Pulsar Astronomy — 2000 and Beyond
ASP Conference Series, Vol. 202, 2000
M. Kramer, N. Wex, and R. Wielebinski, eds.

The Noise Structure of Pulsar Clocks

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Abstract. Pulse arrival times of pulsars have a high – though limited – degree of predictability: they show both discrete 'glitches', and continuous deviations from an analytic extrapolation of earlier data spans; they are 'noisy'. This noise shows a strong dependence on a pulsar's spindown age. Both types of noise can be understood as due to a loose coupling of the charged component of a pulsar's moment of inertia to a neutral superfluid component, of relative moment of inertia usually below 1%, but reaching 10% in extreme cases. Differential spin rates $\delta\Omega/\Omega$ of the two components are $\lesssim 10^{-3}$, usually only $\lesssim 10^{-5}$.

Pulsar clocks can have higher accuracies than the best manmade ones – whose 1998 record was $10^{-14.6}$ – but they are not unlimited either. The limitations come through occasional discrete (upward) frequency jumps – so-called *glitches* – of relative size between $10^{-5.3}$ and less than 10^{-11}, which have been observed in some 22 out of more than 700 pulsars, preferentially in the young ones, with a peak in glitch activity near spindown age $\tau = 10^4 yr$, $\tau := P/2\dot{P}$; see Lyne (1996), Shabanova (1998), J.O.Urama & C.S. Flanagan, and Joe Taylor (these proceedings) who reported a $10^{-11.2}$ glitch in the binary pulsar 1913+16 at 1993.0. Postjump *'healings'* tend to obey exponentials involving sinusoids; on top of these, various odd behaviours have been reported (in above refs.) after small glitches.

Besides the discrete frequency jumps, pulsar clocks show a noisy behaviour which increases with $\dot{P}$, i.e. is smallest for the msec pulsars. This *continuous noise* can be described via the 'braking index' $n := \Omega\ddot{\Omega}/\dot{\Omega}^2$, by the inequality $|n| \lesssim \tau/300yr$, a relation whose reality was recognised by Joanna Rankin some 20yr ago but has been denied in much of the subsequent literature (Gullahorn & Rankin, 1982). It has, however, been rediscovered by Lyne (1996) in the shape $|\ddot{P}|/\dot{P} \lesssim 1/600yr$, an equivalent form for $|n| \gg 3$. I.e. the braking index n senses both dipole braking, with n = 3, and spindown noise, whose contribution grows linearly with τ in magnitude. For the three youngest pulsars, n (evaluated in between glitches, not averaged through them) takes the (small) values 2.51, 2.24, and 2.837, as a consequence of their (frequent) glitches (Kundt, 1998).

Pulsar glitches have been described by the sudden locking of a slightly superrotating neutral superfluid component – consisting mainly of neutrons – to the charged components of the neutron star, which rotate rigidly and couple to the outside world (Link et al, 1993). The required *superrotation rates* are $\delta\Omega/\Omega \lesssim 10^{-3}$. Their healing behaviour is different for different pulsars, with a so-far systematic dependence on (spindown) age, and is apparently governed by

https://doi.org/10.1017/S0252921100059169 Published online by Cambridge University Press

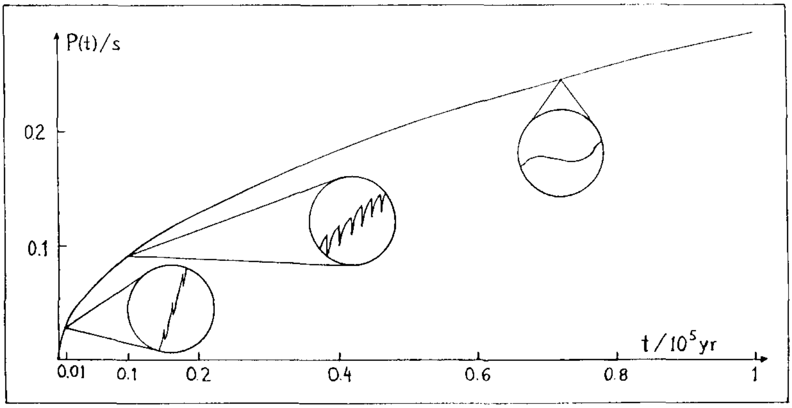

Figure 1. Pulse period P(t) versus age t, for pulsars from different age groups. Note the qualitatively different noise structure at different spindown ages – which is predominantly blamed on loosely coupled superfluid components.

linear differential equations so that it can be modeled by (complex) exponentials; cf. figure 1.

New has been the insight that also the continuous noise can be described by a (slightly) superrotating component whose angular velocity fluctuates around some average value on the timescale of a few years, during which the *effective* (coupled) *moment of inertia* of the star does not change by more than 0.3% (Kundt, 1998). It is apparently due to the same weak coupling between the charged and the neutral superfluid component as for the glitches. Note that the charged component is forced to rotate rigidly, on macroscopic timescales, by its frozen-in magnetic field.

Acknowledgments. Help with the MS has been received from Norbert Wex and from Günter Lay, and with its contents from Gernot Thuma.

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https://doi.org/10.1017/S0252921100059169 Published online by Cambridge University Press