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A new UKIDSS proper motion survey and key early results, including new benchmark systems

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Abstract. We present a proper motion catalogue for the 1500 deg^2 of 2 epoch J-band UKIDSS Large Area Survey (LAS) data, which includes 120,000 stellar sources with motions detected above the 5σ level. Our upper limit on proper motion detection is $3''\!.3\,\mathrm{yr}^{-1}$ and typical uncertainties are of order $10\,\mathrm{mas\,yr}^{-1}$ for bright sources from data with a modest 1.8−7.0 year epoch baseline. We developed a bespoke proper motion pipeline which applies a source-unique second order polynomial transformation to UKIDSS array coordinates to counter potential local non-uniformity in the focal plane. Our catalogue agrees well with the proper motion data supplied in the current WFCAM Science Archive (WSA) tenth data release (DR10) catalogue where there is overlap, and in various optical catalogues, but it benefits from some improvements, such as a larger matching radius and relative to absolute proper motion correction. We present proper motion results for 128 T dwarfs in the UKIDSS LAS and key early results of projects utilising our catalogue, in particular searches for brown dwarf benchmark systems through cross matches with existing proper motion catalogues. We report the discovery of two new T dwarf benchmark systems.

Key words. proper motions – catalogues – binaries: general – brown dwarfs – stars: kinematics and dynamics – Galaxy: kinematics and dynamics

1. Introduction

Stellar proper motion is the angular movement of a star in a given time period. All stars have some component of motion due to their motion around the Galaxy and 'gravitational kicks' they may have received through interaction with other massive objects such as molecular or atomic clouds. Motion perpendicular to a line between the star and the observer is the proper motion, which can be measured through careful observation of its position over two or more epochs, given sufficient time between observations.

Current proper motion surveys are mostly optical in nature (or contain at least an optical component) owing to a need for a large

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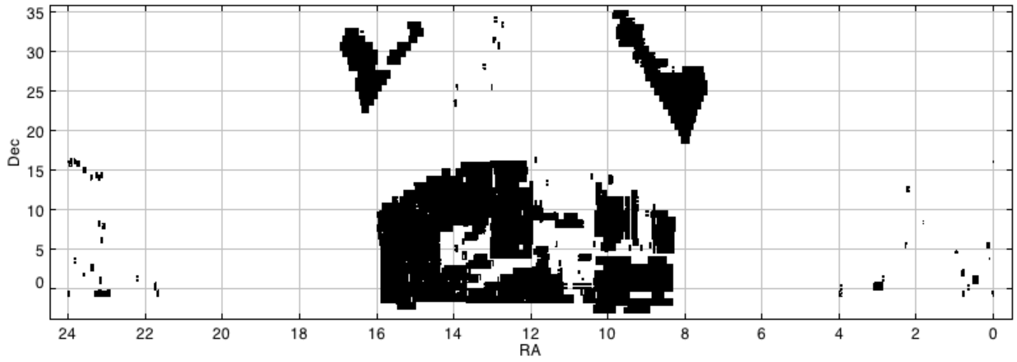

Fig. 1. The area coverage of our UKIDSS LAS proper motion catalogue corresponds to approximately 1500 deg^2.

epoch baseline to gain good precision. This usually means optical photographic plates are used for at least the first epoch. Our catalogue is one of very few wide field near infrared only proper motion surveys and can be expected to reveal objects not detected in optical surveys while also providing kinematic data for known objects than can serve many scientific purposes, such as investigating the ages of T dwarfs (Smith et al. 2013).

2. Method

The UKIDSS LAS covers approximately 3800 deg^2 in YJHK passbands to an approximate 5σ depth of 19.6 in J and is complemented in ugriz optical passbands by the Sloan Digital Sky Survey (SDSS). It included a second epoch of observations in the J passband to calculate proper motions and investigate stellar variability. In the final months of the UKIDSS program great effort was made to observe as much as possible at a second epoch. The final second epoch coverage and the resultant footprint of our catalogue is around 1500 deg^2 (see figure 1). We use a match limit of 6 arcsec and with a minimum epoch baseline of $\sim$1.8 years, giving us a hard upper limit on proper motion detections of $3''\!.3\,\mathrm{yr}^{-1}$. We note that the range of epoch baselines, 1.8 to 7 years, means that in some areas the proper motion limit is somewhat lower.

Our data set contains $\sim$17 million sources separated into $\sim$33,000 $13'\!.65\times13'\!.65$ arrays. We process each array individually, producing global (whole-frame) and local second order polynomial transforms by fitting relatively static star array positions between epochs. A local transform is fit using reference stars from within a smaller radius than the frame, its size being dependant on local source density and distribution. We then fit first epoch source array positions to their first epoch equatorial tangent plane positions using a third order polynomial and apply the resultant transformation to both epochs. Subtraction of the first from the second epoch positions is performed to calculate source motions and division of this by the epoch baseline gives the proper motion. We use locally transformed positions to calculate proper motions in preference due to their lower average uncertainties (see Figure 2). We correct our relative proper motions to absolute by subtracting the median proper motion of sources with flagged as galaxies located within 3 degrees and possessing small proper motion uncertainties.

