LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
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Technical Note	**LIGO-T1900248-v7**	2020/08/03

Record of Real-Time Calibration Pipeline Parameter Changes

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O3 (and ER14) – H1

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1 O3A Time Table Graphic

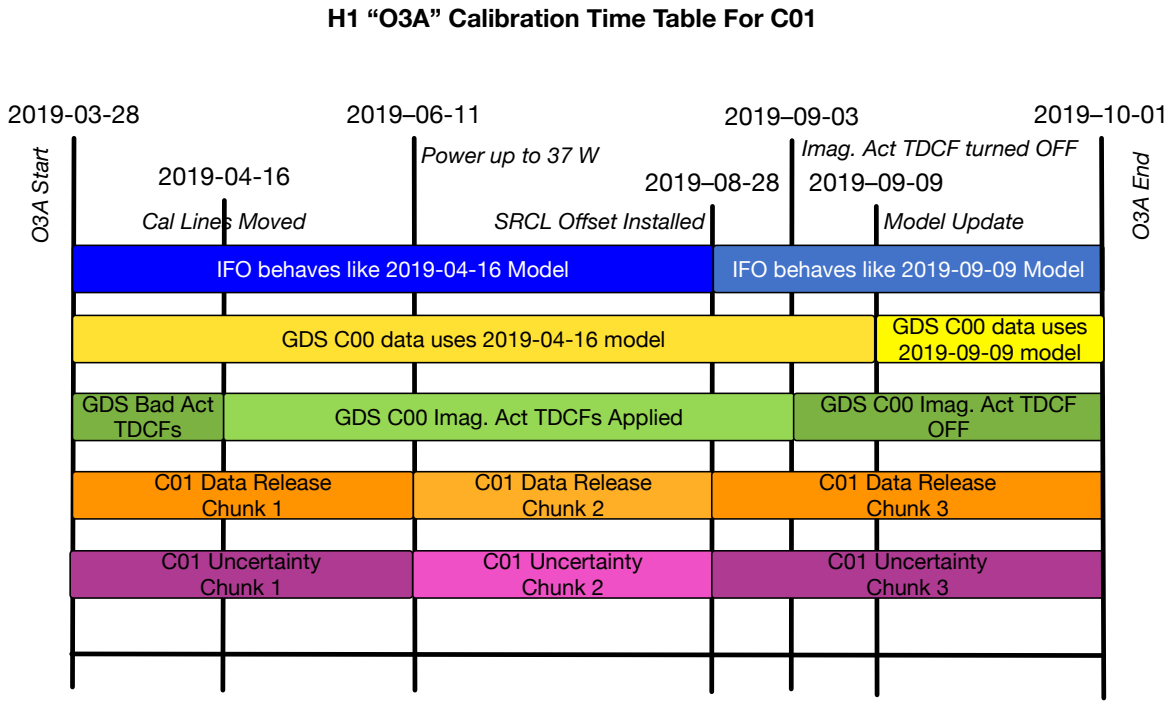

Figure 1: Time table summarizing the major events in O3A, and how the impact the final (C01) data releases.

2 ER14

2.1 Wednesday March 20

GDS filters updated with some old model,

`~/trunk/Runs/O3/H1/params/modelparams_H1_20190316.py`

LHO aLOG 47695 These won't change (and will be wrong by some amount) until Apr 03 2019. (Prior to this date, GDS filters had not been updated since Nov/Dec 2018, i.e. ER13)

2.2 Wednesday Evening Mar 27 2019

Mar 27 2019 17:22:51 PDT
Mar 28 2019 00:22:51 UTC
GPS 1237767789

ER14 model is installed in to CAL-CS with sensing gain of 1.0 and actuator gains of 1.0

