PPL 15: the First Binary Brown Dwarf System?

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Abstract. We have re-examined the HIRES Keck spectra used to detect the presence of Li in PPL 15. These data were obtained over 3 consecutive nights in November 1994 and 2 consecutive nights in March 1995. They are therefore useful in a radial velocity variability study at both very short and intermediate timescales. They are all noisy, and of varying quality, but certainly useable in orders well redward of Li. We find that PPL 15 is a double-lined spectroscopic binary. On all but the first night of observation, a cross-correlation between PPL 15 and an dM6.5 spectral standard produces a double peak, with a separation of roughly 30-35 km/s. The first night is single-lined, and cross-correlations between it and the following nights reproduce the same double peaks. We find that there are plausible orbital solutions which can reproduce our results, suggesting a very short period (less than 2 weeks). It will be very important to obtain further data to determine an orbit solution for the system. The mass of PPL 15 had been estimated at ~78 Jupiter masses assuming it was a single star, but its double-lined spectroscopic binary nature (if confirmed) would imply masses of about 65 MJ for each component.

1. Introduction

Recent red and infrared photometry shows that PPL 15 lies on the outer edge of the binary zero age main sequence for the Pleiades (Zapatero-Osorio et al. 1997). It has long been known that there is a dispersion in the Pleiades color-magnitude sequence, greater than the observational errors. For some time this was thought to be due to an age spread in the cluster, but strong arguments have been brought against that (Stauffer et al. 1995). Its latest proponents (Steele & Jameson 1995) concede the point and instead show that the dispersion is likely due to unresolved binaries. These are not only expected, but explain the amplitude of the spread quite naturally. PPL 15 sits in a place that suggests that it is one of these binaries. An HST image eliminates companions to within 0.15” (18 AU) of the primary with a contrast up to 5 magnitudes at I.

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2. Evidence for binarity

Motivated by the results presented by Zapatero-Osorio et al. (1997), we re-examined our HIRES data to look for radial velocity variations. The spectra were taken on Nov. 22-24, 1994 and Mar. 12-13, 1995, so they sample both very short and intermediate orbital periods. In our original paper (Basri et al. 1996) we reported only that the mean line positions did not change at the level of 5 km/s (1 pixel), then coadded the spectra to analyse lithium. Now we do a proper cross-correlation (XC) analysis of each night, first using an M6 standard spectrum with low rotational broadening. To our great surprise, the XC peaks are double with comparable amplitudes except on the first night (Figure 1), having a separation of 30-35 km/s in all 4 subsequent observations. The line splittings that we have actually measured are given in Table 1. In favorable cases we see the line doubling or its effects directly (Figure 2).

Table 1. PPL15 measured shifts

<table>
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<th>Date(obs)</th>
<th>HJD</th>
<th>ΔVrad a</th>
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<tr>
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<td>49679.92</td>
<td>0.0</td>
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<tr>
<td>24.Nov.1994</td>
<td>49680.81</td>
<td>33.5</td>
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<td>25.Nov.1994</td>
<td>49681.87</td>
<td>35.8</td>
</tr>
<tr>
<td>12.Mar.1995</td>
<td>49788.79</td>
<td>(-)33.1 b</td>
</tr>
<tr>
<td>13.Mar.1995</td>
<td>49789.79</td>
<td>(-)29.0</td>
</tr>
</tbody>
</table>

a Radial velocity difference between the two cross-correlation peaks in km/s. Estimated uncertainty 5 km/s.

b The (-) sign indicates that the primary is blueshifted with respect to the secondary

Why wasn't detected the double-line nature of the system when Li was discovered? The S/N of the Li order is the worst in the spectrum (a combination of being "blue" and molecular absorption). We used the spectrum from the single-line night as our best case, because the spectral lines were most obvious. In retrospect, that was because the two components added together. It was that night on which we based our estimates of the radial velocity and rotational broadening of the star. Our other tactic was to average all the spectra together, which hid the doubling. Because the spectra are very noisy, separating the 2 components makes it substantially harder to measure the line strength (essentially doubling the amount of noise present in the line). Thus it is rather difficult to measure Li in the 2 components separately. It appears that the Li lines share the same ratio as the other lines, but more data will be very helpful.

The only information we have on the orbit at present is that the line goes from single to double in one night, and that when double we have only seen a splitting near 30 km/s. These facts both indicate a rather close orbit, with a fairly short period. There are orbital solutions consistent with all our data. For example, two 65 M_J objects in a 9.2 day orbit with little eccentricity can produce the observed velocity separation on 2 consecutive days, while the day before that has a separation consistent with our "single-line" observation. The short period is consistent with the high velocities and the change over 1 night from single to double lines. By construction the last 2 November observations
are at opposite phase from the March observations, as suggested by the reversed line ratios. Obviously however, we have to find the actual orbital period, and measure the velocity separation at times when it has intermediate values. This can be done by observing the system for a few different phases.

Why is this system of such interest? The first point is that the period and velocity amplitude will establish a dynamical lower mass limit (the first such case for visible BDs). If truly a pair of BDs separated by only a few solar radii, there would be a strong implication that they were trying to become an M star but the angular momentum distribution at the core of the cloud/disk caused fragmentation of the incipient star into two substellar objects. This is consistent with the behavior of some models for binary formation. There is almost no other way this system could form, so it would supply strong supporting evidence. Modes of binary formation are currently a hot topic (see the review of Bodenheimer in this volume). Last, but not least, the binary nature of PPl 15 has implications for the derivation of the Pleiades substellar mass function (Martín et al. in this volume) and for the determination of the cluster age using lithium (Basri et al. 1996). These points will be addressed in a future paper.

References

Figure 1. *(Left panel)* Cross-correlation functions between PPL 15 and the M6 dwarf LHS 523 are given. These are averages of the functions for 12 echelle orders from each night, excluding orders with substantial contamination from telluric absorption lines. The latter 2 panels are also averages of 2 consecutive nights in which each night appears similar to the other. The standard has less rotational broadening than PPL 15. Each pixel is about 5 km/s wide. A single peak is seen on the first night, but the subsequent 2 nights in November show two distinct components in PPL 15, separated by 30-35 km/s. The 2 nights in March are very similar, with both components visible on both nights and a similar velocity separation. There is an indication that one component is slightly brighter than the other, but they are of comparable brightness to each other.

Figure 2. *(Right panel)* Most of the spectrum from PPL 15 is dominated by a haze of molecular lines. Coupled with the fact that our individual spectra have rather low S/N (ranging from little better than unity at the blue end of the worst cases to 10-20 at the red end of the best cases), it is rather difficult to see the two stellar components directly in the spectra. The strongest red atomic features are the Na I doublet near 8200Å. This is a region contaminated by telluric absorption. Nonetheless, the redward component sits between telluric lines, and we can do a reasonable job of subtracting out this contamination anyway. We show a substantially smoothed version of the corrected spectrum on 2 adjacent nights, where the cross-correlation goes from single to double. Not only does the sodium line show a doubling in its core, but a nearby V I lines does also. There are further examples of direct doubling in other spectral orders.