Synergy between asteroseismology and exoplanet observations

Tiago L. Campante

University of Porto

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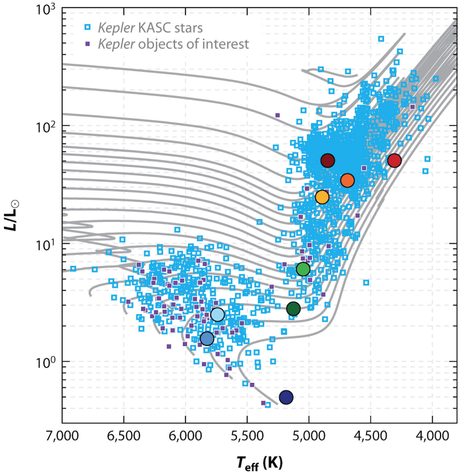
Overview

1. Current key synergies
   - Precise characterization of host stars
   - Dynamical architectures of planetary systems
2. Future synergies
   - Giant planets orbiting evolved stars
   - Densities of sub-Neptunes
3. *TESS* asteroseismology of exoplanet-host stars
   - Overview of *TESS*
   - Asteroseismic yield of exoplanet-host stars

A revolution in cool-star asteroseismology

- Solar-like oscillations excited by turbulent convection
- Cool-star asteroseismology with *Kepler*:
  - Several hundred solar-type stars
  - Over 10,000 red giants
- $>$100 KOIs with detected solar-like oscillations



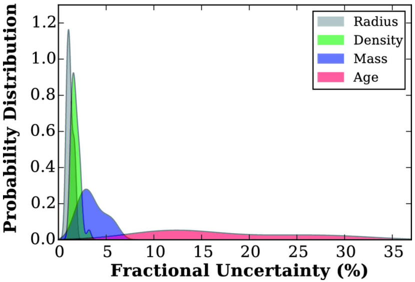
Chaplin & Miglio (2013, ARA&A, 51, 353)

Motivation

- Transit observations only provide estimate of planet-to-star radius ratio ($R_\mathrm{p} \propto R_*$)
- RVs + transits used to estimate planetary masses ($M_\mathrm{p} \propto M_*^{2/3}$)
- From TTVs in multi-planet systems one instead has $M_\mathrm{p} \propto M_*$
- Stellar ages used to assess dynamical stability and relative chronology

Fundamental properties of KOIs

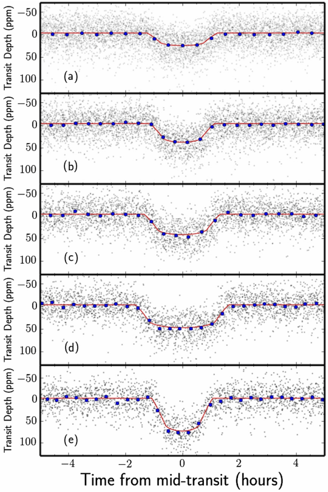
- 33 KOIs with high S/N in the oscillations
- Oscillation frequencies matched to grids of evolutionary models
- 1.2 % precision in R, 3.3 % in M and 14 % in age
- Precision commensurate with that expected from *PLATO* asteroseismology



Silva Aguirre et al. (2015, MNRAS, 452, 2127)

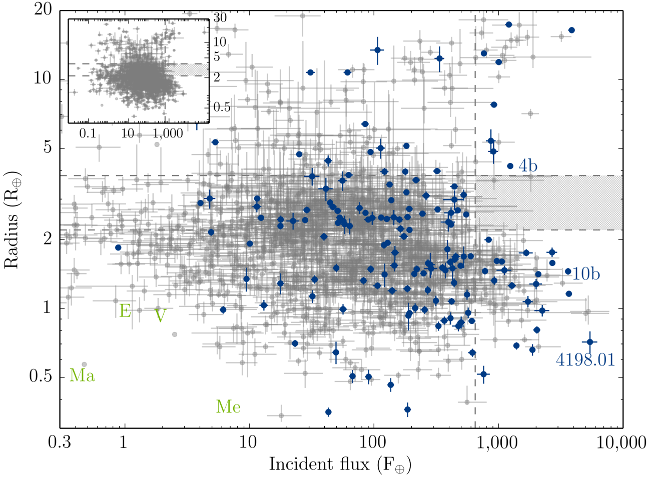
Kepler-444: oldest known system of terrestrial-size planets

- Metal-poor, Sun-like star from Galactic thick disk
- Hosts five sub-Earth-size planets
- All planets orbit in less than 10 days
- Precise age of $11.2 \pm 1.0\,\mathrm{Gyr}$ from asteroseismology



Campante et al. (2015, ApJ, 799, 170)

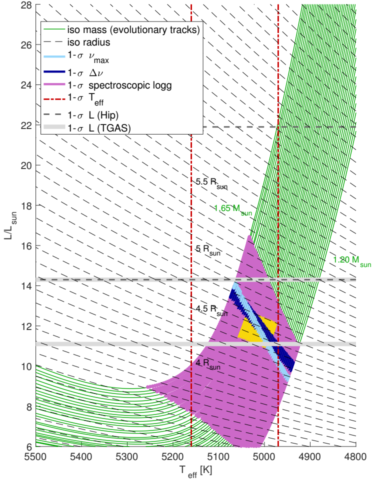
Detection of a 'hot-super-Earth desert'



