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LUCKY IMAGING AT THE OSKAR-LÜHNING-TELESCOPE IN THE NEAR INFRARED WAVELENGTH RANGE

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Abstract. The performance of the Oskar-Lühning-Telescope at the Observatory of Hamburg in combination with a high-end CMOS camera for high resolution astronomy has been investigated. The observations were made with a CMOS camera that is sensitive to photons in a wavelength range from 0.9μm to 1.7μm. In oder to achieve high resolution imaging the exposure time was chosen such that the atmospheric turbulence was frozen during the exposure. The speckle coherence time was found to be (30 ± 17) ms. From these exposures the best were selected and combined to the final result. To properly calibrate the orientation and the pixel scale of the camera binary systems with known orbital elements have been observed. For the pixel scale a value of (273.7 ± 4.2) mas/Pixel and for the orientation an offset angle of $(0.82 \pm 0.75)^\circ$ have been determined.

1. INTRODUCTION

Establishing a high resolution imaging system for the near infrared wavelength range is promising because the majority of stars in the stellar neighbourhood are of late spectral type. Such a system is especially useful for the recently increased research interest in ultracool dwarfs that have their emission maximum in this wavelength range. Furthermore, direct imaging of binaries whose components are of different spectral types is more feasible because the brightness difference is significantly lower in the near infrared wavelength range than in the visual band. Also components that are overlooked in V band surveys might be imaged in this wavelength range.

In addition, the influence of the atmospheric turbulence is less pronounced. This has two important consequences. First, the probability to obtain only slightly distorted images is exponentially higher for longer wavelength. Second, the turbulence induced atmospheric distortions are subject to longer timescales.

The determination of orbits of binary systems is the only way to determine the masses of stellar objects. This information can verify stellar formation models. The other purpose of resolving binaries is to find massive objects that influence the orbit of exoplanets or that might be misinterpreted as planets.

Relatively bright targets were selected to allow short exposure times as well as a high signal to noise ratio. Several thousand exposures were aquired. From all exposures an average bias/dark frame was subtracted and flat fielding was performed. By visual inspection images were rejected that were obviously deteriorated. The reason was improper reading out of the focal plane array by the camera electronics. The best exposures were selected by their Strehl ratio $\mathcal{S}$. The final result was obtained by shifting the brightest pixel always to the same position and adding up the best images. An example of the potential for significant image quality improvement can be seen in figure 1. The left image shows the result obtained by lucky imaging whereas the right image shows the result that was obtained by just adding up all short exposures without further image processing. The latter is what also long time exposures taken

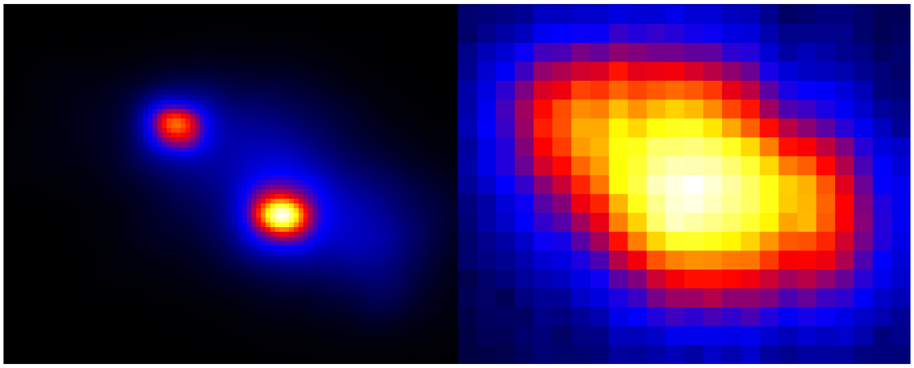

Figure 1: WDS 09184+3522. Distance is 1.″9; north is up and east is to the left.

from ground based telescopes look like. In this case the spatial information is severly degraded while the left image shows clearly the binary system's components.

1. 1. OPTICAL SETUP

The images were aquired with the telescope of the Hamburg Observatory. It is a 1.2 m RC telescope with a focal length of 15.6 m. The focal length of the telescope as well as the pixel size of the camera are fixed. A Barlow lens increases the focal length of the telescope to 23.4 m. It is mounted in a customised adapter that ensures that camera and lens are installed in the correct positions.

1. 2. THE CAMERA

All images were made with an off-the-shelf high-end InGaAs camera with 320×256 pixels manufactured by Xenics. It was chosen because it is able to aquire frames with a maximum framerate of more than 1 kHz for a window of interest of 80×70 pixel.

The camera is equipped with a three-stage thermoelectric cooler that can reach temperatures down to $-52°C$. An operating temperature of $-51°C$ minimises the dark current. For the operating temperature the technical parameters of the camera can be found in table 1. Under the assumption that the total noise is composed of photon and readout noise N_R plus contribution from dark current N_D it can be expressed as

$$\frac{S}{N} \approx \frac{Nt}{\sqrt{Nt + N_D t + N_R^2}} \tag{1}$$

where t denotes the integration time and N the flux. A signal of N=6,500 photons/second and t=30 ms yields to S/N=1.1 which means that the object is too faint to be observed. If N_D and N_R were negligible one would obtain S/N=14.0 which shows that the choice of the detector can significantly influence the magnitude limit.

