Observing Time Request
MDM Observatory

Date: October 31, 2014	*Proposal number:*

TITLE: Spectroscopic follow-up of PTF observations of open clusters

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Abstract of Scientific Justification: We are using Palomar Transient Factory (PTF) observations of open clusters to study the evolution of the stellar age/activity/rotation relation and identify eclipsing binary systems at a fixed age. One season of PTF observations of our first cluster, Praesepe, yielded robust rotation periods for 40 cluster members. We also identified and followed-up a number of interesting low-mass binary systems, which may provide critical insights into the mass-radius relationship for M stars. In 2010-2011, we obtained >700 1-min observations of NGC 752; a paper describing our analysis of the the PTF light-curves and our MDM spectra for stars in this cluster will be submitted soon. Our PTF targets in 2011-2012 included Alpha Per and the Pleiades, which will be the focus of our MDM campaign in 2012-2013.
We propose to use five nights on the 2.4-m MDM telescope to continue the program begun in 2010B to obtain follow-up spectroscopy of interesting PTF-target cluster members. Specifically, we will: 1) continue our low- to moderate-resolution spectroscopic survey of known cluster members to measure Hα emission, a key indicator of chromospheric activity in low-mass stars; and 2) obtain high-resolution spectroscopy of candidate eclipsing binaries to determine orbital parameters. Together, our rotational and spectroscopic data will allow us to investigate the relationship between stellar rotation and activity at ages between ∼50 Myr and ∼1 Gyr — while also characterizing new, interesting binary systems.

• *Is this proposal part of a PhD thesis?* Y

• *Requesting long-term status? If 'Y', please give # of semesters and nights on the next line.* Y

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

Summary of observing runs requested for this project

Run	Telescope	Instrument, detectors, grisms, gratings, filters, camera optics, etc.
1	2.4 m	Modspec
2		
3		

Run	No. nights	Moon age (d)	Optimal dates	Acceptable dates
1	5	5	Feb 15 - Feb 21	Feb 11 - Feb 21, Mar 10 - 21
2				
3				

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

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

Open clusters are homogeneous, coeval populations that provide an ideal environment in which to study the relationship between stellar age, activity, and rotation. One of the (Columbia-led) key science projects of the Palomar Transient Factory (PTF; Law et al. 2009) is to obtain multi-epoch photometric data of open clusters with which to measure stellar rotation periods at different ages. Our first target was Praesepe (M44, the Beehive Cluster), which we chose for its similarities to the Hyades, the benchmark middle-aged (∼500 Myr) cluster for age/activity/rotation studies. Our first season of observations yielded close to 600 individual 1-min observations of an area that included ∼1000 cluster members. As part of her first-year project, Jenna Lemonias merged and analyzed the PTF light-curves, resulting in the identification of 40 robust rotation periods for cluster K & M members. A paper describing these rotation periods is currently being assembled, with submission anticipated for late May 2011.

We recently began a low- to moderate-resolution spectroscopic survey of Praesepe members to diagnose the characteristic level of chromospheric activity as a function of both mass and rotation rate. Prior to this effort, the spectroscopic census of Praesepe was relatively incomplete, particularly at the low-mass end of the main sequence, where many cluster members were only recently identified (Kraus & Hillenbrand 2007; see Figure 1). This survey began with two MDM observing runs in Dec. 2010 and Feb. 2011; these observations have been reduced (see Figure 2) and are currently being analyzed for publication in Fall 2011. We have also been collecting archival X-ray data for Praesepe members, as well as proposing for new observations — the existence of the spectroscopic catalog we are currently assembling, as well as the presence of measured photometric rotation periods for many cluster members, are key elements for strengthening the case for these X-ray observations.

