SLOTMODE Absolute timing

A user's perspective by Marissa Kotze

1 My understanding of known SLOTMODE absolute timing issues

After the fix of the relative timing issues[1] during the BigFix, serious concerns remained about the accuracy of the absolute timing. Those needed to be addressed by specific on-sky testing of sources with accurately timed events. The concerns were legitimised when several SLOTMODE users reported a discrepancy of $\sim 7\times$exposure-time in the observed absolute timing of accurately known eclipses.

Amanda Gulbis confirmed[2] it in 2012 using an LED in the payload (triggered via independent GPS) to create accurately timed pulses that could be observed by RSS and SALTICAM. Several pulse sequences and observations were done. Initial pulses all occurred within $\frac{1}{2}\times$EXPTIME of the UTC-OBS times in the FITS headers produced by the SALT pipeline, after correcting for the $7\times$exposure-time discrepancy.

The reason for the error was a misunderstanding of the time-tags written in SLOTMODE. The time-tags are actually the readout times, but were interpreted in the PySALT pipeline as exposure times of frames. In case of SLOTMODE, the exposed slot is shuffled down 7 times before reaching the readout register. The error affected SALTICAM and RSS SLOTMODE operations.

Steve Crawford developed a PySALT routine (**slotreadtimefix**) to correct the FITS headers[3], which has been part of the SALT pipeline since 7 Nov 2012. Data obtained before that date should be corrected by running the routine prior to any other data reduction routines. The correction subtracts $7\times$(EXPTIME+4ms) from the time-tags written by the instruments in SLOTMODE, where the 4ms is the shuffle time between exposed slot and subsequent storage positions (of which there are 6) before reaching the readout register. Our previous relative timing analysis showed that UTC-OBS time of the majority of consecutive frames are separated by either EXPTIME + 3 or 4ms (shuffle time). We therefore cannot get away from up to $7 \times$ 1ms uncertainty in applying the correction this way. However, by determining the correct shuffle time when possible (if successive frames separated by less than $2\times$EXPTIME) and assuming a 3ms shuffle time when not, the uncertainty may be reduced by up to 7ms and it is quantifiable for each particular frame.

2 Confirming accuracy below $\frac{1}{2}\times$EXPTIME

Amanda's timing tests contain pulse sequences that can be used to determine absolute timing accuracy to lower than $\frac{1}{2}\times$EXPTIME, by comparing all the predicted pulse times to observed pulse times. The UTC times of the pulses were predicted by adding integer increments of the pulse period to their accurately (within ns) known start times, assuming no lags or delays.

Pulse widths were significantly smaller than the pulse period (which were larger than exposure times) so that every pulse should be detected on an exposure, unless it's missing (dropped frames do occur). Lightcurves were extracted from the data (using the entire slot for one amplifier) and pulses can be detected as significant flux increases (see fig1-18).

For each predicted pulse, I determined whether it should have been detectable and also if it was detected. The former was achieved by testing if a predicted pulse occurred within EXPTIME+4ms from any of the corrected UTC-OBS times from the FITS headers of the data. Detectable pulses were considered detected if they exceeded a limiting flux level (close to the max but far from min flux).

Offsets to the observed timing of $-\frac{1}{2}\times$EXPTIME to $+\frac{1}{2}\times$EXPTIME were applied in increments of 1ms. The resulting ratio of (detected pulses)/(detectable pulses) should be 100% when the correct offset is applied to the observed absolute timing.

[1] http://wiki.salt.ac.za/index.php/Timing_issues_with_Slotmode
[2] SALT technical docs (2122AA0001)
[3] https://sciencewiki.salt.ac.za/index.php/SALT_Data_Quality

3 Results

Amanda conducted the first RSS SLOTMODE timing test on 11-09-2012 and a second on 08-11-2012. The results of a detailed analysis of those absolute timing tests are summarized in Table 1 and 2.

The 1st test had fewer pulses and relatively long pulse periods, for which detections were optimized over ranges of offsets. The 2nd test was a single observation at the shortest exposure time, using shorter pulse periods and more pulses, allowing a singular offset to be determined for which detections are optimized. This detailed analysis method therefore allows absolute timing offsets to be determined to 1ms accuracy.

The few pulses that were expected to be detected but were not, originate from exposures with unreliable time-stamps[4] (where successive frames differ by less than 1×EXPTIME). Otherwise the largest number of detections coincided with the offsets for which the ratio of (detected pulses)/(detectable pulses) was 100%.

Table 1: 11-09-2012: Analysis of 1st RSS SLOTMODE absolute timing test

UTC	Exposure	Pulse Period	Pulses Detected Successfully	Pulse Detections Expected	Total Pulses	Additional (-) Offset Required
17:35:30	0.1 s	0.5 s	87	88	90	6-9 ms
17:38:00	0.08 s	0.5 s	61	61	63	6-9 ms
17:40:00	0.08 s	0.5 s	68	68	71	3-9 ms
17:42:00	0.2 s	1 s	64	64	65	0-15 ms
17:44:30	0.1 s	1 s	57	57	60	5-11 ms

Table 2: 08-11-2012: Analysis of 2nd RSS SLOTMODE absolute timing test

UTC	Exposure	Pulse Period	Pulses Detected Successfully	Pulse Detections Expected	Total Pulses	Additional (-) Offset Required
19:19:00	0.08 s	0.5 s	146	146	151	16 ms
19:21:30	0.08 s	0.2 s	446	449	460	16 ms
19:25:00	0.08 s	1 s	61	61	63	14-19 ms
19:28:30	0.08 s	0.1 s	1016	1018	1047	16 ms
19:32:30	0.08 s	2 s	87	87	88	13-17 ms
19:38:00	0.08 s	0.4 s	149	150	154	13-18 ms

4 Discussion

Notice that there is always a negative offset required to optimize the number of detections and in cases where a single offset could be determined, it is -16ms (which is valid for all datasets from 08-11-2012). This highlights the need to run longer pulse sequences to allow accurate determination of the offset. However, the offsets determined for data from 11-09-2012 differ from those obtained on 08-11-2012 by ∼7ms. Since time-tags for SLOTMODE are considered to only be accurate to a few ms, the results seem reasonable.

[4] http://wiki.salt.ac.za/index.php/Timing_issues_with_Slotmode

Table 3: 24-01-2012: Analysis of the only SALTICAM SLOTMODE absolute timing test

UTC	Exposure	Pulse Period	Pulses Detected Successfully	Pulse Detections Expected	Total Pulses	Additional (-) Offset Required
18:42:00	0.2 s	0.6 s	89	89	92	3-13 ms
18:44:30	0.2 s	0.6 s	82	82	85	-1-9 ms
18:47:30	0.1 s	0.3 s	194	194	207	4-10 ms
18:49:30	0.1 s	0.4 s	104	104	112	1-14 ms
18:51:30	0.1 s	1 s	27	27	31	3-11 ms
18:53:30	0.2 s	1 s	30	30	31	1-12 ms
18:55:30	0.1 s	1 s	31	31	34	4-12 ms

The only SALTICAM SLOTMODE timing test was done by Amanda on 24-01-2012 to confirm the 7×exposure-time discrepancy reported by users. The results of the detailed analysis of all pulses (Table3) are comparable to those obtained for RSS on 11-09-2012 (Table1). The test on 08-11-2012 specifically used longer pulse sequences combined with shorter exposure times and pulse periods to facilitate a more successful detailed analysis of the offsets on the order of ms.

5 Complications

Note that: "SALT use a Praecis Gntp server which obtains UTC from the GPS satellite constellation and distributes this time on the network using Network Time Protocol (NTP). In a local area network NTP accuracy is typically a few milliseconds." - email from Geoff Evans. This offset/delay is something the detailed analysis of such absolute timing tests can help quantify to within 1ms.

Observations that require very high absolute timing accuracy are normally converted from UTC to BJD (Barycentric Julian Day), for which even the most accurate calculators[5] only achieve accuracy to a few ms. So there is no alternative but to accept an error of that magnitude in the end, but I would prefer to eliminate as many as possible of the small (compounding) errors that can be quantified.

6 Improving the tests

Further tests need to be run on different nights to ascertain whether the (-)offset is ∼constant or not. The test set-up generating the pulses should remain unchanged between such tests to exclude it as the origin for varying offsets. Having a (semi-)permanent set-up in place to facilitate such tests is therefore preferable, since they should be conducted after instruments have been replaced in the payload to (re)confirm the integrity of the end-to-end processing of data.

For observations that require millisecond absolute timing accuracy, I suggest an absolute timing test at the start of the observation, so that the data may be corrected for the offset that is applicable at that time. PI's willing to sacrifice some of their precious science time for such a test will then be in a better position to determine the correct absolute timing for their observations.

