In the past few decades, astronomers have found the first planets outside of the solar system, which has provided an unparalleled opportunity to understand the physical process of planet formation. By studying exoplanets of specific ages, we can begin to piece together the picture of planet formation and evolution.

During my time as a Pappalardo Fellow, I will advance both of these fields. I will achieve this goal through a variety of ground- and space-based observational campaigns. I will propose for observations with the James Webb Space Telescope (JWST) to broadly characterize the compositions of these young exoplanet atmospheres. From the ground, I am keen to take advantage of MIT's institutional access to the Magellan Telescopes and the new near-infrared high-resolution Warm INfrared Echelle spectrograph to Realize Extreme Dispersion and sensitivity (WINERED).

**Objective 1: Unveiling planet formation locations** – I propose to study the composition of young exoplanet atmospheres in the infrared (IR). The C/O ratio derived from IR measurements of CO, $CH_4$, and $H_2O$ will yield insight into the formation location young transiting planets with respect to the $H_2O$, CO and $CO_2$ snowlines. Theory suggests that large gas-rich planets ($R/R_{\mathrm{Earth}} \geq 4$) which form beyond the aforementioned snowlines and subsequently migrate inwards *after* the disk dissipates will have elevated C/O ($> 0.8$) and low metal enrichment. Planets which form in similar locations, yet migrate *within* the disk will result in a lower C/O ($< 0.5$) and more metal enrichment (Öberg et al. 2011). These considerations have been crucial for testing whether hot Neptunes and Jupiters ($P <$ 10 days) formed in situ or experienced inward migration.

For this task, I will use high-resolution ground-based instruments. I am the PI of a Gemini-S/IGRINS program to observe HIP 67522b, a 17 Myr "Jupiter", from 1.45 - 2.45 micron. I am a collaborator on a similar program to observe DS Tuc Ab, a 45 Myr super-Neptune. I will continue to submit proposals for ground-based spectroscopy every semester. For this previous observing semester, I submitted a proposal to observe a 50 Myr hot-Neptune with the same observing mode. Additionally, I will propose to use novel JWST Near Infrared Imager and Slitless Spectrograph (NIRISS; $\lambda = 0.6 - 2.8\mu$m) observations to observe complimentary transmission spectra. These observations will cover key water and $CO_2$ molecular features. I am the lead developer of a NIRISS data reduction method and have lead a paper on the NIRISS results from the JWST Exoplanet Early Release Science program (Bean et al. (2018); Feinstein et al. in prep.). I will work closely with *MIT Prof. Sarah Millholland* to interpret our observations in the context of planetary migration. I will test if transmission spectroscopy can be used to further constrain the mass of young planets with *MIT EAPS Professors Julien de Wit and Sara Seager* (de Wit & Seager 2013).

**Objective 2: Sculpting planetary atmospheres** – The primary means of measuring ongoing atmospheric mass-loss are through observations of Lyman-$\alpha$ or H-$\alpha$, which traces hydrogen (e.g. Feinstein et al. 2021), or near-infrared observations of He I at 1083.3nm (Oklopčić & Hirata 2018). In the past few years, significant progress has been made to understand atmospheric mass-loss for young planets through detections and non-detections of strong IR He I absorption features (e.g. Kirk et al. 2020). Ly-$\alpha$ and H-$\alpha$ are challenging to detect atmospheric mass-loss with, due to intrinsic stellar variability and contamination from the interstellar medium. As such, many detections of mass-loss have been made through the He I. However, for many of these systems, limited work has been completed by monitoring He I with respect to stellar variability, which has been seen to vary as a function of stellar rotational phase (Poppenhaeger 2022). To fully take advantage of these observations, we need to characterize the stellar.

At the start of my fellowship, TESS (*hosted at MIT*) will begin its Year 5 operations, which re-observes the southern ecliptic hemisphere. I will propose my Magellan observations to be simultaneous with TESS monitoring of the systems. This will achieve two goals: it will (i) allow us to monitor the phase of activity from the host star with spectroscopic absorption features in the near-IR covered by WINERED and (ii) search for signatures of extended tails in the infrared with respect to the broad TESS bandpass (Spake et al. 2021). **By monitoring He I from both the star and the planet, we will present the first confident detection of escaping He I from a young planet and constraint on atmospheric removal rates.**

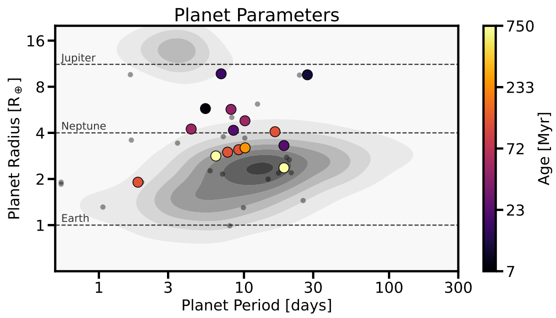


**Figure 1: Young planets in the context of Kepler transiting planets.** A period-radius diagram highlighting the uniqueness of planets < 1 Gyr (gray dots) and those which are young and observable with Magellan/WINERED (colored dots) compared to the *Kepler* distribution of older transiting planets (gray contours).

For my proposed program, I will observe the confirmed 15 young planets observable with Magellan (Figure 1), which provides a sufficient sample for testing atmospheric mass-loss and He I stellar variability as a function of age. I will work with *MIT Prof. Andrew Vanderburg* and his collaborators to detect and confirm new young planets to add to my sample. Together I and my collaborators at MIT will provide the first comprehensive view of young exoplanet atmospheric evolution.

Bean, J. L., Stevenson, K. B., Batalha, N. M., et al. 2018, , 130, 114402

de Wit, J., & Seager, S. 2013, Science, 342, 1473

Feinstein, A. D., Montet, B. T., Johnson, M. C., et al. 2021, , 162, 213

Kirk, J., Alam, M. K., López-Morales, M., & Zeng, L. 2020, , 159, 115

Öberg, K. I., Murray-Clay, R., & Bergin, E. A. 2011, , 743, L16

Oklopčić, A., & Hirata, C. M. 2018, , 855, L11

Poppenhaeger, K. 2022, , 512, 1751

Spake, J. J., Oklopčić, A., & Hillenbrand, L. A. 2021, , 162, 284