

# List of edits and disposition for V3

## 05/22/2020

### Rick's comments:

#### Abstract

1. Remove "continuously" from third sentence, "...power sensors continuously monitoring ...". It was used in the second sentence and isn't really necessary here.  
Took out 'continuously'
2. "...factor of two ..." is no longer true (0.75 -> 0.41). Suggest "almost a factor of two..."  
Changed as suggested.
3. Suggest removing "significantly." "...have significantly increased confidence ..."  
Took out significantly
4. Suggest removing "reference." "... single reference transfer standard..." "Referencing" used at the start of the sentence.  
Removed.

#### 1. Introduction

1. Make acronym, GW, plural -> (GWs)  
Changed.
2. Change "the" to "an." "...installed at an end station of one of ..."  
Changed.
3. Change "discussed" to "presented." "...variations are also presented." We use "discuss" several times in this paragraph.  
Changed.
4. Give dates for O3 observing run. "...during the O3 observing run, from April 2019 to March 2020, to demonstrate..." We define this later, on page 10, so we need to remove it there and define it here.  
Changed.

#### 2. Methodology

##### Section 2.1 Calibration of the power sensors

1. Change order to "A second sensor (Tx) samples a small fraction..." It is not a "Tx sensor," it is a sensor labeled Tx.  
Changed.

2. Suggest remove “100 second long.” “... which is evident in the 100 second long time series ...” And adding “upper panel,” “...plotted in the upper panel in figure 4, limits the precision...”
3. It seems we have a pretty weak motivation for Figure 4 in this paper. All we say for the upper panel is, “This temporal correlation, which is evident in the time series plotted in the upper panel of figure 4. The motivation for adding this figure was more than this. It is actually quite an important figure. It led to an innovation (Ethan was involved in this) when we were trying to decide on standard  $\alpha_{\{WG\}}$  measurement suites. We realized that there was no benefit in using our time to make long (100 s) time series. Better to have many short time series because the laser speckle “resets” each time we move the slides, but stays on it slowly-varying interference condition until it is moved. It is going to take some effort to explain this rather subtle point.

Figure 4 reworked. Lower panel replaced with time series from the other sensor during the Rx measurements. Caption changed. Text in document that refers to this figure changed. Normalizing to the mean value of all the data in each panel now.

4. Caption figure 3.
  - a. Suggest adding “ $\alpha_{\{WG\}} = \dots$ ratios,  $\alpha_{\{WG\}} = \frac{\rho_{\{W\}}}{\rho_{\{G\}}}$ ,”  
Changed.
  - b. Suggest changing to “... 2800 measurements, each from a twenty second ... measurement suite.” (suites -> suite).  
Changed.
5. Caption figure 4.
  - a. Lower panel caption. Isn’t “(240 seconds long)” obvious from the horizontal axis tick marks? Suggest removing. Then need a couple of articles, suggest “Relative variation of a Pcal power sensor output recorded during responsivity ratio measurements at an end station at the LHO.”  
Caption changed. This issue no longer relevant.
  - b. “...of Pcal power sensor output.” needs an article. But more importantly, how can we put this in meaningful context. See comment 3. Above. Maybe “... of a Pcal power sensor output during relative responsivity measurements in the LHO laboratory.” LHO laboratory is noted in the next sentence. Maybe it needs to be moved earlier. This argument, that shorter is better, needs to be made in the text (maybe it is somewhere, but I missed it), not just in the caption.  
Comment about shorter being better moved to text.
  - c. The sensor positions are actually swapped 200 times in the 100 cycles. Maybe “... averaging the results of more measurement suites (100) incorporating shorter time series (5s).” Text should be updated similarly.  
Text updated.
6. “...in in ...” => “...in...”  
Fixed.

