THE EXTRAGALACTIC RADIO/OPTICAL REFERENCE FRAME

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1.0 INTRODUCTION

The celestial positions of extragalactic radio sources may be determined to a precision of less than a milliarcsecond. Further, since these sources are believed to be at great distances from the galaxy, little or no proper motion is expected on scales of order a milliarcsecond. Therefore a reference frame based on the positions of carefully selected sources so that display compact radiation on scales less than a milliarcsecond will noticeably improve the precision of present celestial reference frames. If the radio objects making up the reference frame also emit radiation at optical wavelengths, and assuming the optical/radio radiation is coincident, the radio frame can update the optical frame to the accuracy of the individual optical positions.

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The IAU Working Group on the Radio/Optical Reference Frame, formed by Commission 24 in 1978, has as its charter to draw up a list of suitable candidates. A candidate list of 234 sources was drawn up with their positions based on a weighted mean by error of 9 radio catalogs and had an average accuracy better than 0.01 arcsec (Argue et al. 1984).

A program to establish a radio/optical reference frame was undertaken in 1987 and is described in IAU Symposium 129 (Johnston et al. 1987). This program has as its goal the establishment of a reference frame based on the radio/optical positions determined for 400 sources uniformly distributed over the entire celestial sphere. These sources are to be compact in their radio/optical emission. They should be brighter than visual magnitude 19 and have a total flux density greater than 1 Jy at 5 GHz. The method of construction of the reference frame is to adopt the radio positions as the reference positions of the frame and upgrade the optical frame by adopting the radio positions. In particular this program will provide a major contribution to the absolute orientation of the anticipated HIPPARCOS stellar net currently under observation.

2.0 SOURCE SELECTION

The first step is the selection of appropriate sources that have compact emission at radio wavelengths. The spatial distribution of these sources is to be one every 100 square degrees.

At the initiation of this program in 1987 there was a much greater knowledge of the characteristics of compact radio sources in the northern hemisphere. This was simply due to the large number of VLBI facilities and organized VLBI networks such as the US Network and the European VLBI Network as well as extensive observing campaigns by NASA's Crustal Dynamics Program using numerous telescopes. There were approximately eighty sources north of the equator and forty sources south of the equator with positions of order a few milliarcseconds. However, no attempt was made in the programs which determined these positions to identify them and determine whether they had optical counterparts.

One of the primary tasks currently underway is the selection of the 400 sources with the appropriate radio/optical emission for the reference frame. We are currently sorting the sources into 3 lists -- primary, preliminary, and proposed sources -- which are described in detail at this meeting in Russell et al. The preliminary sources need further data and must be checked for source structure. The proposed sources have not been observed yet, but will be used as a list of candidates from which to fill in the sparse areas of the global distribution.

As of this meeting, the lists of primary, preliminary and proposed candidates contain 220, 139 and 160 sources, respectively. Many sources are also listed which will not be suitable for the reference frame because of problems with radio structure, optical magnitudes which are too faint, no identifiable optical counterparts, etc. The refinement of the lists will continue until the final catalog is completed, but we expect to have finished sorting sources into these lists by the time of the Twenty-First IAU General Assembly in 1991.

3.0 OBSERVING PROGRAM

The radio positions are determined using Very Long Baseline Interferometry (VLBI). All observations are made using the Mark III VLBI recording system and at two frequencies spanning S and X Bands. Stations in the northern hemisphere that have been employed in this program have been Green Bank and Maryland Point on the east coast of the U.S., Hat Creek on the West Coast of the U.S., Fairbanks, Alaska for a northern site and Hawaii for a far western site. Observations of the northern sources are made annually. In the southern hemisphere, the stations are Tidbinbilla, Australia, Hobart, Tasmania and Hartebeesthoek South Africa. Because of the limited resources available, the southern sources are not observed as often but whenever possible. The precision for the VLBI observations is 1 mas in the northern hemisphere and 2 to 10 mas in the southern hemisphere due to the limited observations and system calibration.

The optical program determines the position of the extragalactic radio source via a minimum of two long focus plates obtained with a 4 meter class prime focus telescope for the fainter sources of visual magnitude greater than 18, or various R.C. telescopes, as for example the Calar Alto 2.2 m for the brighter sources. The telescopes must have an astrometrically useable field of 30 arcminutes diameter to provide the necessary density of secondary reference stars, mainly in the magnitude range 12-15. A major problem is the modeling of the large optical distortion of most prime focus correctors. The system of secondary reference stars for each extragalactic source field is obtained from four wide field astrograph plates.

The prime focus plates allow the determination of the position relative to the "local" field stars located within one degree of the object. The astrograph plates

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with a field of approximately five degrees on a side make it possible to determine the relationship of the "local" field stars to FK5 system via the IRS reference stars. The average precision of the optical source positions is 10 to 50 mas.

