Seestar S50
for
Occultation Work

Christian Weber, IOTA/ES V 2.0, 2025 December 17

About this document

This article describes aspects of the use of the ZWO Seestar S50 'smart telescope' (https://store.seestar.com/) for observing stellar occultations by asteroids, as studied by the author. This work does not describe the general capabilities and operation of the Seestar S50. Rather, the aim was to investigate whether and how this device can be used for stellar occultations. As the great advantage of the device lies in its compactness and simplicity, the intention was that no additional equipment (such as a PC) should be required. In this sense, projects such as 'Seestar_ALP' (https://github.com/smart-underworld/seestar_alp) or 'Seestar ALPACA' (ASCOM ALPACA driver (https://ascom-standards.org/About/Overview.htm) implemented in the Seestar firmware, see e.g. (https://forums.sharpcap.co.uk/viewtopic.php?t=9039, https://forums.sharpcap.co.uk/viewtopic.php?t=9188)) are not discussed.

The tests were carried out with a Seestar S50 telescope purchased in January 2024 (with using always the latest S50 firmware and the latest Seestar S50 Android app), partly under stars, but mostly indoors. The Seestar S50 was always controlled with a Google Pixel 4a smartphone on a 4G LTE+ network. A NEXTA device (https://iopscience.iop.org/article/10.1088/1538-3873/acacc8) and a QHY174GPS camera (https://www.qhyccd.com/qhy174gps-imx174-scientific-cooled-camera) were used as a time reference for the indoor tests. Not least due to the lack of a suitably equipped test laboratory and also of a detailed device documentation by ZWO, this work makes no claim to scientific accuracy and completeness, but is rather orientated towards the needs of the occultation community.

Unless otherwise labelled, all contents of this work, all images and data were created by the author. The author would like to thank all developers of the software used.

Changes compared to version V 1.0

In addition to some corrections and updates, several tests were repeated with the NEXTA device in a vertical configuration. This was necessary because the tests for version V 1.0 assumed a rolling shutter readout direction of the CMOS sensor from top to bottom, which was an incorrect assumption. The (vertically arranged) S50 sensor is read out from right to left.

It is therefore strongly recommended that you discontinue use of version 1.0 of this document.

Contents

1 Seestar S50

Seestar S50 (https://store.seestar.com/) is a so-called 'intelligent telescope' developed and marketed by Suzhou ZWO Co, Ltd, China. Figure 1.1 shows the author's Seestar S50 after delivery and in operation. The device is a 5-cm triplet refractor with a focal length of 25 cm. The S50 image sensor is of the Sony IMX 462 type. Seestar's CPU is probably an 8-core Snapdragon processor (not officially confirmed by ZWO). The Seestar S50 telescope is controlled via an Android or IOS smartphone app, see e.g. (https://play.google.com/store/apps/details?id=com.zwo.seestar&hl=en), no PC is required. In 1x zoom mode the field of view of Seestar is 44´ x 77' (in the unusual portrait format due to the adaptation to a smartphone screen).

Figure 1.1. Seestar S50 after delivery and in operation

The main application of a huge worldwide community is deep-sky photography with good results. Some scientific applications are also known, e.g. astrometry, photometry of variable stars or exo-planetary transits. Almost nothing is known about the use for recording asteroidal occultations.

2 S50 recording modes and formats

Seestar S50 modes and file formats are listed in Table 2.1.

S50 mode	File formats	Remarks
'Stargazing'	FIT	Uncompressed raw from sensor, sequence
	JPG	Additional JPG files in two sizes
'Solar System'	AVI	Uncompressed raw from sensor, AVI video stream, frame rate up to 120 fps with zoom 4x
	'… RAW.avi.txt'	A TXT file containing raw AVI metadata
	MP4	Compressed MPEG-4 AVC video stream, variable bit rate, frame rate ~30 fps
	JPG	Additional JPG files in two sizes
'Scenery'	AVI	Like 'Solar System'; not suitable for occultation work due to lack of celestial tracking
	'… RAW.avi.txt'	
	MP4	
	JPG	

Table 2.1. Seestar S50 modes and associated file formats

The only suitable occultation recording mode (apart from conceivable very special cases) is 'Solar System' using the raw AVI file format, which is marked in green in Table 2.1. The file '... RAW.avi.txt' contains a 'DATE-OBS' entry for the raw AVI and also other information of importance. The raw AVI file does not contain timestamps. The output in MP4 format is not suitable for occultation work. The time base of the S50 is the smartphone network, there is no inbuilt GPS timing. The otherwise used GPS 1PPS pulse is missing in the S50 (and also in the Android smartphone, even if it has GPS positioning). The author does not know whether things are different with IOS phones.

3 Using S50 to record an occultation

The general setup of the Seestar, e.g. azimuth/equatorial mode, polar alignment etc., is not covered here as it does not differ from the 'normal' use of the device.

The Seestar app has a star map ('SkyAtlas') that can be used to find celestial objects (Figure 3.1). However, this map is focused on the 'Stargazing' mode. It is therefore not possible to call up the desired 'Solar System' mode using the 'GoTo' command at the bottom of the star map. The solution is, after you have found the target star on the map, to quickly exit the map and press the 'Solar System' button, select any object there (e.g. Moon) and cancel this before S50 starts to approach the Moon. You should now see the desired star field in the live image of 'Solar System' mode (possibly increase the exposure time for the live image and also readjust the position of the target star if required). As shown in Figure 3.1, you can also first switch from star chart mode to 'Stargazing' mode and let Seestar stack a few images to ensure that you are in the correct star field.

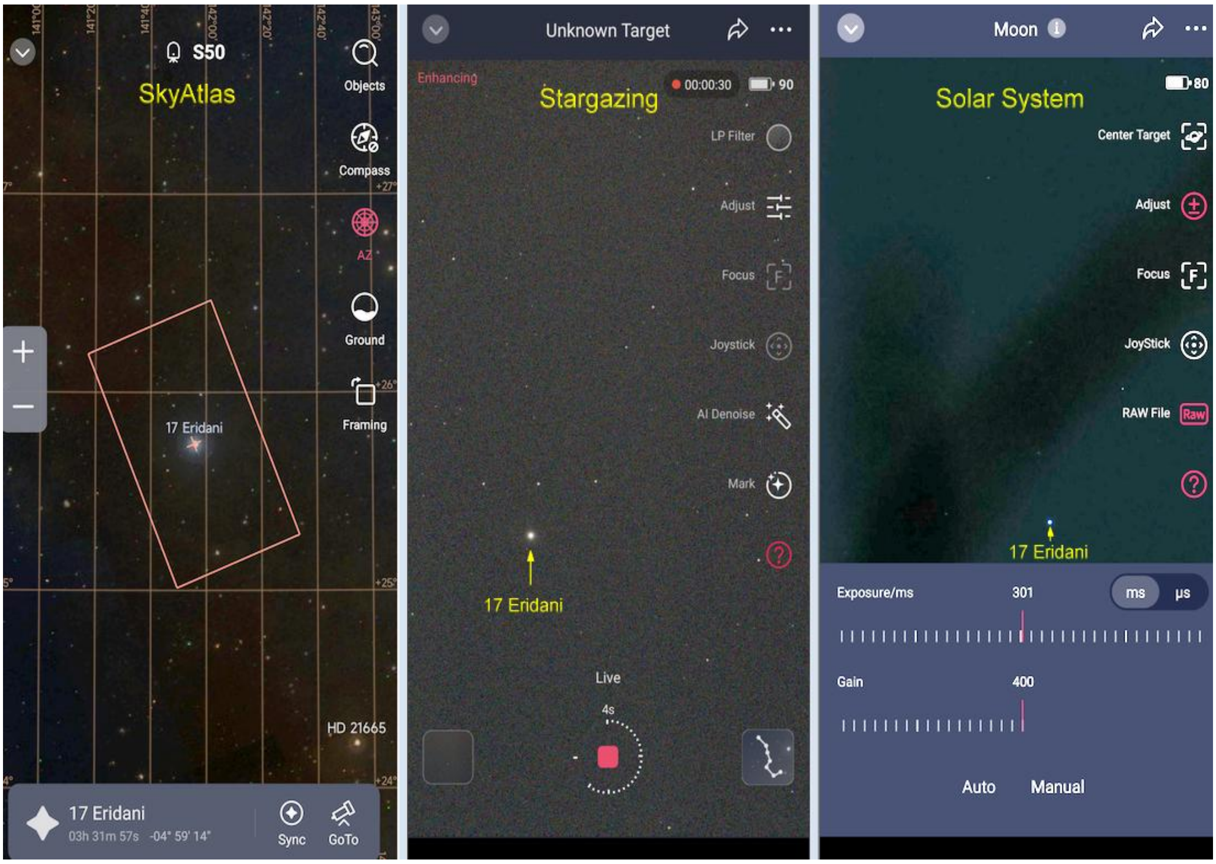


Figure 3.1. Seestar screenshots (yellow entries by the author) showing how to enter occultation recording mode with the target star 17 Eridani. The right part of the image demonstrates the 2x zoom feature; the background is influenced by branches of a tree. A plate-solved zoom 1x single frame of this star field from a 500 ms raw AVI can be seen in Chapter 4, Figure 4.4. It reaches almost 12 mag

There are several ways to find the target star itself on the star map. Usual catalogs for occultation work (TYC, UCAC4) are not available. The star map shows HD, HIP and bright/named stars. However, the search function does not allow to search for HD or HIP stars. Possible searches are for named/bright stars and for many types of deep sky objects (Messier, NGC, IC, LDN, VdB, …). This makes it easy to find the target star or its star field via a neighboring deep sky object. Since a recent firmware update, it is also possible to find the target star using its RA/DEC J2000 coordinates to create a 'Custom Object' (Figure 3.2).

