# MAINTENANCE OF THE ICRF: RADIO

ALAN L. FEY
*U.S. Naval Observatory*
*Washington, DC 20392-5420 USA*

## 1. Introduction

Extragalactic radio sources are assumed to be very distant and thus should exhibit little or no detectable proper motions. A reference frame defined by the positions of extragalactic radio sources may be said to be a quasi-inertial frame (i.e. a frame whose basis is inertial) with little or no time dependency. Unfortunately, although extragalactic sources are good as ICRF objects, most extragalactic sources display intrinsic structure on angular scales larger than the accuracy of their position estimates. Temporal variations of the intrinsic structure of these objects will result in apparent motion when observations are made at several epochs. Because the underlying physics of extragalactic sources is not as well understood as that of the stars which define the stellar reference frame, we can only describe with certainty what the radio sources did during the particular interval of time covered by previous observations. We cannot predict theoretically what behavior can be expected in the future. It is therefore necessary to regularly measure the structure of ICRF sources, and monitor their changes, in order to maintain the ICRF and make it more useful to astronomers.

## 2. Frame maintenance and improvement

### 2.1. CONTINUED VLBI OBSERVING AND ANALYSIS

The National Earth Orientation Service (NEOS)[1] has been appointed by the International Earth Rotation Service (IERS) as the VLBI Coordinating Center charged with observations, analysis, and other related activities toward the maintenance of the ICRF.

NEOS is committed to making the observations required to maintain the ICRF. Observations will be made using the NEOS array of telescopes, including both regular NEOS observing for Earth orientation parameters estimation and special sessions organized specifically for reference frame maintenance. Observations for the new Continuous Observations of the Rotation of the Earth (CORE) program, when operational, will be included as well. The Very Long Baseline Array (VLBA) telescope of the National Radio Astronomy Observatory (NRAO) will also continue to be used for ICRF maintenance, at least down to its southern declination limit.

### 2.2. ACCURACY OF THE ICRF

Factors limiting the accuracy of the ICRF include tropospheric modeling, the paucity of data on some sources (particularly in the southern hemisphere), and intrinsic source structure. Considerable progress has been made toward understanding atmospheric effects by estimating gradients in the troposphere directly from the VLBI data. The resulting effect is a systematic shift of up to about 0.5 mas in source declinations from analyses with and without gradient estimates. The effect is much larger than the position formal errors, and is caused by the greater troposphere thickness nearer the Earth's equator (MacMillan & Ma 1997). While the effect is not large in absolute terms, it is systematic and would distort the celestial reference frame if ignored. Special southern hemisphere experiments involving NEOS antennas and/or selected VLBA antennas are being scheduled

[1] NEOS is a cooperative effort between the Goddard Space Flight Center (GSFC), the U.S. Naval Observatory (USNO), and the National Oceanographic and Atmospheric Administration (NOAA) and serves as the IERS Sub-bureau for Rapid Service and Predictions.



*J. Andersen (ed.), Highlights of Astronomy, Volume 11A,* 317–319.

to obtain additional data on poorly observed southern sources. The VLBA is also being used extensively in the northern hemisphere. Observations obtained with the VLBA accumulate quickly due to the larger number of antennas compared to the NEOS array. As observations accumulate, it should be possible to move candidate sources up or down the scale of usefulness. The remaining factor limiting the accuracy of the ICRF is intrinsic source structure and will be the focus of the remainder of this paper.

### 2.3. INTRINSIC SOURCE STRUCTURE

Until recently, the intrinsic structure of the majority of the ICRF sources has been mostly unknown. The surveys of Fey, Clegg & Fomalont (1996) and Fey & Charlot (1997) show that most sources, when examined in detail, exhibit spatial structure on milliarcsecond scales. Their results show that the variation of intrinsic structure from source to source can be quite extreme, ranging from relatively compact naked–core objects, to compact double sources, to complex core–jet objects. The situation is exacerbated by the fact that compact extragalactic radio sources are known to have variable intensity and to have frequency- and time-dependent intrinsic structure. Consequently, unknown and/or unmodeled source structure effects may be introduced into the astrometric solution.

Charlot (1990) has modeled the effects of radio source structure on measured VLBI group delays and delay rates. Fey & Charlot (1997) calculated structure corrections based on the Charlot (1990) analysis using source models derived from VLBA observations of 169 extragalactic sources. Results of these calculations show that intrinsic structure contributions to the measured bandwidth synthesis delay are significant, ranging from maximum corrections of only a few picoseconds for the most compact sources to maximum corrections of several nanoseconds for the most extended sources. Fey & Charlot (1997) found a correlation between the compactness of the sources and their position formal uncertainties indicating that the more extended sources have larger position formal errors. They also define a source "structure index" based on the median of the calculated structure corrections. They suggest that this index can be used as an estimate of the astrometric quality of the sources.

