Calculating proper motions in the WFCAM Science Archive for UKIDSS

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Survey data release

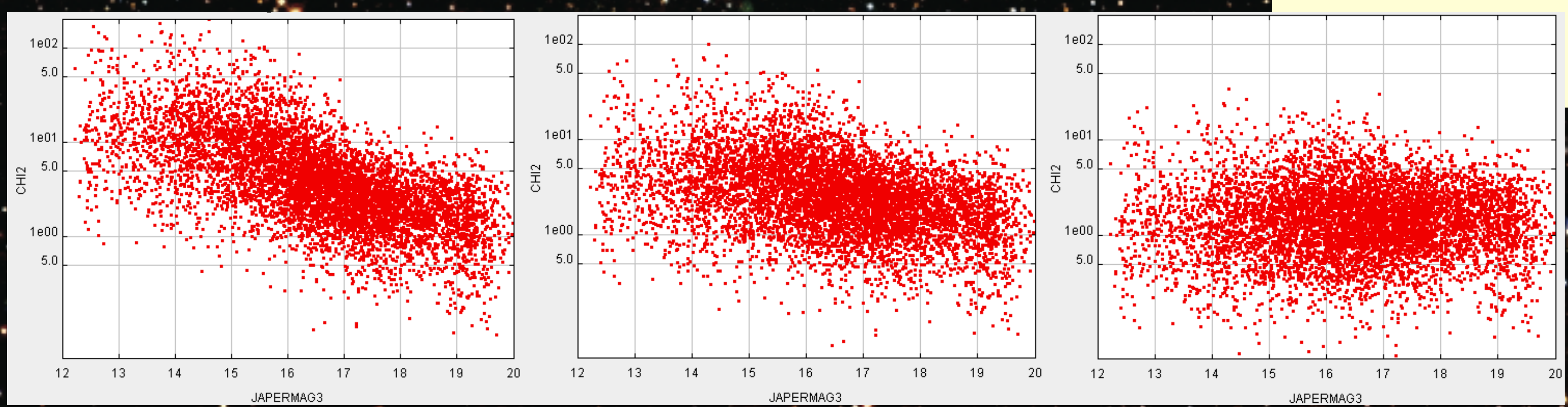
The ninth data release from the UKIRT Infrared Deep Sky Surveys (UKIDSS DR9) represents five years worth of observations by its wide-field camera (WFCAM) and is the first to include proper motion values in its source catalogues for the shallow, wide-area surveys; the Large Area Survey (LAS), Galactic Clusters Survey (GCS) and Galactic Plane Survey (GPS).

http://surveys.roe.ac.uk/wsa

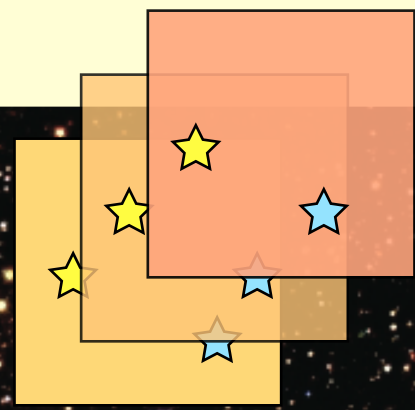
Astrometry optimisations

To calculate useful proper motions we need the astrometry to be as accurate as possible. Corrections were calculated for each overlapping frame that makes up the set of observations in the passband-merged catalogue to account for systematic errors. A master frame was selected (the observation taken with the shortest-wavelength filter) and the transformation of the positions of each detection in the slave frames to the master positions was then calculated via an iterative least-squares fit, rejecting three-sigma outlier displacements, until a set of transformation coefficients describing the systematic error map for that set of frames evolved.

If the systematic error found in any frame in the set is too large then that entire frame set is rejected and no proper motions calculated.



Reduced χ² distribution for all proper motion solutions in the LAS against J magnitude (default aperture) for (left) no minimum measurement error (middle) σ_{min} = 5 mas (right) σ_{min} = 10 mas



Treatment of errors

Calculating the proper motions with measurement errors derived from the catalogue extractor resulted in a distribution of reduced χ² values for the astrometric solution that clearly showed the errors were underestimated for brighter stars. To account for this we introduced a minimum error that we empirically found to be optimal at a value of σ_{min} = 10 mas.

$$\sigma = \mathrm{sqrt}(\sigma_{min}^2 + \mathrm{pixScale}^2.(\sigma_x^2 + \sigma_y^2)/2)$$

Proper motion attributes

The following source attributes found in the catalogue are derived from the proper motion solution (where possible):

- **epoch** (years) *<T>* - inverse variance weighted mean epoch of observations
- **ra** (degrees) α - right ascension position at mean epoch
- **dec** (degrees) δ - declination position at mean epoch
- **sigRa** (degrees) σ_α - uncertainty in right ascension position
- **sigDec** (degrees) σ_δ - uncertainty in declination position
- **muRa** (mas/yr) μ_α - proper motion in right ascension
- **muDec** (mas/yr) μ_δ - proper motion in declination
- **sigMuRa** (mas/yr) $\sigma_{\mu\alpha}$ - uncertainty in proper motion in right ascension
- **sigMuDec** (mas/yr) $\sigma_{\mu\delta}$ - uncertainty in proper motion in declination
- **nFrames** - *N* - number of observations used in the proper motion solution
- **chi2** - reduced χ² goodness-of-fit of the proper motion solution (requires nFrames to be at least 3)