`~/trunk/Runs/O3/H1/params/modelparams_H1_20190401_ER14_095A.py`

LHO aLOG 48012

2.3 Thursday Morning Mar 28 2019

Mar 28 2019 11:02:08 PDT
Mar 28 2019 18:02:08 UTC
GPS 1237831346

Turned OFF L2P and L2Y decoupling, which eliminates parasitic longitudinal coupling (i.e. L2P then P2L) from the DARM loop, which had been cause unmodeled systematic error in the PUM stage. LHO aLOG 47982

2.4 Thursday Morning Mar 28 2019 (O3 Start)

Mar 28 2019 11:04:03 PDT
Mar 28 2019 18:04:03 UTC
GPS 1237831461

First observation ready (`DMT-ANALYSIS_READY = 1`) segment that we are capable of calibrating for ER14 / O3 with out significant effort (i.e. we'd have to model the L2P then P2L coupling in the PUM which we've never done, and likely don't have the measurements to back up the model).

new calibration line frequencies = [7.93, 15.1, 16.7, 36.7, 35.9, and 331.9, 1083.7 Hz]
we should recalibrate to backwards to this point using the

`^/trunk/Runs/O3/H1/params/modelparams_H1_20190404.py`

model parameter set.

3 O3A

3.1 Thursday Evening Mar 28 2019

Mar 28 2019 18:38:34 PDT
Mar 29 2019 01:38:34 UTC
GPS 1237858732

ER14 model scaled actuator by 0.96 (instead of 0.95) in order to improve (at the time mis-understood, now known to be non-existent) large systematic error.

`^/trunk/Runs/O3/H1/params/modelparams_H1_20190401_ER14_095A.py`

installed into CAL-CS, LHO aLOG 48012

3.2 Friday Morning, Mar 29 2019

Mar 29 2019 09:38:29 PDT
Mar 29 2019 16:38:29 UTC
GPS 1237912727

ER14 model remains installed in CAL-CS, but now scaling actuator by 0.95, exactly matching

`^/trunk/Runs/O3/H1/params/modelparams_H1_20190401_ER14_095A.py`

LHO aLOG 48040

3.3 From Mar 29 to Apr 10

Front-end CAL-CS is running with filters and path gains that match for all observation ready segments.

`^/trunk/Runs/O3/H1/params/modelparams_H1_20190401_ER14_095A.py`

LHO aLOG 48115

Apr 01 2019
Commissioning the CAL-CS TDCFs, EPICs records are installed/updated with parameters from

`^/trunk/Runs/O3/H1/params/modelparams_H1_20190401_ER14_095A.py`

LHO aLOG 48130 (but found out later that the installation failed, and plagued by timing slips in SUS CAL Line replicas) (prior to this date, EPICs records had not been updated since Nov/Dec 2018, i.e. ER13.)

Apr 02 2019
EPICs records fixed (but still using errant *modelparams_H1_20190401_ER14_095A.py*) LHO aLOG 48176

Apr 03 2019
GDS filters updated to match ER14 model with scaled actuator

`^/trunk/Runs/O3/H1/params/modelparams_H1_20190401_ER14_095A.py`

LHO aLOG 48163

Apr 09 2019
Small change to ETMX compensation of ESD Driver Pole Frequency (only 0.3% / 0.5 deg at 1 kHz in the TST actuator, where it's contribution to R is already small). LHO aLOG 48352

3.4 Wednesday Morning Apr 10 2019

Apr 10 2019 10:15:00 PDT
Apr 10 2019 17:15:00 UTC
GPS 1238951718

O3 model installed in to CAL-CS and GDS, based on measurement data from 2019-04-04.

`^/trunk/Runs/O3/H1/params/modelparams_H1_20190404.py`

CAL-CS updated LHO aLOG 48378 GDS updated LHO aLOG 48388

3.5 Wednesday Morning Apr 10 2019

Apr 10 2019 11:12:34 PDT
Apr 10 2019 18:12:34 UTC
GPS 1238955172

Observation ready (`DMT-ANALYSIS_READY = 1`) segment starts, and C00 Data OK at the stated uncertainty of 2019-04-04 model from here on out until calibration line frequencies are changed on Apr 16.

