Alien Rubies in the Infrared : Integration and Testing of Visible and IR Wavefront Sensors for the Multiple Mirror Telescope

There are planets where it rains rubies. Specifically, some planets orbiting alien suns show evidence of clouds made of corundum, which is the basis on earth for rubies and sapphires (Wakeford, 2016). This is a romantic discovery from observing exoplanet atmospheres, but more practical research looks for possible signs of life on other planets, be it bacteria or dog in an alien suit, in the form of combinations of molecules that indicate non-equilibrium chemistry (e.g. water, oxygen, methane, ozone). In ground based observatories, research of this nature is only made possible with adaptive optics (a system that corrects observations in real time by using wavefront sensors to observe the shape of incoming light). Infrared (IR) observatories, like the Multiple Mirror Telescope (MMT) have the potential to observe these signs of life, but at present lack the instrument sensitivity or wavelength range to achieve these goals. In collaboration with the NSF funded project MAPS (the MMT Adaptive optics exoPlanet characterization System) **I will test, model, integrate, and perform on sky commissioning with two IR and visible pyramid wavefront sensors on the Multiple Mirror Telescope.** This proposed upgrade to the Multiple Mirror Telescope provides observations of fainter targets yet to be observed, increases wavelength range, and tests new wavefront sensing techniques that inform the next generation of telescopes.

Intellectual Merit :

In the field of exoplanet astronomy, ground-based observations are limited by the Earth's turbulent atmosphere, which causes incoming light to a telescope to spread irregularly over a larger area. When the object is a faint point-like source, **better adaptive optics systems enable observations of star-planet-systems that we could not have seen before.** With adaptive optics (AO), observations are corrected in real time by applying a correction (calculated by wavefront sensors) with mirrors that deform to correct the atmospheric perturbation. Figure 1 demonstrates an example of how light appears after corrections by adaptive optics at Lick Observatory, as well as the predicted improvement to the AO system at MMT with the MAPS upgrade.

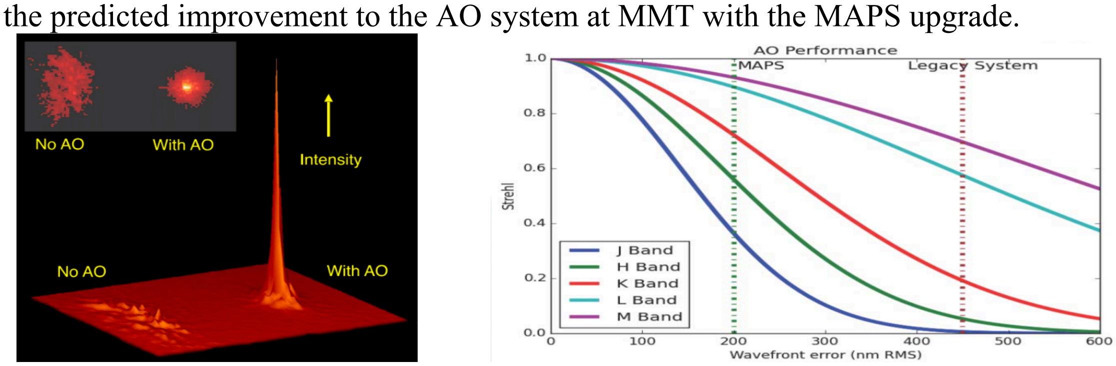

Figure 1. Left : Lick Observatory image with and without applied correction to the wavefront. (Max, 2019) Right : Using Strehl (the ratio of peak intensity for an image with and without aberrations) as a metric, we can see the predicted performance upgrade due to AO on MAPS through J and H bands (the IR regime) (Morzinski, 2018).

