Pulsar VLBI experiment with the Kashima (Japan) – Kalyazin (Russia) baseline

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Abstract

The position of PSR0329+54 on the International Celestial Reference Frame was measured at epochs 1995 March, 1996 May, and 1998 May. Our observations detected the proper motion of PSR0329+54. The position and proper motion agreed well with position determined by Bartel et al. (1985). From combined analysis with our data and that of Bartel, the proper motion of PSR0329+54 was determined: $\mu_\alpha = +17.4 \pm 0.3$ mas yr^{-1}, $\mu_\delta = -11.0 \pm 0.3$ mas yr^{-1}. These results are consistent with the value by Harrison et al. (1993) measured with MERLIN interferometer. We also determined the coordinates of PSR0329+54 very accurately within the ICRF: $\alpha = 03^{\rm h}32^{\rm m}59^{\rm s}.3761 \pm 0^{\rm s}.0002$, $\delta = 54^\circ 34' 43''.5119 \pm 0''.0015$. at epoch 1995.0

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1 Introduction

Pulsars are quite interesting objects for astronomy from many points of view (e.g., for high-energy physics, for their relation with SNR, as probes of the interstellar medium, as stable clocks, for tests of the theory of relativity). Millisecond pulsars are interesting as extremely stable clocks and their coordinates in the dynamical reference frame can be estimated very accurately from pulsar timing observations. Comparison of a pulsar's position in the dynamical reference frame and its position measured by VLBI in a quasi-inertial reference frame (Ma et al., 1998) can provide a frame tie between the two frames. Measurement of proper motion gives us useful information for study of the pulsar–SNR relation and supernova explosion mechanisms that caused pulsar's high birth velocity. An independent measurement of proper motion can contribute to a more reliable estimate of the intrinsic pulse period rate $dP_{\rm int}/dt$, because pulsar proper motion can affect the observed dP/dt. Inaccurate proper motion parameters lead to wrong estimates of the characteristic age of pulsars (Nice & Taylor, 1995). VLBI provides the highest-resolution astrometry suitable for proper motion measurements. In the case of pulsars close to us, direct measurement of the distance via parallax is possible (Gwinn et al., 1986; Campbell et al., 1996).

2 Observation

Both the Kashima space research center of the Communications Research Laboratory in Japan and the Pushchino radio astronomy observatory of the Lebedev Physical Institute in Russia have been doing pulsar timing observations, and started collaboration for pulsar astrometry with VLBI in 1995. The Kashima 34m-diameter telescope and the Kalyazin 64m-diameter telescope have been used for this project. The baseline is about 7000km in an east-west direction in the northern hemisphere (see Fig. 1). The experiments are summarized in Table 1. Pulsar PSR0329+54 was observed as the first target of our experiments because it is the strongest radio pulsar in the northern hemisphere and is suitable to check our measurement performance. The observed frequency ranges were 1400–1450MHz for L-band and 2120–2320MHz for S-band. The K-4 data acquisition system (Kiuchi et al, 1997) was in place on both sites and used for all the experiments. Fifteen channels, each 2 MHz wide, were assigned in these frequency ranges, and sampled data were recorded using K-4 recorder. The data were correlated with the K-3 correlator at CRL without pulsar gating. A phase-calibration tone signal was injected into the band for the calibration of instrumental group delay. Group delays and phase delay rates were derived via bandwidth synthesis. The analysis was carried out in CALC(v.8)/SOLVE(v.5.25), developed by NASA/GSFC for geodetic and

Table 1
Experiments and Observed sources

Experiment date	Pulsar	Reference sources	Freq. band	Observation time (UT)
1995 March 14	PSR0329+54	0300+470(O), 0316+413(O) 0518+165	L-band	05:00–14:00
1996 May 12	PSR0329+54	0300+470(O),0212+735(O) 0133+476(D),3C84(O), NRAO140(O),3C138(D) 3C119	L-band	18:00–11:00
1998 May 25	PSR0329+54	0300+470(O),0212+735(O) 0133+476(D)	S-band	18:00–09:34

The character after each source is class of ICRF source.
'D': Definition source, 'O': Other source

Fig. 1. Kashima - Kalyazin baseline

astrometric analysis. The main source of systematic error in these observations is the calibration of the ionospheric delay, because our single-frequency observations cannot directly estimate it, as is done in dual-frequency geodetic VLBI observations. To remove the uncertain ionospheric delay, we observed reference quasars with PSR0329+54. The reference quasars were chosen from the International Celestial Reference Frame (ICRF) catalogue (Ma et al., 1998). The source coordinates in the catalogue are very accurately measured, so they are useful to estimate clock parameters and tropospheric delay parameters along the line of sight. The angular distance between the pulsar and each of the reference quasars was in the range 8°–22°. Since we observed a limited region of the sky spanned by the pulsar and the reference sources, ionospheric delay easily coupled with tropospheric delay and the majority of it could be absorbed in tropospheric delay parameters in the estimation procedure using the reference sources. The significant part of the delay due to propagation along the line of sight to the pulsar was calibrated by the reference sources.