Lundkvist et al. (2016, Nature Commun., 7, 11201)

Revisiting the retired A star controversy

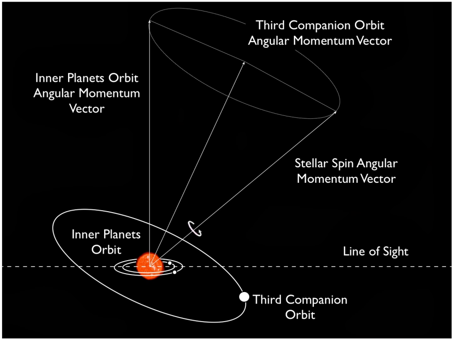
- RV surveys point to increasing occurrence of giant planets with stellar mass
- Surveys rely on *retired A stars* for sample of intermediate-mass stars
- Validity of relation subject to mass accuracy for evolved stars
- Figure shows asteroseismic constraints (from K2) on stellar models of HD 212771



Campante et al. (2017, MNRAS, 469, 1360); see also North et al. (2017, MNRAS, in press)

Obliquities

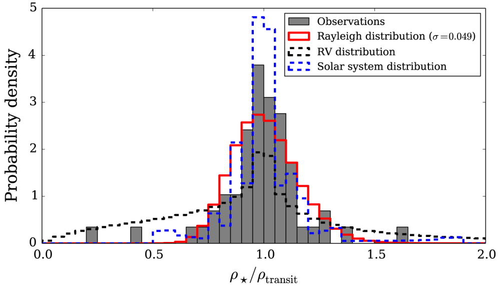
- Stellar inclination from rotationally split modes
- Independent of planet size
- Multi-transiting systems: tests of primordial star-disk alignment hypothesis
- Impact on hot-Jupiter formation theories



Huber et al. (2013, Science, 342, 331)

Eccentricities

- Asterodensity profiling: $\frac{\rho_*}{\rho_{\mathrm{transit}}} = \frac{(1-e^2)^{3/2}}{(1+e\sin\omega)^3}$
- Transits used to constrain eccentricity without RVs (given independent ρ_*)



Van Eylen & Albrecht (2015, ApJ, 808, 126)

A revolution set to continue

- *TESS*, *PLATO* and *WFIRST* to continue asteroseismic revolution
- Dedicated ground-based support (e.g., SONG)
- Number of solar-like oscillators will ascend to a few million
- $>90\,\%$ will be evolved stars
- *PLATO* will contribute the most detections for solar-type stars (80,000)

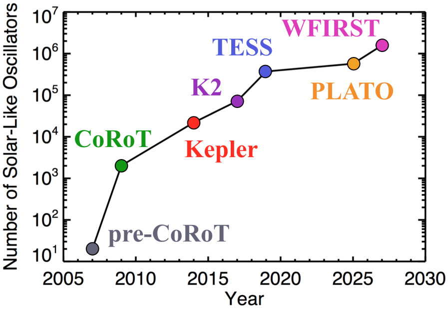
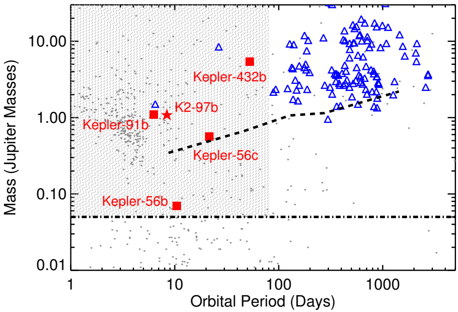


Figure courtesy of Dan Huber
(*PLATO* red-giant yield not included!)

Insight into occurrence and structure of giant planets

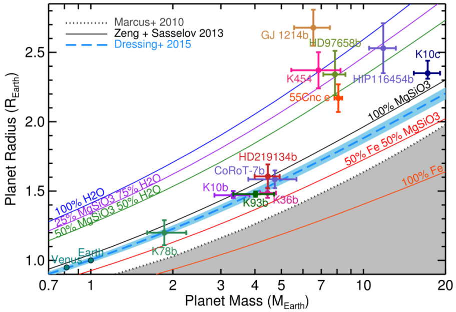
- *Kepler*/K2 discovery of several giant planets around oscillating low-luminosity RGB stars
- *TESS* will allow conducting populational study
- Key unsolved questions:
    - Role of incident flux on hot-Jupiter inflation
    - Giant-planet occurrence as function of stellar mass and evolution
    - Correlation between stellar metallicity and giant-planet occurrence



Campante et al. (2016, ApJ, 830, 138)

