Initial results from the VVV Difference Imaging Analysis pipeline

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Abstract

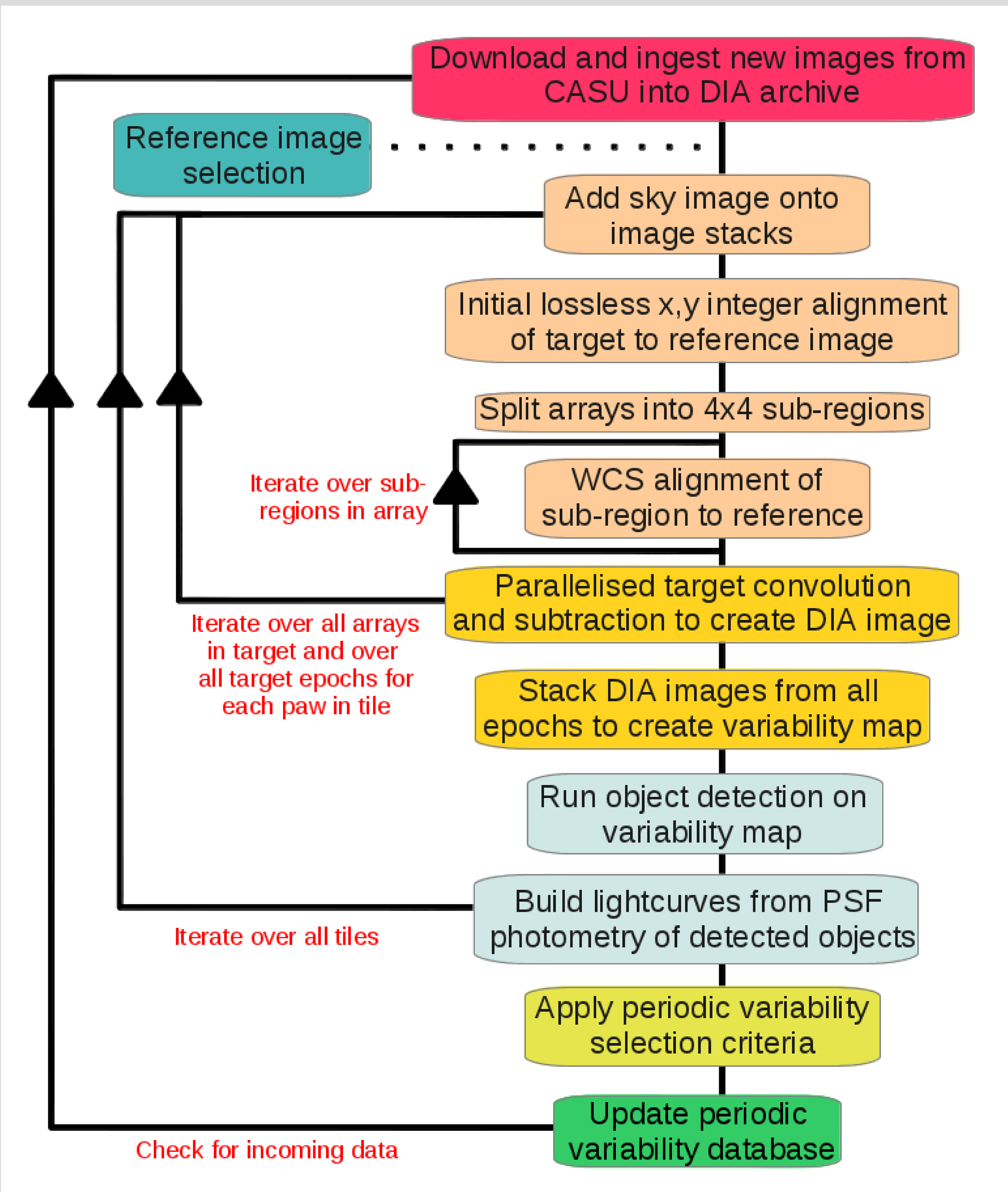
VVV is undertaking a K_s-band variability survey of the inner Galaxy over five years. The VVV Bulge survey fields are highly crowded, with up to a few million stars per square degree. As K_s-band observations penetrate much of the dust, there is a significant background of unresolved stars. To efficiently detect variable objects in these fields, and carry out accurate time-series photometry on them, it is necessary to use difference imaging analysis (DIA). This will be important for obtaining information about the variable populations and for further studies of inner Galactic structure and evolution through analysis of RR Lyrae stars. The DIA pipeline for VVV has been developed at the University of Manchester, UK, and is now in full operation. An overview of the pipeline is given, followed by some initial results and comparisons with CASU aperture photometry.

