Searching for EMRIs in Challenge3.3

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I. METHOD

The underlying method is described in details in arXiv:gr-qc_0902.4133. Here we will give only a brief description of the method and a bit more detailed description of the modifications (motivated by low SNR of the signals and confusion).

The method consists of three steps:

- Stochastic search: randomly chosen points in the parameter space within priors. The likelihood maximized over the amplitude and initial phases, and over plunge time by sliding the template.
- Search on the part of the data. We use best points obtained in the previous step to seed the chains (Markov chain Monte Carlo with Metropolis acceptance-rejection rule) and perform the search on the 1st year of data. We allow the chains to evolve until they find the stationary solution (one of the local maximum). Local maxima correspond to recovery a part of one or several harmonics of the signal. Different chains see different harmonics or different parts of the dominant harmonic(s). We identify those harmonics and use this information to direct the search. Later in this search we use phenomenological template: template which consist of N (specified by user) harmonics with correct (physical) phase evolution and sky modulation, but treat each harmonic as independent and maximize likelihood over the phase and amplitude of each harmonic for each polarization (F-statistic). We call it N-harmonic F-statistic search. This helps us to immediately identify which harmonics are detected in each chain, and build several consistency checks. We conduct search until the result shows high F-statistic values in at least three dominant harmonics.
- The third step is to increase duration of the template to two years and switch back to "physical" template. This includes finding direction of the spin and running MCMC with the full duration template.

The complexity of this challenge lies in low SNR of the signals, so usually only the dominant harmonic can be found. The second complexity is due to presence of several signals which makes harmonic identification much more difficult.

The first novelty is that we have increased duration of the template to one year (sometimes we also used half year long templates). Second, we have improved proposals in Metropolis Monte Carlo search optimizing them for the search of the harmonics around the dominant one. We have used harmonic rotation and made runs with excluded the dominant harmonic from the search.

However the biggest difference was in the identification of the harmonics and in finding the best reference time. We based our harmonic analysis on plotting the accumulation of likelihood as function of time and frequency. If we have found the primary maximum, the accumulative likelihood should be a monotonously increasing function (modulo fluctuations caused by the noise) for each harmonic with significant SNR. Each chain detects part of the harmonic(s). We identify this part by measuring the rate of change of the likelihood: $d\Lambda/dt$ and choosing part of the time-frequency track with high positive slope. We can rebuild harmonics by putting those pieces together (like a puzzle) .

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II. RESULTS

We have focused our search on the medium mass EMRI. We have submitted results for two signals (3 mode for each). The submitted results didn't pass all consistency checks, but deviations where within the range which could be caused by noise contamination. This is the result of our best interpretation of the found harmonics. Different modes come from high degeneracy between the orientation of the MBH's spin and the initial orbital phases.

Next we have started looking at the low mass EMRI. We have not completed analysis (currently we are in the middle of the step 2), therefore we have decided not to submit partial results. Instead we have decided to summarize our findings here (assuming that these notes are considered as a part of the submission).

First of all we should say that we see harmonics of both signals, as it is clearly seen in the figure 1.

