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Status of the International Celestial Reference Frame

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Abstract

There have been two extensions (updates) of the ICRF since its initial definition in 1998. The primary objectives of extending the ICRF were to provide positions for the 109 extragalactic radio sources observed since the definition of the ICRF and to refine the positions of candidate and other sources using additional observations. A secondary objective was to monitor sources to ascertain whether they continue to be suitable for use in the ICRF. Positions of the ICRF defining sources have remained unchanged. Improved positions and errors for the candidate and other sources were estimated and reflect the changes in the data set and the analysis. The 109 new sources were added with ICRF coordinates. A brief overview of the current observing programs contributing to the maintenance and extension of the ICRF will also be presented.

1. Introduction

At the XXIII General Assembly of the International Astronomical Union (IAU) held on 20 August 1997 in Kyoto, Japan, the International Celestial Reference Frame (ICRF) [1] was adopted as the fundamental celestial reference frame. As a consequence, the definitions of the axes of the celestial reference system are no longer related to the equator or the ecliptic but have been superseded by the defining coordinates of the ICRF. The ICRF is currently defined by the radio positions of 212 extragalactic objects obtained using the technique of Very Long Baseline Interferometry (VLBI) at frequencies of 2.3 and 8.4 GHz over the past 20+ years. The ICRF has now replaced the FK5 optical catalog as the fundamental frame and is the realization of the International Celestial Reference System (ICRS) [2] at radio wavelengths. The HIPPARCOS catalog [3] is the realization of the ICRS at optical wavelengths [4].

2. A Brief ICRF Time Line

- 1988: The IAU sets up working groups to establish a new reference frame.
- 1991: The IAU establishes the theoretical basis for a new reference frame.
- 1994: The IAU defines the ensemble of fiducial points for a new reference frame as extragalactic objects.
- 1995: A sub-group of the IAU Working Group on Reference Frames is tasked to construct a new reference frame based on VLBI observations of quasars.
- 1997: The IAU establishes the ICRS and adopts the ICRF.
- 1998: On January 1st, the ICRF replaces the FK5 optical catalog as the fundamental celestial reference frame.

- 1999: The first extension of the ICRF, ICRF-Ext.1, is completed adding 59 new radio sources with ICRF coordinates.
- 2002: The second extension of the ICRF, ICRF-Ext.2, is completed adding 50 new radio sources with ICRF coordinates.

3. The ICRF

The ICRF is currently defined by the radio positions of 212 extragalactic objects. The radio positions are based upon a general solution for all applicable dual frequency 2.3 GHz and 8.4 GHz Mark III VLBI data available through the middle of 1995 consisting of 1.6 million pairs of group delay and phase delay rate observations. The positional accuracy of the ICRF sources is better than about 1 mas in both coordinates. The ICRF "defining" sources set the direction of the ICRS axes and were chosen based on their observing histories and the stability and accuracy of their position estimates. In addition to the 212 defining sources, positions for 294 less observed "candidate" sources along with 102 less suitable "other" sources were also given by [1] to densify the frame. The final orientation of the frame axes was obtained by a rotation of the positions into the system of the International Celestial Reference System (ICRS) [2] and is consistent with the FK5 J2000.0 optical system, within the limits of the latter system accuracy. The sky distribution of the 608 ICRF sources is shown in Figure 1. The sky distribution of the ICRF Defining sources is shown in Figure 2.

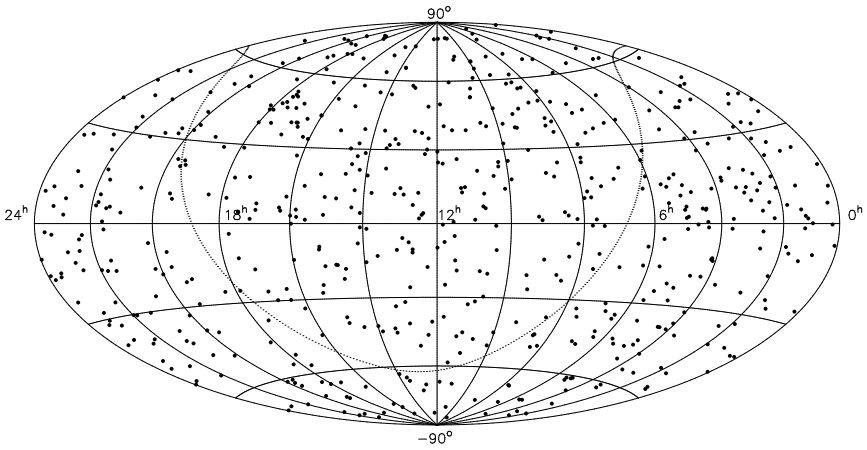

Figure 1. Distribution of the 608 ICRF sources on an Aitoff equal-area projection of the celestial sphere. The dotted line represents the Galactic equator.