3.6 Tuesday Morning Apr 16 2019 (Calibration Line Frequency Changes)

Apr 16 2019 11:03:00 PDT
Apr 16 2019 18:03 UTC
GPS 1239472998

Front-end model changed to ship SUS Cal Line Oscillators from end to corner, by-hand CAL-CS only demod phases adjusted accordingly (mostly). LHO aLOG 48499.
Calibration Line Frequencies Changed, DARM Control Filter Changed, New Model

```
^/trunk/Runs/O3/H1/params/modelparams_H1_20190416.py
```

LHO aLOG 48534

new calibration line frequencies = [7.93, 15.6, 16.4, 17.1, 17.6, 410.3, 1083.7 Hz]

3.7 Tuesday Afternoon, Apr 16 2019

Apr 16 2019 14:02:28 PDT
Apr 16 2019 21:02:28 UTC
GPS 1239483766

Observation ready (`DMT-ANALYSIS_READY = 1`) segment starts, and C00 Data OK at the stated uncertainty of 2019-04-16 model with new calibration lines.

3.8 Wednesday Morning Apr 17 2019

New Calibration Line Amplitudes Adjusted, by-hand CAL-CS only demod phases for PCAL fixed. LHO aLOG 48578.

3.9 Monday, June 10 2019 (PSL Power Increased; 35W to 37W)

Jun 10 2019 16:55:42 PDT Jun 10 2019 23:55:42 UTC

GPS 1244246160 PSL input power increased from “35W” to “37W”, but we didn’t update the model to account for it, thinking that time-dependent correction factors should account for all changes. See LHO aLOG 49783.

3.10 Tuesday Afternoon, Jul 17 2019

Jul 17 2019 16:47:01 PDT
Jul 17 2019 23:47:01 UTC
GPS 1247442439
SRC1 Y Offset Removed.

3.11 Tuesday Evening, Jul 30 2019 (Spot Positions Changed)

Jul 30 2019 21:01:05 PDT
Jul 31 2019 04:01:05 UTC
GPS 1248580883
First observation ready segment with "new" temporary IFO beam spot positions on TMs. This forced change was errantly installed after recovery from initial alignment reference lost, and in the chaos were accepted for some time. LHO aLOG 50935

3.12 Wednesday Afternoon, Aug 21 2019 (Spot Positions Reverted)

Aug 21 2019 02:20:39 PDT
Aug 21 2019 09:20:39 UTC
GPS 1250414457
Evidence built up that these "new" temporary spot positions were bad for the IFO, (see LHO aLOG 51262), and thus they were reverted (it took several attempts over 1.5 weeks for it to become permanent).
The above time marks the first observation ready segment with IFO beam spot positions recovered to original values. LHO aLOG 51436.

3.13 Tuesday Afternoon, Aug 28 2019 (100ct SRCL Offset Installed)

Aug 28 2019 16:49:45 PDT
Aug 28 2019 23:49:45 UTC
GPS 1251071403
Permanently installed 100 ct SRCL offset to improve low frequency sensing function detuning, and thus impacting the DARM loop via the coupled cavity system. IFO now behaves like the future 2019-09-09 model. LHO aLOG 51592

3.14 Monday Morning, Sep 09 2019 (CAL-CS Model Updated)

Sep 09 2019 11:26:28 PDT
Sep 09 2019 18:26:28 UTC
GPS 1252088806
Updated front-end CAL-CS pipeline and GDS pipeline to obey 2019-09-09 model.

```
^/trunk/Runs/O3/H1/params/modelparams_H1_20190909.py
```

LHO aLOG 51819: Installation aLOG
LHO aLOG 51784: Model details
This includes updates to UIM boost and PUM L2A digital filtering addressed / justified / showed to have no impact in LHO aLOG 51782

