Optimal Photometry of Faint companions

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1 *Introduction*

We have proposed a new post-processing technique for the detection of faint companions and the estimation of their parameters from adaptive optics (AO) observations. We apply the optimal linear detector, which is the Hotelling observer, to perform detection, astrometry and photometry on real and simulated data. The real data was obtained from the AO system on the 3m Lick telescope.
The Hotelling detector, which is a prewhitening matched filter, calculates the Hotelling test statistic which is then compared to a threshold. If the test statistic is greater than the threshold the algorithm decides that a companion is present. This decision is the main task performed by the Hotelling observer. After a detection is made the location and intensity of the companion which maximise this test statistic are taken as the estimated values.

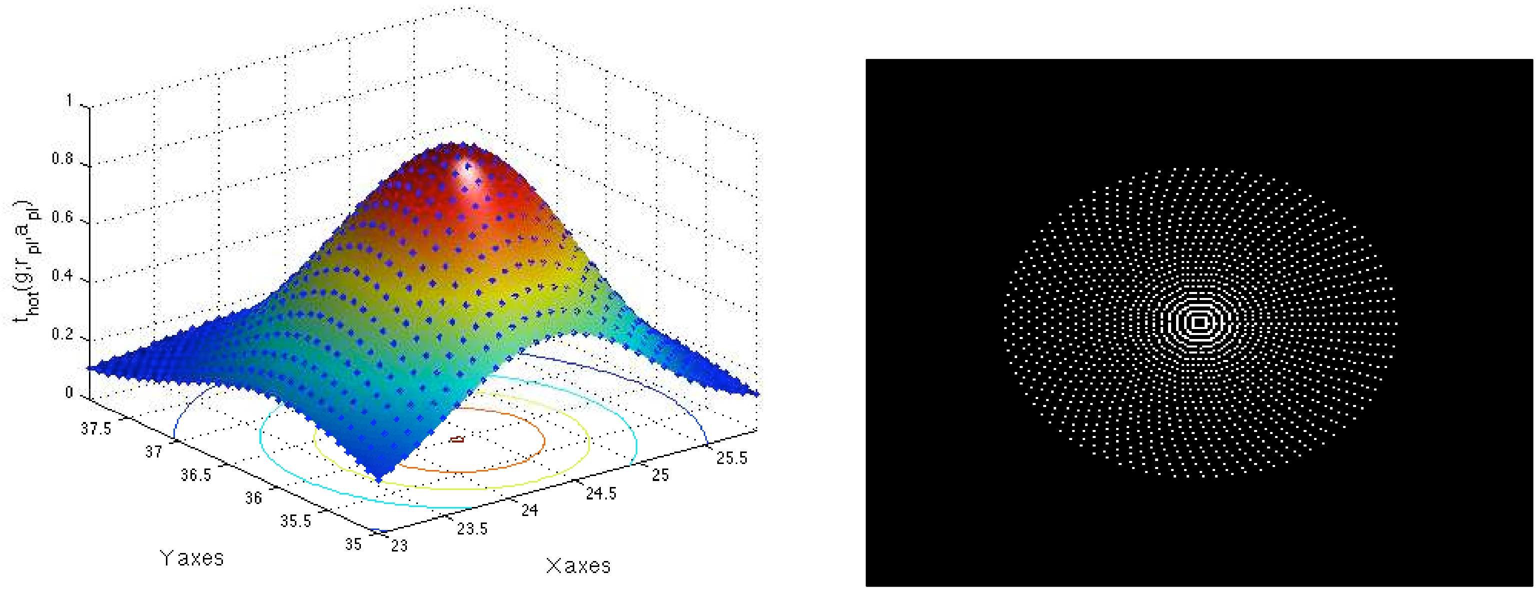
2 *The Hotelling Observer*

The *Hotelling Observer* (Barrett et al., 2006; Barrett & Myres, 2004) is sometimes referred to as a prewhitening matched filter. In the process of prewhitening, the data is divided by the data covariance matrix with the aim of producing spatially stationary, uncorrelated noise. The Hotelling observer provides a framework to include spatial and temporal correlation information about the noise, as well as knowledge about the statistics of the random PSF. The observer calculates a linear discriminant of the form $t(g) = w^t g$, where w is called the template, g is the data and $t(g)$ is the test statistic. For each test location (see figure b) the scanning Hotelling observer calculates its test statistic for a set of test intensities. This set of test statistics is then at a maximum at the location of the companion (see figure 1) with the intensity of the companion.

