X/S versus K Band Source Stabilities from Time Series Analysis

David Gordon[1], Phillip Cigan[1]

Abstract A common assumption is that quasar positions should be more stable at higher radio frequencies. But is this correct? We investigate this question by comparing VLBI source position time series at X/S and K bands for several hundred sources. K band astrometry sessions have been run on the VLBA nearly monthly since 2016, and we compare their data to X/S data from VLBA, IVS-RDV, IVS-R1, and IVS-R4 sessions over a similar time period.

Keywords X/S band, K band, source stabilities

1 Introduction

We generated both X/S and K band source position time series solutions over a similar time period. At K band, this ranged from December 2015 through September 2023 and used only the monthly VLBA K band astrometry sessions. At X/S band, the data ranged from January 2016 through November 2023 and used the monthly VLBA X/S astrometry sessions and also the IVS-RDV, IVS-R1, and IVS-R4 sessions. The K band VLBA astrometry sessions concentrate on $\sim$1000 fairly strong sources, many of which are also routinely observed in IVS sessions. On the other hand, the VLBA X/S astrometry sessions have concentrated on weak sources that are not typically observed in IVS sessions but also have included a few dozen ICRF2 or ICRF3 defining sources in each session for troposphere calibration and frame orientation. Therefore, it was necessary to include X/S IVS sessions in order to get sufficient overlap with the sources observed at K band. Only sources observed in at least three sessions over at least a two-year period were included in the time series solutions. Eight Solve runs were made at each band, in which 1/8 of the selected sources (including 1/8 of the ICRF3 defining sources) were solved as 'arc' parameters (a position for each session). Later, the arc positions from the eight solutions were combined into a single time series file for each band.

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2 X/S vs. K Comparisons

Both the X/S and K band time series required additional editing to remove source positions that were very noisy or for which there were too few observations in the session. For a source to be used, we required that it be in at least ten sessions with at least ten observations in each session and have uncertainties of no more than 1.0 mas in each session. Then, two methods were used to estimate the scatter for each source in each band.

In the first method, weighted root mean squares (WRMSs) of each source's position were computed in right ascension and declination using the right ascension and declination formal errors for weighting. The WRMSs of 438 common sources were then compared. In Figure 1, we show the logarithm of the ratio of the WRMSs at K vs. X/S. Values greater than zero indicate less scatter in the X/S data, and values less than zero indicate less scatter in the K band data. In right ascension, the K band series shows slightly greater stability, with $\sim$55% of the sources (242 out of 438) showing less scatter at K band and $\sim$45% showing less scatter at X/S. However, the situation is reversed in declination, where only $\sim$34% (150 out of 438) of the sources show less scatter at K band and ∼66% show less scatter at X/S.

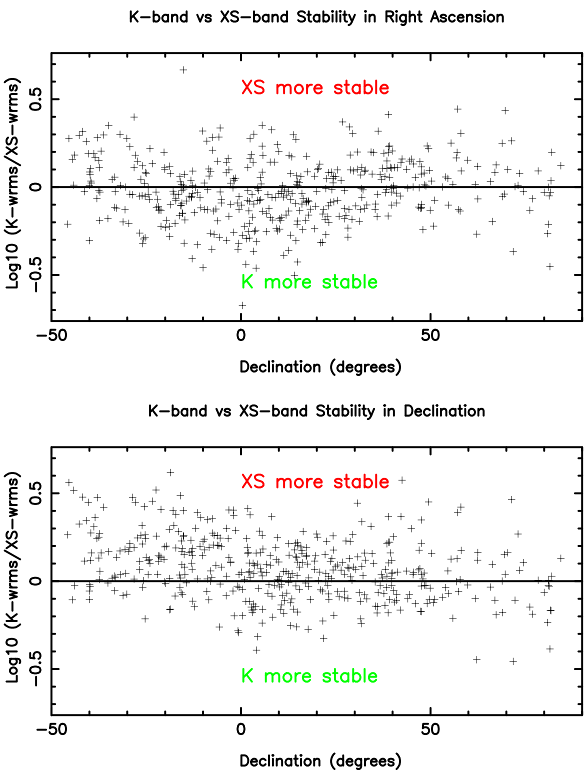

Fig. 1 Source stability comparison of K vs. X/S band using source position WRMSs about the mean. K band data are from VLBA-only sessions. X/S band data are from VLBA, IVS-R1, IVS-R4, and IVS-RDV sessions. 438 sources were matched. At K band, some 55% of the sources show less scatter in right ascension. But in declination, only 34% of the sources show less scatter than X/S. Also, the difference in declination scatter increases south of ∼0° declination. This apparent greater instability in declination of K band is likely a result of the much shorter N–S extent of the VLBA, compared to IVS sessions, resulting in larger K band uncertainties in declination than right ascension, particularly towards the south.

