PULSARS AS A SPACE VERY STABLE TIME STANDARDS

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Abstract. Russian experts proposed a new fundamental time scale based on a very stable pulsar period of rotation. Long observations of pulsar's pulse time of arrival (TOA) (timing) were demonstrated the high stability of pulsar frequency comparable with the atomic standards in more then year. Pulsars are identified with fast rotating neutron stars. They have a very high kinetic energy and moment of inertia. Now it is detected more then 1000 pulsars. Timing of several very stable pulsars was made in more then 10 years at Pushchino Radio Astronomy Observatory (PRAO). Results of precise measurements of TOA are presented. This time set of TOA is considered as a Pulsar Time scale - PT. A new Dynamic Pulsar time scale – BPT is proposed. It is based on a stable orbital pulsar motion in binary system. Impact of Pulsar Time scale is discussed with respect to metrology problems.

Pulsar, time scale, neutron star, timing

1. PULSAR TIME SCALE

Russian experts from the Physical Lebedev Inst and the State Standard Committee proposed in 1979 to use a fast rotating strong magnetized neutron star (radio pulsar) as a reference time standard and to establish a Pulsar Time scale (PT). Ref. 1-4. From that moment several pulsars were being monitored at Pushchino Radio Astronomy Observatory of the Lebedev Physical Inst. (PRAO PhIAN) by timing technique. The suggestion was confirmed abroad in 1983 Ref. 5.after the Backer's millisecond pulsar was detected in 1982.

Very high frequency stability of rotation of several pulsars is comparable with stability of the best atomic frequency standards in long time interval around one year or more. Now more then thousand pulsars have been found out in the Galaxy which period of rotation is known now from 1.5 ms up to 6 s. Among them there are some stable in period of rotation so called "millisecond" pulsars, in particular.

It's well known that pulsar period, in general, must be decreased slowly, because there should be rotation energy losses due to huge radio wave radiation. A time dependence of rotation period derivatives are measured with a satisfactory accuracy for the first order one, in particular The first period derivative of pulsars are confined now within 10^{-13} to 10^{-20} s/s. In principal, Pulsar Time scale can considered as independent from other one forever if the all derivatives are defined well enough Ref. 6-7. Other restriction for PT quality is defined by so called "timing noise", which is connected with some rotation instabilities of a neutron star (precession, inner structure neutron star process, " star-quake", glitches etc.). After selection it has been found out more then several tens of pulsars which timing noise looks as "white noise" in the phase of time of arrival (TOA) pulsar pulses with a variance around several micro sec. during year (fractional stability $3*10^{-13\div14}$). Usually timing noise of "spin" pulsar rotation is more complicated.

There are problem about detachments of Pulsar Time scale from another one Ref. 6. If one pulsar is considered as autonomy time standard the all arguments in Ref. 6 are correct because of its timing observations are based on Time Atomic International (TAI) scale and could not considered as independent. But it is evident, that when three or more reference pulsars, taken as a group time interval keeper, the pulsar timing measurements could be considered as self-consistent Ref. 3. Such technique is used very commonly now by Time services, in general.

Binary pulsar was suggested as excellent time standard at a span of any more ten years, because its "orbital timing noise" is several orders less and is defined mostly by an unknown correction to the General Relativity Ref. 8.

Pulsar Time scale is considered now as a promise one by the United State Naval Observatory (USNO) in long time. On Fig.1 it is shown INTERNET site of USNO.

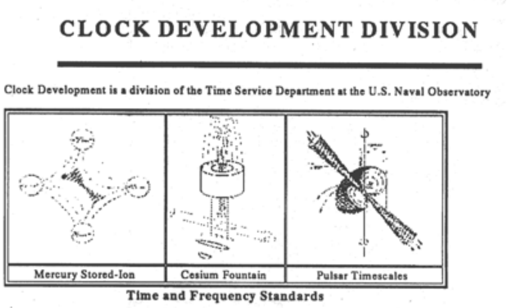

Fig . 1 Pulsar Time scale among the most promising for Time Service in comparison.

Fig 2 Radio telescope with 64-m dish of the Special Research Bureau of MPI at Kalyazin

2. PULSAR TIMING IN RUSSIA

Timing observations of reference pulsars were being made at Pushchino Observatory by the Large Phased Array radio telescope at 111 MHz in 320 kHz bandwidth from 1979 (PSR B0834+06, B1919+21 and some else). Millisecond and binary pulsars are being observed at Kalyazin Observatory from 1995 by using 64-m dish and a sophisticated multi channel filter-bank receiver at 0,6 GHz in 3.2 MHz bandwidth (see Fig.2). Local time service of observatory is based on a hydrogen maser and rubidium standard, and time comparison with UTC is made by GPS. An instrumental accuracy of TOA measurements is less then 100 ns, in general. Reduction of timing pulsar data is produced by TIMAPR software package, made at PRAO. Residuals of Solar baricentrical TOA are shown possibilities to define average pulsar period within accuracy to the 14-th decimal digit after point and predict TOA at telescope for year ahead within accuracy in several microseconds.

