A Method for Identifying M dwarfs with Ultra Cool Companions in 2MASS and WISE

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1. Abstract

Locating companions to M dwarfs is important to enable dynamical mass and transit radi tests of brown dwarf models, to identify warm exoplanets, and to constrain formation models. We present an optimised method for identifying M dwarfs that may have unresolved ultra-cool companions. We identify an all sky sample of bright M dwarfs based on optical and near-infrared colours, reduced proper motion, with strict reddening and photometric quality constraints. We hunt for evidence of mid infrared excess using comparison samples of M dwarfs selected from common near-infrared multi-colour parameter-space. We consider low resolution spectroscopic follow-up to further the selection process as well as adaptive optics, radial velocities, and light curves (for transit) where appropriate.

2. Introduction

M dwarf companions are vital for understanding the fundamental nature of the sub-stellar regime. 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 or luminosity data. 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 search for 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). Our method requires M dwarf multi-colour analysis within a fine colour-grid, and the very large sample of well measured (near minus mid infared) M dwarfs in 2MASS and WISE facilitates our method for the first time.

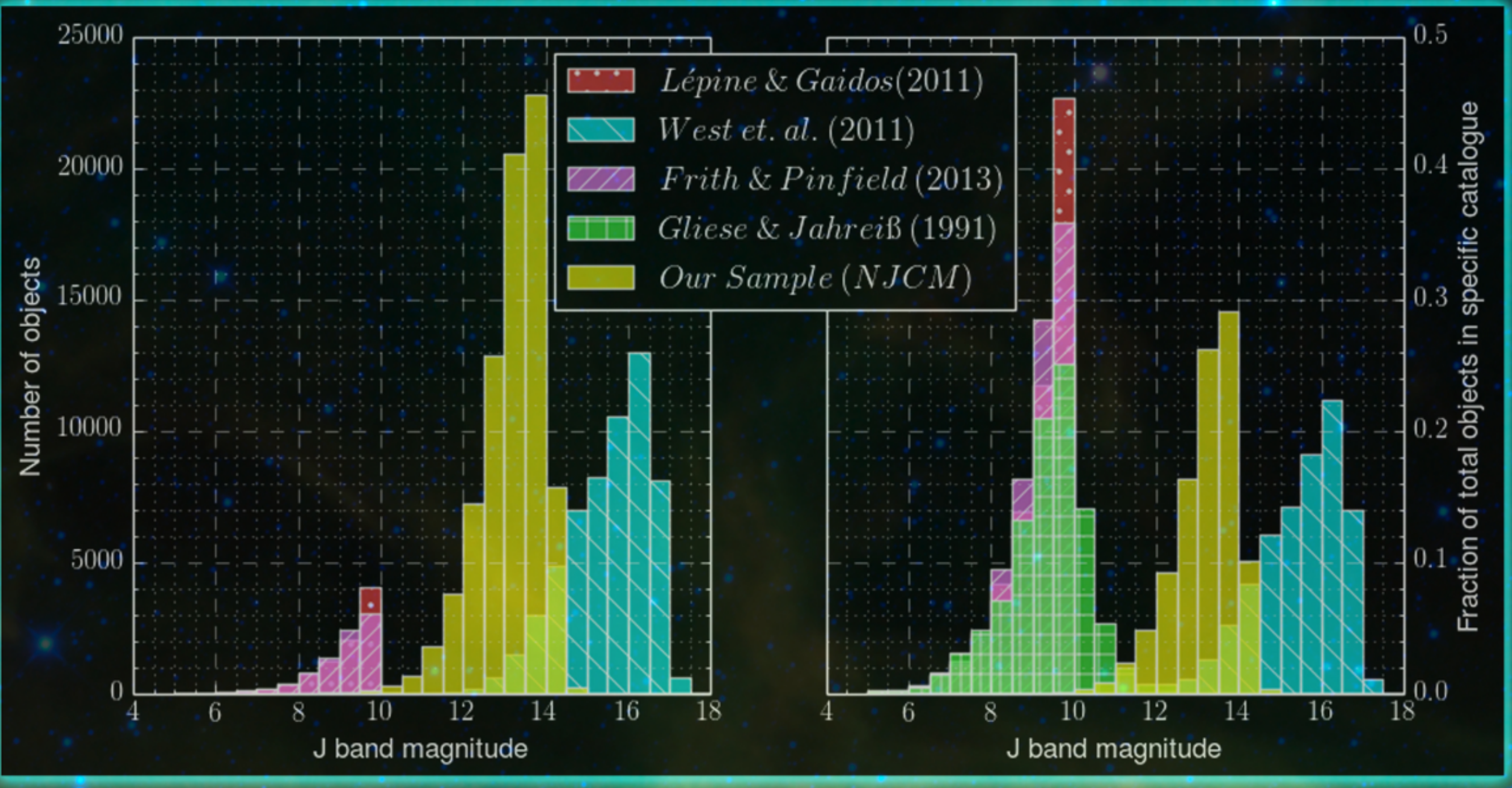