Figure 3.2. Creating a 'Custom Object' for the target star by entering its J2000 coordinates

As soon as the target star is visible in 'Solar System' mode, some settings must be made in this window before recording can be started (Figure 3.3).

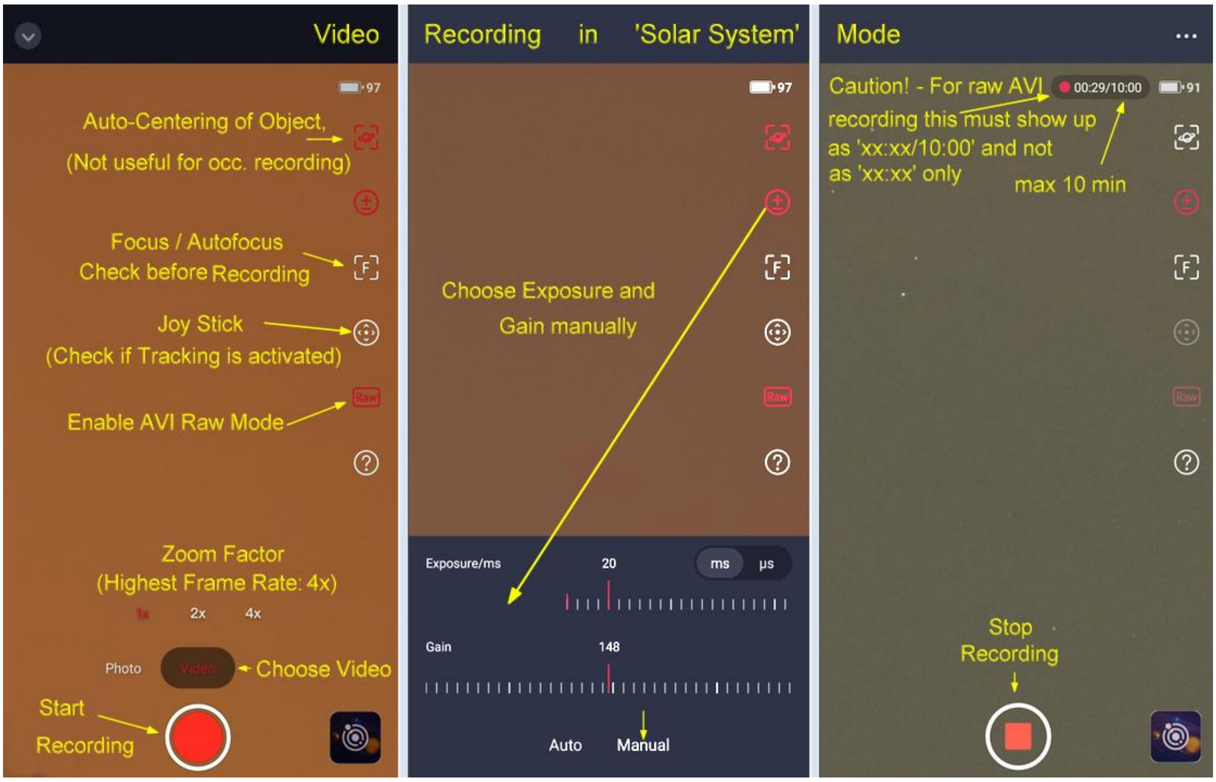


Figure 3.3. Settings in 'Solar System' mode to record stellar occultations

Most of the screenshots in Figure 3.3 should be self-explanatory. The (digital only) zoom function enables higher frame rates in 2x and 4x modes. Figure 3.4 shows the reachable frame durations for the 1x mode. As can be seen, the achievable minimum frame duration for a set exposure time of less than 70 ms stagnates at about 80 ms. Below this border the exposure takes place with the set exposure time, but there is a 'dead time'. With the two zoom modes the minimum exposure times without a 'dead time' are about 18 ms (x2 zoom) and 10 ms (x4 zoom). In general, the device does not implement the set exposure times exactly, in the recording they differ by a few per cent, but this is not a disadvantage for occultation work.

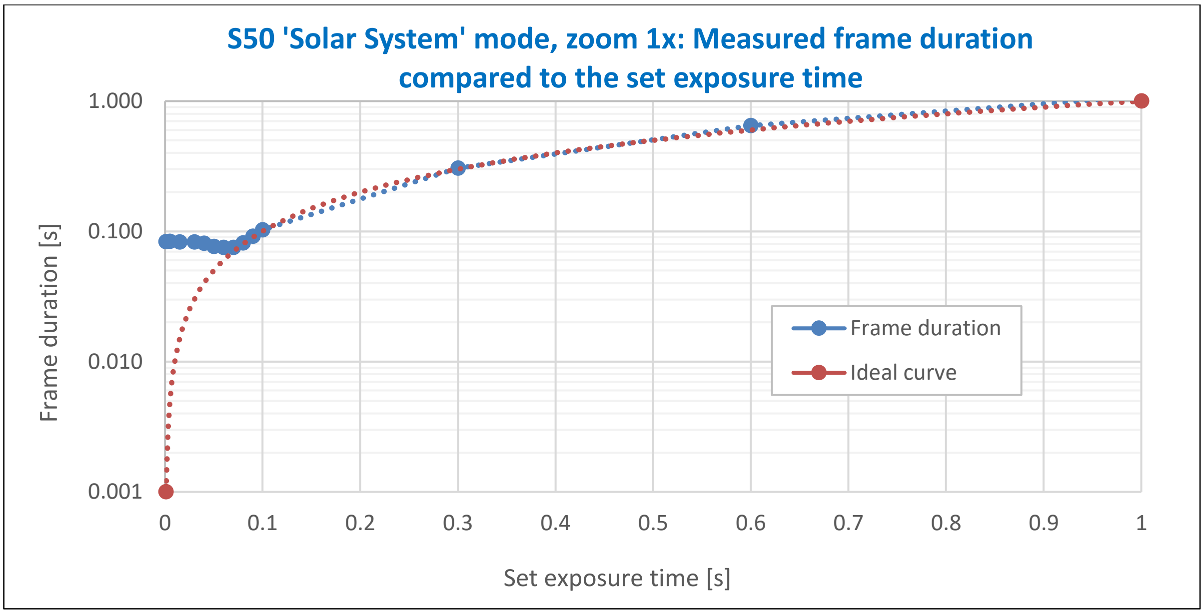


Figure 3.4. S50 frame duration compared to the set exposure time in zoom 1x mode, measured with NEXTA

The raw AVI file sizes for a 180 seconds video with an exposure time of 200 ms are in 1x, 2x, 4x modes about 1.8 GB, 0.45 GB, 0.1 GB. Note that the raw AVI format is a non-debayered format. Debayering is usually not required during photometric processing. Debayering is possible with various tools (e.g. PIPP, https://www.rsastro.com/downloads) and leads to an increase of the file size by a factor of 3.

There are currently several options for operating Seestar unattended (important for setting up multiple stations), but these are not optimal and have not yet been tested by the author. The first (limited to very short distances) is to use it within your own WiFi network. S50 can be set up with the app and started from a distance. The app can then be closed/the WiFi connection terminated - Seestar continues to work independently and saves internally. With WiFi extensions (repeaters), distances of a maximum of several 10 metres are possible. Unfortunately, the Seestar 'Plan' function does not yet work for video recordings, but only for 'Stargazing'.

Since firmware 2.70, Seestar offers the possibility to control the device via the Internet as a beta version ('Telescope Network', https://store.seestar.com/de/blogs/tutorial/seestar-new-feature-telescope-network-remote-function-user-guide).

4 S50 limiting magnitude

Thanks to the highly sensitive SONY IMX 462 sensor, the Seestar S50 delivers surprising results under the starry sky. No systemic tests for the S50 limiting magnitude were carried out, taking into account all possible parameters. However, several examples show good results (Figures 4.2 to 4.5) The occultation observer should carry out specific tests on the star in advance for any occultation events.

For interest only, in 'Stargazing' mode with an exposure time of 10 s a stack of about 600 frames reaches magnitudes near 16.5 to 17 mag under Berlin center light polluted sky conditions (Figure 4.1).

