Graduate Research Plan Statement - Rena Aerey Lee

Background: M dwarfs, the most populous stars and most prolific hosts to rocky, Earth-like planets, are also the longest-lived stars in our galaxy and beyond. This makes M dwarfs important subjects to study in many astronomical contexts, from large-scale Galactic chemical evolution [1], down to rocky planet formation, in the search for worlds like our own [2]. One major source of uncertainty in characterizing M dwarfs is their magnetic field strengths, which can influence surface activity (star spots and flares), rotation, and age modeling.

M dwarfs less than ~0.35 solar masses are particularly promising targets for magnetic field studies. At this mass boundary, their interior structures diverge dramatically. While higher mass M dwarfs have thick, convective envelopes and radiative cores (similar to the Sun), low mass M dwarfs are fully convective, a structure not found elsewhere among main-sequence stars. Magnetic dynamos are closely linked to differential rotation, caused by shearing in the tachocline, the boundary between the convective and radiative regions of a star [3]. Curiously, fully convective M dwarfs have been found to host very strong surface magnetic fields without the presence of a tachocline [4]. Thus, a deeper look into the magnetism of M dwarfs near this mass boundary is vital for expanding stellar dynamo theory at large.

Proposed Research: Surface magnetism can be assessed from stellar spectra in the form of Zeeman effect. The Zeeman effect alters the way a spectral line will appear in the presence of a magnetic field by causing line broadening as a result of angular momentum quantum energy level splitting, with the split energy states taking on different magnetic quantum numbers [5]. These deformations can behave in different ways depending on the magnetic field geometry, such as exhibition of asymmetrical shifts (Fig. 1a). This is distinguished from Doppler broadening, which results from the star's rotation causing shifts in spectral line positions. We can assess Zeeman broadening in stellar spectra by measuring the amplitude of deformations in spectral line profiles caused by the magnetic fields.

I propose to measure the magnetic fields of 25 late M dwarf members of the Beta Pictoris Moving Group (BPMG), a nearby young stellar association. At the age of the BPMG (~22 Myr [6]), circumstellar disks have mostly dissipated, but spin down due to angular momentum loss from winds has not yet begun. This makes BPMG M dwarfs preferred targets for magnetic characterization, as they are very rapidly rotating and highly magnetically active. This research will utilize an extensive atlas of InfraRed (IR) spectra of M dwarfs in the BPMG, available from archived public sources (e.g., iSHELL at NASA's InfraRed Telescope Facility; ESPaDOnS at Canada-France-Hawaii Telescope) as well as my ongoing thesis research (described in my personal statement). IR spectra are ideal for this purpose, since the Zeeman effect increases with wavelength, and because magnetically active and colder star spots contribute more to the total flux at longer wavelengths [5].

Intellectual Merit: Determining the surface magnetic fields of M dwarfs is vital for achieving precise stellar ages from isochrones (Fig. 1b). Isochrone models are curves on a Hertzsprung-Russell (temperature vs. luminosity) diagram representing stars of the same age at different masses. While some recent isochrone models account for magnetic field strengths when fitting an age, they are usually analytically inferred. This leaves systematic uncertainties in the isochrone model ages for M dwarfs across their lifetimes, but especially so at younger ages, where magnetic effects are strongest. Young M dwarfs are very rapidly rotating, leading to increased magnetic activity, increased luminosity, and an inflated radius. If the effects of this early rapid rotation are not considered, stellar temperatures may be miscalculated, and stars can be displaced on a temperature-luminosity plot.

Magnetic fields also affect an M dwarf's rotational evolution in several ways, complicating calibration of an age-rotation relation. Star spots may inhibit convection, and solar flares heat the corona, driving angular momentum loss in stellar winds. Adding to the intrigue, in the presence of a circumstellar disk, ionized gas particles can cause a drag on the magnetic field, even in the absence of accretion. This makes a detailed magnetic field study vital for those studying star-disk interactions in M dwarfs.

Broader Impacts: As mentioned in my personal statement, I have long been committed to increasing access to astronomy and STEM education in secondary schools, most recently through the HI-STAR outreach program and Honua Scholars. With previous experience directing an astronomy research project for high-school students, I'm confident that I will be able to engage others through more HI-STAR summer sessions. I have prepared a beginner-level Python tutorial for my past students, which guides them through spectral data analysis and plotting. I plan to refine this resource for future generations of HI-STAR scholars, who work with data from a variety of sources including the Las Cumbres Observatory and MaunaKea Observatories. I will also be able to share past and ongoing research with wider audiences through Honua Scholars, who host public STEM research talks.

As an observational astronomer, I am also intimately aware of the ongoing conflicts in Hawaii over the development of the Thirty Meter Telescope on Mauna Kea. Outreach is a critical component of my work as an astronomer, to foster understanding and community between astronomy and the public. In efforts to help bring local communities together, I intend to host public events that would build interest and support for astronomy in Hawaii, such as stargazing events, telescope demonstrations, and research talks at Astronomy on Tap, expected to launch in Honolulu in 2022.

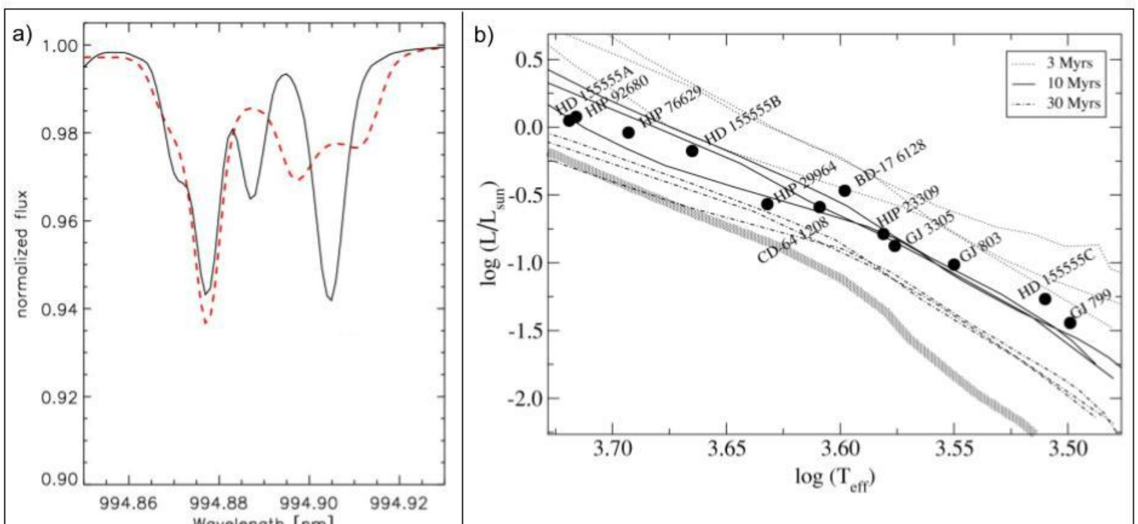

Figure 1. a) from *Reiners et al. 2013* [5], depicting the deformation of magnetically sensitive spectral lines (red dashed) compared to a standard spectrum without magnetic effects (black). b) an example of an isochrone fit to low-mass members of the BPMG, from *Zuckerman and Song, 2001* [7]

References: [1] Laughlin et al. 1997. [2] Gaidos et al., 2016. [3] Kochukov, 2021. [4] Morin et al., 2010. [5] Reiners et al., 2013. [6] Mamajek & Bell, 2016. [7] Zuckerman and Song, 2001.