7.  $1.1e-4/K$ . Do we need to make it clear that this is not the same working standard as for the ratio reported in figure 7, where the ratio was - 2.35 hop/K vs. 1.1 hop/K?  
Done. Now using WS1 and WS2,  $\alpha_{\{W1W2\}}$ , etc.
8. "...the calibration factors for the end station power sensors ..." We also call  $\rho_{\{R\}}$  the power sensor responsivity. Do we want to change to "...the responsivity of the end station power sensor is given by...?"  
We changed to specify both responsivity and calibration factor. And also specified Rx power sensor.
9. Add "LHO." "... $T_{\{L\}}$  is the LHO laboratory temperature, and  $T_{\{E\}}$  is the end station ..."  
Changed

## Section 2.2 Calculation of displacement factors

1. Add "(except for the sign of the relative length change)" to "...without regard to which end station induced the displacement (except for the sign of the relative length change)."  
Text changed to: "...ETM motion without regard (except for the sign of the displacement) to which ETM is moving."
2. Since we use  $X_{\{X\}}$  and  $X_{\{Y\}}$  later, change to "...displacement calibration factors,  $X_{\{X\}}$  and  $X_{\{Y\}}$ , this factor would be 1"  
Changed at suggested

## 3. Measurement results and uncertainty estimates.

1. Move dates and definition of O3 earlier in paper, as noted above. So text here changes to, "...during the O3 observing run are presented here."  
Done
2. Suggest removing "While" and adding "but." "Measurements were made for both the LHO and LLO interferometers, but for simplicity only the LHO results are presented."  
Changed
3. Suggest modifying text, "...values of the parameters that contribute to the displacement factors described in section 2, and their ..."  
Changed
4. Add "listed." "...parenthesis after the relative uncertainty listed in the tables"  
Changed

## Section 3.1 End station power sensor calibration

1. Add "the." "...upon which the calibration of the LIGO, Virgo, ..."  
Changed
2. Add explanation of 20x error bars after "...February 2020." (consider in context of other comments regarding this issue and figure 5 below.  
Fig 5 caption and relevant text updated.
3. "...was caused by changes..." => "...was caused by a change..."

Changed

4. Statement is no longer correct, “The error bars for each measurement have been...”  
This is discussing the lower panel in figure 5 and it no longer has error bars. Need to update info for upper panel (see comment 2. above). Then, need to give explanation, similar to what is in the caption of figure 5, for why there are no error bars in the lower panel.  
Updated caption and text related to fig 5.
5. “...are tabulated in table 1.” => “...are listed in table 1.”  
Changed
6. Figure 5 caption:
  - a. “(1.00359)” => (multiplied by 1.00359)”  
Changed
  - b. “Weighting by the square ...” => “Weighting by the inverse of the square ...”  
Changed
7. Caption of Figure 7: Clarify what is meant by “its mean value.”  
Done. Using 1.1172 from Figure 5.
8. “...normalized to its mean value ...” What is “its mean value?” Maybe “... and  $\alpha_{\{WG\}}$ , normalized to its mean value of 1.1172 (see lower panel in figure 5), are plotted ...”  
Done. See response to comment above.
9. Comma after  $\kappa_{\{W\}}$ . “Together with  $\kappa_{\{W\}}$ , the inferred...”  
Changed to “Using  $\kappa_{\{W\}}$ , the inferred...”
10. “The” inserted. “...between the NIST, the LHO, and the end station measurement environments...”  
Changed
11. “Mean” inserted. “...23deg. C, and the mean X-end and Y-end temperatures...”  
Changed
12. “A time span of” removed. “...over six months.” It is obvious that 6 months is a span of time.  
Changed

### Section 3.2 Displacement factors.

1. Seems  $\eta_{\{R\}}$  should be mentioned in the paragraph before noting that its values are in the table. How about adding it like this: “...power reflecting from the ETM,  $\eta_{\{R\}}$ , using (4).  
Changed
2. First paragraph. Are the error bars really used for weighting?  
Yes. Don’t know why this disposition noted, “But look into more details.”
3. Caption Table 3:
  - a. Omit “Pcal”  
Changed
  - b. “Written” => “noted” everywhere in document (all tables).

Changed everywhere

4. "We are neglecting..." Should it be changed to "Here, we are neglecting...?"  
Changed
5. Should "distribution" be added after "sine wave?"  
Changed a comma
6. Remove comma: "...density function [32] to estimate ..."  
Changed
7. "...lower than the best values ..." -> "...smaller than the lowest value ..."  
Changed
8. "Like LIGO ..." paragraph is redundant. Omit, or move parts to the paragraph under (11). Then, next paragraph, start with, "To compare the X-end and Y-end Pcal calibration, ..."

