Asteroseismology: Synergy With Transit Searches

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The Synergy:

(1) Search for Earth sized planets requires similar precisions and monitoring length as asteroseismology.

(2) Asteroseismology provides information on host stars, in particular tight constraints on stellar radius.

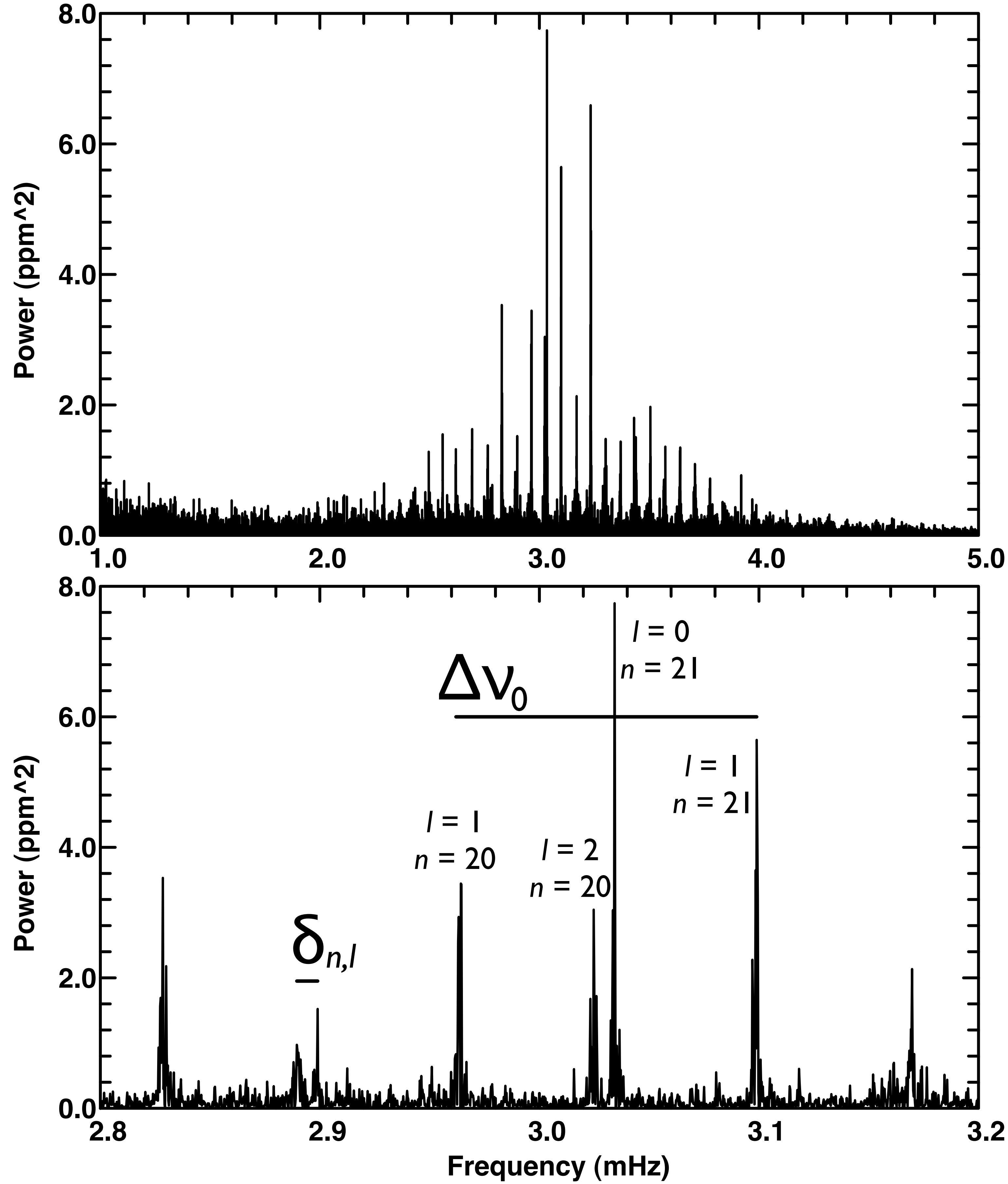
Asteroseismology: Study of stellar interior properties via observations of oscillations visible at the surface in direct analogy to seismology studying the Earth interior.

