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KI Vis2 Jitter Correction

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Abstract

For the Keck Interferometer (KI), the reduction in V^2 with optical path difference (OPD) fluctuations ("jitter") does not appear to follow the form expected for atmospheric seeing. An empirical relation is found, but is difficult to justify physically, as it also does not follow the expected form for OPD fluctuations induced by the low-frequency narrow-band vibrations known to exist at the observatory. Moreover, this empirical relation fails to improve the final calibration of an independent set of data. Based on these results, we recommend that a jitter correction factor not be used as part of the standard KI V^2 data calibration.

1 Introduction

In an interferometer, optical path fluctuations during the fringe integration time cause "blurring" and a loss of coherence, resulting in a reduction of the measured visibility. However, if one understands the nature of the OPD fluctuations, the effect may be corrected.

At KI, a measure of OPD fluctuations is recorded in the "jitter" quantity which is part of the level-1 (L1) data products [R. L. Akeson 2001]; and is measured as the sample-to-sample phase difference RMS. As a function of jitter (j), one expects the visibility to be reduced as:

$$V_1^2 = V_0^2 \cdot e^{-C \cdot j^2} \tag{1}$$

where V_1^2 is the measured visibility, and V_0^2 is the visibility that would be measured in the absence of temporal smearing. The Palomar Testbed Interferometer (PTI) [M. Colavita 1999 et al.] uses a fringe measurement method very similar to the one used at KI. At PTI, a correction based on the above formula is routinely applied, with a coefficient $C = 0.04$ which conservatively represents what is expected from atmospherically induced OPD fluctuations [M. Colavita 1999].

The above formula does not appear to represent well the visibility reduction as a function of jitter for KI, as is illustrated in Figure 1. This is likely due to the fact that the measured jitter contains significant contributions from instrumental vibrations, in addition to the atmosphere. In this memo, we report on our conclusions following some experiments attempting to determine a jitter correction law appropriate for KI.

2 A Candidate KI Vis2 Jitter Law

The difficulty in empirically finding a jitter correction law, is that typically the data spans a relatively narrow range of jitter values (the example shown in Figure 1 is an exception), and is not adequate for fitting an exponential law with 2 parameters (the zero-jitter value must be a free parameter given that, even if unresolved stars are used, the system visibility is allowed to change with time and observing conditions).

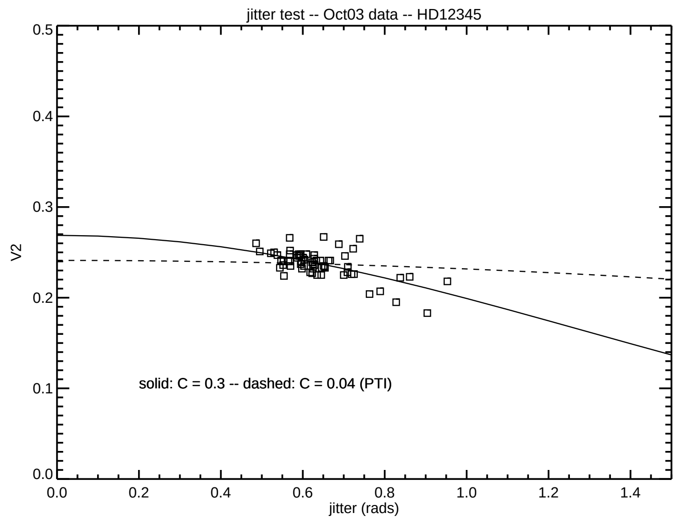

Figure 1: KI data showing vis2 vs. jitter for a resolved (hence the relatively low zero-jitter visibility) test star, along with two correction models discussed in the text.

Instead, a two-step approach has been attempted. Observations of a set of calibrator stars has been used to compute V^2 for a set of synthetic coherent integration times (by co-adding the fringe quadratures X and Y), from 1 to 5 samples, i.e.: 2-10 msec for data taken at the 500 Hz FATCAT rate or 5-25 msec for the 200 Hz rate.

The data are shown in Figure 2 on a log linear plot of V^2 vs. number of coadded frames. The two lower curves are for the 500 Hz data, and the rest are for 200 Hz. The data are not normalized by system visibility or source diameter.

