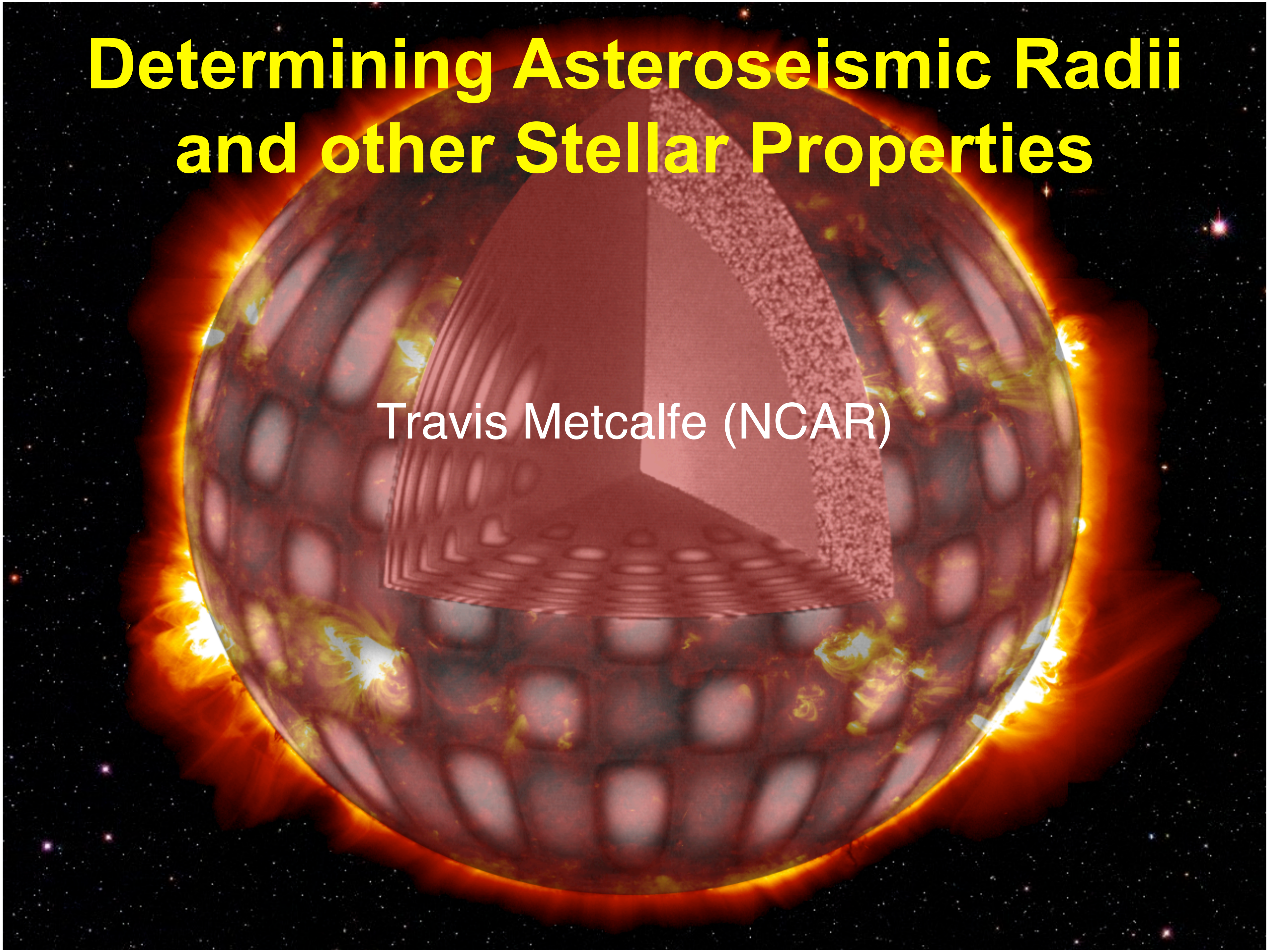
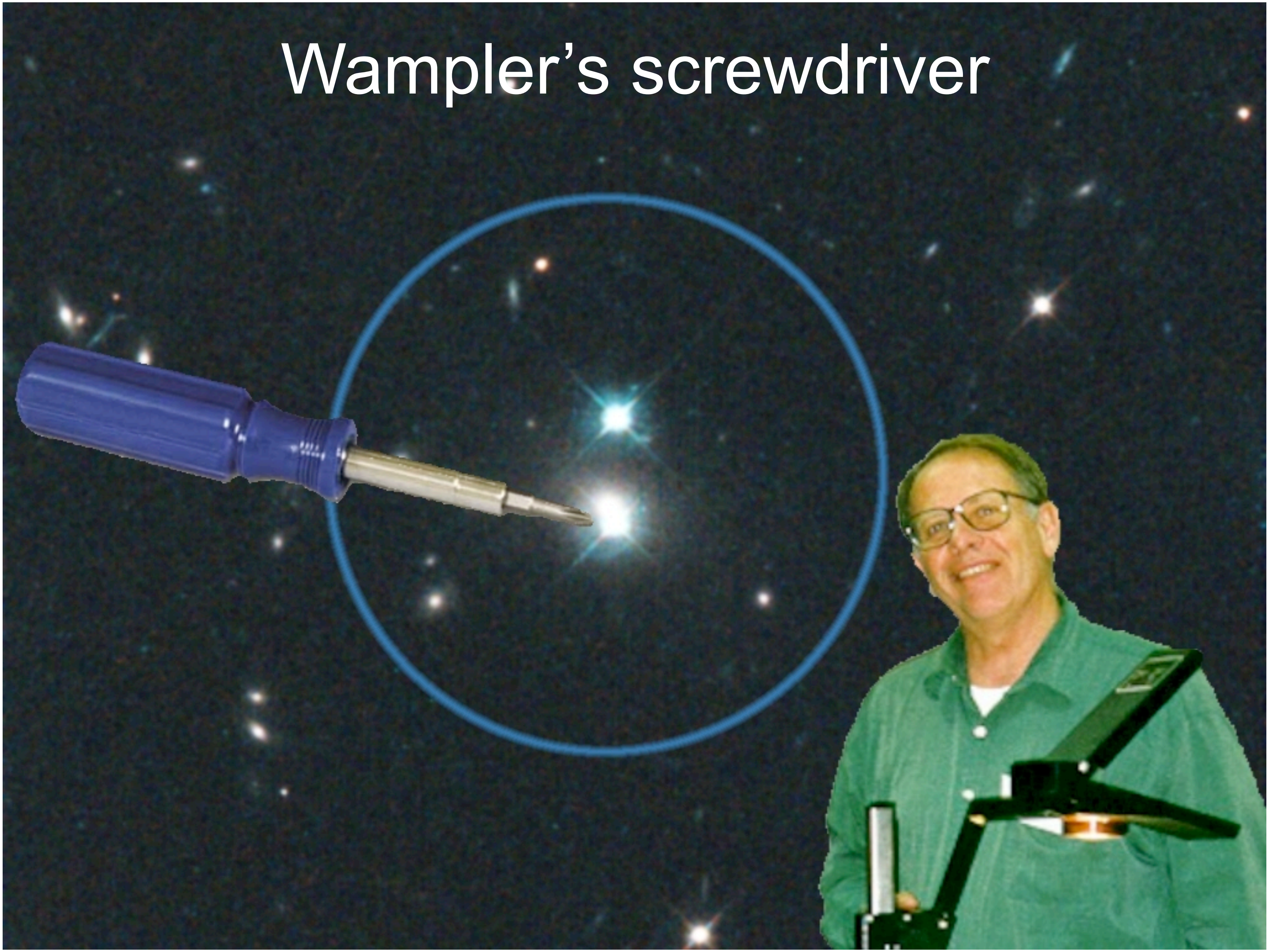
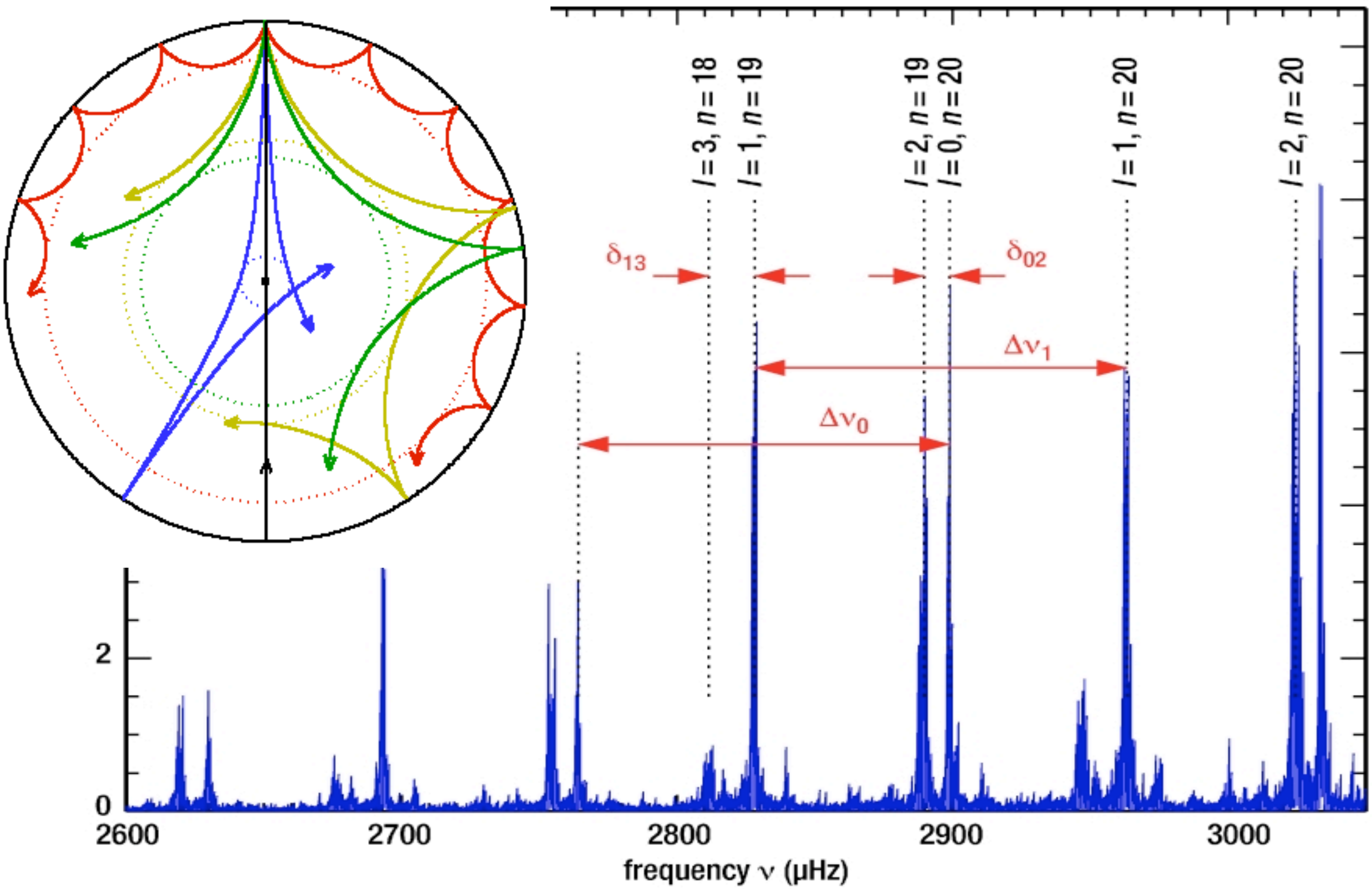
Determining Asteroseismic Radii and other Stellar Properties