Why does the Sun Oscillate?

- Near surface convection produces velocities comparable to sound speed.
- Turbulence in outer convection zone continually pumps energy into random sound waves.
- Regions of the Sun form a natural acoustical resonant cavity -- waves traveling inwards are refracted back toward the surface by increasing sound speed, rapidly changing conditions near the surface reflect waves.
- The solar eigenmodes form a set of resonant waves characterized by different *n* - number of nodes in the interior, and *l* - number of nodes around the circumference. Also known as p-modes since restoring force is pressure.
- Observed without spatial resolution (Sun as star) we see modes only of *l* = 0,1,2,3.
- The low-*l* modes penetrate nearly to the stellar core and therefore are sensitive to global properties.
- In this talk I am only discussing oscillations in "solar-like" stars, there will also be a significant number of classical pulsators (RR Lyrae, δ Scuti, etc.) for which the unique CoRoT and Kepler observations can provide fundamental results.

Characteristics of Solar Oscillations

- These data are courtesy of Thiery Toutain and Claus Fröhlich -- IPHIR photometric data over 31 days from the Phobos (Russian Mars) mission.
- Peak of solar oscillations near 5 minutes ~ 3 mHz
- Obvious picket fence effect
- Two sets of mode separations are labeled -- to be defined next.
- Amplitudes are a few ppm in photometry (shown), and a few 10's of cm/s in velocity.
- Mode lifetimes are several days to a few weeks.



Physical Interpretation of Frequency Splittings

The regular spacing of modes in radial order *n* and angular degree *l* is (for $n \gg l$):

$$\nu_{nl} \;=\; \Delta\nu_0 \left(n + \frac{l}{2} + \epsilon\right) + \text{2nd order}$$

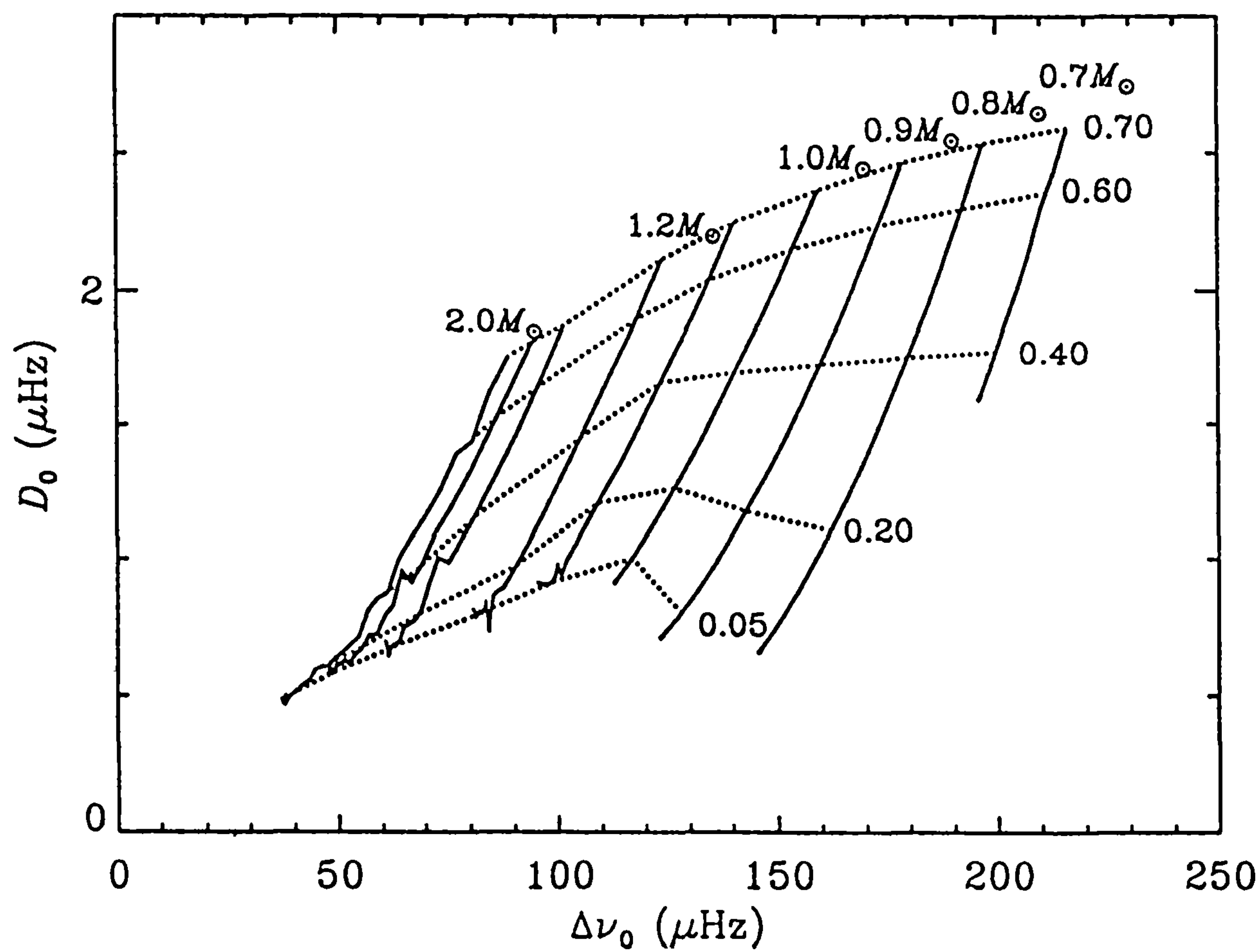
The large splitting is simply related to the sound travel time through the star:

$$\Delta\nu_0 \;=\; \left(2 \int_0^{R_*} \frac{dr}{c}\right)^{-1} \;\propto\; \left(\frac{M_*}{R_*^3}\right)^{1/2}$$

The degeneracy of *n* and *l*/2 is broken by a 2nd order term, the small separation, which is sensitive to sound speed gradients near the stellar core:

$$\delta_{n,l} \;\propto\; \int_0^{R*} \frac{dc}{dr} \frac{dr}{r}$$

The Asteroseismic HR diagram.



J. Christensen-Dalsgaard, 1993, ASP Conf. Series 42.

Current status of Asteroseismology

- Promise has been recognized for two decades, major progress only in last few years using high precision RV capabilities developed for exoplanet searches (see Bedding and Kjeldsen, May 2007 astro-ph/0705.1376 for current review).

- Excellent results are available for α Cen A and B, μ Ara, β Vir, β Hyi, ν Ind -- large splitting secure, power spectra comparable to my solar example, many individual frequencies available. These are F, G, K dwarfs and subgiants.

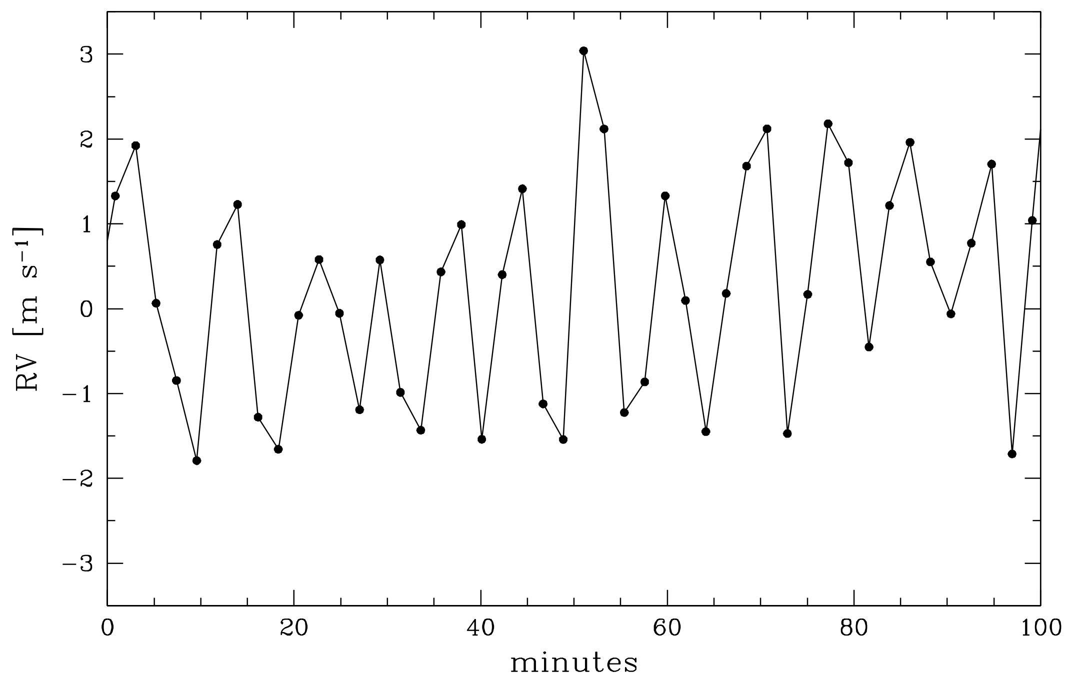
- For a somewhat larger list of stars observations are available sufficient to provide the large splitting.

