A Program for Pulsar Time Study in China

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Abstract We review research progress on pulsar time scales resulting from millisecond pulsar timing observations. An algorithm for ensemble pulsar time scale is introduced. The results from wavelet decomposition algorithm for ensemble pulsar time scale are shown. We introduce in some details a newly designed pulsar timing program in China. One of the scientific goals of the program is to study pulsar time by timing millisecond pulsar using Chinese 50 m radio telescope.

1 Introduction

Millisecond pulsars exhibit a very stable spinning period. The time derivative of the rotational period $\dot{P}$ for millisecond pusars is usually less than 10^{-19}s/s. Timing observations of pulsars measure the time of arrival (TOA) of the radio pulses relative to an atomic time scale. The technique allows mesurement of TOA with a precision better than 1μs. Long term timing data analysis to some millisecond pulsars, for example PSR1937+21 and PSR1855+09, showed that the stability of rotation of such millisecond pulsars rivals that of atomic clocks: the relative frequency instability for averaging time over one year is of order 10^{-14}[1,2]. It is difficult to interpret the instability of the timing data by instability of the millisecond pulsar rotation itself because some phenomena are known to possibly disturb the timing data. These may include errors in atomic time standard used as reference, effect of solar system ephemeris used as reference frame to transform the observed TOAs to an inertial frame. Unmodeled effect of interstellar propagation could also contribute to the timing error. A passing gravitational wave could cause a change in the observed rotational frequency of pulsar by an amount proportional to the amplitude of the wave. Among these, the errors in atomic time scale would produce similar effects for all observed millisecond pulsars. Comparison between pulsar time scale PT and atomic time scale AT can reveal some errors of AT. In doing this, G. Petit and P. Tavella proposed a scheme to establish an ensemble pulsar time $PT_{\rm ens}$. $PT_{\rm ens}$ can be more stable and accurate than any individual PT, because effects of some sources of noise which are independent for different pulsars may be removed from $PT_{\rm ens}$.

As many new millisecond pulsars are discovered, it is possible that we monitor almost simultaneously several millisecond pulsars using one radio telescope. Applying timing array, we could study $PT_{\rm ens}$ for long time scales and detect background of gravitational radiation (GWB)[3]. Chinese 50 m radio telescope which is specially designed for timing millisecond pulsars will take part in studying $PT_{\rm ens}$ and detecting GWB.

2 Long Term Stability of PT and Algorithm for $PT_{\rm ens}$

Timing measurement precision depends mainly on observing system. A large effort has been made to improve the precision of timing observations. The pioneering work in this area is research work at Princeton University. High quality timing data spanning almost a decade from the Arecibo radio telescope has demonstrated that the timing stability of millisecond pulsars over long time scales is comparable to terrestrial atomic clocks[4]. The results from Ref.[4] indicated that the stability for PSR1855+09 becomes competitive with the atomic clocks in about 3 yr scale. The timing stability of PSR1937+21 seems to be limited by a power law component. If a cubic term of time is added to the timing model for PSR1937+21, consequently the phenomena stability becomes similar to PSR1855[1]. The absence of timing noise in long time scales for PSR1855+09 is probably related to its characteristic age 5 Gyr which is about a factor of 20 larger than PSR1937+21[5]. In order to evaluate the long term stability of millisecond pulsars timing data set spanning a large time scale is needed.

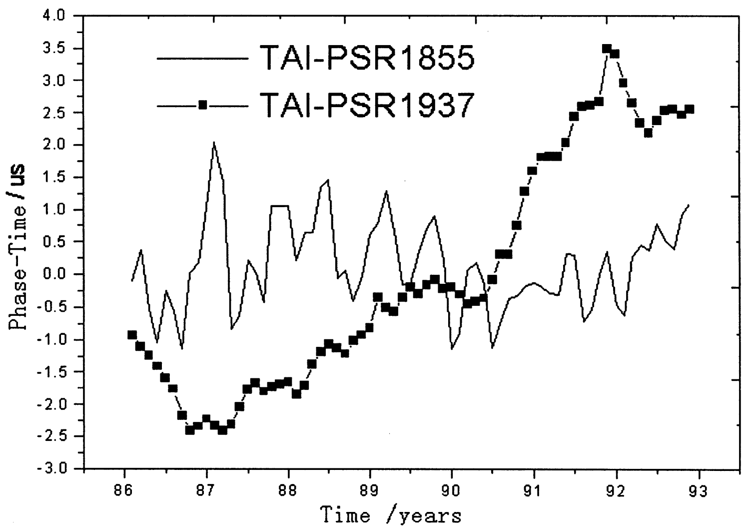

Fig. 1 Phase-difference Between Two Pulsars and TAI.

