Analysis of the flux bias in KI visibility data

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Abstract

Using internal fringes we have quantified a flux-dependent bias in the calculated squared visibility amplitude for the Keck Interferometer (KI). The magnitude of this bias is within the 0.05 systematic error previously advertised for observations which follow the recommendation of no more than 1 magnitude difference between targets and calibrators in the K band. Although the source of the bias is unknown, its form is well characterized by a log(flux) model, with different coefficients for the white light and dispersed spectrometer data. A correction has been implemented as part of the wbCalib/nbCalib package. This correction has been shown to substantially improve the agreement between fully calibrated KI data and predicted visibilities for binaries with known orbital parameters. With this correction, the absolute systematic calibration is good to 0.03 in squared visibility for both the white light and spectrometer channels and we recommend that users utilize this correction, particularly if their target and calibrator K band magnitudes are different by more than 0.2 mags.

1 Introduction

For many years, a small flux bias was suspected in KI visibility data, but data taken on astronomical sources had additional atmospheric and measurement noise which made quantifying the effect difficult. The data verification observations taken for the visibility operations readiness review (ORR) showed that if calibrators were chosen within 1 magnitude of the target magnitude, the systematics in the visibility amplitude were 0.05 or less, although the performance on the spectrometer channels was always worse than expected despite the larger fringe packet width of these channels.

After a user provided a particularly clear example of data taken during 2006, the KI team further investigated the issue by examining more archival data and doing a series of internal fringe tests.

2 Internal fringe tests

A series of internal fringe tests were performed in May 2007. In these tests, the light level was deliberately varied by orders of magnitude to search for a flux bias. An example of the visibility amplitude as a function of flux for the white light and spectrometer channels is plotted in Figure 1. The visibility amplitude clearly increases with higher fluxes and in proportion to the log of the flux. This relationship is steeper for the spectral channels than for the white light channel.

The following possible causes for the flux bias were examined in the internal tests and none produced any significant changes: modified array clocks with the read line held constant, extra resets and a longer settling time. We note that PTI (Palomar Testbed Interferometer), which uses the same fringe scanning and calibration algorithms as KI, but a different infrared array, does not show this flux bias.

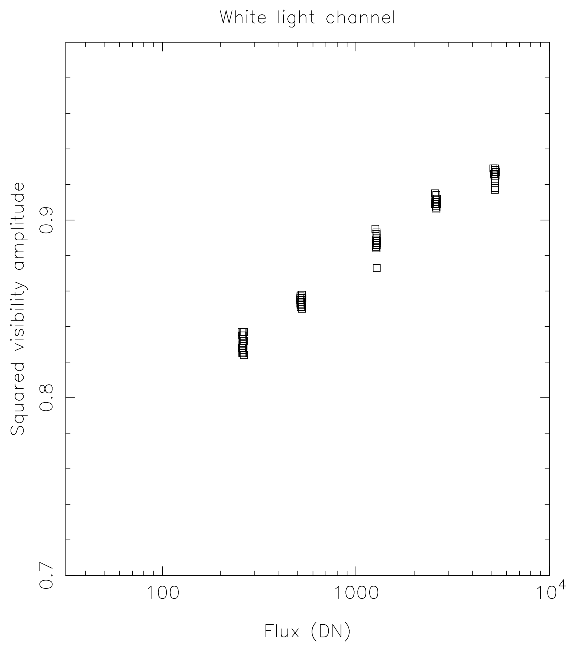

Figure 1: Internal fringe visibility amplitudes as a function of flux for the white light and an example spectrometer channel. Note the different slope in the visibility-log(flux) relation for the WL and spectrometer channel.

3 The flux bias correction

A compilation of the internal fringe data was used to derive the following correction formula:

$$V^2_{corrected} = V^2 * \left(1 - k \log \frac{N + 20}{1020}\right),$$

where N is the flux in DN (0.26 DN per photon) and k is the coefficient determined from the internal fringe experiments. The correction is set to be unity at a flux of 1000 DN. The coefficient k has a value of 0.063 for the white light (WL) channel and 0.16 for the spectrometer channels, resulting in a correction of 2.5% per magnitude for the WL channel and 6.4% per magnitude for the spectrometer channels. The spectrometer coefficient applies to all currently supported dispersions (5, 10 and 42 channels).

