Progresses of Search for Gravitational Wave Events using TAMA300 Data

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Abstract

We implemented and evaluated the Gravitational wave event search in TAMA 300 data analysis. Our searches are for the inspiral gravitational wave from coalescing compact binary, Black Hole (BH) quasi-normal ringing, supernova bursts, and continuous wave from SN1987a remnant. Using TAMA's over 2000 hours of observation data, we have progresses of the searches and improved the upper limits.

1. Introduction

The TAMA project is a research for the gravitational wave detection using 300m base line length laser interferometer since 1995. The aims of the project are construct, to operate the detector system, and to establish the searches for gravitational wave evidence in its observation data. The construction of the detector progressed successfully, and we had several times of scientific observation since 1999. [1] A total amount of the observation data exceed 2500 hours until year 2003. The time series signal which derived from the interferometer $s(t)$ should be sum of detector noise $n(t)$ and the gravitational wave component $h_{obs}(t)$.

$$s(t) = h_{obs}(t) + n(t) \tag{1}$$

The gravitational waveform h_{obs} and occasional frequency of the event depend on the kind of sources. The amplitude is determined by the distance and directional response from the detector to the source. The event search is a extraction of the embedded gravitational wave signal from the huge amount of noises. Since the gravitational wave events expected as so rare occasion and the amplitude is very weak, a lower noise level is important to increase event survey range. The typical

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pp. 3059–3062

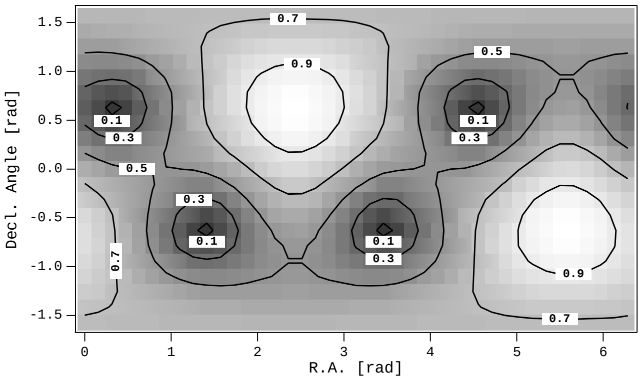

Fig. 1. The sky coverage of TAMA300 Gravitational Wave Detector.

sensitivity of TAMA, $h \sim 3 \times 10^{-21} [/\sqrt{\mathrm{Hz}}]$ around 1 kHz in strain, is a enough to detect the kind of gravitational wave events in our galaxy. (See Figure 2 and its explanation in following sections.) The detector's sky coverage is also the factor of acceptance for the event. It is called as *'antenna pattern'* which can be given with sensitivity relative to optimal direction. Figure 1 displays the antenna pattern of TAMA as a projection to the celestial coordinates. Two brightest directions are corresponding to the azimuthal direction of TAMA. In the laser interferometric detector, whole sky average is $1/\sqrt{5}$ relative to azimuthal direction [2].

2. Inspiral Gravitational Wave from Binary Stars

The most promising source for the ground-based interferometric gravitational wave detector is a coalescence of compact binary such as neutron stars, BH or combination of them. A *'inspiral'* waveform during the orbit radius is shrinking before merging of stars, is well predicted using Post-Newtonian approximation [3]. The waveform is characterized with mass of each starts m_1, m_2. We can search the expected waveform h using correlation between $s(t)$ and $h(t)$. To optimize the noise reduction and the advantage for the calculation cost, a matched filter method.

$$\rho(\tau) \; = \; \int_{f_{min}}^{f_{max}} \frac{\widetilde{h}^*(f) \cdot \; \widetilde{s}(f)}{\widetilde{S_h}(f)} \; e^{-i2\pi f \tau} df, \tag{2}$$

where $\widetilde{s}(f)$ and $\widetilde{h}(f)$ are Fourier represent of $s(t)$ and $h(t)$. Hear $h(t)$ is a expected gravitational waveform. $\widetilde{S_h}(f)$ is a average detector noise power spectrum. The maximum value of $\rho/\sqrt{2}$ is defined as a SNR (Signal-to-Noise Ratio) for the event. SNR ≥ 10 is a good index to identify the event against the statical fake of noises. With TAMA300's latest noise spectrum, the expected SNR for neutron star binary at the galactic central is ~ 30. Figure 2 displays the observable distance for binary coalescence event as a function of total mass $m_1 + m_2$ for the case of $m_1 = m_2$.

