Observing Time Request
MDM Observatory

Date: May 10, 2021	*Proposal number:*

TITLE: An Expanded Survey of Activity in Key Stellar Structures, Starting With the Hyades and Coma Ber

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Abstract of Scientific Justification: An empirical age-rotation-activity relation (ARAR) could provide accurate stellar ages from rotation and activity measurements. We are surveying open clusters and new, *Gaia*-discovered stellar structures and combining rotation periods (P_{rot}) from the Palomar/Zwicky Transient Factory, *K2*, and *TESS*, new and archival X-ray detections, and Hα measurements to calibrate the ARAR. Coronal and chromospheric activity are traced by X-ray and Hα emission, respectively; comparing these two measurements tests theories of stellar dynamos and magnetic field structure. We propose to use five nights of queue time on the 2.4-m telescope to continue our program to obtain spectroscopy of low-mass members of key stellar structures. Our targets this semester include the Hyades and Coma Ber. In the Hyades, our goal is to continue acquiring spectra for stars with known P_{rot}, especially those observed recently in the cluster's tidal tails by *TESS*, in order to examine the dependence of chromospheric activity on rotation and to study the correlation between chromospheric and coronal activity in this cluster. In Coma Ber, our goal is to complete the Hα census of known members (now updated to include newly identified members based on *Gaia* data) to produce a color-chromospheric activity plot that we can compare to older clusters.

- *Enter 'C' for classical or 'Q' for queue scheduling ('Q' is only for the 2.4m with OSMOS)* Q
- *Requesting long-term status? If 'Y', please give # of semesters and nights on the next line.* Y

Five nights per semester for the next two years with the 2.4m telescope.

Summary of observing runs requested for this project

Run	Telescope	Instrument, detectors, grisms, gratings, filters, camera optics, etc.
1	2.4 m	OSMOS Queue, Blue Grism, 1.2 arcsec inner slit
2		
3		

Run	No. nights	Moon age (d)	Optimal dates	Acceptable dates
1	5		Any	Any
2				
3				

- *List dates you cannot use for non-astronomical reasons on the next line.*

Scientific Justification *Try to include overall significance to astronomy.*

In general, there is no direct way to determine the ages of main-sequence stars. Rotation and chromospheric activity decrease over time at the same rate for stars with convective outer layers, leading to hopes that an empirical age-rotation-activity relation (ARAR) would provide stellar ages from rotation and activity signatures. However, the precise evolution of rotation and activity for low-mass stars is still poorly constrained (e.g., Curtis et al. 2020). Empirical forms of the ARAR rely largely on observations of stars in open clusters, which have well-defined ages and where rotation periods (P_{rot}) and activity indices can be measured across a range of stellar masses.

The proximity of the Hyades makes it an ideal test-bed for studying the relationship between rotation and activity. In Douglas et al. (2014), we combined literature P_{rot} with archival and new spectra—primarily from MDM—for the Hyades and Praesepe (an analogous middle-aged open cluster) into the largest rotation and activity sample at a single age. Because stellar activity evolves with rotation in a mass-dependent way, we analyzed activity as a function of Rossby number, $R_o = P_{rot}/\tau$, where τ is the convective overturn time, thereby removing this mass-dependence. We tracked the behavior of $L_{H\alpha}/L_{bol}$, a measure of chromospheric activity, and of L_X/L_{bol}, a measure of coronal activity, as a function of R_o. We found that stars with $R_o \lesssim 0.1$ are magnetically saturated; in this regime, activity is constant and insensitive to rotation. At larger R_o, activity is unsaturated and decreases with increasing P_{rot} and R_o.

We also found, however, that the Hα rotation-activity relation is inconsistent with that for X-ray activity, a fact which allows us to test the mechanisms by which dynamos heat stellar atmospheres. Several explanations have been advanced for why L_X/L_{bol} saturates and then supersaturates: saturation of the dynamo mechanism (Collier-Cameron & Li 1994), changes in the field topology (Stępień et al. 2001), or centrifugal stripping of the corona (Jardine & Unruh 2001). If either of the first two explanations holds, chromospheric activity should saturate in lockstep with coronal activity. In the coronal stripping scenario, however, there is no such requirement.

Although our results tentatively support the coronal-stripping scenario, we could not draw firm conclusions because the stars with X-ray emission and Hα emission measurements have different mass distributions. We have therefore continued to obtain data for members of the Hyades and of Praesepe in order to extend this analysis. In Figure 1, we show the result of these ongoing efforts.

