The link between seismology and exoplanet research

Ronald L. Gilliland, Space Telescope Science Institute

The links:

(1) Search for Earth sized planets requires similar photometric capabilities as asteroseismology.

-- exoplanet missions can naturally support asteroseismology

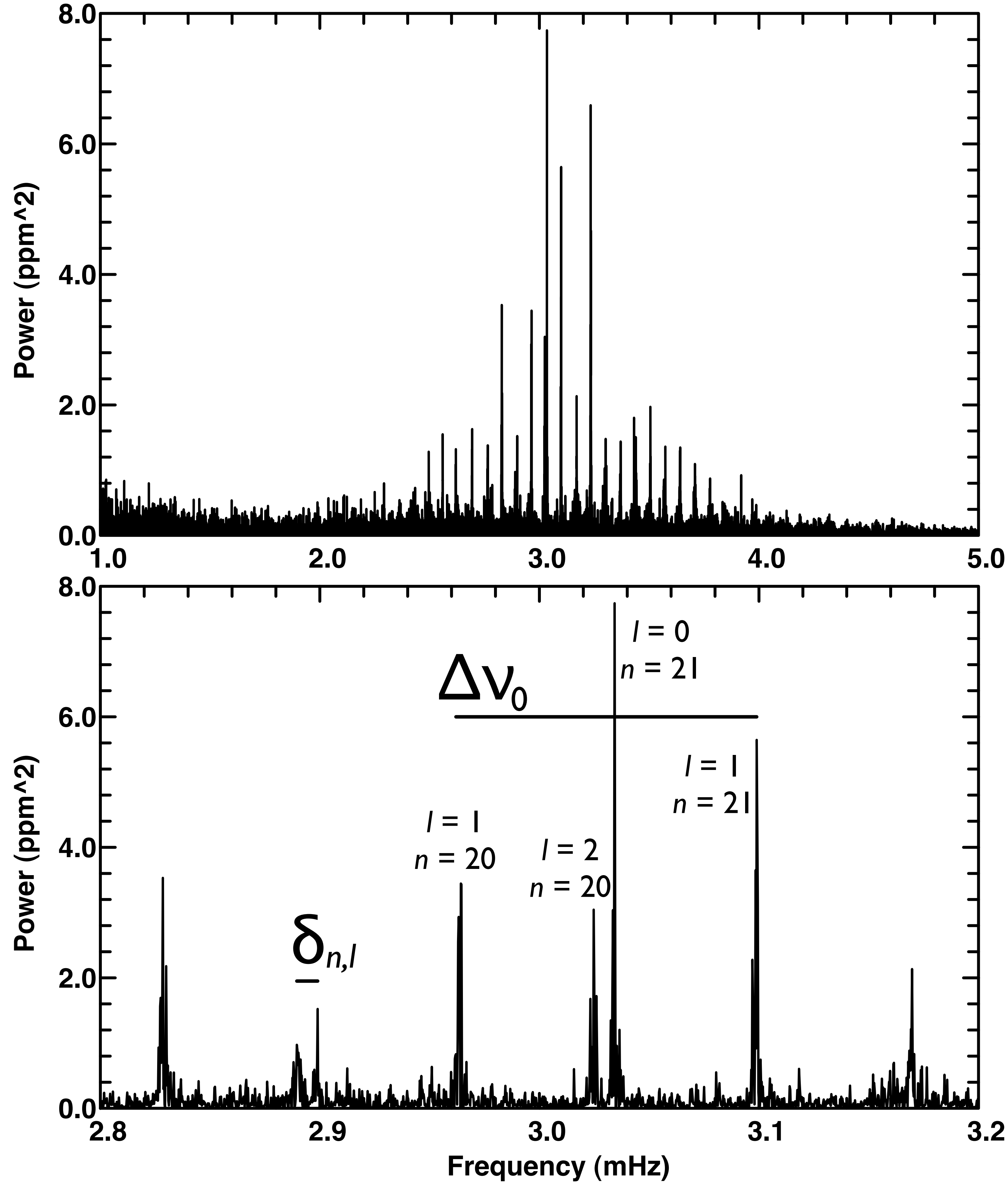
(2) Asteroseismology provides information on host stars, in particular tight constraints on stellar radius.

-- this is a primary input for quantifying knowledge of exoplanets

(3) For rare cases with Asteroseismology plus high precision transit light curves redundant and complementary stellar parameter constraints will exist.

