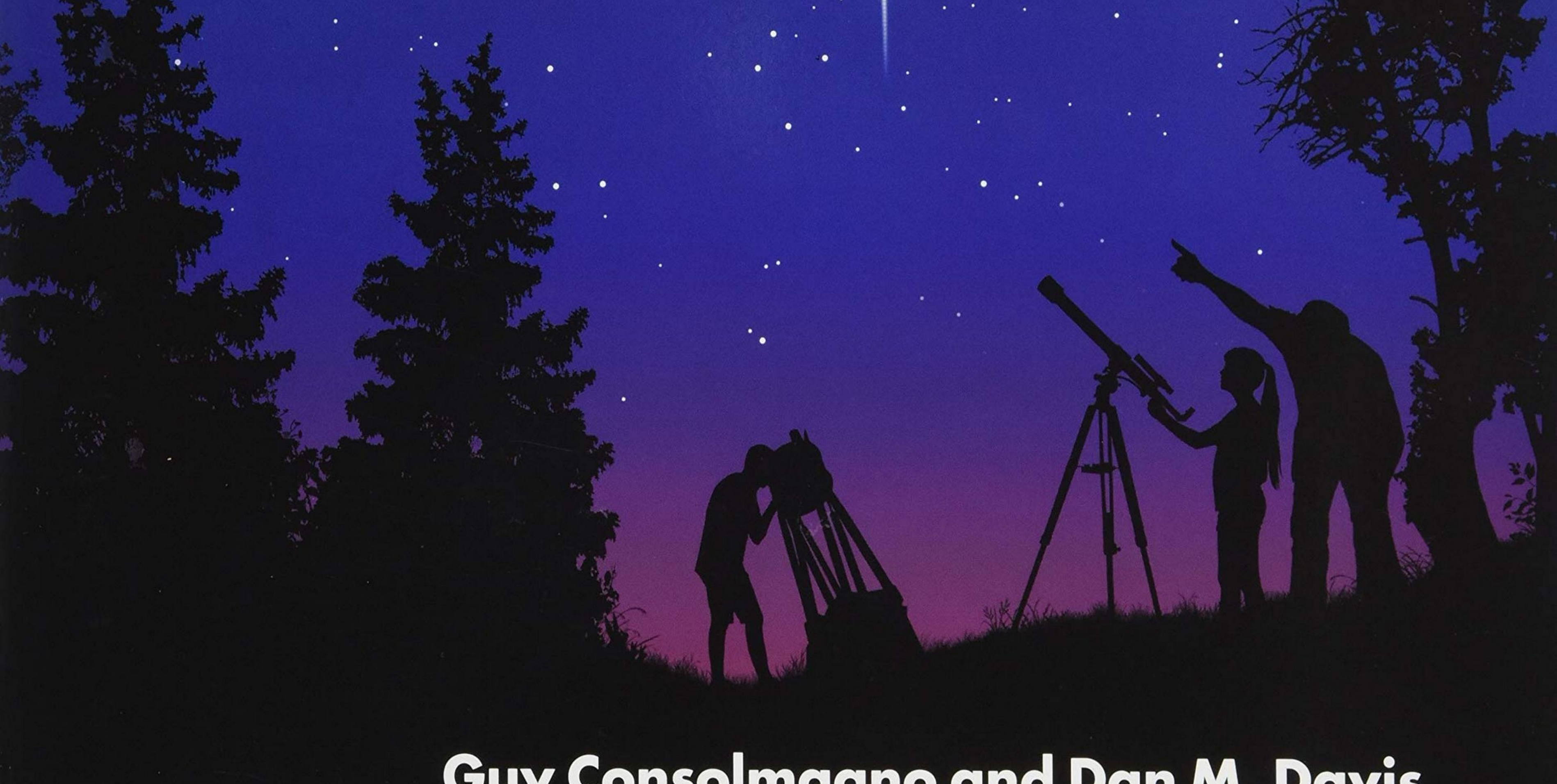
TURN LEFT AT ORION

HUNDREDS OF NIGHT SKY OBJECTS
TO SEE IN A HOME TELESCOPE
– AND HOW TO FIND THEM

Fifth Edition



Guy Consolmagno and Dan M. Davis

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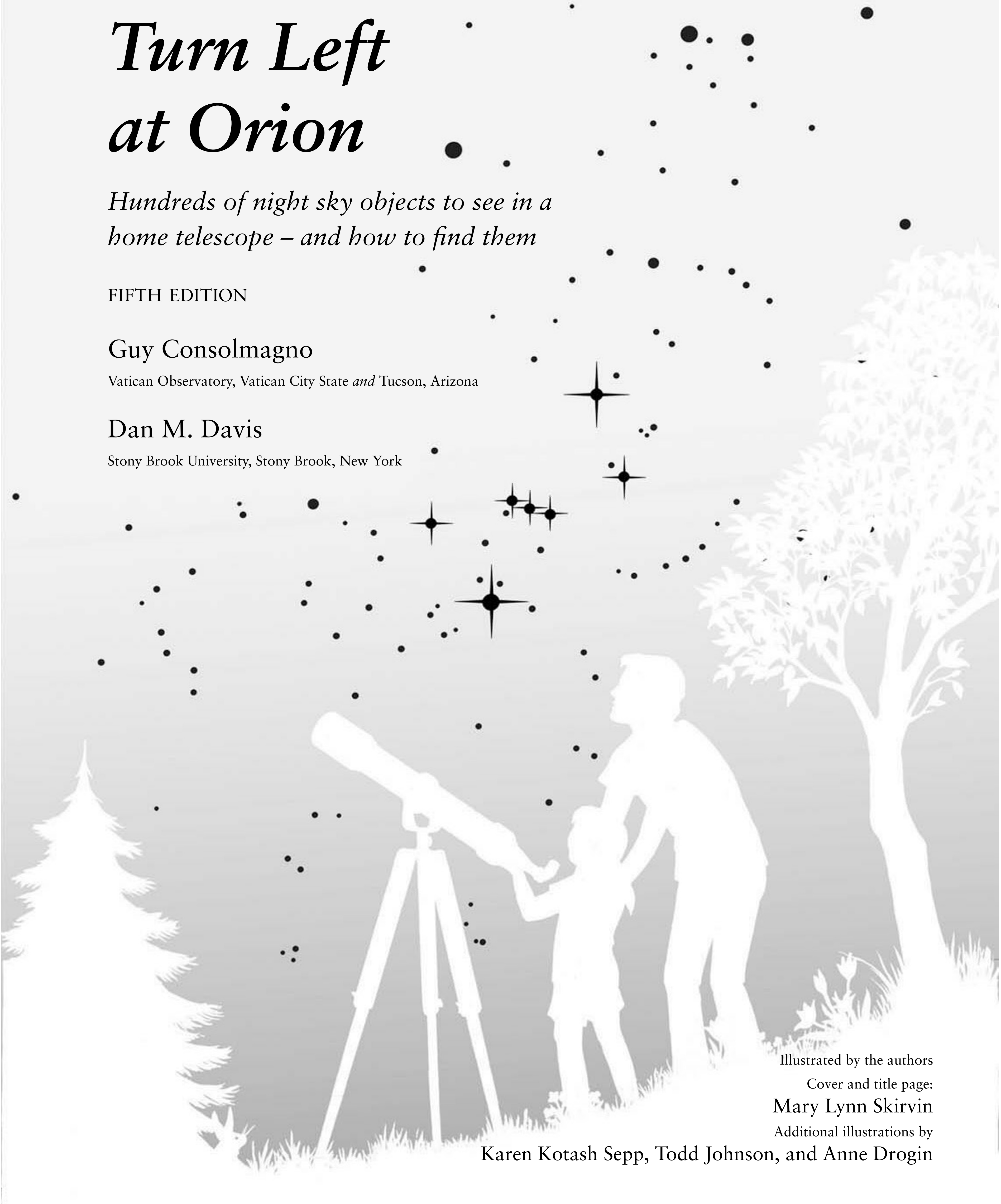

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Contents

How do you get to Albireo?

A while back I spent a couple of years teaching physics in Africa, as a volunteer with the US Peace Corps. At one point during my service I had to return to the US for a month, and while I was home I visited with my friend Dan in New York City. We got to talking about the beautiful dark skies in Africa, and the boundless curiosity of my students about things astronomical…and so that afternoon we went into Manhattan and, with Dan's advice, I bought a little telescope to take back with me to Kenya.

Dan was far more excited about my purchase than I was. He'd been an avid amateur astronomer since he was a little kid, something of an achievement when you're growing up in the grimier parts of Yonkers and your eyesight is so bad you can start fires with your glasses. And he was just drooling over some of the things I'd be able to see in Africa.

I didn't really understand it, at first. You see, when I was a kid I'd had a telescope, too, a little two-inch refractor that I had bought with trading stamps. I remembered looking at the Moon; and I knew how to find Jupiter and Saturn. But after that, I had sort of run out of things to look at. Those glorious color pictures of nebulae that you see in the glossy magazines? They're all taken with huge telescopes, after all. I knew my little telescope couldn't show me anything like that, even if I knew where to look. And of course I didn't know where to look, anyway.

But now here was Dan getting all worked up about my new telescope, and the thought that I'd be taking it back to Africa, land of dark skies and southern stars. There were plenty of great things to look at, he insisted. He gave me a star atlas, and a pile of books listing double stars and clusters and galaxies. Could it be that I could really see some of these things with my little telescope?

Well, the books he gave me were a big disappointment. At first, I couldn't make heads or tails of their directions. And even when I did figure them out, they all seemed to assume that I had a telescope with at least a six-inch mirror or lens. There was no way of telling which, of all the objects they listed, I might be able to see with my little three-incher.

Finally, Dan went out with me one night. "Let's look at Albireo," he said.

I'd never heard of Albireo.

"It's just over here," he said. "Point it this way, zip, and there you are."

"Neat!" I said. "A double star! You can actually see both of them!"

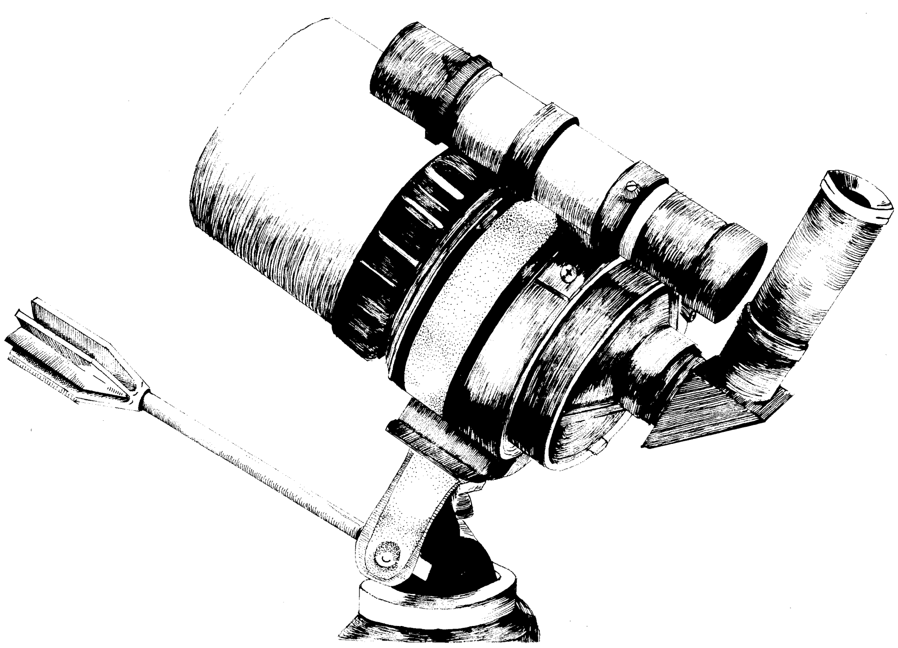
"And look at the colors," he said.

