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VII Workshop on Robotic Autonomous Observatories (October 16-20, 2023)
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CHARACTERIZATION OF THE KL4040 SCMOS FOR USE ON THE BOYDEN RESEARCH TELESCOPES

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RESUMEN

Recientemente, los sensores sCMOS se han vuelto más populares en la investigación astrofísica debido a su asequibilidad y disponibilidad en comparación con los sensores CCD, pero también debido a su rápida velocidad de lectura y bajo ruido de lectura. Sin embargo, la tecnología que utiliza sCMOS es diferente a la CCD, por lo que es importante una caracterización completa para garantizar una reducción y un procesamiento válidos para los procesos científicos. Se muestran los resultados de las pruebas de laboratorio y en el cielo para el comportamiento de parámetros como la polarización, corriente oscura y respuesta fotográfica del modelo Kepler KL4040 de la casa Finger Lake Instruments. Las imágenes de bias analizadas mostraron un aumento en los recuentos medios del bias de un 8,24 por ciento a medida que la temperatura aumenta de -15 a 10 C, lo que indica una relación con la temperatura. Se investigó la corriente oscura promedio en función del tiempo de exposición, entre 0,1 s a 60 s, en un rango de temperaturas absolutas de -15 a 10 C, con una clara indicación de una correlación entre la corriente oscura y la temperatura del sensor. La tasa de aumento del ruido de corriente oscura muestra claramente tendencias lineales para todas las temperaturas. La curva de respuesta es lineal hasta el rango completo de profundidad del pozo de potencial, con una tendencia similar tanto en el modo de baja ganancia como en el de alta ganancia. Utilizando tanto las filas como las columnas de las imágenes, se muestra el procesamiento de reducción desde imágenes sin procesar hasta imágenes científicas listas para el análisis fotométrico. Los resultados indican que los sensores sCMOS son opciones viables para las observaciones astronómicas, dado que están bien caracterizados, a sabiendas de sus ventajas y posibles inconvenientes.

ABSTRACT

Recently sCMOS sensors have become more popular in astrophysics research due to affordability and availability versus CCDs, but also due to their fast readout speed and low read noise. However, the technology that sCMOS utilize is different than CCD, because of this, full characterization is important to ensure valid reduction and processing for science pipelines. In lab as well as on-sky testing results for the bias, dark current and photo response behavior of the Kepler KL4040 by Finger Lake Instruments will be shown. Analyzed bias frames showed an increase in mean bias counts by 8.24 percent as the temperature increases from -15 to 10 C, indicating a temperature relation. The average dark current as a function of exposure time was investigated, from 0.1 s to 60 s, at an absolute temperatures range of -15 to 10 C, with a clear indication of a correlation between dark current and sensor temperature. The rate of the Dark Noise increase clearly shows linear trends for all temperatures. The photo response curve is linear up to full well depth range, with a similar trend to both low-gain and high-gain modes. Using images with row and column plots, the reduction processing from raw to science images ready for photometric analysis is shown. The results indicates that sCMOS sensors are viable options for astronomical observations given that a thorough understanding of the characteristics and possible drawbacks of sCMOS sensors are understood and compensated for.

Key Words: instrumentation: detectors — instrumentation: photometers — techniques: image processing — techniques: photometric — telescopes

1. INTRODUCTION

Scientific Complementary Metal-oxide-Semiconductor (sCMOS) cameras have become as good, or for some use cases better performing, than Charge Coupled Devices (CCDs). sCMOS cameras are also more affordable than CCDs for similar specifications. Although they work on the same principles, one big difference is that sCMOS sensors show more pixel to pixel variability due to each pixel and each row of pixels having its own readout amplifier. The sCMOS however has the benefit of low readout noise, unlike CCDs where

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the cumulative read-noise is amplified by a single readout amplifier. Some sCMOS sensors have 12-bit readout amplifiers, whereas high quality CCDs use 16-bit, which leads to sCMOS sensors having a lower dynamic range than CCDs. To enhance the dynamic range, these sCMOS sensors reads the pixels out at a high and a low gain. The camera driver software of the sCMOS then merges these images into a single high dynamic 16-bit image.

