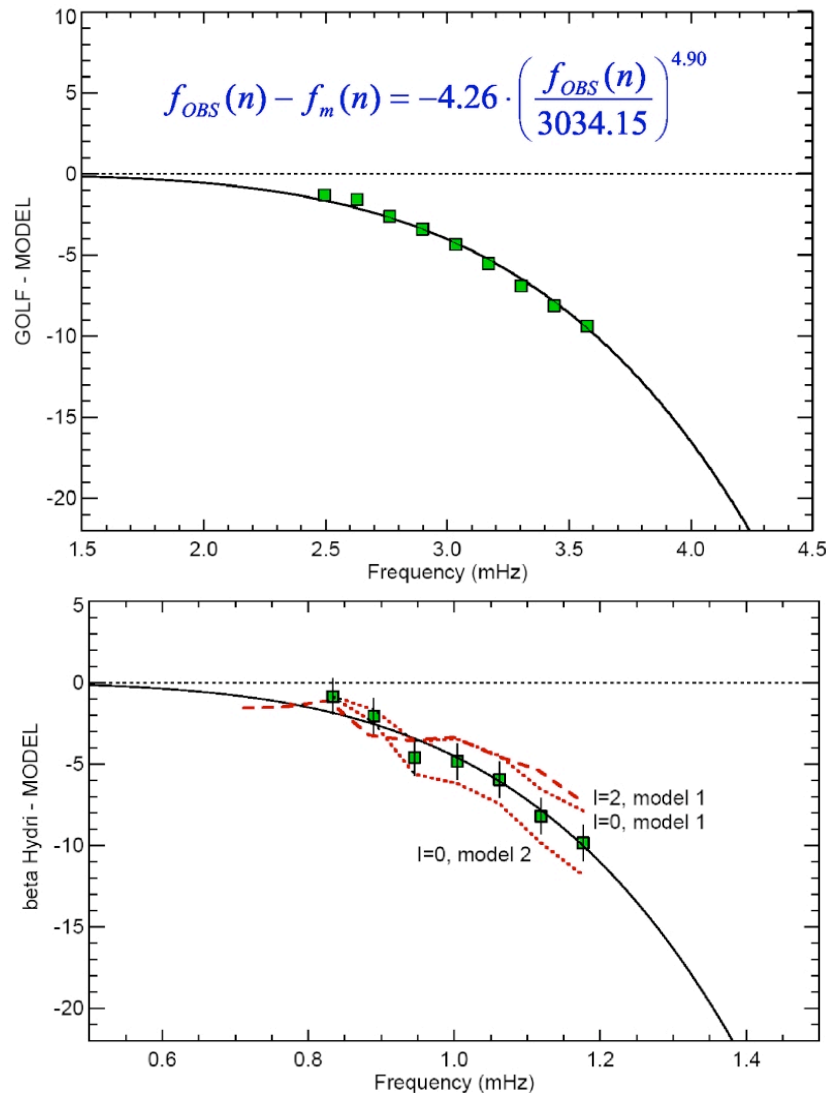
Evolved stars



Pipeline analysis

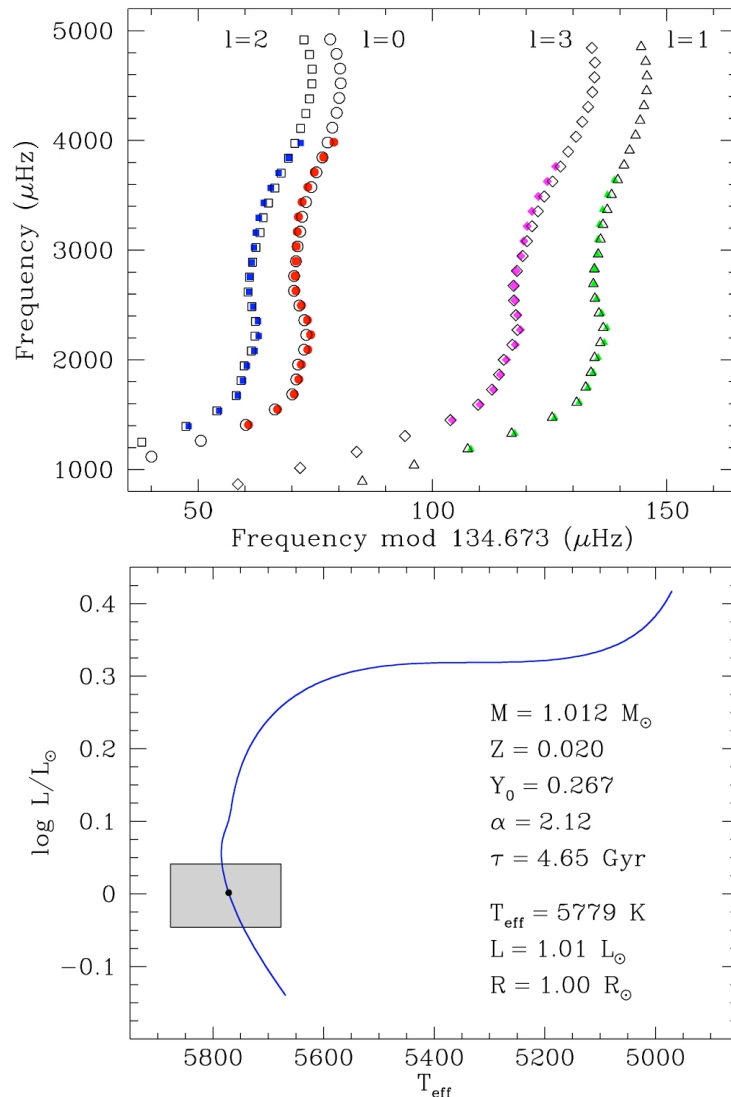


Surface effects



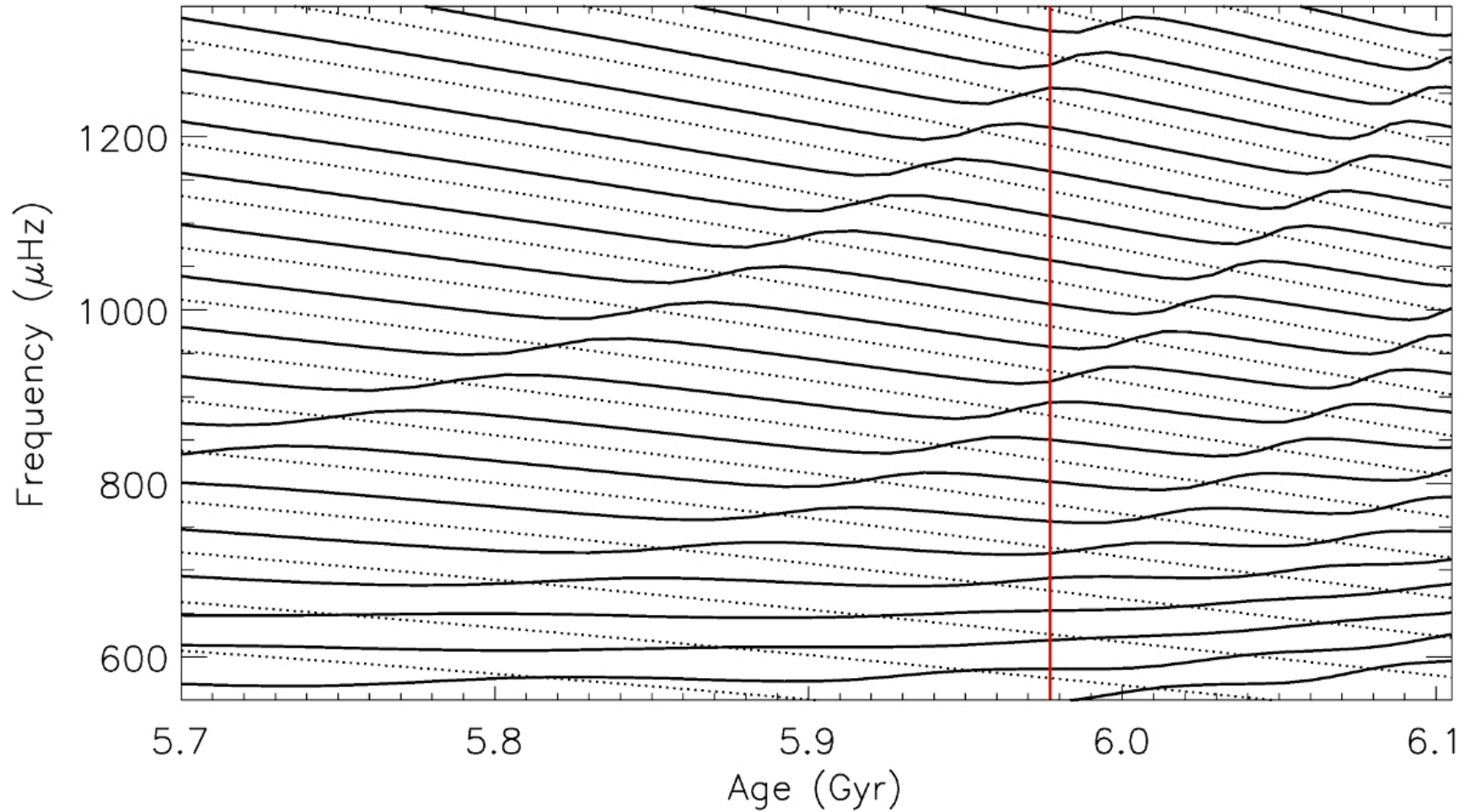
- Incomplete modeling of surface convection zone leads to systematic errors
- Parameterize the offset, calibrate with solar data, apply homology scaling
- For near-optimal models, this procedure is enough to correct β Hydri data

