2018 NASA Hubble Fellowship Program Application

Jamie Tayar
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PhD Title: Rotation In Red Giants
PhD Advisor: Marc Pinsonneault, OHIO STATE U.
PhD Date: 08/2018

Proposed Host #1: Daniel Huber, IFA
Proposed Host #2: Sarbani Basu, YALE
Proposed Host #3: Juna Kollmeier, CARNEGIE OCIW

Research Title: Subgiants: Models, Rotation, Convection, and Planets
Science Categories: Stellar Physics: Evolved Stars, Exoplanet Host Stars, Stellar Evolution
Techniques: Simulations/Models, Surveys, Theory

Abstract: Stellar models are the pillars of many areas of astrophysics and make a rich web of predictions for the properties and evolution of stars. While these models perform well for stars like our sun, important inconsistencies have been identified in other regimes. With the launch of the TESS satellite next year, in combination with Gaia data and ground based spectroscopy, there will finally be a large sample of stars with measured masses, radii, surface gravities, temperatures, metallicities, core and surface rotation rates, granulation and macroturbulence, which can be used to improve stellar models and therefore the inferences drawn from them. Specifically, I will use this sample to calibrate the masses and radii of stellar models, and better our understanding of stellar evolution, especially the physics of rotation and convection. This work will also improve the measured masses, radii, and ages of planets, provide insight into which stars are most likely to have detectable planets, and improve estimates of the planet distribution as a function of stellar mass and metallicity. In short, this work will improve both our understanding of our own cosmic origins, and our ability to study planetary systems outside our own.

Reference #1: Marc Pinsonneault, OHIO STATE U.
Reference #2: Jennifer Johnson, OHIO STATE U.
Reference #3: Daniel Huber, IFA

Jamie Tayar

Stellar Rotation – Stellar Evolution
Stellar Physics – Red Giants – Stellar Populations
Spectroscopy – Asteroseismology – Modeling

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Education

Ohio State University, Columbus, Ohio, USA
Doctor of Philosophy, Astronomy, Summer 2018 (Expected)
Master of Science, Astronomy, December 2014
Thesis: Rotation in Red Giants
Advisors: Marc Pinsonneault

California Institute of Technology, Pasadena, California, USA
Bachelor of Science, Astrophysics, June 2012
Thesis: FU Orionis Stars
Advisor: Lynne Hillenbrand

Honors and Awards

Best Graduate Student Poster, Cool Stars 19, 2016
Sigma Xi Full Member
Early Career Astronomer Travel Fund Award, SDSS-IV Collaboration Meeting, $1200
Graduate Affiliate at KITP program *Galactic Archaeology and Precision Stellar Astrophysics*

Publications

Summary: 23 total, 3 first author, 2 second author; 1,047+ citations; h-index: 10

First Author Publications

1. **Tayar, Jamie**; Somers, Garrett; Pinsonneault, Marc H.; and 28 coauthors. *"The Correlation Between Mixing Length and Metallicity On the Giant Branch: Implications for Ages in the Gaia Era"* 2017, ApJ, 840, 17.
2. **Tayar, Jamie**; Ceillier, Tugdual; García-Hernández, D. A. and 17 coauthors. *"Rapid Rotation of Low-mass Red Giants Using APOKASC: A Measure of Interaction Rates on the Post-main-sequence"* 2015, ApJ, 807, 82.
3. **Tayar, Jamie**; Pinsonneault, Marc H.. *"Implications of Rapid Core Rotation in Red Giants for Internal Angular Momentum Transport in Stars"* 2013, ApJL, 775, 1.

Contributing Author Publications: Significant Contribution

4. Ceillier, T.; **Tayar, J.**; Mathur, S.; and 7 coauthors. *"Surface rotation of Kepler red giant stars"* 2017, A&A, 605, 111.
5. Cody, Ann Marie; **Tayar, Jamie**, Hillenbrand, Lynne A.; and 2 coauthors. *"Precise High-cadence Time Series Observations of Five Variable Young Stars in Auriga with MOST"* 2013, AJ, 145, 79.

