Handbook of CCD Astronomy, Second edition.

Charge-coupled devices (CCDs) are the state-of-the-art detectors in many fields of observational science. Updated to include all of the latest developments in CCDs, this second edition of the *Handbook of CCD Astronomy* is a concise and accessible reference on all practical aspects of using CCDs. Starting with their electronic workings, it discusses their basic characteristics and then gives methods and examples of how to determine these values.

While the book focuses on the use of CCDs in professional observational astronomy, advanced amateur astronomers and researchers in physics, chemistry, medical imaging, and remote sensing will also find it very valuable. Tables of useful and hard-to-find data, key practical equations, and new exercises round off the book and ensure that it provides an ideal introduction to the practical use of CCDs for graduate students, and a handy reference for more experienced users.

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Handbook of CCD Astronomy

Second edition

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Contents

Preface to the first edition

We are all aware of the amazing astronomical images produced with telescopes these days, particularly those displayed as color representations and shown off on websites and in magazines. For those of us who are observers, we deal with our own amazing images produced during each observing run. Just as spectacular are photometric, astrometric, and spectroscopic results generally receiving less fanfare but often of more astrophysical interest. What all of these results have in common is the fact that behind every good optical image lies a good charge-coupled device.

Charge-coupled devices, or CCDs as we know them, are involved in many aspects of everyday life. Examples include video cameras for home use and those set up to automatically trap speeders on British highways, hospital X-ray imagers and high-speed oscilloscopes, and digital cameras used as quality control monitors. This book discusses these remarkable semiconductor devices and their many applications in modern day astronomy.

Written as an introduction to CCDs for observers using professional or off-the-shelf CCD cameras as well as a reference guide, this volume is aimed at students, novice users, and all the rest of us who wish to learn more of the details of how a CCD operates. Topics include the various types of CCD; the process of data taking and reduction; photometric, astrometric, and spectroscopic methods; and CCD applications outside of the optical bandpass. The level of presentation was aimed not only at college or professional level readers but also at a more general audience including the ever-growing number of highly trained and motivated amateurs and other professionals in technical areas in which CCDs play a role.

Chapters 2 and 3 contain all the fundamental information on CCD operation and characteristics while each remaining chapter can be mastered individually. In a book of this length, many aspects must be treated briefly. However, I have made an effort to provide self-contained detail of the important aspects

of CCDs while including numerous references to the detailed professional literature for those desiring a deeper understanding. Additionally, throughout the book, examples related to common observational occurrences as well as footnotes discussing interesting but not mainstream topics are included. Appendices list other reference works of interest, CCD manufacturers, numerous website addresses of interest, and a brief introduction to image displays.

This book started with an idea for a new series of handbooks, including a volume on CCDs. I am happy to thank the editor, Adam Black, and Peter Stetson for allowing me to be involved in this series and write this book. The folks at Cambridge University Press, particularly Adam, have been very helpful, dealing with my many questions during the writing process. Michie Shaw and the staff at TechBooks have helped greatly in the final steps of production. I would like to thank the anonymous readers of an early draft of this book for their comments and for pointing out some important areas and results I had overlooked. Two readers, Peter Stetson and John Huchra, suggested coverage of material that has led to the inclusion of additional topics in the final version. A number of colleagues have provided information, graphs, references, and support during the writing of this book, all of which I appreciate. I thank my former and current students and postdocs for keeping me on my toes regarding many of the topics herein. Chris Sabbey kindly provided Figure 6.8, and the color figures in the book (Figs. 1.1 and 4.6) were taken by Simon Tulloch and provided by Derek Ives, both of the UK Astronomy Technology Centre.

I would like to acknowledge and thank my parents, Cecil and Barbara, for allowing me to be "scientific" during my childhood. My experimentation, often at the expense of household items, was not always successful but was never discouraged. These experiences deeply planted the seed of scientific fascination in my being. Appreciation is also passed along to my brother Terry, for the many hours we spent together exploring the world around us. Particularly noteworthy were the times we spent watching, analyzing, and laughing at "B" sci-fi movies.