"Wow…one of them's yellow, and the other's blue. What a contrast."

"Isn't that great?" he said. "Now let's go on to the double-double."

And so it went for the next hour.

Eventually it occurred to me that all of the books in the world weren't as good as having a friend next to you to point out what to look for, and how to find it. Unfortunately, I couldn't take Dan back to Africa with me.



I suspect the problem is not that unusual. Every year, thousands of telescopes are sold, used once or twice to look at the Moon, and then they wind up gathering dust in the attic. It's not that people aren't interested – but on any given night there may be 2,000 stars visible to the naked eye, and 1,900 of them are pretty boring to look at in a small telescope. You have to know where to look, to find the interesting double stars and variables, or the nebulae and clusters that are fun to see in a small telescope but invisible to the naked eye.

The standard observer's guides can seem just incomprehensible. Why should you have to fight with technical coordinate systems? All I wanted to do was point the telescope "up" some night and be able to say, "Hey, would you look at this!"

It's for people who are like I was when I was starting out, the casual observers who'd like to have fun with their telescopes without committing themselves to hours of technical details, that we decided to write *Turn Left at Orion.*

— Guy Consolmagno (Easton, Pennsylvania; 1988)

to read more about the 2018 Fifth Edition, see page 242

How to use this book

This book lists our favorite small-telescope objects, arranged by the months when they're best visible in the evening and the places in the sky where they're located. For all these objects, we assume you have a telescope much like one of ours: either a small scope whose main lens or mirror is only 2.4" to 4" (6 to 10 cm) in diameter; or a modest Dobsonian with an aperture of 8" to 10" (20 to 25 cm). Everything in this book can be seen with such small telescopes under ordinary sky conditions: it's how they looked to us.

The facts of life about small telescopes

How night-sky objects look in a telescope depends on the kind of telescope you have. That, in turn, will determine the sort of objects you will want to observe. We talk at great length later on about different kinds of telescopes, but it's worth outlining here at the start a few basic telescope facts of life.

A good telescope can magnify the surface of the Moon, reveal details on the small disks of the planets, and split double stars. But just as importantly, it can also gather light and concentrate it at the eyepiece to make faint nebulae bright enough for the human eye to see. A telescope's light-gathering ability, or *aperture*, is key.

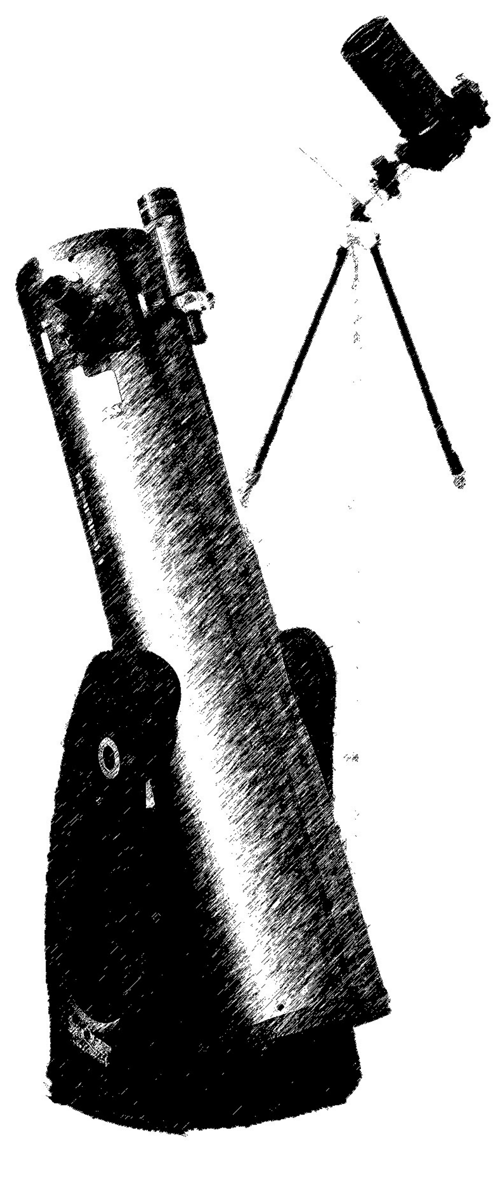
Every telescope has a big lens or mirror to gather in starlight and bring it to a focus near the eyepiece. The bigger the lens or mirror, the more light it can capture. All things being equal, then, bigger is better. But in the real world, all things are never equal. Thus there are a variety of different ways to gather that light. For this book we've divided scopes into three classes: binoculars, small telescopes, and Dobsonian telescopes. They each have their strong points and weaknesses.

Binoculars are relatively inexpensive, very portable, and they give you a wide field of view. Furthermore, by using both eyes most people can pick out more detail in a faint nebula seen with binoculars than you would using a single telescope of the same aperture. Still, their very portability means that they're usually limited to an aperture of a couple of inches, maximum. And most binoculars don't attach easily to a tripod, making it hard to keep them steady and fixed on faint objects.

At the other extreme, a *Dobsonian* is essentially a big mirror at the bottom of a large lightweight tube, with the eyepiece at the top, all fixed in a simple mount. It has fantastic light-gathering power. But Dobs are very awkward to take on trips, or even just to carry into your back yard for a brief look at the sky. And their simplicity comes at a sometimes subtle cost to their optical quality.

In between are the small telescopes, ranging from the classic refractors (a tube with a lens at each end) to the more sophisticated *catadioptric* designs that combine mirrors and lenses in a compact package. "Cats" are portable and powerful; but to gather as much light as a "Dob" you have to spend about four times the money. Still, a small Cat prowling through dark skies can outperform a big Dob fighting city lights. Note also, as we explain below, Cats and refractors use a star diagonal and that gives them a view of the sky that's the mirror image of what's seen in binoculars or a Dob.

We provide two views for each object in this book: one is the view with a small Cat or refractor, the other the view in a larger Dob. For binoculars, use our finder-scope views as a guide. If you're lucky enough to have an 8" Cat, you'll see the greater detail in our Dob views, but with the orientation of the Cat view. Figures drawn with this orientation can be downloaded from our website, www.cambridge.org/turnleft



Finding your way

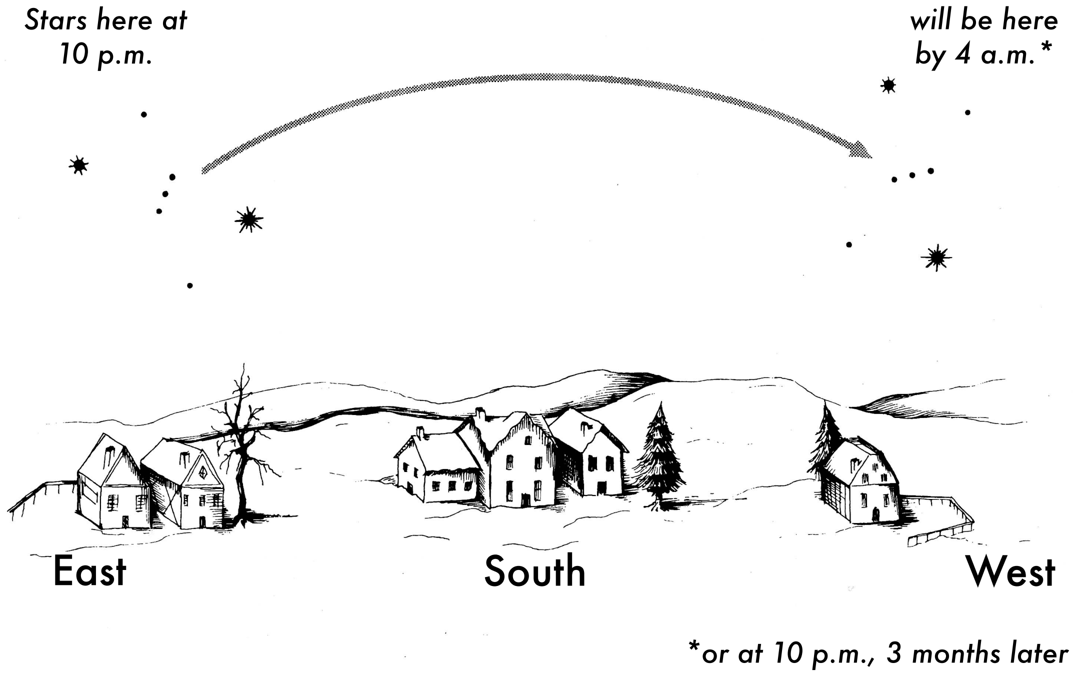
Once you've got your telescope, where do you point it? Answering that question is what this book is all about.

There are two classes of night-sky objects. The *Moon* and *planets* move about in the sky relative to the stars; fortunately they are bright enough that it's easy to find them. *Seasonal objects* – double stars, clusters, nebulae, and galaxies – stay fixed in the same relative positions to each other, rising and setting together each night, slightly faster than the Sun, thus changing location slowly as the seasons change.

The Moon, Sun, and planets: Finding the **Moon** is never a problem; in fact, it is the only astronomical object that is safe and easy to observe directly even in broad daylight. (Indeed, unless you're up in the wee hours of the morning, daytime is the only time you can see the third quarter Moon. Try it!)

The Moon changes its appearance quite a bit as it goes through its phases, and for each phase there are certain things on the Moon that are particularly fun to look for. We've included pictures and discussions for seven different phases of the Moon, plus what to look for during lunar and solar eclipses. We also give a brief introduction to observing the **Sun** itself… but only try that if you have the proper equipment.

Planets are small bright disks of light in the telescope. In a good telescope with a high powered lens they can be spectacular to look at! But even a pair of binoculars will be able to show you the phases of Venus and the moons of Jupiter.



The stars and deep-sky objects stay in fixed positions relative to one another. But which of those stars will be visible during the evening changes with the seasons; objects that are easy to see in March will be long gone by September. Thus we refer to these objects as seasonal. *Some objects are visible in more than one season. When we talk about "January skies" we're referring to what you'd see in January at around 10:00 p.m. local standard time. If you are up at four in the morning the sky will look quite different. The general rule of thumb is to advance one season for every six hours, so spring stars will be visible on winter mornings, summer stars on spring mornings, and so forth.*

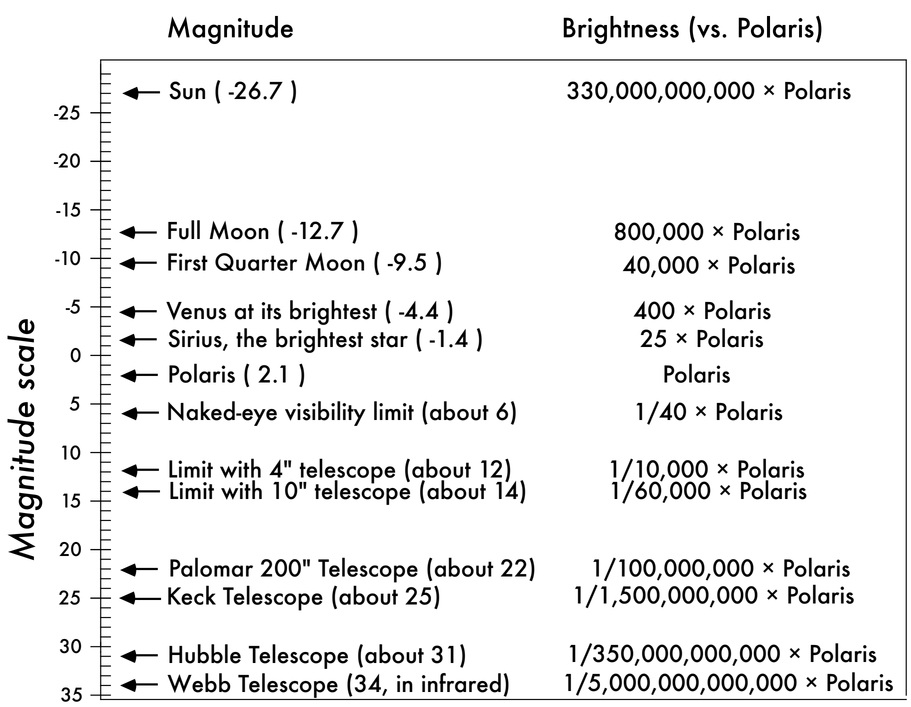
The positions of the planets, relative to the other stars, change from year to year; but if you know in general where to look for them, they're very easy to find. They're generally as bright as the brightest stars. We describe here things to look for when you observe them. Our website www.cambridge.org/turnleft links to tables of when and where to find each planet.