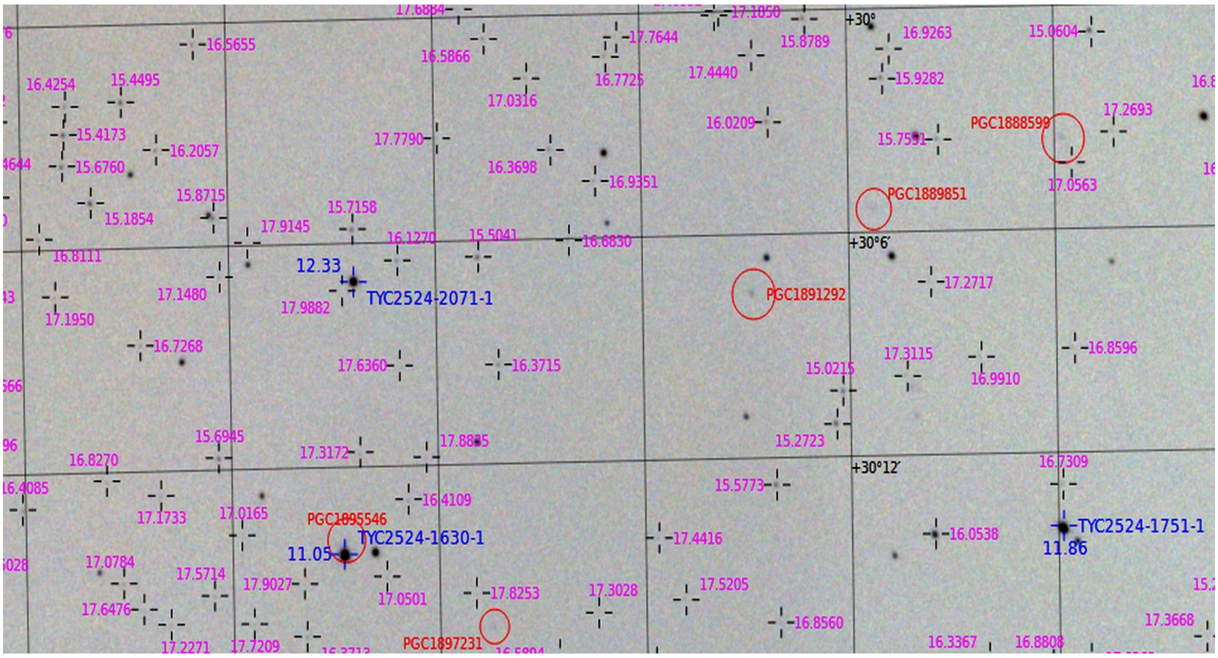


Figure 4.1. Stack of about 600 10-second frames ('Stargazing' mode), Gaia Gmag magnitudes, (Annotation - Credit: PixInsight, http://pixinsight.com/)

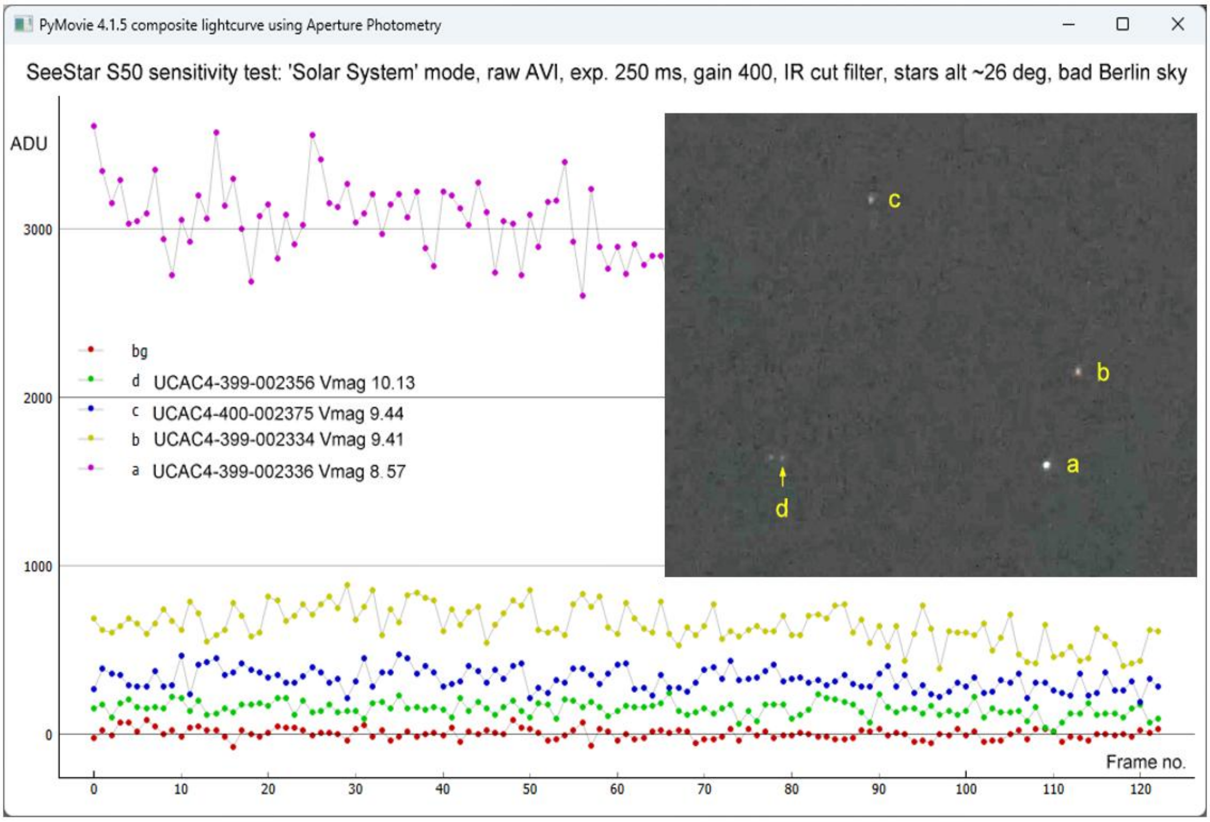


Figure 4.2. S50 sensitivity test with 250 ms exp. time, see explanations in the image. The inserted single frame (debayered) image shows the stars used for PyMovie photometry. The IR cut filter (the IMX 462 is highly IR sensitive) mentioned in the image caption cannot be removed from the S50 optical path, (Credit: PyMovie, PyOTE, https://occultations.org/observing/software/pymovie)

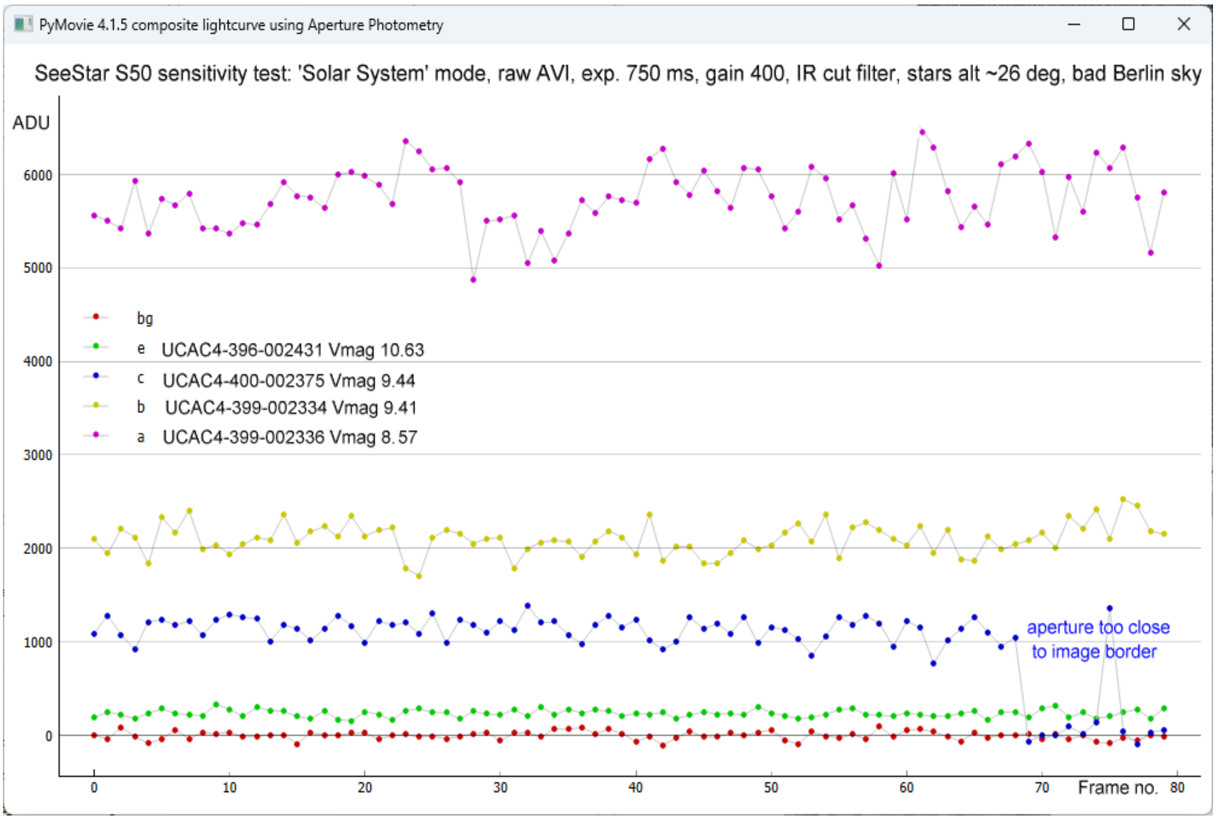


Figure 4.3. S50 sensitivity test with 750 ms exposure time, (Credit: PyMovie)

Figure 4.4 shows another example where a magnitude of almost 12 mag is reached with 500 ms exposure time. Figure 4.5 presents the photometry with acceptable SNR for a 11.5 mag star.

