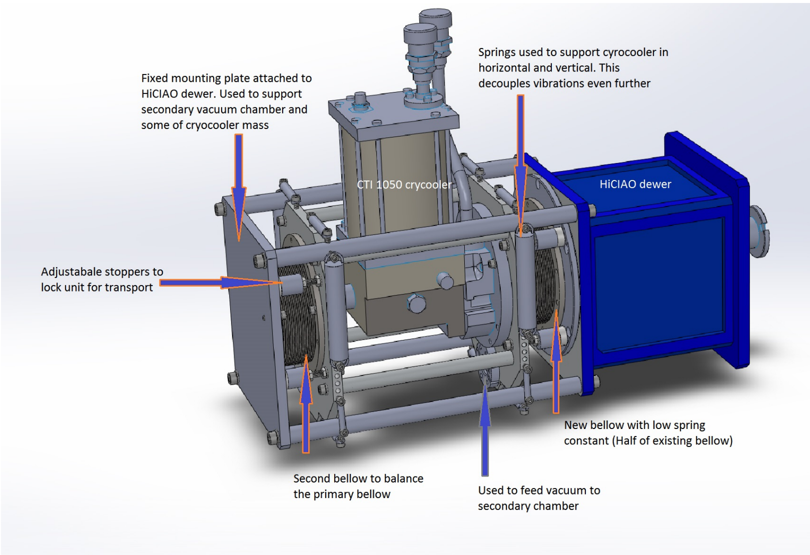
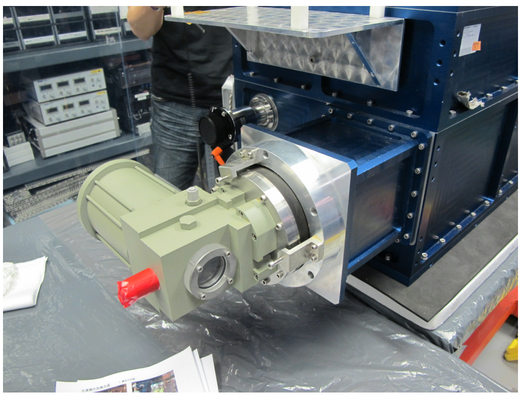
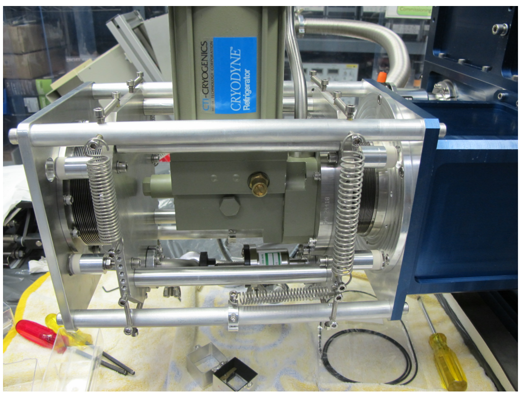
SCExAO PSF Vibration report post HiCIAO upgrade - observing run 14-15th April 2014

The rebuilt HiCIAO:
The aim of the HiCIAO rebuild was to minimize the vibration transfer from the CTI cryo-pump to the HiCIAO dewer and hence to the SCExAO instrument via the common support frame. Cryo-pumps are typically attached to a dewer via a stainless steal bellow (essentially a corrugated spring). However, when you pull a vacuum, the atmospheric pressure outside the chamber sees a pressure gradient and pushes the cryo-pump towards the dewer. If you dont stop it, the pump will end up collapsing the bellow entirely and the pump will sit up against the dewer which is the worst possible case as all vibrations are effectively transmitted in this regime. Thus far HiCIAO has used a soft rubber ring around the bellow to support the pump and stop it from colliding with the chamber (see figure on the left below). However, the rubber has a finite stiffness as it must support the mass of the 25 kg cryo-pump and hence is limited in how well it can eliminate the transfer of vibrations.

The concept we adopted was to use a secondary vacuum chamber on the opposite side of the cryo-pump which pulls the pump in the opposite direction to that which the primary chamber pulls. If you get the surface area of the two chambers matched just right the forces cancel and the pump simply floats between the two bellows. In this case each pulse from the pump is damped by the soft springs of the bellows. No solid contact is made between the cryo-pump and the dewer in this way. To support the mass of the pump we added mechanical springs in both the vertical and horizontal directions. This way the cryo-pump is only coupled to the body of the dewer via either a spring or a bellow. The figure below shows some of the features of what I just described. There were several minor hiccups but the build was completed in 3 days.