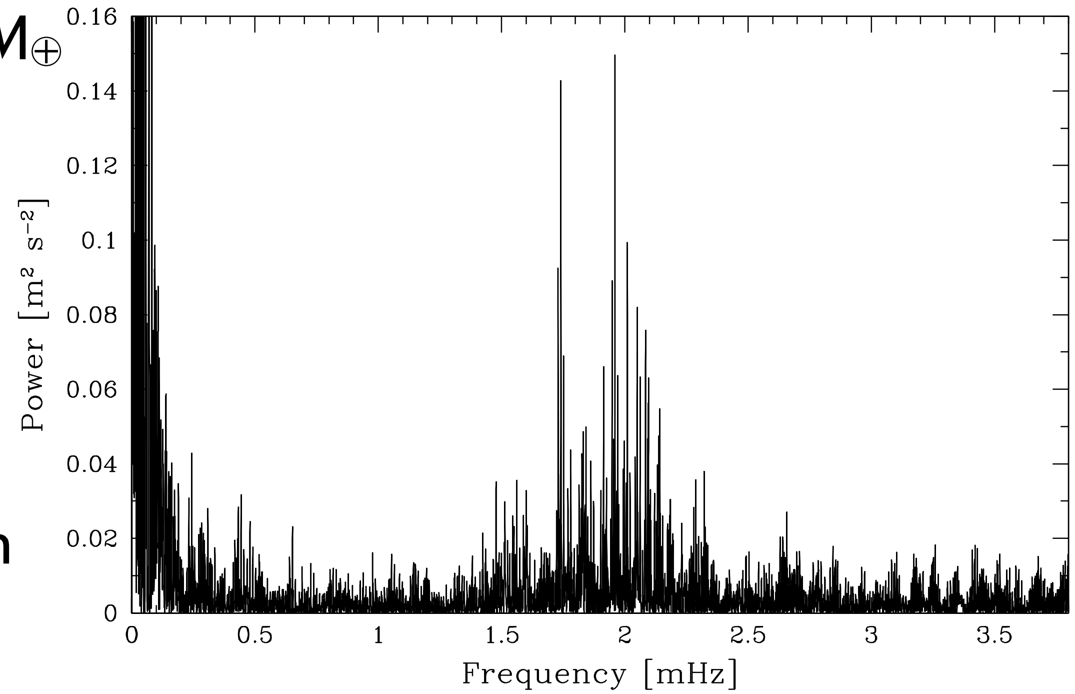
- Observations are best if conducted from two sites at different longitudes over at least 7-10 days, and even then the less than ideal window function hampers conclusions given a high density of modes, some of which naturally have spacings comparable to 1/day aliases. Need RV precisions to ~ 1 m/s.

- CoRoT will now be producing results based on stable photometric monitoring over extended periods.

