Astronomy: Principles and Practice

Second Edition

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**To our students
who have learned almost as much from us
as we have from them**

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Foreword to the Second Edition

Very little need be added to the foreword of the First Edition. Astronomy has continued to develop in fruitful and exciting ways both in its more traditional branches and in space research. There is a need more than ever for a comprehensive and systematic treatment of astronomy from first principles for those students who want to obtain a thorough grounding in physical and mathematical topics so often omitted from other text books. Because of this, because of the gratifying reception of the First Edition of this book and also because our further teaching experience has not fundamentally changed our opinions regarding what the contents of a textbook on the principles and practice of astronomy should be, we have confined ourselves largely to correcting a number of errors, removing some defects and improving some presentations. In the worked examples we have retained the logarithmic displays of reduction since even now there are many places in the world where pocket calculators are still not available. To help those people who use calculators, however, we have expanded on the 'Number' column inserting additional steps.

Archie E Roy
David Clarke

Foreword to First Edition

The present text has grown out of university and extra-mural courses in astronomy given by both authors over a number of years. In particular, much of the material here is presented in lectures and practical work given in the first-year course in the Department of Astronomy at Glasgow University. At this stage of their degree course, most of the students study a range of science disciplines in order to obtain a broad base of general science before taking more specialised courses in later years.

The course at Glasgow also attracts some arts students who wish to gain some knowledge of the workings of science and the scientific method. We feel that astronomy is perhaps the best discipline within science for doing this. Many of the major break-throughs in the subject (for example, the understanding of the nature of stellar spectral lines) can best be appreciated by putting them into their historical perspective. They allow an inspection of how our knowledge of a subject develops—facts may stare us in the face but until the right person comes along at the right time to take perhaps just one new simple step, making all the facts fall into a series of connected relationships, they remain just a confusing jumble.

This book in conjunction with a companion volume—*Astronomy: The Structure of the Universe*—has therefore been written to fulfil the need of a *preliminary science course* or a *liberal arts course* at the first year university level. Indeed those polytechnics that now provide courses in astronomy may find the present text suitable. We also hope that the serious amateur astronomer will find helpful discussions of topics in which he is interested.

The contents of this volume prepare the student for the presentation to be found in the companion volume of the facts about the Universe and their interpretation. In a sense this book presents the basic software and hardware of the subject, so providing some of the simple mathematical tools and discussing some of the simple physical processes which are either involved in the astronomer's tools of trade or concerned in the mechanisms associated with astronomical bodies.

Our experience has shown that where a serious attempt is to be made to teach the basic principles of astronomical methods by which our present knowledge of the Universe has grown, the student must be prepared to step beyond the easy "Oh-the-wonder-of-it-all" reading of purely descriptive matter and to come to grips with the methods in current use.

The best way of doing this and appreciating the techniques and the difficulties involved is to observe, to measure, to apply formulae, to solve problems. For these purposes, a certain level of mathematics is included though its use is not, we feel, to excess. The basic mathematical structure is kept to a level suitable for a first-year student with a

knowledge of high school mathematics and physics. Indeed the intelligent student without such a mathematical background will find it possible to read around the mathematical sections and still gain a measure of understanding.

The book has been divided into four parts. Briefly these perform the following functions:

Part 1: Sets the scene.
Part 2: Provides the software—the ideas and mathematics of positional and dynamical astronomy.
Part 3: Describes the hardware—the physics of radiation and the astronomer's tools.
Part 4: Provides exercises and practical work.

Problems are also given in the relevant places to test thoroughly the student's appreciation of the principles involved. Many of the problems are worked out in detail in the text as examples; all the problems have answers provided. Although logarithms have been used throughout the tabulated examples, the authors appreciate that many students now possess pocket calculators; because these machines use different languages, the authors believe it best to leave the modification of the examples to the students.

Most of the problems are original to the authors; these and others presented have appeared in examinations set in the past by the Department of Astronomy of Glasgow University.

Exercises suitable for laboratory or outdoor work are also provided in Part 4 and indeed have been developed and tested in recent years in the laboratories of the Department of Astronomy, Glasgow University. A guide is given to practical laboratory and observational work which can be carried out according to the availability of apparatus.

With respect to references, a small, carefully selected list of books is included but no papers from research journals are listed since our experience suggests that a first-year student has not yet developed either the ability to profit by reading in great detail or the necessary critical power. The references given seem to us to enlarge usefully on particular topics.

The book contains more material than would normally fill a first-year course, allowing teachers to select portions well-adapted to their particular needs and resources.

