The Ever-Changing Sky
A Guide to the Celestial Sphere

The Ever-Changing Sky provides a comprehensive and non-mathematical guide to spherical astronomy. The reader is guided through terrestrial and celestial coordinate systems, time measurement, and celestial navigation, to the prediction of the rising and setting of the stars, Sun, and Moon. It focuses on the geometrical aspects of the night sky without using complex trigonometry. The book progresses to a general study of the Earth and sky, including the stars and constellations (with useful star maps provided), the motions and appearance of the Moon, tides and eclipses, the orbits of the planets, and the smaller bodies of the Solar System (asteroids, meteors, meteorites, and comets). Finally, there is a brief overview of atmospheric phenomena (including rainbows and halos). This text will be invaluable to students taking courses in naked-eye astronomy, amateur and professional astronomers, as well as more general readers wanting to know how the night sky changes.

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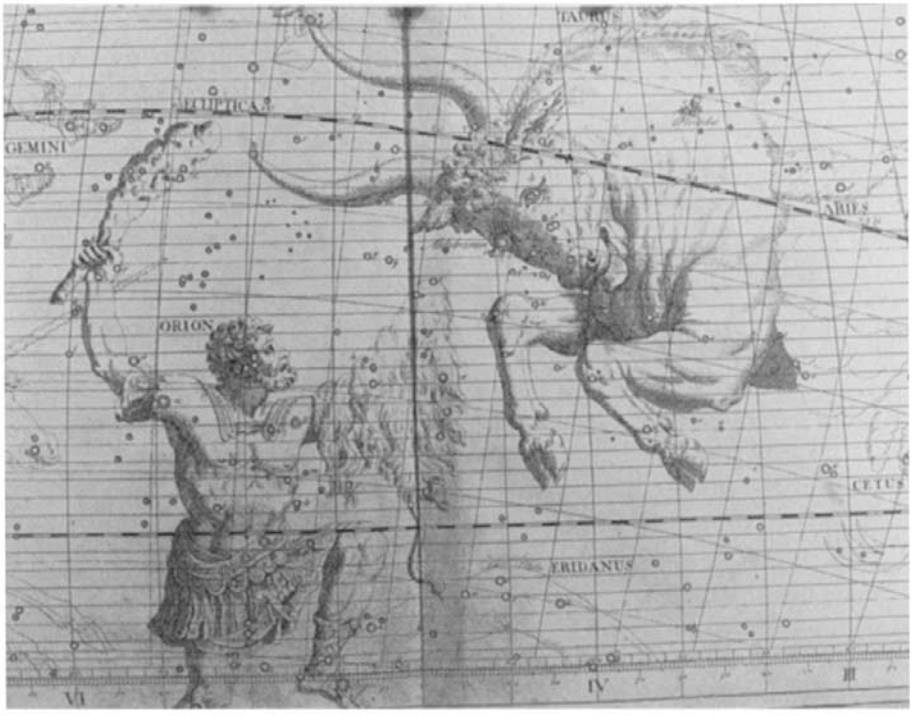

Our changing perceptions of the sky are epitomized by John Flamsteed's *Atlas Coelestis* of 1729, which shows ancient mythologies (the great hunter Orion in combat with the zodiac's Taurus) superimposed on a scientifically precise star atlas.

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To my teachers. Thank you Gertrude Rosenberg, Benjamin Boss, Hazel Losh, Dean McLaughlin, Hermann Zanstra, Albrecht Unsöld, and Lawrence Aller.

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Preface

As the subject of astrophysics has grown over the years, it has gradually replaced much of the traditional material once commonly found in elementary textbooks. As a result, an entire body of knowledge revolving primarily around terrestrial and planetary motions and aspects of the celestial sphere is becoming less accessible. It is not that these subjects are unimportant but that there is simply less and less available text space.

The problem was first made clear to me when I was asked to give a seminar to a graduate anthropology class that was exploring subjects in South American ethno-astronomy. My task was to explain some basic astronomical principles – the rising and setting of the Sun and stars for example – needed to help the students make sense of Incan building alignments. This discussion, plus a series of related experiences (I was even helping a doctoral candidate in agronomy who was doing a project on ancient agriculture and needed information on planting times as indicated by the rising of star groups), demonstrated that there was little available in the way of qualitative, relatively non-mathematical reading material on the subject: I was recommending out-of-print, and often out-of-date, 1930s and 1940s textbooks.

At that point I decided to fill the gap by writing what was initially intended to be a cross-disciplinary guide to spherical astronomy for anthropologists, archaeologists, classicists, etc. However once this venture was underway I could begin to see a more general purpose: a complete non-mathematical treatment of all aspects of the sky, useful not only to those in other professions who need to know these elements of astronomy, but to astronomers as well, whether student, professional, or amateur.

