Effects of AGN Jet Evolution on VLBI Astrometric Positions

Romuald Bouffet[1,2], Patrick Charlot[1,2], Sébastien Lambert[3]

Abstract Astrometric positions of extragalactic radio sources derived from VLBI data are used to build highly-accurate reference frames such as the International Celestial Reference Frame. Despite their distant locations, instabilities in the position of these sources are often seen on time scales of months to years, which is generally thought to be caused by source structure evolution. In this paper, we compare position instabilities and structural evolution for a sample of 68 sources observed over a ten-year period (1994–2003). Our results indicate that the two phenomena are linked at some level although the correlation is not perfect.

Keywords Reference frames, astrometry, active galactic nuclei, quasars, VLBI

1 Introduction

The current IAU fundamental celestial reference frame, namely the ICRF2 (second realization of the International Celestial Reference Frame), which has been in use since January 1, 2010, includes positions for a total of 3414 extragalactic radio sources distributed over the entire sky. Such positions were determined from VLBI data acquired at 8.4 and 2.3 GHz over 30 years (1979–2009). The ICRF2 has a floor of 40 microarcseconds (μas) in the individual source coordinate accuracies and an axis stability of 10 μas (IERS, 2009). Joint observational efforts of the VLBI community aiming at a denser and even more accurate celestial frame continue in order to further improve the quality of the frame.

One limitation in improving the accuracy of the individual VLBI source positions originates in actual astrometric instabilities which are found in these positions. Due to their location at cosmological distances, no proper motions are expected for these sources and their astrometric positions should thus be stable with time. While this is indeed the case on the long term, it is not true for shorter time scales (months to years) where instabilities at the level of several hundreds of microarcseconds are commonly detected (IERS, 2009). Such instabilities are usually attributed to varying source structure which is often spatially extended at the level of the VLBI resolution (Fey and Charlot,, 2000). Structural variations are generally due to ejection of material from the central VLBI core in a recurrent although unpredictable manner, causing shifts in the brightness centroid of the radio emission and hence potential VLBI astrometric instabilities.

In this paper we compare source position instabilities and structural variations based on astrometric and imaging VLBI data covering a period of ten years (1994–2003). The datasets are presented in Section 2 while Section 3 describes the analysis scheme. Section 4 reports our findings and discusses correlations between the two phenomena. In the last section, we draw prospects for further work in this area.

2 Observations

The data used to derive astrometric positions were acquired during numerous VLBI sessions conducted by the International VLBI Service for Geodesy and As-

1. Univ. Bordeaux, LAB, UMR 5804
2. CNRS, LAB, UMR 5804
3. Observatoire de Paris/SYRTE, CNRS/UMR 8630, Université Pierre et Marie Curie

trometry (IVS) over the past 30 years (Behrend,, 2013). A large number of observations is available for many sources which permits monitoring of their astrometric positions on time scales of days to weeks. Analysis was carried out in a similar way as that described in Gontier et al., (2006). For our study we averaged the individual session-based positions over monthly intervals in order to have a sampling similar to that of the imaging data.

Structural variations were taken from the analysis of VLBI jet kinematics reported in Piner et al., (2012). This analysis has made use of 2753 images at 8.4 GHz obtained from 50 Research & Development VLBI sessions organized by the IVS and the Very Long Baseline Array between 1994 and 2003. Six such sessions are carried out every year with a sampling of approximately two months. The network includes 15–20 stations, yielding high-quality VLBI images. Sixty-eight sources observed at 20 epochs or more (with a median of 43 epochs per source) are included in the present study.

3 Analysis

For our study, we used a simplified representation of the source structures in the form of a limited number of Gaussian components obtained through model-fitting [as available in Piner et al., (2012)]. Such a representation was preferred, because it identifies the VLBI core of each source from epoch to epoch and aligns automatically the brightness distributions over time, assuming that the core position is stable. This alignment is crucial since the absolute map position is lost during the imaging process due to self-calibration.

