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MAGELLAN ECHELLE SPECTROSCOPY OF TW HYDRAE BROWN DWARFS

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ABSTRACT

We present high-resolution optical spectroscopy of four candidate members of the nearby TW Hydrae young association including three brown dwarfs (2MASS 1207−3932, 2MASS 1139−3159, and TWA 5B) and one T Tauri multiple star (TWA 5A). Using echelle spectra from the Magellan Baade 6.5 m telescope, we confirm the pre–main-sequence status and cluster membership of the substellar candidates, through the detection of Li I, Na I consistent with low gravity, and radial velocity. Given their late spectral type (∼M8) and the youth of the association (age ∼ 10 Myr), cluster membership certifies these three objects as young brown dwarfs. One of them (2MASS 1207−3932) shows strong emission both in the hydrogen Balmer series (Hα to Hϵ) and in He I (4471, 5876, 6678, and 7065 Å), compared with other young brown dwarfs of similar spectral type. The Hα line is also relatively broad (10% width ∼200 km s^{-1}) and asymmetric. These characteristics suggest that 2MASS 1207−3932 is a (weak) accretor. While we cannot rule out activity, comparison with a flaring field dwarf implies that such activity would have to be quite anomalous. The verification of accretion would make it the oldest actively accreting brown dwarf known to date, suggesting that inner-disk lifetimes in substellar objects can be comparable to those in stars, consistent with a similar formation mechanism. The close triple TWA 5A also appears to be a variable accretor, implying that long-lived disks can exist in multiple systems.

Subject headings: circumstellar matter — open clusters and associations: individual (TW Hydrae) — stars: low-mass, brown dwarfs — stars: pre–main-sequence

1. INTRODUCTION

The recent identification of several groups of young stars within 100 pc of the Sun has generated widespread interest (Jayawardhana & Greene 2001). Given their proximity and age differences, these groups are ideally suited for detailed studies of the origin and early evolution of stars, brown dwarfs (BDs), and planets. Perhaps the most intensely studied among these groups is the TW Hydrae Association (TWA), which consists of ∼20 comoving stars (Zuckerman et al. 2001) at a distance of 47–67 pc and dispersed over some 20° on the sky. The members are mostly late-type (K and M) stars and include several interesting multiple systems (Brandeker, Jayawardhana, & Najita 2003, hereafter BJN03, and references therein) and one A star. At an age of ∼10 Myr, the TWA fills a significant gap in the age sequence between ∼1 Myr old T Tauri stars in molecular clouds like Taurus-Auriga and the ∼50 Myr old open clusters such as IC 2391. That is particularly useful for deriving strong constraints on disk evolution timescales. Their diverse disk properties suggest that the TWA stars are at an age when disks are rapidly evolving, through coagulation of dust and dissipation of gas (Jayawardhana et al. 1999).

Lowrance et al. (1999) found a BD candidate ∼2″ from TWA 5A (CD −33°7795); TWA 5A and 5B are now confirmed as a common proper motion pair (BJN03 and references therein). Recently, Gizis (2002) reported two isolated substellar candidates from the 2 Micron All-Sky Survey that may be members of the TWA. Together, these three objects constitute a unique sample to explore the evolution of BD characteristics on a 10 Myr timescale.

Here we report high-resolution optical spectroscopy that confirms the youth, group membership, and substellar status of these three objects. We also present a spectrum of the T Tauri multiple system TWA 5A, to which TWA 5B is bound. We use these spectra to investigate accretion, rotation, and chromospheric activity.