[5] http://astroutils.astronomy.ohio-state.edu/time/utc2bjd.html

A RSS SLOTMODE lightcurves: 11-09-2012

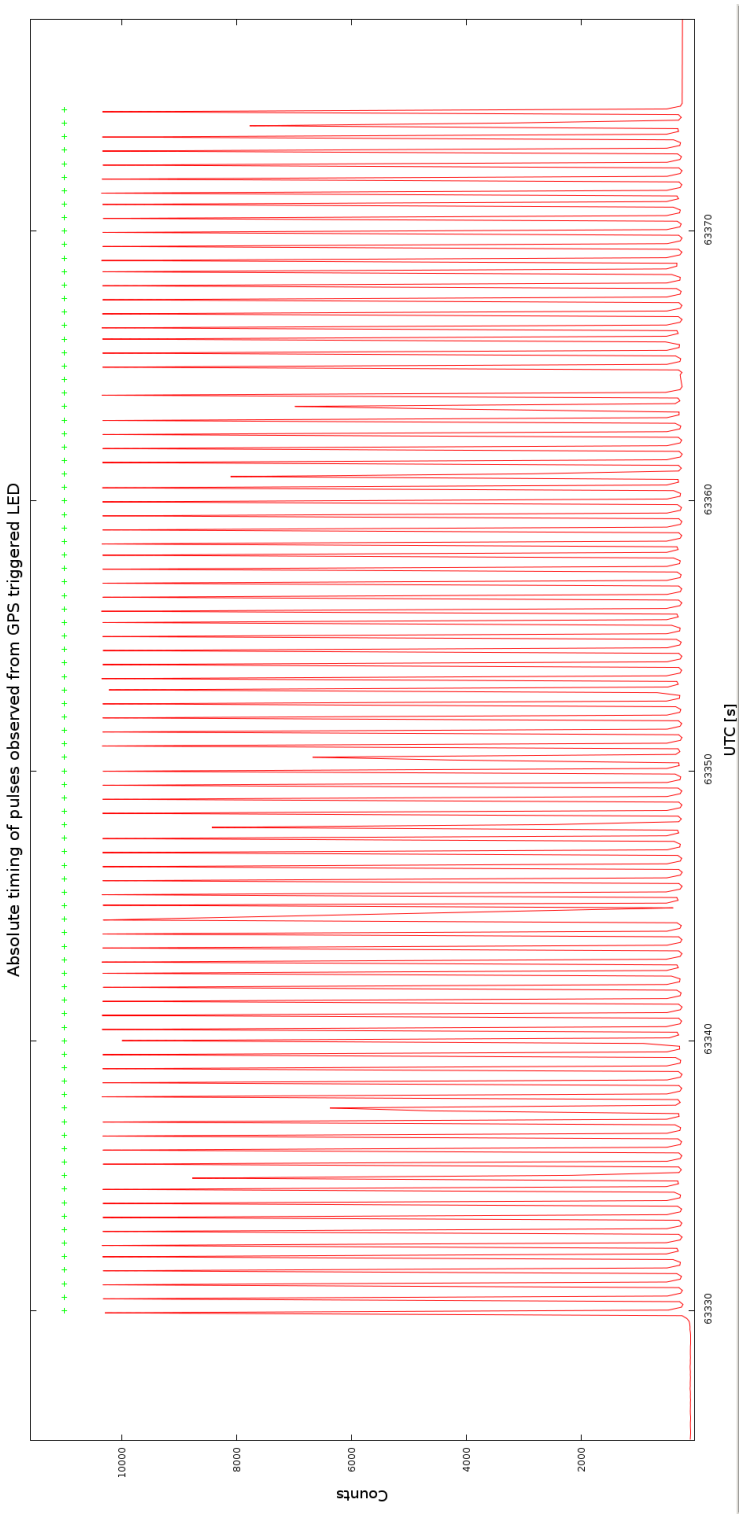

Figure 1: 17:35:30 UTC - Pulse period: 0.5s. Exposure time: 0.1 seconds.

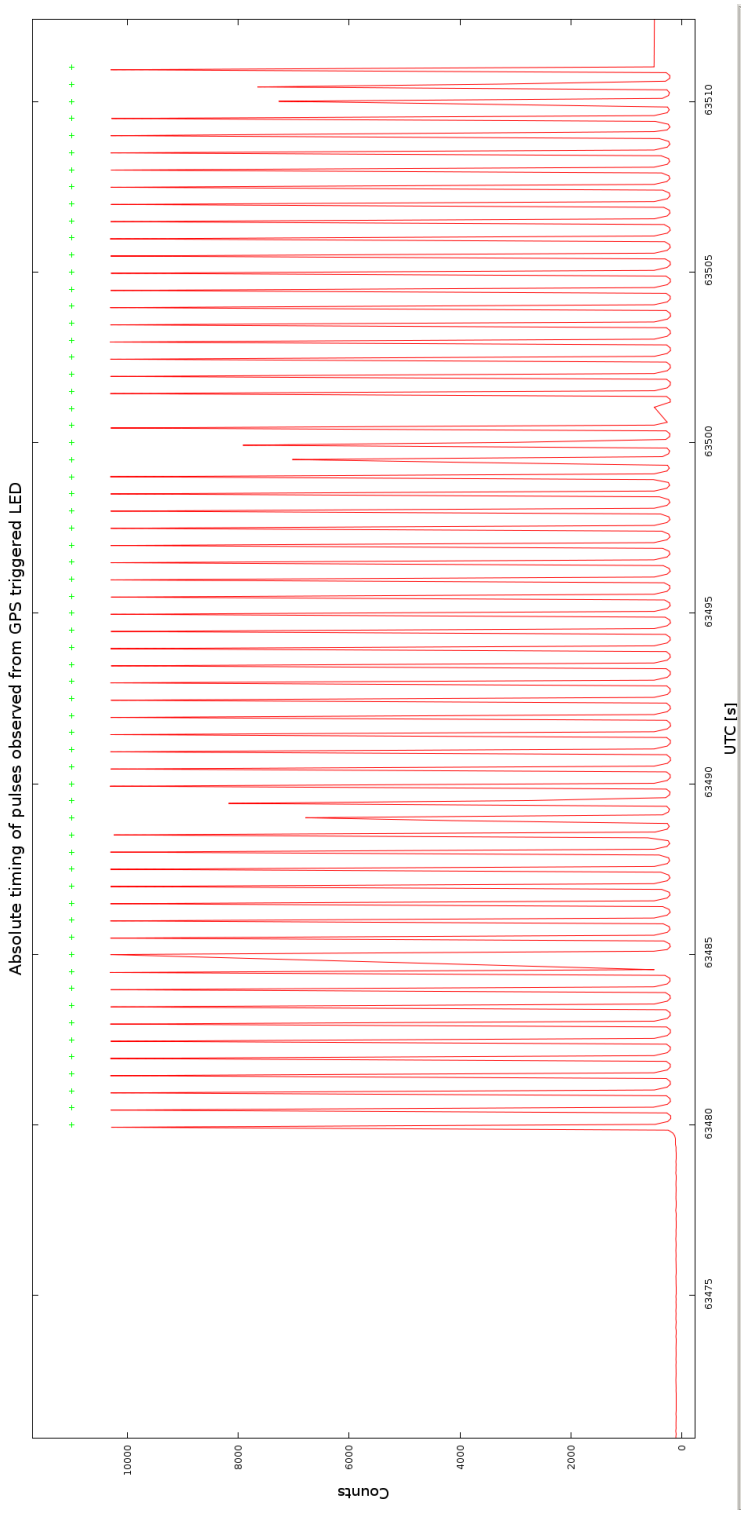

Figure 2: 17:38:00 UTC - Pulse period: 0.5s. Exposure time: 0.08 seconds.

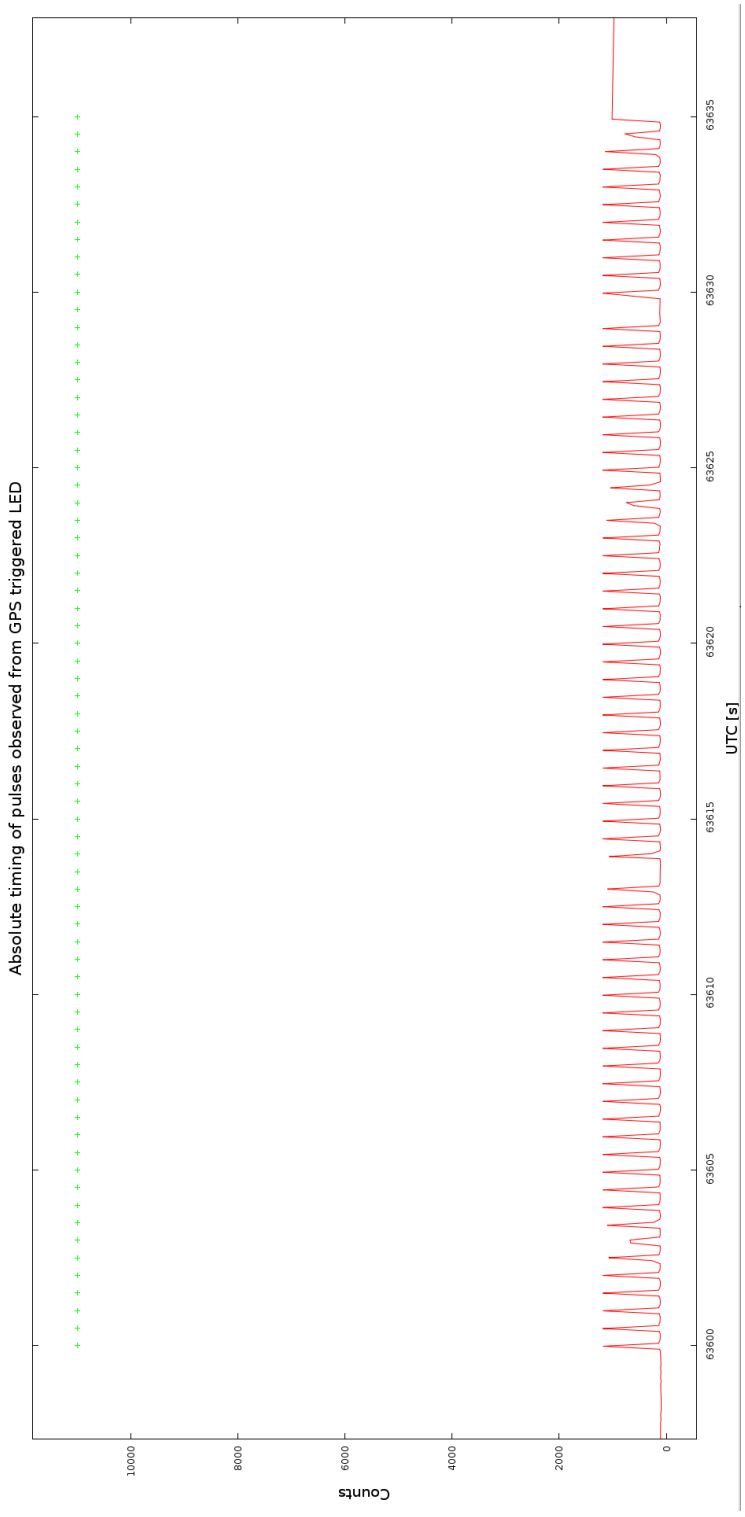

Figure 3: 17:40:00 UTC - Pulse period: 0.5s. Exposure time: 0.08 seconds.

