Empirical determination of the delay in the between the time the LMI shutter is commanded to open, and the time it actually opens.

(v. 20181205a)

Reduction and write up by S. Levine
Images taken by T. Pugh and J. Sanborn
Idea originally proposed by N. Moskovitz

We have known for a while that there was a delay between the time the user commands the start of an exposure and the time when the shutter actually triggers. The delay has been presumed to be on the order of a few seconds. For most applications, this was not an issue. However, for astrometry of near Earth objects (e.g. NEOs, comets, etc), an uncertainty in the exposure mid-time of a second can translate into unacceptably large positional uncertainties.

To assess this uncertainty, we took short images of low Earth orbiting satellites with well known ephemerides. Then, we compared the measured satellite positions to the predicted positions and derived the image mid-time.

We also checked that the exposure times were as requested by measuring streaked stars on untracked sky flat.

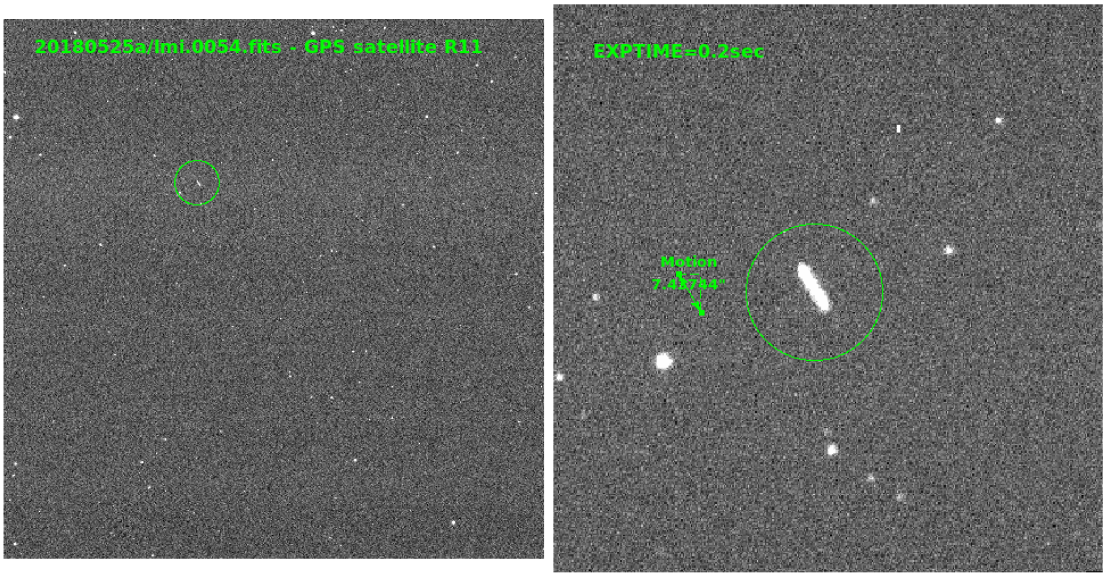
The attached pages are a printout of the spreadsheet used for the reduction. The simple summary is that:

1) The exposure times are as recorded to within a few hundredths of a second, based on the star streaks.
2) The shutter throw time in each direction is between roughly 0.1 and 0.2 seconds, meaning that there is also a temporal gradient across all the images.
3) Formal uncertainty on the measured time offsets are an underestimate of the true variation. The shutter throw time alone means the mid-time varies across the frame systematically by at least 0.1second (added as the systematic uncertainty below).
4) The shutter opens 2.05 +/- 0.06 (ran) +/- 0.1 (sys) seconds later than the UTCSTART in the image header.
5) The shutter closes 0.19 +/- 0.06 (ran) +/- 0.1 (sys) seconds earlier than the UTCEND in the image header.

Exposure times should be computed as:

1) Start time = UTCSTART + 2.05sec
2) End time = UTCEND - 0.19sec
3) Mid-time = UTCSTART + 2.05 + EXPTIME/2 or
4) Mid-time = [(UTCSTART + 2.05) + (UTCEND-0.19)] / 2

Useful web site: https://www.projectpluto.com/gps_expl.htm
The site provides explanatory materials and an ephemeris calculator.



Sample image from 20180525 UT showing a 0.2second exposure with the satellite R11. Left: full LMI image; Right: zoom of the region around the satellite

Summary: The LMI shutter opens 2.05 seconds later than the recorded UTCSTART time, and closes 0.19 seconds before the UTCEND time.

