Measurements of Visual Binary Stars with M-type Companions with a SWIR Camera and a 280 mm Reflector

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Abstract: This paper presents the results of a preliminary experiment aiming at observing and measuring visual binary stars with M spectral type secondary component by means of an 11" reflector telescope and a SWIR camera operating in the 800-1600 nm band.

1. Introduction

Binaries having companions with late spectral types (M, typically) are very rarely observed—and consequently measured—by amateurs. A major reason for this is the low sensitivity of CDD detectors, mainly used by these amateurs, in the NIR† and *a fortiori* SWIR†† band, where these stars emit the most significant part of their energy. This is illustrated for example in Figure 1. Recent back-illuminated, CMOS-based sensors, such as the Sony IMX290 for example [1] have a slightly improved sensitivity in the NIR band (see Figure 2) but the quantum efficiency still quickly drops to zero in the SWIR band.

A possible solution to compensate for the low QE of CCD or CMOS sensors at longer wavelengths is to use longer integration times (typically up to a few hundreds of ms). But this in turn raises two problems. First, the blurring effect of seeing becomes very destructive with such long exposures. The image of faint sources is “spread out” on a large number of pixels, which ultimately counterbalances the benefit of integration. This is specially true when working at small pixel scales (high F-ratio). Second, augmenting integration times in order to get a faint secondary component frequently leads to saturating the primary component. This is especially true for pairs with a large difference in magnitude (DeltaM) and when working with sensors with limited dynamic range. Saturated components preclude any reliable photometric measurement of the observed pairs. In the case of close pairs, it can also make astro-

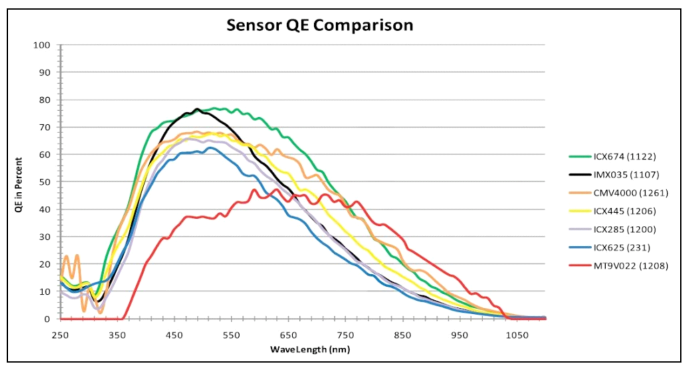

Figure 1. Quantum Efficiency curve for several well-know CCD sensors used in astronomy (source : Point Grey Research, Inc)

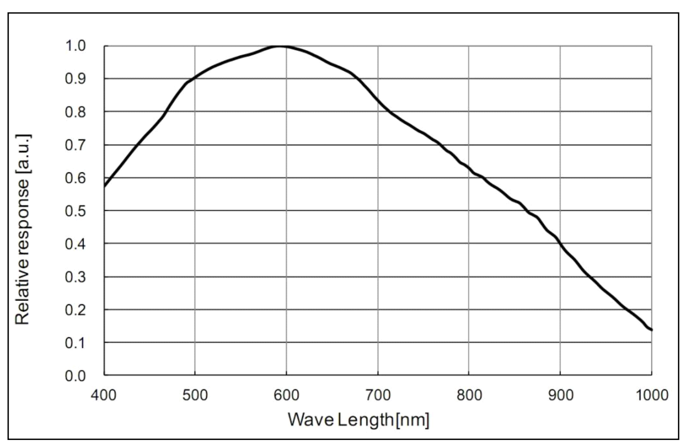

Figure 2. QE curve of the Sony IMX 290 BI CMOS sensor

†*NIR: Near Infrared, typically from 0.75 to 1um.*
†† *SWIR: Short Wave Infrared, typically from 1 to 2.5 um*

metric measurements difficult, if not impossible, even when using some dedicated techniques as described for instance in [2].