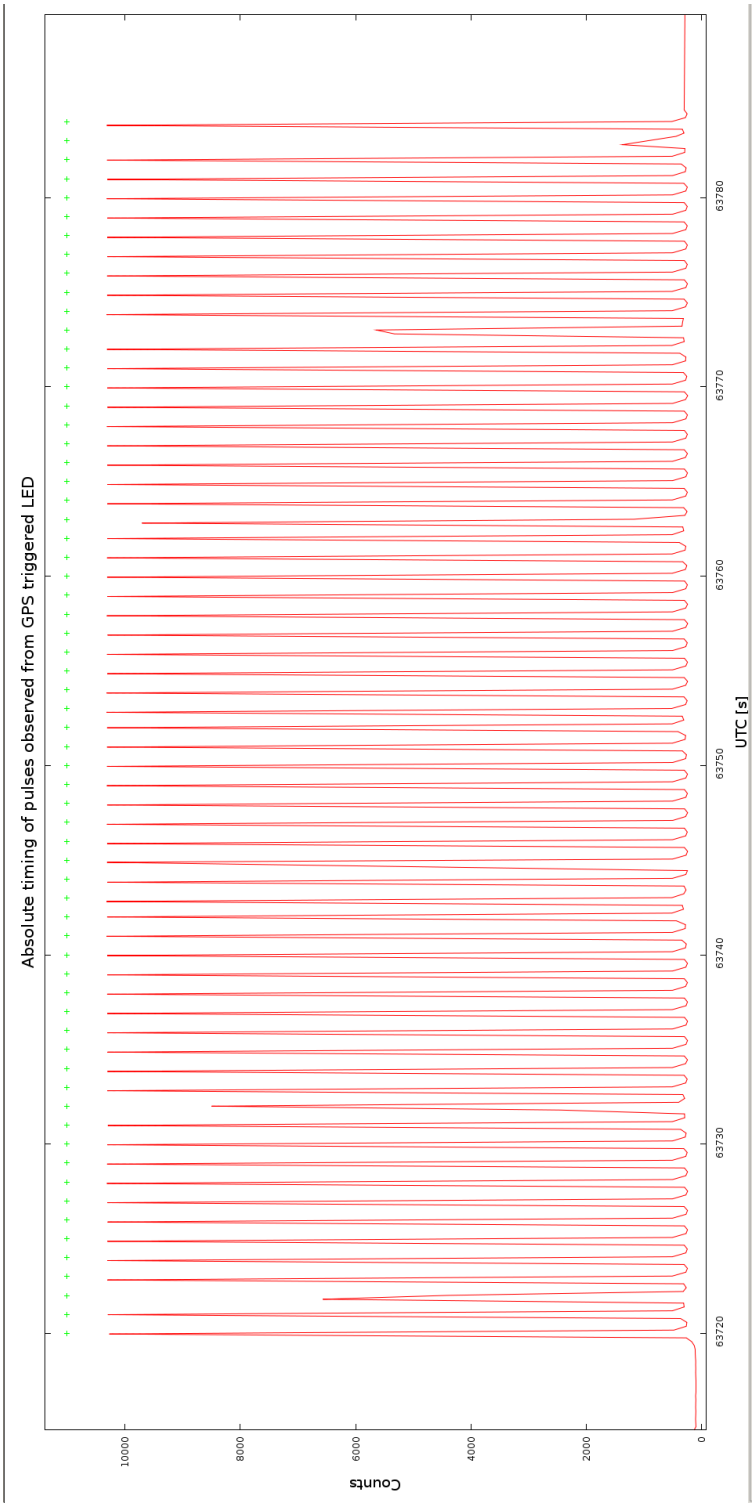

Figure 4: 17:42:00 UTC - Pulse period: 1s. Exposure time: 0.2 seconds.

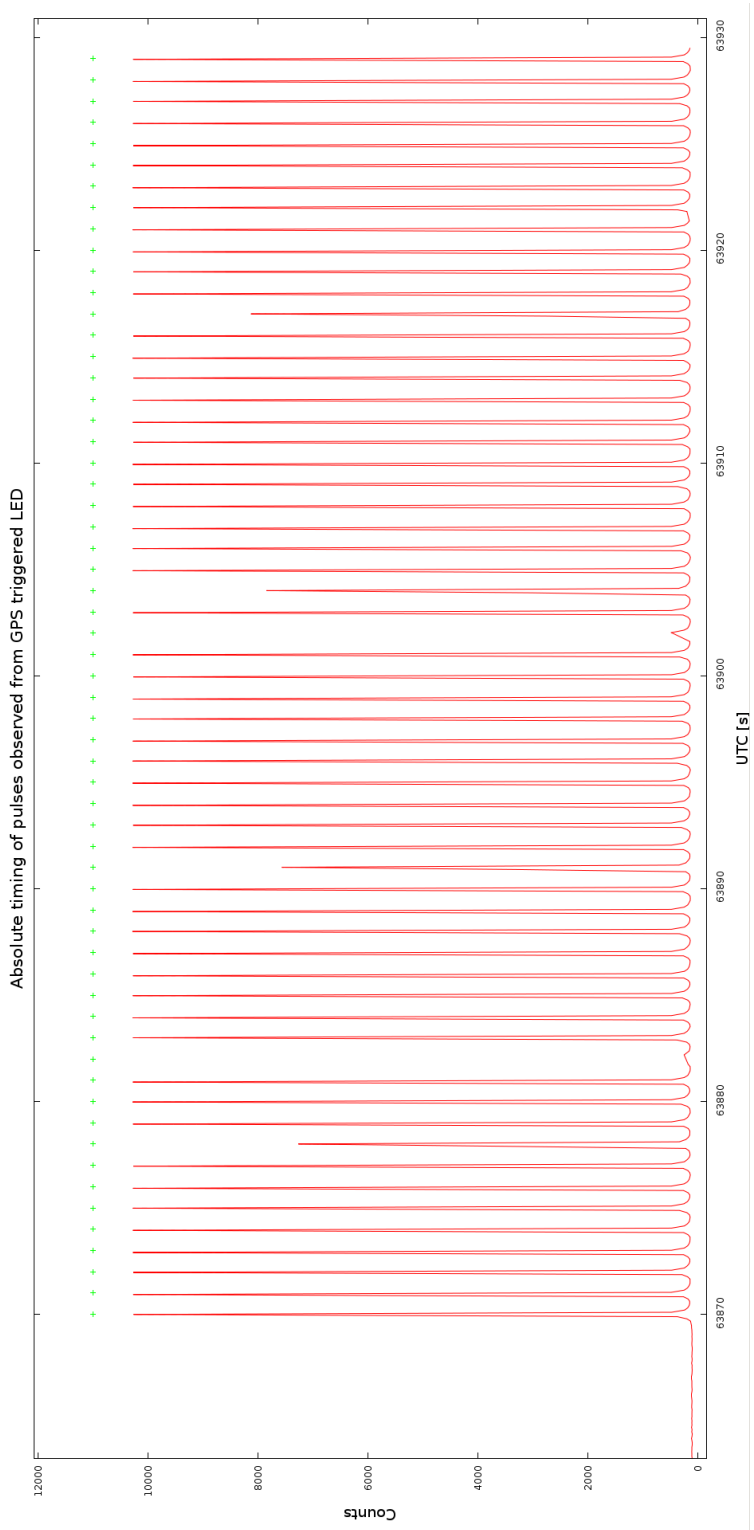

Figure 5: 17:44:30 UTC - Pulse period: 1s. Exposure time: 0.1 seconds.