4 O3B Time Table Graphic

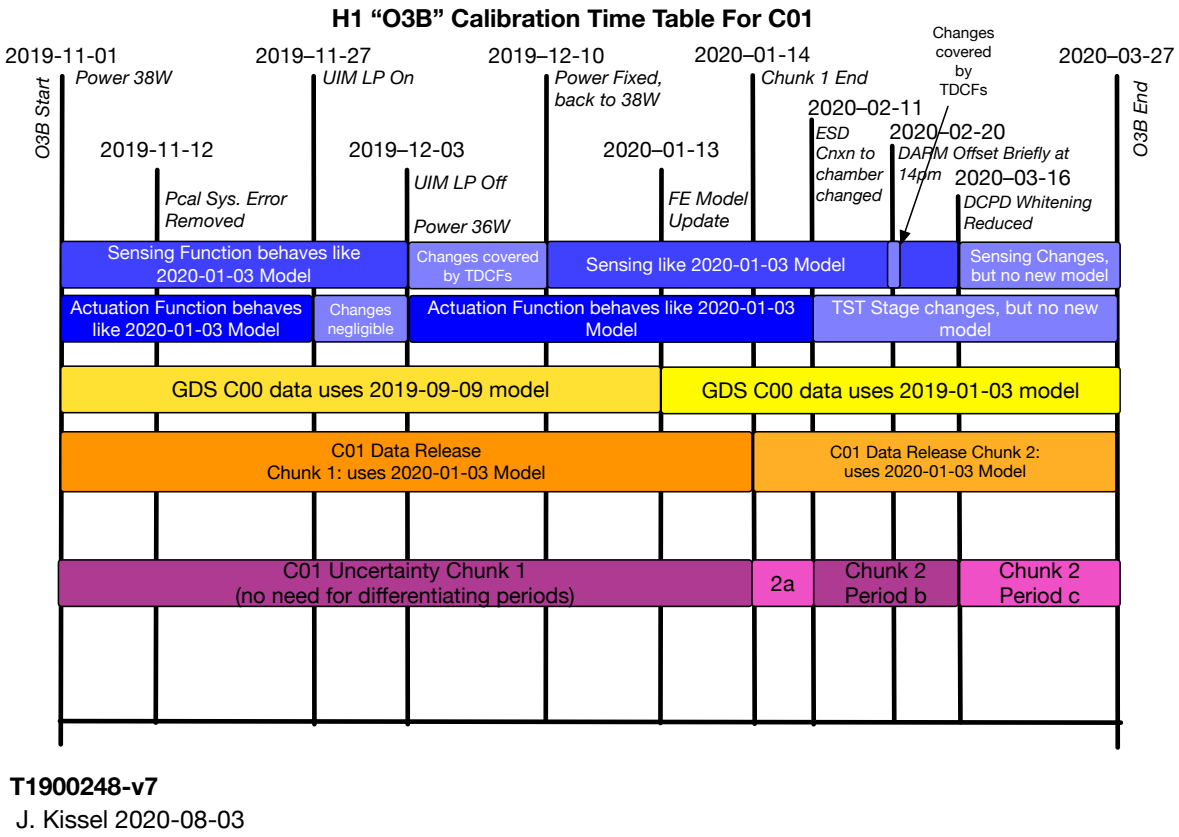

Figure 2: Time table summarizing the major events in O3B, and how the impact the final (C01) data releases.