On a star-by-star basis, the data were fit to a model of the form: $V_n^2 = V_0^2 \cdot e^{-a \cdot n^s}$ where a is a scale factor, n is the number of co-added samples, s is an assumed power law, and is the zero-frame-time visibility. For Kolmogorov turbulence, we would expect s=5/3; for low-frequency narrow-band vibration, we would expect s=2. As can be seen in Table 1, somewhat surprisingly, the data is well fit using a much shallower power law with s=0.75.

One way to process interferometer data to correct for temporal smearing would be to do processing like this on each star and use the fit for science. Alternatively, we may use phase jitter as a proxy for temporal variance, and use the extrapolated zero-frame-time V_0^2 from the data set above to calculate the correction coefficient (C) for each star, using Equation 1. Using the best-fit exponent s=0.75, this procedure yields a relatively constant value of the correction coefficient, as expected, with a mean value $\overline{C} = 0.3 \pm 0.015$, where the error is given by the rms of the star-by-star values.

Although this result might suggest that C=0.3 is the appropriate correction coefficient to apply to KI data, several cautionary notes are in order:

1. The total V2 correction is quite large: for a jitter of 0.97 (which is of the typical order for 200 Hz data) the correction is 33%, which makes the correction susceptible to the model quality, especially for jitters > 1 rad.

2. The fit to V^2 vs. number of co-added samples, while good, uses a different power law than expected.

3. The jitter correction may be expected to be partially redundant with the calibration provided by a well-chosen calibrator star, whose visibility reduction with jitter (and other instrumental effects) is presumably similar to the science star. Note however that in practice this is not always the case: there

are instances with significant jitter differences among stars within the same target-calibrator cluster, so that clearly the jitter effect will not calibrate out.

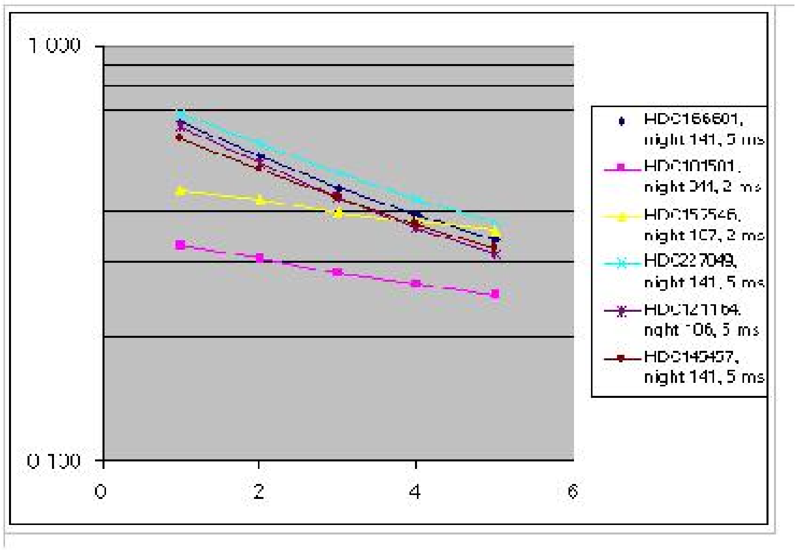

Figure 2: V^2 vs. synthetic coherent time.

Table 1: Fits to data shown in Figure 2, as described in the text. For each power-law exponent s, the fits are done to all 30 data points (6 stars, 5 frame times each).

s	fit RMS
2.0	0.023
1.5	0.015
1.0	0.005
0.75	0.002
0.5	0.006

3 Testing the KI Vis2 Jitter Law

We have conducted a test of the above correction by subjecting a set of data to the full analysis and calibration process, with and without the jitter correction. The dataset selected are observations of the known binary HD9939 taken in October 2003, appropriate for this test due to the fact that the data (3 target and 4 calibrator observations) actually span a relatively wide range of jitter values (0.5 to 1.5 rads). This binary system has a well known orbit established by observations at the PTI, and thus can be used to compare the final data accuracy under both methods.

The results are summarized in Table 2, and for illustration in Figure 3 for the synthetic white light (SWL) channel. Two plots are shown for each of the reductions methods. In each case, the top plot shows the raw V^2 for the calibrators and target star, along with the scan-averaged target and system V^2 produced by wb/nbCalib [A. Boden 2002]; while the bottom plot shows the calibrated target V^2, along with lines representing the model prediction and its uncertainty.

Table 2: Results of analysis of HD9939 dataset without jitter correction and with the new jitter correction described in the text. For each method, and each fringe tracker channel, we give the weighted RMS of the fully calibrated V^2 data with respect to the model prediction, with error bars given by the 1-sigma uncertainties in the model parameters.

