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Halo brown dwarf and Gaia potential

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Abstract. The known number of L subdwarfs has increased rapidly largely because of the success of large scale surveys. Our $i - j$ vs $J - K$colour diagram suggests a possible detection of the substellar subdwarf gap. Larger samples of subdwarfs from forthcoming surveys will be required to establish its reality. We found that Gaia could impact halo brown dwarf research if it could extend the pick up magnitude to $G < 21$.

Key words. brown dwarfs – subdwarfs – stars: Population II

1. Introduction

Halo brown dwarfs have different characteristics from brown dwarfs in the Galactic disc and are not yet well understood due to a lack of known objects and well tested atmospheric models (Burgasser et al 2009; Cushing et al. 2009). They have spectral types of ⩾ sdL5 and ⩾ esdL6, and are kinematically associated with the Galactic halo (Zhang et al. 2013a). They have age of ~8-14 Gyr and would be more massive than normal field brown dwarfs with similar effective temperature (Zhang et al. 2013a). They appear more luminous than L dwarfs of same spectral types (Faherty et al. 2012; Zhang et al. 2013b). There are only three late-type L subdwarfs and three metal-poor L dwarfs known in the literature (see Table 1). There are about nine metal-poor late-type T dwarfs discovered in the metallicity range of -0.7 < [M/H] < -0.3 (see Table 1). Six new ⩾ sdL5 and ⩾ esdL6 subdwarfs from our SDSS-UKIDSS programme are confirmed with spectroscopy (Zhang et al. in preparation).

2. Searching for new L subdwarfs

L subdwarfs were first noticed by their bluer near infrared colours compared to normal field L dwarfs. The current set of known L subdwarfs were mainly found in large scale optical and near infrared surveys, e.g. SDSS (York et al. 2000), 2MASS (Skrutskie et al. 2006), UKIDSS (Lawrence et al. 2007) and WISE (Wright et al. 2010). They exhibit characteristic spectral signatures of strong metal hydrides (e.g. FeH at 1 μm), weak or absent metal oxides (e.g. CO at 2.3 μm), and enhanced collisionally-induced H_2 absorption. Figure 1 shows the near infrared spectrum of the first halo brown dwarf discovered by Burgasser et

