National Aeronautics and Space Administration

Asteroseismology -- Noise and Signal for PRVs

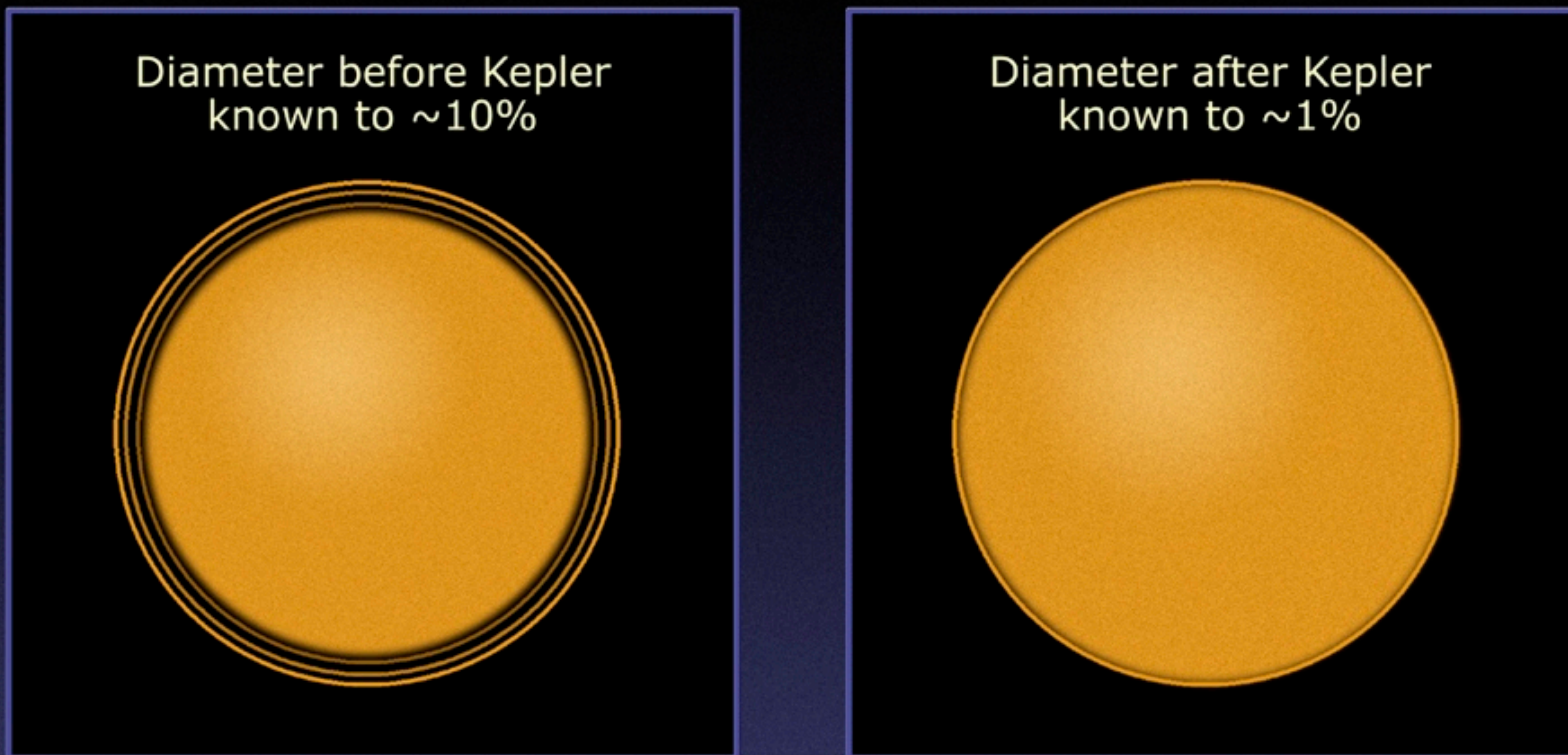
Ron Gilliland -- STScI -- 16 August 2010

Topics covered.

1. The *Kepler Mission* has fundamentally changed the game for asteroseismology -- the field has moved from being starved for detections to an embarrassment of riches.
   1.1. Example of science utility of asteroseismology -- complementing PRVs for exoplanets to deliver planet density.
   1.2. Ensemble characteristics of oscillations on many stars.
2. One person's signal may be another's noise -- what to do if you want PRVs in which noise from oscillations is minimized.

Asteroseismology is a very large field, I will restrict myself to discussing results for oscillating stars (solar-like) in which the driving mechanism is stochastic excitation. This would include nearly all targets of PRV interest for exoplanet study.

Kepler Determines Accurate Size for Exoplanet Host Star HAT-P-7



Before- and after-Kepler knowledge of planet's density improves from ~50% to ~ 5% confidence

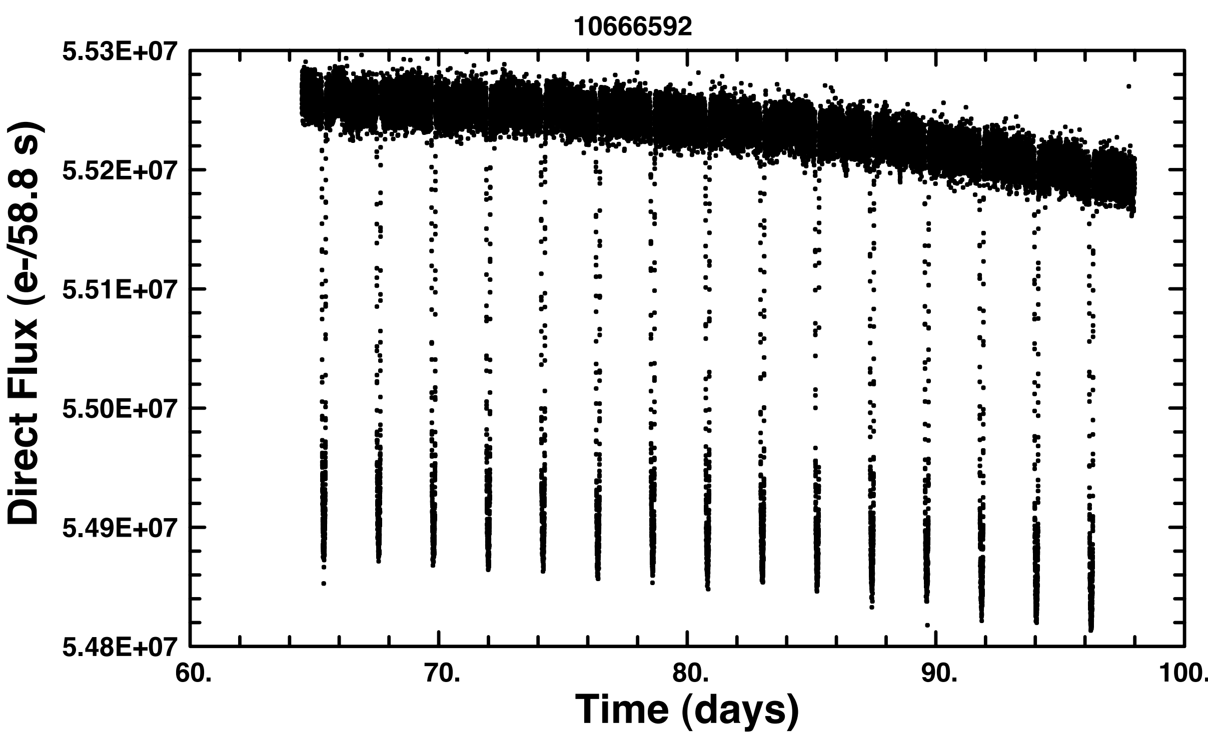
Jørgen Christensen-Dalsgaard, Aarhus University