My proposal is unique because I plan to incorporate the two wavefront sensors in a single system with a dynamic choice of IR or visible wavefront sensing, drastically improving image quality for the final IR science images. The observer will choose which wavefront sensor will provide better correction for their observation; for a source that is significantly brighter in the IR or visible, collecting more photons means faster and more accurate corrections, which is especially vital when the atmosphere is moving in real time. To that end, the switch to pyramid wavefront sensors will provide an additional improvement to photon collection over the present Shack-Hartman wavefront sensor installed on MMT. Additionally, two new detectors will be used for the wavefront sensors: a CCID-75 visible detector (which is new to astronomy applications), and a SAPHIRA IR avalanche photo diode detector; both have reduced readnoise over the current detector used for wavefront sensing with MMT (Morzinski, 2018). As shown in Figure 1, the proposed **improvements to the AO system will provide a 40-50% improvement in the observed intensity in the IR as compared to the existing MMT system.**

Plan of Work :

(1) Run an initial analysis to select our exact infrared regime. Specifically I will predict if the J band (1.1-1.4 microns), H band (1.5 – 1.8 microns), or an overlap, will be better for our proposed targets. This will be informed by my work with the Exoplanet Characterization Tool Kit, with an emphasis on the atmospheric retrieval tools contributed by Mike Line (Fowler, 2018.) I will evaluate to what extent water, carbon monoxide, and carbon dioxide (the molecules we expect to find in our initial round of Jupiter-like targets) are observable in these proposed bands given varying host stars shining through varying planetary atmospheres. **(2) Perform initial experiments to setup and test the two wavefront sensors** in the optics lab facilities at the University of Arizona. Specifically I will integrate the two wavefront sensors in the Arizona lab facilities and find ways to programmatically take images and control hardware on the testbed. This work will be streamlined by my work on GLARE (the Generalized Lab Architecture for Restructured optical Experiments), a Python suite of automated experiment software and testbed-agnostic controllers for hardware common in optical testbeds (Fowler, 2020). **(3) Perform further testing to reduce and correct for alternate noise factors** including dark current, readnoise, optical ghosts, etc. Specifically, I will generate multiple images, isolate signs of these alternate noise factors, and test alternative hardware configurations and modes and/or calibration software to optimize final image quality. My work on the Wide Field Camera 3 Quicklook project (a codebase including a dark current and readnoise monitor) will inform the detection and removal of noise from these experiments. **(4) Integrate the wavefront sensors into MMT** alongside on-sky commissioning of the full adaptive optics system.

Unique Resources :

Many of the investigators of MAPS are at the University of Arizona, including Dr. Katie Morzinski (the principal investigator and an Assistant Astronomer) who will advise me for this project. The University of Arizona has two lab spaces that will support this project, as well as a vibrant instrumentation group to support and facilitate this work. The University of Arizona has unfettered access to MMT as well as 50% of its telescope time for calibration observations and experiments, and as it is local to the university at Mount Hopkins, we can actively iterate with MMT and the lab to test and improve new components.

Broader Impact :

The original NSF MAPS proposal includes a Winter School, a brief **winter workshop aimed at graduate students, postdocs, and professionals to teach the science of exoplanet instrumentation**. The Winter School is based on previous NSF Professional Development Program funded programs like Adaptive Optics Summer School led by the Center for Adaptive Optics. As part of this work, I will design a lab demonstration exploring the distinction between an IR and visible wavefront sensor. My experience as a teaching assistant and Software Carpentry instructor will facilitate creating and leading a lab for my colleagues, under the advisement of Dr. Morzinski who is leading the Winter School.

Fowler, J. et al. "G.L.A.R.E..", AAS Meeting #235, 2020 --- Fowler, J. et al. "ExoCTK", AAS Meeting #231, 2018 --- M., Claire "Introduction to AO and the CfAO." AO Summer School. 2019. --- Morzinksi, K. "MAPS: The MMT AO ExoPlanet Characterization System ." Cf AAO Retreat. 2018. --- Wakeford, H. R. et al. "High-Temperature Condensate Clouds in Super-Hot Jupiter Atmospheres." MNRAS, (2016)