[GW Project] Design your own Gravitational Wave (GW) Laser Interferometer

After 100 years of Einstein's first prediction, gravitational waves from *a binary black hole merger (GW150914)* have been detected by aLIGO (advanced Laser Interferometer Gravitational-Wave Observatory; refer Fig. 1.) [1,2] and 2017 Nobel Prize in Physics was given to R. Weise, K. S. Thorne, and B. C. Barish for their dedicated effort for the construction of LIGO and the detection of gravitational waves. This observation was a start of *the Gravitational-Wave Astronomy*. In Oct. 16, 2017, right after the announcement of the 2017 Nobel Laureates in Physics, the detection of *both gravitational waves and electromagnetic waves* from *a binary neutron star inspiral (GW 170817)* was announced [3]. The importance of this observation was discussed in a Korean article [4]. These observations indicate that the new era of *the Multi-Messenger Astronomy* has been arrived (refer Fig. 2).

Let's assume that we're designing our own laser interferometer gravitational-wave detector in Korea with the following constraints.

- Arm length: 3 km each (distance between two test masses in each arm)
- Laser power (Nd:YAG, 1064nm): 500 kW Circulating Power (laser power within two test masses)
- Test masses (fused silica) are made such that the photons circulates about 300 times between two test masses before going out to the photodetector.

[**Problem**:] For the simple estimates, let's assume that the black hole mass is $20M_\odot$ and the neutron star mass is $1.5M_\odot$. With our own laser interferometer;

a) Estimate the maximum distance you can detect the gravitational waves from the merger of a black hole binary.

b) Do the same for the merger of a neutron star binary.

c) Compare the number of galaxies within the distances obtained in a) and b). If the ratio of the detection rates between black hole binary mergers and neutron star binary mergers is 5:1, can you have a rough estimate on the merger rates of black hole binaries and neutron star binaries in one galaxy?

Useful tips

1. In order to make rough estimates, you can use the strain noise curve in Fig. 1 and the estimates provided in the Korean references [2] and lecture notes (will be provided later).
2. PDF files of the references can be obtained by clicking the references below.

REFERENCES

[1] LIGO Scientific Collaboration and Virgo Collaboration, *Observation of Gravitational Waves from a Binary Black Hole Merger*, Phys. Rev. Lett., **116**, 061102 (2016).

[2] H.M. Lee, New Phys.: Sae Mulli **66**, 258 (2016). ; J. J. Oh and G. Kang, New Phys.: Sae Mulli **66**, 264 (2016). ; H. Paik, K. Cho, H. M. Lee, and J. W. Kim, New Phys.: Sae Mulli **66**, 272 (2016). ; S. H. Oh, E. J. Son, H. W. Lee, Y.-M. Kim, W. Kim, J. Oh, and J. Kim New Phys.: Sae Mulli **66**, 283 (2016). ; C. Kim, H. S. Cho, H. W. Lee, C.-H. Lee, H. K., Lee, and G. Kang, New Phys.: Sae Mulli **66**, 293 (2016). .

[3] LIGO Scientific Collaboration and Virgo Collaboration, *GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral*, Phys. Rev. Lett., **119**, 161101 (2017).

[4] 이창환, *2017 노벨물리학상: 중력파 검출 성공*, The Science & Technology (과학과 기술), Vol.582, November 2017.

