Lucky imaging at the Oskar-Lühning-Telescope in the near infrared wavelength range

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BELISSIMA Conference 2012

Hamburger Sternwarte

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 maximum possible exposure time was found to be $30 \pm 17ms$. 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** $273,7 \pm 4,2mas/Pixel$ **and for the orientation an offset angle of** $0,82 \pm 0,75°$ **have been determined.**

OVERVIEW

Background

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 mainly in this wavelength range.

Optical Setup

The focal length of the telescope as well as the pixel size of the camera are fixed. A Barlow lens is used to increase the focal length of the telescope. It is mounted in a customised adapter that ensures that camera and lens are installed in the correct positions (see fig 2).

Observing Strategy & Data Reduction

Relatively bright targets were selected to allow short exposure times. Several thousand exposures were aquired. 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 all images.

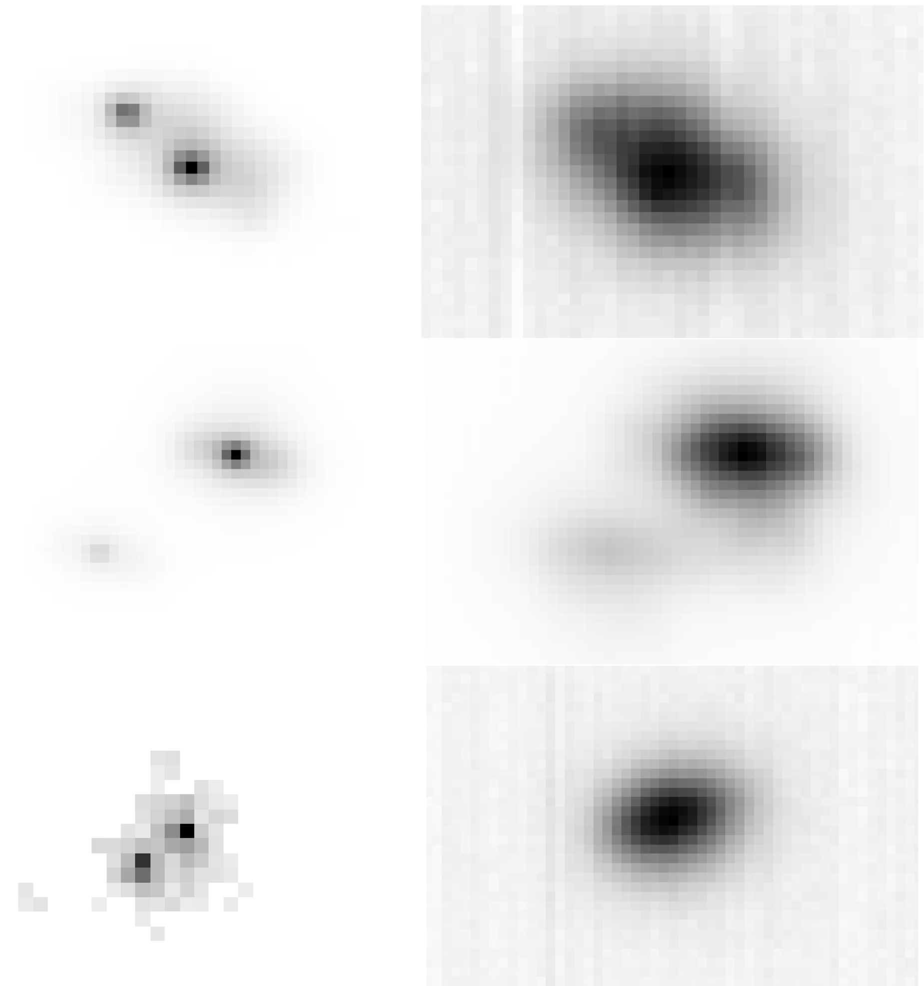

Fig 1. Left: top and middle: final results
bottom: selected image with the highest $\mathcal{S}$ value out of several thousand
Right: addition of all aquired images without any further image processing

Observing Strategy & Data Reduction (cont.)

Some examples of image quality improvement by this simple approach can be seen in fig. 1, left column. If all images are simply added the result looks like a long time exposure, see right column. It is obvious that the image quality has been drastically improved.

The Camera

To aquire the astronomical images an off-the-shelf high-end camera manufactured by Xenics was used. The camera is equipped with a three-stage thermo-electric cooler that can reach temperatures down to $-52°C$. An operating temperature of $-51°C$ was used to minimise the dark current. For the operating temperature the technical parameters of the camera have been determined as follows:

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	$171,5 \pm 12,5e^-$

Table 1. Parameters of the camera at operating temperature.

O.-VIEW & FIRST RESULTS

Optical Setup (cont.)