The left figure is the pre-rebuild HiCIAO. The black neoprene ring can be seen keeping the pump from colliding with the dewer. The right figure shows the post rebuild HiCIAO. The secondary vacuum chamber/bellow can be seen to the left. Also a host of springs as described above. You will also notice that the cryo-pump was rotated to be oriented in the vertical post rebuild as it was easier to balance the mass when the torque due the cryo-pump being on its side was eliminated.

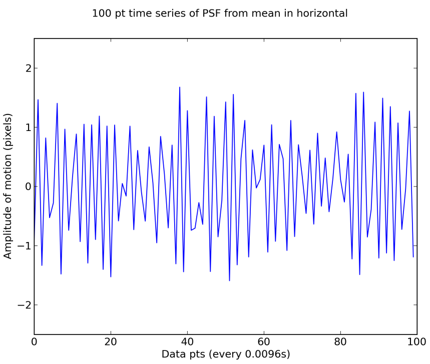
HiCIAO's affects on the PSF of SCExAO:

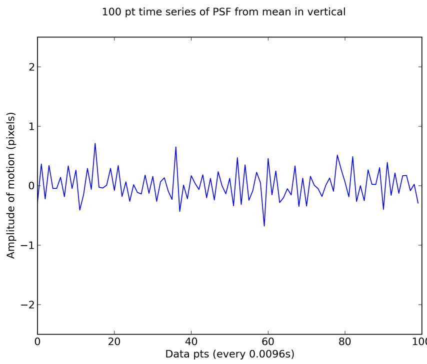
This report summarizes the findings of the PSF vibration data taken after the HiCIAO vibration isolation unit installation and during the observing run on the 14th/15th of April 2014.

We compare the PSF motion in the horizontal and vertical as seen by the internal SCExAO Science camera which can save frames at ~100 Hz. This data was taken off-sky with the internal SCExAO laser source. To process the images I subtracted a mean dark frame and then I found the centre of mass in the horizontal and vertical directions for each frame, plotted them as a time series, took the Fourier transform and plotted the amplitude spectra for comparison. To get the most benefit I will compare the data taken pre-HiCIAO rebuild (taken on the 18th December) and post-HiCIAO rebuild (taken on the 13th of April).

First we start by looking at the time series for the pre-rebuild and post rebuild case as well as with the cryo-pump for comparison. Note the vertical scale is the same in all plots for ease of comparison.

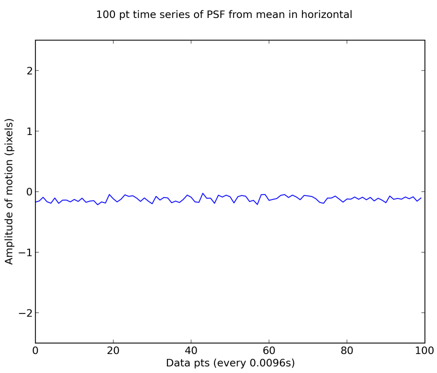
Pre-rebuild:

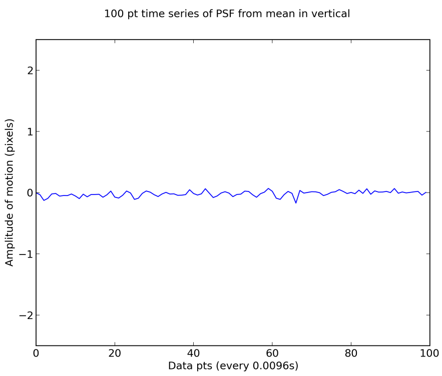




Clearly the horizontal axis has a greater amplitude of oscillation and is periodic. $\sigma_{horiz.}$=0.94 pixels, $\sigma_{vert.}$=0.24 pixels. This is more evident in the amplitude spectra below.