5 O3B

5.1 Oct 28-30 2019 (Pre-Start-of-O3 Changes)

In the nights before the run resumes, the 100 ct $\approx$ 50 nm SRCL offset installed on 2019-08-28 (see 3.13) is reduced to 50 ct $\approx$ 25 nm (see LHO aLOG 52861).
This is done in order to "re-tune" the *thermalized* IFO's sensing function to show "no signs of detuning," based on a measurement taken only 30 minutes in to a lock stretch (see LHO aLOG 52751).
Much later, we find this shifts the f_s^2 report of beginning-of-lock-thermalization progression from

- O3A: "$\sim$ 25 Hz^2 anti-spring to $\sim$ 25 Hz^2 pro-string" in the first two hours

to

- O3B: "as much as $\sim$ 75 Hz^2 anti-spring to $\sim 0-10$ Hz^2 NO spring" in the first two hours.

as shown in see e.g. LHO aLOG 54269.
Thus, rather than the swing of detuned sensing function response being "covered" by a "$\pm$10%/5deg at 10 Hz" GPR estimate of systematic error and unimportant for O3A response uncertainty and events (see G2000281), every lock stretch has an über anti-spring in its beginning, which results in as much as 8% systematic error in the response function during the early bits of the first two hours (see LHO aLOGs 55182 and 55349).
For how this will be accounted in the uncertainty and systematic error budget for events (and long-duration searches like CWs) is TBD.

5.2 Nov 1 2019 (Start of O3B, 37.2 W in to the IFO)

Nov 01 2019 10:10:16 PDT
Nov 01 2019 17:10:16 UTC
GPS 1256663434
Start of the First DMT ANALYSIS READY segment for O3A.
Power in to the IMC is now 38W.
SRCL offset is now 50 ct $\approx$ 25 nm
Front-end/GDS pipeline is still using "no detuning," 2019-09-09 model that has $f_s = 0.0$ Hz and $Q_s = 1e-2$.
Actuator gains are still that from 2019-04-03 measurement, and dynamical model is still old out-dated O2 model.
LHO aLOG 52905

5.3 Nov 12 2019 (All PCAL Force Coefficients Updated)

Nov 12 2019 14:58:33 PST
Nov 12 2019 22:58:33 UTC

GPS 1257634731
Force coefficients and force-to-displacement transfer function (i.e. parts of H_{Pcal} used for calculating ΔL_{Pcal}) are updated to account for fix in test mass masses and idiosyncrasies of the end station ADC channels for RXs and TXs.
Results in "removal" of systematic error of $\eta_{\mathrm{Pcal}} = 1.0043\%$ from online estimate of ΔL_{Pcal} from H1 EY RXPD.
LHO aLOG 53188: Installation aLOG

5.4 Nov 27 2019 (Turn on UIM State 2)

Nov 27 2019 18:21:29 PST
Nov 28 2019 02:21:29 UTC
GPS 1258942907
Under suspicion that the UIM actuators were limited by quantization noise, we tried applying one stage of analog low pass to ETMX UIM. This analog filter is automatically digital compensated with "reasonably precise" accuracy, and thus we felt we didn't need to create a new epoch.
LHO aLOG 53528: UIM LP filter turned on.

5.5 Dec 03 2019 (Revert UIM State 2)

Dec 03 2019 07:49:42 PST
Dec 03 2019 15:49:42 UTC
GPS 1259423400
As a consequence of the (frequency-dependent) amplification needed to digitally compensate the analog low-pass, ETMX UIM was continually running out of DAC range to drive the same needed ΔL_{ctrl} request, and was thus impacting lock re-acquisition. Deemed "not worth it," the configuration was reverted back to no low-passes. Above times reflects the end of last observation stretch with the UIM LP on.
See further investigation in PART I of G2000527

LHO aLOG 53652

5.6 Monday late night, Dec 03 2019 (Rotation stage goes bonkers, power drops to 36W)

Dec 03 2019 23:21:24 PST
Dec 04 2019 07:21:24 UTC
GPS 1259479302
Problem present for quite some time: the PSL power control rotation stage (i.e. that which is in charge of the relative angle between a polarizer / analyzer combo in the PSL path before the IMC, and thus in control of laser power into the IMC / IFO) is ... "quirky" in that the "power per angle" calibration drifts with time, and often does not return the requested power.
"Bootstrapping" fix was first tried in 2016 (LHO aLOG 27923), and then quickly removed

(LHO aLOG 27956).
This same bootstrapping was *re-installed* in the LASER_PWR guardian on Nov 5th (see LHO aLOG 53010.)
Suspecting that the interaction between the gaurdian implementation of this bootstrapping and the ISS 2nd loop during lock-acquisition (LHO aLOG 53068) bootstrapping was commented out of the PSL power guardian, and thus turned OFF, late at night at the time indicated above. (LHO aLOG 53672).
This results in running at 36W for 7 days.
We suspect (hope) this is covered by κ_C TDCF.