A more radical solution is to rely on sensors with an extended sensitivity in the SWIR band, such as those based upon the so-called InGaAs technology (Indium, Gallium Arsenide). Due to their very high cost, such sensors have long been reserved to professional observatories. But the rapid development of the surveillance cameras market has recently made them more affordable.

We had the occasion to test such a camera, the Owl 640 from Raptor Photonics [3]. The result of this preliminary test campaign are reported in this paper.

2. The Owl 640 VIS-SWIR camera

The main characteristics of the camera are given in Table 1 and its QE curve reproduced in Figure 3. It is equipped with an on-board NonUniformity Compensation system, which can perform on the fly offset correction, gain dispersion compensation, dark current subtraction and hot pixel correction. Our best results were obtained with the following settings:

- sensor cooled to -15°C
- offset + gain correction ON
- dark current compensation OFF
- Hi gain mode, gain = 5 … 10

Control of the camera and acquisition are carried out by the Genika software (version 2.8.0) [4].

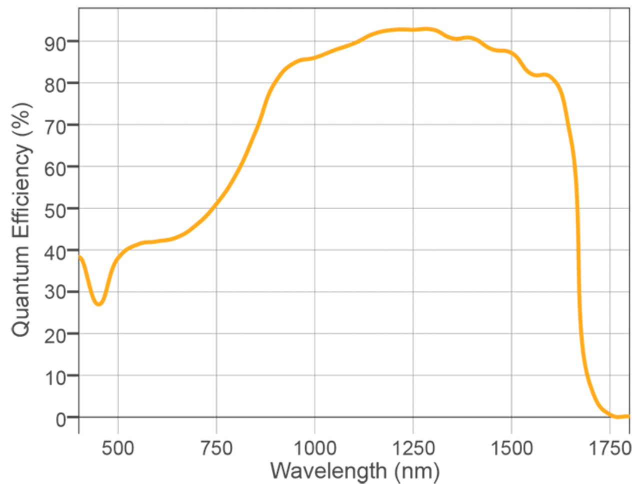

Figure 3. QE curve of the Owl 640 camera

3. Instrumental Setup

The telescope is a 280 mm Schmidt-Cassegrain reflector (Celestron C11, see Figure 4). The relatively large pixels of the camera (15 x 15 um) give a plate scale factor of 0.91 arcsec / pixel at prime focus. In order to measure pairs with separation under 5 arcsec, we used eyepiece projection, as illustrated in Figure 5. An eyepiece with a focal length of 10 mm, placed at a 50 mm distance of the sensor gives a total equivalent focal of 8900 mm and a plate scale factor of 0.35 arc/pixel. This is still much larger than the factors we normally use for close "visible band" pairs but we did not intend to go under the 1 arcsec limit for this experiment.

Table 1 – Main Specifications for the Owl 640 Camera

Sensor Type	InGaAs PIN-Photodiode
Active Pixel	640 x 512
Pixel Pitch	15µm x 15µm
Active Area	9.6mm x 7.68mm
Spectral response	0.4mm to 1.7mm
Noise (RMS)	<195 e- Low Gain (176 e- typical) <50 e- High Gain (40 e- typical)
Quantum Efficiency	Peak >85% (>73% @ 1.064mm, 78% @ 1.55mm)
Pixel Well Depth	Low Gain: 650Ke-, High Gain: 15Ke-
Digital Output Format	14 bit CameraLink (Base Configuration)
Exposure time	1ms to 1 / frame rate
Shutter mode	Global shutter
Frame Rate	Up to 120Hz programmable 25ns resolution
TE Cooling	yes
Image Correction	3 point NUC(offset, Gain & Dark Current) + pixel correction
Dimensions & Weight	50mm x 50mm x 82mm / 282g

Figure 4. Experimental setup. From top left to bottom right: focuser, flip-mirror (with centering eyepiece), filter-wheel, eyepiece projection tube, Owl640 camera.

