2MASSI J1315309−264951: AN L DWARF WITH STRONG AND VARIABLE Hα EMISSION

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Accepted to ApJL December 6, 2001

ABSTRACT

2MASSI J1315309−264951 is an L3 dwarf with strong Hα emission discovered in the course of a color-selected survey for active galactic nuclei using the Two-Micron All-Sky Survey (2MASS). The strength of its Hα emission decreased by about a factor of two between two epochs separated by 137 days. This is the first time that variable Hα emission has been reported in an L dwarf, and is probably the first observation of an Hα flare in an L dwarf. The value of \( \log(L_{H\alpha}/L_{bol}) > -4.17 \) observed at the discovery epoch is larger than that of any other L dwarf but comparable to that of 2MASSI J1237392+652615, the only reported T dwarf with Hα emission. The observed variability indicates that the Hα emission of 2MASSI J1315309−264951 is powered either by magnetic fields or by accretion in a binary system. Spectroscopic or narrow-band Hα monitoring of L and T dwarfs on timescales of hours to days would be the most useful step toward a better understanding of their Hα emission mechanism(s).

Subject headings: stars: activity, stars: low mass, brown dwarfs, stars: individual (2MASSI J1315309−264951, 2MASSI J1237392+652615, 2MASSW J0036159+182110)

1. INTRODUCTION

For many years the coolest, lowest-mass stars known were M dwarfs, but in recent years the L and T dwarfs have extended the stellar sequence to even lower temperatures and masses (Kirkpatrick et al. 1999). These three classes of low-mass stars and brown dwarfs exhibit distinctly different spectral features due to the decrease in photospheric temperature from M through L to T. In addition, M dwarfs often show Hα in emission. Down to the early M dwarfs, Hα activity correlates with rotation and thus decreases with age as stars lose angular momentum over time via stellar winds. Beyond objects of spectral type M8, however, it appears that Hα activity is stronger in more massive objects, even if they are older (Gizis et al. 2000). The frequency of Hα emission peaks around type M7 and declines for later-type L and T dwarfs, reaching zero at L5 (Gizis et al. 2000). However, contrary to this trend, Burgasser et al. (2000) reported the discovery of a T dwarf with strong Hα emission. Here I report the discovery of an L3 dwarf with similarly strong Hα emission.

2. SPECTROSCOPY

2MASSI J1315309−264951 (hereafter 2MASS 1315−2649) was targeted for spectroscopy as part of a color-selected survey of AGN candidates from the Two-Micron All-Sky Survey Second Incremental Data Release (2MASSI). That survey will appear elsewhere (Hall 2002, in preparation).

Potential AGN candidates were selected from the 2MASS Point Source Catalog by requiring \( \alpha < 5^h \) or \( \alpha > 15^h, -55^\circ < \delta < +5^\circ, |b| > 25^\circ \), and that they not be affected by blending, saturation or confusion with other objects, known artifacts or minor planets. Actual AGN candidates were then selected from the list of potential candidates using color criteria based on those of Barkhouse & Hall (2001). 2MASS 1315−2649 was included in a subsample of objects with \( J - K_s > 1.5 \) and \( K_s < 13.5 \).

Spectra of 2MASS 1315−2649 were secured during two runs with CSPEC at the CTIO 1.5m telescope. Both runs used a 300 lines/mm grating blazed at 6750˚A, for a resolution of 8.6˚A given the 1′5 slit. Wavelength coverage was 5780−9270˚A at 2.89˚A/pixel. Two 12-minute exposures were begun at UT 06:09 on 2001 March 30. A 12-minute and a 24-minute exposure were obtained through cirrus beginning at UT 23:39 on 2001 August 15. The two-dimensional spectra were debiased and flatfielded in the usual manner using IRAF. Each pair of reduced two-dimensional spectra was then coadded with exposure time weighting and 5σ cosmic ray rejection.

