Pulsar as Barycenter Coordinate Clock

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Introduction

- Pulsars can be considered as a high-quality stable clocks if observed from the barycenter of the Solar system.
- Stability of the set of pulsar clocks is affected by non-linear relative motion of pulsar and the Solar system.
- Attempt is made to estimate pulsar time scale stability caused by both the Solar system and pulsar motion with respect to the Galaxy barycenter (the local standard of rest) .

Historical Background

- Sazhin (1978), Detweiler (1979) – pulsars as detectors of GW
- Cordes et al. (1980), Kopeikin (1997,1999) – discussion and implications of pulsar timing noise
- Backer et al. (1982) – discovery of millisecond pulsar 1937+21
- Il'in, Ilyasov et al. (1984) – pulsar time scale
- Rawley, Taylor et al. (1987) – experimental proof of PSR1937+21 stability
- Sazhin (1989) – theoretical limitations on long-term stability of millisecond pulsars
- Romani (1989), Foster & Backer (1990) - Pulsar Timing Array
- Doroshenko, Ilyasov et al. (1990) – pulsar reference frame
- Petit, Tavella (1996), Ilyasov, Kopeikin, Rodin (1998) - binary pulsar time scale
- Matsakis, Taylor, Eubanks (1997) – σ_z statistics

Coordinate systems and time scales

- ICRF – TCB
- ITRF – TT
- DE405 – T_{eph}

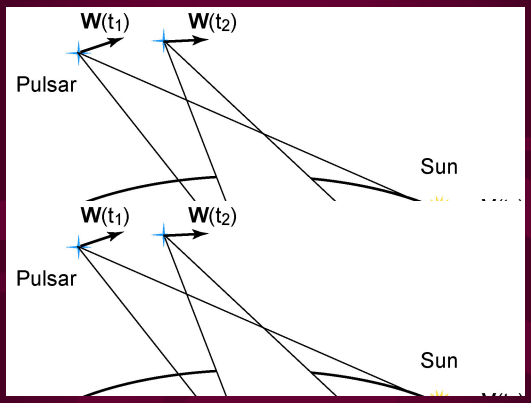
Connection of time scales

- TT = TAI + $32^s.184$
- Pulsar Time (PT) – TAI

$$PT = T_0 + P_0 N + \frac{1}{2} P_0 \frac{dP_0}{dt} N^2 + O(c^3)$$

where N is the number of pulse from the pulsar

Motion of the Solar System and pulsar



- Solar system velocity V= 220 km/s, orbit radius R= 8.5 kpc
- Change of the direction of the Solar system velocity is 5 mas/yr

Time of arrival

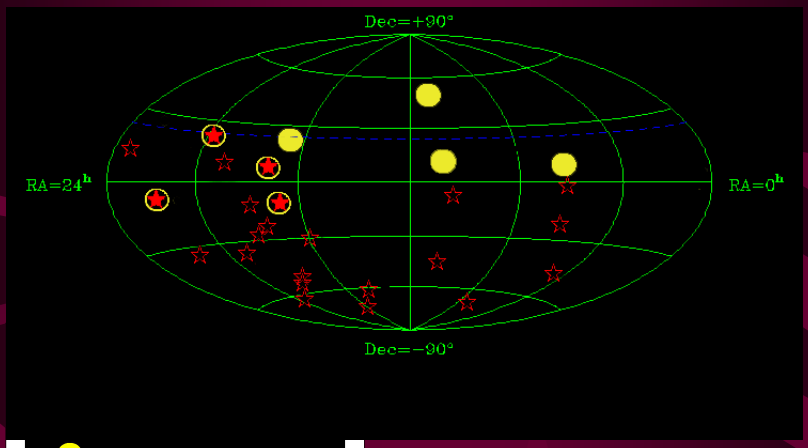
Pulsar time unit definition (second)

$$\tau = (P_0)_i \cdot \left[1 + \frac{\vec{k}_i(\vec{V} - \vec{W}_i)}{c}\right] \cdot N$$

Corrected pulsar time definition

$$PT = T_0 + \tau + \left\{ \frac{1}{2}\frac{(\dot{P}_0)_i}{(P_0)_i} + \left[\frac{\dot{\vec{k}}_i(\vec{V} - \vec{W}_i)}{c} + \frac{\vec{k}_i(\dot{\vec{V}} - \dot{\vec{W}}_i)}{c} \right] - \frac{1}{2}\frac{(\dot{P}_0)_i}{(P_0)_i}\frac{\vec{k}_i(\vec{V} - \vec{W}_i)}{c} \right\} \tau^2$$