4. ICRF-Ext.1

The primary objectives of extending the ICRF were to provide positions for extragalactic radio sources observed since the definition of the ICRF and to refine the positions of candidate and other sources using additional observations. A secondary objective was to monitor sources to ascertain whether they continue to be suitable for use in the ICRF.

The data added to the ICRF in ICRF-Ext.1 [5] spanned December 1994 through April 1999

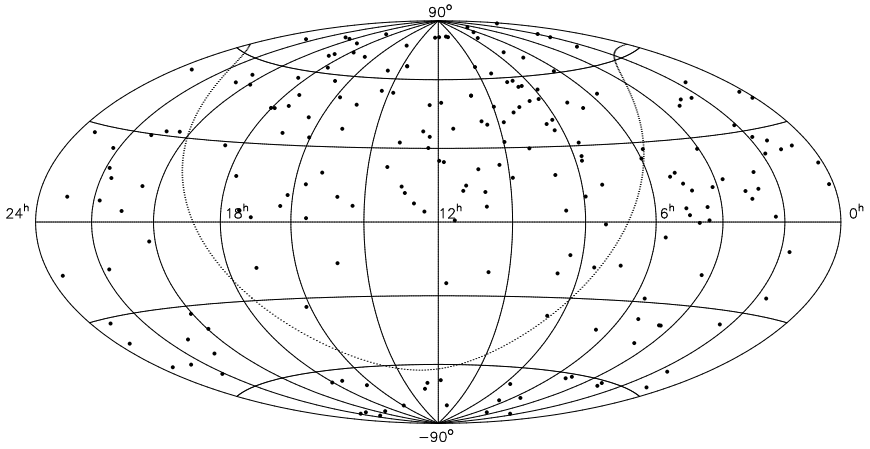

Figure 2. Distribution of the 212 ICRF Defining sources on an Aitoff equal-area projection of the celestial sphere. The dotted line represents the Galactic equator.

and were obtained from both geodetic and astrometric observing programs. Approximately 0.6 million new observations from 461 sessions were added. There were 59 new sources. The positions and errors for the defining sources were unchanged from the ICRF. Improved positions and errors for the candidate and other sources were estimated and reflect the changes in the data set and the analysis. (While the coordinates of individual sources may change to better match the available observations, the IAU recommendation adopting the ICRF states that any updates of the ICRF will keep the same coordinate axes by means of a statistical no-net-rotation condition.) The 59 new sources were added with ICRF coordinates. The distribution on the sky of the new sources is shown in Figure 3.

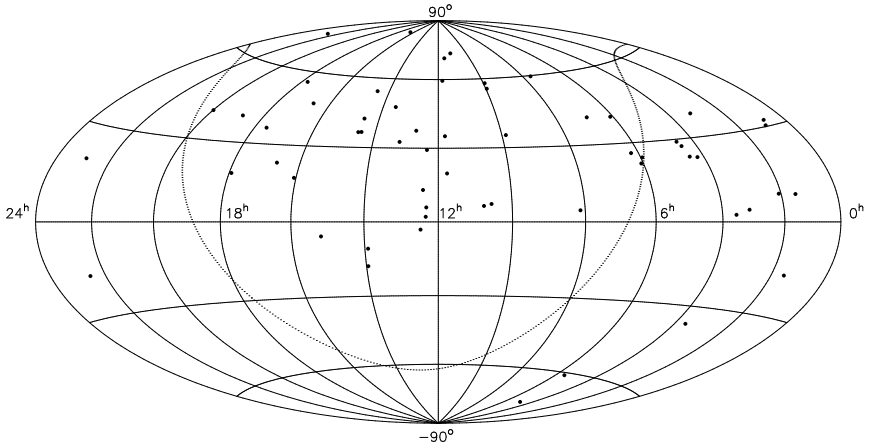

Figure 3. Distribution of 59 new sources in ICRF-Ext.1 on an Aitoff equal-area projection of the celestial sphere. The dotted line represents the Galactic equator.

5. ICRF-Ext.2

The data added to the ICRF in ICRF-Ext.2 [6] spanned May 1999 through May 2002 and were obtained from both geodetic and astrometric observing programs. Approximately 1.2 million new observations from approximately 400 sessions were added. There were 50 new sources. The positions and errors for the defining sources were unchanged from the ICRF. Improved positions and errors for the candidate and other sources were estimated and reflect the changes in the data set and the analysis. The 50 new sources were added with ICRF coordinates. The distribution on the sky of the new sources is shown in Figure 4.