The seasonal objects: The stars, and all the *deep-sky objects* we talk about in this section, stay in fixed positions relative to one another. But which of those stars will be visible during the evening changes with the seasons; objects that are easy to see in March will be long gone by September.

How do you know, on any given night, what objects are up? That's what the **What, where and when** chart at the back of the book is all about. For a given month, and the time when you'll be observing, it lists each of the constellations where seasonal objects are located; the direction you should turn to look for that constellation (e.g. W = west); and if you should be looking low, towards the horizon (e.g. "W – "), or high up (e.g. "W + "). Constellations marked with only a "++" symbol are right overhead. Then you can turn to the seasonal pages to check out the objects visible in each constellation available that night.

But note, you don't need to memorize the constellations in order to use this book. Constellations are merely names that astronomers give to certain somewhat arbitrarily defined regions of the sky. The names are useful for labeling the things we'll be looking at; otherwise, don't worry about them. If you do want to know the constellations, there are a number of good books available (our personal favorite is H. A. Rey's *The Stars*) but for telescope observing, all you need is an idea of where to find the brightest stars, to use them as guideposts.

Note that the brightness of a star, its *magnitude*, is defined in a somewhat counter-intuitive way that goes back to the ancient Greeks: the brighter a star, the lower the numerical value of its magnitude. The common rule is that a star of the *first magnitude* is about $2\frac{1}{2}$ times brighter than a *second-magnitude* star, which is about $2\frac{1}{2}$ times brighter than a *third-magnitude* star, and so forth. The very brightest stars can be zeroth magnitude, or even have a negative magnitude! The star Vega has a magnitude of 0; Sirius, the brightest star of all, has a negative magnitude, –1.4. There are only about 20 stars that are first magnitude or brighter. On a dark night, the typical human eye can see down to about sixth magnitude without a telescope.



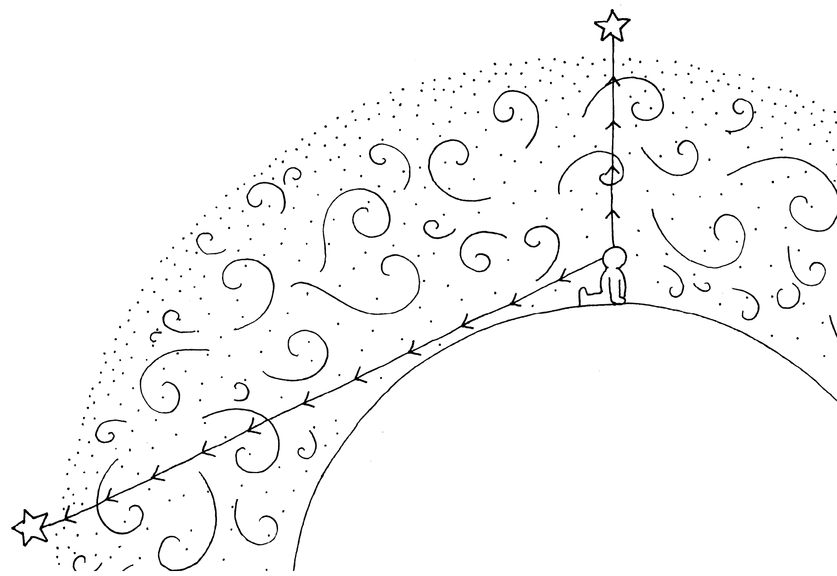
We start off each season by describing the location of our **guideposts**, a selection of the brightest and easiest stars to find in the evening skies. Most of our readers are in the northern hemisphere, so we have set our guidepost charts to be appropriate for what you will see at about 10 p.m. in the USA, Canada, Europe, China, Japan … anywhere between latitudes 30° and 60° N. Most of these objects will also be visible from Australia, New Zealand, Africa, or South America, but their positions will all be shifted northwards.

Stars set in the west, just like the Sun, so if you're planning a long observing session you should start by observing the western objects first, before they get too low in the sky. The closer to the horizon an object sits, the more the atmosphere obscures and distorts it, so you want to catch things when they're as high up in the sky as possible. (However, telescopes with alt-azimuth mounts – see page 19 – have trouble aiming straight up, so try to catch such objects sometime before or after they get to that point.)

Most objects are visible in more than one season. Just because the Orion Nebula is at its best in December doesn't mean you should risk missing it in March. Some of the nicest objects from the previous season that are still visible in the western sky are listed in a table at the beginning of each season.

You'll be able to see objects around your hemisphere's celestial pole at some time during any night, year round; but objects around the opposite pole will always be hidden. Northerners will always be able to find the Little Dipper but never see the Southern Cross; southerners get the Cross but never the Dipper. Thus we have sorted the northernmost and southernmost objects into separate chapters.

Also, remember that when we talk about "January skies," for instance, we're referring to what you'd see then at around 10:00 p.m., standard time. If you are up at 4 in the morning the sky will look quite different. The general rule of thumb is to advance one season for every six hours, so spring stars will be visible in the wee hours of winter, summer stars in early spring morning hours, and so forth.



When you look directly overhead, you don't have to look through as much dirty, turbulent air as you do when you look at something low in the sky. Try to avoid looking at things near the horizon.

If you live in the north, stars to the south never do rise very high; there's nothing you can do about that. (Southern hemisphere residents have the same problem with northern stars, of course.) But stars along the other horizons will appear higher in the sky during different seasons, or at different times of the night.

Who are these guys?

We start with the name and **official designation** of each object. Catalogs and catalog numbers can seem confusing at first, but these are the methods that everyone uses to identify objects in the sky, so you may as well get to know them. It's fun to compare what you see in your telescope with the glossy color pictures that appear in astronomy magazines, where these objects are often identified only by their catalog number.

Brighter stars usually have names – historically, a variety of names. Starting in 2017 the IAU began designating official names and spellings, which we use here.

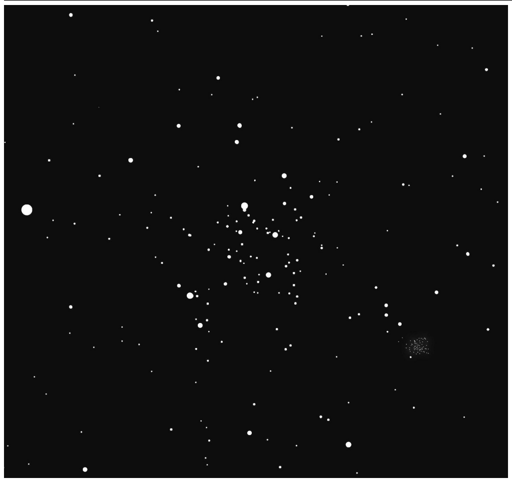
In addition, stars are also designated by Greek letters or Arabic numerals, followed by the Latin name of their constellation (in the genitive case, for the benefit of Latin scholars). The Greek letters are assigned to the brighter stars in the (very approximate) order of their brightness within their constellation. For example, Sirius is also known as *Alpha Canis Majoris* (or *Alpha CMa* for short) since it's the brightest star in Canis Major, the Big Dog. The next brightest are *Beta*, *Gamma*, and so on. Fainter naked-eye stars are known by their *Flamsteed number,* e.g. *61 Cygni,* assigned by position west to east across the constellation.

Subsequent catalogs have followed for fainter stars. The most common are the *Yale Bright Star Catalog* (numbers beginning with HR, after its predecessor, the *Harvard Revised Catalogue*); the *Henry Draper Catalogue* (numbers beginning with HD); and the *Hipparcos/Tycho Catalogue* (HIP numbers) assembled for the Hipparcos spacecraft, which measured parallax distances to a hundred thousand stars.

Double stars also have catalog numbers. Friedrich Struve and Sherburne Burnham were two nineteenth-century double-star hunters; doubles that filled their catalogs now bear their names. Struve variables are traditionally marked with the Greek letter Σ followed by a number. (Friedrich's son Otto also made a catalog of doubles; his stars are denoted with the letters OΣ.)

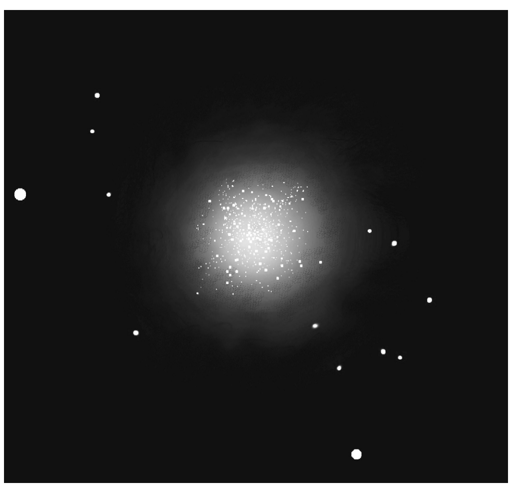
Variable stars are given letters. The first known in each constellation were lettered R through Z. As more were discovered, a double-lettering system was introduced: e.g. *VZ Cancri*. After they ran out of letters, they used numbers as in *V1016 Orionis*.

For clusters, galaxies, and nebulae, two catalogs most used in this book are the *Messier Catalog* (with numbers like *M13*) and the *New General Catalog* (with numbers like *NGC 2362*). Charles Messier was a comet-hunter in the 1700s who had no use for galaxies and nebulae. He kept finding them over and over again, and would get confused because many of them looked like comets to him. So he made a list of them, to let him know what *not* to look at while he was searching for comets. In the process he wound up finding and cataloging most of the prettiest objects in the sky. But he managed to number them in a totally haphazard order. The *New*

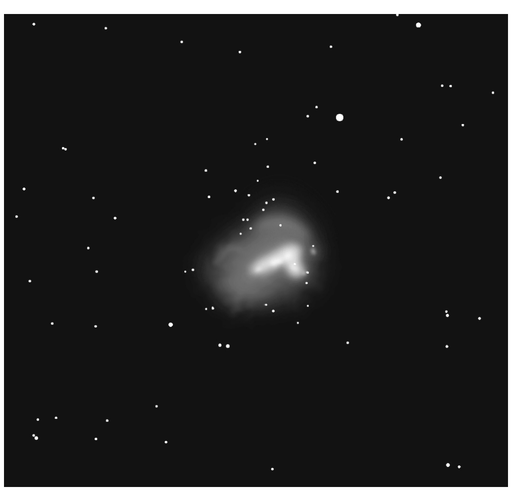


Open cluster: M35

Galaxies: the Leo Trio



Globular cluster: M13



Diffuse nebula: the Swan Nebula

General Catalog, assembled in the 1880s from a century of observations by William Herschel and his son John, numbers objects from west to east across the sky. Objects that you see in the same area of the sky have similar NGC numbers.

What are these guys?

An *open cluster* is a group of stars, often quite young (by astronomical standards), that are clumped together. Viewing an open cluster can be like looking at a handful of delicate, twinkling jewels. Sometimes they are set against a background of hazy light from the unresolved members of the cluster. On a good dark night, this effect can be breathtaking. We discuss open clusters in more detail when we talk about the clusters in Auriga, on page 71.

Galaxies, globular clusters, and the various types of nebulae will all look like little clouds of light in a small telescope.