B RSS SLOTMODE lightcurves: 08-11-2012

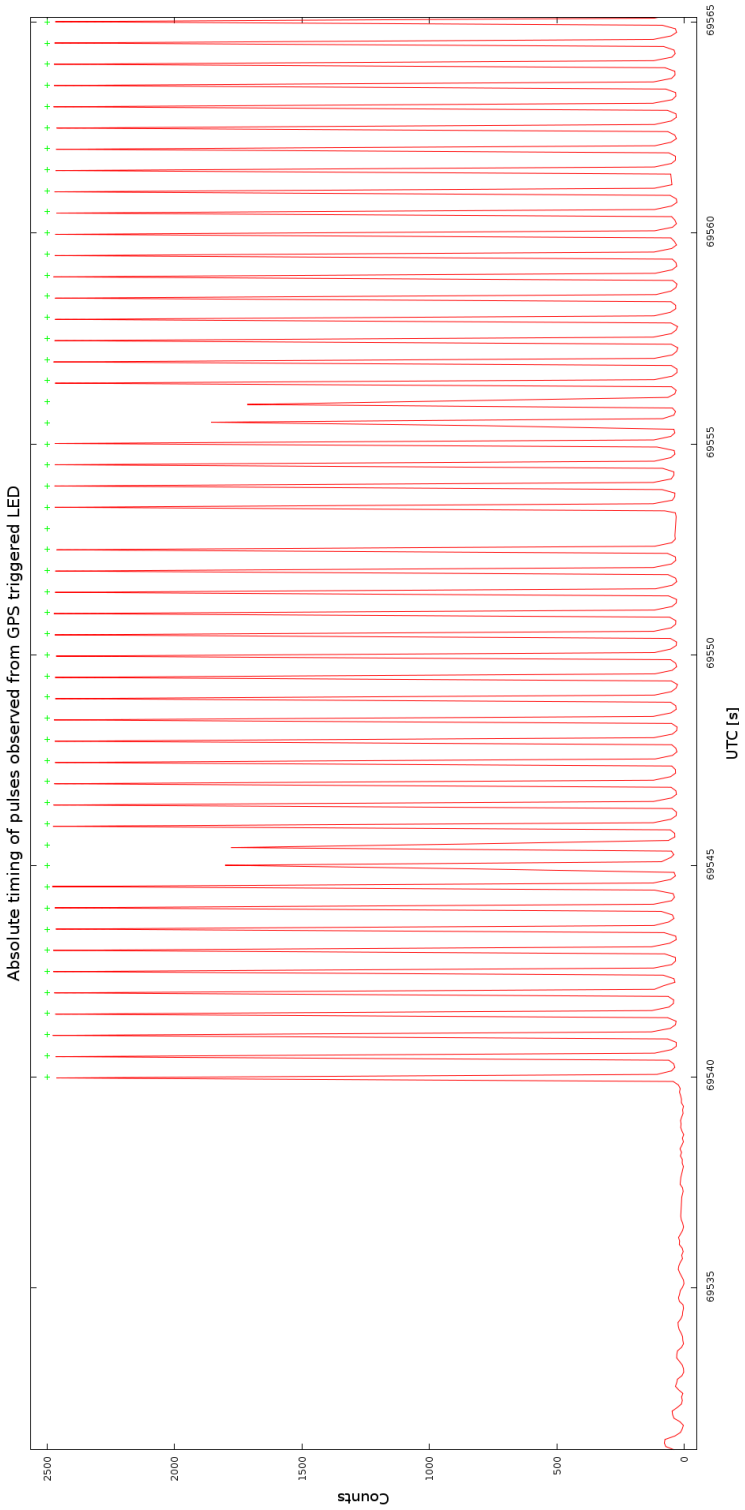

Figure 6: 19:19:00 UTC - Pulse period: 0.5s. Exposure time: 0.08 seconds.

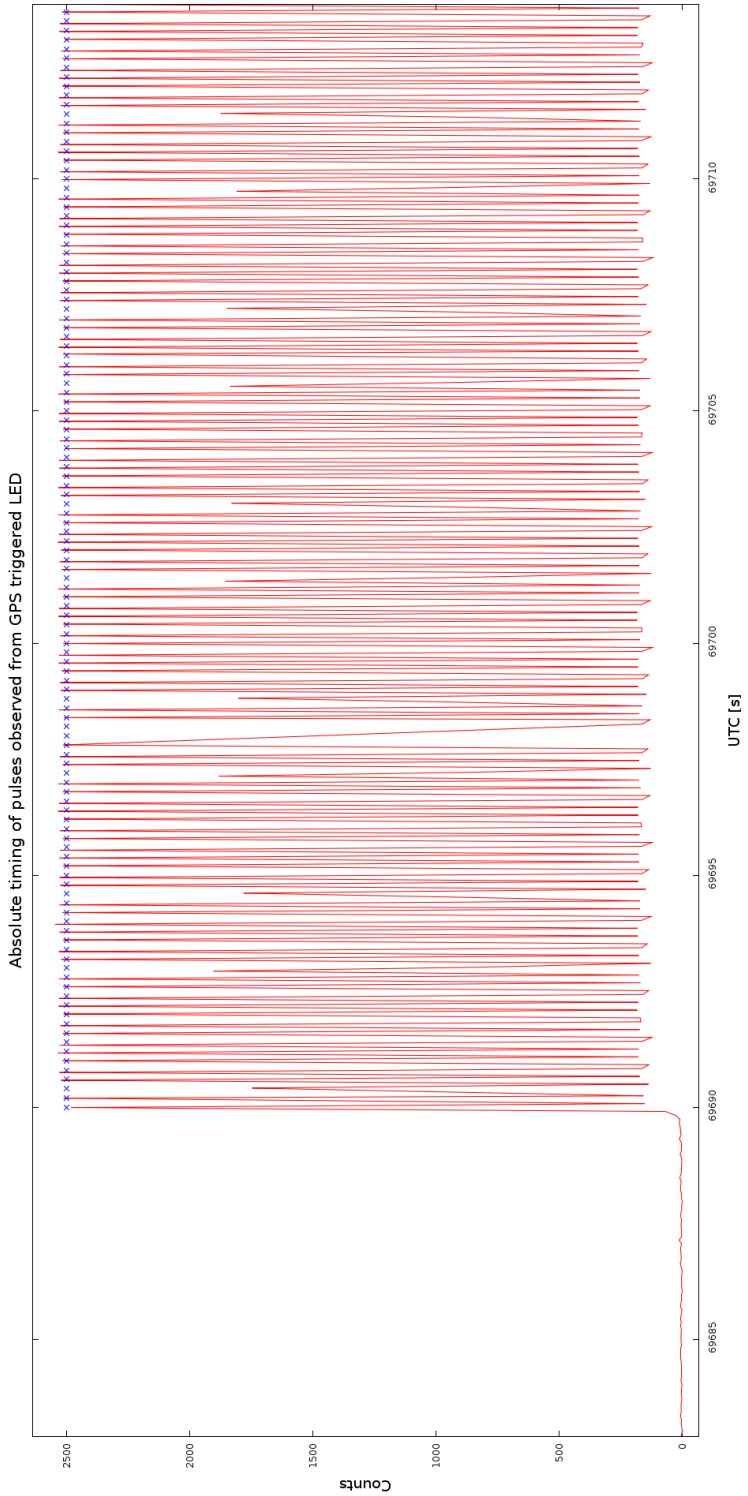

Figure 7: 19:21:30 UTC - Pulse period: 0.2s. Exposure time: 0.08 seconds.

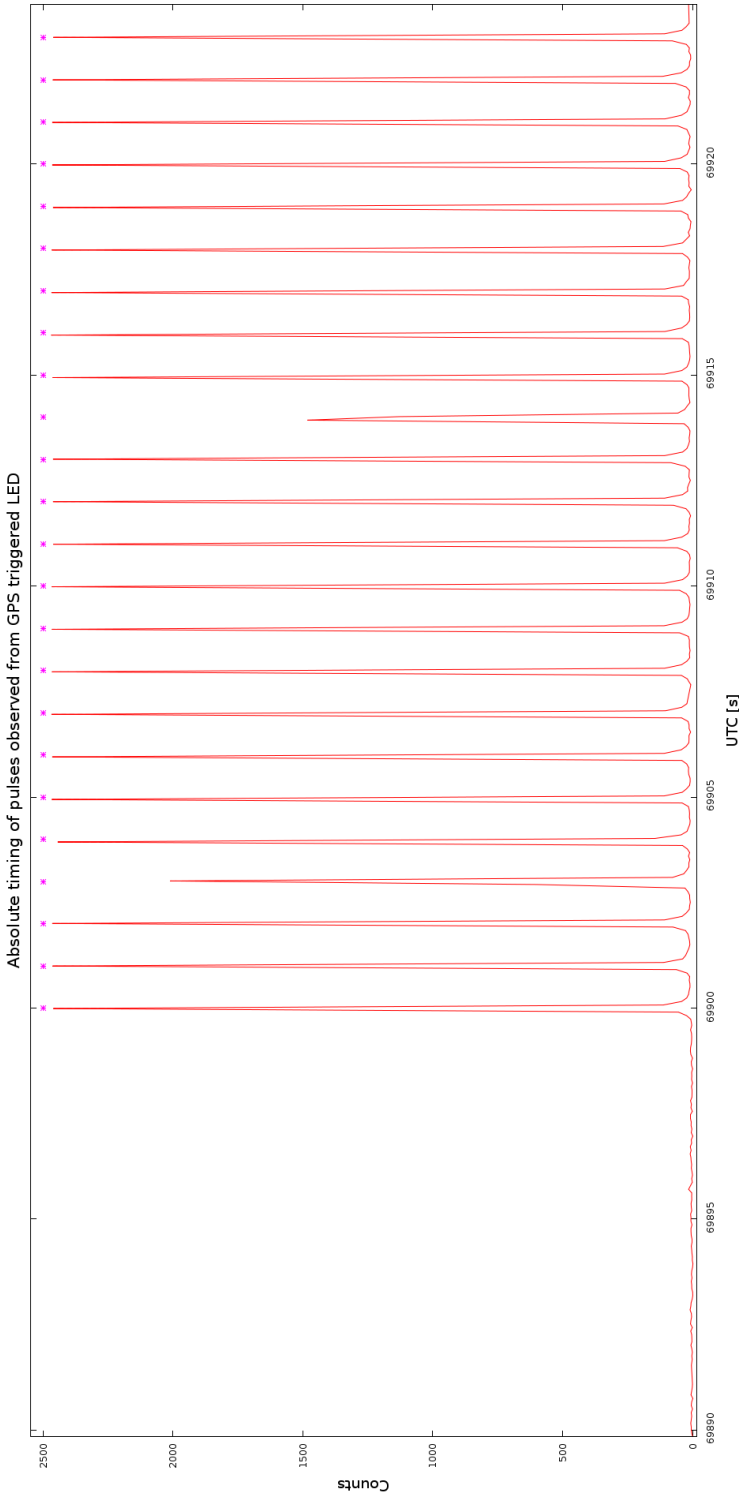

Figure 8: 19:25:00 UTC - Pulse period: 1s. Exposure time: 0.08 seconds.

