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A $W2$ only search for late T and Y dwarfs in WISE

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Abstract. A method is defined for using the maximum sensitivity of WISE to find late T and Y dwarfs. This requires a WISE detection only in the $W2$-band and uses the statistical properties of the WISE multi-frame measurements and profile fit photometry to reject contamination resulting from non-point-like objects, variables and moving sources. To trace our desired parameter space we use a control sample of isolated non-moving non-variable point sources from the SDSS, and identify a sample of 158 WISE $W2$-only candidates down to a signal-to-noise limit of 8. For signal-to-noise ranges >10 and 8-10 respectively, ~45% and ~90% of our sample fall outside the criteria published by the WISE team (Kirkpatrick et al. 2012), due mainly to the type of constraints placed on the number of individual $W2$ detections. We present some early follow-up of our sample and identify one new very late object with high proper motion (1.8 arcsec yr^{-1}). Based on its spectrum, we here classify this object as a T9 ± 0.5. Using absolute magnitude against spectra type relations we estimate a distance and space motions for this candidate. Allowing radial velocities to vary between −250 and +250 km s^{-1} we show that this object is most likely a thick disc/halo T dwarf, which if confirmed would have important impact on the current knowledge of our Galaxy star formation history and evolution at such low mass ranges.

Key words. Surveys - stars: low-mass, brown dwarfs

1. Introduction

Brown dwarfs studies have come a long way since the discovery of the first exemplars in 1995 (Rebolo et al. 1995; Nakajima et al. 1995). One of the last breakthroughs has been recently made with the identification of the first Y dwarfs (Cushing et al. 2011; Kirkpatrick et al. 2011; Tinney et al. 2012) with WISE. Like T dwarfs, Y dwarfs exhibit deep H_2O and CH_4 absorption bands which dominate their spectral morphology. They present extremely red colours ($J - W2 > 4$) and the $J - H$ red colour of WISE1828+2650 (Cushing et al. 2011) indicates a reverse of the previously known colour trend of T dwarfs (for bluer $J - H$), showing a collapse in the near-infrared flux relative to that of ~ 5 microns. As expected, the transition between T and Y dwarfs follows a gradual change which is predominantly quantified by the narrowness of the J-band peak (Mace et al. 2013).

Here we present a new search method designed to effectively identify late T and Y dwarfs candidates in the full WISE sky down to near the faint detection limit of $W2$.

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2. Candidate selection

2.1. Initial selection

We used the WISE All Sky Catalogue to select candidates with S/N > 10 in the $W2$ band. Taking into account typical Y dwarf colours, $W1 - W2 > 3.9$, $W2 - W3 = 1.7$-2.6 and $W2 - W4 \sim 5$, we thus expect Y dwarfs around the $W2$ 10-σ limit to be non detections in the other three bands. Our selection criteria also requires that no 2MASS source is found within 3 arcseconds of the WISE source and at least 8 individual exposures in each band. Finally, and in order to minimise contamination from reddened sources, we have removed objects towards reddened regions of the sky. These selection criteria resulted in 6,067 sources.

2.2. Rejection methods

In order to assess the photometric quality of our sources, we developed additional selection criteria in the form of three rejection methods. The main goal was to remove contamination from resolved sources such as galaxies and nebulosities, variable sources and sources that moved significantly over the time-scale of the multi-frames.

We started by creating a control sample of isolated, point-like non-variable nonmoving sources. This control sample was created by combining the Sloan Digital Sky Survey (SDSS) with WISE. The control sample consisted of sources that had been spectroscopically confirmed as stars in SDSS, that were point-like and with proper motions > 20 mas yr^{-1}. We excluded the galactic plane and imposed the following colour cuts: $g < 2.0$ and $g - r < 0.3$, to select stars with reasonably blue colours. These SDSS sources were then crossmatched with WISE with a 1 arcsecond radius to avoid mis-matches.

