New members in the Upper Scorpius association from the UKIRT Infrared Deep Sky Survey Early Data Release*†

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ABSTRACT
We present the results of a 9.3-deg² infrared (ZyJHK) survey in the Upper Scorpius association extracted from the UKIRT Infrared Deep Sky Survey (UKIDSS) Galactic Cluster Survey Early Data Release. We have selected a total of 112 candidates from the (Z−J, Z) colour–magnitude diagram over the Z = 12.5–20.5 magnitude range, corresponding to M ≃ 0.25–0.01 M⊙ at an age of 5 Myr and a distance of 145 pc. Additional photometry in J and K filters revealed most of them as reddened stars, leaving 32 possible members. Among them, 15 have proper motion consistent with higher-mass members from Hipparcos and optical spectra with strong Hα in emission and weak gravity features. We have also extracted two lower-mass candidate members for which no optical spectra are in hand. Three members exhibit strong Hα equivalent widths (>20 Å), suggesting that they could still undergo accretion, whereas two other dwarfs show signs of chromospheric activity. The likelihood of the binarity of a couple of new stellar and substellar members is discussed as well.

Key words: techniques: photometric – techniques: spectroscopic – stars: low-mass, brown dwarfs – open clusters and associations: individual: Upper Scorpius – infrared: stars.

1 INTRODUCTION

Scorpius Centaurus is the nearest OB association, located at a mean distance of 145 ± 2 pc from the Sun (de Bruijne et al. 1997). The association covers 120 deg² and is composed of three subgroups: Upper Scorpius (Upper Sco), Upper Centaurus Lupus, and Lower Centaurus Crux (Blaauw 1964; de Zeeuw et al. 1999). The age of the Upper Sco association is about 5 Myr with little scatter (Preibisch et al. 1998). The current census of spectroscopic brown dwarfs in the Upper Sco includes 46 M6, 10 M7, six M8 and two M9 dwarfs, all confirmed as members on the basis of their chromospheric activity and weak gravity features (Martín et al. 2004; Slesnick et al. 2006). Recently, we extended the cluster sequence down to 0.008 M⊙ using UKIRT Infrared Deep Sky Survey (UKIDSS) Galactic Cluster Survey (GCS) science verification data. A dozen new brown dwarf candidates with spectral types later than M9 and masses below 0.02 M⊙ were extracted over 6.5 deg² (Lodieu et al. 2006).

The UKIDSS (Lawrence et al. 2006) constitutes the new generation of deep large-scale infrared surveys. The project is subdivided into five surveys: The Large Area Survey, the GCS, the Galactic Plane Survey, the Deep Extragalactic Survey and the Ultra-Deep Survey. The GCS will survey over a thousand square degrees in 10 star-forming regions and open clusters down to K = 18.4 mag at two epochs. The main goal of the GCS is to study the initial mass function well down into the substellar regime in an homogeneous manner in 10 star-forming regions and open clusters.

In this paper, we concentrate on the selection of new cluster member candidates in a 9.3-deg² area in the Upper Sco association.
from the UKIDSS Early Data Release (EDR; Dye et al. 2006). The photometric, proper motion and spectroscopic results presented in this paper represent the first step towards the ultimate goal of the GCS. In Section 3, we briefly present the infrared photometric observations conducted in Upper Sco. In Section 4, we describe the selection of new candidates from various colour–magnitude diagrams (CMDs) complemented by proper motion. In Section 4, we present the optical spectroscopic follow-up carried out with the ESO 3.6-m telescope. We infer spectral types and measure equivalent widths for the He emission line and Na I doublet to assess the membership of the new candidates. Finally, we summarize our work in Section 5.

2 THE UKIRT INFRARED DEEP SKY SURVEY GALACTIC CLUSTER SURVEY IN UPPER SCORPIUS

2.1 The Early Data Release

12 WFCAM tiles were observed in the association during the first phase of survey observations in 2005 June (Table 1), covering a total of 9.3 deg² (Fig. 1) in ZYJHK broad-band filters (Hewett et al. 2006). A summary of the observations, including the 12 WFCAM tiles, central coordinates and date of observations, is provided in Table 1. Uniformity of quality in the UKIDSS EDR (e.g. seeing, pho- tometry, etc.) is discussed at length in Dye et al. (2006). We refer the reader to Lawrence et al. (2006) for more details on the observing strategy of the UKIDSS project and its individual components.

