

# Peering through the dust

## Precise astrometry in the Galactic mid-plane with the VVV survey

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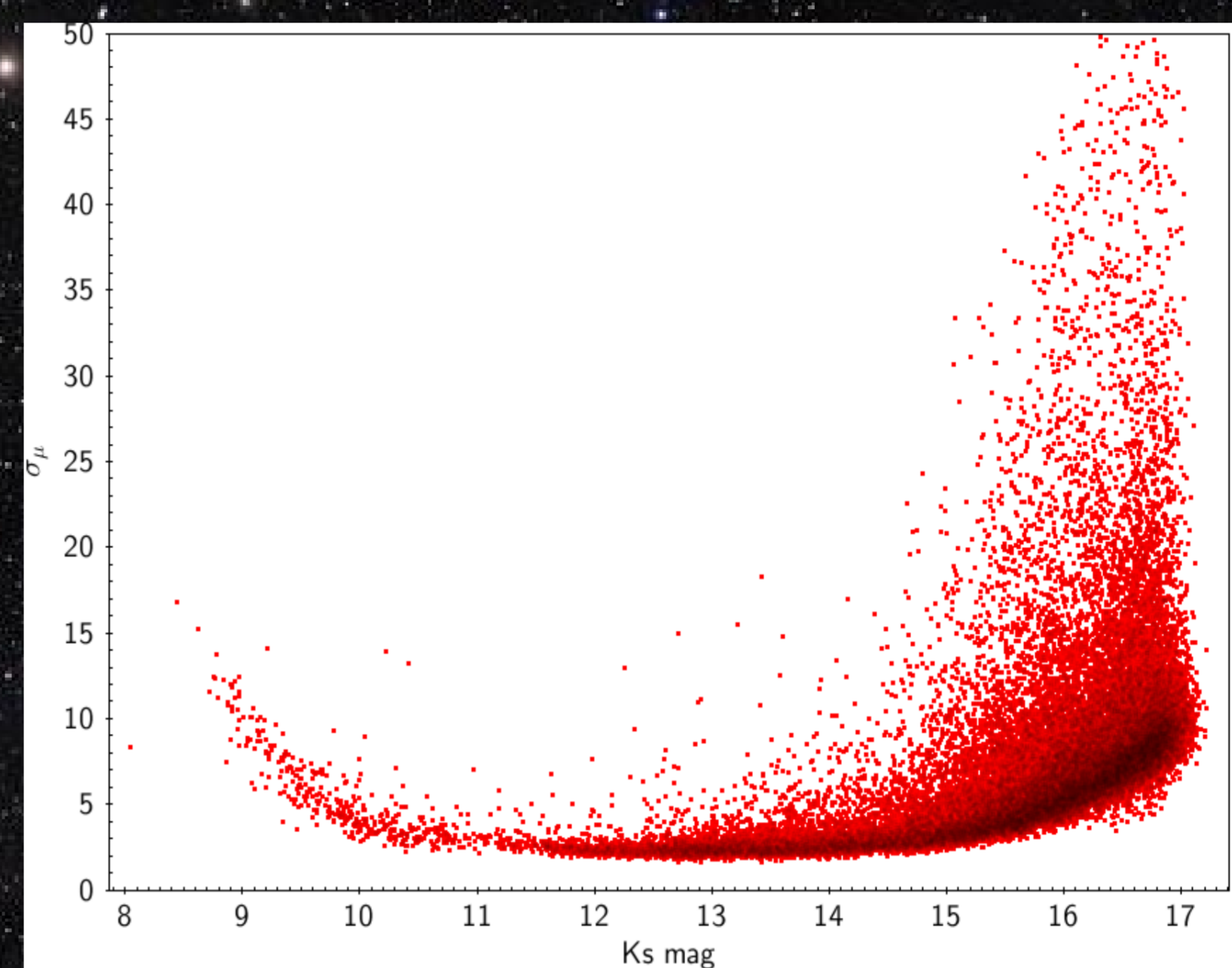
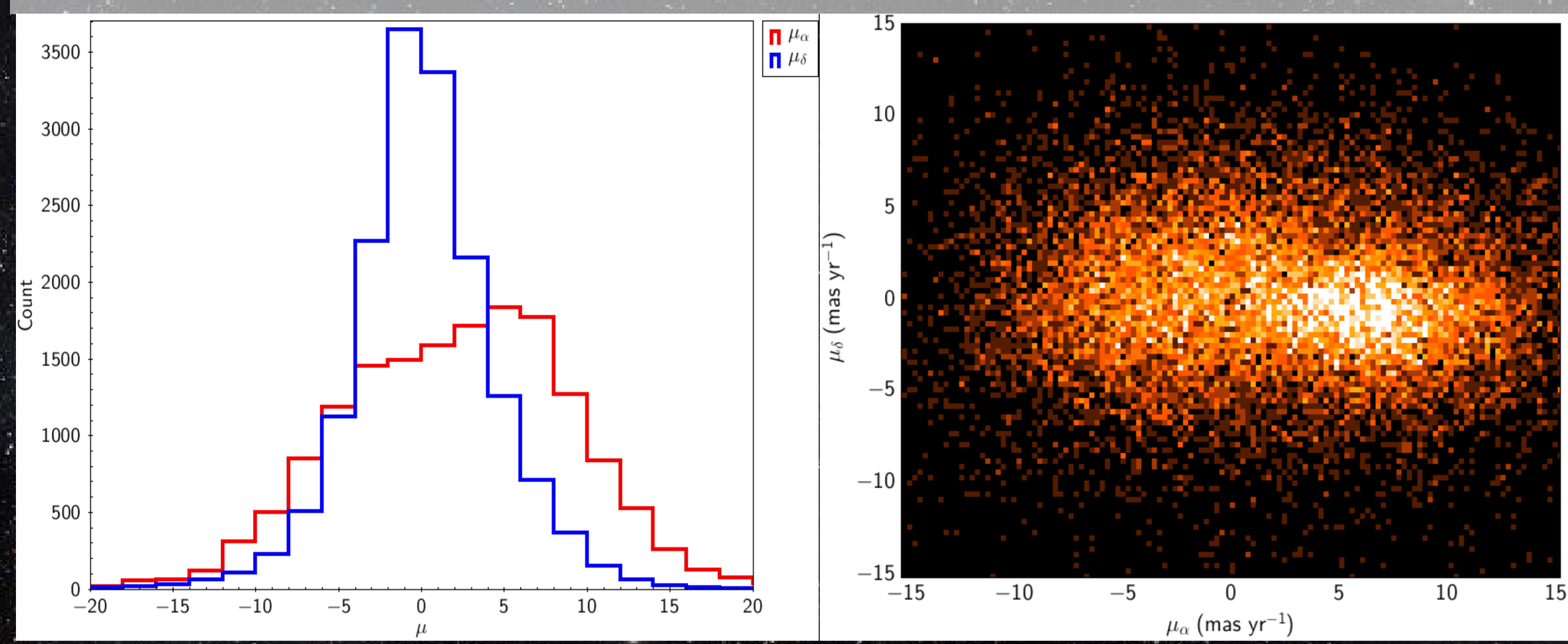
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Gaia will see little of the Galactic mid-plane and nuclear bulge due to high extinction at optical wavelengths. To study the structure and kinematics of the inner Galaxy we must look at longer wavelengths. The Vista Variables in the Via Lactea (VVV, [1]) survey currently provides just over 4 years of observations covering approximately 560 square degrees of the Galactic bulge and plane. Typically each source is observed 50-150 times in the Ks band over this period. Using these data we provide relative proper motions for approximately 200 million unique sources down to Ks~16 with uncertainties approaching 1 mas/yr. In addition, we fit a solution of the parallactic motion of all sources with significant proper motion and discover a number of new nearby brown dwarfs. These results will allow us to identify faint common proper motion companions to stars with Gaia parallaxes, increasing the number of brown dwarf benchmark objects. Our absolute astrometric calibration precision is currently ~2 mas/yr, based on PPMXL. The Gaia absolute astrometric reference grid will allow us to precisely anchor our results and measure the streaming motions of stars in the bulge. Finally, we anticipate that the catalogue could provide kinematic distances to the numerous optically invisible high amplitude variable stars that VVV is discovering.