In addition to the intrinsic noise of the rotation of millisecond pulsars and errors of AT used as a reference, several other sources of noise could affect timing data, mainly interstellar propagation effects, uncertainties in the ephemeris of the solar system, and gravitational waves. In order to find a stable pulsar time scale, an ensamble pulsar time scale $PT_{\rm ens}$ can be constructed using individual PTs. In convenience, one assumes that all sources of timing noise except AT are independent for different pulsars and then average them by defining $PT_{\rm ens}$ as a weighted average of the individual PT from all the available pulsars. G.Petit et al. (1992) have designed a stability algorithm which is similar to that used for atomic clocks[1,2]. $PT_{\rm ens}$ is weighted average of the available PTs. Hereafter AT-PT refers to timing residuals which are obtained after correctly applying a timing model to the observed pullsar timing data. $AT - PT_{\rm ens}$ can be defined by

$$AT - PT_{\rm ens} = \sum W(AT - PT)\,, \tag{1}$$

where W is the relative weight assigned to each pulsar. Weights are designed as inversely proportional to the instability of each pulsar. This can be realized by simply taking the inverse of the Allan variance and normalized to unity. Each pulsar enters the ensemble with a fixed weight according to its level of instability. When the number of pulsars changes a suitable correction should be added to avoid a time jump. So the removal or entry of a new pulsar is accompanied by a time correction α which is defined as

$$AT - PT_{ens} = AT - (PT'_{ens} + \alpha), \tag{2}$$

where PT'_{ens} is the new ensemble pulsar time computed from the data after the change. Following this algorithm G. Petit et al. (1992) calculated an ensemble pulsar time scale using data from PSR1937+21 and PSR1855+09[1].

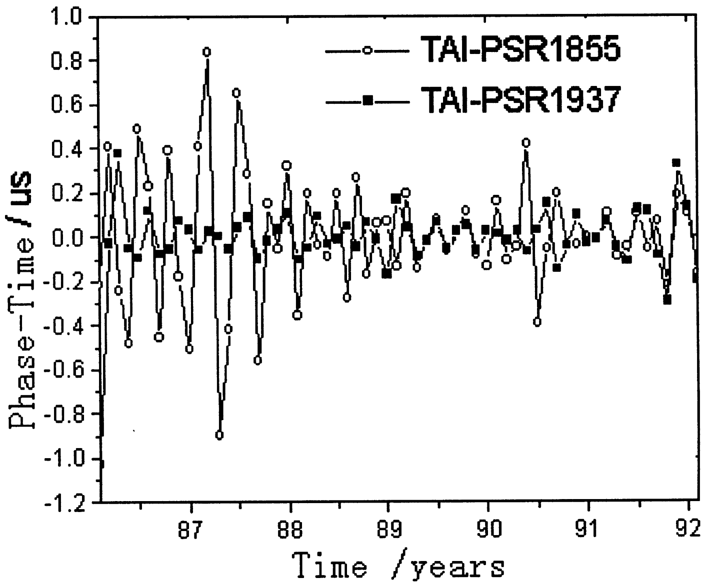

Fig. 2 High frequency content

We have applied wavelet decomposition algorithm (WDA) to define ensemble pulsar time scale using the same data of these two pulsars. The method of using wavelet analysis to calculate time scales is different from that of uniform weighting in the time domain. WDA can decompose signal's subsection components in the range of various frequencies and then pick up them again to weight in subdomains. WDA considers, analyzes and solves the stability of subsection frequency in the range of various frequencies. So the time scale calculated by the wavelet analysis may be more stable. The results from the wavelet decomposition algorithm is shown in Fig. 1.- Fig. 4.