A benefit of using sCMOS is the ability of taking science grade images with low noise at 20 frames per second for low dynamic range images and 10 frames per second for high dynamic range images. This gives an observer the ability to undertake very high speed photometry, with a low cost instrument. This can be especially useful for objects like active galactic nuclei (AGN), Blazars and cataclysmic variable (CV) systems. This research aims to characterise the Kepler KL4040 sCMOS sensor from Finger Lake Instruments (FLI), which is implemented at the Boyden Observatory near Bloemfontein. The limits and parameters of the sensor are studied. A processing pipeline specific to the sensor is being developed.

2. OBSERVATION & ANALYSIS

The Kepler KL4040 sCMOS camera was tested both in laboratory and on-sky. Laboratory tests include: Bias current response to operation and environment conditions. Dark current response at different temperatures and exposure times. The plots for the dark current versus temperature versus exposure time was generated by processing individual dark frames and correcting for bias and Fixed Pattern Noise (FPN) (as per the FLI Kepler Manual[4]), and then averaging them together to create relevant master dark frames. For more on FPN in CMOS cameras refer to Zhang et al. (2020).

Photo-Response Curves (PRC) were also produced for the camera by exposing the camera to simulated spectral light using a VeraSol-2 LED Class AAA Solar Simulator[5] and an integrating sphere in combination with neutral density (ND) and colour filters. The PRC reveals the saturation level, high and low gain switch over and any pixel to pixel and frame to frame variation in the sCMOS sensor. Refer to Karpov et al. (2021); Wocial et al. (2022) regarding PRC and cross-over regions for CMOS sensors.

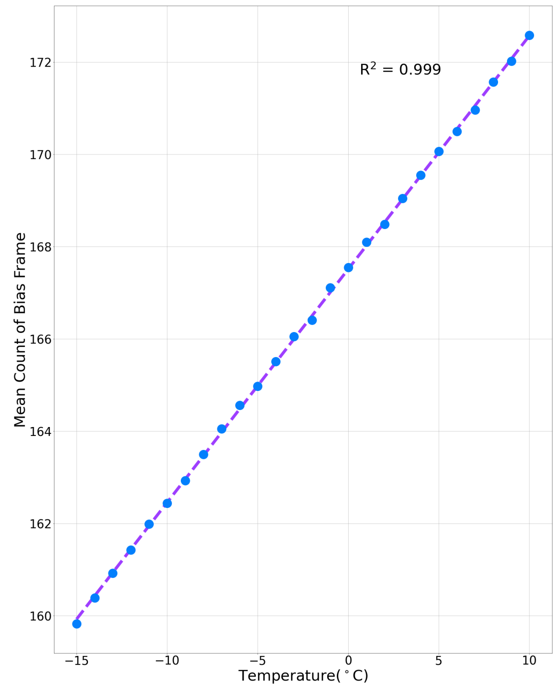

Fig. 1. Temperature dependence of mean bias based on initial in-lab testing results. Mean bias increases with a linear trend with an increase in sensor temperature.

On-sky testing was completed using both a 14 Celestron and the 1.5 m Boyden reflector telescope. Beside flat-fielding tests, observational tests included standard photometry fields (AAVSO-SA107[6]), time-domain CV stars and limiting magnitude tests on Blazars/AGN.

3. RESULTS

Based on initial analysis of the in laboratory testing results, the temperature dependence of the mean bias count (Figure 1) shows a linear trend, indicating that the sCMOS bias is dependant on the temperature. The strong dependence of the dark current to temperature (Figure 2) as is documented for sCMOS electronic architecture due to each pixel hosting an analog to digital converter (ADC) can be observed, i.e. at specific temperatures, the mean dark current increases relative to the exposure times. This indicates that careful notation must

[4] `https://www.flicamera.com/downloads/KeplerManual.pdf`.

[5] `https://www.newport.com/f/class-aaa-led-solar-simulators`.