A *galaxy* consists of billions of stars in an immense assemblage, similar to our own Milky Way but millions of light years distant from us. It is astonishing to realize that the little smudge of light you see in the telescope is actually another "island universe" so far away that the light we see from any of the galaxies that we talk about (except the Magellanic Clouds) left it before human beings walked the Earth. We discuss galaxies in greater detail on page 109, with the Virgo galaxies.

A *globular cluster* is a group of up to a million stars within our own galaxy, bound together forever in a densely packed, spherical swarm of stars. On a good crisp dark night, you can begin to make out individual stars in some of them. These stars may be among the oldest in our galaxy, perhaps in the Universe. On page 115 (M3 in Canes Venatici) we go into the topic of globular clusters in greater detail.

Diffuse nebulae are clouds of gas and dust from which young stars are formed. Though they are best seen on very dark nights, these delicate wisps of light can be among the most spectacular things to look at in a small telescope. See page 55 (the Orion Nebula) for more information on these nebulae.

Planetary nebulae have nothing to do with planets; they are the hollow shells of gas emitted by some aging stars. They tend to be small but bright; some, like the Dumbbell and the Ring Nebulae, have distinctive shapes. We talk about them in greater detail on page 99 (the Ghost of Jupiter, in Hydra).

If the dying star explodes into a supernova, it leaves behind a much less structured gas cloud. M1, the Crab Nebula, is a *supernova remnant*; see page 67.

A *double star* looks like one star to the naked eye, but in a telescope it turns out to be two (or more) stars. That can be a surprising and impressive sight, especially if the stars have different colors. They're also generally easy to locate, even when the sky is hazy and bright.

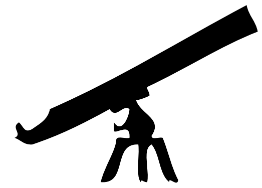
Variables are stars that vary their brightness. We describe how to find a few that can change brightness dramatically in a matter of an hour or less.

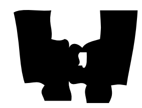
Ratings and tips

For each object you'll see a little box where we provide a *rating*, and list the *sky conditions, eyepiece power,* and the *best months* of the year to look for them. We also note the objects where a *nebula filter* might help the view. And we point out some of the reasons why this particular object is worth a look.

The rating is our own highly subjective judgement of how impressive each object looks. Since each kind of telescope will see the object in a different way, we repeat the ratings three times, with the appropriate symbols for Dobsonians, small telescopes, and binoculars. Obviously some objects are better seen in a large telescope with lots of light-gathering power, and so they'll rate a higher number of Dobsonians than binoculars. But some objects are too spread out to fit into a Dobsonian field of view, such as the Beehive Cluster; these will look better in binoculars.

A few of these objects can be utterly breathtaking on a clear, crisp, dark, moonless night. The Great Globular Cluster in Hercules, M13, is an example. And even if the sky is hazy, they're big enough or bright enough to be well worth seeing. Such an object, and in general any object that is the best example of its type, gets a *four telescope* rating. (The Orion Nebula and the Large Magellanic Cloud rate *five telescopes*. If they are visible in your sky, they are not to be missed on any night.)





Objects that are still quite impressive but which don't quite make "best of class" get a *three telescope* rating. An example is the globular cluster M3; it's quite a lovely object, but its charms are more subtle than M13's.

Below them in the ratings are *two telescope* objects. They may be harder to find than the three telescope objects; or they may be quite easy to find, but not necessarily as exciting to look at as the other examples of their type. For instance, the open clusters M46 and M47 are pleasant enough objects in a small scope, but they're located in an obscure part of the sky with few nearby stars to help guide you to their locations. The open clusters M6 and M7 are big and loose, and easy to find, rating high for binoculars, but they look less impressive in a bigger telescope: only two Dobs.

Finally, some objects are, quite frankly, not at all spectacular. As an example, the Crab Nebula (M1) is famous, being a young supernova remnant, but it's very faint and hard to see in a small telescope. You may have a hard time finding such objects if the night is not really dark or steady. They're for the completist, the "stamp collector" who wants to see everything at least once, and push the telescope to its limits. In their own way, of course, these objects often turn out to be the most fun to look for, simply because they are so challenging to find. But they might seem pretty boring to the neighbors who can't understand why you're not inside watching TV on a cold winter's night. These objects we rate as *one telescope* sights.

Matching the telescope to the weather

Sky conditions control just how good your observing will be on any given night, and so they will determine what you can plan on seeing. The ideal, of course, is to be alone on a mountain top, hundreds of miles from any city lights, on a still, cloudless, moonless night. But you really don't need such perfect conditions to have fun stargazing. We've seen most of the objects in this book even amid suburban lights.

Any night when the stars are out, it's worth trying. True, the visibility of the fainter objects can be obscured by thin clouds, especially when they reflect the light of a nearly full Moon (or the glow of city light pollution); but that is not necessarily all bad news. Some things, like colorful double stars, actually look better with a little background sky brightness to make the colors stand out. And objects that require the highest magnification – double stars again, or planets – demand really steady skies which often occur when there is a thin cloud cover. (The clearest nights are often those associated with a cold front passing through, when the air tends to be turbulent... not to mention hard on the observer's hands and feet!)

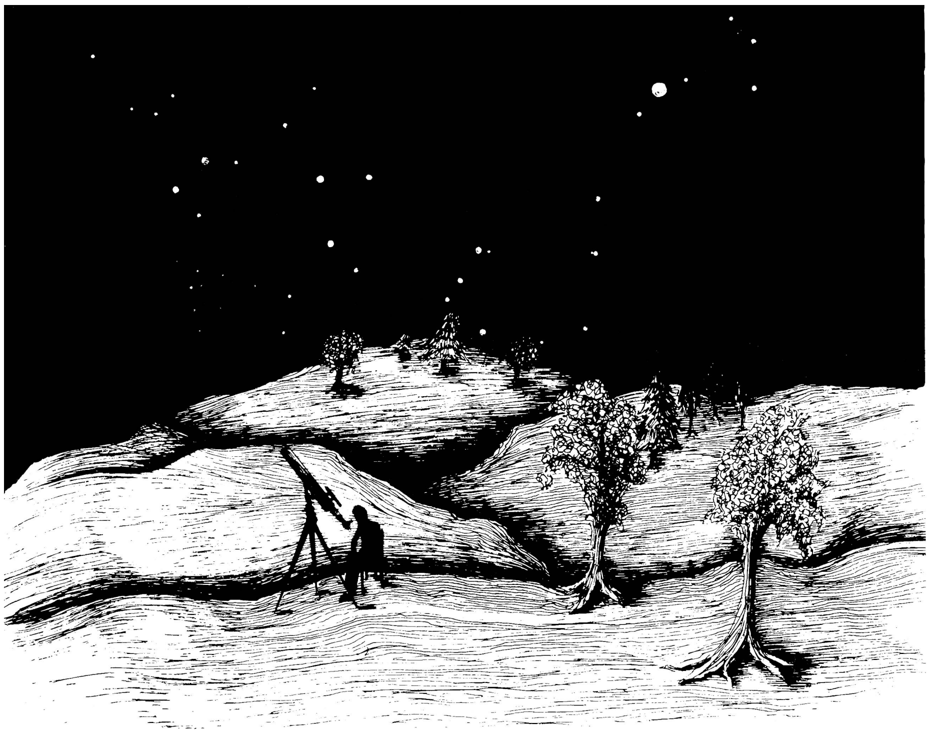
On the other hand, the fainter objects on our list can stand no competition from other sources of light. They are listed as *dark sky* – wait for when the Moon is not up. To see them at their best, take your telescope along on your next camping trip. Not only will the dim ones become visible, but even the bright nebulae will look like brand new objects when the sky conditions are just right.

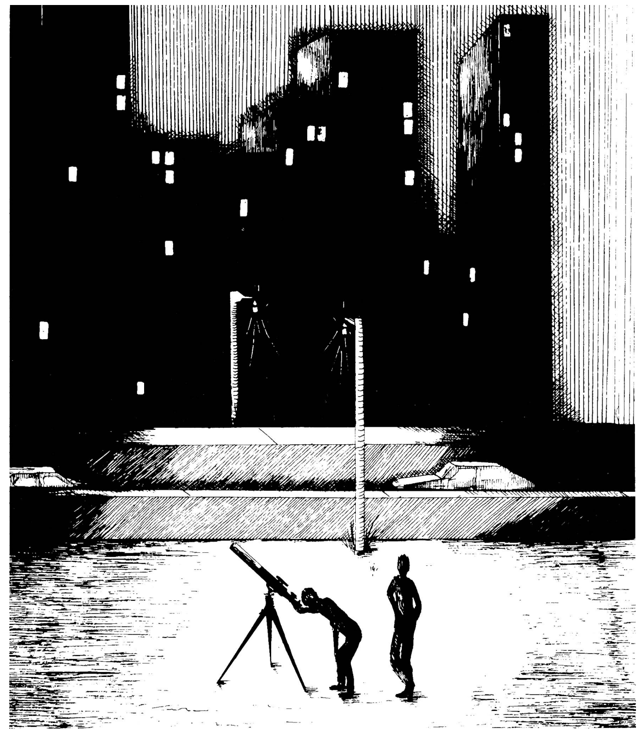
How to look, when to look: eyepieces, filters, best seen

As we mentioned above, telescopes have two different functions: to make small things look bigger, or to make faint things brighter. You control which of those roles it's doing by the eyepiece you choose. In **eyepiece power** you're trading off magnification against brightness and field of view. Your shorter focal length eyepiece will give higher magnification and the longer eyepiece will generally give a greater field of view. For more detail, see pages 18–21, *Know Your Telescope*.

Extended objects like open clusters need low power to fit in the field of view; dim objects like galaxies need low power to concentrate their light. Small, bright objects like planets and double stars may need a high-power eyepiece. Planetary nebulae are small but dim; since the lower-power eyepiece shows you more of the sky, a good technique is to find the object with low power, and then observe it at medium power; then try high power if it is bright enough or the skies are dark enough. Some objects, like the Orion Nebula, are interesting under both low and high power!

Low power makes faint objects appear brighter; unfortunately, it can also make a murky suburban sky brighter as well. Sometimes, once you've found a faint object in low power, you can increase its contrast against the sky by switching to a higher power eyepiece. A more elegant (but more expensive) way to increase this contrast





The ideal observing conditions are to be alone on a mountain top, hundreds of miles from city lights, on a cool, crisp, moonless night. Be sure to bring your telescope along when you go camping! You shouldn't wait for perfect conditions, however. Most of the objects we describe in this book can be seen from the suburbs; many of them, even within a city. The roof of an apartment building can make a fine place for an informal observatory.

is by using an appropriate **filter**. A specially colored filter that cuts out the yellow light put out by sodium street lamps can make a remarkable difference in what you can see through your telescope even when you're fighting light pollution. Even better, a filter that lets through only the greenish light emitted by some nebulae can really bring out detail in otherwise faint objects. But these filters only work for certain objects, mostly diffuse nebulae and planetary nebulae. We indicate when a nebula filter might be appropriate. (Of course, you don't want to use colored filters if you're trying to pick out the colors of a double star.)

The indication for *best seen* lists the specific months of the year when these objects can be found relatively high in the sky, from the end of twilight until about ten o'clock, at about 45° north – roughly, anywhere between Florida and Scotland. (For the southern-hemisphere chapter we assume you're at 35° south, roughly the latitude of Sydney, Cape Town, Buenos Aires, and Santiago.) Of course, as mentioned above, staying up later can gain you a few extra months to preview your favorites.

Where to look, what to look for

The first map for each object is a **naked-eye chart**. These charts generally show stars down to third magnitude. As we mentioned above, magnitude is the measure of a star's brightness, and smaller numbers mean brighter stars. On the best night, the human eye can see down to about sixth magnitude without a telescope; with the glow of city lights, however, seeing even a third-magnitude star can be a challenge.

