Date: October 22, 2017
Refer to: **LIGO-T1700485-v1**

From: M. Zucker, H. Overmier, S. McCormick
To: LIGO Vacuum group
cc: LIGO Systems group
Re: **LLO X beamtube leakage**

Summary: Using newly commissioned RGA instruments, we've confirmed that, in addition to a previously known leak through the LGV11 stem at the X end, there exists another leak of approximately 5e-6 Tl/s somewhere near the middle of the X arm.

Significantly, however, an argon bag test appears to rule out midpoint valve LGV8 stem failure as the source; it is not the same mechanism as seen on the Y arm (or on LGV11). The planned sarcophagus fabrication project, based on the assumption that LGV8 was failing in the same way as LGV7 did, should be put on hold. A new testing campaign is evidently needed to locate and stop this new leak.

Also significantly, the new data suggest that our prior hypothesis that the LGV11 leak had accelerated dramatically between 2013 and 2015 may have been mistaken. It now seems more likely that the larger mid-arm leak first appeared in that interval, affecting the 2015 total pressure accumulation, and we just assigned the increase to GV11 without considering the possibility of an unrelated new source.

Furthermore, the total leak rate found here seems to be about 50% higher than found in March 2015. It is not clear whether this is an artifact of employing different measurement and calibration methods, or a real acceleration. Taken with the evidence that the leak only recently appeared, the indication is worrisome.

We hope to find the new leak is a simple ConFlat or annulus piping problem. If not, we confront the daunting prospect of bagging and gassing the X arm, as we did most of the Y in 2013 and 2014.

Steady state gas composition: New Pfeiffer QMG220 RGA's recently commissioned at LLO MX and VEAX were exposed to the beamtube on 10/17/17 for a series of measurements running through 10/20. During this time the vertex volume was sealed off at GV5. Steady-state pumping was primarily through the three Gamma 1200LX-DI pumps mounted at X1-7, MX and X2-7, plus cryopumps CP2 and CP4 (for condensable species).

The MX instrument indicated about 68% N_2 for a local partial pressure of approximately 5.8e-9 Torr[1], the remainder being mostly hydrogen. Near the corner, the other RGA showed the composition to be about 42% N_2 giving a local partial pressure of about 4.0e-9 Torr. The EX RGA was not functioning properly and wasn't used; if we presume about 50% of the corrected EX cold-cathode gauge reading was due to nitrogen,[2] the local partial pressure would be about 2e-9 Torr.

Inversion of gradient: An impedance network was formulated using the three 1200LX-DI pumps, each with calculated net N_2 conductance Z^{-1}(IP) ~ 534 l/s after derating for tubulation and valve. Interconnecting beamtube sections were assigned conductances Z^{-1}(250m) ~ 744 l/s and Z^{-1}(1750m) ~ 106 l/s, including restriction by internal baffles. Leaks were then assigned to reproduce the three observed partial pressures.

There's no consistent solution with a single leak at EX. One plausible two-leak solution (Figure 1) requires about 8e-7 Tl/s of N_2 entering at EX (e.g., GV11) and 5e-6 Tl/s entering at or near MX. The location of the latter is only weakly implied; the EX RGA is needed to perform localization. Additional ion gauges along the tube will also help.

