Distinguishing between real transients and ghost sources in Swift/UVOT observations

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UCL

Introduction

In recent years Swift/UVOT has taken on a key role in identifying and following up transients. While automated source detection and difference imaging can help in finding transients, these tools cannot distinguish between real transients and star-like image artefacts caused by stray light. Image artefacts such as readout streaks or various ring structures are easy to identify by eye, and we have programs to identify these and flag sources within them. However, during the gravitational wave EM follow-up searches begun in 2016[1], we started to identify a small number of star-like features, "ghosts" of bright sources lying within a certain radius of the centre of the field of view, on the opposite side from the bright source.

Ghost spotting and mapping

Point-like but slightly extended objects, known as ghosts, are occasionally found on the opposite side of the image from a bright source (bs) due to scattered light (Figure 1). They only appear when the bs is brighter than ~10th magnitude and lies on/near the 'scattered light ring' seen in summed-up images of the sky background (see Figure 2). The approximate circles in which ghost and bs lie are not rotationally symmetric and are therefore best characterized in raw coordinates.

Taking 48 ghost–bs pairs identified during gravitational wave follow-up[1], we plotted their positions in X and Y using raw pixel coordinates (Figure 3). The parameters from straight-line fits can be used to predict positions of ghosts from bs positions (or vice versa).

