Summary of instrumental investigations of potential H1-H2 correlation artifacts

We think that the H1-H2 investigation adequately addressed known potential sources of systematic error, and we have no evidence that the H1-H2 experiment is uniquely susceptible to unknown systematics. We note that we have dealt with correlation artifacts in published H1-L1 stochastic GW studies, and we argue that the H1-H2 investigation, while being more susceptible to correlation artifacts, is not in a different class. The instrumental investigations that convince us that we have adequately addressed the possibility of instrumental correlations canceling an astrophysical signal are summarized below.

1) We know of no environmental influences that could produce correlated signals in H1 and H2 without being detected with much higher SNR by the PEM sensors. We monitored magnetic, seismic, acoustic and RF fields, as well as mains voltages, weather and cosmic rays. All external influences that we could imagine affecting the detector should have produced signals in one or more of our sensors. If we missed something, we argue that it is no more likely to affect the stochastic search than other searches, especially since few environmental signals produce time-invariant power law spectra. The PEM sensors have been shown to be more sensitive to environmental signals than the interferometer itself using injections of acoustic, magnetic, RF and seismic signals (links to the injection reports can be found here). The injections produced signals in the environmental monitors with SNRs that were, over most of the band, at least an order of magnitude greater than the SNRs produced on the gravitational wave channel. So, even an external signal that only showed up in H1-H2 correlations after a year of integration would be well above the noise floor of the PEM sensors and detectable without cross correlation. We performed these injections multiple times during S5, searching for under-monitored coupling sites.

H1 and H2 were only approximately co-located; they were separated by design. No vacuum chamber held both H1 and H2 components. The closest H1 and H2 components were the ITMs, in two different BSC chambers, separated by about 5 m. This separation is comparable to the separation between PEM sensors (each ITM chamber was instrumented), and so an environmental signal (other than light) traveling from one interferometer to the other or affecting both H1 and H2 should have been monitored by the PEM system. The minimum propagation time between H1 and H2 for vibrational signals was about the same as the light propagation time between H1 and L1.

2) We statistically tested for self-inflicted sources of correlations from control and data systems. We tested for DAQ correlations by looking for coherence in about 150 pairs of channels that should not be correlated (reports here, here, and here). The assumption here is that there is nothing special about the DAQ treatment of DARM, and looking for correlations in other pairs of channels gives a statistical estimate of the likelihood of a correlation between H1 and H2 DARM that could cancel a power law-shaped astrophysical signal. I don't think we have done this yet, but we could be even more thorough by looking for unexplained correlations in spectra for cavity error signals that share similar locking electronics with DARM.

3) We argued that light leaking from H1 into H2 could not produce a correlation, and we tested for one anyway. The frequencies of the H1 and H2 lasers were probably gigahertz apart and so light from one laser should not produce an in-band signal when beat against the reference beam for the other laser. Nevertheless, we searched for calibration lines from one interferometer in the other.

4) We searched extensively for scattering sites that might modulate both H1 and H2 light and ensured that the sites that we found were well covered by the PEM system. We mounted shakers and accelerometers on the vacuum system at 21 different locations that were selected as the most likely scattering sites, and we searched for the shaking signals in the gravitational-wave channels (here, and here). All scattering sites that we found in this way were driven by seismic or acoustic signals that were well monitored by the PEM system. At the site that produced the greatest coherence between the two interferometers (a reflective flange close to and perpendicular to the beam paths of both interferometers), we mounted an accelerometer and found that the coherence between this accelerometer and the two GW channels was no greater than for the sensors in the pre-existing PEM sensor system (here). These results suggest that the PEM system adequately monitored scattering coupling between H1 and H2.

5) To test our understanding of correlation mechanisms and to search for any mystery sources of correlations, we attempted to identify the sources of all excess coherence features in H1 – H2 between 80 and 400 Hz. There were no power law-shaped features. The spectral peaks that were observed (reports here and here) fell in two categories: those produced by acoustic coupling and those produced by bilinear coupling of low frequency seismic motion. The level of linear acoustic coupling was consistent with that measured from acoustic injections. Most of the peaks were tracked to electronics cooling fans in specific power supply racks in the vertex station by comparing coherence spectra to spectra for accelerometers mounted temporarily on each of the electronics racks. There was a feature at 113 Hz that we were unable to establish the source of, but it was similar to the features produced by dozens of fans that we were able to identify. The second type of coherence feature was associated with bilinear coupling of low frequency (< 15 Hz) seismic motion and harmonics of 60 Hz, producing side-band features around the harmonics that were similar to the seismic features in the 0-15 Hz band. This H1-H2 coherence was expected since the coherence length of low-frequency seismic signals was greater than the distance separating sensitive parts of the two interferometers at the vertex station, and the seismic isolation of the interferometers was minimal below 10 Hz. In summary, studies of the H1-H2 coherence spectrum confirmed our expectations of sources, and we found no unexplained mystery sources, particularly ones that produced power law-shaped spectra.