Summer Research Project Development Worksheet 2021

The goal of this exercise is to outline the specifics of your mentee's research project. At our Project Development Workshop we will plan to share and discuss these outlines.

Mentors have a lot of freedom in designing summer research projects, but there exists very little guidance on what makes a good project. By taking the time to fill out this worksheet, the hope is that your project will become more fleshed out, more readily adaptable to the needs of your mentee, more flexible as the research progresses, and better set up for success by the end of the summer.

Once the summer starts, consider sharing this outline (or its content) with your mentee. Often, students will describe the inevitable change in project direction/expectations with a feeling of failure. Having the expectation that things will change, and that you're prepared for it, will hopefully provide the mentee with more realistic/healthy expectations.

Some things to keep in mind while filling this out:

- A good summer research project is one that you could probably do yourself in one week

- Between the quarantine period, program ramp up, the trip to McDonald Observatory, and prepping for the end of summer symposium, you realistically have 5-6 weeks where focused work can take place

- The average summer research project achieves next to nothing, with a long tail extending toward something like a refereed publication
    - This point is important for setting realistic expectations for the mentor and prioritizing the student experience over a specific research gain

- Ideally, each student will submit a RNAAS at the end of the summer, or shortly thereafter

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1) Describe your mentee's project. What is the scientific motivation? What is the technical motivation? What are the specific science goals?
   (If there are multiple "routes" your project could take, describe the science goals for each.)

Scientific Motivation

Measurements of stellar radii from eclipsing binaries (EBs) do not match the predictions of stellar models. This has been known for more than 20 years and has been dubbed the "radius inflation problem", i.e., we measure the radii of stars to be larger than models predict. This problem is most apparent for low mass stars and it is even worse for young (t<200 Myr), low-mass systems. Part of the problem is that young, low-mass EBs are generally hard to find, so we don't have a lot of "benchmark" systems for modelers to test against.

Why are models and measurements not in agreement? There are two angles to that question we're interested in pursuing. 1) Models don't include magnetic fields. Magnetic fields have been proposed to inflate the radii of stars, but there are no robust measurements of magnetic fields in an EB that models can directly test. Young EBs offer an opportunity here because they are expected to have strong magnetic fields, so if we have a shot of detecting them, it is in these extreme systems. 2) Observers are not including the effect of star spots in their analysis of EB light curves. A persistent level of spot coverage has the effect of biasing stellar radius measurements to larger values. Measuring the spot covering fraction is hard, which is why this hasn't been done, but young EBs are profoundly spotted, providing our best chance to characterize spots and their effect on radius measurements.

Technical Motivation

TESS light curves are allowing us to find many young EBs and we are in an era now where we can pick the "best" EBs to do detailed studies on. Young, low mass EBs are particularly exciting because many of them are still on the pre-main sequence, allowing us to improve this temporal regime of models that has very few observational constraints.

The Data

TESS light curves - We have a few systems already picked out but there are many more that need to be mined.

IGRINS spectra - For a small subset of the systems, we have some IGRINS spectra. The resolution is ~45,000 across H and K bands. These will be used to measure the RV for both stars to determine the orbital solution. They also contain some magnetically sensitive lines that increase in width/strength with the magnetic field strength, and provide access to detect the spectral signature of spots.

LCO/NRES spectra - optical spectra for a handful of the EBs, can be used to measure stellar RVs and determine orbital solutions.

Potential Routes

Route 1 – Searching for New EBs
Mine and analyze TESS light curves. Create a pipeline to quickly download and analyze TESS light curves to search for new EBs. Confirm their membership to young moving groups/associations. Perform a light curve-only analysis that constrains the orbital parameters and the relative radii of the two stars.

Route 2 – Characterizing Recently Found EBs
Perform joint fits of the TESS light curves and the RV measurements to determine the masses and radii for the stars in our sample where we have spectra in hand. These can then be compared to stellar models.

Route 3 – Searching for Zeeman Broadening
Investigate evidence for magnetic broadening in IGRINS spectra. Comb through the IGRINS spectra we have in the search for "narrow-lined** systems" where the observations happened to have occurred with the stars widely separated in velocity. This provides a clean separation of the lines for both stars where you can search for Zeeman broadening. Where present, we can fit spectral models to measure the magnetic field strength.

Route 4 – Searching for/Characterizing Spot Signatures
Investigate the spot covering fraction. Comb through the IGRINS spectra, again, for "narrow-lined" systems with large velocity separations to search for spectroscopic signatures of spots. From these and the TESS light curves we can assess the total and relative spot-covering fractions as a function of rotational/orbital phase.

** - narrow lined means that the star's lines are narrow. Most will have rotationally broadened lines (rapid rotators), so we'll be looking for the slowest rotators for the spot and magnetic field analyses.

