The Patrick Moore Practical Astronomy Series

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The Patrick Moore Practical Astronomy Series is a treasure trove of how-to guides for the amateur astronomer. The books in this series are written for hobbyists at all levels, from the enthusiastic newcomer to the veteran observer. They thus go far beyond more general, popular-level books in both scope and depth, exploring in detail the latest trends, techniques, and equipment being used by amateur astronomers around the world.

You will find herein a diverse list of books on constellations, astronomy catalogues, astrophotography, eclipse chasing, telescope equipment, software, and so much more. All books in the series boast full-color images as well as practical sections for putting your newfound knowledge to use, including star charts and target objects, glossaries, hands-on DIY projects, troubleshooting walk-throughs, and a plethora of other helpful features.

Overall, this series bridges the gap between the many introductory books available and more specialized technical publications, providing digestible, hands-on guides for those wishing to expand their knowledge of the night skies.

Astrophysics Is Easy!

An Introduction for the Amateur Astronomer

Michael Inglis

Third Edition

Springer

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Dedicated to the memory of my great friends.

Michael Alan Mercer 1954–2020

Nigel Brian Pointer 1955–2020

Iain Nicolson 1945–2020

Donald Tinkler 1947–2022

And to my wonderful mother

Myra Doreen Inglis 1924–2021

Preface

When Springer asked me to consider a third edition of the book, I was delighted. It would allow me to correct any errors, expand certain chapters, and even add new chapters. Furthermore, as well as updating the book with the latest research results, I could add something I had been thinking about for quite some time—Thought Questions—embedded in the main text. These simple questions have no mathematics content, but rather are a way of testing yourself about the many disparate aspects of astrophysics.

In addition, at the end of the chapters are a few simple mathematically based questions that one could attempt. Note that all the answers to the questions and problems are provided at the end of the book. Finally, for the first time, I have included a few photos in the book. These are just to illustrate some of the objects under discussion. They were taken by amateur astronomers with simple equipment from suburban locations. There are many books that have far more photos, as well as the internet where there are literally thousands, but that was not the purpose of the book.

So, once again, I took paper to pen for this third edition, and began a journey to explain the mysterious, beautiful, and sometimes astounding complexities of stars, galaxies, the material that lies between, and the universe itself. It was a journey that took many roads with numerous side turnings as I often spent many long, lonely hours worrying whether I was being too obtuse, or at times patronizing, as it is a fact that many amateur astronomers are very knowledgeable of the subject that they pursue with a passion. However, the new edition eventually came into sight, and this, for me a mammoth task, was completed.

Throughout the entire process of writing the third edition, I was fortunate enough to have the support of the Hannah Kauffman, astronomy editor at Springer Publishing, who knows only too well that astronomy authors are a breed apart and need to be pampered and dealt with using extreme patience. Thank you, Hannah, dinner is on me! I must also thank my great friend John Watson, also associated with Springer, who gave the initial thumbs up when I first outlined expanding the original book with a third edition. John is an amateur astronomer himself, so he knows exactly what should go into a book, and perhaps even more importantly, what should be left out! John, I owe you a pint. I would also like to thank Janny Jonkers, a wonderful friend from the Netherlands, who took on the onerous task of proofreading the entire text.

I was fortunate to have been taught astronomy by some of the world's leading experts, and it was, and still is, a privilege to have known them. In my humble opinion, not only are they superb astronomers, whether theoretical or observational, but also wonderful educators. They are Chris Kitchin, Alan McCall, the late, great Iain Nicolson, Robert Forrest, and the late Lou Marsh. They were the best teachers I ever had.

It is important to acknowledge the pioneering work that is being done in amateur astronomical spectroscopy, and to that end I would like to thank the following spectroscopists for allowing me to use their work in the book. They are Tom Field, for designing a simple and affordable but superb piece of spectroscopic equipment, and for spearheading the revolution, along with Hansen Torsen, Ken Wright, William Wiethoff, and David Strange.

During the time spent writing both the first, second, and third editions, usually alone, usually at night, usually tired, I had the company of some wonderful musicians whose music is truly sublime. They are Steve Roach, David Sylvian, John Martyn, and the Blue Nile. And let's not forget the input of Arfur the Cat, who spent a lot of time lying on the keyboard as I was trying to type.

