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Comparison of the VLBI Observables from Mk3 and Mk4 Correlation of a 24-hour Geodetic Experiment

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Abstract

Data from geodetic experiment CORE-B605 were processed on a Mk3A and a Mk4 correlator, and the resulting X-band delays, rates, and fringe amplitudes were compared. The scatter in multiband delay differences is larger than expected. Time series of phase delay differences exhibit geometry-dependent systematic variations of a few ps. The singleband delay differences have baseline-dependent biases as large as 5-8 ns. Mk4 fringe amplitudes are generally 2-5% lower than Mk3.

1. Introduction

This report presents the preliminary results of a comparison of the primary geodetic VLBI observables generated from correlation of a 24-hour geodetic experiment on a Mk3 and a Mk4 correlator. A similar study is reported by Nothnagel *et al.* [2] in these proceedings.

2. Geodetic Session

The geodetic experiment selected for multiple correlation is CORE-B605 (CB605), which was recorded on 4–5 October 1999. Fourteen frequency channels, each 2 MHz wide, were 1-bit sampled and recorded on tape. The "narrowband" geodetic frequency sequence was used, with eight X-band channels spanning 360 MHz and six S-band channels spanning 85 MHz. Seven stations participated, but one station (Yellowknife) was not included in the Mk4 correlation. The six stations that were processed on both correlators are: Algonquin Park 46m, Canada; DSS65 34m, Spain; Fortaleza 14m, Brazil; Kashima 26m, Japan; Kokee Park 20m, Hawaii, U.S.; and Onsala 20m, Sweden.

3. Correlation and Fringe-fitting

Correlation of CB605 was done on the Mk3A and Mk4 correlators at Haystack Observatory in November 1999 and July 2000, respectively. The Mk3A [3] has a baseline-based XF architecture, and the Mk4 [4] has a station-based XF design. CB605 was correlated with 8 lags on the Mk3A and 32 lags on the Mk4. The time tags associated with the accumulated Mk3 correlator data are the wavefront arrival times at the reference station, which is the first station in the baseline name; the Mk4 time tags are the hypothetical wavefront arrival times at the center of the Earth.

The Mk3 and Mk4 correlator data were fringe-fit with programs `mk3fit` and `fourfit` in November 1999 and January 2002, respectively. Fringe phases were aligned across frequency channels using the 10 kHz phase cal tones, except for Kokee S- and X-band and DSS65 X-band, which were fringed with manual phases due to phase cal instabilities. The same manual phases and additive phase cal corrections were used in Mk3 and Mk4 fringing. In order to allow geodetic analysis programs designed for Mk3 data to work with Mk4 data, `fourfit` converts the total delay and rate observables from the geocentric frame of the Mk4 correlator to a Mk3-style reference station frame. The Mk4 data for each scan were fringe-fit with the fringe reference time (FRT) forced to be the same as the Mk3 FRT.

4. Comparison of Observables

Differences in the Mk3 and Mk4 results can be expected if the time spans of the data read from the VLBI tapes in the two correlations are not identical due to, *e.g.,* differing playback quality or tape synchronization times. In order to minimize this effect, only scans for which the total amounts of Mk3 and Mk4 correlator data differed by <10% were included in the comparisons.

Analysis to date of the results has concentrated on the Mk4-Mk3 differences in the total (correlator model + residual to model) X-band multiband delay (MBD), singleband delay (SBD), phase delay, and delay rate, and on the X-band fringe amplitude ratios. Figure 1 shows the time series of the differences and ratios of the five observables for two representative baselines that have significantly different sensitivities. It is obvious from figure 1 that, for all the observables except phase delay, the larger the error in the undifferenced data, the larger the scatter in the differences.

