LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
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Space gravitational wave antenna

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1 Introduction

Gravitational waves (GWs), oscillations in the spacetime metric that propagate at the speed of light, were already implied in Albert Einstein's works a centure ago. In 1916 he showed that accelerating massive bodies generate time-dependent gravitational fields that propagate at the speed of light as warpages of spacetime [2]. Half a century afterwards the existence of GWs was indirectly proved by Hulse and Taylor [4], who were awarded the 1993 Nobel Prize in Physics for the discovery of a binary pulsar. Their high-precision measurements of the orbital period of this binary star system revealed that the pulsars orbit is gradually contracting at just the rate predicted by general relativity for such a contraction due to the loss of orbital energy and angular momentum by GW emission [5]. However, GWs have not been directly observed yet due to the weakness of gravitational interaction. Therefore, new interferometry techniques, filters for different types of noise sources and upgrades in sensitivity of detectors are essential.

2 GW detectors

Several gravitational wave detectors have been or are being constructed.

The ground-based detectors instruments like LIGO, Virgo, GEO600 and TAMA300 perform measurements in the high- frequency band where $10 \lesssim f \lesssim 10^4 Hz$. They are limited at low frequencies by seismic and gravity-gradient noise.

Space detectors: LISA, eLISA, BBO, DECIGO and ALIA and others are intended to work in the low-frequency band with $10^5 \lesssim f \lesssim 1 Hz$.

2.1 LIGO

The Laser Interferometer Gravitational-wave Observatory (LIGO) is a pair of L-shaped Michelson laser interferometers with 4 km long arms: one in Hanford, Washington, the other in Livingston, Louisiana. They are about 3000 km apart. When gravitational waves pass they distort the space and change the distance between the mirrors. This leads to accumulation of the phase which can be observed on the photodetector.

The need for the second interferometer is based on, first of all, the ability to filter out local noise. By measuring a time delay between signals from different detectors we can determine the distance from the object emitting GWs as well.

2.2 LISA

The Laser Interferometer Space Antenna (LISA) and its evolved and cheaper version eLISA have three spacecraft which form an equilateral triangle with million kilometre arms (5 million km for classic LISA, 1 million km for eLISA) and share Earth's orbit trailing the earth by $\sim 20^\circ$. Each of the three spacecraft contains two telescopes, two lasers and two test masses, arranged in two optical assemblies pointed at the other two spacecraft. From the central satellite, a laser beam is sent to the others using a large beam expanding telescope. [3]

Because of the extreme lengths of the interferometers arms, Fabry Perot interferometry as in the ground-based detectors is not possible: diffraction spreads the laser beam over a diameter of about 20 km as it propagates from one spacecraft to the other. A portion of that 20 km wavefront is sampled with the telescope. That light is then interfered with a sample of light from the on-board laser. Each spacecraft thus generates two interference data streams. Thus six signals are totally generated by the LISA (the new eLISA concept has only two interferometric links between spacecraft). From these signals, we can construct the time variations of armlengths.

2.3 UNGO

Our mission is to come up with a new smaller and cheaper LISA-like detector. The arm length will be 100 km. There will be only 4 interferometric links. The diamete of the Telescope mirror will be 37.5 cm. The laser will have power 20 W and the wavelength 542 nm.

The sensitivity of this detector is expected to be between one of the LISA and Advanced LIGO (Figure 1).

The calulated sensitivity curve for UNGO is represented in the Figure 2.

3 Objectives

It is needed to estimate the precision with which the binary parameters (mass, distance, sky location, etc) can be determined from the gravitational wave signal and the maxmimum distance to detectable binary black hole mergers.

UNGO could also provide an early warning system for smaller mass binaries before they enter the band of ground-based detectors. Therefore, it is necessary to understand how well a low-mass binary's sky location can be determined and calculate how this space interferometer can be coherently combined with the ground based network.

4 Project Schedule

Week 1-2: Learn how a basic gravitational waveform looks like, what waveforms BNS and massive black hole binaries have and how to generate basic waveforms.

Week 3-4: Learn how to calculate the detector response to a gravitational wave, do simulations on instrument sensitivity and compute the signal-to-noise ratio of a gravitational wave signal.

Weeks 5-6: Do simulations on BNS coalescence and learn the Fisher Matrix.