In parallel, we propose to complete our observations of low-mass members of the ≈450-Myr-old Coma Ber cluster, for which we have been collecting spectra since Feb. 2011. We currently have Hα data for nearly 100 stars in the cluster, and there are ≈100 more members we wish to observe. A small fraction of our previous observations were taken under poor weather conditions, and will need to be re-observed with higher signal-to-noise. Because Coma Ber has now been observed by *TESS* and its membership has grown significantly thanks to *Gaia*, there are far more stars for us to target than previously.

We propose to use a total of five nights on the 2.4-m telescope to conduct observations of the Hyades and Coma Ber. We will obtain low- to moderate-resolution spectra of known members (down to $V \approx 18$ mag) of these clusters to measure Hα emission for:

- Hyades members with measured rotation periods and that have *TESS* light curves, which are particularly interesting for newly identified cluster members far from the cluster core;
- Hyades members detected in X-rays, in order to compare L_X/L_{bol} and $L_{H\alpha}/L_{bol}$ for these stars and investigate whether the reported decay of L_X relative to young and middle-aged clusters is also seen in $L_{H\alpha}$; and
- newly identified and fainter members of Coma Ber, for which we have not yet obtained spectra,

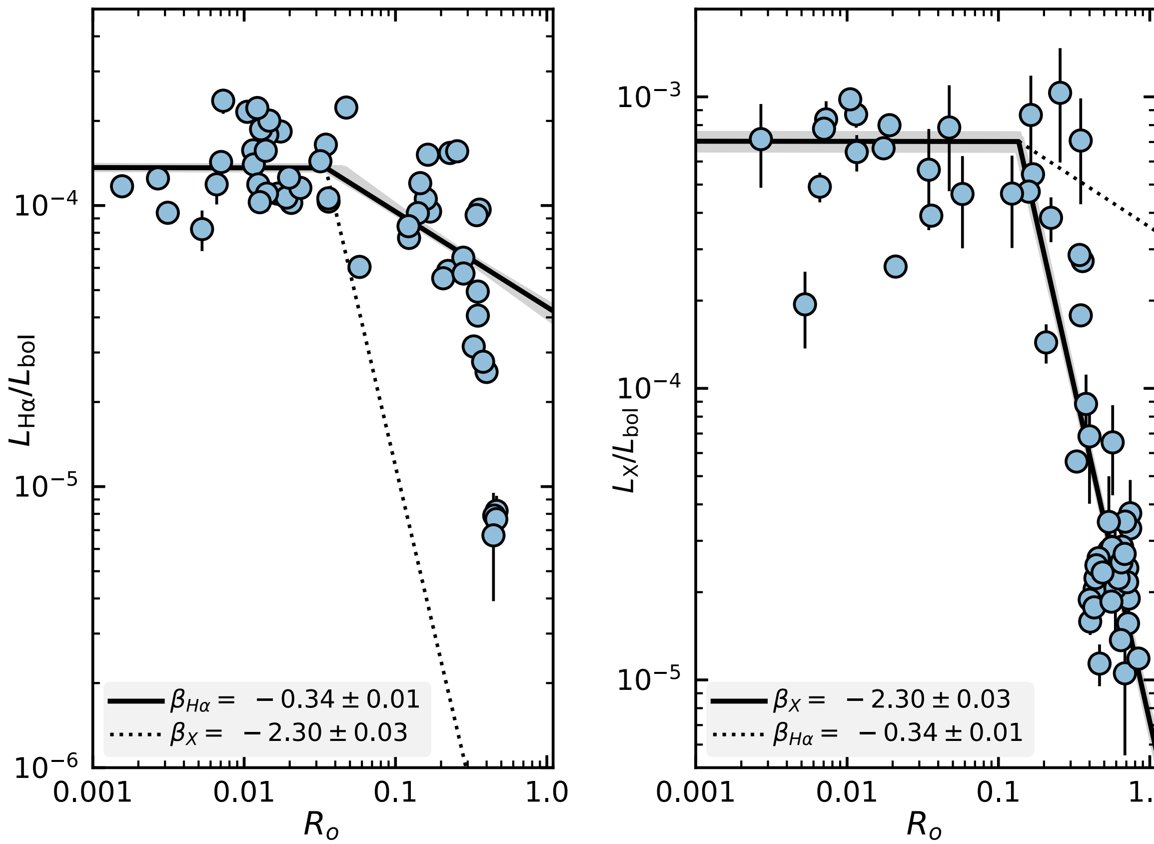

Figure 1: Left — $L_{H\alpha}/L_{bol}$ vs. R_o for Hyades stars. The gray lines are 200 model fits to our data drawn randomly from the posterior probability distribution; the solid black line is the maximum *a posteriori* model. Upper limits are not included in the fit. The dotted black line is our best fit to the unsaturated regime for L_X/L_{bol} vs. R_o (next panel). Right — Same as the left panel, but for the L_X/L_{bol} vs. R_o relation. The $H\alpha$ data are consistent with a shallow decline of activity with rotation ($\propto R_o^{-0.3}$), while X-ray activity appears to decline in a manner more consistent with the steeper Randich (2000) or Wright et al. (2011) power-laws ($\propto R_o^{-2.1}$ and $R_o^{-2.7}$, respectively).

along with a handful for which our previous MDM observations were too noisy to be useful.

References

Agüeros et al. 2018, ApJ, 862, 33 • Collier-Cameron & Li 1994, MNRAS, 269, 1099 • Curtis et al. 2020, ApJ, 904, 140 • Douglas et al. 2014, ApJ, 795, 161 • Jardine & Unruh 1999, A&A, 346, 883 • Kounkel & Covey 2019, AJ, 158, 122 • Randich 2000, ASP Conference Series, 198, 401 • Stępień et al. 2001, A&A, 370, 157 • Wright et al. 2011, ApJ, 743, 48

Technical and Scientific Feasibility *List objects, coordinates, and magnitudes (or surface brightness, if appropriate), desired S/N, wavelength coverage and resolution. Justify the number of nights requested as well as the specific telescope, instruments, and lunar phase. Indicate the optimal detector, as well as acceptable alternates. If you've requested long-term status, justify why this is necessary for successful completion of the science.*