Figure 1: Apparent J band magnitude histogram comparing our catalogue (NJCM) and the catalogues of Lépine & Gaidos (2011), West et. al (2011), Frith & Pinfield (2013) and Gliese & Jahreiss (1991).

3. M dwarf Catalogue and Excess Selection

We constructed our catalogue of M dwarfs 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 J/H minus W1/W2 as the best colours to determine excess. We used the following colour cuts, V-J>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 excess colours, and variable sources were removed using WISE multiple measurements (following Pinfield et al. 2014) and requiring greater than 4σ significance for the proper motion measurements, giving 78,454 M dwarfs candidates. A comparison between our M dwarfs and that of Lépine et, al (2011), West et. al (2011), Frith & Pinfield (2013) and Gliese & Jahreiss (1991) can be seen in Figure 1.

To detect excess we identified similar M dwarfs using small volumes in the colour space, V-J, J-H, and H-K around each of the M dwarf targets (see Figure 2a and 2b). Targets with few to no sources in their sub volume were rejected. The mean and standard deviation of the excess colours of each target's colour volume were recorded.

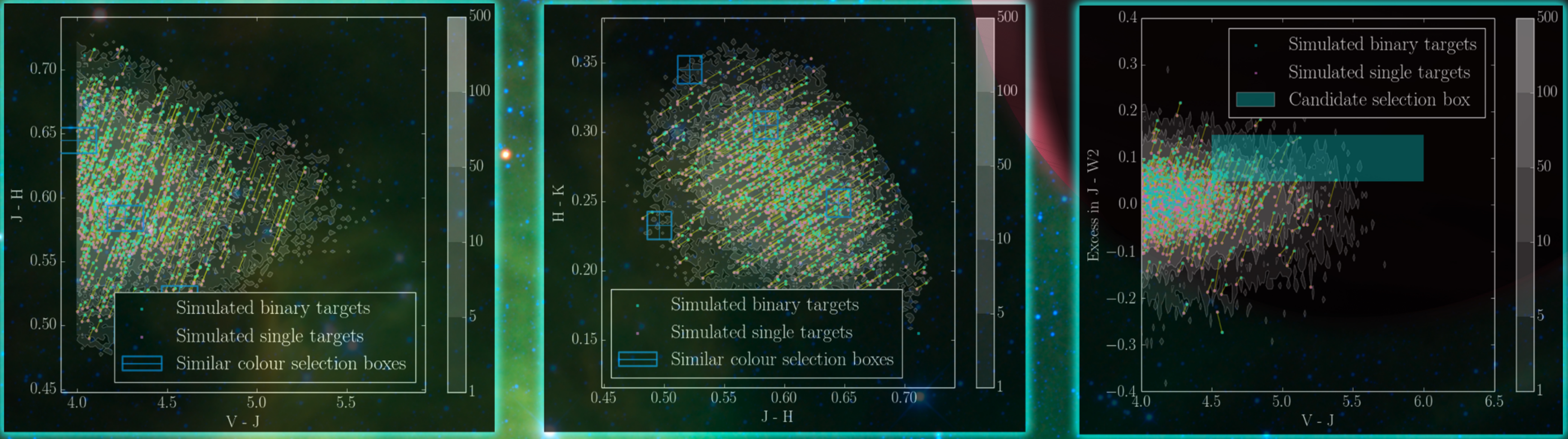
We calculated the excess by subtracting the target excess colours from the mean of each target subvolume. Using the same colour similar selection proces we injected simulated M dwarf-brown dwarf systems (using photometry from Gliese & Jahreiß 1991, Lépine & Gaidos 2011, Dupuy et. al. 2012) and thus selected a specific region of excess-spectral type space (see Figure 2c), to select the best possible companion candidates.