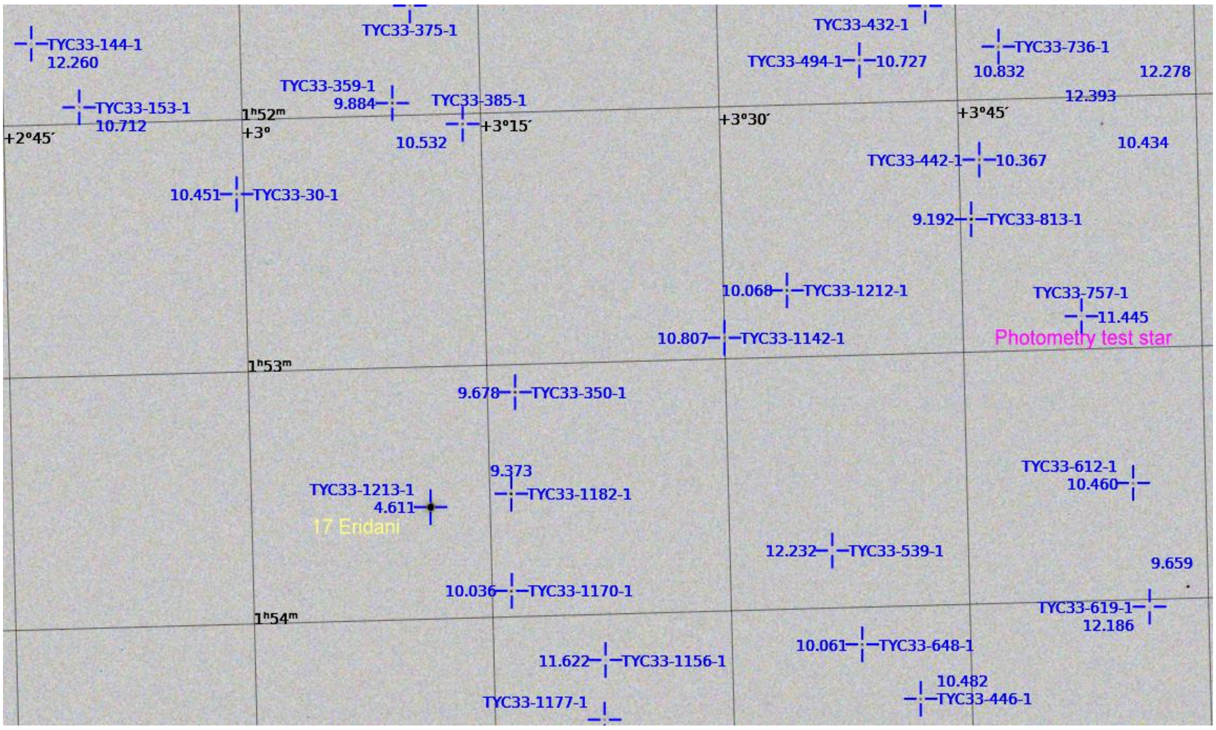


Figure 4.4. Single frame (90 deg rotated, debayered) from a S50 raw AVI in 'Solar System' mode, exposure time 500 ms, zoom 1x, gain 400, IR cut filter, stars alt ~27 deg, light polluted Berlin center sky. Compare Figure 3.1 The 'Photometry test star' with 11.445 mag was used for PyMovie photometry, see Figure 4.5, (Annotation - Credit: PixInsight)

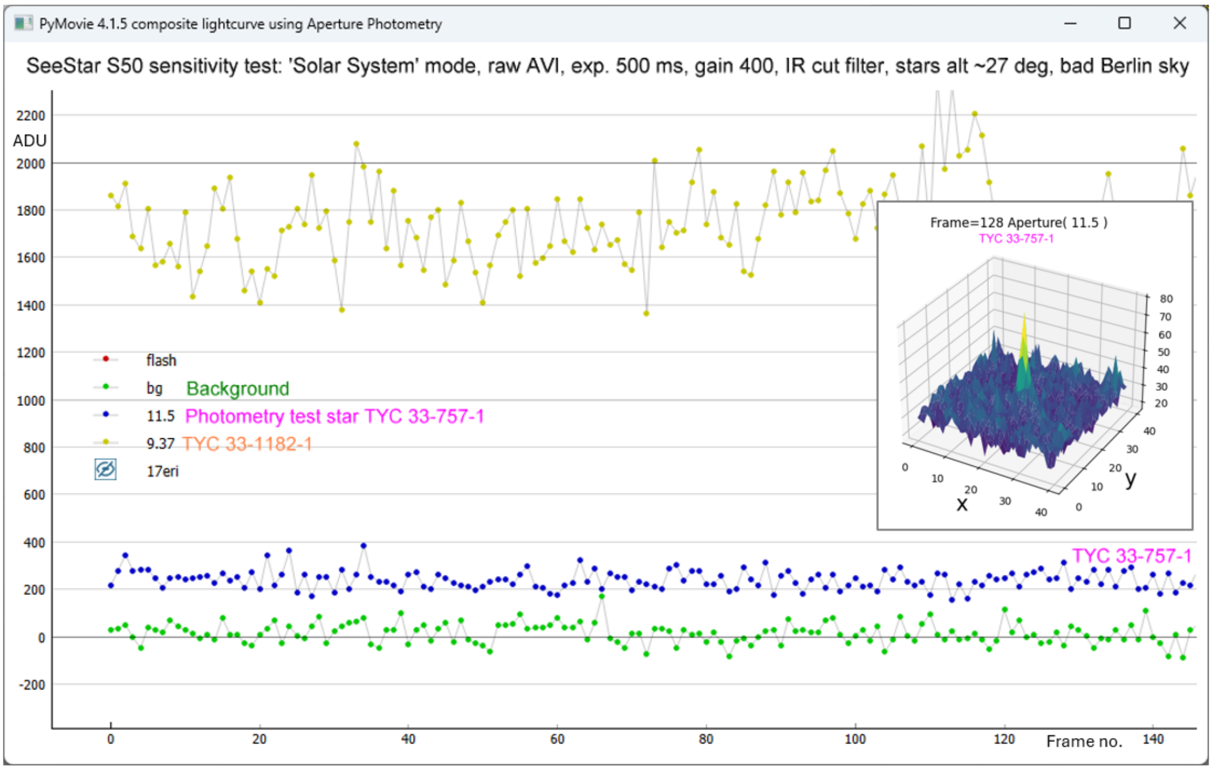


Figure 4.5. Photometry test for a 11.5 mag star, exposure 500 ms, compare Figure 4.4, (Credit: PyMovie)

5 S50 recordable occultation events

It is very clear that the S50 is not an 'occultation telescope'. But thanks to the fairly good sensitivity despite the small aperture of only 5 cm, it should be suitable for recording stellar occultations (with suitable parameters). In view of the very widespread use of the instrument worldwide, its owners could make a significant contribution to occultation astronomy. Currently there is only one observation with this telescope in the Occult4 database (a negative one by the author).

To get an idea of the number of potential events, a conservative and an ambitious filter were defined in OccultWatcher Cloud (https://cloud.occultwatcher.net/) and searched for events within 7 days (OWC does not allow longer time periods) from 1 December 2025 in the 1,000 km area around Berlin. Using the conservative filter, three events were found (Figure 5.1).

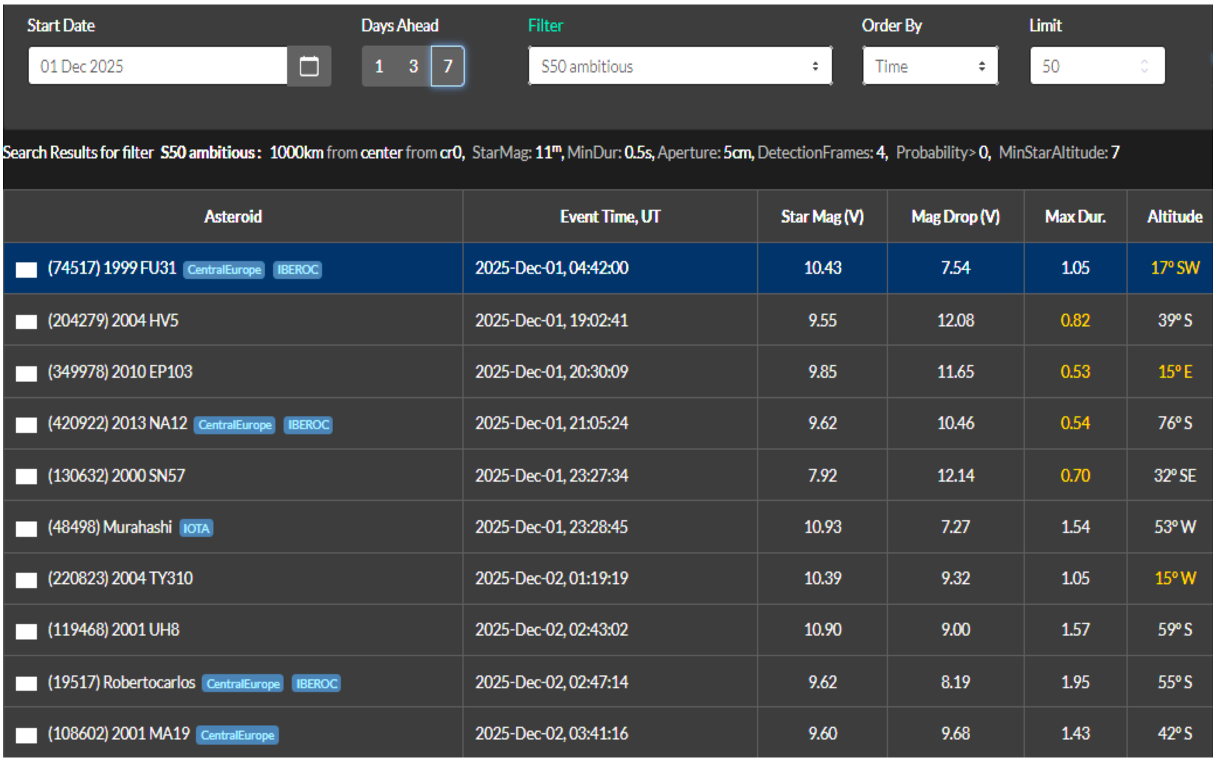
Start Date: 01 Dec 2025 | Days Ahead: 1 3 7 | Filter: S50 conservative | Order By: Time | Limit: 50

Search Results for filter **S50 conservative: 1000km** from **center** from **cr0,** StarMag: **8.5ᵐ,** MinDur: **1s,** Aperture: **5cm,** DetectionFrames: **6,** Probability> **0,** MinStarAltitude: **8**

Asteroid	Event Time, UT	Star Mag (V)	Mag Drop (V)	Max Dur.	Altitude
(44247) 1998 QR40	2025-Dec-04, 20:46:14	8.48	10.10	2.61	50° S
(15410) 1997 YZ CentralEurope IBEROC	2025-Dec-05, 01:18:55	8.22	8.68	1.59	47° SW
MY (7287) Yokokurayama CentralEurope	2025-Dec-06, 19:11:58	4.71	11.89	1.95	24° SE

Figure 5.1. With the conservative filter (1,000 km from center from observer's home station, star magnitude 8.5 mag, minimal duration 1 s, detection frames 6, probability > 0, minimal star altitude 8 deg) three events were found for 7 days after 1 December 2025, (Credit: OWC)

Figure 5.2 presents the first of more than 50 potential events gotten with the ambitious filter, for details see the caption of the figure.



