An automated 2 epoch Proper Motion search of UKIDSS and VISTA

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Op/IR Galactic plane meeting

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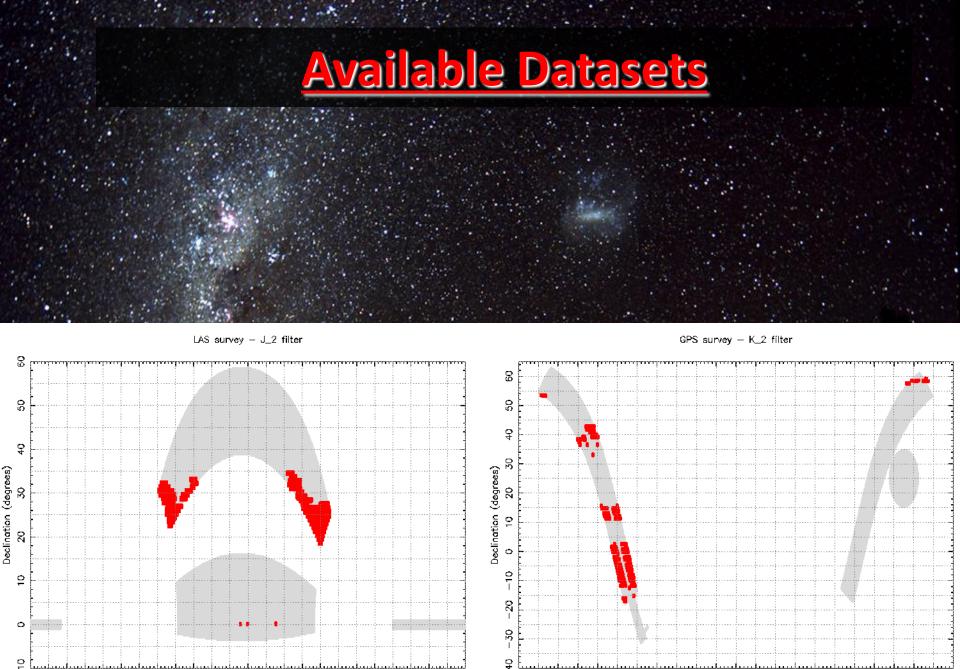
- 1. Available datasets
- 2. Motivation
- 3. Methods and first test
- 4. Results for the full UKIDSS LAS DR8 dataset
- 5. Conclusions and next steps

Available Datasets

- UKIDSS Large Area Survey (LAS) DR8 260 sq. deg.
 - 2 to 4 year baseline, 2 epochs of J band.

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- Sources have YJHK fluxes. SDSS or 2MASS can provide a 3rd epoch.
- UKIDSS Galactic Plane Survey (GPS) DR7 156 sq. deg.
 - 2 to 3 year baseline, 2 epochs of K band.
 - Sources have JHK fluxes. IPHAS or 2MASS can provide a 3rd epoch.



3

4

2 1

6 5

0

24 23

22 21 20

Right Ascension (hours)

9

8 7

24 23 22 21 20 19 18 17 16 15 14 13 12 11 10

Right Ascension (hours)

12

11 10

9 8

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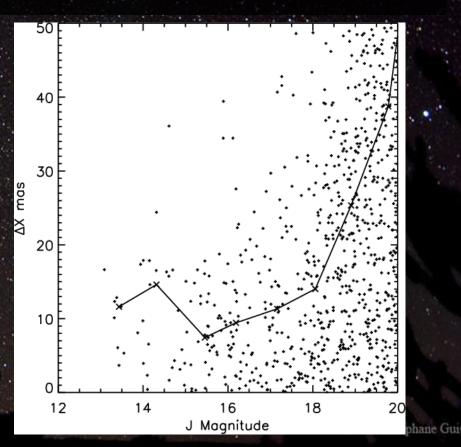
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19 18 17 16 15 14 13



- UKIDSS astrometry delivered by the CASU pipeline is good:
 - ≈ 20 mas coordinate changes detected at 1 sigma for bright sources.
 - Smart & Jones ongoing T dwarf parallax programme uses the CASU pipeline X,Y coords.

