Rotation and Activity in Late-type M Dwarfs

Andrew A. West* † and Gibor Basri ‡

*MIT Kavli Institute for Astrophysics and Space Research, 77 Massachusetts Avenue, Cambridge, MA 02139
†Astronomy Department, University of California, 601 Campbell Hall, Berkeley, CA, 94720-3411

Abstract. We have examined the relationship between rotation and activity in 14 late-type (M6-M7) M dwarfs, using high resolution spectra taken at the Keck Observatory and flux-calibrated spectra from the Sloan Digital Sky Survey. Most are inactive at a spectral type where Hα emission has previously seen to be very common. We used the cross-correlation technique to quantify the rotational broadening; six of the stars in our sample have $v \sin i \geq 3.5$ kms$^{-1}$. Three of these stars do not exhibit Hα emission, despite rotating at velocities where previous work has observed strong levels of magnetic field and stellar activity. Our results suggest that rotation and activity in late-type M dwarfs may not always be linked, and open several additional possibilities including a rotation dependant activity threshold, or a Maunder-minimum phenomenon in fully convective stars.

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INTRODUCTION

Many M dwarfs, which are the most abundant stars in the Milky Way, have strong magnetic dynamos that give rise to chromospheric and coronal heating, producing emission from the x-ray to the radio. Although this magnetic heating (or activity) has been observed for decades, the exact mechanisms that control magnetic activity in M dwarfs are still not well-understood.

In the Sun, activity is strongly linked to rotation. The rotation in solar type stars slows with time due to angular momentum loss from magnetized stellar winds; as a result, magnetic activity decreases. There is strong evidence that the rotation-activity relation extends from stars more massive than the Sun to smaller dwarfs [1, 2]. However, at a spectral type of $\sim$M3 [0.35 $M_\odot$; 3, 4], stars become fully convective. This transition marks an important change in the stellar interior that has been thought to affect the production and storage of internal magnetic fields.

A few studies have uncovered evidence of a possible rotation-activity (using Hα) relation extending past the M3 convective transition and into the brown dwarf regime [5, 6, 7]. However, the lack of an unbiased sample of high resolution spectra of late-type M dwarfs complicates the situation.

Using over 30,000 spectra from the Sloan Digital Sky Survey [SDSS; 8], West et al. [9, 10] showed that the activity fraction of M dwarfs varies as a function of stellar age (using Galactic height as a proxy for age) and that the Hα activity lifetime for M6-M7.5 stars is 7-8 Gyr. Nearby samples of late-type M dwarfs are therefore biased towards young populations with high levels of activity; until recently every known M7 dwarf was observed to be magnetically active [11, 12, 13].
We present results from our study of the $v_{\text{sin}i}$ rotation velocities for a small sample of M6-M7 dwarfs, most of which were selected to be inactive or weakly active from the SDSS low-mass star spectroscopic sample.

DATA

Our sample was selected from the West et al. [10] Sloan Digital Sky Survey (SDSS) M dwarf catalog, a spectroscopic sample of almost 40,000 M and L-type dwarfs. We selected the brightest M7 and M6 stars which were either inactive or weakly active (as measured by their H$\alpha$ emission). 12 stars were selected using these criteria. Two additional active M7 dwarfs were added to the sample for comparison to previous studies. While our sample is not a complete unbiased sample, representative of the underlying M dwarf population, it does consist of late-type M dwarfs with activity properties selectively different than previously observed.

ANALYSIS

To measure the $v_{\text{sin}i}$ rotation velocities for our sample, we used a cross-correlation technique similar to that of previous studies [e.g. 5, 6]: we cross-correlated each program spectrum with the spectrum of a slowly rotating comparison star. The width of the resulting cross-correlation function is a direct probe of the rotational broadening. To measure the rotational broadening of each spectrum, we compared the resulting cross-correlation function to that of a rotationally broadened template. The GL406 template was rotationally broadened to larger rotation velocities using the technique of Gray [14] and cross-correlated with the original (unbroadened) template. A $v_{\text{sin}i}$ was determined based on the best fit spun-up template. Figure 1 shows the cross-correlation function of SDSS094738.45+371016.5 with GL406 in the 7080-7140Å region (solid) compared with the cross-correlation function of GL406 with the best-fit rotationally broadened GL406 spectrum (dotted; 6 kms$^{-1}$), and the auto-correlation function of GL406 (dashed; 0 kms$^{-1}$ broadening). The cross-correlation reveals that SDSS094738.45+371016.5 appears to be rotating with a velocity $\geq$ 6 kms$^{-1}$.