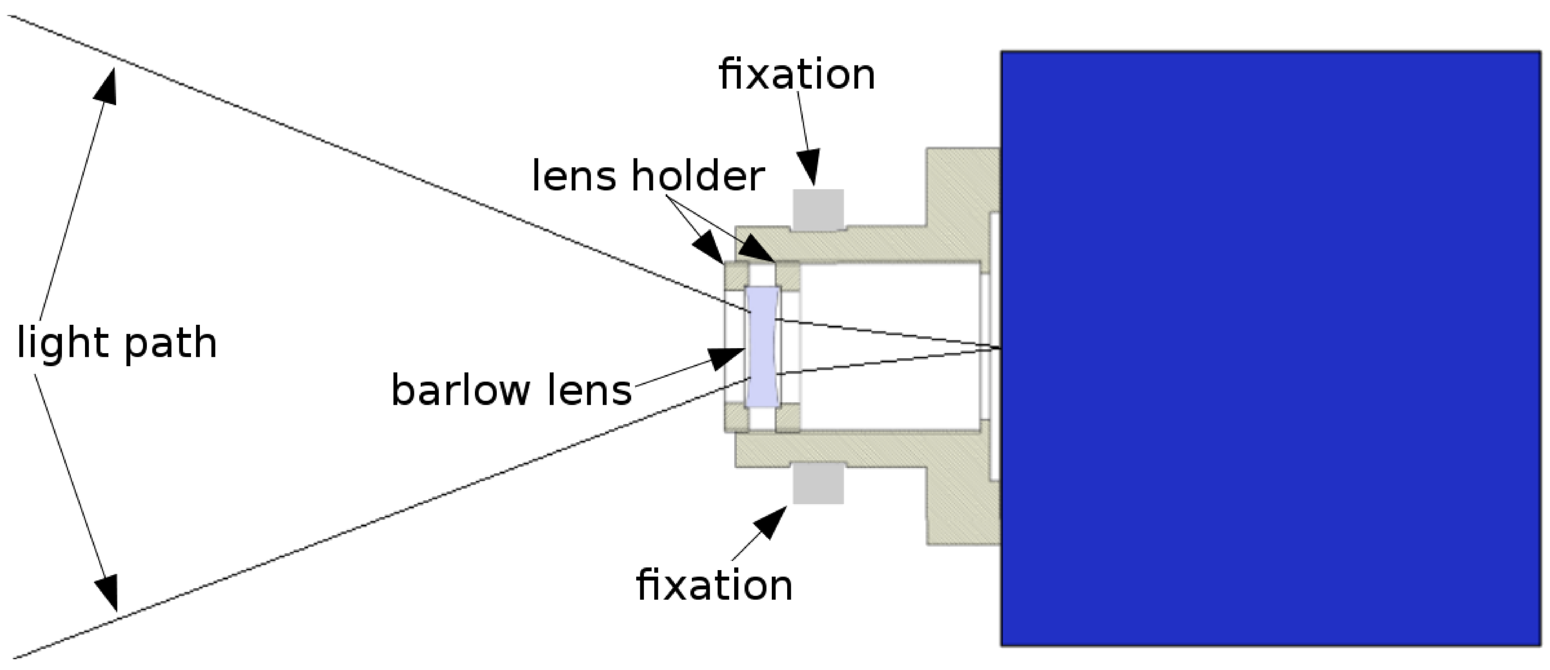

Fig 2. The incoming light (from left) reaches the barlow lens and is focused on the detector. The lens is fixed by two lens holders to ensure that the lens is at the right distance from the detector. The fixation is used to mount the optical system at the output of the O.L.T.

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. Binary systems with well known orbital parameters were observed to calibrate the optical setup. The orbital elements can be used to calculate ρ and θ for the epoch of the observation. From these observations the pixel scale and the orientation of the camera were derived.
The following table lists the designation that is given in The Washington Visual Double Star Catalog (hereafter WDS), the calculated distances ρ_c and position angles θ_c as well as the observed quantities.

WDS 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

Table 2. Comparison of calculated and observed double star parameters.

FIRST RESULTS (cont.)

Astrometric Calibration (cont.)

The calibrators were chosen from the Sixth Catalog of Orbits of Visual Binary Stars. All calculated quantities refer to the epoch 2012.224.
This calalog lists binary systems that were frequently observed thus making it possible to derive orbital elements (see fig 4).

Exposure time selection

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

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

Exposure time selection (cont.)

where t denotes the time that elapsed since the aquisition of the first image. Figure 3 compares the theoretical model to the experimental values.