X-residuals as a fn of magnitude for a WFCAM field (Smart et al.2010, A&A 511, A30)





Rare objects

- 1. Brown dwarfs
 - i) <u>finding very cold brown dwarfs</u>. Objects too faint for normal multiband colour selection, or those with unusual colours (e.g. recent WISE 300 K object).
 - ii) <u>brown dwarf companions to stars</u>. These are benchmark objects with known age, metallicity and Hipparcos distance that can be used to test model atmospheres.
 - iii) <u>brown dwarf kinematics</u>. A probe of formation history over the lifetime of the Galaxy. Kinematics can also test model atmospheres, which suggest that the coldest T dwarfs are mostly young, very low mass objects (5-20 Mjup.)
- 2. White dwarfs (ideas from Ralf Napiwotzki)
 - i) searches for cold, helium-rich WDs none have been discovered yet.
 ii) complete searches of the Galactic thick disc and halo population to understand the evolution of the disk.

Motivation (3)

Rare objects

3. Hyper-velocity stars and runaway stars (thanks to Ralf again)

- i) Hyper-velocity stars move fast enough to escape the Galaxy believed to come from the Galactic Centre.
- ii) Runaway stars are young stars (usually OB types) with unusually high velocity, attributed to a kick from the supernova explosion of their former companion.

Decontamination of Stellar Clusters

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Proper motions are commonly used to determine whether stars in the vicinity of a nearby cluster are genuine members or not.

Beatriz Barbuy demonstrated at the 1st VVV science meeting that this can be applied to distant clusters across the Galaxy. This will be challenging, but should be possible in some cases.

Basics of the Method

We use the X,Y coordinates provided in the WFCAM Science Archive.

The coordinate transformation for reference stars at the two epochs is calculated with CP2TFORM in Matlab.

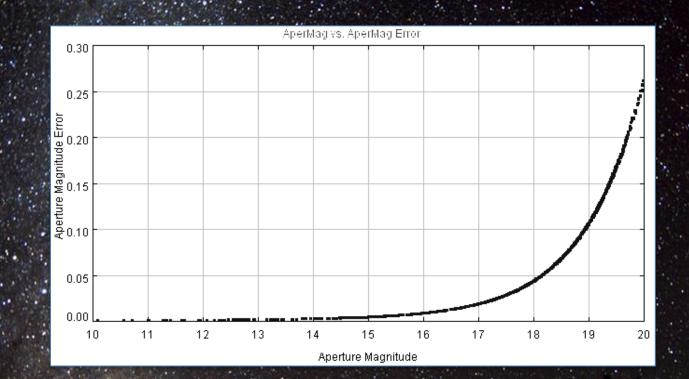
Reference stars must satisfy the following criteria:

- 1) J < 18.1 mag
- 2) class=-1 at both epochs
- 3) ppErrbits<256 at both epochs
- 4) |J1-J2| < 0.5 mag
- 5) ellipticity < 0.3 at both epochs

Stars with large residuals (i.e. large motion) are removed from the reference star list and the solution is re-calculated.

The solution is then applied to stars of all magnitudes that satisfy criteria 2 to 5.

Basics of the Method



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- The next question is how to fit the solution.
- In astrometry there is a trade off between the number of reference stars and their proximity to the star in question.
- We have tried 5 approaches with CP2TFORM in Matlab
 - a) 2nd order polynomial fit to an entire WFCAM array (NF1 method)
 - b) 2nd order polynomial fit to 2x2 sub-windows (NF2 method)
 - c) 3rd order polynomial fit to an entire WFCAM array (TOP method)
 - d) 2nd order polynomial fit to NxN sub-windows, where N is the largest number that allows a solution for all sub-windows in that array (NFV method)
 - e) unique 2nd order <u>polynomial fit for every star</u>. The search radius for local reference stars is widened until there are at least X stars in each quadrant around it, where X is typically 2 to 4. (UTF method).