We have implemented this correction as part of the V2Calib programs (wbCalib and nbCalib, version 1.4.4 and later). This is the stage of the visibility calibration process (see references for link) where the system visibility is calculated and applied to the target object. The flux bias correction is turned on with the -fluxBias command line flag. It is applied to all data selected.

4 Verification of the correction

This correction has been validated with astronomical data in two ways. The first was to apply the correction to all calibrators observed over two nights in May 2007. The ratio of the WL to spectrometer visibilities had a flux dependence before the correction was applied due to the different slopes of the flux bias, and no dependence after. The second was to reanalyze several of the binary comparisons made for the operational readiness review and two binary observations made more recently. The binary systems and nights are listed in Table 1. The calibrators and average fluxes are listed in Table 2.

The 2003 binaries were chosen as they were used in the original KI validation process and cover the nominal fringe tracking brightness range (see Kvis recommended settings memo for more details). The May 2006 binary has the largest number of integrations and uses the real-time software version (2.1) of

Run	Date (yyyyddd)	System	FATCAT rate (Hz)	# of integrations	# spec channels
Jan03	2003018	HD78418	500	4	4
May03	2003141	HD144208	200	4	4
Oct03	2003288	HD9939	200	3	4
May06	2006137	HD102713	200	6	5
Dec06	2006343	HD9939	200	3	10

Table 1: Calibration binaries used for flux calibration verification. All observations are at K band.

Name	White light flux (DN)	Spec flux (DN)
HD78418	3031	2430
HD73192	12119	5359
HD79452	5033	3302
HD144208	1076	238
HD145457	879	178
HD144579	514	117
HD145675	521	115
HD9939(Oct 03)	210	46
HD7964	322	71
HD7034	433	91
HD3765	116	18
HD6920	358	22
HD102713	2122	747
HD101501	5444	1913
HD113797	965	332
HD9939(Dec 06)	614	88
HD7964	750	110
HD7034	1204	207

Table 2: White light and average spectrometer fluxes in DN for the binaries listed in Table 1 and their calibrators. Note that the spectrometer alignment was questionable for the observations of HD 78418 and HD 144208. The HD 78418 white light to spec ratio is non-standard to due deliberate mis-tuning of the flux coupling to prevent saturation of the white light channel.

current observations, while the Dec 2006 data validates the 10 channel modes. All data were processed with the standard Kvis and V2Calib parameters both with and without the flux bias correction. The calibrated visibilities were then compared to predicted visibilities based on the orbital parameters. The orbital parameters for HD 9939 are given in Boden et al (2006) and were kindly provided by A. Boden for the others from PTI data. Table 3 gives the mean deviation, the mean of the absolute value of the deviation (Abs. Dev.), the total uncertainty (the quadrature combination of the measurement uncertainty and the predicted visibility uncertainty, σ) and the reduced chi-squared (χ_r^2) of the data compared to the model for each observation set both with and without the flux bias correction. Plots of the data with and without the correction against the predicted visibility are in the Appendix.

As can be seen in Table 3, the results of the correction vary, but in no case is the data with the flux bias correction significantly further from the predicted visibility than the data without. The WL channel has always had a better absolute calibration level than the spectrometer channels and little or no improvement is seen in the WL channel. However, in three of the five cases (the medium flux binary from 2003 and both 2006 tests) the performance of the spectrometer channels is substantially improved and in all cases except the faint binary test from 2003 (which has large measurement errors) the spectrometer channels now have an absolute calibration of 0.04 or better in squared visibility amplitude. Interestingly, the channel-to-channel relative calibration is better for the 10 channel configuration than the 5 channel one. Given the spectrometer channel improvements, we recommend that all users utilize this option in wbCalib if their target and calibrator magnitudes vary by more than 0.2 magnitudes.