1.1 Asteroseismology of a solar-like Star -- Planet Density.

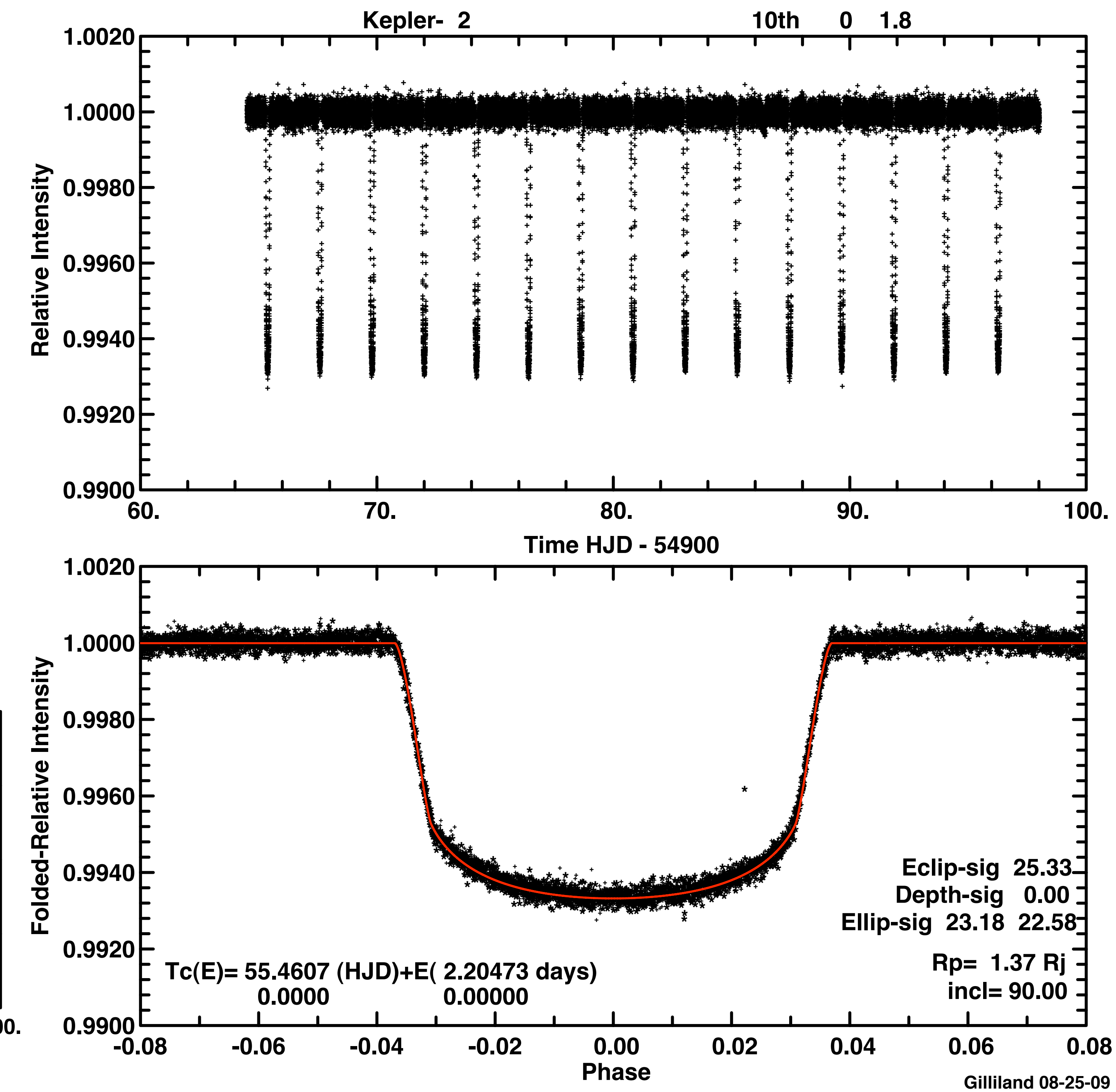
From Time Series to Asteroseismology Inferences -- HAT-P-7

Based on Christensen-Dalsgaard et al. 2010, ApJL. Time domain processing this page.