3 Position of PSR0329+54

For each of the three experiments, coordinates of PSR0329+54 in the framework of the ICRF were determined. Proper motion was clearly seen in the time series of the pulsar positions. The coordinates, right ascension and declination, are plotted against time in Fig. 2. Each of the points plotted at a single epoch is a solution using different estimation conditions. First, because the position of the Kalyazin station has never been determined in a geodetic VLBI campaign, we performed CALC/SOLVE runs in which we treated the Kalyazin position as a fixed parameter, and then as an estimated parameter. Second, because the group delays and phase-delay rates are affected inversely by ionospheric propagation, we made CALC/SOLVE runs using only group delays, and then both group delays and phase-delay rates, as the observational data. Hence, combining these two "dimensions" yields four kinds of solutions per epoch. We interpret the distribution of these solutions as representing the systematic error pertaining to each epoch, because it should include the effects from the uncalibrated ionospheric delay residual and the uncertainty of the Kalyazin station position.

4 Discussion

Figure 2 shows that the extrapolation from our position determinations to 1981.21 coincides well with that of Bartel et al. (1985). Their pulsar position was referenced to NRAO150. The coordinates they used for this reference source were slightly offset from its coordinates in the newer ICRF ($\Delta\alpha = 0.14\,\mathrm{ms}$, $\Delta\delta = 0.5\,\mathrm{mas}$). In order to place their pulsar position on a reference frame consistent with ours, we shifted it by these NRAO150 offsets. After this correction, the proper motion of PSR0329+54 was derived via weighted least square analysis using our three epochs and that of Bartel et al. (1985). For each of our three epochs, we included all four kinds of solutions described in §3. The weight of each point was taken as the inverse square of the formal

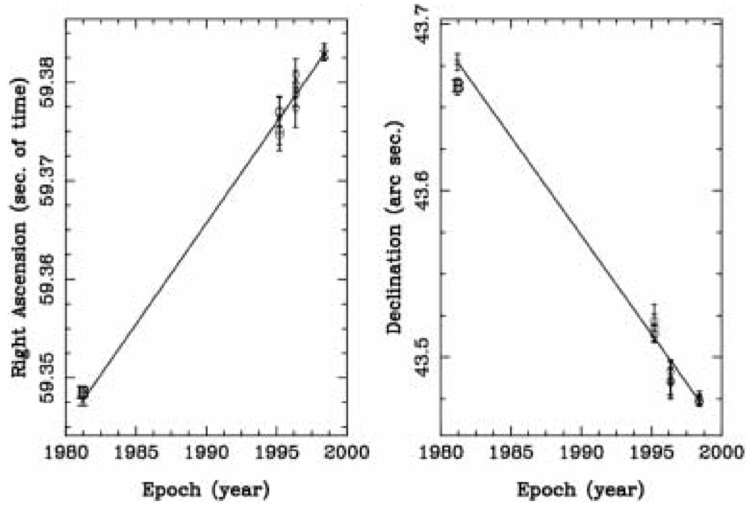

Fig. 2. Proper motion in right ascension (left) and in declination (right). The mark "B" indicates the position of Bartel et al. (1985). The symbols ∘, ⋄, and △ indicate our results from 1995 March, 1996 May, and 1998 May, respectively. The solid line shows proper motion calculated only from our results.

error of the respective SOLVE solution. As for the effect of source structure on the group delays, the structure index (Ma et al., 1998) of reference sources 0300+470 and 0212+735 are 1 and 2, respectively, implying effects less than $\sim 10\,\mathrm{ps}$. Since this is one order of magnitude smaller than our delay residuals, source structure can be neglected. The pulsar position and proper motion at epoch 1995.0 on the ICRF (J2000) were derived as follows:

$$\begin{cases} \alpha = 03^{\mathrm{h}}32^{\mathrm{m}}59\overset{\mathrm{s}}{.}3761 \pm 0\overset{\mathrm{s}}{.}0002 \\ \delta = 54^{\circ}34'43\overset{''}{.}5119 \pm 0\overset{''}{.}0015 \end{cases} \begin{cases} \mu_{\alpha} = +17.4 \pm 0.3 \ \mathrm{mas\,yr^{-1}}, \\ \mu_{\delta} = -11.0 \pm 0.3 \ \mathrm{mas\,yr^{-1}}. \end{cases}$$