Many friends have helped raise my spirits during those times when not all was going right, according to the Inglis Master Plan. They listened to me complain, laughed at my jokes, and helped me remain sane—for the most part. So, I want to say thank you to my great friends—Professor Peter Harris and Dr. William Worthington. It is nice to know that beer is the universal lubricant of friendship, whether it is McMullen's or Harvey's.

Astronomy is a very important part of my life, but not as important as my family; my brother Bob is a great friend and a strong source of support, especially during the formative years as a young astronomer. My mother Myra was amazing, full of energy, spirit, and laughter, and had been

supportive of my dream to be an astronomer since I was knee-high to a tripod. She was truly an example to us all. And of course, Karen, I am not exaggerating when I say this book would not have originally seen the light of day without her help. "*Diolch Cariad.*"

For making my life worthwhile and fun, cheers!

Long Island, NY, USA Michael Inglis

Rationale for the Book

To most normal people, astrophysics—the science of stars, galaxies, and the universe we live in—would seem to be a topic suited to a university-level textbook, and so the idea of a guide to astrophysics for the amateur astronomer may not, on first appearance, make any sense. However, let me assure you that anyone can understand how a star is born, lives its life, and dies, how galaxies are thought to evolve and what their shape can tell us about their origins and age, and even how the universe began and how it may end. It can even tell you how and why the planets move. In fact, very little mathematics is needed, and when it is used, it is only a matter of multiplication, division, subtraction, and addition[1]!

What's more, there are many wonderful objects that can be observed in the night sky that will illustrate even the most obtuse astrophysics concepts. All one needs is a willingness to learn and a dark night sky.

Learning about, say, the processes that give rise to star formation, or what happens to a very large star as it dies, what keeps the Moon orbiting Earth, or even why some galaxies are spiral in shape whereas others are elliptical can add another level of enjoyment and wonder to an observing session. For instance, many amateur astronomers are familiar with the star Rigel, in the constellation Orion, but how many of you know that it is a giant star, with a mass more than 40 times that of our Sun, and it is nearly half a million times more luminous than the Sun! Or that our closest large galaxy, M31 in

[1] OK, we do use powers of ten occasionally, and numbers multiplied by themselves from time to time. But nothing else … honest!

Andromeda, has a supermassive black hole lurking at its center with a mass of over 50 million times that of the Sun. Or that the Orion Nebula, regarded by many as the premier nebula in the sky, is in fact an enormous stellar nursery where stars are being born as you read this book. Knowing details such as these can add another level of enjoyment to your observing sessions.

Each section of this book addresses a specific aspect of astrophysics. The first part focuses on the concepts needed for a complete understanding of the remainder of the book, and as such will be divided into specific topics, such as the brightness, color, and distance of stars. Then we look at what is probably the most basic, yet important, tool of an astronomer, namely spectroscopy. It is true to say that nearly all of what we know about stars and galaxies was and is determined from this important technique, and there has been a revolution in amateur astronomical spectroscopy in the past few years.

We then spend a fair amount of time looking at something called the Hertszprung-Russell diagram; if ever a single concept or diagram could epitomize a star's life (and even a star cluster's life), the HR diagram, as it is known, is the one to do it. It is perhaps the most important and useful concept in all of stellar evolution, and it is fair to say that once you understand the HR diagram, you understand how a star evolves.

Moving on to the objects themselves, we then cover a topic that many may think strange to find in a book devoted to astrophysics, namely the Solar System. But as you will see, there is a surpassingly large amount of what could be described of as introductory astrophysics when discussing certain aspects of our Solar System, especially the dynamics of the planets (and indeed asteroids and comets). A small amount of history will also be covered dealing with the main antagonists in the story and how their ideas led, more or less, to the picture we have today of our Solar System.

Following this chapter, we look at the formation of stars from dust and gas clouds and conclude with the final aspect of a star's life, which can end in the spectacular event known as a supernova, resulting in the formation of a neutron star and even perhaps a black hole!

Such is the interest in Black Holes that they have a chapter all to themselves. But before this we diverge slightly to a short discussion on Einstein's Theories of Relativity.

Another chapter is the inclusion of a topic that only 15 years ago was a fledgling, and somewhat obscure field of study, but is now at the forefront of discovery, namely the detection of exoplanets[2]!

[2] As well as exomoons, exocomets, and exoasteroids!

