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A Proposed Astrometric Observing Program for Densifying the ICRF in the Northern Hemisphere

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Abstract

The International Celestial Reference Frame (ICRF) could be of significant importance to the astronomy community for observing weak objects angularly close to ICRF sources with the phase-referencing technique. However, the current distribution of the ICRF sources is found to be largely non-uniform, which precludes the wide use of the ICRF as a catalog of calibrators for phase-referencing observations. We show that adding 150 new sources at appropriate sky locations would reduce the distance to the nearest ICRF source for any randomly-chosen location in the northern sky from up to 13° to up to 6°, close to the requirement of the phase-referencing technique. Accordingly, a set of 150 such sources, selected from the Jodrell Bank–VLA Astrometric Survey and filtered out using the Very Long Baseline Array Calibrator Survey, has been proposed for observation to the European VLBI Network (EVN) extended with additional geodetic stations. The use of the EVN is essential to this project since most of the new sources will be weaker and thus difficult to observe with standard geodetic networks.

1. Scientific Objectives

The International Celestial Reference Frame (ICRF) (Ma *et al.* 1998), the most recent realization of the VLBI celestial frame, is currently defined by the radio positions of 212 extragalactic sources distributed over the entire sky. These "defining" sources set the initial direction of the ICRF axes and were chosen based on their observing histories with the geodetic networks and the stability and accuracy of their position estimates. The highest quality positions in the ICRF are accurate at the 0.25 milliarcsecond (mas) level. In addition, positions for 294 less observed candidate sources and 102 other sources unsuitable for defining the frame at this level of accuracy were given, primarily to densify the frame and make it more accessible. The first maintenance and extension of the ICRF, ICRF-Ext.1, provides positions for 59 newly observed sources and refines the positions of candidate sources from additional observations (IERS 1999).

Despite its stated accuracy, the ICRF suffers from a deficit of sources with an average of only one object per $8° \times 8°$ on the sky, which is a limitation for attaching other reference frames (e.g. at optical wavelengths) to the ICRF. Moreover, the distribution of the 667 ICRF-Ext.1 sources is found to be largely non-uniform (see e.g. the northern-sky distribution in Fig. 1). For example, the distance to the nearest ICRF source for any randomly-chosen sky location is up to 13° in the northern sky and 15° in the southern sky. This precludes the use of the ICRF as a

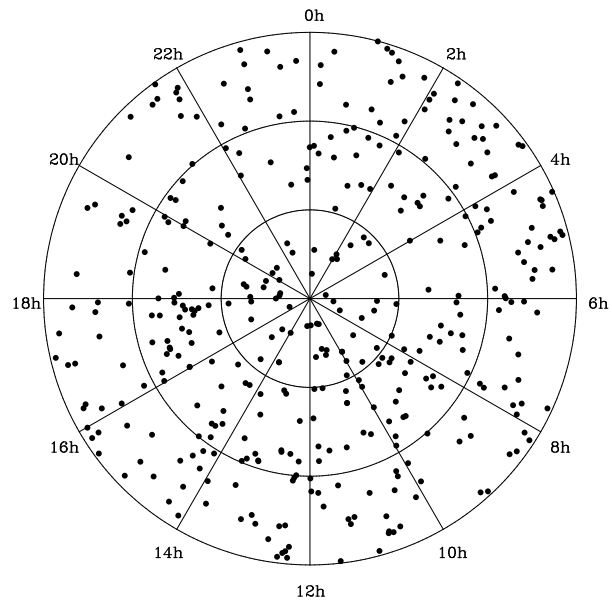

Figure 1. Northern-sky distribution of the ICRF-Ext.1 sources in polar coordinates. The outer circle corresponds to a declination of 0° while the inner central point is for $\delta = 90°$. The intermediate circles correspond to declinations of 30° and 60°.

catalog of calibrators serving as fiducial points to determine the relative positions of nearby weaker objects (radio stars, pulsars, weak quasars) with the phase-referencing technique (e.g. Lestrade *et al.* 1990), because the separation between the calibrator and the target source should be a few degrees at most in such observations. The non-uniform source distribution also makes it difficult to assess and control any local deformations in the ICRF. Such deformations might be caused by tropospheric propagation effects and the apparent motions of the sources due to variable intrinsic structure (see Ma *et al.* 1998).