Processing further the source structural information, we calculated the centroid of the brightness distribution (i.e., the centroid of the Gaussian components) at every epoch, allowing us to assess the relative motion of the brightness centroid with time. This calculation was carried out for 68 sources observed at 20 epochs or more for which model-fits are available in Piner et al., (2012). The result is a time series of centroid positions which may be compared with the monthly-averaged VLBI astrometric positions. This comparison assumes that the source motion as seen from the astrometric data is well matched with the motion of the centroid of the brightness distribution detected from VLBI imaging.

4 Results and Discussion

An example of the comparisons that we carried out using the scheme explained in the previous section is presented in Figure 1. The upper panels show the evolution in right ascension and declination of the astrometric position of the source 1308+326 from 1996–2003, while the lower panels show the motion of its brightness centroid over the same period of time. Uncertainties in the astrometric positions were derived as weighted averages (over monthly intervals) of the individual session-based uncertainties. Declination has higher uncertainties due to the predominantly East-West baselines of current VLBI networks. No error bars are given for the centroid positions, because model-fitting does not provide a direct means to estimate reliable uncertainties for the Gaussian components representing the structures.

Examination of the plots in Figure 1 indicates similar trends in the evolution of the astrometric and brightness centroid positions. This is also confirmed when calculating correlation coefficients between the two series, which are 0.30 in right ascension and 0.63 in declination. Applying the same calculation to all sources, an overall positive correlation is found (median value of 0.22 in right ascension and 0.19 in declination) as shown in Figure 2. This indicates that structural variations and astrometric instabilities are linked at some level.

Looking at Figure 2, one also notes that a fraction of the sources shows a negative correlation. At this stage, it is not understood however whether this negative trend is real or whether it results from the lack of significance of some of the correlation coefficients. For example, the correlation coefficients may be questionable when there is no notable evolution in both the astrometric and brightness centroid positions. Further studies are thus necessary to assess the significance of the correlation coefficients. Ultimately, every source may have to be examined separately to understand any discrepancy that may happen between the two series of positions.

Different trends in the astrometrically derived and structurally derived positions (possibly leading to negative correlation) may result from misidentification of the core component over the successive epochs (thereby affecting the alignment of images and the brightness centroid relative locations) or from effects

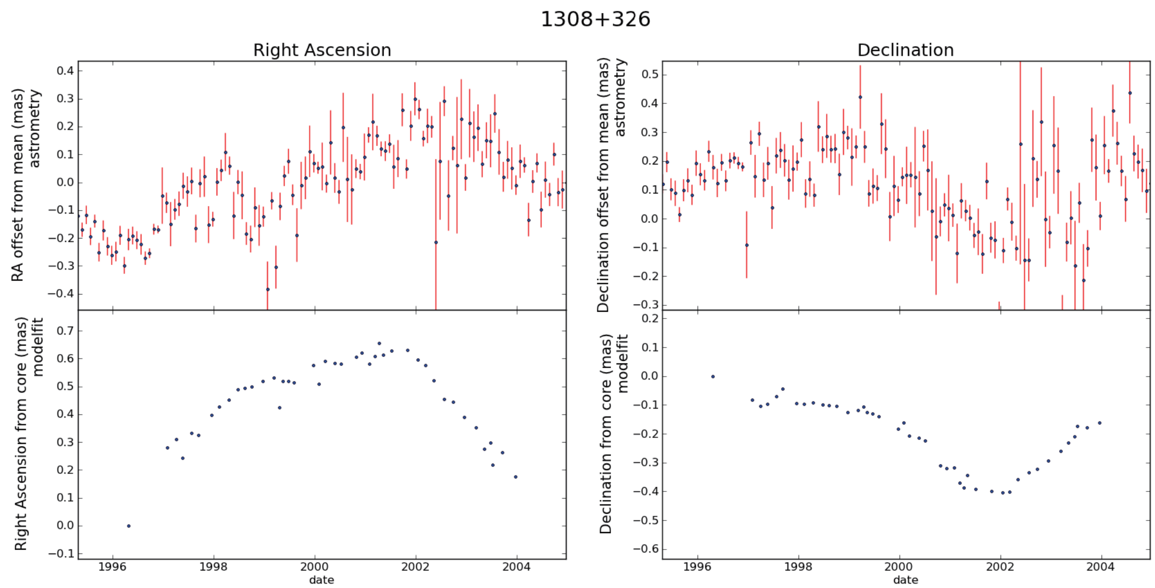

Fig. 1 Comparison of the astrometric position instabilities (upper panels) and brightness centroid motions (lower panels) for the source 1308+326 between 1996 and 2003. The left panels are for right ascension, while the right panels are for declination. The vertical scale is in milliarcseconds (mas).

