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Performance Review of Pcal Power Standard Detector Spacers

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1 Purpose

The purpose of this document is to evaluate the performance of recently manufactured detector spacers, which are designed to attach to the Photon Calibrator power standards. In particular, we hope to assess their performance relative to the current no-spacer configuration before deciding which configuration to employ before O4.

We have determined that the relevant factors to spacer performance are responsivity change, laser speckle, robustness against disassembly, and temperature dependence.

2 Spacer design

The new detector spacer design consists of two parts, the photodetector spacer (DCC link here), and the integrating sphere clamp (DCC link here). The old detector spacer was purchased from Labsphere, but unfortunately their inventory site has no photos of the detector spacers (link here in case that changes).

The central purpose of this detector purpose is to reduce the temperature dependence of our Working Standards. The average Working Standard exhibits a 0.06%/K change in responsivity, which is thought to be due to the thermal expansion of the integrating sphere's internal spectralon shell. Since the aluminum Working Standard outer shell has a lower coefficient of thermal expansion, the spectralon is thought to expand inwards with rising temperature. The part of the integrating thought to contribute most to the temperature dependence is the aperture connected to the photodetector head, which has its own spectralon lining.

To mitigate this effect, a new detector spacer was designed (see figure 1 and figure 2) that would limit the viewing angle of the photodiode to exlcude the spectralon-lined aperture edge. The clamping mechanism mirrors that of the front plate on the photodetector head. Given equal torquing/spacing on either side of the two clamping pieces, the fastening proves much more stable than the old detector spacers.

3 Responsivity change

Due to the reduced aperture size of the detector spacer, the amount of light reaching the photodiode is also reduced. In this section, we check the relative responsivities of a single Working Standard (WST) with and without the spacer attachment. From this, we can optimize a transimpedance amplification value to span the range of our voltmeters.

In order to do this, we take the ratio of the averages for two sets of WST/WSH measurements, one with the a spacer on WST and the other without. These values are shown in figure 3, along with their means. From this we calculate that the responsivity with the spacer attached is 9.04 times lower than without the spacer. As the current transimpedance amplification resistor is 20kΩ, I propose we make increase the transimpedance amplification by a factor of 10, making the new resistor 200kΩ.

Figure 1: Side-view of new detector spacer, which has an identical clamping mechanism to the photodetector head front plate.

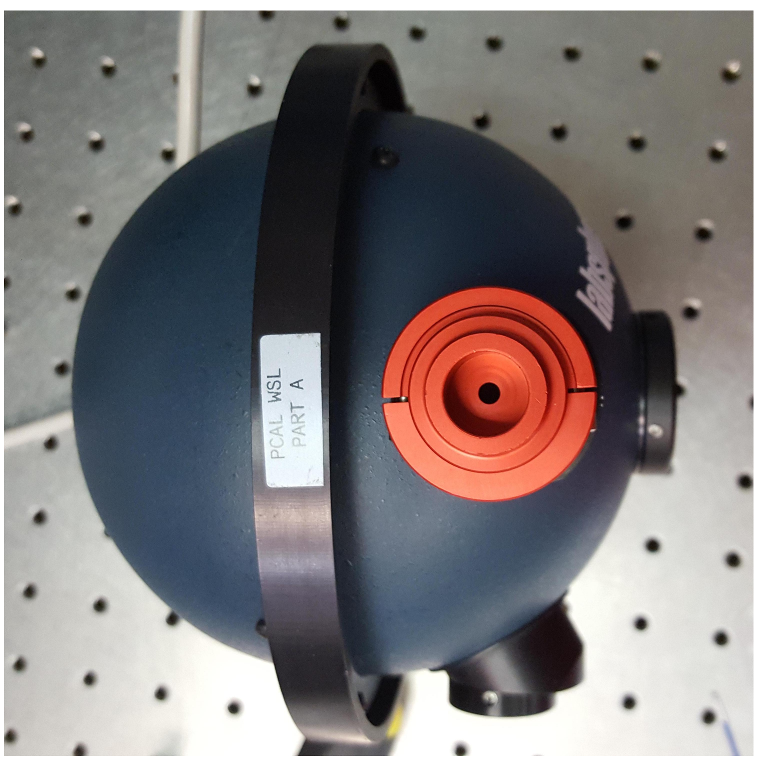

Figure 2: Top-view of new detector spacer. Notice the reduced spacer aperture size to occlude the edges of the spectralon inner sheel at the integrating sphere aperture.