3 50 m Radio Telescope and Designed Pulsar Timing Program

Construction of 50 m radio telescope is underway and will be available in 2004. The details for the parameters of the telescope can be found in "An introduction to the new Miyun 50 m radio telescope" by Chengjin Jin in this proceeding. Observational frequency 1420 MHz is used and second frequency will be lower than 1420 MHz, T_{sys} is 30 K, bandwidth 300 MHz. More than 10 millisecond pulsars will be monitored regularly . Integration time is 60 min or more in each day observation for each pulsar. Assuming signal to noise ratio S/N=1, then sensitivity S can be given by

$$S = \frac{1.4KT_{sys}}{\eta_A A\sqrt{\Delta f \cdot t}} \tag{3}$$

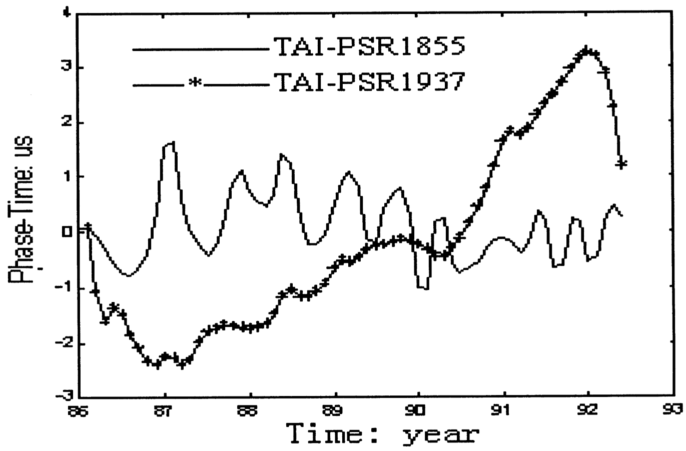

Fig. 3 Low frequency content

where K is Boltzmann constant, $T_{\rm sys} = 30\,{\rm K}$, A is area of the antenna, effeciency of the antenna η_A =0.5, bandwidth $\Delta f = 300\,{\rm MHz}$. For the 10 day observations, the total integration time t can reach to 10 hours. So we estemated that the pulsar with flux density $S > 0.018\,{\rm mJy}$ may be observable. When we observe millisecond pulsar with $S > 1\,{\rm mJy}$ $S/N = 56$ can be reached.

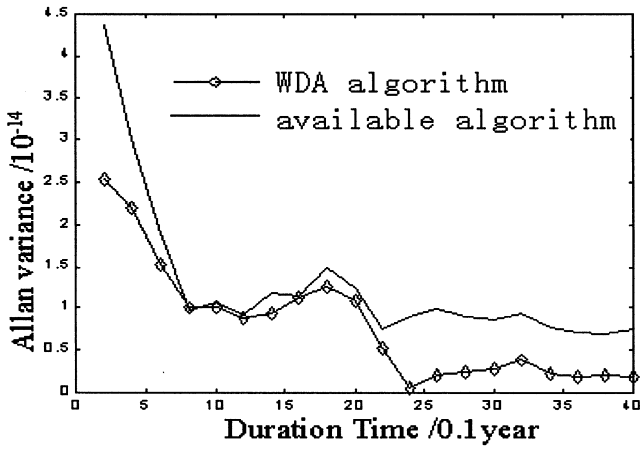

Fig. 4 Stability of two algorithms

Up to now about 56 Galactic disk millisecond pulsars were descovered[5]. According to estimated parameters of these millisecond pulsars, Dr. Han JinLin has selected 27 pulsars available for Chinese 50 m telescope timing observation. Finally about 10 suitable objects with higher flux density , sharper pulse, and shorter rotational period will be monitored by this telescope. When more suitable millisecond pulsars are found, they can be added to the program to insure that the spatial distribution of monitored pulsar population can be more isotropical and more uniform. This is needed for the scientific goals of the pulsar timing program.

Ensemble pulsar time study is one of scientific drive for the pulsar timing program with 50 m telescope. The regular and continuous timing observations should be made for the target pulsars to get timing data spanning many years. We hope that some insight about behavior of long term stability of pulsar time scales could be learned. Furthermore, an ensemble pulsar time $PT_{\rm ens}$ can be studied by a suitable algorithm. Then $PT_{\rm ens}$ may be used to detect some errors in atomic time scales. The observations of a number of millisecond pulsars distributed across the sky lead to the possibility of timing several pulsars against each other with terrestrial clocks providing merely the end point times and a means of interpolating observations[6]. Now several long term timing projects are underway to monitor these millisecond pulsars[5]. Timing data from different sites may be linked together by common target observations to get more ideal spatial distribution of observed millisecond pulsars. In this way timing model should be correctly determined and any systematic trends in different data sets should be removed. To have fruitful results for $PT_{\rm ens}$ study a continuous effort in pulsar survey is also important to find more stable millisecond pulsars.

Another scientific goal is to detect low frequency gravitational radiation. We hope that some detail information about GWB can be obtained besides determining limit on the energy density of GWB from our elaborately designed pulsar timing program.

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