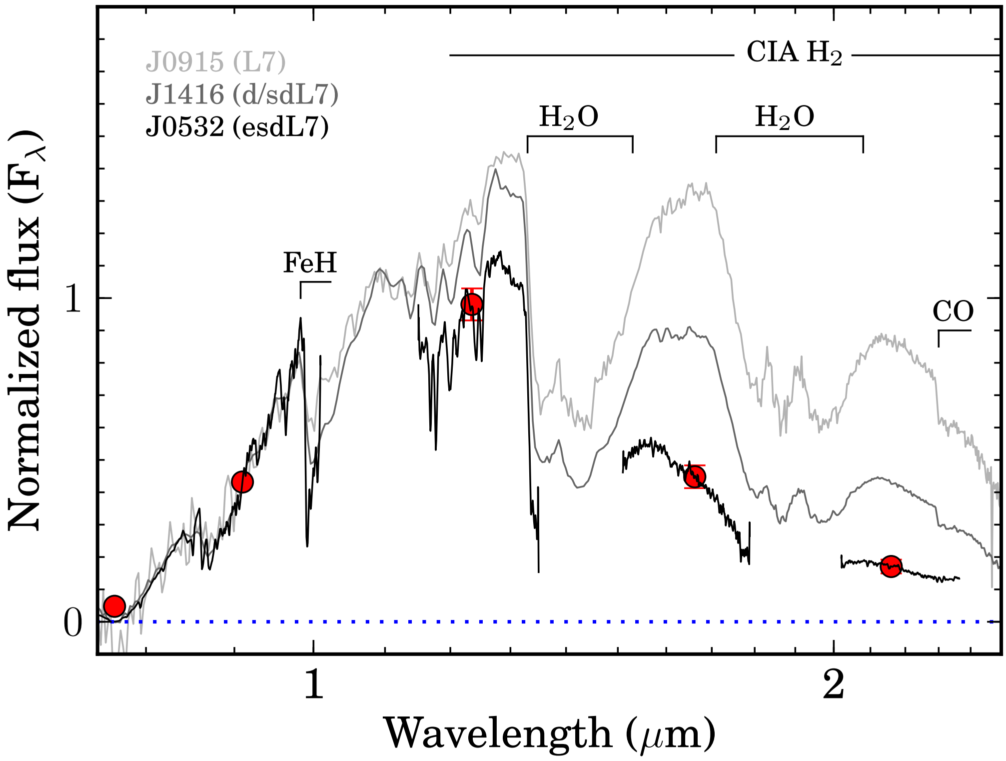

Fig. 1. Near infrared spectra of 2MASS J05325346+8246465 (Burgasser et al. 2003) compared with that of SDSS J141624.08+134826.7 (Schmidt et al. 2010) and 2MASS J09153413+0422045 (Burgasser et al. 2010). Red circles are SDSS and 2MASS spectral energy distribution of 2MASS J05325346+8246465.

al. (2003) compared to spectra of a metal-poor L dwarf and a normal L dwarf.

We searched for L subdwarf candidates by colour and proper motion criteria by combining SDSS and UKIDSS. L subdwarf candidates are followed up with optical and near infrared spectroscopy. We have confirmed 19 new L subdwarfs so far. Six of them have spectra types of ⩾ sdL5 and ⩾ esdL6, thus could be brown dwarfs. Figure 2 shows the $i - J$ and $J - K$ colours of L subdwarfs compared to main sequence stars, mid- to late-type M and L dwarfs. A dotted line in Figure 2 indicates the likely boundary between low-mass stars and brown dwarfs. The location of sdL and esdL subdwarfs is indicated with solid lines below the M and L dwarfs, and separated by a dashed line. Our SDSS-UKIDSS programme has doubled the previously known number of halo brown dwarfs. These results will be presented in upcoming papers.

3. Revealing the substellar subdwarf gap

Brown dwarfs are not massive enough to support stable nuclear fusion. The hydrogen burning minimum mass lies between 0.075-0.092 solar-mass at solar and zero metallicity, respectively, according to theoretical models (Burrows et al. 2001). As brown dwarfs cool with time, old (≳ 8 Gyr) massive brown dwarfs would have a larger difference of effective temperature from low-mass stars than would young (≲ 8 Gy) massive brown dwarfs. Thus there would be an effective temperature gap between populations of old brown dwarfs and low-mass stars, the so called substellar

Table 1. Known low-metallicity brown dwarfs from the literature.

Name	SpT	J	Reference
WISEA J005757.65+201304.0	d/sdL7	16.32	(Kirkpatrick et al. 2014; Luhman et al. 2014)
2MASS J05325346+8246465	esdL7	15.18	(Burgasser et al. 2003)
2MASS J06164006−6407194	esdL6	16.40	(Cushing et al. 2009)
2MASS J06453153−6646120	sdL8	15.60	(Kirkpatrick et al. 2010)
2MASS J11582077+0435014	d/sdL7	15.61	(Kirkpatrick et al. 2010)
SDSS J141624.08+134826.7	d/sdL7	13.15	(Bowler et al. 2010; Schmidt et al. 2010)
WISE J001354.39+063448.2	sdT8	19.75	(Pinfield et al. 2014)
WISE J083337.83+005214.2	sdT9	20.28	(Pinfield et al. 2014)
2MASS J09373487+2931409	T6p	14.65	(Burgasser et al. 2002)
ULAS J123327.45+121952.2	T4.5p	17.87	(Murray et al. 2011, Marocco et al. in prep.)
ULAS J131610.28+075553.0	sdT6.5	19.21	(Burningham et al. 2014)
ULAS J141623.94+134836.3	T7.5p	17.26	(Burningham et al. 2010)
WISEP J142320.86+011638.1	T8p	18.76	(Pinfield et al. 2012)
ULAS J150457.66+053800.8	T6p	16.59	(Murray et al. 2011)
WISE J200520.38+542433.9	sdT8	19.64	(Mace et al. 2013)