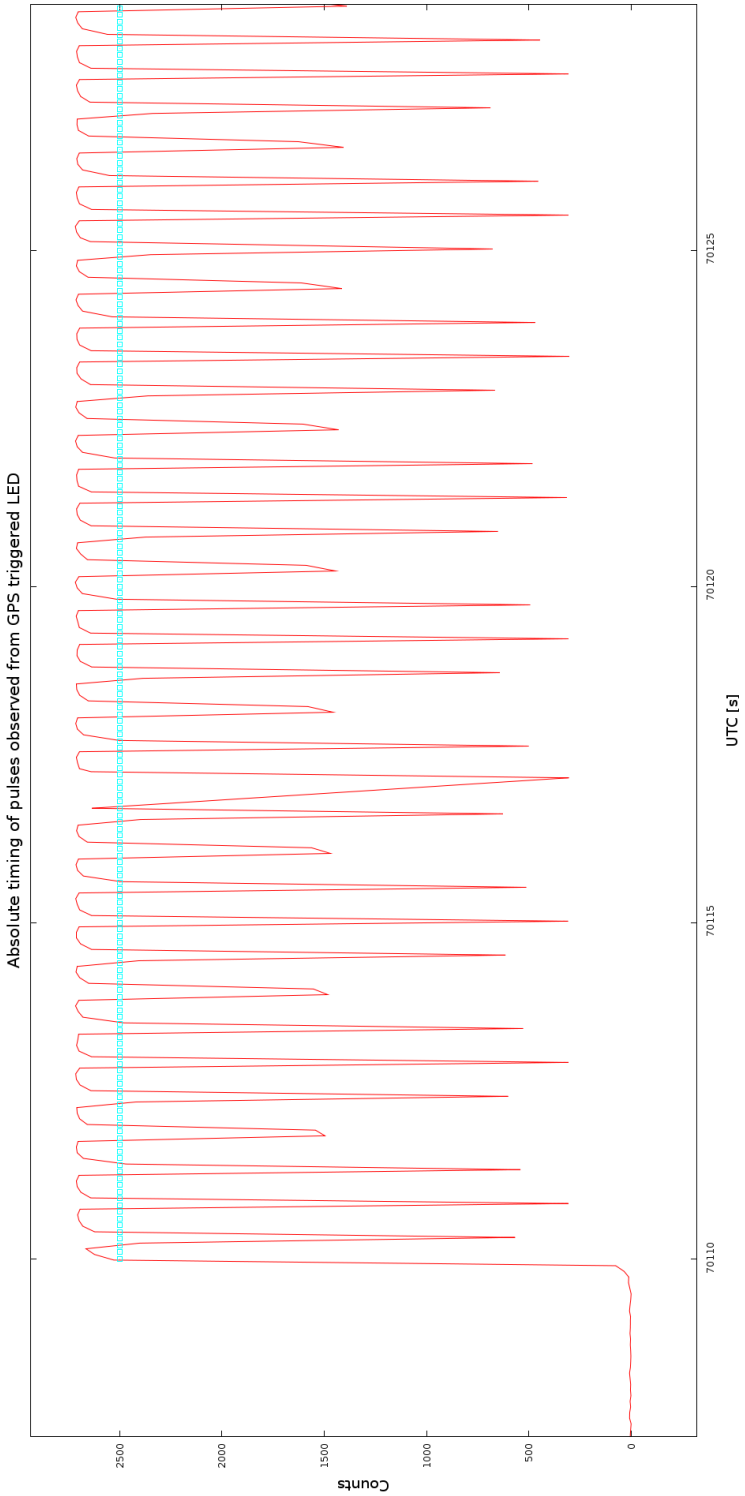

Figure 9: 19:28:30 UTC - Pulse period: 0.1s. Exposure time: 0.08 seconds.

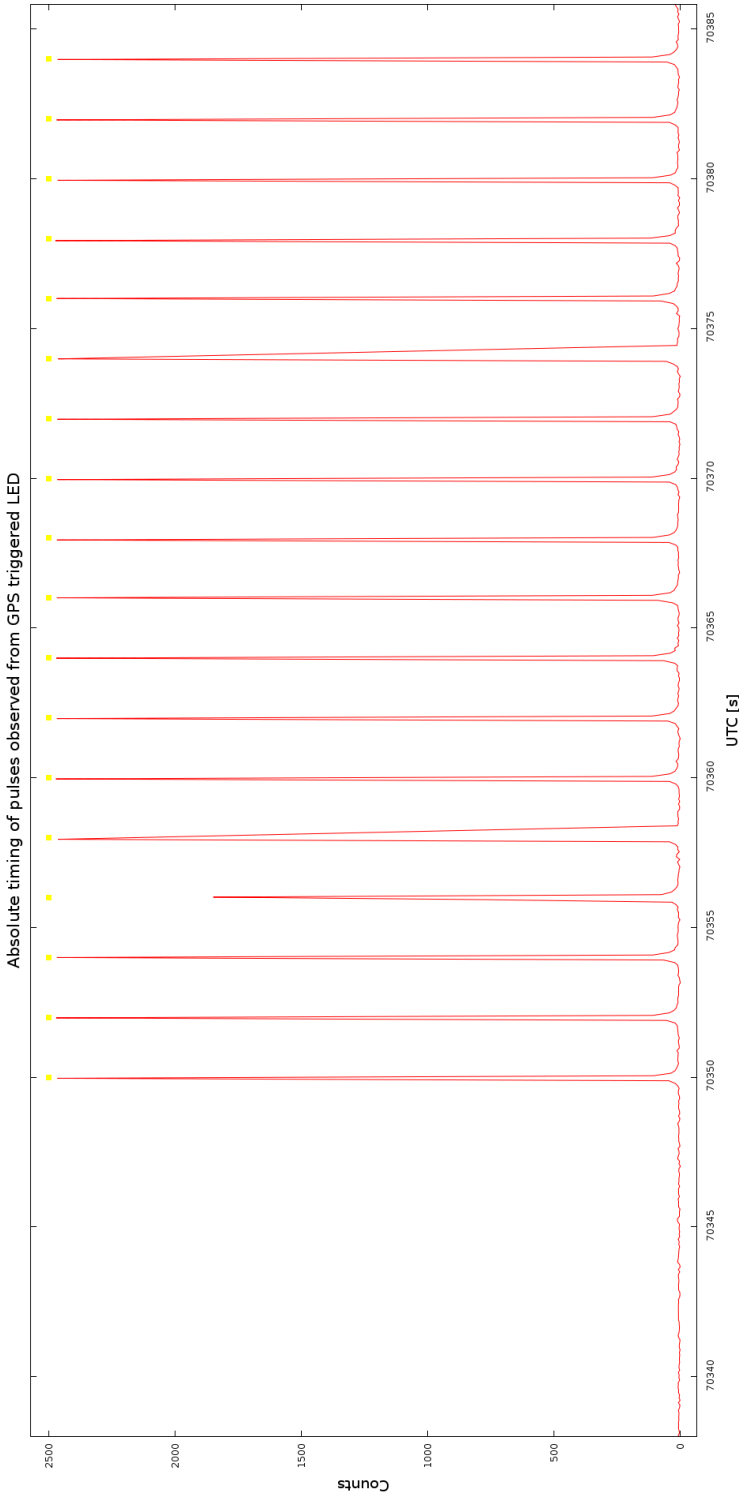

Figure 10: 19:32:30 UTC - Pulse period: 2s. Exposure time: 0.08 seconds.

