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Extragalactic Radio Source Selection for Radio/Optical Frame Ties

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Abstract

Future space–based optical astrometric satellite missions present the possibility of directly linking the radio and optical reference frames at the micro–arcsecond level. We have evaluated the current database of radio observations of the extragalactic objects which make up the International Celestial Reference Frame to determine the optimum candidates, in terms of their radio properties, for use as radio/optical frame tie sources. We suggest that the radio astrometric quality as described in this paper can be applied to the next realization of the ICRF.

1. Introduction

In the next decade, there will be significant advances in the area of space–based optical astrometry. Current or planned missions will be able to determine the positions of stars with a precision approaching the micro–arcsecond level. Measurements at this level of precision will allow the determination of astronomical distances with unprecedented accuracy. To achieve these goals, these mission will need to construct their own precise reference frames, as no previous astrometric observations have ever achieved the planned level of accuracy. To maximize their utility to the entire astronomical community, these astrometric grids will also need to be anchored to the quasi–inertial celestial frame defined by extragalactic objects – currently the International Celestial Reference Frame (ICRF).

We use radio astrometric and ancillary data to evaluate ICRF objects in terms of their suitability for use as radio/optical frame tie sources. These data include radio source position uncertainties derived from least–squares astrometric analyses of VLBI observations taken from the USNO astrometric/geodetic database, radio source positional stability information also derived from least–squares astrometric analyses, and intrinsic radio source structure information obtained from Very Long Baseline Array observations. Using these data, each source is evaluated and graded (with respect to all other sources) to obtain an estimate of their radio astrometric quality and hence their suitability as possible frame tie objects. Optical information on the radio objects is currently limited to estimates of the redshift and visual magnitude of their optical counterparts.

Additional details concerning this investigation and a complete description of the analysis can be found in Fey et al. (2001, AJ, 121, 1741).

2. Criteria for Estimating Radio Astrometric Quality

Criteria for estimating radio astrometric quality are listed below along with their relative weight in the combination (see Section 3).

- (1.0) position uncertainty – the right ascension and declination formal uncertainties from least–squares global SOLVE solutions
- (1.0) position stability – weighted root–mean–square uncertainty estimates in right ascension and declination from "arc" position time series
- (0.5) compactness – source spatial extent as measured from X–band radio images
- (0.5) structure index – an estimate of the contribution of intrinsic structure to the measured group delay

3. Application of Criteria for Radio Astrometric Quality

Rather than defining categories and setting cutoffs for inclusion in a particular category (eg. in the construction of the ICRF, all sources with position uncertainties less than or equal to 1 mas were considered for inclusion in the defining category), each source is evaluated and graded individually for each selection criteria, usually on a scale from 1 to 10. The individual scores based on each selection criteria are then totaled for each source, resulting in an estimate of their radio astrometric quality.

For example, the distribution of position formal uncertainties in right ascension is divided into 10 approximately equal number bins, i.e., bins are defined such that each bin has an approximately equal number of sources. The sources in each bin are then given a score from one to ten, with the sources having the smallest formal uncertainties receiving the highest score and the sources with the largest formal uncertainties receiving the lowest score. The same procedure is repeated for the other criteria with the appropriate weighting as listed in Section 2.

The final step is to sum the score for each source. Because sources with no structure information (either radio compactness or structure index) are essentially not evaluated for these criteria (they receive no score so the maximum possible score is different than for those sources with structure information), they are consequently on an absolute scale different from those sources for which this information is available. Thus, we normalize the total score for each source to a scale ranging from zero (for the worst astrometric sources) to one hundred (for the best astrometric sources). The resulting score is our estimate of radio astrometric quality. The distribution of radio astrometric quality for 392 ICRF sources taken from Fey et al. (2001, AJ, 121, 1741) is shown in Figure 1.

4. Source Selection for Radio/Optical Frame Ties

Future space–based optical astrometric satellite missions present the possibility of *directly* linking the radio and optical reference frames through mutual observations of extragalactic objects. For the particular case of the Space Interferometry Mission (SIM), the limiting magnitude will be about $m_v \approx 21$. However, the optical counterparts of the extragalactic radio sources ideally should be brighter than about $m_v \leq 18$ to minimize on–source integration time. The distribution of visual magnitudes for the potential ICRF link sources is shown in Figure 2. About half of the available sources are bright enough for SIM to observe efficiently. However, in addition to optical brightness, the candidate link sources should also have a high radio astrometric quality.