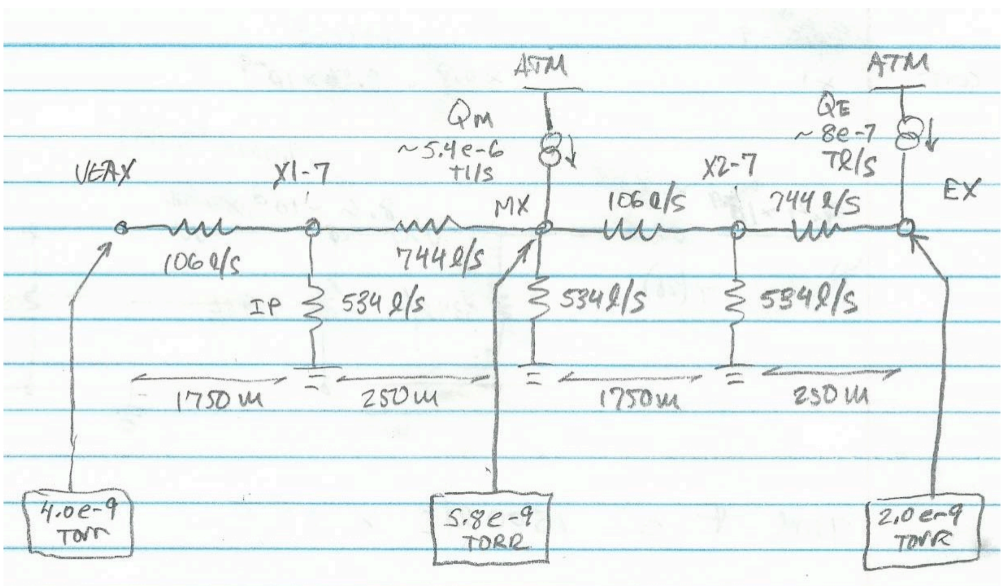

Figure 1: Plausible solution for observed local steady-state partial pressures (bottom row) with major air leak Q_M assigned near MX (GV8 or ??) and smaller air leak Q_E assigned at EX (GV11). We assume nominal specified ion pump speeds and about 50% N_2 concentration at EX (VEAX and MX concentrations were measured to be 42% and 68%, respectively).

[1] We use cold-cathode gauges PT-644B (VEAX), PT-653B (MX), and PT-823B (EX) for total pressure calibration. We assume differential ionization efficiencies between H_2 and N_2 are similar for the RGA and for the CC gauges, and also that the CC's are calibrated nominally for nitrogen. The raw pressure reading from PT-653B was corrected by a factor of 0.81 to agree with the other two heads when the un-pumped beamtube had equilibrated.

[2] Main conclusions will be fairly insensitive to this assumption

Rate of rise test: We did a quick-and-dirty rate of rise test (log 36332) by sealing off all three ion pumps (plus the small "maintenance" ion pumps attached underneath each CP) for about 7 hours on 10/18. The indicated N_2 slope was consistent with about 5e-6 Tl/s leakage, fair agreement given the uncertainty of actual ion pump speeds.

GV8 argon bag test: We bagged the head of GV8, on the theory it might be leaking through the stem in the same manner as GV7 and GV11. We sought to repeat the test done on GV7 in October 2013 (E1300891, figure 8), which showed delayed substitution of argon for air inside the tube starting about 4 hours after replacing the air surrounding the stem.

Figure 2: Bag encapsulating GV8 actuator mechanism on 10/19/17. Argon was admitted through a 1/4" Polyflo tube laid alongside the electrical cables at bottom. The end followed the cables into the rectangular motor housing.

In this case, however, flooding the bag with 30 SCFH of pure argon for 24 hours yielded *no detectable change* of partial pressures inside the tube (Figure 2). This appears to rule out a GV7-like leakage mechanism, at a resolution better than 1% of the nitrogen rate measured above (log 36337).

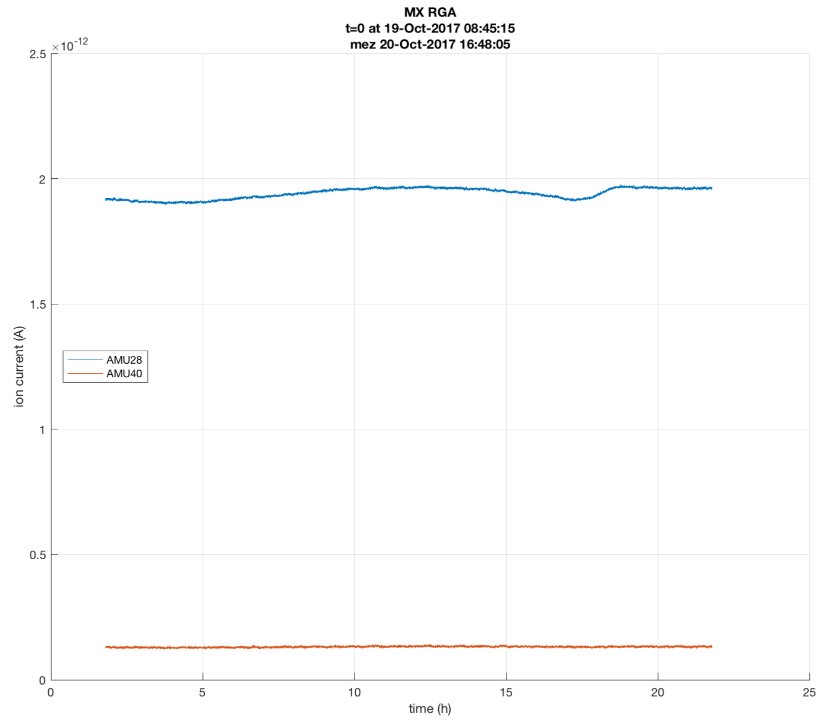

Figure 3: Argon purge test on LGV8 stem. No significant change in internal gas composition is seen over more than 20 hours, during which the atmosphere surrounding the valve stem was replaced by argon gas.

