EVIDENCE FOR ACCRETION IN A NEARBY, YOUNG BROWN DWARF

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ABSTRACT

We report on the discovery of the young, nearby, brown dwarf 2MASS J0041353−562112. The object has a spectral type of M7.5; it shows Li absorption and signatures of accretion, which implies that it still has a disk and suggests an age below 10 Myr. The space motion vector and position on the sky indicate that the brown dwarf is probably a member of the ~20 Myr old Tuc-Hor association, or that it may be an ejected member of the ~12 Myr old β Pic association; both would imply that 2MASS J0041353−562112 may in fact be older than 10 Myr. No accreting star or brown dwarf was previously known in these associations. Assuming an age of 10 Myr, the brown dwarf has a mass of about 30 $M_{\text{Jup}}$ and is located at 35 pc distance. The newly discovered object is the closest accreting brown dwarf known. Its membership to an association older than 10 Myr implies that either disks in brown dwarfs can survive as long as in more massive stars, perhaps even longer, or that star formation in Tuc-Hor or β Pic occurred more recently than previously thought. The history and evolution of this object can provide new fundamental insight into the formation process of stars, brown dwarfs, and planets.

Key words: planetary systems: formation – stars: individual (2MASS J0041353−562112) – stars: low-mass, brown dwarfs – stars: pre-main sequence

1. INTRODUCTION

At the age of ~1 Gyr, a typical brown dwarf is about $10^4$ times less luminous than the Sun (Burrows et al. 1997), with the consequence that detailed investigation of old brown dwarfs is only possible within a distance of a few pc. At young ages, brown dwarfs are warmer and larger so that they can be seen in star-forming regions as distant as 100 pc or more. Only a few young brown dwarfs are known at distances closer than 100 pc. In the solar neighborhood, a number of stars younger than a few 100 Myr are known (Wichmann et al. 2003; McGehee 2008), the majority belonging to young associations. Only rare cases exist of stars that are apparently born in isolation; these are usually high mass stars (e.g., Aarnio et al. 2008).

Two competing formation scenarios exist for brown dwarfs, one suggesting that brown stars form the same way stars do (Padoan & Nordlund 2004) and another suggesting that brown dwarfs are stellar embryos ejected from the collapsing cloud before they could build up enough mass to become a star (Reipurth & Clarke 2001; Bate et al. 2003). Young stars and brown dwarfs can harbor accretion disks in which planets can form (Millan-Gabet et al. 2007), so the first few million years of star formation are particularly interesting for multiple reasons. For example, the lifetime of an accretion disk puts severe constraints on the brown dwarf formation scenario and sets the timescale for planet formation.

The lifetime of accretion is also observed in brown dwarfs that are members of very young star-forming regions (~5–10 Myr). It was studied in regions as far away as 150 pc, e.g., ρ Ophiuchus, Upper Scorpius, Taurus, and others (Natta et al. 2004; Mohanty et al. 2005; Jayawardhana et al. 2006; Herczeg et al. 2009). Only a handful of young objects are known with spectral types later than M5 (cooler than ~3000 K) that are at the end of the disk accretion phase. They are all members of young associations; three of them are members of TW Hya (~8 Myr); TWA 5B, TWA 26, and TWA 27. HR 7329B (η Tel B, Lowrance et al. 2000) is a brown dwarf companion to an A0 star and associated with β Pic (Zuckerman & Song 2004). Another young brown dwarf, RX J1857.5−3732W, was found in the Ext R CrA region (Neuhäuser et al. 2000). Only one of the five objects, TWA 26, is known to be an accretor (Mohanty et al. 2005). Furthermore, TWA 26 harbors a planet (Chauvin et al. 2004) and shows signatures of an outflow (Whelan et al. 2007). This object became a benchmark in the studies of young brown dwarfs, but at a distance of ~70 pc, the apparent magnitude of TWA 26 is $J \approx 13$, which makes detailed investigations of the object very difficult. The newly discovered accreting brown dwarf 2MASS J0041353−562112 (hereafter 2M0041) seems to be very similar to TWA 26 and probably somewhat older. At about half the distance, it appears 1 mag brighter.