Shown in Figure 3 are the 50 optically brightest sources having the highest radio astrometric quality with the additional criterion that 25 sources are selected from the Southern Hemisphere independent of the 25 selected in the Northern Hemisphere. These objects represent our current

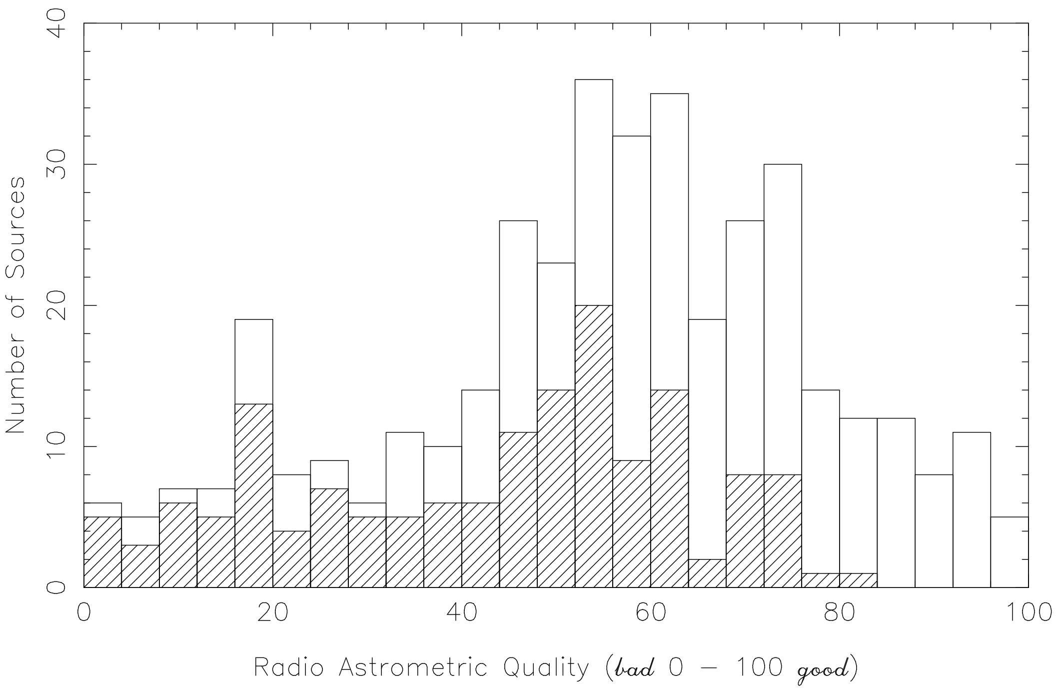

Figure 1. Distribution of radio astrometric quality for 392 ICRF sources taken from Fey et al. (2001, AJ, 121, 1741). The astrometric quality ranges from zero for the worst astrometric sources to 100 for the best astrometric sources. Sources with declinations south of the Celestial Equator are shown hatched. The median of the distribution is 57.

best attempt to construct the most suitable list of ICRF sources for a SIM radio/optical frame tie. Examination of this figure shows a fairly uniform distribution of sources on the sky, but at the cost of having significantly lower radio astrometric quality sources in the Southern Hemisphere (median 57) compared to those in the Northern Hemisphere (median 87).

5. Summary

The ideal situation for a radio/optical frame tie would be to observe as many extragalactic objects as possible to minimize systematic errors. However, with finite SIM mission time, the amount of observations dedicated to the frame link will be limited. Even with these limitations, a reasonably accurate frame link can still be achieved. For example, using 50 sources will result in a frame tie accuracy in one coordinate on the order of $0.25\ \mathrm{mas}/\sqrt{50} \approx 35\ \mu\mathrm{as}$ (assuming the SIM mission reaches the expected μas level for extragalactic objects).

We have attempted to construct a suitable set of frame tie sources but found a significant deficit of candidate sources in the Southern Hemisphere. More radio observations are required, particularly in the Southern Hemisphere. In addition, we conclude that the ICRF will limit the accuracy of any radio/optical frame tie based on future optical astrometric satellite observations if the projected accuracies for these missions are realized.

Finally, we suggest that the radio astrometric quality as described in this paper can be applied to the next realization of the ICRF.