Figure 5. Details of the optical train, showing the 10 mm projecting eyepiece in front of the camera

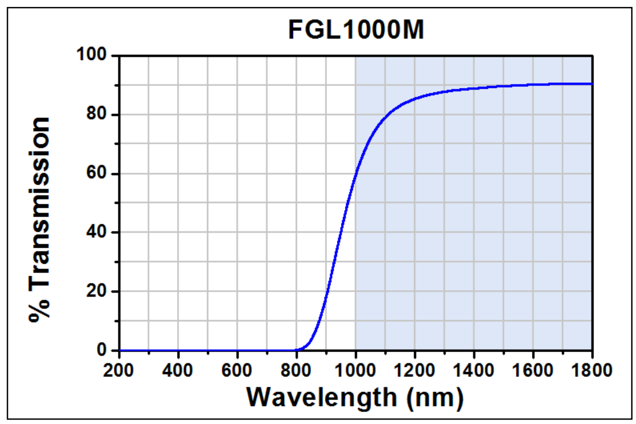

Figure 6. Transmission curve for the FGL1000M Thorlabs high-pass filter

Because an important potential application of such a system is the measurement of pairs with large ΔM, we decided to use a high-pass NIR filter. The goal is to avoid, as much as possible, the saturation of a typically F or G spectral type primary component, while favoring the detection a M type secondary component. The filter used is a ThorLabs FGL-1000M, whose transmission curve is reproduced in Figure 6.

Since atmospheric dispersion is significantly lower at these longer wavelengths (and because we also wanted to minimize the number of glass surfaces to be traversed), no ADC was used in this experiment.

4. Target Selection

The selection of potential target was carried out by searching the WDS [5] catalog for pairs with the following characteristics†:

- magnitude of both components < 15
- 1 < separation < 90 arcsec
- 0 < declination < 60°
- spectral type of first component: O, B, A, F or G
- spectral type of second component: M

This gave us a list of 52 targets. Ruling out those not observable at the corresponding period (mid April), we ended up with a list of only 9 potential targets. It must be underlined, however, that this small number can be explained by the fact that very few entries in the WDS gives a spectral type for the secondary component††.

5. Acquisition and processing

For each pair 1000-4000 frames were acquired, along with a «dark» frame (obtained with the same gain and exposure time on the sky background). Individual exposure times ranged from 10 to 400 ms.

Calibration was carried out by means of calibrating pairs as reported in [6].

Image reduction is carried out with the Reduc software (version 5.05) [7]. A master dark frame is first computed by averaging the dark frames associated to each pair and then substracted to each frame of the sequence. Frames are then sorted by quality, recentered and added to be measured. Measurement is carried out

† *In practice, we imported the WDS as a MySQL database and performed the search by means of MySQL queries.*

††*This in turn shows the crucial need for any kind of research program being able to provide this kind of data.*

Table 2. Measurements

NAME	WDS ID	m1	m2	date2	PA (°)	SEP (arcsec)	DeltaM	SP	DATE	NOTE
MUG 1	09035+3750	5.5	7.7	2013	4.3	1.65	2.5	G0v+M3	2017.299	2
STT 523	10172+2306	5.8	11.4	2005	300.2	7.91	4.2	F6v+M1.5	2017.299	2
LDS5771	13114+0938	8.8	12.3	2012	168.9	81.8	2.4	G0+M0	2017.301	2
JNN 151AC	13316+5857	8	12.7	2003	53.5	11.38	3.0	G2v+M1.0v	2017.288	2
STT 270AB	13473+1727	4.5	11.1	2001	76.3	1.5	1.3	F6v+M2v	2017.299	2,3
RED 24	14139+4620	7.2	13.1	2004	215.1	83.38	2.7	G0v+M2v	2017.301	2
DEA 52	15369+2959	5.3	12.4	2010	84.2	36.13	6.1	F5v+M6.5	2017.307	1,4

Notes for Table 1

1. E=0.91"/pixel
2. E=0.35"/pixel
3. Has orbit (see Table 3 for residuals)
4. Reported magnitude in WDS is for K-band

directly by centroid adjustment or, in case of closest pairs (MUG 1 and STT 270) using the Surface algorithm.