Weeks 7-8: Continue the work on the coalescence and use the Fisher Matrix to calculate

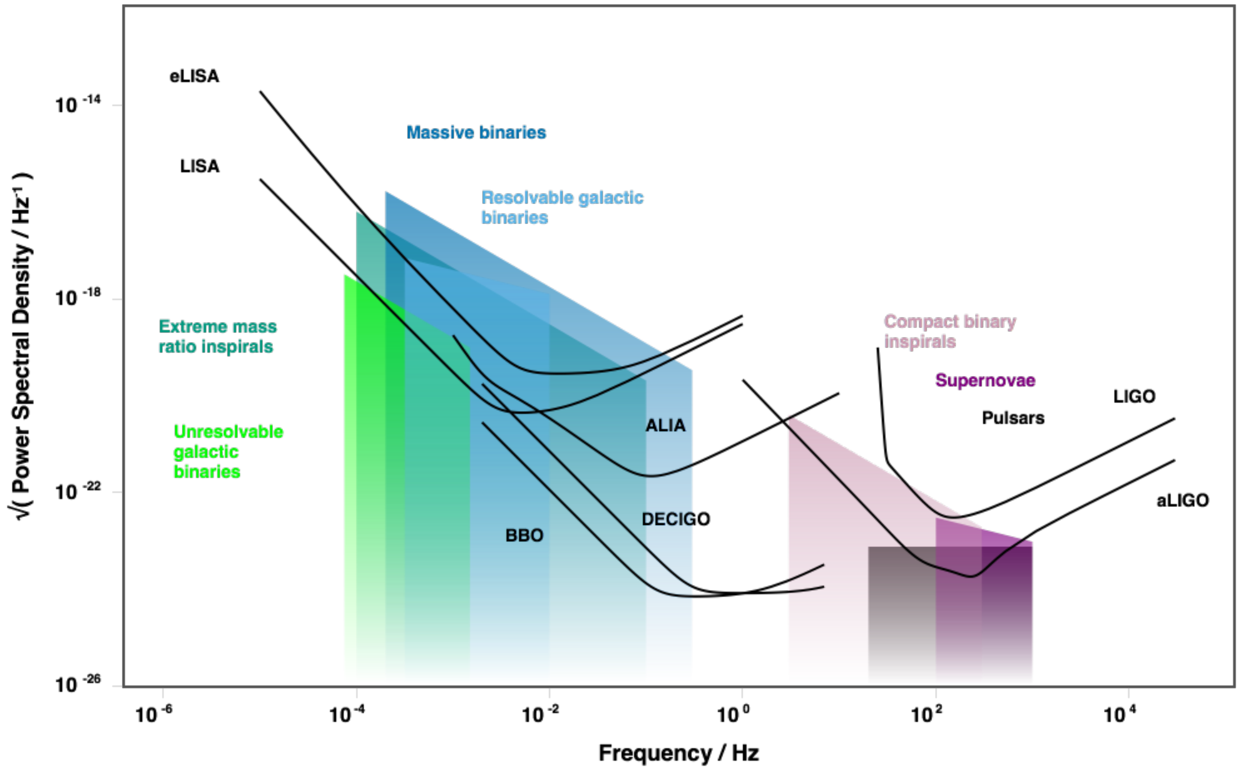

Figure 1: A plot of the square root of power spectral density against frequency for a variety of detectors and sources.

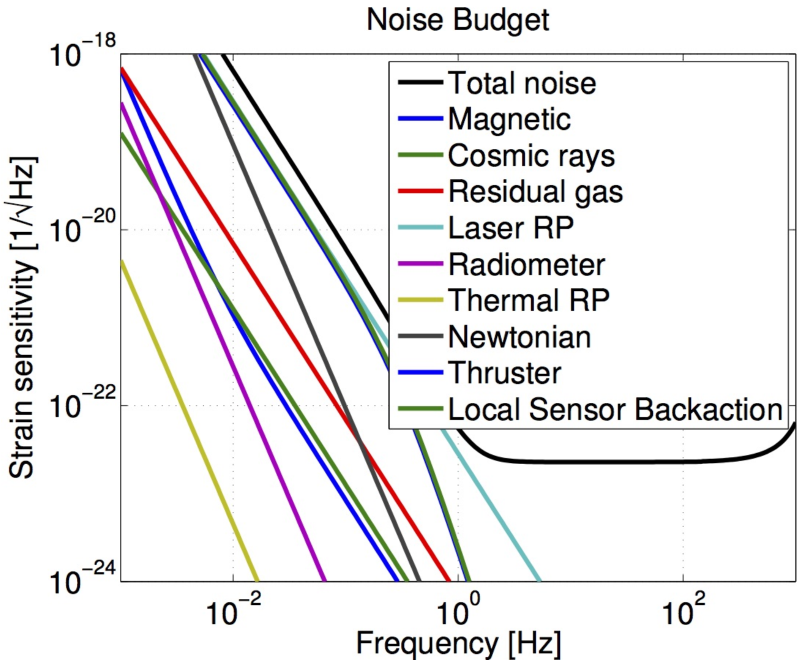

Figure 2: The calculated sensitivity curve for UNGO.

expected parameter estimation errors for massive black hole binaries and determine the accuracy of sky localization of a low-mass black hole binary.

Weeks 9-10: Do the rest of the work and prepare the report for the final presentation.

References

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