The primary objective of our proposed observing program is to densify the ICRF using an approach that will also improve the overall sky distribution of the sources. A secondary objective is to identify new sources of high astrometric value which could potentially be used as defining sources in a further future realization of the ICRF. For this reason, the newly selected sources will be required to have no or limited extended structure to ensure the highest possible astrometric accuracy. The proposed observing program, as described below, will focus on the northern sky to take advantage of the existing standard VLBI networks like the European VLBI Network (EVN) and the Very Long Baseline Array (VLBA).

2. Strategy for Selection of New Sources

The approach used for selecting new sources to densify the ICRF was to fill first the "empty" regions of the sky. The largest such region for the northern sky is located near $\alpha = 22$ h 05 min, $\delta = 57°$, where no ICRF source is to be found within 13°. A new source should thus be preferably added in that part of the sky. By using this approach again and repeating it many times, it is then possible to progressively fill the "empty" regions of the sky and improve the overall ICRF

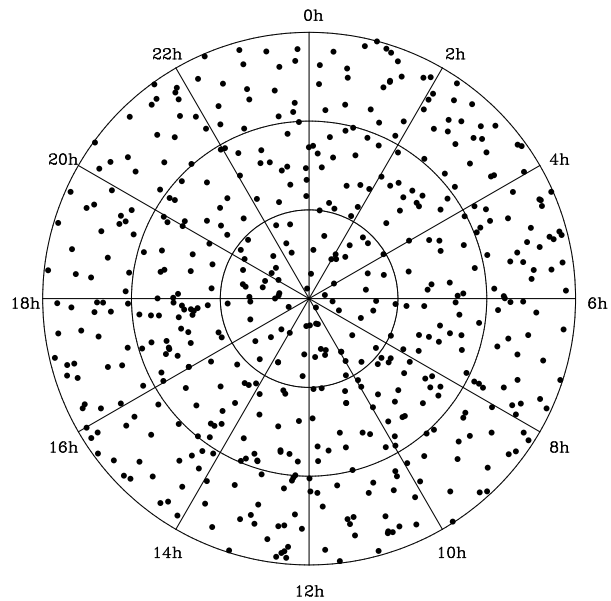

Figure 2. Northern-sky distribution of the ICRF-Ext.1 sources together with the additional 150 proposed new sources in polar coordinates. The outer circle corresponds to a declination of 0° while the inner central point is for $\delta = 90°$. The intermediate circles correspond to declinations of 30° and 60°.

source distribution. The input catalog for selecting the new sources to observe was the Jodrell Bank–VLA Astrometric Survey (JVAS) which comprises 2118 compact radio sources distributed over all the northern sky (Patnaik *et al.* 1992, Browne *et al.* 1998, Wilkinson *et al.* 1998). Each JVAS source has a peak flux density at 8.4 GHz larger than 50 mJy at a resolution of 200 mas, contains 80% or more of the total source flux density, and has a position known to an rms accuracy of 12–55 mas. For every "empty" region in ICRF-Ext.1, all JVAS sources within a radius of 6° (about 10 sources on average) were initially considered. These sources were then filtered out using the VLBA calibrator survey (Peck & Beasley 1998) to eventually select the source with the most compact structure in each region. The VLBA calibrator survey is an ongoing program to image all JVAS sources with milliarcsecond resolution at 2.3 GHz and 8.4 GHz.

The results of this iterative source selection scheme show that 30 new sources are required to reduce the distance to the nearest ICRF source from up to 13° to up to 8°. Another 40 new sources would further reduce this distance to a maximum of 7° while for a maximum distance of 6°, approximately 150 new sources should be added to ICRF-Ext.1. Carrying this procedure further, it is found that the number of required new sources doubles for any further decrease of this distance of 1° (approximately 300 new sources for a maximum distance of 5° and 600 new sources for a maximum distance of 4°) with the limitation that the JVAS catalog is not uniform enough to fill all the regions below a distance of 6°. Based on these results, the choice of 150 new sources to add to the ICRF appears to be a good compromise between the amount of VLBI observing time required and the improvement of the source distribution. With at least one source within 6° of any target in the northern sky, the proposed densified ICRF catalog is much improved (see Fig. 2) and would be especially useful as a catalog of reference sources for phase-referenced VLBI observations of weak objects.