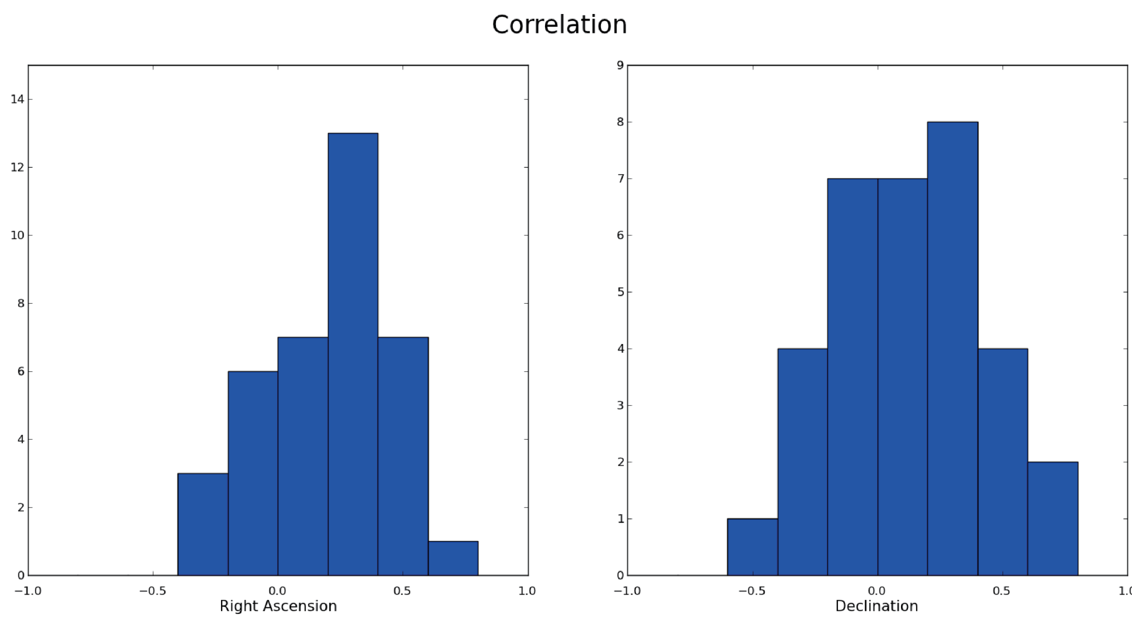

Fig. 2 Distribution of correlation coefficients between astrometric position instabilities and structural variations for all sources with significant astrometric instabilities (reduced $\chi^2 > 4$). Note that the source 0923+392, which shows atypical evolution, was removed from the sample for the purpose of this histogram.

coming from the S-band (2.3 GHz) data. For a full analysis, the S-band structures should indeed be considered as well, since the astrometric positions are derived from a combination of the data at the two frequencies, whereas only the X-band (8.4 GHz) structures have been considered in the above comparisons. The S-band data have a lower weight though and are thus a priori less likely to affect strongly the positions, hence the reason for neglecting them in the first stage.

5 Conclusions

A comparison between the evolution of astrometric positions and the variations of source structure (characterized as the motion of the centroid of the brightness distribution) was carried out for a sample of 68 sources observed over a period of ten years between 1994 and 2003. This comparison reveals similar trends in the astrometric and structural time series of positions for some sources showing significant motions like 1308+326. On the other hand, the correlation for sources with smaller motions is more difficult to assess. Overall, a positive correlation is found between the two time series, which favors an explanation of VLBI position instabilities in terms of structural variations.

In the future, we plan to refine this comparison by examining carefully each individual source in the sample. In some cases the comparison may not be reliable, because the position errors are too large and the motions are not significant, while in other cases different trends are seen, which needs to be understood. Possible explanations for such discrepancies include misidentification of the core components over the epochs and effects of the S-band data. In the longer term, enlarging the source sample and expanding the time span covered by the astrometric and imaging data up to recent years would be desirable.

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