Paragraph removed from section 3.2 and combined with paragraph after equation 11 as: Like LIGO, most GW observatories have implemented, or plan to implement, Pcal at both end stations. The Pcal systems at each end station are calibrated using the same procedures. Laser interferometers are designed and tuned to sense differential arm length variations induced by ETM motion without regard (except for the sign of the displacement) to which ETM is moving. Thus, comparing the Pcal fiducials produced at both end stations in the interferometer output signal directly measures the ratio of the Pcal calibrations at each end. This comparison can be used to reduce the uncertainty in the Pcal induced displacements due to factors that are not common to both ends. For LIGO, the largest uncertainty of this type is  $\epsilon_{\text{rot}}$ .

Changed the beginning of the following paragraph to:

The X/Y calibration comparison is realized by modulating...

Changed the beginning of the paragraph after the removed paragraph to:

To compare the Pcal calibrations at the two end stations...

9. Figure 10 caption.
  - a. Maybe better to start with, " $\chi_{\{XY\}}$ , the ratio of the amplitudes of the displacements ..."  
Changed
  - b. Right panel: Do we need to say which (orange or green) if for X-end and which for Y-end?  
Changed
10. Remove s (plural) from "...respective peak in the interferometer output signal."  
Changed
11. "... with a relative standard uncertainty of 0.01%" For which measurement? The higher SNR one?  
Done in response to earlier comments
12. Table 6 caption. Remove comma, add "and." "Calculated X-end and Y-end combined ..."

Changed

13. Paragraph after table 6: “We determine” => “We calculate”

Changed

14. “...uncertainty contributions calculated above ...” Where? Can we be more specific. Let’s make sure this is clear enough to the reader. Can “other contributing factors” be clarified? Other, non-common factors that contribute to the weighting for calculating  $\backslash my\_g$ ?

Resolved (??) added details to make it clear

15. Table 6:  $\cos(\theta)$ ,  $M$ ,  $\backslash \epsilon_{\{\text{rot}\}}$  listed in different order than in Table 5. Should they be the same?

Fixed it. Using the order same as in table 6 →  $\cos(\theta)$ ,  $M$ ,  $\backslash \epsilon_{\{\text{rot}\}}$

16. Is the last sentence of section 3 clear enough to everyone?

Ok

17. Chi and C should be specific for X and Y and add an extra digit on C.

Fixed it.

#### Section 4

1. Remove the last sentence of the first paragraph. This has been said many times before.

Done

2. “... for some time...” => “...for a long time...”

Done

3. “...described in this paper ...” => “...described here...”

Changed to “...described herein...”

#### Acknowledgements

1. Sundae’s first name is Xu. “...assistance of S. Chen,...” => “...assistance of X. Chen,...”

Done.

## Dripta (05/22/2020)

1. Abstract: Not a factor of two anymore.  
Now it says 'almost a factor of two'.
2. Introduction: Do we need the line after reference [9,10] - Accurate determination of the distance to GW sources requires low overall network calibration uncertainty. Also, the relative calibration accuracy between detectors in the global network plays an important role in sky localisation of sources, .....Don't they mean the same?  
One is talking about direction the other about distance.
3. Section 1.1: paragraph after fig 2.  $R(\omega)$  is plotted in the lower left panel of figure 2 for a LIGO ETM and for both pitch and yaw. Do we need the first 'and'? Shouldn't it be 'R( $\omega$ ) is plotted in the lower left panel of figure 2 for a LIGO ETM for both pitch and yaw'?  
Done.
4. Caption fig 2 for right panels: Is it a force-to-displacement discrepancy? Isn't it the discrepancy between the model and the free mass approximation?  
It now says, 'S( $\omega$ ) discrepancy is less than 0.1%, and R( $\omega$ ) discrepancy is less than 0.3%.'
5. Legend for fig 2: Are I\_P and I\_Y double subscripted? Not a significant comment, I don't mind leaving it as is.  
Sudarshan fixed it.
6. Section 2.1: ....Calibrating the Rx ..... ETM and the sensor. → Does it seem like we compensate only for the optical loss between ETM and Rx?  
Left as is.
7. Section 2.1, pg 6: inline equation in the first paragraph should say  $P_T(\omega)$  not simply  $P_T$ .  
Done.
8. Section 2.1, pg 6: Second to last paragraph, last line → ...100 second long time series plotted in figure 4,... Fig 4 has two panels, one is 100 s long time series, other is 240 s long. Do we need to specify which panel of fig 4 or is it obvious?  
Figure 4 completely updated.
9. Section 2.1, pg 7: ....during this nine hour long measurement.... Fig 3 lower panel shows a 15 hour long measurement.  
Changed the text to 15 hour from 9 hour.
10. Section 2.1, pg 8:...end station data system → data acquisition system?  
Left as is.
11. Section 2.1, pg 9: Last paragraph → .....using the same procedures. OR procedure?  
Left as is.
12. Is  $X_X/X_Y = \chi_{XY}$  true in equation 13?