Example of μ Arae

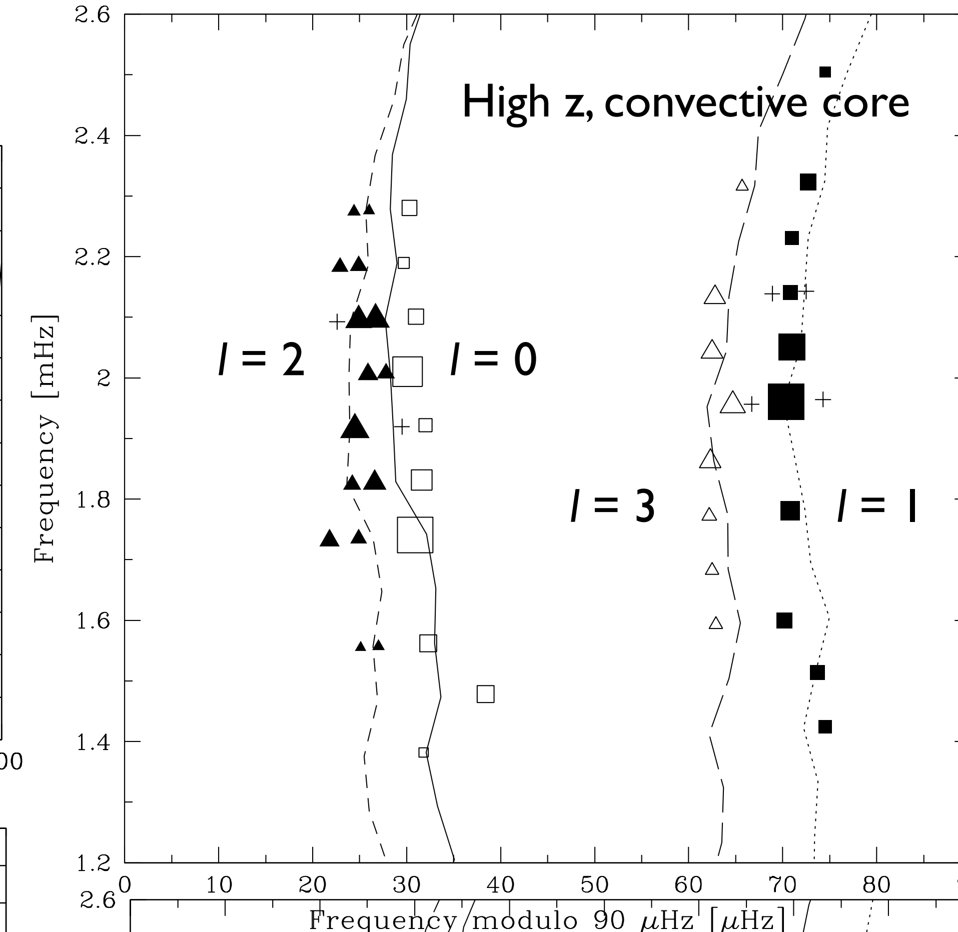
- Bouchy et al. 2005, and Bazot et al. 2005.
- 8 nights with HARPS for asteroseismology campaign
- Detected new planet at P = 9.55 days, 14 $M_\oplus$
- Over 40 p-modes detected.
- Attempt test of high metallicity of host throughout, or just in convective envelope by accretion