2. EXPOSURE TIME SELECTION

The choice of the exposure time τ is critical. For the accumulation of a large number of photons it is advantageous to choose τ as long as possible. On the other hand

Table 1: Parameters of the camera at operating temperature.

Parameter	Value
gain	$9,08 \pm 0,31 \frac{e^-}{ADU}$
dark current	$(1,05 \pm 0,20)\, 10^5 \frac{e^-}{s}$
readout noise	$171.5 \pm 12.5 e^-$

τ has to be short enough such that the earth's atmosphere is not changing during the exposure. To find a resonable value for τ the time-only variations of the stellar speckles are observed. A large number of images of a bright star have been aquired. In all images the same pixel has been selected and the time-only autocorrelation of its count rate has been evaluated. Theoretically, the autocorrelation $C(t)$ is given by (Aime et al. 1986)

$$C(t) = \frac{2ab}{b^2 + 4\pi^2 t^2} \tag{2}$$

where t denotes the time that elapsed since the aquisition of the first image. Figure 2 compares the theoretical model to the experimental values. From the least squares fit of the data to the experimental values a speckle coherence time of $\tau = (30 \pm 17)$ ms has been determined.

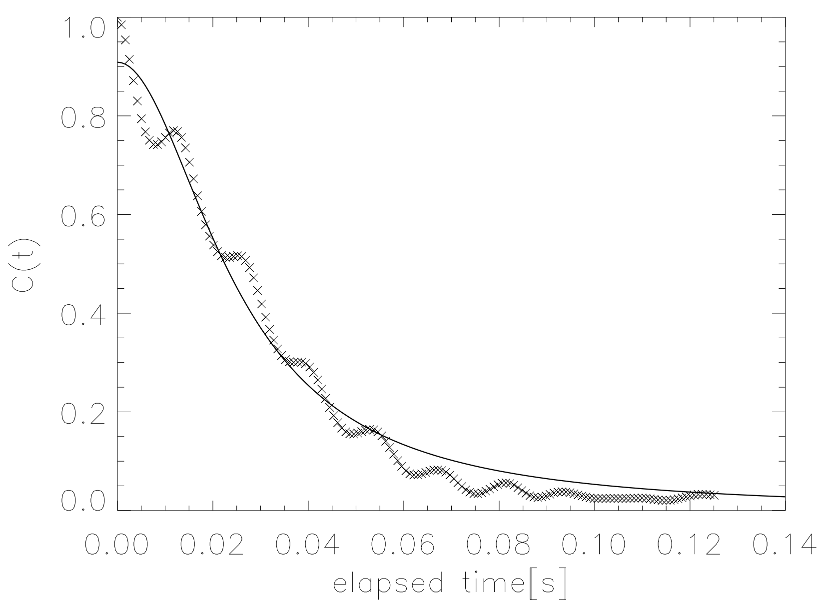

Figure 2: Time-only autocorrelation function $C(t)$ of the stellar speckle pattern. The crosses denote the values derived from the observation of Arcturus and the line denotes the fit to the theoretical model.

3. ASTROMETRIC CALIBRATION

One goal of high resolution imaging is to obtain angular distances ρ and position angles θ of astronomical objects, e.g. double or multiple stellar systems, with the highest possible accuracy. To calibrate the optical setup binary systems with already precisely known orbits were observed. First, the orbital elements as listed in a catalog can be taken to predict ρ and θ for the epoch of observation. In the next step the calculated quantities are compared to the observations. From these observations the pixel scale and the orientation of the camera were derived.

Table 2 lists the designation that is given in the Sixth Catalog of Orbits of Visual Binary Stars (Hartkopf et al. 2001), hereafter VB6, the calculated angular distances ρ_c and position angles θ_c as well as the observed quantities ρ_o(in pixels) and θ_o(in degrees).

Table 2: Comparison of calculated and observed double star parameters

VB6 no.	ρ_c[“]	θ_c[°]	ρ_o[Pixel]	θ_o[°]
10200+1950	4.621	126.0	16.81±0.28	125.65±0.88
12244+2535	1.805	323.4	6.13±0.34	328.98±3.07
15038+4739	1.359	62.7	5.51±0.83	54.16±7.67
17053+5428	2.444	5.7	10.34±0.95	9.65±1.64

The calibrators were chosen from the VB6. All calculated quantities refer to the epoch 2012.224.

From table 2 a pixel scale of $(273,7 \pm 4,2)$mas/Pixel and an orientation angle of $(0,82 \pm 0,75)^\circ$ have been determined. The determined uncertainty is consierably greater than the one claimed by another observation campaign. For example an M dwarf survey at the Calar Alto 2.2m telescope has reported a standard deviation for ρ of several milliarc seconds and for θ of less than one degree (Janson et al. 2012)

The designed pixel scale of the optical system was 264.6 mas/Pixel.

4. CONCLUSIONS

Although the results are promising there is still room for improvements. One possibility is the usage of a detector with lower readout noise to increase the limiting magnitude. Second, the optical setup has to be improved because the accuracy of the astrometric calibration is less than the accuracies reported for other calibrations.

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