

Foreword

Detecting gravitational waves is still a dream. After several years of commissioning of Virgo, and after reaching its target sensitivity, we know that a gain of roughly one order of magnitude is still necessary, so that a new detector called “Advanced Virgo” is in construction. Gravitational waves are not only a unique messenger coming from extreme regions of the universe, but also, it is well known, an experimental challenge. Starting from the very beginning, with resonant bars, if a gravitational signal is detected in 2015, it will crown one century of General Relativity theoretical studies, and half a century of technological developments. The coupling coefficient between matter energy and waves is so tiny, and the amplitude of waves so weak that any spurious physical effect negligible in an ordinary context must be carefully assessed: shot noise, frequency noise, residual seismic activity, thermal noise, stray light, and other microscopic effects are however much larger than the signal if no care.

This particular circumstance has defined since years the matter now called “experimental gravitation.” The lessons presented in this book reflect the various fields that proved necessary to allow some hope for a first historical detection. We hope that for the young searchers who took part in this school, it will be some day classical science.

Jean-Yves Vinet
Virgo spokesperson

Preface

Why this book? Whom is it intended for? How should the reader use it? These are the questions a preface is called to answer.

Let us start by pointing out *what this book is not*: it is not an introduction to the theory and basics of gravitational waves (GW), that our reader should have already acquired. Any recent textbook on General Relativity has a chapter on GW generation, propagation, and detection. Besides, there are excellent monographs on GW, from the books of P. Saulson (unfortunately out of print) and M. Maggiore to the reviews of D. Blair and the thorough online overview of B. Schutz and Sathyaprakash [1–5].

However, very little is required to read and fully exploit the contents of this book: the reader should be familiar with the fundamentals of GW detection (not much more than the very basic $h(t) = \delta L(t)/2L$) and be at ease with concepts like interferometers and noise spectral density, signal-to-noise ratio and chirp.

This book *is not* an overview of all current experimental efforts to detect GW: we cover neither Pulsar Timing Array, a promising technique to detect sub- μHz radiation, nor Laser Interferometer Space Antenna, the so-called LISA concept for a space mission that will fly in the early 2030s, placing a Gm long interferometer in a heliocentric orbit to observe GW in the 1 mHz–1 Hz frequency range. This book only deals with the present and the future of ground-based, km-long interferometers, aiming at detecting GW in the 10 Hz–3 kHz range. We did not attempt to cover the advances in data analysis, that would deserve a book on its own [6].

What is then the goal of this book? Its goal is to be a guide for both new and experienced scientists that decide to venture in the field of experimental search for gravitational radiation. It aims to be a handbook for the physicist who wants to join, or is already a member of one of the large collaborations now engaged in the construction of ground based, second generation, GW detectors; Advanced LIGO in the USA, Advanced Virgo and GEO in Europe, KAGRA in Japan. It aims to be a reference book on how to tackle the huge, impressive technological challenges that can intimidate even the experienced experimentalists.

The past of gravitational radiation is well known: it is part of scientists' common knowledge since the papers [7, 8] of 1916 and 1918, almost a century ago, where A. Einstein himself worked out the wave solution to his field equations, passing through the debate of the 1950s on the detectability of these waves to the first attempts of building a detector and the indirect, but indisputable evidence of

GW from observation of binary pulsars [9, 10]. Resonant antennas, where the vibration of a massive cylinder is to be detected against thermal and readout noise, held the scene from the early 1960s, with the pioneering work of J. Weber, to the cryogenic apparatus of the 1980s and finally the ultra-cryogenic detectors (Nautilus, Auriga, Minigrail) of the 1990 and early 2000s, when they were finally surpassed, both in sensitivity and bandwidth, by the large interferometers. Interferometers themselves have a long history of technological development: from the first, table-top, seed work of Forward, Miller, and Moss [11] in 1971, they have grown in size, sensitivity, and complexity, passing through the 30 or 40 m of arm length of the prototypes in Garching, Glasgow, and Caltech, to the 600 m of GEO600, still active as a test bench for new technologies. The last 15 years have seen the construction, commissioning, and operation of the km-scale interferometers, some of the largest research infrastructures in the world: the scientific teams have grown from local groups of a dozen scientists to international collaborations of several hundreds people; the two 4 km observatories of LIGO, in the USA and the 3 km Virgo detector, in Italy (a French–Italian joint venture, now grown to a European collaboration with The Netherlands, Poland, Hungary) have observed the cosmos, producing relevant upper limit science (an overview of these results can be found in [Chap. 2](#)) but missing the “smoking gun” of an evidence for direct detection of GW. This task is thus passed on to the next generation of devices, the advanced detectors, now under construction.

The present of the experimental search of GW is what this book is mainly about: after several years of successful data taking, the large interferometers have been decommissioned and dismantled, and the construction of the advanced detectors has begun within the same infrastructures (the end buildings and the 3 or 4 km long vacuum system), both on the two LIGO sites and at Virgo. This “second generation” is characterized by physical and technological advances that are described in detail in the [Chaps. 3–11](#) and will provide a sensitivity ten times better: it is common belief that direct detection of GW cannot be missed by these detectors.

And finally the future of GW detectors: in the short term, the years 2014–2017, will see the commissioning and then operation of Advanced LIGO and Advanced Virgo and, most likely, will deliver a direct detection, sought after and relentlessly chased for over 50 years. In 2018, according to optimistic schedules, also KAGRA will join the detectors’ network: a Japanese effort that will fold into an Advanced detector some features, like cryogenics and underground location, typically considered as further, delayed improvements, so that we can call it a “second and half generation.” More detectors may appear in the coming years: LIGO-India, a joint venture of LIGO and several Indian scientific institutions (Indigo) is, at the moment of writing, seriously considered by funding agencies.

For the not-so-near-future, running over into the next decade, a third generation of detectors, again ten times more sensitive, is already being conceived and designed: the last two chapters describe this long-term effort, that should move the status of GW observations from detection to routine astronomy. The Einstein

Telescope will probably complement the wealth of physics information that we can expect from a LISA space mission.

This book springs as a by-product of a specialized course, held at the EGO-Virgo site in May 2012, that focused on the science and technology that are at the core of the so-called Advanced Interferometers. The course, that I was called to direct, attracted many enthusiastic students and a dozen of excellent lecturers: there was immediately a large consensus and interest in collecting the lecture notes in a publication, that could serve as a guide for future schools and as a handbook for any GW experimentalist. The table of contents of this book closely retraces the course syllabus, and all of the authors (with one exception) had lectured the same topic in the course. Each one of them is an experienced specialist, extremely knowledgeable, and deeply involved in the development that she or he discusses, chosen among the very best scientists in that particular field. Each of their contribution has been thoroughly revised both by the book editor and by the internal refereeing system of the author's own scientific collaboration (Virgo, GEO, or LIGO) In this respect, we are confident that we are providing contents that are rigorous, nontrivial and up-to-date.

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An exciting time is ahead of us all, gravitational waves hunters: the Holy Grail of detection has never been so likely and so near!

Rome, October 2013

Massimo Bassan

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