References

[Boden et al 2006] Boden, A., Torres, G. and Latham, D., 2006, ApJ, 644, 1193

[Kvis recommended settings memo] Millan-Gabet, R., Akeson, R.L., and Boden, A.F.,

`http://msc.caltech.edu/software/KISupport/dataMemos/kvis_params.pdf`

[KI calibration cookbook] `http://msc.caltech.edu/software/KISupport/calibration.html`

Night	Channel (μm)	Mean Dev.	Abs. Dev.	σ	χ_r^2	Mean Dev.	Abs. Dev.	σ	χ_r^2
		Without correction				With correction			
2003018	WL	0.022	0.022	0.016	2.56	0.018	0.018	0.016	1.71
	2.0	0.042	0.043	0.026	3.65	0.036	0.038	0.027	2.79
	2.1	0.044	0.044	0.021	6.02	0.038	0.038	0.022	4.43
	2.2	0.047	0.047	0.019	8.67	0.042	0.042	0.019	6.73
	2.3	0.049	0.049	0.018	10.17	0.045	0.045	0.019	8.33
2003141	WL	-0.020	0.020	0.025	1.15	-0.006	0.014	0.024	0.49
	2.0	-0.043	0.043	0.032	2.27	-0.015	0.024	0.030	0.76
	2.1	-0.046	0.046	0.027	3.68	-0.017	0.020	0.025	0.90
	2.2	-0.046	0.046	0.024	4.50	-0.016	0.016	0.022	0.97
	2.3	-0.042	0.042	0.023	3.94	-0.014	0.014	0.022	0.72
2003288	WL	0.007	0.075	0.101	0.59	-0.002	0.079	0.103	0.62
	2.0	-0.027	0.027	0.291	0.02	-0.038	0.038	0.295	0.02
	2.1	-0.069	0.069	0.115	0.45	-0.084	0.084	0.117	0.58
	2.2	-0.052	0.055	0.102	0.28	-0.075	0.075	0.104	0.44
	2.3	-0.047	0.056	0.098	0.28	-0.070	0.070	0.101	0.43
2006137	WL	0.009	0.033	0.070	0.37	-0.010	0.033	0.071	0.26
	2.032	0.072	0.072	0.065	2.62	0.020	0.036	0.068	0.48
	2.098	0.051	0.051	0.062	1.51	-0.008	0.021	0.066	0.10
	2.186	0.046	0.046	0.058	1.34	-0.015	0.018	0.062	0.08
	2.282	0.052	0.052	0.055	1.63	-0.008	0.013	0.058	0.05
	2.360	0.060	0.060	0.052	2.13	0.004	0.011	0.054	0.10
2006343	WL	0.003	0.003	0.046	0.04	-0.005	0.008	0.046	0.04
	1.995	0.069	0.069	0.071	1.25	0.059	0.059	0.073	0.95
	2.059	0.051	0.051	0.057	1.12	0.038	0.039	0.059	0.70
	2.106	0.052	0.052	0.054	1.21	0.037	0.037	0.056	0.69
	2.151	0.053	0.053	0.052	1.38	0.040	0.040	0.053	0.82
	2.201	0.047	0.047	0.051	1.05	0.032	0.032	0.053	0.55
	2.260	0.047	0.047	0.052	1.09	0.032	0.032	0.053	0.60
	2.307	0.046	0.046	0.052	1.00	0.031	0.031	0.053	0.56
	2.358	0.049	0.049	0.054	1.05	0.034	0.034	0.055	0.58
	2.400	0.049	0.049	0.056	0.99	0.035	0.035	0.057	0.56
	2.433	0.052	0.052	0.057	1.11	0.037	0.037	0.058	0.67

Table 3: The mean deviation, mean absolute deviation, total uncertainty (σ) and reduced chi-squared (χ_r^2) of the binary observations as compared to the predicted visibility.

