Astrophysical Spectropolarimetry

The polarization of light is the key to obtaining a wealth of essential information that lies encoded in the electromagnetic radiation reaching us from cosmic objects. Spectropolarimetry and imaging polarimetry provide powerful diagnostics of the physical conditions in astrophysical plasmas, for instance, concerning magnetic fields, which cannot be obtained via conventional spectroscopy. Spectropolarimetry is being used with great success in solar physics. Yet, its application to other fields of astrophysics is still in an early stage of development.

This book on Astrophysical Spectropolarimetry comes at a time of growing awareness of the new possibilities offered by this field. This is mainly due to the observational opportunities opened up by the new generation of telescopes, both ground-based and space-borne, and their associated instrumentation as well as to recent advances in the theory and numerical modelling of the generation and transfer of polarized radiation. The book contains the lectures delivered at the XII Canary Islands Winter School of Astrophysics on the following topics: the physics of polarization, polarized radiation diagnostics of solar magnetic fields, stellar magnetic fields, polarization insights for active galactic nuclei, compact objects and accretion disks, astronomical masers and their polarization, interstellar magnetic fields and infrared-submillimeter spectropolarimetry, and instrumentation for astrophysical spectropolarimetry. They are written by prestigious researchers working in several areas of astrophysics, all of them sharing an active interest in theoretical and observational spectropolarimetry.

This timely volume provides graduate students and researchers with an unprecedented introduction to Astrophysical Spectropolarimetry.

Astrophysical Spectropolarimetry

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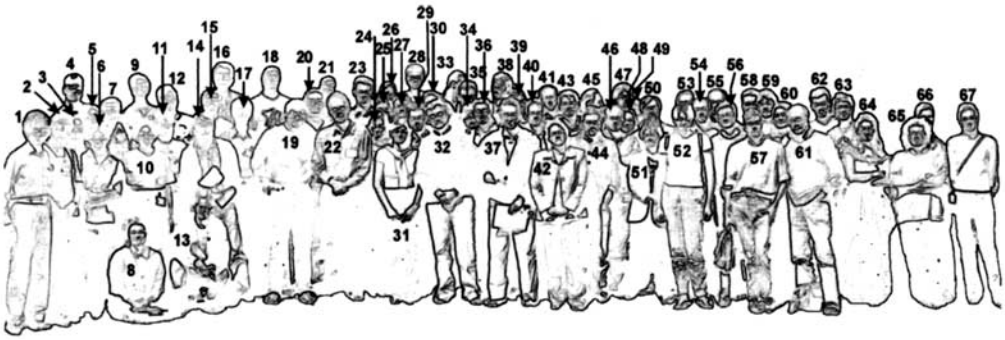

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Preface

Most observational work in astrophysics has so far been carried out mainly on the basis of the intensity of the radiation received from the object observed as a function of wavelength. However, an important and frequently overlooked aspect of electromagnetic radiation is its state of polarization, which is related to the orientation of the electric field of the wave. The state of polarization can be conveniently characterized in terms of four quantities that can be measured by furnishing our telescopes with a polarimeter. These observables are the four Stokes parameters (I, Q, U, V) which were formulated by Sir George Stokes in 1852 and introduced into astrophysics by the Nobel laureate Subrahmanyan Chandrasekhar in 1946. A quick, intuitive definition of the meaning of these four parameters can be obtained from Figure 1 of the chapter by Prof. Landi Degl'Innocenti in this book, which we borrowed for the poster announcing the Twelfth Canary Islands Winter School on Astrophysical Spectropolarimetry.

In physics laboratory experiments, where the magnetic field is known beforehand, the observed polarization signals are used to obtain information on the atomic and molecular structure of the system under study. In astrophysics we have the inverse problem, the magnetic field being the unknown quantity. To obtain information about cosmic magnetic fields, therefore, we have to learn how to interpret spectropolarimetric observations correctly by resorting to our knowledge of atomic and molecular physics.

The importance of the information contained in the polarization of electromagnetic radiation has been recognized for decades in solar physics, where the spatial resolution and signal-to-noise ratio in spectroscopic observations are much more favourable than in night-time observation. In recent years, developments in theoretical astrophysics and astronomical instrumentation (telescopes with large light-collecting areas and innovative spectropolarimeters) are leading an ever-growing number of astrophysicists to learn to appreciate the enormous diagnostic potential offered by spectropolarimetry. The polarization of light is the key to unlocking new discoveries and obtaining the information we need to understand the physics of many phenomena occurring in the Universe. Particularly relevant examples, besides the magnetized plasmas of the Sun and peculiar A- and B-type stars, are young stellar objects and their surrounding discs, Herbig-Haro objects, symbiotic stars, hot stellar winds, active galactic nuclei, radio galaxies, black holes, the interstellar medium, the cosmic microwave background radiation and its cosmological implications, etc.

This book contains the lectures delivered at the XII Canary Islands Winter School of Astrophysics, organized by the Instituto de Astrofísica de Canarias (IAC), on Astrophysical Spectropolarimetry. The time is clearly ripe for such a book on the subject. There is increased awareness of the relevance of spectropolarimetry for astrophysics thanks, in part, to the new generation of 10-metre-class telescopes. Some of these large telescopes, such as the GTC at the Observatorio del Roque de los Muchachos (La Palma), are right now under construction while others are already in operation at observatories worldwide. Because of the large collecting surface of this class of telescope, the development of spectropolarimeters capable of quantifying with high precision the state of polarization of the light, and the recent unprecedented advances in the field of theoretical and numerical astrophysics, spectropolarimetry is gradually emerging as a powerful new diagnostic tool for probing the physical conditions and the magnetic fields of the Universe.

The application of spectropolarimetry in astrophysics is still at an early stage of de-

velopment. This makes it especially attractive for young researchers eager to contribute to the advance of astrophysics. In this field, theoretical and observational astrophysics, numerical simulations and instrumental developments are frequently called upon. This new window on the Universe offers the opportunity to make new discoveries through the rigorous physical interpretation of spectropolarimetric observations, which provide information that it is impossible to acquire through conventional spectroscopy.

We have edited this book in the desire to present an introduction to the field of Astrophysical Spectropolarimetry, with a view to encouraging young researchers to investigate rigorously and in depth the "polarized Universe". We are convinced that the achievements of spectropolarimetry in solar physics will soon be possible in other areas of astrophysics as well.

Javier Trujillo-Bueno & Fernando Moreno-Insertis
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Foreword

After twelve years, the Canary Islands Winter School continues to provide a unique opportunity for the participants to broaden their knowledge in a key field of astrophysics. The idea works because promising young scientists and invited lecturers interact, learn and enjoy science in the pleasant environment of the Canary Islands.

The XII edition of the Canary Islands Winter School looked at the Universe from a relatively unexploited viewpoint, namely that fostered by a multidisciplinary branch of science which has a great future in store: spectropolarimetry. Thanks to theoretical and observational spectropolarimetry we will be able to explore new facets of the Universe while unveiling new discoveries still hidden in the electromagnetic radiation we receive. The large telescopes of the future – among them the 10.4 m Gran Telescopio Canarias – and advanced postfocus instrumentation should be designed with a view to rendering feasible high precision spectropolarimetric observations. The theoretical interpretation of observed polarization signals will allow new fundamental advances in our knowledge of cosmic magnetic fields. Spectropolarimetry could well be a revolutionary technique in the astrophysics of the XXI century. That is why the XII Canary Islands Winter School of Astrophysics has been devoted to this promising and exciting field.

Francisco Sánchez
Director of the Instituto de Astrofísica de Canarias

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