Contributing Author Publications: Work Uses My APOGEE-*Kepler* Catalog

6. Silva Aguirre, V.; Bojsen-Hansen, M.; Slumstrup, D.; and 21 coauthors. *"Confirming chemical clocks: asteroseismic age dissection of the Milky Way disk(s)"* 2017, ArXiv.
7. Serenelli, Aldo; Johnson, Jennifer; Huber, Daniel; and 23 coauthors. *"The First APOKASC Catalog of Kepler Dwarf and Subgiant Stars"* 2017, ArXiv.
8. Bossini, D.; Miglio, A.; Salaris, M.; and 9 coauthors.*"Kepler red-clump stars in the field and in open clusters: constraints on core mixing"* 2017, MNRAS, 469, 4718.
9. Zasowski, G.; Cohen, R. E.; Chojnowski, S. D.; and 32 coauthors. *"Target Selection for the SDSS-IV APOGEE-2 Survey"* 2017, AJ, 154, 198.

10. Huber, Daniel; Zinn, Joel; Bojsen-Hansen, Mathias; and 17 coauthors. *"Asteroseismology and Gaia: Testing Scaling Relations Using 2200 Kepler Stars with TGAS Parallaxes"* 2017, ApJ, 844, 102.
11. Abolfathi, Bela; Aguado, D. S.; Aguilar, Gabriela; and 324 coauthors. *"The Fourteenth Data Release of the Sloan Digital Sky Survey: First Spectroscopic Data from the extended Baryon Oscillation Sky Survey and from the second phase of the Apache Point Observatory Galactic Evolution Experiment"* 2017, ArXiv.
12. Corsaro, E.; Mathur, S.; Garca, R. A.; and 9 coauthors. *"Metallicity effect on stellar granulation detected from oscillating red giants in open clusters"* 2017, A&A 605, 3.
13. Blanton, Michael R.; Bershady, Matthew A.; Abolfathi, Bela; and 350 coauthors. *"Sloan Digital Sky Survey IV: Mapping the Milky Way, Nearby Galaxies and the Distant Universe"* 2017, AJ, 154, 28.
14. SDSS Collaboration; Albareti, Franco D.; Allende Prieto, Carlos; Almeida, Andres; and 336 coauthors. *"The Thirteenth Data Release of the Sloan Digital Sky Survey: First Spectroscopic Data from the SDSS-IV Survey MApping Nearby Galaxies at Apache Point Observatory"* 2016, ArXiv.
15. Alam, Shadab; Albareti, Franco D.; Allende Prieto, Carlos; and 301 coauthors. *"The Eleventh and Twelfth Data Releases of the Sloan Digital Sky Survey: Final Data from SDSS-III"* 2015, ApJS, 219, 12.

Contributing Author Publications: Contributed Data Analysis and/or Model Interpretation

16. Sandquist, Eric L.; Mathieu, Robert D.; Quinn, Samuel N.; and 16 coauthors. *"The K2 M67 Study: A Curiously Young Star in an Eclipsing Binary in an Old Open Cluster"* Submitted.
17. Ceillier, T.; van Saders, J.; Garcia, R. A.; and 7 coauthors. *"Rotation periods and seismic ages of KOIs - comparison with stars without detected planets from Kepler observations"* 2015, MNRAS, 456, 119.
18. Martig, Marie; Rix, Hans-Walter; Aguirre, Victor Silva; and 30 coauthors. *"Young α-enriched giant stars in the solar neighbourhood"* 2015, MNRAS, 451, 2230.
19. Pinsonneault, Marc H.; Elsworth, Yvonne; Epstein, Courtney; and 42 coauthors. *"The APOKASC Catalog: An Asteroseismic and Spectroscopic Joint Survey of Targets in the Kepler Fields"* 2014, ApJS, 215, 19.
20. Epstein, Courtney R.; Elsworth, Yvonne P.; Johnson, Jennifer A.; and 29 coauthors. *" Testing the Asteroseismic Mass Scale Using Metal-poor Stars Characterized with APOGEE and Kepler"* 2014, ApJL, 785, 28.

Contributing Author Publications: Contributed Observational Data

21. Fausnaugh, M. M.; Grier, C. J.; Bentz, M. C.; and 69 coauthors. *"Reverberation Mapping of Optical Emission Lines in Five Active Galaxies"* 2017, ApJ, 840, 97.
22. Mathur, S.; Gupta, A.; Page, K.; and 147 coauthors . *"Space Telescope and Optical Reverberation Mapping Project. VII. Understanding the UV anomaly in NGC 5548 with X-Ray Spectroscopy"* 2017, ApJ, 846, 55.
23. Pei, L.; Fausnaugh, M. M.; Barth, A. J.; and 153 coauthors. *"Space Telescope and Optical Reverberation Mapping Project. V. Optical Spectroscopic Campaign and Emission-Line Analysis for NGC 5548"* 2017, ApJ, 837, 131.

