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変革を駆動する先端物理・数学プログラム（FoPM）
国外連携機関長期研修　報告書

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Overview

In this program, I visited Professor Rana Adhikari's group in the California Institute of Technology (Caltech) for two months. The group is working on the R&D for the future gravitational wave detectors and has the prototype detector: Caltech 40m that can test the cutting-edge technologies. I applied to this group to learn the techniques used in the field of gravitational wave detectors, which are very compatible with my laser interferometric dark matter search experiment in the University of Tokyo. During my stay in Caltech, I was mainly working at Caltech 40m and was able to contribute to the development of the laser interferometer. In addition, I was able to do some networking in the field of the gravitational wave physics.

Research Background

Gravitational wave is the wave of distorting spacetime, which is predicted from the General Relativity. The source of the gravitational wave can be binary neutron stars, binary black holes, the cosmic inflation and so on. Currently, many types of gravitational wave detectors have been developed and the mainstream scheme is using laser interferometers as can be seen in the successful detector LIGO (Laser Interferometer Gravitational-Wave Observatory). Figure 1 shows the simplified setup of the laser interferometric gravitational wave detector. When gravitational wave passes through this interferometer, it changes the length of the two arms and the gravitational wave can be observed as the change of the laser interference.

LIGO has a good sensitivity to gravitational waves due to the long arm of 4 km. In Caltech, there is a prototype laser interferometric gravitational wave detector: Caltech 40m, which has the arms of 40 m and has been contributed to the development of the LIGO since the beginning of the field of the gravitational wave detectors. Caltech 40m is still a central research base for the development of cutting-edge technologies for the future gravitational wave detectors.

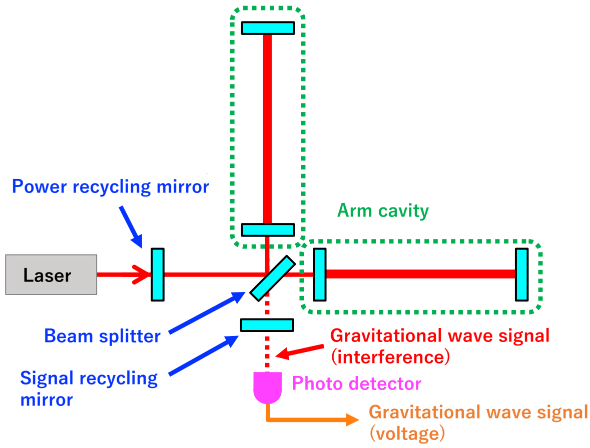

Figure 1: Simplified scheme of a laser interferometric gravitational wave detector.

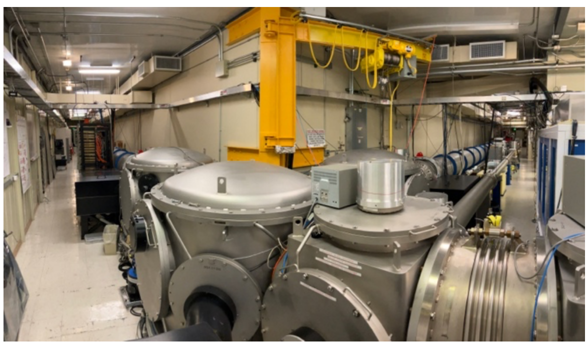

Figure 2: Vacuum chambers and beam tubes of the Caltech 40m.

Research Activities

During my stay in Caltech, I worked on the following research topics:

➢ **Development of alignment algorithm for PRFPMI**

As shown in Figure 1, the laser interferometric gravitational wave detectors are composed of many mirrors. The laser light can circulate back and forth between these mirrors and this process increases the sensitivity to the gravitational wave. To operate the laser interferometric gravitational wave detector, the mirrors need to be aligned precisely and the laser need to be resonant on the interferometer. The alignment of the mirrors is crucial because if the mirrors are misaligned, the laser cannot be resonant on the interferometer and even if the mirrors are aligned, slight misalignment can introduce noises for the observation.

In Caltech 40m, the mirrors are aligned manually through digital systems, and I developed the algorithm to align the Power-Recycled Fabry-Perot Michelson Interferometer (PRFPMI). Generally, the quality of the alignment depends on the skill of the experimenter but with this algorithm, everyone can align the mirrors easily in short time. This algorithm will also be helpful when the automated aligning system is introduced to the Caltech 40m.

- **Locking of sideband-resonant PRMI**

For the laser resonance on the interferometer, we need not only the alignment of the mirrors but also the precise control of the distance between the mirrors. The state where all the mirrors are controlled and the laser is resonant is called "locked" and to operate the current complex laser interferometric gravitational wave detectors, many degrees of freedom of the interferometer need to be locked.

The Caltech 40m is currently aimed at locking the PRFPMI with the new experimental setup and I succeeded in locking the sideband-resonant Power-Recycled Michelson Interferometer (PRMI) by developing the control system. This locking is crucial and helpful when trying to lock the PRFPMI.

- **Construction of mode-matching telescope**

For the future gravitational wave detectors, the method of the Balanced Homodyne Detection (BHD) has been proposed. This new technique can reduce the laser intensity noise and improve the sensitivity of the gravitational wave detector.

Currently, Caltech 40m is also aimed at testing the BHD. To test the BHD, the Output Mode Cleaner (OMC), which gets rid of junk laser light will be installed. For the installation of the OMC, a mode-matched beam is required, and I developed the mode-matching telescope to obtain the required beam (Fig. 3). This telescope is composed of lenses and a fiber collimator on a breadboard and is movable. Therefore, this mode-matching bread board can be used not only for the alignment of the BHD OMC but also for the development of a new OMC for example.

- **Development of error-tolerant mode-matching tool**

For the laser resonance on the OMC, we need to inject the mode-matched laser beam, which is defined by the geometry of the OMC. Such a mode-matched beam can be prepared by constructing the mode-matching telescope as shown in Fig. 3. However, when we design the mode-matching telescope, there are generally many solutions of the combination of focal length and lens position, and it is desirable to choose a solution that is robust to the error of the focal length and lens position.

Therefore, I developed a mode-matching tool that calculates the error-tolerant design of the mode-matching telescope using MATLAB. This tool estimates how much the quality of the beam gets worse when uncertainty is added to the design parameters and chooses the best solution. This mode-matching tool will be helpful for the future gravitational wave detectors because they require the highly mode-matched beam for the better sensitivity.

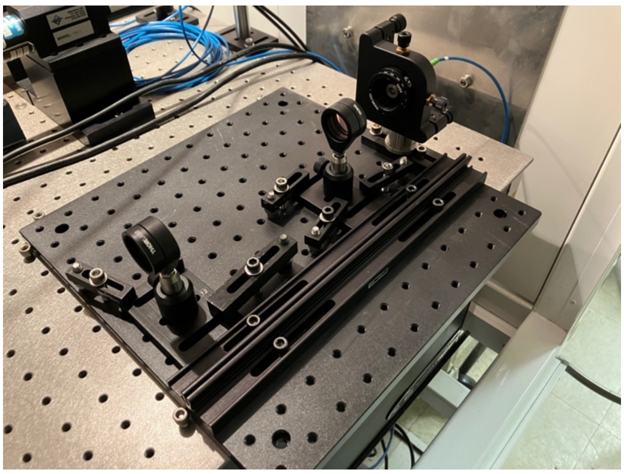

Figure 3: Mode-matching telescope.