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Photometric brown dwarf classification

A method to identify and accurately classify large samples of brown dwarfs without spectroscopy

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Abstract. We have developed a method *"photo-type"* to identify and accurately classify L and T dwarfs, onto the standard system, from photometry alone. We combine SDSS, UKIDSS and WISE data and classify point sources by comparing the izYJHKW1W2 colours against template colours for quasars, stars, and brown dwarfs. In a sample of 6.5×10^6 bright point sources, $J < 17.5$, from $3150\,\mathrm{deg}^2$, we identify and type 898 L and T dwarfs, making this the largest homogeneously selected sample of brown dwarfs to date. The sample includes 713 (125) new (previously known) L dwarfs and 21 (39) T dwarfs. For the previously-known sources, the scatter in the plot of photo-type vs spectral type indicates that our photo-types are accurate to 1.5 (1.0) sub-types rms for L (T) dwarfs. Peculiar objects and candidate unresolved binaries are identified.

Key words. Stars: low-mass – Techniques: photometric – Methods: data analysis

1. Introduction

Brown dwarfs were discovered less than twenty years ago, but the number known is growing rapidly, and the total number of spectroscopically classified LTY dwarfs catalogued at DwarfArchives.org recently surpassed 1000. This sample is heterogeneous, culled from several surveys with different characteristics, particularly SDSS, 2MASS, UKIDSS, and WISE, using search strategies that at each stage have explored new parameter space. The temperature sequence of substellar objects is now mapped all the way down to $\sim$ 400 K. Individual large samples include those of Kirkpatrick et al. (2000, 2011), Hawley et al. (2002), Burningham et al. (2010, 2013), Schmidt et al. (2010), and Martín et al. (2010). All these samples explore or have been optimised for a limited section of the brown dwarf spectral sequence, e.g. primarily L dwarfs from SDSS, T dwarfs from UKIDSS, and late T dwarfs and Y dwarfs from WISE. Some of these samples are themselves heterogeneous, and so not suitable for statistical analysis – which of course is understandable in the phase of exploring a new population. Spectroscopic classification requires substantial resources. For example, at $J \sim 17.5$, something like 30 min on an 8 m class telescope is required for a good spectrum.

A good example of the state of the art in deriving a statistical sample of brown dwarfs is

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the study of the sub-stellar birth rate by Day-Jones et al. (2013). They selected candidate mid-L to mid-T dwarfs, using well-defined selection criteria, and discovered 63 new brown dwarfs brighter than $J = 18.1$, using XShooter spectroscopy on the VLT. To make a substantial step forward in this type of work we need to produce statistical samples that are an order of magnitude larger. A large sample is needed to reduce the statistical errors, but may also be used to quantify the variation in properties for any spectral subclass, and to discover rare types, by identifying outliers.

This paper describes an alternative search and classification method that starts from existing survey data, SDSS+UKIDSS+WISE, and exploits the wide wavelength range to determine accurate spectral types without the need for spectroscopy.

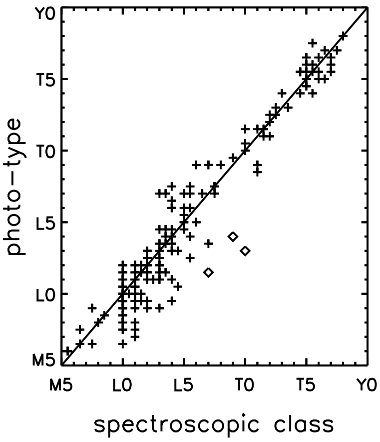

Fig. 1. Plot of *"photo-type"* class against spectroscopic class. This scatter indicates an accuracy of 1.5 spectral types rms for the L dwarfs and 1.0 spectral types rms for the T dwarfs.

2. Method

The basis of the method is to compare the multiwavelength $izYJHKW1W2$ photometry from SDSS+UKIDSS+WISE against the colours of previously classified L and T dwarfs, in the form of polynomial relations of colour against spectral type[1]. In this way the classification is ultimately tied to the templates that define spectral types for L and T dwarfs.