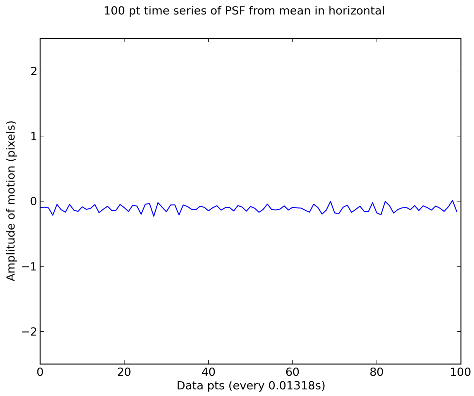
Post-rebuild:

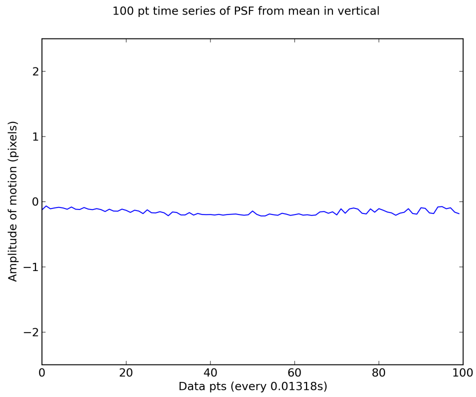




Post rebuild the time series has a much smaller amplitude and there is no obvious structure. $\sigma_{horiz.}$=0.06 pixels, $\sigma_{vert.}$=0.08 pixels. The standard deviation in the horizontal plane is a factor of ~16x improved and ~3x in the vertical.

Cryo-pump off (reference):
For reference we look at the time series and standard deviation of the PSF in the horizontal and vertical over a cube with the cryo-pump off. This will tell us how much of the motion left is due to the cryo-pump itself. Note this data set was taken back on December 18th. The environment on the Nasmyth may have changed since and the data should be compared carefully.



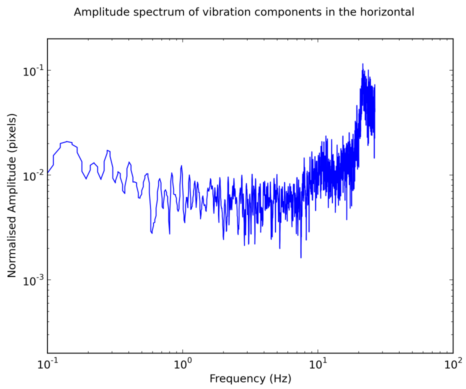


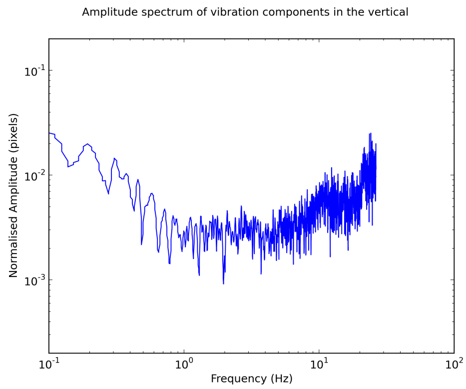
Its clear that the time series amplitude is very similar in appearance to the post rebuild case. Indeed, $\sigma_{horiz.}$=0.09 pixels and $\sigma_{vert.}$=0.11 pixels agree very well with the post-rebuild values provided above. So now the stability of the PSF is within the limits of uncertainty of measuring its position (0.1 pixels). Also, the residual vibrations do not have a measureable affect on the PSF any longer. This is a significant reduction in the motion of the PSF. Wohhoooo!

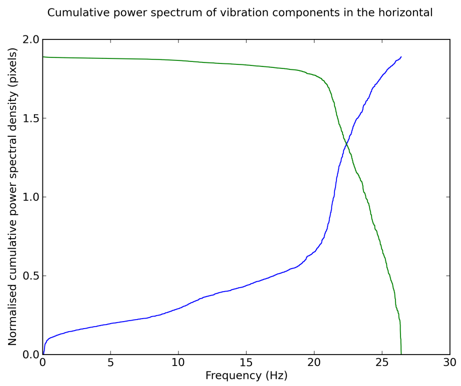
With a plate scale of 11.21 mas/pixel this means that the PSF will be stable to <1 mas (assuming motion only due to internal components, no telescope of AO188).

