Magnetic Fields throughout Stellar Evolution
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Age, Activity and Rotation in Mid and Late-Type M Dwarfs from MEarth

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Abstract. Using spectroscopic observations and photometric light curves of 280 nearby M dwarfs from the MEarth exoplanet transit survey, we examine the relationships between magnetic activity (quantified by Hα emission), rotation period, and stellar age (derived from three-dimensional space velocities). Although we have known for decades that a large fraction of mid-late-type M dwarfs are magnetically active, it was not clear what role rotation played in the magnetic field generation (and subsequent chromospheric heating). Previous attempts to investigate the relationship between magnetic activity and rotation in mid-late-type M dwarfs were hampered by the limited number of M dwarfs with measured rotation periods (and the fact that $v\sin i$ measurements only probe rapid rotation). However, the photometric data from the MEarth survey allows us to probe a wide range of rotation periods for hundreds of M dwarf stars (from less than one to over 100 days). Over all M spectral types we find that magnetic activity decreases with longer rotation periods, including late-type, fully convective M dwarfs. We find that the most magnetically active (and hence, most rapidly rotating) stars are consistent with a kinematically young population, while slow-rotators are less active or inactive and appear to belong to an older, dynamically heated stellar population.

Keywords. stars: activity, stars: low-mass, brown dwarfs, stars: late-type, stars: magnetic fields, stars: rotation, stars: kinematics, Galaxy: kinematics and dynamics

1. Introduction

Many M dwarfs have strong magnetic fields that can heat their stellar chromospheres and coronae, creating "magnetic activity" that is observed from the radio to the X-ray (e.g. Hawley *et al.* 1996; West *et al.* 2004; Reiners & Basri 2008; Berger *et al.* 2011). Although magnetic activity has been observed in M dwarfs for decades, the exact mechanism that gives rise to the chromospheric and coronal heating is still not well-understood.

In solar-type stars, magnetic field generation and subsequent heating is closely tied to stellar rotation and age; the faster a star rotates, the stronger its surface activity and younger its age (e.g. Skumanich 1972; Soderblom *et al.* 1991; Mamajek & Hillenbrand 2008). All indications suggest that this connection between age, rotation and activity extends to early-type M dwarfs ($<$ M4), where rotation and activity are strongly correlated (e.g. Kiraga & Stepien 2007). The finite active lifetimes of early-type M dwarfs observed

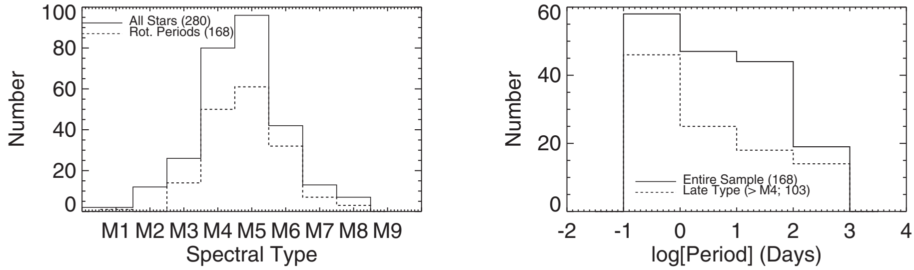

Figure 1. Distribution of MEarth stars with FAST spectroscopic observations (left), including stars with measured rotation periods (dashed). Distribution of rotation periods for all MEarth M dwarfs (solid) and late-type M dwarfs (dashed) with spectroscopic observations (right).

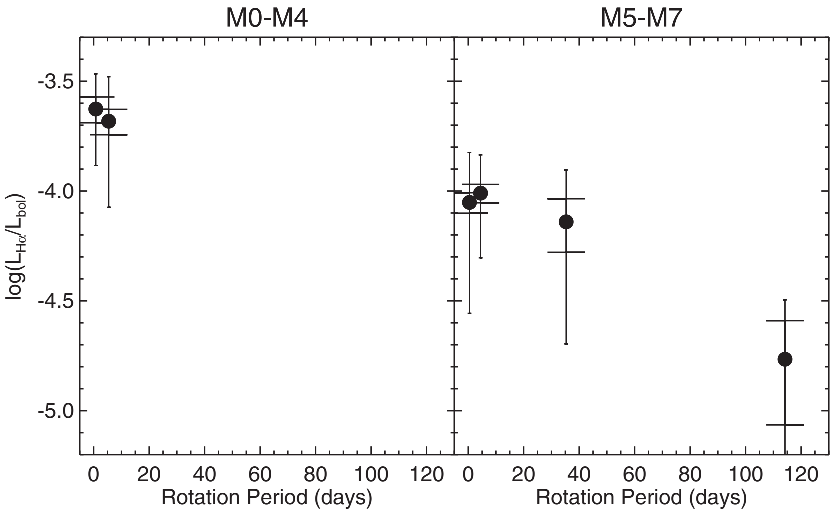

Figure 2. $(L_{\mathrm{H}\alpha}/L_{\mathrm{bol}})$ as a function of rotation period for early-type (left) and late-type (right) M dwarfs. Each data point corresponds to the mean value (of activity and rotation period) for the stars in the bin. The vertical error bars represent the spread of the data (short bars) and the uncertainty in the mean values (long bars).

in nearby clusters suggest that age continues to play an important role in the rotation and magnetic activity evolution of low-mass stars (Stauffer *et al.* 1994).

