EXTREME ULTRAVIOLET ASTRONOMY

The study of the universe in Extreme Ultraviolet (EUV) wavelengths is a relatively new branch of astronomy. Lying between the X-ray and UV bands, Extreme Ultraviolet has proved to be a valuable wavelength for the study of specific groups of astronomical objects, including white dwarf stars and stellar coronae, as well as the interstellar medium.

This text describes the development of astronomy in the EUV wavelength range, from the first rocket-based experiments in the late 1960s through to the latest satellite missions. Discussions of the results from the most important space projects are followed by an analysis of the contributions made by EUV astronomy to the study of specific groups of astronomical objects. Within this framework, the book provides detailed material on the tools of EUV astronomy, dealing with the instrumentation, observational techniques and modelling tools for the interpretation of data. Prospects for future EUV missions are discussed and a catalogue of known EUV sources is included.

This timely text will be of great value to graduate students and researchers. It is the first to give a complete overview of EUV astronomy, and comes at the end of a major phase of discovery in the field.

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EXTREME ULTRAVIOLET ASTRONOMY

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The authors dedicate this book to Dr C. Stewart Bowyer who, through a unique personal combination of foresight, tenacity and self-belief, has done more than anyone else to realise the field of Extreme Ultraviolet Astronomy.

We would also like to dedicate this work to our families, who have had to endure our absences for all the travel associated with our research together with late nights and lost weekends preparing scientific papers, proposals and reports.
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Preface

This book is the first comprehensive description of the development of the discipline of astronomy in the Extreme Ultraviolet (EUV) wavelength range (≈100–1000 Å), from its beginnings in the late 1960s through to the results of the latest satellite missions flown during the 1990s. It is particularly timely to publish this work now as the Extreme Ultraviolet Explorer, the last operational cosmic EUV observatory, was shut down in 2001 and re-entered the Earth's atmosphere in early 2002. Although new EUV telescopes are being designed, it will be several years before a new orbital observatory can come to fruition. Hence, for a while, progress beyond that reported in this book will be slow.

We intended this book to be for astrophysicists and space scientists wanting a general introduction to both the observational techniques and the scientific results from EUV astronomy. Consequently, our goal has been to collect together in a single volume material on the early history, the instrumentation and the detailed study of particular groups of astronomical objects. EUV observations of the Sun are not within the scope of this current work, since the Sun can be observed in far more detail than most sources of EUV emission, providing material for a book on its own. We have found it useful to deal with the subject in its historical context. Therefore, we do not have specific chapters on instrumentation but integrate such material into the development of the scientific results on a mission-by-mission basis. The overall framework can be divided into three main sections:

1. Early history of the subject leading up to the first orbital missions, which had an EUV capability but were not dedicated to EUV astronomy (chapters 1 and 2).
   
   The first dedicated EUV astronomy orbital telescopes and the sky surveys carried out by them to produce reference catalogues of EUV sources (chapters 3 and 4). We include an integrated catalogue of all EUV sources known at the time of publication in appendix A.

2. EUV spectroscopy techniques and study of specific groups of astronomical objects: stars, the interstellar medium, white dwarfs, cataclysmic variables and extragalactic sources (chapters 5 to 10).

Since we are very active in the field of EUV astronomy, it is inevitable that much of the material included here has been drawn from our own work. However, we have made a concerted attempt to represent all of the many astronomers who have made significant contributions. It has not been possible to include all the EUV astronomy results published, as this would constitute several volumes. Therefore, we have had to carefully select representative material, which we hope gives the overall flavour of work in each subtopic. We have tried to make the
Preface

bibliography extensive to compensate for these necessary omissions. As will be seen from
the book, we have obtained a large number of figures and tables from the many original
authors of scientific papers. It would be invidious to single out particular individuals from
this list: rather, we would like to collectively thank all who have contributed to the content
of this book. Specific acknowledgement of individual figures or tables can be found in the
captions. We have been extremely pleased by the positive support received from everyone
that we have asked for help. It is clear to us that this reflects the general friendly nature of
the EUV astronomy community, with shared interests and common goals. It has been a great
pleasure to work with you all over many years. Thanks to everyone for that.