All observations carried out within the framework of the UKIDSS project are pipeline-processed at the Cambridge Astronomical Survey Unit (CASU; Irwin et al., in preparation). The processed data are then archived in Edinburgh and released to the European community through the WFCAM Science Archive (WSA; Hambly et al., in preparation).

2.2 Observations and colour–magnitude diagrams

The UKIDSS GCS observations taken in Upper Sco and included in the EDR amount to a total of 9.3 deg² (Fig. 1). There are three main blocks centred approximately at (RA, Dec.) = (237:0, −21:55), (248:0, −21:55), and (250:05, −25:15) with three additional small blocks (made of two pawprints) contributing for 0.3 deg² in total. The survey was conducted in ZYJHK and reached 5σ completeness limits of $Z = 20.0$, $Y = 19.6$, $J = 18.6$, $H = 18.1$ and $K = 17.5$ mag. Hence, this survey is 3 mag deeper than any previous study in the region and is able to probe young L dwarfs according to the DUSTY 5-Myr isochrones. The two lowest-mass spectroscopic members reported in Upper Sco to date have spectral types of M9 corresponding to ~20 Jupiter masses (Martín et al. 2004; Slesnick et al. 2006).

We have selected from the EDR point sources (class parameter set to −1 or −2 in all passbands) detected in all five filters (ZYJHK) by use of the Structured Query Language (SQL) script, given in Appendix A, injected in the WSA. The total number of point sources is 174 010 (dots in the CMDs in Fig. 2) in the $Z = 11.4$–20.5 mag range, corresponding to masses between 0.35 and 0.008 $M_\odot$ at an age of 5 Myr and a distance of 145 pc (Baraffe et al. 1998; Chabrier et al. 2000).

The CMDs resulting from the GCS observations in Upper Sco are shown in Fig. 2, including the $(Z - J, Z)$, $(Z - K, Z)$ and $(J - K, J)$ diagrams. Overplotted are 5- and 10-Myr NextGen (solid lines; Baraffe et al. 1998), DUSTY (dashed lines; Chabrier et al. 2000) and COND (dotted lines; Baraffe et al. 2002) isochrones shifted at the distance of the association ($d = 145$ pc). Note that isochrones were computed for the UKIDSS passbands (courtesy I. Baraffe and F. Allard).

3 NEW CANDIDATE MEMBERS OF THE UPPER SCORPIUS ASSOCIATION

This section describes the selection of new candidates in the Upper Sco association using CMDs and proper motions.

3.1 Selection of candidates in Upper Sco

Candidates in open clusters are generally selected to the right-hand side of the theoretical isochrones or the zero-age main sequence (Leggett 1992). To select all possible members in Upper Sco at the expense of including some contaminants, we have extracted all candidates to the right-hand side of a straight line running from $(Z - J, Z) = (0.8, 11.5)$ to $(2.1, 21.5)$. The total number of candidates is 192. However, we have limited our analysis to objects fainter than $Z = 12.5$ $(J \sim 11.5)$, leaving 112 candidates. This threshold translates into a mass of 0.25 $M_\odot$ and corresponds to completeness limit of the survey conducted by Preibisch & Zinnecker (2002) in the region. We provide an electronic table with all photometric candidates, including those classified later as non-members after proper motion and spectroscopic analysis (Table 2). Some candidates fainter than $Z = 17$ mag are running along the straight line defined as our criterion and located to the left-hand side of the theoretical isochrones (Chabrier et al. 2000) in the $(Z - J, Z)$ diagram. Consequently, we cast doubt on the membership of those objects and do not consider them in the subsequent analysis for two reasons: first, one candidate located at $Z \sim 16.2$ and $Z - J \sim 1.5$ turned out as a non-member after optical spectroscopy and, secondly, the cluster sequence runs further to the red and to the right-hand side of the isochrones as demonstrated in Lodieu et al. (2006).

