Toward a Tie of the Celestial Reference Frames via the Observations of the Pulsars

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Abstract

Pulsar astrometry is useful for the tie of dynamical reference frame and extragalactic reference frame (ICRF) because the position of the pulsars are sensible on both frames. Pulsar research group of Communications Research Laboratory is conducting both pulsar timing observation and VLBI observations of pulsars. Our status and prospect for frame tie by means of these observations are shown in this paper.

1. Introduction

Recently, with the rapid improvement of measurement accuracy of the position of the astronomical objects, the definition and the realization of the celestial reference frame has been changed drastically. In 1997 IAU General Assembly, a reference frame, based on the positions of the extragalactic radio sources, has adopted as the international fundamental reference frame (International Celestial Reference Frame:ICRF). The internal accuracy of this frame is estimated to be as 0.1 - 0.4 mas (Feissel et al., 1992, Arias et al., 1995). On the other hand, there is another, dynamical reference frame based on the orbital motion of the Earth and other planets. Famous realizations of that are the Ephemeris JPL DE 200 series. The internal accuracy of these frames are comparable to ICRF. The best tie of them so far is that by Folkner (1993), with a standard error of 3 milliarcseconds (mas) about any axis, though it is not a direct tie and still below the internal accuracy of each frame. In order to tie these frames directly, we have to observe the objects that can be measured in both frames with sufficient accuracy. Observation of the position of the pulsars is one of the best candidates for this purpose, since its position in dynamical reference frame is determined through timing observation and that in ICRF is observed by VLBI. The co-observation of pulser position by timing and VLBI is, however, somewhat difficult. For the accurate timing observation, the pulsar with stable and fast rotation is better. In general, however, such pulsars are not so bright and hard object for VLBI. Up to now, the pulsar whose position is obtained in both way with sufficient accuracy is only PSR1937+21 (Kaspi et al., 1994, Bartel et al., 1996). Bartel et al. showed that the position of PSR1937+21 in ICRF agrees with the pulse-timing position using JPL's DE200 ephemerides within 0.3 mas. For the tie of ICRF and dynamical reference frame, at least one more position of the pulsar measured by both method is needed. We, CRL pulsar research group, are conducting both timing measurements and VLBI observation of the pulsars. We are also developing our own gating correlator system and are now planning to observe some pulsars in both methods. In this paper we show the status and the plan of the pulsar observation in CRL for aiming the frame tie.

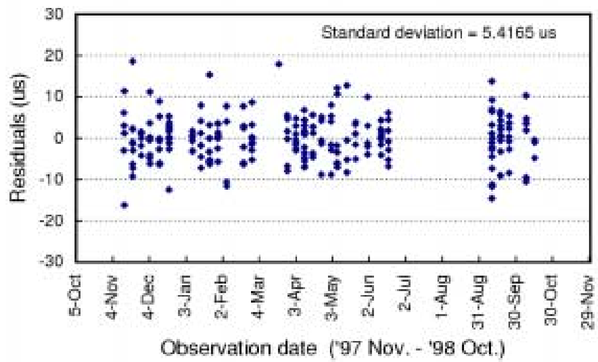

Figure 1. Timing residuals of PSR1937+21 observed by Kashima 34m antenna.

2. Timing observation status

Establishment of Pulsar Time Scale has been proposed by many authors (Il'in et al. 1986, Taylor, 1991, Matsakis et al., 1995). Il'in et al. (1986) enumerates PSR0834+06, 0950+08, 1919+21 and 1937+21 as primary reference clocks of pulsar time. In addition to these pulsars, PSR1713+07 would be a good candidates for one of the primary reference clocks. Aiming the construction of pulsar time scale, we have developed our pulsar timing observation system for Kashima 34 m antenna. This system uses an AOS as a spectral divider instead of filter banks, and we can detect a signal up to 200 MHz bandwidth. We confirmed its performance by detecting PSR1937+21 and PSR1713+07 with the 34 m telescope and PSR1855+09 with the 64 m telescope at Usuda. Using this system, we have conducted weekly observation of PSR1937+21 at Kashima since November 1997. Each pulse profile is obtained after averaging 1,048,576 pulses (1632 seconds of integration), and 6-8 profiles are obtained in one day. Residual R(t) is calculated as the difference between the observed peak phase and the predicted phase calculated by the Tempo program (Princeton pulsar timing analysis package, Taylor et.al., 1989). Figure 1 shows the R(t)s from the AOS#1 unit for 2150 - 2200 MHz. A linear fit is made on each day to remove the systematic trend. We observe 5.4 μsec. of the standard deviation of the timing measurement in one day observation, which is comparable to the expected observation precision of 3.2 μ sec. (Hanado et al., 1998). This shows that our system has almost attained the expected accuracy. Now we are planning to add PSR1713+07 and PSR0950+08 in our regular observation schedule. As for PSR1713+07, we simulated the TOA (Time of Arrival) error caused by its position error (Figure 2). About 1 μ sec. of timing accuracy is expected with our full band width of 200 MHz and four hours integration. Therefore, when we observe PSR1713+07 for a few years, we can determine its position with the error of less than 0.1 mas.