The two-dimensional spectra show a close pair of objects. 2MASS 1315−2649 at \( \alpha = 13:15:30.94, \delta = -26:49:51.3 \) (J2000) is an optically faint L dwarf with Hα emission, and USNO J131531.23−264953.0 an optically brighter star slightly south of east. Both objects were visible on the guide camera, and the east-west slit was positioned as best as possible to obtain spectroscopy of both. However, unlike USNO J131531.23−264953.0, 2MASS 1315−2649 is faint enough that it may have drifted off the slit without being immediately noticed. The east-west separation between the objects in the two-dimensional spectra is 5.5±0.3′, as determined from the centroids of the spatial profiles of the two objects in the spectra from the two independent epochs. This is significantly larger than the 3.9′ east-west separation expected for the 2MASS-USNO separation of 4.2′ at PA 114.5° E of N. This suggests that one or both of the objects exhibited proper motion between the 2MASS epoch of 1998.411 and the spectroscopic observations. However, better data are needed to verify this since CSPEC delivers a 2-3 pixel
FWHM spectrum at a spatial scale of 1.3′/pixel.

The spectra were optimally extracted using IRAF, with the USNO star’s trace used for both objects. Flux calibration was provided by GD108 (Oke 1990) in March and LTT1788 (Hamuy et al. 1994) in August. The spectral type of USNO J131531.23–264953.0 must be no later than K5, since its spectrum lacks strong features. The spectra of 2MASS 1315–2649 are discussed next.

3. ANALYSIS

Figure 1 shows the March and August spectra of 2MASS 1315–2649. By comparison to the spectral atlas of Kirkpatrick et al. (2000), I estimate a spectral class between L2 and L4 on the Kirkpatrick et al. (1999) system, and adopt L3. Due to the poor quality of the spectra, this classification is not based on single features, but on the agreement between numerous features. The absence of strong TiO and VO features at 7000-8400˚ from 8000–9260˚ puts the class no earlier than L2. The flatness of the spectrum from 7500 ˚A to 8400-9000˚ the agreement between numerous features. The absence of this classification is not based on single features, but on the agreement between numerous features. The absence of strong TiO and VO features at 7000-8400˚ from 8000–9260˚ puts the class no earlier than L2. The flatness of the spectrum from 7500 ˚A to 8400-9000˚ puts the class no earlier than L2. The flatness of the spectrum from 8400-9000˚ and the continuum level there compared to 7500˚ A are inconsistent with spectral types L5 and higher.

Hα is visible in both the two-dimensional and one-dimensional spectra from both observing runs, but it is clear that at least its equivalent width (EW) varied between the two runs. The total Hα flux may not have been measured accurately in either run because the east-west slit was comparable in size to the seeing and was not centered precisely on 2MASS 1315–2649. Also, the August spectrum was obtained through cirrus and so its absolute fluxing is untrustworthy. On the other hand, EW measurements from both runs will be accurate unless the Hα emission is extended, for which there is no evidence in the two-dimensional spectra, or the contamination of the L dwarf spectrum by the USNO star spectrum was different.

To estimate the contamination of the L dwarf spectrum by the USNO star spectrum, in each two-dimensional spectrum the L dwarf aperture was reflected in the spatial direction around the centroid of the USNO star aperture and the flux in the mirrored aperture was extracted. This contaminating flux is negligible at 8000˚ A in both epochs, but is larger at 8000˚ A in the August spectrum, yielding the stronger continuum seen there in Figure 1b. This makes the August EW measurement an underestimate, but does not affect the spectral typing of the object.

The Hα EW was 121±31˚ A in March but only 25±10˚ A in August. The Hα flux was measured to be 3.23±0.82 × 10^{-16} ergs s^{-1} cm^{-2} in March. Even including a correction factor of 1.42 for the nonphotometric conditions of the August measurement estimated by scaling the flux from 8000-9260˚ A to match the March data, the August Hα flux is only 1.49±0.58 × 10^{-16} ergs s^{-1} cm^{-2}, about a factor of two below the March measurement. Thus it does appear that the absolute flux as well as the equivalent width of the Hα emission varied.