To further assess the membership of the 112 candidates, we have investigated their location in the $(Z - K, Z)$ and $(J - K, J)$ CMDs (top-right hand and bottom left-hand graphs in Fig. 2, respectively) as well as in the $(Z - K, J - K)$ two-colour diagram. The $(Z - K, Z)$

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1 The main page is http://www.ukidss.org.
2 The CASU WFCAM webpage can be found at http://apm15.ast.cam.ac.uk/wfcam.
3 The WSA is accessible at http://surveys.roe.ac.uk/wsa.
Figure 1. The UKIDSS GCS coverage in the Upper Sco association from the EDR is depicted with the boxes. Early-type stars from Hipparcos are displayed as the five-pointed star symbols (de Zeeuw et al. 1999). We have included known members: the triangles are from Preibisch & Zinnecker (2002), the diamonds from Ardila et al. (2000), the squares from Martín et al. (2004), and the pluses from Slesnick et al. (2006). The new spectroscopic members and non-members from this study are shown as the filled circles and star symbols, respectively. The diamonds located in the area surveyed by the EDR are potential reddened members. The filled circles outside the boxes represent new members of the association extracted from the UKIDSS GCS science verification (Lodieu et al. 2006). Spectroscopic non-members are located in an area affected by reddening at (RA, Dec.) ∼ from this study are shown as the filled circles and star symbols, respectively. The diamonds located in the area surveyed by the EDR are potential reddened members. The filled circles outside the boxes represent new members of the association extracted from the UKIDSS GCS science verification (Lodieu et al. 2006). Spectroscopic non-members are located in an area affected by reddening at (RA, Dec.) ∼ (250°, −21°).

3.2 Proper motions

Optical or near-infrared photometry alone is not sufficient to extract a clean sample of members in open clusters. We have exploited the Two-Micron All-Sky Survey (2MASS) data base and the GCS observations as the first and second epoch, respectively, to compute proper motions for candidates brighter than $J = 15.8$ mag, corresponding to the 2MASS 5σ completeness limit and a mass of 0.015 $M_\odot$ in Upper Sco (Chabrier et al. 2000). The vector point diagram (proper motion in RA versus proper motion in Dec.) is presented in the bottom right-hand panel in Fig. 2. Most of the sources classified as reddened stars exhibit a small proper motion (small dots), hence confirming their status of distant objects and non-members. However, there remain 15 objects (diamonds; Table 3) considered as reddened stars in the previous section which do have a proper motion within the 2σ circle plotted in the vector point diagram in Fig. 2. Although most of them are likely to be reddened stars because they lie in the same part of the diagram as the spectroscopic members (Fig. 1), there might be some reddened members (Table 3). Unfortunately, we do not provide optical spectroscopy for them, but they need to be followed up to determine how complete is the sample selected from the sequence alone. Two other groups of sources for which we obtained optical spectra (see Section 4 for more details) are overplotted. On the one hand, 12 candidates classified as non-members and plotted as star symbols in Fig. 2 have small proper motion close to $(\mu_\alpha \cos \delta, \mu_\delta) = (0, 0)$ mas yr$^{-1}$. On the other hand, 20 new candidates shown as the filled circles and triangles in Fig. 2 exhibit proper motion consistent with the mean motion of the association from Hipparcos (de Bruijne et al. 1997; Preibisch et al. 1998). The faintest photometric member candidate is too faint to compute its proper motion from the 2MASS images.

4 SPECTROSCOPIC FOLLOW-UP

This section describes the spectroscopic observations of new candidates in Upper Sco and discusses their membership.

4.1 Spectroscopic observations

We have carried out low-resolution optical spectroscopy of 31 candidates in Upper Sco with EFOSC2 on the ESO 3.6-m telescope in La Silla, Chile. The observations were obtained over five nights on 2006 March 27 to 2006 April 1. Conditions were photometric during the first three nights, whereas the last two nights were affected by thin cirrus. Seeing was typical in the 0.5–1.0 arcsec range during the observing run.

