

Technical Document for Spinning Massive Black Hole Binaries.

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I. INTRODUCTION

For the 3rd MLDC we have used a Parallel Tempering MCMC algorithm. This algorithm uses the Metropolis-Hastings Markov Chain (MHMC) algorithm that was used in previous challenges as a base algorithm. The algorithm again uses the frequency and thermostated annealing that was used in previous challenges. The frequency annealing works by starting off with a small portion of the waveform and gradually increases the length as we progress through the search. As well as allowing us to match the earlier less relativistic parts of the waveform, the frequency annealing allows us to very quickly identify a source (normally on the scale of minutes). In the past we found that simulated annealing (initially heating the likelihood surface and slowly cooling) was essential in converging quickly to a solution. However, it was clear that the choice of the initial heat was ambiguous and source dependent. To circumvent this problem, we introduced the concept of thermostated annealing. This scheme injected heat into the likelihood surface depending on the current performance of the chain. As the chains converged more heat was injected, thus flattening any high lying secondaries. After a certain number of iterations, the thermostated heating was turned off and we slowly cooled the likelihood surface to unit heat.

For this challenge, the main change is the introduction of parallel tempering. The parallel tempering works by starting a number of MHMC chains at different temperatures. Each of the chains attempts to progress using the various proposal distributions in the algorithm. At a regular pre-determined point, the chains are analysed and information is passed amongst the chains. This allows the hotter chains to widely explore the parameter space, while the cooler chains investigate local features. As we progress through the search phase, we reduce the number of live chains as we converge on a solution. The reason being, we no longer need the wider investigation of the parameter space and the hotter chains therefore become uninformative. The second major change is the inclusion of spin dependent proposal distributions where we try and exploit symmetries in the spin directions.

While the algorithm has been successful in detecting sources in the blind data sets, we have identified a number of areas where improvements need to be made. As in the past, the algorithm quickly converges on the mass parameters, the time to coalescence and the distance. However, we feel that the algorithm in its current form is unable to satisfactorily resolve the spin parameters and the associated spin directions. It has been clear that the spins produce a number of modes that are close in signal to noise ratio to the primary value. While our proposal distributions manage to exploit mode hopping in spin directions, we need to carry out further investigations to reach an optimal solution. As we are not able to properly resolve the spins, this effects the phasing of the waveform. So while we are confident we are in the ballpark of the true mass, time to coalescence and distance parameters, we are not as close as we feel we could be. We have also identified some issues in the performance of the Fisher matrix for these sources. We intend to explore issues such as re-parameterization of the Fisher matrix in the near future to see if we can increase the convergence of the chains.