Draft version November 10, 2023
Typeset using LaTeX **twocolumn** style in AASTeX62

Correlations between Ca II H&K Emission and the Gaia M dwarf Gap

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(Received; Revised; Accepted)

Submitted to ApJ

ABSTRACT

Previous work has demonstrated a paucity of Hydrogen Alpha emission at the same Gaia G Magnitude as the Jao Gap in the solar neighborhood. The exact mechanism which results in this paucity is as yet unknown; however, the authors of the originating paper suggestion that it may be the result of complex variations to a stars magnetic topology driven by the Jao Gaps characteristic formation and breakdown of stars radiative transition zones. Here I present a brief summary of a potential extension to this work looking at Ca II H&K emission lines. Preliminary work with archival data shows a much stronger correlation between the calcium emission lines and the Jao Gap than was observed between hydrogen emission and the Jao Gap. If this observation withstands further testing then it may provide a new way to locate the gap in populations which lack the large counting statistics currently required — and which are only practically available from Gaia data at moment.

Keywords: Stellar Evolution (1599) — Stellar Evolutionary Models (2046)

1. INTRODUCTION

Due to the initial mass requirements of the molecular clouds which collapse to form stars, star formation is strongly biased towards lower mass, later spectral class stars when compared to higher mass stars. Partly as a result of this bias and partly as a result of their extremely long main-sequence lifetimes, M Dwarfs make up approximately 70 percent of all stars in the galaxy. Moreover, some planet search campaigns have focused on M Dwarfs due to the relative ease of detecting small planets in their habitable zones (e.g. Nutzman & Charbonneau 2008). M Dwarfs then represent both a key component of the galactic stellar population as well as the possible set of stars which may host habitable exoplanets. Given this key location M Dwarfs occupy in modern astronomy it is important to have a thorough understanding of their structure and evolution.

Jao et al. (2018) discovered a novel feature in the Gaia Data Release 2 (DR2) $G_{BP} - G_{RP}$ color-magnitude-diagram. Around $M_G = 10$ there is an approximately 17 percent decrease in stellar density of the sample of stars Jao et al. (2018) considered. Subsequently, this has become known as either the Jao Gap, or Gaia M Dwarf Gap. Following the initial detection of the Gap in DR2 the Gap has also potentially been observed in 2MASS (Skrutskie et al. 2006; Jao et al. 2018); however, the significance of this detection is quite weak and it relies on the prior of the Gap's location from Gaia data. Further, the Gap is also present in Gaia Early Data Release 3 (EDR3) (Jao & Feiden 2021). These EDR3 and 2MASS data sets then indicate that this feature is not a bias inherent to DR2.

The Gap is generally attributed to convective instabilities in the cores of stars straddling the fully convective transition mass (0.3 - 0.35 $M_{\odot}$) (Baraffe & Chabrier 2018). These instabilities interrupt the normal, slow, main sequence luminosity evolution of a star and result in luminosities lower than expected from the main sequence mass-luminosity relation (Jao & Feiden 2020).

The Jao Gap, inherently a feature of M Dwarf populations, provides an enticing and unique view into the interior physics of these stars (Feiden et al. 2021). This is especially important as, unlike more massive stars, M Dwarf seismology is infeasible due to the short periods and extremely small magnitudes which both radial

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and low-order low-degree non-radial seismic waves are predicted to have in such low mass stars (Rodríguez-López 2019). The Jao Gap therefore provides one of the only current methods to probe the interior physics of M Dwarfs.

(Jao et al. 2023) identify the Jao gap as a strong discontinuity point for activity in M dwarfs. Two primary observations from their work are that the Gap serves as a boundary where very few active stars in their sample of 640 M dwarfs exist below the gap and that the overall downward trend of activity moving to fainter magnitudes is anomalously high in within the 0.2 mag range of the gap. Their figures 3 and 13 are of particular relevance here and have been included below for convince. Based on previous work from Spada & Lanzafam 2020, Curtis et al. 2020, and Dungee et al. 2022 the authors propose that the mechanism resulting in the reduced fraction of active stars within the gap is that as the radiaive zone disipates due to core expansion, angular momentum from the outter convective zone is dumped into the core resulting in a faster spin down than would otherwise be possible. Effectively the core of the star acts as a sink, reducing the amount of angular momentum which needs to be lost by magnetic breaking for the outer convective region to reach the same angular velocity. Given that Hα emission is strongly coupled magnetic activity in the lower photosphere and that a stars angular velocity is a primary factor in its magnetic activity, a faster spin down will serve to more quickly dampen Hα activity.

2. CONCLUSION

The Jao Gap provides an intriguing probe into the interior physics of M Dwarfs stars where traditional methods of studying interiors break down. However, before detailed physics may be inferred it is essential to have models which are well matched to observations. Here we investigate whether the OPLIB opacity tables reproduce the Jao Gap location and structure more accurately than the widely used OPAL opacity tables. We find that while the OPLIB tables do shift the Jao Gap location more in line with observations, by approximately 0.05 magnitudes, the shift is small enough that it is likely not distinguishable from noise due to population age and chemical variation. However, future measurement of [Fe/H] for stars within the gap will be helpful in constraining the degree to which the gap should be smeared by these theoretical models.

We also find that both the color and magnitude of the Jao Gap are correlated to the convective mixing length parameter. Specifically, a lower mixing length parameter will bring the gap in the populations presented in this paper more in line with the current best estimate for the actual gap magnitude. Using this relation it may be possible for mixing length to be calibrated for low mass stars such that models match the Jao Gap location. Further, the Jao gap location may provide a test of alternative convection models such as entropy calibrated convection (Spada et al. 2021). Both of these potential uses require careful handeling of other uncertanties such as the uncertanties in bolometric correction, popupulation composition, and population age. As we currently do not have reason to suspect that the mixing length for the low mass stars in the DR2 and ERD3 CMD is substantially lower than that of the sun we leave the investigation of these potential additionl uses for future work.

Finally, we do not find that the OPLIB opacity tables help in reproducing the as yet unexplained wedge shape of the observed Gap.

This work has made use of the NASA astrophysical data system (ADS). We would like to thank Elisabeth Newton, Aaron Dotter, and Gregory Feiden for their support and for useful discussion related to the topic of this paper. We would like to thank our reviewer for their critical eye and their guidance to investigate to effects of the mixing length on the Gap Location. Additionally, we would like to thank James Colgan and the Los Alamos T-1 group for their assistance with the OPLIB opacity tables and support for the public release of `pyTOPSScrape`. We acknowledge the support of a NASA grant (No. 80NSSC18K0634).

Software: The Dartmouth Stellar Evolution Program (DSEP) (Dotter et al. 2008), `BeautifulSoup` (Richardson 2007), `mechanize` (Chandra & Varanasi 2015), `FreeEOS` (Irwin 2012), `pyTOPSScrape` (Boudreaux 2022)

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