The chief theme of the book is the exploration of the things that move, or seem to move, across the heavens, with the emphasis on what can be seen with the naked eye. I introduce a variety of phenomena, and then explain them in a generally non-mathematical way. Mathematics – its usefulness and grandeur – is indeed constantly a presence, but it is largely silent: there are few equations, but much geometry, couched in non-technical terms and, where necessary, explained from the beginning. The reader should finish the book with a firm conceptual foundation of the science of spherical

astronomy and celestial motions, and would be well equipped to move on to more technical treatments.

The text begins (*Chapter 1*) with an introduction to the sky, where I define the basic architecture of the celestial sphere, including the fundamental concepts of circles, angles, and arcs. In *Chapter 2* the reader sees how the stars appear to move when the Earth is set turning and the observer sent traveling around the globe. Here we explore the rising and setting of stars, and how the observer's position affects what he or she sees.

With these basics in place, *Chapter 3* shows what happens in the sky as the Earth moves through space in its orbit about the Sun, causing that body to appear to travel through the stars. The chapter defines the ecliptic (the solar path), explains the seasons, establishes why the length of the day and the positions of sunrise and sunset change with the time of year and the observer's location, and demonstrates what happens when the observer travels to the arctic regions of the globe and to the tropics. More technical matters are then developed in an examination of celestial coordinate systems, which was begun in Chapter 2. These geometrical concepts provide a foundation for subsequent discussions.

In *Chapter 4* the reader is placed under the nighttime sky and begins the study of the subject that in the popular mind defines astronomy, the stars and constellations. The text examines the history and significance of constellation lore, the Milky Way, and various non-stellar objects. Extensive tables of the stars and constellations are given in conjunction with basic but fairly detailed star maps that are presented in *Appendix 2*. *Chapter 5* adds further to the complexity of the explanations of celestial motions that were developed in the first three chapters with a detailed account of precession and its attendant movements, and uses the material of Chapter 4 to make the slow motion seem more real.

With the basics of celestial motions in place, *Chapter 6* develops the subject of time measurement, including the practicalities of keeping precise time on a world-wide basis. This material leads naturally into *Chapter 7*, in which we see how the times and positions of sunrise and sunset can be found, and into *Chapter 8*, which examines the science of star positions and celestial navigation.

In the next four chapters we turn specifically to a study of the bodies of the Solar System. *Chapter 9* takes up a detailed examination of the motions and phenomena of the Moon, beginning with the most fundamental concepts of the lunar phases, and successively adding complexities that lead to the development and definition of the elements of orbital mechanics and the niceties of gravitational perturbations. Here we also examine the special problems of moonrise and moonset. *Chapter 10* continues the discussion to include tides, eclipses, and calendars.

In *Chapter 11*, this subject is extended to the planets, to examine their observed characteristics and apparent motions. The material introduced in Chapter 9 is expanded to encompass the history and development of the laws of planetary motion and the underlying concept of gravity, that elegant construction that explains how the planetary system works. A brief telescopic view of the planets is included and the chapter closes with a critical look at astrology, which can then be intelligently juxtaposed against the

science that both parallels and opposes it. *Chapter 12* then turns to the other bodies of the Sun's family, the comets, meteors, and meteorites, phenomena to which even a casual observer can easily relate.

Finally, *Chapter 13* moves the reader back toward the Earth to examine atmospheric phenomena that are played out against the backdrop of the starry or sunlit sky. The chapter begins with elementary optical principles and uses the workings of telescopes as practical examples. We then explore the extraordinary richness of atmospheric optics: rainbows, halos, sundogs, sunsets, the green flash, aurorae, the twinkling of stars, and a variety of other topics.

The book terminates with three appendices. The first, initially referred to in Chapter 3, presents various graphs and tables that involve the times and positions of the rising and setting of the Sun and Moon. The second relates to Chapter 4, and consists of a set of star maps that are sufficiently detailed to illustrate the positions of all the constellations and a few non-stellar objects. *Appendix 3* develops the basic rules of spherical trigonometry, allowing the student of this subject to make a variety of astronomical calculations and providing a transition to more mathematically oriented texts. The ultimate goals throughout the book are to interest the reader in the myriad aspects of the sky and to provide clear, useful explanations of them.

I am indebted to R. Tom Zuidema for starting me on this project and for his interest and enthusiasm. Deep thanks also go to David Bright and Ray White, who read, commented on, and improved the manuscript, to Dennis D. McCarthy, who instructed me on various matters of time and the Earth's rotation, and to Lauren Kaler Brewer, who checked the clarity of the mathematics in Appendix 3. I also thank Simon Mitton for his patience while the manuscript was being completed, Bob MacFarlane for his excellent draftsmanship, Jack Gladin for his fine photographic work, and Maxine for continuous encouragement over the years of preparation.