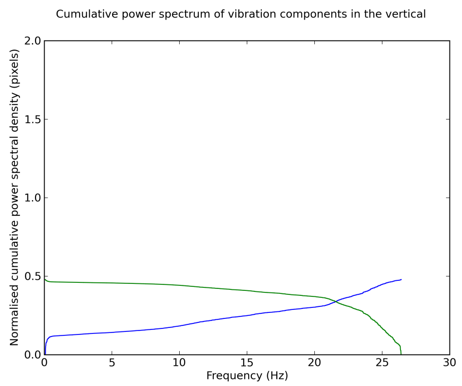
Next we look at the power spectral density curves to see the frequency components of the noise. Again all curves are scaled the same for direct comparison. However, the post rebuild data has a higher Nyquist frequency.

Pre-rebuild:



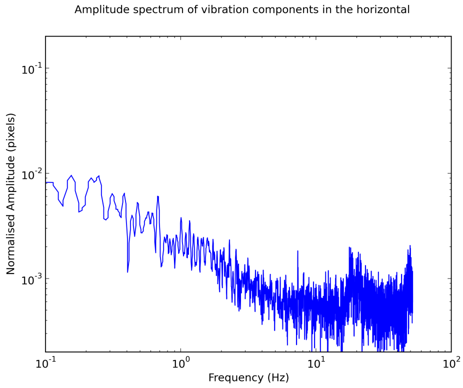


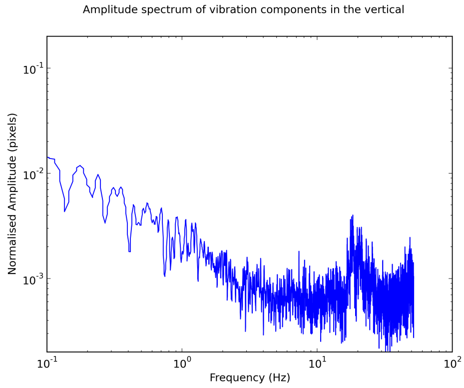


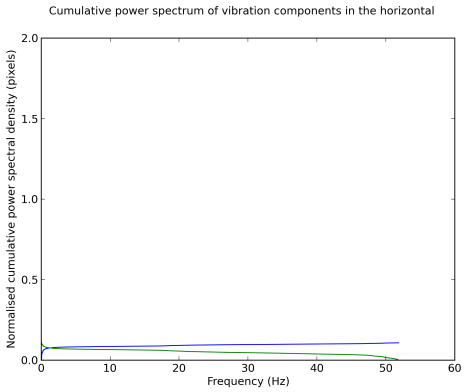


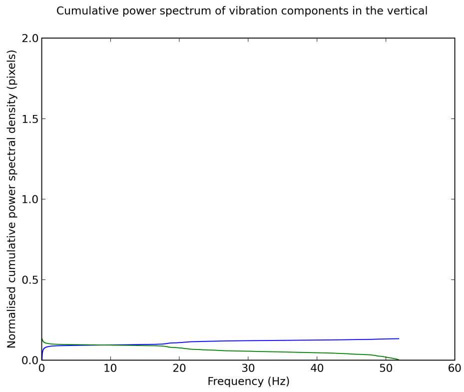
The cumulative power spectral density simply shows you, which frequencies are contributing to the oscillation. For the horizontal its the broad peak around 21-25 Hz while for the vertical there is no specific frequency. Note the 1 Hz peak, due to the cryo-pump, can not really be seen in either plot. Ive checked and there was enough data for a 1 Hz oscillation to be seen, so these results indicate that it was not the dominant frequency of vibration in our system, but is certainly the excitation frequency.

Post-rebuild:



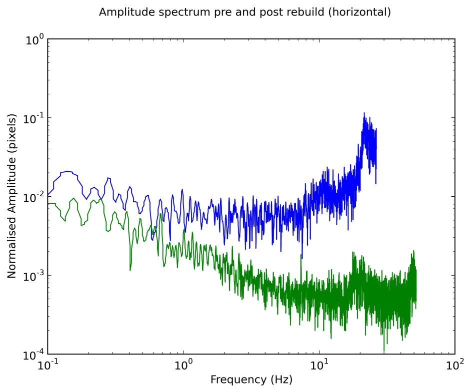


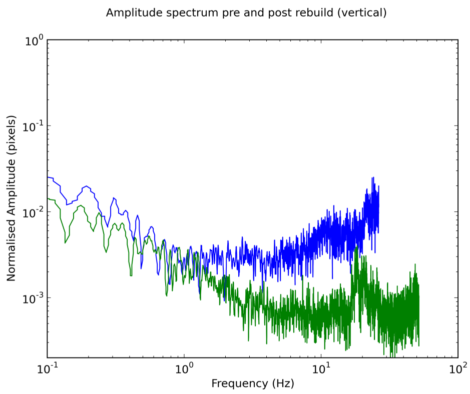




It can be seen from the above figures that post-rebuild that the amplitude across the entire spectrum has reduced significantly. In addition the horizontal axis has almost no structure while the vertical has a small peak around 20 Hz. This confirms our suspicion that the time series also does not have any structure to it. The remainder of the tip/tilt error, which has a structure, may be corrected with clever LQG or Kalman filtering loops.

To see the true gains I plot the pre and post rebuild spectra on a common plot.

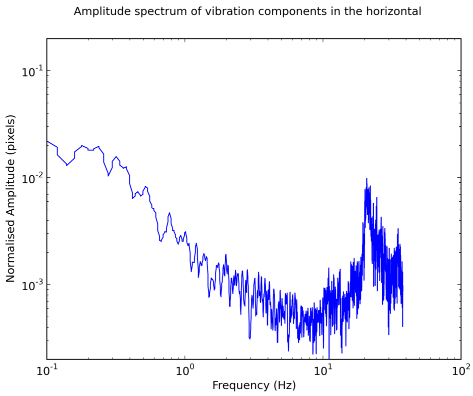


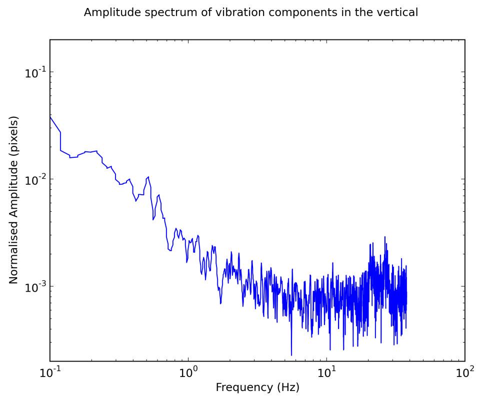


It is clear that there is little reduction in PSF motion at frequencies below ~1 Hz (almost none for the vertical). However, at 10 Hz, there is an order of magnitude improvement in the horizontal and almost the same in the vertical. The maximum improvement occurs at the 23 Hz peak which is attenuated by ~100 times in the horizontal direction!

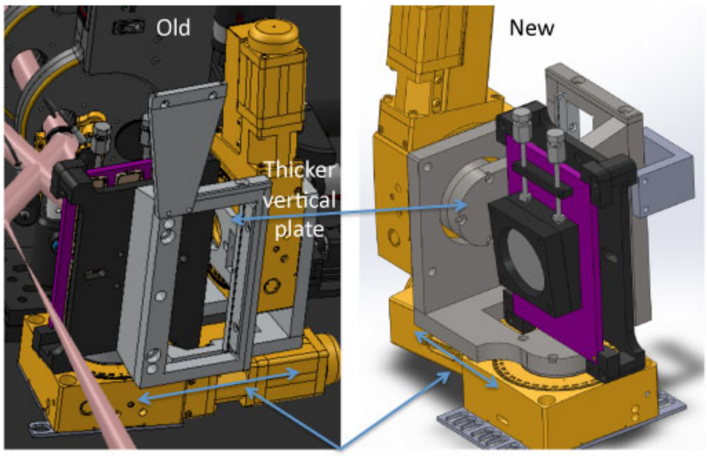
On the June run we will see if we can use the residuals from the pyramid WFS, which is a lot more sensitive than this technique to measure the structure to the tip/tilt error more precisely. In addition as that loop has a 1.7 kHz bandwidth, we can see if there are higher frequencies at play. If we can get a spectrum we can then work on creating a filter to get rid of the remainder of the vibrations if they have structure. Of course for random noise, long exposures with HiCIAO will help beat down the noise or alternatively, very fast frames with a high frame rate camera (like MKIDS) which can be co-added after wards.

