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The Data Analysis in Gravitational Wave Detection† ⋆

WANG Xiao-ge[1△] ERIC Lebigot[1] DU Zhi-hui[1] CAO Jun-wei[1] WANG Yun-yong[2] ZHANG Fan[2] CAI Yong-zhi[2] LI Mu-zi[2] ZHU Zong-hong[2] QIAN Jin[3] YIN Cong[3] WANG Jian-bo[3] ZHAO Wen[4] ZHANG Yang[4] DAVID Blair[5] JU Li[5] ZHAO Chun-nong[5] WEN Lin-qing[5]

[1] *Tsinghua University, Beijing 100084*

[2] *Department of Astronomy, Beijing Normal University, Beijing 100875*

[3] *Chinese Academy of Metrology, Beijing 100013*

[4] *University of Science and Technology of China, Hefei 230026*

[5] *University of Western Australia, WA 6009*

Abstract Gravitational wave (GW) astronomy based on the GW detection is a rising interdisciplinary field, and a new window for humanity to observe the universe, followed after the traditional astronomy with the electromagnetic waves as the detection means, it has a quite important significance for studying the origin and evolution of the universe, and for extending the astronomical research field. The appearance of laser interferometer GW detector has opened a new era of GW detection, and the data processing and analysis of GWs have already been developed quickly around the world, to provide a sharp weapon for the GW astronomy. This paper introduces systematically the tool software that commonly used for the data analysis of GWs, and discusses in detail the basic methods used in the data analysis of GWs, such as the time-frequency analysis, composite analysis, pulsar timing analysis, matched filter, template, χ^2 test, and Monte-Carlo simulation, etc.

Key words gravitational wave—laser—interferometer—data analysis

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△ wangyunyong@bnu.edu.cn

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1. INTRODUCTION

Gravitational waves (GWs) are the most important prediction of general relativity[1,2], and the GW detection is one of frontier domains of modern physics. The GW astronomy based on the GW detection is a newly-rising interdisciplinary field[3,4], and due to the unique physical mechanism and character of gravitational radiation, the studied range of GW astronomy is even broader and comprehensive. With a quite new tool and idea to search the unknown mass systems in the universe, it can provide the information never obtained by the other methods of astronomical observations, to deepen the human knowledge about the celestial body structures in the universe. Followed after the traditional astronomy with the electromagnetic waves (optical, infrared, ultraviolet, X-ray, gamma-ray, and radio) as the detection measures, the GW detection becomes a new window for humanity to observe the universe. It has a quite important significance for studying the origin and evolution of the universe, and for extending the astronomical research field.

Because the GW signal is very weak, the research of GW astronomy needs not only the detectors with a high sensitivity and broad waveband, and the superior detecting techniques, but also the scientific methods for data processing and analysis. At present, the mainstream equipment of GW detection—the laser interferometer GW detector has been developed vigorously around the world. The second generation of laser interferometer GW detectors, represented by the Advanced LIGO, Advanced Virgo, KAGRA, and GEO-HF, are at the tensely mounting and adjusting stage, and will be put into operation to acquire data in the near future. At the same time, the studies on the data processing and analysis of GWs and the corresponding common-used software have made great progresses as well, and the special and general-purpose software and hardware systems for different research projects and with different features have also been established quickly in various large laboratories around the world, to make a solid base for the GW detection and the study of GW astronomy.

2. GENERAL-PURPOSE TOOLS FOR DATA ANALYSIS

In order to perform better the data analysis, it is necessary for physicists to establish a large number of general-purpose software systems, such as the tool software, simulative calculation software, the database for saving the corrected parameters of calibration constants and the parameters of detectors, the software system for managing and controlling the operation procedures, the sample selection and reconstruction system, and the analysis pipeline in respect to a specific research field, etc. Before making the data analysis, it is necessary to make a thorough study and understanding of their functions, formats, contents, operation methods, etc., and thus we can handily get twice the result with half the effort.

In general, there is a perfect set of software systems for each laboratory, in which each program package contains over one million lines of source program. Professional people are required for seriously writing, maintaining, correcting, and updating these programs. Taking