Presentations

APOGEE-2 Team Meeting, Santiago, Chile, 2017	Invited Tutorial
KASC-10/TASC-3, Birmingham University, Birmingham, England, 2017	Contributed Talk
LBTO Users' Meeting, Firenze, Italy, 2017	Contributed Poster
Kepler/K2 Science Conference IV, Mountain View, CA, 2017	Contributed Talk
Ohio State CCAPP Summer Seminar, Ohio State, Columbus, OH, 2017	Invited Talk
APOGEE-2 Team Meeting, Carnegie Observatories, Pasadena, CA, 2017	Contributed Talk

Ohio State CCAPP Summer Seminar, Ohio State, Columbus, OH, 2016	Invited Talk
SDSS-IV Collaboration Meeting, Madison, WI, 2016	Invited Plenary Talk
SDSS-IV Collaboration Meeting, Madison, WI, 2016	Contributed Lighting Talk
APOGEE-2 Team Meeting, Madison, WI, 2016	Contributed Talk
Cool Stars 19, Uppsala, Sweden, 2016	Prize Talk (Best Graduate Poster)
Cool Stars 19, Uppsala, Sweden, 2016	Contributed Poster
2^{nd} Católica-Ohio State Astronomy Workshop, 2016	Contributed Talk
KASC-8/TASC-1, Stellar Astrophysics Center, Aarhus, Denmark, 2015	Contributed Talk
APOGEE Collaboration Meeting, Airlie, Virginia, 2015	Contributed Talk

Proposals

1. TESS Guest Investigator Cycle 1, PI: Pinsonneault, Co-I: 5 including **Tayar**, "Subgiants as Precision Tests of Angular Momentum Evolution", submitted
2. Large Binocular Telescope 2016A, PI: **J. Tayar**, "Surface Rotation of the Secondary Clump", awarded 9 hours

Observing Experience

MDM 1.3 meter, CCDS spectrograph — 12 nights

Teaching Experience

Teaching Assistant, Astronomy Department, Ohio State
Astronomy Lab (General Education/Non-majors), Fall 2015, Fall 2016
Methods of Observational Astronomy & Data Analysis (Upper Division Astronomy Majors), Fall 2016
Principles of Stellar Evolution & Nucleosynthesis (Upper Division Astronomy Majors), Spring 2014
Introductory Astronomy (General Education/Non-majors), Fall 2012,Summer 2013, Fall 2014

Teaching Assistant, Astrophysics Department, Caltech
Introductory Astronomy (General Education/Non-majors), Spring 2011

Service and Outreach

Committee On Inclusiveness in the SDSS (COINS) Member, 2016-present
Sigma Xi Science Café Invited Talk: Eclipse 2017
Public Talk, Astronomy on Tap, Columbus
Regular Volunteer, Ohio State Public Roof Nights and Star Parties
Breakfast of Science Champions Co-organizer 2016
Regularly Run Astronomy Demos at Schools, Libraries, and Camps

RED GIANTS: NEW OBSERVABLES, NEW THEORIES

My thesis research has focused on using the newly obtained large and precise asteroseismic and spectroscopic data sets in comparison with stellar models to better understand red giant stars and has resulted in the **identification of a major problem with all current grids of stellar models**. Much of my research has focused on using new measurements of core and surface rotation to place constraints on the physics of evolved stars. **I have demonstrated that the coupling between the core and surface rotation rates of evolved stars are evolutionary state dependent, shown that a standard Kawaler angular momentum loss law is insufficient for evolved stars, found evidence for radial differential rotation in the convective zones of intermediate mass stars, calculated that the timescales for rotational coupling of giants are long compared to the pre-main-sequence, and placed a lower limit on the fraction of stars that interact on the giant branch of 10%.**

The APOGEE-Kepler (APOKASC) Sample: Accurate and precise models of solar type stars have formed a cornerstone of astrophysics for almost fifty years. From such models, we extrapolate everything from the masses and radii of extrasolar planets to the evolutionary history of galaxies, allowing us to work towards answering questions like "How did we get here?" and "Are we alone?". However, while we have been able to calibrate models for dwarf stars using fundamental measurements including eclipsing binaries and interferometry, similarly precise constraints on our understanding of red giant stars have historically been lacking. For this reason, the APOKASC Collaboration was created to combine *Kepler* asteroseismic data with APOGEE spectroscopy. I have been generating and maintaining the APOKASC Catalog for the past four years, which combines asteroseismic results like mass, radius, and evolutionary state with spectroscopic observables like metallicity, temperature, and individual element abundances, as well as properties like age which could not be derived from either data set alone. My work has also been fundamental to APOGEE collaboration's studies of the evolution of our galaxy, as I have helped to use this sample to determine spectroscopic proxies for evolutionary state, compute evolutionary state dependent corrections to the spectroscopic gravities, and compute metallicity dependent corrections to the temperature and gravity scales.