subdwarf gap. Figure 29 of Kirkpatrick et al. (2014) shows a $J - W2$ colour difference between an esdL7 subdwarf and some early-type L subdwarfs that might due to the substellar subdwarf gap.

The optical-NIR colour $i - J$ is positively correlated with spectral type through L and T types, thus might be better to investigate the gap than $J - W2$. The area around the dotted line in Figure 2, below M and L dwarfs and without any L subdwarfs is the likely location of the substellar subdwarf gap. A larger L subdwarf sample would provide a better vision of this gap, which would be very important for our understanding of brown dwarf evolution and stellar nuclear reactions.

Figure 3 shows a cartoon picture of a four-parameter space (spectral type, effective temperature, metallicity and age) of low-mass stars and brown dwarfs. Known L subdwarfs do not have good measurements of age and metallicity, and their spectral typing also has large uncertainty. Thus they are carefully placed in the four-parameter space manually based on information obtained from the literature. The metallicity and age scales are not as clean and simple in reality as they are shown in 3, because there are overlaps of metallicity and age between populations of the thin disc, thick disc and the halo, according to FGK (Spagna et al. 2010) and M subdwarfs (Zhang et al. 2013b). The dotted lines show where the substellar subdwarf gap would likely be.

4. Gaia potential

Distance is a fundamental parameter for the study of brown dwarfs. The Gaia mission will provide parallax measurement better than 0.3 milliarcsecond for objects with magnitude of $G < 20$. About one thousand luminous brown dwarfs would be observed by Gaia (Smart et al. 2014). About ten known L subdwarfs have $G < 20$ according to the transformation between SDSS r and Gaia G Jordi (2012). Only one of them is a brown dwarf, SDSS J141624.08+134826.7, which is a metal-poor L dwarf of the Galactic disc. Thus none of the known halo brown dwarfs will be picked up by Gaia at $G < 20$, but 2MASS J05325346+8246465 could be observed by Gaia at $G < 21$. Large area proper motion surveys like NEOWISE-R (Wright et al. 2014) would be able to find more early type L subdwarf targets for Gaia $G < 20$, and potentially