The next chart shows the **finderscope view**. The little arrow pointing to the west indicates the way that stars appear to drift in the finderscope. (Since most finderscopes have very low power, this westward drift of the stars will seem very slow.)

Finderscopes come in all sizes and orientations. We have assumed that your finderscope turns your image upside down, but does *not* give a mirror image of the sky (see below); check to see how yours behaves, and use our charts accordingly. (Before sunset, aim your telescope at a distant street sign or car license plate: is it upside down? Is it mirror imaged?) Likewise, the field of view of finderscopes can vary, but they usually show about 5° to 6° of the sky. The circle we draw in our views assumes a 6° field, and the whole finderscope-view box is generally 12° square.

On the right-hand page we show the **telescope view:** what the object should look like through your eyepiece. Usually we give two views, one as seen in a small telescope through a star diagonal (see below) and the other as seen in a Dobsonian or other Newtonian telescope. Notice that one is the mirror image of the other, as we will explain shortly.

These pictures are based on our own observations with small telescopes. The idea is that if you can match up what you see with what's in our picture, then you'll know that you are actually looking at the same object we're talking about. What we have drawn is what a typical person is likely to notice, and we don't always show all of the fainter stars in the field of view. These pictures are not meant to serve as technical star charts – don't try to use them in celestial navigation!

Again, follow the links on our website www.cambridge.org/turnleft to find these charts in other orientations.

Note that we treat double stars somewhat differently. These stars are relatively bright and usually easy enough to see (if not split) with the naked eye. For that reason, you don't need the same kind of elaborate directions to find them as you do for the fainter clusters and nebulae. Within each season we have gathered the best of the doubles into occasional double-star spreads with a more detailed finder chart pointing out the locations of the best examples in the area. Then each double is pictured in a close-up circle: a circle of two thin lines represents a view ten arc minutes across, while a thick/thin pair of circles denotes a closer, higher-powered view, only five arc minutes in diameter. These close-up views assume a Dobsonian orientation. Their purpose is merely to give you an idea of the relative distance and brightness of the companion, and if there are any other stars in the field of view. These pages also include a little table describing the individual double stars, their colors and brightness, and how close together (in *arc seconds*) they appear to be.

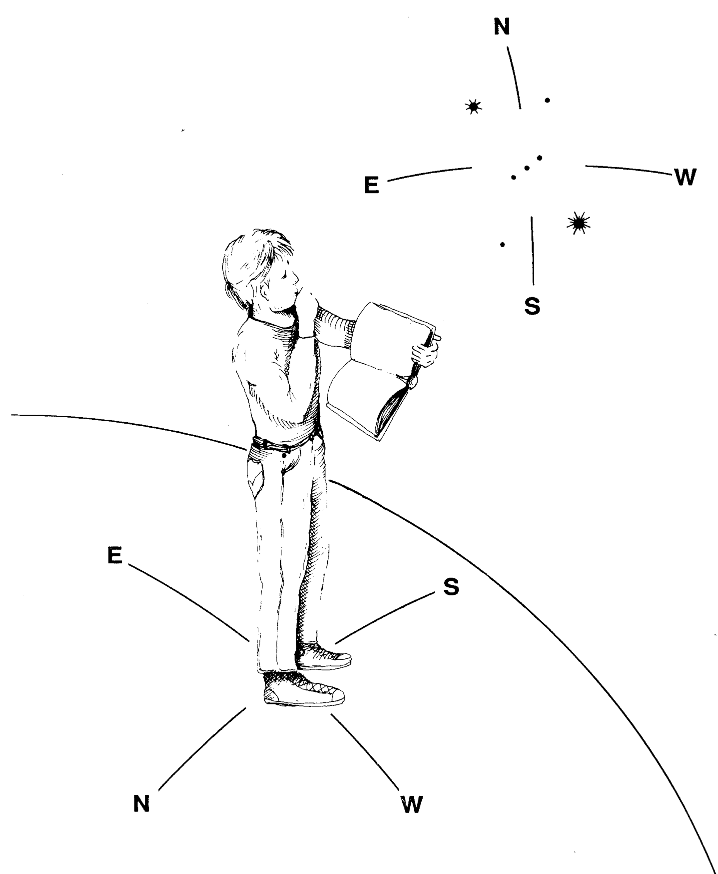
(What are arc minutes and arc seconds? They are the way we indicate the size of a very small angle. The arc of the sky from horizon to zenith is an angle of 90°. Each degree can be divided further into 60 minutes of arc, usually written 60' (the full Moon is about 30' across) and each minute can be further divided into 60 seconds of arc, or 60". Thus one arc second is 1/3,600 of a degree – as tiny a separation as you'll ever be able to make out in a small telescope.)

The low-power eyepiece view assumes a power of between 35× to 40×; this is what you'd use for large clusters of stars and a few big galaxies. The medium-power eyepiece drawing assumes roughly a 75× view. The high-power eyepiece drawing gives a view magnified about 150×. And because larger telescopes like Dobs can handle even higher power, in a few of the Dobsonian fields we include an inset with a very high-power view of 300×. To get this kind of magnification, you either need a very short focal length eyepiece or an additional lens called a Barlow. (We talk about Barlow lenses with other *Accessories* on page 244.)

Note again that we've included an arrow to show the direction that stars will drift. As the Earth spins, the stars will drift out of your field of view; the higher the power you are using, the faster the drift will appear. Though this drift can be annoying – you have to keep readjusting your telescope – it can also be useful, since it indicates which direction is west.

In the text, we describe where to look and how to recognize the object. And we comment about some of the things worth looking for in the telescope field – colors, problems that might crop up, nearby objects of interest. Finally, we describe briefly the present state of astronomical knowledge about each object, a guide to what you're looking at.

Standing on the Earth, looking out from inside the globe of the sky, the directions east and west appear to be reversed from what we're used to on ordinary maps.



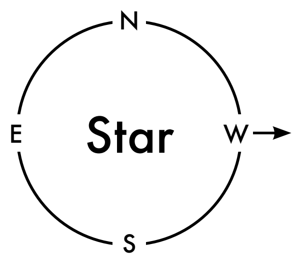
East is east, and west is west… except in a telescope

What about the orientations of these pictures? Why do we seem to confuse south and north, or east and west?

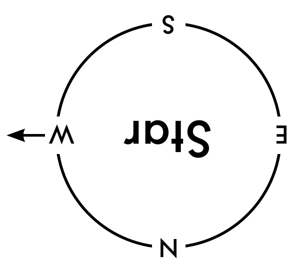
There are several things going on. First, we're all used to looking at road maps or geographical atlases: maps of things on the ground under our feet. There, traditionally, north is up and east is to the right. However, when we look at the sky our orientation is just backwards from looking at the ground. Instead of being outside the globe of the Earth, looking down, we're inside the globe of the sky, looking up. It's like looking at the barber's name painted on a window; from inside the barber shop, the lettering looks backwards. In the same way, a sky chart keeping north up must mirror east and west: west is to the right and east is to the left.

Next, many finderscopes are simple two-lens telescopes. This means that, among other things, they turn everything upside down. (Binoculars and opera glasses have to have extra lenses or prisms to correct for this effect.) So instead of north at the top, we'd see south at the top and north at the bottom, with east and west likewise reversed. But nowadays many finderscopes do have an extra lens or prism to turn the image rightside up again. Some evening before it gets dark, check out your finder by aiming it at a nearby street sign and see what kind of orientation it gives you.

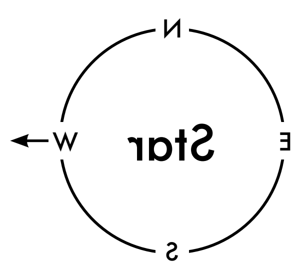
We've chosen to orient the finder views with south at the top: this matches the view of what a typical simple two-lens finder will show to most of our readers (living in the northern hemisphere) when looking at most of the objects in this book as they arc across the southern sky. It also matches what southern hemisphere observers will see when looking south at all the glorious objects around the south pole. For our northern circumpolar objects, however, we twist the finder view to have "north" at the top. (Southern hemisphere observers looking at objects in the north can find rotated versions on our website; or just turn the book upside down!) And, of course, once you're pointed up at the sky, what's "up" is likely to be any direction: as the night progresses its apparent orientation will twist around as it moves across the sky.



• Naked eye
• Binoculars and "spotter scopes"
• Some finderscopes



• Dobsonians (and other Newtonians)
• Simple telescopes without star diagonals
• Some finderscopes



• Telescopes with star diagonals (typically refractors, catadioptrics, and some finderscopes)

A star field as it appears to the naked eye; upside down, as it appears in a Dobsonian; and mirror imaged, as it appears in most telescopes with a star diagonal. To determine your telescope's orientation, try reading the lettering on a distant sign.

The arrows show the directions that stars appear to drift, moving east to west, across the field of view.

Finally, most refractors and catadioptric telescopes sold nowadays have an attachment called a *star diagonal,* a little prism or mirror that bends the light around a corner so you can look at objects up in the sky without breaking your neck. This means, however, that what you see in your telescope is a mirror image of your finderscope view. It's also a mirror image of almost any photograph you'll find in a magazine or book. The orientation as seen through a star diagonal is what we use in our "small telescope with a star diagonal" views.

But Dobsonian telescopes do not use star diagonals. (A Dobsonian is the most common example nowadays of what is classically called a Newtonian design. What we say here applies to all Newtonian telescopes.) So it does not have that extra mirror image affect. But it does show the object upside-down from what you expect, which means that to push an object into the center of the field of view can often mean moving the telescope in just the opposite direction of what you might expect. (One trick is to "drag the object;" in other words, push or pull the telescope in the direction you want to push or pull the object in order to center it in your field.) Since a Dobsonian usually has at least twice the aperture (and thus at least four times the light-gathering area) of a small scope, the Dob view will also include more stars, fainter stars, and larger areas of nebulosity. We try to show just how much more, in our drawings.

Notice, finally, that many spotter scopes sold for terrestrial use nowadays come with a 45° angle prism called an *erecting prism*. This does *not* give a mirror-imaged view. Don't confuse these devices with true star diagonals; they're handy for bird-watching, but they'll still give you a crick in your neck when you try to use them to look at stars overhead. If you can, see if your telescope dealer will replace this with a true 90° findercope. The view you get through an erecting prism will be better represented by the Dobsonian view, at least in terms of the orientation of the stars, though not of course in the detail you'll actually see … unless you have a very large spotter scope indeed.

There's more to be found online

Throughout this book you'll see links to the accompanying web resources. This book can be used without ever referring to these internet resources, but we hope that you'll explore the website and use it to enhance your experience.

How do you do that? Start by going to the site (www.cambridge.org/turnleft). Along the left banner you'll see a link for the Home Page and one for How to Use This Website. Below them are about a dozen more links. Let's explore each of these in turn:

The Moon: On pages 26–37 we follow the Moon through the month and we show images of features to look at each night. Depending on the telescope, finderscope, or binoculars you're looking through and the hemisphere in which you live, there are four different orientations in which things can appear: rotated 180° (or not) and mirror-flipped (or not). In the book, the way in which we show objects on the Moon is how they appear using binoculars or the naked eye in the northern hemisphere (this is the same orientation as with a Dobsonian telescope in the southern hemisphere).

But what if you're using a Dobsonian in the northern hemisphere (or binoculars in the southern hemisphere)? On the Moon part of the website (www.cambridge.org/features/turnleft/the_moon.htm), that's the first of the three alternative orientations for each Moon phase. The other two options are for a refracting or catadioptric telescope, in either the northern or southern hemisphere. Whichever version of the charts you need, just bring them to the telescope by either printing them out or having them on your laptop or tablet.

