

Current status of Japanese detectors

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Abstract

The current status of the TAMA and CLIO detectors in Japan is reported in this paper. These two interferometric gravitational wave detectors are being developed for the large cryogenic gravitational wave telescope (LCGT) which is a future plan for detecting gravitational wave signals at least once per year. TAMA300 is being upgraded to improve the sensitivity in a low-frequency region after the last observational experiment in 2004. To reduce the seismic noises, we are installing a new seismic isolation system, called the TAMA seismic attenuation system, for the four test masses. We confirmed stable mass locks of a cavity and improvements of length and angular fluctuations by using two SASs. We are currently optimizing the performance of the third and fourth SASs. We continue TAMA300 operation and R&D studies for the LCGT. The next data taking is planned for the summer of 2007. CLIO is a 100 m

baseline length prototype detector for LCGT to investigate interferometer performance in cryogenic condition. The key features of CLIO are that it locates the Kamioka underground site for a low-seismic noise level, and adopts cryogenic Sapphire mirrors for low-thermal noise level. The first operation of the cryogenic interferometer was successfully demonstrated in February 2006. Current sensitivity at room temperature is close to the target sensitivity within a factor of 4. Several observational experiments at room temperature have been done. Once the displacement noise reaches the thermal noise level of room temperature, its improvement by cooling test mass mirrors should be demonstrated.

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(Some figures in this article are in colour only in the electronic version)

1. TAMA

The TAMA project has been holding observational experiments for detecting gravitational wave (GW) signals since 1999, and by the beginning of 2004, 3000 h of data in total were accumulated through the nine observational experiments.

Since the last observational experiment in 2004, the TAMA detector has been upgraded to reduce the low-frequency noises. To reduce the seismic noise, a new isolation system called the TAMA seismic attenuation system (SAS) [1, 2] is being installed. The fundamentals of SAS are conceptually similar to the superattenuator of the Virgo Collaboration [3], while the SAS utilizes novel geometries. To isolate horizontal motions, an inverted pendulum is employed. For vertical motion, double stage monolithic geometric anti-spring (MGAS) filters are used. The test mass mirror is suspended by a double pendulum as a final stage of the system. The SAS installation was started in September 2005.

In the summer of 2006, a 300 m Fabry–Perot cavity formed by the mirrors suspended by SASs was operated. Since the other arm was still formed by the old suspension system, we could directly compare the performance of the vibration isolation systems. In this locked Fabry–Perot configuration, the old suspension arm was controlled by the laser frequency, and the SAS arm was controlled by the coil-magnet actuators located at the test mass mirror. Figure 1 shows the comparison of cavity length and angular fluctuations with SASs and the old suspension systems. The improvement of about 24 dB was observed above 2 and 3 Hz for the length and pitch motion, respectively.

The actuator response of the test mass for SAS was reduced by a factor of 3 so as to reduce the actuator associated noises. Therefore, the ability of the lock acquisition and drift level of the interferometer with SASs should have been confirmed. To ensure the ability of the lock acquisition, a digital servo system was employed for the test mass length control. This system is driven by a DSP processor with the sampling frequency of 200 kHz, and a unity gain frequency of about 800 Hz was achieved. This system utilizes two techniques for the error signal operation. The first is the gating of the error signal; the error signal is forced to be zero when the transmitted light level of the cavity is below a preset threshold. This cleans up undesirable signals caused by resonances of modulation sidebands and higher order spatial modes of the beam. The other technique is normalization of the error signal with regard to the transmitted light. This widened the linear range of the error signal by a factor of 3. The locked Fabry–Perot interferometer was locked with the help of the digital servo system, and operated continuously for the 6.5 h.

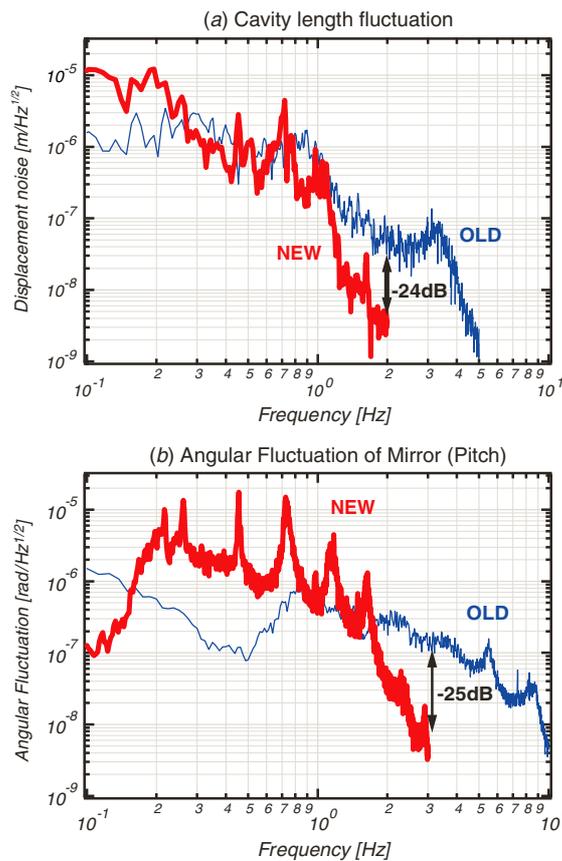


Figure 1. Measurement of the mirror fluctuations of TAMA: (a) cavity length fluctuation and (b) angular fluctuation in pitch of the mirror which is suspended by SAS. An improvement of about 24 dB was observed above 2 and 3 Hz for the length and pitch motion, respectively.