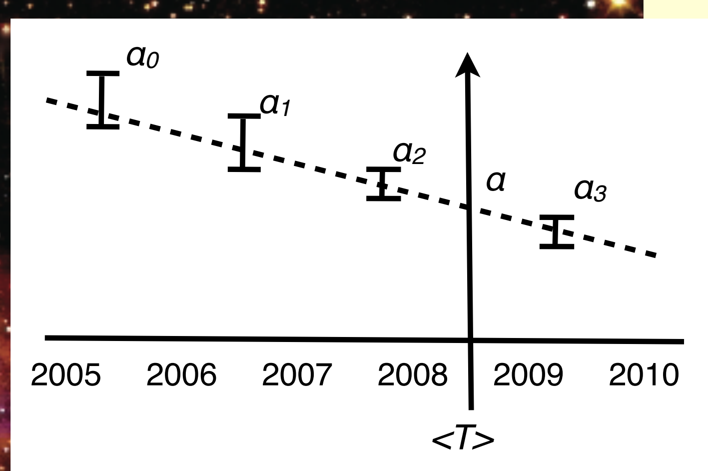
Proper motion solution

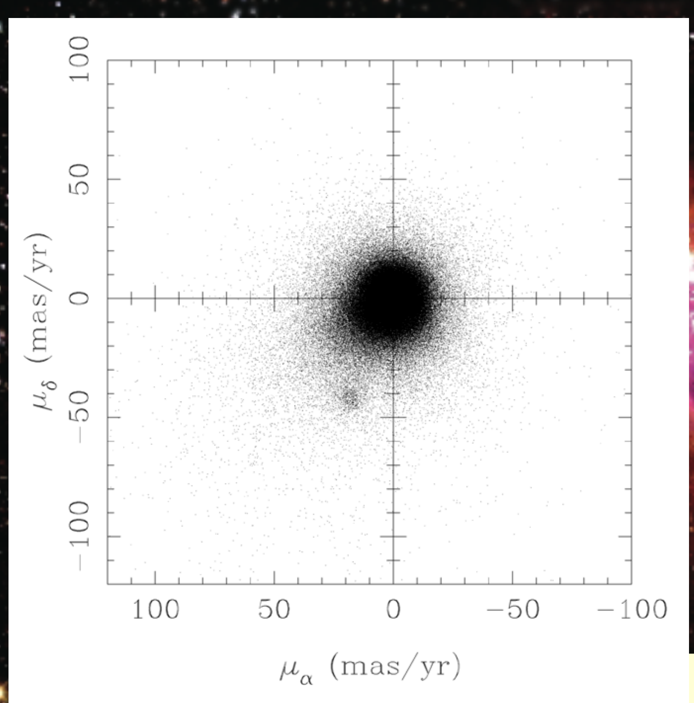
The proper motions are calculated during the formation of the passband-merged source catalogue and thus are limited by the matching tolerance used in this process of 2", so only small proper motions can be measured, down to an astrometric precision of about 5 mas/yr for brighter stars with the full 5-year baseline. To improve their reliability proper motion solutions are only calculated if the individual detections are separated by at least half a year, resulting in the largest measurable proper motion of 4"/yr.

$$\alpha = \alpha_0 + \mu_\alpha . T'_0 \qquad \delta = \delta_0 + \mu_\delta . T'_0 \qquad T'_0 = T_0 - \langle T \rangle$$

$$\begin{pmatrix} 1/\sigma & T'_0/\sigma & 0 & 0 \\ 0 & 0 & 1/\sigma & T'_0/\sigma \\ \vdots & \vdots & \vdots & \vdots \\ 1/\sigma & T'_N/\sigma & 0 & 0 \\ 0 & 0 & 1/\sigma & T'_N/\sigma \end{pmatrix} \cdot \begin{pmatrix} \alpha \\ \mu_\alpha \\ \delta \\ \mu_\delta \end{pmatrix} = \begin{pmatrix} \alpha_0/\sigma \\ \delta_0/\sigma \\ \vdots \\ \alpha_N/\sigma \\ \delta_N/\sigma \end{pmatrix}$$

A design matrix is formed for a series of linear equations describing the proper motion in the position of the detections (with systematic errors removed) and is solved via SVD. The errors on these measurements are then calculated through the covariance matrix and a goodness-of-fit of the resulting solution is then made with a reduced χ² test.





Proper motions in the Pleiades

A plot of the proper motions calculated for stars observed in the region of the Pleiades cluster clearly identifies the cluster members through a common proper motion centred around μ_α = 20 mas/yr & μ_δ = -40 mas/yr.

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