Ensemble pulsar time scale

Alexander Rodin

Pushchino Radio Astronomy Observatory

Lebedev Physical Institute

Russian Academy of Sciences

rodin@prao.ru

Journees-2010, Paris, 22 September 2010

Introduction

- There is an interest to new algorithms for averaging time scales.
- One of such possible algorithms can be the optimal Wiener filters that estimate a signal on the additive noise background (Rodin, 2006).

Plan of the presentation:

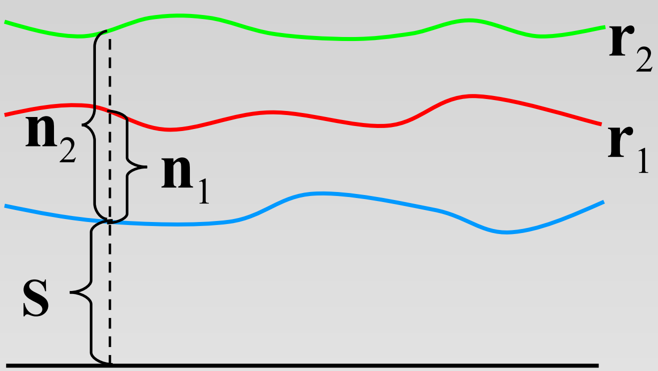
1. Basic formulas,
2. Numerical simulation,
3. Results.

Basic formulas

$\mathbf{r}_i = \mathbf{s} + \mathbf{n}_i$ – $N\times1$ vector of post-fit residuals (i=1, 2,..., M)

$\mathbf{s}$ – $N\times1$ clock contribution vector (signal),

$\mathbf{n}_i$ – $N\times1$ vector of variations of the pulsar phase.



Basic formulas

$$H(\omega)=\frac{P_s(\omega)}{P_s(\omega)+P_n(\omega)}$$ – optimal Wiener filter

$$P_s=\frac{2}{M(M-1)}\sum_{k=1,\,l=i+1}^{M-1,\,M} {}^{kl}X,$$ M is number of pulsars

$${}^{kl}X(\omega)=\frac{1}{2\pi}\left|{}^{k}x(\omega)\,{}^{l}x^{*}(\omega)\right|,\quad k\neq l,\ k,l=1,\dots,M$$ – cross spectra

$${}^{k}x(\omega)=\frac{1}{\sqrt{N}}\sum_{t=1}^{N} {}^{k}r_t h_t e^{i\omega t},\quad k=1,\dots,N$$ N is length of data

h_t is bell-shaped weighting function for reduce side-lobe leakage in frequency domain