Computed Shutter Offset Time based on GPS satellite observation on 2018-05-30 UT @ DCT with LMI

	FITS UTCSTART	FITS UTCEND	FITS EXPTIME	Start Offset	End Offset	Computed START	Computed END
180530/lmi.0040	3:32:02.340	3:32:04.770	0:00:00.200	0:00:02.021	-0:00:00.209	3:32:04.361	3:32:04.561
180530/lmi.0042	3:36:01.640	3:36:04.080	0:00:00.200	0:00:02.018	-0:00:00.222	3:36:03.658	3:36:03.858
180530/lmi.0045	3:50:01.500	3:50:03.930	0:00:00.200	0:00:02.052	-0:00:00.178	3:50:03.552	3:50:03.752
180530/lmi.0050	4:18:01.470	4:18:03.910	0:00:00.200	0:00:02.068	-0:00:00.172	4:18:03.538	4:18:03.738
180525/lmi.0054	9:30:02.500	9:30:04.930	0:00:00.200	0:00:01.971	-0:00:00.259	9:30:04.471	9:30:04.671
180525/lmi.0081	9:45:07.300	9:45:10.040	0:00:00.500	0:00:02.151	-0:00:00.089	9:45:09.451	9:45:09.951
Mean:				0:00:02.047	-0:00:00.188		
Sample RMS:				0:00:00.061	0:00:00.058		

Computing Shutter Offset Time from GPS Satellite Observation - Sat: R04, Img: 20180530/lmi.0040

Frame	RA (HMS)	Dec (DMS)	RA(deg)	Dec (deg)	Time (HMS) / Tmid(RA)	Tmid(Dec)	Mean Offset & Updated Times
180530/lmi.0040							
Ephem T0	12:01:05.557	15:15:05.481	180:16:23.349	15:15:05.481	3:32:00.000		
Ephem T1	12:02:06.907	15:52:10.408	180:31:43.600	15:52:10.408	3:33:00.000		
Object			180.2921184	15.2975740	3h 32m 4s 452ms	3h 32m 4s 471ms	
			Tmid - EXPTIME/2 - UTCSTART:		0:00:02.012	0:00:02.031	0:00:02.021
	FITS HDR		**Tmid + EXPTIME/2 - UTCEND:**		-218	-199	-0:00:00.209
UTCSTART	3:32:02.340				3:32:04.352	3:32:04.371	3:32:04.361
UTCEND	3:32:04.770				3:32:04.552	3:32:04.571	3:32:04.561
EXPTIME	0:00:00.200						
						FILL IN BOXES WITH HEAVY OUTLINE	
180530/lmi.0040	3:32:02.340	3:32:04.770	0:00:00.200	0:00:02.021	-0:00:00.209	3:32:04.361	3:32:04.561

Computing Shutter Offset Time from GPS Satellite Observation - Sat: R04, Img: 20180530/lmi.0042

Frame	RA (HMS)	Dec (DMS)	RA(deg)	Dec (deg)	Time (HMS) / Tmid(RA)	Tmid(Dec)	Mean Offset & Updated Times
180530/lmi.0042							
Ephem T0	12:05:13.699	17:43:28.415	181:18:25.481	17:43:28.415	3:36:00.000		
Ephem T1	12:06:16.931	18:20:35.073	181:34:13.966	18:20:35.073	3:37:00.000		
Object			181.3235462	17.7633879	3h 36m 3s 750ms	3h 36m 3s 767ms	
			Tmid - EXPTIME/2 - UTCSTART:		0:00:02.010	0:00:02.027	0:00:02.018
	FITS HDR		**Tmid + EXPTIME/2 - UTCEND:**		-230	-213	-0:00:00.222
UTCSTART	3:36:01.640				3:36:03.650	3:36:03.667	3:36:03.658
UTCEND	3:36:04.080				3:36:03.850	3:36:03.867	3:36:03.858
EXPTIME	0:00:00.200						
						FILL IN BOXES WITH HEAVY OUTLINE	
180530/lmi.0042	3:36:01.640	3:36:04.080	0:00:00.200	0:00:02.018	-0:00:00.222	3:36:03.658	3:36:03.858

Computing Shutter Offset Time from GPS Satellite Observation - Sat: R04, Img: 20180530/lmi.0045

Frame	RA (HMS)	Dec (DMS)	RA(deg)	Dec (deg)	Time (HMS) / Tmid(RA)	Tmid(Dec)	Mean Offset & Updated Times
180530/lmi.0045							
Ephem T0	12:20:52.509	26:22:22.193	185:13:07.635	26:22:22.193	3:50:00.000		
Ephem T1	12:22:04.711	26:59:17.773	185:31:10.663	26:59:17.773	3:51:00.000		
Object			185.2370481	26.4103937	3h 50m 3s 642ms	3h 50m 3s 662ms	
			Tmid - EXPTIME/2 - UTCSTART:		0:00:02.042	0:00:02.062	0:00:02.052
	FITS HDR		**Tmid + EXPTIME/2 - UTCEND:**		-188	-168	-0:00:00.178
UTCSTART	3:50:01.500				3:50:03.542	3:50:03.562	3:50:03.552
UTCEND	3:50:03.930				3:50:03.742	3:50:03.762	3:50:03.752
EXPTIME	0:00:00.200						
						FILL IN BOXES WITH HEAVY OUTLINE	
180530/lmi.0045	3:50:01.500	3:50:03.930	0:00:00.200	0:00:02.052	-0:00:00.178	3:50:03.552	3:50:03.752