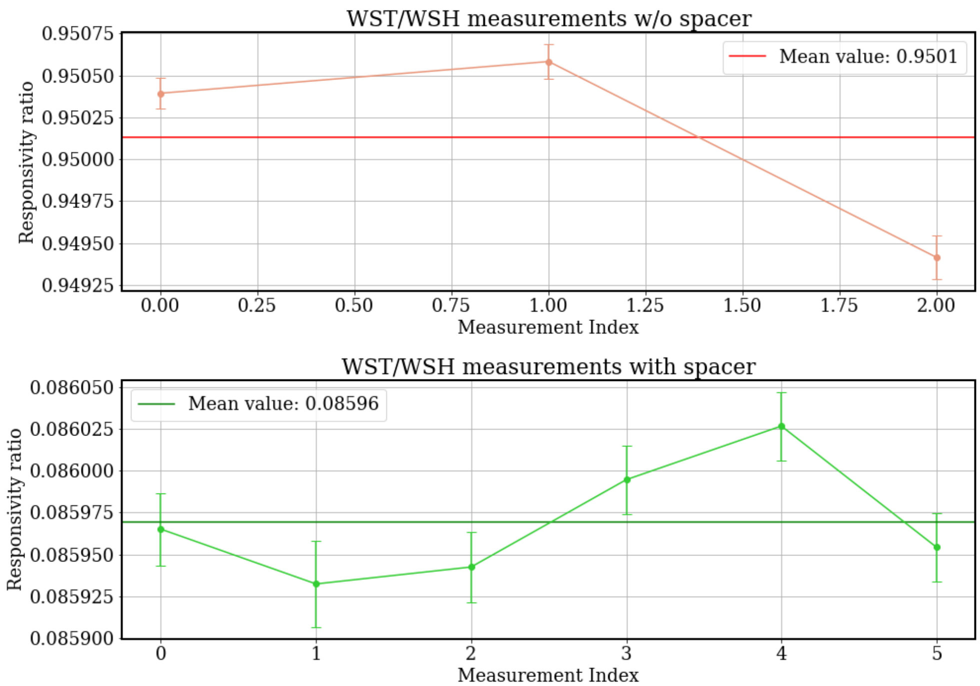

Figure 3: WST/WSH measurement without the detector spacer (top) and with the detector spacer (bottom). It should be noted that the majority of the bottom values are the same values taken in the disassembly/reassembly measurements.

4 Laser speckle

The spectralon interior of the integrating spheres reflects incoming laser light in all directions, some fraction of which recombines on the suface of the photodiode. Laser speckle describes when the recombined beams, with a wide range of phases, change in position due to external factors, causing a shifting speckle pattern on the photodiode. The severity of laser speckle is mitigated by increasing the viewing angle of the photodiode, allowing more shifting rays on the photodiode to average each other out.

With the reduced aperture size on the spacer, we expect the laser speckle severity to increase. While laser speckle is hard to quantify, we will try to assess the difference in laser speckle for the spacer and no-spacer configurations by calculating the relative standard error on the mean for standard measurements in both configurations. The two measurements we will be looking at are shown in figures 4 and 5.

The relative standard errors on the mean for both measurements are listed below:

$$\sigma_w = 2.3268e - 05$$
$$\sigma_{w/o} = 9.9560e - 06$$

with "w" meaning "with spacer" and "w/o" meaning "without spacer". The laser speckle with the detector spacer is approximately 2.4 times worse than without. This can be mitigated by extending the number of measurements in a standard measurement set.