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 $n \gg l$):

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

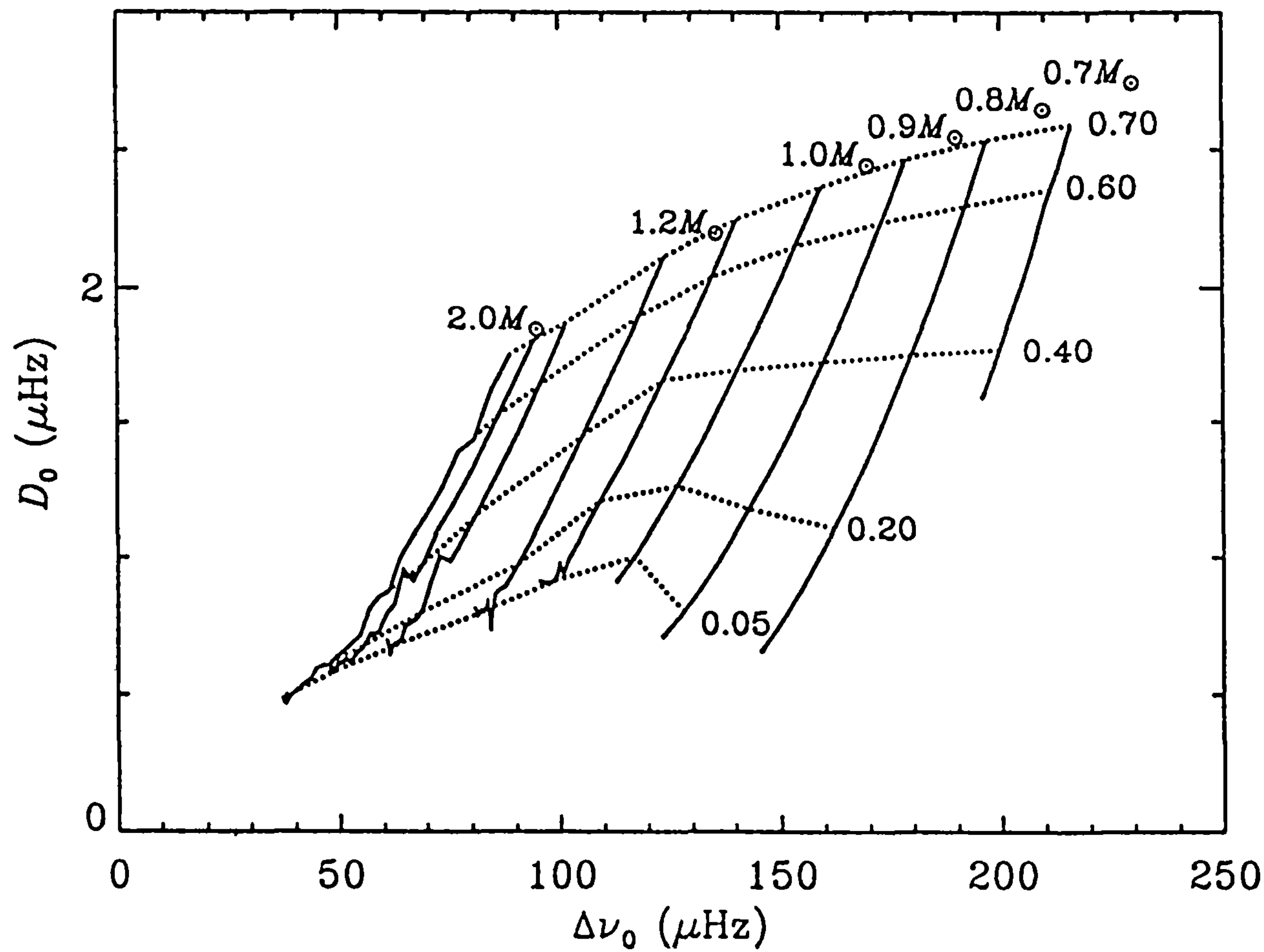
The large splitting is simply related to the sound travel time through the star:

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

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.

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 provide 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 with longer observations and/or brighter stars the small splitting and individual modes will follow. Note: TrES-2 has V = 11.4.
- 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 $\Delta\nu_0$ 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 $\delta R \sim 3\%$.
- If the small splitting can be determined the stellar ages to 5 - 10% of the main sequence lifetime will also be available for exoplanet interpretation.