The EFOSC2 detector is a $2048 \times 2048$-pixel MIT CCD with a pixel size of 0.157 arcsec pixel$^{-1}$, yielding a $5.5 \times 5.5$-arcmin$^2$ field of view. We have employed the grism #16 with a 1-arcsec slit to cover the wavelength range from 6000 to 10 300 Å at a resolution of $R \sim 300$. We have obtained an internal flat-field after each spectrum to remove fringing longwards of 7500 Å. Each target was observed once with exposure times ranging from 240 s for the brightest objects...
Figure 2. CMDs for 9.3 deg$^2$ in the Upper Sco association from the UKIDSS EDR. The large filled circles are new spectroscopic Upper Sco members. The open triangles and star symbols are spectroscopic and proper motion non-members, respectively. The dots represent all candidates classified photometrically as reddened stars from their location in the $(J - K, J)$ and $(Z - K, J - K)$ diagrams. The diamonds are possible reddened members for which no optical spectroscopy is currently available. Overplotted are the 5- and 10-Myr NextGen (solid line; Baraffe et al. 1998), DUSTY (dashed line; Chabrier et al. 2000) and COND (dotted line; Baraffe et al. 2002) isochrones. The mass scale is shown on the right-hand side of the diagrams and spans 0.3–0.008 M$_\odot$. Top left-hand panel: $(Z - J, Z)$ diagram. Top right-hand panel: $(Z - K, Z)$ diagram. Bottom left-hand panel: $(J - K, J)$ diagram. Bottom right-hand panel: vector point diagram for sources brighter than $J = 15.8$ mag, because the faintest ones do not have proper motion measurements due to the lack of 2MASS detection. The last three diagrams contain only photometric candidates selected in the $(Z - J, Z)$ diagram.

Table 2. All 112 photometric candidates selected from the $(Z - J, Z)$ CMD in 9.3 deg$^2$ in the Upper Sco association. This table provides coordinates (J2000), $ZYJHK$ photometry from the GCS, and proper motion from the GCS/2MASS cross-correlation for members and non-members. This is a sample of the full table, which is available in electronic format on Synergy (see Supplementary Material).
Figure 3. Optical (6400–8500 Å) spectra of 15 new members in the Upper Sco association obtained with EFOSC on the ESO 3.6-m telescope. The spectral types range from M3.5 to M8 with a typical uncertainty of half a subclass. We have added three known members for comparison purposes: SCH160147−244101 (M5; Slesnick et al. 2006), DENIS J160514−240653 (M6; Martín et al. 2004) and SCH162528−165851 (M8; Slesnick et al. 2006). All objects show strong Hα emission and weak Na I doublets, indicator of low gravity.

4.2 Data reduction

The data reduction was carried out under the IRAF environment following standard procedures. First, we combined 10 bias frames and subtracted the averaged bias from the combined flat-field and the science target. Secondly, we divided the science frame by the normalized response function of the internal flat-field observed immediately after each target. Afterwards, we extracted a one-dimensional spectrum interactively with apsum by choosing the appropriate aperture and background intervals. We then used the arc lamps to calibrate our spectra, yielding typical rms better than 0.35 Å. The flux calibration with the spectrophotometric standard stars was not possible due to the presence of second-order contamination longwards of 7200 Å. All four standards targeted during the observing are white dwarfs or early-type stars, yielding an overestimate of the detector response in the red part of the spectrum. To solve this issue, we used the optical spectra of three Upper Sco members4 to correct the shape of our spectra. However, the amount of flux from the blue end of the M dwarf spectra kicks in redwards of ~9000 Å, making the calibration very difficult. Thus, the shape of the science target and then comparison with templates is only valid between 6400 and 8500 Å. No correction for telluric bands was made to the spectra. The optical spectra (normalized at 7500 Å) of Upper Sco members are displayed in Fig. 3.