[6] `https://app.aavso.org/vsp/chart/?title=SA107&ra=234.7025&dec=-0.224722&fov=70&maglimit=14.5&special=std_field&all=on&north=down&east=right`.

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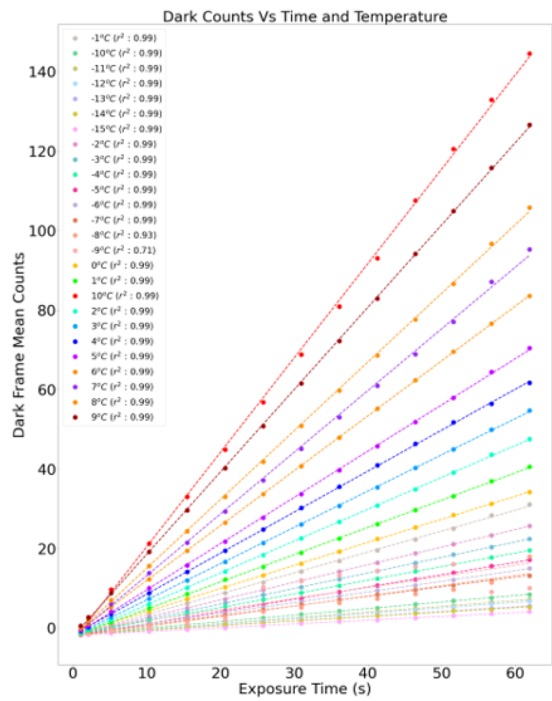

Fig. 2. Temperature dependence of mean Dark Current based on initial in-lab testing results. As can be seen, the dark current increases based on both temperature and exposure times. Sensor temperature indicated by legends.

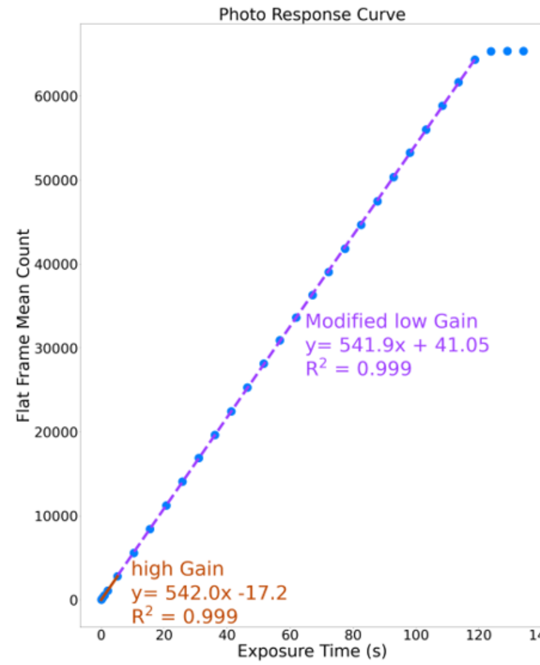

Fig. 3. Photo response curve based on initial in-lab testing results. Both high gain and low gain indicated. Transition point is at 3800 counts from high gain to modified low gain.

be made of the absolute sensor temperature during observations to compensate for strong dark current temperature dependence. Relatively good linearity of the photo response of the camera (Figure 3) for both modes of operation up to full well depth was found.

To inspect and compare pre- and post-reduction images, column and row profiles were used to evaluate pixel variations and trends across the sensor for the various data types, i.e. BIAS, DARK, FLAT and SCIENCE. Figures 4, 5 & 6 are the column summed side profiles of master calibration/reduction images and Figures 7 & 8 are raw and cleaned science/star frame side profiles after using the master reduction frames to remove electronic as well as optics effects. Figure 9 is a composite image to compare a raw (left) vs cleaned (right) sky image.

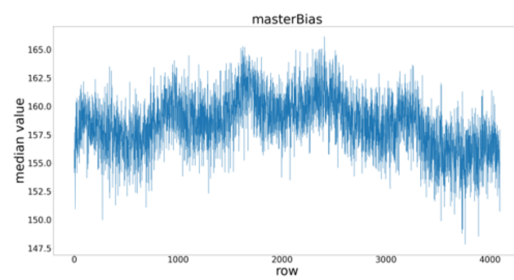

Fig. 4. Summed column profile for Master BIAS images.

