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Finding unresolved brown dwarf and exoplanet companions to M dwarfs using mid-infrared excess

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Abstract. We present an optimised method for identifying brown dwarf and exoplanet companions to very low mass stars. We identify an all sky sample of bright M dwarfs based on optical and near-infrared colours, reduced proper motion, with strict $E(H - W2)$ constraints and $H - W2$ photometric uncertainty less than 4%. We hunt for excess in the mid infrared using $H - W1$ and $H - W2$ colours, and comparison samples of other M dwarfs from common multi-colour parameter-space (not including $H - W1$ and $H - W2$). These candidates will be followed up with adaptive optics, radial velocities, and light curves (for transit) where appropriate.

Key words. Stars: Brown Dwarf Companions – Stars: M dwarfs – Planets: Exoplanets Companions – Method: Mid-Infrared Excess

1. Introduction

Locating unresolved ultra cool (brown dwarf and giant exoplanet) companions to M dwarfs is vital to understand the fundamental nature of these sub-stellar objects. The properties of ultra cool dwarfs (UCDs) are strongly dependent on mass and age. Thick cloudy atmospheres mean that UCD properties also depend on effective temperature, surface gravity and metallicity. For a complete understanding of UCDs it is important to have accurate measurements of mass, radius, metallicity and luminosity. It is for this reason that a UCD as a companion allows us to measure all of these properties. As UCDs are inherently faint, the use of faint M dwarfs as primaries are ideal to enable unresolved companions. With the recent full-sky release (March 2012) of the *Wide-Field Infrared Survey Explorer*, WISE (Wright et al. 2010) and the *Two Micron All Sky Survey*, (2MASS; Skrutskie et al. 2006), we present an optimised method for finding ultra cool companions to M dwarfs based on identifying colour excesses. This method would not be possible without the vast number of sources present in the WISE and 2MASS databases.

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2. Method

We constructed an initial sample by cross matching WISE sources with 2MASS, using a set of basic cuts, including removing the galactic plane at a galactic latitude of ±15°. We chose the colours $H - W1$ and $H - W2$ as the best candidates to determine excess. The

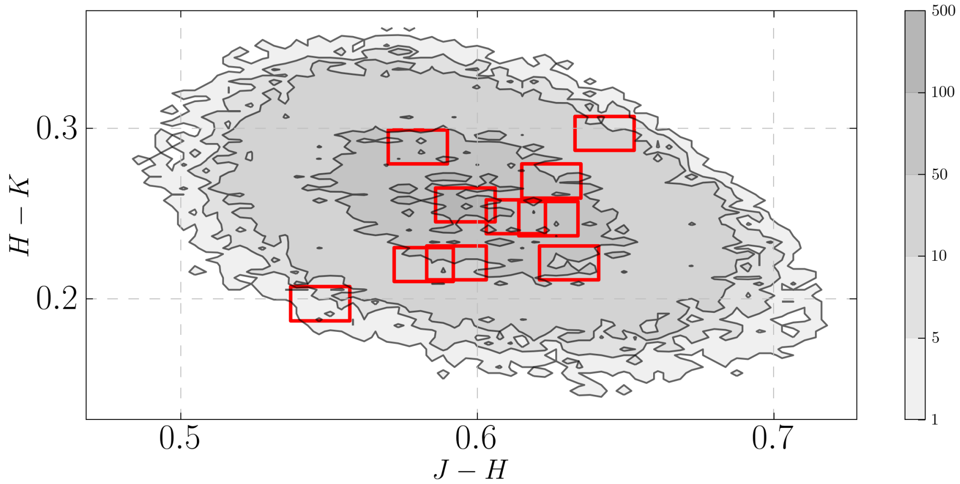

Fig. 1. Colour-colour contour diagram for $J-H$ and $H-K_S$ illustrating the the populations of M dwarfs used in the multi-colour-space analysis ($V-J$, $J-H$, and $H-K$). Boxes represent targets and their respective sub-volumes, for which means and standard deviations in $H-W1$ and $H-W2$ were recorded.

