Book Review

An Overview of Gravitational Waves: Theory, Sources and Detection Edited by Gerard Auger and Eric Plagnol (World Scientific Publishing Company, Singapore, 2017)

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General Relativity (GR), Einstein's relativistic theory of gravity, was given in 1915 and even after a century acknowledged for its mathematical elegance, conceptual depth and observational success. Using the linearized approximation of GR, in 1916, Einstein proposed the existence of Gravitational Waves (GW) as one of its important consequence. In 1918, he obtained his famous quadrupole formula for the flux of GW, and in analogy to electrodynamics discussed radiation reaction or radiation damping. Though qualitatively similar to electromagnetism (EM), quantitatively GR is very different due to the weakness of the gravitational interaction relative to EM and the quadrupolar order of GW in contrast to the dipolar order of EM radiation. This implies low efficiency for conversion of mechanical energy to gravitational radiation except in strong fields and relativistic velocities: likely sources are astrophysical systems where there are potentially huge masses accelerating very strongly. And furthermore, feeble effects of GW on any potential detector we can design even today. The direct detection of GW was the Holy Grail for more than half a century and it was not surprising that the announcement of the discovery of gravitational waves from the merger of two black holes on Feb 11 last year was the headline of media coverage the world over. There is immense curiosity about the discovery, the theory that predicted it and the generations that intellectually wrestled and skillfully fabricated the understanding and technology to calculate, detect and decipher them. The present volume is a concise and timely resource for students,

post-docs and researchers to efficiently learn about different aspects of GW research.

The volume consists of eight chapters organized pedagogically. It begins with the Theory of gravitational waves by A. Le Tiec and J. Novak followed by Gravitational wave sources in the era of multi-band gravitational wave astronomy by M. Colpi and A. Sesana. Next is the Theory of Gravitational wave detection by J. Y. Vinet followed by Present and future ground-based detectors by G. Ciani and P. Fulda. Changing track are papers related to space-based GW detection: Space-based laser interferometric laboratories by G. Mueller and the remarkable LISA pathfinder by R. Dolesi. Moving on to GW at nano-hertz range is the paper on Pulsar Timing Array by A. Petiteau. The volume concludes with an paper on Future gravitational wave observatories based on atom interferometry by R. Geiger.

The first chapter begins with a fast-track introduction to general relativity and the language of differential geometry before going on to linearized gravity and a primer on gravitational waves based on it to introduce the reader to the properties of GW and the derivation of the important quadrupole formula of Einstein.

Chapter 2 is a comprehensive and well-written review of GW sources in various frequency bands (kHz to nano-)Hz, their characteristic features and the science one will be able to extract from them. A hundred pages long, this chapter is a succinct introduction to the topic for a beginner and a very compact reference for an advanced researcher.

It compellingly highlights the excitement and potential of multi-band GW astronomy. I would bookmark it for myself as a very useful resource on this topic and pass it on as a good reference on this topic if asked.

Changing gears, Chapter 3 is about the theory of GW detection. It develops formalisms to treat complex optical systems like large scale interferometric detectors both ground-based and space-borne. This compact review of 50 pages begins with the theory of Michelson-type interferometers and proceeds to discuss Fabry–Perot cavities, sidebands, power and signal recycling, Gaussian optics, and finally fundamental limitations due to noise sources. It then moves on to space borne detectors like LISA and time delay interferometry relevant there.

Building on the previous chapter, Chapter 4 provides a status summary of the present generation of ground-based detectors and future prospects for their improvement. It provides a historical perspective of laser interferometric GW detection from initial and enhanced detectors to the present second generation advanced detectors. It summarizes the main features that contribute to the improved sensitivity of the second generation GW detectors: higher laser power, massive test mass, improved coatings and much better seismic isolation. The chapter ends with the anticipated improvement in the third generation GW detectors like the Einstein Telescope.

Up till now, the volume has focused on GW from stellar mass compact binaries whose frequencies are in the range of a few Hertz to a kiloHertz and referred to as high frequency GW. However, like electromagnetic waves, GW span a four decade frequency range generated by other classes of sources. Chapter 5 deals with low frequency GW generated by the population of galactic binaries or merger of supermassive BH binaries at centers of galaxies and the space-based laser interferometric

observatories like LISA required to detect and investigate them. It provides a concise overview of the LISA history, sources, design and technology.

This naturally leads to the next chapter on the LISA Pathfinder, the technology mission that has been spectacularly successful and which coupled to the first detection of GW by LIGO has made the feasibility of a LISA class space mission more probable. Once again, the chapter provides the highlights of the technologies tested and their interfaces to the LISA mission.

The next chapter deals with Pulsar timing arrays and how they look for very low frequency GW both as a stochastic background and from individual massive black hole binaries.

The last chapter in the volume gazes into the future and discusses the possibility of GW detectors based on atom interferometry. It provides a useful introduction for any starting researcher who would like to look into more specialized papers on this topic.

In summary: The volume of about 300 pages is a useful resource to any researcher who would like to catch up with the excitement of GW research post the first discovery of GW by LIGO. A minor quibble. In the first chapter, I am not sure if the brief introduction to differential geometry would be adequate to take an uninitiated novice to a level of a user. The volume may have been more pedagogically complete if this chapter provided a bird eye overview of the current status of source modeling. I enjoyed reading through the volume and am sure that others who do will refer their younger colleagues to it for a concise introduction to an exciting emergent field of research: the new gravitational wave astronomy.

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