VLA+PT OBSERVATIONS OF 19 RADIO STARS

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ABSTRACT

The link between the HIPPARCOS catalog and the International Celestial Reference Frame was accomplished through Very Long Baseline Interferometry observations of 12 radio stars. The current errors associated with this link are too large to enable milliarcsecond level astrometry between radio and optical images, and notably, the link is actually degrading with time. We present results of observations of 19 radio stars using the Very Large Array as part of a program to obtain improved astrometric parameters for about 50 radio stars and to improve the link between the radio and future optical astrometric (satellite) frames. The study of active stars will benefit significantly from an improved radio/optical link.

INTRODUCTION

The International Celestial Reference Frame (ICRF) is currently defined by the Very Long Baseline Interferometry (VLBI) positions of 212 extragalactic objects [1] and is the International Astronomical Union sanctioned fundamental astronomical position reference frame. The HIPPARCOS catalog serves as the realization of the ICRF at optical wavelengths. The link between the HIPPARCOS catalog and the ICRF was accomplished through observations of 12 radio stars [2]. The standard errors in the alignment of the coordinate axis of the ICRF and Hipparcos frames, at epoch 1991.25, are believed to be 0.6 mas, with a possible rotation between the frames of about 0.25 mas/yr. The errors associated with this link are too large to enable milliarcsecond level astrometry between radio and optical images, and notably, the link is actually degrading with time. Upcoming astrometric satellite missions such as SIM will likely define optical frames with internal accuracies that are better than the extragalactic VLBI frame by an order of magnitude, and these frames may define the next generation ICRF.

We present results of observations of 19 radio stars using the National Radio Astronomy Observatory (NRAO) Very Large Array (VLA) telescope while in the A-configuration in conjunction with the Very Long Baseline Array (VLBA) antenna at Pie Town (PT), New Mexico. These combined VLA+PT observations provide high sensitivity and high resolution at the same time. The observations reported here are part of a long-term program [3][4] to obtain accurate astrometric radio positions, parallaxes, and proper motions for approximately 50 radio stars which can be used to connect the current ICRF to future optical astrometric (satellite) frames. We use the current positions of the 19 stars observed using the VLA+PT link, together with those of previous observations using the VLA from 1978 through 1995, to obtain improved estimates of the proper motions of these 19 stars. We also compare the derived proper motions with the corresponding HIPPARCOS values.

The study of active binary stars will benefit significantly from an improved radio/optical link. For example, no consensus has yet developed concerning the physics of the formation and evolution of the radio emission associated with these active binary star systems. For most active binaries, the location of the radio emission with respect to the binary components is unknown; e.g. is the radio emitting region centered on one of the stars, is it located in the intra–binary region, or does it surround both stars? This uncertainty can be attributed, in part, to inadequacies in the radio/optical frame link. Observations of the isolated chromospherically active stars in our observations will provide equally interesting results. Like the active binary systems, these stars suffer from a lack of knowledge of the position of the radio emission relative to the stellar optical photocenter. For these stars, the registration should be easier since there is no companion.