2. DATA

In an effort to characterize space motion and stellar activity in nearby stars (Reiners & Basri 2009), we observed a sample of ultracool M7–M9 dwarfs with UVES at the Very Large Telescope (Dekker et al. 2000), using a setup centered at 830 nm that provides a spectrum in the range 640−1020 nm in the red arm. UVES was used in dichroic mode that also provided a spectrum at 376−500 nm in the blue arm. Data reduction followed standard procedures implemented in the ESO CPL pipeline version 4.3.0; this includes bias subtraction, two-dimensional flat-fielding, and wavelength calibration using ThAr frames.
3. LI ABSORPTION

Young brown dwarfs of several ten $M_{\text{Jup}}$ have spectral types late-M (Burrows et al. 1997) and are difficult to distinguish from older stars of the same spectral type. One method for identifying a young brown dwarf is the detection of a Li absorption line. We detect a strong absorption line of Li at 6708 Å in our spectrum of 2M0041 (shown in Reiners & Basri 2009), which means that it is a brown dwarf younger than $\sim 200$ Myr, and that it is less massive than 65 $M_{\text{Jup}}$ (Basri 2000).

4. ACCRETION

4.1. Indicators of Accretion

The most important indicator of accretion is a strong and asymmetric Hα emission line. Stars with equivalent widths larger than 10 Å are often categorized as accreting classical T Tauri stars (e.g., Jayawardhana et al. 2003; Muzerolle et al. 2003, and references therein), but this cutoff is higher for low-mass objects because chromospheric Hα is more easily visible because of the decreased photospheric continuum. A more robust indicator of accretion is profile shape; objects with broad and asymmetric Hα lines are likely to be accretors (e.g., Muzerolle et al. 2003). Jayawardhana et al. (2003) argue that a 10 % Hα full width of $\lesssim 200$ km s$^{-1}$ is a good accretion cutoff. Natta et al. (2004) have shown that the Hα 10 % width correlates very well with mass accretion rates derived by other means. Following Jayawardhana et al. (2003) and Mohanty et al. (2003), accretion can conservatively be identified based on asymmetric and broad Hα and the detection of other emission lines.

Emission lines of other elements indicative of accretion are lines of He i, O i, and Ca ii (e.g., Muzerolle et al. 1998); most prominent are the lines of He i λλ 5876 and 6678, O i λλ 7773 and 8446, and lines of the infrared Ca triplet, Ca ii λλ 8498, 8542, and 8662. All lines appear stronger with higher mass accretion rate, O i lines are only found in CTTS with very strong accretion; $M_{\text{accr}} \geq 10^{-8}$ $M_{\odot}$ yr$^{-1}$ (Muzerolle et al. 1998).

A comprehensive discussion of the appearance of emission lines in young brown dwarfs is given in Mohanty et al. (2005). They conclude that emission in O i, He i, and Ca ii 8662 seems reasonably well correlated with accretion in very-low mass stars and brown dwarfs, and that these lines, while not detected in all low-mass accretors, appear preferentially associated with accretion and not activity.

Fuhrmeister et al. (2008) show a spectrum of the mid-M dwarf CN Leo observed during a giant flare. They show that all lines observed in accretors can also be found in non-accretors during a very strong flare. However, these lines appear very narrow so that even in the unlikely event of a giant flare, the shape of the Hα line is a good discriminator between activity and accretion, which also implies that an asymmetric Hα line is not likely to be explained by activity.

Our UVES spectrum of 2M0041 covers Hα–Hδ, He i 6678, the two O i lines, the Ca ii infrared triplet, and Ca H&K. Emission is observed in Hα–Hδ, in the He i line, in all three lines of the Ca ii triplet, and in Ca H&K. The only lines that do not exhibit detectable emission are the two O i lines.

We show the Hα line together with He i 6678 and Ca ii 8662 in Figure 1. For comparison, we overplot the spectra of two very active late-M dwarfs. The equivalent width of the Hα line of 2M0041 is $-92.7$ Å; the line shows a strongly asymmetric shape. Both of the strength and shape of the Hα line are difficult to explain by chromospheric activity.

The two comparison stars also exhibit strong Hα emission lines, but in both cases, the line is symmetric and relatively narrow. In one case, there is even emission observed in Ca ii, but it is fairly narrow. In the two comparison stars, emission lines are probably related to strong activity, but even in the case with detected Ca ii emission, Hα emission does not appear asymmetric or unusually broad for activity. This supports that broad Hα emission lines are not observed in active low-mass stars but in accretors (see also Muzerolle et al. 2000). We conclude that the broad and strong Hα emission in 2M0041 is unlikely to be due to activity. Together with the detection of the Li absorption line and many other emission lines, the most probable explanation is that 2M0041 is accreting.

4.2. Hα Variability

Hα was measured before by Phan Bao & Bessel (2006), who found an equivalent width of $-37.1$ Å, and Schmidt et al. (2007) report an equivalent width of $-24.0$ Å. Both values are lower than the new measurement, which may indicate that during our UVES observation, 2M0041 was observed in a phase of transient accretion. Both of the other values are derived from low-resolution spectroscopy, which may affect the equivalent width measured in such a broad line; specifically the wings are probably difficult to detect at low resolution. This effect, however, can certainly not account for the large differences between individual Hα observations.