cuts comprised of cuts in colour of $V-J$ greater than 4, and the J, H, K colour cuts, as well as the reduced proper motion cut defined in Lépine & Gaidos (2011). We required un-reddened photometry with an extinction $E(H-W2)$ no greater than 3%, equivalent to $A(V)$ less than 0.22. Photometric quality cuts of 4% were applied for $H-W1$ and $H-W2$, as well as identifying variable sources (Pinfield et al. 2013) and requiring all proper motions had greater than $4\,\sigma$ uncertainties, giving 78,454 M dwarfs candidates. We identified similar M dwarfs using a control sample and a small volume in the colour space, $V-J$, $J-H$, and $H-K$ around each of the M dwarf targets (see Figure 1). Targets with few to no sources in their sub volume (SV) were rejected leaving 68,349 candidates. The mean and standard deviation for $H-W1$, $H-W2$ and $H-0.5(W1-W2)$ of each target's colour space SV was recorded.

We calculated the excess by subtracting the $H-W1$ and $H-W2$ colours from the mean of each target SV assuming that M dwarfs with similar $V-J$, $J-H$, and $H-K$ colours also have similar $H-W1$ and $H-W2$ colours. Using simulated M dwarf-brown dwarf systems, and a control sample constructed using catalogues from Gliese & Jahreiß (1991) and Stauffer et al. (2010) we selected a specific region of excess-spectral type space, giving ∼ 2000 candidates (see Figure 2). To reduce the number of candidates we increased the quality cut required in $H-W1$ and $H-W2$ giving a total of ∼300 targets for a cut of less than 3.25% and a total of ∼800 for a cut of less than 3.5% in both $H-W1$ and $H-W2$.

3. Summary

With the recent full data release of WISE combined with 2MASS we have constructed a new sample of M dwarfs. Using colour, reduced proper motion and photometric quality selections we select 78,454 high quality M dwarf candidates that occupy un-reddened regions of the sky. These M dwarfs have 2MASS J band magnitudes between 10 and 14.5. We use mid-infrared excess to select 68,349 of these candidates identifying colour excess by comparing similar M dwarfs in multi-colour-space. By simulating M dwarf-brown dwarf systems we select ∼300 candidates, and expect to find companions through a full follow-up programme. Using our multi-colour-space approach, made possible with a large WISE-

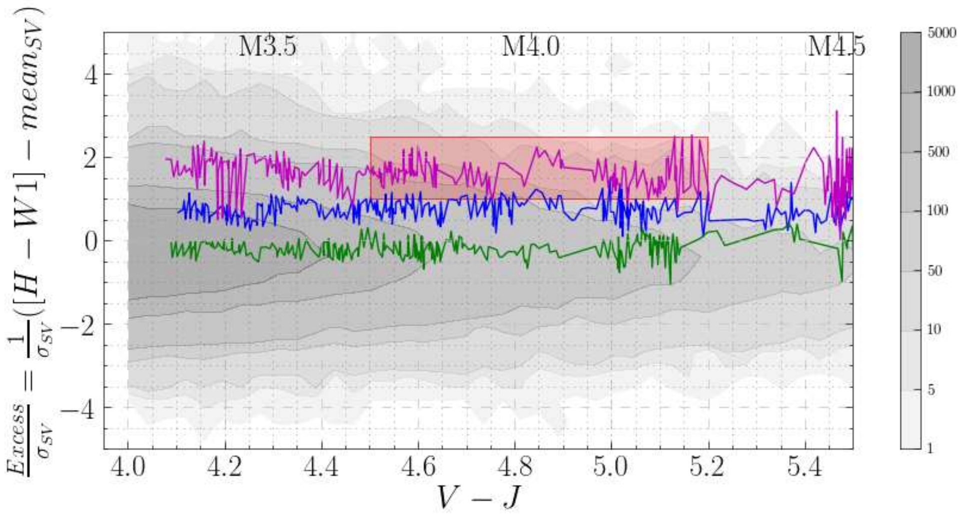

Fig. 2. Contour plot to show our sample of M dwarfs after the colour space analysis. The three lines represent the positions of simulated M dwarf-brown dwarf systems run through the multi-colour-space analysis. The candidates were selected by choosing an area between simulated primaries with no overall excess (middle lines), and one standard deviation excess (top line) with a one standard deviation deficit for comparison (bottom line). All analysis was completed in excess per standard deviation space. The rectangle represents the region in which ~300 candidates were selected.

2MASS sample, reduces the standard deviations in colour excess by a factor of ~2, increasing the chances of possible candidates detections in a full follow-up program.

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