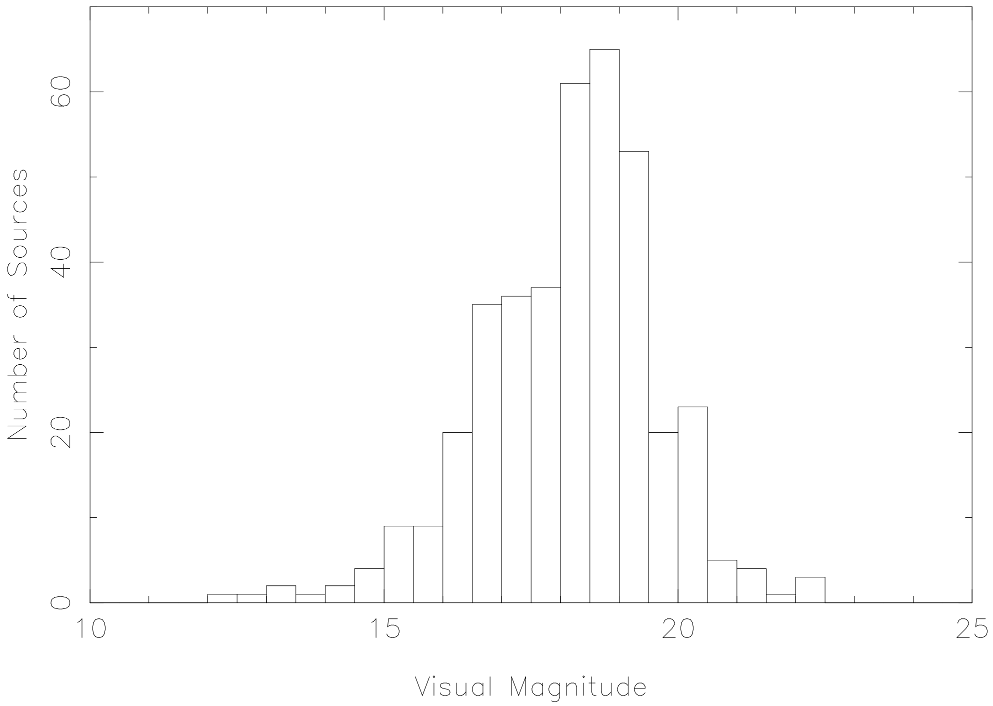

Figure 2. Distribution of visual magnitude for the optical counterparts of 392 ICRF sources listed in Fey et al. (2001, AJ, 121, 1741). The median of the distribution is $m_v = 18.1$.

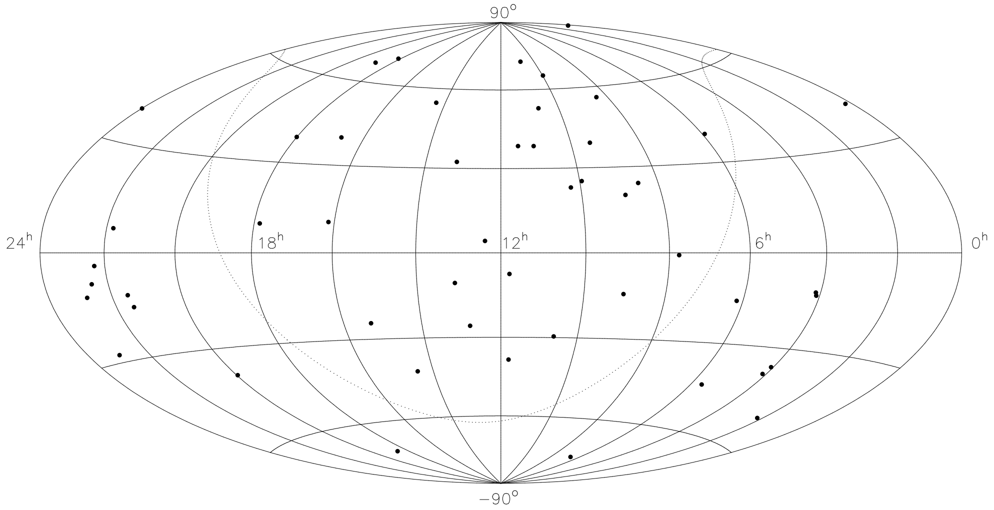

Figure 3. Distribution of the 25 Northern Hemisphere and the 25 Southern Hemisphere ICRF sources listed in in Fey et al. (2001, AJ, 121, 1741) selected independently as having the highest astrometric quality and $m_v \leq 18.0$, plotted on an Aitoff equal area projection of the celestial sphere. The dotted line represents the Galactic equator.