As mentioned in §1, temporal variations of the intrinsic structure of extragalactic sources will result in apparent motion when observations are made at several epochs. The position variations for some sources show clear correlations with changes in intrinsic structure and, to some extent, the position changes can be derived from the structure, but there is no strong evidence of any regularly repeated behavior. Fig. 1 shows the time evolution of the right ascension of 0923+392 (4C 39.25). The astrometric time series agrees very well with the differential motion of the brightest image component measured relative to an assumed stationary image component in VLBI images. Essentially, the brightest component of this source has traversed a distance of $\sim 2$ mas in the span of about 17 yrs.

## 3. The Future

New VLBI observations of ICRF sources will be made and added to the current database. Sources will be monitored for variability and/or structural changes. The current realization of the ICRF condenses the information from a particular VLBI dataset spanning a defined interval of time and reflects a certain state of VLBI analysis. As new observations are added and the modeling is improved, we expect the realization of the ICRF to evolve, although changes in the ICRF catalogue will be infrequent compared to past practice in VLBI astrometry. The problem of position variation may be solved in the future if the application of source structure information permits the identification and use of truly kinematically stable points in the sky.

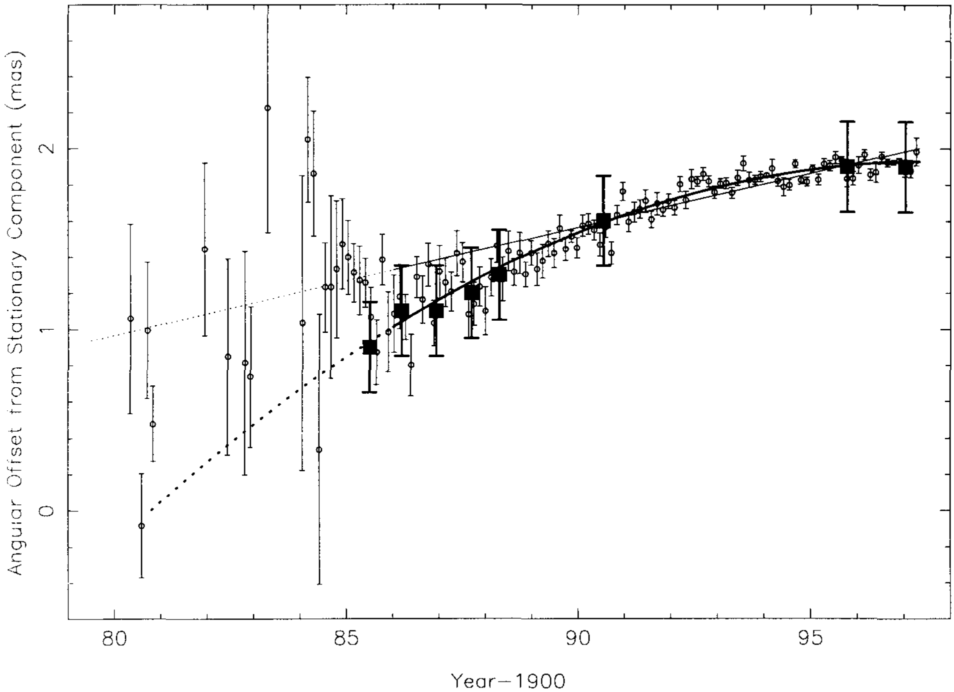


*Figure 1. The astrometric right ascension $\alpha\cos\delta$ of 0923+392 (4C 39.25) offset from the position of an assumed stationary image component. Superposed are the angular separations in right ascension between the positions of the brightest image component at $\lambda = 3.6$ cm (large solid squares) and the position of the stationary image component for VLBI images from several epochs. Also shown are linear and quadratic weighted least-squares fits to the astrometric positions. The dashed portions of these curves represent extrapolations.*

## References

Charlot, P. (1990) Radio-Source Structure in Astrometric and Geodetic Very Long Baseline Interferometry, AJ, **99**, 1309–1326

Fey, A.L., Clegg, A.W. & Fomalont, E.B. (1996) VLBA Observations of Radio Reference Frame Sources. I., ApJS, **105**, 299–330

Fey, A.L. & Charlot, P. (1997) VLBA Observations of Radio Reference Frame Sources. II. Astrometric Suitability Based on Observed Structure, ApJS, **111**, 95–142

MacMillan, D.S. & Ma, C. (1997) Atmospheric gradients and the VLBI terrestrial and celestial reference frames, Geophys. R. Lett., **24**, 453–456