COMPARISON OF THE OPTICAL AND RADIO REFERENCE FRAMES

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I. INTRODUCTION

The Very Large Array (VLA) has made possible the measurement of the precise positions of the radio emission associated with stars. This allows the direct comparison of the optical reference frame (FK4) with the radio reference frame which is defined by the quasi-absolute positions of extragalactic radio sources. This comparison is limited by the small number of bright stars that display detectable radio emission and the lack of knowledge of the precise coincidence of the radio emission with the optical photocenter of the star. Since the VLA is the most sensitive astrometrically capable radio telescope, positions of the largest number of stars north of declination -20 degrees can be measured. The accuracy of the positions on the extragalactic reference frame should approach a milliarcsecond.

II. CHARACTERISTICS OF THE RADIO EMISSION FROM STARS

The sensitivity of the VLA allows the easy detection of emission at 6 cm wavelength at a level of a millijansky in five minutes integration time. The strongest radio emission associated with stars is typically a few hundred millijansky for a large flaring event on a nearby star such as Algol or the RS CVn binary HR1099. Radio emission is detected in a very heterogeneous sample of stars. There are stars in which there is evidence for enhanced chromospheric activity such as the RS CVn stars which display intense non-thermal radio flares. There are binary systems which contain a widely separated M supergiant and an early B main sequence star. The ultraviolet flux from the B star ionizes the cool wind from the M star, causing a radio emitting plasma cloud of thermal emission. An example of such a star is VV Cep. Thermal radio emission is also associated with early type stars that exhibit stellar winds such as Wolf-Rayet and Of stars. There is also radio emission from close binary star systems consisting of early B stars such as beta Lyr and also late type binary systems having a late type subgiant in contact with its Roche lobe causing extensive mass transfer in the binary system. An example of such a system is Algol. Finally there is emission from other binary systems such as W UMa

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binaries, and other peculiar and highly magnetic stars. The radio emission from these stars is typically of order a few millijanskys. Florkowski et al. (1985) surveyed a total of 35 stars which they believed had radio emission and found that 20 stars emitted enough flux density (1 millijansky or greater) for precise position measurement with the VLA at the epoch of observation. For comparison the typical emission at 6 cm from a well known radio loud quasar is a Jansky.

The stars to be preferred for comparison of reference frames are those which are most likely to have coincident optical photocenters with the radio emission. Those which are most likely to meet this criterion are those with non-thermal flaring emission. If the flares are confined to the stars or the binary systems, the coincidence of the radio and optical emission should be of order 3 milliarcseconds or better. Those stars which display thermal emission due to stellar winds may have very complex radio structure on scales which are large compared to the stellar dimensions. Here the coincidence of the optical and radio photocenters for nearby stars, say within 50 parsecs could be of order the size of the radio emission which is of order an arcsecond. At distances further away from the sun, the coincidence is improved and some of these stars may be of use in comparing the reference frames.

Another type of star, those which display maser emission in their circumstellar envelopes, may be useful. This emission is usually distributed in a volume of diameter ten to one thousand AU centered on the star. This emission consists of small maser spots which are distributed in the stellar envelope and associated with large mass loss from a late type Mira or supergiant star. Models for these envelopes are of an isotropic outflow from the star that may be distorted by turbulence. The spot-like masers map this outflow. Models of the overall emission would probably locate the optical photocenter to an accuracy ranging from a tenth to a hundredth of an arcsecond. The position of the most blue shifted maser feature may be amplifying the photospheric emission and may be coincident with the star. Research is underway to verify this and, if true, these stars could be used to relate the reference frames.

III. ACCURACY AND RESOLUTION

The accuracy with which the radio position of stars has been measured on the radio reference frame is of order 0.03 arcsecond (Johnston et al. 1985a; Florkowski ét al. 1985). These measurements were made with the VLA and are relative to a nearby background extragalactic source. The accuracy with which the position of a source may be measured with the VLA is dependent on the method of observation and integration time. Path length fluctuations caused by water vapor irregularities of scale size kilometers in the troposphere are the main limitation to accuracy. This effect must be averaged out by a series of measurements that are long compared to the atmospheric variations. Short observations of ten minutes duration yield a formal accuracy of 0.1 arcsecond. The present VLA measurements reported by Johnston et al. (1985a) make five or six measurements over a large range of hour angles during a single day. From measurements of the position of HR1099 and UX Ari at eight and seven epochs, a scatter in the positions of 0.03 arcsecond rms is found after removal of the parallax and proper motion from the positions.