The Planets: Keeping track of where to find the planets is tough to do in a book; simple tables like we used in earlier editions are imprecise and quickly go out of date. Faint objects, like Uranus and Neptune, really need detailed finder charts; fast moving objects like comets and asteroids are even harder to describe. But in fact, precisely this material is best found online. We give links to our favorite resources.

Seasonal Skies: These pages are organized as in the book, by the seasons of the year (or parts of the world) that are favorable for observing each object. Simply choose the part of the sky (say, April–June or Northern skies) and click on the link. There you'll find all the objects in that chapter of the book. As with the Moon, we provide alternative orientations for all the seasonal object charts in the book.

The book's naked-eye charts are shown as seen in the northern hemisphere; the webpage has a version that is flipped for southern hemisphere observers.

The finderscope charts in the book are rotated 180°, to match the northern hemisphere view in a simple finderscope without a star diagonal. The charts in the website cover the three other possibilities: with a star diagonal in either hemisphere or without a star diagonal in the southern hemisphere. As with the Moon charts, simply find the appropriate version for your finderscope and hemisphere and use it at your telescope.

There are two versions of the telescope view charts in the book; one is for a small (3" or 4") catadioptric or refractor and the other is for a moderately large (8") Dobsonian. The website includes the corresponding charts as seen in either a small Dob or a large Cat or refractor.

For each object, there are also additional links to things like white-on-black drawings, Astronomy Picture of the Day images, data sheets on the objects, and chart numbers where they can be found in some popular star atlases.

Where Do You Go From Here? Here we give suggestions for the next steps to take after you've seen most of what is in this book – websites, magazines, software, clubs and organizations, and stargazing equipment.

What's Up This Month? It's really frustrating to decide that you want to see something like Uranus or Neptune, a lunar eclipse, a Saturn ring-plane crossing, or a favorable apparition of Mercury only to find that you're a month too late and you'll have to wait a year (or a decade or more) for your next chance. Magazines and other websites are the best place to get detailed information on what's happening in the sky, but this link can give you warning of some key things not to miss.

Tables: Here you'll find enhanced versions of the tables at the back of the book, in .pdf and .txt formats; and for those who want to keep records of their own observations of objects in the book, in .xls (spreadsheet) format as well.

At www.cambridge.org/turnleft *you can find flipped, mirrored, and inverted versions of all our star charts.*

Know thyself (and thy telescope)

If you're just starting to observe, the next section of this chapter on knowing and using your telescope may be handy. We explain how your telescope works, and how that affects your choices of what to observe, what lenses and accessories to use, and why objects look different from one telescope to another.

At the end of the book, we talk a bit more about this new fifth edition, and Dan suggests some more advanced books you might like to look into to become a more knowledgeable observer. For those thinking to upgrade their 'scopes, we talk about telescope accessories and the relative advantages of Cats and Dobs. And we provide **tables** of all the objects we've talked about, with their coordinates and technical details. Check it out while waiting for the Sun to set.

But, except for these first and last chapters, the rest of this book is meant to be used outdoors. Get it dog-eared and dewy. After a year of observing, you'll be able to tell your favorite objects by the number of grass-stains on their pages!

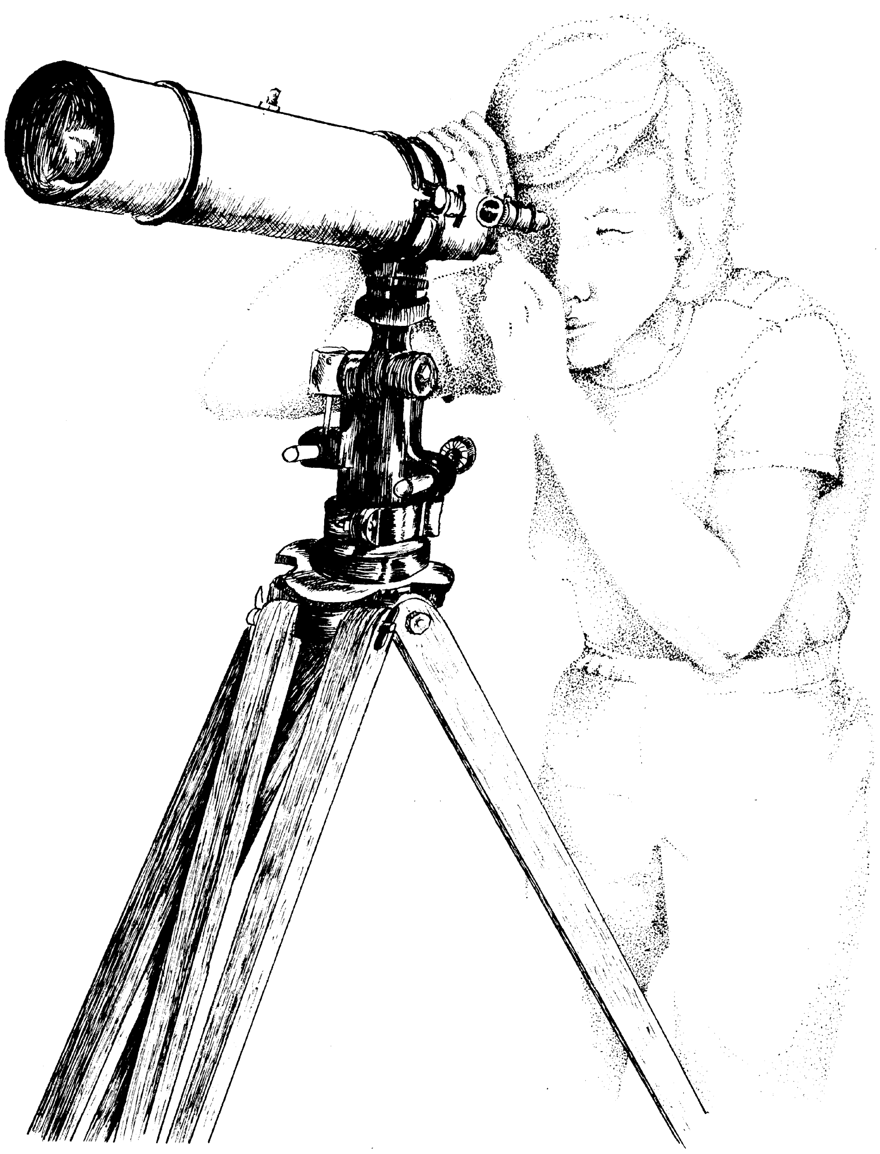
Using your telescope

Find a place to observe

The easiest place to observe is your own back yard. Certainly, you'll have trouble seeing faint objects if there are bright streetlights nearby; and you'll have trouble seeing anything at all through tall trees! But don't sit around waiting for the perfect spot or the perfect night. Observe from some place that's comfortable for you … say, someplace with easy access to hot tea or coffee (and a bathroom). You shouldn't have to make a major trip every observing night. Save that for special occasions.

If you live in a city, the roof of a building can be a fine place to observe. You'll be above most of the streetlights, and if your building is tall enough you may be able to see more of the sky than your suburban tree-bound friends.

However, you do have to be outdoors. The glass in most windows has enough irregularities that, magnified through the telescope, it can make it impossible to get anything into really sharp focus. In addition, the slightest bit of light in your room will cause reflections in the glass that will be much brighter than most of the things you'll be looking at. You could get around these problems by looking through an open window, but – besides the obvious problem that your field of view would be very restricted – during most seasons you have the problem of warmer air from inside mixing with colder air from outside: light travelling through alternately hot and cold air gets bent and distorted, causing an unsteady, shimmering image.



The time you spend aligning your finderscope will spare you hours of fruitless searching for objects later on.

Find your finderscope

One thing that's well worth your time doing while it's still daylight outside is lining up your finderscope.

The finderscope is a big key to making your telescope fun to use. If it is properly aligned, then you can find most objects in the sky pretty quickly. If it isn't, finding anything (even the Moon!) becomes painfully frustrating.

Your finderscope comes with a set of screws that can be adjusted, either by hand or with a small screwdriver, to point it in slightly different directions. Go outside, and set up your telescope where you can aim it at some distinctive object as far away as possible … a streetlight down the road, the top of a distant building, a tree on a far-off hilltop. Just keep looking through the telescope itself until you see something distinctive.

Now, try to find it in the finderscope. (We assume you've chosen something big enough for you to see through your finderscope as well as in the telescope.) Twist the screws until that object is *exactly* lined up with the cross-hairs of the finder. "Close" is *not* good enough. The set screws always seem to move the finderscope in some totally unpredictable direction, but be patient and keep working until you've got it exactly right.

Then – here's the worst part – be sure all the set screws are as tight as possible, so that the finderscope won't move out of alignment as soon as you move the telescope back inside. Tightening up the screws inevitably goofs up the alignment, so you'll probably have to go though this procedure two or three times before you've got it right.

But it is time well spent. A telescope with a misaligned finderscope is a creation of the devil, designed to infuriate and humiliate and drive stargazers back indoors to watch re-runs. Don't let it happen to you.

Cool it

Temperature changes cause problems when you first take your telescope into the cold outdoors from a warm, heated house. Warm mirrors and lenses may warp out of shape as they cool down and contract. Worse yet, warm air inside the tube can set up distorting currents as it mixes with the cold outside air. This can seriously hurt your telescope's resolution.

For a small telescope, ten minutes' cooling time should prevent this problem. You don't have to stand around doing nothing during this time; just wait awhile before looking at objects that require your telescope's best resolution.

But a Dobsonian has a lot more mirror to cool, and that mirror is at the bottom of a long tube. It takes a lot longer to cool down. Set it up outside just after sunset (no sense letting the Sun's rays heat up the tube) and wait at least half an hour, during twilight, before doing any serious observing.

Evening dews and damps

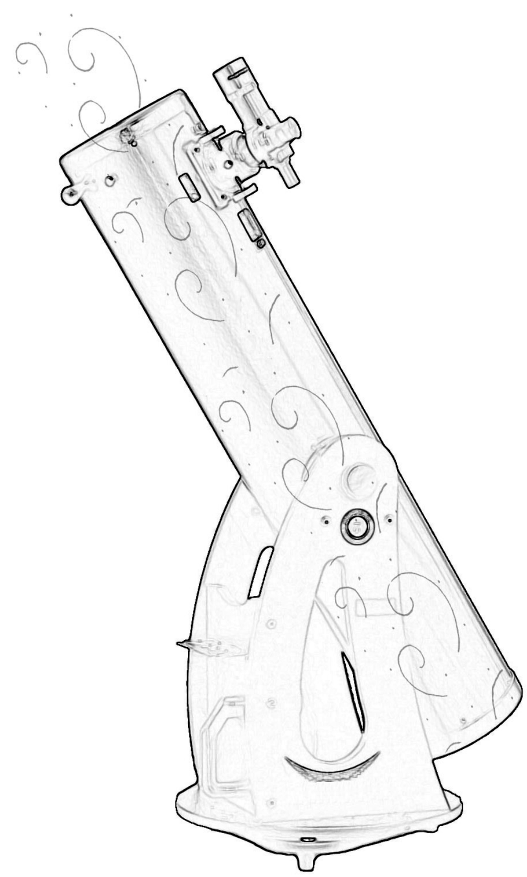
If every star looks like a nebula to you, check for dew on your lenses!

Dew forms on your telescope because, ironically enough, it's possible for the telescope to cool down too much. On nights with a moderate amount of humidity (not enough to form clouds, but enough to make the grass damp) you'll find that solid objects taken outdoors can radiate away their heat faster than the moist air around them cools off. (Why? Because solid objects can radiate in many wavelengths, including wavelengths not absorbed by the air; but water-laden air absorbs in the same limited wavelengths it radiates, so it takes a longer time for its heat to escape.) This means that your telescope will soon be cooler than the air, and it will start beading up like a cold can of soda pop on a muggy summer day.

Whatever you do, resist the temptation to wipe the surfaces of your lenses. It runs the certain risk of damaging the lenses. And it doesn't do much good in the long run, as they'll just dew up again anyway!