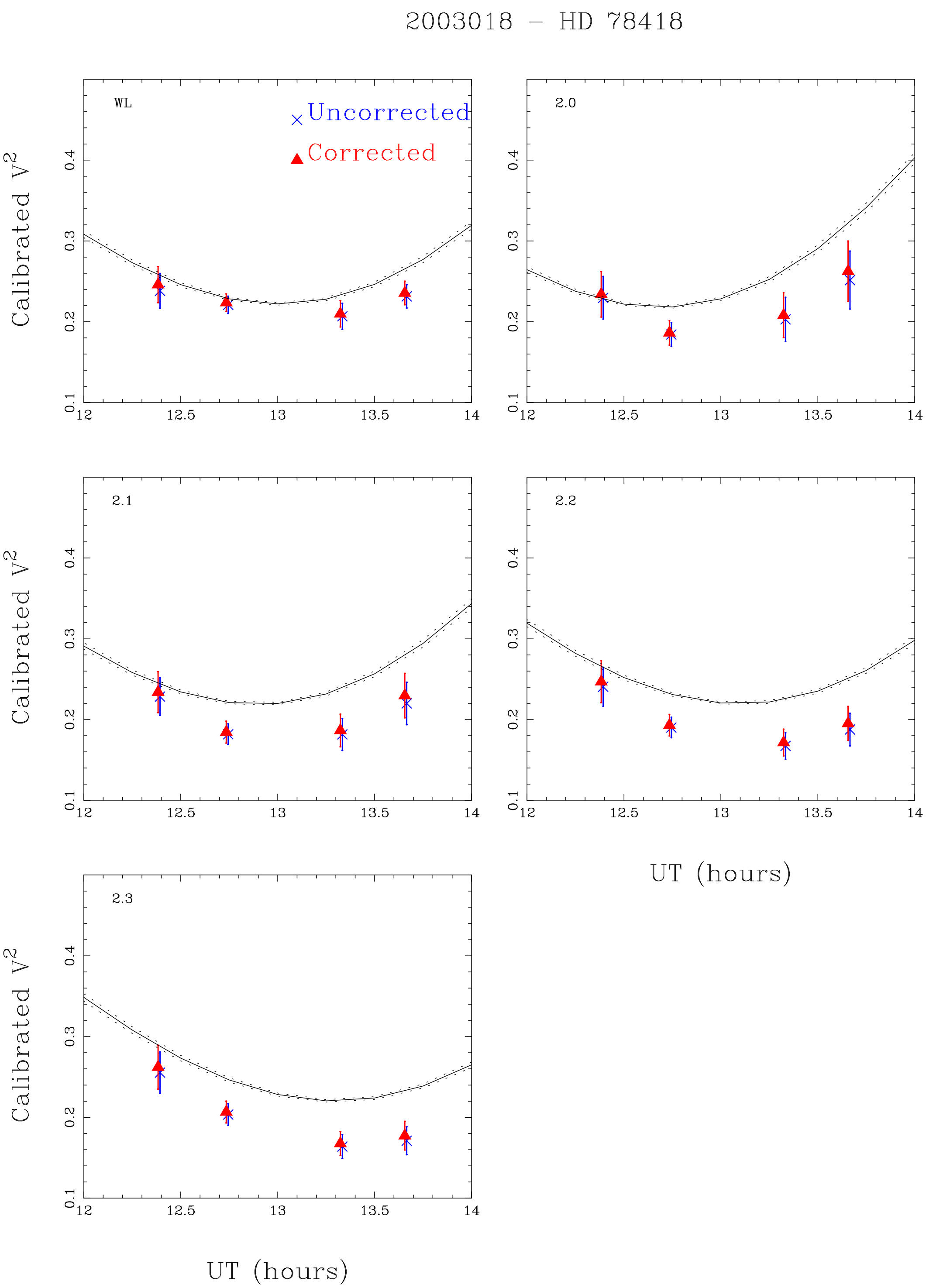

Figure 2: Comparison of the calibrated binary observations and predicted visibilities for night 2003018. Note that a small time shift has been introduced to separate the data points for better viewing. The panels show the WL channel and each of the spectrometer channels.