Travis Metcalfe (NCAR)




Wampler's screwdriver

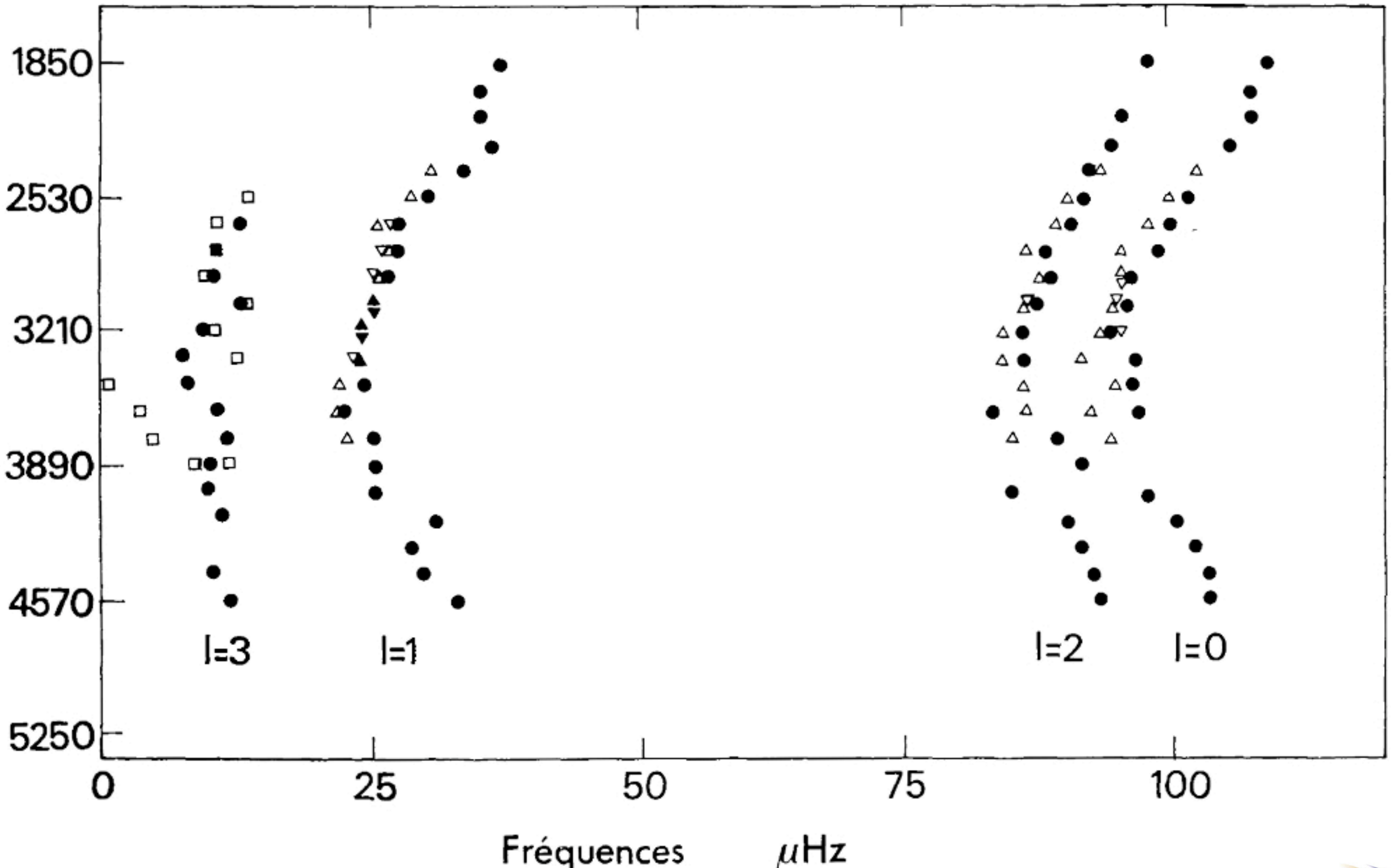
Frequency spacings



Elsworth & Thompson (2004)