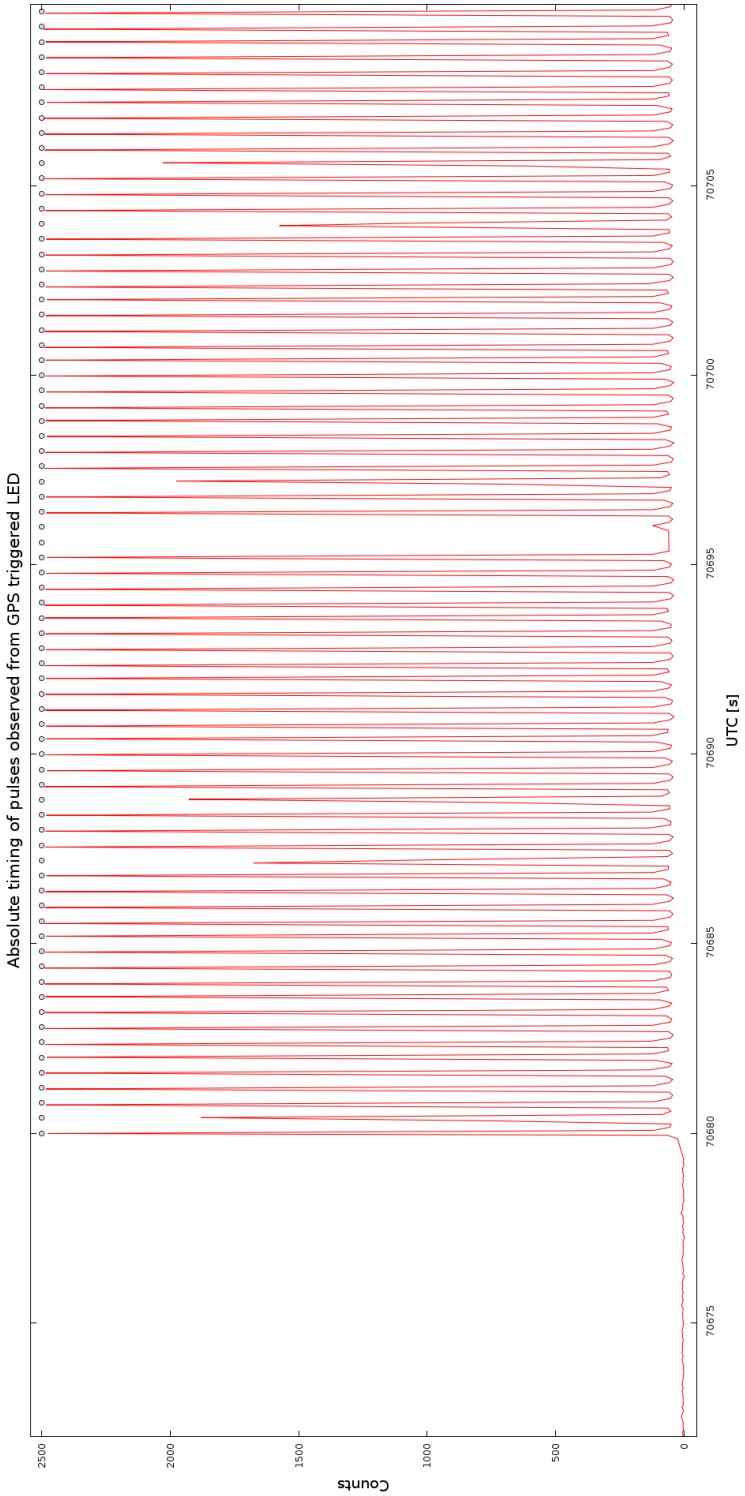

Figure 11: 19:38:00 UTC - Pulse period: 0.4s. Exposure time: 0.08 seconds.

C SALTICAM SLOTMODE lightcurves: 24-01-2012

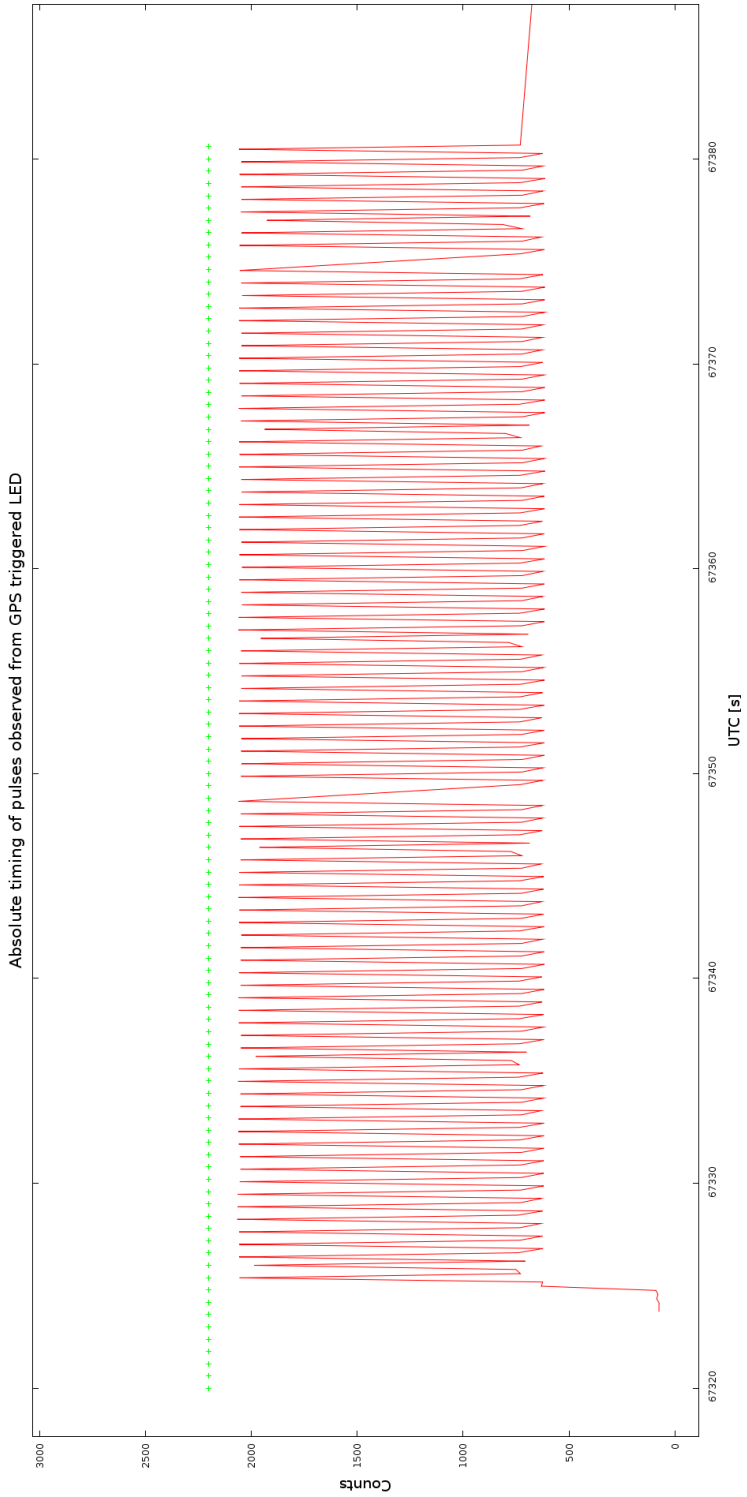

Figure 12: 18:42:00 UTC - Pulse period: 0.6s. Exposure time: 0.2 seconds.

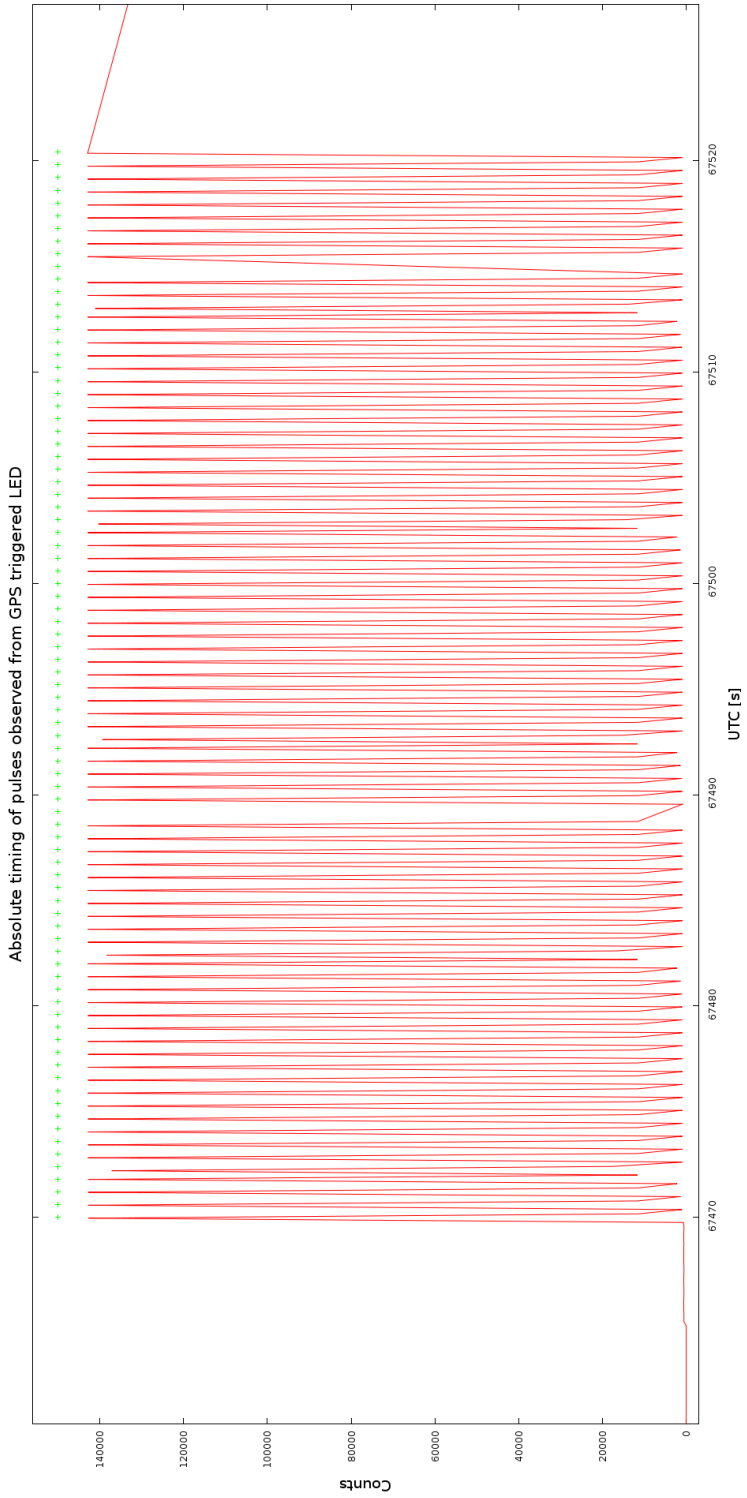

Figure 13: 18:44:30 UTC - Pulse period: 0.6s. Exposure time: 0.2 seconds.