In the second method, a more complicated procedure was used to compute WRMSs by using the full covariance matrix for each session. The results are similar to the first method and are shown in Figure 2. In the second method, ∼56% of the sources show less scatter in right ascension at K band and ∼30% show less scatter in declination.

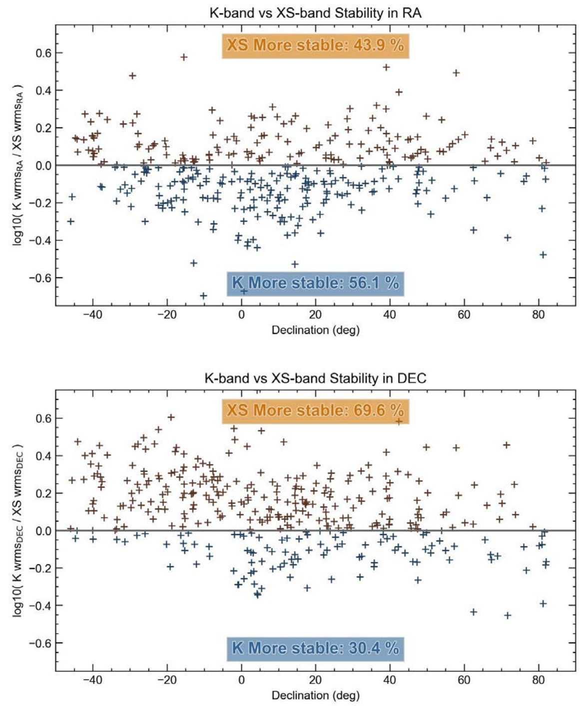

Fig. 2 Similar to Figure 1, but the WRMS scatter is computed using the full covariance matrix for each session. Some 56% of the sources show less K band scatter in right ascension, but only ∼30% of the sources show less K band scatter in declination. Also, as in Figure 1, K band scatter increases rapidly south of ∼0° declination, compared to X/S scatter, likely due to the shorter N–S extent of the VLBA compared to the IVS X/S networks and the fact that we start losing the northern VLBA stations.

3 Discussion

Examples of the times series are shown in Figure 3. Active Galactic Nuclei (AGN) sources generally become more compact with increasing frequency. Figure 4 shows an example of this for the source NRAO140 (J0336+3218) with increasingly smaller images at S, X, K, and Q bands. It is thus natural to assume that VLBI source positions, as defined by the source's VLBI phase center, should also be more stable at higher frequencies. This is the assumption we are testing with these comparisons. But these comparisons are difficult to interpret due to the different nature of the X/S and K sessions and to the different networks used. The X/S and K VLBA astrometry sessions mostly look at different sources. The X/S IVS-R1, IVS-R4, and IVS-RDV sessions have larger