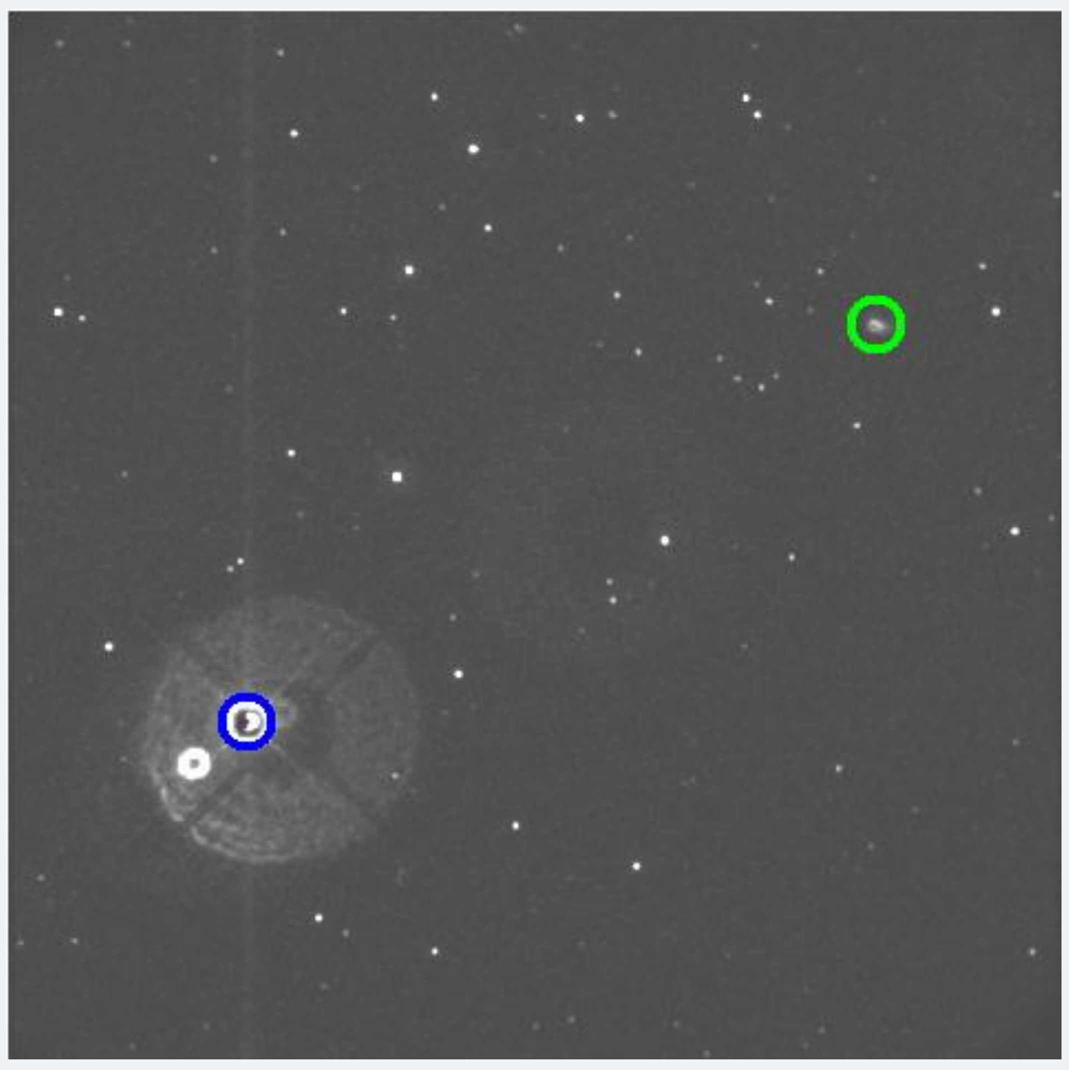

Figure 1: Example image from obsid 07017182001 showing a bright source (blue) – ghost (green) pair.

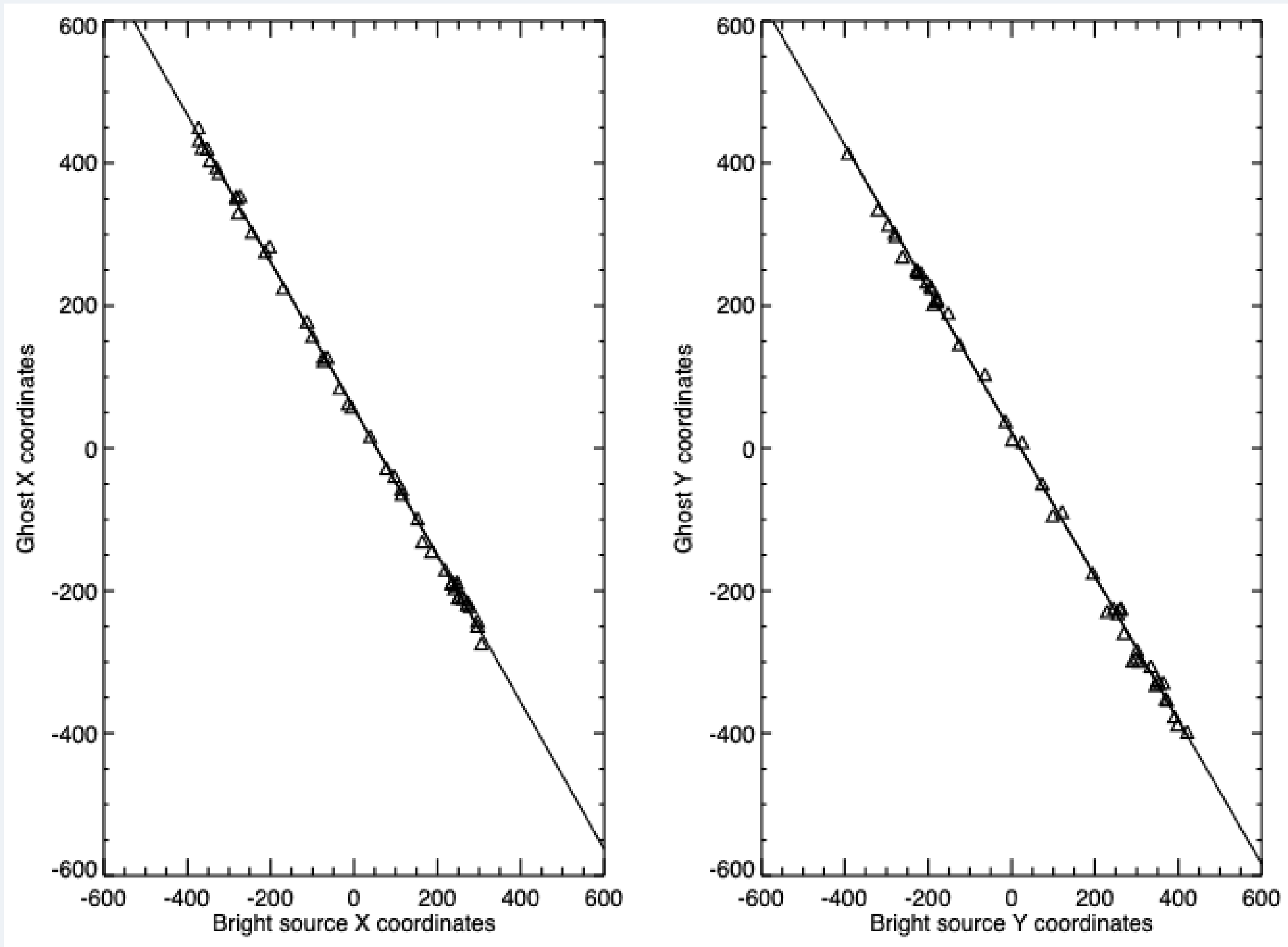

Figure 3: Ghost pixel (~1"/pix) raw X (left) and Y (right) coordinates plotted against bright source coordinates, U filter.