At a spectral type of ∼M3 (0.35 $M_{\odot}$; Chabrier & Baraffe 1997), stars become fully convective, a property that may affect how magnetic field (and the resulting heating) is generated. Despite this change, magnetic activity persists in late-type M dwarfs; the fraction of active M dwarfs peaks around a spectral type of M7 before decreasing into the brown dwarf regime (Hawley *et al.* 1996; West et al. 2004).

One method for studying stellar rotation is to use photometrically derived rotation periods (e.g. Kiraga & Stepien 2007). Periodic signals result from brightness variations caused by long-lived spots on the stellar surface rotating in and out of view. Recent programs to search for transiting planets around late-type M dwarfs have produced large catalogs of time-domain photometry from which can be gleaned several important stellar properties, including rotation periods.

One of these transit programs, MEarth (Nutzman & Charbonnaeu 2008; Berta *et al.* 2012) is surveying ∼2000 nearby, late-type M dwarfs at the Fred Lawrence Whipple Observatory (FLWO) at Mount Hopkins, Arizona using eight 0.4 m telescopes. Irwin *et al.* (2011) measured the rotation periods for 41 of the MEarth M dwarfs and found

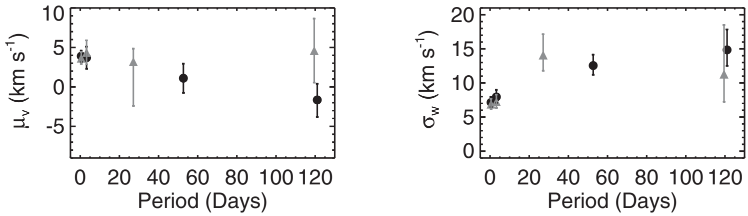

Figure 3. The mean V velocity (left) and the W velocity dispersion (right) as a function of rotation period for active (gray) and the entire FAST sample (black).

periods ranging from 0.28 to 154 days. The MEarth sample is an ideal sample of nearby (and therefore relatively bright) late-type M dwarfs from which to extract additional rotation periods and magnetic activity (from follow-up observations).

In this contribution, we use an expanded sample of MEarth rotation periods, along with low-resolution spectroscopy (taken from FLWO) and full 3D space motions to investigate the relation between rotation, activity and age in mid and late-type M dwarfs.

2. Observations and Methods

The photometric data used for measuring rotation periods come from the MEarth transit survey, which is searching for transiting exoplanets around ~2000 nearby M dwarfs (see Nutzman & Charbonnaeu 2008; Berta *et al.* 2012). Rotation periods were extracted using a least-squares periodogram fitting algorithm that is described in detail in Irwin *et al.* (2011). We also obtained R ~2000-3000 optical spectra for 298 MEarth targets using the FAST spectrograph on the 1.5m Tillinghast Telescope at FLWO.

Parallaxes from MEarth astrometry were derived for 198 of the stars in our spectroscopic sample (see Dittmann *et al.* 2013). For stars without MEarth parallaxes, we adopted distances from previous parallax determinations or photometric parallax techniques (Lèpine 2005). Proper motions for all of the stars were measured as part of the LSPM-North catalog (Lèpine & Shara 2005).

The FAST spectra were processed with the Hammer spectral-typing facility (Covey *et al.* (2007) - we identified and classified 280 M dwarfs (see Figure 1). Of the 280 M dwarfs for which we obtained FAST spectroscopy, 168 have measured rotation periods.

From the spectra we measured Hα equivalent widths and radial velocities as defined by West *et al.* (2004). We identified 145 magnetically active stars in our sample. For those (active) stars with Hα emission, we calculated the magnetic activity strength, $L_{\mathrm{H}\alpha}/L_{\mathrm{bol}}$ using the χ factor from Walkowicz, Hawley & West (2004).

Using stellar positions, proper motions, distances and radial velocities we measured (U, V, W) space velocities for 231 M dwarfs in our sample. We calculated the mean motions and velocity distributions (in U, V and W) for the M dwarfs within our sample as a function of rotation period and magnetic activity state. We used a Bayesian framework and calculated the posterior probabilities that sub-groups of stars were selected from a grid of Gaussian velocity distributions.

3. Results

For the 114 active stars with measured rotation periods, we examined the relation between magnetic activity and rotation period in both early-type (M0-M4) and late-type (M5-M7) M dwarfs. Figure 2 shows the magnetic activity strength (quantified by $L_{\mathrm{H}\alpha}/L_{\mathrm{bol}}$) as a function of rotation period. Each data point corresponds to the mean

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value (of activity and rotation period) for the stars in the bin. The vertical error bars represent the spread of the data (short bars) and the uncertainty in the mean values (long bars). We find that late-type M dwarfs are less active than their early-type counterparts and show a clear trend of decreasing activity level with increasing rotation period.

Our kinematic analysis suggests clear ties between both age and activity and age and rotation. Figure 3 shows the mean V velocity (left) and the W velocity dispersion (right) as a function of rotation period for active (gray) and the entire FAST sample (black). The W velocity dispersion increases with increasing period, indicating that stars with longer rotation periods have undergone more dynamical heating and are therefore older. For the entire FAST sample, the decrease in V motions as a function of rotation period is consistent the model that as stars age, their orbits become more elliptical (through dynamical encounters) and they exhibit asymmetric drift. However, the active stars do not appear to show asymmetric drift and are consistent with a younger population.

4. Discussion

Our results suggest that there is a correlation between activity and rotation in fully convective late-type M dwarfs and that in general, fast rotators are younger than slow rotators. Our kinematic analyses confirm previous findings that active stars appear to be younger than their inactive counterparts. However, we find surprisingly a small number of apparently young, active, slow rotators, which will be the topic of future investigations.

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