One solution is to blow hot dry air across the lens – try a hair dryer, or hold the lens near the defroster vent in your car, but be sure not to overheat the lens. If you can, bring a dewed-up telescope (or at least your eyepieces and maybe your finderscope if it easily detaches from the main 'scope) indoors for fifteen minutes or so to dry out. There's no point using a lens if you can't see through it!

It takes a surprisingly long time to cool down a Dob. Set it up outside just after sunset and wait at least half an hour before serious observing.



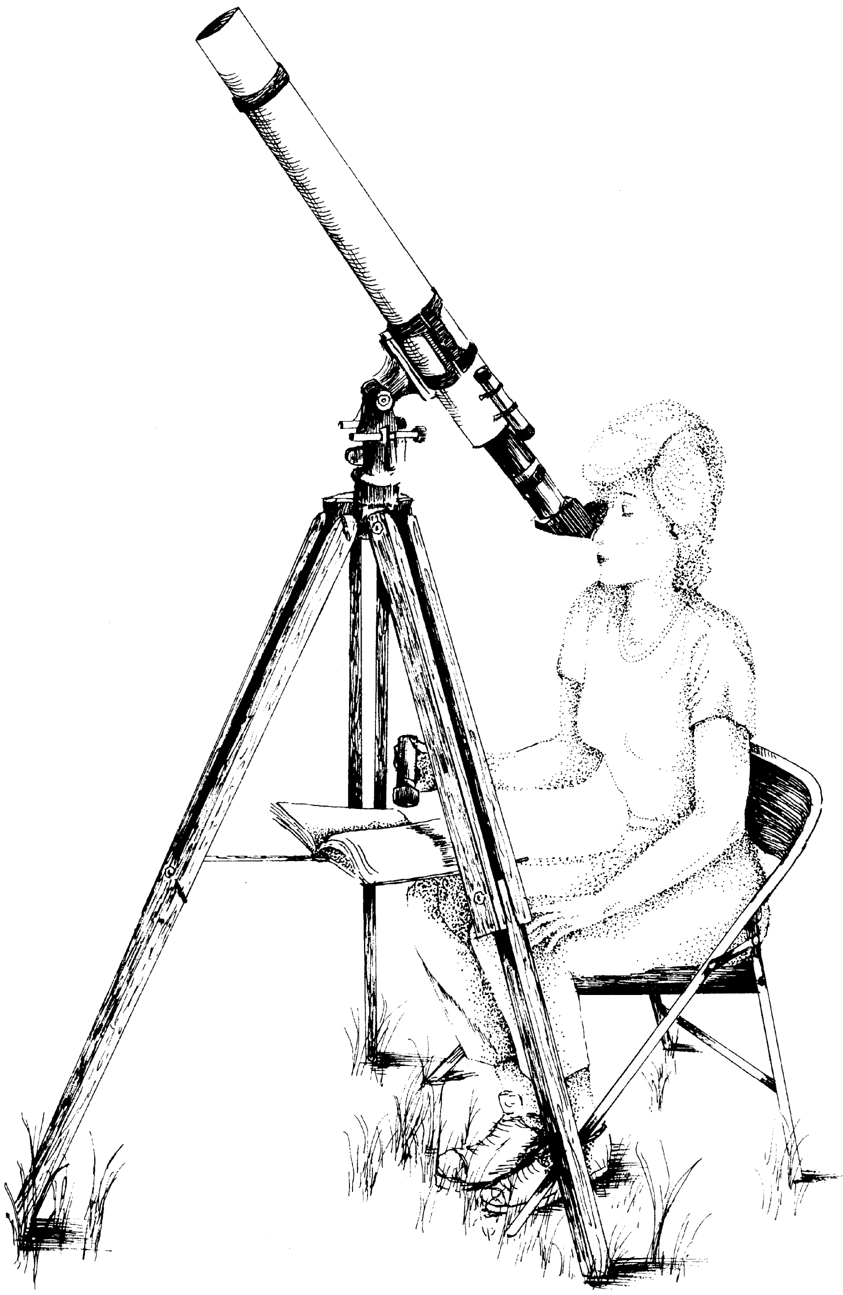
The simplest solution is to block the telescope lens from radiating its heat. A long black tube (called a *dew cap*) sticking out beyond the lens stops the radiation and keeps the lens warm. Lacking a dew cap, in a pinch you can just roll a piece of black paper around the lens; or point the telescope down towards the ground when you're not using it. Or, if you can afford it, electric powered bands to heat your lenses are available (see page 244). Dan swears by his.

Dobsonian and other Newtonian telescopes, of course, have their mirror at the bottom of just such a long tube, so that's less likely to dew up (though if you're out long enough, they will dew, too). However, their finderscopes and eyepieces can still turn milky with dew before you realize it.

On cold winter nights, moisture trapped inside a telescope with a closed tube (a refractor or catadioptric) can condense on the *inner* sides of the lenses when the telescope cools off outside. The best way to deal with this kind of condensation is to eliminate the warm, moist air altogether. When you take out your telescope into the cold, remove the star diagonal so that the inside of the tube is open to the air, and point the telescope down towards the ground so that the hot air inside the tube can rise out and be replaced by the cooler outdoor air. But on especially dewy nights, beware lest condensation drip down the eyepiece tube into the telescope! This can be a serious problem with the larger catadioptric designs.

Prepare yourself

The whole point of your telescope is to gather starlight and bring it to a good, sensitive detector: your eye. And, just as professional detectors are housed in elaborate containers to keep the environment around them perfect, so too you should keep your eye's container – you! – warm and safe and comfortable.



Be prepared for the cold. You'll be sitting still for a long time, so dress extra warmly. In the winter, an extra layer of everything is a good idea, and gloves are a necessity for handling the metal parts of a telescope. A thermos of coffee or hot chocolate can make all the difference in the world. In the summertime, keep your arms and legs covered as protection from the chill, and from bugs as well.

Get a chair or stool to sit on, or a blanket to kneel on, and a table or a second chair for your flashlight and book. These are the sorts of things you may think are too elaborate to bother with, but in fact they're just the sort of creature comforts that allow you to enjoy yourself while you're observing. It only takes a minute to set up a stool and a table, and it will keep you happy for hours. After all, the point is to have fun, not to torture yourself.

It takes time for your eyes to get used to the dark. At first the sky may seem good and black, but you may not see so many stars in it. Only after about fifteen minutes or so will you begin to see the dimmer stars … and the glare from the shopping center ten miles away. That's the point when you can try to observe faint nebulae.

And once you get dark-adapted, avoid lights. You can lose your dark adaptation in an instant, and it can take another ten minutes to get it back again.

You'll want a small red-light flashlight to read your book and star chart. Red fingernail polish on a flashlight lens is a stargazer's time-honored tradition; it makes it easier for your eyes to remain adapted to faint light.

Dobsonian users: align your optics

One of the prices you pay for the large size of a Dobsonian telescope is that the primary and secondary mirrors need to be adjusted almost every night to make sure that they are actually sending the starlight straight into your eyepiece. (Catadioptrics and refractors have their lenses and mirrors fixed at the factory, and usually don't need to be adjusted.) The more the tube gets shaken up, the more likely the mirrors are to get out of alignment. Since these telescopes tend to be rather heavy and bulky, carrying them regularly from your garage or closet to your back yard is just the sort of thing to shake up those mirrors.

How do you align your mirrors? Every telescope is different. The easiest way is to purchase a laser collimation device, but they can be expensive – a good fraction of the cost of the telescope. Still, if you find yourself using your Dob several times a month, they're worth the price.

Absent such a system, the simplest way to align your mirror is to aim the telescope at a very bright star and put it out of focus until you see a donut of light with a big black spot (the shadow of the secondary mirror). Adjust the primary mirror, twisting the set screws where it is mounted, until the spot sits right in the center of the donut.

Get a chair or stool to sit on, or a blanket to kneel on, and a table for your flashlight and book. Red fingernail polish on the flashlight lens is an astronomer's time-honored tradition. It cuts down the glare from the flashlight, so that your eyes can stay sensitive to the faint starlight.

When you're finished: storing the telescope

In big observatories, there's a regular procedure the astronomers go through every night after observing, to arrange the telescope so that the weight of the massive mirror won't cause it to warp out of shape. Your 2" telescope doesn't have that problem! Basically, anyplace that is reasonably clean and cool will serve well as a storage area. (The cooler the telescope is before you take it out, the less time you'll have to wait for it to adjust to the outdoor temperature.)

If you've got the room, you may want to consider keeping the telescope assembled on its mount, ready for use at a moment's whim. The easier it is to get at, the more likely you are to use it; and the more you use it, the easier (and more fun) it'll be to find and observe faint objects in the nighttime sky. As long as it's out of reach of puppies and toddlers, your telescope is better off set up and visible than stored disassembled in a closet where its pieces can get stepped on or lost.

The care and feeding of lenses

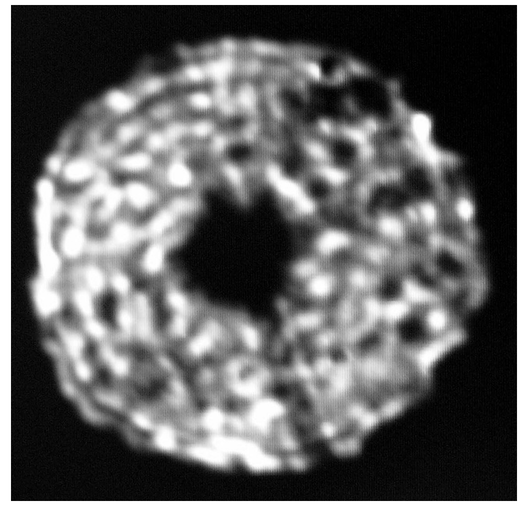
Dust is your lenses' constant enemy. Not only will it scatter light every which way, but as the dust moves along the lens it can scratch the delicate optical coatings, leaving behind a permanent scar.

Camera stores sell many different little gizmos that can blow dust off your lenses. Cans of compressed air are popular, for instance; but be careful in case the one you want to use ends up depositing something other than air. (Try it out first on a clean glass from your kitchen; any residue on that glass would also be deposited on your lens, bad news.) Above all, don't use your breath to blow on your eyepiece lens unless you want to mar it with whatever else (like moisture) that is in your mouth!

Fingerprints are a true horror. An imperfection on the lens of as little as a thousandth of a millimeter can degrade the efficiency of your lens; the layer of grease that comes off your finger every time you touch something is just such an imperfection. A year's worth of accumulated fingerprints and dust can turn an eyepiece into a milky nightmare. It's great to let children look through your telescope, but maybe have them use an older lens, lest sticky little fingers wander where you don't want them.

Prevention is the best solution. The only way to keep dust and prints off your lenses is to store them covered until you need them, so they won't get touched even by accident.

Lens caps are easily lost if you're not careful. It is well worth your while to become a fanatic about keeping track of them. Make it a habit always to keep them in the same place – a certain pocket, or a certain corner of the telescope case. And use your lens caps, even while you're observing, whenever you're not looking through the lens itself. It helps prevent you (or your helpful neighbor) from accidentally touching the glass. It can also help in limiting the amount of dew on the lenses.



Dobsonian telescope mirrors need to be collimated regularly. The simplest way to align your mirror is to aim the telescope at a very bright star, and put it out of focus so that you can see a big donut of light, looking like this. The black spot is the shadow of the secondary mirror; the black lines, the shadows of the "spider" struts that hold the secondary in place. Adjust your primary mirror (usually there are small screws at the back of the mirror) until the black spot sits right in the center of the donut. Note: this image is not actually from a Dob, but from the 1.8-meter Vatican telescope – all large reflectors need collimation!

How to clean your lenses

The default answer is always the same: Don't do it. The fact is, cleaning your lenses is always a risk. It's usually one not worth taking.