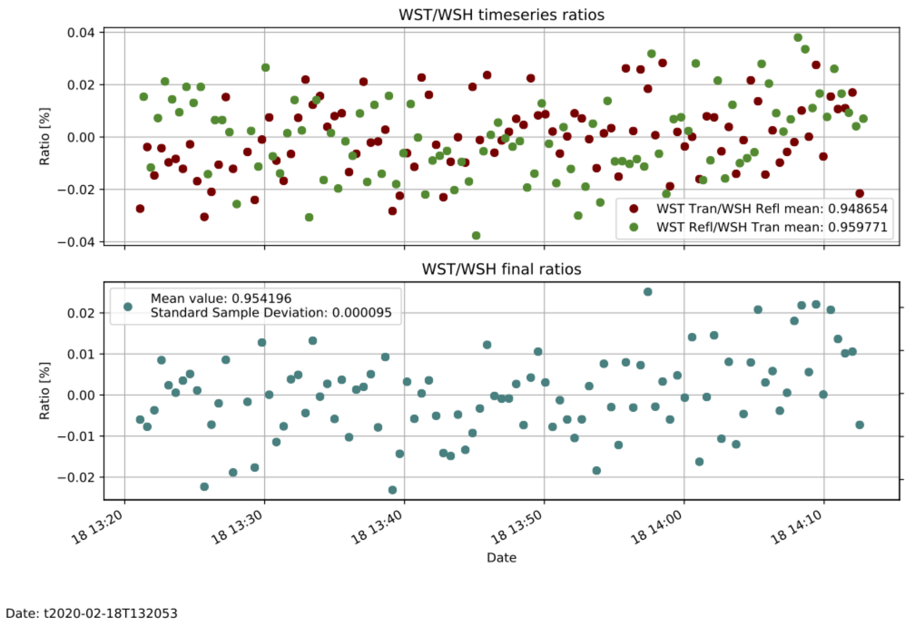

Figure 4: Responsivity ratios for standard WST/WSH measurement without a spacer attached to WST. Notice the low range on the lower panel responsivity ratio values.

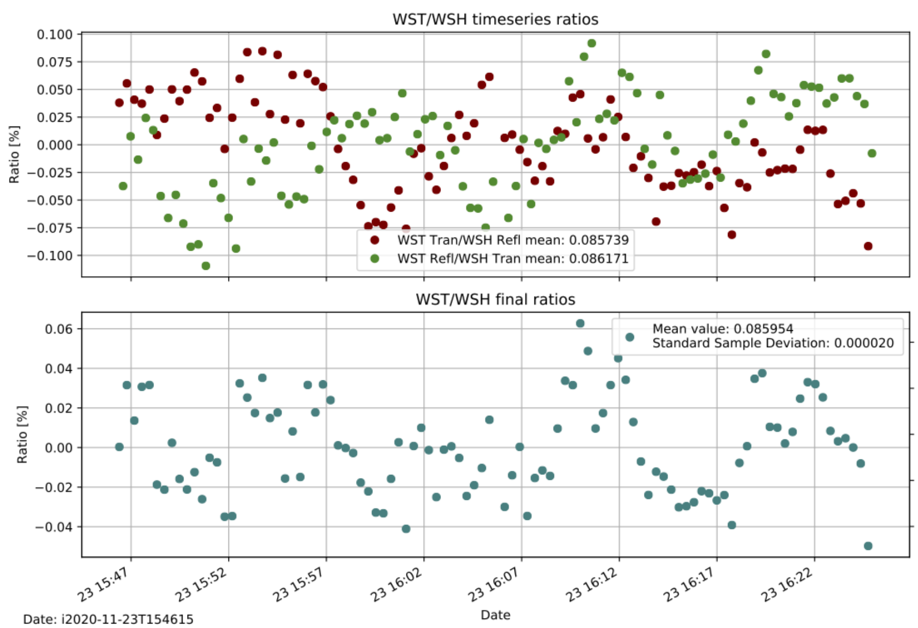

Figure 5: Responsivity ratios for standard WST/WSH measurement with the spacer attached to WST. The range of responsivity ratio values in the lower panel has increased due to increased laser speckle.