Model Calibration: With the APOKASC catalog, we have a sample of several thousand stars with precise and accurate masses, compositions, temperatures and gravities. I was able to compare this data to the predictions of stellar models I ran using the Yale Rotating Evolution Code (YREC, Pinsonneault et al. 1989), and **found that the predicted temperatures of the models were off** systematically as a function of metallicity by over 100K (Tayar et al. 2017). Similar offsets were found in the PARSEC grid of models. I suggested that either there are metallicity dependent systematic errors in the physics of our models, or the parameterization of convection, the convective mixing length, should be a function of metallicity and evolutionary state rather than a single value. Such a change would affect the inferred properties of galaxies, the location of the instability strip, and the chemical enrichment yields of low-mass stars.

Rotation- Cores: In the past, people often assumed that all stars rotate as simple solid bodies. While this is not a terrible assumption for solar-like stars, it was quickly made clear by the *Kepler* data that it was inconsistent with measurements in red giants. Using some of the earliest core rotation rates, **I showed that the strength of core-envelope coupling differed between low-mass subgiants and massive core helium burning stars** (Tayar

& Pinsonneault 2013). I was also able to compute a decoupling timescale for subgiants that was substantially longer than the coupling timescales measured in pre-main-sequence stars.

In a paper nearing completion, I have followed up that work with a more detailed examination of the trends in core rotation in intermediate mass (2-3 $M_\odot$) stars (Tayar et al., in prep). This analysis is consistent with the initial finding of strong coupling between the core and envelope of these stars, although the profile is not exactly rigid. Cores of these stars rotate between one and three times as fast as the surfaces. Additionally, this carefully chosen sample of stars shows that the core rotation rates decrease as the star evolves on the secondary clump, clear **model independent evidence for rapid angular momentum exchange between the core and the envelope.** Finally, the lack of strong mass trends in the core rotation sample suggests that substantial angular momentum loss can not be the only factor setting the rotation rate for these stars.

Rotation-Surfaces: Because of the generally slow rotation of the surfaces of evolved stars, the core rotation rates of these stars are often better constrained than the surface rotation rates. As part of my thesis, I have worked to improve the samples of stars with measured surface rotation rates, both through spectroscopic velocity broadenings (v sin(i)s) (Tayar et al. 2015) and star spot rotation periods (Ceillier et al. 2017). With these samples, it is possible to gain a better understanding of the real distribution of surface rotation rates as a function of mass and gravity. Additionally, given this understanding, it is possible to identify stars rotating much more rapidly than single stellar evolution would allow, which therefore must have gained angular momentum through an interaction with some other body, either stellar or planetary. Using low-mass red clump stars, which should not have detectable rotation, I suggest that at minimum **between seven and fifteen percent of low-mass stars interact on the giant branch.** These findings provide an interesting constraint on binary population synthesis models and might also provide information on the distribution of giant planets out to several AU.

One of the most surprising results from these studies was the fact that **intermediate-mass stars have much slower surface rotation rates on the secondary clump that would have been expected given their rapid main sequence rotation.** By forward modeling the predicted distributions of secondary clump rotation rates from the main sequence population, I show in a paper nearing completion that either enhanced angular momentum loss or radial differential rotation in the surface convection zones of these stars could explain the slow surface rotation rates, and that these two mechanisms produce substantially different predictions for the surface rotation distributions as a function of mass and surface gravity (Tayar & Pinsonneault, in prep). While none of the current data is sufficient to conclusively discriminate between these two mechanisms, comparison of the core and surface rotation distributions suggests that a combination of the two processes might be a better fit than either one alone. In either case, such radical changes in the physics of stellar rotation could have dramatic effects on the gyrochronologically measured ages of low-mass stars and the predicted rotation profiles of stars before they go supernova.

