Preface

In brief, the first half of this book is about first-stage data analysis—the analysis of 0-level data, of the space-based gravitational wave detector (e)LISA, with the help of various types of Kalman filters and other algorithms, and to achieve ultra-precise inter-satellite ranging and clock synchronization for (e)LISA. The second half is about the design of a novel space-based gravitational wave detector and a few novel gravitational wave data analysis algorithms.

Gravitational waves are propagating space-time ripples on the static space-time background. Laser Interferometer Space Antenna (LISA) is a space-based GW detector concept, which consists of three spacecraft forming an equilateral triangle orbiting the Sun trailing the Earth. The proper distances between the spacecraft are modulated by gravitational waves, which will be measured by (e)LISA through heterodyne interferometers. Thus, the gravitational wave signals are encoded in the phase evolution of the lasers. The phasemeter raw data of (e)LISA are not directly usable for time-delay interferometry techniques and astrophysical data analysis, since clock jitter contaminates the ranging measurements and introduces noise into the time stamps of the measurements. This has been a long-lasting gap and needs to be solved in the first-stage data analysis of (e)LISA.

Chapters 2–9 focus on the development of 0-level data analysis algorithms for (e)LISA, which calibrate and synchronize the phasemeter raw data, estimate the inter-spacecraft distances and the clock errors, and hence make the raw measurements usable for time-delay interferometry techniques and astrophysical data analysis algorithms. An introduction to an entire LISA data processing chain is presented in Chap. 2, followed by an exemplary application of the basic Kalman filter on a single laser link of LISA in Chap. 3. In Chaps. 4 and 5, the inter-satellite measurements are precisely modelled and a hybrid-extended Kalman filter is applied to the (e)LISA problem. In Chaps. 6 and 8, different state vectors and their corresponding dynamic equations are designed and investigated, which has been found to be crucial to the efficiency and success of the first-stage data analysis. Emergent cases with different combination of broken laser links are studied in Chap. 7 via a sequential Kalman filter, while the posterior measurements are used to improve the estimates via an RTS filter. In Chap. 9, the effect of the clock errors on both the measurements and recording time stamps is studied. A combination of different algorithms is designed and investigated, in order to make the Kalman filter variant work for measurements sampled at different time, with erroneous time stamps contaminated by different timing errors of the three different clocks. The relative ranging accuracy achieved is around 10^{-11} in the end.

In the second part, several aspects of gravitational wave detection and data analysis, in general not restricted to (e)LISA, are studied. For the first time, an octahedral displacement-noise-free space-based GW detector is proposed and studied in Chap. 10. A phenomenological waveform is proposed for the most challenging type of sources for (e)LISA—extreme-mass-ratio inspirals in Chap. 11. A data analysis pipeline, including particle swarm optimization, Markov chain Monte Carlo, genetic algorithm, and clustering algorithms is designed to search for the extreme-mass-ratio inspiral signals. As an innovation, the detection and the parameter estimation are in two separatestages. In Chap. 12, a novel method based on compressed sensing is designed, which can quickly detect gravitational wave signals with moderate to high signal-to-noise ratios and estimate the parameters automatically. In the final chapter, the likelihood transform is defined, which gradually modifies and traces the geometry of the likelihood surface, and hence makes the search for weak signals in noisy data, such as gravitational wave signals, easier.

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