PARAMETRIC INVARIANCE OF THE RELATIVISTIC COORDINATE PULSAR TIME SCALES

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To implement the pulsar time scale corresponding to modern requirements of accuracy and stability, one needs to find coordinated answers to a number of interrelated challenges:

a) the uncertainty of the observed intervals of pulsar time which are determined by the physical conditions that are known very approximately;

b) the extension of barycentric pulsar scales to other observational reference frames (Klioner at al., 2009);

c) parameterization of pulsar scales which suppresses effect of unmodeled timing noise and random residuals deviations.

It is evident that these problems require a precise analytical solution. Our approach, in general, is to find analytical relation of the pulsar time intervals and the physical parameters so that the numerical values of these parameters should be determined and best matched with measured values of the observed intervals. From fitting can be excluded any parameters that can't be obtained directly from observations.

Analytical form of the pulsar time intervals PT, expressed by the rotation parameters of the pulsar, is reduced to Maclaurin power series:

$$PT(P_0, \dot{P}, \ddot{P}) = P_0 N + \frac{1}{2} P_0 \dot{P} N^2 + \frac{1}{6}(P_0^2 \ddot{P} - 2P_0 \dot{P}^2) N^3, \quad N = 1, 2, 3, \ldots \tag{1}$$

The equation of the observed intervals of PT_i in accordance with (2) is:

$$PT_i = (1 + \alpha_i)(P_0^* N + \frac{1}{2} P_0^* \dot{P} N^2 + \frac{1}{6}(P_0^{*2} \ddot{P} - 2P_0^* \dot{P}^2) N^3)_i. \tag{2}$$

Here are: PT_i is the numerical values of the observed intervals obtained from the planetary ephemeris; P_0^*, $\dot{P}$, $\ddot{P}$ are the pulsar rotation parameters obtained by solving equation (2); α_i is divergence of series of the PT_i approximated by the rotation parameters of pulsar.

By parametric approximation of the intervals PT_i (2), the fixed rotation period and its derivatives on the initial epoch, are defined.

It is evident, for any choice of the initial epoch, the value of period is different, taking into account the gap between epochs and the derivatives $\dot{P}$, $\ddot{P}$. The corresponding settings of rotation parameters also satisfy the convergence of the series expansion (2) for any extension in the vicinity specified by the variable $t = P_0^* N$:

$$P(t) = P_0^* + \dot{P}_0 \cdot t + \ddot{P} \cdot t^2; \qquad t = P_0^* N, 1 < N < \infty. \tag{3}$$

where

$$P(t) = P_0^* + \dot{P} \cdot t; \qquad \dot{P} = \dot{P}_0 + \ddot{P} \cdot t.$$

Values of N_i, determined by the equation (2), unlike the ratio (1), are not integer due to random variations in the pulse time of arrival (propagation, error of AT, planetary ephemeris of the Solar system, fitting, etc.). The real values N_i are different from integer value by $\Delta N_i = \dfrac{\Delta\varphi(t)_i}{2\pi}$ determined by the observed pulse phase shift $\Delta\varphi(t)_i = \dfrac{2\pi}{P}\Delta t_i$ within the current period of rotation. Real value $(N_i + \Delta N_i)$ corresponds to the minimum of random variations of the divergence α_i and matches the phase of the observed event to the stable rotation parameters of the pulsar. Random variations of the observed intervals are limited by nanosecond range, although the scattering of the time of arrival can reach several milliseconds.

According to the principle of relativity (Poincare, 1906), all physical processes occurring in any inertial system under the same conditions, which are defined by the Lorentz transformations, are identical. Logunov (1990) extended the principle of relativity of Poincare without any changes physical entity to the non-inertial reference systems as well.

It has been shown (Avramenko, 2009) that the equation of the pulsar time (2) is form-invariant under coordinate transformations, in which the numerical values of the observed rotation period are coincide in the barycentric and topocentric coordinate systems at the same epochs of the local time. Left part of the equation (2) consists the observed topocentric TT_{obs} or barycentric TB_{obs} intervals. The right part contains the intervals TT_{calc} or TB_{calc}, which are calculated by the observed rotation parameters obtained by approximation of TT_{obs} or TB_{obs}.

Figure 1 compares the intervals of the pulsar time PSR B0809+74 in the barycentric and topocentric coordinate systems. Monotonically growing intervals TT_{obs} and TB_{obs} (left, up) have a cyclical differential variations, due to the orbital motion of the Earth around the Sun (left, down). The quasi-stationary differences $TT_{obs} - TT_{calc}$ and $TB_{obs} - TB_{calc}$ (right) with near zero average confirm precise consistency of intervals PT_{obs} counted by the metric of General relativity (GR) of the numerical ephemeris, and by the metric of Special relativity (SR) of the parameterized intervals, in both topocentric and barycentric coordinate systems. Long-term instability of the parametric pulsar time scales about 10^{-18}–10^{-19} within the 40-year span is several orders better than of the quantum standards.

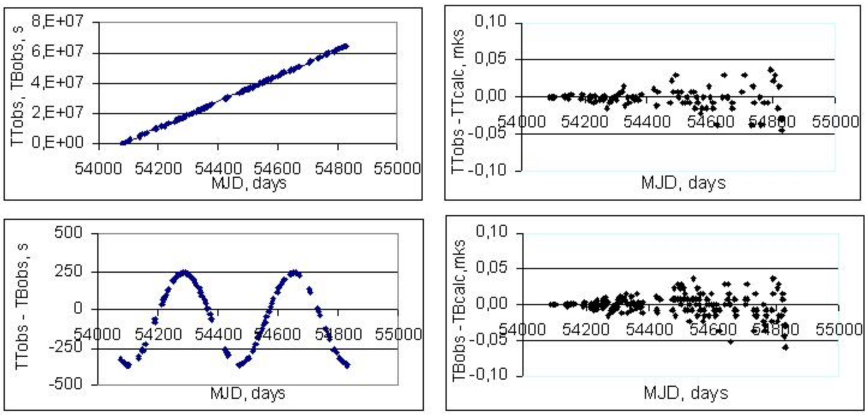

Figure 1: Consistency of the topocentric and barycentric intervals of the PSR B0809+74.

Thus, coordinate pulsar time scales determined by the observed rotation parameters of the pulsar, are the physical implementation of the barycentric dynamical time TDB and terrestrial time TT, expressed by numerical planetary ephemeris of the solar system. Together with reference ICRF-ICRS, to which are oriented Cartesian observational systems and planetary ephemeris, the parametric pulsar scales constitute a single astronomical 4-dimensional reference system based on the periodic radiation of the pulsars and the coordinates of the quasars.

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