BASICS OF THE SOLAR WIND

The Sun continually ejects matter into space, blowing a huge bubble of supersonic plasma: the solar wind, which engulfs the Earth and the other planets, shaping their environments.

Basics of the Solar Wind presents a modern introduction to the subject, starting with basic principles and including the latest advances from space exploration and theory. The book discusses the structure of the solar interior and atmosphere, the production of the solar wind, and its perturbations. It addresses the basic physics of the objects of the Solar System, from dust to comets and planets, and their interaction with the solar wind. The final sections explore the subject from an astrophysical point of view, including the interaction with the interstellar medium, cosmic rays and winds from other stars. The book contains a historical survey and a short introduction to plasma physics.

This volume is the first to present a comprehensive basic coverage of this subject. The topics are discussed at various levels of difficulty, by including qualitative as well as quantitative treatments and emphasising physical processes rather than mathematics or observation. This book will appeal to students and researchers in physics, astronomy, space physics and engineering, geophysics and atmospheric sciences.

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This series of upper-level texts and research monographs covers the physics and chemistry of different regions of the Earth's atmosphere, from the troposphere and stratosphere, up through the ionosphere and magnetosphere and out to the interplanetary medium.

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To my sons François and Alain Meyer,

and to the memory of my father, Jean Vernet,
for the intellectual enrichment he gave me

Contents

Preface

Why chase the wind?
J. Cocteau, *Antigone*

For science-fiction writers and some space engineers, the 'wind from the Sun'[1] is a wind of photons – the light we see, whose pressure might allow solar sailing and drive space windjammers through the solar system. Yet the Sun blows another kind of wind, made of material particles, whose importance is considerable since it bathes the whole Solar System and shapes all planetary environments.

This wind has many faces. To the layman, it sounds rather mysterious, being made of a strange medium, a plasma: the fourth state of matter. Not only do its tempests affect our everyday technology by disrupting communications and power stations, but it drives two bewildering sky displays: comet tails and auroras. To the space scientist, in contrast, the solar wind is a close companion, and the challenge is to explore and tame a jungle where his or her instruments reveal a strange fauna. The plasma physicist is delighted to find there a number of stunning surprises and extreme properties which are virtually impossible to simulate in the laboratory. And to the astronomer who is trying to understand how cosmic bodies – from planets and comets to stars and galaxies – eject particles into space, it is the only stellar wind that can be studied in detail.

The solar wind has been explored *in situ* by numerous space probes, from inside Mercury's orbit to far beyond the distance of Neptune, and, quite recently, at virtually all heliocentric latitudes. The last decade has seen an explosion in the volume of data, and the solar wind is now measured in almost embarrassing detail. Yet, from the beginning of modern physics to the present epoch, its origin has motivated – and still motivates – much debate.

This book explores the physics involved, from the solar origin, to the frontier of the Solar System. The object of the game is to retrieve (in a quantitative, albeit approximate, way) the basic properties from first principles, within the limits of our incomplete understanding, keeping in mind that Nature always turns out to be subtler than we had imagined.

This book is intended for scientists, for technical workers involved in space missions, for science students and teachers, and more generally for those who enjoy the application of basic physics to a realm unattainable in Earth's laboratories. The emphasis is aimed at physical intuition rather than mathematical

[1] Clarke, Arthur C. 1972, *The Wind from the Sun*, London, Victor Gollancz.

rigour. The calculations only require a basic background in physics and mathematics and assume no prior knowledge of plasma physics, for which a first-aid kit is given in Chapter 2.

This subject has hideously complicated aspects, and I had to make gross simplifications in order to avoid the fundamental ideas being lost in a morass of details. Resisting the temptation of replacing basic understanding by classification, detailed mathematics, and/or computer modelling, creates a dilemma: how be useful to non-specialists, without angering the specialists too much. I therefore made no attempt to be comprehensive, either in the topics, or in the references. Instead, I have tried to follow Victor Weisskopf, who used to say at the start of a course: 'I will not cover the subject, I will try to uncover part of it.'[2] In the same spirit, the references are meant to help the readers, not to give credit to the authors. Unless otherwise stated, units are SI.

Although I take full responsibility for the errors that have crept in,[3] I should not give the impression that this book was written by me alone. Many people of diverse languages and cultures have contributed, either personally or through their writings. It is impossible to acknowledge all of them properly and to give credit to the scientists whose viewpoints influenced me. I offer my warm thanks to the generous friends and colleagues who have scrutinised sections of the manuscript and provided suggestions for improvements, or contributed in other ways, especially to Jean-Louis Steinberg (who got me started on space research), Alex Dessler (who got me started on this book), Marcia Neugebauer, Ludwik Celnikier, Joseph Lemaire, Marco Velli, Serge Koutchmy, Jorge Sanchez-Almeida, Pascal Démoulin, Dominique Bockelée, Karine Briand, Darrell Strobel, Rosine Lallement, Guillaume Aulanier, Françoise Launay, Milan and Antonella Maksimovic and Danielle Briot. I owe much to my friends and colleagues of the Observatoire de Paris at Meudon for the warm environment and numerous discussions, and to several outstanding former graduate students for their insightful and stimulating questions. This work would not have been possible without the kind help of the efficient staffs of the library at Meudon (Observatoire de Paris) and of the laboratory LESIA (CNRS and Universities Paris 6 and 7). The students who endured my lectures on the solar wind at the University Paris 11, and on astrophysical plasmas at the Observatoire de Paris (and the Universities Paris 6, 7 and 11) have contributed in no small way too. Thanks to all of them! Last but not least, I am very grateful to my family and my friends for their encouragement and help. Special thanks are due to my son François Meyer for the drawings he made to illustrate this book.

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[2] Weisskopf, V. F. 1989, *The Privilege of Being a Physicist*, New York, W. H. Freeman, p. 32.

[3] I encourage readers to send me typographical or other errors at nicole.meyer@obspm.fr. I intend to post an updated list of errors at www.lesia.obspm.fr/∼meyer/BSW.html.