Cryo-pump off (reference):





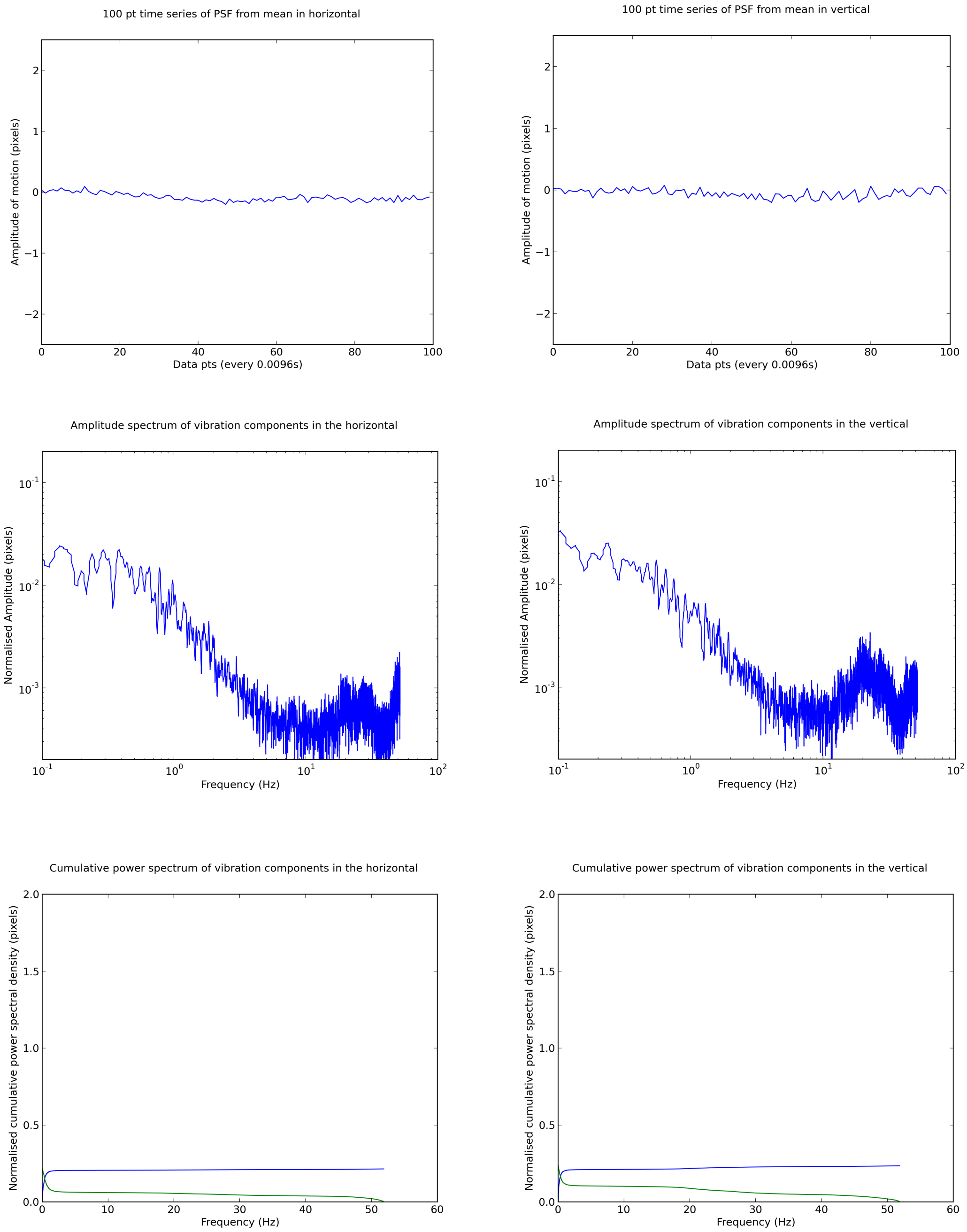
The amplitude spectra almost had no features except the small bump around 23 Hz in the horizontal. This indicates that the majority of the tip/tilt jitter in the PSF was indeed due to the cryo-pump (in December) as suspected and also that the cryo-pump is not the only source of noise. As described in January when we initially analyzed the data, our understanding was that the cryo-pump, which operates at 1 Hz is only the excitation source, which creates a ring down affect in the mounts holding the DM in SCExAO. As the beam path from the DM to the camera is long, then even a very slight motion can cause a large excursion in the PSF position. In addition to the HiCIAO upgrade outlined above, we also changed the DM mounts and made use of stainless steal instead of aluminum plates as well as increasing the thickness from 5-10 mm to 12 mm all round. Some of the changes we made to the DM mounting can be seen in the CAD drawings below.