The cross-correlation of the template vector, w, and the data, g, can be computed either in the image plane or in the Fourier plane. In the Fourier plane the position of the companion is estimated by using a parabolic fit to interpolate the peak of the cross-correlation(Poyneer, 2003; Leroux & Dainty, 2010). In this study both the data and the template vector were zero padded to five times their original size to improve the resolution of the cross-correlation. In the image plane the peak of the cross-correlation is found, and hence the companion position, by shifting the position of the template spot until maximum is found. In practice this PSF fitting type approach is carried out by an unconstrained maximisation of the Hotelling observer where the value of the Hotelling observer is only dependent upon the position of the test spot in the template vector(Burke et al., 2009). The intensity of the companion is also estimated in this process.

3 *Simulations and Results*

Artificial binaries ($\Delta m_K = 3.5$ or 4.5, separation $\theta = 0.6''$) were simulated by scaling and shifting the real single-star images. For each case 8 positions for the companion were tested in order to minimise the bias from anisotropy in the PSF, see figure 2. The Hotelling Observer (Burke et al., 2009) was



(a) Test Statistics as a function of location and intensity

(b) Test Locations

Figure 1: Values of the Hotelling observer around the position of a faint companion.

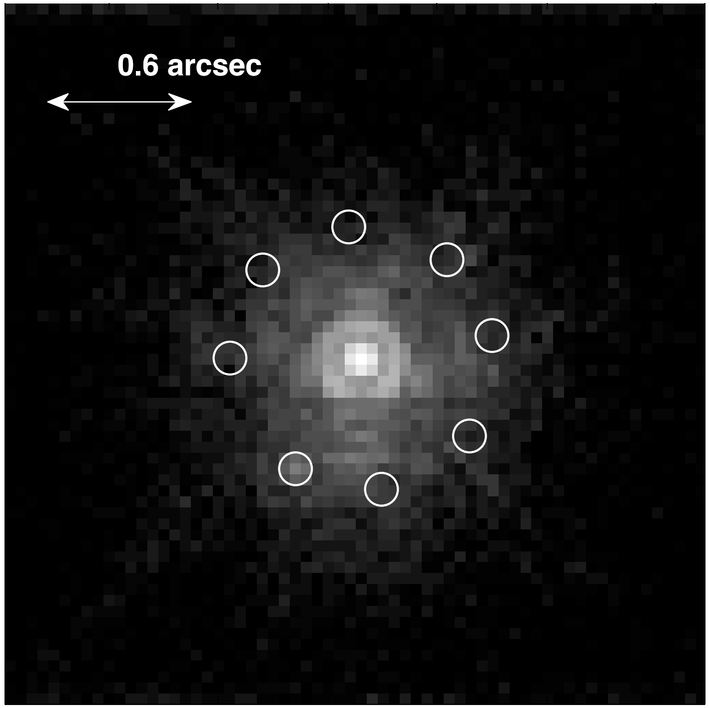
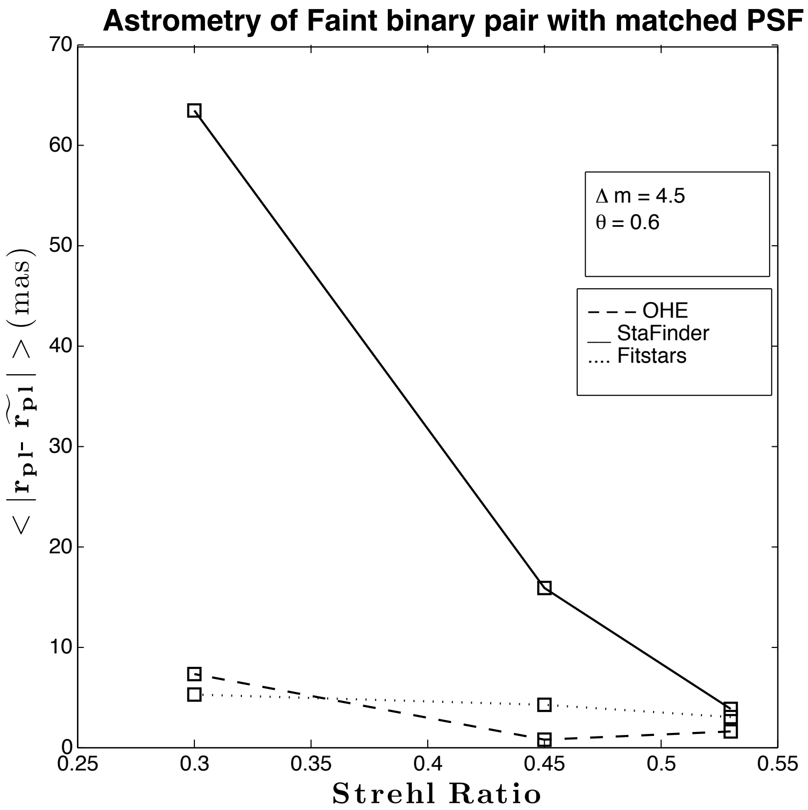