2. OBSERVATIONS AND ANALYSIS

We obtained high-resolution optical spectra using the Magellan Inamori Kyocera Echelle spectrograph (Bernstein et al. 2002) on the Baade 6.5 m telescope at Las Campanas Observatory, Chile, in 2003 May. Consecutive spectra were obtained for the three BD candidate members: 3 × 1200 s for 2MASS 1207−3932 (May 8), 3 × 1500 s for 2MASS 1139−2649 (May 9), and 2 × 1800 s for TWA 5B (May 10). Additionally, we obtained two 600 s exposures of TWA 5A, one each on May 8 and 10. The spectra of the 2MASS objects (from now on, 2M1207 and 2M1139) and the May 8 spectrum of TWA 5A were taken with a 1″ wide × 5″ long slit. The May 10 spectra of TWA 5A and 5B were obtained with a narrower 0″.7 × 5″ slit. The separation between TWA 5A and 5B is ∼2″, and TWA 5B is ∼7 mag fainter in the optical. To ensure no contamination of the 5B spectrum by 5A, we observed 5B with a narrower slit (0″.7), under optimal seeing conditions (better than 0″.5), with the slit positioned roughly perpendicular to the 5A–5B axis. The coverage was ∼3200–4800 Å in the blue and ∼4800–8800 Å in the red, with overlapping orders. The spectra are unbinned in wavelength, and binned by 2 pixels in the spatial direction. The 1″ slit yielded a spectral resolution of $R \sim 19{,}000$ in the red and 25,000 in the blue; the 0″.7 slit gave $R \sim 27{,}000$ and 36,000, respectively. The data were reduced in standard fashion using IDL routines. We derive rotational velocities ($v \sin i$) by cross-correlating with a "spun-up" template; the template is an average of a slowly rotating dwarf and giant standard (see Mohanty & Basri 2003, hereafter MB03; Jayawardhana, Mohanty, & Basri 2002, hereafter JMB02). Radial velocities ($v_{\rm rad}$) were found by cross-correlating against the M6 dwarf Gl 406; $v \sin i$ and $v_{\rm rad}$ are listed in Table 1.

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TABLE 1

Spectroscopic Properties of TWA Targets

Object	Spectral Type[a]	v_{rad} (km s^{-1})	$v \sin i$ (km s^{-1})	Li I EW[b] (Å)	Hα EW[b] (Å)	Hα 10% FW[c] (km s^{-1})
2MASS 1207−3932	M8	11.2 ± 2	13 ± 2	0.5	27.7	204 ± 10
2MASS 1139−3159	M8	11.6 ± 2	25 ± 2	0.5	7.3	111 ± 10
TWA 5B	∼M8.5	13.4 ± 2	16 ± 2	0.3	5.1	162 ± 10
TWA 5A[d]	M1.5	…	…	0.6	7.2/6.6[e]	266 ± 10

[a] Spectral types for 2MASS objects are from Gizis 2002; spectral types for TWA 5A and 5B are from Webb et al. 1999.

[b] *Pseudo*–equivalent widths, for Li I and Hα; estimated Hα EW errors of $\lesssim$10%.

[c] For 2M1139 and TWA 5B, we quote the average width from their consecutive spectra over a single night. For 2M1207, we adopt the Hα 10% width of only the second spectrum as the realistic value (see text); the average width from all three spectra is 187 ± 10 km s^{-1}. For TWA 5A, we quote 10% FW values for both nights; they are very similar.

[d] We did not derive v_{rad} or $v \sin i$ for the TWA 5A system, given its known v_{rad} variability (Torres et al. 2003), and the questionable accuracy of $v \sin i$ given possible line blending.

[e] In TWA 5A, the larger Hα EW is for the spectrum with excess accretion-related emission.

3. RESULTS AND DISCUSSION

3.1. *Membership and Substellar Status*

All three TWA BD candidates have spectral types of ∼M8–M8.5 (Gizis 2002; Webb et al. 1999), consistent with the features in our high-resolution data (e.g., strong TiO bands). In all three, we detect Li I 6708 Å. They also exhibit narrow Na I (∼8200 Å) absorption profiles indicative of low gravity (intermediate between giants and dwarfs) and strong dMe-like Hα emission (Fig. 1; equivalent widths [EW] for Hα and Li I given in Table 1). In concert, these facts confirm the pre–main-sequence (PMS) status of TWA 5B, 2M1207, and 2M1139: we can confidently exclude field M dwarfs (no Li I), low-mass field BDs with undepleted Li (type ∼L2 or later; gravity $\gtrsim$ dwarfs values), Li-rich giants (much lower gravity; Hα in absorption), and subgiants (MS lifetime of M dwarfs too long for M-type subgiants to have formed yet).

For all three objects, our derived v_{rad}-values are commensurate with those found for other, bona fide members of the association (Torres et al. 2003). TWA 5B is also confirmed as a common proper motion companion to TWA 5A (BJN03 and references therein). Gizis (2002) has found a proper motion consistent with membership for 2M1207. In conjunction with our v_{rad} measurements and confirmation of PMS status, these observations verify TWA membership for both TWA 5B and 2M1207. For 2M1139, Gizis (2002) found a proper motion apparently inconsistent with membership. However, he notes that the astrometric uncertainty is large. Therefore, given its PMS status and a v_{rad} consistent with other members, we consider it likely that 2M1139 also belongs to the TWA. More precise astrometric measurements are required to verify this.

