Techincal Note for MLDC Challenge 1.2 Entry

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This entry is based on a Metropolis-Hastings algorithm that uses thermostated frequency annealing followed by a Markov Chain Monte Carlo exploration of the posterior distribution of the source parameters. The barycenter waveforms match those used to generate the MLDC data sets, and the detector response is modeled using the Rigid Adiabatic Approximation.

The search code is based on a slightly modified version of the algorithm described in (Cornish & Porter, gr-qc/0605135 [1]). The modifications are (1) The low frequency response has been replaced by the Rigid Adiabatic Approximation [2] (2) The Simulated Annealing has been replaced by a hybrid Frequency Annealing, Simulated Annealing scheme (3) Following the MCMC exploration of the posterior the chain is "super cooled" to recover maximum likelihood estimates for the parameters. Our reported results for the recovered parameters are these maximum likelihood estimates.

Our frequency annealing scheme works by cutting off the template generation and the noise weighted inner products at a frequency $f_{\rm stop}$. The value of $f_{\rm stop}$ is incremented from some $f_{\rm min}$ to some $f_{\rm max}$ using the power law schedule

$$f_{\rm stop}(i) = f_{\rm min} 10^{\log_{10}(f_{\rm max}/f_{\rm min})(i/N_f)} \,. \qquad (1)$$

Here i is the iteration number and N_f is the number of iterations it takes to reach $f_{\rm max}$. We set $f_{\rm min} = 4\times 10^{-5}$ Hz and $f_{\rm max}$ was chosen to accommodate the largest merger frequency allowed by the priors on the the two masses. During the frequency annealing the noise weighted inner product was thermostated to ensure that the effective SNR never exceeded 20. The thermostating is accomplished by applying a heating factor of $({\rm SNR}/20)^2$ to all the noise weighted inner products when the SNR exceeded 20. The thermostating causes the chains to explore the parameter space more vigorously and stops the search from getting stuck in secondary maxima. The frequency annealing makes the initial search phase extremely fast as we only have to generate the waveforms at low cadence. Most of the run time was in the later MCMC portion of the program. The algorithm also tested for converge of the search chains, and if it was determined that the merger occurred outside of the observation time the frequency annealing was terminated at the maximum frequency reached by the signal during the observation period. Following the frequency annealing the chains were allowed to cool to a heat of unity using a standard power law cooling curve. This cooling phase lasted N_c steps. Once the cooling was complete the non-Markovain elements of the search were suspended [1], and a MCMC exploration of the posterior was conducted for N_m steps. Finally, the chains were supercooled to a heat of 0.01 in N_{sc} steps.

TABLE I: Recovered Intrinsic Parameters for Challenge 1.2.1

	θ	ϕ	m_1	m_2	t_c
ML	-0.4911	0.8644	2.89098e+06	7.2840e+05	1.33740314e+07
BE	-0.4911	0.8646	2.89101e+06	7.2840e+05	1.33740314e+07
σ	0.0024	0.0029	1.2e+03	2.7e+02	2.6

TABLE II: Recovered Intrinsic Parameters for Challenge 1.2.2

	θ	ϕ	m_1	m_2	t_c
ML	-0.1050	1.3620	1.3066e+06	5.741e+05	3.63142e+07
BE	-0.1040	1.3622	1.3072e+06	5.799e+05	3.63138e+07
σ	0.0090	0.0082	1.4e+05	5.4e+04	5.3e+03

For each Challenge 1.2 data set we ran many short searches with $N_f = N_c = N_{sc} = 5000$ and $N_m = 10000$, and a couple of longer searches with $N_f = N_c = N_{sc} = 10000$ and $N_m = 20000$. The longer searches were used to check that the annealing had not been too aggressive. We found consistent results between the long and short runs. The Challenge 1.2.1 chains took ~ 24 hours on a single 2 GHz processor, while the Challenge 1.2.2 chains took ~ 6 hours on a single 2 GHz processor. (The initial detections take tens of minutes, most of the time is spent refining the fit and exploring the posteriors). The posterior distributions functions were derived by merging together the MCMC portions of the different chains.

While testing our algorithm on the Training data we found indications of slight modeling errors in the 1.2.1 analysis (where merger is seen during the observation time). Using the parameters quoted in the key file our template generator did not produce a perfect match to the noise free training data. While the discrepancies were very slight, their effect on the parameter recovery is amplified by the fact that most of the SNR accumulates during the last few cycles. In our runs on the 1.2.1 training data we found small systematic offsets in most of parameters. We attribute these problems to the break down of the rigid adiabatic approximation during the final few cycles of the merger. We hope to correct this problem in the future by switching to the full LISA Simulator response for the final 30 cycles or so of each template.

Because the extrinsic parameters are recovered from an F-statistic, quantities like the phase at coallesence and the polarization angle get cast into the range $[0, \pi]$, so some care must be taken when comparing them to the key files. There is also a degeneracy between signals with $\psi \to \psi + \pi/2$ and $\phi_c \to \phi_c - \pi$. In addition, we had to convert between the gravitational wave phase at coallesence, ϕ_c, used in our codes and the initial orbital phase, ϕ_0 quoted in the key files. These sometimes are out by $\pi/2$ due to the aforementioned degeneracy. Once again, care should be taken when comparing the recovered ϕ_0 to those in the key file.