DIA

A highly successful DIA algorithm is Optimal Image Subtraction (OIS; Alard & Lupton 1998; Alard 2000). In OIS, a best-seeing reference image is convolved to match its PSF with that of each other "target" image in a multi-epoch dataset before being subtracted from the target image. The PSF-matching convolution kernel is derived from bright, unsaturated, stars distributed across the image pair, by minimising the residual of each convolved reference star subtracted from its target equivalent. In OIS, the kernel model comprises three Gaussian-like basis functions, which provides great flexibility for matching spatially varying PSFs between images. If PSFs are well-matched, the difference images will contain only the flux differences, between reference and target epochs, of truly variable objects.

The VVV DIA Pipeline

The VVV DIA pipeline is shown in the schematic below. The VVV DIA convolution is performed with a parallelised and modified version of `mrj_phot` from Christophe Alard's ISIS package[a]. A Generalised Lomb-Scargle periodogram analysis is carried out on all detected objects, with more than 10 datapoints, to generate period-folded lightcurves. Loose selection criteria are applied (phase coverage, smoothness). The period-search is currently only performed between 0.5 and 10 days, due to the limited number of epochs of processed data.



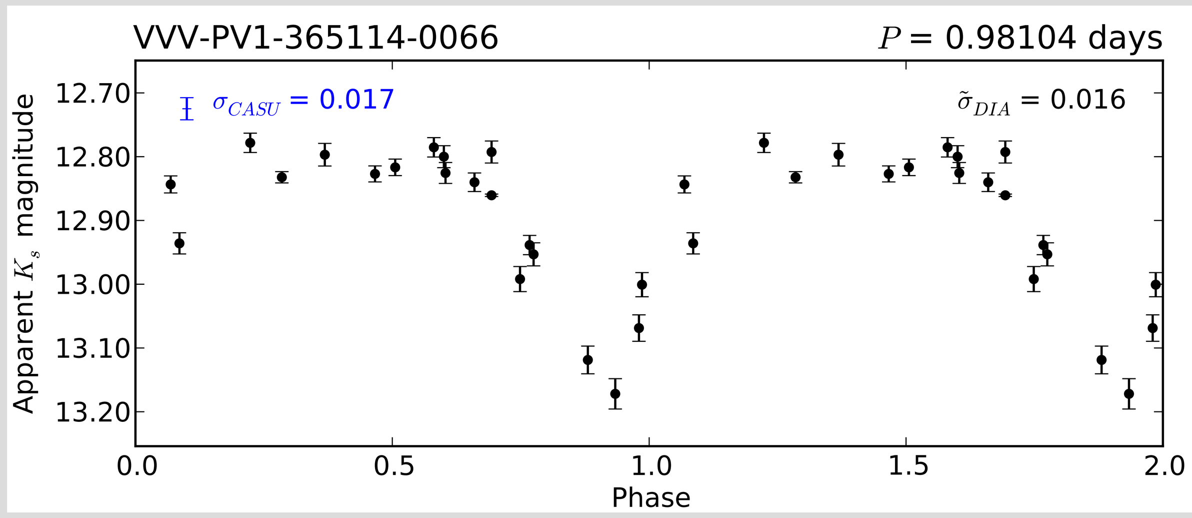
[a] `www2.iap.fr/users/alard/package.html`