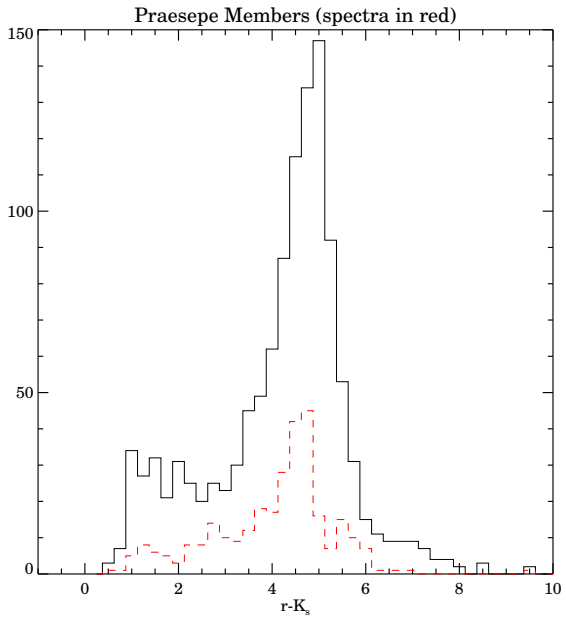

Figure 1: Histogram of Praesepe members (in black) as a function of $(r - K_S)$ with members with existing spectroscopy overplotted (in red). Spectroscopic follow-up is significantly incomplete at all masses, but the need for additional spectroscopy is greatest for M-type candidates ($r - K_S > 4$), which are the stars that dominate our PTF survey of Praesepe.

In Fall 2010, we extended our PTF survey to include the older cluster NGC 752 (∼1–2 Gyr). Far less is known about stellar activity at this age: this program will be an essential step in bridging the gap between our understanding of activity in stars under 1 Gyr old and in the Sun.

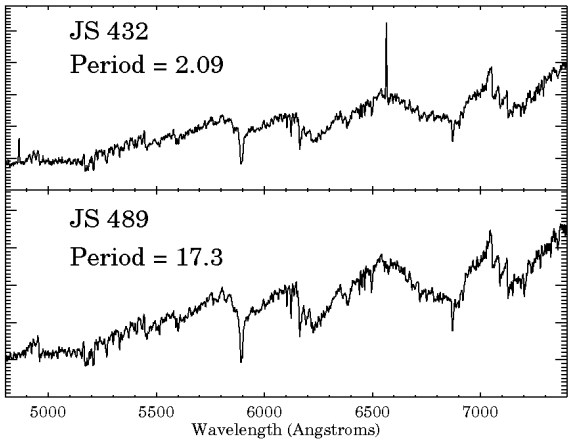

Figure 2: Example spectra from our survey of Praesepe with the 2.4-m telescope at MDM Observatory. *Top panel:* A spectrum of a rapidly rotating M dwarf in Praesepe. Note the strong Hα and Hβ emission lines, indicative of significant chromospheric activity. *Bottom panel:* A spectrum obtained from a slowly rotating M dwarf; while its photospheric emission is nearly identical to that of its cousin in the top panel, no chromospheric emission is detected, demonstrating the presence of a strong link between rotation and activity in this cluster.

Giardino et al. (2008) published a detailed X-ray analysis of NGC 752, measuring L_X for $\sim$40 cluster stars from a 140 ks *Chandra* observation and a 40 ks *XMM* observation. Combining these archival L_X measurements with rotation periods from our PTF observations, we will be able to provide the best characterization of the relationship between stellar coronal activity and rotation at 1–2 Gyr. Completing this picture requires spectroscopic follow-up, however, as there is far less information in the literature about low-mass membership of this cluster — and little-to-no archival spectroscopy available to analyze the relationship between chromospheric activity and rotation. Our PTF monitoring of NGC 752 has obtained >700 1-min observations of the cluster sampling baselines as long as 5 months (Aug. 2010 through Feb. 2011). While these data are still to be fully analyzed, a preliminary look at the light-curves reveals that we are already sensitive to the periods of fast rotators and have detected a few eclipsing binaries.