Comparison with prior measurements: The proposed N_2 rate solution for EX is not far from that found by accumulation on the X arm in August 2013 (and later attributed to GV11), about 1.2e-6 Tl/s (T1300757). It does *not* appear consistent with the arm leak rate of 3.2e-6 Tl/s measured subsequently in March 2015 (T1500126). A December 2013 accumulation *with GV11 sealed* (T1301007) measured an N_2 rate of less than 6e-8 Tl/s for the arm, indicating that any mid-arm leak component was absent or much smaller then.

A possible explanation is that a new leak appeared somewhere in the middle of the X arm after the December 2013 measurement. The 2015 measurement picked up this new leak as well as the pre-existing leak in GV11, and interpreted the increased total as a dramatic increase in the GV11 rate. Forensic analysis of pressure trends may be able to illuminate when the leakage started, and perhaps better indicate its location.

The total arm leak rate of about 5e-6 Tl/s determined here is 1.5x higher than the accumulation of March 2015. It unclear how statistically significant the increase is; but noting that the leak had first appeared sometime in the preceding 15 months, the apparent subsequent change is worrisome.

Noise consequences: I ran the residual gas index noise model with a source of 5e-6 Tl/s placed halfway between X1-7 and MX, and a source of 1e-6 Tl/s placed at EX. Other source and pumping conditions were nominal (including the measured enhanced water vapor on the Y arm due to its prior leakage history). As expected the resulting gas noise (Figure 6) is dominated by the mid-arm N_2 source. It comprises $h_{gas} \sim 1.2 \times 10^{-24}$ Hz$^{-1/2}$, degrading the 'late O2' inspiral range by a few percent.

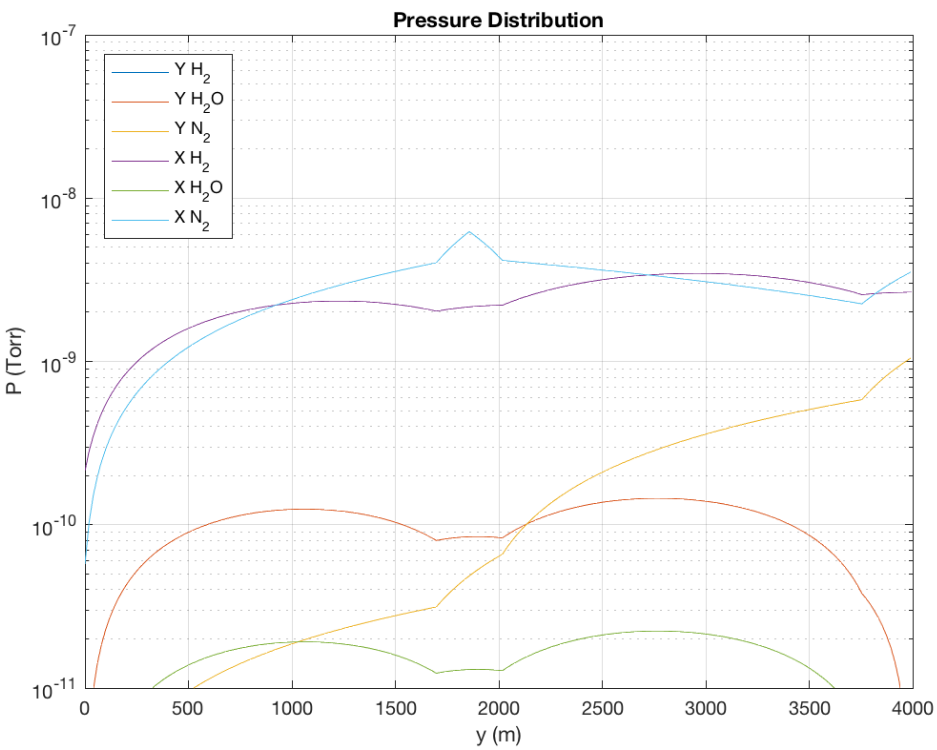

Figure 4: Pressure distributions for main gas species with nominal O2 pump configuration (including vertex and end cryopumps, 4 LVEA ion pumps at vertex, and three ion pumps per arm). Postulated air leaks as shown in Figure 1 are assigned at X= 1875m and X=4000m.

