Introduction to Astronomical Spectroscopy

Spectroscopy is the principal tool used in astronomy to investigate the Universe beyond Earth’s atmosphere. Through the analysis of electromagnetic radiation, spectrographs enable observers to assess the chemical composition, kinematics, and local physical properties of distant stars, nebulae, and galaxies. Thoroughly illustrated and clearly written, this handbook offers a practical and comprehensive guide to the different spectroscopic methods used in all branches of astronomy, at all wavelengths from radio to gamma-ray, and from ground and space-borne instruments. After a historical overview of the field, the central chapters navigate the various types of hardware used in spectroscopy. In-depth descriptions of modern techniques and their benefits and drawbacks help you choose the most promising observation strategy. The handbook finishes by assessing new technologies and future prospects for deep-sky observation. This text is an ideal reference for today’s graduate students and active researchers, as well as those designing or operating spectroscopic instruments.

IMMO APPENZELLER is Emeritus Professor of Astronomy at the University of Heidelberg, Germany, and Director of the Heidelberg State Observatory.
Cambridge Observing Handbooks for Research Astronomy

Today’s professional astronomers must be able to adapt to use telescopes and interpret data at all wavelengths. This series is designed to provide them with a collection of concise, self-contained handbooks, which covers the basic principles peculiar to observing in a particular spectra region, or to using a special technique or type of instrument. The books can be used as an introduction to the subject and as a handy reference for use at the telescope or in the office.

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Introduction to Astronomical Spectroscopy

IMMO APPENZELLER

Center for Astronomy
University of Heidelberg
## Contents

**Preface**  
page xi

### 1 Historical Remarks  
1. Early Pioneers  
2. The Photographic Era  
3. The Impact of Linear Detectors  
4. Extending the Wavelength Range  

### 2 Spectroscopy in Present-Day Astronomy  
1. Spectral Classification  
2. Radial Velocities  
3. Gravitational and Cosmological Redshifts  
4. Astrophysical Applications  
5. Magnetic Fields  
6. The Importance of Spectral Resolution  

### 3 Basic Physics of Spectral Measurements  
1. Electromagnetic Radiation  
2. Measuring Frequencies  
3. Measuring Wavelengths  
4. Accuracy Limits  

### 4 Optical-Range Grating and Prism Spectrometers  
1. Commercially Available Spectrometers  
2. Basic Components of Astronomical Spectrometers  
3. Slitless Spectroscopy  
4. Single-Object Slit Spectrometers  
5. Fiber-Coupled Instruments
4.6 Multiobject Spectrometers 110
4.7 Integral Field Spectroscopy 115
4.8 Cold IR Spectrometers 119

5 Other Techniques for the Optical Spectral Range 127
  5.1 Fabry-Perot Techniques 127
  5.2 Fourier Transform Spectrometers 134
  5.3 Direct Detection of Visual Photon Energies 138

6 Preparing and Reducing Optical Observations 145
  6.1 Planning and Preparing Observing Runs 145
  6.2 The Execution Phase 154
  6.3 Calibration Procedures 156
  6.4 Reduction of Raw Spectra 159
  6.5 Archiving Spectral Data 176

7 UV, X-Ray, and Gamma Spectroscopy 179
  7.1 UV and X-Ray Optics 180
  7.2 UV Spectrometers 187
  7.3 Photon-Energy Sensitive X-Ray Detectors 189
  7.4 X-Ray Grating Spectrometers 191
  7.5 Gamma Spectroscopy 194

8 Spectroscopy at Radio Wavelengths 200
  8.1 Detection of Radio Waves from Space 201
  8.2 Filter Banks 203
  8.3 Fast Fourier-Transform Spectrometers 204
  8.4 Autocorrelation Techniques 206
  8.5 Cross-Correlation Spectroscopy with Arrays 209
  8.6 Acousto-Optical Instruments 210
  8.7 Chirp-Transform Spectrometers 212

9 Special Techniques of the FIR and Submillimeter Range 214
  9.1 Spectroscopy with Bolometers 215
  9.2 Heterodyne Spectroscopy at FIR and Submillimeter Wavelengths 221