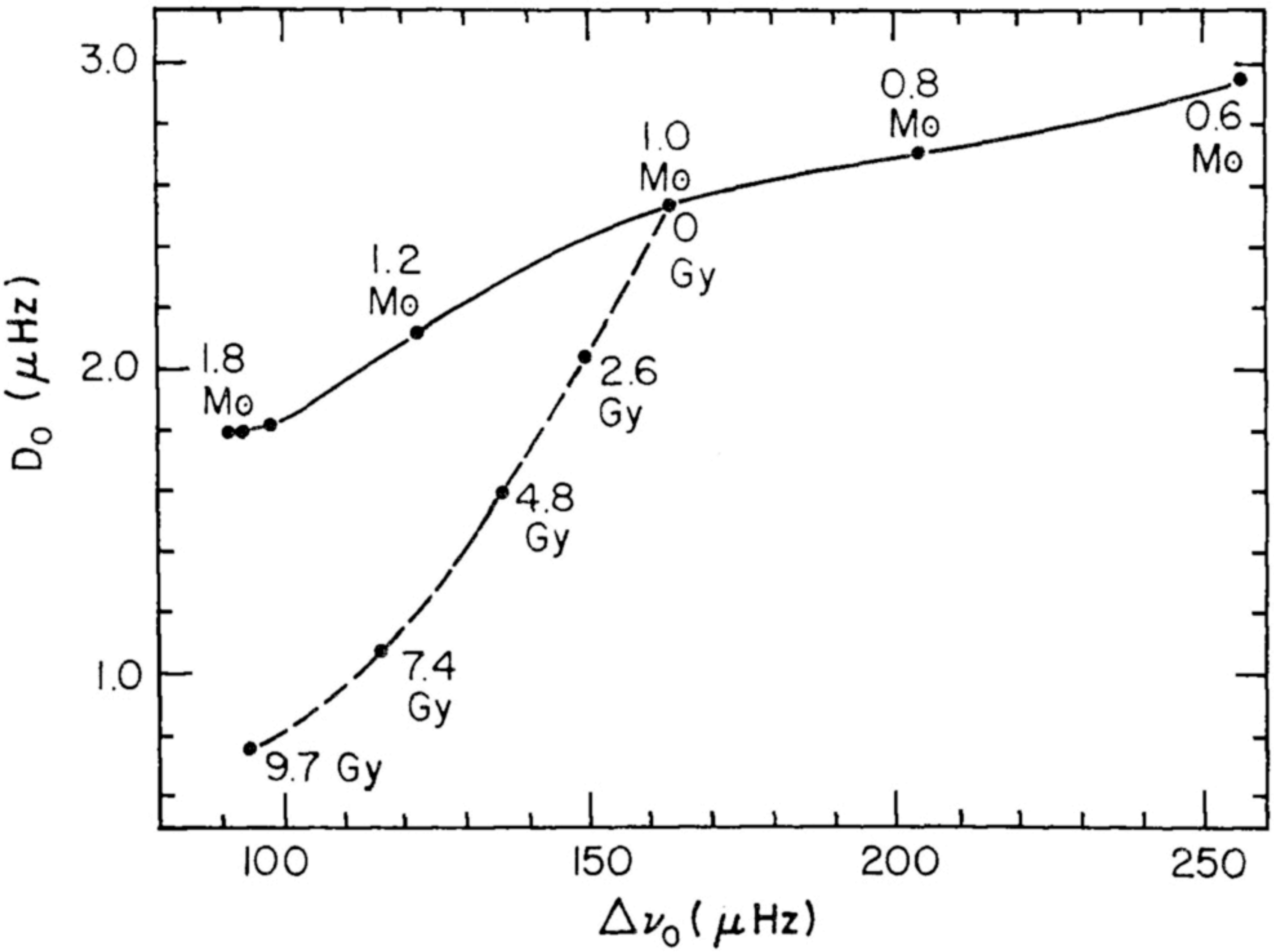
NCAR

Échelle diagram



Grec, Fossat & Pomerantz (1983)

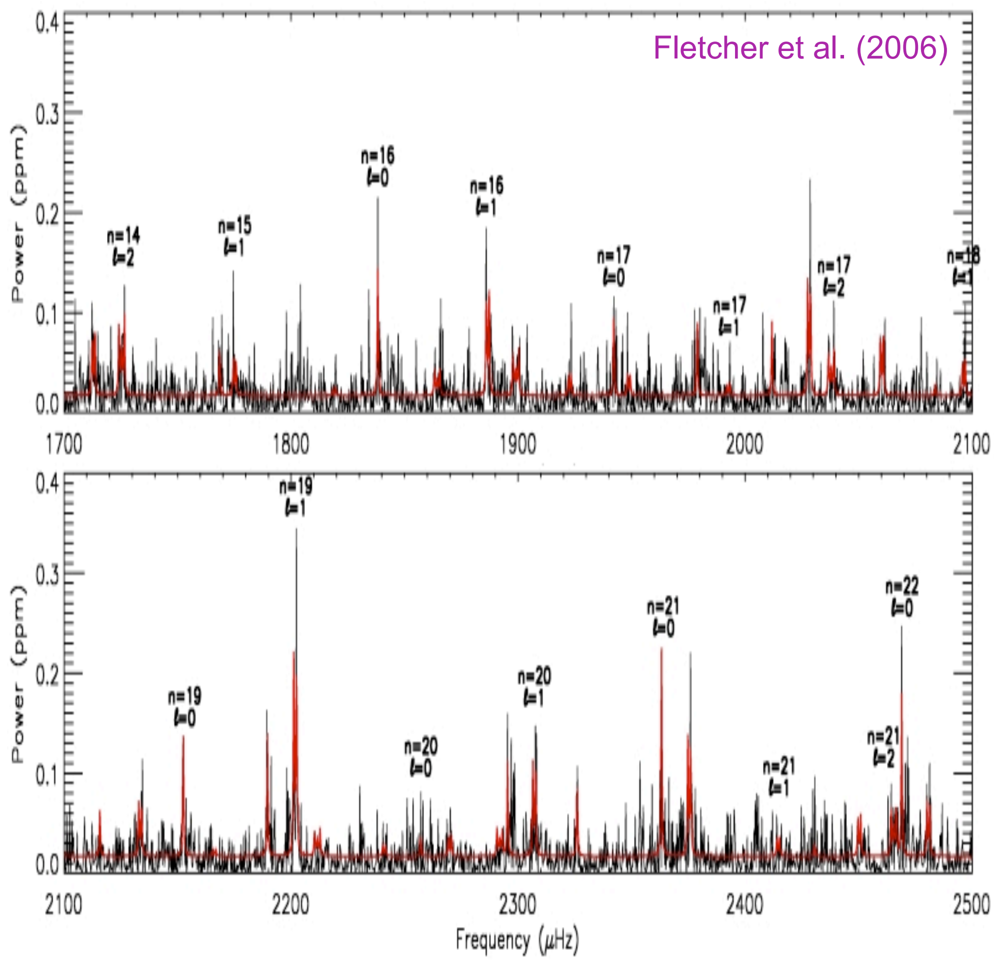
Asteroseismic H-R diagram



Christensen-Dalsgaard (1984)