The ratio of the Hα luminosity (or flux) to the bolometric luminosity (or flux) is a useful quantity since it can constrain the emission mechanism. The bolometric flux of 2MASS 1315–2649 was estimated using the bolometric correction from the $K_s$ band of $BC_K$=3.33 found by Tinney et al. (1993) for the L4 dwarf GD165B. This yields an apparent bolometric magnitude of $m_{bol}$ = 16.79. Since $f_{bol} = 2.48×10^{-5} \text{ergs s}^{-1} \text{cm}^{-2}$ for $m_{bol}$ = 0 (Cox 2000), $f_{bol} = 4.77×10^{-12} \text{ergs s}^{-1} \text{cm}^{-2}$ for 2MASS 1315–2649. Thus $log(L_{H\alpha}/L_{bol}) \geq -4.17$ in March, and $\geq -4.51$ in August (after accounting for nonphotometric conditions). Both values are lower limits due to the use of a narrow slit with uncertain placement relative to the object.

4. DISCUSSION

How does the Hα emission in 2MASS 1315–2649 compare to that in other late-type dwarf stars? Gizis et al. (2000) studied the Hα emission properties of a sample of nearby M and L dwarfs and found that 20±10% of L2-L4 dwarfs show Hα emission. However, the strongest Hα emission object in their sample has only $log(L_{H\alpha}/L_{bol}) \approx -5$. Subsequently, Burgasser et al. (2000) reported Hα emission with $log(L_{H\alpha}/L_{bol}) \approx -4.3$ in the T dwarf 2MASSI J1237392+652615. Possible variability in this object’s Hα flux was reported at the 2.8σ level in one spectrum, but more detailed analysis shows that the spectra are consistent with no variability (Burgasser et al. 2002).

Thus even the August spectrum of 2MASS 1315–2649 has stronger Hα emission than reported in any other L dwarf, and the variable Hα emission in this object is the first reported for any L dwarf. The study of Gizis et al. (2000) indicates that as an L dwarf with Hα emission, 2MASS 1315–2649 is likely massive enough (and old enough) to have burned lithium, but the physical explanation for this correlation with mass is unknown. The various explanations considered by Burgasser et al. (2000) for Hα emission in the T dwarf 2MASS 1237+6526 can also be considered for 2MASS 1315–2649. Acoustic heating is ruled out as a possible dominant energy source for strong Hα emission in L or T dwarfs (§3.3 of Burgasser et al. 2000), but several other possibilities remain viable.

4.1. Accretion In An Interacting Binary System

Burgasser et al. (2000) discuss the possibility of sustained Roche lobe overflow in close brown dwarf binaries. Such accretion might explain steady Hα emission without a strong accompanying thermal spectrum if the accretion produces Hα emission from ionization at a shock front or from magnetic field lines streaming onto the pole of the primary, rather than from an accretion disk. Burgasser et al. (2000) suggest that the T dwarf 2MASS 1237+6526 and the M9.5e dwarf PC0025+0447 could be examples of such systems. Such an explanation cannot be ruled out for 2MASS 1315–2649, but its confirmed variable Hα would require variability in some part of the accretion process. Such variability has not been convincingly observed in the other two objects and might not be expected in the case of accretion from sustained Roche lobe overflow.

4.2. A Strong Magnetic Field

Magnetic fields are believed to drive Hα emission from F to early M stars via an internal dynamo which is stronger for faster-rotating stars, such as the α-Ω dynamo (Parker...
1955). Such dynamos require a radiative/convective boundary to anchor flux lines and therefore break down as stars become fully convective ($\sim 0.3 M_\odot$, spectral type M4). However, the observed Hα activity level in M dwarfs shows no sign of this transition, remaining constant at $\log(L_{\text{H\alpha}}/L_{bol}) \approx -3.8$ (Hawley, Gizis, & Reid 1996). This suggests that some other mechanism, probably a turbulent dynamo (Durney, De Young, & Roxburgh 1993), contributes substantially to the magnetic field in very late type dwarfs.