On a grander scale, we delve into galaxies, their shapes (or morphology, as it is called), distribution in space, and origins.

We follow this with a chapter dealing with those galaxies that seem to have a lot more going on within them than one usually sees, or expects—active galaxies and their nuclei, or AGN as they are more properly referred to.

Our penultimate chapter discusses maybe the biggest subject of all—cosmology. Not a topic that is often discussed from an amateur astronomy point of view, but even here, there are a few surprising aspects that can be observed, including one deceptively simple, yet stunningly deep, question that can be asked at star parties, along with its surprising answer!

Finally, and new to this edition, is a chapter on those very esoteric parts of astrophysics that seem more fantasy than fact but are nevertheless discussed by many astrophysicists.

The topics covered are chosen specifically so that examples of objects under discussion can be observed; thus, at every point in our journey, an observing section will describe the objects that best demonstrate the topics discussed. Many of the objects, whether they are stars, nebulae, or galaxies, will be visible with modest optical instruments, and many with the naked eye. In a few exceptional cases, a medium-aperture telescope may be needed. Of course, not all observable objects will be presented, but just a representative few (usually the brightest examples). These examples will allow you to learn about stars, nebulae, and galaxies at your own pace, and they will provide a detailed panorama of the amazing objects that most of us observe on a clear night.

For those of you who have a mathematical mind, some mathematics will be provided in the specially labeled areas. But take heart and fear not—you do not have to understand any mathematics to be able to read and understand this book; it is only there to highlight and further describe the mechanisms and principles of astrophysics. However, if you are comfortable with the mathematics, then I recommend that you read these sections, as they will further your understanding of the various concepts and equip you to determine such parameters as a star's age and lifetime, distance, mass, and brightness. All the mathematics presented will be simple, of a level comparable to that of a high-school student. In fact, to make the mathematics simpler, we will use rough (but perfectly acceptable) approximations and perform back-of-the-envelope calculations, which, surprisingly, produce rather accurate answers! To further your expertise in the simple mathematics, several very easy problems are included at the end of each chapter. A completely new aspect of the book is the inclusion, throughout the text, of "Thought Questions." These seek to test how well you have understood the

sections. However, with both the end of chapter problems and thought questions, you do not need to attempt any of them to enjoy the book, rather they are just there for fun.

An astute reader will notice immediately that there are *no* star maps in the book! The reason for this is simple. In previous books that I have written, star maps were included, but their size generated some criticism. Some readers believed that the maps were too small, and I tended to agree. To be able to offer large and detailed star maps of every object mentioned in this book would entail a doubling of its size, and probably a tripling of cost. With the plethora of star-map software that is available these days, it is far easier for readers to make their own maps than to present any here.

A final point I wish to emphasize here is that the book can be read in several ways. Certainly, you can start at the beginning and read through to the end. But if you are particularly interested in, say, supernovae and the final stages of a star's life, or in galaxy clusters, there is no reason that you shouldn't go straight to that section. Some of the nomenclature might be unfamiliar, but I've attempted to write the book with enough description that this shouldn't be a problem. Also, many of you will undoubtedly go straight to the observing lists. Read the book in the way that is most enjoyable to you.

Without further ado, let us begin on your voyage of discovery.

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The plethora of people who bought the first edition of the book and kindly pointed out the typos. I hope I caught them all.

In developing a book of this type, which presents a considerable amount of detail, it is nearly impossible to avoid error. If any arise, I apologize for the oversight, and mistakes are due to me and me alone.

Contents

About the Author

Mike Inglis was born in Wales in the United Kingdom but lives and works in the United States, where he is Professor of Astrophysics at the State University of New York. His qualifications include a BSc Physics, MSc in Astronomy and Astronautics, and a PhD in Astrophysics. He is a Fellow of the Royal Astronomical Society, a NASA Solar System Ambassador, a member of the European Astronomical Society, and a member of the International Astronomical Union. He is the author of many books and papers, including *Field Guide to Deep Sky Objects* (Springer), *An Observer's Guide to Stellar Evolution* (Springer), *Astronomy of the Milky Way*, Vols I & II (Springer), and *Observer's Guide to Star Clusters*. He is also the Series Editor of Springer's Astronomy Observing Guides, the Springer Lecture Notes in Undergraduate Physics and Astrophysics.