NCAR

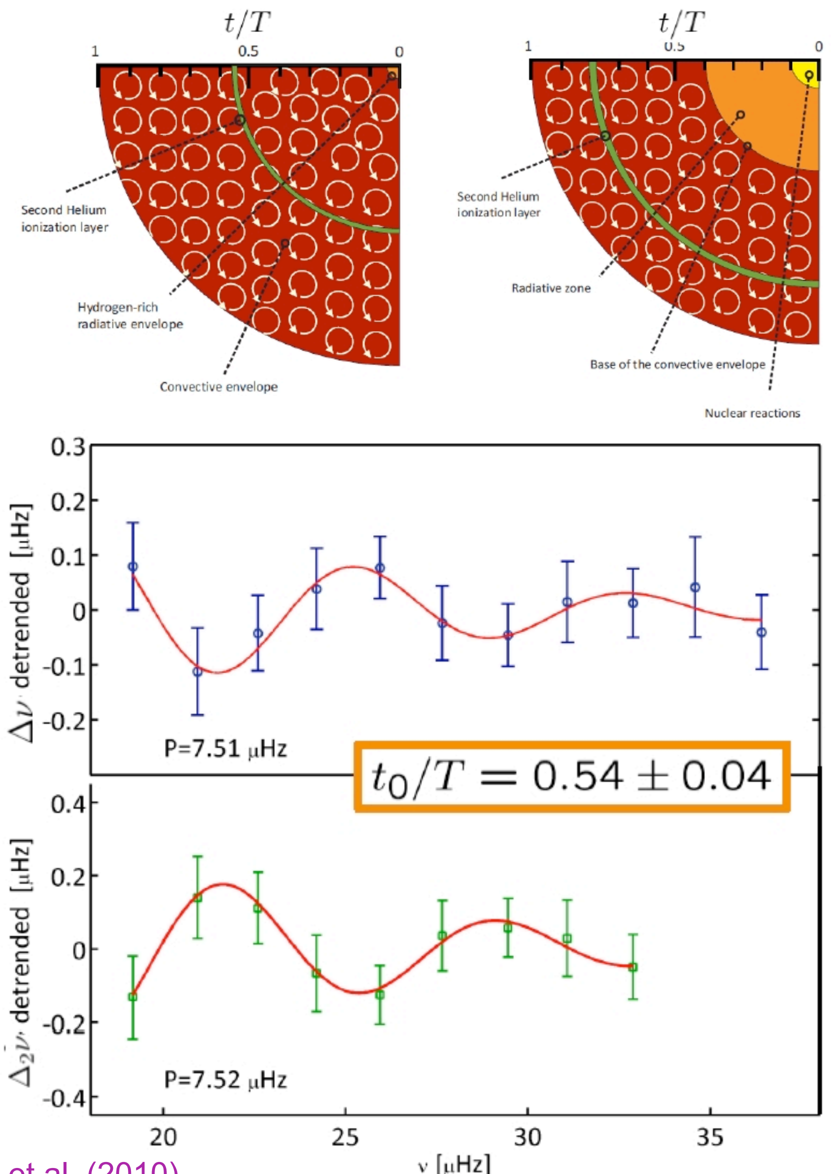
Differential rotation



- 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

NCAR

Convection zone depth

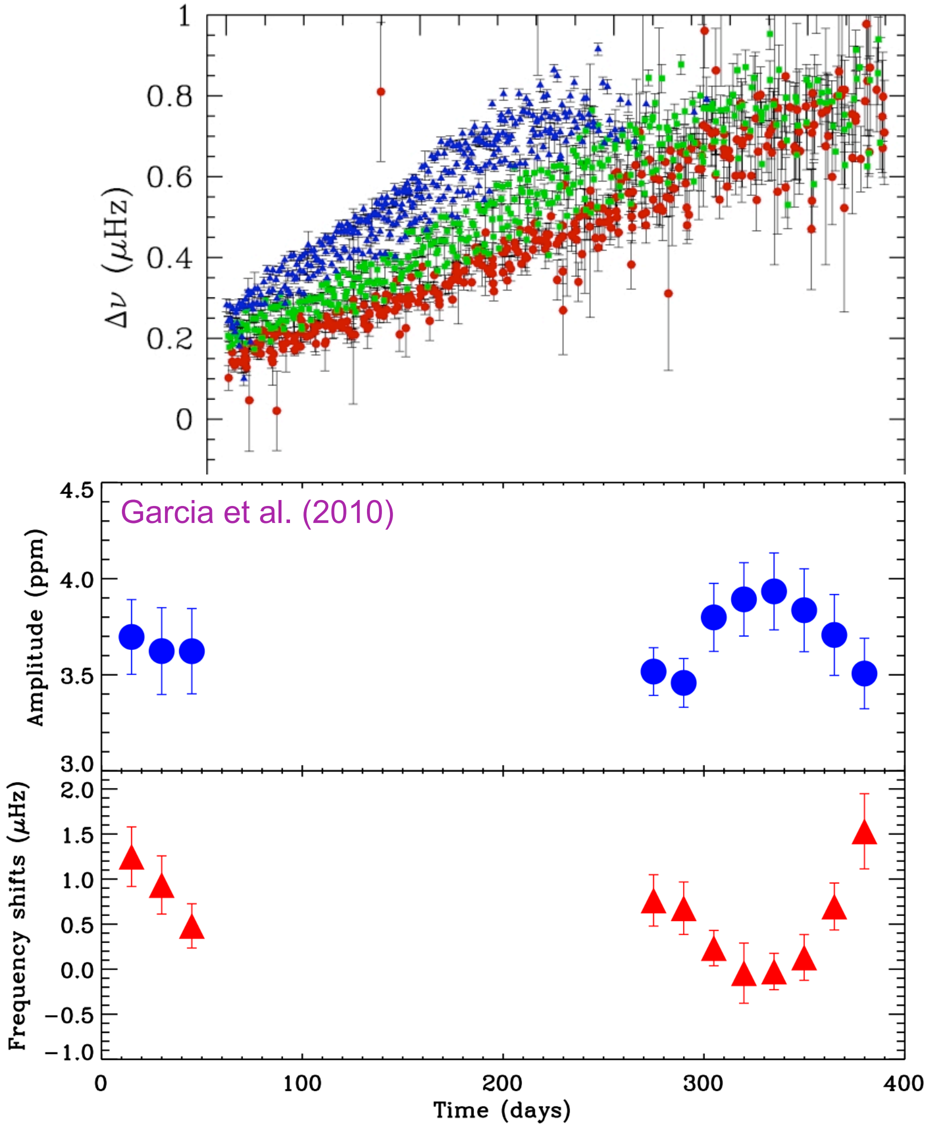


Miglio et al. (2010)

- 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

NCAR

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.