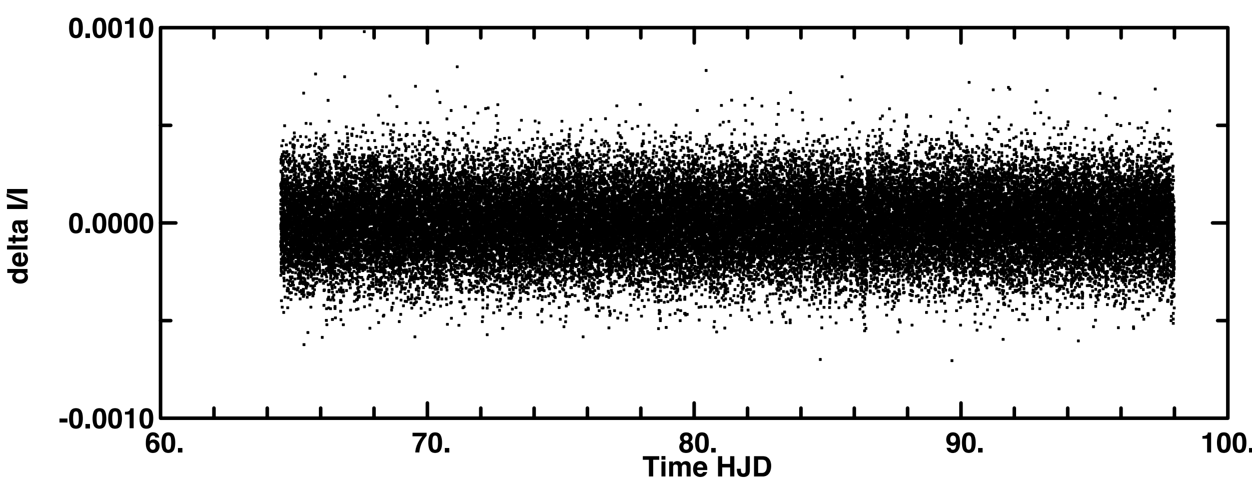
1: Aperture Photometry data from SOC.



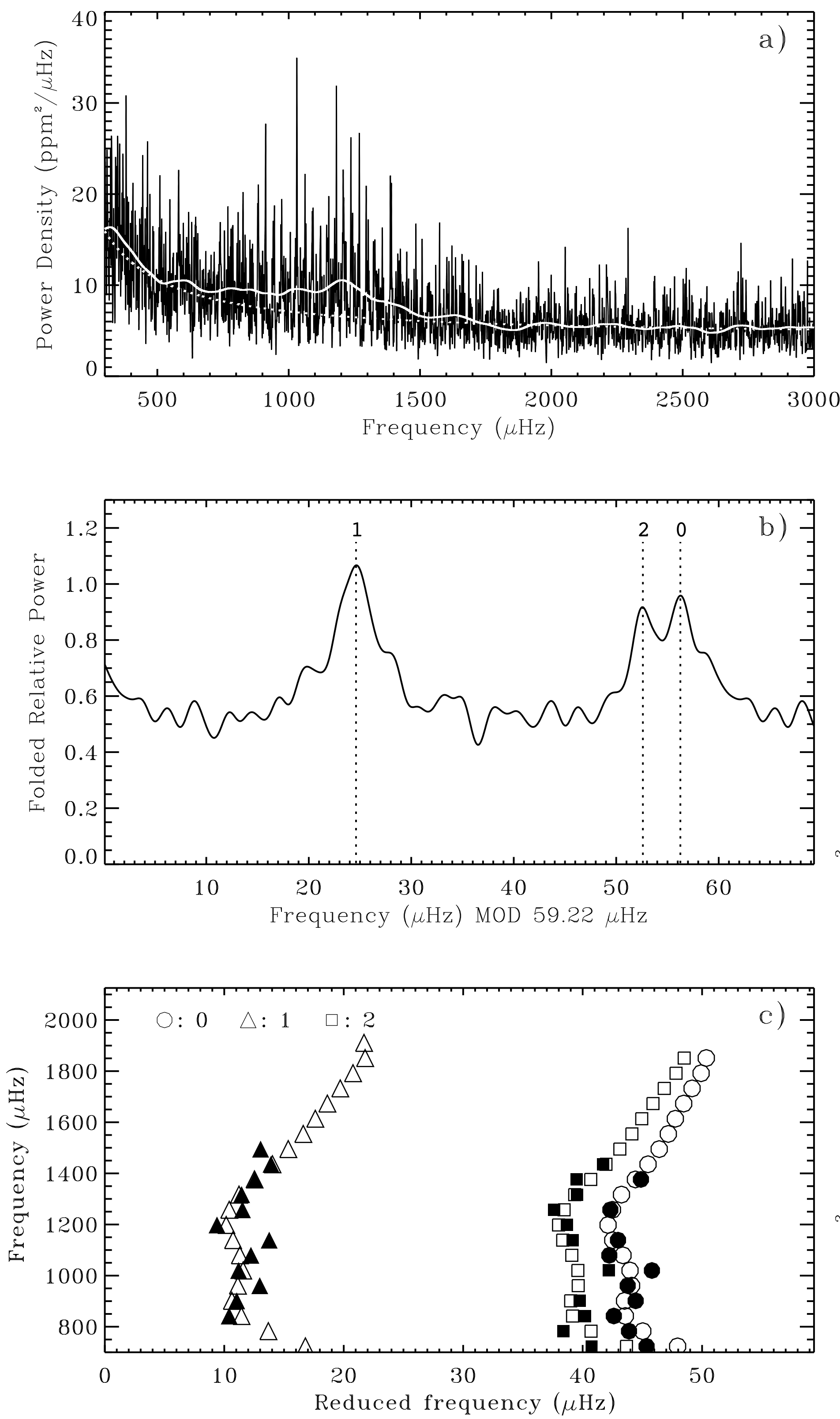
2: Detrend, fit transit, then subtract.

