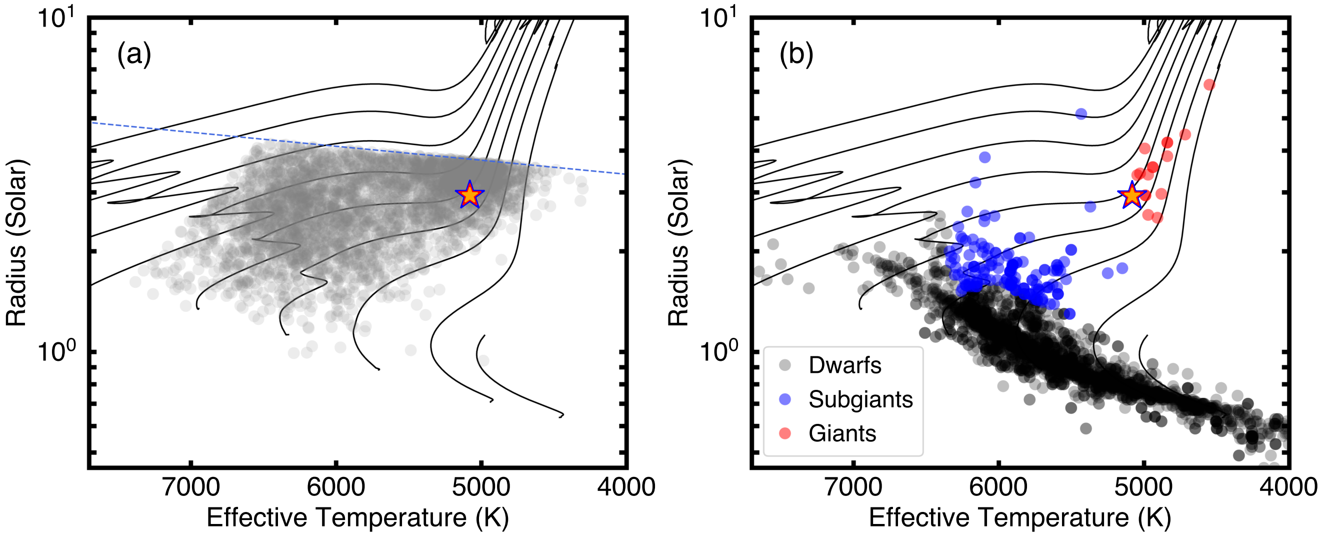

Figure 7. Stellar radius vs. effective temperature for the expected *TESS* Cycle 1 yield of solar-like oscillators (panel a; Schofield et al. 2019) and for all stars with confirmed transiting planets (panel b). The blue dashed line in panel (a) marks the approximate limit below which 2 minute cadence data are required to sample the oscillations. Symbols in panel (b) are color coded according to the evolutionary state of the star using solar-metallicity PARSEC evolutionary tracks. HD 221416 falls on the border between subgiants and red giants, and is highlighted with an orange/red/blue star symbol. HD 221416 is a typical target for which we expect to detect solar-like oscillations with *TESS*, but occupies a rare parameter space for an exoplanet host.