3. Pulsar VLBI in CRL

Since 1995, CRL and Lebedev Physical Institute Astro Space Center Pushchino Radio Astronomy Observatory have started a project of pulsar VLBI observation for astrometry. The Kashima 34m antenna and the Kalyazin 64m antenna were used for the observation (Figure 3). The 7000km long baseline make the fringe spacing of 6mas at L band and

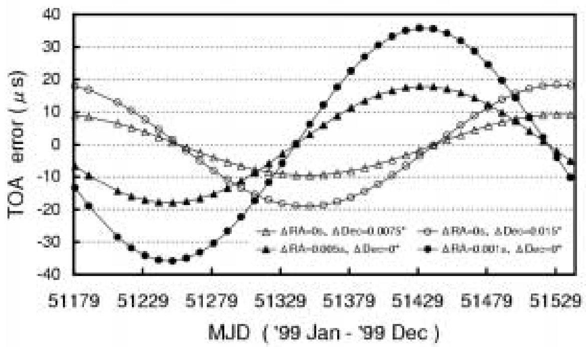

Figure 2. Estimated timing error for PSR1713+07 due to its position error.

Table 1. Pulsars observed in our VLBI experiment.

Experiment date	Pulsars
1995 Mar. 14	PSR1919+21, PSR1933+16, PSR0329+54, PSR1133+16, PSR1937+21, PSR2021+51, PSR0355+54, PSR2016+28
1995 Apr. 10	PSR1929+10, PSR2020+28, PSR2310+42, PSR0950+08, PSR0809+74
1996 May 12	PSR039+54, PSR0950+08
1996 Dec. 17	PSR2111+46, PSR0950+08, PSR1937+21
1997 Mar. 20	PSR2111+46, PSR1937+21
1997 May 23	PSR2111+46, PSR0329+54
1997 Dec. 17	PSR2111+46, PSR 0950+08, PSR1937+21
1998 Mar 17	PSR0355+54, PSR0136+57, PSR0329+54, PSR0138+59, PSR0450+55, PSR0809+74, PSR1508+55, PSR1839+56, PSR1937+21

4mas at S band, respectively. The pulsars which have been observed is listed in Table 1. PSR0329+54 was observed intensively in the first phase, because of its brightness and a good UV coverage with our single east-west baseline. Accurate coordinate and proper motion of PSR0329+54 at 1995.0 on ICRF (J2000) are derived from joint analysis of our observation data in March 1995, May1996, and May 1998 together with the coordinate measured by Bartel (1985).

$$\left\{ \begin{array}{lll} \alpha & = 03^h 32^m 59^s.3761 & \pm 0.0002 \\ \delta & = 54^\circ 34' 43''.5119 & \pm 0.0015 \end{array} \right. \left\{ \begin{array}{lll} \mu_\alpha & = 17.4 & \pm 0.3 mas/yr \\ \mu_\delta & = -11.0 & \pm 0.3 mas/yr \end{array} \right.$$

Considering co-observation with the timing, PSR0950+08 and PSR1713+07 seems to be good candidates for frame tie. At current state, we have measured the position of P-SR0950+08 by VLBI. Preliminary position accuracy of that is 16 mas and 60 mas for right ascension and declination, respectively. As for PSR1713+07,we are going to try this source when we complete K4 correlator with pulsar gating function. Pulsar gating is important for pulsar VLBI correlation processing to increase signal to noise ratio (SNR). K4 correlator has gating function for millisecond pulsar and the implementation is just before the finish. We have confirmed that the pulsar gating processor with K3 correlator makes SNR improve. So we are expecting further increase of the sensitivity of our VLBI observation.

Figure 3. Baseline of Japan - Russia pulsar VLBI observation.

4. Conclusion

Although co-observation of timing and VLBI of the pulsars are rather difficult, it seems that PSR1937+21, PSR0950+08 and PSR1713+07 are the good candidates for such co-observation toward a tie of celestial reference frame and dynamical reference frame. As we showed above, co-observation of these pulsars are within reach of our observation system. When we determine the position of PSR0950+08 and PSR1713+07 in both timing and VLBI, we can tie the celestial reference frame and the dynamical reference frame. Since these pulsars are located at almost opposite side of the celestial sphere, they will enable us to make good tie of two frames. Also the co-observation of PSR1937+21 will be useful for the consistency check of our observation with the results of other observations.

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