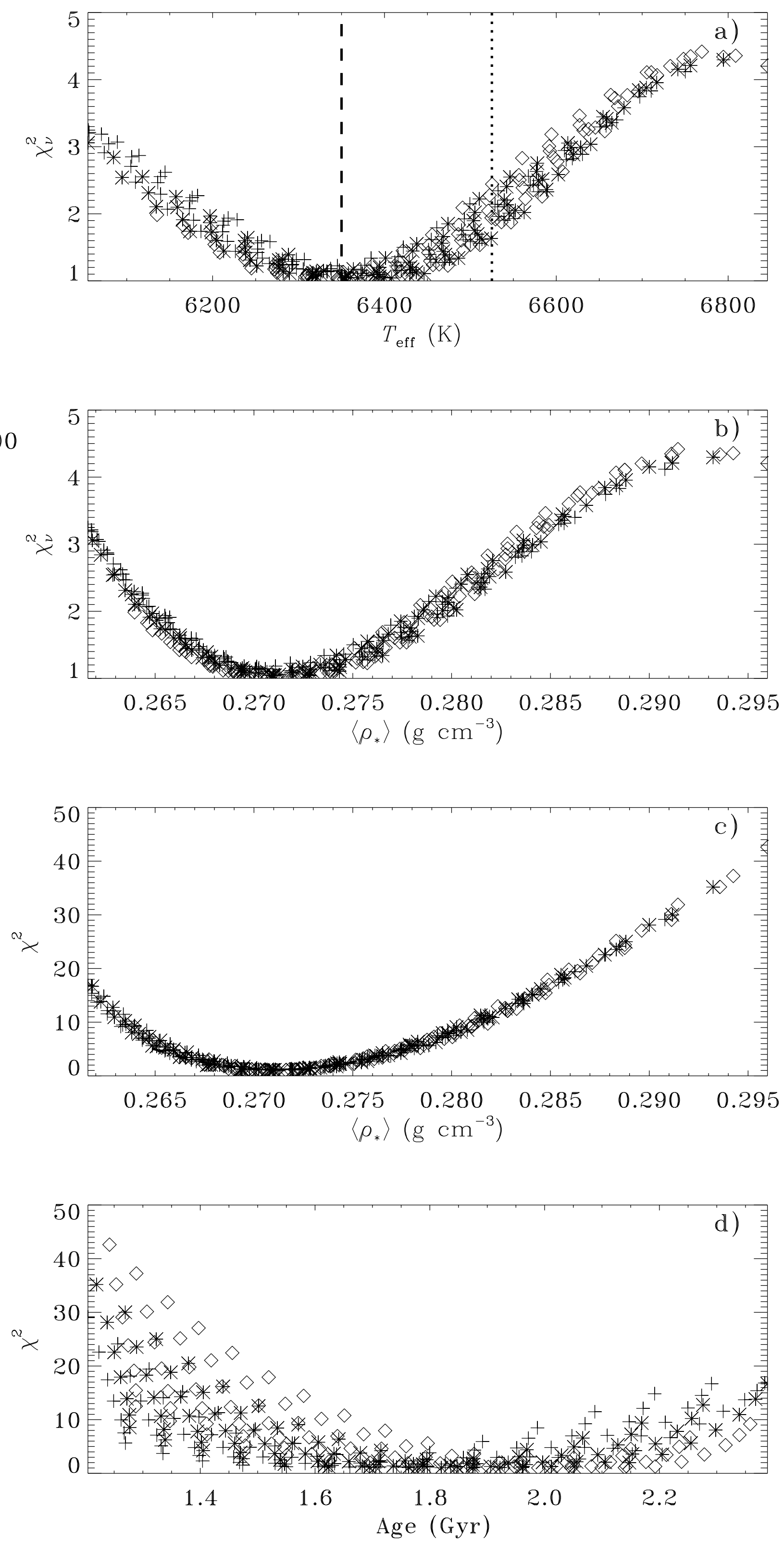


3: Time series ready for asteroseismology.



From Time Series to Asteroseismology Inferences -- HAT-P-7
Based on Christensen-Dalsgaard et al. 2010, ApJL in press. Frequency domain and inferences.





A mean stellar density of 0.271 +/- 0.003 g/cm^3 results.

A fit of the stellar density, Teff and [Fe/H] are then made to Yonsei-Yale evolutionary tracks arriving at (using Brown ApJ 2010 approach):

R = 1.991 +/- 0.018 solar
M = 1.520 +/- 0.036 solar
age = 2.14 +/- 0.26 Gyr

$$\nu_{nl} \approx \Delta\nu_0(n + l/2 + \epsilon) - D_0 l(l+1)$$

$$\Delta\nu_0 = \left(2\int_0^R dr/c\right)^{-1}$$

$$\Delta\nu_0 \approx 135(M_*/R_*^3)^{1/2}\,\mu\text{Hz}$$

1.2 Ensemble Characteristics

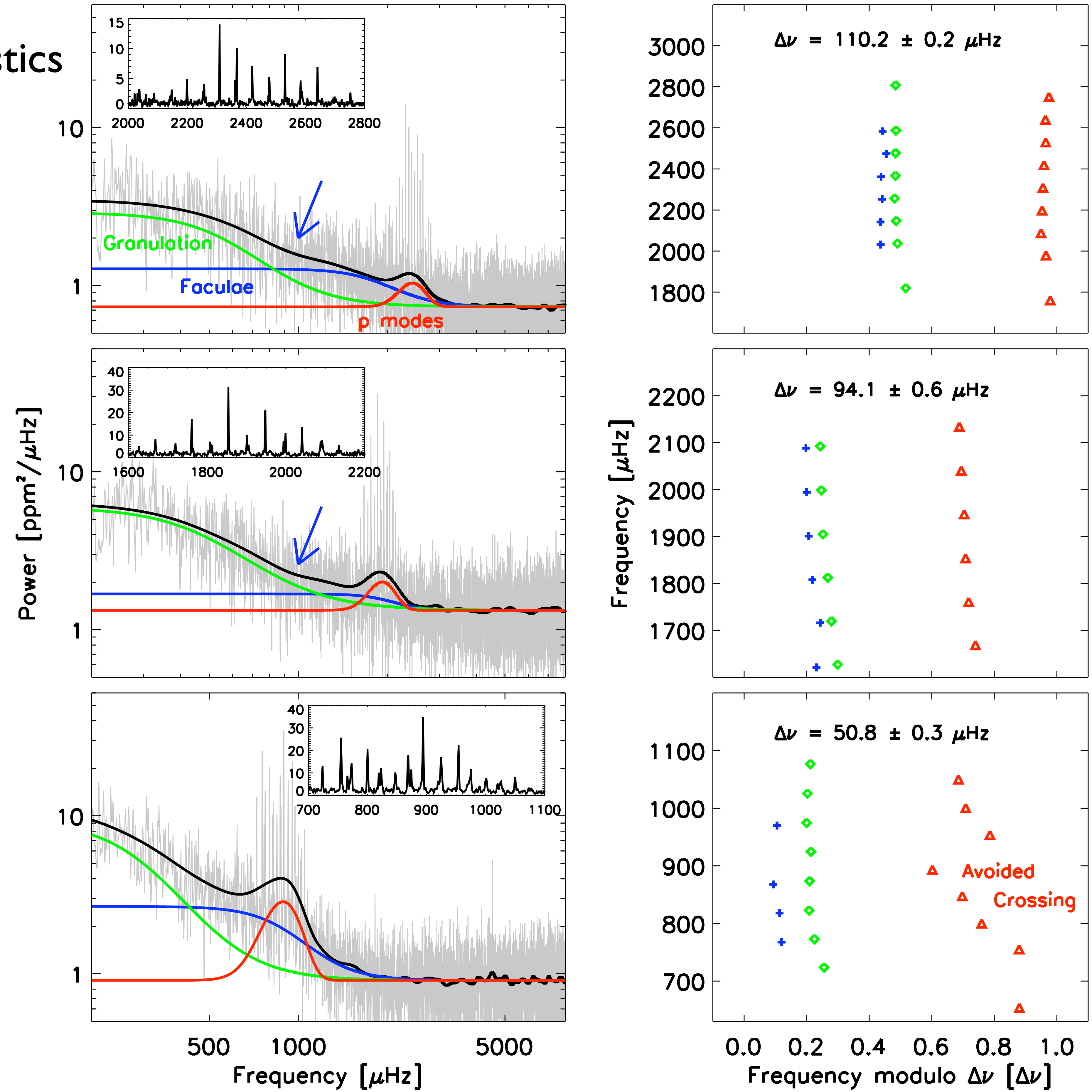
More Solar-like stars.