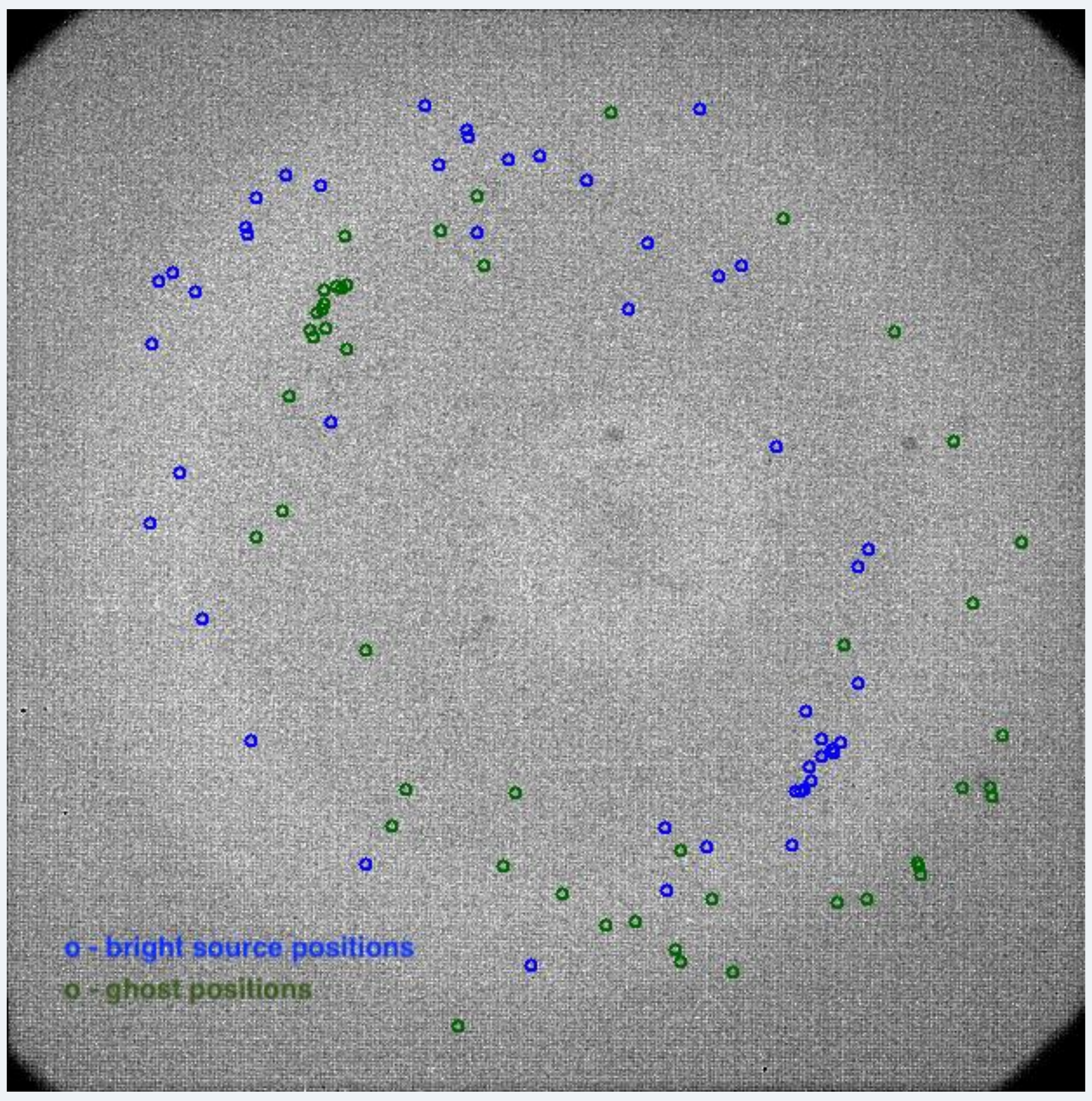

Figure 2: Raw coordinate positions of identified bright-source (blue) – ghost (green) pairs overlaid on an image of the diffuse scattered sky background (made by summing up many images after removing sources) in the U filter. The positions map out a pair of offset circles that are closely aligned to the large scattered light ring. Bright sources well outside or inside the ring do not appear to trigger ghosts.

