Maastricht University

Gravitational wave astronomy with current and future generation detectors

Citation for published version (APA):

Singha, A. (2024). *Gravitational wave astronomy with current and future generation detectors*. [Doctoral Thesis, Maastricht University]. Maastricht University. https://doi.org/10.26481/dis.20240404as

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

DOI:
10.26481/dis.20240404as

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

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license above, please follow below link for the End User Agreement:

www.umlib.nl/taverne-license

Take down policy
If you believe that this document breaches copyright please contact us at:

repository@maastrichtuniversity.nl

providing details and we will investigate your claim.

Download date: 28 Apr. 2024

Impact Paragraph

Gravitational waves are produced by the accelerated motion of massive objects, changing the curvature of space and time. In binary systems, where neutron stars or black holes orbit each other, their interaction modifies the curvature of space-time and emits energy in the form of gravitational waves. Detecting gravitational waves is extremely challenging because of their weak interaction with matter. Measuring the minuscule strain caused by gravitational waves using gravitational wave detectors poses significant challenges, as various sources of noise mask the signal, requiring advanced mitigation techniques for effective suppression.

In the first part of the dissertation I look at a specific source of noise known as seismic Newtonian noise. This type of noise arises from local density variations due to seismic wave propagation and introduces additional gravitational pull on the test masses, causing them to move. Newtonian noise can potentially limit the sensitivity of advanced detectors in the low frequency range up to 15 Hz. In particular, it is a significant source of noise for third-generation detectors, which aim to achieve improved low-frequency sensitivity. Low-frequency sensitivity is essential for better observations of our target astronomical sources, such as pulsars and massive black hole mergers, etc. Therefore, it is imperative to explore methods to mitigate the Newtonian noise. I have shown that this noise can be reduced for surface detectors by creating cavities around the test masses. This technique has significant implications for the design of future surface detectors so that Newtonian noise can be minimized.

For site-specific noise mitigation, it is important to understand the primary sources of seismic noise. I have therefore carried out detailed seismic analyses to characterize the spatial and temporal characteristics of the seismic field. This technique provides valuable insights into seismology and geoscience. Understanding the sources, velocities and propagation directions of seismic waves has applications in earthquake studies and environmental monitoring. The propagation of seismic waves is influenced by the subsurface geology. By studying these waves, researchers can obtain information about the composition and structure of the Earth's subsurface. I have used comprehensive seismic field information, including details of the subsurface structure, to calculate the reduction in Newtonian noise for the Virgo gravitational wave detector.

As mentioned above, third generation detectors such as the Einstein Telescope and Cosmic Explorer are expected to have improved sensitivity compared to detectors currently in operation. For the Einstein telescope, two topology options are being considered by the collaboration: the L-shape and the triangular topology. Understanding which topology of the Einstein telescope will lead to better scientific results is crucial for determining the final configuration. Therefore, the decision on the topology has to be made soon. In the second part of my dissertation, I analyze how the two different topologies of the Einstein telescope (L versus triangle) affect the accuracy of sky localisation within networks of third-generation gravitational wave detectors. The L-shaped topology of the Einstein telescope considered here consists of two co-located detectors with an aperture angle of 90°, one of which is oriented at an angle of 45°relative to the other. The proposed triangular setup consists of three detectors arranged in an equilateral triangle with a 60°aperture angle. In particular, improved gravitational wave detectors have the potential to have a more significant scientific impact.

The triangular configuration has an additional advantage in that it contains a redundant number of detectors that can produce a null stream. In the general case, the null stream can be constructed by combining data from the network of detectors while canceling out the underlying gravitational wave signal. Canceling out the signal requires prior knowledge of the source location. However, the null stream for the Einstein telescope, with its triangularly arranged detectors, does not depend on the source location. This feature distinguishes the triangular configuration from others and makes it unique in its ability to generate a source location independent null stream. In the dissertation, I have demonstrated the usefulness of this null stream using rigorous analysis and specialized techniques for source localisation and detector calibration. To measure the gravitational wave signal accurately, we need to understand the response of the gravitational wave detector as precisely as possible. This requires knowing the parameters of the gravitational wave detector with high precision. The process of determining these parameters is known as calibration. The technique I have developed using the null stream has the potential to have a significant impact on improving the calibration of all three detectors of the Einstein telescope. The null-stream methods can be applied to any instrument that has a redundant number of outputs compared to the number of parameters being evaluated.