Indeed, these monitoring programs have identified a number of eclipsing binaries in both clusters, as well as many in the surrounding field population captured by these observations. Follow-up observations are observationally intensive, requiring multiple epochs of high-resolution spectroscopy to derive full orbital solutions and characterize masses, radii, and T_{eff}s. With CoI Law, we have been following up these systems using MDM and other facilities accessible through our PTF collaborators (i.e., Keck, Palomar 200-in Telescope, Las Cumbres Observatory Global Telescope).

We therefore propose to utilize a five night run on the 2.4-m telescope to conduct follow-up observations of these two clusters. During this time, we will obtain:

- low- to moderate-resolution spectra of known members (down to $V \sim 18$ mag), in order to measure Hα emission. Our targets will be the known cluster members lacking spectroscopy and/or previously identified as X-ray sources, e.g., by Franciosini et al. (2003) for Praesepe and by Giardino et al. (2008) for NGC 752. The Hα data will allow us 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 $L_{H\alpha}$.
- spectra for the fastest rotators in the cluster that are undetected in the X-ray, in order to test whether there is any evidence for chromospheric activity in these stars — which might

suggest a difference in the evolution of coronal and chromospheric activity.

- higher resolution spectra of candidate eclipsing binaries to determine orbital parameters, particularly for known cluster members. Our first season of observations of Praesepe yielded at least four M-dwarf binaries and two K-dwarf eclipsers with likely M-dwarf companions. We anticipate that our PTF observations of NGC 752 are likely to yield a number of equally interesting systems requiring follow-up observations. The expected radial velocity amplitudes for M-dwarf eclipsers are 50 – 200 km s^{-1}.

References

Franciosini et al. 2003, A&A, 405, 551

Giardino et al. 2008, A&A, 490, 113

Kraus & Hillenbrand 2007, AJ, 134, 2340

Law et al. 2009, PASP, 121, 1395

West et al. 2008, AJ, 135, 785

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.*

NGC 752 ($\alpha = 01^{\rm h}57.7^{\rm m}$, $\delta = +37°47'$) is a full night object in mid-November, with Praesepe ($\alpha = 08{\rm h}40.4^{\rm m}$, $\delta = +19°41'$) only becoming accessible toward the end of the night. This availability is well aligned with the current needs of our program: having focused most heavily on observing Praesepe members in Dec. 2010 and Feb. 2011, obtaining spectra for more NGC 752 cluster members is our highest priority going forward. Balancing the need to maximize access to NGC 752, while still providing some access to Praesepe for the most compelling outstanding targets (such as new objects of interest identified in our second season of PTF monitoring), has driven us to request a run in Nov. 2011. We will also be able to fill in gaps at the end of the nights with targets from our next PTF cluster, Coma Ber ($\alpha = 12^{\rm h}22.5^{\rm m}$, $\delta = +25°51'$).

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. Similar studies of chromospheric activity in field stars (e.g., West et al. 2008) have adopted 1Å equivalent width (EW) as a key benchmark for diagnosing the presence of chromospheric activity from the presence of Hα emission. Our experience on the Dec. 2010 and Feb. 2011 observing runs indicates that we can obtain spectra 50-100 targets per night with satisfactory signal-to-noise; we estimate that we require 5 nights of MDM time to obtain spectra for ∼200 NGC 752 cluster members.

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

Praesepe and NGC 752 are part of our PTF survey of open clusters. PTF's flexible queue scheduling and wide field of view makes it an optimal facility for monitoring clusters on timescales from hours to months. Characterizing the overall clusters' properties and the most interesting objects and systems identified in PTF observations, however, requires follow-up observations. Our MDM data will enable this analysis, producing a larger-than-typical scientific return for a modest investment of MDM time.

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?*

$\boxed{\star}$ Several hundred spectra of stars in the Pleiades, Hyades, Praesepe, Coma Ber, and NGC 752 have been obtained with the 2.4 m to date. Nearly all of these have been reduced and analysis is underway, with submission of a paper describing the results of our spectroscopic survey of NGC 752 anticipated for this fall. Another paper comparing the rotation-activity relations derived for Praesepe and the Hyades that will use our MDM data has been published in *ApJ* (Douglas et al. 2014).