Search for Burst Gravitational Waves Using TAMA300 Data

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Abstract

Burst gravitational waves from stellar-core collapses are one of the promising targets for ground-based interferometric detectors. However, search for their signals in detector output is not easy because their waveforms are not predicted precisely, and thus signals are largely affected by non-Gaussian noises of the detector. Thus, we developed a robust and effective scheme to reject non-Gaussian noises and to extract burst signals. In this method, non-Gaussian noises are distinguished from real gravitational-wave signals by time scales, and are rejected with small false dismissal rate for real signals. We will present this data analysis method and the analysis results using over 2000 hours of data obtained with TAMA300 gravitational wave detector; false alarm rate was improved by 10^3 times with this non-Gaussian noise evaluation and rejection method.

1. Introduction

There are several expected GW sources for current interferometric GW detectors [1,4,7,11]: chirp signals from inspiraling compact binaries, continuous waves from rotating neutron stars, burst waves from gravitational core-collapse of stars, stochastic background from primordial universe, and so on. Among them, data analysis technique for chirp waves are well-developed because the waveforms are predicted precisely with a post-Newtonian approximation. In this case, signals are found in an optimal and clear method of matched filtering [2,10]. In addition, most of the non-Gaussian noises are rejected by signal behavior (by

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the method called χ^2 rejection). On the contrary, data analysis for burst signals is not straightforward; matched filtering method cannot be used because precise waveform templates are not available. Although some typical waveforms have been obtained by numerical simulation of gravitational core collapse [8,12], they are not sufficient to be used as templates in matched filtering because of their poor and rough coverage in search parameter space.

Therefore, semi-optimal filters, which are sensitive to unusual non-Gaussian events, are required and proposed for burst-wave search [3,5,6,9]. Though these filters are sufficiently effective if we have some information on the waveforms (frequency bandwidth and time duration), they are also sensitive to non-Gaussian noises caused by interferometer instability. This is because burst filters are designed to detect unusual events without distinguishing real signal from non-Gaussian noises. Non-Gaussian noises increase false alarm rate of the filter output and, as a result, real signals are likely to be buried in these false alarms, or likely to be dismissed with larger detection threshold set to reduce false alarms. Thus, we developed a detection method for burst events which is less affected by non-Gaussian noises.

2. Search method

In our scheme, noise behavior (time scale of the non-Gaussian events) is evaluated. While typical time scale of gravitational waves from stellar-core collapse is less than 100 msec, noises caused by detector instability tend to last longer than a few second. By the difference of the time scale, we can distinguish real gravitational-wave signals from non-Gaussian noises. By treating the data with non-Gaussian noises as dead time of the detector, we can improve the efficiency of burst gravitational-wave filters.

At first, two statistics are calculated for a given time chunk: the averaged power P_1 and the second-order moment of the power P_2. From these two statistics, two evaluation parameters,

$$c_1 = \frac{P_1}{P_0} - 1 \quad \text{and} \quad c_2 = \frac{1}{2}\left(\frac{P_2}{P_1^2} - 2\right), \tag{1}$$

are calculated, where P_0 is an averaged power with longer time data. Since c_1 is related to an averaged power in the given time chunk, it has an information of the stability of the noise level. On the other hand, c_2 is related to Gaussianity of the detector output. Since it is normalized by the averaged power P_1, the c_2 value becomes constant if the signal power is much larger than the background noise level. In this case, the constant number is determined only by the waveform of the event: large in short burst case, and small in a case of slow change in noise power. From these evaluation parameters, two independent information on the event, power and time scale, are extracted. Then, events with different time