Three 9th magnitude G V-IV stars with clear oscillations.

By design these all have Teff within ~100 K of solar. Each has an estimated mass of 1.05 to 1.1 solar with 0.1 errors.

From the top gravities range over: 4.56, 4.32, 3.84 with corresponding radii of 1.18, 1.31 and 2.1 solar.

Kepler has now provided 100s of detections of this quality, theoretical interpretation is well underway, but a large task.

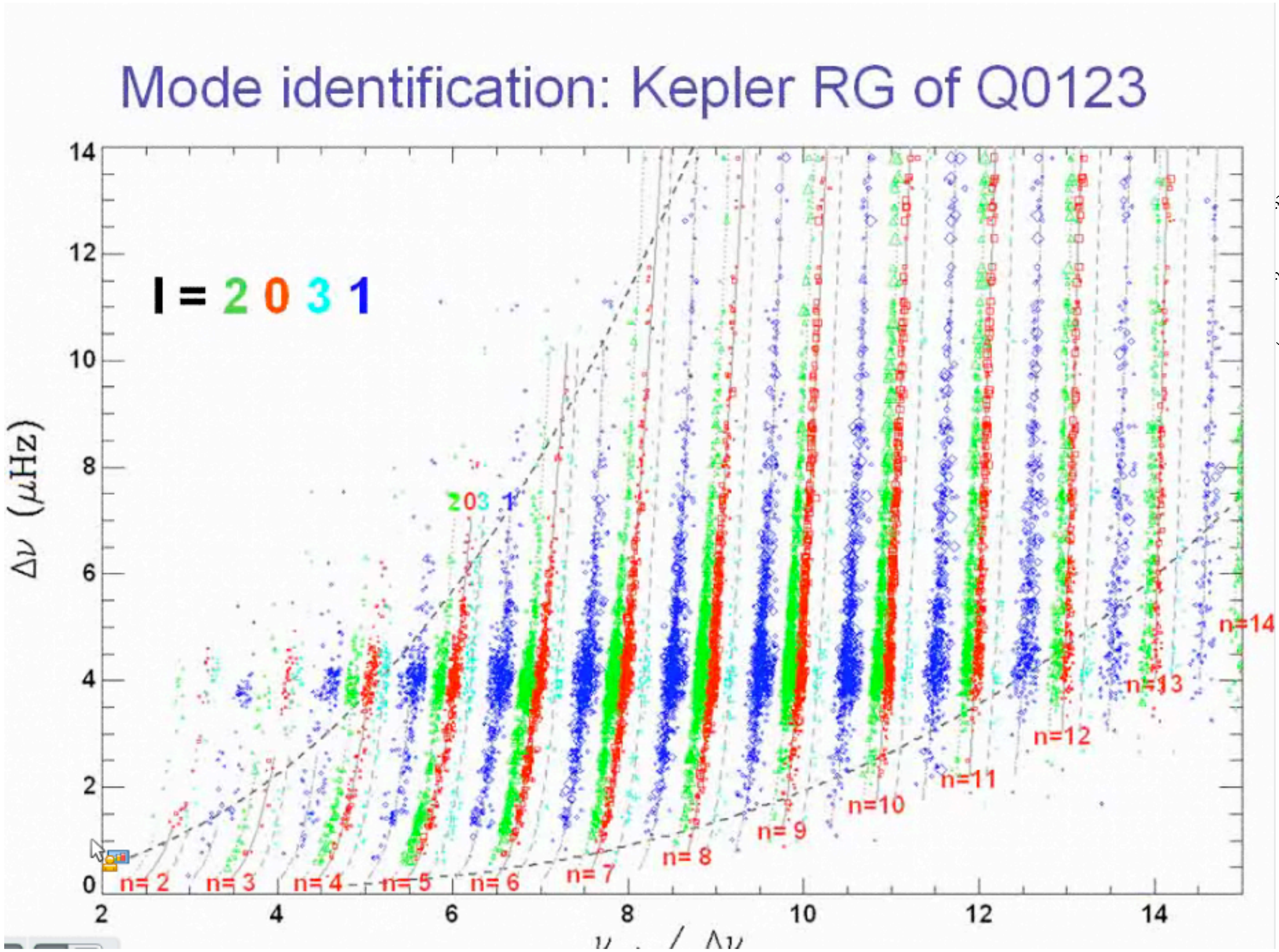


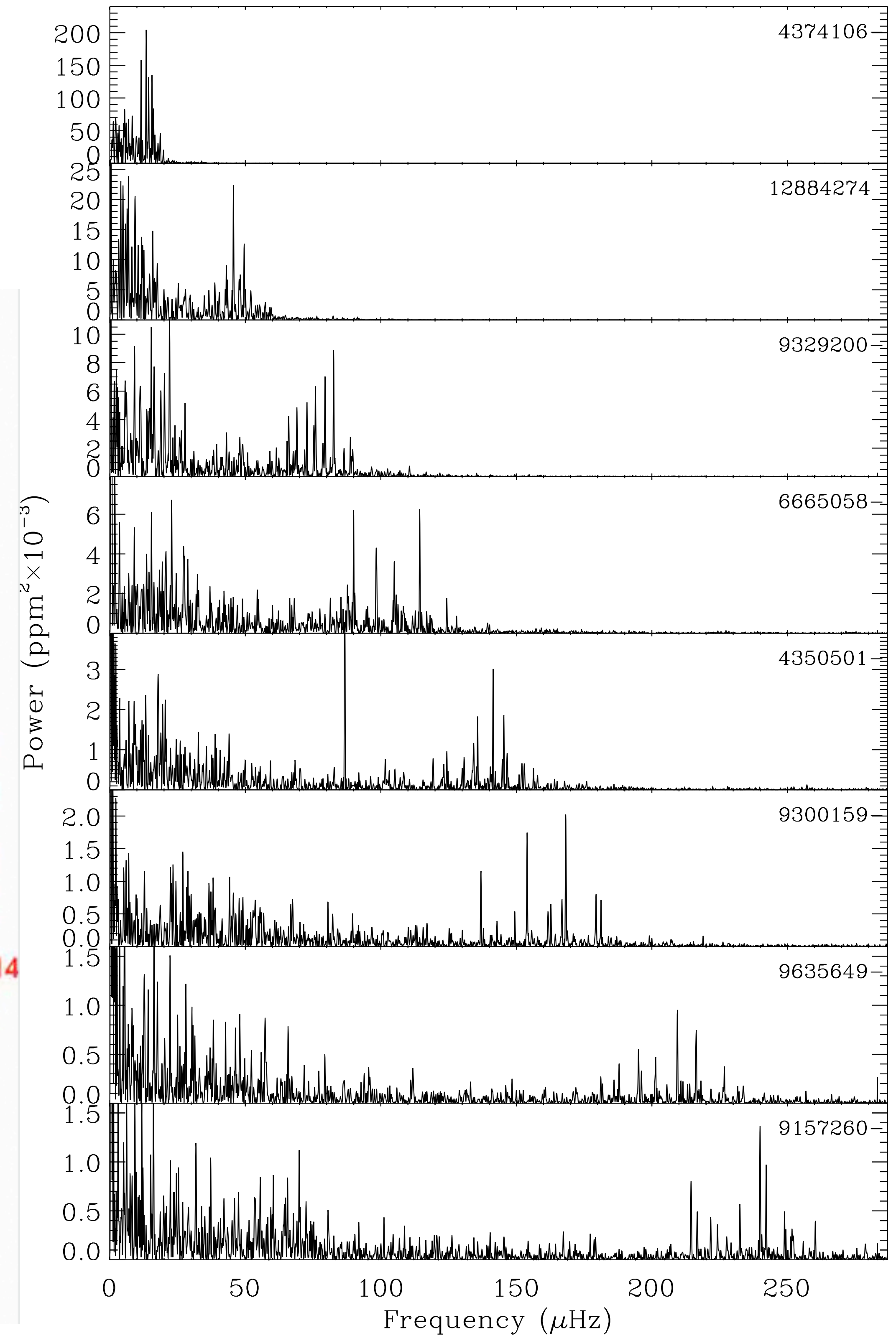
Chaplin et al. 2010, ApJL. and Metcalfe et al. 2010, ApJ submitted.

Oscillations in Red Giants.

Figure to right shows progression of peak power in oscillations for large red giants at the top at ~15 micro-Hz to small red giants at the bottom near 240 micro-Hz.