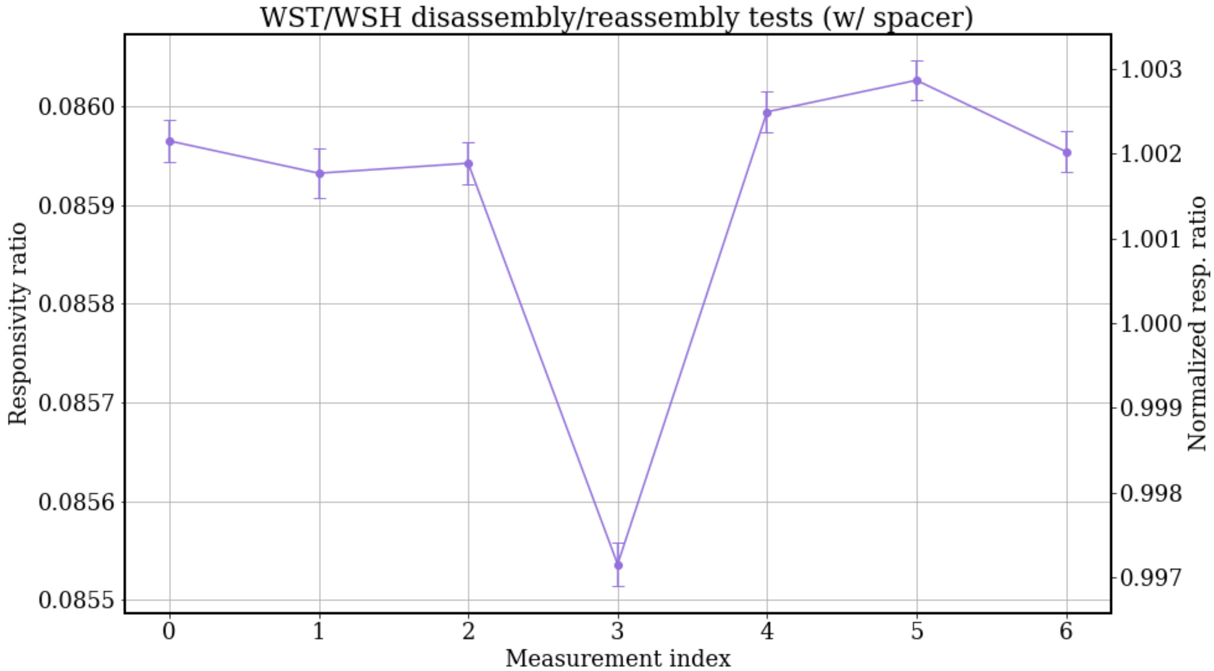

Figure 6: Set of seven standard WST/WSH measurements with the WST spacer/front plate system being disassembled and reassembled between each measurement. Note the large outlier at index number 3. This is believed to have been caused by overtorquing the detector spacer.

5 Robustness to disassembly

The original detector spacer design was abandoned due to inconsistent lateral stability. Removing the spacer and replacing it would result in responsivity variations of 1-3%, potentially due to inconsistent torquing of the set screws. Afterwards, the spacer was removed from the configuration and the photodetector front plate was redesigned to have a more consistent clamping.

Despite this, the updated front plate design was not subjected to any rigorous tests of robustness against disassembly/reassembly. By the time O3 began, the general consensus was to not subject any observatory-specific standards to unnecessary strain. Now that O3 is over and we have manufactured the new detector spacer, we are conducting a series of measurements to determine our robustness against dissassembly/reassembly. We take a series of standard measurements, in between each of which the detector spacer and front plate are disassembled and reattached with each piece rotated a certain amount. The robustness of the standard to diassembly and reassembly is determined by the range of responsivity ratio values.

