
1 Introduction

This book explores the designs of telescopes, eyepieces, and the specialized imaging telescopes called astrographs. For all the optical systems packed between its covers, we describe the whys and wherefores of the mirrors and lenses that define each design, analyze their optical properties, and assess their performance as a complete package. While providing accurate, authoritative, and up-to-date information that professional optical designers, telescope manufacturers, and advanced amateurs will find useful, we have sought to make this book one that ordinary amateur astronomers will understand and value. We trust that it will join the other indispensable books in your astronomical library.

1.1 A Tour of Telescopes

Imagine this book as a great exhibition hall full of telescopes in every size, shape, and design. In one vast gallery you find classic refractors with shiny brass tubes and wooden tripods; another hall is filled with Newtonians of every size and shape. A sign points to the Cassegrain Wing where the elegant Ritchey-Chrétiens, compact Schmidt-Cassegrains, and magnificent Maksutovs are on display; while down a long hallway you gawk at quirky Tri-Schiefspiegler beside the looming Schupmann telescope. You are free to wander, to take in the sights, to touch and point and peer through any of them for as long as you want.

1.1.1 Getting Started

As you enter the gates of the exposition, you encounter three exhibit halls designed to enrich your learning experience. One hall features vision and the human eye; another focuses on astrocameras and imaging; and the last displays lenses, mirrors, glass, and computers — a complete optical design shop where you will see and learn what goes into making telescopes.

Those rooms are the three preparatory chapters following this introduction: Visual Observing (Chapter 2), Astronomical Imaging (Chapter 3), and Optics for Observers (Chapter 4). These chapters review key concepts you'll need, and serve as reference material that you can return to from any point in the book. If you are new to amateur astronomy, in Chapters 2 and 3 you will encounter terms and ideas

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that elementary books pass over. Chapter 4 is a college-level introduction to optics and optical terminology with lots of practical “good stuff” for almost every amateur astronomer. These chapters serve as points of reference for the rest of the book. Should you feel swamped in optical jargon, return to these special exhibit halls to gain new insight and reinforce your understanding.

1.1.2 Telescope Designs

In this book, as in many exhibitions, telescopes are organized along historical lines. Chapter 5 introduces the oldest type of telescope: the refractor. As you enter the main exhibition space, you see before you the long-focus single-lens refractors responsible for virtually every astronomical discovery in the 17th century. Through these simplest of telescopes, you will meet and master the bugaboo of all refractors: chromatic aberration. Progressing, you will meet the wiggled and powdered geniuses who developed the achromatic doublet that drove progress in the 18th and 19th centuries, and then explore in detail the workings and performance of modern achromatic objectives. In the adjacent gallery, you return to the 21st century to examine apochromatic refractors — the pride of today’s visual observer. If you’ve never *quite* grasped the difference between **achromat** and **apochromat**, the exhibits in Chapter 6 will satisfy your curiosity — and you’ll see why visual observers treasure these instruments!

As you pass from the refractor galleries, you enter the Hall of Mirrors. Here you find the reflectors, the telescopes with mirrors — and first among them is the brainchild of Isaac Newton, his solution to the chromatic aberration of the single-lens refractor, the Newtonian telescope. The most basic all-reflecting telescope, the Newtonian is diffraction-limited on-axis and completely free of color aberrations. Long favored by do-it-yourself telescope makers, Newtonians deliver excellent value for the time, money and effort expended in building them. Because they are ubiquitous and so varied, this book examines Newtonian performance both on-axis and off-axis at $f/4.5$, $f/6$, and $f/8$, a range that embraces the 6-inch $f/8$ beloved of “telescope nuts” in days gone by, to the typical 16-inch $f/4.5$ Dobsonian of the late 1980s through the present.

The Hall of Mirrors doesn’t end with Newton’s design: that was just the beginning! So extensive is it that it takes four chapters to deal with all the varieties of the Cassegrain reflector: Chapter 8 is devoted to all-reflecting Cassegrains; Chapter 9 covers the Schmidt-Cassegrain; Chapter 10 demystifies the Maksutov-Cassegrain; and Chapter 11 reviews catadioptric Cassegrain designs.