Asteroid	Event Time, UT	Star Mag (V)	Mag Drop (V)	Max Dur.	Altitude
(74517) 1999 FU31 CentralEurope IBEROC	2025-Dec-01, 04:42:00	10.43	7.54	1.05	17° SW
(204279) 2004 HV5	2025-Dec-01, 19:02:41	9.55	12.08	0.82	39° S
(349978) 2010 EP103	2025-Dec-01, 20:30:09	9.85	11.65	0.53	15° E
(420922) 2013 NA12 CentralEurope IBEROC	2025-Dec-01, 21:05:24	9.62	10.46	0.54	76° S
(130632) 2000 SN57	2025-Dec-01, 23:27:34	7.92	12.14	0.70	32° SE
(48498) Murahashi IOTA	2025-Dec-01, 23:28:45	10.93	7.27	1.54	53° W
(220823) 2004 TY310	2025-Dec-02, 01:19:19	10.39	9.32	1.05	15° W
(119468) 2001 UH8	2025-Dec-02, 02:43:02	10.90	9.00	1.57	59° S
(19517) Robertocarlos CentralEurope IBEROC	2025-Dec-02, 02:47:14	9.62	8.19	1.95	55° S
(108602) 2001 MA19 CentralEurope	2025-Dec-02, 03:41:16	9.60	9.68	1.43	42° S

Figure 5.2. First of more than 50 potential events found with the ambitious filter (1,000 km from center from observer's home station, star mag. 11 mag, minimal duration 0.5 s, detection frames 4, probability > 0, minimal star altitude 7 deg) for 7 days after 1 December 2025, (Credit: OWC)

A further consideration was made based on the current events (11 October 2025 to 11 January 2026; around 16,500 events) of the author's OccultWatcher Desktop. (https://www.occultwatcher.net/). Note that all filters in OW are set very generously, this is not the place to report all filter settings. Looking only at 'My events', 45 out of 180 events had a magnitude of 11.5 mag or better. Taking into account the enormous number of all other (but filtered) events, there were about 2,700 with a magnitude of 11.5 mag. 340 of these had a duration of at least 1 s, 160 events were at a maximum distance of 50 km and 1,300 had a rank of over 50 %.

The potential risk of not being able to see (fainter) comparison stars in star-poor areas is somewhat mitigated by the S50's large field of view, at least in 1x and 2x zoom mode.

6 S50 timing

Timing is the main issue when using the Seestar S50 for occultation work. As mentioned above, Seestar relies on the time base of the smartphone network and does not have GPS-1PPS timing.

Setup

To analyse the time reference and time accuracy of the Seestar, a test arrangement was set up on the basis of a NEXTA device (https://iopscience.iop.org/article/10.1088/1538-3873/acacc8). Since the minimum focusing distance of the S50 is several tens of metres, a finder telescope was used in the opposite direction to focus on the NEXTA display, which is about 3 m away (Figure 6.1).

Figure 6.1. Test setup for mapping the NEXTA LED display (image inserted top left) using a finder scope in reverse orientation. The image inserted at the bottom right shows an example from an S50 recording (not showing the actual LED sequence of the image at the top left)

S50 DATE-OBS

The raw AVIs from Seestar have no time stamps. Only the file '... RAW.avi.txt', written together with the raw AVI file, contains a 'DATE-OBS' entry as shown in the example below:

2025-11-07-222841-Lunar-RAW.avi.txt

```
[Seestar S50]
Bin = 1
Capture Area Size = 1080 * 1920
Colour Format = RAW8
Flip = None
StartX = 0
StartY = 0
Temperature = 20.625 C
Bayer = GR
White Balance (B) = 187
White Balance (R) = 110
DATE-OBS = 2025-11-07T21:28:42.673628
SITELONG = 13.xxx
SITELAT = 52.xxx
OBJECT = Lunar
Duration=121 Sec
```

ZWO has not documented what DATE-OBS refers to. However, with a few simple tests it is easy to determine that DATE-OBS refers to the start of the recording, estimated from the duration of the recording and the time Seestar registered the end of the recording.

The NEXTA device was used to test how far DATE OBS deviates from the true (NEXTA) time for various raw AVI video settings (Figure 6.2). As Figure 6.2 shows, Seestar's DATE-OBS apparently deviates randomly and strongly from the true time. In this respect, DATE-OBS cannot be used (together with the known frame rate, for example) for timing S50 raw AVI videos.

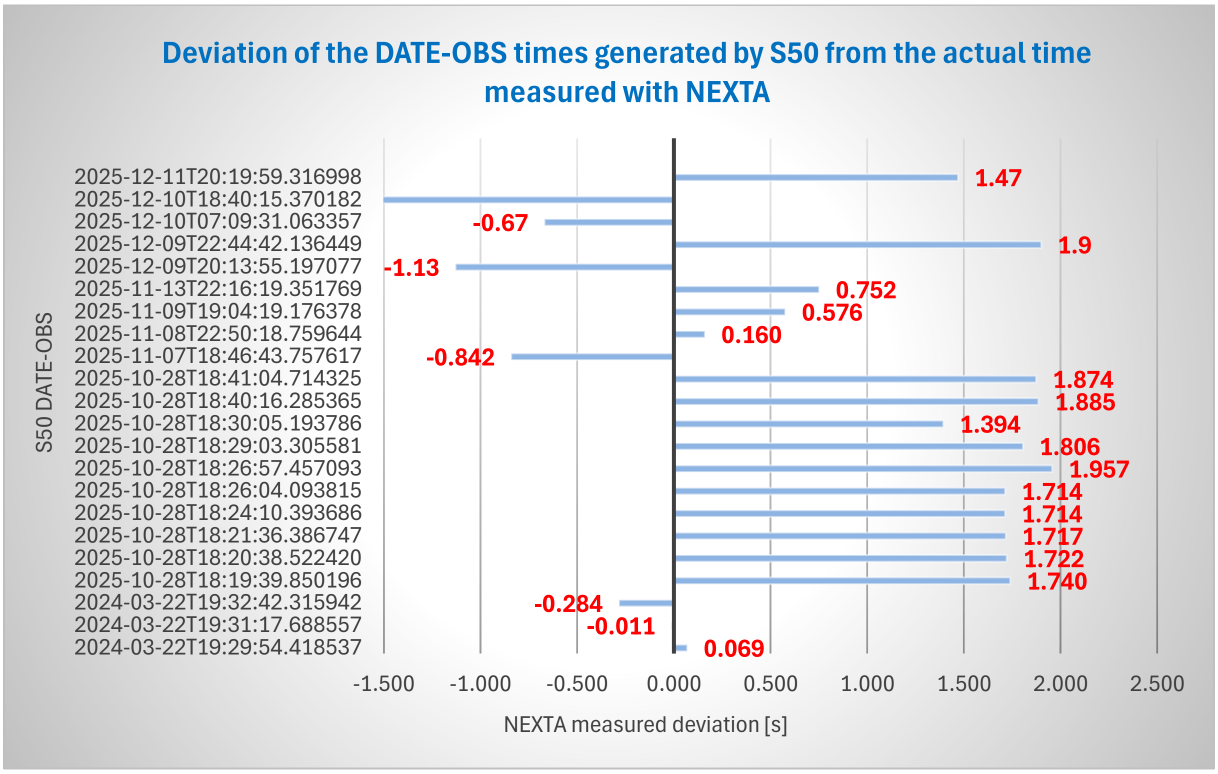


Figure 6.2. Deviation of Seestar's generated DATE-OBS times from the actual time measured with NEXTA for video raw AVI 'Solar System' mode

The only timing method that seems possible is 'goalpost' flashing, which means that 1PPS GPS synchronised flashes are inserted into the telescope optics before and after the occultation event (or at the beginning and end of the recording), which are then used to manually time-stamp the raw AVI file.

S50 flash timing

The most suitable programme for this is PyOTE with its 'Flash-Tag' aperture (white aperture) feature. Unfortunately, the need for an additional device destroys the intended simplicity of the system, but no other way is conceivable. In addition, a simple flashing device with continuous 1PPS pulses is not sufficient, as the deviations of DATE-OBS from the true time can be greater than 1 second and it is also not possible to assign continuous pulses to the frames of the raw AVI.

A flashing device is much more necessary, which provides the pulses at adjustable times or pulse patterns at known times. The latter can be easily realised with the NEXTA device itself by connecting a LED to one of the four 1-second LEDs of the NEXTA display, which shines into the S50 optics (Figure 6.3).