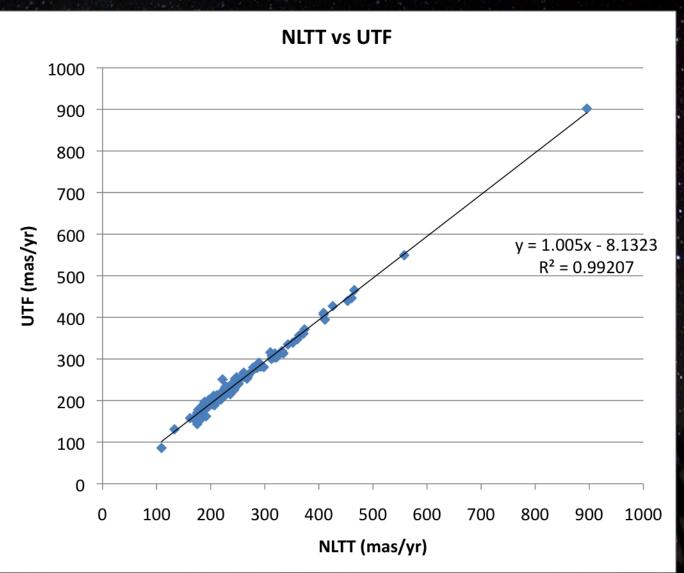
All methods worked well in the first test array with approx. 700 stars.

This first test yielded one high PM late K/early M dwarf (USNO-B1.0 1146-0144279) with a PM already in SuperCosmos and USNO-B that agreed with ours. PM ≈ 75 mas/yr is too small to see on the images – nice to know it works!



- The first 4 methods (NF1, NF2, TOP and NFV) were then applied to the whole UKIDSS LAS DR8 dataset, comprising 260 sq. deg. and 2 million stars.
 - The NFV method (using lots of small sub-windows) was the worst. A small no. of reference stars unevenly spread around the sub-window can make the fit very poor in the parts away from the reference stars.
- Results were tested by comparison with the NLTT proper motion catalogue.
 - NLTT has 120 sources for comparison in our 260 sq. deg. area.
 - NF1 (whole array method) and UTF (unique transformation method) both yield excellent results. Correlation coefficient, r = 0.99.

Results (2)



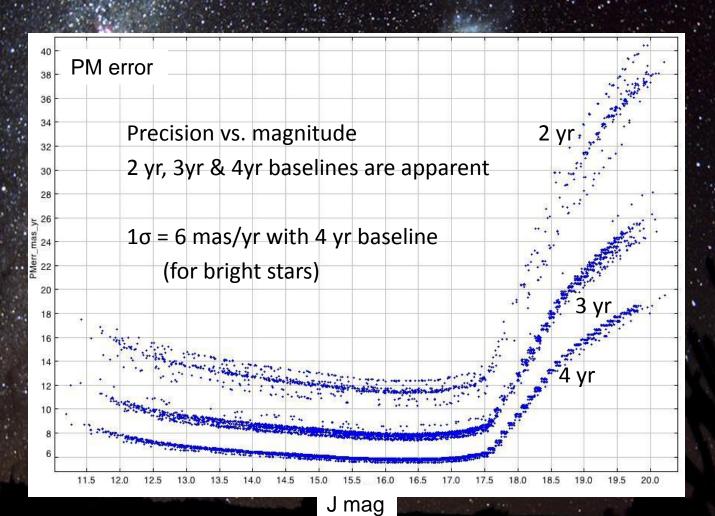


 We find: approx 1600 stars with PM measured at >10σ. approx 7500 stars with PM measured at >5σ !!

for which the first 4 methods all agree to within 1σ. (Sigma is computed for all stars in the survey as a fn. of magnitude).

This increase of 1 to 2 orders of magnitude over NLTT is due to including sources with smaller motions – typically 30-100 mas/yr for the 5σ sources.





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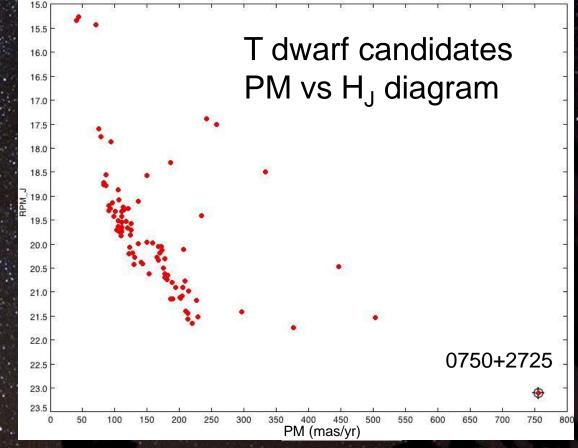


 Results include L and T type brown dwarfs (some already known) and some likely white dwarfs.