No attempt has been made in the book to discuss every aspect of astronomy. With a subject which includes so great a diversity of method, and range in condition of and assembly of matter, this must be left to the canopy of an astronomical dictionary or encyclopedia. Thus we hope that the professional astronomer will excuse us if his particular pet theme has been excluded or if we appear to have oversimplified any treatment which perhaps deserves better and deeper attention. We have tried wherever possible to treat the included topics of the subject at the same level. The authors have been very conscious of the difficulty in treating the subject systematically. It has been found that some overlap of material has been inevitable; for instance some seeming repetition results where the nature of the observed source is described and elsewhere the technology of observation makes reference to the same source.

It will be appreciated that with recent spectacular advances in space research, as well as in the more traditional branches of astronomy, much new knowledge has accumulated; we have made a particular effort to

include this so that the text is as up-to-date as possible without adding material which may have only transient value.

Where new concepts are defined or introduced for the first time they are given a bold typeface. Figures and equations are given the number of the chapter in which they appear, followed by a number denoting their order in that chapter.

Astronomers use various systems of units, depending upon the astronomical topic under discussion. Without being slaves to pedantry, we have tried wherever possible to keep to a consistent set of units (SI) and symbols and to adopt those preferred by the *International Astronomical Union.* In an Appendix, a useful set of constants and conversion factors has been included.

Astronomy has long been called the Queen of the Sciences because of the fascination and influence it has exerted on the minds of men. If this book, together with its companion volume—*Astronomy: The Structure of the Universe*—manages to engender some degree of that fascination as well as to provide the main facts of the subject, the authors will be well content.

Acknowledgements

Teaching is a constant process of reiteration and regeneration. The response that a teacher has from his students provides a form of feedback, effecting an improvement in the content and method of presentation of succeeding courses. Without this intelligent response from students, courses would remain dull and static. Our first acknowledgement must be to our former students who have helped in giving shape to the contents of this book.

The presentation of many of the topics in the book has undoubtedly benefited from innumerable discussions with past and present members of the staff of the Department of Astronomy, Glasgow University. In particular we would like to thank Professor Peter A Sweet not only for helpful advice but also for providing some source material.

We would like to acknowledge and thank the Oxford University Press and Professor A Thom for permission to include in our text Figure 7.17 redrawn from Figure 12.2 of his work, *Megalithic Sites in Britain*, and the Senate of Glasgow University for permission to use a number of examination problems set by the Department of Astronomy.

The authors also acknowledge with sincere gratitude their debt to Mrs Margaret I Morris, MA, FRAS, of the Department of Astronomy, Glasgow University; not only did she type the first draft of the manuscript but she also read it critically, suggesting a large number of improvements in the mode of presentation that the authors have been happy to incorporate. Our thanks are also due to Mrs L Williamson, of the same Department for much additional typing.

Inevitably, however, some errors of fact and misprints will remain and the authors would be glad to hear of them.

Second edition. We are sincerely grateful to those who have taken the trouble to notify us about some errors which have now been corrected.

Archie E Roy
David Clarke

Contents

Part 1
Introduction

Chapters 1–5

PROGRAMME: This first part presents the simple observations which can be made by eye and discusses how such observations were interpreted by previous civilizations. It describes the nature of the observables by which we gain knowledge of the Universe and comments on the role the astronomer has to play. The effects of the Earth's atmosphere on such observations are described. Comment is made on how the present scientific age has advanced the range of astronomical instruments. The concepts and terms related to the basic measurements of position in the sky, brightness and time are introduced.

1
Naked Eye Observations

1.1 Introduction

The etymology of the word "Astronomy" implies that it was the discipline involved in "the arranging of the stars". Today, we might say that astronomy is man's attempt to study and understand celestial phenomena, part of his never-ending urge to discover order in nature. We do not know who were the first astronomers; what we do know is that the science of astronomy was well advanced in parts of Europe by the middle of the third millennium B.C. and that the Chinese people had astronomical schools as early as 2000 B.C. In all ages, from the first burgeoning of man's intelligence, there have been people fascinated by the heavens and their changing aspect, and these people, as far as their cultural environment has allowed them, have tried to formulate cosmologies. We are no different today.

If our theories of the Universe are nearer the truth, it is probably not that man's intelligence has increased in the past six millenia. It is more likely that the main factor has been the discovery and development of the scientific method, which has led to our present civilization based on the flood of technological advantages provided by this method. This has enabled men in far greater numbers than ever before to devote their lives to the study of the heavens, assisted by telescopes, computers, space vehicles and a multitude of other equipment. Their attempts to interpret and understand the wealth of new information provided by these instruments have been aided by allied sciences such as physics, chemistry, geology, mathematics and so on.