4 Spectra kindly provided by Eduardo Martín and Catherine Slesnick.
4.3 Spectral classification

The classification of M dwarfs is generally based on spectral indices measuring the strength of molecular absorption bands and atomic lines (Kirkpatrick et al. 1999; Martín, Delfosse & Basri 1999). Spectral indices are defined over a large wavelength range and are valid for old field dwarfs. The effect of gravity can influence the computation of the indices (Martín et al. 1996). Thus, we preferred to rely on the direct comparison with known Upper Sco members and field M dwarfs observed with the same telescope/instrument set-up in order to classify our targets. We used three known Upper Sco members, SCH1661−2441 (M5; Slesnick et al. 2006), DENIS1605−2406 (M6; Martín et al. 2004) and SCH1625−1658 (M8; Slesnick et al. 2006), as young M dwarf templates.

The spectral classification of all candidates followed up spectroscopically revealed the following three subgroups (we do not have spectra for the two faintest candidates).

(i) 12 proper motion non-members (star symbols in Fig. 2; Table 4) classified photometrically as reddened sources are indeed spectroscopic non-members. All but two sources are reddened early-type stars. They are clearly concentrated in one part of the association (Fig. 1) associated with reddening and possibly due to the presence of a nearby early-type star. The presence of interstellar absorption is seen in the $\text{IRAS}$ 100-μm map of the association displayed in fig. 1 in Slesnick et al. (2006). The other two sources are classified as an M5 dwarf (15°50′39″55′′, −21°39′47″5) and the remaining one is a late-M dwarf (15°50′11″5, −22°01′21″9). The latter is redder than the coolest Upper Sco member observed in this study (spectral type of M8) and exhibits Hα emission. The Na I equivalent width (7.3 Å) is larger than measurements for Upper Sco members and its proper motion is inconsistent with the association. It is also redder than vB10 (M8; Kirkpatrick, Henry & McCarthy 1991) which we included in our programme as a field M dwarf template. We tentatively classify this source as an M9 dwarf.

(ii) Three proper motion members classified as spectroscopic non-members (triangles in Fig. 2): two turned out to be early-type stars, and the remaining one is an M5 dwarf.

(iii) 15 proper motion members confirmed spectroscopically as young M dwarfs belonging to the Upper Sco association. We can subdivide those members into five groups (Table 5; Fig. 3): two objects are classified as M3.5 dwarfs, six as M4.0, five as M5, three as M6, and the faintest object is an M8 dwarf. We assign an uncertainty of half a subclass to our spectral types (note that we rely on previous classifications). Young cluster members with spectral types of M6 or later are considered as brown dwarfs (Martín et al. 1996; Luhan et al. 1998). All but one spectroscopic members lie within a 2σ circle centred on (−11, −25) mas yr$^{-1}$, assuming 10 mas yr$^{-1}$ as typical errors on the proper motion measurement.

Consequently, 15 out of 18 proper motion members were confirmed as spectroscopic members, yielding a contamination of $3/18 = 16.5$ per cent among our sample, lower than observations of the studies in the Pleiades (31 per cent; Moraux, Bouvier & Stauffer 2001) and α Per (30–45 per cent; Barrado y Navascués et al. 2002) open clusters.

4.4 Chromospheric activity and gravity

To assess the youth of the M dwarfs having photometry and proper motion consistent with Upper Sco, we investigated the pseudo-equivalent widths of the Hα emission line (6365 Å) and the Na I doublet (8183/8195 Å).

The Hα equivalent widths measured for all Upper Sco members range from −4.4 to −30.7 Å (filled circles in Fig. 4) and lie below the empirical boundary between accreting and non-accreting low-mass and brown dwarfs defined by Barrado y Navascués & Martín (2003). Three objects with strong Hα emission lines lie above this line and are discussed in Section 4.5. Finally, we confirm the increasing strength of the Hα equivalent width with later spectral type.