All of the spectra were spectral typed by eye using the Hammer spectral analysis package [15] on the SDSS spectra. We measured the equivalent widths (EW) of the H$\alpha$ emission lines in both the SDSS and Keck spectra. The Keck spectra are more sensitive to low levels of emission (they can be distinguished better against the pervasive molecular features); it is also true in general that equivalent widths tend to be smaller when measured from high resolution spectra. Almost all of our targets chosen to be inactive at low resolution proved inactive even at high resolution, and the EWs when detected were similar.
RESULTS

Six of the fourteen M6-M7 dwarfs in our sample have detectable rotation. 3 of the rotating stars have measurable activity but the other 3 show no signs of activity in any of the emission lines in either the SDSS or Keck spectra. The cross-correlation shown in Figure 1 (SDSS094738.45+371016.5) is an example of one of the inactive M7 dwarfs that appears to be rotating despite not being magnetically active.

![Cross-correlation function of SDSS094738.45+371016.5 with GL406 in the 7080-7140 Å region (solid) compared with the cross-correlation function of GL406 with the best-fit rotationally broadened GL406 spectrum (dotted; 6 kms\(^{-1}\)), and the auto-correlation function of GL406 (dashed; 0 kms\(^{-1}\) broadening). The cross-correlation reveals that SDSS094738.45+371016.5 appears to be rotating with a velocity \(\geq 6\) kms\(^{-1}\) despite not having any signs of activity in either the SDSS or Keck spectra.](image)

**FIGURE 1.** Cross correlation function of SDSS094738.45+371016.5 with GL406 in the 7080-7140 Å region (solid) compared with the cross-correlation function of GL406 with the best-fit rotationally broadened GL406 spectrum (dotted; 6 kms\(^{-1}\)), and the auto-correlation function of GL406 (dashed; 0 kms\(^{-1}\) broadening). The cross-correlation reveals that SDSS094738.45+371016.5 appears to be rotating with a velocity \(\geq 6\) kms\(^{-1}\) despite not having any signs of activity in either the SDSS or Keck spectra.

Figure 2 shows \(L_{\text{H\alpha}}/L_{\text{bol}}\) (activity) as a function of \(v\sin i\) for the M6-M7.5 dwarfs from this paper. Lower limits in both velocity and activity denote the levels to which our sample could probe. All previous M6-M7.5 dwarfs were found to be active, while 9 of the 14 stars in our sample show no activity in either the SDSS or Keck spectra. The lack of activity is not surprising since that was our main selection criterion, however it highlights the fact that we are probing a sample with very different properties than previously studied.

DISCUSSION

We conducted high resolution spectral observations of 14 M6-M7 dwarfs and found \(v\sin i\) rotation velocities for 6 for the stars. Three of the stars showed both activity and rotation, 6 of the stars showed neither rotation nor activity, 2 of the stars showed activity but no rotation and 3 stars showed rotation but no activity. These results are in contrast with previous studies that found a strong connection between rotation and activity in all (active) M6-M7 dwarfs [5, 6, 7]. Our sample is the first rotation study to include M6-M7 dwarfs that are inactive.

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vsini (kms$^{-1}$)

$10^{-7}$

$10^{-6}$

$10^{-5}$

$10^{-4}$

$L_{\text{H}\alpha}/L_{\text{bol}}$

FIGURE 2. $L_{\text{H}\alpha}/L_{\text{bol}}$ (activity) as a function of vsini (rotation) for the M6-M7.5 dwarfs from this study. $L_{\text{H}\alpha}/L_{\text{bol}}$ values were calculated from Equivalent Width measurements using the $\chi$ conversions of Walkowicz et al.\[16\]. Our sample includes M6-M7 dwarfs with both measured rotation as well as activity from the SDSS and Keck spectra (filled circles), measured rotation and activity from the Keck spectra (CaII K detected in SDSS; filled diamonds), activity from the Keck spectra but no rotation (filled squares), activity from the SDSS spectra but no rotation (filled squares), no rotation or activity (hexagonally aligned dots; number denotes number of stars) and measured rotation but no activity (filled stars). Lower limits in both velocity and activity denote the levels to which our sample (and previous studies) could probe. All previous M6-M7.5 dwarfs were found to be active, while 9 of the 14 stars in our sample show no activity in either the SDSS or Keck spectra. The dearth of inactive late-type M dwarfs in previous studies is due to a selection effect that biases nearby samples to younger, more active stars\[9,10\]. 3 of our stars show strong evidence for rotation despite having no activity.

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