The size of the radio emission for large non-thermal flaring events is of order 0.1 AU for the stars HR1099 and UX Ari (Mutel et al. 1984; Lestrade et al. 1984). This directly leads us to believe that the radio emission from RS CVn stars is probably due to gyrosynchrotron emission similar to that of solar flares. This radio emission as already stated should be close to the optical photocenter. The radio emission, which is associated with large plasma clouds due to mass loss from a single star or members of a binary system, is of order one hundred to a thousand AU. This emission may be amorphous and difficult to relate to the optical photocenter at accuracies of an AU. The masers associated with the stellar envelopes of late type Mira and supergiant stars are of individual size an AU or less.

The VLA at 6 cm has a resolution of 0.4 arcsecond in the A configuration. The array contains 27 antennas with spacings from a fraction of a kilometer to 35 kilometers making it sensitive to spatial structures up to size scales of order 30 arcseconds. VLBI measurements have less sensitivity than the VLA and their spatial resolution is of order a milliarcsecond at 6 cm. These measurements promise the detailed mapping of the emission of a few stars at this resolution. This will be very important in determining the precise spatial relationship of the radio and optical emission. The coincidence of radio and optical emission will probably be at the three milliarcsecond level for stars which display non-thermal flaring radio emission. However it will be more important to determine the offsets between the optical and radio reference frames for a large number of stars distributed over the entire sky. Future VLA measurements as well as VLBI should be capable of positional measurements at the milliarcsecond level when relating the stellar radio emission to that of a group of background radio sources symmetrically placed around the star. To obtain a large number of stellar radio positions, the VLA observations are preferred.

IV. PRESENT STATUS

Johnston et al. (1985b) present a preliminary comparison of the optical FK4 and radio reference frames for the northern hemisphere. The optical reference frame of the northern hemisphere is as represented by the AGK3RN catalog. These positions probably have a formal accuracy of 0.05 arcsecond. The accuracy at any epoch will depend upon knowledge of the proper motions of the stars making up the reference frame. The radio reference frame used in this comparison was that defined by the catalog of Witzel and Johnston (1982). This catalog is in B1950 coordinates with the zero point of right ascension defined by the coincidence of the radio and optical emission of 3C273B with the position given by Hazard et al. (1971). The precision of the coordinates is believed to be of order 0.01 arcsecond. The comparison was made in the B1950 system to avoid difficulties in transforming the AGK3RN into the J2000 system.