The all-reflecting Cassegrain includes three forms: the classical Cassegrain, the Dall-Kirkham, and the Ritchey-Chrétien — products of centuries of hard work and brilliant invention. Cassegrains offer a long focal length in a reasonably short tube, perfect on-axis images, and perfect color correction. They are the basis of all big, modern, professional telescopes today. Among amateur astronomers, and especially among those devoted to CCD imaging, the coma-free Ritchey-Chrétien has gained considerable *caché* — and as our spot diagrams, ray-fan plots, and Strehl ratio graphs demonstrate — justly so.

Chapter 9 occupies major exhibit space in the Hall of Mirrors, for it is here that we spotlight the popular Schmidt-Cassegrain Telescope (SCT). Combine two spherical mirrors like a Cassegrain and put a thin lens in front to correct spherical aberration, and you have the standard 8-inch $f/10$ SCT. But wait! This gallery opens to reveal six different SCTs. Take the baseline two-sphere SCT and shift the corrector lens to remove coma. Make it $f/15$ and its spherochromatism is tamed. Figure the primary or the secondary to an asphere, and the coma vanishes. Add a field corrector, and the system becomes the aplanatic, flat-field SCT — the compact, high-performance telescope you wanted all along.

Like the SCT, the Maksutov-Cassegrain offers a long focal length in a compact package — and its thick, deep corrector shell is exceptionally robust. In Chapter 10, we explore “dream-telescope” 200 mm $f/15$ Maksutov designs that offer excellent on-axis images in short, closed optical tubes.

The classical, Ritchey-Chrétien, Schmidt, and Maksutov variations of the Cassegrain are well known to today’s amateurs. But lurking in the corners of this exhibit hall are still more Cassegrain designs! Chapter 11 explores two-mirror systems in which the mirrors do the “heavy lifting,” while small correcting lenses add the finishing touches. Offering well-corrected wide-angle and flat-field optics, these hybrid systems are not only telescopes but also astrographs. Take your time and meet the Klevtsov, the Ritchey with a field corrector, and new designs for serious imaging, the CDKs (a.k.a. Corrected Dall-Kirkham Cassegrains).

Finally, in an alcove near the end of the Hall of Mirrors, you will find two modest catadioptric telescope types: the Schmidt-Newtonian and the Maksutov-Newtonian (Chapter 12). These systems build on the Newtonian, but replace the Newtonian’s paraboloidal mirror with a sphere and add a Schmidt or Maksutov correcting lens. They offer fast-to-moderate focal ratios and good field correction in a neat, reasonably compact configuration.

As you leave the Hall of Mirrors, you spy a strange glittering that seems to emanate from an obscure gallery. Cautiously you peep in: what you see is a small, but dedicated cadre of telescope makers gathered about mirrors that seemingly tilt every which way! This is the famous Hall of TCTs — Tilted Component Telescopes. Maybe you’ve heard of them, perhaps you have not: but in Chapter 13 you will make their acquaintance.

TCTs comprise a broad class that includes both reflector and refractor designs. They seem to break all the rules, yet they are capable of exquisite performance in the hands of a skilled maker. Based on mirrors carefully arranged so that one mirror does not shadow another, or on a single lens aided by a Mangin mirror to produce perfect color-free images, the TCT is an advanced project for the experienced amateur telescope maker, and a crowd-pleaser at star parties. Obscure as it seems, this odd Hall of TCTs includes nine full-fledged high-performance designs.

1.1.3 Auxiliary Optics

Another alcove off the main exhibit hall houses an important collection you don’t want to miss: Barlows, coma correctors, focal reducers, and field flatteners. Chap-

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ter 14 explores these auxiliary optical systems that extend telescope functionality — for without altering your main optics, these “plug-in modules” change its basic characteristics to support a particular task. Focal extenders (Barlows) multiply the effective focal length of your telescope, while coma correctors reduce the off-axis coma of fast Newtonians. Focal reducers reverse the action of a Barlow: they shorten the focal length and focal ratio, allowing you to cover a larger field and to get deep-sky images in shorter exposure times. Last but not least, for telescopes that have a curved focal surface, the field flattener can enlarge the useful field of view. Though this alcove and its exhibits are small, they are mighty useful.