Hα variability in accreting low mass stars was investigated by Scholz & Jayawardhana (2006); they report Hα equivalent widths between $-13$ and $-387$ Å for accretors of spectral types M7.5–M8. The two measurements of low Hα equivalent widths for 2M0041, $-24$ and $-37$ Å, are on the lower end of this range, but still not unusual for similar low-mass accretors (e.g., TWA 26, EqW = $-27.7$ Å; Mohanty et al. 2003, 2005).

4.3. Accretion Rate

Following Natta et al. (2004) and Mohanty et al. (2005), we derive mass accretion rates for 2M0041 from the Hα 10% width and from the equivalent width of the Ca ii line at 8662 Å. Equivalent widths of Hα and Ca ii 8662, and Hα 10% width are summarized together with the other parameters of 2M0041 in Table 1.
Parameters for 2M0041; the Lower Part Shows Radius, Distance, and Space Velocities for Three Different Ages

| Parameter              | Value          |
|------------------------|----------------|
| R.A. (J2000.0)         | 06°41′35″39″   |
| Decl. (J2000.0)        | −56°21′12″77″ |
| pmR.A. (mas yr⁻¹)      | 121 ± 19      |
| pmDecl. (mas yr⁻¹)     | −64 ± 19      |
| 2 MASS J (mag)         | 11.96 ± 0.02  |
| 2 MASS H (mag)         | 11.32 ± 0.02  |
| 2 MASS Kᵣ (mag)        | 10.86 ± 0.03  |
| v_rad (km s⁻¹)         | 6.8 ± 1       |
| Hα EqW (Å)             | −92.7         |
| Hα 10% width (km s⁻¹)  | 200.6         |
| log M (Hα 10%)         | −10.9         |
| Ca ii 8662 EqW (Å)     | −0.8          |
| log Ca flux⁺ (log erg s⁻¹ cm⁻²) | 4.83 |
| log M (Ca) (log(M⊙ yr⁻¹)) | −10.5      |
| Hεt 6678 EqW (Å)       | −1.1          |
| Ca ii 8498 EqW (Å)     | −1.0          |
| Ca ii 8542 EqW (Å)     | −2.0          |

Model age (Myr) 5 10 MS  R (R⊙) 0.34 0.23 0.11  d (pc) 50 35 17  U (km s⁻¹) −15.7 ± 5.8 −10.4 ± 4.1 −4.1 ± 2.0  V (km s⁻¹) −29.2 ± 1.0 −21.2 ± 0.7 −11.7 ± 0.3  W (km s⁻¹) 0.4 ± 2.4 −1.5 ± 1.7 −3.8 ± 0.8

Note.
⁺ Flux at stellar surface.

We calculate a mass accretion rate of \( \dot{M} = 10^{-10.9} M_\odot \text{ yr}^{-1} \) from the Hα 10%-width, and \( 10^{-10.5} M_\odot \text{ yr}^{-1} \) from the Ca ii 8662 equivalent width. The rates calculated from different diagnostics are consistent with each other, and they are typical for an \( \sim 30 M_{\text{Jup}} \) accreting brown dwarf at an age of a few Myr (Mohanty et al. 2005; Herczeg et al. 2009).

5. DISTANCE AND SPACE MOTION

The discovery of accretion in 2M0041 indicates that this object is very young, probably in the range 5–10 Myr (Mohanty et al. 2005). In order to test membership to known young associations on the basis of space motion, we require the distance to the young brown dwarf together with its proper motion and radial velocity. Radial velocity was calculated from our spectrum. Unfortunately, no trigonometric parallax is available, but proper motion is known (Phan Bao & Bessel 2006) and a spectrophotometric distance of 17 pc is reported under the assumption that the object is on the main sequence (Faherty et al. 2009). At the age of only a few Myr, the radius of 2M0041 is larger than the radius of a star with the same temperature on the main sequence, which means that it must be at greater distance to appear at the observed apparent brightness. We show evolutionary tracks of young brown dwarfs in Figure 2. The spectral type of 2M0041 is M7.5 with an uncertainty of \( \pm 0.5 \) (Phan Bao & Bessel 2006), i.e., the effective temperature is \( T_{\text{eff}} \sim 2600 \text{ K} \) (Golimowski et al. 2004) with an uncertainty of \( \sim 100 \text{ K} \). According to evolutionary models (Baraffe et al. 1998, 2002), 5–10 Myr old objects at this temperature are brown dwarfs with masses in the range 20–40 \( M_{\text{Jup}} \). Their radii are 2–3 times larger than the radii of old, main-sequence stars with masses of about 90 \( M_{\text{Jup}} \) in the same temperature range. Note that the radius-temperature relation is rather shallow at this age so that the uncertainty in temperature is uncritical. If the real age of 2M0041 is between 5 and 10 Myr, the distance is roughly 35–50 pc.