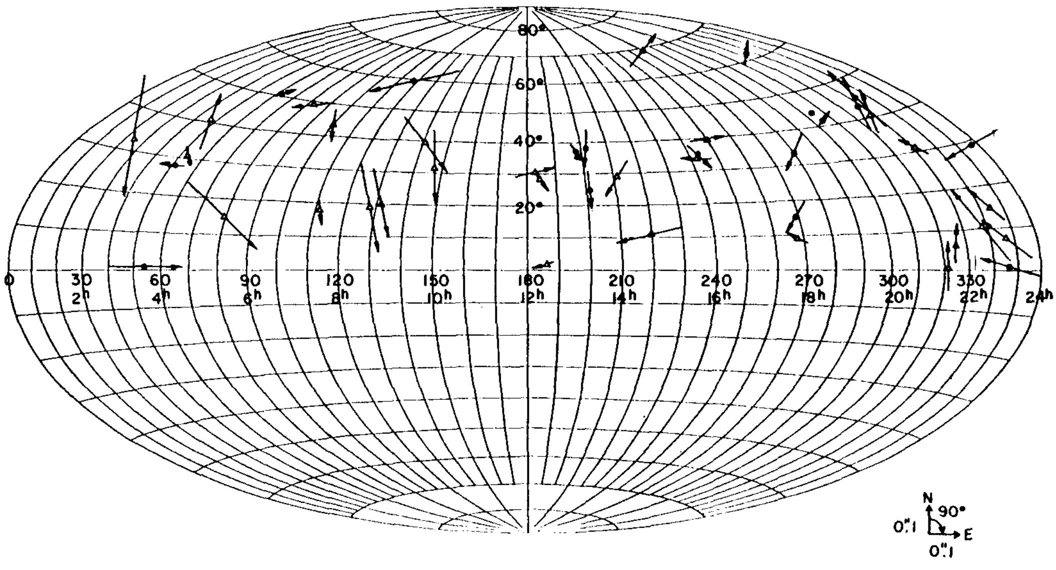

Figure 1. An Aitoff-equal area projection of the sky showing the position of the reference optical/radio sources. The difference between the optical-radio positions are shown as vectors on a superimposed rectangular grid. The directions to the east (increasing R. A.) and north are considered positive. The error bars are about 0".05 in each coordinate. In most parts of the sky, the vectors are aligned, which indicates a close correlation of formal errors in larger sky areas. Some individual points are discrepant; for details see the text.

Seventeen stars in the northern hemisphere were used for this comparison. The radio and optical positions of the stars were measured approximately at epoch 1982. The almost coincident measurement of the radio and optical positions was necessary to reduce the error in the comparison due to our lack of accurate knowledge of the proper motions of the stars. Thus this comparison is a comparison of the FK4 system

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as represented by the AGK3RN catalog with the radio reference frame at epoch 1982. This comparison was also compared with the difference between the optical and radio catalogs based upon the positions of extragalactic sources (de Vegt and Gehlich 1982). There does not appear to be an offset in the right ascension or declination coordinates of the two systems or a rotation between the two systems at a significant level. In figure 1 a two dimensional plot of the difference between optical and radio coordinates for the stars (filled circles) and extragalactic sources (open triangles) are presented as taken from Johnston et al. (1985b). It can be seen that the sky coverage is not adequate to draw contours of the offset between the reference frames. There are abrupt changes in the offset as is evidenced by the change in the offset between 20 hours, forty degrees and 21 hours 30 minutes, forty degrees. The offset changes from (0,0) to (0.1,0.1) in arcsecond. The precision of the comparison is believed to be 0.05 arcsecond. There are offsets as large as 0.3 arcsecond as is the case for HR1099. These offsets in optical - radio positions are due to 1) zonal offsets in the optical reference frame, 2) zonal offsets in the radio reference frame, or 3) structural differences in the optical and radio images causing a shift between the optical and radio centers of emission. The most probable cause of the differences is zonal offsets in the optical reference frame.

V. FUTURE IMPROVEMENTS

From this preliminary work it can be seen that there are many promising future improvements in our knowledge of the reference frames especially the optical. The SRS will hopefully be a reasonable reference frame for the southern hemisphere allowing optical positions at 0.05 arcsecond accuracy. The HIPPARCOS mission will give the relative positions of a large number of stars at the three milliarcsecond level over the entire sky. Future radio measurements will establish a reference frame over the entire sky. At present the accuracy of the radio reference frame is approximately a few milliarcseconds, but is only available for the northern hemisphere. Measurement of the positions of extragalactic radio sources and stars with radio emission are urgently needed before the culmination of the HIPPARCOS program to relate the optical reference frame of HIPPARCOS with the radio reference frame and to eliminate zonal errors that will certainly be present in the ground-based optical measurements. In this way by 1992 a reference frame will be available in the optical and radio spectrum that will allow the comparison of optical images obtained by HST at a resolution of 80 milliarcseconds and radio images obtained by the VLA, the Parkes/Tidbinbilla interferometer and VLBA, which will have resolutions ranging from 1 to 70 milliarcseconds with an accuracy of three milliarcseconds. For radio position measurements below -20 degrees declination, only VLBI measurements and those made with the Australian Telescope (AT) will be available. A significant effort will be necessary to assure that high quality radio measurements will be made for the southern hemisphere.

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