The Parks Pulsar Timing Array- PPTA and Kalyazin Pulsar Timing Array - KPTA



- KPTA (7)
- PPTA (21)
- PPTA & KPTA (28)

ITCRF – International Time-Celestial Reference Frame

Systematic PT long-time variations

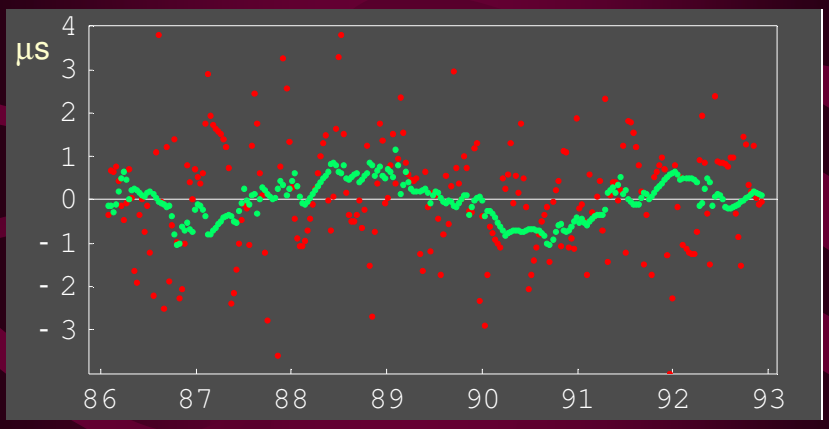
- Proper pulsar instability (10^{-18} – 10^{-20}) (Sazhin, 1989)
- Medium pulsar signal propagation

  a – interstellar (10^{-17}) (Kaspi et al., 1994)

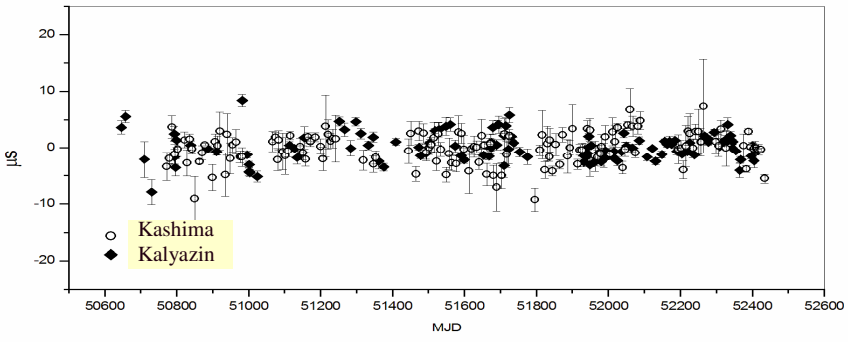
  b – gravitational wave background (GWB) (10^{-15}-?) (Stinebring, Ryba, Taylor, Romani, 1990)

  c – microlensing (10^{-17} – 10^{-19}) (Pshirkov, Sazhin, poster session, 2006)
- Proper motion of the Solar system and pulsar relative to the Galactic center (10^{-19} – 10^{-20})

Time Of Arrival (TOA) residuals pulsars: PSR 1855+09 and PSR 1937+21 (Kaspi, et al., 1994)

