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Towards precise ages and masses of free floating planetary mass brown dwarfs

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Abstract. We use medium-resolution spectroscopy (R∼5000 Gemini\NIFS) to measure the pseudo-equivalent widths (pEWs) of the *K* band Na I lines of a set of brown dwarfs, ranging in age from ∼1 Myr to field dwarfs. We find a correlation between the pEWs and the surface gravities of these objects. We also find a correlation between surface gravity and the slope of the *K* band, and describe a simple, empirically-derived spectral index which can be used to make a statistical determination of the ages of brown dwarfs in very young clusters. The index verifies the low gravity of the planetary mass objects in the Orion Nebula Cluster, supporting their ∼1 Myr ages and planetary masses.

Key words. Stars: formation – Stars: low mass, brown dwarfs – Stars: luminosity function, mass function – Stars: pre-main-sequence

1. Introduction

The rate of contraction of a brown dwarf is a decreasing function of age, with changes in surface gravity occurring most rapidly soon after formation. Thus, methods of age determination using surface gravity are well suited for differentiating planetary mass objects (PMOs) from slightly older and more massive brown dwarfs, which may have similar spectral types. The radii of very young brown dwarfs and PMOs are proportional to their masses, so that surface gravity has very little dependence on mass for these objects (Burrows & Liebert 1993; Chabrier & Baraffe 2000).

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2. A new index for age determination

The strength of gravity-sensitive neutral alkali metal lines is a well-proven method in establishing the ages of late-type M dwarfs. However, measuring the pEWs of these lines requires high quality spectra. This is difficult for faint PMOs, particularly in the Orion Nebula Cluster (ONC), where the nebulosity makes spectroscopy more difficult.

An alternative to assigning age based on the strength of narrow spectral features is to examine the effect of surface gravity on the slope of the *K* band itself. The peak flux in the F_λ spectra of late-type M dwarfs occurs between $2.14\,\mu$m and $2.28\,\mu$m and is age-dependent. In this region, the slope is largely shaped by collision-induced absorption (CIA) by H_2 which is linearly dependent on the gas density which in turn is proportional to the sur-

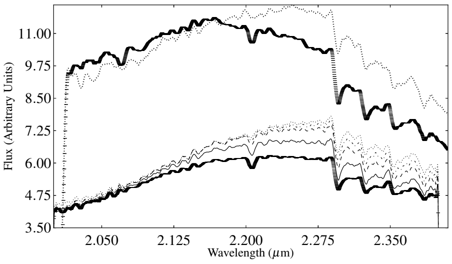

Fig. 1. The lower set of plots were produced from theoretical models made using new calculations of H_2 CIA. These models show the K band slope decreasing with increasing surface gravity. The temperature for these models was set at 2200K (the typical $T_{\rm eff}$ of an M9.5–L0 dwarf). The surface gravities of the models are $\log g = 3.5$ (dotted line), $\log g = 4.0$ (dot-dash line), $\log g = 4.5$ (dashed line), $\log g = 5.0$ (solid line) and $\log g = 5.5$ (heavy dashed line). The topmost plots are two spectra from our dataset of brown dwarf calibrators, a young Taurus object (dotted line), and a much older field dwarf (heavy dashed line). Spectra have been smoothed to aid separation. Models supplied by Saumon & Marley (Saumon et al. 2012).

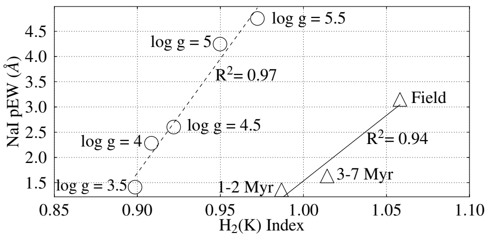

Fig. 2. The correlation between the pEWs and $H_2(K)$ indices for our dataset of calibrator brown dwarfs (triangles, solid line), and the Saumon & Marley model spectra (circles, dashed line). Note that we have used the means of these values for our brown dwarf dataset.

face gravity. Models of H_2 CIA show the K band slope decreasing with increasing surface gravity. See Figure 1.

To study the effect of H_2 CIA on the K band flux of late-type M dwarfs, we examined a set of seven brown dwarf calibrators from young clusters with constrained ages (Taurus and σ Orionis), and two field dwarfs. Although the ages of the field dwarfs are poorly constrained, they are known to be significantly older than the other objects in the dataset. Our sample consisted of objects with spectral types M8 - L0. These spectral types are appropriate for PMOs and low mass brown dwarfs in very young clusters.