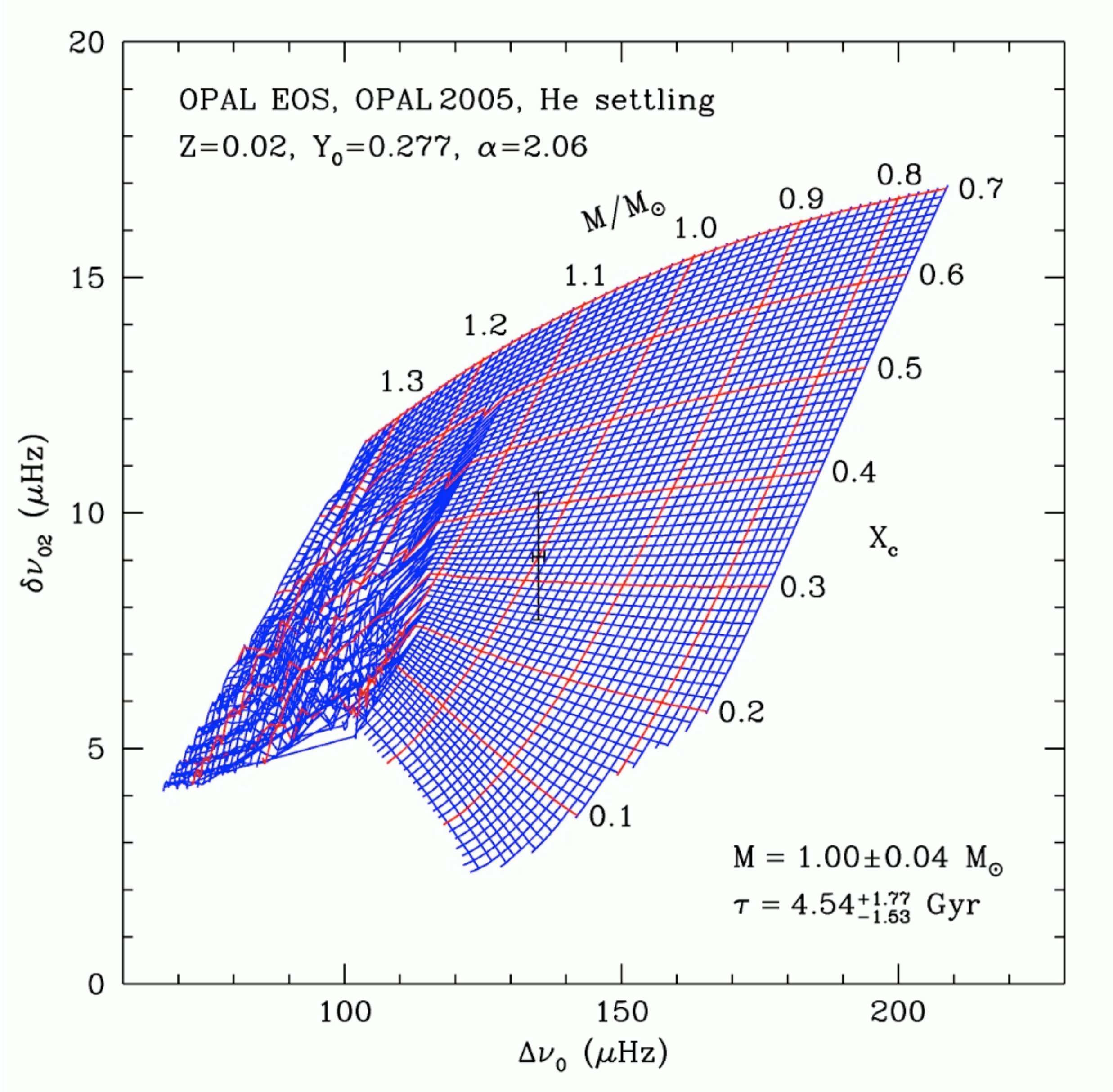
n	$\ell = 0$	$\ell = 1$	$\ell = 2$	$\ell = 3$	$\ell = 4$
6	972.613 ± 0.002				
7		1185.592 ± 0.004			
8	1263.162 ± 0.012	1329.629 ± 0.004	1394.680 ± 0.011		
9	1407.481 ± 0.006	1472.836 ± 0.005	1535.861 ± 0.008	1591.575 ± 0.014	
10	1548.336 ± 0.007	1612.723 ± 0.007	1674.540 ± 0.008	1729.092 ± 0.016	
11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

$\langle \Delta\nu_0 \rangle = 135.07 \pm 1.03\ \mu\mathrm{Hz}$

$\langle \delta\nu_{02} \rangle = 9.08 \pm 1.35\ \mu\mathrm{Hz}$

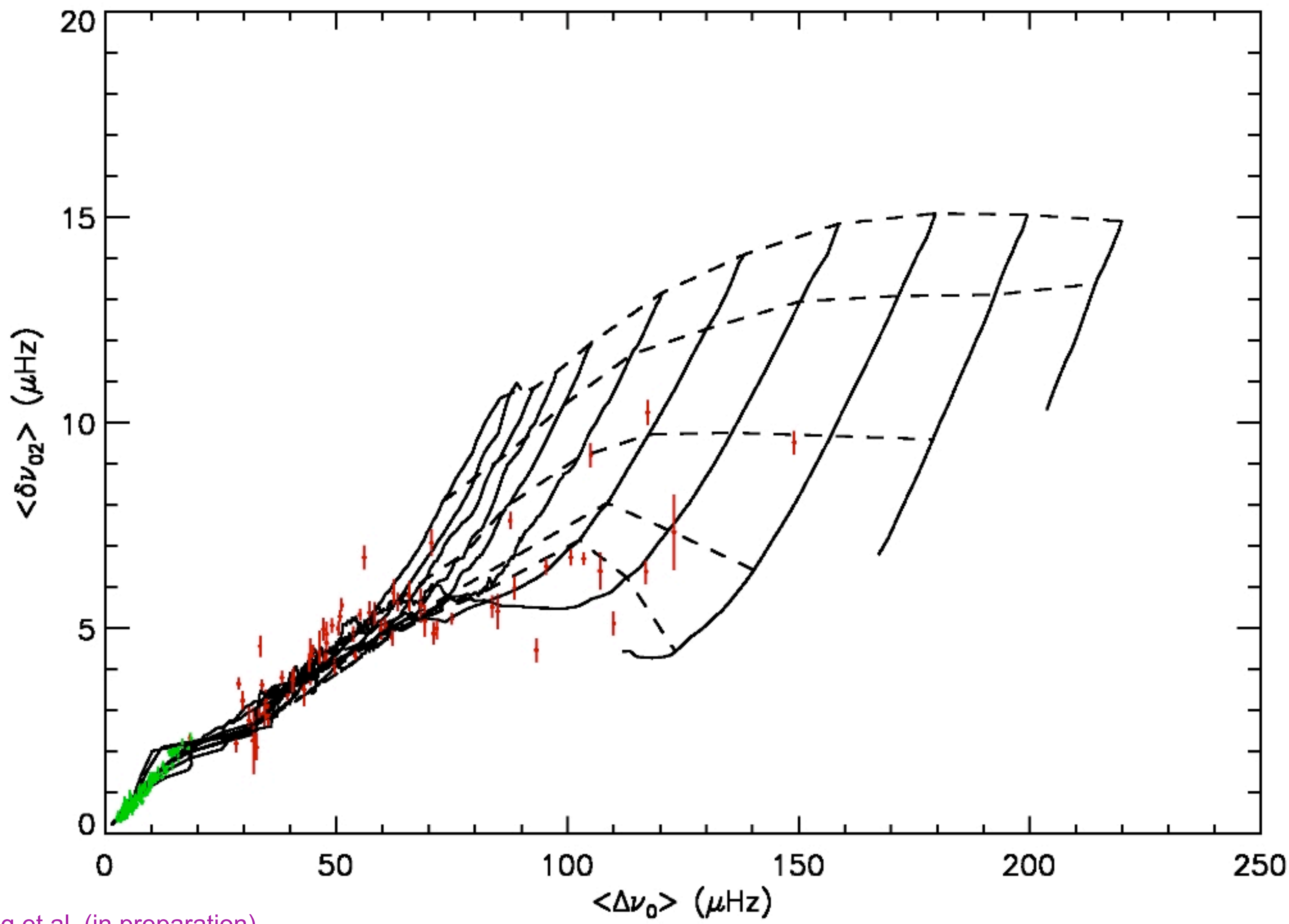
Broomhall et al. (2009)