Fixed it.

13. Section 3.1 pg 11: ....both before shipping the GS to NIST and immediately after its return from calibration → return from NIST?  
Changed to 'return from calibration at NIST'
14. Fig 7: Aren't the responsivity ratios normalized to 1.1172? Should it be specifically mentioned?  
Done. Yes, normalized to 1.1172.
15. Section 3: For Type A estimates .... → Perhaps delete this sentence since we mention it in the caption of the tables.  
Left as is.
16. Fig 5 caption: Shall we specifically mention that +/- 1 sigma variation is the standard deviation and +/- 1 sigma statistical uncertainty is the relative standard error ? Or is it obvious?  
Updated text and caption related to fig 5.
17. Table 2: delta T is a Type C uncertainty, isn't it?  
Fixed.
18. Section 3.1, pg 15: K or deg C?  
Left as is.
19. Section 3.2, pg 16: Do we really want to say equation 10? Or should it be equation 11?  
Left as is but changed a few issues.
20. Section 3.2 pg 19: Do we need to mention that 0.01% uncertainty in 1.0046 comes from the blue data points alone?  
Fixed it. Added a sentence that gives the result from both the studies.
21. Section 4, pg 21: ...with beams close to centered → ...with beams close to center  
Changed to 'the beams located close to the center of the ETM surfaces'



## Sudarshan's Comments:

### Section 1

1. Accurate determination of the distance to GW sources requires low overall network calibration uncertainty.

→ change network to detector.

Left as is.

2. Fig 1 caption: located at the interferometer end stations. *It is not clear if power sensors are part of Pcal system.*

→ located within the Pcal system at the interferometer end stations.

Left as is.

### Section 2:

1. The power reflectivity of the ETM is greater than 0.9999 but the anti-reflection coated vacuum windows and relay mirrors located inside the vacuum envelope. *If anti-reflection can be used as a noun then the sentence is correct, if not maybe we can reword as below.*

→ but the vacuum windows and relay mirrors, with anti-reflection coatings, located inside the vacuum envelope

Fixed as much as possible.

2. Though less reliable because it is subject to variations in the beamsplitter that reflects the small sample of the input light and because it is insensitive to changes in the optical efficiency,  $\eta$ , the power at the ETM can also be calculated as  $P(\omega) = \eta_T P_T$  with  $P_T(\omega)$  the power measured on the Tx side. *I find this sentence confusing*

→ The power at the ETM can also be calculated as  $P(\omega) = \eta_T P_T$  with  $P_T(\omega)$  the power measured on the Tx side. However, this is not a preferred monitor as it is subject to variations in the beamsplitter that reflects the small sample of the input light and is insensitive to changes in the optical efficiency,  $\eta$ .

Changed as suggested

3. The LIGO transfer standards and the Rx power sensors. Is *LIGO necessary* ?  
 → These transfer standards  
 Changed to “The transfer standards...”

### Section 3

1. Page 11 → The error bars for each measurement → Both plots dont have error bar, need to clarify that → In order to achieve that we can move some last two sentences of Fig 5 caption to here. This will also make the caption tighter.
2. Fig5 caption → Lower panel: ....between the measurement suites and not the statistical variations within each suite of between 25 and 1200 measurements.→ this is confusing. Maybe write it as: between the measurements (data points) and not by the measurement uncertainty of each data point.
3. Same caption: Take the last sentence out of caption and move it to text. See above

Updated caption for fig 5.

4. Page 12 → discussion of lower panel of Fig 4 → may be figure is not needed to say that uncertainty is calculated from standard deviations. The lower panel confuses the reader more than illuminating the reader.  
 This lower panel removed from Fig. 4.