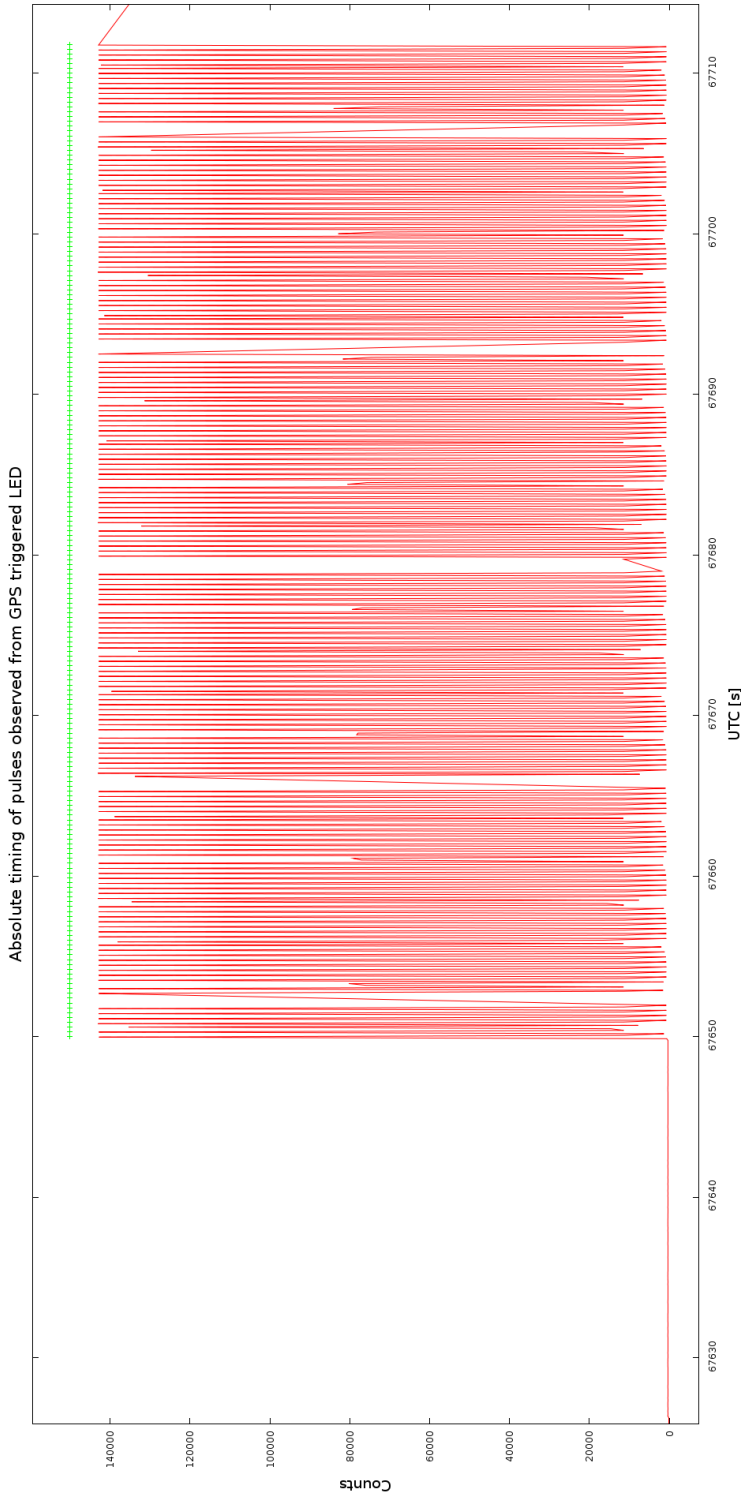

Figure 14: 18:47:30 UTC - Pulse period: 0.3s. Exposure time: 0.1 seconds.

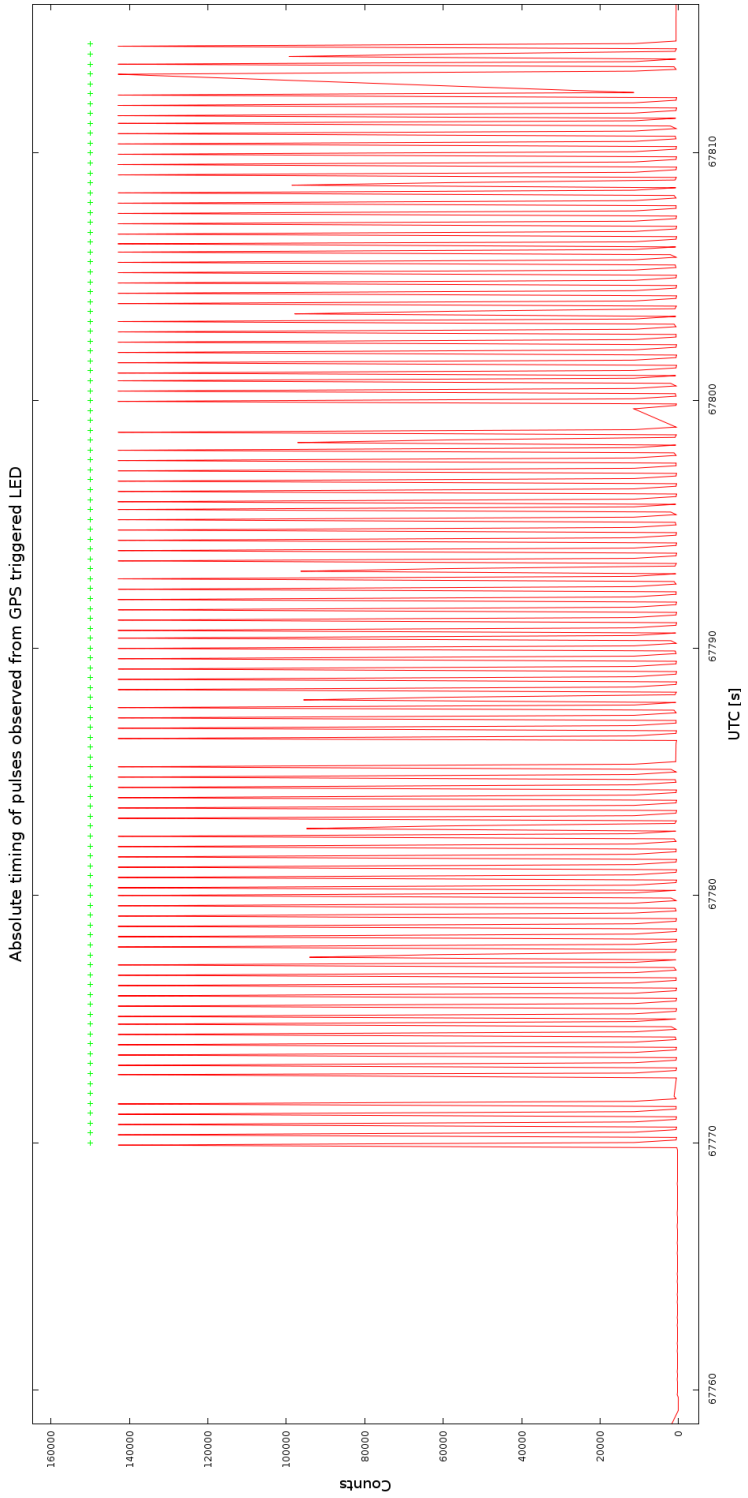

Figure 15: 18:49:30 UTC - Pulse period: 0.4s. Exposure time: 0.1 seconds.