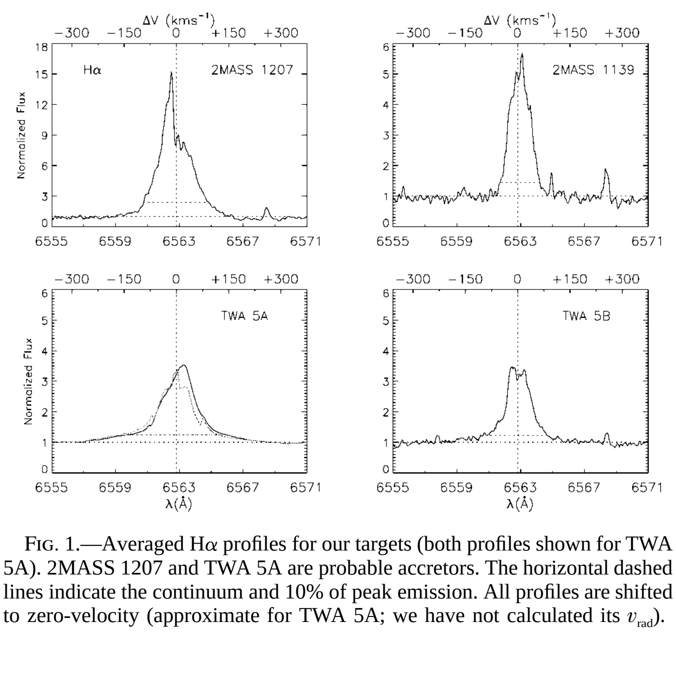

Fig. 1.—Averaged Hα profiles for our targets (both profiles shown for TWA 5A). 2MASS 1207 and TWA 5A are probable accretors. The horizontal dashed lines indicate the continuum and 10% of peak emission. All profiles are shifted to zero-velocity (approximate for TWA 5A; we have not calculated its v_{rad}).

All objects with detected lithium and T_{eff} less than about 2800 K are expected to be substellar, regardless of age (see Basri 2000). The M8–M8.5 spectral type of 2M1207, 2M1139, and TWA 5B, which implies $T_{eff} < 2800$ K (e.g., Luhman 1999), therefore ensures that they are BDs, since they all show Li. An age is required, however, to derive a mass. Since we confirm association membership for at least 2M1207 and TWA 5B, an age of ∼10 Myr is justified for them. Comparing with the evolutionary tracks of Chabrier et al. (2000) then yields ∼35M_{Jup} for both. The same value is obtained for 2M1139, if it too is a member. Even if it is not, one can still use the fact of Li detection, and a T_{eff} estimate (∼2700 K; Luhman 1999), to put upper limits on mass and age of ∼65M_{Jup} and ∼250 Myr, respectively, using the same models.

3.2. *Accretion*

It is difficult to distinguish between disk accretion and chromospheric activity in weakly accreting very low-mass objects (e.g., Jayawardhana, Mohanty, & Basri 2003a, hereafter JMB03). Here we conservatively identify probable accretors based on asymmetric and broad Hα (10% width $\gtrsim$200 km s^{-1}, following JMB03) *and* the detection of usual indicators of accretion at larger masses, such as He I and upper Balmer lines, at a level *higher* than the average for a given spectral type (the same criteria adopted by Muzerolle et al. 2003). By these conditions, 2M1139 and TWA 5B are chromospherically active, but not accreting. 2M1207 and TWA 5A, however, do appear to be accretors, as discussed below.