### Kinematics of Globular Clusters (*below*):

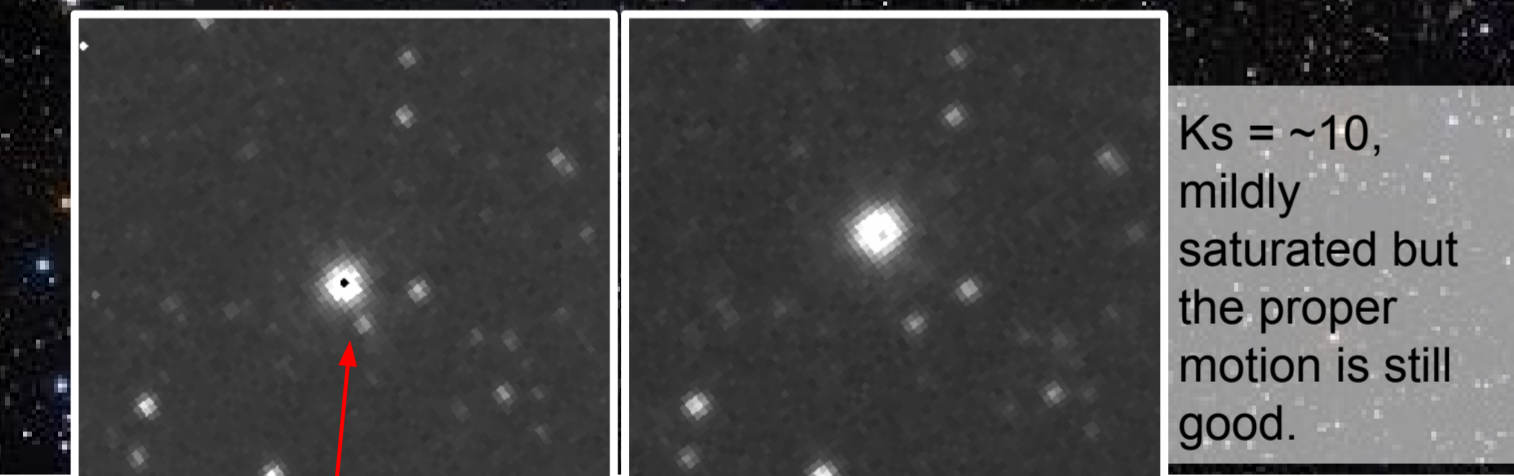
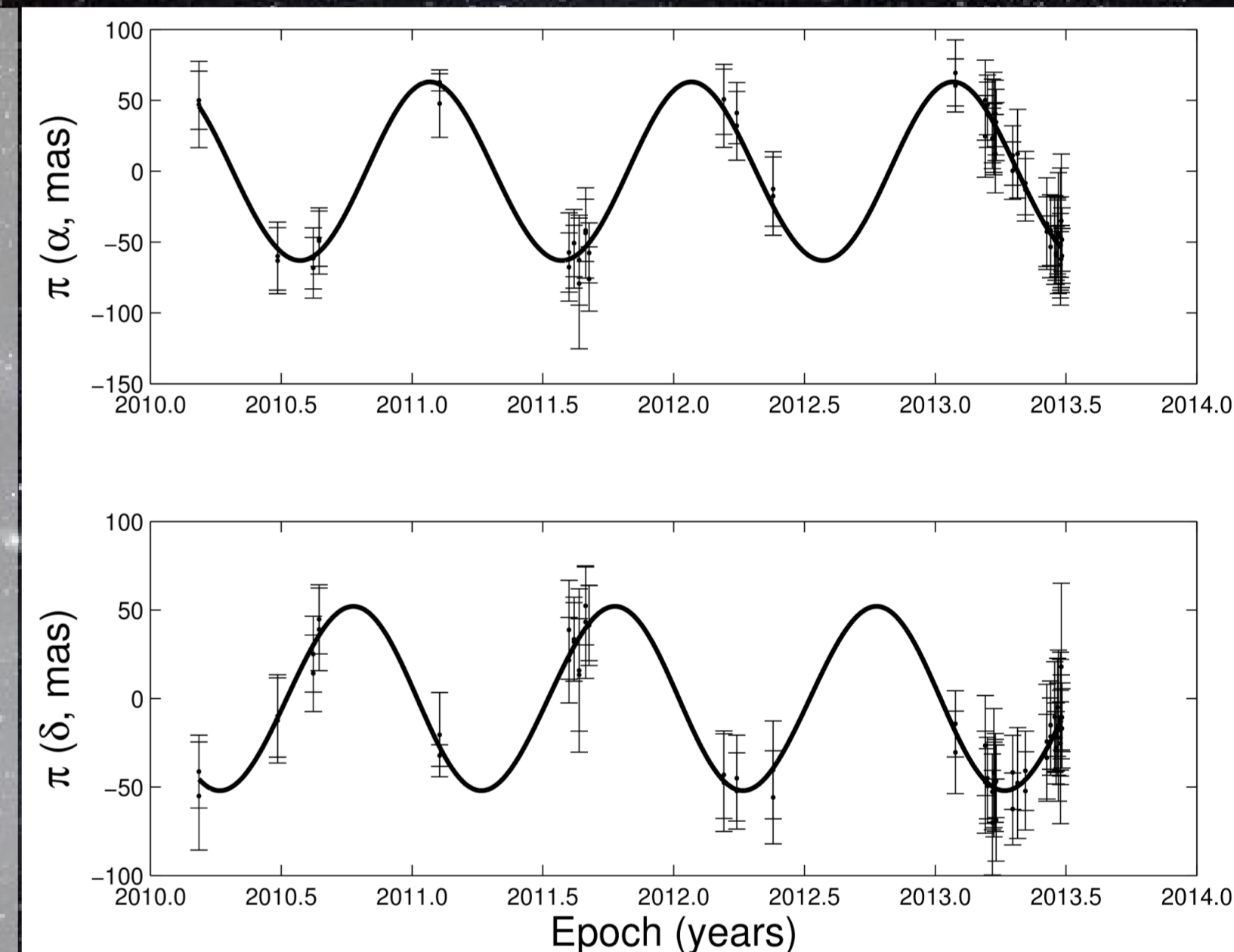
Proper motion in RA and Dec for the 16,000 sources flagged as stellar and with  $\sigma_\mu < 10 \text{ mas/yr}$  within 10 arcmin of the center of NGC 6656 (M 22, 3Kpc). The proper motion distribution of M 22 is visible ( $\mu_\alpha \sim 6 \text{ mas/yr}$ ,  $\mu_\delta \sim 0 \text{ mas/yr}$ ). This is a quick example based on the standard catalogue for which we select astrometric reference sources in a homogeneous manner. A careful selection of astrometric reference sources in specific cases such as this could improve such results. Note that this is without a relative to absolute correction, for which Gaia will be useful...