The integrated pulse profiles of millisecond and binary pulsars, which timing is being made at Kalyazin, are shown at Fig.3

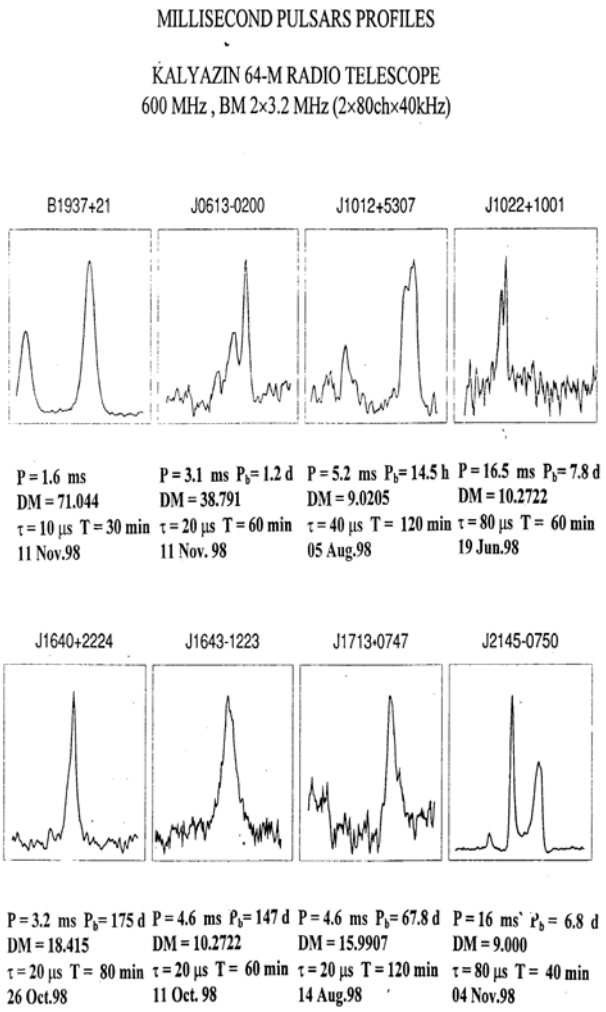

Fig.3. Integrated (mean) pulse profiles after timing observation at Kalyazin

From Fig.3 it is seen, that signal to noise ratio (SNR) is very good for the most pulsars, especially for the fastest Backer's pulsar B1937+21, that its TOA can be measured precisely within 0.5 microsec. RMS accuracy in total Ref. 9.

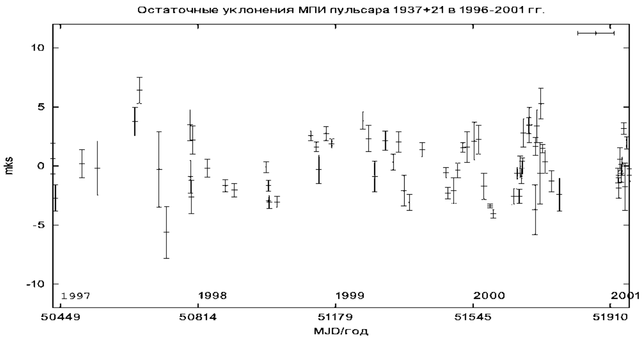

Fig. 4 Residuals PSR B1937+21 in 1996-2001 from timing (600MHz, Kalyazin)

It could be seen from Fig 4 data, that total RMS, estimated for "white phase noise" through all span as 3 microsec , gives PT-scale regularity about $10^{-13} \div 10^{-14}$ per year or less. These timing observations are going to be continued.

"Normal" pulsars, slow rotating with period around seconds, were observed by the LPhA telescope at Pushchino, and timing data were collected in 21 years span. Residuals for the most stable PSR B0834+06 and B1919+21 are studied in frequency domain Ref. 10. The results of calculations are shown at Fig 5

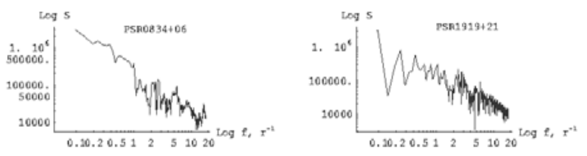

Fig 5. Spectral density of RES (relative units) vs. frequency as log r^{-1} (r-year).

There is evidence that at least for these two pulsars the dependence looks as proportional 1/f and can be considered as a phase flicker noise. It means that if timing of these pulsars will be continued after 20 years observations the Allan variance of spin pulsar rotation frequency will be decreased linearly proportional a span time Ref. 11, i.e. a definition of average time interval as standard unit will be made accurate. In spite of pulsar barycentrical residuals of these two normal pulsars contain "red noise", they can be consider as reliable time interval keeper now at least in twenty years interval with respect to atomic time standards.

It is evident that pulsar timing of "normal", millisecond and binary pulsars has to be continued not only for proper neutron stars physic but also for PT–scale establishes purpose. One can say, that a new direction has been appeared in time fundamental metrology, in particular for intervals more then year, with pulsar timing, which has their features, peculiarity and amendment

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