Current Status of TAMA300 Online Search for Inspiraling Binaries

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Abstract

A gravitational wave detector of TAMA300 was pioneer in development of interferometric one with over one hundred meter scale. We archived long-term observations over one hundred hours with sufficient sensitivity to monitor within our galaxy [1, 2]. This was marvelous step to the first and direct detection of gravitational wave signals. In such long-term observations, online processes are important for the detector operation and for the signal search. By focusing on the most promising source of neutron star binaries, we make a brief introduction to the online processes.

1. Introduction

The Japanese gravitational wave detector, TAMA300, has been constructed to detect signal from inspiraling neutron star binaries around our galaxy. We have succeeded to make long-term observations over one hundred hours. The first was one of the world's greatest advancement of the year 2001. The second was done from 14 February to 14 April in 2003 with the power-recycling technique. In the long-term observations, online processes are important to check detector conditions and to search gravitational wave signals. These include calibration of detector response, detector noise evaluation and the GW signal search. We report these online processes especially for inspiraling compact star binaries.

2. Detector Calibration

Our detector is a laser interferometer with 300 m arm length cavities. More exactly it is called a power-recycled Fabry-Perot Michelson scheme. It cannot works without length control between mirrors, because seismic motion disturbs to keep resonance of it. Such a control signal is the detector output to detect gravitational wave (GW) signals. Therefore the detector response depends on the control servo.

The detector response was measured beforehand by electrical exercitation of the mirror as a function of frequency. But it would be changed due to laser

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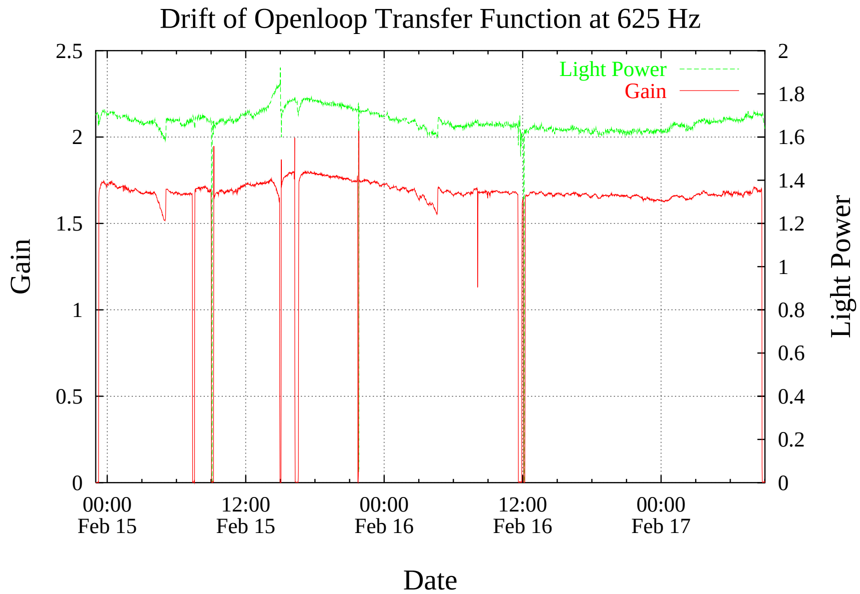

Fig. 1. Drifts of openloop servo gain and light power which transmits to the mode cleaner cavity. The gain strongly depends on light power. At the time of zero gain, the detector could not keep resonance and was out of control. @

power fluctuation or finess of the cavities. So we monitored the detector response at a fixed frequency of 625 Hz during the long-term observations as shown is Fig. 1. It also shows a drift of light power which transmits to the mode cleaner cavity. Generally openloop servo gain strongly depends on the light power fluctuation.

Both of the openloop servo gain and phase delay was corrected by this monitor. The accuracies of calibration are 1% in gain and 1 degree in phase within the observation frequency band from 50 Hz to 5 kHz. Therefore we can get the accurate signal which is equivalent to the strain (space-time distortion).