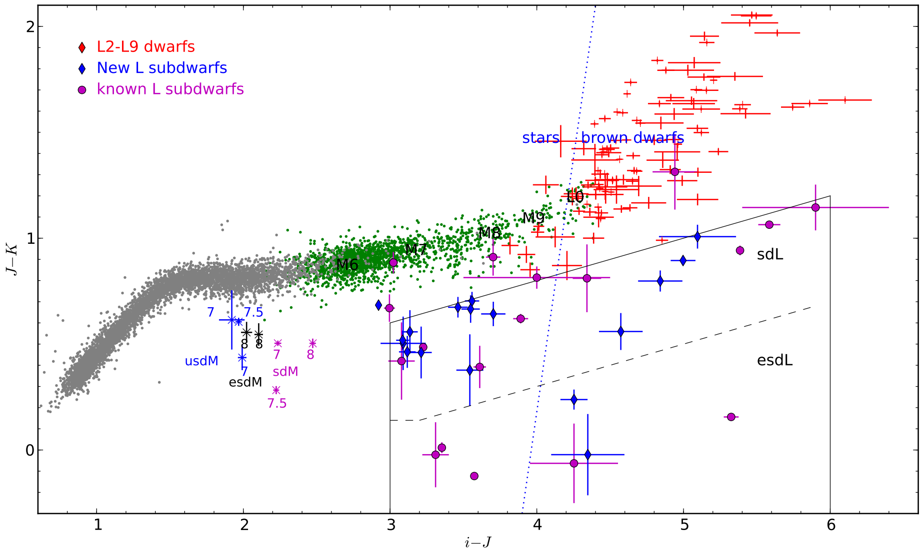

Fig. 2. The $i - J$ and $J - K$ colours of L subdwarfs. Magenta filled circles are known L subdwarfs from the literature. Blue filled diamonds are new L subdwarfs from our SDSS-UKIDSS programme. Grey dots are 5000 point sources selected from 10 square deg area of UKIDSS with $14 < J < 16$. Green dots are 1820 spectroscopically confirmed late M dwarfs (spectral types are indicated) from West et al. (2008). Red pluses are known L dwarfs with $i - J$ error less than 0.2 and $J - K$ error less than 0.12. The solid lines indicate our $i - J$ and $J - K$ colour selection criteria. The dashed line shows the likely boundary of sdL and esdL. The dotted line indicates the possible location of the substellar subdwarf gap. Notice that the break at $2.5 < i - J < 3.0$ is due to selection effect, only a small number of M subdwarfs are plotted.

a few late-type L subdwarf targets for Gaia $G < 21$.

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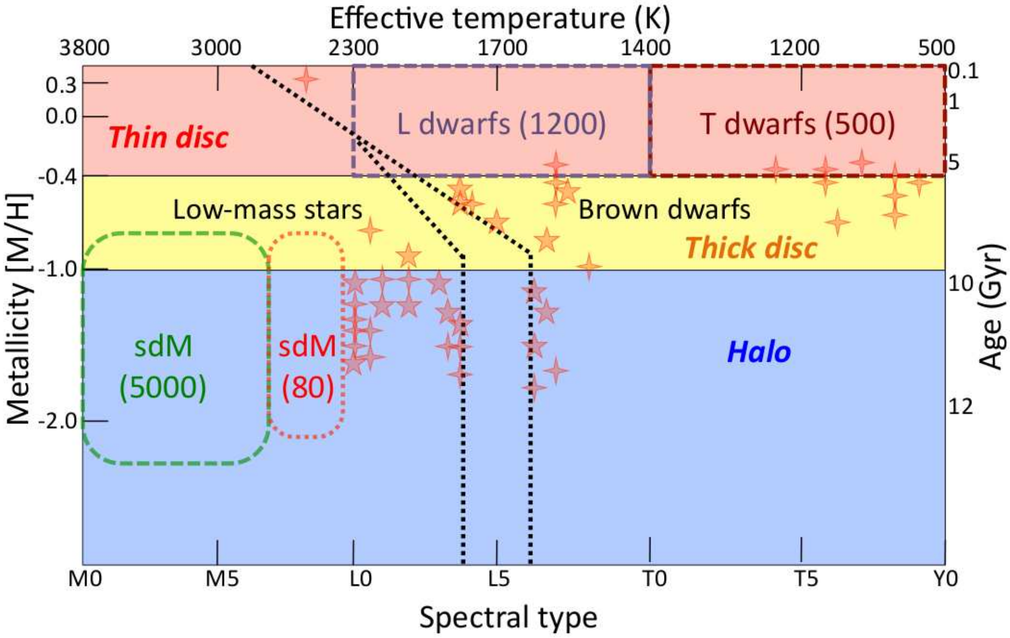

Fig. 3. Spectral type, effective temperature, metallicity and age distributions of Galactic populations of low-mass stars and brown dwarfs. Known numbers of different populations are indicated in brackets. Red, yellow and blue shaded areas indicate thin disc, thick disc and halo populations respectively. Black dotted lines indicate the substellar subdwarf gap. Red quadrangulars are known L subdwarfs from the literature, and red pentacles are new L subdwarfs discovered from our SDSS-UKIDSS programme.

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