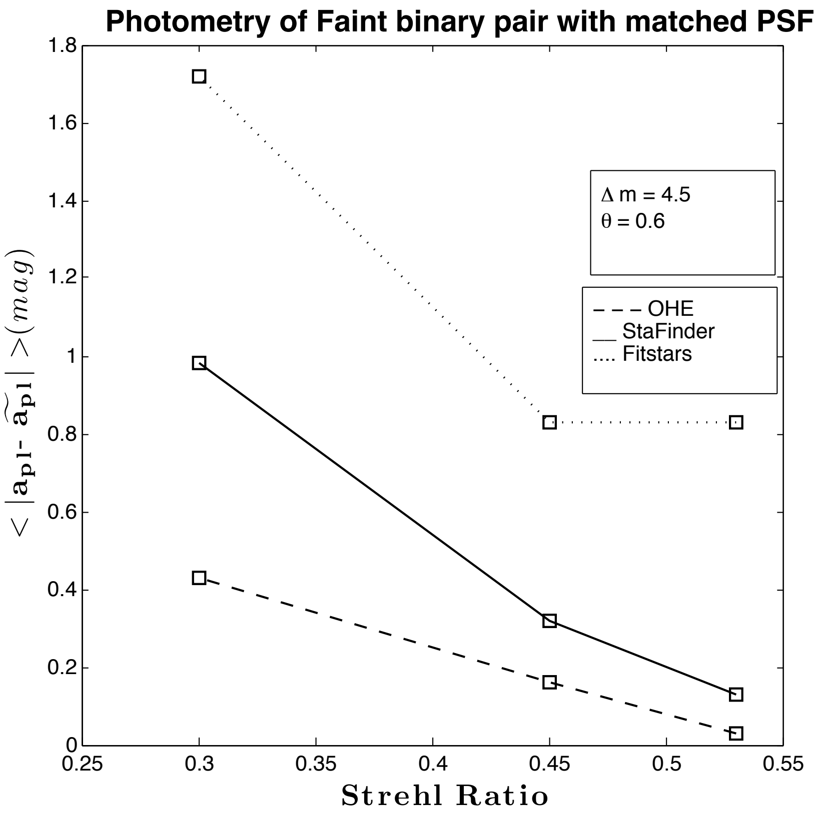
Figure 2: Location of the 8 artificial faint companions.

compared to two the PSF fitting algorithms: StarFinder(Diolaiti et al., 2000) and the iterative blind deconvolution algorithm Fitstars (Barnaby et al., 2000).

The Hotelling algorithm derived the most accurate estimates for the position and intensity of the companion, see figure 3. The minimum error in astrometry achieved using this approach was $0.07\ mas$, the corresponding error in photometry, at this estimated position, was 0.01 magnitudes.



(a) Comparative Astrometry



(b) Comparative Photometry

Figure 3: Error in astrometry for the three observers (left), error in photometry (right) of the faint companion with a matched PSF. One pixel = 0.76 mas.

4 *Conclusion*

We have presented a new likelihood-maximisation method, based on the Hotelling observer, to extract differential astrometry and photometry of faint companions in AO corrected images. This technique requires knowledge of the data covariance matrix. Multiplying the data by the inverse of the covariance matrix is akin to the familiar signal processing operation of prewhitening.

While the algorithm developed in this paper assumes Gaussian noise and therefore does not take static speckle noise into account, we have found that it provides better results than standard algorithms when applied to ÔrealÕ data i.e. simulated binaries using real single-star observations. Knowledge of static speckle statistics would allow the algorithm to be improved by incorporating this information in the data covariance matrix. This would lead to more effective prewhitening and hence more accurate estimation of the binary star parameters. Alternatively the static speckle can be reduced by different approaches including SDI (Marois et al., 2000), ADI(Marois et al., 2006) or modulation of the pupil shape(Ribak & Gladysz, 2008). In all these cases, the Hotelling approach can be modified to optimise estimation of the faint companion position and brightness.

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