3. Noise Evaluation

By using the calibrated signal, GW signals were searched for. To search the signal, we should specify a target astronomical source. The most concrete target is neutron star binary such as PSR 1913 +16, because gravitational wave radiation is precisely predicted by general relativity and consists well with observations. For the well-known signals, the following matched filtering gives an optimal signal-to-noise ratio (SNR).

$$SNR = \sqrt{\frac{(s\,|\,h_\times)^2 + (s\,|\,h_+)^2}{2}} \tag{1}$$

$$(s\,|\,h) = 2\int_{-\infty}^{\infty} \frac{s^*(f)\cdot h(f)}{S_n(f)} df. \tag{2}$$

Here $s(f)$ is calibrated detector output spectrum, $h(f)$ is a predicted GW spectrum (called template) and $S_n(f)$ is a power spectrum of averaged detector noise. The suffixes of cross ($\times$) and plus ($+$) show polarization of GWs, respectively.

In this analysis, an averaged power spectrum $S_n(f)$ should be defined carefully. Because detector noise level is not stationary in practice. For example, a diurnal change was clearly seen due to seismic disturbance. By careful studies on it, we found that burst (short-term) noises cause large and long-term influence with the simple averaging scheme. It also makes serious misevaluation of SNR. Therefore we use inversed power spectrum for the averaging.

$$S_n(f)^{-1} = \left\langle \frac{1}{s \cdot s^*} \right\rangle \tag{3}$$

Here $\langle\rangle$ means moving time-averaging. And we choose the decay time constant (averaging time) to be 4 minutes.

Since an amplitude of GW signal depends on source distance ($\propto 1/D$) and mass of the binary, noise level was evaluated as observable distance with SNR=10. Figure 2. shows distribution of the observable distance for typical mass combinations. An average value for neutron star binaries was 30.7 kpc and its deviation was about 20%. As a result, our detector has a capability to monitor the GW radiation within our galaxy.

4. Online Analysis

As described above, all of the preparation for GW signal search is finished. The rest work is finding an optimal GW waveform (template) in a parameter phase space. For example, the parameter consists of mass of the binary (m_1, m_2) and an arrival time (t_c). To minimize the overlap area to be searched, a diagonalization of the phase space is applied [3]. Even after this minimization, a lot of templates are nesessary for the search as shown in Table. 1. To obtain the search results on time, several PC clusters are cooperated with each other by sharing the mass region. For this cooperation, we start to distribute the data to our colaborators. Data distribution was successful at the last long-term observation, and now the search processes are under studying. In the conference, some preliminary search results will be presented.

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2. Tagoshi H., Kanda N., Tanaka T., Tatsumi D. et al. 2001, Phys. Rev. D 63, 062001
3. Tanaka T., Tagoshi H., 2000, Phys. Rev. D 62, 082001

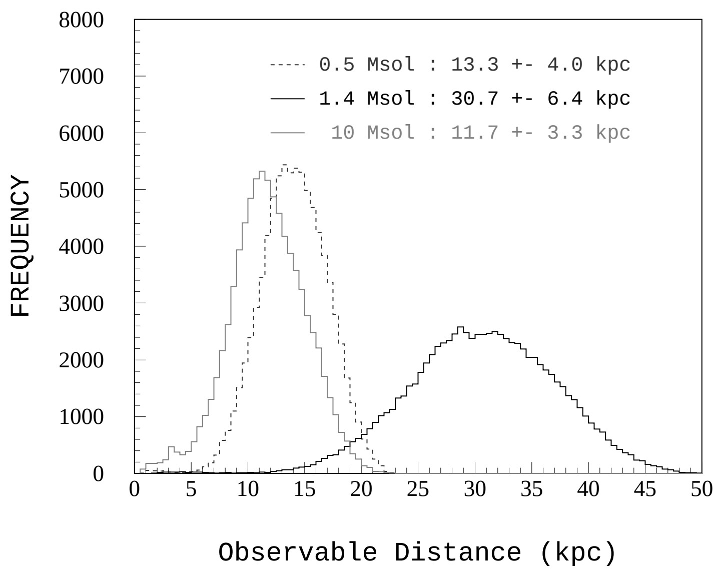

Fig. 2. Histogram of expected signal-to-noise ratio for inspiraling compact binaries. Typical mass combinations of (0.5, 0.5), (1.4, 1.4) and (10, 10) in a unit of solar mass were chosen. For the neutron star binary, an average value was 30.7 kpc and its deviation was about 20%. As a result, our detector has a capability to monitor the GW radiation within our galaxy.

Table 1. Number of templates for inspiraling compact binary search. When the design noise level is archived, values of second column are needed. Both of average and deviation is the value of the long-term observation.

Mass Region	TAMA design	Average	Deviation
0.5 – 1.0	5156	1911	703
1.0 – 2.0	1644	601	214
2.0 – 10.0	723	307	117