Figure below shows the universal nature of oscillations in about 1,000 red giants observed with Kepler.





Courtesy of Benoit Mosser 2010

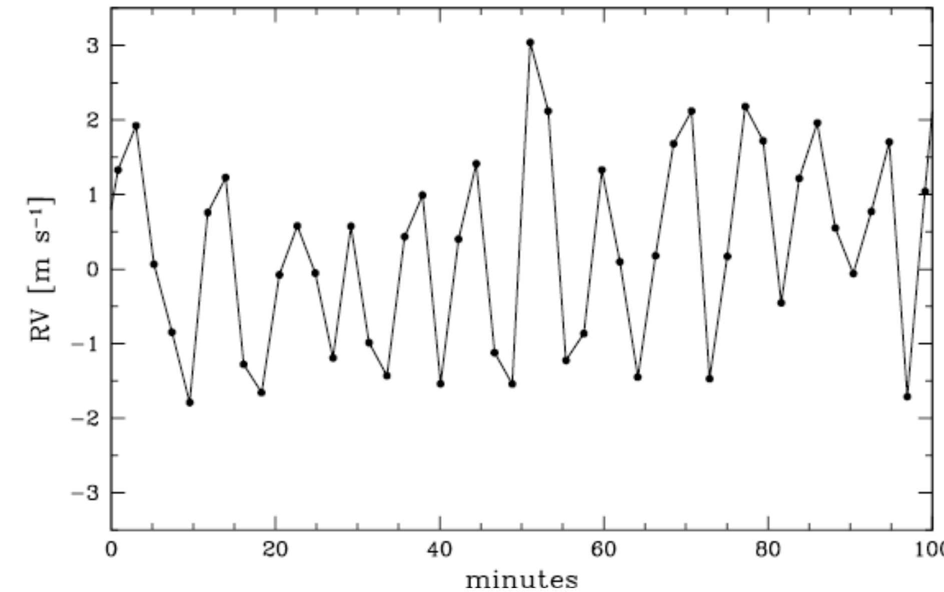
Bedding, et al. 2010, ApJL.

2. Controlling oscillations as a noise source for PRVs.

Two basic approaches:

- Approach number 1, illustrated at the right -- observe a star of interest for 8 nights on HARPS with 100 s integrations and directly resolve and study oscillations. Subtract their signal to then use RVs for exoplanet search.
  μ Arae -- V = 5.1, L = 1.9 solar,
  M = 1.09 solar, Teff = 5825, R = 1.35 solar.

- Second approach (detailed below) is to understand expected oscillations signal and design integrations to minimize resulting PRV noise for other applications.