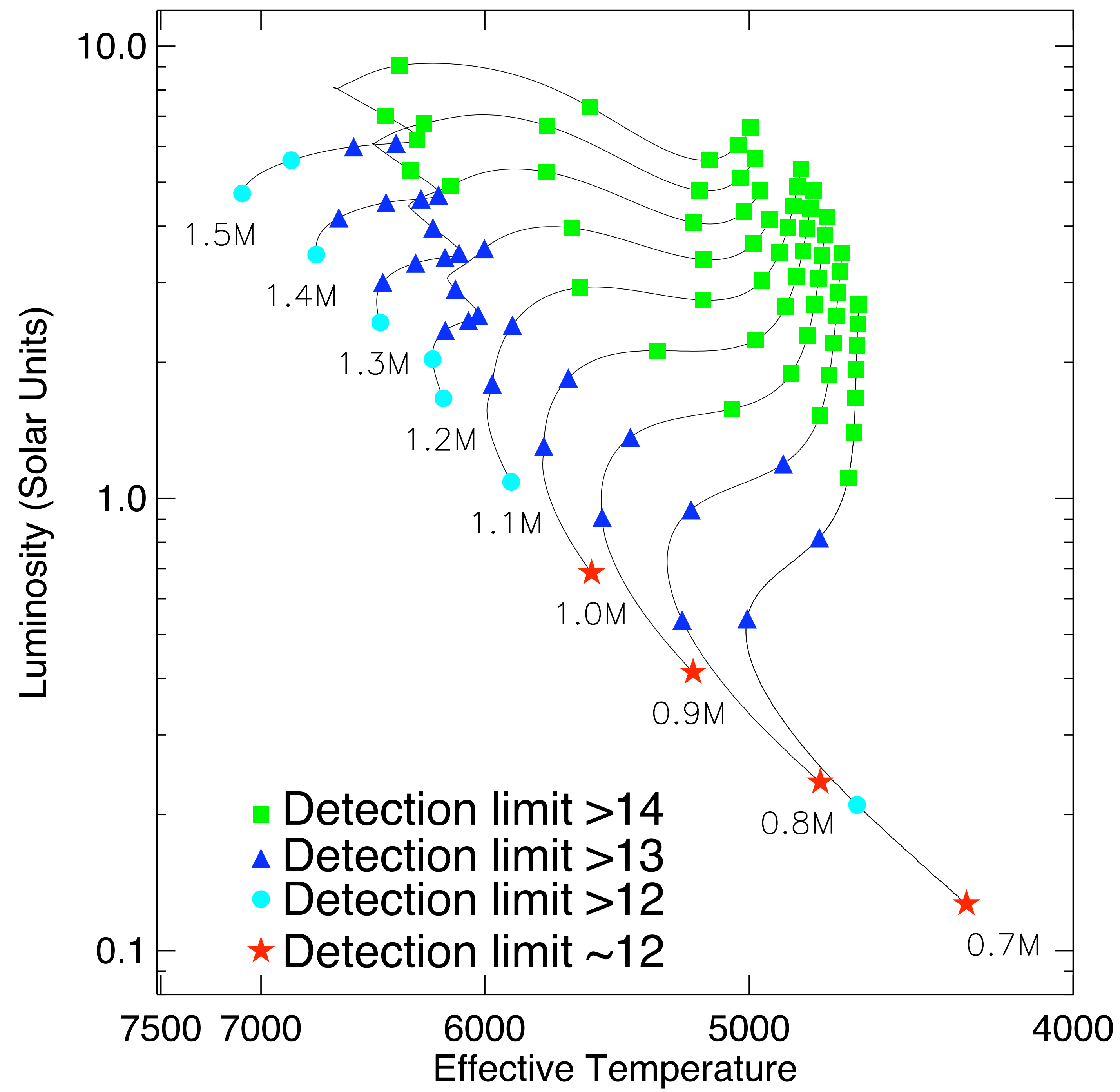
Detection Limits for Kepler Assuming One Year Observations

- 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.



Generic benefits of asteroseismology for exoplanet program.

- Asteroseismology will only be available for order 1,000 stars over the Kepler mission lifetime.
  - These will tend to be the brightest stars available.
  - Many if not most stars with planet candidates cannot be followed with useful asteroseismology.
- A ground-based photometric and spectroscopic effort is underway to pre-classify all potential targets, and especially to obtain radius estimates.
  - From comparing asteroseismic results for the subset of 1,000 stars in common it seems likely improved calibrations for algorithms to estimate radius can be developed allowing better estimates for the full catalog.

Redundant and complementary information on stars

- Asteroseismology provides a direct, high precision constraint on stellar density with detection of the large splitting.

- Detailed transit light curve modeling also provides a direct measure of stellar density to high precision -- for giant planet transits with photometric errors < 0.001 a/R_* is a direct output of light curve fit, and determines cube root of stellar density through Kepler's third law.

  - (Sozzetti et al 2007) find for TrES-2 $\rho_* = 1.375 \mp 0.065$ (observational)
  - Inclusion of stellar evolution constraints on mass yields $R_* = 1.000 \mp 0.035$

- Within the first year of Kepler observations of TrES-2 stellar density constraints from two independent methods should both provide < 1% accuracy -- will they agree?

- With further observations of TrES-2 asteroseismology should detect the small splitting and provide age to 5-10% -- vastly superior to other approaches. If individual frequencies can be obtained over the lifetime of Kepler, then additional inferences about interior structure will be available.

- The exquisite transit light curve Kepler will provide for TrES-2 will generate direct constraints on limb-darkening -- dependent upon surface details of T, z.

Summary

- Asteroseismology and exoplanet transit research are natural partners thanks to common needs for photometric precision.
- Asteroseismology can provide improved stellar radii and hence the planetary radii in many cases -- a critical need for exoplanet research.
- For bright stars with Hot Jupiters both redundant and complementary information about the host stars will be returned from transit light curve modeling and asteroseismology.