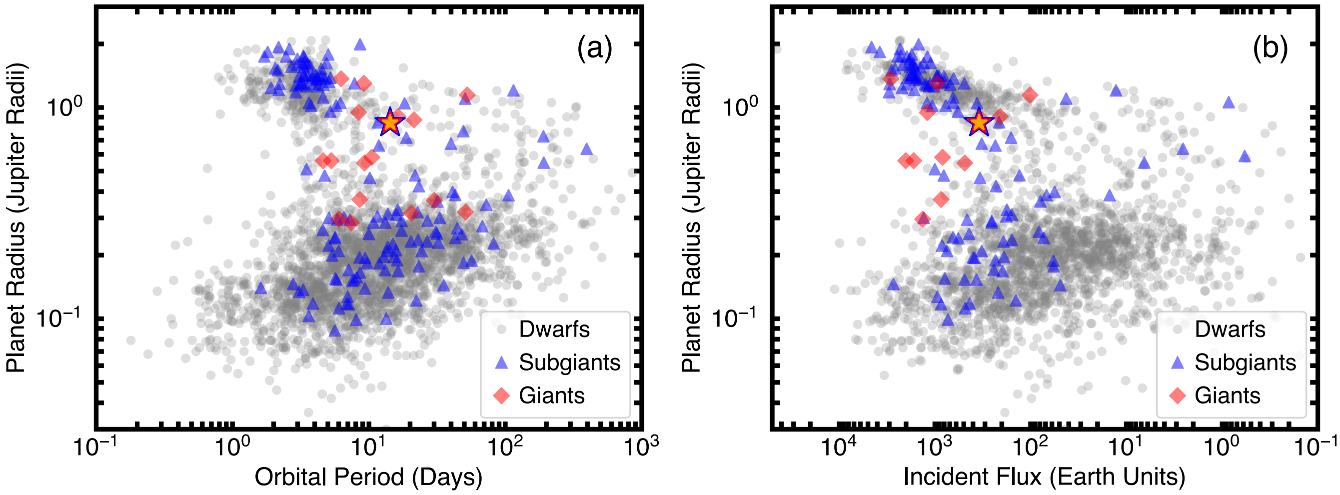

Figure 8. Planet radius vs. orbital period (panel a) and incident flux (panel b) for confirmed exoplanets. Symbols are color coded according to the evolutionary state of the host star (see Figure 7). HD 221416 b is highlighted in both panels with an orange/red/blue star symbol.

dissipation in the planet, which drives the circularization of the orbit. Using the formalism by Mardling (2011; see also Gizon et al. 2013; Ceillier et al. 2016; Davies et al. 2016), the current constraints would imply a minimum value of the planetary tidal quality factor $Q_{p;\min} \approx 3.2 \times 10^4$, below which the system would have been already circularized in ∼5 Gyr. Compared to the value measured in Saturn ($Q \approx 1800$; Lainey et al. 2017), this would demonstrate the broad diversity of dissipation observed in giant planets. Because tidal dissipation mechanisms vary strongly with internal structure (see, e.g., Guenel et al. 2014; Ogilvie 2014; André et al. 2017), this may also contribute to understanding the internal composition of such planets. We caution, however, that further RV measurements will be needed to confirm a possible nonzero eccentricity for HD 221416 b.

The precise characterization of planets orbiting evolved, oscillating stars also provides valuable insights into the diversity of compositions of planets through their mean densities. HD 221416 b falls in the transition region between Neptune and sub-Saturn-size planets for which radii increase as $R_P \approx M_P^{0.6}$, and Jovian planets for which radius is nearly constant with mass (Weiss et al. 2013; Chen & Kipping 2017; Figure 9). Recent studies of a population of sub-Saturns in the range ∼4–8 $R_\oplus$ also found a wide variety of masses, approximately 6–60 $M_\oplus$, regardless of size (Petigura et al. 2017b; Van Eylen et al. 2018). Furthermore, masses of sub-Saturns correlate strongly with host star metallicity, suggesting that metal-rich disks form more massive planet cores. HD 221416 b demonstrates that this trend does not appear to extend to planets with sizes $>8\,R_\oplus$, given its mass of $\sim 60\,M_\oplus$ and a roughly subsolar metallicity host star ([Fe/H] ≈ -0.08 dex). This suggests that Saturn-size planets may follow a relatively narrow range of densities, a possible signature of the transition in the interior structure (such as the increased importance of electron degeneracy pressure; Zapolsky & Salpeter 1969) leading to different mass–radius

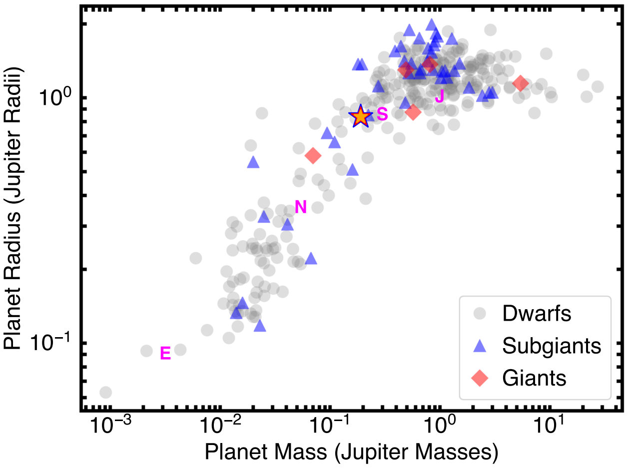

Figure 9. Mass–radius diagram for confirmed planets with densities measured to better than 50%. Symbols are color coded according to the evolutionary state of the host star (see Figure 7). HD 221416 b is highlighted with a orange/red/blue star symbol. Magenta letters show the position of solar system planets.