Numerical simulation

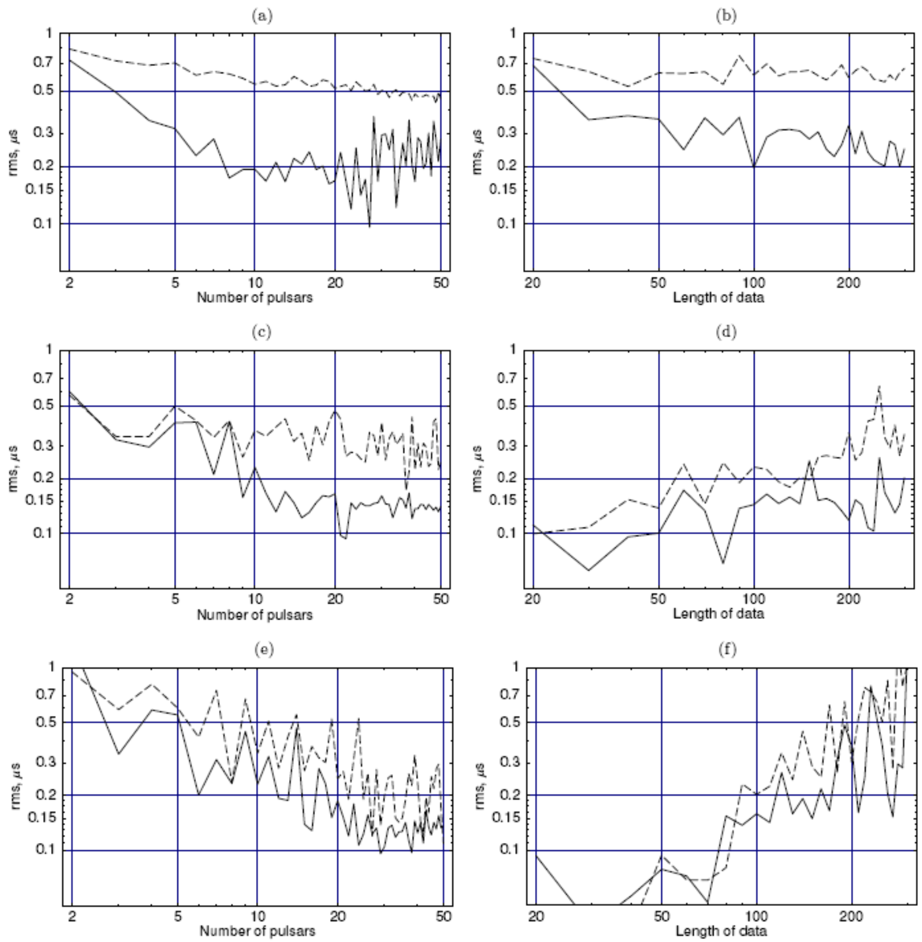


Figure 1. The accuracy of signal estimation based on the methods of weighted average (dashed line) and Wiener filter (solid line) as dependent on the number of pulsars (left panels) and length of the data (right panels). For the calculation shown in the left panels 256 points of data were taken, for calculations shown in the right panels five pulsars were used. Different types of noise were generated: (a), (b) - white phase noise, (c), (d) - white noise in frequency, (e), (f) - random walk noise in frequency. Data in the panels (d) and (f) were scaled accordingly for fitting within in all the panels.

Results of numerical simulations (Rodin, MNRAS, **387**, 1583, 2008).

The accuracy of signal estimation based on the methods of weighted average (dashed line) and Wiener filter (solid line) as dependent on the number of pulsars (left panel) and length of data (right panels).

(a)-(b) white noise,

(c)-(d) white noise in frequency,

(e)-(f) random walk in frequency.

Results

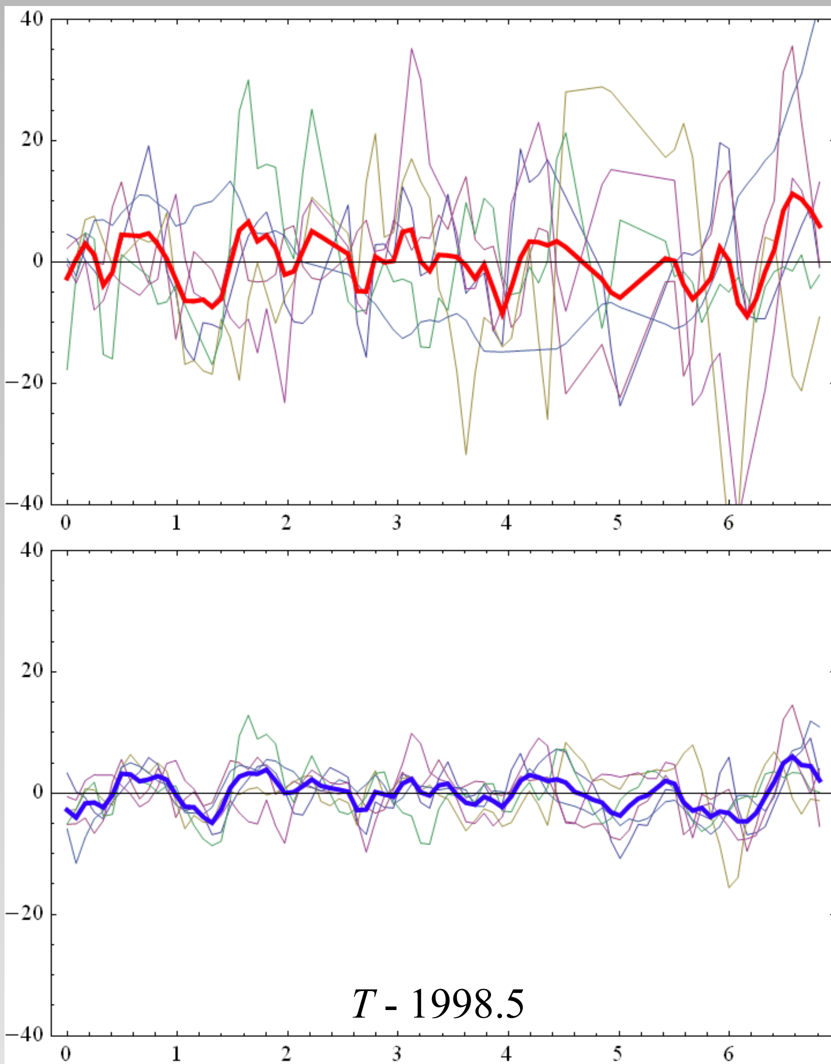
Table1. Pulsar parameters

Pulsar name	Spin period, ms	DM, $cm^{-3} \cdot pc$	Binary period, days	RMS, mcs
J0613-0200	3.062	38.78	1.2	14.8
J1640+2224	3.163	18.42	175.46	5.4
J1643-1224	4.622	62.41	147.02	11.6
J1713+0747	4.570	15.99	67.83	10.5
J1939+2134	1.558	71.04	-	2.2
J2145--750	16.052	9.00	6.84	14.9