There are a few individuals that deserve specific thanks. First, to Bob Stern who was
originally a co-author but was forced to drop out owing to other commitments. Nevertheless,
he played an important role in developing the proposal for the book. We hope you like the
result, Bob. Also a number of people have done some sterling work in helping to generate
figures or tables that we could not obtain directly from the original authors. These are: Reni
Christmas, Graham Wynn, Elizabeth Seward, Nigel Bannister, Jim Collins and David Sing.

Finally, we have made an attempt at prescience by looking at the possible future of EUV
astronomy in the final chapter (11) of our EUV Astronomy book. We hope it is a bright one
and that this book can be part of its foundation.

Martin Barstow and Jay Holberg
Abbreviations

ACS     attitude control system  
AGB     asymptotic giant branch  
AGN     active galactic nuclei  
ALEXIS  Array of Low Energy X-ray Imaging Sensors  
ALI     Accelerated Lambda Iteration  
ASCA    a Japanese X-ray astronomy satellite  
ASTP    Apollo–Soyuz Test Project  
BSC     Bright Source Catalogue  
CEM     channel electron multiplier  
CHIPS   Cosmic Hot Interstellar Plasma Spectrometer  
CMA     channel multiplier array  
CSM     Command and Service Module  
CSPN    central stars of planetary nebulae  
CV      cataclysmic variable  
DEC     astronomical position coordinate: declination  
DEM     differential emission measure  
DM      dispersion measure  
DS      deep survey  
DSS     deep survey/spectrometer  
ESA     European Space Agency  
EUV     Extreme Ultraviolet  
EUVE    Extreme Ultraviolet Explorer  
EUVI    Extreme Ultraviolet Imager  
EUVS    Extreme Ultraviolet Spectrograph  
EUVT    Extreme Ultraviolet Telescope  
EXOSAT  European X-ray Astronomy Satellite  
FIP     first ionisation potential  
FOS     Faint Object Spectrometer  
FOV     field of view  
FUSE    Far Ultraviolet Spectroscopic Explorer  
fwhm    full width half maximum  
GHRS    Goddard High Resolution Spectrometer  
HEAO    High Energy Astronomical Observatory  
HEW     half energy width
List of abbreviations