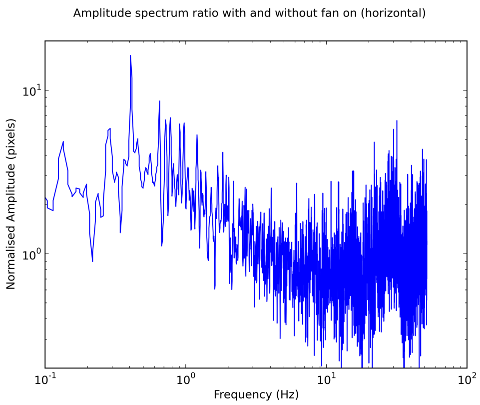
- This distance has been reduced by mounting the vertical rotation stage on the back of the plate. This reduces the leaver and balances the mass of the DM with the mass of the stage.
- The vertical plate which attaches the DM to the rotation stage has been increased from 5 to 12 mm thick.
- All other load bearing plates have been increased to 12 mm thickness and made from stainless instead of aluminum.

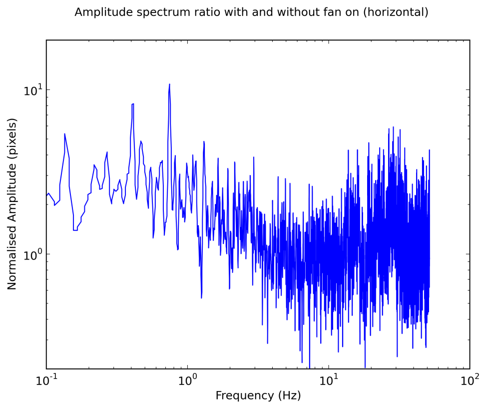
It should be made clear that this PSF motion analysis does not include the affect of misalignment between AO188 and SCExAO as this data was taken with the SCExAO internal source. This will add to the PSF motion. From what we observed in April however, it did contribute to the PSF motion, but it seems like the affect is not very large (I estimate σ = 0.3-0.5 pixels altogether). However we didn't collect a data set to confirm this but will in June.

Finally, we now have a mains power mini-cooling fan extracting warm air from the bench in order to prevent turbulence. The fan sits off the Nasmyth-platform (near the staircase) and is connected via a very soft flexible duct to the covers of SCExAO. I measured the PSF motion for the case with the fan-on (post rebuild) and got $\sigma_{horiz.}$ = 0.11 and $\sigma_{vert.}$ = 0.13, which are consistent but slightly larger than with the fan-off case presented above ($\sigma_{horiz.}$ = 0.06 and $\sigma_{vert.}$ = 0.08). Here are the plots:



To see it more clearly we show the ratio of the fan on to fan off case. Now its clear to see that below 20 Hz, there is an increase in the noise. So the cooling system has a minor affect, but mainly at the low frequencies, which can be countered by the low order wavefront sensing loops. This could be due to vibrations (mechanical motion) or due to seeing (optical refraction) on the bench.





Clearly these two upgrades have resulted in a dramatic boost in performance, which was obvious on the April run. This is a victory and will aid us in our quest for ever-greater contrast in the near future!

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Cost/Time of upgrade:
Cost:
- Bellows: $1680.00
- Vacuum parts: $724.00
- O-rings: $30.00
- Nuts/bolts/springs: $204.00

Total: $2638.00

Time:
Nem:
- 1.5 weeks of design work,
- 0.5 weeks of procurement,
- 0.5 weeks of installation,
- 0.5 weeks of testing

Total 3 weeks
+ Kudo-san (1 week) + Bill/Matt (0.5 weeks) + Brian (5 weeks)

I should point out that frames were not saved perfectly periodically with the IR cameras. However, for the purposes of this analysis we simply assumed they were. This just means that the frequency components may be narrower than they actually are. However, if there was no lines in a given spectrum, then this affect will not change this outcome.

In addition the python script to analyse a stack of IR images as per the figures at the beginning of this report can be found in /media/scexao/data/Nem/20140413/
Its called Vibration_analyser.py and is commented as well.