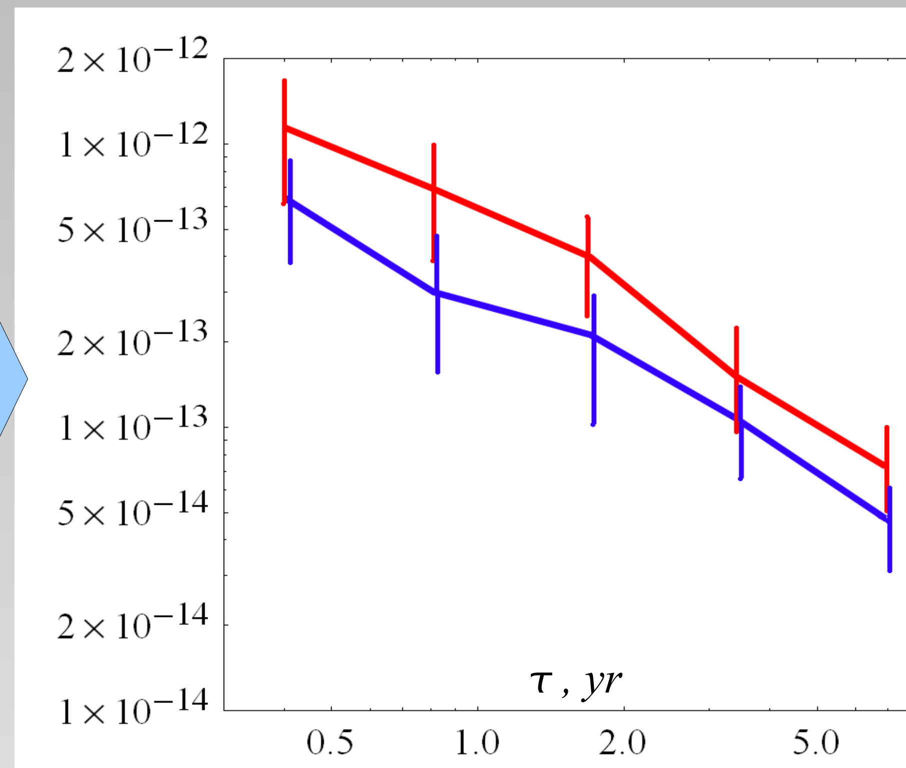
Pulsar timing observations were carried out with 64 m radio telescope of Kalyazin radio astronomy observatory (KRAO) at frequency 610 MHz in bandwidth 3.2 MHz (Oreshko.V.V., *Pulsar timing instrumental errors. AC-600/1600 facility*. Proceedings of the Lebedev Physical Institute., Moscow, 2000, v. 229, p. 110 (*in Russian*).

Ilyasov, Y. P.; Oreshko, V. V.; Potapov, V. A.; Rodin, A. E., *Timing of Binary Pulsars at Kalyazin, Russia*, 2004, IAUS, 218, 433.

