論文の内容の要旨

Fast localization of coalescing binaries with gravitational wave detectors and low frequency vibration isolation for KAGRA

（ 重力波検出器による連星合体の早期方向特定及び KAGRA のための低周波防振 ）

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The first detection of a gravitational wave (GW) signal from the coalescence of two neutron stars by the LIGO-Virgo network in coincidence with an electromagnetic transient opened the era of multi-messenger astronomy. In order to expand GW astronomy with better sky localization, better sky coverage, and more precise parameter estimation, the global network of advanced GW detectors will be extended with KAGRA and LIGO-India. In the upcoming years, it is expected that the detectors in the network will have heterogeneous sensitivities, with detectors still at an early configuration and commissioning stage being less sensitive than the more advanced detectors.

In this work, we investigate the expected performance regarding fast sky localization of coalescing binaries with a network of three or four GW detectors having heterogeneous sensitivities, such as the LIGO-Virgo, LIGO-KAGRA and LIGO-Virgo-KAGRA network. A hierarchical approach can be used in order to make an effective use of information from the least sensitive detector. In this approach, the presence of an event seen in coincidence in the two more sensitive detectors triggers a focused search in the data of the third (and fourth), less sensitive, detector(s) with a lower SNR threshold. The basic idea of this approach is shown in Figure 1.

We show the expected fast localization performance when a hierarchical search is implemented into a GW-EM follow-up pipeline composed of MBTA and Bayestar. We

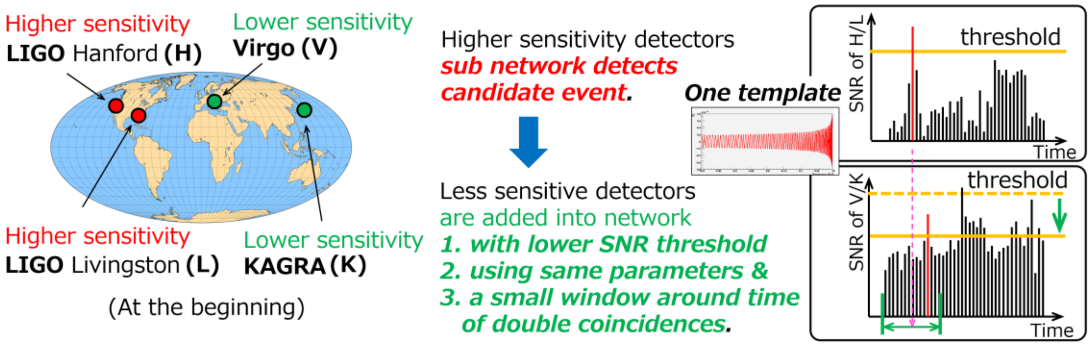

Figure 1: Basic idea of hierarchical approach

confirm that the hierarchical search will improve both the localization accuracy and precision compared to those achieved by a double coincidence search with the two LIGO detectors alone. The hierarchical network effectively improves the localization accuracy and precision when threshold SNR for the lower sensitivity detector is set to around 3.5 provided that the BNS range of that the detector is greater than 20% of the more sensitive detectors in the case where the detector network is composed of the two LIGO detectors and the Virgo detector. In the case where the detector network is composed of the two LIGO detectors and KAGRA detector, we found a clear sky localization improvement when the relative sensitivity of KAGRA becomes greater than 20% of the more sensitive detectors. In addition, the hierarchical network by four detectors will improve the localization accuracy and precision when threshold SNR for the lowest sensitivity detector is set to around 3.5 provided that the BNS range of that the detector is greater than 30% of most sensitive detectors. This result assumes that the sensitivity of the middle sensitive Virgo detector is half of the LIGO one.

Consequently, we conclude that once the sensitivity of the third or fourth detector reaches the required one, the search with this hierarchical approach will be most useful when adding new, less sensitive detectors to the network, as they are undergoing commissioning.

As another aspect, operating a fourth robust interferometer is of paramount importance to achieve high network duty cycle and also to reduces the chances to miss detectable events.