2.2.1. Profile fit photometry rejection method

This rejection method compares the source $W2$ S/N with the parameter *w2rchi2*, which is the reduced χ^2 of the $W2$ profile fit photometry and is a direct indicator of how well the source is represented by the optimised point-spread function fit. The method assesses how point-like each source is. Using the control sample as comparison, we have found that in all but a small number of outlier cases *w2rchi2* lies in a band between 0.7 and 1.2. When comparing these results with the census of late T and Y dwarfs from Kirkpatrick et al. (2012), it was found that only seven of Kirkpatrick's objects fall outside our criteria. Upon further inspection, these turned out to be sources slightly overlapping with neighbouring sources in WISE images, which would increase the value of *w2rchi2*. This method should effectively retain isolated point-like sources.

2.2.2. Photometric uncertainty rejection method

This rejection method takes into account the sources S/N in $W2$ as well as two parameters, *w2sigp1* and *w2sigmpro*. The first, *w2sigp1* represents the standard deviation of the individually measured fluxes in all frames that cover the source, whereas *w2sigmpro* measures the integrated flux uncertainty. Variable sources will have a larger *w2sigp1* value due to variability, and the same will happen for solar system bodies if they are only detected in a fraction of the available frames. We found that the majority of the control sample sources lie in a well defined region in the log*(w2sigp1-w2sigmpro)* vs log*(w2snr)* space, and guided by this we have rejected all WISE sources with log*(w2sigp1-w2sigmpro)* > 1.3 − 1.38 log*(w2snr)*. As for outliers, only two T dwarfs from Kirkpatrick et al. (2012) census are excluded with this method, and these sources appear to be blended in the WISE images.

2.2.3. Detection number rejection method

The third rejection method addresses the number of times a source is detected in the individual exposures and it is only applied to the candidates with ≤ 8 individual detections. Once again, the control sample traces out a sequence in the *w2nm/w2m* vs *log(w2snr)* space, where *w2nm/w2m* represents the fraction of individual $W2$ frames in which the source is detected with S/N > 3. Using the control sample to define a rejection limit, we have thus excluded all sources with *w2nm/w2m* < 1.8 log*(w2snr)* – 1.7. There are eight T-dwarf and two Y dwarfs from the Kirkpatrick census that are excluded by our method, accounting for ~ 6% of the total census. However, these objects are all detected in more than eight frames and would not be excluded by this method.

After applying the rejection methods the initial sample of $W2$ sources was reduced to 904 objects.

2.3. Expanding the search

We expanded our search by including in our candidate list sources with S/N in the 8-10 range. An initial list of 18,112 sources was reduced to 3,252 after applying the three rejection methods. However, a visual inspection of some of these sources revealed that many were poor quality detection within the extended and nearby bright star halos. To remove such contamination we have implemented another rejection criteria, based on the proximity of the sources to 2MASS bright stars. A large fraction of candidates are found within 600 arcseconds of stars with magnitudes $J_{\mathrm{2MASS}} \leq 3.5$, and are thus the result of halo contamination. We have therefore removed all sources close to a bright star if their separation s from the star fulfills the criterion: $s \leq (-0.00636 \times J_{\mathrm{2MASS}}) + 5.409$. This removed approximately half of the sources.

In order to better assess the quality of each source, we have used the WISE Image Service to visually examine all $W2$ only sources. This was done to reject sources associated with artefacts, such as diffraction spikes, optical ghosts, glints, spurious halo associations and some sources in regions with a poor fit sky. We have also excluded sources that were part of extended structures such nebulosities and galaxies, and visually blended sources.

After the visual inspection, the new sample consists of 158 $W2$-only sources, 52 with S/N > 10 and 106 with S/N in the range 8-10.

3. Results

3.1. WISE0833+0052

WISE0833+0052 is the brightest new object in our sample, with $W2$ = 14.96. We have obtained extra imaging for this candidate from UKIDSS and from the instrument HAWK-I, at the VLT. Warm-Spitzer IRAC photometry was also obtained via Cycle 8 GO program 80077 (PI Leggett), for the two bands [3.6] and [4.5].

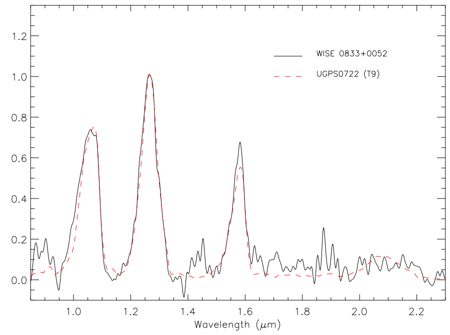

Fig. 1. Spectrum of WISE0833+0052 shown as a continuous line and spectrum of the T9 standard UGPS0722 show as a dashed line.