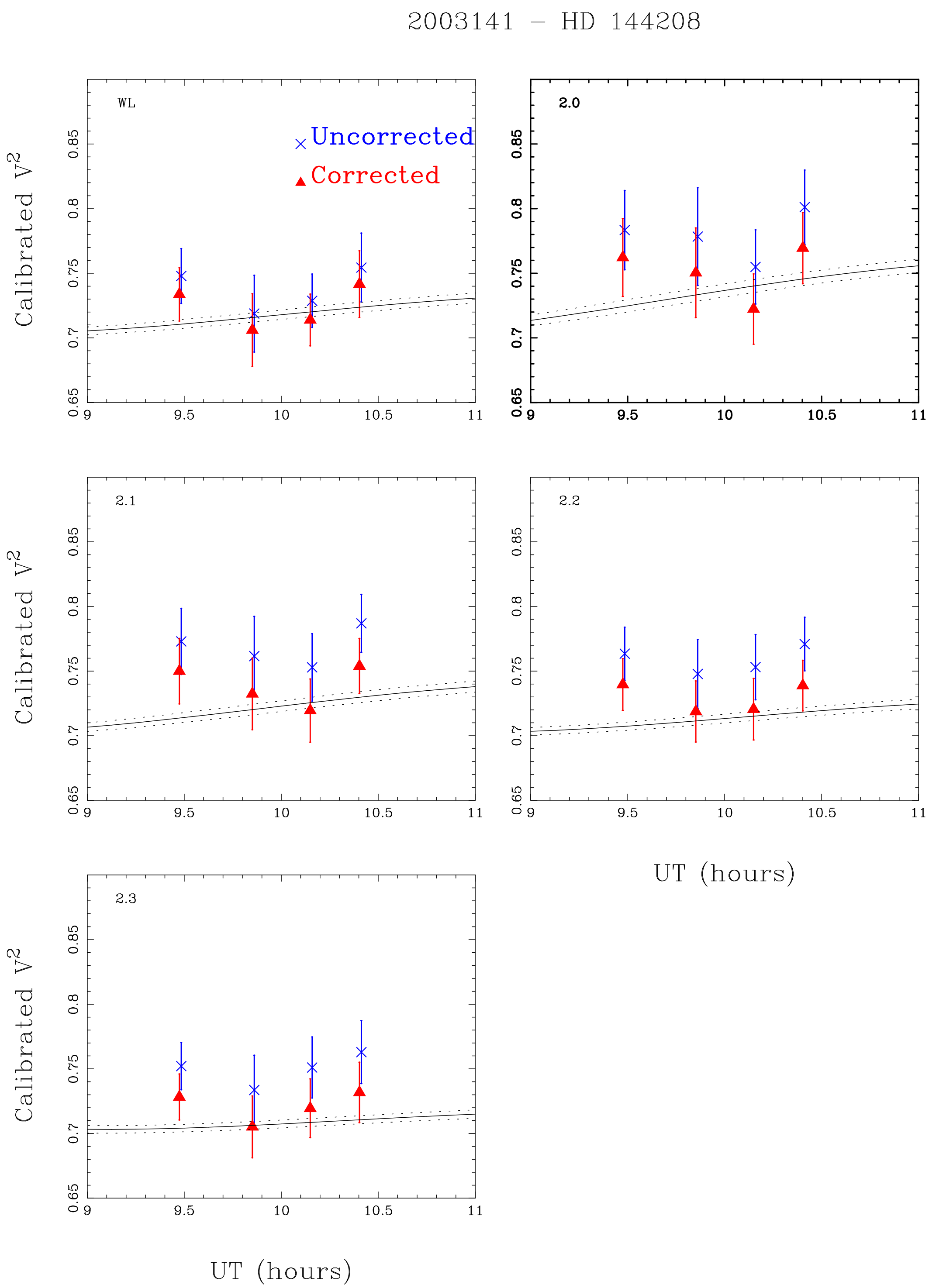

Figure 3: Comparison of the calibrated binary observations and predicted visibilities for night 2003141. Note that a small time shift has been introduced to separate the data points for better viewing. The panels show the WL channel and each of the spectrometer channels.