ICRF-Ext.2 marks a milestone in that it utilizes all available Very Long Baseline Array (VLBA) RDV data. The VLBA RDV data is obtained through a collaborative program of geodetic and astrometric research between the U.S. Naval Observatory (USNO), the Goddard Space Flight Center (GSFC) and the National Radio Astronomy Observatory (NRAO). A total of over 652 000 delay observations (almost 20% of all available observations!) from 30 VLBA geodesy/astrometry sessions were included in the ICRF-Ext.2 solution.

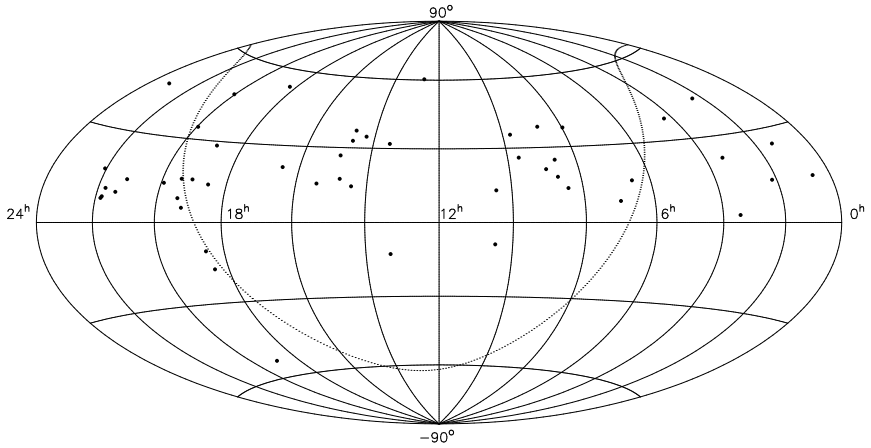

Figure 4. Distribution of 50 new sources in ICRF-Ext.2 on an Aitoff equal-area projection of the celestial sphere. The dotted line represents the Galactic equator.

6. ICRF Maintenance

The IAU has charged the International Earth Rotation and Reference Systems Service (IERS) with the maintenance of the ICRF. Maintenance activities are run jointly by the IERS ICRS Product Center and the International VLBI Service (IVS).

The IERS ICRS Product Center is directly responsible for the maintenance of the ICRS and ICRF. The Center is run jointly by the Observatoire de Paris and the USNO. More information can be obtained from the Product Center Web page at `http://www.iers.org/iers/pc/icrs/`.

The IVS is an international collaboration of organizations which operate or support VLBI. The IVS provides a service which supports geodetic and astrometric work on reference systems, Earth science research, and operational activities. Many of the observing programs for maintenance of the ICRF are coordinated by the IVS. More information about the IVS can be obtained from the IVS Web page at `http://ivscc.gsfc.nasa.gov/`.

6.1. Observing Programs for ICRF Maintenance

The following observing programs are among those that contribute astrometric data for maintenance of the ICRF.

- **IVS CRF Experiments:** These 24^{hr} duration VLBI experiments, coordinated by the IVS, concentrate primarily on observation of southern hemisphere ICRF sources for monitoring and to increase the sky density of ICRF defining sources.
- **VLBA RDV Experiments:** These 24^{hr} duration VLBI experiments are part of a collaborative program of geodetic and astrometric research between the USNO, GSFC and NRAO. VLBA RDV experiments concentrate primarily on observation of northern hemisphere ICRF sources ($\delta > -30°$). Intrinsic source structure information is also obtained from these experiments.
- **IVS Geodetic/Astrometric Experiments:** These 24^{hr} duration VLBI experiments, coordinated by the IVS, concentrate primarily on observation of sources for geodetic purposes and for Earth Orientation Parameter estimation but are also useful for astrometric purposes.
- **VLBA Calibrator Surveys:** These 24^{hr} duration VLBI experiments are part of a joint NRAO/GSFC program to expand both the list of high quality geodetic sources and the list of phase reference calibrators for imaging.
- **EVN Experiments:** These 24^{hr} duration VLBI experiments are part of a Bordeaux Observatory program to expand the list of ICRF defining sources in the northern hemisphere using the European VLBI Network (EVN).
- **LBA:** These 24^{hr} duration VLBI experiments using the Australia Telescope National Facility (ATNF) Long Baseline Array (LBA) are part of a joint USNO/ ATNF program to expand the list of ICRF defining sources in the southern hemisphere. Intrinsic source structure information is also obtained from these experiments. Astrometric results for 22 sources are now available [7].

References

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[7] Fey, A. L., et al. 2004: "Accurate Astrometry of 22 Southern Hemisphere Radio Sources," AJ, accepted for publication