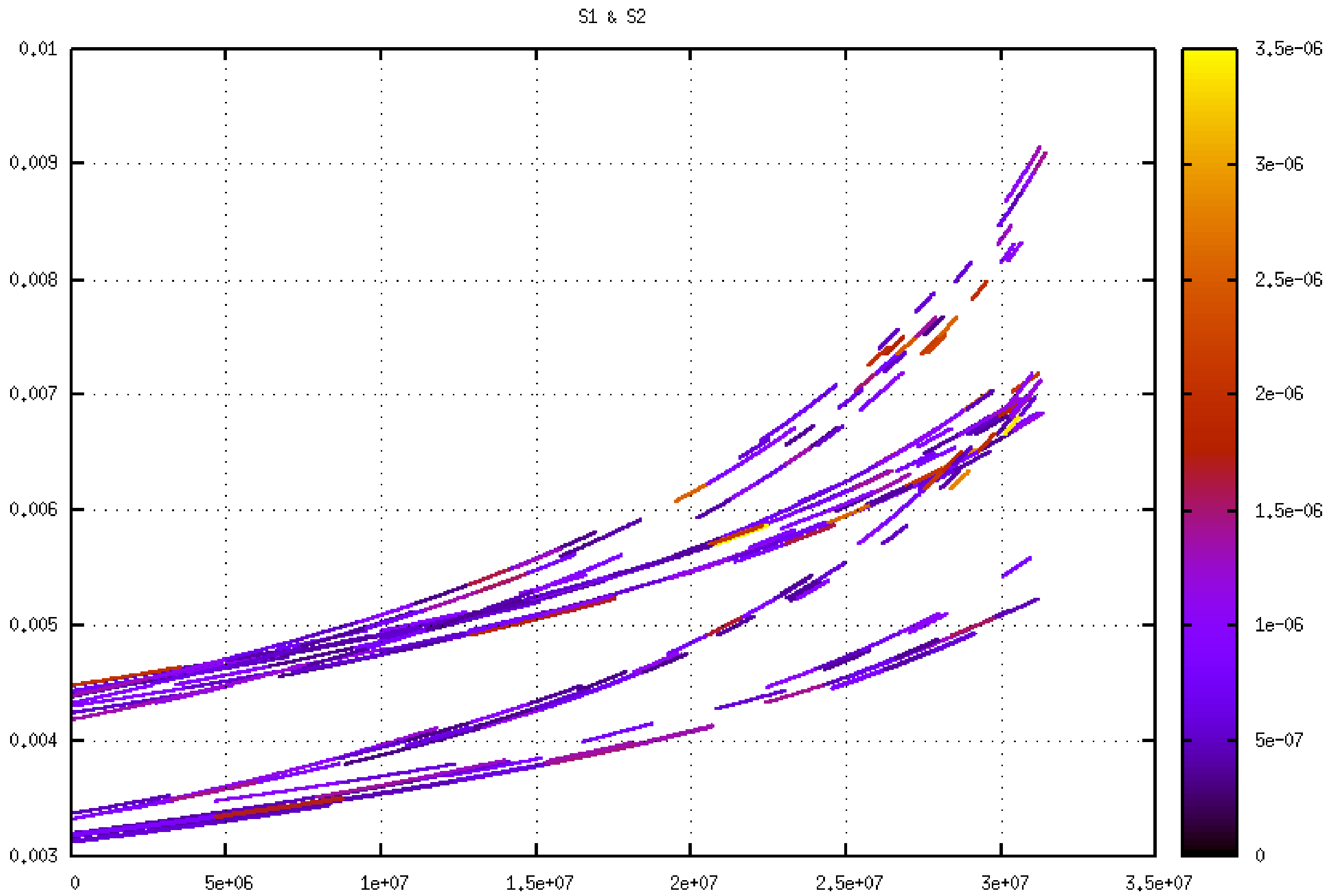

FIG. 1: Identified harmonics of two low mass EMRI signals. One can see two sets of parallel tracks in the time-frequency plane. Signals have different rate of harmonic evolution. This is the result of the analysis of the first year of data. We have color-coded the slope of F-statistic at each point (dF/dt), and we have plotted only the points with the slope above $3 \times 10^{-7}\,Hz$.

In the figure 2 we have singled out harmonics of the first signal in time-frequency plane.

And in the last figure 3 we have plotted the harmonics identified with the second signal for the whole duration template.

The next step in the search is to derive the orbital frequencies from the detected harmonics assuming some harmonic index. Then find the reference time where the slope of all harmonics positive (and high) and start the search with the fixed estimated orbital harmonics. That is were we stand at the moment, and those are our partial results. It will be interesting to overplot the true harmonics on top of the identified.