2) For each route above, identify 3-4 “stopping points" that the student could reach with a sense of accomplishment and be able to present their results as-is. For reference, a RNAAS can have one plot (or table); each stopping point should ideally have that plot in mind.
(These “off ramps” make your project flexible and easier to match to students of varying incoming skill levels.)

Route 1 – Searching for New EBs

- Present the discovery of some young EBs from TESS data.
    - Plot would be some phase-folded light curves from TESS

- Present new EBs with membership confirmation
    - In addition to finding EBs, confirm their membership to going moving groups using FriendFinder
    - Plot could be a multi-panel CMD highlighting the cluster sequence, the EB, and the phase folded light curve

- Present brief analysis of EB light curves modeling out-of-eclipse (OOE) variability
    - Plot could be side-by-side panels with and without OOE variability

- Present a more in-depth analysis of the EB parameters.
    - Measure period, eccentricity, radius ratio, etc. from light curves alone
    - Plot could include models plotted over light curves with residuals

Route 2 – Characterizing Recently Found EBs

- Present orbital solution for a given system
    - Plot could be the RV curve phased up with the TESS light curve

- Present a joint fit of the light curve and RV measurements
    - Plot could be the RV curve phased up with the TESS light curve with a model over plotted with residuals.

- Compare derived parameters to models
    - A multi-panel plot comparing the derived radii, masses, temperatures, colors to different models in different planes.

Route 3 – Searching for Zeeman Broadening

- Qualitatively compare a synthetic model to a spectrum.
    - Plot could be the model plotted over an IGRINS spectrum with varying magnetic field strengths.

- Measure the *v*sin*i* of the star(s) and compare the width of Zeeman broadening-sensitive lines to models in a more quantitative approach.
    - Plot could be the IGRINS spectrum showing the model B=0, model with an informed vsini, and then additional curves with increasing magnetic field strengths

- Create a high-S/N empirical spectrum (measure RVs and shift, median), to compare in a quantitative approach.
    - Same plot as above, but with a higher-S/N empirical spectrum

- With a high-S/N empirical spectrum, fit for the vsini, macro/micro turbulence for lines that are not magnetically sensitive, apply results to the magnetic model, qualitatively compare different B-strength models
    - Same as plot above with a more informed model

- With a high-S/N empirical spectrum, fit for the vsini, macro/micro turbulence for lines that are not magnetically sensitive, apply results to the magnetic model, and finally fit a B-field strength.
    - Plot the spectrum with the best-fit model over plotted

Route 4 – Searching for, and Characterizing Spot Signatures

- Measure RVs, make an empirical template, quantitatively compare spectrum to models with two temperature components
    - Plot could be the empirical template with a by-eye fit of two components

- Analyze TESS and other publicly available light curves to assess spot covering fraction
    - Plot of light curve side-by-side with spectrum with models

- Perform a quantitative fit of the comparisons made above.
    - Plot of the spectrum with a best fit model with a lower panel of the temperature contrast/filling factor posterior.

- Perform a quantitative fit of the comparisons made above and include a light curve analysis
    - Plot of the spectrum with a best fit model with a lower panel of the temperature contrast/filling factor posterior, and another panel with the light curve with a variability model

3) For each route above, describe the type of high-level skill(s) the student will be gaining/exercising through this project.
   Some examples are:
   - Learn/improve coding skills
   - Analyze reduced data and draw conclusions
   - Search for undiscovered planets/galaxies/asteroids
   - Deep technical dive (e.g., PSF fitting)

   (If different routes involve different high-level skills, consider asking your student what skill(s) they're most interested in learning/exploring/honing.)

Route 1 – Searching for New EBs
- Search for undiscovered EBs
- Learn/Improve coding skills, specifically w.r.t automation and web query interfaces

Route 2 – Characterizing Recently Found EBs
- Deep technical dive into an analysis technique
- Learning/improving coding skills, specifically w.r.t MCMC fitting

Route 3 – Searching for Zeeman Broadening
- Analyze reduced data and draw conclusions
- Leaning/improving coding skills, specifically w.r.t manipulating complex data structures (echelle spectra)

Route 4 – Searching for, and Characterizing Spot Signatures
- Analyze reduced data and draw conclusions
- Leaning/improving coding skills, specifically w.r.t manipulating complex data structures

4) Identify the skills and knowledge that are necessary for your project(s) and specify whether the student should (a) already have this skill/knowledge, (b) gain it on their own, or (c) learn through the research experience.

Scientific / Mathematical Knowledge	**Skills**	**a/b/c**
Gravity, Keplerian motion, the scientific value of eclipsing binaries.		a/b
	Manipulating data structures with python	a/c
	Measure radial velocities from spectra via broadening functions	c
	Plotting in python	a/b/c
	Basic least squares fitting in python/scipy	a/b/c
	MCMC fitting in python with emcee	a/b/c
Information content of stellar spectra		a/b
	Linux/Mac terminal commands	a/b
	LaTeX document processing in Overleaf	a/b/c