The space motion vector of 2M0041 sensitively depends on the distance to the object, which is a function of age. We calculated the space motion of 2M0041 from the proper motion (Phan Bao et al. 2001) and the radial velocity following Johnson & Soderblom (1987). We employ the IDL procedure gal_uvw, but we use a right-handed coordinate system with \( U \) towards the Galactic center. Space velocities and distances for ages of 5 and 10 Myr, and for the main sequence are given in Table 1.

\[ \text{http://idlastro.gsfc.nasa.gov/contents.html} \]
6. MEMBERSHIP TO A YOUNG ASSOCIATION

Very young objects only a few Myr old can often be identified as members of star-forming regions and young associations (Zuckerman & Song 2004; Torres et al. 2008), but only a few associations are as young as 5–10 Myr and closer than 50pc. A reliable indicator of membership to an association is the space motion of an object. Stars born together usually move into the same direction with only a few km s$^{-1}$ velocity dispersion. Furthermore, young associations can be concentrated in a narrow region on the sky because they are still spatially connected and relatively far away. In these cases, the position of an object on the sky is another important membership test.

Three associations younger than 30 Myr are significantly closer than 100 pc (we use the values from Fernandez et al. 2008); they are TW Hya (age 8 Myr, $d \sim$ 60 pc), β Pic (12 Myr, $\sim$35pc), and Tuc-Hor (20 Myr, $\sim$50pc). The distance of 2M0041 at the ages of TW Hya, β Pic, and Tuc-Hor are approximately 40 pc, 35 pc, and 30 pc, respectively. For β Pic, the distance to the center of the association exactly matches the distance to 2M0041 at the age of the association. For TW Hya and Tuc-Hor, the values are somewhat different, but they are not significantly outside the dispersion of the known association members (and when taking into account the uncertainties of the spectrophotometric distance).

In Figure 3, we show the celestial polar projection of the southern hemisphere and the position of 2M0041. We overplot the loci of the three nearby young associations (Torres et al. 2008). Both β Pic and Tuc-Hor are distributed over a very large area on the sky, and both regions cover the position of 2M0041. On the other hand, TW Hya is concentrated in a very narrow region far away from the position of 2M0041. Thus, on the basis of its coordinates, membership of 2M0041 to TW Hya can be ruled out.

The space motion of 2M0041 for different ages is plotted together with the velocities of TW Hya, β Pic, and Tuc-Hor in Figure 4. The age-dependent values of $U$, $V$, and $W$ follow straight lines in both diagrams. The space motion vector of β Pic is about 10 km s$^{-1}$ away from the most likely position of 2M0041, assuming an age of 10 Myr. Thus, from $V$ and $W$ velocities, membership of 2M0041 to β Pic is rather unlikely. It may, however, have been ejected from the main association so that it moves into a slightly different direction.

Assuming an age of 10–15 Myr, the space motion of 2M0041 very well matches the space motion of Tuc-Hor in all three velocities. Together with the signatures of youth and its position on the sky, we conclude that 2M0041 is very likely a member of the Tuc-Hor association, that its age is probably in the range 10–15 Myr, and that the distance to the object is around 35 pc.

7. SUMMARY

We found evidence for accretion in a nearby brown dwarf that is probably a member of the Tuc-Hor association. The most probable age of Tuc-Hor is around 20 Myr, but ages in the range 10–40 Myr are reported in the literature (see Fernandez et al. 2008). If 2M0041 was formed together with Tuc-Hor (or even β Pic), it is probably at least 10 Myr old. The detection of accretion implies that disks in brown dwarfs can survive at least as long as in more massive stars. If the age is even 15 Myr or more (which would imply a distance of 30 pc or less), it means that disks around brown dwarfs may actually live longer than around stars, which would have serious implications for brown dwarf formation and for planet formation around brown dwarfs. An alternative explanation is that the age of 2M0041 is below 10 Myr and that it formed later than the members of Tuc-Hor or β Pic. In this case, one has to explain how the brown dwarf reached its current position in the Galaxy, far away from very young star-forming regions.

In either case, 2M0041 is the closest brown dwarf with evidence for accretion known so far. It promises important insight into brown dwarf formation theory and the physics of young low mass objects.

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