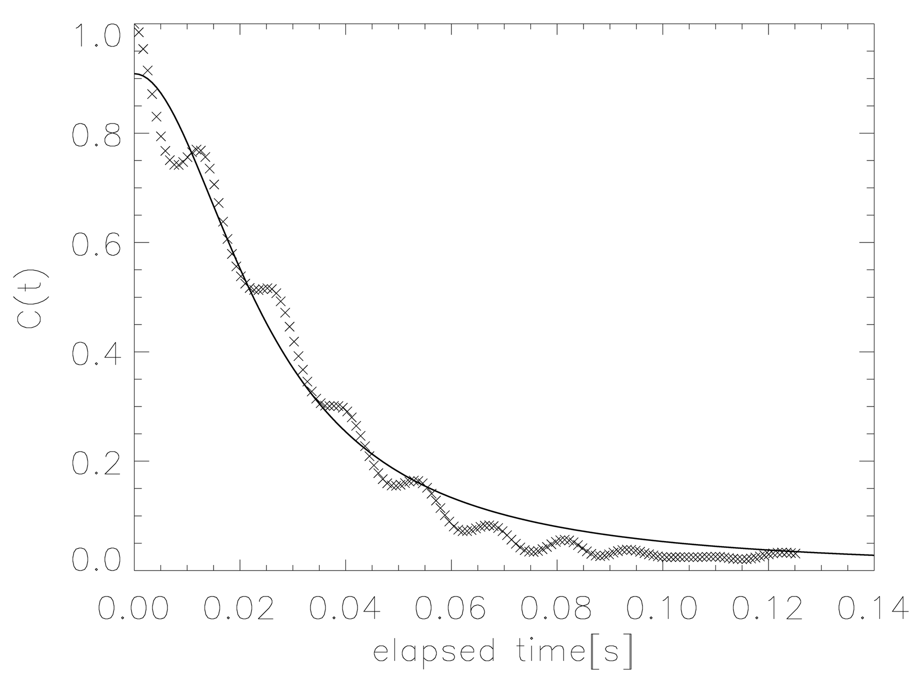

Fig 3. Time-only autocorrelation function $C(t)$ of the stellar speckle pattern. The crosses denote the values derived from the observation of Arcturus and the line denotes the fit to the theoretical model.

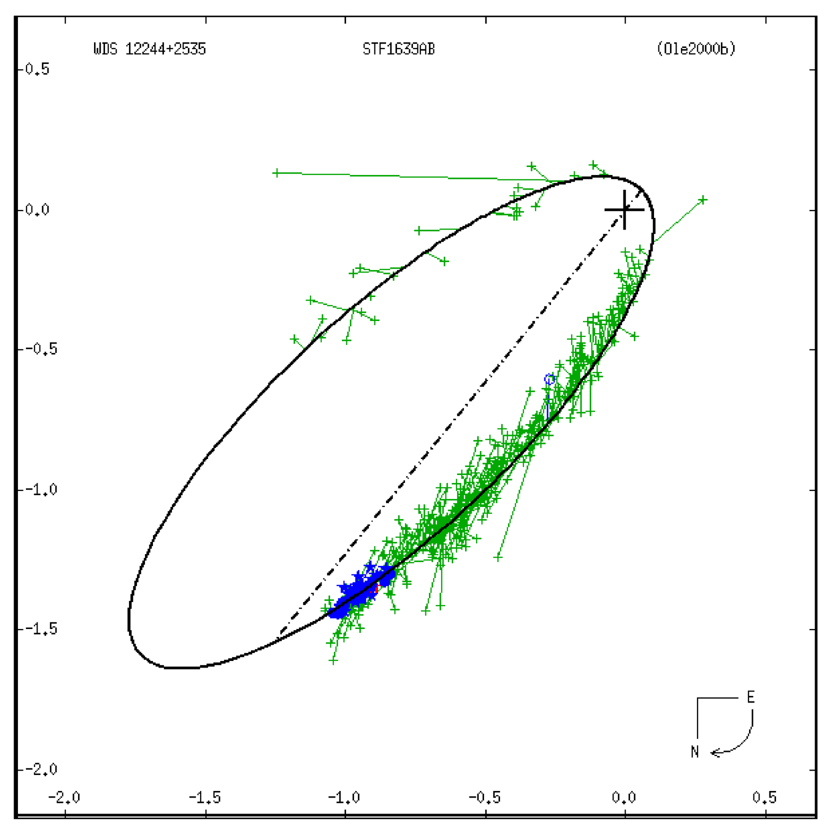

Fig 4. WDS 12244+2535 as an example of a binary system. Green symbols denote visual observations and blue symbols interferometric measurements.

Acknowledgements

First I would like to thank G. Wiedemann for the opportunity to work at this subject under his supervision. Further I would like to thank J. Susol for writing the camera control software.