E.g. ULAS 0750+2725, a T10 dwarf with PM=756 mas/yr.

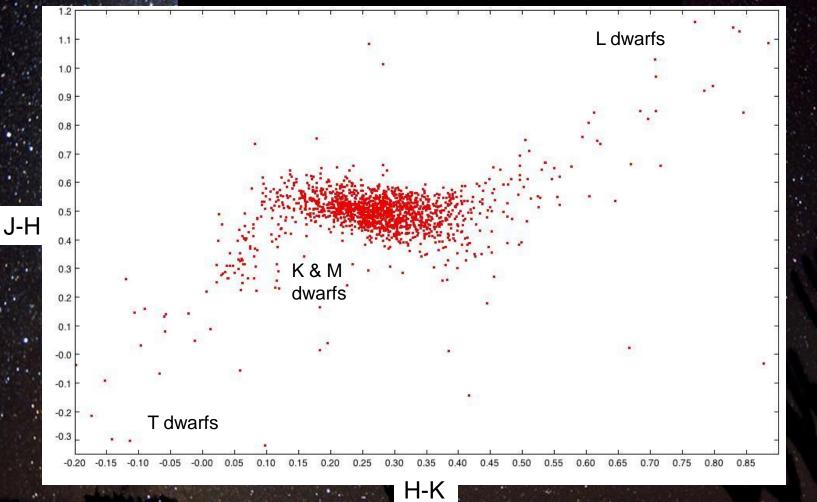
- missed by the UKIDSS brown dwarf group's colour search. It was recovered by this search and by the WISE team (Kirkpatrick et al.2011, submitted)
- Very low luminosity is indicated by the reduced proper motion $H_J = 23.1$ (definition of RPM is $H_J = J + 5 \log(PM) + 5$)





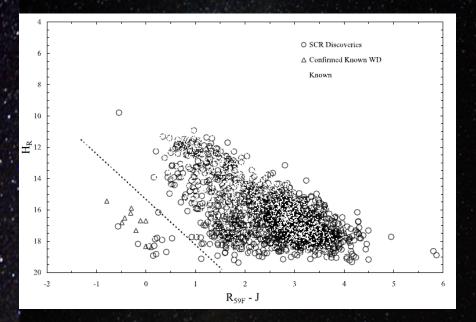


Plot is for the 10σ PM detections.

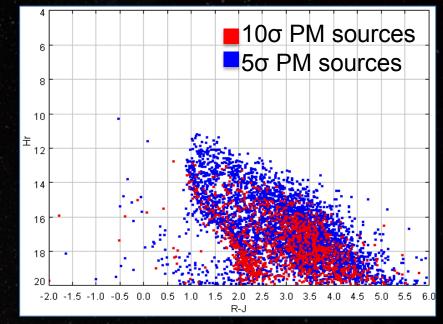




White dwarf candidates



R band RPM vs R-J colour for SuperCOSMOS-RECONS 180-400 mas/yr PM system discoveries and known WDs. (Fig 5; Finch et al.2007, Astron J 133)



Recreation of Hr vs R-J plot as in Finch et al. using NF1 data (SDSS R mags). 133 candidates, 2% of range.

Conclusions and future work

- NF1 (2nd order fit to the whole array) is the simplest and quickest method NF1 is very accurate for UKIDSS data, so UKIRT/WFCAM must have negligible higher order astrometric distortion.
- UTF (unique transformation for each star) is a good way to confirm the results of NF1 it is best to use several methods for confirmation.
- UTF, or a higher order approach like TOP, may be better for VISTA, which has larger astrometric distortions due to the wider field & faster beam.
- The GPS and VVV must be investigated to determine the best method in crowded fields.