Mixing: In addition to the studies of rotation that have been my main focus, I have also been using this expansive sample of well studied stars to look at stellar processes like mixing on the giant branch, which have previously lacked large cohesively analyzed data sets. It is well established that the depth of the first dredge up and thus the carbon to nitrogen ratio ([C/N]) in red giants is a function of mass of the red giant branch (Martig et al. 2016). It is also well known that in solar metallicity clusters like M67, the [C/N] ratio stays fixed on the giant branch while in low metallicity globular clusters the [C/N] ratio drops again after the red giant branch bump due to so called extra mixing. With the APOGEE sample, we can map out in great detail the effects of extra mixing as a function of metallicity, and show that **the amount of extra mixing smoothly increases as metallicity decreases**, which provides a constraint on the mechanism behind this extra mixing (Shetrone, Tayar, et al., in prep) and clearly demarcates the regime where [C/N] can be used as a mass and age diagnostic for galactic archaeology studies.

In short, the combination of asteroseismology and spectroscopy for thousands of stars has allowed me to expand and correct our understanding of stellar physics and stellar evolution in a way that has not previously been possible. During my thesis, I have found major problems in the temperatures of stellar models, suggested mass and evolutionary state dependent core-envelope coupling, provided evidence of enhanced angular momentum loss and radial differential rotation in the surface convection zones of intermediate mass giants, identified a number of interaction products on the giant branch, put a lower limit of ∼10 percent on the fraction of stars that gain angular momentum from the interaction with a companion on the giant branch, and mapped the metallicity dependence of extra mixing.

Ceillier, T., et al. 2017, A&A, 605, A111
Martig, M., et al. 2016, MNRAS, 456, 3655
Pinsonneault, M. H., et al. 1989, ApJ, 338, 424
Tayar, J., et al. 2013, ApJ, 775, L1
—. 2015, ApJ, 807, 82
—. 2017, ApJ, 840, 17

SUBGIANTS: MODELS, ROTATION, CONVECTION, AND PLANETS

Stellar models are the pillars of many areas of astrophysics and are required for everything from measuring the properties of extrasolar planets to reconstructing the history of galaxies. While these models perform well for stars like the sun, they are grossly inconsistent with measurements of evolved stars. In order to improve these models, we must better understand the physics of stars on the subgiant branch, where the models start to deviate from reality, including the influence of rotation and convection. **My expertise in combining results from a variety of observational techniques to test and refine stellar models has perfectly positioned me to undertake this work, which will improve our understanding of evolved stars and impact many areas of astrophysics, including and in particular our understanding of the planetary systems.**

Stellar models make a rich web of predictions for the properties and evolution of stars. In the past, only stars like the sun could be easily studied in any detail and so stellar models are calibrated to reproduce the sun. With the advent of missions like *Kepler* and *K2*, and large spectroscopic surveys, it is now possible to measure the properties of a wide variety of stars at high precision. In my thesis work, I have combined data from a variety of sources, including asteroseismology and spectroscopy, to compare the properties of evolved stars to model predictions and found **vast differences between data and models.** I have proposed fixes to the predicted model temperatures (Tayar et al. 2017) and found that current models do not adequately capture the rotational evolution (Tayar & Pinsonneault 2013; Tayar et al. 2015).

With the launch of the *TESS* satellite next year, in combination with *Gaia* data and ground based spectroscopy, there will finally be a large sample of stars with measured masses, radii, surface gravities, temperatures, metallicities, core and surface rotation rates, granulation and macroturbulence. This means that it will no longer be acceptable to use a simple solar calibration and one or two properties of the models, but will become possible to study stars holistically, combining information from temperatures and gravities with rotation and convection, and basing these comparisons on a large sample of precisely studied calibrators. While legacy data from *Kepler* subgiants and *Kepler* and *K2* clusters will be invaluable, the vast majority of these calibrators will be subgiants in the *TESS* continuous viewing zone, where all these properties can be simultaneously measured, and I have submitted a *TESS* Guest Investigator proposal to ensure they are observed (see Figure 1). As a Hubble Fellow, I will use these subgiants to improve our understanding of stellar physics and properly calibrate stellar models. This will yield more accurate and precise masses, radii, and ages of starsand their planets, allowing us to better understand how stars evolve and better study planets around other stars.