Figure 2:

Left: Colour distribution J - H vs V - J with example of colour similar boxes (blue), and injected simulation brown dwarfs (cyan squares) and their seed M dwarf (pink squares) .

Middle: Colour distribution in H - K and J - H, all colour and symbols the same as above.

Right: Resulting excess distribution with candidate selection box in blue, all colour and symbols the same as above.



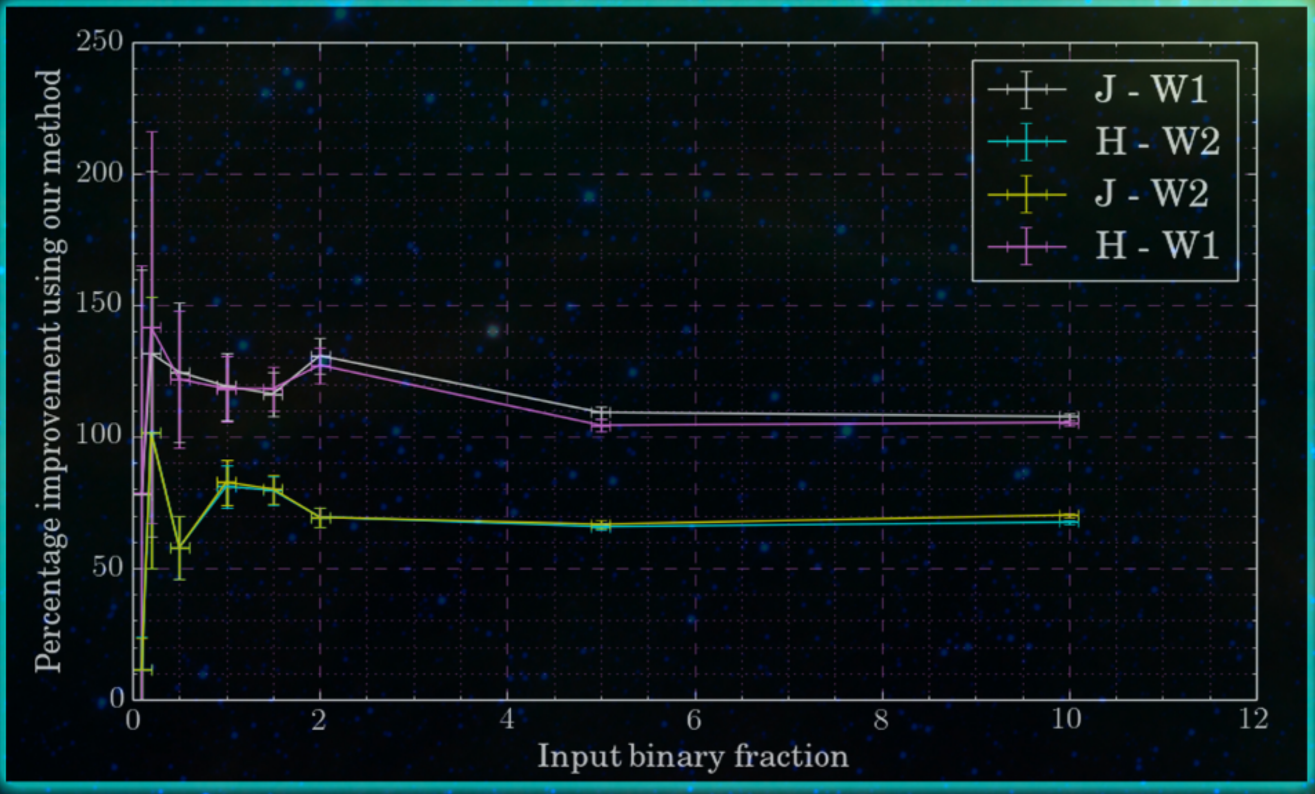


Figure 3: Improvement our method yields on the fraction of companions detected given a simulated input binary fraction of companion systems. Our simulations show that we return ~100% more companion systems than a given binary fraction.