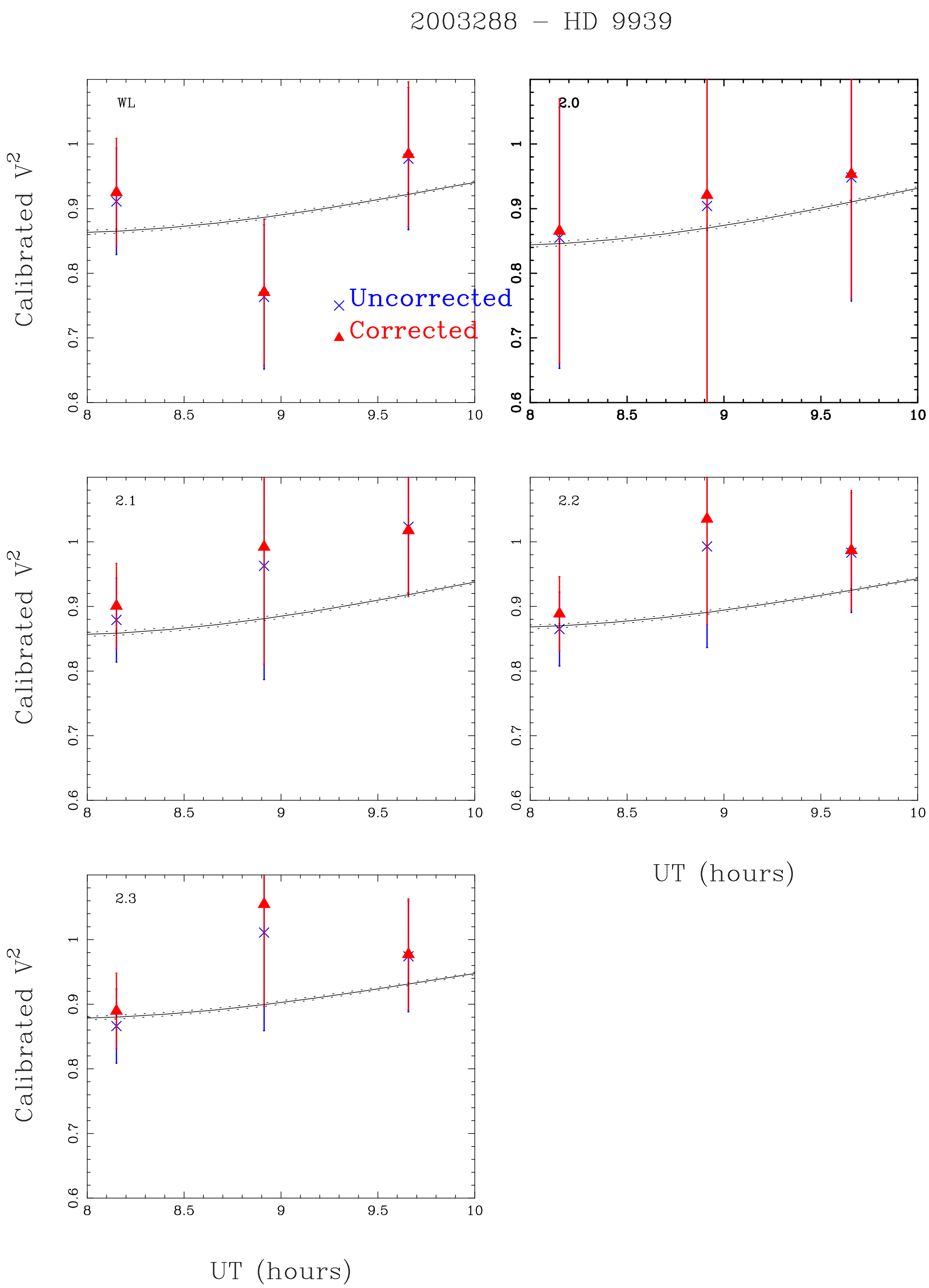

Figure 4: Comparison of the calibrated binary observations and predicted visibilities for night 2003288. Note that a small time shift has been introduced to separate the data points for better viewing. The panels show the WL channel and each of the spectrometer channels.