We must remember, however, that for more than nine-tenths of the last five thousand years of man's study of the heavens, he had to rely on his unaided eyes. The Mediterranean people who set the constellations in the sky, the Babylonians, Egyptians and Greeks, the Arabian astronomers who flourished during the Dark Ages of Post-Roman Europe, the Chinese, the Mayan and other early American astronomers, all built their theories of the Universe on naked eye observations. And so we begin by following in their footsteps and seeing what they saw as they observed for a few minutes (see Section 1.2), a few hours (see Section 1.3), for a month (see Section 1.4), or for at least a year (see Section 1.5). In this way we will find it easier to understand why their cosmological theories were formulated in their particular ways.

1.2 Instantaneous Phenomena

1.2.1 Day During the day a variety of phenomena may be seen. In a particular direction lies the Sun, so bright it is impossible to look directly at it. In general the sky background is blue. The Moon may also be visible, having a distinct shape, though certainly not circular. If the Sun has just set, or if dawn is not far away, there is sufficient daylight to see clearly; we call this condition **twilight**.

On the horizon opposite to the twilight glow, a dark purple band is sometimes seen. This area corresponds to a zone on the sky which is cut off from the direct sunlight by the Earth and is receiving very little light by scattering from the atoms and molecules in the atmosphere; it corresponds, in fact, to the shadow of the Earth in the sky. Its presence tells of the extreme purity and low humidity of the local atmosphere. Needless to say, it is very rarely seen in Britain.

To the ancients, clouds, wind, rain, hail and other atmospheric phenomena were inadequately distinguished from what we term celestial events. Our civilization includes them in **meteorology**, a science quite distinct from astronomy, so that we need not consider them further, except to remark that astronomers' observations have until recently been dependent entirely upon good weather conditions being available. With the development of radio telescopes and the fact that other equipment can be placed in artificial satellites and operated above the Earth's atmosphere, this dependence is no longer complete.

1.2.2 Night If seeing conditions are favourable, a view of the night sky provides a far wider variety of celestial phenomena. If the Moon is visible, its brightness will dominate that of all other objects. Its shape will be crescent or gibbous or even circular. At the last condition its apparent diameter is very close to that of the Sun. To anyone with reasonable eyesight, its surface will not be evenly brilliant; areas darker than their surroundings will be noticed, so that the fancy of primitive man could see a Man in the Moon, or a Beautiful Lady, or a Rabbit, sketched out by these features.

In addition to the Moon, some two to three thousand tiny, twinkling points of light—the stars—are seen, ranging in brightness from ones easily visible just after sunset to ones just visible when the Moon is below the horizon and the sky background is darkest. Careful comparison of one bright star with another shows that stars have different colours; for example, in the constellation of *Orion*, *Betelgeuse* is red in contrast to the blue of *Rigel*. The apparent distribution of the stars across the vault of heaven seems random.

A faint band of light, the Milky Way, catches the observer's attention as his eyes become accustomed to the darkness. Modern astronomers, with the aid of their telescopes, know that this luminous region stretching from horizon to horizon across the sky in a great circle is made up of a myriad of stars too faint to be resolved with the naked eye. To the ancient observer, its presence inspired all kinds of speculations, none of them verifiable.

One or two of the tiny points of light visible may draw a closer scrutiny. They shine steadily, in contrast to the twinkling of the stars, and they are among the brightest of the star-like objects. There must be some reason why they are different. If our observer is going to watch for a few hours, he will find his attention coming back to them.

1.3 A Few Hours

1.3.1 Day The heavens are never static. The slowly-moving shadow cast by an upright rod or a boulder or tree reveals the Sun's movement across the sky. If observation is kept up throughout the day, the Sun is seen to rise above the eastern horizon, climb up the sky in a circle inclined at some angle to the plane defined by the horizon, and **culminate**, that is, reach a maximum altitude above the line joining the north to the south points, then descend in a mirror image of its forenoon path to set on the western horizon. If the Moon is seen during that day, it will appear to imitate the Sun's behaviour in rising and setting.

1.3.2 Night As darkness falls, the first stars become visible above the eastern horizon. With the ending of twilight the fainter stars can be seen, and, as the hours pass, the stellar groups rise from the eastern horizon, reach their maximum altitude like the Sun, then set or become dim and invisible as daylight returns. The impression of being on a flat plane surmounted by a dark revolving bowl to which the stars are attached is strong, especially when it is seen that