Computing Shutter Offset Time from GPS Satellite Observation - Sat: R04, Img: 20180530/lmi.0050

Frame	RA (HMS)	Dec (DMS)	RA(deg)	Dec (deg)	Time (HMS) / Tmid(RA)	Tmid(Dec)	Mean Offset & Updated Times
180530/lmi.0050							
Ephem T0	13:01:27.754	43:14:27.185	195:21:56.314	43:14:27.185	4:18:00.000		
Ephem T1	13:03:16.224	43:49:17.690	195:49:03.361	43:49:17.690	4:19:00.000		
Object			195.3928521	43.2763420	4h 18m 3s 612ms	4h 18m 3s 664ms	
			Tmid - EXPTIME/2 - UTCSTART:		0:00:02.042	0:00:02.094	0:00:02.068
	FITS HDR		**Tmid + EXPTIME/2 - UTCEND:**		-198	-146	-0:00:00.172
UTCSTART	4:18:01.470				4:18:03.512	4:18:03.564	4:18:03.538
UTCEND	4:18:03.910				4:18:03.712	4:18:03.764	4:18:03.738
EXPTIME	0:00:00.200						
						FILL IN BOXES WITH HEAVY OUTLINE	
180530/lmi.0050	4:18:01.470	4:18:03.910	0:00:00.200	0:00:02.068	-0:00:00.172	4:18:03.538	4:18:03.738

Computing Shutter Offset Time from GPS Satellite Observation - Sat: R11, Img: 20180525/lmi.0054

Frame	RA (HMS)	Dec (DMS)	RA(deg)	Dec (deg)	Time (HMS) / Tmid(RA)	Tmid(Dec)	Mean Offset & Updated Times
180525/lmi.0054							
Ephem T0	21:25:51.400	30:17:38.282	321:27:51.000	30:17:38.282	9:30:00.000		
Ephem T1	21:34:17.245	33:05:03.933	323:34:18.675	33:05:03.933	9:35:00.000		
Object			321:29:44.642	30:20:13.976	9:30:04.493	9:30:04.650	
			Tmid - EXPTIME/2 - UTCSTART:		0:00:01.893	0:00:02.050	0:00:01.971
	FITS HDR		**Tmid + EXPTIME/2 - UTCEND:**		-337	-0:00:00.180	-0:00:00.259
UTCSTART	9:30:02.500				9:30:04.393	9:30:04.550	9:30:04.471
UTCEND	9:30:04.930				9:30:04.593	9:30:04.750	9:30:04.671
EXPTIME	0:00:00.200						
						FILL IN BOXES WITH HEAVY OUTLINE	
180525/lmi.0054	9:30:02.500	9:30:04.930	0:00:00.200	0:00:01.971	-0:00:00.259	9:30:04.471	9:30:04.671

Computing Shutter Offset Time from GPS Satellite Observation - Sat: G10, Img: 20180525/lmi.0081

Frame	RA (HMS)	Dec (DMS)	RA(deg)	Dec (deg)	Time (HMS) / Tmid(RA)	Tmid(Dec)	Mean Offset & Updated Times
180525/lmi.0081							
Ephem T0	22:05:18.480	-1:57:03.698	331:19:37.200	-1:57:03.698	9:45:00.000		
Ephem T1	22:11:06.325	-4:18:19.901	332:46:34.875	-4:18:19.901	9:50:00.000		
Object			331:22:25.632	-2:01:38.250	9:45:09.684	9:45:09.717	
			Tmid - EXPTIME/2 - UTCSTART:		0:00:02.134	0:00:02.167	0:00:02.151
	FITS HDR		**Tmid + EXPTIME/2 - UTCEND:**		-106	-0:00:00.073	-0:00:00.089
UTCSTART	9:45:07.300				9:45:09.434	9:45:09.467	9:45:09.451
UTCEND	9:45:10.040				9:45:09.934	9:45:09.967	9:45:09.951
EXPTIME	0:00:00.500						
						FILL IN BOXES WITH HEAVY OUTLINE	
180525/lmi.0081	9:45:07.300	9:45:10.040	0:00:00.500	0:00:02.151	-0:00:00.089	9:45:09.451	9:45:09.951