Using the calibration to predict ghosts from bright source positions

We measure the distance between predicted ghost positions and measured positions, plotting X and Y separately (Fig 4), in 2d (Fig 5) and as histograms (Fig 6). Table 1 gives a summary of the mean distances of the predicted positions from measured positions in both raw and sky. Prediction in sky coordinates has far more scatter because the circles illustrated in Figure 2 are not rotationally symmetric and so, after rotation to sky coordinates (North up), they no longer lie on a consistent circle. To get a better result the sky images have to be rotated back using the position angle (plus an offset angle chosen to minimize the scatter). This gives the result in Table 1. For even better results the distortion correction should be reversed.

Other sources of scatter include the fact that neither the bs nor ghost is a point source because of the distortion caused by coincidence loss[2]: the brightest part of the ghost may not correspond to the centre of the bs. Also, the raw coordinates of the first image after a slew can be shifted by several arcsecs.

The calibration is being incorporated into `uvotflagqual` to flag potential ghosts during image processing, thus avoiding ghosts appearing in the serendipitous source catalogue[2] (UVOTSSC) masquerading as real sources. An `idl` program is already available[3] to check individual observations and this will be improved with the inclusion of better distortion reversal.

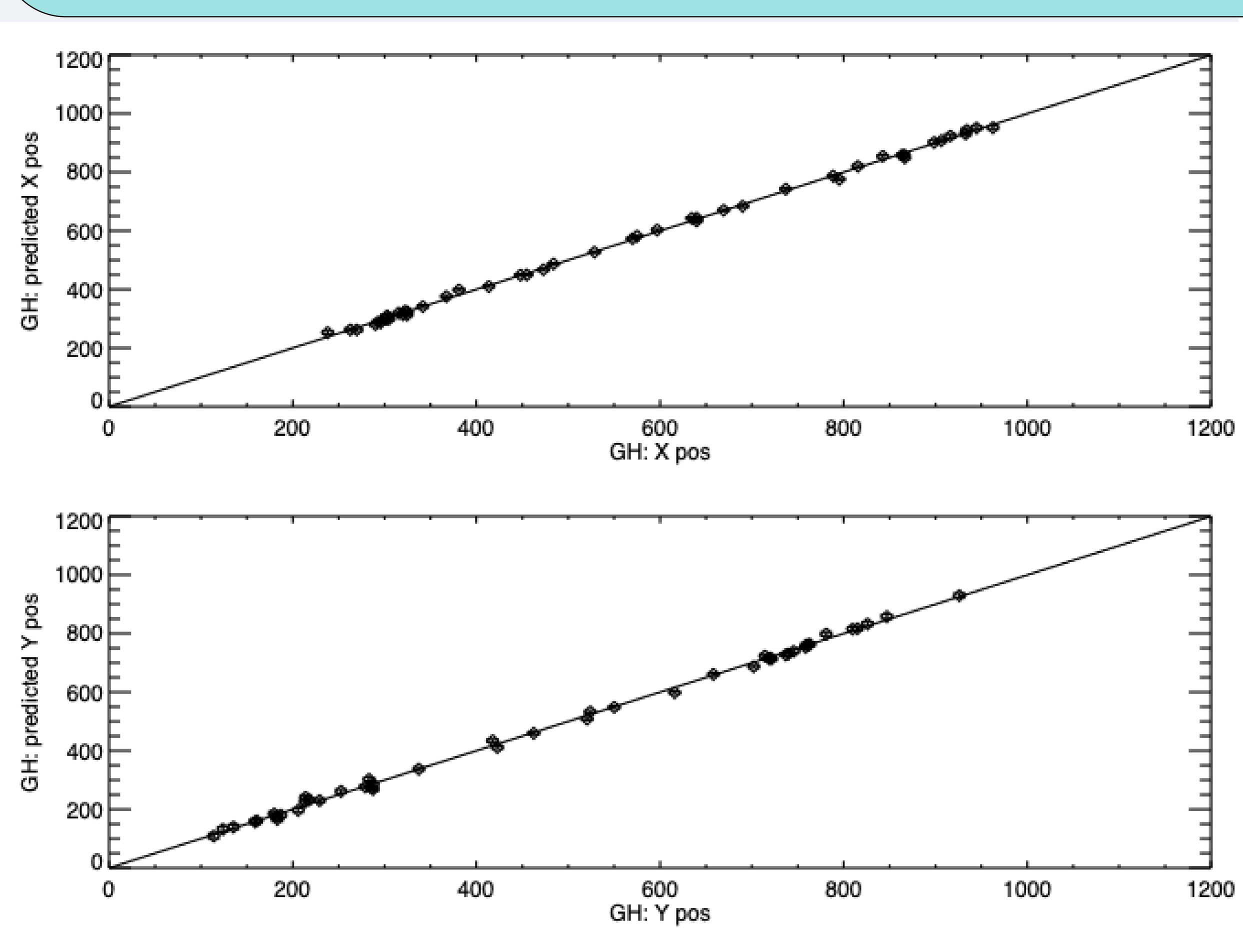

Figure 4: Comparing predicted ghost coordinates with measured coordinates. Raw images, U filter. Formal error bars are too small to see and do not reflect the scatter.

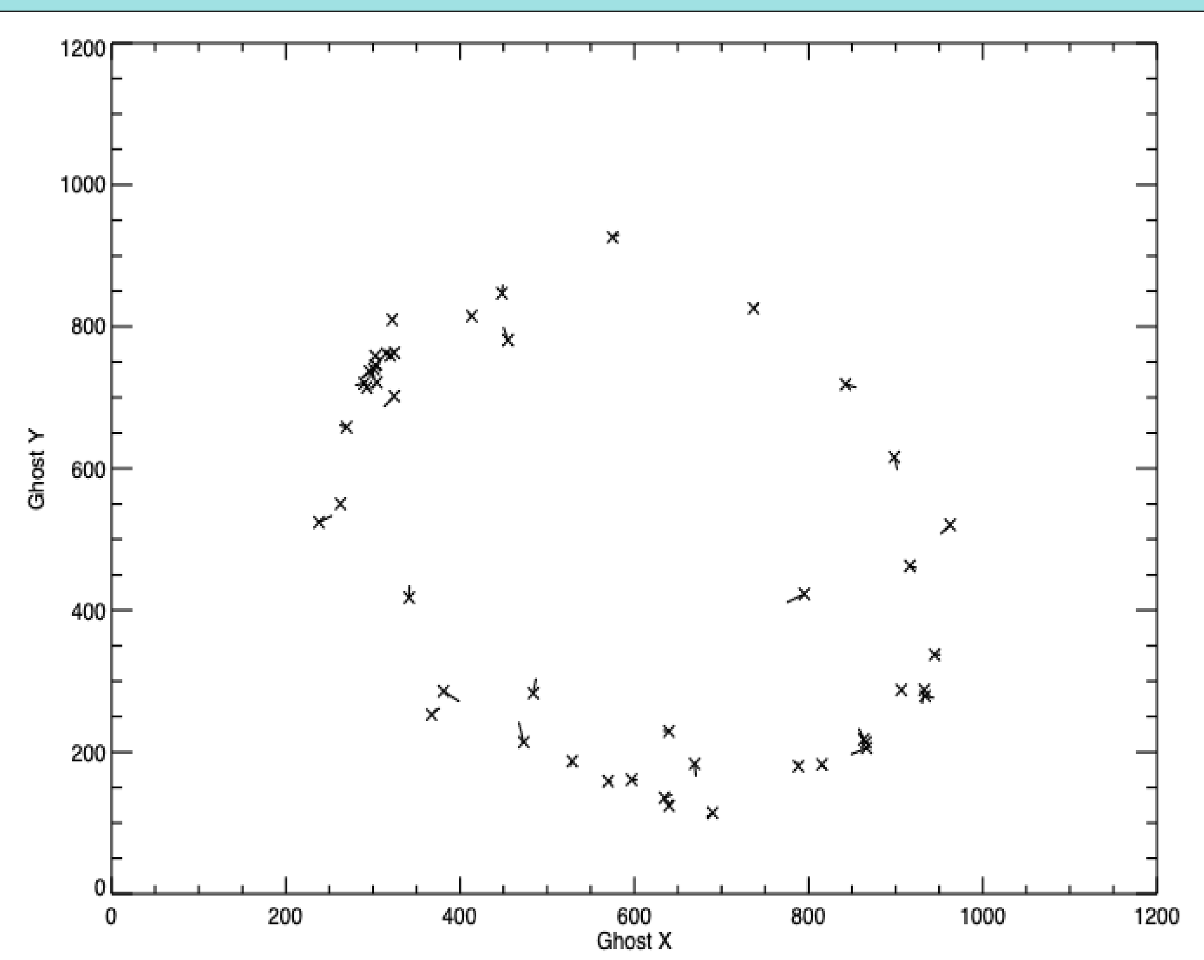

Figure 5: Ghost positions (crosses), with a line indicating the shift between the actual and predicted positions, showing there is no particular pattern to the error scatter.

