Comparison of performance of matched filter and excess power toy models on Supernova waveforms

The University of Texas Rio Grande Valley

EMBRY-RIDDLE Aeronautical University PRESCOTT, ARIZONA

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Abstract

In this poster, we compare the receiver operating curves and efficiency curves for toy model implementations of matched filtering and excess power detection approaches, in the case of Core Collapse Supernovae waveforms and publicly released LIGO data. We also address the degradation of the performance with the template mismatch to be expected from the stochastic nature of the SN signals and the foreseeable small pool of templates available in the nearby future. The implications for possible future usages of Matched filtering in Supernova searches as well as improvements of existing burst methodologies are discussed.

Method

The toy models of matched filter and excess power are Matlab codes. Toy model of matched filter consists of cross-correlation in time domain between LIGO data stream with injections and waveform templates. Cross-correlation defined as such: $A(k) = |\sum_{j=1}^{L} a(j+k) * w(j)|$ (cross correlation output), where 'L', 'w', and 'a' are length of the waveform template, normalized waveform template, and whitened data stream from L1 or H1 (Livingstone and Hanford interferometers). Whole analysis has been done purely in time domain with 4096 sampling frequency. Similar idea has been used for toy model of excess power: $\mathrm{B}(\mathrm{k}) = |\sum_{i=k}^{k+D} L1(i) * H1(i)|$ (excess power output), where L1 and H1 are data streams with simultaneous injections and 'D' is duration window for correlating two detectors. Waveforms were used are short duration Sine Gaussian and Yakunin 2015 waveforms.

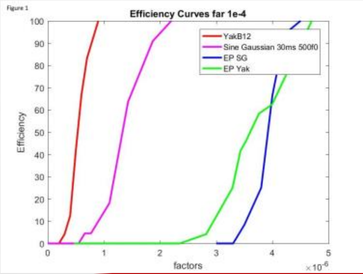
Procedure

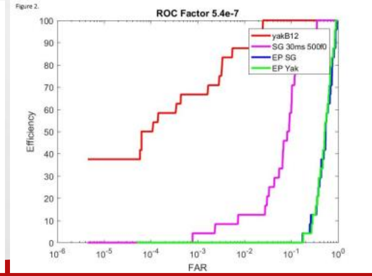
Test statistic is first applied to data without injections to estimate noise distribution, which is used to calculate false alarm rates (FARs) for different thresholds. Next, set of waveform factors are chosen and for each factor we: inject waveforms with selected factor into data stream, applying test statistic, and for fixed FAR we calculate how many injections pass that threshold. This in turn should give us an estimate on how efficient method at finding injections of selected factors and we produce efficiency curve plot. Same procedure is applied for different methods, which in this presentation are toy model of excess power and matched filter. The fixed FAR for efficiency curves is relative to the noise distribution for the selected methods, so that it becomes independent of the test statistic and valid for comparison.

Another approach at comparing methods is to calculate receiver operating characteristic (ROC) curves. The idea is instead of fixing FAR is to fix injection factor and to check how each method manages to detect it. For different FARs efficiency is calculated and produced at the plot.

Discussion

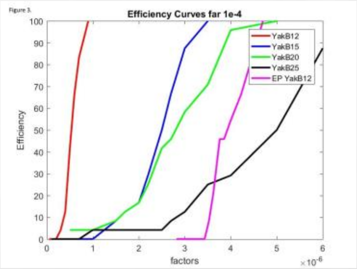
In this section, we will discuss plots obtained by implementing toy models of matched filter and excess power. We have used data from S6 about 4 min. The data is later resampled to 4096Hz, band passed between 40 to 2048Hz, and whitened. About 0.55s of YakuninB12 waveform is taken, resampled to 4096Hz, and normalized. 30ms normalized Sine Gaussian is produced with central frequency 500Hz and width 10. These two waveforms are used for the analysis in the plots on figure 1 and 2.

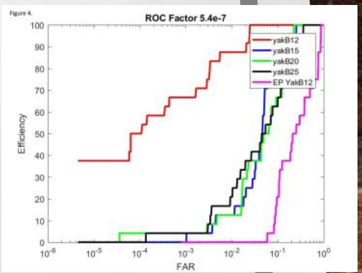




For the figure 1. If we look at the 50% efficiencies and check factors we obtain 5.3333e-07, 1.3310e-06, 3.9200e-06, 3.6033e-06 injection factors, from left to right respectively. The first two curves are produced by matched filter and next two by excess power. It can be seen from this plot that detection efficiency for YakuninB12 is higher than for Sine Gaussian with matched filter. However, the main reason for such difference can be length of waveform template and not the features of the template. On the figure 2, we can see rather dramatic difference if we look at 50% efficiencies: we get 8.1733e-05, 0.0859, 0.5432, 0.5226 FARs. For relatively low factor 5.4e-7 It can be said that excess power does not detect any injection. Rather suspicious difference of order of 3 (10^3), can be observed in the increase for the YakuninB12 waveform.

On figure 3. we can see efficiency curves for matched filter by using Yakunin waveform templates with different progenitor masses as correlation templates. The actual injection we were looking for is YakuninB12. As it can be seen the more massive difference the worse the correlation – worse detection efficiency. However, the difference in masses is very big, where for actual matched filtering bank progenitor masses can be chosen with an extremely low difference. On figure 4. we observe ROC for the same procedure, but ROC is done for the very low injection factor. Apart from noticing that noise starts to dominate for the excess power method, very little is observed.





Conclusion

This toy model test indicates that for realistic CCSNe waveforms matched filtering can improve the range of detection almost by one order of magnitude at a fixed FAR. However, a mismatch between the template and the actual waveform can make the performance worse than the excess power. The next step is to check the degradation of the fitting factor between different waveforms of the same progenitor by randomizing the source orientation in 3-D models (which should be available in the next months).

Acknoledgements

The authors would like to thank the Center for Gravitational Wave Astronomy (CGWA) and the Department of Physics and Astronomy at the University of Texas at Brownsville for financial support.

References

1. Yakunin et al. (2015) *Gravitational Wave Signatures of Ab Initio Two-Dimensional Core Collapse Supernova Explosion Models for 12-25 Solar Masses Stars.* *http://chimerasn.org/*

LSC-Virgo Meeting, March 2017, Pasadena