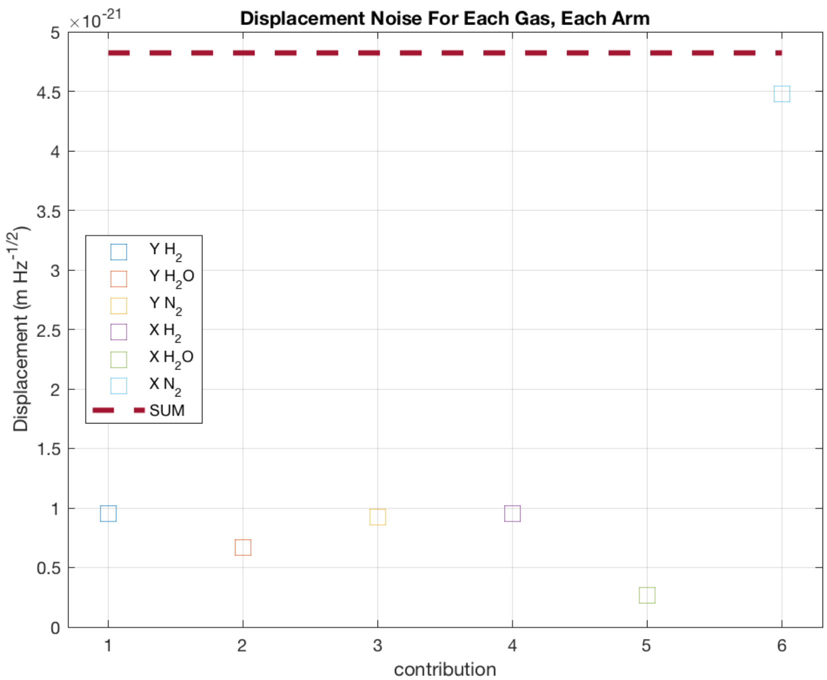

Figure 5: Displacement noise contributions for each species in the model of Figure 4.

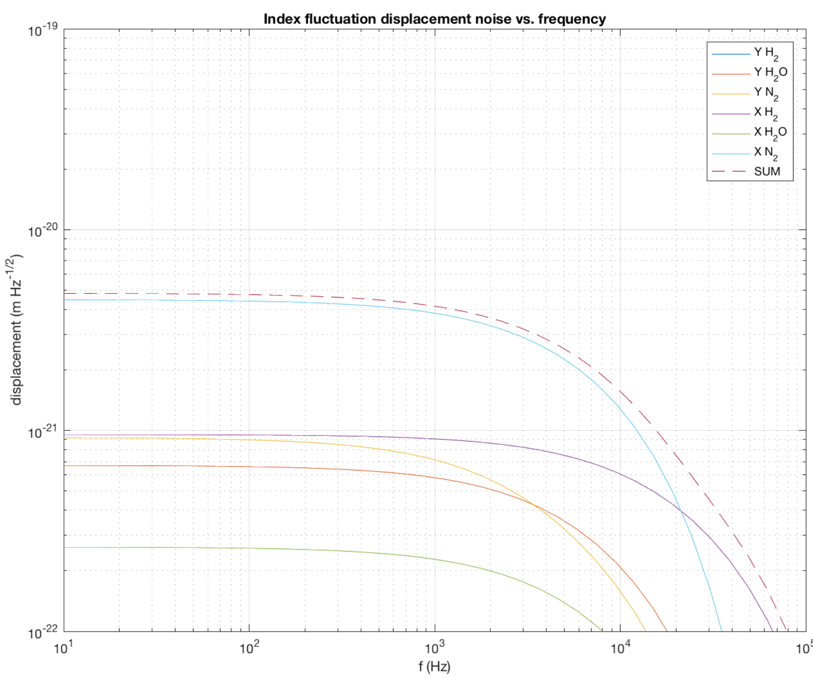

Figure 6: Displacement spectral densities corresponding to model in Figure 4.