Melbourne University

Canonical method for single source detection with PTA

T. Kimpson

July 13, 2023

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1 Preamble

These notes summarise the "canonical" method by which the pulsar/PTA community detect single GW sources (i.e. a supermassive BH binary inspiral, rather than a stochastic background).

We will consider Sesana & Vecchio 2010 (SV2010 hereafter) and Ellis et. al. 2012 (Ellis2012 hereafter) as representative of these canonical methods. Other methods exist (e.g. Zhu et al 2016) but they are generally derivative of these two original works (e.g. Zhu 2016 uses the same base equations, but then works in the frequency domain and explores impact of PSR terms on SNR).

2 Fundamental Equations

Both SV2010 and Ellis2012 treat the PSR timing residual as the fundamental observable. That is, they assume the true PSR evolution is "known" - described by a pulsar timing model. Deviations between this known solution and the what they actually observe at the detector is characterised by a residual. The GW imprints onto these residuals.

The general approach is as follows:

1. Take the data timeseries for a single pulsar as a residual corrupted by some noise

$$d_\alpha(t) = r_\alpha(t) + n_\alpha(t) \tag{1}$$

2. Use TEMPO and least-squares fitting to generate some post-fit residuals $\tilde{r}_\alpha(t)$. i.e. update pulsar parameter estimations given this new data

3. Define a signal model, s, for the timing residuals due to the influence of a GW. Define a Gaussian likelihood $\mathcal{L}(s|\tilde{r})$.

4. Drop the pulsar terms and derive an F-statistic by analytically maximising over the extrinsic parameters $\left(\frac{\mathcal{M}^{5/3}}{D}, \iota, \Phi_0, \psi\right)$ Note that for a single pulsar the maximisation is ill-poised. At least two pulsars are required.

5. Perform a maximum likelihood search given the F-statistic to search for the intrinsic parameters.