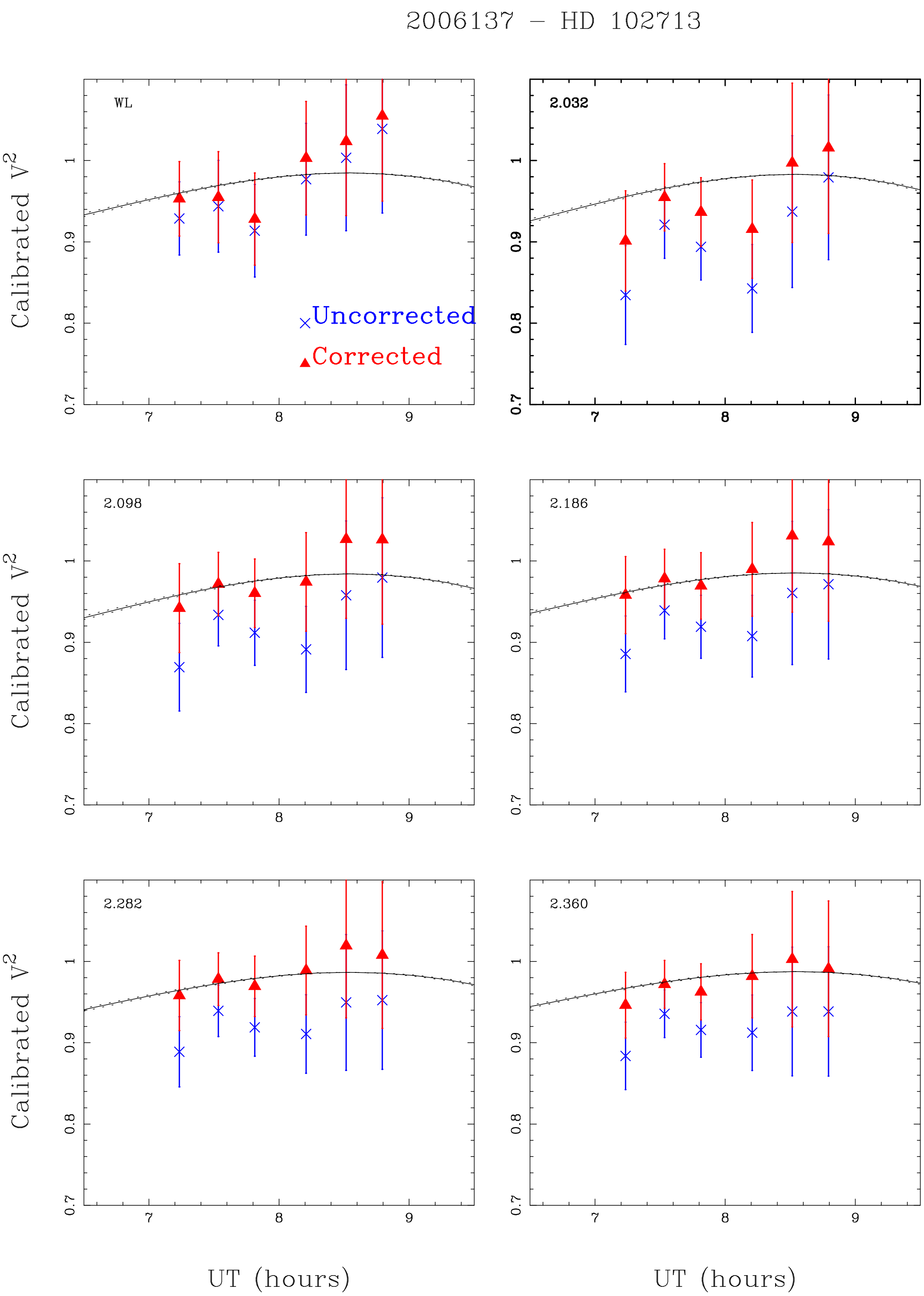

Figure 5: Comparison of the calibrated binary observations and predicted visibilities for night 2006137. Note that a small time shift has been introduced to separate the data points for better viewing. The panels show the WL channel and each of the spectrometer channels.