Generally the mirrors of the ground-based GW detectors are suspended in order to realize a situation where the test masses are in free-fall condition, and also in order to attenuate the vibration transmission from the ground to the mirror. Since we use multistage pendulum system for the suspension, we have to damp the mechanical resonances and freeze the mirrors in order to start GW observation. Consequently, a system which enables to damp the mechanical resonances rapidly and to suppress the mirror residual motion, is required for more robust interferometer operation. Such system is realized by active controls with sensors and actuators implemented on the suspension system.

KAGRA detector is 3-km interferometric ground-based GW detector in Japan, whose construction started in 2012. KAGRA is now being commissioned and is planned to join to the network in second half of O3 as the fourth detector.

In this work, we construct active control system for the low-frequency vibration isolation system for KAGRA, especially for the suspension system which holds the arm cavity mirrors. The target is to achieve required performance for acquiring the interferometer lock.

The suspensions which hold the arm cavity mirrors are called Type-A system, which has 13.5 m height, and which consists of 9-stage pendulum, as shown in Fiugre 2. The lower 4 stages of the Type-A system are to be operated at cryogenic temperature for the detector noise reduction. For the purpose of cooling, the stages of the lower 4 stages are connected each other with high purity aluminum cables, called heat links. The absorbed heat on the mirror flows to upper stages and is then extracted to the cryostat structure through the heat links including its vibration isolation system. I.e, Type-A suspension is mechanically large and a highly complex system.

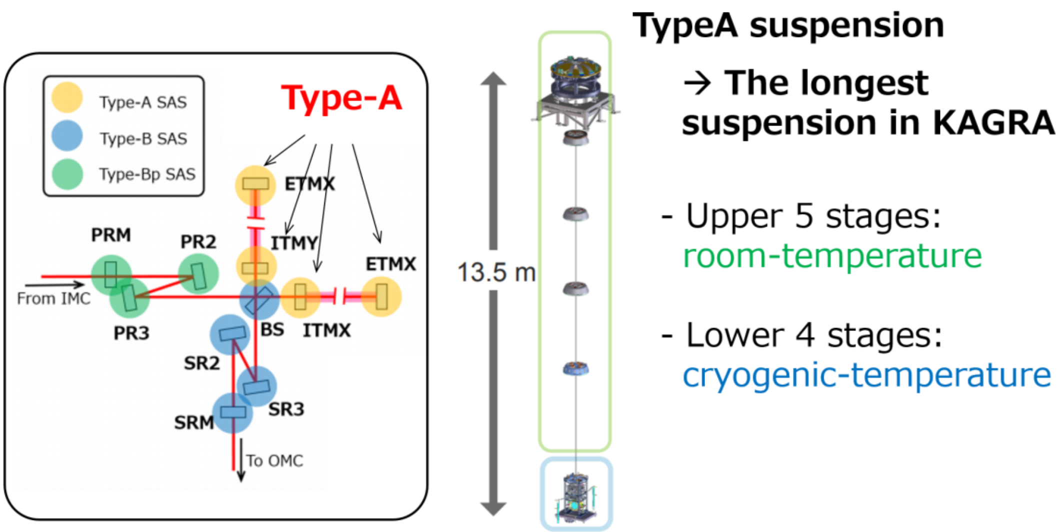

Figure 2: Overview of Type-A suspension

In this work, after implementing the control system, we then conduct the following tests for the evaluation of the KAGRA Type-A suspension and its control system:

1. suspension mechanical response,
2. damping control performance for the mechanical resonance damping mode,
3. RMS suppression control performance for the lock-acquisition mode.

Based on the first test, we conclude that the assembled Type-A suspension has the characteristics of the pendulum, although some of the unexpected resonances which would related to the heat link system are observed. From this issue, we find that we have to include the heat link system in the model of the suspension mechanics for the further precise estimation. From the second test, we confirm that the installed damping control system satisfies its requirement for the lock-recovery mode. The third test demonstrates the feedback control system using displacement sensors by a feed-forward system with seismometer on the ground effectively suppressed the mirror residual motion and it satisfies the requirement in the time scale of 1 min.

Consequently, we conclude that this work contributes to accomplishment of KAGRA suspension local control system toward the more robust operation.