The value of $\log(L_{\text{H\alpha}}/L_{bol})$ in 2MASS 1315−2649 is an order of magnitude larger than in most L dwarfs, but is still lower than the average value of $\sim 3.8$ measured for M dwarfs (see Figure 7 of Gizis et al. 2000). Thus it is at least plausible that the same mechanism at work in late M dwarfs (whether a turbulent dynamo or something else) could provide the magnetic field required to explain the Hα flux in 2MASS 1315−2649 and possibly the T dwarf 2MASS 1237+6526. This would mean that they have stronger than average magnetic fields for L and T dwarfs.

If this is the case, then the variable Hα emission in 2MASS 1315−2649 requires at least a slow variation in its magnetic field. However, no late type dwarf is known to show long-term variability of more than a factor of two at X-ray or extreme ultraviolet wavelengths (§4 of Drake et al. 1996), and variability in Hα in L is not likely to be greater than variability at those wavelengths. On the other hand, flares are known to occur in M dwarfs and have been detected at radio wavelengths in the L3.5 dwarf 2MASSW J0036159+182110 (Berger 2002). Thus while the spectra presented here do not rule out a slow variation in its magnetic field as the cause of the Hα variability in this L dwarf, a more rapid variation — a flare — seems much more likely, as discussed next.

### 4.3. Flaring

Flares (seen in Hα, the radio, the UV, and X-rays) on late type stars are powered by the energy released during a sudden reconfiguration of the magnetic field structure. Detection of a flare therefore confirms the existence of a stellar magnetic field. However, strong flares in M dwarfs typically last only a few hours (Hawley & Pettersen 1991) and occur unpredictably, making them difficult to observe.

It may very well be that 2MASS 1315−2649 was flaring when the discovery spectra were obtained. The Hα emission did not vary more than 1σ (25%) on a timescale of ∼15 minutes between successive two-dimensional spectra in March, but this is consistent with the rate of change of the Hα flux in the M9.5 dwarf 2MASS 0149+2956 during the flare observed by Liebert et al. (1999). Given that Hα flaring is known to occur in M dwarfs and radio flaring in at least one L dwarf (Berger 2002), flaring seems the most likely explanation for the Hα variability in 2MASS 1315−2649. However, the other possibilities discussed earlier cannot yet be ruled out. The current data does not prove that the variation in Hα occurred on a timescale short enough to be called a flare, and radio, Hα and X-ray and activity may be decoupled for spectral types later than M8 (Berger 2002). Further monitoring of 2MASS 1315−2649 is needed to firmly determine the energy source for its Hα emission.

If its variable Hα emission is due to flaring, 2MASS 1315−2649 is probably similar to the M9.5 dwarf BR10021−0214 (Reid et al. 1999). Both objects show only Hα in emission and have peak log($L_{\text{H\alpha}}/L_{bol}$) values lower than the average for M dwarfs. However, the spectra do not rule out the possibility that 2MASS 1315−2649 is a flare star with emission from lines other than Hα, similar to 2MASS 0149+2956 (Liebert et al. 1999). There is no evidence for such lines in March to limits of 0.5$f_{\text{H\alpha}}$, but in 2MASS 0149+2956 the strongest other lines had 0.1$f_{\text{H\alpha}}$. There is also no evidence in the March spectra for the stronger continuum and veiling of molecular bands seen during the flare in 2MASS 0149+2956. Only changes of a factor of two or more in the continuum level can be ruled out, but this is sufficient to place 2MASS 1315−2649 at either an earlier or later stage in any such flare, as follows. The Hα EW in 2MASS 0149+2956 increased (from 200 Å to 330 Å) during the observed portion of the flare because the continuum flux at Hα decreased more quickly (from ten to three times the quiescent flux) than the Hα line flux did. In 2MASS 1315−2649 the Hα EW was 121 Å in March, but the continuum flux at Hα was at most twice the quiet flux (estimated from the August spectrum). This Hα EW and continuum level cannot be simultaneously reproduced by simply scaling any of the 2MASS 0149+2956 observations, even accounting for the weaker continuum at Hα in an L3 dwarf. Thus, if they were the same type of flare, and if the relationship between the continuum and Hα line flux in this type of flare is independent of its luminosity, then 2MASS 1315−2649 must have been observed at a later (or perhaps earlier) stage of its flare. Any model for such flares must then incorporate the observed limit of ∼25% variation in Hα on ∼15 minute timescales at such a stage in the flare.