The Na I doublet is a good gravity indicator for spectral types later than about M3 as it weakens with lower gravity, that is, younger ages. The equivalent widths measured for the Upper Sco members (filled circles) and field dwarfs (squares) observed with the same instrument are plotted as a function of spectral type in Fig. 5. Our measurements indicate that young Upper Sco members exhibit weaker Na I doublets than those exhibited by field dwarfs of similar spectral type (Fig. 6). To put our work into a wider picture, our equivalent width measurements tend to be weaker than values reported in the literature for the Pleiades (Martín et al. 1996), although the spectral resolution was different. This argument remains, however, qualitative as lower resolution tends to overestimate equivalent widths.
4.5 Activity and accretion

Two different mechanisms can account for the Hα emission line detected in all Upper Sco members (Fig. 4): chromospheric activity is characterized by weak lines with Gaussian profiles, whereas accretion and winds are characterized by strong emission with asymmetric line shapes (Mohanty, Jayawardhana & Basri 2005).

We have measured Hα equivalent widths which are discrepant from values reported in the literature for spectroscopic templates. We attribute this variation to chromospheric activity. We should nevertheless emphasize that the difference in spectral resolution between our observations and those published in the literature could account for some of the discrepancy. The first object, DENIS J160514−240653 (Martin et al. 2004), was included in our programme as a known Upper Sco member. We measured an equivalent width of \( -15.7 \) Å in our spectrum compared to \( -24 \) Å reported in Martin et al. (2004). The second object is SCH160311−13454, classified as an M5 field dwarf by Slesnick et al. (2006). We have

To summarize, 15 out of 18 photometric and proper motion selected members have confirmed signatures of weak Na\(_t\) and H\(_\alpha\) emission (see optical spectra in Fig. 3). Our measurements are in agreement with results obtained for three known Upper Sco members published by Martin et al. (2004) and Slesnick et al. (2006) that we observed as templates during our programme.

Table 4. This table lists the equatorial coordinates (in J2000), the ZYJHK magnitudes and the proper motion of 15 photometric candidates classified as non-members after optical spectroscopic follow-up (star symbols and open triangles in Fig. 2). The spectra look like reddened early-type stars apart from two objects classified as an M5 dwarf (15\(^{h}\)50\(^{m}\)59.55, \(-21^\circ\)39'45.7) and a late-M dwarf (15\(^{h}\)50\(^{m}\)11.5, \(-22^\circ\)01'21.9). All spectroscopic non-members but three exhibit proper motions discrepant with the mean motion of the association.

Table 5. 17 new members of the Upper Sco association confirmed from their photometry, proper motion and spectroscopy (filled circles in Fig. 2). This table lists the name of the object according to the IAU nomenclature, the equatorial coordinates (J2000), the magnitudes from the GCS, the proper motions (in mas yr\(^{-1}\)), the H\(_\alpha\) and Na\(_t\) equivalent widths (in Å), and the spectral types with an accuracy of half a subclass. The two faintest candidates (Z > 17.0 mag) have neither spectral types nor equivalent width measurements, because they are too faint for optical spectroscopy with ESO 3.6-m/EFOSC2, but one has a proper motion consistent with the association.

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Figure 4. Hα equivalent widths as a function of spectral type for 15 new spectroscopic members (filled circles) and non-members (asterisks). The level of chromospheric activity confirms that those candidates are members of the Upper Sco association. We have also included equivalent widths for members (open triangles) published by Slesnick et al. (2006) as well as for field dwarfs observed with EFOSC2 and showing Hα emission (squares). Overplotted is the accretor/non-accretor empirical function (solid line) defined by Barrado y Navascués & Martín (2003). Three objects with spectral types of M4 and M5 lie above the solid line and could be accretors.

Figure 5. NaI equivalent widths as a function of spectral type for 15 spectroscopic new members (filled circles) and non-members (asterisks). Three known members published by Martín et al. (2004) and Slesnick et al. (2006) were chosen as spectroscopic templates and are plotted as the diamonds. Equivalent widths for five field dwarfs targeted with the same telescope and instrument configurations as the Upper Sco sample are displayed as the squares. The weak NaI doublet equivalent widths measured for the Upper Sco candidate members indicate low gravity and add credence to their membership.

measured an Hα equivalent width of ~18.8 Å, stronger than the one reported previously (~8.7 Å). This type of variation in the Hα is common among mid-M field dwarfs (Hawley, Gizis & Reid 1996). We have also investigated the NaI doublet for this object and measured equivalent widths of 5.5 and 7.0 Å in our spectrum and Slesnick’s spectrum, respectively. Those values are suggestive of an age older than Upper Sco. We also measured a proper motion of (90, −54) mas yr⁻¹ between the 2MASS observations and the optical survey by Slesnick et al. (2006), clearly inconsistent with the association.