2MASS 1207−3932.—As Figure 2 shows, significant emission is seen in He I and in the upper Balmer series lines up to Hϵ in this object. A perusal of the recent study by Muzerolle et al. (2003), meanwhile, shows that nonaccreting M7–M8.5 objects in their sample usually do not show He I (at 6678 Å, the only He I line they include), or Balmer lines beyond Hβ. Next, in Figure 3, we show the normalized Hα profiles from our three consecutive spectra of 2M1207. A clear asymmetry is seen in the first and third profiles, with much enhanced emission blueward of line center. In the second profile, the full width at 10% of peak flux is ∼200 km s^{-1}: not unreasonable

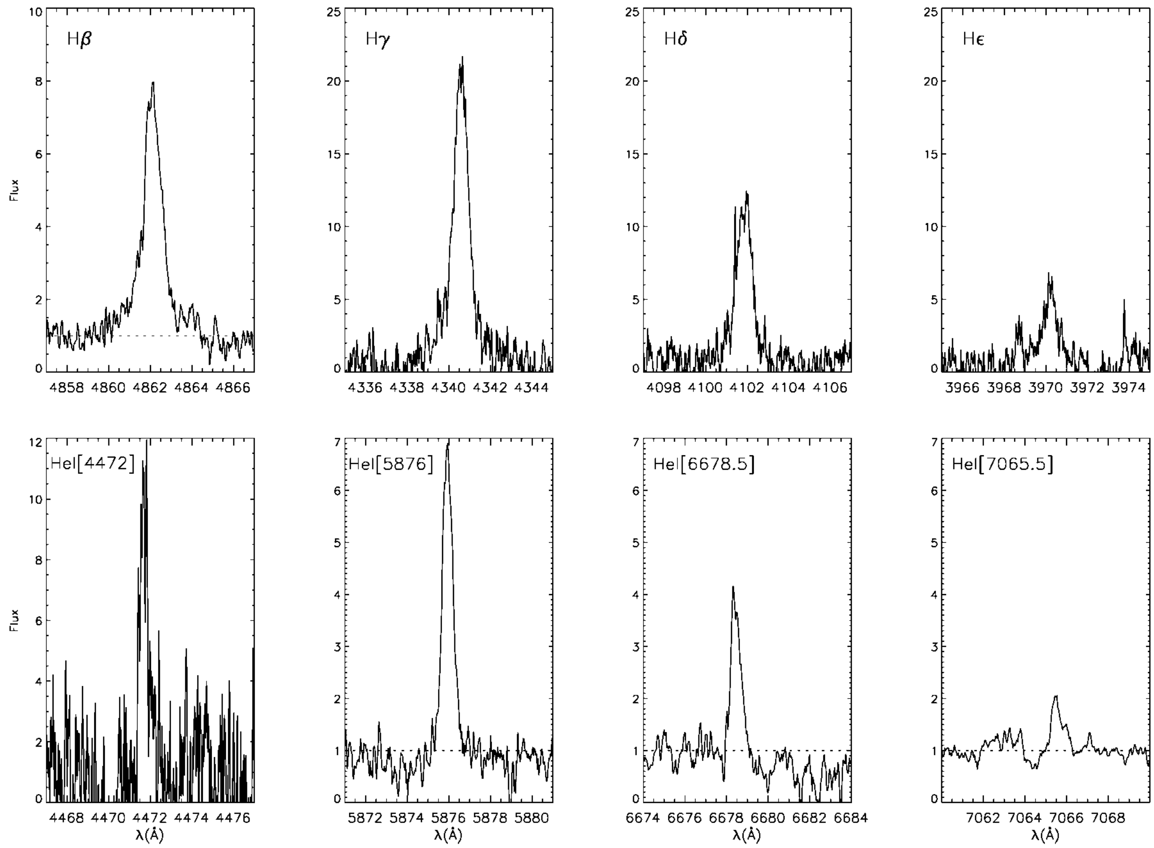

FIG. 2.—Averaged H I and He I emission in 2MASS 1207. A continuum was detected around only some of these lines; these have been continuum-normalized (continuum: *dashed horizontal line*). In the others, no true continuum was detected, making flux or EW measurements impossible; these have only been divided by the rms of the surrounding noise for clarity.