UKIDSS lies wholly within SDSS, and WISE is all-sky, so the common overlap of these three surveys is currently the best multi-wavelength dataset for a search for brown dwarfs. We computed that, brighter than $J = 17.5$, nearly all spectral types L0 to T8 will be detected in all the bands Y, J, H, K (UKIDSS) and $W1$, $W2$ (WISE), as well as in at least one of the SDSS i or z bands (meaning that a photometric measurement will exist in both bands). The exceptions, discussed later, are the latest T dwarfs near the sample limit. The brown-dwarf search is one element of a larger programme to classify all bright point sources in UKIDSS into categories star, brown dwarf and quasar.

We found it simpler to execute the search in two stages. Starting with UKIDSS DR9 we selected all point sources detected in $YJHK$, with a match in SDSS within $10''$(the fraction of sources lost due to high proper motion is tiny). This initial catalogue contained 6.5×10^6 sources over 3150 deg^2. We classified all sources by min-χ^2 fitting against the template library. Then for all sources that were classified as cool stars of class M6 or later we matched to WISE in order to extract the $W1$ and $W2$ photometry. We then reclassified all sources using the complete $izYJHKW1W2$ data. The quasar and star templates are taken from Hewett et al. (2006), but we found that the brown-dwarf templates are deficient in some respects, and so we produced our own. We identified 130 spectroscopically classified L and T dwarfs in DwarfArchives in our catalogue, supplemented with late M stars from SDSS, and then fit polynomials to the variation of the seven colours $i-z$, $z-Y$, $Y-J$, $J-H$, $H-K$, $K-W1$, $W1-W2$ against spectral type. The value of the fit to each colour at each spectral type then defined the templates. For each source we record the spectral type that provides the min-χ^2 fit over all the templates, and the value of χ^2. The final sample contains 838 L dwarfs (of which 125 are previously known) and 60 T dwarfs (39 previously known).

[1] See Aberasturi et al. (2011) for an earlier search for brown dwarfs using SDSS+2MASS+WISE.

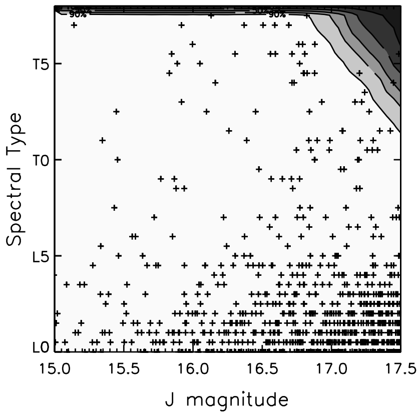

Fig. 2. Plot illustrating the completeness of our sample, with the 838 L and 60 T dwarfs overplotted as crosses.

We can gauge the accuracy of the spectral type using the known objects. In Fig. 1 we plot the *photo-type* classification against the spectroscopic classification in DwarfArchive. Our L- and T-dwarf classifications are accurate to 1.5 and 1.0 rms sub-classes respectively. The 3 outliers (diamonds) are potential binaries currently under investigation. It is possible that the classification may be even more accurate, because part of the scatter in the plot comes from the spectroscopic classification, due to the limited wavelength coverage of most spectra. So far we have obtained four follow-up spectra and all classifications agree within one subclass.

3. Completeness

To quantify the completeness of the sample we performed Monte Carlo simulations, creating synthetic colours for each spectral type, over the magnitude range of the search, adding realistic errors, and accounting for the detection limits in each band. The results are shown in Fig. 2, showing that we only miss the coolest T dwarfs, close to the sample magnitude limit. This is primarily because as we approach $J = 17.5$ the coolest T dwarfs fall below the SDSS detection limit, and in some cases the UKIDSS K-band limit. It would be possible to include these sources in principle, by performing aperture photometry on the original images. However the effort was not felt justified at this stage bearing in mind that the UKIDSS dataset has already been searched extensively for late T dwarfs by several teams, e.g. Burningham et al. (2013).

4. Discussion

We have presented a new method to identify and classify L and T dwarfs from SDSS+UKIDSS+WISE data, which provides quite accurate classifications without the need for follow-up spectroscopy. We consider "photo-type" to be analogous to photometric redshifts for galaxies ("photo-z"), and that it could be an easier route to classification for some statistical applications. The χ^2 measure for each object quantifies the goodness of fit. We are investigating sources with large χ^2 in two ways. In one case we test whether a binary solution provides a significantly better fit. In this way we may be able to quantify the fraction of binaries of different spectral-type combinations. Sources where a binary solution does not improve the fit significantly, and the χ^2 remains high, may be peculiar and follow-up spectroscopy is planned for these sources.

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