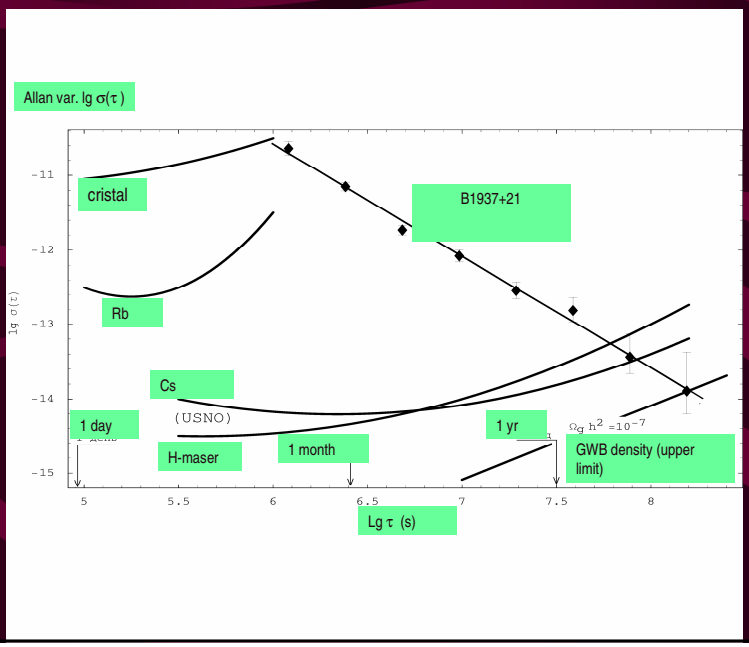


Time Of Arrival (TOA) residuals of pulsar PSR 1937+21 (Kalyazin-Kashima): 1997-2003

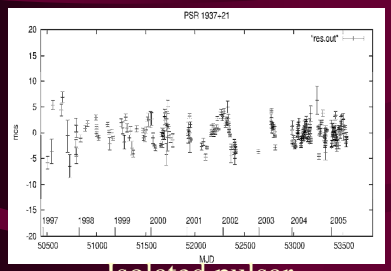


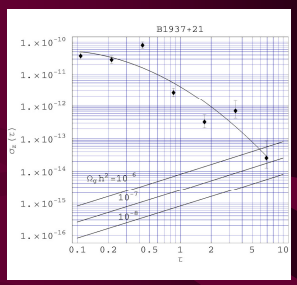
RMS 1.88 μs

Allan variance of Pulsar Clock

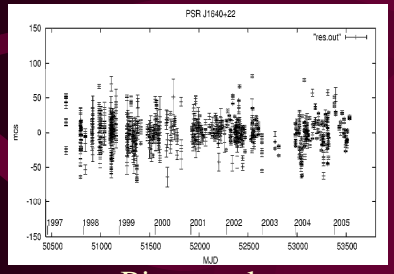


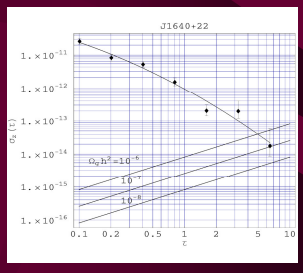
LONG TIME INTERVAL RESIDUALS (a) and ALLAN VARIANCE of PSR: J1640+2224, B1937+21 from KALYAZIN TIMING





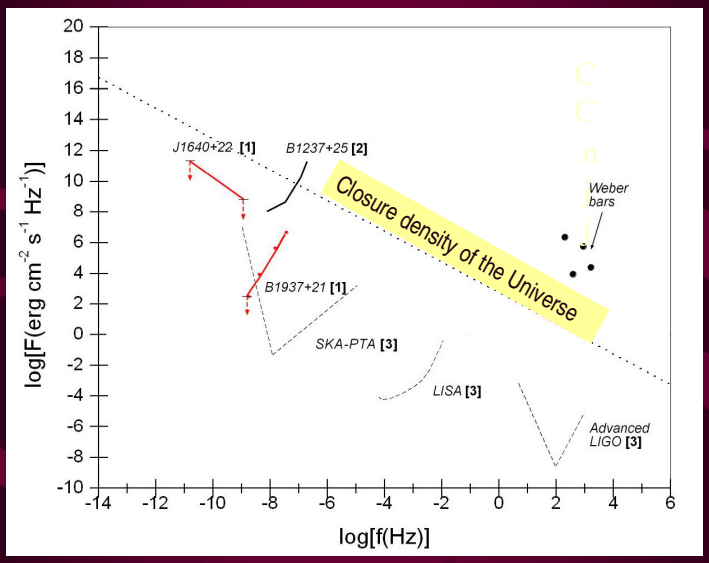
Isolated pulsar





Binary pulsar

Gravitational Wave Background Density



Conclusions

- **Presently there are two working Pulsar Timing Arrays: the Parks (PPTA) and Kalyazin (KPTA)**
- **Total span of TOA measurement is about 10 years**
- **Intrinsic and extrinsic (interstellar medium) instabilities for the best millisecond reference pulsars are about 10^{-14} in 10 years**
- **Instability of PT during 50-100 years will be about 10^{-18}**
- **Secular aberration of the Solar system should be taken into account on the level: 10^{-20}/yr**
- **Each of effects which affect pulsar long-term stability will be very important astronomical discovery**

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