C-D diagram



NCAR

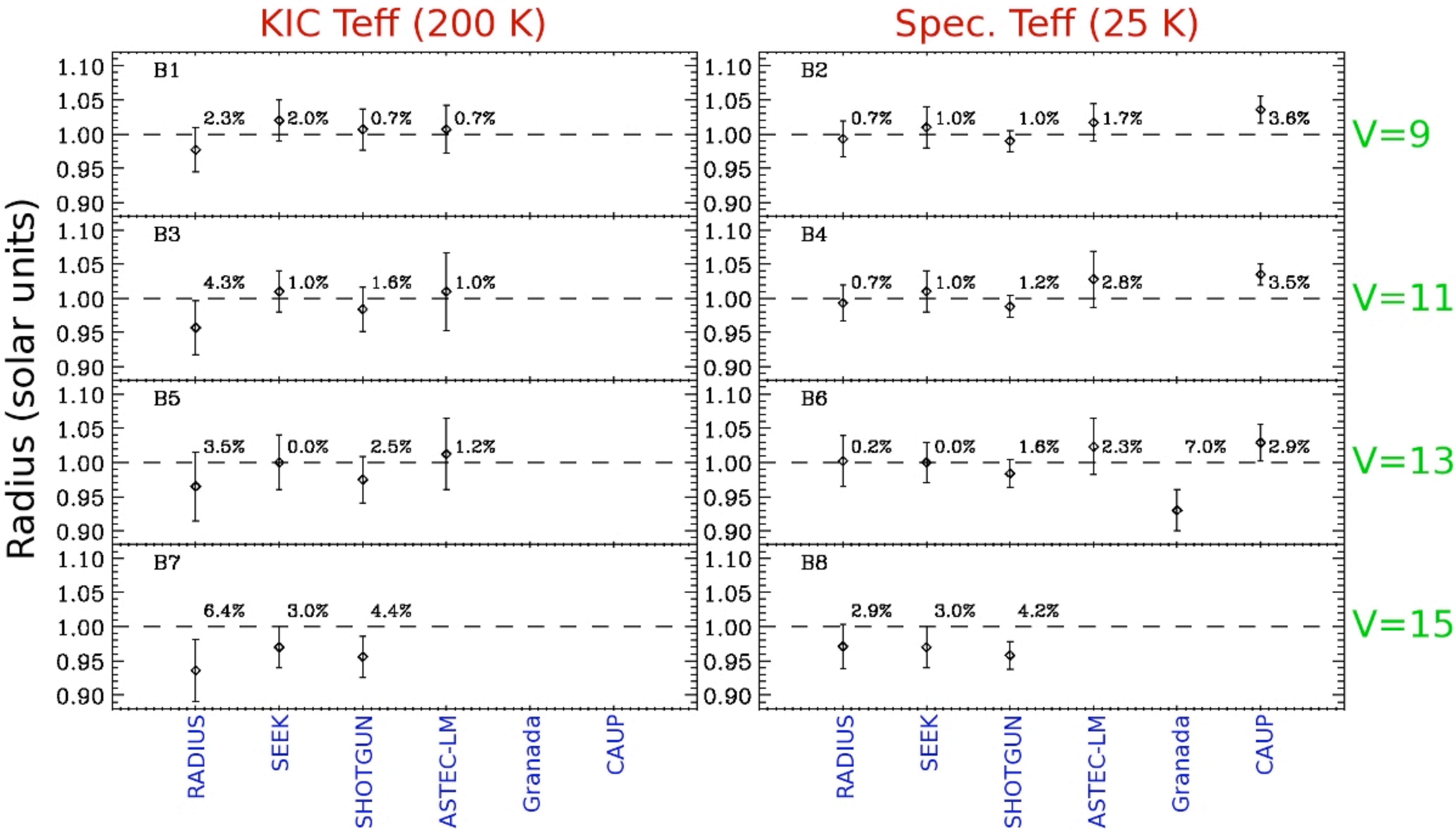
Evolved stars



Bedding et al. (in preparation)

NCAR

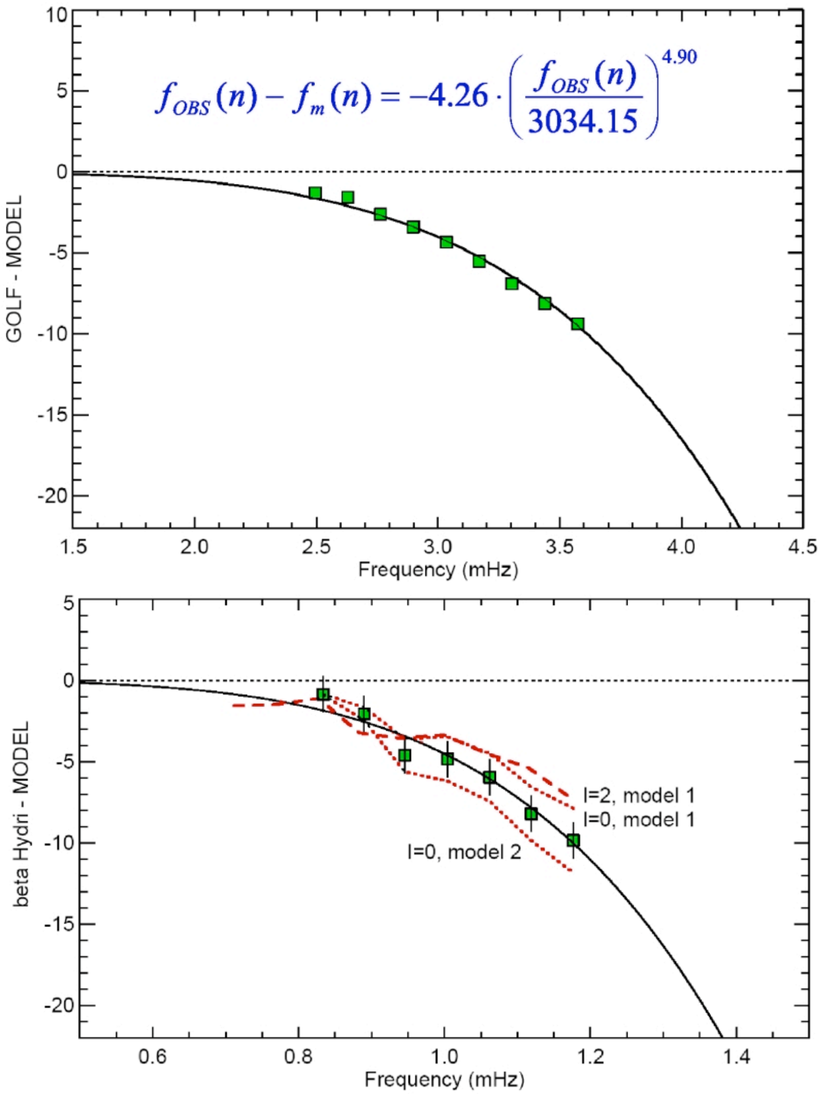
Pipeline analysis



Stello et al. (2009)

NCAR

Surface effects

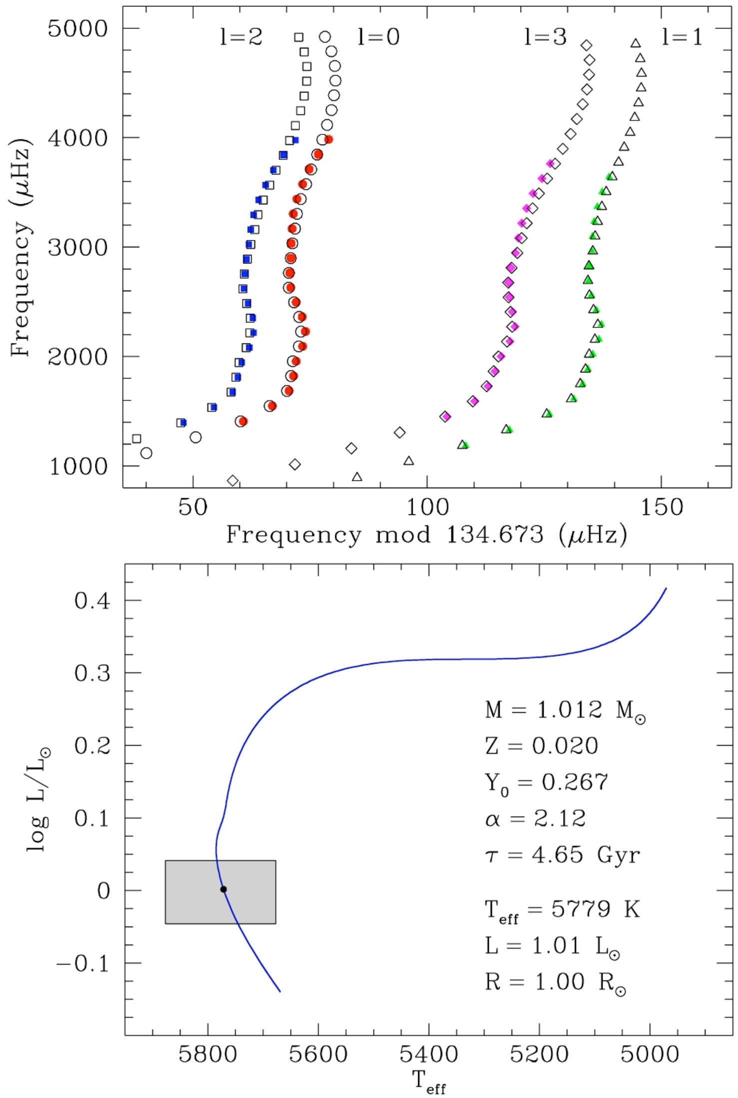


- Incomplete modeling of surface convection zone leads to systematic errors
- Parameterize the offset, calibrate with solar data, apply homology scaling
- For near-optimal models, this procedure is enough to correct β Hydri data