5.7 Tuesday night, Dec 10 2019 (Rotation Stage "fixed" now at 38 W)

Dec 10 2019 18:33:20 PST
Dec 11 2019 02:33:20 UTC
GPS 1260066818
Latest attempt at solving the unruly rotation stage is to add a "bandaid" on the "bootstrap:" The "fine adjust" feature of the bootstrapping is turned off, and bootstrapping is reengaged. Further the bootstrapping is adjusted to add a 1 second wait timer between the request of laser power by user to LASER_PWR gaurdian and the sub-process call to engage the bootstrap.
This "fixes" the problem and we return to 38 ± 0.1 W power accuracy. LHO aLOG 53802: Rotation stage fixed aLOG.

5.8 Jan 03 2020 (Reference Data for 2020-01-03 Model)

Jan 03 2020 09:05:44 PST Jan 03 2020 17:05:44 UTC
GPS 1262106362
Complete reference data set taken for the future 2020-01-03 model. Time of broadband injection sis listed here. LHO aLOG 54260: Measurement aLOG.

5.9 Monday, Jan 13 2020 (2020-01-03 Model Installed in CAL-CS / GDS)

Jan 13 2020 16:47:59 PST
Jan 14 2020 00:47:59 UTC
GPS 1262998097

Sensing function parameters are updated with 2019-01-03 measurements, as per standard.
Actuation strength model coefficients are estimated by analyzing the old 2019-04-03 measurements but divided against the updated dynamical model, because "the actuator hasn't changed since then, so let's keep that value so we win on the GPR uncertainty by stacking all measurements since then."
At the *very* last minute (i.e. during install) we remember the PCAL systematic error of η_{Pcal} that's present in that 2019-04-03 data (i.e. that which wasn't corrected until Nov 12, see 5.3), so we quickly regenerate actuator coefficients by installing that which is corrected for by 1.0043.

κ_{act} values become closer to one, confirming that this was the right thing to do (and we got the direction of application right). Resolve to generate GPR systematic error uncertainty for this model by stacking sensing and actuation measurements taken after 2019-11-12.
Time listed in this section is first observation ready segment in which C00 uses this model.
LHO aLOG 54473: CAL-CS installation aLOG
LHO aLOG 54476: GDS installation aLOG

5.10 Wednesday, Jan 14 2020 (End of Chunk 1; Start of Chunk 2, Period a)

Jan 14 2020 10:00:00 PST
Jan 14 2020 18:00:00 UTC
GPS 1263060018

Though there was no detector configuration change on this date, here marks the differentiation between Chunk 1 and Chunk 2 of O3B. Because O3B chunk 2 has three distinct time periods of differing unknown systematic error (as shown by the collection of sweeps and uncertainty analysis), **this marks the start of the first of those periods, O3B, Chunk 2, Period a.**

5.11 Tuesday, Feb 11 2020 (ESD Drive Connection to Chamber Changed; Start of Chunk 2, Period b)

Feb 11 2020 08:47:30 PST
Feb 11 2020 16:47:30 UTC
GPS 1265474868

As a part of continued 60 Hz and/or comb noise hunting efforts, the ETMX ESD driver's connection from the chassis to the chamber (namely, right at the chamber feedthrough), which was a small interface chassis that contained 10k Ohm current limiting resistors (D1500113), was replaced by simple SHV barrel connectors (with negligible resistance) during maintenance on Feb 11 2020. The interplay between *having* this 10k Ohm resistor in series with the $\sim$ 600 pF cable capacitance between the chamber feedthru and the end reaction mass ESD pattern and *not* having the 10k in place causes a slight shift in actuation strength, most notably in *phase*. Namely, prior to the change, the 10k resistor created a voltage divider system, with a pole at $1/(2\pi RC) = 26525$ Hz.