Method	SWL	SPEC0 2.3μm	SPEC1 2.2μm	SPEC2 2.1μm	SPEC3 2.0μm
no jitter correction	0.038 ± 0.003	0.071 ± 0.003	0.052 ± 0.003	0.063 ± 0.003	0.013 ± 0.002
jitter correction, C=0.3	0.095 ± 0.002	0.101 ± 0.001	0.108 ± 0.001	0.135 ± 0.001	0.058 ± 0.002

4 Conclusions

From the results in the previous section, it can be seen that use of the jitter correction does not improve the final calibrated data, and in fact makes it noisier. Based on these results, and the caveats described in Section 2, we recommend that the jitter correction not be used. We note however that the wb/nbCalib packages allow, via one of their command-line arguments, to specify any value of the coefficient C when using the jitter correction, if it is believed that a particular data set warrants its use.

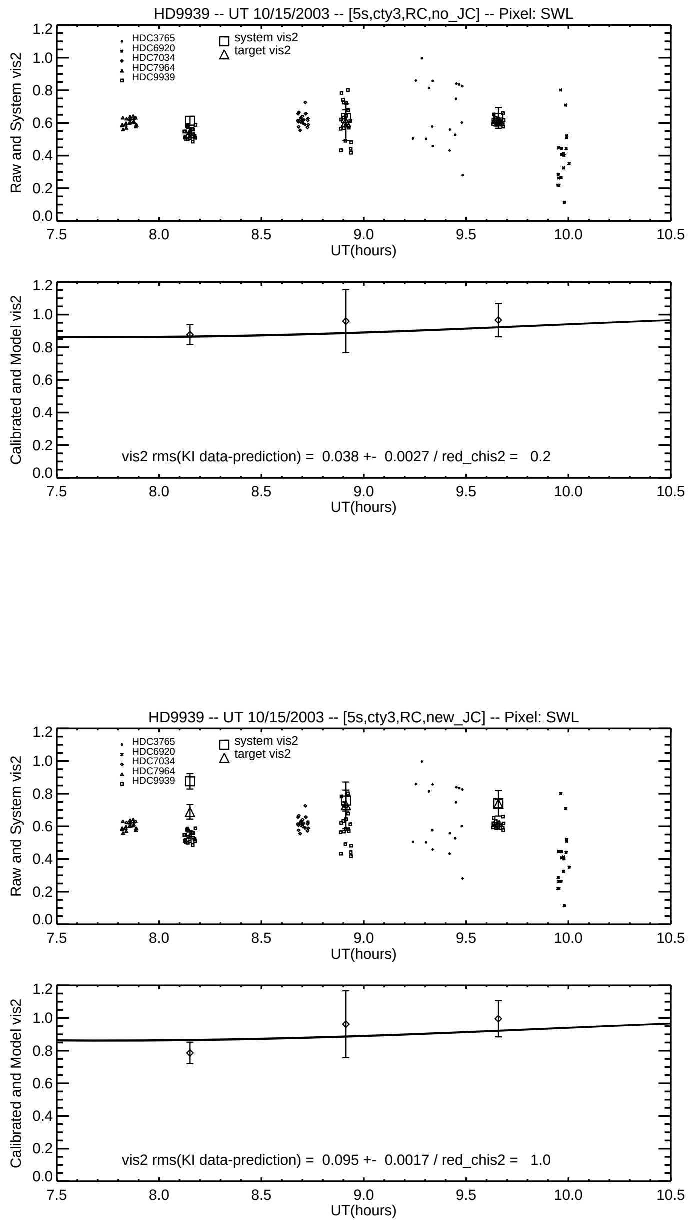

Figure 3: Raw and calibrated V^2, not using a jitter correction (top pair of plots) and using the empirical jitter correction described in the text (bottom pair).

References

[R. L. Akeson 2001] R. L. Akeson, 2001, "Users Guide for Kvis". [1]

[A. Boden 2002] A. Boden, 2002, "Users Guide for wbCalib". [2]

[M. Colavita 1999 et al.] M. M. Colavita et al., 1999, ApJ, 510, 550

[M. Colavita 1999] M. M. Colavita, 1999, PASP, 111, 111

[1] available at: http://msc.caltech.edu/software/Kvis/usersGuide/usersGuide.html
[2] available at: http://msc.caltech.edu/software/wbCalib/index.html