Volume I - Chapter 3

Gravitational waves and their interactions with detectors: global detector networks

Whereas the challenge to detect the elusive gravitational wave signal drives the technological design of laser-interferometer gravitational wave (GW) detectors, the identification and characterization of astrophysical sources emitting the gravitational wave signals require a global network of GW detectors and are driving the network design. This chapter focuses on the importance of a network of gravitational wave detectors for gravitational wave detection, gravitational wave astrophysics, and multi-messenger astronomy.

The chapter starts with an introduction that includes an overview of the different classes of detectable sources (transient, continuous and stochastic sources) and focusing on their characteristics that place demands and drive the design of the network. The introduction gives historical examples of the importance of the multi-wavelength approach and sky localization improvement in understanding the nature of astrophysical sources.

The first section of the chapter describes the limitations of individual detectors and show why a network is necessary to fully exploit the information in the GW signal. It discusses the fundamental physics underpinning how a network overcomes the limitations of an individual device, and describes the practical considerations that constrain the design space of detector networks. It answers to the questions: how does a network of detectors improve the GW detection capabilities? How do sensitivity, sky localization ability and parameter estimation change by increasing the number of detectors on Earth?

The second section describes the ability of the GW network to detect a GW source and reconstruct its source parameters. It gives an overview of the techniques to extract a GW signal from multi-interferometer instrumental noise, to determine the sky localization and estimate the source parameters. The topic is illustrated by investigating the capabilities of the initial and advanced network of the two LIGO and the Virgo interferometers, and future scenarios that include KAGRA and also a possible IndIGO detector.

The third section of the chapter shows the capabilities of the network to identify and characterize gravitational-wave sources in a multi-messenger context. It is explained how the design of a GW detector network is strictly connected to the identification of a gravitational wave source. Its complete characterization and understanding require to observe all the messengers (GWs, photons and neutrinos) coming from it and its environment. In order to shed light on details of the physical processes acting in astrophysical sources it is necessary that the GW network is part of a global network of multi-messenger facilities. The section shows how the GW network “design requirements” need to be defined on the basis of the capabilities of the space and ground based electromagnetic/neutrino observatories and the state of art of the transient domain astronomy (analysis and rate).

3.0 Brief Introduction:

-2 pages, including brief recounting of source characteristics that drive network design (wavelength comparable to earth, transparency of earth to GWs, strong polarization expected, etc.) and goals for GWs astrophysics (source localization for multimessenger astronomy, determination of source parameters, etc.)

Experience and history of GRBs

3.1 The need for a network

3.1.1 Characteristics and limitations of single detectors that require networks

Lack of directionality, single polarization response, limited duty factor: ~1 page including Figure: the peanut diagram (if not already presented in Chapters 1 or 2)

3.1.2 Network Fundamentals

how does a network of detectors improve the GW detection capabilities? How do sensitivity, sky localization ability, operational duty factor and parameter estimation change by increasing the number of detectors on Earth?

3.1.3 Practical considerations

Need to orient detectors parallel to earth's surface, site characteristics, national funding constraints, cost, etc.

3.2 Designing and evaluating a network

Network performance goals, overview of the network data analysis, figures of merit for different networks, examples using current and possible future networks

3.3 Multi-messenger astronomy using a GW network

Linking a GW network to other astronomy facilities, how GW observations and EM/neutrino channels can work together to solve problems in physics and astronomy