5. Results

Observations have been conducted during three nights, between 2017-04-16 and 2017-04-23. Results are reported in Table 2 and Figure 7.

For two targets of our list, we were unable to detect the companion, even when increasing the exposure time and/or the number of stacked frames:

- DEA 45 (listed with m1=7.4, m2=12.5, sep=37.3’’ in the WDS)
- DEA 46 (m1=6.8, m2=14, sep=17.6’’)

It occurred afterwards that these two pairs were listed with a “K” note in the WDS, meaning that the reported magnitudes (12.5 and 14 resp.) were obtained in the K band (2-2.4 micron) or “other infrared (> 1 micron)” band. It is likely that the magnitude in the J band (1.1-1.4 micron) is lower, which would account for these non detections.

One of the measured pair STT 270AB, has an entry in the Sixth Catalog of Orbits [8], though of grade 5. The O-C computed from our measurement is given in Table 3

6. Conclusion

The results reported here show that pairs with M-type secondary components up to magnitude 13 can be measured with an 11" telescope.

They also show that large V-DeltaM, as reported in the WDS, can be significantly reduced by observing in the SWIR band, thus allowing the corresponding pairs to be measured accurately without resorting to ad-hoc instrumental techniques such as aperture masks.

The number of pairs with such yet unobserved M companions is probably important, especially in the 1-5" separation range

The price of a SWIR camera, like that used for this paper, is still a bit high for the moderately financed amateur, but does not exceed that of relatively large telescopes which can found in small observatories run by associations or groups of amateurs. A systematic observation program, using such a telescope, equipped with a SWIR camera, operated manually or, better, automatically would therefore open significant opportunities for discoveries and subsequent scientific exploitation of measurements.

Acknowledgments

This research has made use of the Washington Double Star and 6th Orbit catalogs maintained at the U.S. Naval Observatory. Data reduction was carried out using the Reduc software (v5) developed and maintained by F. Losse. We have been using the Owl 640 camera courtesy of J.E. Communal (Raptor Photonics)

References

[1] Sérot, J., “Measurements of Close Visual Binaries with a 280 mm Reflector and the ASI 290MM Camera”, *Journal of Double Star Observations*, **13** (2), 268-284, 2017.

[2] Foley, E., Genet R., Ridgely J., Rowe D., Zimmerman N., “Observation of Large Delta Magnitude Close Binaries with Shaped Aperture Masks”, *JDSO*, **11**(1s), 343-360, 2015.

Table 3. O-C Residuals for Pairs Having a Known Orbit

NAME	WDS ID	DATE	O-C PA (°)	O-C SEP (")	GRADE	REF
STT 270AB	13473+1727	2017.299	5.4	0.02	5	Dru2014

[3] http://www.raptorphotonics.com/products/owl-640-cameralink-stabilized

[4] http://genicapture.com

[5] Mason, D.B., Wycoff G.L., Hartkopf, W.I. Washington Double Star Catalog, USNO, 2015. http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/WDS

[6] Sérot, J., "Speckle Interferometry of Close Visual Binary Stars with a 280 mm Reflector and an EM-CCD", *JDSO*, **12**(5), 488 - 499, 2016.