Reduced chi-squares for the least-squares analysis were 0.65 and 0.87 for right ascension and declination, respectively. This is the most precise position determination of PSR0329+54 yet published. Our proper motion agrees with that of Harrison et al. (1993) to within three of their 1σ uncertainties. The pulsar coordinates as measured by VLBI, linked interferometers, and pulsar timing are shown in Fig. 3. The VLBI and VLA results are fairly consistent with each other, but there seems to be a discrepancy among the positions determined via interferometry and those from timing analysis. The main cause of these differences is likely the large timing noise of PSR0329+54.

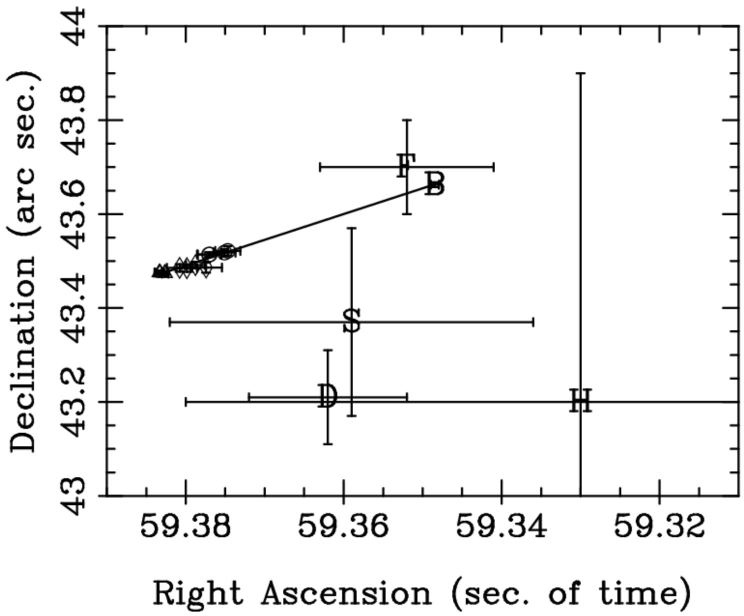

Fig. 3. Coordinates of PSR0329+54. All the pulsar positions are cited from Bartel et al. (1985) and the epoch of the positions is 1981.21, except for ours. The single-letter marks are: "B"—Bartel et al. (1985), by VLBI; "F"—Fomalont et al., by VLA; "S"—Backer & Sramek, by the NRAO 35km interferometer; "D"—Downs & Reichley, by timing; and "H"—Helfand, by timing. Marked with ∘, ⋄, and △ are our results from 1995, 1996, and 1998, respectively. The solid line indicates the least-squares fitted proper motion using our positions and that of Bartel et al. (1985).

5 Conclusion

We measured the celestial coordinates of PSR0329+54 at 3 epochs by VLBI. Proper motion was clearly seen from the results. The position and the proper motion were consistent with the result by Bartel et al. (1985). By using our results and that of Bartel et al., we could accurately determine the position and proper motion of PSR0329+54 on the ICRF. The derived proper motion was consistent with the result of Harrison et al. (1993).

References

Bartel, N., Ratner, M.I., Shapiro, I.I., Cappallo, R.J., Rogers, A.E.E., & Whitney, A.R., 1985, AJ, 90, 318.

Campbell, R.M., Bartel, N., Shapiro, I.I., Ratner, M.I., Cappallo, R.J., Whitney, A.R., & Putnam, N, 1996, ApJ, 461, L95.

Gwinn, C.R., Taylor, J.H., Weisberg, J.M., & Rawley, L.A., 1986, AJ, 91, 338.

Harrison, P.A., Lyne, A.G., & Anderson, B., 1993, MNRAS, 261, 113.

Kiuchi, H., Amagai, J., Hama, S., & Imae, M., 1997, PASJ, 49, 699.

Ma, C., Arias, E.F., Eubanks, T.M., Fey, A.L., Gontier, A.-M., Jacobs, C.S., Sovers, O.J., Archnal, B.A., & Charlot, P., 1998, AJ, 116, 516.
Nice, D.J. & Taylor, J.H., 1995, ApJ, 441, 429.