The results of our test can be seen in figure 6. There is a large outlier at measurement index 3. In this measurement specifically, the spacer was purposefully overtorqued on one side to test the limits of the clamping mechanism. This resulted in a 0.3% shift in responsivity

	Head rotation (deg)	Spacer rotation (deg)
0	0	0
1	180	0
2	0	180
3	0	90
4	0	0
5	0	0
6	0	90

Table 1: Rotation of photodetector head and photodetector spacer by measurement index for the measurements in figure 6. The nominal state (0 degrees of rotation for head and spacer) is the state shown in figure 1.

	Head rotation (direction)
0	Centered
1	Clockwise
2	Counterclockwise
3	Centered
4	Clockwise
5	Counterclockwise

Table 2: Rotation of photodetector head by measurement index for the measurements in figure 2. The photodetector head is either centered or rotated in the indicated direction until it touches the integrating sphere rib.

ratio, caused by the clamp engaging with itself rather than the aperture. As an additional check, the spacer/photodetector rotation from that measurement was recreated in measurement 5 but with even torquing, resulting in a measurement back at the baseline. In light of this, the Pcal team has decided that overtorquing the shoulder screws is an avoidable instance, and that the robustness of the Working Standard to disassembly/reassembly in this configuration should be evaluated as the range of the remaining points (∼0.1%). A table of the spacer/photodetector head rotations by index can be found at 1.

For reference, this test was also performed on the Working Standard configuration without the detector spacer (see figure 7). This measurement set also had a large outlier that was corrected by putting more focus into the front plate torquing. The range of rotation in these measurements was limited by the integrating sphere rib, so the measurements alternated between keeping the photodetector head parallel with the rib and rotated clockwise/counterclockwise until touching the rib. When the outlier is removed, the remaining points have a range of approximately 0.04%.

Disregarding the outliers, the spacer-on configuration displayed approximately twice the responsivity ratio range after reassembly (both ranges were relatively small). However, given the second outlier was not a result of intentional over-torquing, it might be good to take large variations such as this into account during future disassemblies of Working Standards (with the knowledge that large changes in responsivity may be corrected by balancing the shoulder screw torques).