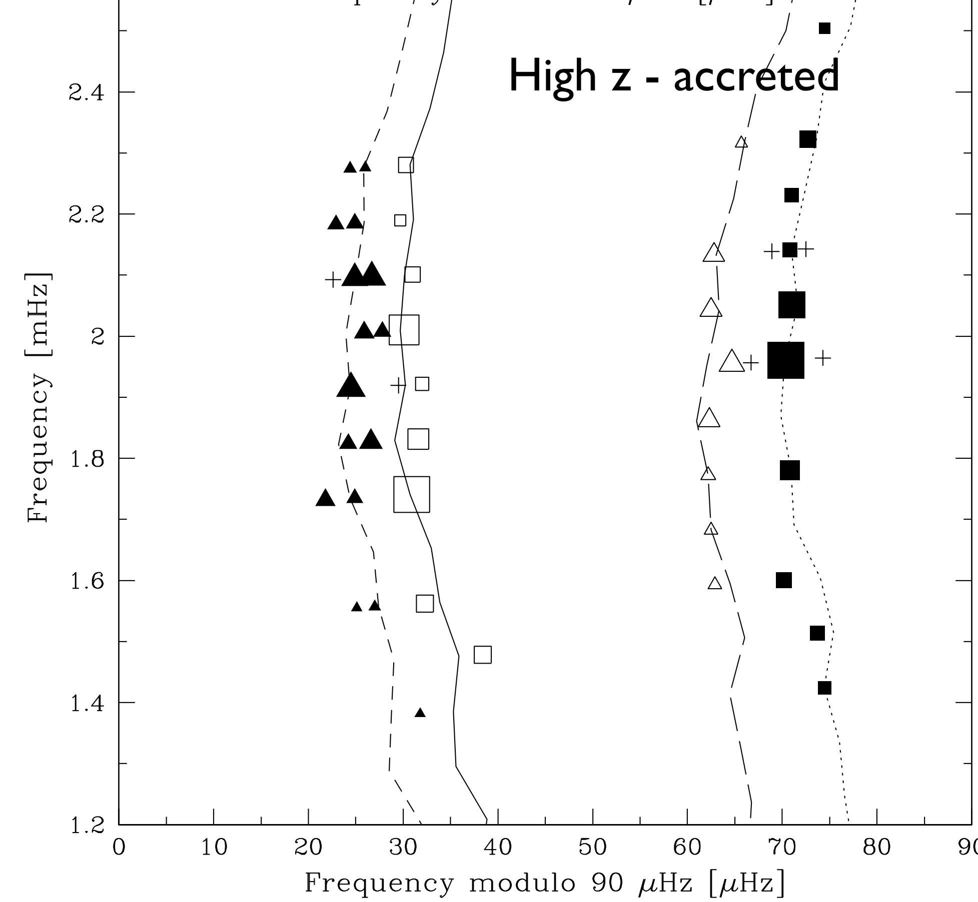




M ~ 1.1, L = 1.9, R = 1.37, T = 5813

m_V = 5.1, z = 0.32





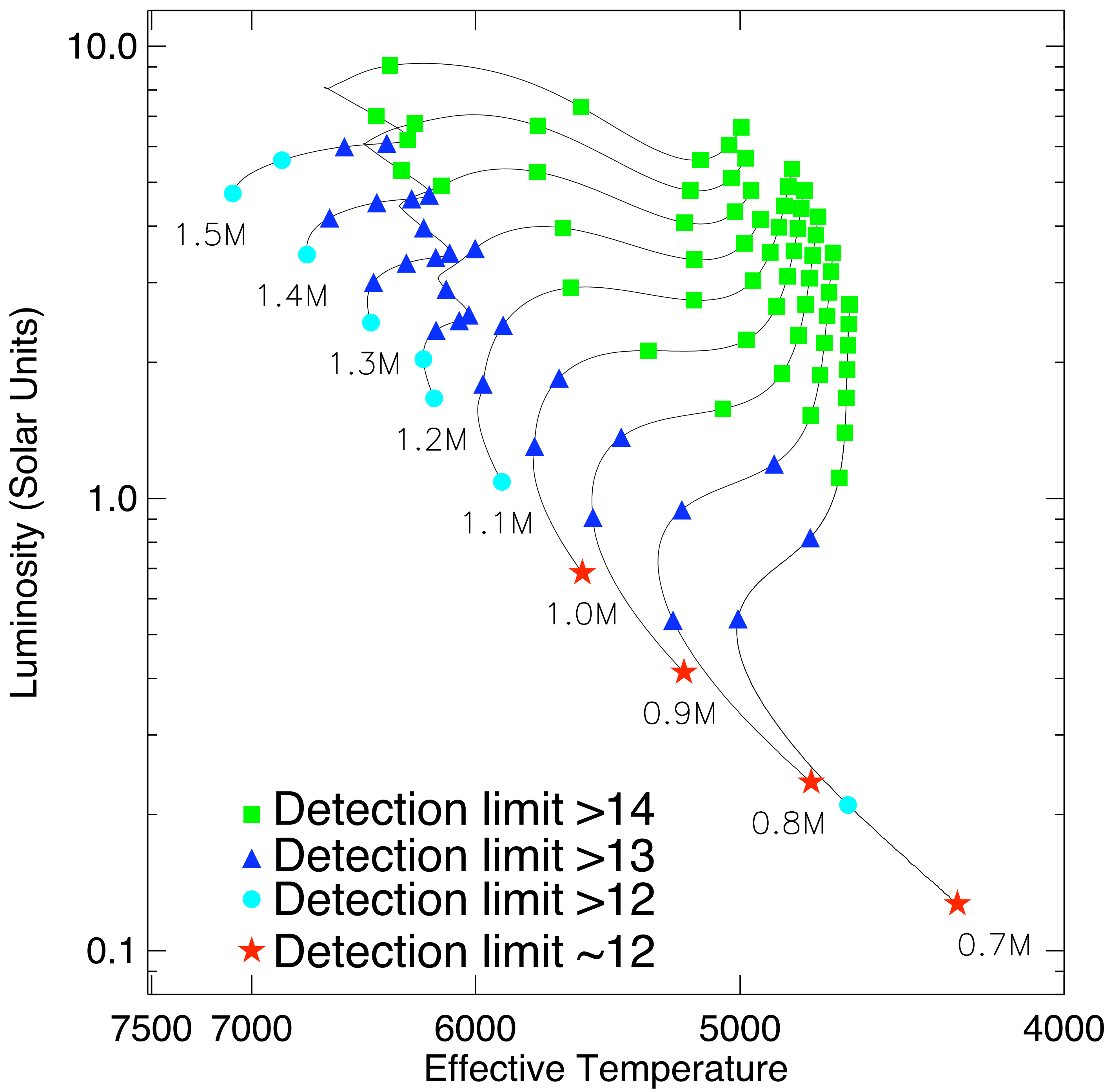
Asteroseismology with Kepler

- 512 targets will be followed with 1-minute integrations -- allows sampling of p-modes for solar-like stars.
  - A subset will be reserved for asteroseismology, a comparably large number will be used to provided better sampling on interesting transits.
- At V = 11.4 the collection of 10^{12} photons per month allows photon noise of 1ppm sufficient to identify large splitting, and for favorable cases small splitting and individual modes. Note: TrES-2 has V = 11.4.
- At the bright limit for Kepler power spectra will approach the quality shown earlier for the Sun.
- Benefit to exoplanet research: Assume prior knowledge (photometry, spectroscopic analysis) provides estimates of stars to $\delta M \sim 10\%$, $\delta R \sim 20\%$.

  Asteroseismology will provide $\delta(\Delta\nu_0)$ to 0.2%, hence mean density to 0.4% and the error on the radius would now be dominated by the cube root of assumed mass error, or $\delta R \sim 3\%$.
- Asteroseismology with Kepler will be conducted via an international consortium of interested astronomers and managed at the Kepler Asteroseismic Science Operations Center in the Department of Physics and Astronomy, University of Aarhus, Denmark. See http://astro.phys.au.dk/KASC/ for information on workshop 29-31 Oct. 2007 to start this.

Detection Limits for Kepler Assuming One Year Observations

- HR diagram of calculated models, masses in solar units showing evolutionary tracks and limiting magnitudes for which one year of Kepler data allowed correct large separation to be derived in all 10 simulations.
- J. Christensen-Dalsgaard et al 2007, astro-ph/0701323
- For stars near the listed limits detections would be only of large splitting and asteroseismology would serve as tool for providing improved stellar radii.
- At one magnitude brighter would obtain small splitting and many individual frequencies as well.



Intrinsic Asteroseismic Results from Kepler

- Over the 3.5 year Kepler mission asteroseismic targets might be: 60 stars observed for full 3.5 years, 160 stars observed for 1 year, and 1,000 stars observed for 90 days.

- For most of the above we would expect to not only detect the large splitting, but also the small (hence accurate age constraint), and a large number of individual frequencies.

- The oscillation frequencies can be measured much more accurately than other observables, and they are intimately tied to interior structure, composition distribution, and rotation.

- Having accurate oscillation frequencies for a large number of stars densely distributed over the HR diagram will allow testing fine details of stellar structure and evolution theory.

- Measurements of power distributions with frequency and amplitudes over the HR diagram will yield important constraints on the physics related to excitation and damping of these oscillations.