Kjeldsen et al. (2008)

NCAR

Fitting the frequencies

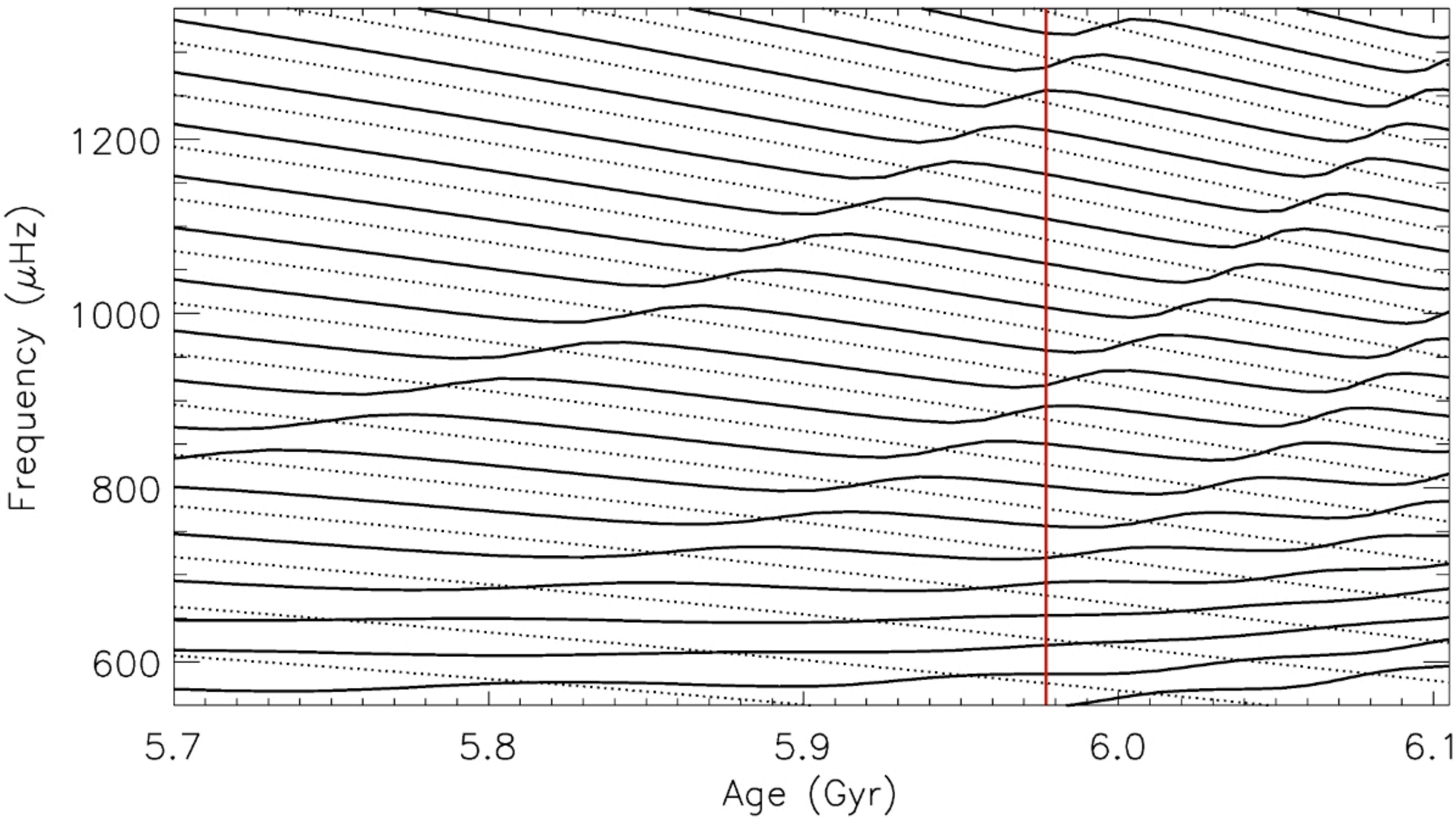


- Fit to 36 frequencies with l = 0-2 and constraints on temperature, luminosity
- Matches the observed oscillation frequencies better than about ±2%
- **Precision:** radius to ±0.3%, mass to ±0.8%, age to ±3.7% for the Sun

Metcalfe et al. (2009)