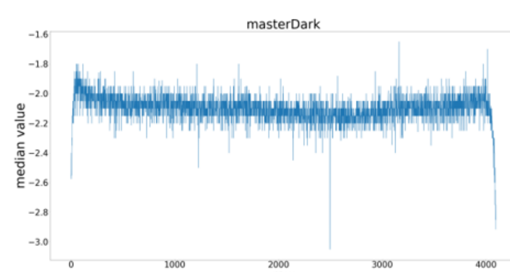

Fig. 5. Summed column profile for Master DARK images.

4. CONCLUSION

Based on results from both in laboratory as well as on-sky testing, the sCMOS seems to be a good option for science on a low budget as long as the dependence on temperature is fully understood and considered during post acquisition processing. Thankfully

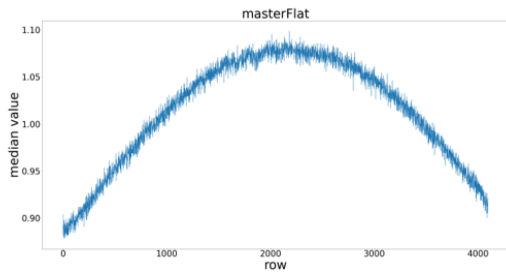

Fig. 6. Summed column profile for Master FLAT images.

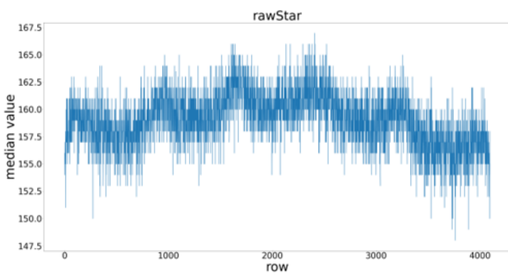

Fig. 7. Summed column profile for raw science/star images.

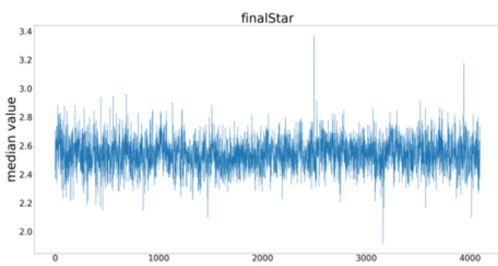

Fig. 8. Summed column profile for final reduced science/star images.

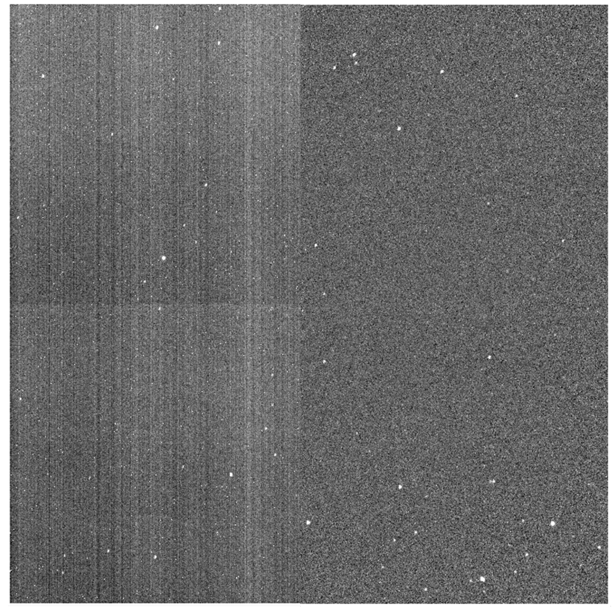

Fig. 9. Composite image to indicate the difference between a raw (left) vs cleaned (right) science / star image.

these additional considerations that have to be applied during processing can be incorporated into custom pipelines that can easily be developed in python using AstroPy[7] packages.

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[7]https://www.astropy.org/.