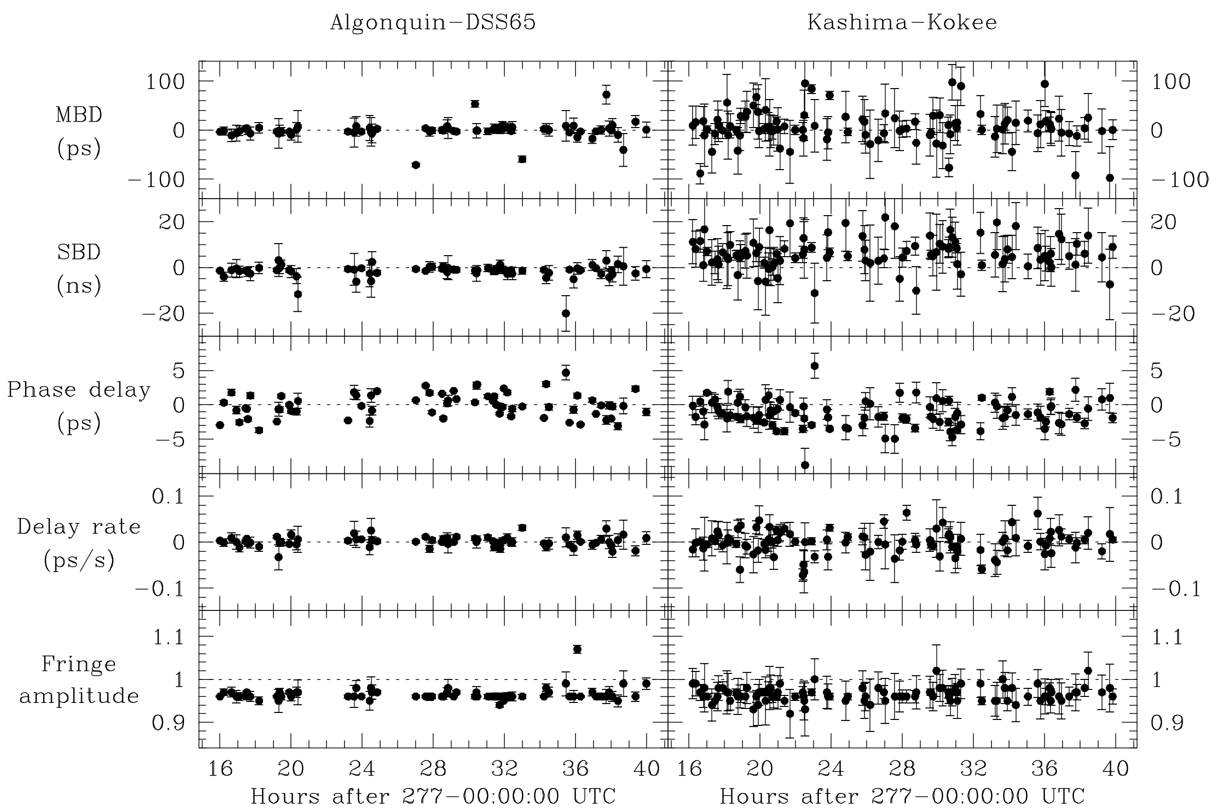

Figure 1. Mk4-Mk3 X-band delay and rate differences and Mk4/Mk3 X-band fringe amplitude ratios for the Algonquin-DSS65 (left) and Kashima-Kokee (right) baselines. Only data with SNR>15 are shown. Error bar = σ_u (see text for definition).

In the remainder of this paper, σ_u refers to the smaller of the two standard errors for the *undifferenced* Mk3 and Mk4 observables that go into each difference or ratio.

4.1. Multiband Delay

The relationship between MBD difference and SNR is shown in the lefthand panel of figure 2. (For the CB605 X-band sequence, SNR is related to the standard error σ_{MBD} of the undifferenced MBD by σ_{MBD} = 1135 ps/SNR.) There appear to be two fairly distinct populations: (1) the majority of points, which lie between, or close to, the $\pm 1\sigma_u$ curves and whose scatter scales inversely with SNR, and (2) outliers whose magnitude of 50-100 ps is nearly independent of SNR. The distribution of the majority, after scaling by σ_u, is well described by a normal distribution. A useful statistic, suggested by A. Niell, for estimating the scatter relative to σ_u in a manner less sensitive to outliers than the χ^2 statistic is the value of S for which $|\Delta\text{MBD}/\sigma_u| < S$ for 68% of the points. This is the percentage of points in a normal distribution that lie within 1σ of the mean, so if ΔMBD were distributed normally with standard deviation σ_u, S would be unity. The actual value of S is 0.64.