4. Excess Candidates and follow-up

From our simulated binaries we calculated the overall improvement our method gives over just selecting random M dwarfs. By using different fractions of simulated binaries we plot the percentage improvement as a function of input binary fraction (see Figure 3). We predict an improvement in the probability that an M dwarf has an ultra cool companion due to the excess selection process (over an unbiased selection) of around a factor of 2, or ~100% we still have high contamination. To reduce this we propose further follow-up including V-band photometry and spectral typing. In addition to this we have designed a robust method to detect companions spectroscopically. Using colour-similar spectra and subtracting these from spectra of our candidates would leave a 'noisy UCD' spectrum, from which a spectral difference was then taken in specific bands. This process has been simulated and the detectablilty of companions are shown in Figure 4. After additional cuts our candidates will be followed up with this low resolution spectral detection approach. The best candidates will be targetted with adaptive optics, radial velocities, and light curves (for transit) where appropriate.

We present here our M dwarf catalogue for which we have identified candidates with excess and propose additional follow-up to provide companion detection. This is one use of our M dwarf catalogue. We are also using the catalogue to serach for wide Tycho 2 binaries and smaller exoplanet companions.

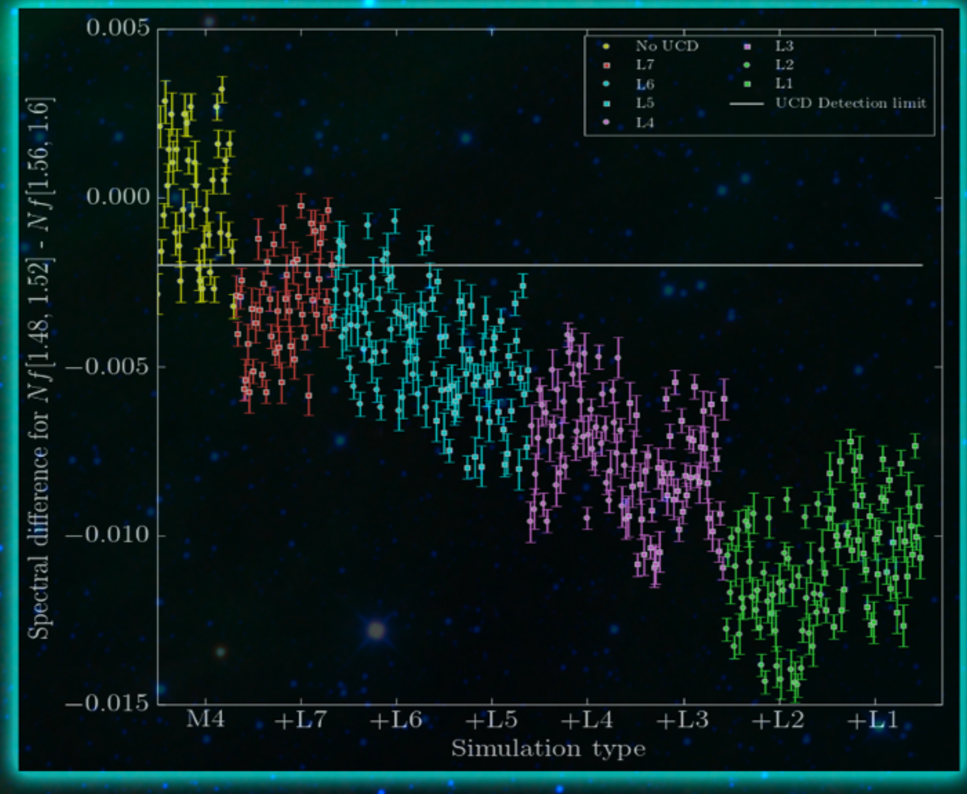


Figure 4: Results of the spectroscopic difference found from subtracting two colour similar M dwarfs, one with a simulated brown dwarf companion. Results are the difference in flux between 1.48 to 1.52 and 1.56 and 1.6 microns.

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Background image Neil J. Cook adapted from WISE “PIA14881: Jabbah and Associates” NASA/JPL-Caltech/UCLA. Inset skymap composite from Atlas Image mosaic obtained as part of the Two Micron All Sky Survey (2MASS), 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 and WISE mosaic from the Wide-field Infrared Survey Explorer, which is a joint project of the University of California, Los Angeles, and the Jet Propulsion Laboratory/California Institute of Technology, funded by the National Aeronautics and Space Administration

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