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Use of CMOS cameras in exoplanet transit photometry

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Abstract

For a few years modern CMOS cameras revolutionized amateur astrophotography. Their use can be seen also in some scientific aspects, parallel with widely used CCD cameras. I present my photometric results of 21 detected exoplanet transits obtained so far from SOTES observatory, using cooled camera with 1/1.8" IMX178 sensor developed by ZWO[1]. Attempts on targets with different magnitudes, depths and durations allowed to determine limits for low budget photometric setup, that can be also accessed for astronomy amateurs. CMOS efficiency allows a short exposure recording, which is necessary in high cadence photometry.

1. Introduction

Observatories around the world (also the amateurs) are mostly equipped with CCD cameras. Recently, CMOS sensors began to play important role especially in planetary imaging. Low noise sensors with high quantum efficiency work great deep sky astrophotography, especially after adding of cooling and reducing the ampglow.

Photometric accuracy with a specified telescope is mostly determined by scintillation and noise level. By observing known targets with different magnitudes, we can predict if an exoplanet transit in front of star with similar brightness could be detected. Other aspects, such as background light level (light pollution, Moon), elevation or duration must be also taken into account.

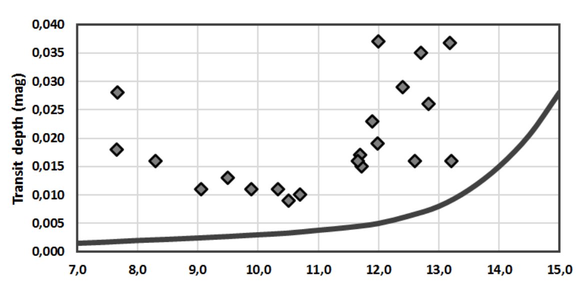
All tests were performed for a preparation of TESS ground-based follow-up observations, to show amateur role in detection of exoplanet candidates. The start of the program is planned for the beginning of 2020, after first expected release of possible targets in northern hemisphere.

Frames were acquired using *SharpCap v3.0* software[2]. To perform photometry, *C-Munipack*[3] and *AstroImageJ v3.2.0*[4] were used. For lucky imaging analysis, *MS Excel* spreadsheet program is necessary.

2. Results

IMX178 is a small 1/1.8" sensor and was chosen due to its 14-bit output, low ampglow and small pixel size giving a large 3096x2080 resolution. Other sensors in ZWO's offer (IMX290 and IMX174) were not chosen mostly due to higher ampglow, which has a large impact in photometry, where milimagnitude accuracy is needed. Also, little pixel size (2.4μm) with Canon FD 300mm f/2.8 L lens (aperture 107mm) give a scale of 1.65"/px. It is good enough to resolve blended eclipsing binaries primarily found as possible exoplanet candidates by observatories such as KELT[5], which I also collaborate with, Kepler or upcoming TESS.

The determinant if a specified dip can be seen, is the photometric accuracy. Based on 3-minute (time precision) and additional 15-minute bins (depth check) of the star's brightness flux, we can measure how small decrease of brightness could be detected. Mostly, results are consistent from observations made in the previous nights.



Ground-based photometry observations by amateurs are less accurate than the space-based TESS ones. However, amateurs can still play an important role on detecting false positives, where a fainter nearby star (unresolved by TESS) show eclipsing binary behavior (NEB), or redefine the ephemeris[6]. The main task is to find the variability source. If it's the brightest star, it could be tested later with radial velocity observations or high resolution imaging. To make it possible, a decrease of brightness in a predicted moment must be observed, also proving that other blended (on TESS frames) stars are stable. This is a very important test for CMOS sensors, if it's performance allow to rule out targets as NEBs.

If true variable companion is far enough, the drop would be easier to detect than from the main star itself. Sessions of targets having expected depth below the limit are also useful, as no detection of neighbour stars variability is an indication that the brightest object contains a small transiting object. If the predicted depth is large enough, a photometric filter can be applied. This is also preferable in observing TOI (TESS Objects of Interest) candidates. A difference of depth in other bands may suggest that the target is an eclipsing binary. The highest S/N was seen in R band, followed by V filter, afterwards.

All observations resulted in discovery of more than new 50 variable stars (mostly eclipsing binaries), which have been submitted to Variable Star Index (VSX) database[7]. Moreover, results of K2-232 b candidate detection in September 2017 were also presented in discovery paper by Yu et al. 2018[8].

3. Use of short exposure frames

The CMOS sensors tend to have low noise levels, but atmosphere has larger impact on photometric accuracy. Thanks to the fast download time, frames can be acquired up to few per second. If a target is bright enough and is located close enough to a proper reference star, one can crop the image for even higher FPS rate. This is opposite to CCD, where we need to wait a few seconds to get an image. This advantage can be used in high cadence photometry.

4. Summary and Conclusions

CMOS sensors, as well as CCDs, can be also used in photometry. Thanks to their price, amateurs can now explore exoplanet transits at lower cost. The precision is also comparable on both type of sensors, so low budget cameras can be used too. The next goal is to upgrade SOTES observatory with three small-sized Newtonian telescopes (0.20m f/4.0) and cameras based on CMOS IMX178 sensor. Each one would allow to observe 3 different targets at the same time (for better accuracy), or a single star with multiple photometric filters, which give many possibilities around KELT and TESS candidates.

5. Acknowledgements

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