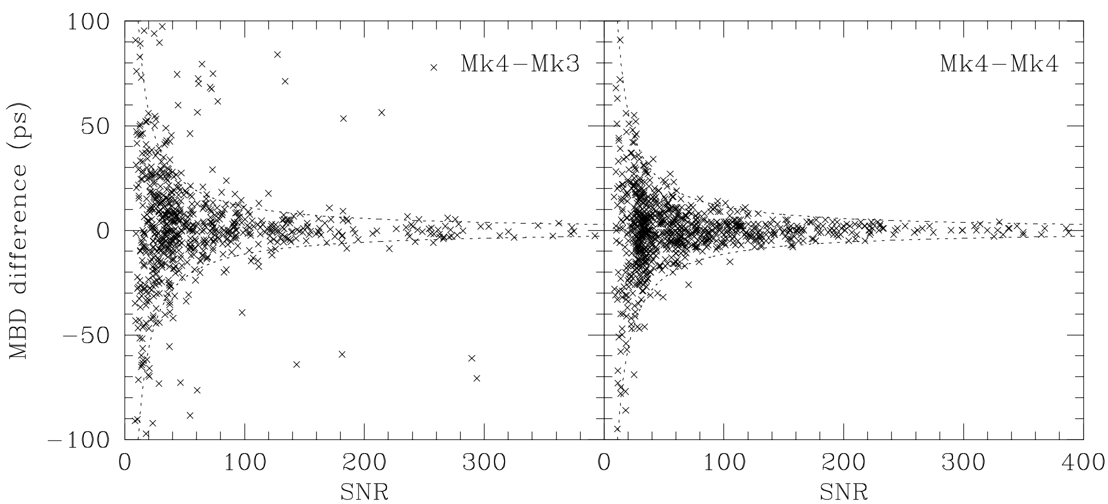

Figure 2. X-band MBD difference *vs.* SNR for all baselines. SNR shown is lesser of two SNRs of undifferenced data. Dotted curves are $\pm 1\sigma_u$. *Left:* Mk4-Mk3 differences. *Right:* Differences from fringing each set of Mk4 correlator data twice, once with central 60 seconds of data and once with central 48 seconds.

A dependence of the observable differences on SNR is to be expected if the time spans of the correlator data differ. In order to simulate the effects of disjoint input data, 907 Mk4 scans were fringed using first the central 60 seconds of data and then just the central 48 seconds. The Mk4-Mk4 differences are shown in the righthand panel of figure 2. Their scatter is smaller than for Mk4-Mk3: S = 0.49, which is close to the value of 0.45 calculated under some simple but reasonable assumptions for the case of two input data sets differing by 20% (12 seconds out of 60). But the disparity in integration time is larger, not smaller, for Mk4-Mk4 (20%) than for Mk4-Mk3 (a maximum of 10%). So the Mk4-Mk3 scatter is greater than can be explained simply by differences in the input data sets.

The outliers, which can also be seen in the top panels of figure 1, are distinctive for their large $|\Delta \text{MBD}/\sigma_u|$ ratio. Nine scans from four baselines with $|\Delta \text{MBD}/\sigma_u| > 8$ and $|\Delta \text{MBD}| > 50$ ps were investigated by examining the two sets of fringe plots and by refringing portions of the data. We were unable to identify the cause for any of the large discrepancies. Mk4 recorrelation of the scans in February 2002 yielded MBDs that agreed to within 2 ps with the original values. One of the scans happened to have been correlated three times on the Mk3 processor; even though the integration time ranged from 45 to 65 seconds in the three tries, the total spread in MBD was only 12 ps, which is much less than the Mk4-Mk3 difference. The S-band MBDs are too imprecise to provide a complementary comparison. In sum, the outliers remain a mystery.

For all 15 baselines that were processed, the bias in the MBD differences is small compared with the rms scatter, with bias typically <10% the rms scatter.

4.2. Singleband Delay

Unlike the MBD, the SBD differences exhibit significant biases on some baselines, particularly those involving Kokee (see figure 1), for which the biases are 5-8 ns. Of all six stations, Kokee happened to have the largest residual SBD (~50 ns) relative to the correlator model in both correlations. Large SBD residuals can lead to systematic errors in the SBD, phase delay, and fringe amplitude due to the limited number of correlator lags available [1]. A 50-ns correlator residual is too small to cause a 5-ns SBD error on either the Mk3 or Mk4 correlator, however.

The rms scatter in SBD differences about the baseline means is 5 ns. A normal distribution agrees very well with the distribution of SBD differences adjusted by the baseline means and scaled by σ_u. As a fraction of σ_u, the SBD scatter about zero on non-Kokee baselines is given by $S = 1.0$.