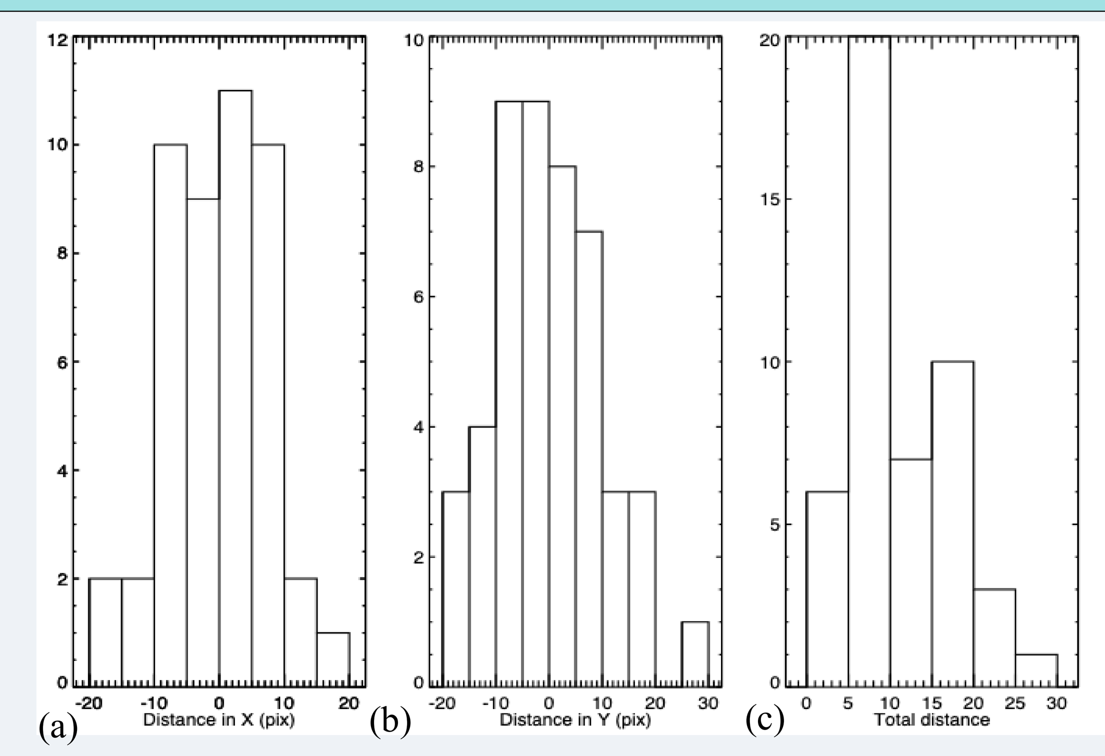

Figure 6: The distance (in pixels/arcsec) between predicted and measured ghost positions expressed as histograms in (a) X, (b) Y and (c) total.

Table 1: Mean and sd of distance in pixels (~1"/pix) between ghost positions predicted from bs positions and actual ghost positions and bs positions predicted from ghost positions with actual bs positions.

	Predicting ghost position from bs		**Predicting bs position from ghost**	
	Mean (arcsec)	Standard Deviation	Mean (arcsec)	Standard Deviation
Raw pixel coordinates	11.20	6.23	11.04	6.04
Sky pixel coordinates	16.31	7.86	15.96	7.68

References

[1] Oates S. R. et al., 2021, 'Swift/UVOT follow-up of gravitational wave alerts in the O3 era', MNRAS 507, 1296–1317

[2] Page M. J. et al., 2014, 'The Swift UVOT Serendipitous Source Catalogue', Proc. Sci., Vol. 223, Swift: 10 Years of Discovery (SWIFT 10). Sissa, Trieste, PoS#37

[3] Available on request

Conclusions

- We have a simple ghost calibration for the U filter that allows us to predict the position of a ghost from a known bright source position (or vice versa) within 11.2±6 arcsec in raw coordinates or 16.4±8 arcsec in sky coordinates.
- Sky images need to be transformed to raw coordinates, and ideally have distortion reversed, to use the calibration.
- Still to do: (i) extend to the other filters where possible (U is used for most follow-up and therefore there are more examples.) (ii) test and release the calibration incorporated into uvotflagqual, (iii) upgrade the idl checking program to use a better distortion correction.