Probing transition from rocky to gaseous

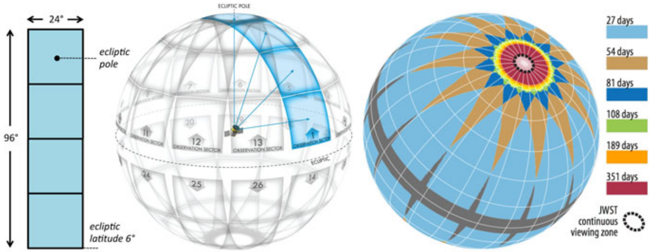
- Composition models sensitively dependent on radius
- *PLATO* asteroseismology provides unique opportunity to precisely study composition diversity
- *Gaia* parallaxes alone will not reach comparable precision
- Kepler-10, Kepler-36 and Kepler-454 (see figure) have radius and mass from asteroseismology



Gettel et al. (2016, ApJ, 816, 95)
(only masses measured to better than 20 %)

An all-sky survey for transiting planets

- Stars observed for at least 27 days
- 2-min cadence ($\sim 2 \times 10^5$ pre-selected FGKM dwarfs)
- 30-min cadence (full-frame images or FFIs)



https://tess.gsfc.nasa.gov

An overview

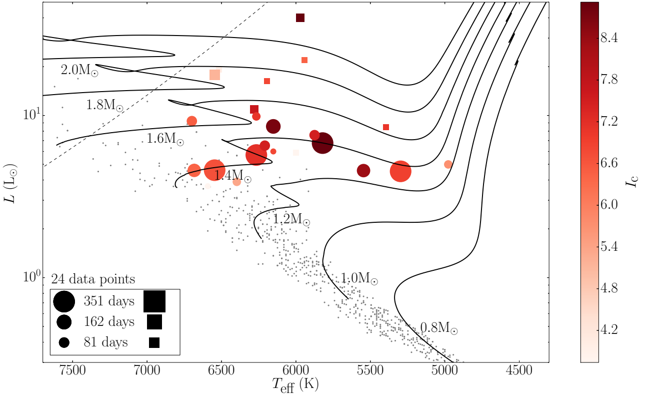
There are three separate contributions to this yield:

- *TESS* target hosts (2-min cadence)
- *TESS* FFI hosts (30-min cadence)
- Previously known hosts (transiting or not)

Asteroseismic yield of *TESS* target hosts

Based on synthetic target-host population of Sullivan et al. (2015, ApJ, 809, 77)

($\Delta t = 2$ min; $\sigma_{\rm sys} = 0$ ppm hr$^{1/2}$)

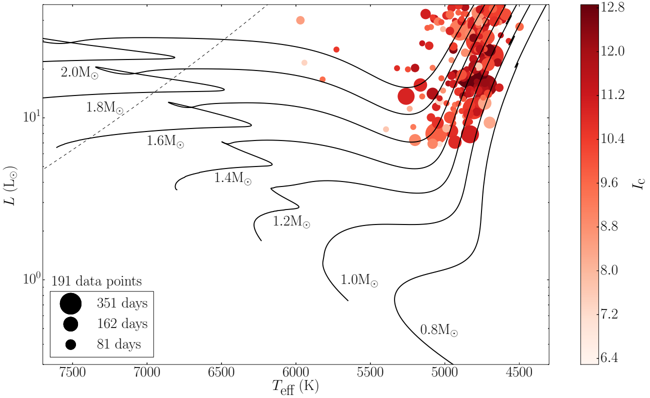


Campante et al. (2016, ApJ, 830, 138)

Asteroseismic yield of *TESS* FFI hosts

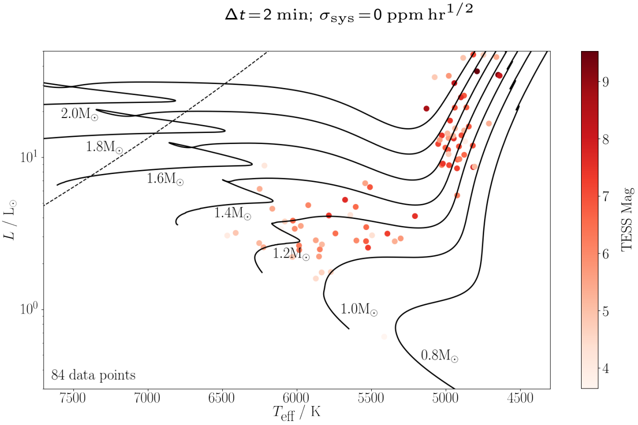
Based on synthetic FFI-host population of Sullivan et al. (2015, ApJ, 809, 77)

($\Delta t = 30$ min; $\sigma_{\rm sys} = 0$ ppm hr$^{1/2}$)



Campante et al. (2016, ApJ, 830, 138)

Asteroseismic yield of known hosts and link to *CHEOPS*



Campante et al. (2016, ApJ, 830, 138)

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This book presents the proceedings of the IVth Azores International Advanced School in Space Sciences entitled "Asteroseismology and Exoplanets: Listening to the Stars and Searching for New Worlds". The school addressed the topics at the forefront of scientific research being conducted in the fields of asteroseismology and exoplanetary science, two fields of modern astrophysics that share many synergies and resources. These proceedings comprise the contributions from 18 invited