3. Analysis of results

We scrutinised 1/5th of the results, approximately 300 deg^2. This area corresponds to the overlap with second epoch J coverage of UKIDSS DR10. To this we compared our absolute proper motions to those in two existing large baseline optical proper motion catalogues, the revised NLTT catalogue (rNLTT; Salim & Gould 2003) and the LSPM-north cat-

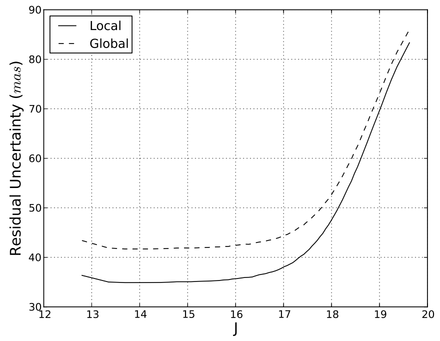

Fig. 2. We selected sources with no post processing error flags, low ellipticity and classified as stellar in both J band images with measured local and global residuals (3.5 million sources total) and split them into 70 J magnitude bins. The mean local and global residual uncertainties in each bin are shown. The local residual uncertainties are consistently lower than the global ones.

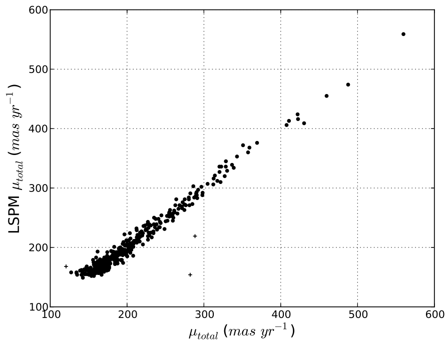

Fig. 3. LSPM total proper motions (vertical axis) versus those calculated by our pipeline (horizontal axis) for the 381 matches between the two catalogues. The crosses are LSPM J1644+3203, LSPM J1625+2519, and LSPM J1609+2457 for which the total proper motions differ greater than 4σ. The data are nevertheless well correlated; the Pearson product-moment correlation coefficient is 0.980.

alogue of Lépine & Shara (2005). We matched the catalogues using $3''$separation and 0.5 J magnitude variation tolerances and find 381 and 109 matches in the LSPM and rNLTT catalogues respectively. Figure 3 shows the good correlation in total proper motion with the LSPM catalogue. The data are very well correlated with Pearson's r values of 0.99 and 0.98 for rNLTT and LSPM respectively. The match is encouraging since both catalogues benefit from typical epoch baselines an order of magnitude greater than ours.

With the WFCAM Science Archive's 9$^{\rm th}$ release of LAS data came proper motions (Collins & Hambly 2012) to which we compared results from our pipeline. We compared our relative proper motions only since the WSA proper motions are not relative to the ICRF. The proper motion results agree well between the catalogues. We determine Pearson product-moment correlation coefficients of 0.80 and 0.82 in $\mu_\alpha \cos\delta$ and μ_δ respectively. We find that 86% and 99% of proper motions match within their 1σ and 2σ uncertainties respectively.

Typical absolute proper motion uncertainties for stellar sources are 7.5 to 12.5 mas yr^{-1} for $J > 17$, rising to between 15 and 25 mas yr^{-1} for $J = 19$ (see Figure 4).

3.1. Results

The catalogue has been briefly scrutinised for interesting objects. We find several new examples of cool white dwarfs (see Catalán et al., in prep.) and ultracool dwarfs, including new candidate benchmark objects, see Smith et al. (submitted) for further details. We refer the reader to Catalán et al. (2012) for detailed analysis of the brightest Pure H ultra cool white dwarf ($T_{\rm eff} = 3880 \pm 90$ K) which was identified in our catalogue due to its high proper motion. We also refer the reader to Burningham et al. (2013), which describes a search for UKIDSS LAS benchmark T dwarfs using our catalogue among others and where we provide proper motions for 128 UKIDSS LAS T dwarfs.

Two new T dwarf benchmarks were identified within our catalogue by Burningham et al. (2013): LHS 6176B and HD 118865B. LHS 6176B reaffirms previous findings that J-$W2$ and H-[4.5] colours are more sensitive to metallicity than current atmospheric models predict. Furthermore we have identified two

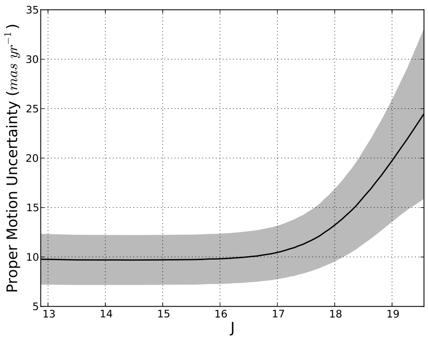

Fig. 4. We selected sources with no post processing error flags, low ellipticity and classified as stellar in both J band images (5.4 million sources) and split them into 53 J magnitude bins each containing approximately 100,000 sources. The mean uncertainty on μ_{total} in each bin is plotted. The shaded section shows the region bound by 1 standard deviation.

high proper motion thick disk/halo T dwarf candidates. Their identification and follow up will be reported in a future publication.

4. Summary

We have produced a 1500 deg^2 proper motion catalogue using two epochs of near infrared UKIDSS LAS data. We calculate absolute proper motions for stellar sources and 70% of these have uncertainties in the range of 7.5 to 12.5 mas yr^{-1} where J>17 (see Figure 4). Within the catalogue we have identified a number of scientifically interesting high proper motion sources. The catalogue will be made publicly available during 2013 and more detail can be found in Smith et al. (submitted). Until then we encourage the reader to contact and collaborate with the authors if our catalogue may be of use to them.

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