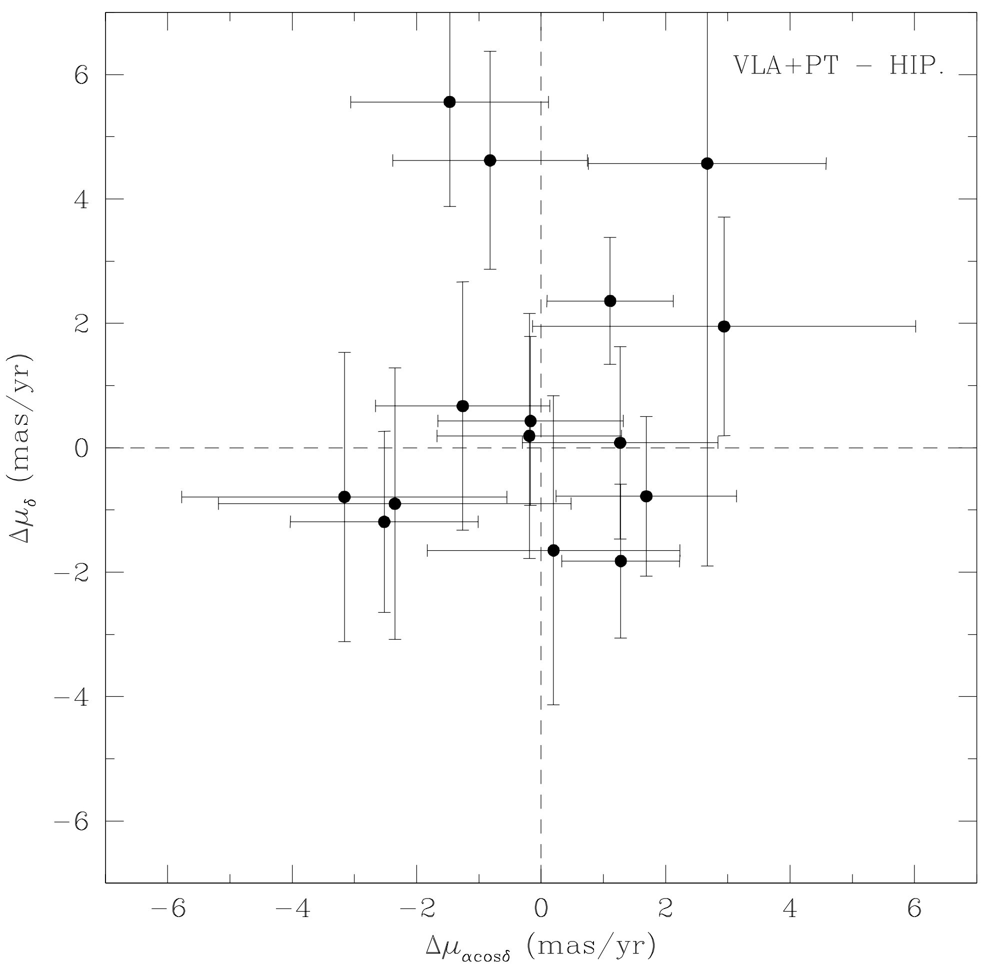

Figure 1: Differences in the proper motions, $\Delta\mu_{\alpha\cos\delta}$ vs. $\Delta\mu_\delta$, between those derived from our VLA+PT observations and those from the HIPPARCOS mission. Values are listed in Table 1.

OBSERVATIONS AND ANALYSIS

The VLA+PT observations occurred over a 24-hour period beginning 10 December 2000 at 06:30 LST. Continuum observations were conducted at X-band at a frequency of 8435.1 MHz using two 50-MHz bandwidth channels with an integration time of 3.3 seconds. For each star, two nearby ICRF reference sources were observed for phase calibration. The input positions for the stars were HIPPARCOS values updated to the epoch of our observations using the HIPPARCOS proper motions and parallaxes. Input positions for the ICRF reference sources were those given in [1]. A fast-switching technique was used to observe each star and its primary phase calibrator in an attempt to mitigate phase fluctuations due to the atmosphere/ionosphere. Over the 24-hour

Table 1: Comparison of radio-star proper motions.

Star	Number of Measurements	VLA Proper Motions		HIPPARCOS Proper Motions	
		$\mu_{\alpha\cos\delta}$ (mas yr^{-1})	μ_δ (mas yr^{-1})	$\mu_{\alpha\cos\delta}$ (mas yr^{-1})	μ_δ (mas yr^{-1})
LSI61303	1	...	...	0.62 ± 1.95	1.63 ± 1.75
Algol	6	3.67 ± 0.55	-3.26 ± 0.87	2.39 ± 0.77	-1.44 ± 0.88
UX Ari	14	38.82 ± 0.54	-105.46 ± 0.54	41.35 ± 1.41	-104.29 ± 1.35
HR1099	13	-31.87 ± 0.41	-161.07 ± 0.52	-32.98 ± 0.93	-163.45 ± 0.88
B Per	5	43.58 ± 2.89	-57.03 ± 2.08	46.59 ± 1.17	-56.43 ± 0.94
T Tau-N	1	...	...	15.45 ± 1.88	-12.48 ± 1.62
α Ori	3	24.17 ± 1.24	10.07 ± 1.81	27.33 ± 2.30	10.86 ± 1.46
HD50896-N	2	-1.19 ± 1.90	9.21 ± 6.43	-3.86 ± 0.43	4.75 ± 0.66
KQ Pup	4	-8.50 ± 1.45	8.07 ± 1.70	-7.73 ± 0.64	3.62 ± 0.53
54 Cam	2	-35.33 ± 3.07	-57.12 ± 1.68	-38.28 ± 0.78	-59.08 ± 0.63
TY Pix-N	2	-45.24 ± 1.34	-45.28 ± 1.94	-43.99 ± 0.47	-44.80 ± 0.55
RS CVn	4	-50.63 ± 1.32	26.96 ± 1.55	-49.14 ± 0.88	21.49 ± 0.72
HR5110	5	84.51 ± 1.42	-9.38 ± 1.30	84.70 ± 0.45	-9.81 ± 0.39
δ Lib	4	-65.98 ± 1.84	-5.49 ± 2.39	-66.20 ± 0.86	-3.40 ± 0.81
σ^2 CrB	2	-266.61 ± 1.21	-86.67 ± 1.63	-266.47 ± 0.86	-86.88 ± 1.12
β Lyra	4	2.79 ± 1.38	-5.22 ± 1.20	1.10 ± 0.44	-4.46 ± 0.51
HD199178	1	...	...	26.77 ± 0.77	-1.15 ± 0.61
AR Lac	5	-50.49 ± 1.48	47.20 ± 1.43	-52.48 ± 0.46	47.88 ± 0.53
IM Peg	1	...	...	-20.97 ± 0.61	-27.59 ± 0.57