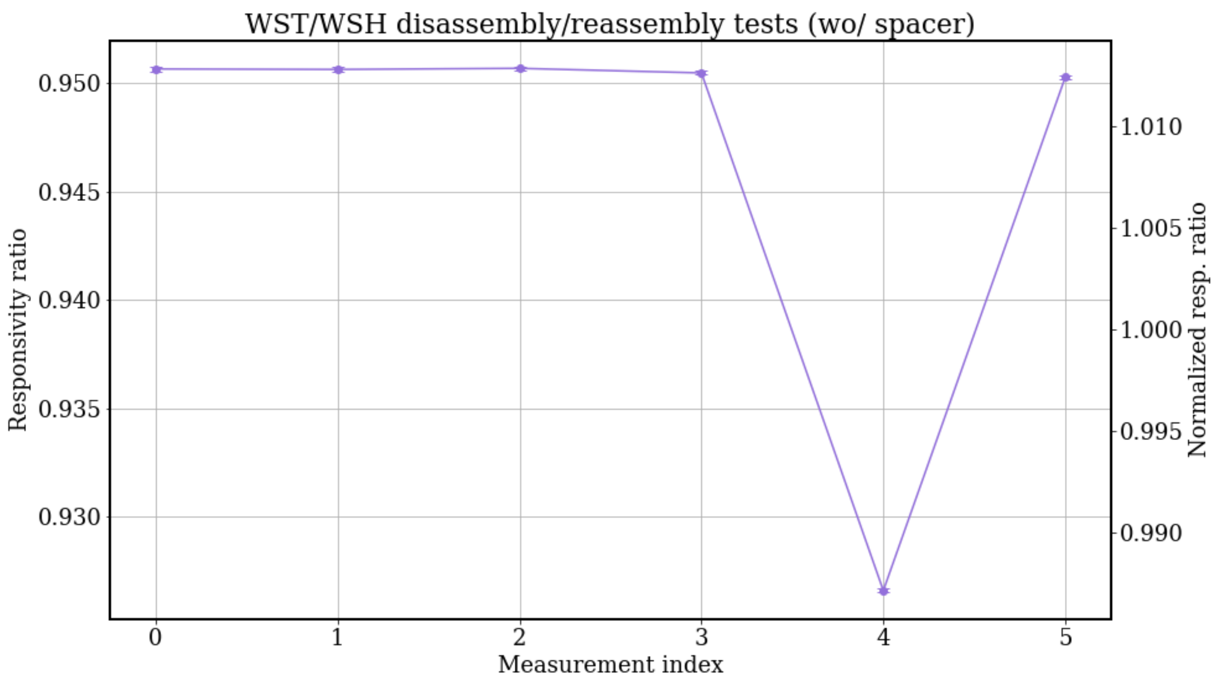

Figure 7: Set of seven standard WST/WSH measurements with the WST front plate system being disassembled and reassembled between each measurement (no spacer attached). Note the large outlier at index number .

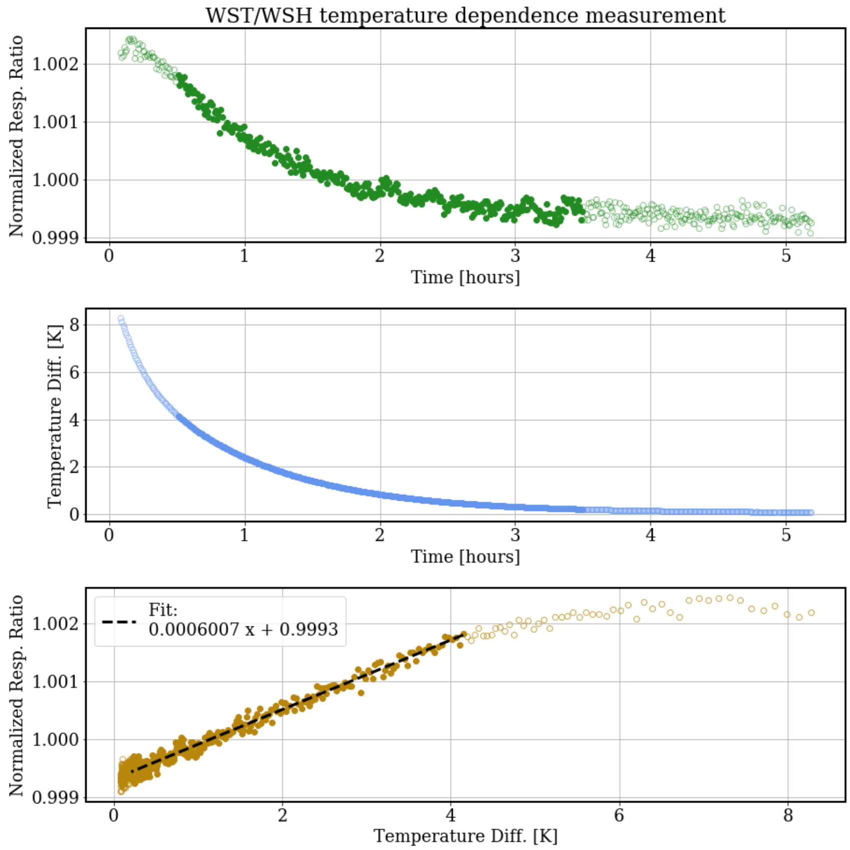

Figure 8: WST/WSH temperature dependence measurement, no spacer on WST. Simultaneous responsivity and temperature decay allows us to calculate a temperature dependence value of 0.06%/K. Points that are clear inside are not being used in the fit.

6 Temperature dependence

The most important feature of the detector spacer was reducing the temperature dependence of our Working Standards. Previous temperature dependence measurements on WST (without the spacer) yielded a responsivity coefficient of ∼0.06%/K (see figure 8). This temperature dependence coefficient was obtained taking a responsivity ratio measurement where the test standard (WST) was left in the oven overnight at 35 C before being being measured against a room temperature standard (WSH). The responsivity decay is measured against WST's decrease in temperature over time, allowing us to fit the responsivity vs. temperature slope.