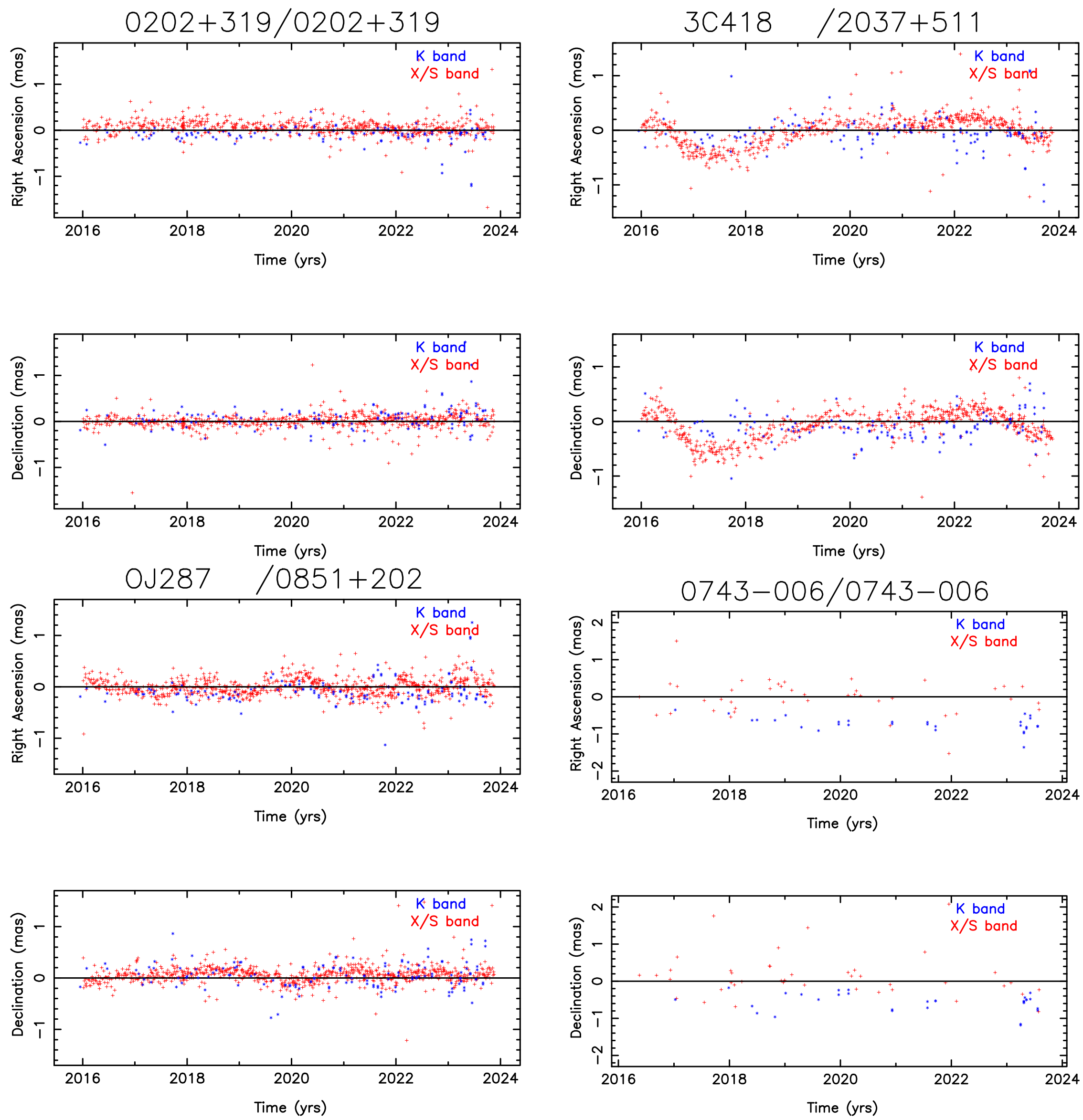

Fig. 3 Comparison plots of X/S and K band source position time series. Plotted are the differences from the ICRF3-SX catalog positions, with K band in blue and X/S in red for four sources. Source 0202+319 is an example of a source that shows stable behavior and good agreement between the K and X/S positions, but not necessarily with ICRF3-SX. Sources 3C418 and OJ287 are examples of sources that show significant position variations. For OJ287, X/S and K follow each other fairly well, but for 3C418, K band seems to show less variation. Source 0743-006 is an example where K and X/S show significantly different positions.

networks than the VLBA, particularly with better North–South extent and baselines crossing the equator, leading to smaller declination uncertainties and less asymmetry in precision. The East–West coverage of the IVS networks vs. the VLBA are not so different though, and the data gives a slight edge to K band in right ascension in terms of WRMS scatter. There is no reason to expect that the true average source position variability would be systematically greater in declination than right ascension. And there is also no reason to expect that the true average source position variability would increase from the northern to the

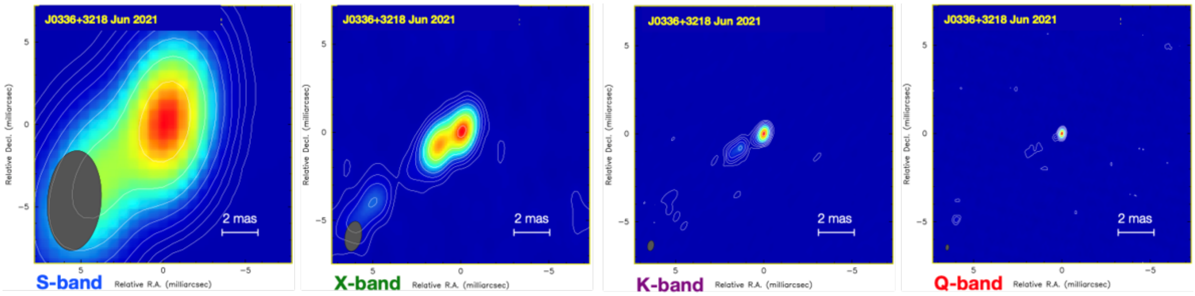

Fig. 4 Near-simultaneous S (2.3 GHz), X (8.4 GHz), K (24 GHz), and Q band (43 GHz) images based on VLBA observations of 453 ICRF sources between April and June 2021 demonstrate that ICRF VLBI sources become more compact with increasing frequency. In particular, note how the jet in this example (NRAO140/J0336+3218) fades with increasing frequency. The VLBA synthesized beam is shown as the gray ellipse in each sub-figure.

southern part of the sky. Therefore we attribute the larger WRMS scatter for K band in declination to be a network effect, and we believe the indication is that the true source position variability is less at K band, though we cannot quantify by how much with this limited dataset.

4 Conclusions

We conclude that sources are slightly more stable at K than at X/S band, on average. But our ability to measure this is limited by network differences and the limited amount of overlapping source data at the two bands.

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