The prime focus telescopes currently used are the Kitt Peak 4m, the AAT 3.9m and ESO 3.6m. The astrographs are the Hamburg Observatory astrograph, the USNO astrograph at Black Birch Astronomical Observatory and the Lick Observatory 20 inch astrograph. All astrographs are used in the yellow spectral range, as provided by 103aG+OG515 plate-filter combination (Hamburg and Lick) and 103aG+GG495 (Black Birch). Typically about 70-100 secondary reference stars inside a 1x1 degree field centered at the source position are measured. Based on 4 plates, the accuracy of a single reference star position is about 0.06 arcsec. In addition to the photographic plates deep CCD images are taken to evaluate possible optical structure, particularly for low redshift sources.

The source list is about 65% quasars, 10% BL Lac's and 10% compact galaxies; the remainder are unidentified or empty fields. The present distribution covers the whole sky, with slightly more sparse coverage in the south and with the largest gaps along the galactic plane. The unidentified sources are at present carried in the program until their identifications are made or, if not they will be removed from the program.

4.0 PRESENT STATUS

The source positions are adopted from the radio. The data are the Mark III group delays and phase delay rates. In the data reduction of the radio observations (Ma et al. 1990) the IAU sanctioned definitions of precession, sidereal time (J2000.0) and nutation (IAU 1980), and the PEP ephemeris for the solar system model are used. The troposphere is calibrated using the CfA 2.2 model or the Chao model. The differential pathlength due to the ionosphere is calibrated out by use of simultaneous dual frequency S/X observations. The cable delays in the systems are calibrated using a phase calibration signal at each site. Source positions are solved for globally, while site positions, nutation offsets in longitude and obliquity, clock offsets, zenith atmosphere delays and rates solved for. From the individual data bases, a reference date of 1980 October 17 is presently being used (Ma et al. 1990).

The first portion of the radio/optical data was published in Ma et al. (1990) and was based on the geodetic data available from the data base maintained at the Crustal

Dynamics Project (CDP). The zero point of right ascension was established from optical positions of 28 quasars determined on the system of the FK5, with a precision of about 20 mas. Additional publications in preparation contain additional sources. These publications contain radio positions for 325 sources with an average precision better than 1 mas. By mid-1990 we had obtained VLBI observations of 422 sources, including 69 whose positions are not yet reduced.

In general the optical photographic program has been more difficult to accomplish. Not only have we had to contend with the expected problems of cloudy weather and bad seeing, but the most difficult problem has been the availability of time on large telescopes needed to take the prime focus plates for these faint objects. These large instruments are needed to obtain plates with measurable positions of 19th magnitude objects relative to intermediate reference stars which can be tied to the fundamental system. It is imperative that more large telescope time be made available for this type of astrometric observations. Furthermore the data accumulation on the southern hemisphere has been even more difficult. The number of sources where sufficient source plates, normally 2-4, are available is about 150 on the northern hemisphere and less than 50 on the southern hemisphere at present. We expect substantial improvements from adding the ESO Schmidt telescope to the program on the southern hemisphere although the precise astrometric reduction of Schmidt-type plates is much more complicated.

5.0 ARCHIVAL DATA BASES

Now that a significant fraction of the data for the establishment of the radio/optical reference frame has been obtained, the long term archiving of this data is underway. The primary goal of the archive is to have available at one site and in an accessible format a data base of all of the original data obtained at both the optical and radio wavelengths. This can be easily accomplished with current computer technology, which should continue to improve.

Having centralized data bases for the optical and radio data would allow observations to be rereduced at will. It would avoid all of the problems associated with the formation of compilation catalogs and give future investigators complete flexibility with reference frame work.

The largest current collection of radio data is the Geodetic data base currently maintained by the Crustal Dynamics Project. (We will not include radio observations before about 1980 which were not made at dual frequencies since they cannot be reduced satisfactorily for ionospheric effects.) The U.S. Naval Observatory and the Naval Research Laboratory are beginning a new program to archive and maintain the radio data base, including the CDP collection and the additional astrometric VLBI data available to date. This is described at this meeting in McCarthy et al. With the archive the radio reference frame can be redefined as necessary. Finally the archive will provide a collection of research data for the astrometric community.

A similar data base of optical data is being created at Hamburg Observatory and will be duplicated at the USNO. It will include the original optical plate measurements and CCD frames. With the data centralized and available on-line, any change in the reference star catalog, including the Hipparcos net, can be immediately incorporated by rereduction of the original data.

6.0 FUTURE PLANS

The future plans for the project include finishing the original catalog of 400 sources by 1991. The establishment of the data bases of the original data will allow easy updating of the reference frames in a consistent manner and system when needed, about every 5 years, and allow for continued research in the field without the hazards of depending on compilation catalogs.

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