PREFACE

This book is a collection of 13 articles corresponding to lectures and research works exposed at the Summer school of the CNRS titled “Bases mathématiques pour l’instrumentation et le traitement du signal en astronomie”. The school took place in Nice and Porquerolles, France, from June 1 to 5, 2015.

Many Sciences like Physics, Biology or Economy heavily rely on mathematical models and tools. But Mathematics do not only provide toolboxes for such Sciences. Mathematical concepts and methods are also a genuine source of inspiration and creativity. Mathematics can provide new ways of extracting relevant information and even to build new instrumental concepts.

This book contains three parts.

The first part, titled “Astronomy in the coming decade and beyond”, presents in a first chapter a panoramic view of the main questions tackled by modern Astrophysics. This view covers current and upcoming large infrastructures and instruments on ground and in space, which will produce major discoveries in the coming decades. The two other articles in this part focus respectively on the largest radio telescope in the world, the Square Kilometre Array and its development as a huge international project, and on a prototype terrestrial hypertelescope paving the way to giant diluted telescopes and their future space versions with flotillas of small mirrors over 10 to 1000 km.

This part emphasizes the strong interdisciplinary nature of Astrophysics, both at theoretical and observational levels, and the increasingly larger sizes of data sets produced by increasingly more complex instruments and infrastructures. These remarkable features call in the same time for more mathematical tools in signal processing and instrumentation, in particular in statistical modeling, large scale inference, data mining, machine learning, and for efficient processing solutions allowing their implementation.

The second part, titled “Mathematical concepts, methods and tools”, proposes a zoom on the theory underlying some of these mathematical tools. This part starts with an example of how pure mathematics –Diophante’s algebraic relations between powers of integers– can lead to new instrumental concepts, in this case for exoplanet detection. The four other chapters of this part provide a detailed introduction to four main topics: Orthogonal functions as a powerful...
tool for modeling signals and images, covering Fourier, Fourier-Legendre, Fourier-Bessel series for 1D signals and Spherical Harmonic series for 2D signals; Optimization and machine learning methods with application to inverse problems, denoising and classification, with on-line numerical experiments; Large scale statistical inference with adaptive procedures allowing to control the False Discovery Rate, like the Benjamini-Hochberg procedure, its Bayesian interpretation and some variations; Processing solutions for large data sets, covering the Hadoop framework and YARN, the main tools for the management of both the storage and computing capacities of a cluster of machines and also recent solutions like Spark. The chapters of this part are of a methodological nature but also propose examples of possible applications in Astronomy.

The last part, titled “Application: tools in action”, collects a number of current research works where some tools above are presented in action: optimization for deconvolution, statistical modeling, multiple testing, optical and instrumental models. The applications of this part include astronomical imaging, detection and estimation of circumgalactic structures, and detection of exoplanets.

Slides and numerical experiments can be found at https://basmati.oca.eu.