$$(180/\pi) * \arctan(-2\pi * 1000 \text{ Hz} * 10e3 \text{ Ohms} * 600e-12 \text{ Farads}) = -2.15 \text{ deg} \quad (1)$$

The first observation ready segment after this change started Feb 11 2020 22:25:54 UTC, at GPS time 1265495172, or 14:25:54 PST.

This change also demarks the start of O3B, Chunk 2, Period b in the uncertainty budget.

LHO aLOG 55041

5.12 Tuesday, Feb 19 2020 (PCALX Laser OFF)

Feb 18 2020 16:16:57 PST to Feb 25 2020 09:38:49 PST
Feb 19 2020 00:16:57 UTC to Feb 25 2020 17:38:49 UTC
GPS 1266106635 to 1266687547

EX Interlock tripped due to ISC EX IO chassis reboot, causing PCAL X laser to shut off. Wasn't caught/discovered until several days later.
Fortunately inconsequential to IFO calibration because PCAL Y is used for in-band calibration lines.
Only losses are one sweep of high-frequency roaming lines and the corresponding amount of days worth of CW injections.
LHO aLOG 55291
LHO aLOG 55257

5.13 Feb 20 2020 (2 Short Segments with high DARM Offset)

Feb 20 2020 between 13:08 PST and 13:29 PST
Feb 20 2020 between 14:07 PST and 15:00 PST
Feb 20 2020 between 21:08 and 21:29 UTC
Feb 20 2020 between 22:07 and 23:00 UTC
GPS between 1266268098 and 1266269358
between 1266271638 and 1266274818

In hopes to combat junk light transmitted through the OMC, improving sensitivity by increasing arm-carrier light at dark port / DCPDs, the DARM offset was increased from *10 ppm* to *14 ppm*. More light at the dark port means more optical gain, which means lower κ_C. Quite quickly reverted because more light means less head room in DCPD analog electronics for glitches, and caused too many lock-losses.
LHO aLOG 55204: aLOG documenting affected times.
LHO aLOG 55105: Discussion of improvement aLOG
LHO aLOG 55205: Reverted.

5.14 Mar 16 2020 (OMC Whitening Configuration Change; Start of Chunk 2, Period c)

Mar 16 2020 14:18:54 PDT
Mar 16 2020 21:18:54 UTC
GPS 1268428752

Still on the junk light kick, but figuring out how to gain more head room, the amount

of OMC analog whitening was reduced from all 3 stages (2 whitening stages and one low pass) to just 1 stage of whitening. The above times are the first observation ready segments in which this change was applied permanently.
The difference in accuracy of digital compensation of the three vs. one filter configuration on both DCPDA and DCPDB chains causes a frequency dependent change in the sum of the two. Initial data suggests as much as 1.0-1.5% frequency-dependent error in the response function, but after further investigation using the final DCS C01 calibration (i.e. after removing the confusing influence of TDCFs), the systematic error is determinated to be at most 0.5% at 100 Hz, and 0.25 degrees at 50 Hz. See further investigation in PART II of G2000527, and summary comment to the following aLOG.

This change also demarks the start of O3B, Chunk 2, Period c in the uncertainty budget.

LHO aLOG 55620: Installation aLOG

5.15 Friday March 27 2020 (End of O3)

Mar 27 2020 10:00:00 PDT
Mar 27 2020 17:00 UTC
1269363618

Official end of O3B (and thus also O3B Chunk 2, Period c).