Fitting the frequencies

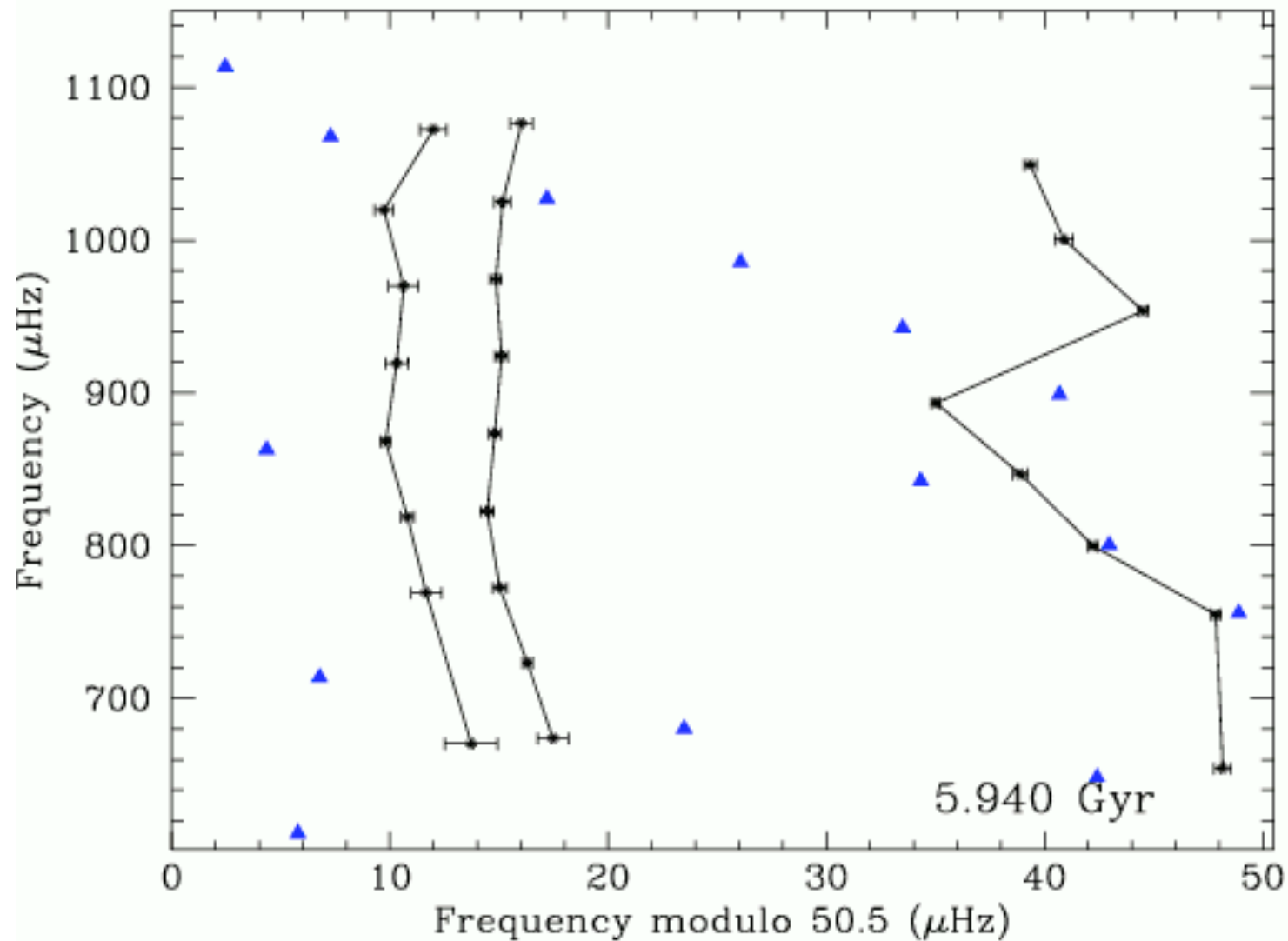


- Fit to 36 frequencies with $l = 0-2$ and constraints on temperature, luminosity
- Matches the observed oscillation frequencies better than about $\pm 2\%$
- **Precision:** radius to $\pm 0.3\%$, mass to $\pm 0.8\%$, age to $\pm 3.7\%$ for the Sun