This method was duplicated for the temperature dependence measurement we performed with the new detector spacer on WST. The results of this measurement are shown in figure 9. The temperature dependence is now around 0.015%/K, or 4 times less than the temperature dependence with no spacer. Points that are clear in their center are not being used as part of the fit. For earlier points in time, this is due to some non-linear dependence that appears at the beginning of our temperature dependence measurements. This is suspected to be caused by a spectralon phase transition that occurs at 30 C, but this is as of now unverified. The clear points at the end of the measurement remain unused because the standards have more

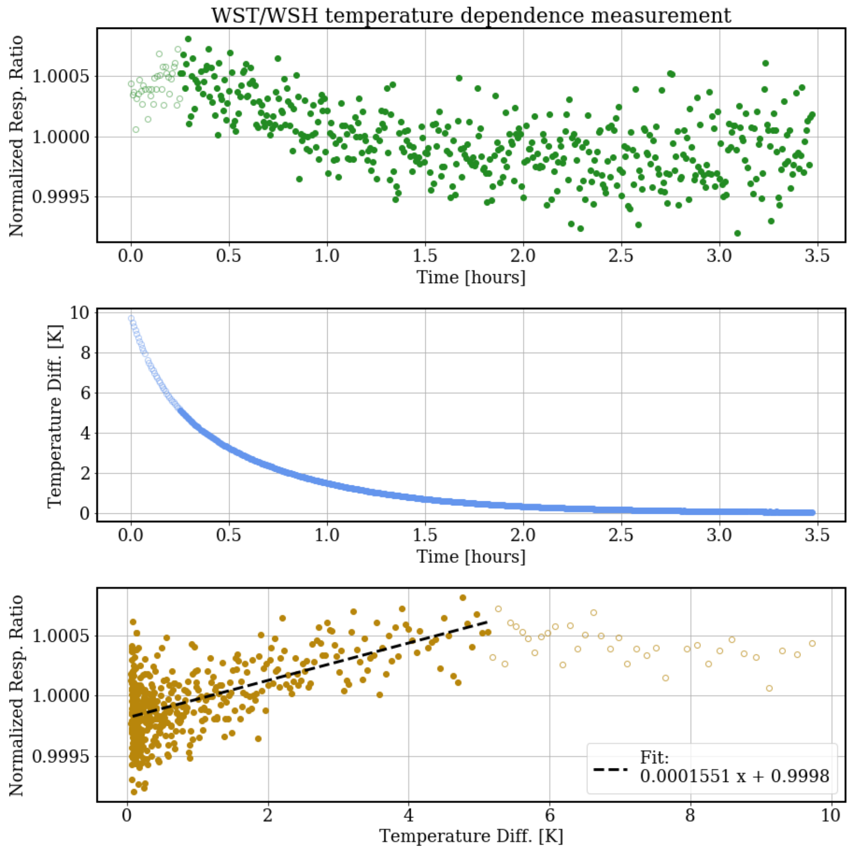

Figure 9: WST/WSH temperature dependence measurement with a spacer on WST. The spacer has reduced the temperature dependence to 0.015%/K.

or less equalized in relative temperature, but continue to vary with lab temperature. This results in perceived changes in responsivity with no change in relative temperature, which offsets the fit.

7 Conclusion

The decision whether or not to use the detector spacer is still underway. From the current measurements, we conclude that adding a detector spacer would likely involve adding a 200kΩ resistor to the circuitboard to account for the drop in responsivity. Additionally, we conclude that including the spacer in the standard configuration would drop temperature dependence by a factor of ∼4, increase laser speckle variation by a factor of ∼2.4, and increase uncertainty related to disassembly/reassembly by a factor of ∼2.

Next steps would be to look at the WST temperatures for each of the measurements shown above. This would add small corrections (based on the difference between WSH's and WST's temperature dependencies) that may cause us to re-evaluate our estimates. Another step might be to repeat some of these measurements after a 200kΩ resistor to ensure the Standard isn't hitting a noise floor.