The empirical relation defined by Barrado y Navascués & Martín (2003) from low-resolution optical spectroscopy to distinguish accreting and non-accreting low-mass stars and brown dwarfs is overplotted in Fig. 4. Most members lie below this empirical relation. However, three objects, one M4 and two M5 dwarf members of Upper Sco exhibit Hα equivalent widths two to three times those of sources with the same spectral type and larger than the dividing line between accretors and non-accretors. Although weaker than the strongest Hα equivalent widths reported by Slesnick et al. (2006) in several objects (open triangles in Fig. 4) and despite our low spectral resolution which might have overestimated the equivalent widths, those sources could still undergo accretion unless we observed strong flares due to chromospheric activity. Higher-resolution spectroscopy centred on Hα is required to investigate the line profiles and the origin of the strong emission.

4.6 Binarity

Bouy et al. (2006) reported a possible excess of wide binaries with separations between 100 and 150 au among low-mass stars and brown dwarfs in Upper Sco. Similarly, Luhman (2005) discovered serendipitously a wide low-mass pair with a projected physical separation of 130 au in the association.

A couple of objects brighter than J = 14 mag lie clearly to the right-hand side of the cluster sequence which runs almost vertically in the (J − K, J) CMD, suggesting that they are possible low-mass binaries. The object at J = 15.5 mag (M ∼ 0.015 M⊙) could also be a multiple substellar system and of particular interest to test evolutionary models at low masses (if confirmed as such). Other binary candidates might be hidden in the list of potential reddened members. Because we selected only point sources in the EDR catalogue, we are not sensitive to separations of about 1–2 pixel or 0.4–0.8 arcsec. This corresponds to projected physical separations of 50–100 au at the distance of the association (d = 145 pc). We are
also insensitive to closer companions as it requires high-resolution imaging or adaptive optics although the location of objects in the various CMDs can give some clues about the possible multiplicity of a source. Finally, we should be sensitive to larger separations and be able to detect wide companions on seeing-limited images (separation larger than a few hundreds of astronomical units) especially on the $K$-band images where microstepping is used to measure accurate proper motions when the second epoch observations are released.

5 SUMMARY

We have presented the analysis of a 9.3-deg$^2$ survey in the Upper Sco association conducted for the UKIDSS GCS and extracted from the EDR. Combining infrared photometry, proper motion and optical spectroscopy, the membership of the original 112 candidates can be summarized as follows.

(i) 80 photometric candidates selected from the $(Z - J, Z)$ CMD were rejected on the basis of their $J - K$ affected by reddening. Among them, 15 sources could be reddened members as they exhibit proper motion consistent with the association.

(ii) 13 photometric candidates have proper motions inconsistent with the Upper Sco association and optical spectra of early-type stars affected by reddening.

(iii) Three objects have optical spectroscopy inconsistent with membership despite their photometry and proper motion suggesting that they are possible members.

(iv) 15 candidates are definite members confirmed from photometry, proper motion and optical spectroscopy, including four new brown dwarfs (spectral types later than M6). They span masses between 0.2 and 0.01 M$_\odot$.

(v) Two faint photometric candidates with estimated masses below 20 M$_{\mathrm{Jup}}$ according to the DUSTY models (Chabrier et al. 2000). One object has proper motion consistent with Upper Sco and no spectroscopy, whereas the other one has neither proper motion nor spectroscopy currently available.

