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Tools of Radio Astronomy

Fifth Edition

Springer

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Cover image: The Japanese MELCO 12 meter antennas on the ALMA Operation Support Facility. Credit: (c) ALMA / ESO / NAOJ / NRAO.

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Preface to the Fifth Edition

Four significant factors have led us to update this text. The first is the breathtaking progress in technology, especially in receiver and digital techniques. The second is the advance of radio astronomy to shorter wavelengths, and the increased availability of astronomical satellites. The third is a need to reorganize some of the chapters in order to separate the basic theory, that seldom changes, from practical aspects that change often. Finally, it is our desire to enhance the text by including problem sets for each chapter. In view of this ambitious plan, we have expanded the number of authors.

In the reorganization of this edition, we have divided Chap. 4 of the 4th edition into two Chaps. 4 and 5. The first remains Chap. 4, with a slightly different title, *Signal Processing and Receivers: Theory*. This was expanded to include digital processing and components including samplers and digitizers. In Chap. 5, *Practical Receiver Systems*. we have relegated the presentations of maser and parametric amplifier front ends, which are no longer commonly used as microwave receivers in radio astronomy, to a short section on "historical developments" and We have retained and improved the presentations of current state-of-the-art devices, cooled transistor and superconducting front ends. We have also included descriptions of local oscillators and phase lock loops. Chapters 5 and 6 in the 4th edition has now become Chap. 6, *Fundamentals of Antenna Theory* and Chap. 7, *Practical Aspects of Filled Aperture Antennas*. Our goal is to have an exposition of the rather mathematical theory, in Chap. 6 followed by a treatment of the practical aspects of antennas. Chapter 7 in the 4th edition is now Chap. 8, titled *Single Dish Observational Methods*. Chapter 9 deals with *Interferometers and Aperture Synthesis*. Aperture synthesis has become the most important imaging technique in radio astronomy; this provides the only general method available for obtaining images of extremely high resolution and quality, so the discussion has been extended and improved with material pertenant to interferometers such as the Atacama Large Millimeter Array (ALMA) and the Square Kilometer Array (SKA). Chapters 10 to 14 of this edition have been updated to include recent observational results. Chapter 15 of the 4th edition, *Molecules in Interstellar Space*, has been divided into two Chapters, *Overview of Molecular Basics* and Chap. 16, *Molecules in the Interstellar Medium*. Chapters 15 and 16 have been updated to take new developments into account.

The existing facilities are providing new results on a daily basis. The increased number of ground based radio single dish telescopes, especially in the millimeter and sub-mm wavelength range, such as ASTE, APEX, and NANTEN2, and the availability of astronomical satellites starting with IRAS, and then ISO, ODIN, MSX, CHANDRA and SPITZER have increased the number of discoveries. Somewhat more specialized are the radio telescopes dedicated to the study of the 3 K microwave background: these include the satellite missions COBE and WMAP and the balloon mission Boomerang, as well as numerous additional ground based facilities. Taken together, these have changed our concepts of astronomy. A sample of these results have been included. This trend is expected to continue with the launch of the *Herschel Satellite Observatory* and the start of scientific measurements with the *Stratospheric Observatory for Infrared Astronomy*, SOFIA.

We believe that this text is of interest for communications engineers as well as radio astronomers. We hope this new edition will serve a useful purpose as radio astronomy enters the era of Herschel, SOFIA, ALMA, SKA, SKA precursors.

The Table of interstellar molecules was provided by T. Millar (Queen's University Belfast) & E. Herbst (Ohio State University). Advice from G. H. Tan, H. Rudolf, R. Laing (all ESO) and A. Veronig (Graz University), W. Alef (MPIfR, Bonn), A. Clegg (NSF), D. Boboltz (USNO) and A. Fey (USNO) is greatfully acknowledged. We thank E. Janssen, J. Howard and M. Martins (ESO) who provided new or updated figures for this edition. As in previous editions, we have corrected a number of errors in the text. Most of these were kindly provided by J. J. Condon (NRAO), A. Guzmann (Chile) and Biwei Jiang (Peking).

Web sites are a new mode of communicating recent results. However we have limited our references to these as much as possible since the addresses change often. A remark about nomenclature: in the index, we have (with some arbitrariness) ordered single radio telescopes under *antennas*, arrays of antennas with coupled outputs under *interferometers* and facilities such as Herschel and SOFIA under their names.

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Excerpts from the Prefaces of Previous Editions

This book describes the tools radio astronomers need to pursue their goals. These tools consist of: (1) descriptions of the properties and use of radio telescopes and various types of receivers needed to analyze cosmic radio signals, and (2) descriptions of radiation mechanisms responsible for broadband and spectral line radiation. This book developed from a one-year graduate course that was given repeatedly at the Ruhr-Universität at Bochum. We hope that this text will be useful for all who use results obtained from radio astronomy. Our aim is to help them to understand the origin of well known results particularly the underlying assumptions and this book may occasionally save some scientists working in the field of radio astronomy from long searches in the literature when questions concerning tools occur.

The students to whom this course was addressed have had a rather thorough background knowledge of physics. However, difficulties often arose when the instrumental tools were discussed. Clearly there is a difference between how such a subject is treated in general physics books and the way it is presented in texts intended for engineers. Our explanations are meant to use concepts familiar to astrophysicists and physicists.

For each chapter, a list of references is given. Usually this list has two parts: general references give a list of papers and books that cover the general aspects and which often give a more thorough treatment of the subjects covered, and special references document the sources for specific topics. However, these references do not give a complete review of the relevant literature. The papers cited are those that present the subject in a convenient way.

The basic concepts used in the first edition have remained unchanged. This book gives an outline of the methods and tools of radio astronomy. Results are given to illustrate aspects of the theories or to make the approach used plausible. The book is intended to be of help in applying radio astronomy, but it is *not* a description of the many results. This book is not intended to be a review of the entire field of radio astronomy in the literature but describes only the basic and undisputed concepts and results.

Another problem encountered when writing a textbook is that of consistent designations, symbols, and units. Since the astronomical community prefers their traditional mixed set of units, we use the *Gaussian CGS system*, augmented when

necessary with other units. Where needed, we give the relations in their respective units in the equations.

References to the current literature have been updated. We do not attempt to give a complete review and we chose those references that are the most recent or cover the subject most comprehensively.

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