We have measured the proper motion of WISE0833+0052 using the UKIDSS and HAWK-I J-band images, and have verified these results by deriving proper motions using UKIDSS and WISE images. WISE0833+0052 has a very high total proper motion of 1.89 ± 0.04 arcsec yr^{-1}.

We have obtained spectroscopic data for WISE0833+0052 with the FIRE instrument, at the Magellan telescope. The smoothed and normalized spectrum is shown in Figure 1, where we also display the spectrum of the T9 standard UGPS 0722-05 (Lucas et al. 2010). We have compared the spectrum of WISE0833+0052 with standard T dwarfs, especially focusing on the J-band peak and hence classify our candidate as a T9 ± 0.5 dwarf.

WISE0833+0052 has $Y - J$ = 0.15 ± 0.24 and is uniquely blue in $Y - J$ compared to other T dwarfs, and despite its T9 spectral type has a $Y - J$ colour that is in the range of Y dwarfs. This object is also rather redder in $H - W2$ (5.67 ± 0.14) than typical T9 dwarfs, with a colour consistent with the early Y dwarfs. The other colours of WISE0833+0052 ($W1 - W2$ > 3.39, $J - H$ = –0.35 ± 0.14, $[3.6] - W2$ = 2.06 ± 0.11, $[3.6] - [4.5]$ = 2.22 ± 0.04 and $W2 - [4.5]$ = 0.16 ± 0.11) are consistent with

Table 1. Distance estimates for WISE0833+0052 using absolute magnitude versus spectral type relations in the Y, J, H, [3.6], [4.5] and $W2$ bnads a spectra type of T9 ± 0.5.

WISE0833+0052 (T9 ± 0.5) Band	Distance range (pc) Single object	Distance range (pc) Unresolved binary
Y	13-36	19-50
J	17-52	25-74
H	19-51	27-73
[3.6]	12-23	16-35
[4.5]	12-19	16-29
W2	13-22	19-32

T9 and Y dwarfs, since these objects have overlapping colour ranges. So WISE 0833+0052 is a T9 dwarfs with a relative excess in the Y-band and also in the mid-infrared bands ([3.6], [4.5] and $W2$).

Using the absolute magnitude against spectral type relations from Dupuy et al. (2012) we have estimated the distance of WISE0833+0052 and these are shown in Table 1. Overall the distance constraints fall into tow groups, with distance estimates from the J and H-band being greater than those from the Y and mid-infrared bands. The $J + H$ distance constraint is 17-52 pc, while the Y + mid–infrared distance constraint is 13-23 pc.

We have used these two constraints to construct space motion diagrams. We have considered a radial velocity in the range −250 to +250 km s^{-1} and taken into account proper motion uncertainties. The resulting space motions are consistent with WISE0833+0052 being part of the thick disc/halo. This result will have to be confirmed with a more accurate distance measurement if possible. There are currently no confirmed halo T dwarfs and therefore if this results is confirmed it will have important impact in the current knowledge of the star formation history and evolution in the Galaxy.

4. Conclusions and future work

We have presented a new method for identifying late T and Y dwarf candidates in the WISE database, with detections only in the $W2$ band. After an initial selection, we have refined our selection method by creating three rejection methods and have expanded our search to probe the faintest limits of the WISE survey. We identify 158 candidate late objects and have initiated an observing campaign to follow up and assess the nature of most of these candidates. One of these candidates, WISE0833+0052, is a T9 ± 0.5 dwarf, with a high proper motion and a spectral type derived from a FIRE spectrum. We have estimated a distance for WISE0833+0052 and estimated space motions that are consistent with being a thick disc/halo object.

Our collaboration is pursuing an ongoing follow-up programme to confirm and characterise Y dwarfs in the new sample. To confirm Y dwarfs we will then obtain near-infrared spectroscopy and mid-infrared follow-up for near-infrared non-detections. We have also started to obtain multiple epoch data to constraint the parallax distance of WISE0833+0052.

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