for very low-mass, low accretion-rate objects, and similar to that seen by JMB03 in a couple of mid- to late-M accretors. In the first and last profiles, the width is slightly less, at ∼170 km s^{-1}. However, superimposing the three spectra (not shown) reveals that the line wings are exactly the same; the smaller 10% width in the first and last is artificially induced simply by the increase in peak flux. We therefore adopt ∼200 km s^{-1} as the more robust value. By all our criteria, therefore, 2M1207 appears to be (weakly) accreting. Can the emission in this object simply be a result of enhanced activity compared with other, similar spectral type objects? While we cannot rule this out, the following argument makes this seem unlikely. In one of our high-resolution spectra of the field M7.5 dwarf LHS 2397A, taken during a flare, the Hα EW is ∼30 Å (MB03), i.e., almost exactly the same as observed in 2M1207. If the emission in 2M1207 were due to chromospheric activity, we would expect its line profiles to look very similar to those of LHS 2397A. given the nearly identical spectral types. The line profile comparison is shown in Figure 3. Clearly, the LHS 2397A Hα profile is much more symmetric compared with the first and last 2M1207 spectra, and significantly narrower in all three cases: 2M1207 exhibits broader Hα line wings, as expected from accretion. The He I line at 6678 Å is also much stronger in 2M1207 than in LHS 2397A; since the spectral types (and hence the underlying continuum) are almost the same, the actual flux in He I emission is thus also higher. This too indicates that the same physical process is not responsible for the emission in the two objects; in particular, excess He I emission can arise from the very hot accretion-shock region. We suggest, therefore, that 2M1207 is a bona fide accretor. However, our arguments against activity are not ironclad, and the presence of accretion needs to be checked through other diagnostics. The lack of a $K-L'$ excess in 2M1207 (Jayawardhana et al. 2003b) could be the result of a nearly edge-on disk inclination or grain growth.

If accretion in 2M1207 is confirmed, it would suggest that inner-disk lifetimes of substellar objects can be comparable to those of their stellar counterparts and further strengthen the case for a common formation mechanism for BDs and stars.

TWA 5A.—The 10% full width of the Hα line in TWA 5A is ∼270 km s^{-1}, which is commensurate with accretion (e.g., JMB03). However, this object is known to be a triple, with a ∼0″.06 binary resolved by adaptive optics (BJN03) as well as a spectroscopic companion (Torres et al. 2003).

To discount the possibility that the Hα line is broadened to accretion-like widths simply due to blending of Hα from the three stars, we compare our two spectra of TWA 5A, obtained 2 days apart. Figure 4 shows that the spectra are exactly the same, *except* in lines that are accretion indicators. This implies that the spectral change is not due to variations in line blending, but in the intrinsic parameters of (at least) one of the TWA 5A components. In particular, we see that the first spectrum (*in black*) shows excess redshifted emission and blueshifted absorption in Hα, He I λ5876, and Na D, as well as excess emission in [O I] λ6300, compared with the second spectrum (*in gray*). Though Hα, Na D, and He I emission may conceivably arise from chromospheric activity, the blueshifted absorption seen in these three lines strongly suggests accretion. Furthermore, [O I] λ6300 is an excellent diagnostic of outflowing winds associated with accretion; it is often seen in