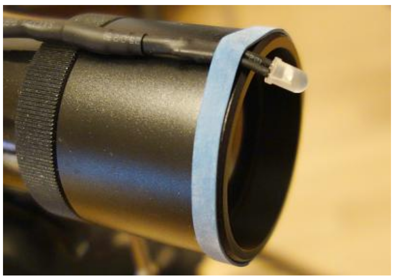


Figure 6.3. Flashing LED connected with the NEXTA device, in this case mounted to the finder telescope, compare Figure 6.1

Figure 6.4 demonstrates the flashing pattern of NEXTA's a1s LED, compare also Figure 6.1.

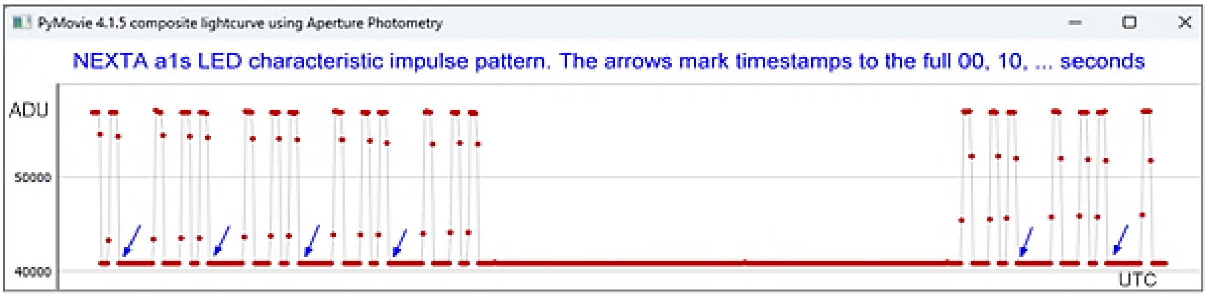


Figure 6.4. Characteristic flashing pattern of NEXTA's a1s LED from a PyMovie 'Flash-Tag' (white) aperture, (Credit: PyMovie, PyOTE)

It must also be expected that even raw AVIs time-stamped by flashes at the beginning and end will still show deviations from the true time. However, in several configurations, these deviations were always smaller than one frame duration. Figure 6.5 illustrates this using a 117-second raw AVI file.

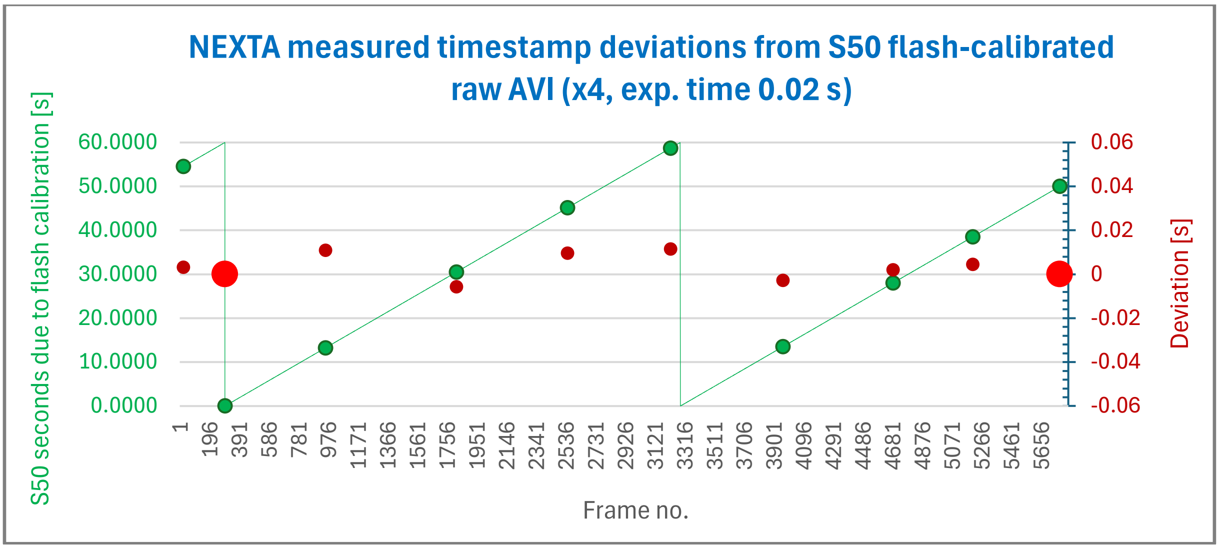


Figure 6.5. Seestar time deviations for a 117-second raw AVI (exposure time was set to 20 ms, zoom x4). The two thick red dots signify the time calibration flashes. The average deviation is 3.3 ms

S50 rolling shutter effects

As the S50 sensor IMX 462 has a rolling shutter, its influence was analysed using a similar configuration as described in Section 2.4.3 (see in particular Figure 20) of the NEXTA article (https://iopscience.iop.org/article/10.1088/1538-3873/acacc8). Because the CMOS sensor is aligned vertically (portrait format) in order to adapt the S50 to the screen orientation of a smartphone, the NEXTA LED bar must also be aligned vertically to analyse the rolling shutter effect. The S50 sensor readout direction is from right to left. Figure 6.6 shows the configuration with Seestar. The readout time of a single sensor line of the S50 was determined based on the characteristic patterns of individual LEDs of the NEXTA 0.1-ms section (Figure 6.7) and was found to be 29 µs. The resulting readout times for the entire sensor are listed together with the minimum frame durations in Table 6.1.

Zoom mode	Sensor readout time [ms]	Minimum frame duration [ms]
1x	31.3	80
2x	15.7	18
4x	7.8	10

Table 6.1. Seestar S50 measured sensor readout times and minimum frame durations

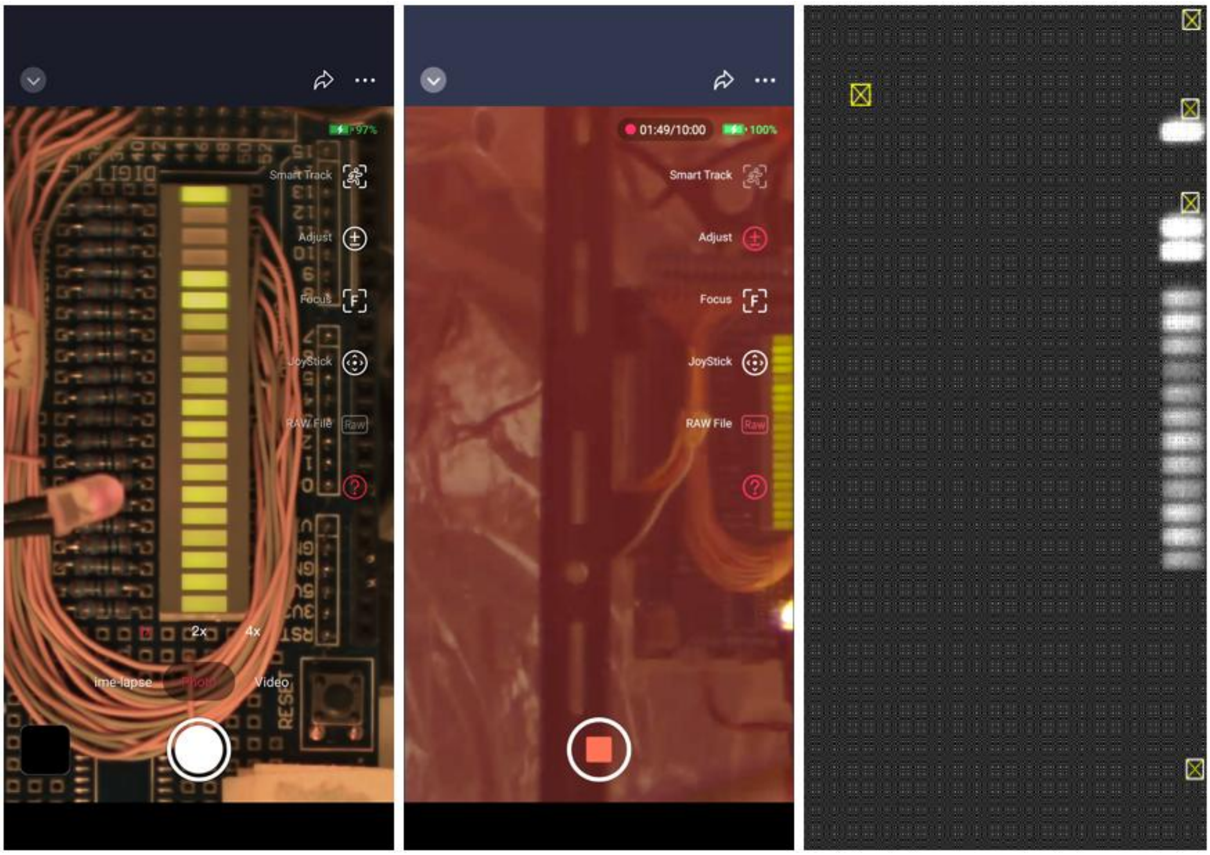


Figure 6.6. Vertically arranged NEXTA LED array (left) for processing the actual CMOS readout mode from right to left. The middle image shows a smartphone screenshot, while the right image shows a frame from a recorded AVI raw file with PyMovie photometric apertures, (Credit: PyMovie, PyOTE)