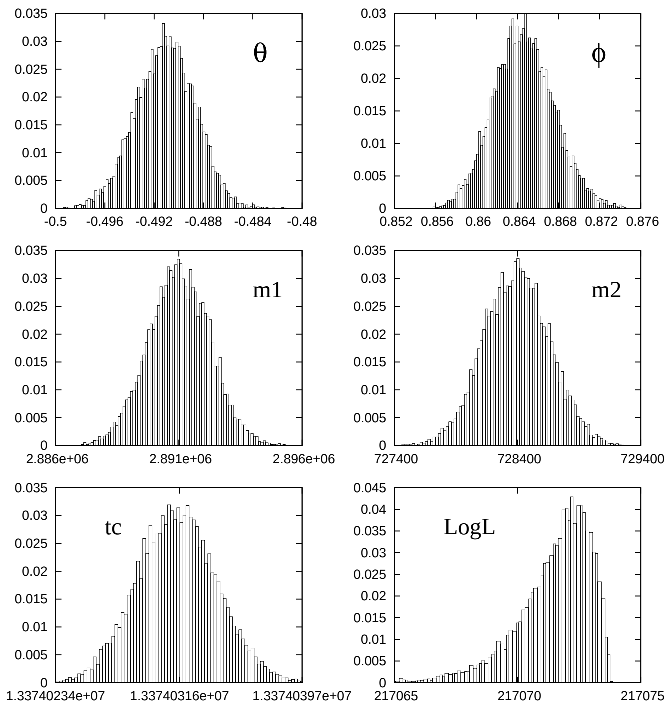

FIG. 1: Marginalized PDFs for the intrinsic parameters and the log Likelihood for Challenge 1.2.1.

Table I displays the Maximum Likelihood and Bayes estimates for the intrinsics parameters for Challenge 1.2.1. We also quote an estimate for the standard deviation in each parameter. Since the Bayes estimates and the standard deviations were calculated using F-statistic chains they are only applicable to the intrinsic parameters. The Maximum Likelihood estimates for the extrinsic parameters are: Polarization 0.093; Initial Orbital Phase 0.144; Luminosity Distance 7.67 Gpc; Inclination 1.93. Figure 1 shows the marginalized PDFs for the intrinsic parameters and the log Likelihood.

Table II displays the Maximum Likelihood, Bayes estimates and standard deviations of the intrinsics parameters for Challenge 1.2.2. The Maximum Likelihood estimates for the extrinsic parameters are: Polarization 2.59; Initial Orbital Phase 1.71; Luminosity Distance 2.91 Gpc; Inclination 0.813. Figure 2 shows the marginalized PDFs for the intrinsic parameters and the log Likelihood.

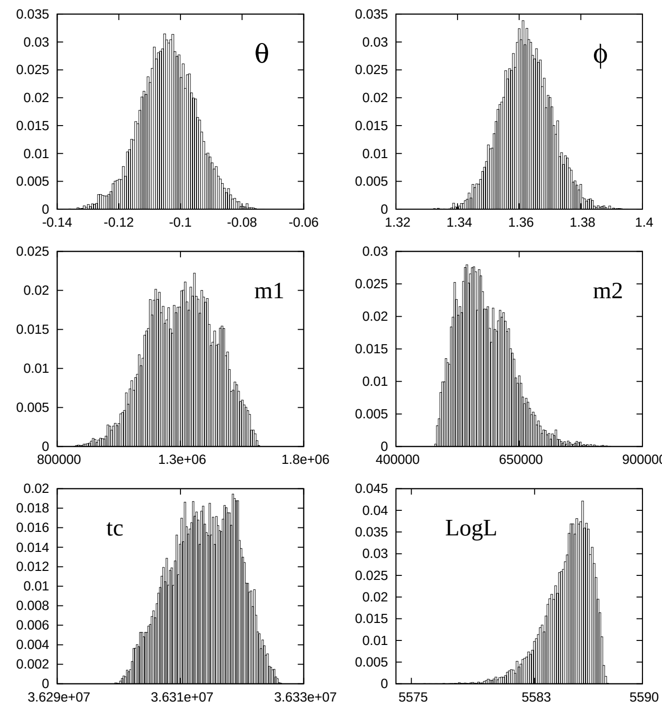

FIG. 2: Marginalized PDFs for the intrinsic parameters and the log Likelihood for Challenge 1.2.2.

At a later date we will run a full 9-parameter MCMC chain to fully map out the PDFs and get error estimates on the extrinsic parameters.

[1] N. J. Cornish & E. K. Porter, gr-qc/0605135 (2006).
[2] L. J. Rubbo, N. J. Cornish & O. Poujade, Phys. Rev. D**69** 082003 (2004).