**Proper Motion Accuracy (*left*):** Total PM error vs. Ks band magnitude for the 30,000 sources detected within 10 arcmin of NGC 6656 (M 22). These measurements are made from 70-80 epochs in total. We expect to see approximately 30% improvement with the inclusion of the most recent 2014 data. The parallax accuracy will improve to a variable degree.

### Example Parallax (*right*):

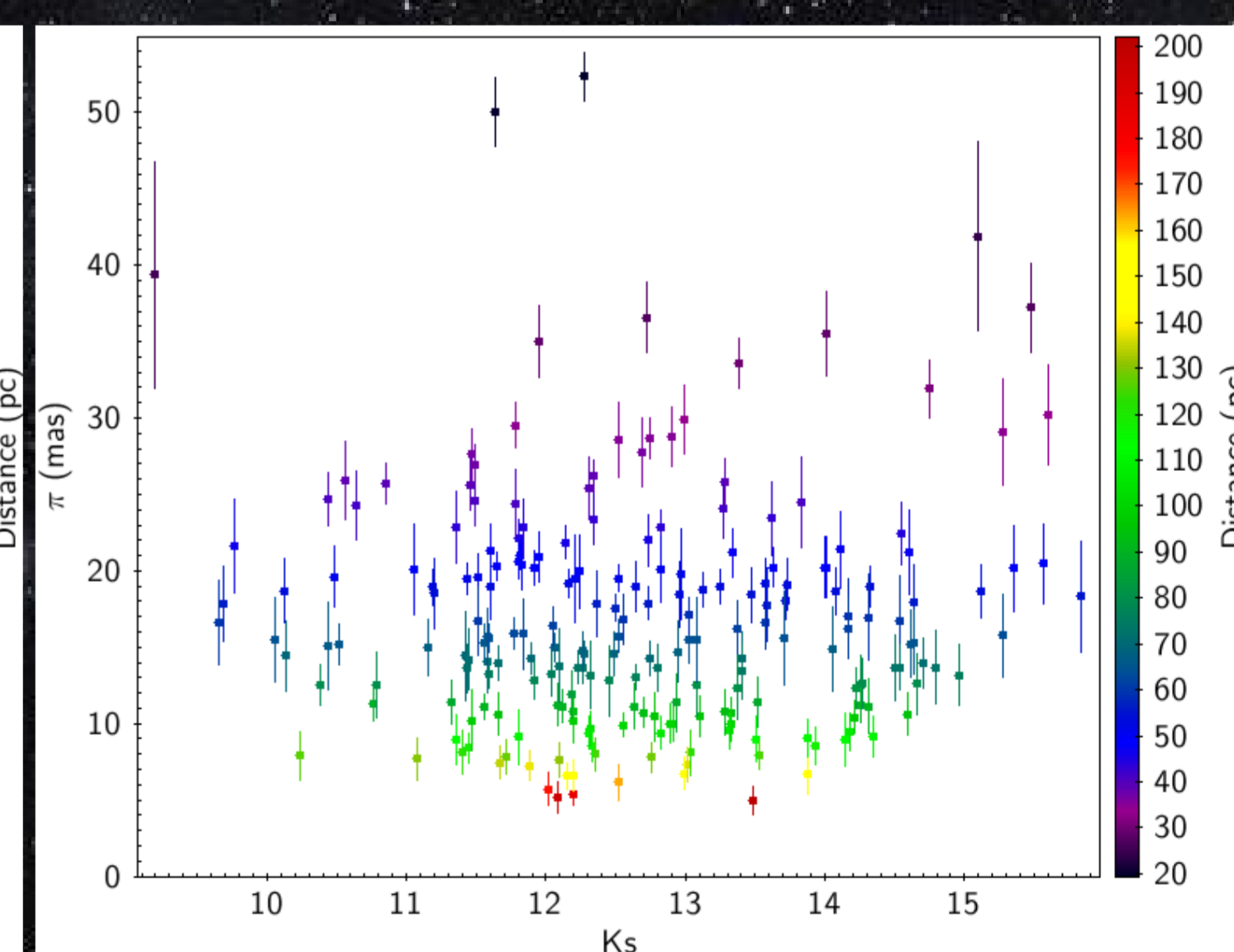
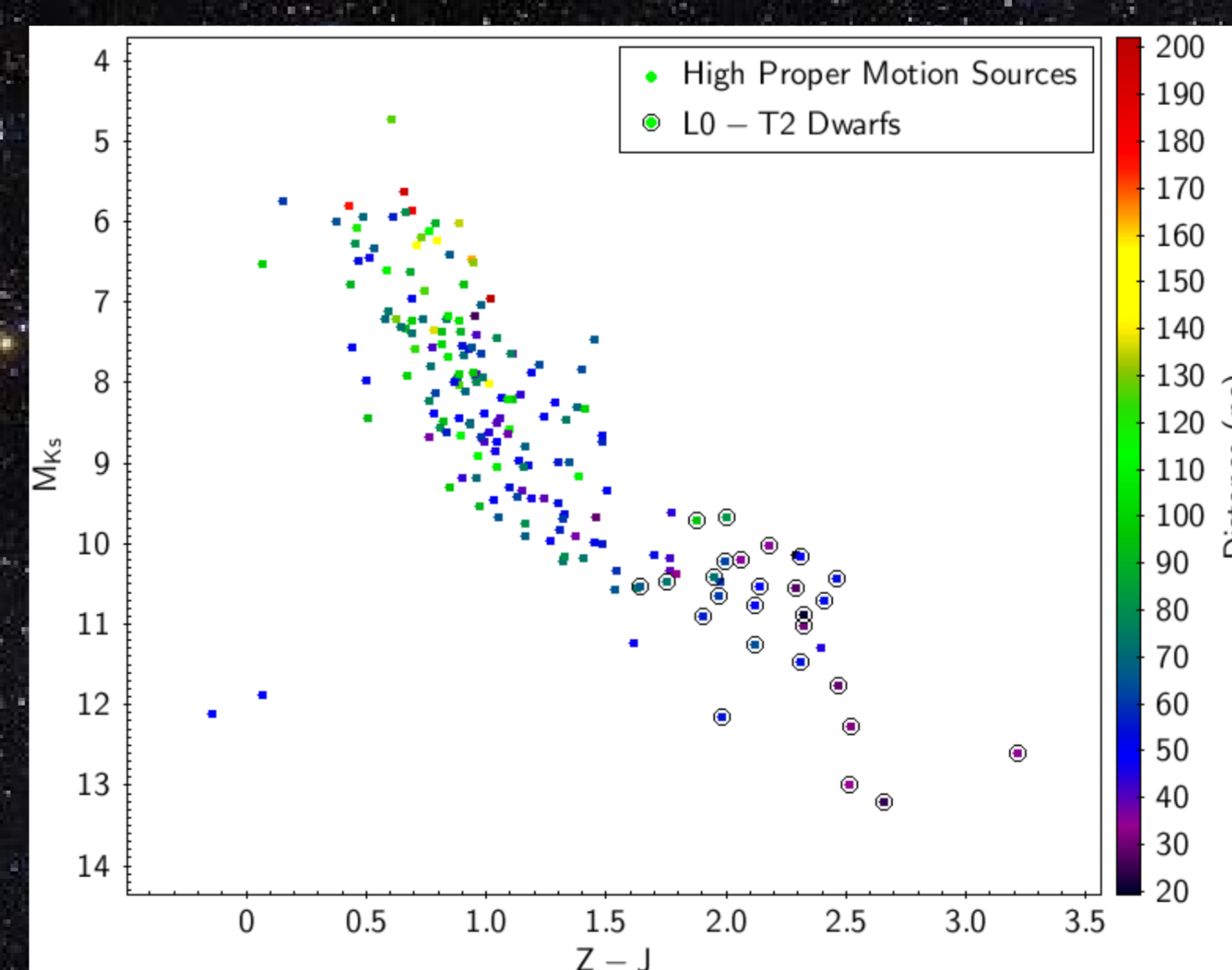
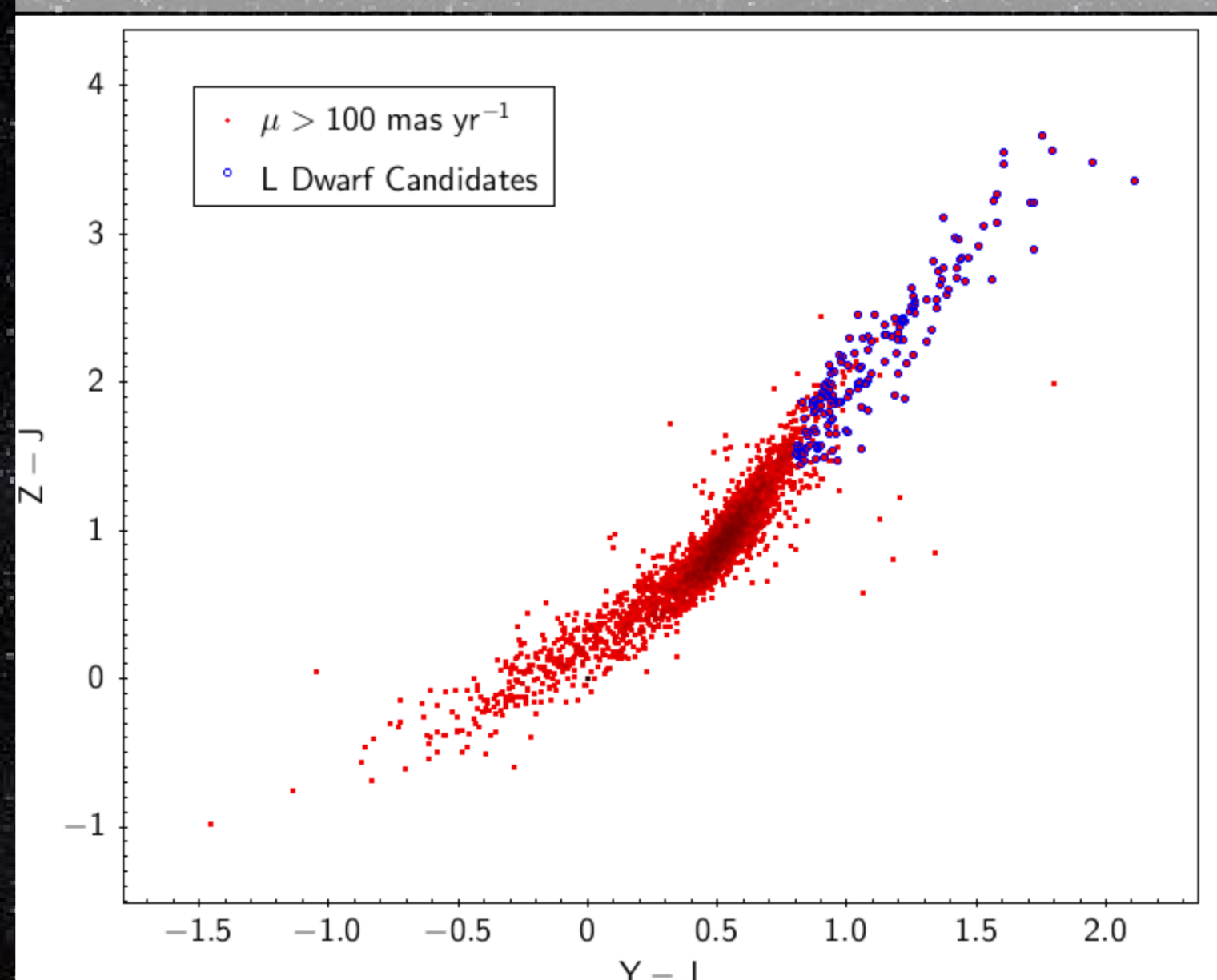
A 44 sigma parallax of a newly discovered object at 15pc ( $K_s = 13.78$ ,  $\pi = 67.5 \pm 1.5 \text{ mas}$ ,  $\mu = 97.8 \pm 1.7 \text{ mas/yr}$ ). The VVV NIR colours of this object are consistent with a  $t_{\text{eff}} = 6000\text{K}$  pure-H white dwarf at 15pc. The variable epoch distribution of the survey means such high quality parallax measurements are not always possible. Despite this we are expecting thousands of  $>5\sigma$  parallaxes at up to 200pc at completion, currently ~1 mas errors in the best of cases though this will improve with the inclusion of the 2014 data.