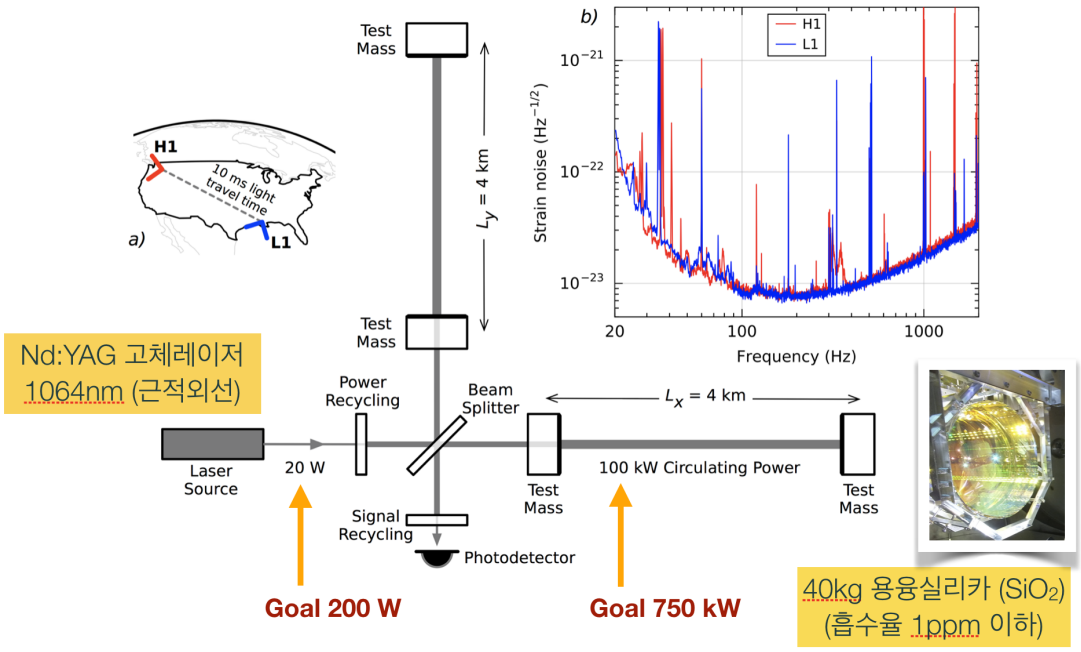


Fig. 1. Basic design concepts of aLIGO for the first GW detection, GW150914 [1]. Final goals of the laser power are marked in red color.

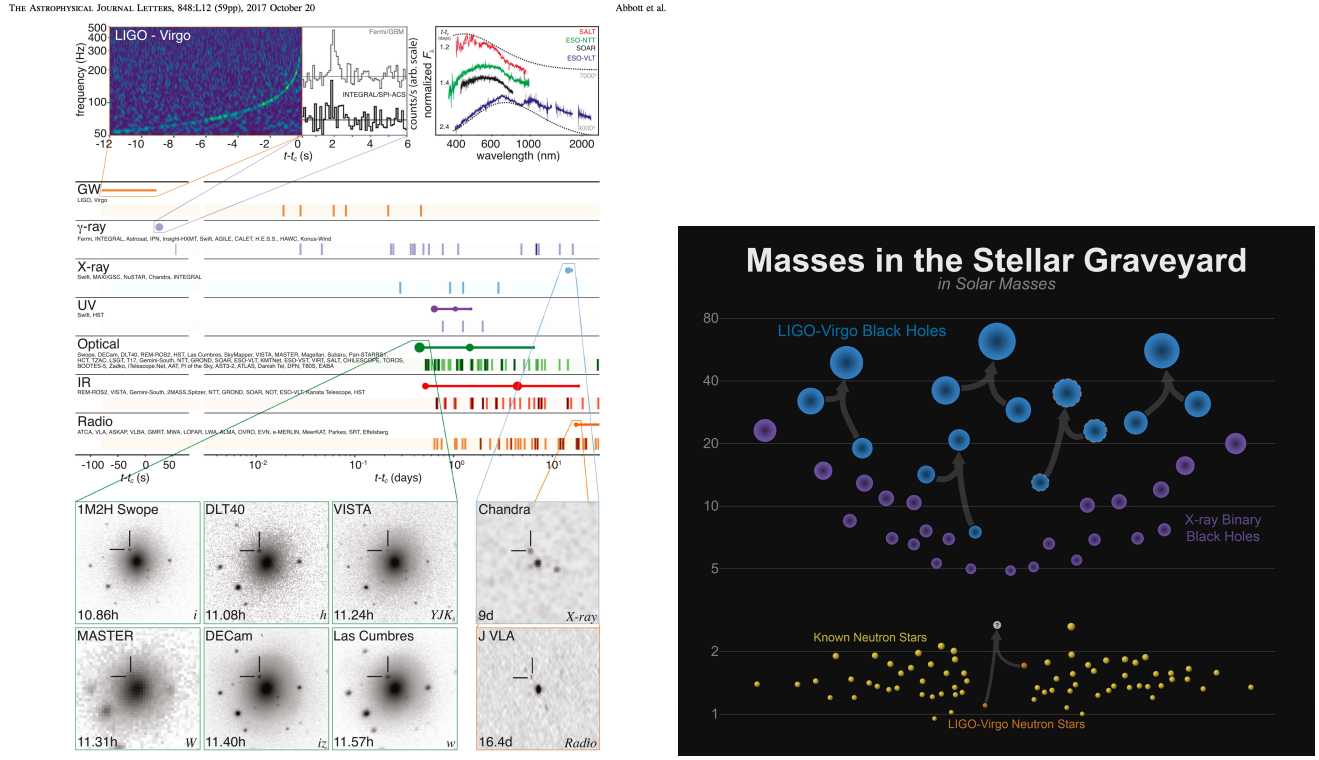


Fig. 2. Left panel: summary of observations of both gravitational waves and electromagnetic waves from a binary neutron star inspiral [3]. Right panel: distribution of masses of observed black holes and neutron stars. Black holes with higher masses ($> 30 M_\odot$) have been detected by gravitational-waves only. Black holes with blue circles are from gravitational-wave observations and those with violet are from X-ray observations. Neutron stars are marked with yellow circle.