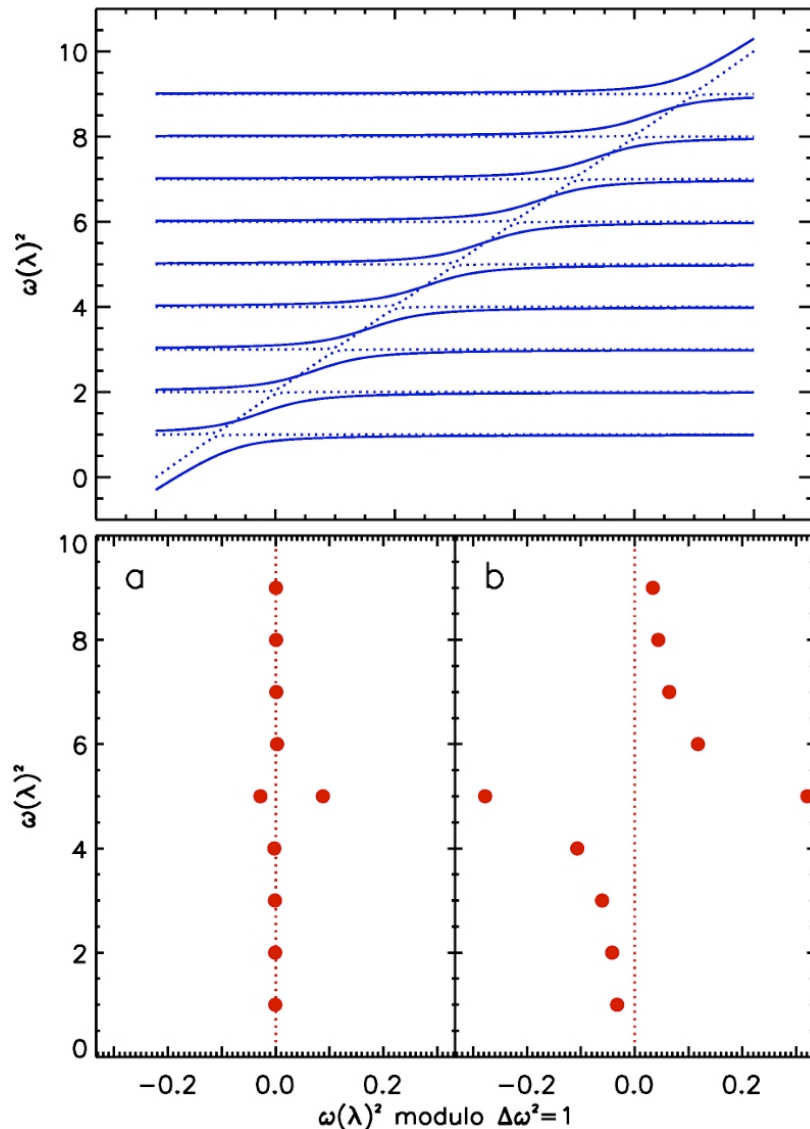
Avoided crossings



Fitting mixed modes



Mode coupling



- Mixed modes behave like g-modes in the core, and p-modes in the envelope
- Strength of the coupling determines size of shift and range of influence
- Coupling in “Gemma” is strong for $l = 1$, may help reveal mixed $l = 2$ modes