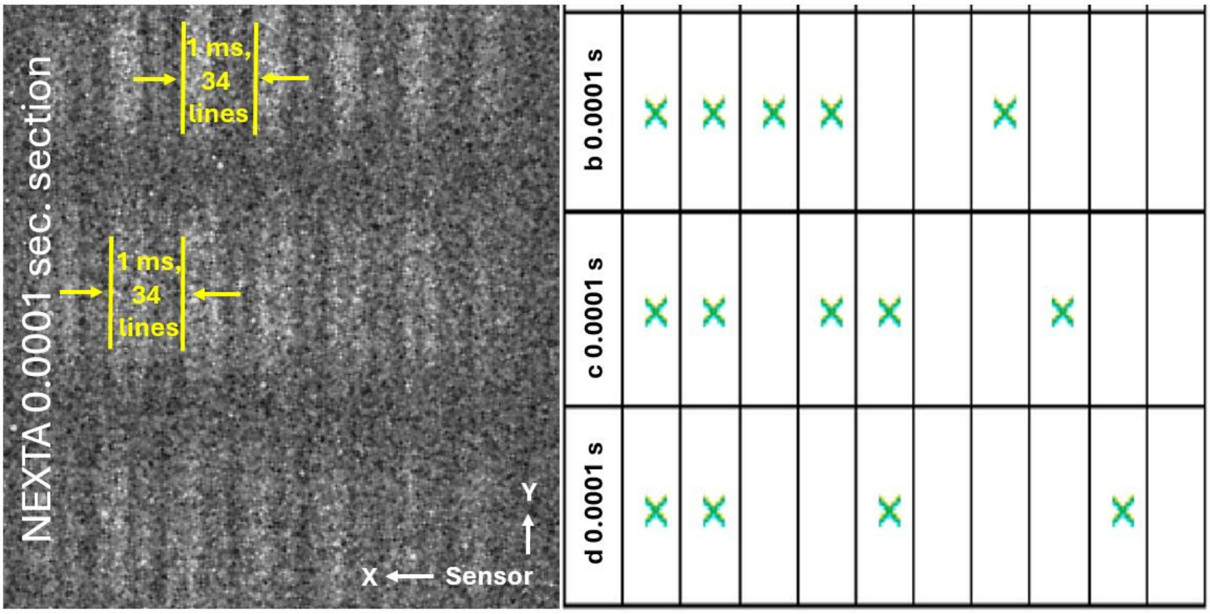


Figure 6.7. Recording of the LEDs *d, c, b* of NEXTA's 0.0001-seconds section. The characteristic patterns (left part of the image) repeat every 1 ms, corresponding to 34 sensor lines. The readout time of a single sensor line can be calculated by dividing 1 ms by the number of sensor lines. The right part of the image refers to Figure 5 of the NEXTA paper; (Credit: PyMovie, PyOTE)

Table 6.1 shows that the rolling shutter effect can be disregarded when operating the Seestar, as the minimum frame durations are always greater than the sensor readout times. However, the example in

Figure 6.8 shows a delay of one frame between an aperture located on the left edge and one located on the right edge of the sensor. Tests with various S50 settings sometimes showed this effect, but it was never greater than 1 frame. If the target star is positioned in the right third of the sensor, the effect is eliminated.

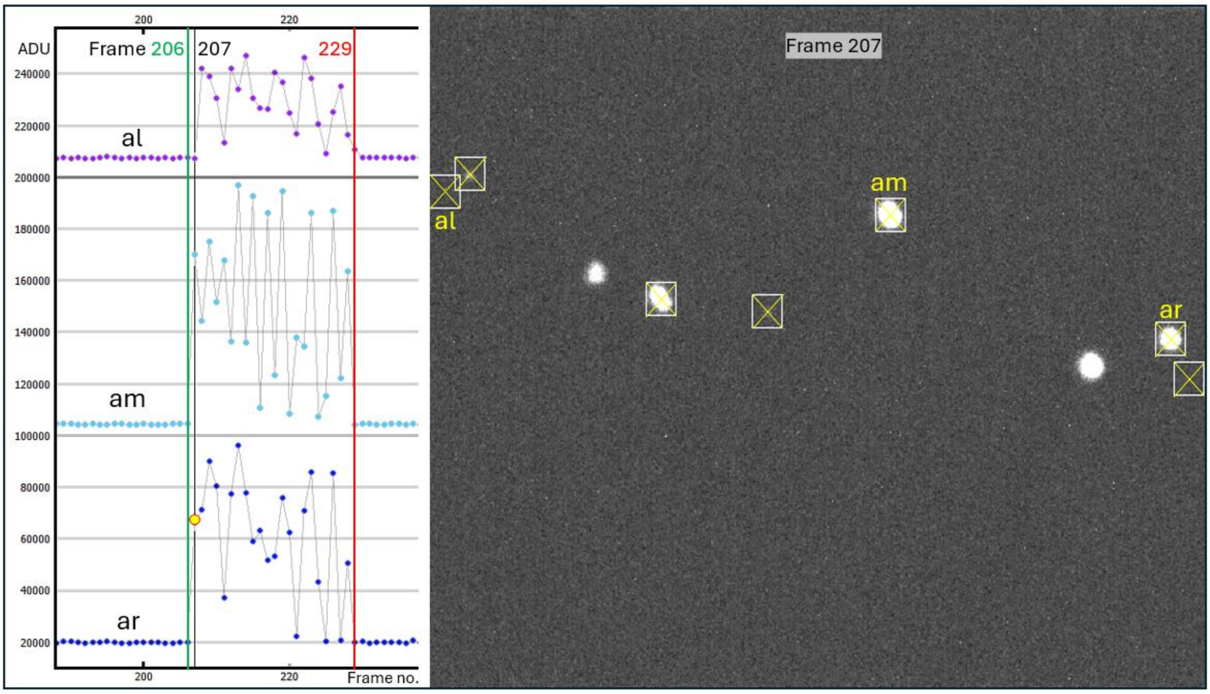


Figure 6.8. Investigation of the influence of target positioning in relation to the sensor readout direction from right to left. The setup uses artificial and flashing ‘stars’. The right part of the image shows a single frame from a raw AVI file (zoom 1x, frame duration 83 ms). The PyMovie apertures *ar*, *am* and *al* point to targets that in reality light up and fade out simultaneously. The corresponding light curves in the left part of the image show simultaneity for apertures *ar* (right edge) and *am* (centre of the sensor) but a delay of one frame for aperture *al*. For better visibility, the light curves are partially vertically shifted, (Credit: PyMovie, PyOTE)

7 Tests with artificial ‘occultation events’

Since for various reasons (mostly weather) no real positive star occultations could be recorded so far, a test setup for indoor occultation event simulations was established (Figure 7.1).

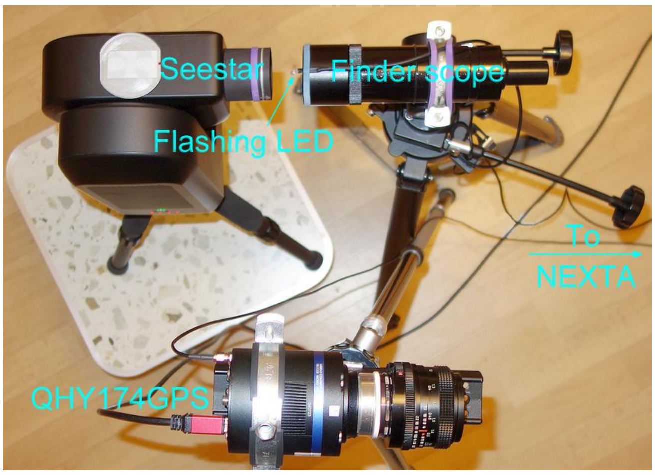


Figure 7.1. Test setup to simulate stellar occultations

On the one hand, the system uses an LED that is switched on and off manually to simulate stellar occultations. On the other hand, LED pulses from the 1-second section of the NEXTA are also used (see the chapter "NEXTA for light-curve simulation" in the NEXTA paper). The QHY174GPS camera with minimum 4 times the frame rate compared to the S50 frame rates was used as a reference. The S50 raw AVI output files were time calibrated with PyOTE's 'Manual timestamps' using two flashes from an LED (connected to NEXTA's a1s LED) shining into the lens of Seestar, see Figure 6.3. Figure 7.2 shows an example, Figure 7.3 the results.