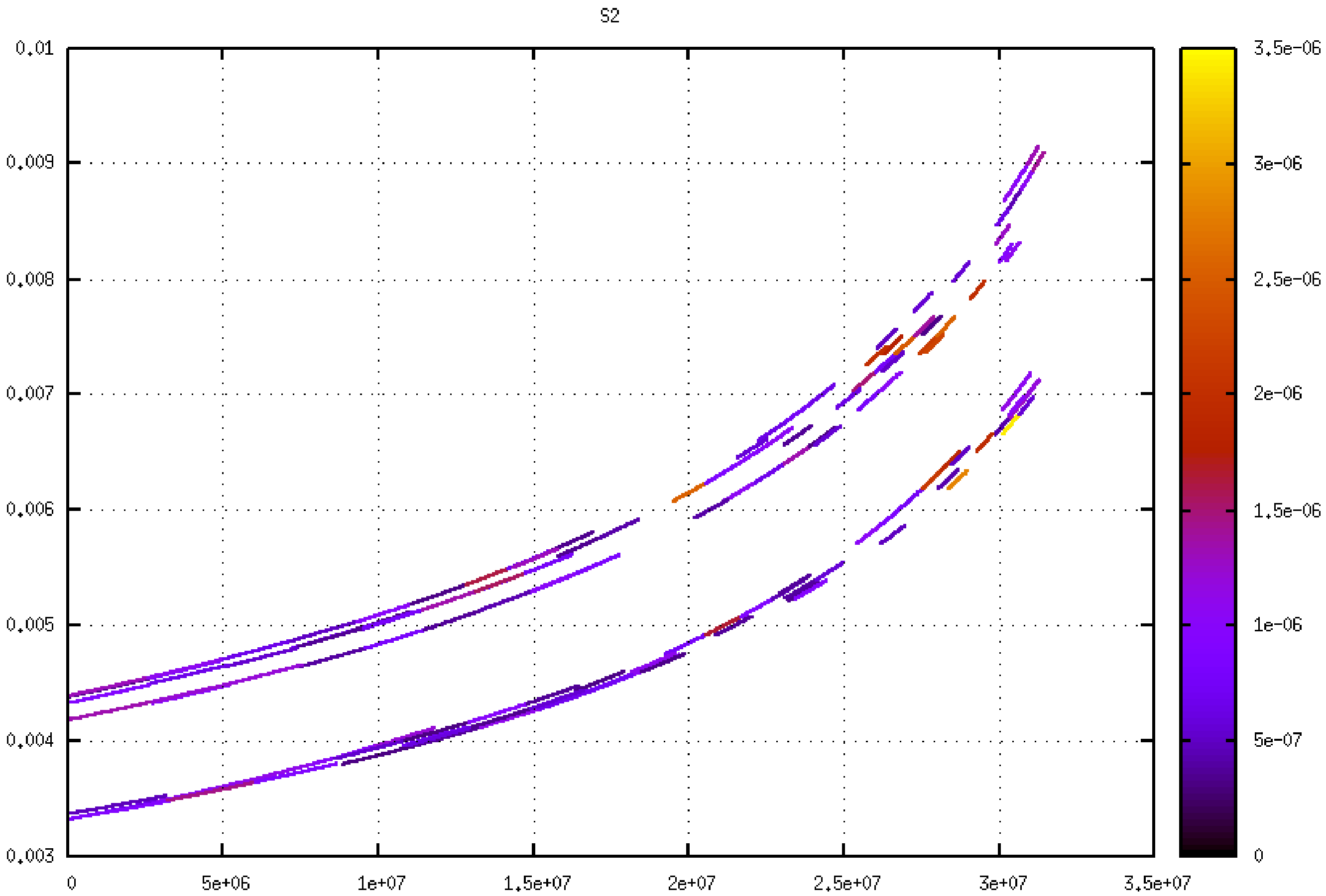

FIG. 2: Result of the analysis of the first year of data. Harmonics identified with one of the low mass EMRI signals. It is again the time-frequency plane and we have color-coded dF/dt.

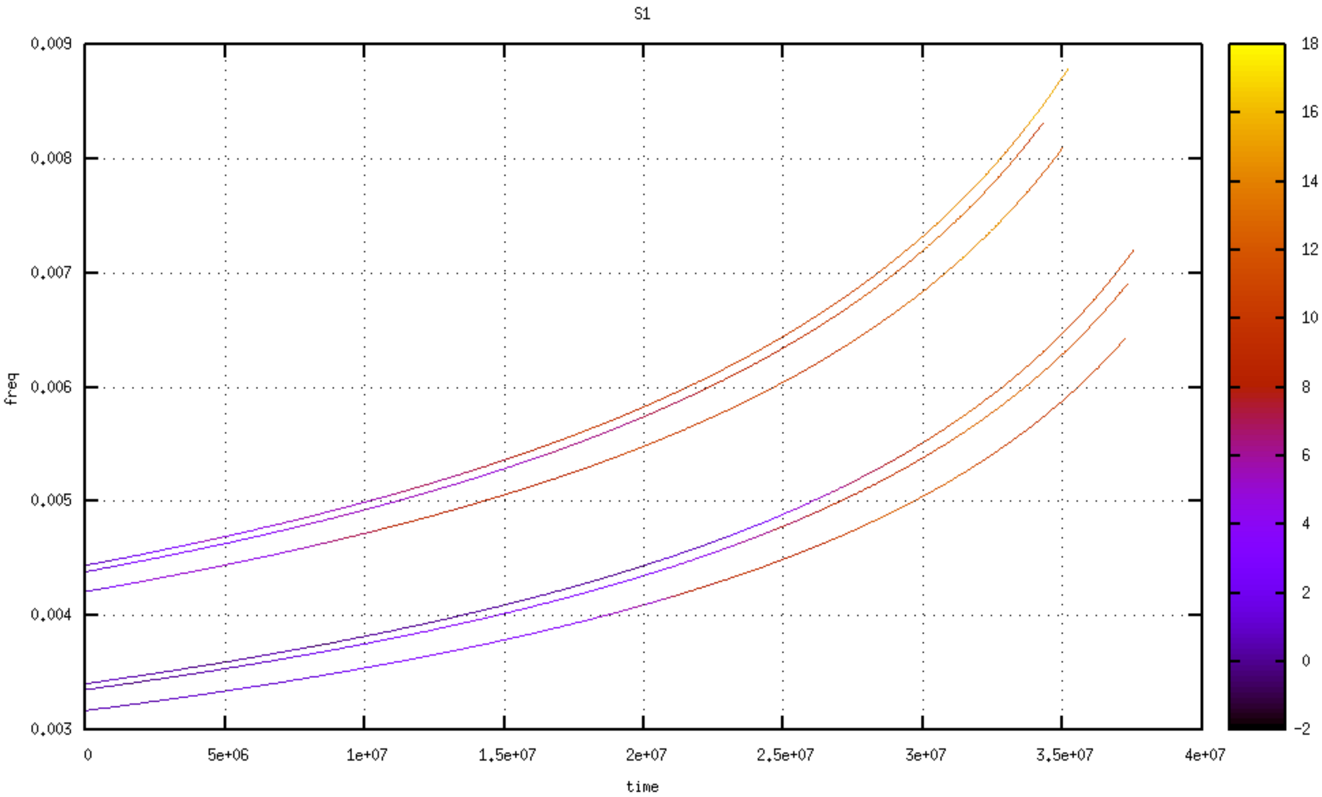

FIG. 3: Harmonics identified with the second low mass EMRI signals. It is again time-frequency plane and we color-coded accumulation of F-statistic.