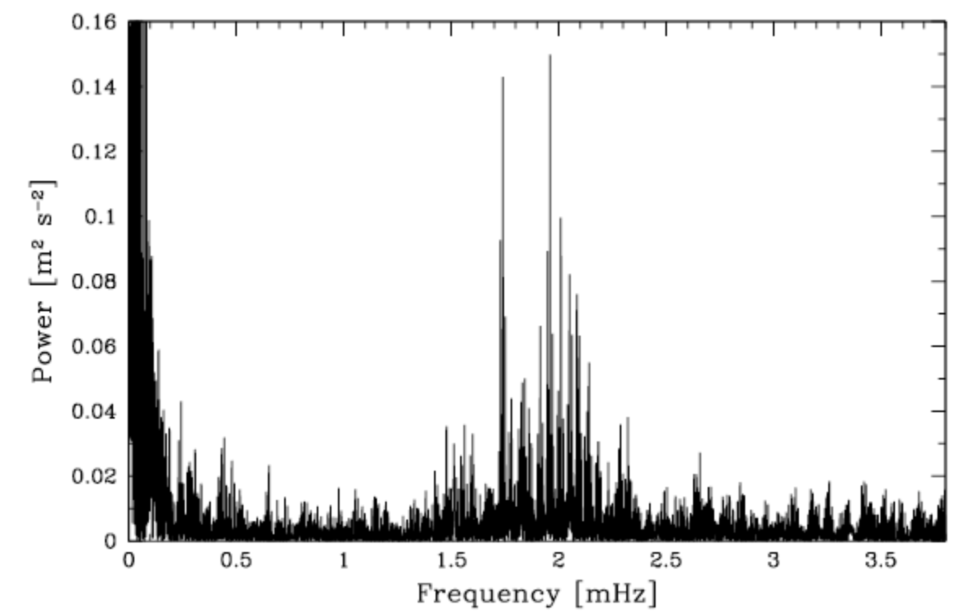
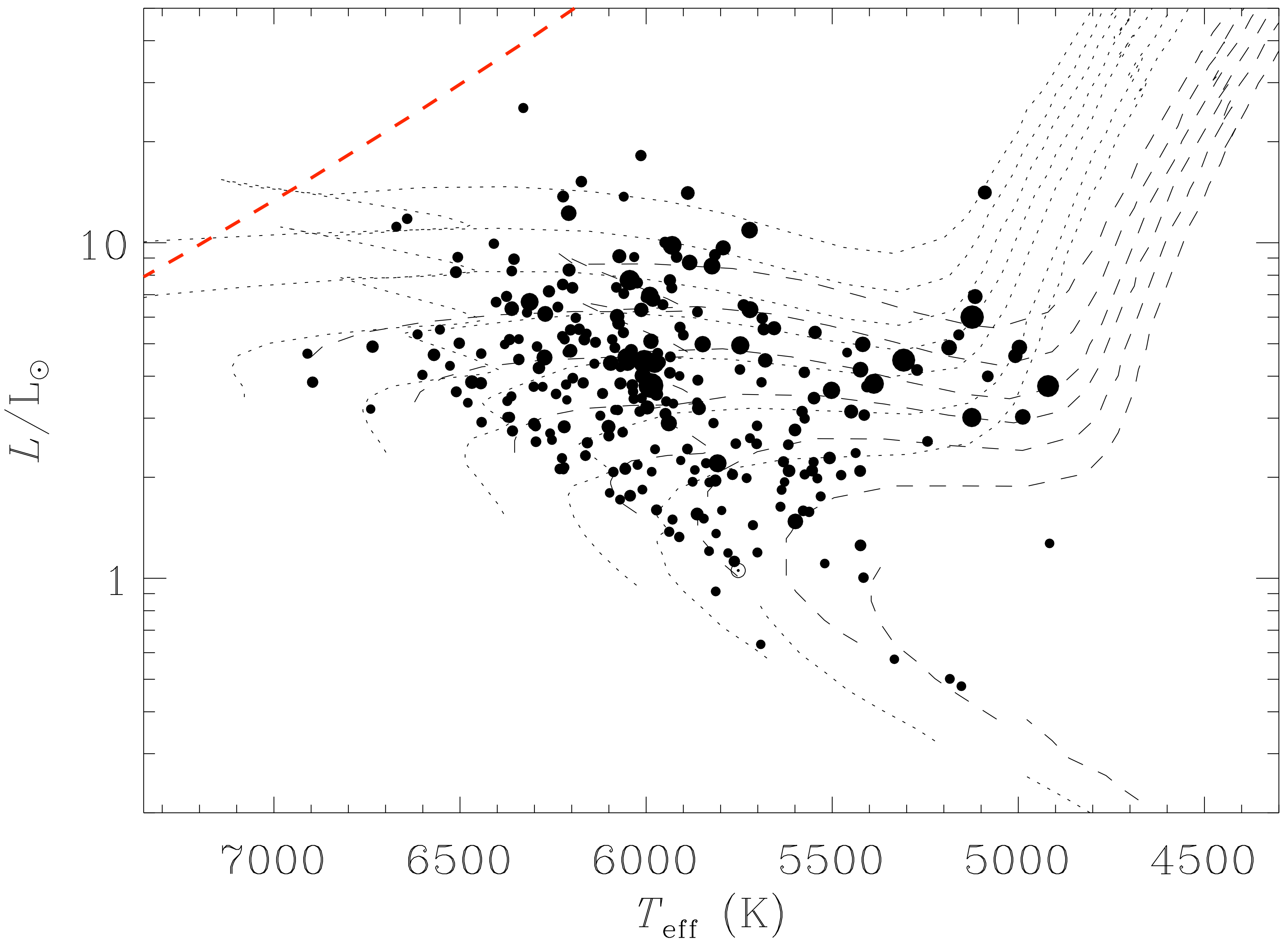


Fig. 7. Power spectrum of radial velocity measurements of HD 160691.

Bazot, et al. 2005, A&A, 440, 615.
Bouchy, et al. 2005, A&A, 440, 609 -- resulted in detection of a Neptune mass planet and excellent asteroseismic constraints on host star.

Results from first 30% of Kepler asteroseismology survey program.



Courtesy of Bill Chaplin and KASC WG#1.

272 total detections -- all with S/N sufficient to provide large splitting.

For the ~100 largest S/N one month of data provides secure detection already of order a dozen modes with per mode frequency errors well under one micro-Hz.