If the Hα emission in 2MASS 1315−2649 in March was from a flare, regardless of what type, then the large range in log($L_{\text{H\alpha}}/L_{bol}$) for flaring M dwarfs extends to L dwarfs as well. As pointed out by Reid et al. (1999), this suggests a wide variation in intrinsic magnetic field strength, efficiency of energy transport to the stellar chromosphere during a flare, or both.

### 5. Conclusion

2MASSI J1315309−264951 is an L3 dwarf with strong Hα emission which decreased in strength by about a factor of two between two epochs separated by 137 days, the first reported variable Hα emission in an L dwarf. The Hα emission in 2MASSI J1315309−264951 must be powered either by magnetic activity or by accretion in a binary system. Accreting binaries are rare, so that hypothesis is unlikely. The spectra presented here do not rule out a slow variation in Hα strength, but slow variations of the observed amplitude are rare among M dwarfs. Since flaring powered by reconnection of magnetic fields is common in M dwarfs and a radio flare has been detected in the L3.5 dwarf 2MASSW J0036159+182110 (Berger 2002), a flare is the logical explanation for the Hα variability in 2MASSI J1315309−264951.

The value of log($L_{\text{H\alpha}}/L_{bol}$) > −4.17 observed at the discovery epoch is larger than that of any other L dwarf but comparable to the value of −4.3 observed for 2MASSI J1237392+652615, the only reported T dwarf with Hα emission. However, both these values lie well below the
average log($L_{\text{H} \alpha}/L_{\text{bol}}$) = −3.8 observed in M dwarfs.

Only two L dwarfs and one T dwarf are known to exhibit Hα emission of log($L_{\text{H} \alpha}/L_{\text{bol}}$) > −5. Thus perhaps two percent of L or T dwarfs exhibit Hα emission this strong at any given time. Given the small number statistics, this is consistent with the duty cycles observed for Hα flares (≈7%; Gizis et al. 2000) and radio flares (2-10%; Berger 2002) among late-type dwarfs. Spectroscopic or narrow-band Hα monitoring of L and T dwarfs on timescales of hours to days is needed to determine if the frequency of strong Hα emission is governed by flaring, by the upper envelope of the magnetic field strength distribution, or by accretion in binary systems.

I thank an anonymous referee and A. Bugasser for helpful comments, CNTAC for observing time, A. Alvarez and A. Guerra for operating the CTIO 1.5m and putting up with my musical tastes, CTIO for excellent observing support, and Fundación Andes and Chilean FONDECYT grant #1010981 for financial support. The Two Micron All Sky Survey (2MASS) is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

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Table 1
Properties of 2MASSI J1315309−264951

|   | B   | R   | J   | H   | Ks  | J – H | H – Ks | J – Ks | Ho EW, Å |
|---|-----|-----|-----|-----|-----|------|-------|-------|----------|
|   | >18.90 | >17.70 | 15.18±0.05 | 14.06±0.04 | 13.46±0.04 | 1.13±0.06 | 0.60±0.05 | 1.73±0.06 | 121±31 | 25±10 |

Note. — The 2MASS database is matched to the USNO-A2.0 catalog within a radius of 5".0, and so the optical magnitudes of USNO J131531.23−264953.0 are listed in the 2MASS database entry for 2MASS J1315−2649 (see §2). We list them here merely as lower limits to the optical magnitudes of 2MASS J1315−2649.
Fig. 1.— Optical spectra of 2MASSI J1315309−264951 obtained in (a) March and (b) August 2001. Both spectra have been smoothed by a five pixel boxcar, and the dashed lines show the zero level for each spectrum. The August spectrum was obtained in nonphotometric conditions, but nonetheless it is clear that the H\(\alpha\) emission was greatly diminished compared to March.