NCAR

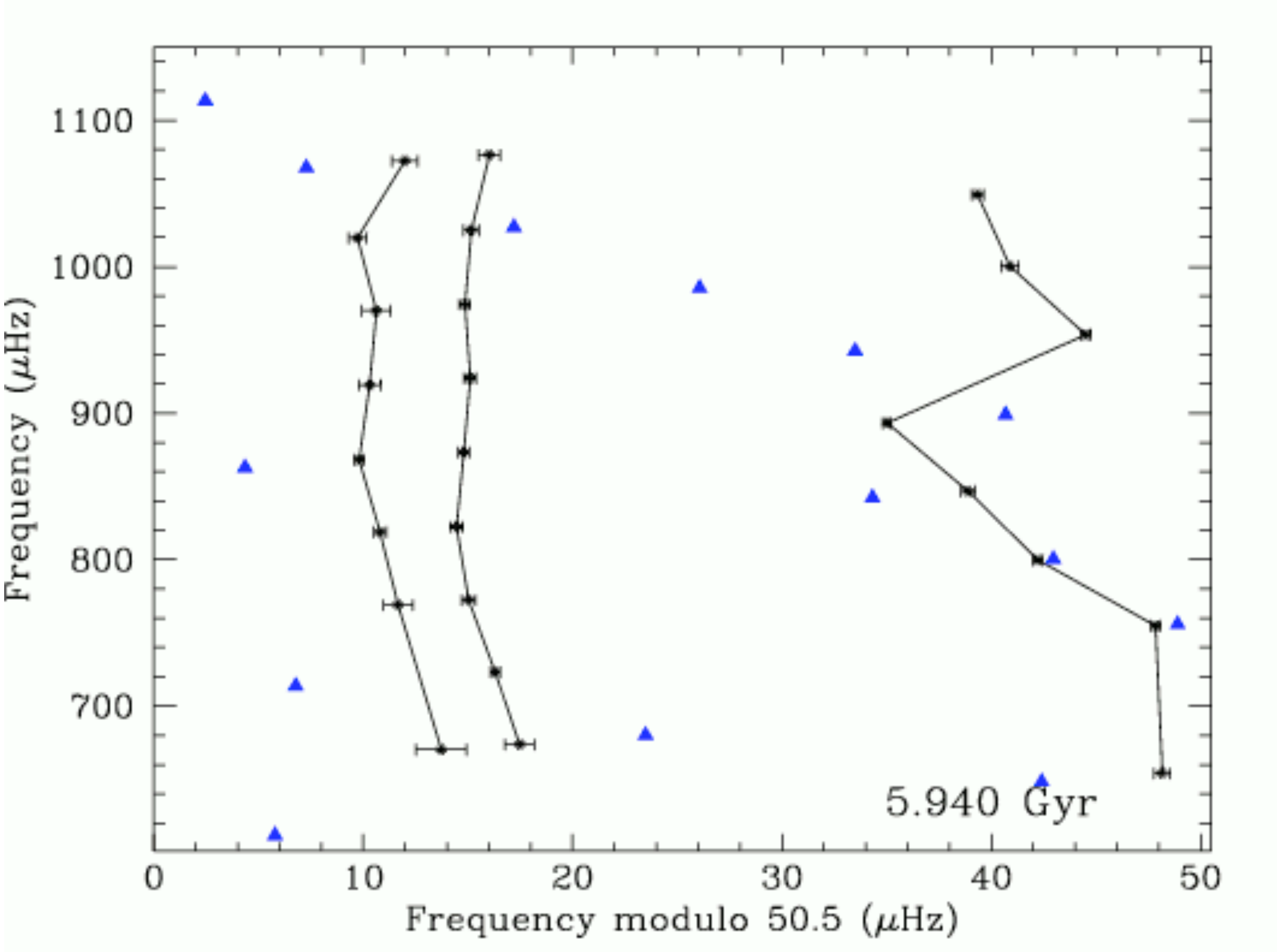
Avoided crossings



Metcalfe et al. (2010)

NCAR

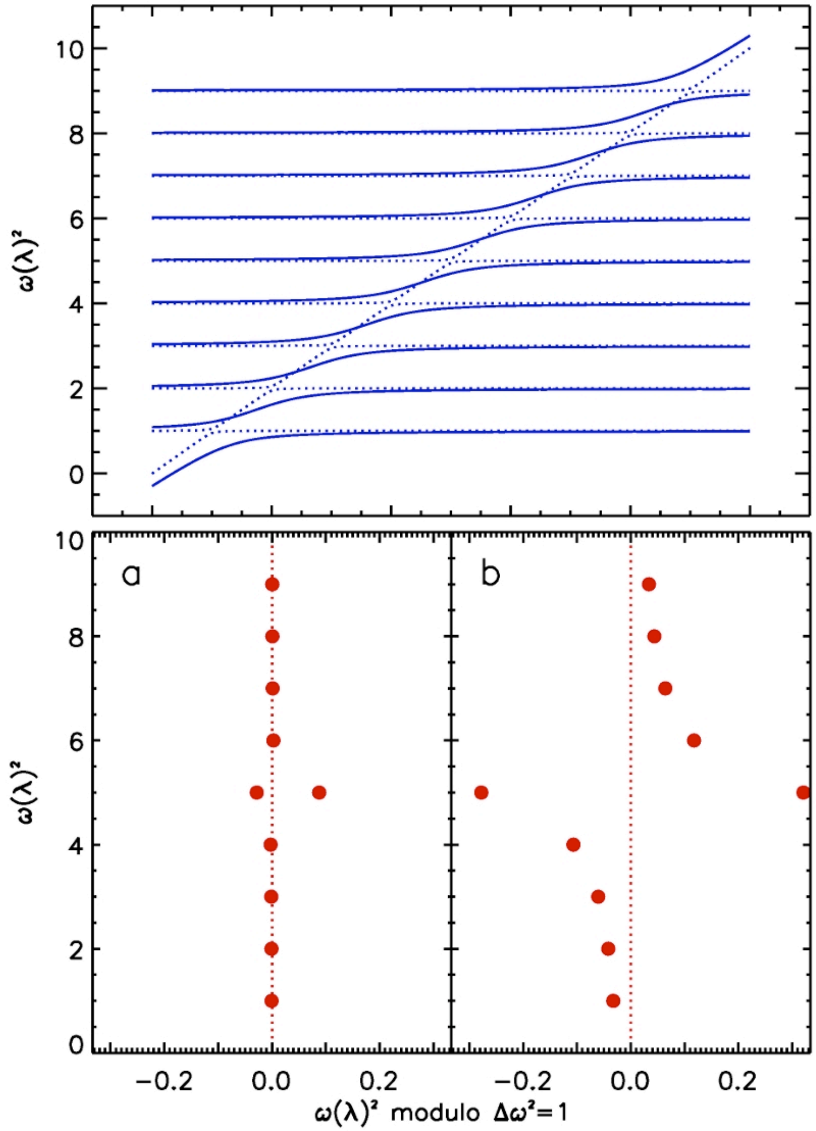
Fitting mixed modes



Metcalfe et al. (2010)

NCAR

Mode coupling



Deheuvels & Michel (2010)

- 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

NCAR

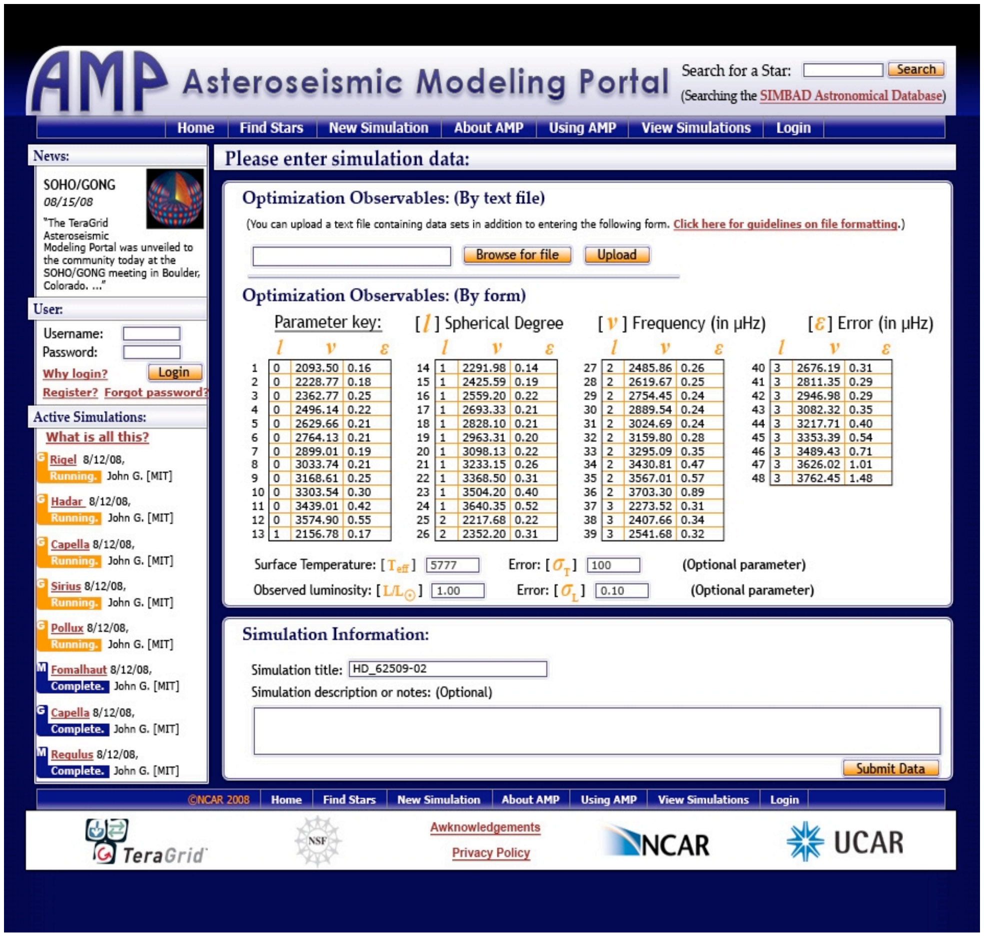
Precision of methods

	SUN-LIKE			EVOLVED		
Method	R/Ro	M/Mo	age	R/Ro	M/Mo	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

NCAR

TeraGrid Science Gateway



http://amp.ucar.edu/

- 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

Metcalfe et al. (2009)

NCAR

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.