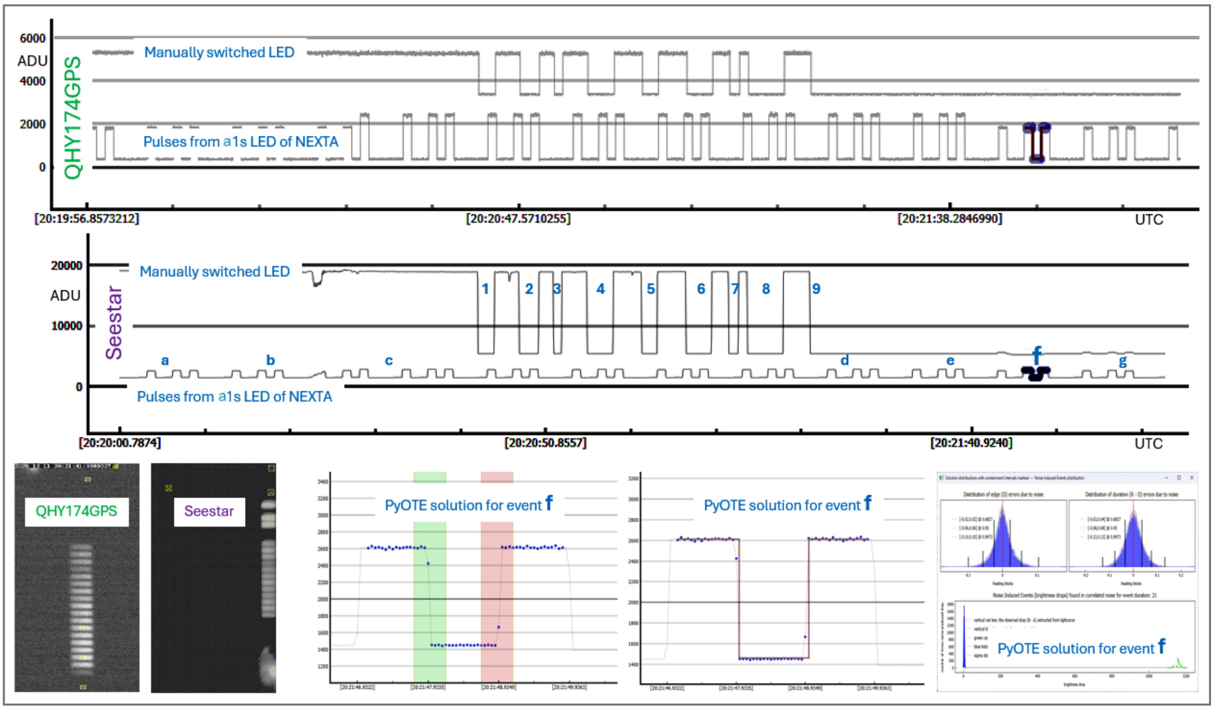


Figure 7.2. Example demonstrating the two ways used for occultation event simulations, recorded in 'Solar System' mode using zoom x4 and exposure 50 ms. The QHY174GPS recorded with 4 ms. For better visibility, the light curves are partially vertically shifted, (Credit: PyMovie, PyOTE)

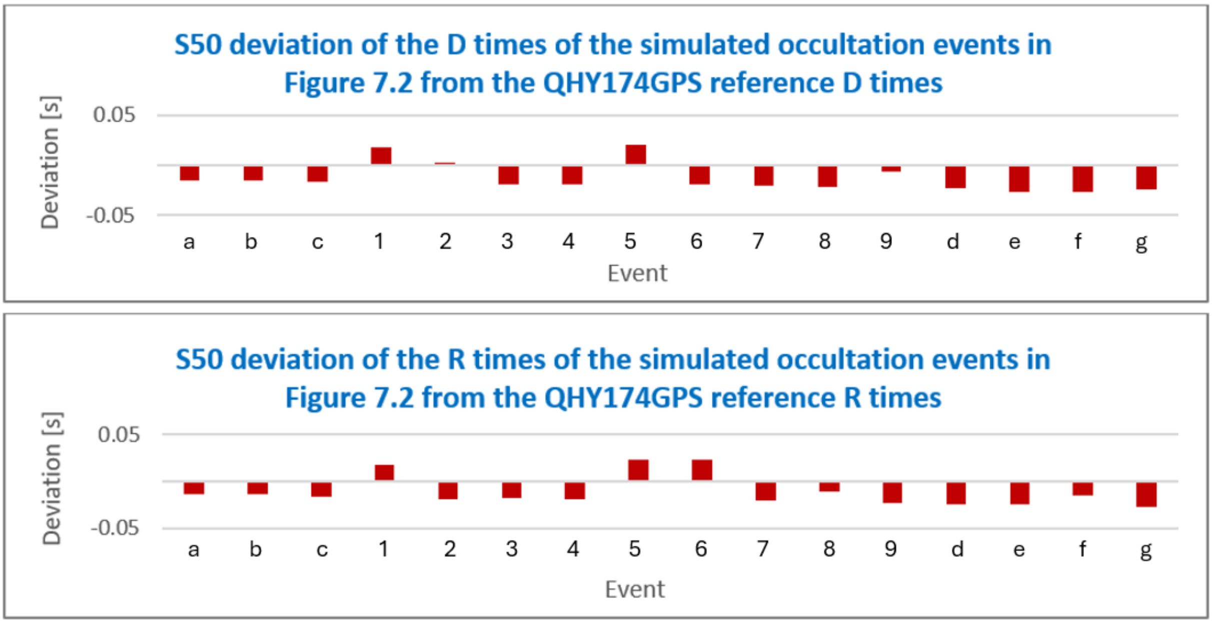


Figure 7.3. Deviations according to the simulations shown in Figure 7.2. For both variants of artificial occultations the deviations are well within one frame duration (50 ms), the average D deviation is -13 ms, that of R -11 ms

Figure 7.4 shows simulated occultation events for a range of exposure times, again compared with the QHY174GPS. To simulate occultation events, the light from a permanent lit LED was manually interrupted for these tests.

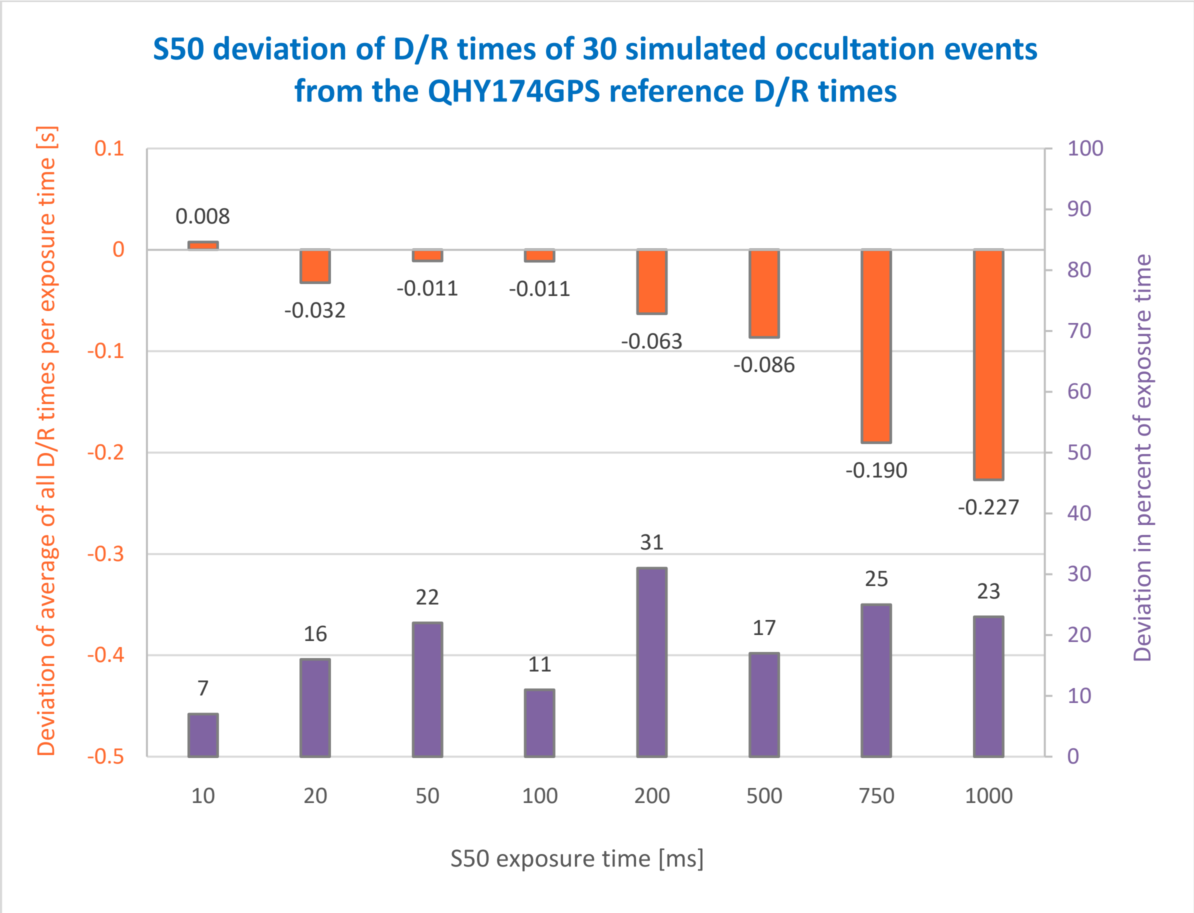


Figure 7.4. S50 NEXTA measured deviation of D/R times of 30 simulated occultation events from the QHY174GPS reference. Summary of all results for several exposure times, (Credit: PyMovie, PyOTE)

Figure 7.4. demonstrates that the deviations of the D/R times of the S50 compared to the QHY174GPS standard were on average 19% of the S50 exposure time, also in good agreement with the 50-ms exposure example presented in Figures 7.2 and 7.3.

Photometry software

As far as photometry software for the Seestar S50 is concerned, PyMovie and PyOTE (https://occultations.org/observing/software/pymovie) have proven to be ideal, as has already been shown several times in this work. Tangra (http://www.hristopavlov.net/Tangra3/) cannot read the S50 raw AVIs. However, this is possible if the raw AVIs are debayered. There are various programmes for this, e.g. PIPP (https://www.rsastro.com/downloads) is very suitable. Another problem with Tangra is that the manual input of time stamps is limited to the first/last frame.

8 Conclusions

After extensive testing (including new tests for version 2.0 of this work), the author sees good opportunities for using the Seestar S50 for suitable events (i.e. those possible with an aperture of 5 cm and sufficient durations).

However, due to the timing problem, a time error can be assumed, which (according to the investigations carried out) does not exceed plus/minus one frame duration.

In any case, however, the use of an 1PPS controlled flashing device with known or adjustable flash times is necessary.

In addition, there is still a lack of practical experience with occultations - every Seestar S50 owner in the occultation community should try to gather this.