<u>Precise Masses and Radii:</u> There are two major problems with inferring the masses and radii from stellar models. The first of these is that these models are not calibrated to match the temperatures and gravities of the stars at the measured masses and radii. This effect was most obvious in the temperature offsets measured for red giant stars (Tayar et al. 2017), but earlier work on less evolved stars suggested that the luminosity dimension also requires calibration (Bonaca et al. 2012). The other historic problem with calibrating stellar models has been defining what values to use for calibration. Recent work by Huber et al. (2017) has suggested that even when radii have been measured carefully, there can be discrepancies of five percent between asteroseismic scaling relation measurements and radii determined using *Gaia* parallaxes. As a Hubble Fellow at the Institute for Astronomy (IfA), I will

work with Professor Daniel Huber to determine the source of this discrepancy and whether it can be alleviated with the more precise parallaxes expected to be released next year or measurements of individual seismic modes. The *TESS* and *Kepler* subgiants in this sample will then be used to calibrate the helium abundances and mixing lengths of the models so that they correctly match the measured temperatures as a function of metallicity and mass. These will then be **the most accurate stellar models** available, thereby improving the masses and radii that can be inferred for all stars from more simply measured properties. As evidenced by recent work on the California-*Kepler* survey, improvements on the stellar properties lead not just to improved properties for individual planets, but also qualitatively new discoveries, like the evaporation gap (Fulton et al. 2017), which substantively alter our understanding of planetary evolution. Once I have produced models that accurately predict the bulk properties of the star, I will then move on to the two largest uncertainties in our understanding of low-mass stars, namely rotation and convection.

Rotation-Physics: Having calibrated the models, I will use them to better understand the angular momentum transport and core-envelope coupling in each star. The available data suggests that core-envelope decoupling occurs on the subgiant branch on timescales much longer than we see in pre-main-sequence stars (Tayar & Pinsonneault 2013). Work on red giants suggests that the angular momentum transport is mass and evolutionary state dependent (Tayar & Pinsonneault 2013). The *TESS* data will cover the gravity range where this decoupling is thought to be occurring and the mass range where stars transition from slow rotation due to main sequence angular momentum loss to rapid rotation with minimal angular momentum loss (see Figure 2). Combined with the ability to measure both core and surface rotation rates in these stars, this makes the subgiant regime the perfect place to map out the core-envelope decoupling as a function of mass, metallicity, gravity, and surface rotation rate. It has also been suggested that the angular momentum loss predictions for these stars are incorrect both by work on old field stars (van Saders et al. 2016) and by my own thesis work on evolved stars. As a Hubble Fellow at the IfA, I will work with Professor Jennifer van Saders to determine whether a modified breaking law better matches the measured surface rotation distributions as a function of mass and metallicity.

Rotation- Ages: One of the best ways of inferring ages for isolated low-mass stars is through gyrochronology, because the rotation of these stars slows down as they age. With the constraints on the rotational evolution of the core and surface that I will produce, I will map out the angular momentum loss through magnetized winds as a function of mass, metallicity, radius, and surface rotation rate. These constraints on the dependence of the angular momentum loss law will allow me to distinguish between older wind loss laws (e.g. Kawaler 1988) and newer parameterizations (Matt et al. 2015) that are calibrated to reproduce the solar rotation but make very different predictions in other regimes. This will allow me to **better predict rotation rates as a function of age** leading to better ages for planets around stars, especially M dwarfs, that do not have the mass, radius, or metallicity of the sun.

Rotation- Interactions: As a star expands on the post-main-sequence, it begins to interact tidally with stellar and planetary bodies at wider initial separations. One common result of such an interaction is the increase in stellar rotation rate as orbital angular momentum is converted to spin angular momentum. Once I have mapped out the expected rotation rates of evolved stars, I will identify stars rotating more rapidly than single stellar evolution would allow (as in Tayar et al. 2015). I will then follow up these stars with the numerous spectrographs and high contrast imaging options available at the IfA to characterize the architecture of the system and the properties of their companions. These measurements will provide insight into the products of binary evolution as well as a new way of identifying likely non-transiting planetary systems and a limit on the fraction of stars hosting giant planets out to several AU.

Convection- Physics: Assuming these investigations do not strongly contradict current understanding in a way that requires the development of substantial new physics, I will use my *TESS* and *Kepler* subgiant sample to constrain the biggest uncertainty in the evolution of low-mass stars, namely convection. With this sample, I will have several different measurements of convection (flicker, granulation, macroturbulence, and inferred convective mixing length). Using the available data, as well as very high resolution follow-up spectra from the High Dispersion Spectrograph on Subaru (R$\sim$160,000, allowing discrimination between rotation and macroturbulent broadening down to about two kilometers per second) as necessary, the effects of convection can be disentangled from rotational effects which would normally bias the results. I will compare these measurements to each other and to the predictions of three dimensional simulations of convection, which are able to reproduce the sun but disagree with measurements of red giants (Tayar et al. 2017). These comparisons will pave the way to a better understanding of the efficiency of convection and its dependence on composition, temperature, and surface gravity.