The Hyades ($\alpha = 04^{\rm h}27^{\rm m}$, $\delta = +15°52'$) is up nearly the entire evening target through much of the semester. Coma Ber ($\alpha = 12^{\rm h}22.5^{\rm m}$, $\delta = +25°51'$), by contrast, late at night and late in the semester. Queue observing is therefore ideal for this program.

Our signal-to-noise requirement is driven by the ability to reliably measure the strength of Hα emission in each star's spectrum, and thereby diagnose chromospheric activity. Our experience indicates that we can obtain spectra for 40 (faint) – 100 (bright) targets per night with satisfactory signal-to-noise; we estimate that the equivalent of five nights of MDM time will yield spectra for ≈200 stars.

We are requesting long-term status because the Hyades and Coma Ber are only two of the many stellar structures that we are targetting for this work. In particular, we have recently started working on validating and characterizing stellar structures identified by Kounkel & Covey (2019) using a machine-learning approach to clustering in *Gaia* data. This has yielded dozens of potentially invaluable stellar structures (many are more filament- than cluster-like) with which to benchmark the ARAR at previously unexplored ages. We envision our MDM time as being an essential component of this work.

Why MDM? *If other optical/IR facilities are being used for this project, explain the role that MDM observations will play.*

We are not currently using any other optical/IR facilities to target either cluster. For a handful of stellar structures recently identified in *Gaia* data that we are surveying, we have applied for time on other facilities (e.g., MMT/Magellan) to do similar work. Those targets are more distant and/or require higher-resolution spectra.

How is it Going? *List your allocations of telescope time at MDM during the past 3 years, together with the current status of the project (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal. For ongoing projects, are they achieving their goals?*

⋆ More than 800 spectra of stars in the Pleiades, Hyades, α-Per, Praesepe, Coma Ber, and NGC 752 have been obtained with ModSpec/OSMOS on the 2.4m as part of a long-term program led by the PI. All of these spectra have been reduced (save for a handful of recent queue observations) and a large fraction have been published. For example, Douglas et al. (2014) compared the rotation-activity relations derived for Praesepe and the Hyades, and Agüeros et al. (2018) included an analysis of activity in NGC 752. Both papers relied heavily on MDM data. We have had several undergraduates and a high-school student work on the more recent MDM data for the Hyades, Praesepe, and Coma Ber, and their preliminary results were presented at the January 2021 AAS meeting in three separate posters. We anticipate publishing an update to the Douglas et al. analysis in the next year (Núñez et al. in prep.).