[7] Losse, F., Reduc, v5.0. http://www.astrosurf.com/hfosaf

[8 Hartkopf, W.I., Mason, D.B., "Sixth Catalog of Orbits of Visual Binary Stars", USNO, 2009. http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/w

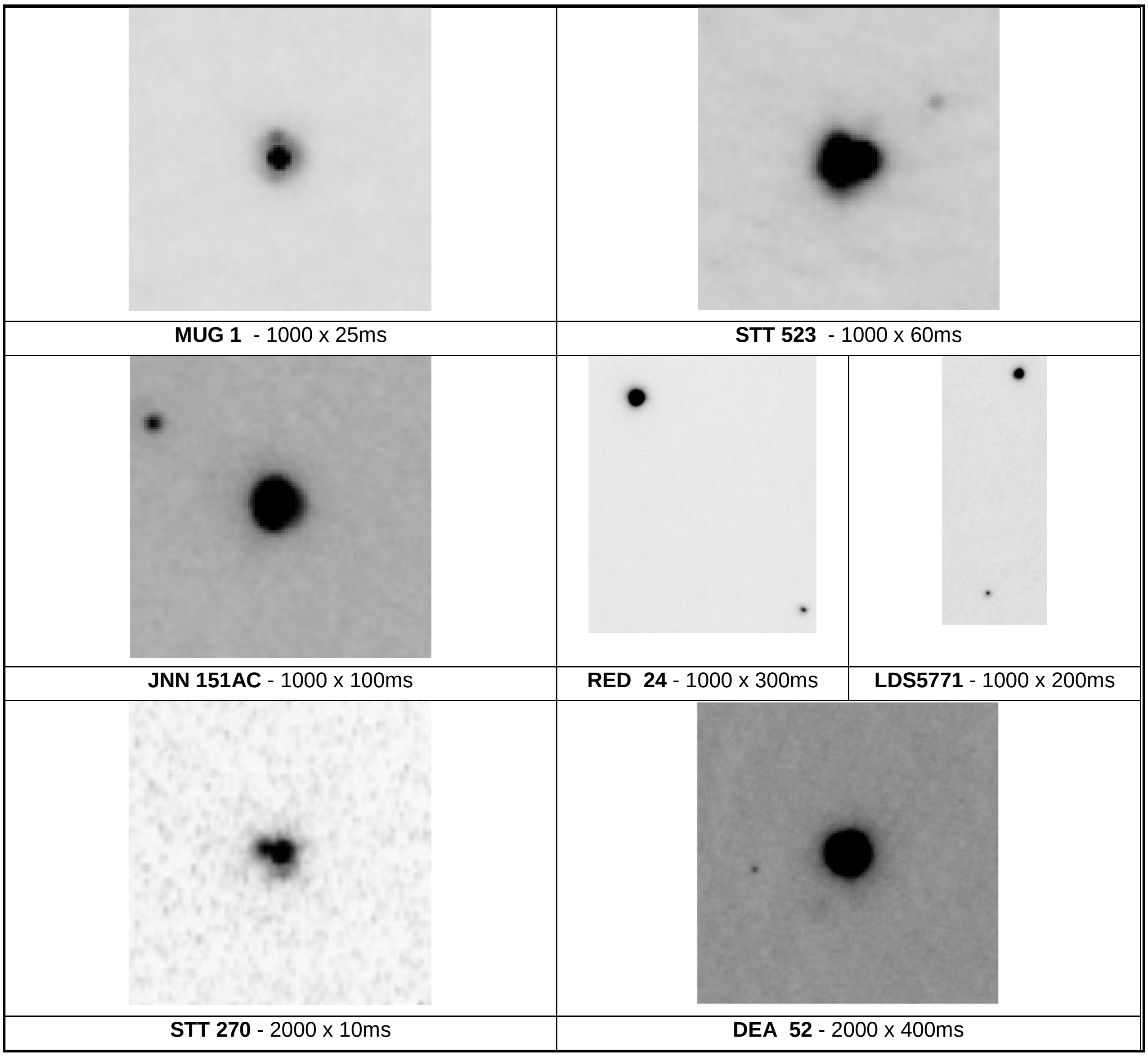

Figure 7. Post-reduction images