中国科学院粒子天体物理重点实验室

Key Laboratory of Particle Astrophysics Chinese Academy of Sciences v timing Results of the MSPs Zheng Shijie (<u>zhengsj@ihep.ac.cn</u>)

Introduction

Pulsars are called celestial clocks or celestial pillars, as their long-term stability (particularly for MSPs) is comparable to that of the current atomic time-scales as shown below. The high-precision timing of the pulsars can be used to constrain the mass-radius relation of NSs, detect nanohertz gravitational waves from supermassive black hole binaries starting long before the system mergers. In addition, they are also the ideal candidates for pulsar navigation or time-keeping in PNT

Results



system.

Deneva et al. (2019) has demonstrated high-precision X-ray timing of three MSPs with one year observations of NICER. Now the new results with more than five years observations and more MSPs are shown



Pulsar characters (from IPTA, https://gitlab.com/IPTA)

Name	Frequency (Hz)	Frequency derivative (Hz/s)	EPOCH	Distance (kpc)	
PSR B1937+21	641.9282345354 8132107	-4.331222e-14	54999.9998161 70382115	5.2	
PSR B1821-24	327.4055880600 0466419	-1.735305e-13		5.0	
PSR J0437-4715	173.6879457375 1827756	-1.728374e-15		0.1559	binary
PSR J0030+0451	205.5306991252 5549182	-4.297782e-16		0.312	
PSR J0218+4232	430.4610612201 2963541	-1.434116e-14		6.25	binary
PSR J2124-3358	202.7938968903 887218	-8.459579e-16		0.4617	

PSR B1937+21 (~2µs)

• Profiles of the MSPS



• Long-term stability of the MSPs

 σ_{7} reaches ~ 10⁻¹⁴-10⁻¹³ in 1-4 years

this work

> NICER observations

Time span: 57929.5 – 59962.2

Exposure duration (Ms)

PSR	PSR	PSR	PSR	PSR	PSR
B1937+21	B1821-24	J0218+4232	J0437-4715	J0030+0451	J2124-3358
1.40	0.98	0.78	1.78	2.82	1.41

> Method

1) Data reduction: criteria is the same with Deneva et al. (2019) and Bogdanov et al. (2019);













2) Barycentric corrections and profiles with certain bins;

3) Update the PSR ephemeris with TEMPO2 and recalculate the TOA

4) The long term stability is valuated with σ_z (Matsakis, 1997);

For an interval of length τ starting at time t₀, we can fit a cubic polynomial to timing residuals in that interval,

 $X(t) = c_0 + c_1(t - t_0) + c_2(t - t_0)^2 + c_3(t - t_0)^3$ where X(t) minimizes the sum of $[(xi - X(t_i))/\sigma_i]^2$ over all TOAs t_i with

uncertainties σ_i and residuals x_i . Then

 $\sigma_z = \frac{\tau^2}{2\sqrt{5}} < c_3^2 > 0.5$

> Summary

Using more than five years of NICER observations, we perform Xray timing for six MSPs, including PSR B1937+21, PSR B1821-24, PSR J0437-4715, PSR J0030+0451, PSR J0218+4232, and PSR J2124-3358. From the timing residuals, we can obtain the timing stability of PSR B1821-24, PSR J0437-4715 and PSR J0030+0431 on the order of 10⁻¹⁴ while the rest pulsars on the order of 10⁻¹³.