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New algorithm for high-precision photometry in crowded star fields

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A new technique simultaneously determines the point spread function, position, and brightness of stars in crowded fields.

An increasing number of astronomical problems require accurate measurements of the brightness of stars situated in crowded fields. These include the search for extrasolar planets by the transit method, which looks for decreases in stellar brightness that happen when a planet passes in front of a star. In this case, the low probability that a planet will pass in front of its parent star implies that a large number of targets have to be monitored at the same time, hence the high degree of crowding. Other applications include dating the oldest stellar clusters and measuring the light curves of bright variable stars in external galaxies (the standard candles used to determine cosmological distances).

When the fields are so crowded that the images of neighboring stars overlap, separating the stellar images requires a knowledge of the shape of point sources, the so-called point spread function (PSF). Most methods rely on images of sufficiently isolated stars to construct the PSF. However, in very crowded fields, no such isolated objects can generally be found and an accurate PSF cannot be constructed, which undermines the quality of the brightness measurements.

Method and results

While traditional techniques, such as the DAOPHOT stellar photometry package,[2] first determine the PSF and afterwards rely on a fit of that PSF on the individual (possibly blended) point sources, our method carries out a simultaneous determination of the PSF and of the point sources' positions and intensities.[3] It is based on the same principles as the MCS (Magain-Courbin-Sohy) deconvolution algorithm,[4] which seeks to improve the resolution while still conforming to the sampling theorem.

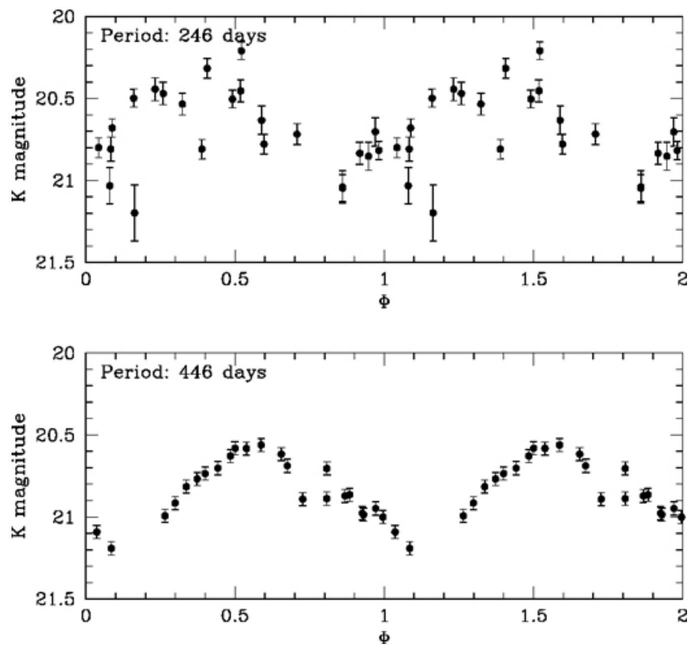

Figure 1. Top: The light curve of a Mira-type star as determined from a traditional PSF-fitting technique, which gives a 246-day period.[1] *Bottom: The light curve from our method, which gives a 446-day period.*

We write the solution of the deconvolution problem as an analytical sum of point sources, whose positions and intensities are unknown. The shape of these point sources in the deconvolved image is fixed by the user. We generally adopt a Gaussian of two to three pixels full width at half maximum (FWHM), so that the sampling is satisfactory. We then seek the convolution kernel (and hence the PSF) that allows us to transform the analytical solution into the original images. The source positions and intensities are determined together with the PSF, by minimizing a χ-square merit function that measures the agreement between the model and the observations.

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We have tested the method on a variety of synthetic as well as real astronomical images, with varying degrees of crowding and a large range of signal-to-noise ratios. We have shown that it provides both accurate PSFs and accurate astrometry and photometry. It gives optimal results in the sense that it uses the information contained in all point sources, and not just isolated or semi-isolated ones, to construct the PSF. An example is shown in Figure 1, which displays the light curve of a variable star in an external galaxy compared to the results obtained with a traditional technique.

We have also extended the method to images containing a mixture of point sources and diffuse objects (such as nebulae or distant galaxies). In this case, we use an iterative technique that tries at each step to improve both the PSF and the determination of the diffuse component.

Further work

So far we have emphasized accuracy rather than computing speed. Our algorithm thus gives more accurate results but is also much slower than traditional PSF-fitting methods, and so is not yet adapted for processing images containing more than a few hundred point sources. We are presently working to improve the processing speed so that it can cope with images containing several thousand sources.

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