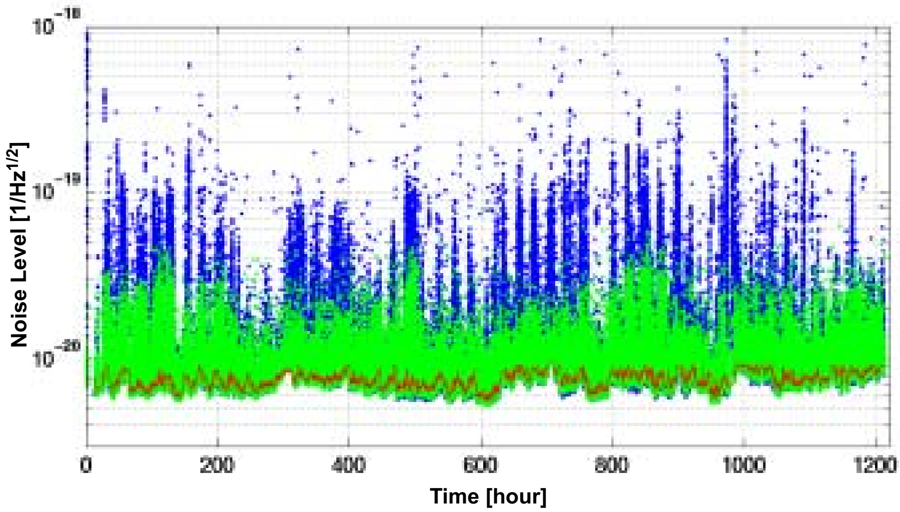

Fig. 1. Averaged power in every 3.2 sec in the TAMA data taking 6 (DT6). Black points represent all the data points in DT6. Gray points are the survived ones after non-Gaussian noise rejection.

scales from that of real gravitational-wave signals are considered as non-Gaussian noises. As a result, only non-Gaussian noises are rejected without rejecting real gravitational-wave signals. In addition, survived events with large power are recorded as gravitational-wave signal candidates.

3. Burst-wave search with TAMA300 data

We applied the data analysis method described above to the data taken by TAMA300 gravitational-wave detector. TAMA300 is placed in national astronomical observatory of Japan (NAOJ). After several observation runs since 1999, the 6th data-taking run (DT6) was carried out with TAMA300 in the summer of 2001. It was a 50 days' observation run aiming to collect over 1000 hours of data. In addition, two-month observation run (the 8th data-taking run, DT8) was carried out in the spring of 2003. The detector was operated stably most of the runs, and we have got over 2000 hours of data in total. Although the detector was operated with a high duty cycle (over 80%), the noise level was not stationary during the observation.

Figure 1. shows the averaged power in every 3.2 sec. The black points represent all the data points in DT6. The noise power was not so stationary. In particular, it usually got worse in daytime because of larger seismic disturbances. The gray points in Fig. 1. are survived ones after non-Gaussian noise rejection. About 10% of the data were rejected. While only 1.7% of the data were rejected for smaller data than $1.1 \times 10^{-20}\,/\sqrt{\mathrm{Hz}}$, 86.3% of the data were rejected for larger

events than $1.7 \times 10^{-20} / \sqrt{\text{Hz}}$. These results show the effectiveness of the rejection method. For example, the event rate larger than $6 \times 10^{-20} / \sqrt{\text{Hz}}$ was improved by a factor of 1000 to be 10^{-2} events/hour. This noise level corresponds to a gravitational-wave amplitude of $h \sim 3 \times 10^{-17}$ in strain for 10 msec short burst signal model.

4. Conclusion

Rejection of non-Gaussian noises is in particular, important for a burst gravitational-wave detection, in which waveform is not predicted precisely, because real signals are easily buried in non-Gaussian noises. We proposed a new method to characterize non-Gaussian noises with their power and time scale. Evaluating the noise behavior with two parameters, we can distinguish real signal from non-Gaussian noises. As a result, non-Gaussian noises are rejected without losing real signals. We applied this method to 2000 hours of data from TAMA300, and confirmed that the non-Gaussian noises were rejected effectively. Only with a 10% data loss and with estimated false dismissal rate of 1 ppm, event rate was improved by 1000 times.

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