During the writing of this volume on CCDs, many opportunities were missed related to spending time with my son Graham and my wife and friend Mary. Both were always supportive of the effort, encouraged its completion, and have accumulated many IOUs, which I will now have the pleasure of paying off. I appreciate their unfailing love.

I have had fun writing this book and learning even more about CCDs, almost as much fun as I have when I observe with them. I hope that you the reader will find this work of interest as well and enjoy paging through it often. Astronomy has always fascinated humans and if this treatise allows

you to obtain a better knowledge of CCDs and with it even more fascination with the Universe around us, it will have been a success.

"Since The Beginning Of Time, The Universe Has Called To Awaken Each Of Us. To Understand The Universe Is To Understand Ourselves."

Preface to the second edition

Seven years ago, Cambridge University Press began a new series of books called Handbooks. I was fortunate enough to be asked to author the one on CCDs. Little did I realize how wonderful of an undertaking that writing this book would be. I have learned and relearned a number of details about CCDs and had cause to read many scientific and popular papers and articles I otherwise would have overlooked. The greatest benefit, however, has been the many gracious colleagues and students who have provided comments, revisions, suggestions, support, and simply said thanks. The first edition of the *Handbook of CCD Astronomy* was written for you and you have truly made it your own through this volume.

When I was first asked to write a second edition, I have to admit I was skeptical that enough had changed to warrant it. I am happy to say I was completely wrong. Upon going back and reading the original volume, I had no problem seeing its many pages of outdated material. There are, however, some fundamental discussions and properties of CCDs that are timeless, and remain in the present volume. New areas of CCD development abound and to highlight a few this second edition is a bit longer and has a few more illustrations. The areas of faster and higher performance electronics to control and read out a CCD, better analog-to-digital circuitry, and better manufactured CCDs are some of the additions discussed within. The largest advance since the first edition is the continued development of new types of CCD. In the first edition, it was remarked that since CCDs have quantum efficiencies of nearly 80% or more, increases in this area will have little impact in overall performance. Today's CCD makers are providing surprising additional advances such as output registers with gain stages to amplify weak signals *in situ*, or the ability to manipulate the shape and location of the collected change during an exposure. These "wafer level" design changes, output speed and

reliability, and a new generation of instruments and telescopes has provided a renaissance in CCD astronomy.

I would like to thank the many students of astronomy for their kind acceptance of this volume and the equally kind words of support they have provided. Abhishek Rawat and Joe Harrington found a few typos and provided specific comments leading to some clarifications in presentation. Three anonymous reviewers examined the first edition and my suggestions for changes, additions, and deletions to it. They provided sound guidance for the present volume. At Cambridge University Press, Simon Mitton has been a constant supporter and his experience and kind words have helped this project reach completion. Jacqueline Garget has kindly answered many questions and orchestrated the process for the second edition with alacrity. Vince Higgs and Tom Dolan have dealt with the detailed day-to-day issues of illustrations and page limits. I also wish to thank Wendy Phillips and my copy editor Karen Sawyer for their hard work and many explanatory emails. John Feldmeier and Jill Gerke were a great help in proofing the book and Elain Owens, once again, helped me produce the index. I thank them all for their continued kindness.

While writing the predecessor to the current book, my son Graham was a teenager just beginning to drive cars and still a boy in many ways. Now, a few cars later, he is a grown man and has a life of his own but still teaches me many things about how to live a good life and be a whole person. I am writing this preface on the eve of his birthday. My wife Mary is a constant inspiration to me as she always seems to know how to "do the life thing" much to my chagrin and amazement. She still shares her "Mary money" with me. Thanking my family, both direct relatives and those who have adopted me, can not express my full appreciation to them. They have supported me during this undertaking as well as in everyday life.

I hope you, the reader, will view this book as a starting point for your exploration and relationship with CCDs and astronomical detectors of all sorts. I encourage you to try them out in person as often as you can and pursue their use particularly in ways no one else has thought of. This is how astronomy and science advances and you are the future, our future. Enjoy.