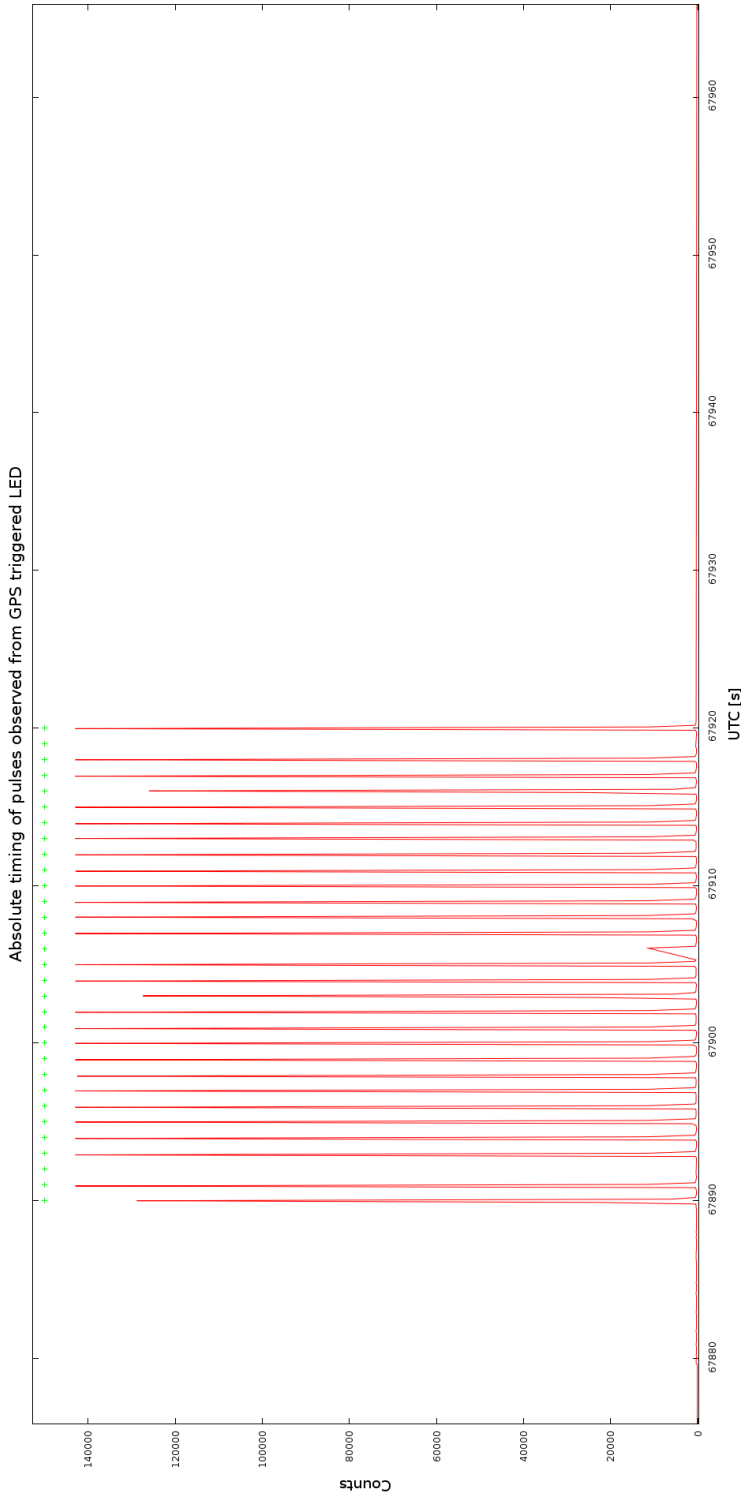

Figure 16: 18:51:30 UTC - Pulse period: 1s. Exposure time: 0.1 seconds.

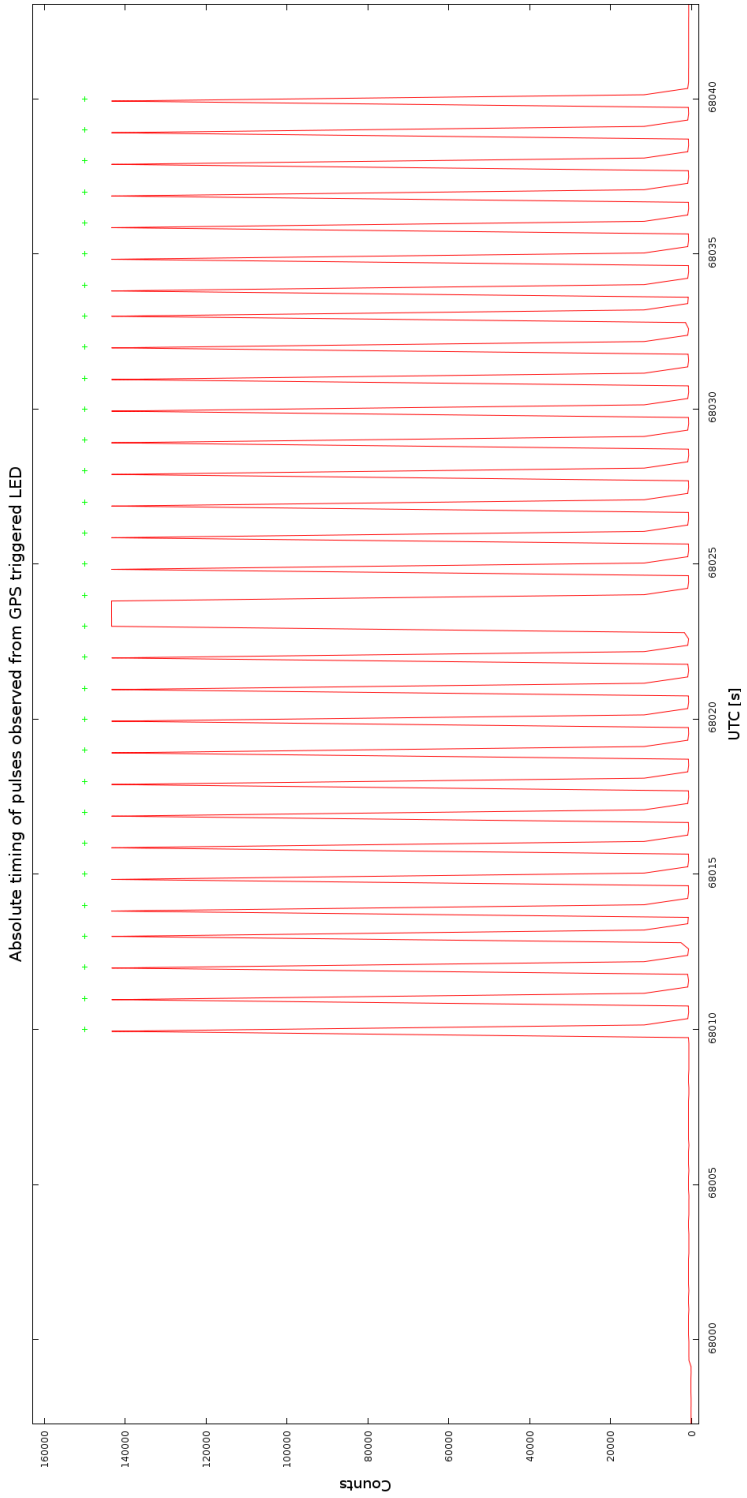

Figure 17: 18:53:30 UTC - Pulse period: 1s. Exposure time: 0.2 seconds.

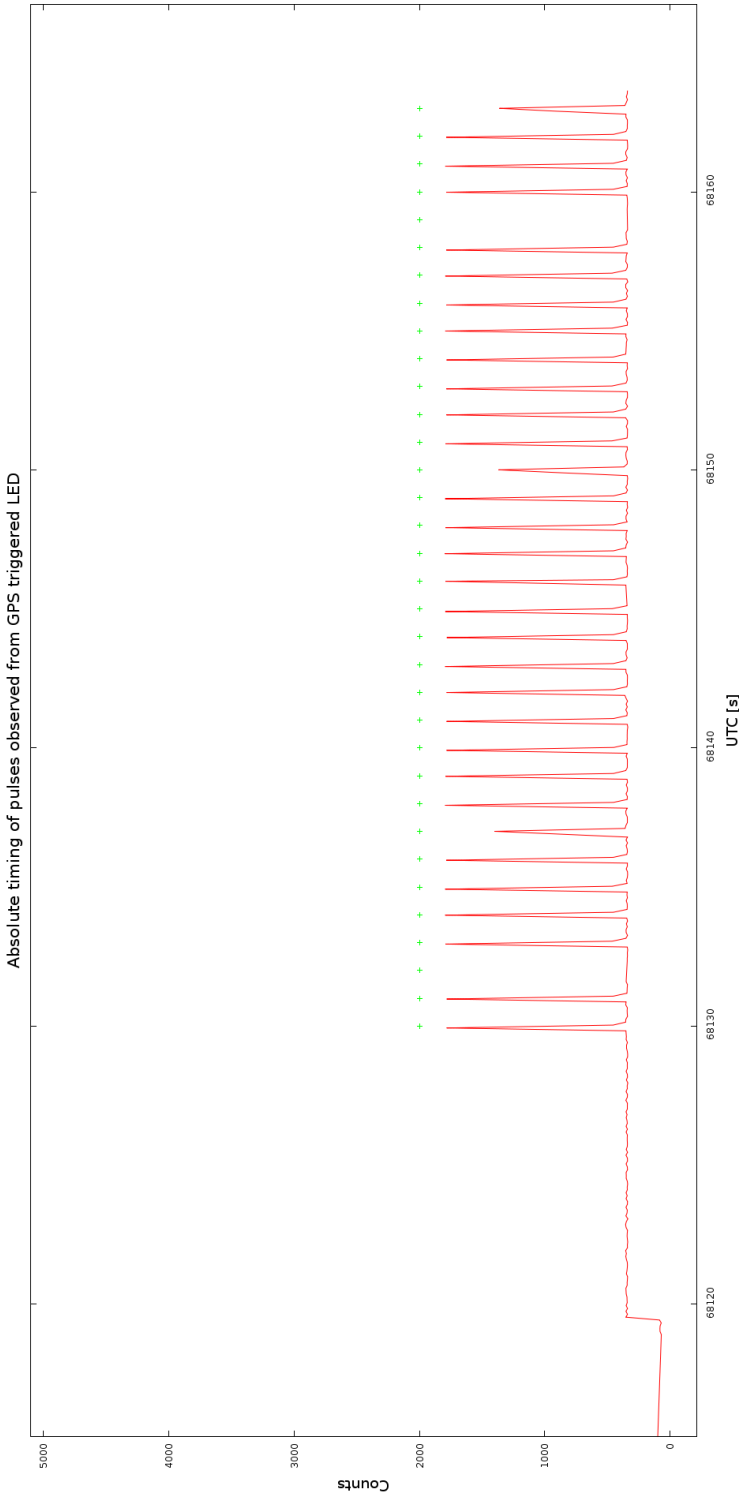

Figure 18: 18:55:30 UTC - Pulse period: 1s. Exposure time: 0.1 seconds.