Gravitational wave astronomy with current and future generation detectors

Document status and date:
Published: 01/01/2024

DOI:
10.26481/dis.20240404as

Document Version:
Publisher's PDF, also known as Version of record

Propositions accompanying the dissertation

Gravitational Wave Astronomy With Current And Future Generation Detectors

Ayatri Singha

1. Gravitational wave astronomy aims to observe and study ripples in spacetime caused by massive objects like black hole mergers and neutron stars. This helps us explore fundamental physics, study unique cosmic phenomena, and potentially peer back to the universe's earliest moments.

2. Newtonian noise, which is associated with the fluctuation of the gravitational field due to density fluctuations, may limit the sensitivity of these advanced detectors in the low-frequency band (up to 10 Hz). It is certainly a limiting noise source for 'third-generation' detectors such as the Einstein Telescope, as their sensitivity is 1000 times better below 10 Hz compared to currently operating detectors.

3. Although Newtonian noise cannot be directly screened out from the test mirror of the detector, the coupling between the test mirror and the surrounding environment can be reduced by modifying the infrastructure. For example, building recesses or moats surrounding the test mass can act as a shield against Newtonian noise.

4. The Virgo gravitational wave observatory has incorporated open spaces or recesses, which are part of clean rooms located beneath the test masses. The extent of reduction in Newtonian noise depends on several factors, including the geometry of the recess, the velocity of seismic waves within the local geology, and the direction of the dominant seismic source. The inclusion of recesses beneath the test mirrors has significantly contributed to the refinement of the Newtonian noise model for Virgo.

5. Through spectral analysis of Virgo ground noise, it has been observed that the velocity of surface Rayleigh seismic waves remains below 100 m/s within the frequency range of 10-20 Hz. This observation is significant as it can lead to a tenfold reduction in Virgo's Newtonian seismic noise.

6. The sensitivity of a gravitational wave detector depends not only on its noise characteristics but also on its orientation and geometry. The performance of the detector can be characterized by assessing the maximum attainable redshift for different masses of binary systems. Additionally, estimating the detection efficiency for 50% or 90% of the best sources is dependent on their positions and orientations relative to the detectors.

7. The sky localization accuracy of a gravitational wave source, determined by a network of gravitational wave detectors, plays an important role in multi messenger astronomy. Therefore, it can serve as a crucial figure of merit for characterizing the topology and orientation of the detector network.

8. The Einstein Telescope is proposed to consist of three xylophone interferometers arranged in a triangular topology. As a result, the sum of the signals from these three interferometers will be zero. Hence, it will possess an intrinsic null stream that will contain the sum of noises, irrespective of the direction of sources.

9. “Up to now, humanity has been deaf to the universe. Suddenly we know how to listen. The universe has spoken and we have understood.” - Professor David Blair