$K_s \approx 10$ , mildly saturated but the proper motion is still good.

### Colours of High Proper Motion Sources (*below*):

The same  $\mu > 100 \text{ mas/yr}$  sources in a Y-J/Z-J colour/colour diagram with a selection of 149 L0-T2 dwarf candidates ( $J-K > 1.0$ ,  $Y-J > 0.8$ ,  $Z-J > 1.4$ ) highlighted.

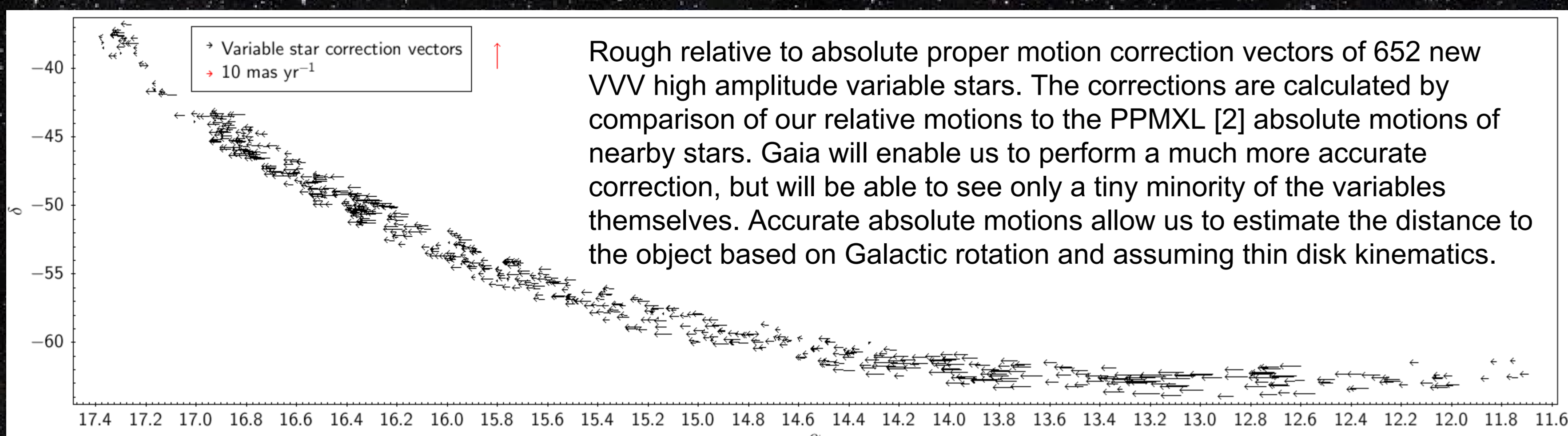


### New Discoveries (*above*):

We have identified 4874 sources with  $\mu > 100 \text{ mas/yr}$ ,  $\sigma_\mu < 10 \text{ mas/yr}$  and low  $\chi^2$  (588 with  $\mu > 200 \text{ mas/yr}$ ). Only 4% of these are currently present in SIMBAD. Visual inspection of a number of these indicates a minimal false positive rate, even among saturated sources.

**High Proper Motion HR Diagram (*left*):** A selection of 167 objects with  $\mu > 200 \text{ mas/yr}$ , and 26 newly discovered L0-T2 dwarfs from the  $\mu > 100 \text{ mas/yr}$  selection. This includes only sources with VVV Z and J detections and well fitted  $5\sigma$  parallaxes. The 26 brown dwarfs increase the number of L0-T2 dwarfs with trigonometric parallaxes by ~20%.

**Parallax Accuracy (*right*):** The same objects in Ks vs parallax, with parallax uncertainties shown.



Rough relative to absolute proper motion correction vectors of 652 new VVV high amplitude variable stars. The corrections are calculated by comparison of our relative motions to the PPMXL [2] absolute motions of nearby stars. Gaia will enable us to perform a much more accurate correction, but will be able to see only a tiny minority of the variables themselves. Accurate absolute motions allow us to estimate the distance to the object based on Galactic rotation and assuming thin disk kinematics.

### Summary:

The VVV contains a wealth of useful astrometric data that will be complementary to Gaia. Gaia will provide the VVV with an astrometric reference frame tied to the ICRS, which can then be used kinematically investigate distant variable sources, Galactic clusters, the Galactic bulge, etc.

We are currently undertaking further searches using a method which more reliably detects the faintest objects and those with motion sufficiently high to go unmatched between epochs or blend with background sources. This has already identified a number of new objects with higher proper motion and recovered eg. VVV BD001 [3].

[1] Minniti, D. et al., New Astronomy, 15, 5, 433-443. (2010)  
[2] Roeser, S. et al., Astron. J., 139, 2440-2447 (2010)  
[3] Beamin, J.C. et al., A&A, 557 (2013)