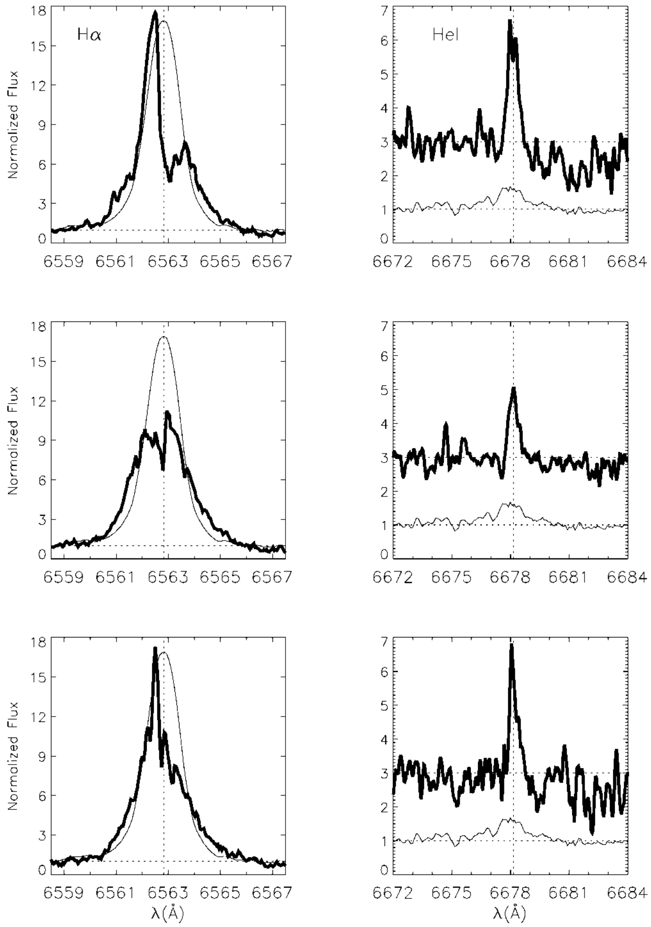

FIG. 3.—*Top to bottom, left panels*: Hα from our three spectra of 2MASS 1207 (*thick lines*) compared with the Hα in the flaring field M7.5 dwarf LHS 2397A (observed at similar resolution on Keck HIRES). *Top to bottom, right panels*: He I λ6678 comparison.

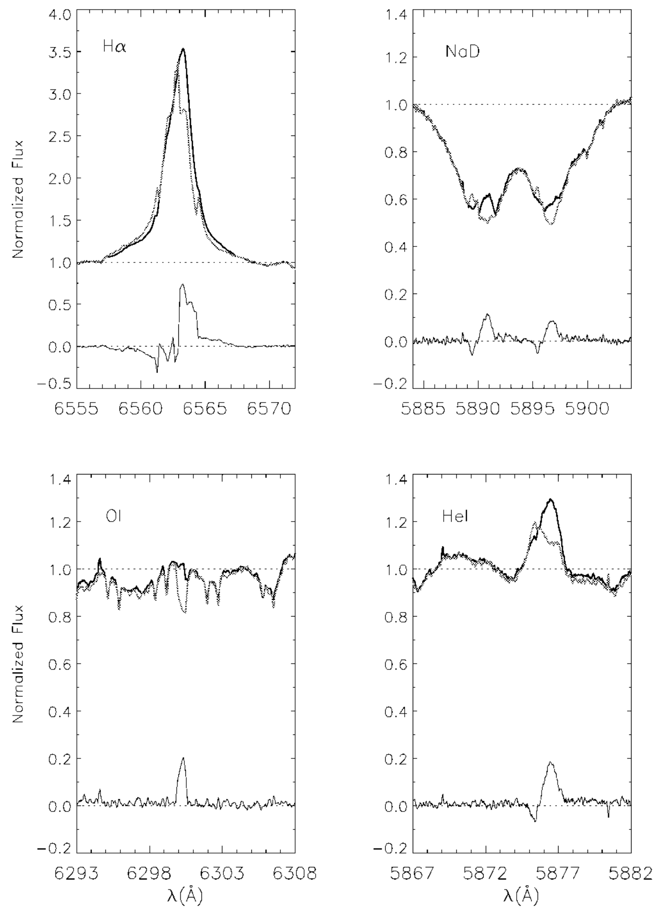

FIG. 4.—Comparison of two TWA 5A spectra, in regions containing accretion-indicating lines (Hα, Na D, [O I] λ6300, He I λ5876). The two spectra are exactly the same, except one of them (*black*) shows excess emission in Hα, Na D, O I, and He I, and blueshifted absorption in Hα, Na D, and He I, compared with the other spectrum (*gray*).

accreting CTTs, but never in nonaccreting WTTs (Muzerolle et al. 2003). All this supports ongoing accretion in the TWA 5A system. The fact that the two spectra differ significantly in the accretion diagnostics implies that the process is variable. Our results also suggest that inner disks can be long-lived even in close multiple systems.

3.3. *Rotation and Activity*

Down to ~M8, field M dwarfs with $v \sin i \gtrsim 5$ km s^{-1} exhibit saturated levels of chromospheric Hα emission (MB03). For our PMS targets, we will discuss the rotation-activity connection in detail in a future paper, with a larger sample and Hα flux calibrations. However, we note here that the Hα EWs in our three ~M8 objects are, at the very least, comparable to those in saturated field dwarfs of similar type, consistent with their moderately rapid rotation (>10 km s^{-1}). As discussed, Hα emission in 2M1207 is in fact far stronger and akin to that in flaring M8 dwarfs. Similar EWs are seen in some other young, (apparently) nonaccreting late-M objects, supporting the idea that activity is enhanced in young low-mass objects compared with field dwarfs of similar type (e.g., JMB02; JMB03). However, the Hα profile in these cases is narrow and symmetric. If 2M1207 were a nonaccretor, the strong asymmetries seen in at least two of its Hα profiles would be puzzling.

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