Precision of methods

Method	SUN-LIKE			EVOLVED		
	R/R _o	M/M _o	age	R/R _o	M/M _o	age
C-D diagram	2.2%	4.0%	35%	---	---	---
SEEK pipeline	1.8%	3.7%	25%	3.0%	7.1%	29%
RADIUS pipeline	1.1%	3.4%	27%	1.3%	3.3%	10%
Frequencies	0.3%	0.8%	3.7%	1.5%	1.2%	0.8%

- **C-D diagram:** Sun-like, comparing large samples
- **Pipelines:** more precision for hundreds of targets
- **Frequencies:** highest precision for dozens of stars

TeraGrid Science Gateway

AMP Asteroseismic Modeling Portal Search for a Star: Search (Searching the SIMBAD Astronomical Database)

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News: SOHO/GONG 08/15/08 "The TeraGrid Asteroseismic Modeling Portal was unveiled to the community today at the SOHO/GONG meeting in Boulder, Colorado. ..."

User: Username: Password: Login Register? Forgot password?

Active Simulations: What is all this? Rigel 8/12/08, Running, John G. [MIT] Hadar 8/12/08, Running, John G. [MIT] Capella 8/12/08, Running, John G. [MIT] Sirius 8/12/08, Running, John G. [MIT] Pollux 8/12/08, Running, John G. [MIT] Fomalhaut 8/12/08, Complete, John G. [MIT] Capella 8/12/08, Complete, John G. [MIT] Regulus 8/12/08, Complete, John G. [MIT]

Please enter simulation data:

Optimization Observables: (By text file)
(You can upload a text file containing data sets in addition to entering the following form. [Click here for guidelines on file formatting.](#))
 Browse for file Upload

Optimization Observables: (By form)

Parameter key:				[l] Spherical Degree	[v] Frequency (in μHz)	[ϵ] Error (in μHz)									
l	v	ϵ		l	v	ϵ	l	v	ϵ	l	v	ϵ			
1	0	2093.50	0.16	14	1	2291.98	0.14	27	2	2485.86	0.26	40	3	2676.19	0.31
2	0	2228.77	0.18	15	1	2425.59	0.19	28	2	2619.67	0.25	41	3	2811.35	0.29
3	0	2362.77	0.25	16	1	2559.20	0.22	29	2	2754.45	0.24	42	3	2946.98	0.29
4	0	2496.14	0.22	17	1	2693.33	0.21	30	2	2889.54	0.24	43	3	3082.32	0.35
5	0	2629.66	0.21	18	1	2828.10	0.21	31	2	3024.69	0.24	44	3	3217.71	0.40
6	0	2764.13	0.21	19	1	2963.31	0.20	32	2	3159.80	0.28	45	3	3353.39	0.54
7	0	2899.01	0.19	20	1	3098.13	0.22	33	2	3295.09	0.35	46	3	3489.43	0.71
8	0	3033.74	0.21	21	1	3233.15	0.26	34	2	3430.81	0.47	47	3	3626.02	1.01
9	0	3168.61	0.25	22	1	3368.50	0.31	35	2	3567.01	0.57	48	3	3762.45	1.48
10	0	3303.54	0.30	23	1	3504.20	0.40	36	2	3703.30	0.89				
11	0	3439.01	0.42	24	1	3640.35	0.52	37	3	2273.52	0.31				
12	0	3574.90	0.55	25	2	2217.68	0.22	38	3	2407.66	0.34				
13	1	2156.78	0.17	26	2	2352.20	0.31	39	3	2541.68	0.32				

Surface Temperature: [T_{eff}] 5777 Error: [σ_T] 100 (Optional parameter)
Observed luminosity: [L/L_{\odot}] 1.00 Error: [σ_L] 0.10 (Optional parameter)

Simulation Information:
Simulation title: HD_62509-02
Simulation description or notes: (Optional)

Submit Data

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- Web interface to specify observations with errors, or upload as a text file
- Specify parameter values to run one instance of the model, results archived
- Source code available for those with access to large cluster or supercomputer

<http://amp.ucar.edu/>

Summary

- The asteroseismic H-R diagram offers a powerful diagnostic of masses and evolutionary states, but may be subject to a variety of systematic errors.
- Analysis of individual oscillation frequencies can break the degeneracies inherent in methods that fit only the characteristic frequency spacings.
- Kepler observations have sufficient precision to distinguish between various descriptions of the physics, and maybe to require new ingredients.