Convection-Jitter: While convection is an interesting science topic for stellar physicists, it is considered a nuisance parameter by astronomers searching for planets. Preliminary work on cluster giants has suggested that the granulation amplitude and flicker are strongly metallicity dependent (Corsaro et al. 2017). It is also known that the granulation is correlated with radial velocity jitter (Oshagh et al. 2017), and we therefore expect the detectability of extrasolar planets by both the transit and radial velocity methods to be a function of the stellar parameters. Using the measurements of convection in the subgiant sample, **I will construct a prediction of the stellar variability and radial velocity jitter as a function of stellar mass, radius, and metallicity**. These predictions can be used both to target quieter stars where planet detections are more feasible, and to more accurately compute the detection efficiency for planets as a function of stellar type, leading to improved planet distributions as a function of stellar mass and metallicity.

In short, I propose to use my time as a Hubble Fellow to improve the calibration of stellar models and our understanding of rotation and convection in low-mass stars. In addition to the improved knowledge of stellar physics and stellar evolution, this work is expected to impact the inferred properties of planets, provide insight into which stars are most likely to have detectable planets, and improve estimates of the distribution of planets as a function of stellar mass and metallicity. The Institute for Astronomy at the University of Hawaii is the perfect place to carry out both the theoretical portion of this work and its application to planetary systems. This work will benefit from collaboration with Professors Daniel Huber and Jennifer van Saders, leading experts on asteroseismic analysis and rotational evolution, respectively. Additionally, the access to follow-up resources including high contrast imaging and very high resolution spectrographs will be required to maximize the scientific return of this project, which will use the *TESS* and *Kepler* data to improve our understanding of our cosmic origins and characterize targets for the search for life on other planets.

Bonaca, A., et al. 2012, ApJ, 755, L12
Campante, T. L., et al. 2016, ApJ, 830, 138
Corsaro, E., et al. 2017, A&A, 605, A3
Fulton, B. J., et al. 2017, AJ, 154, 109
Huber, D., et al. 2017, ApJ, 844, 102
Kawaler, S. D. 1988, ApJ, 333, 236
Matt, S. P., et al. 2015, ApJ, 799, L23
Oshagh, M., et al. 2017, A&A, 606, A107
Tayar, J., et al. 2013, ApJ, 775, L1
—. 2015, ApJ, 807, 82
—. 2017, ApJ, 840, 17
van Saders, J. L., et al. 2016, Nature, 529, 181