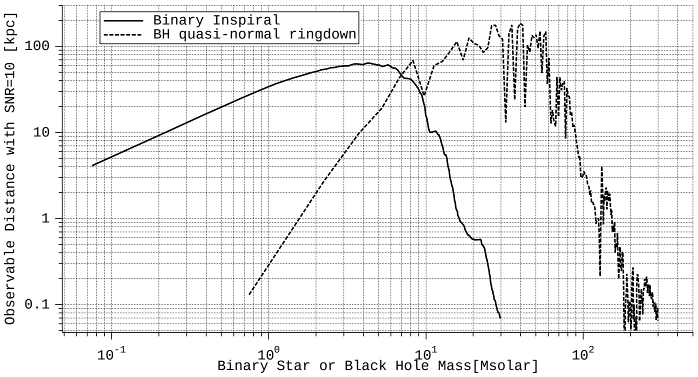

Fig. 2. The observable range of TAMA, which is defined as the SNR(Signal to Noise Ratio)=10 for gravitational wave sources at the distance. The solid line shows the observable distance for the inspiral gravitational wave from compact binary coalescence. The dashed line shows same for Black Hole quasi-normal mode ringdown wave.

The solid line of the figure show the range for inspiral events. We implement this technique to TAMA data to search the event of binary coalescence events [4]. We did not found the significant real gravitational wave evidence yet, but got the observational upper limit. A preliminary results using data of year 2001 is 0.014 event/hour (C.L. 90%) fro our galaxy.

3. Ringdown Wave from Black Holes

The linear perturbation around the Black Hole spacetime predicts that the BH can radiate the gravitational wave from its dumping oscillation, which called as *'quasi-normal ringdown modes'* (QNRM)[5]. Since the wave form is expected with only BH's total mass and angular momentum, we adapt the matched filter method for the QNRM wave. The linear perturbation cannot predict the amplitude of QNRM signal. If the binary stars are source of BH, the amplitude is expected [6], and the observational distance should be as Figure 2 dashed-line. Comparing with the inspiral analysis, TAMA is sensitive more higher mass sources with BH QNRM wave. The SNR expected over 100 for several 10 $M_\odot$ BH.

4. Burst Wave from Supernovae

Supernova is an another promised sources of gravitational wave detection for the ground base detector. However, the prediction of the burst gravitational waveform is a hard in time series. We paid attention to the time-frequency characteristics of burst waveform in some prediction of supernova core collapse [7]. Comparing with typical non-Gaussian noise behavior of TAMA detector, such a burst waveform has a different time duration and gaussianity. We defined first and second order momentum of signal power distribution for short chunked data as

$$c_1 = \frac{< P_i >}{P_0} - 1 \quad \text{and} \quad c_2 = \frac{1}{2}\left(\frac{< P_i^2 >}{< P_i >^2} - 2\right), \tag{3}$$

where P_i is a i-th chunk power, and P_0 is a average of more longer duration. c_1 gives the index of signal power average drift, and c_2 corresponds to Gaussianity of noise fluctuation. We represent the signal as a points on $c_1 - c_2$ plane. The slow drift of the noise level will distribute along c_1 axis. Ordinary stochastic noises which due to detector instruments or disturbances in the experimental site scatter the points along c_2 axis. However, the burst gravitational waves will appear as points that has a correlation between c_1 and c_2. Therefore, it is possible to separate the burst events from the noises.

5. Continuous Wave from SN remnant pulsar

We focused on SN1987a remnant pulsar[9] as a candidates for continuous gravitational wave source. We calculate a truncated FFT with complex heterodyne technique, correct the Doppler motion, correct response due to change of incident direction, and the noise level drift with the over 1200 hours data. The processed spectrum around 935Hz does not have a evidence of the gravitational wave signal. The upper limit is $h \sim 5 \times 10^{-23}$.

6. Conclusion

The gravitational wave search using TAMA300 detector has been progressed steadily. The evidence of the gravitational wave did not found yet. However, the implementation of the methods on the real data analysis is a remarkable progress with the evaluation of quality of the data and accuracy of statical treatment.

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