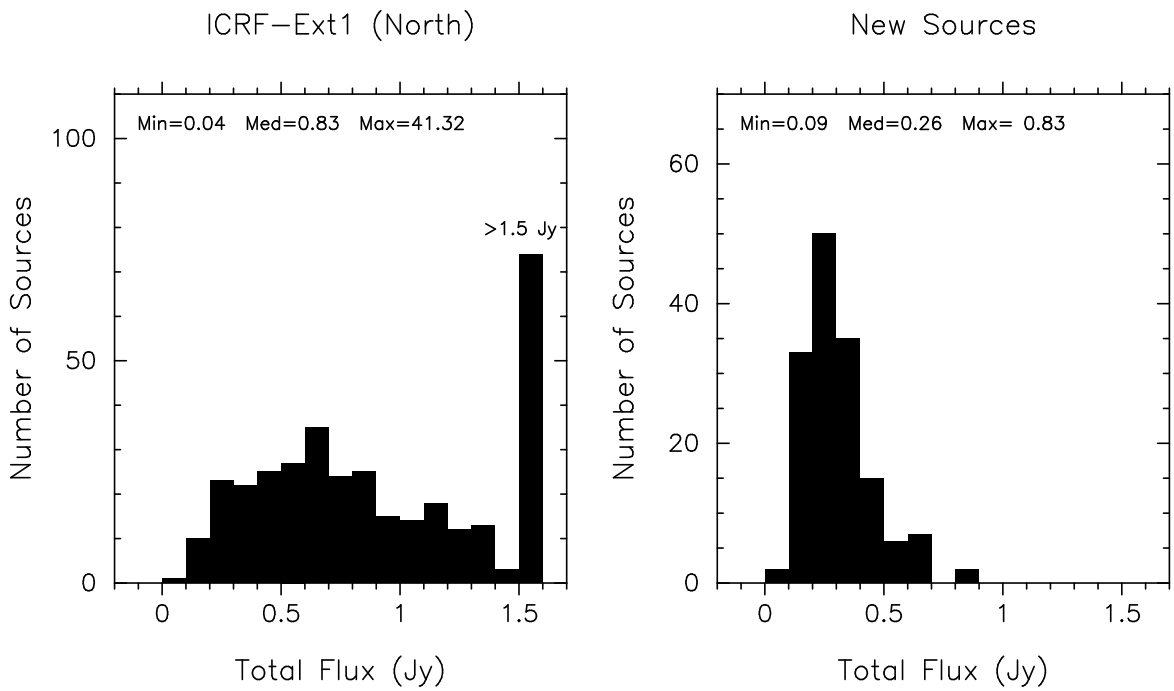

Figure 3. Comparison of the total flux of the ICRF-Ext.1 sources (left) with that of the 150 new sources proposed for densification of the ICRF (right). The total flux values are from the JVAS catalog and were measured at 8.4 GHz. All ICRF-Ext.1 sources present in the JVAS catalog (341 sources out of a total of 392 northern sources) are included. The minimum, median and maximum of the total flux values are indicated in each panel.

3. Proposed VLBI Observing Program

The goal of our observing program is to determine the VLBI astrometric positions of the first 150 sources selected above for possible inclusion of these sources in a further future extension of the ICRF. A comparison of the total flux of these new sources with that of the current ICRF sources (Fig. 3) indicates that the new sources are much weaker (median total flux of 0.26 Jy against 0.83 Jy for the ICRF-Ext.1 sources). For this reason, we have considered using the EVN, which includes large radio telescopes like the 100 m Effelsberg antenna, for carrying out these observations. Additional non-EVN geodetic stations will also be added to increase the baseline length. In particular, the external stations of Algonquin Park (Canada), Hartebeesthoek (South-Africa) and Ny Ålesund (Spitsbergen) have been contacted and agreed to participate in such observations.

The proposed observing strategy will consist in observing about 50 new sources in each experiment of 24-hr duration, and repeating the observation of each source three times over a time scale of two years to ensure the position accuracy required for inclusion in the ICRF (see Ma *et al.* 1998). Our observing program will therefore require a total of nine 24-hr experiments for completion. The new sources will be scheduled jointly with a set of 10 highly-accurate ICRF sources so that their positions can be linked directly to the ICRF. Accordingly, a proposal has been submitted to the

EVN for carrying out these observations, with the initial request consisting of a single experiment to first demonstrate the feasibility of this project. This initial request has been approved and the proposed experiment is planned for May-June 2000. For the future, we are also considering using the global VLBA+EVN network to observe all the 150 new sources at once, which would reduce the amount of observing time required for this project. This observing strategy, however, needs to be further studied, especially in terms of scheduling feasibility.

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