Lack of detections at high Teff, high Luminosity is significant.

Characteristics of oscillations -- timescale and velocity rms.

The timescale for oscillations has been extensively shown to be well represented as:

$$\tau = 317(R/R_{\odot})^2(5777/T_{eff})\ \text{seconds}$$

(Brown et al, 1991, ApJ)

The velocity amplitude, expressed as *rms* in m/s may be given as:

$$v = 0.54[1 - e^{-(T_{red}-T_{eff})/1250}](R/R_{\odot})^2(T_{eff}/5777)^{2.5}\ (\text{m/s}\ rms)$$

Where $T_{red} = 10^{-(L/L_{\odot}-42.46)/10.75}$ is the red cutoff for the classical instability strip and is used in the term in brackets calibrated with *Kepler* data. (Chaplin; Kjeldsen et al, 2008, ApJ)

τ -- examples (seconds) over HR diagram

T/L	7000	6500	6000	5500	5000	4500
9	1092	1582	2361	3648	5874	9948
3		527	787	1216	1958	3316
1			262	405	653	1105

v -- examples (m/s *rms*) over HR diagram

T/L	7000	6500	6000	5500	5000	4500
9	0.69	1.86	2.92	3.95	5.05	6.29
3		0.96	1.23	1.52	1.84	2.22
1			0.46	0.54	0.64	0.76

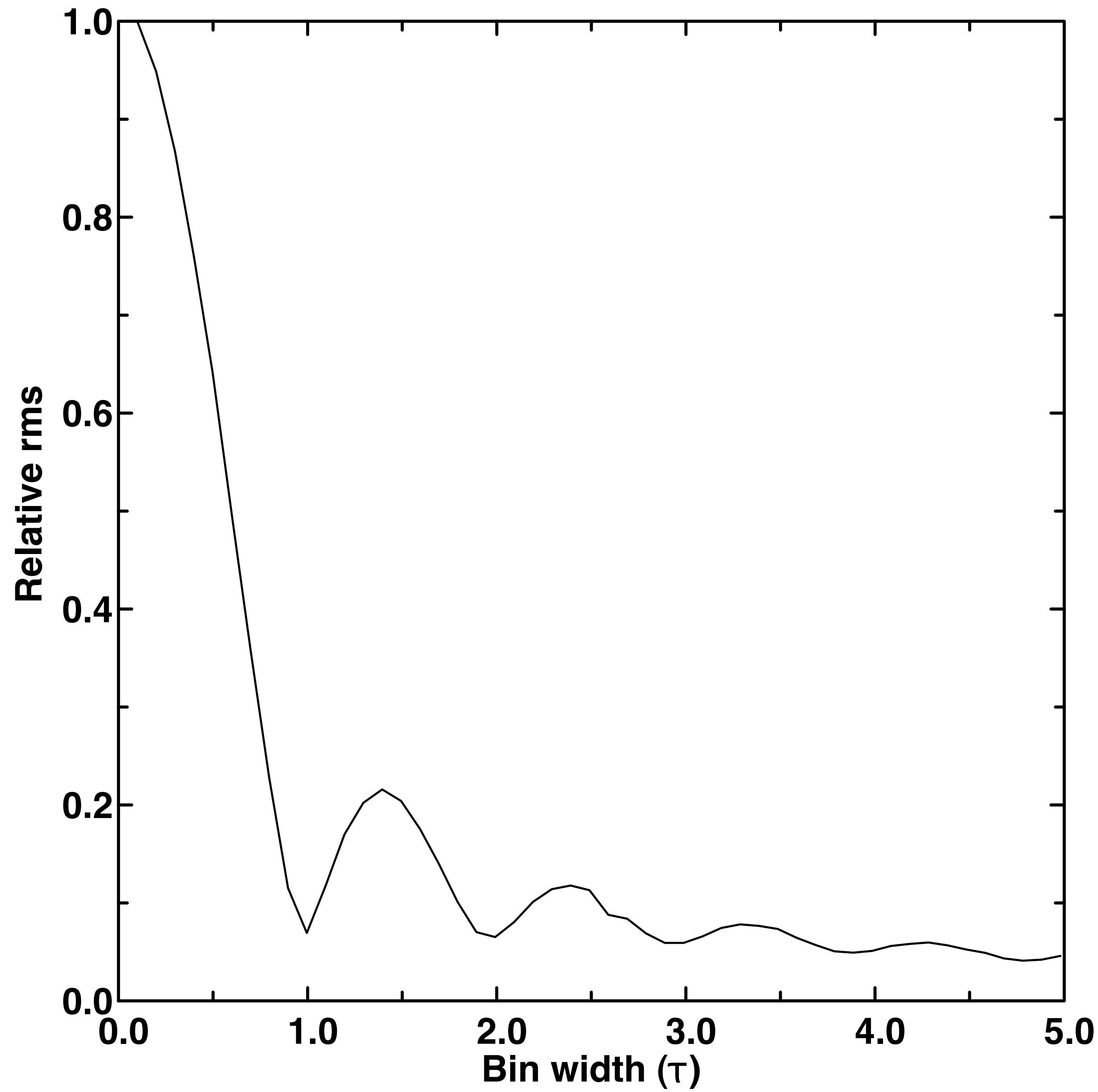
Note that a canonical clump red giant with L of 50 solar, R of 10 solar at 4670 K would have τ equal to 13 hours, and added *rms* noise from oscillations of about 10 m/s.

The observer can now take one of two options:
(1) examine expected additional *rms* from oscillations and if small enough ignore,
(2) choose exposure times that optimally average over the oscillations -- see next page

Attenuation of added *rms* by exposure length choice.

By choosing an exposure time = τ, the period of oscillations (or taking lots of short exposures over this and averaging) the added *rms* velocity signal can be suppressed by > X10.

As an example consider the V = 5.1 star μ Arae -- this has τ = 9 minutes, and v(*rms*) = 1.0 m/s. The extra noise from oscillations can be reduced to less than ~7 cm/s by using 9 minute exposure times.



Summary

- *Kepler* based asteroseismology is proving very successful, the community is now flooded with high quality detections.
- Applications of asteroseismology are central to better understanding host star parameters for *Kepler* detected exoplanets.
- The ‘noise’ induced by stellar oscillations may be strongly suppressed by judicious selection of effective integration times.