Results

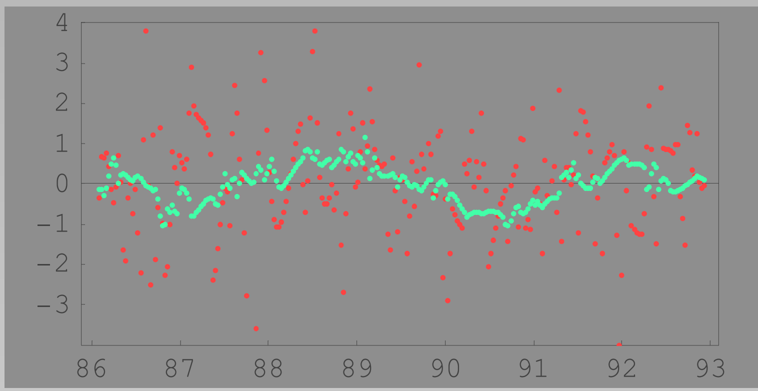


Fractional instability σ_z

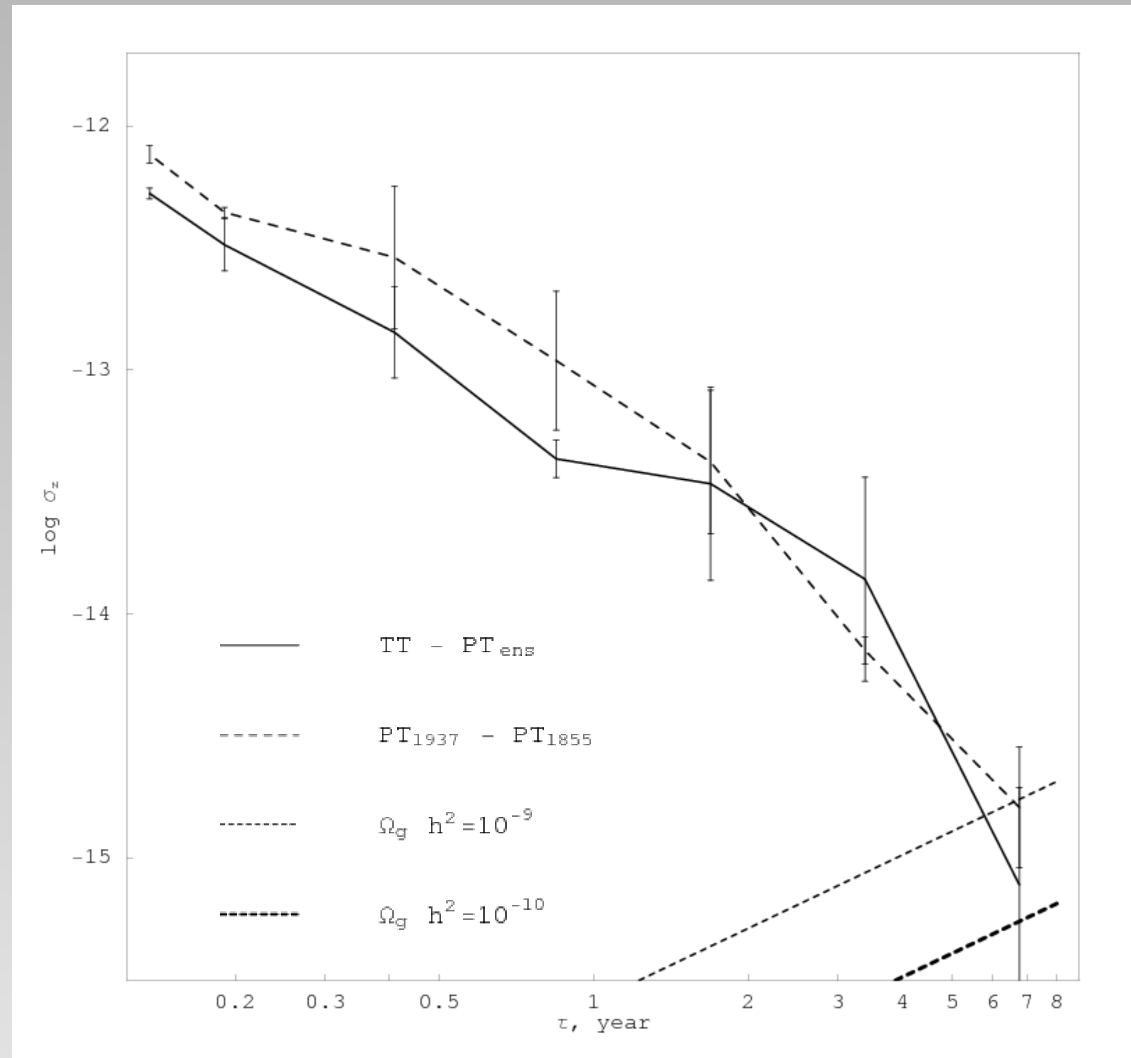


Comparison of the weighted average and optimal filtering.

Results



Post-fit timing residuals of PSR 1855+09 and 1937+21 (Kaspi et al, 1994)



Fractional instability σ_z of the difference TT(BIPM06) – PT$_{ens}$ (solid line) and PT$_{1937}$ – PT$_{1855}$ (dashed line) (Rodin,2008).

Conclusion

- An algorithm of the ensemble pulsar timescale based on the method of the optimal Wiener filtration is proposed.
- Fractional instability of the difference $PT_{ens} - TT$ is $\sim 10^{-15}$ at 7 yr interval.
- Even despite a great progress in atomic frequency standards technology, millisecond pulsars still have their own «ecological niche» as absolutely independent time keepers.