Since the detected length fluctuation is the addition of that of the SAS arm and the old suspension arm, this means that the actuator range was enough to compensate the drift motion of the SASs. This indicates that TAMA300 would be operable even if both arms were formed with SASs.

Actual improvements of length and angular fluctuations at 100 Hz region should be confirmed by the locked Fabry–Perot configuration formed by four SASs. Now all of the four test mass mirrors are suspended by SASs. We are currently optimizing the performance of the third and fourth SASs. We continue R&D studies of SAS and TAMA300 operations. The next data taking is planned for the summer of 2007.

2. CLIO

The cryogenic laser interferometer observatory (CLIO) is located in the Kamioka mines of Japan as an underground site. The purpose of the CLIO project is the technical demonstration of the key features of the LCGT. The LCGT is planned to be located at the Kamioka underground site for the low-seismic noise level, to adopt cryogenic Sapphire mirrors for the low-thermal noise level and to have 3 km long arms. Except for the arm length, CLIO has same features of the LCGT. Therefore, the detector can demonstrate them as a prototype of the LCGT.

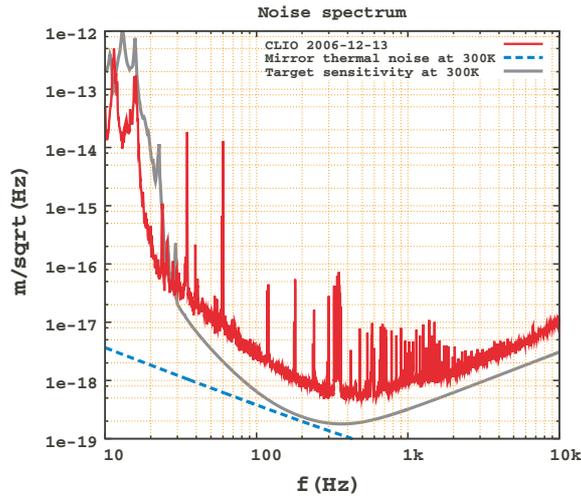


Figure 2. Noise spectrum of the CLIO detector on 13 December 2006. At the time, the mirror temperature was about 300 K. In all of the frequency regions, the differences from the target sensitivity at room temperature were about a factor of 4.

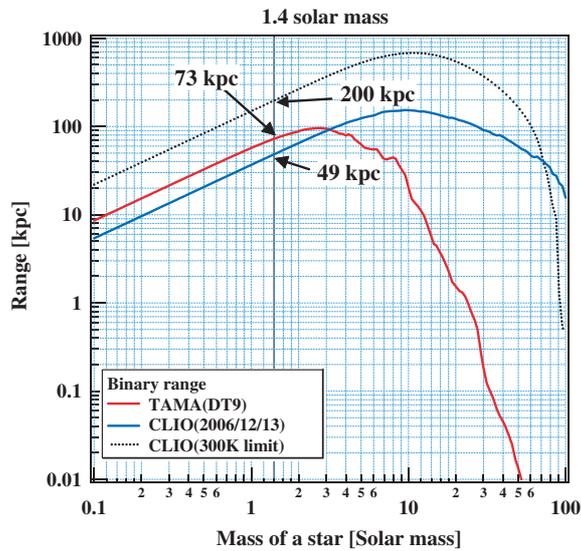


Figure 3. The observable ranges with $\text{SNR} = 10$ for inspiral GW signals estimated by the noise spectra. For neutron star binaries, CLIO and TAMA can observe the event within 49 kpc and 73 kpc, respectively. We can say that the two detectors have almost the same sensitivity. At over 10 solar mass regions, CLIO keeps good sensitivities due to its low-seismic noises. This is the greatest benefit of the underground site.

Construction of CLIO started in 2002. All of the vacuum pipes, cryostats and cryocoolers were installed by June 2005 [4]. After the cooling tests of the system, the first operation of the cryogenic interferometer was demonstrated on 18 February, 2006. The details of the interferometer, cryogenic systems and seismic environments have been published in [5–8]. Input power to each cavity was 200 m W. The measured finesse and reflectance of the

cavity were about 3100 and 0.01, respectively. The accumulated power inside the cavity was estimated to be 200 W. During the lock of 50 min, the mirrors' temperature was kept around 20 K.

Ever since the cryogenic operation was established, noise investigations at room temperature have been in progress. Figure 2 shows the best noise spectrum on 13 December 2006. In all of the frequency regions, the differences from the target sensitivity at room temperature were about a factor of 4.

The observable ranges with $\text{SNR} = 10$ for inspiral GW signals can be estimated by the noise spectra as shown in figure 3. For neutron star binaries, CLIO and TAMA can observe the event within 49 k pc and 73 k pc, respectively. We can say that the two detectors have almost the same sensitivity. At over 10 solar mass regions, CLIO keeps good sensitivities due to its low-seismic noises. This is the greatest benefit of the underground site.

Several observational experiments at room temperature have been done. Once the displacement noise reaches the thermal noise level, its improvement by cooling should be demonstrated.

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