We found that for objects with the largest surface gravity (the field dwarfs), the mean peak in the K band flux was at $2.17\,\mu$m, while for objects with the smallest surface gravity (the 1–2 Myr objects), the mean peak was at $2.24\,\mu$m. The ratio of the median flux over a range of $0.02\,\mu$m, centred at these wavelengths, defined an index, $H_2(K)$

$$H_2(K) = \frac{F_\lambda(2.17\,\mu m)}{F_\lambda(2.24\,\mu m)}, \tag{1}$$

3. Testing the $H_2(K)$ index

Figure 2 shows a strong correlation between the pEW of the gravity-sensitive Na I doublet at $2.206/2.208\,\mu$m and the $H_2(K)$ index calculated from our dataset of brown dwarf calibrators and from the Saumon & Marley models. This correlation suggests that the $H_2(K)$ index is at least as good an age indicator as neutral alkali metal lines.

To further test the correlation of the $H_2(K)$ index with surface gravity, and hence age, we determined the $H_2(K)$ indices of an extended dataset from the literature, containing field dwarfs and objects in clusters with constrained ages. The results are shown in Figure 3.

Using the $H_2(K)$ index is only likely to be appropriate for solar metallicity atmospheres since metallicity has effects on the K band spectrum comparable to those of gravity. Fortunately, most nearby star formation regions are of solar metallicity. The $H_2(K)$ index can also be affected by extinction. However, the effect is small, owing to the $H_2(K)$ index's small wavelength baseline, and it will usually be possible to accurately deredden spectra.

Emission from dust disks around very young brown dwarfs can affect the K band. As

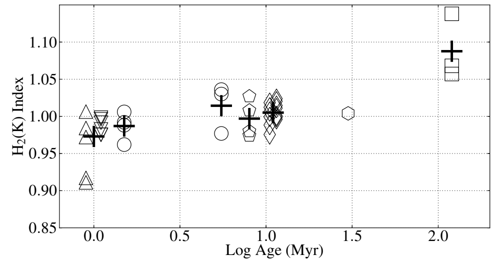

Fig. 3. The $H_2(K)$ indices of the extended dataset, plotted as a function of age. Triangles are young 1–2 Myr PMOs in the ONC (Lucas et al. 2006; Weights et al. 2009). Inverted triangles are Taurus association objects (Luhman 2004), diamonds are ~11 Myr brown dwarfs in Upper Sco (Lodieu et al. 2008), the pentagons are ~8 Myr TW Hya objects, the hexagon is GSC08047B, an M9.5 dwarf in the ~30 Myr Tuc Hor association, and the squares are substellar objects in the ~120 Myr Pleiades cluster (Pinfield et al. 2003). Large crosses are the mean values at each age bin. The Taurus and ONC objects probably have similar ages so are shown slightly offset either side of 1 Myr, and share a common mean. For clarity, the Upper Sco objects are offset 0.5 Myr either side of 11 Myr. The circles are the $H_2(K)$ indices of our brown dwarf calibrators.

we are are sampling from a very narrow range of the K band, the effect on the $H_2(K)$ index is minimal, and is significantly less than the scatter in our sample.

4. Conclusions

The $H_2(K)$ index is a good indicator of surface gravity, particularly for the youngest sources (1–10 Myr), where it is more sensitive to surface gravity than the triangular H band peak. It is at least as good as the pEW of the 2.206 / 2.208 μm Na I doublet in differentiating the surface gravities of late-type objects, and does so with less scatter and without the need for spectra capable of resolving narrow spectral features.

Both the $H_2(K)$ index and the pEW of the Na I doublet can find the difference, at least statistically, between populations of ~1 Myr objects and field dwarfs. In addition, the $H_2(K)$ index statistically differentiates populations of ~1 Myr objects and populations of ~10 Myr objects at $> 3\sigma$. The $H_2(K)$ index verifies the low gravity of the PMOs in the ONC, supporting their ~1 Myr ages and planetary masses, and can also be used to separate low-mass members from foreground and background objects in young clusters and associations.

The pEW of neutral alkali metal lines and the $H_2(K)$ index show good correlations between age and the measured quantities and will allow researchers to ascribe statistical ages to samples of brown dwarfs in pre-main sequence clusters, and thus help in distinguishing brown dwarfs and planetary mass objects.

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