4.3. Phase Delay

Unlike the other four observables considered here, the scatter in the phase delay differences is approximately the same on all baselines and is independent of SNR. Displaying all the data for a baseline together in one plot, as in figure 1, obscures the fact that there are systematic trends for individual sources. In figure 3, attention is restricted to two sources, 0552+398 and 4C39.25, on two independent baselines. The declinations for these sources differ by <1°. In the bottom two panels of figure 3, the 0552+398 points have been shifted 3.53 hours to the right from their correct position, to simulate moving 0552+398 across the sky to the same right ascension as 4C39.25. Note how closely the two sources, now forced to be in nearly the same location on the sky, track each other. Similar behavior is observed on other baselines and with other sources. Clearly the delay differences are related to the source/baseline geometry, as reflected in the correlator model. This is most surprising, as total quantities should be insensitive to the model. The magnitude of the delay differences is generally <5 ps, or <15° in phase. If such systematic variations are present at the same level in the MBD, they are too small to be detected there, as least with this data set.

4.4. Delay Rate

The delay rate differences have small biases relative to the scatter, with mean values of only a few fs/s on most baselines. There is no evidence of systematic trends with source. The scatter increases with σ_u, but the distribution of $\Delta\text{rate}/\sigma_u$ deviates from a normal distribution in the excessive number of points in the tails of the distribution. The same is true of Mk4-Mk4 rate differ-

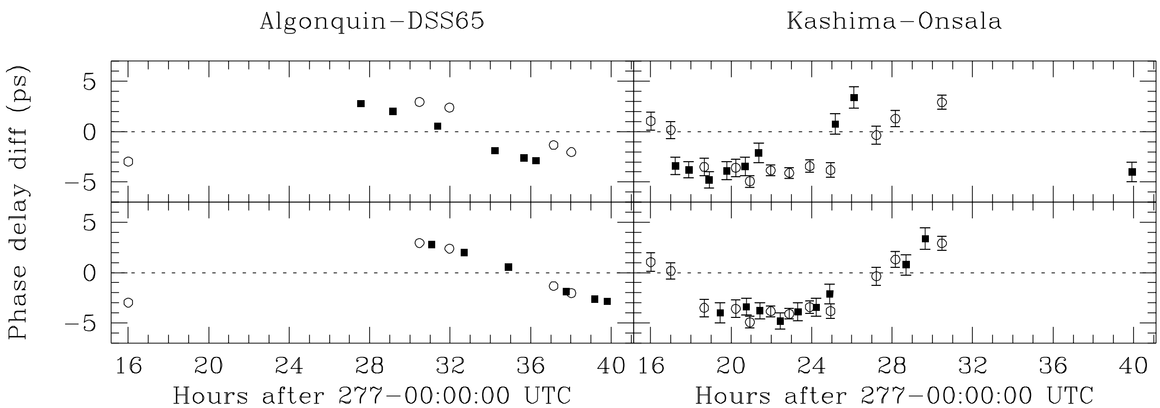

Figure 3. Time series of Mk4-Mk3 phase delay differences for 0552+398 (solid squares) and 4C39.25 (open circles) on the Algonquin-DSS65 (left) and Kashima-Onsala (right) baselines. 1 ps delay ⇔ 3.0° fringe phase. Error bar = σ_u. Error bars for Algonquin-DSS65 are smaller than plot symbols. *Top:* Original data. *Bottom:* Epochs of the 0552+398 points have been shifted by the RA difference for the two sources.

ences created in the same manner as the Mk4-Mk4 MBD differences. The cause is almost certainly temporal phase variations induced by propagation media effects with a red noise spectrum; small differences in the data span analyzed can lead to relatively large changes in the estimated rate. The value of S for the Mk4-Mk3 differences is 1.0.

4.5. Fringe Amplitude

On almost all baselines, the Mk4 fringe amplitudes are systematically biased 2-5% lower than the Mk3 (see figure 1). The only definite exception is Fortaleza-Kokee, for which the mean Mk4/Mk3 ratio is 0.996 ± 0.005. With correlator residual delays smaller than 100 ns, biases in the Mk3 amplitudes due to the finite number of lags should be <1% [1]; Mk4 biases should be even smaller.

References

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