10 New Developments and Future Prospects 224
  10.1 Scientific Drivers 224
  10.2 New Facilities 225
### Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.3 New Technologies</td>
<td>231</td>
</tr>
<tr>
<td>10.4 Organizational Challenges</td>
<td>236</td>
</tr>
<tr>
<td>Appendix: List of Acronyms</td>
<td>239</td>
</tr>
<tr>
<td>References</td>
<td>245</td>
</tr>
<tr>
<td>Index</td>
<td>251</td>
</tr>
</tbody>
</table>
With the exception of a few objects that have been successfully identified as sources of highly energetic charged particles or of neutrinos, all our knowledge about the universe outside the inner solar system is based on the analysis of electromagnetic radiation. Some valuable information has been derived by measuring the flux, the time variations, or the polarization of astronomical radiation sources. By far the most important tool for investigating cosmic objects, however, has been the analysis of their energy distributions and of their line spectra. There are obvious reasons for this predominance of spectroscopic methods in modern astronomy. First, spectra contain a particularly large amount of physical information. If properly analyzed, spectra allow us to determine the chemical composition, local physical conditions, kinematics, and presence and strength of local physical fields. Second, apart from the cosmological redshift and the reduced observed total flux of faraway objects, spectra are independent of the distance, making spectroscopy a particularly valuable remote-sensing tool. Finally, there exists a well-developed theory of the formation of continua and line spectra.

The gathering of information on distant objects by means of spectral observations requires several steps. First, suitable instruments must be designed that allow us to measure the spectra of the faint astronomical sources. Then, these instruments must be employed to obtain spectra of optimal quality. Finally, the spectra must be analyzed and physical information on the observed objects must be extracted. In astronomy, the term spectroscopy is used for all these steps. Moreover, the theory of radiative transfer and line formation in stellar atmospheres is often included in the term astronomical spectroscopy. The content of this book is focused on the first two of these topics – that is, on the techniques and the practice of obtaining spectra of cosmic objects. Apart from space restrictions, there are several reasons for this emphasis on observational aspects. One obvious reason is the fact that this book belongs to a series
Preface

of observing handbooks. Moreover, whereas astronomers observing different types of objects often use the same or similar instrumentation, the methods used for analyzing the spectra usually depend on the nature of the radiation sources. Because modern astronomy comprises many different types of objects, including stars, black holes, interstellar gas and dust, galaxies, and a variety of nonthermal emitters, the methods for analyzing astronomical spectra are correspondingly diversified. It would be difficult to treat them adequately in a single volume. Finally, there already are excellent books describing the analysis of astronomical spectra of different types. Examples of these books are cited in the second chapter of this volume.

Astronomical spectroscopy started in the nineteenth century in the optical spectral range. It later spread to all wavelengths at which astronomical observations are possible. In the early days, the observers typically built their own instruments and were specialists for a single wavelength regime. Today, much of the cutting-edge science is done at large ground-based and space-based observatories that are accessible to large observer communities, and present-day observers typically carry out observations at many different wavelengths. Therefore, this book tries to include all wavelengths at which astronomical spectroscopy is possible at present. It aims at providing all information that a researcher needs to plan and to execute astronomical spectroscopic observations with existing instrumentation. It provides the level of technical detail that is required for selecting the techniques and methods that are best suited for a given task. By describing the present-day technical state of the art, along with the limitations of present instruments, the book can furthermore be a good introduction to the topic for scientists and engineers who aim at improving present methods and on developing future, superior instrumentation. Finally, the book will, hopefully, help the reader to better understand and appreciate the opportunities of the vast amount of spectroscopic data that are available in astronomical data archives.

As this series is written for research astronomers, it is expected that the reader has some basic knowledge of astronomy and of elementary physics. Moreover, it will be assumed that the reader is familiar with the special notations and definitions that are frequently used in astronomy. Some of these notations and definitions have been changing with time. This book normally follows the notations currently defined by the International Astronomical Union (IAU) and specified on the IAU Web sites. For historic reasons, some technical terms are used with a different meaning in the astronomical literature. In these cases, I adopted the meaning that is preferred by a majority of the professional astronomers in the current scientific literature. Finally, topics that have been
discussed in other volumes of this series of observing handbooks will not be
treated here in detail, but references will be given in all such cases.

Present-day science depends on cooperation and teamwork. This book is
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