VVV and DIA

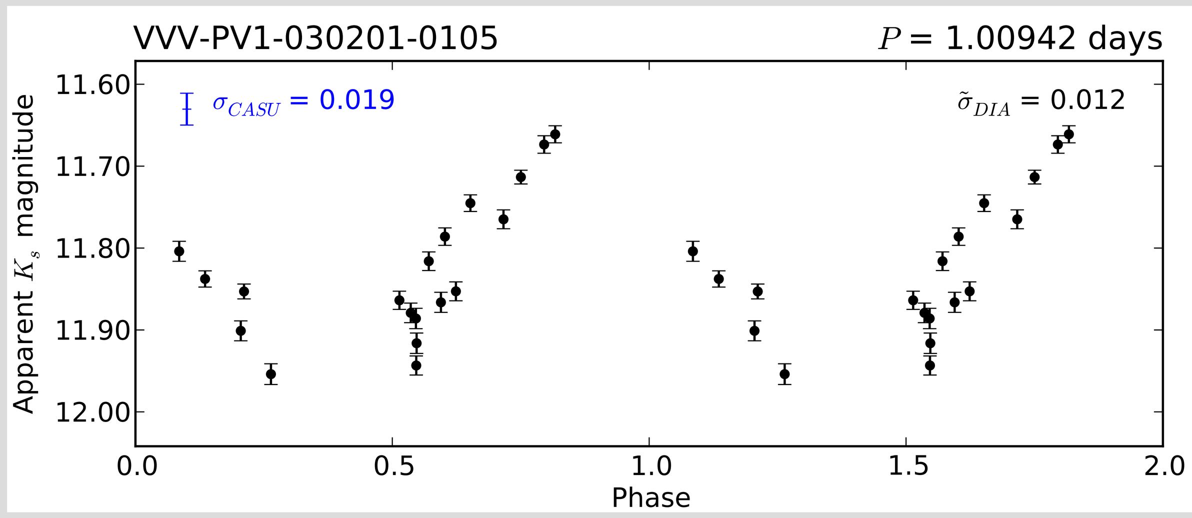
Due to the low saturation limit in VVV data, most bright stars are saturated, and cannot be used in kernel fitting. Additionally, images frequently have seeing $\leq$ 2.5 pixels, where the PSF is spatially undersampled. Undersampling can cause problems in geometrically registering and PSF-matching image pairs during DIA (Wozniak, 2008).
The choice of reference is important for minimising residuals and optimising photometric accuracy, as it is common to all difference images produced. For VVV, we flip the approach used in OIS and choose the poorest seeing image as a reference, convolving/degrading each target to match it before subtraction. While standard OIS makes the best use of signal-to-noise in each image, our approach makes more bright stars accessible to the kernel fitting (as they are more dilute and less frequently saturated) and allows for greater spatial sampling of the reference star PSF (Huckvale, Kerins & Sale, in prep.).

Initial results

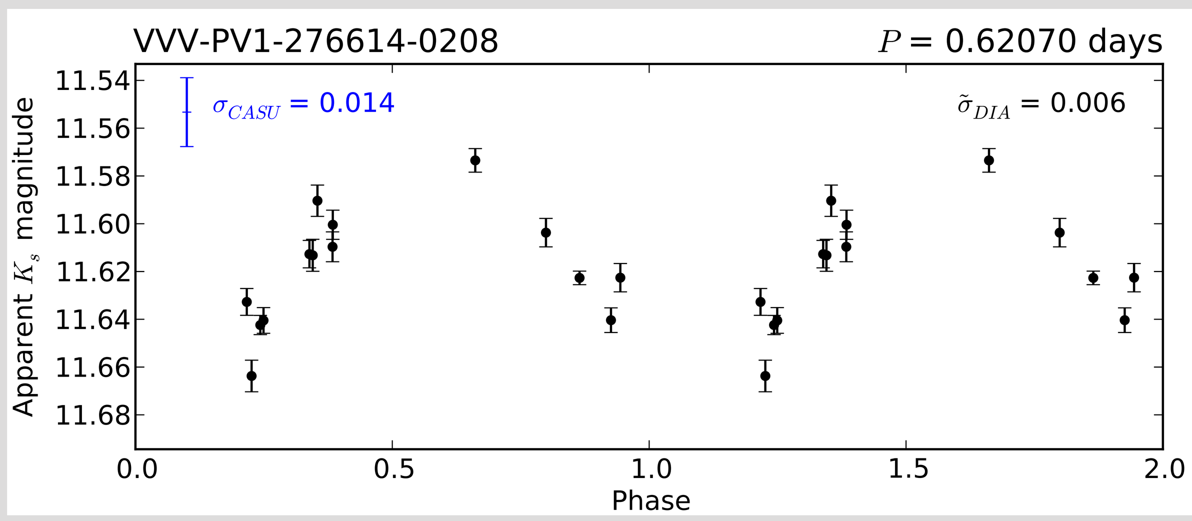
The pipeline is performing well in the crowded bulge and disk fields, having already detected over 400,000 periodic variable candidates in only 3.7% of the VVV survey area over an average of 19 epochs. It is well on the way to detecting the $> 10^6$ variables expected to exist in the VVV survey region. Some example lightcurves are shown below, with systematic error (on the baseline magnitude) shown by the blue error bars. Note that the photon error on the DIA points is of a similar order to the systematic error, which is dependent on the error from CASU aperture photometry (`Aper_flux_3`).



(a) A possible eclipsing binary



(b) Another short period variable, from a disk field



(c) A possible RR Lyrae

Future developments

The pipeline is now fully operational and we expect to have processed all available data over the next few months. Additional epochs will reduce the number of false positives and enable shorter-period variables to be detected.

References

Alard, C., & Lupton, R. H. 1998, APJ, 503, 325
Alard, C. 2000, A&AS, 144, 363
Wozniak, P. 2008, Manchester Microlensing Conference Proceedings
Huckvale, L., Kerins, E., & Sale, S. in prep.