We detected variation in the H$_\alpha$ equivalent widths for one Upper Sco member and one field dwarf, hence showing signs of chromospheric activity. In addition, three new members exhibit H$_\alpha$ emission lines stronger than the lower limit of the empirical relation between accreting and non-accreting low-mass stars and brown dwarfs. Finally, a handful of members present a high probability of being binary systems from their location in the CMDs.

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APPENDIX A: sql QUERY SUBMITTED TO THE WFCAM SCIENCE ARCHIVE

Initial sample selection for this Upper Sco study was made by accessing the UKIDSS EDR data base (UKIDSSEDR) held at the WSA. The SQL query given in Fig. A1 was used.

For more details concerning the use of SQL and data in the WSA, see Hambly et al. (in preparation) and references therein.
SELECT
/* Attribute selection: */
g.ra, g.dec, zmyPnt, ymjPnt, jmhPnt, hmk_1Pnt,
zaperMag3, yaperMag3, japerMag3, haperMag3, k_1aperMag3,
3.6e6*COS(RADIANS(g.dec))*(g.ra-T2.ra)/((mj.mjdObs - T2.jdate+2400000.5)/365.25) AS pmRA,
3.6e6*(g.dec-T2.dec)/((mj.mjdObs - T2.jdate+2400000.5)/365.25) AS pmDEC
FROM
/* Table(s) from which to select the attributes: */
gcsMergeLog AS l, Multiframe AS mj,
    (SELECT t.ra AS ra, t.dec AS dec, x.slaveObjID AS slaveObjID,
     x.masterObjID as masterObjID, t.j_m, t.h_m, t.k_m, t.jdate
     FROM gcsSourceXtwomass_psc as x, TWOMASS..twomass_psc as t
     WHERE x.slaveObjID=t.pts_key AND distanceMins IN (
         SELECT MIN(distanceMins) FROM gcsSourceXtwomass_psc WHERE masterObjID=x.masterObjID
     )
     AS T2
RIGHT OUTER JOIN gcsSource AS g ON (g.sourceID=T2.masterObjID)
WHERE
/* Sample selection predicates: */
only Upper Sco data (no other GCS target is south of the equator) */
g.dec < 0.0
/* Bright saturation cut-offs */
AND zaperMag3 > 11.4
AND yaperMag3 > 11.3
AND japerMag3 > 10.5
AND haperMag3 > 10.2
AND k_1aperMag3 > 9.7
/* Limit merged passband selection to +/-1 arcsec */
AND zXi BETWEEN -1.0 AND +1.0
AND yXi BETWEEN -1.0 AND +1.0
AND jXi BETWEEN -1.0 AND +1.0
AND hXi BETWEEN -1.0 AND +1.0
AND k_1Xi BETWEEN -1.0 AND +1.0
AND zEta BETWEEN -1.0 AND +1.0
AND yEta BETWEEN -1.0 AND +1.0
AND jEta BETWEEN -1.0 AND +1.0
AND hEta BETWEEN -1.0 AND +1.0
AND k_1Eta BETWEEN -1.0 AND +1.0
/* Retain only point-like sources */
AND zClass BETWEEN -2 AND -1
AND yClass BETWEEN -2 AND -1
AND jClass BETWEEN -2 AND -1
AND hClass BETWEEN -2 AND -1
AND k_1Class BETWEEN -2 AND -1
/* Retain only the best record when duplicated in an overlap region */
AND (priOrSec = 0 OR priOrSec = g.frameSetID)
/* Table join predicates: */
AND g.frameSetID=l.frameSetID
AND l.jmfID=mj.multiframeID

Figure A1. SQL query used on the WSA data base UKIDSSEDR to select the GCS Upper Sco sample discussed in the paper. The query returns 174010 rows of data.

SUPPLEMENTARY MATERIAL

The following supplementary material is available for this article online.

Table 2. All 112 photometric candidates selected from the (Z – J, Z) CMD in 9.3 deg² in the Upper Sco association. This table provides coordinates (J2000), ZYJHK photometry from the GCS, and proper motion from the GCS/2MASS cross-correlation for members and non-members.

This material is available as part of the online article from http://www.blackwell-synergy.com.

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