relations between sub-Saturns and Jupiters. We note that HD 221416 b is one of the most precisely characterized Saturn-size planets to date, with a density uncertainty of ∼15%.

6. Conclusions

We have presented the discovery of HD 221416 b, the first transiting planet orbiting an oscillating host star identified by *TESS*. Our main conclusions are as follows:

1. HD 221416 is a late subgiant/early red giant with a clear presence of mixed modes. Combined spectroscopy and asteroseismic modeling revealed that the star has just started its ascent on the red-giant branch, with $R_\star = 2.943 \pm 0.064\,R_\odot$, $M_\star = 1.212 \pm 0.074\,M_\odot$ and near-solar age (4.9 ± 1.1 Gyr). HD 221416 is a typical oscillating star expected to be detected with *TESS*, and it demonstrates the power of asteroseismology even with only 27 days of data.
2. The oscillation amplitude of HD 221416 is consistent with ensemble measurements from *Kepler*. This confirms that the redder bandpass of *TESS* compared to *Kepler* only has a small effect on the oscillation amplitude (as expected from scaling relations; Kjeldsen & Bedding 1995; Ballot et al. 2011a), supporting the expected yield of thousands of solar-like oscillators with 2 minute cadence observations in the nominal *TESS* mission (Schofield et al. 2019). A detailed study of the asteroseismic performance of *TESS* will have to await ensemble measurements of noise levels and amplitudes.
3. HD 221416 b is a "hot Saturn" ($F = 343 \pm 24\,F_\oplus$, $R_\mathrm{p} = 0.836 \pm 0.031\,R_\mathrm{J}$, $M_\mathrm{p} = 0.190 \pm 0.018\,M_\mathrm{J}$) and joins a small but growing population of close-in, transiting planets orbiting evolved stars. Based on its incident flux, radius, and mass, HD 221416 b may be a precursor to the population of gas giants that undergo radius reinflation, due to the increased irradiance as their host star evolves up the red-giant branch.
4. HD 221416 b is one the most precisely characterized Saturn-size planets to date, with a density measured to ∼15%. HD 221416 b does not follow the trend of increasing planet mass with host star metallicity discovered in sub-Saturns with sizes between 4 and $8\,R_\oplus$, which has been linked to metal-rich disks preferentially forming more massive planet cores (Petigura et al. 2017b). The moderate density ($\rho_\mathrm{p} = 0.431 \pm 0.062\,\mathrm{g\,cm^{-3}}$) suggests that Saturn-size planets may follow a relatively narrow range of densities, a possible signature of the transition in the interior structure leading to different mass–radius relations for sub-Saturns and Jupiters.

HD 221416 provides a first glimpse at the strong potential of *TESS* to characterize exoplanets using asteroseismology. HD 221416 b has one the most precisely characterized densities of known Saturn-size planets to date, with an uncertainty of ∼15%. Thanks to asteroseismology, the planet density uncertainty is dominated by measurements of the transit depth and the radial-velocity amplitude, and thus can be expected to further decrease with continued transit observations and radial-velocity follow-up, which is readily performed given the brightness ($V = 8$) of the star. Ensemble studies of such precisely characterized planets orbiting oscillating subgiants can be expected to yield significant new insights into the effects of stellar evolution on exoplanets, complementing current intensive efforts to characterize planets orbiting dwarfs.

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Software: Astropy (Astropy Collaboration et al. 2018), Matplotlib (Hunter 2007), DIAMONDS (Corsaro & De Ridder 2014), isoclassify (Huber et al. 2017), EXOFASTv2 (Eastman 2017), ktransit (Barclay 2018).

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