1.1.4 Optics for Imaging

Beyond the Hall of Mirrors, taking nearly a whole wing of the exposition, our tour has arrived at the Grand Salon of Astro-Imaging. In the optical designer’s pantheon, astrographs occupy a unique space — partly overgrown hybrids of camera lenses, and partly high-performance telescopes designed not for the eyepiece, but for the CCD camera.

On one side of the Grand Salon are all-refracting astrographic cameras (Chapter 15), and on the other, the wide-field mirror-and-lens hybrid astrographs (Chapter 16). The division is not entirely arbitrary: in the refracting systems, lenses are responsible for optical power and correcting aberrations; in the hybrid astrographs, mirrors supply the optical power while lenses control the aberrations.

The distinction between wide-field telescopes and astrographs is a subtle one, often blurry, and often having more to do with the observer’s use of the instrument than the actual design itself. Suffice it to say that we class a well-corrected wide-field design as “astrograph” if field coverage and field flatness, rather than axial image quality, are paramount in the design specification. For this book, we treat the Schmidt-Newtonian as a telescope (*i.e.*, optimized for axial images), while we class the paraboloid-plus-Wynne-corrector as an astrograph.

Although we would have liked to compare every design at the same aperture and focal ratio, with astrographs, head-to-head comparisons simply do not work. For refracting astrocameras, the cost and availability of low-dispersion optical glass limits them to apertures less than 200 mm. With catadioptric astrographs, the large secondary mirror necessary to cover a 16-megapixel CCD becomes impractical for an aperture as small as 200 mm.

Astrographs are finicky: some do an outstanding job at $f/3$ while others do best at $f/8$ — and neither can do a creditable job at the optimum focal ratio for the other. It was therefore impractical to compare astrograph performance at a constant focal ratio. As a practical matter we treat each astrograph in the range of aperture and focal ratio where it can excel.

1.1.5 Eyepieces

Our tour of the exposition now takes us to the vast Ocular Exhibit, and the longest chapter in the book: Eyepieces (Chapter 17). Although small, eyepieces play a crucial role in observing satisfaction; they receive, magnify, and deliver the image

formed by the telescope to the eye. Poor oculars force you to suffer with chromatic aberration, astigmatism, and field curvature in the images; outstanding eyepieces transmit a clean, flat, crisp rendition of the telescopic image to the eye. A fine planetary ocular delivers close-up views of Mars or Jupiter; a great wide-field one simulates a porthole view into deep space.

The chapter begins with the simplest type of all: the singlet eyepiece of Johannes Kepler, and proceeds to explore systematically the Huygens, Ramsden, Kellner, Plössl, Orthoscopic, Erfle, and Nagler designs — noting for each type the strengths, weaknesses, and performance trade-offs that the optical designer must make. Today's most sophisticated designs are based on one or more of these fundamental types.

1.1.6 Glossary and Bibliography

No tour of a great exposition is complete without passing the Cafeteria and Gift Shop — and in this book, both are free. If you're feeling hungry for information, stop at the Glossary for a quick definition or explanation of a term that seems unfamiliar. Our Gift Shop is an extensive bibliography that traces the history and intellectual framework of optics and telescope design. Organized by chapter and section, the bibliography allows you to research popular articles, historical source documents, patents, and other works about optics and telescope design.

Your tour of this book is complete. Feel free to roam through its pages, explore every gallery, taking in everything all at once: or enter a tiny alcove and spend a rainy afternoon in contemplation of the creative splendor of a great optical design. With each telescope, eyepiece, and astrocamera you will find its layout and optical prescription. So our museum is open, hands-on, and interactive. If you wish, the radii, spacings, glass types, and figures are right there at your fingertips, just waiting for you to explore and evaluate designs with the ray-trace software of your choice.

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