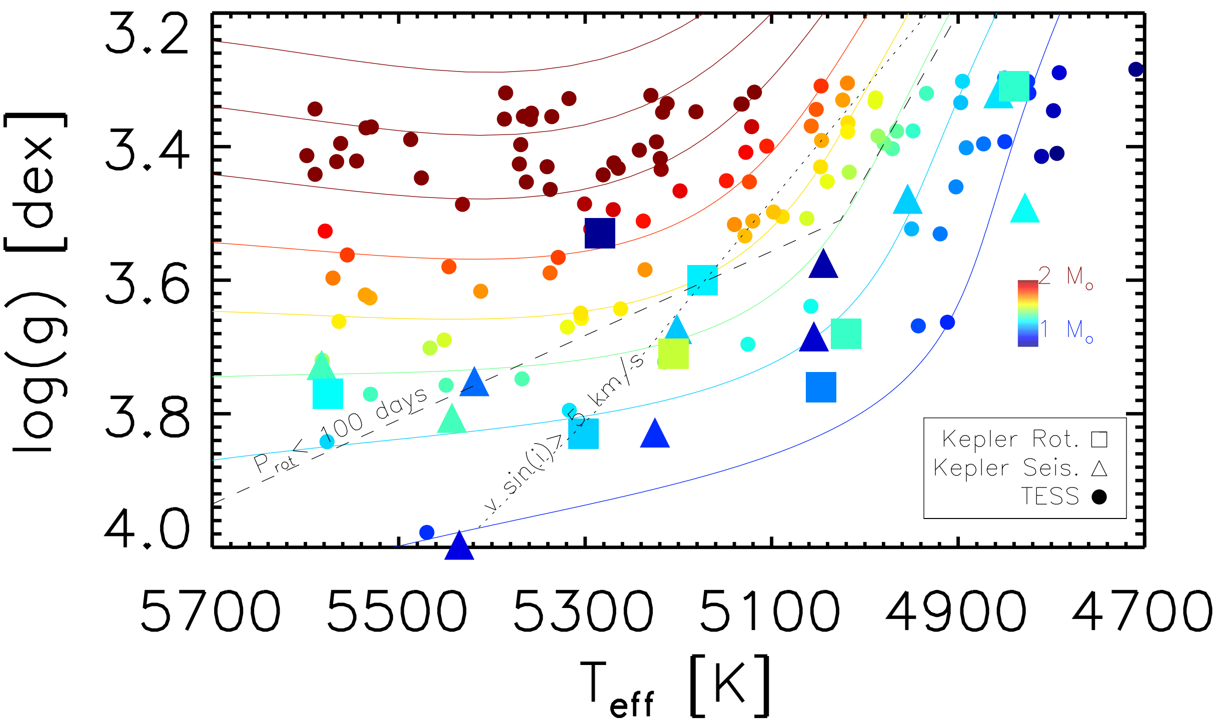

Figure 1: The temperatures and gravities of the 120 subgiants in the *TESS* southern continuous viewing zone amenable to this analysis (circles, color coded by expected mass). The *TESS* stars are compared to my stellar models for stars between 1.0 and 2.6 $M_\odot$, color coded by mass. I have added to the plot all *Kepler* targets in the same regime with detected mixed modes (triangles) including the 7 stars with published core rotation rates (squares). I also mark where the surface rotation period is expected to be less than 100 days (left of the dotted line) and v sin(i) is expected to be greater than 5 km s^{-1} (left of the dashed line).

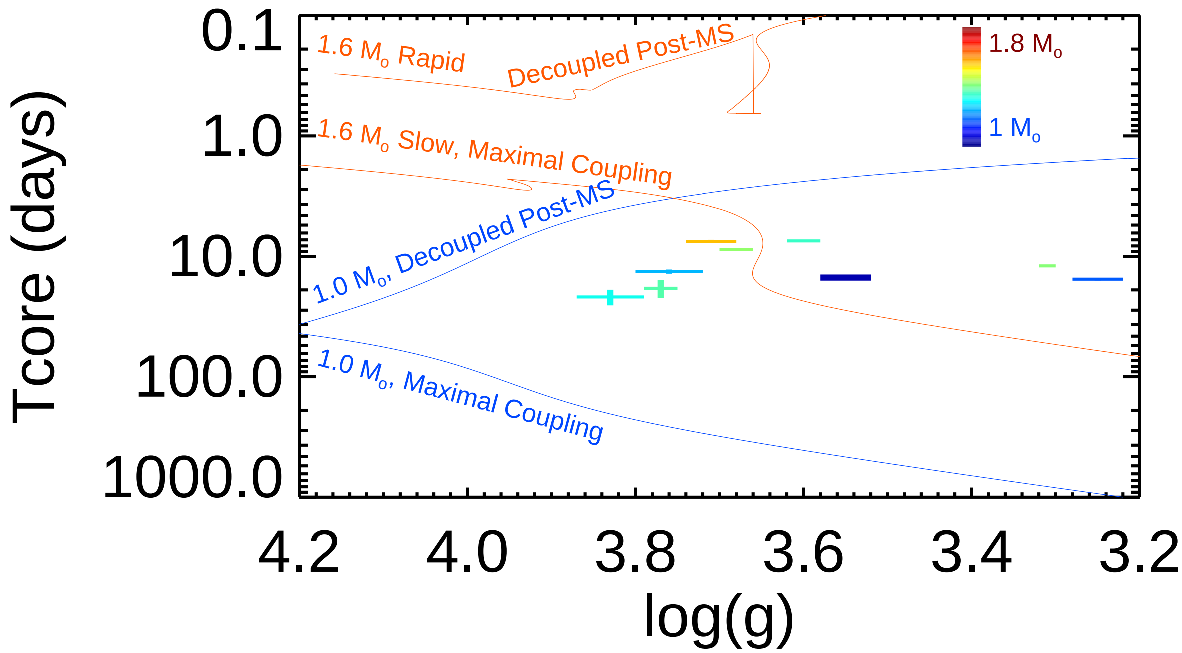

Figure 2: The core rotation rates for subgiant solar-like oscillators from the *Kepler* mission, as a function of surface gravity, color coded by mass, with stars evolving from left to right. Overlaid lines indicate the predicted core rotation rates in the models depending on the initial rotation velocity of the star on the main sequence and the coupling between the core and the envelope on the post-main-sequence. See Tayar & Pinsonneault (2013) for more discussion of the coupling cases labeled here. My analysis of the *TESS* data is expected to add up to an additional 100 measurements of core rotation between surface gravities of 3.8 and 3.3 dex.