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<th>Abbreviation</th>
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<tbody>
<tr>
<td>HR</td>
<td>Hertzsprung–Russell</td>
</tr>
<tr>
<td>HRI</td>
<td>High Resolution Imager</td>
</tr>
<tr>
<td>HST</td>
<td>Hubble Space Telescope</td>
</tr>
<tr>
<td>HUT</td>
<td>Hopkins Ultraviolet Telescope</td>
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<tr>
<td>IAU</td>
<td>International Astronomical Union</td>
</tr>
<tr>
<td>IEH</td>
<td>International Extreme-ultraviolet Hitchhiker</td>
</tr>
<tr>
<td>IPC</td>
<td>imaging proportional counter</td>
</tr>
<tr>
<td>IRAS</td>
<td>Infrared Astronomical Satellite</td>
</tr>
<tr>
<td>ISM</td>
<td>interstellar medium</td>
</tr>
<tr>
<td>IUE</td>
<td>International Ultraviolet Explorer</td>
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<tr>
<td>J-PEX</td>
<td>Joint Plasmadynamic Experiment</td>
</tr>
<tr>
<td>LANL</td>
<td>Los Alamos National Laboratory</td>
</tr>
<tr>
<td>LE</td>
<td>low energy</td>
</tr>
<tr>
<td>LEIT</td>
<td>low energy imaging telescope</td>
</tr>
<tr>
<td>LETG</td>
<td>low energy transmission grating</td>
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<tr>
<td>LIC</td>
<td>local interstellar cloud</td>
</tr>
<tr>
<td>LISM</td>
<td>local interstellar medium</td>
</tr>
<tr>
<td>LLNL</td>
<td>Lawrence Livermore National Laboratory</td>
</tr>
<tr>
<td>LTE</td>
<td>local thermodynamic equilibrium</td>
</tr>
<tr>
<td>LW</td>
<td>long wavelength</td>
</tr>
<tr>
<td>LWR</td>
<td>Long Wavelength Redundant camera on IUE</td>
</tr>
<tr>
<td>MAD</td>
<td>metal abundance deficiency</td>
</tr>
<tr>
<td>MAMA</td>
<td>multi-anode microchannel array</td>
</tr>
<tr>
<td>MCP</td>
<td>microchannel plate</td>
</tr>
<tr>
<td>MIT</td>
<td>Massachusetts Institute of Technology</td>
</tr>
<tr>
<td>MJD</td>
<td>Modified Julian Date</td>
</tr>
<tr>
<td>MPE</td>
<td>Max-Planck Institut für Extraterrestriche Physik</td>
</tr>
<tr>
<td>MSSL</td>
<td>Mullard Space Science Laboratory</td>
</tr>
<tr>
<td>MW</td>
<td>medium wavelength</td>
</tr>
<tr>
<td>NEWSIPS</td>
<td>The new version of IUESIPS, the original processing of IUE data</td>
</tr>
<tr>
<td>NRL</td>
<td>Naval Research Laboratory</td>
</tr>
<tr>
<td>ODF</td>
<td>Opacity Distribution Function</td>
</tr>
<tr>
<td>OGS</td>
<td>objective grating spectrometer</td>
</tr>
<tr>
<td>ORFEUS</td>
<td>Orbiting Retrievable Far and Extreme Ultraviolet Spectrometers</td>
</tr>
<tr>
<td>OSO</td>
<td>Orbital Solar Observatory</td>
</tr>
<tr>
<td>PG</td>
<td>Palomar Green</td>
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<tr>
<td>PMS</td>
<td>pre-main sequence</td>
</tr>
<tr>
<td>PSC</td>
<td>position sensitive proportional counter</td>
</tr>
<tr>
<td>RA</td>
<td>astronomical position coordinate: right ascension</td>
</tr>
<tr>
<td>RAP</td>
<td>Right Angle Program</td>
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<tr>
<td>RE</td>
<td>ROSAT EUVE</td>
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<tr>
<td>ROSAT</td>
<td>Roentgen Satellit</td>
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<tr>
<td>RXTE</td>
<td>Rossi X-ray Timing Explorer</td>
</tr>
<tr>
<td>SAA</td>
<td>South Atlantic Anomaly</td>
</tr>
<tr>
<td>SIC</td>
<td>surrounding interstellar cloud</td>
</tr>
<tr>
<td>SIMBAD</td>
<td>a database operated by the Centre de Donnes astronomiques de Strasbourg</td>
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# List of abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>SM</td>
<td>Service Module</td>
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<tr>
<td>SPIE</td>
<td>Society for Photoinstrumentation Engineers</td>
</tr>
<tr>
<td>SSS</td>
<td>Solid State Spectrometer</td>
</tr>
<tr>
<td>STIS</td>
<td>Space Telescope Imaging Spectrograph</td>
</tr>
<tr>
<td>SW</td>
<td>short wavelength</td>
</tr>
<tr>
<td>SWP</td>
<td>Short Wavelength Prime camera on IUE</td>
</tr>
<tr>
<td>TGS</td>
<td>transmission grating spectrometer</td>
</tr>
<tr>
<td>UNEX</td>
<td>University-Class Explorer</td>
</tr>
<tr>
<td>UVS</td>
<td>ultraviolet spectrometer</td>
</tr>
<tr>
<td>UVSTAR</td>
<td>Ultra Violet Spectrograph Telescope for Astronomical Research</td>
</tr>
<tr>
<td>VHF</td>
<td>very high frequency</td>
</tr>
<tr>
<td>WFC</td>
<td>Wide Field Camera</td>
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<tr>
<td>WIRR</td>
<td>Wind-accreditation Induced Rapid Rotators</td>
</tr>
<tr>
<td>WS anode</td>
<td>wedge-and-strip anode</td>
</tr>
<tr>
<td>WSMR</td>
<td>White Sands Missile Range</td>
</tr>
<tr>
<td>XMA</td>
<td>X-ray mirror assembly</td>
</tr>
<tr>
<td>XRT</td>
<td>X-ray telescope</td>
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</tbody>
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