experiment, three observations of each radio star were conducted at three different hour angles in order to maximize the uv–plane coverage. Two 5 minute scans were recorded on the sources 3C48 and 3C147 for use in the absolute flux density calibration. Data were reduced using the standard routines within the Astronomical Image Processing System (AIPS). At no time was self-calibration performed on any of the data. Images were generated for each source and a two-dimensional Gaussian function was fitted to the peak flux in each dirty image. The results of these fits were used in the derivation of source positions.

POSITION DETERMINATION

Estimation of the star positions was performed outside of AIPS using the results of the Gaussian fits to the images. Peak and root–mean–square (RMS) flux densities for each source were derived from fits to CLEANed images with all three observations included. To avoid any possible position shifts due to the CLEANing of the images, positions in right ascension and declination were determined from the dirty images combining all of the data for each source. The formal errors in the positions resulting from the Gaussian fits were deemed unrealistically small at ~1 mas and were not used. Instead we computed a root–sum–square combination of two different error estimates to provide a more conservative description of the position errors. The first estimate associated with the fitting of Gaussian functions to the image peak was given by $\sigma \approx \theta_{beam}/2\,SNR$, where SNR is the signal–to–noise ratio in the CLEANed image and θ_{beam} represents the the geometric mean of the synthesized beam. The second value, which provided an estimate of the error due to the changing troposphere/ionosphere, was a weighted RMS error in the position derived from each of the three individual observations recorded for each source at each of the three different hour angles.

PROPER MOTIONS

The positions of the 19 radio stars from our VLA+PT observations were combined with previous VLA observations [3][4] to determine stellar proper motions, $\mu_{\alpha\cos\delta}$ and μ_δ, for the 15 sources common to both programs. Although the data cover a long time range, 1978–2000, the sampling is not sufficient to enable the determination of source parallaxes. We therefore computed proper motions for the 15 stars using the parallaxes obtained from HIPPARCOS. The proper motions derived from the combined VLA and VLA+PT data are listed in Table 1.

Also listed in Table 1 are the proper motions from the HIPPARCOS mission for comparison with our VLA+PT values. With an average error of $\sim$1.6 mas yr^{-1}, the combined VLA and VLA+PT proper motions are approaching accuracies comparable to those of HIPPARCOS, with an average error of $\sim$0.9 mas yr^{-1}. For a few of the stars, the proper motion errors are actually smaller than those derived from the HIPPARCOS observations. Figure 1 plots the differences between the proper motions in $\alpha \cos \delta$ ($\Delta\mu_{\alpha \cos \delta}$) and δ ($\Delta\mu_{\delta}$) as derived from our VLA+PT observations and those of HIPPARCOS. The error bars are the root–sum–square of the errors reported for the two data sets.

DISCUSSION

We have determined the astrometric positions for 19 radio stars using the VLA+PT configuration. The resultant positions, with uncertainties on the order of 10 mas or better, represent a factor of three improvement over the previous VLA results of [4]. For many of the stars in our list, our VLA+PT positions are better than the corresponding HIPPARCOS positions at epoch. The proper motions derived from our VLA+PT observations combined with previous VLA data of [4] have uncertainties which are on the order of, and in some cases are better than, those obtained from HIPPARCOS.

The VLA+PT configuration provides a useful tool for radio-star astrometry because of its ability to do both high resolution and high sensitivity observations at the same time. To observe the same 19 stars plus phase calibration sources would have taken on the order of 120 hours of time on the VLBA. To observe the $\sim$50 stars in the [4] list at multiple epochs using the VLBA would require a tremendous allocation of time, and such a project is probably unfeasible.

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