If you've been taking good care of your lenses, then they will be so clean that the tiniest imperfection may stand out like an eyesore. One fingerprint and a few dust grains don't really affect the performance of your telescope that much, certainly not enough to risk permanent damage to the optics. What may look glaring when looking at the Moon or a planet might have no discernible effect when looking at deep-sky objects: the cure (cleaning) may be much worse than the disease! This is doubly true of a reflector's primary mirror: it's amazing how much dust can accumulate there without causing problems.

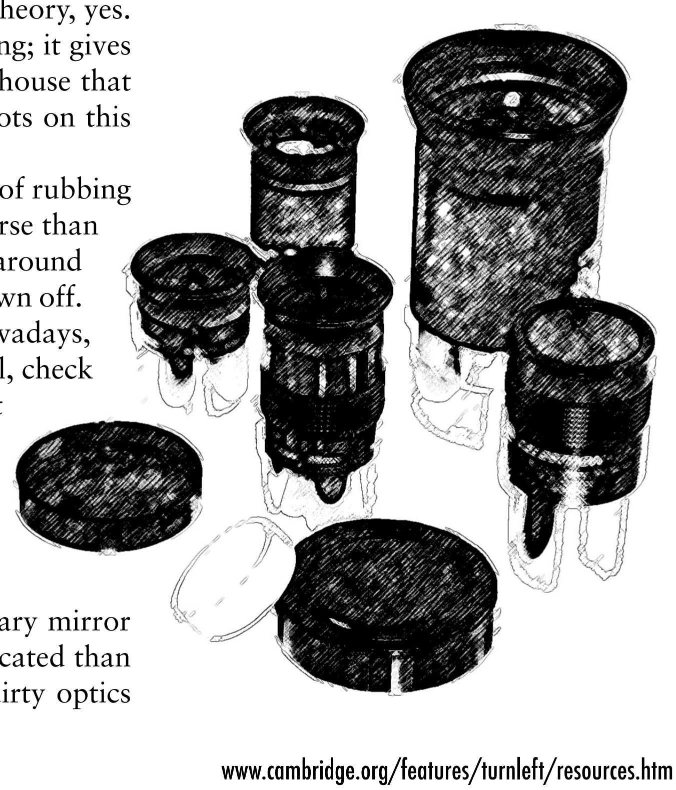
But what if, in spite of all your efforts, there's a perfect thumbprint on your favorite eyepiece? Is it possible to clean it off without hurting the lens? In theory, yes. But the trouble is, every high-quality lens has a thin anti-reflection coating; it gives the lens its characteristic bluish color. Most obvious things around the house that you could think of to clean fingerprints off the lens will either leave spots on this coating or destroy it outright.

And anything you use to apply these cleaning solutions runs the risk of rubbing the grime across the coating, leaving behind permanent scratches far worse than the original fingerprint. What's more, any liquid used in cleaning can settle around the edges of the lens, carrying the grunge there where it can't easily be blown off.

That said, there are good commercial lens cleaning kits available nowadays, and the coating on modern lenses is more durable than in years past. Still, check your lens specifications: some cleaners might be safe on one surface, but damage another. For example, some cleaners use isopropyl alcohol which can stain certain eyepiece coatings. (Distilled water is usually safe.)

A number of websites have useful instructions on the care and cleaning of lenses and mirrors; our website directs you to some of them.

The important things to remember are that you should only use a high quality lens cleaning kit; and that cleaning large surfaces (like the primary mirror of a Dob or, worse, the front corrector lens to a Cat) is far more complicated than cleaning an eyepiece. Above all, remember that the default regarding dirty optics should always be to prevent rather than to clean.



www.cambridge.org/features/turnleft/resources.htm

Know your telescope

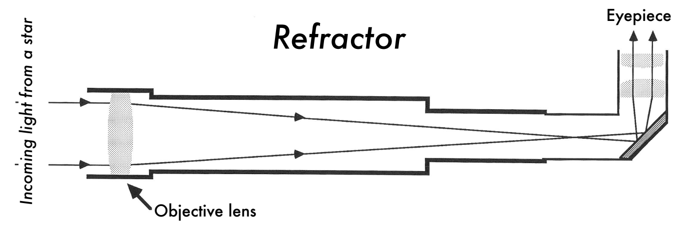
Galileo discovered the four major moons of Jupiter (forever after called the Galilean satellites *in his honor); he was the first to see the phases of Venus and the rings of Saturn; he saw nebulae and clusters through a telescope for the first time. In fact, a careful checking of his observations indicates that he even observed, and recorded, the position of Neptune almost 200 years before anyone realized it was a planet. He did all this with a 1" aperture telescope.*

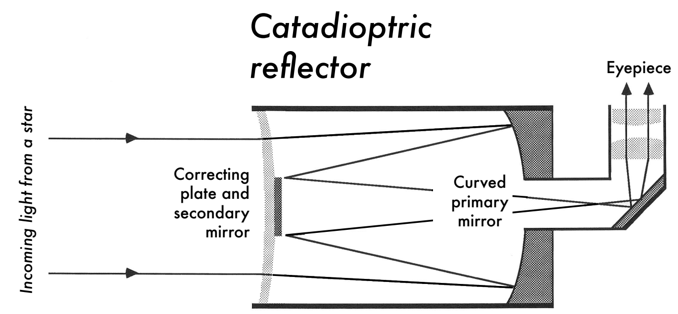
Charles Messier, who found the hundred deep-sky objects in the catalog that bears his name, started out with a 7" reflector with metal mirrors so poor that, according to one account, it was not much better than a modern 3" telescope. His later instruments were, in fact, 3" refractors.

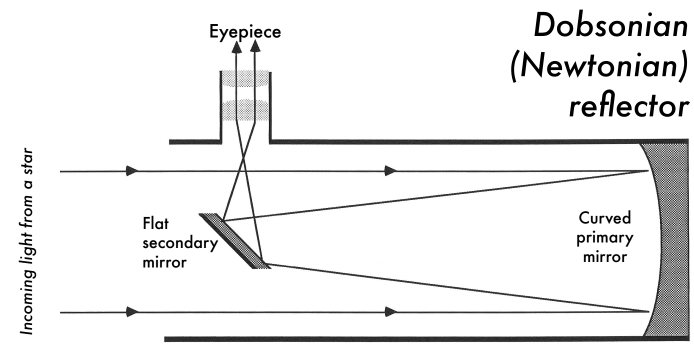
The point is this: there are no bad telescopes. No matter how inexpensive or unimpressive your instrument is, it is almost certainly better than what Galileo had to work with. It should be treated well. Don't belittle it; don't apologize for it; don't think it doesn't deserve a decent amount of care.

Get to know your optics

An astronomical telescope has two very different jobs. It must make dim objects look brighter; and it must make small objects look bigger. A telescope accomplishes these jobs in two stages. Every telescope starts with a big lens or mirror called the *objective*. This lens or mirror is designed to catch as much light as possible, the same way a bucket set out in the rain catches rainwater. (Some astronomers refer to their telescopes as "light-buckets.") Obviously, the wider this lens or mirror is, the more light it can catch; and the more light it catches, the brighter it can make dim objects appear. Thus, the first important measurement you should know about your telescope is the diameter of the objective. That's called the *aperture*.







If your telescope uses a lens to collect light, it's called a *refractor*; if it uses a mirror, it's called a *reflector*. In a refractor, the light is refracted, or bent, by a large lens called the objective lens. In a reflector, the light is reflected from the primary mirror, sometimes called the objective mirror, to a smaller mirror sitting in front of the objective, called the secondary mirror. In both cases, the light bent by the objective is further bent by the eyepiece lens, to make an image that can be seen by your eye.

A reflector where the light is sent back through a hole in the main mirror is a *Cassegrain* reflector. *Catadioptric* reflectors have, in addition, a lens in front of the primary mirror that allows the telescope tube to be much shorter. A specific catadioptric design that works well for amateurs is one called the *Maksutov* reflector; bigger Cats often use a slightly different design, called a *Schmidt*.

A reflecting telescope in which the secondary mirror bounces the light sideways through a hole near the top of the telescope tube is a *Newtonian* reflector. The most popular amateur version of the Newtonian design nowadays is the *Dobsonian*, a Newtonian with a simple but elegant alt-azimuth mount invented by John Dobson.

The primary mirror (or, in a refractor, the objective lens) bends the light to concentrate it down to a small bright image at a point called the *focal point*. The light has to travel a certain distance from the objective until it is fully concentrated at this point; this distance is called the *focal length*.

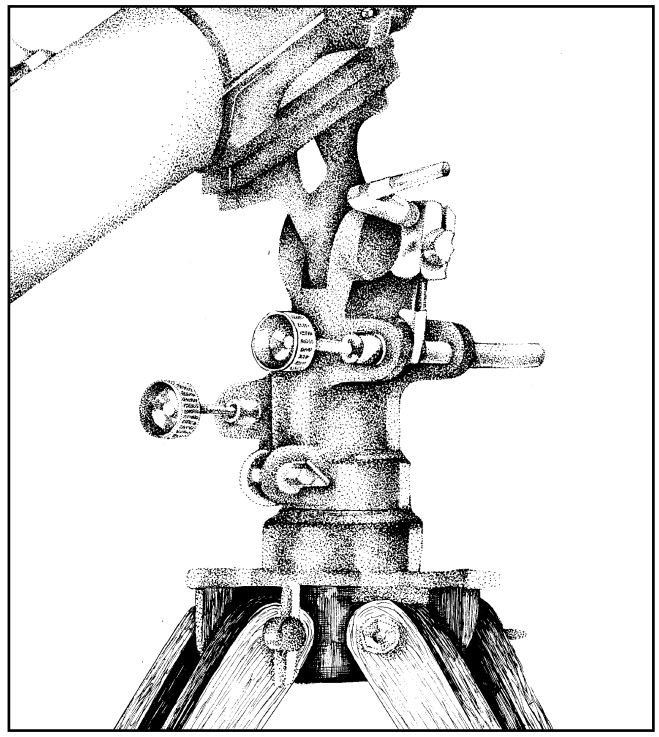
The small, bright image made by the objective seems to float in space at the focal point. Put a sheet of paper at that spot (or piece of film, or a photographic CCD chip, or a slice of ground glass) and you can actually see the little image that the objective makes. This is what's called the *prime focus* of the telescope. If you attach a camera body there, with the camera lens removed, you can take a picture. The telescope is then just a large telephoto lens for the camera.

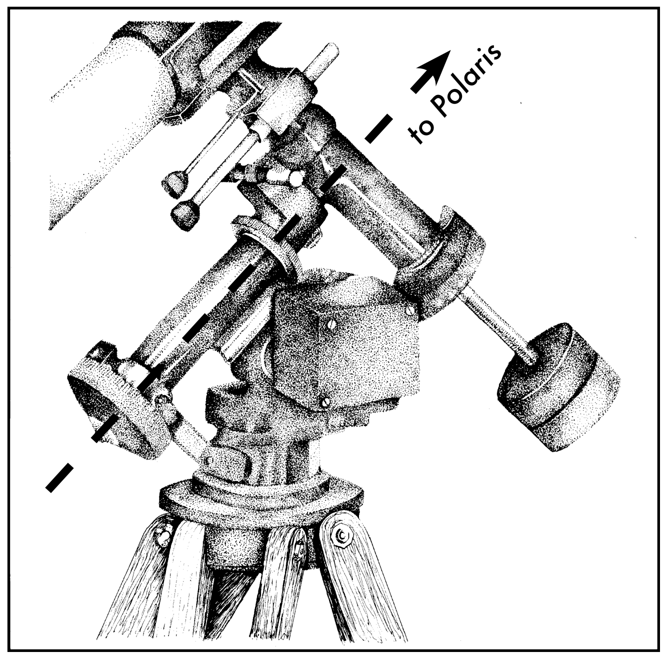
The second stage of the telescope is the eyepiece. One way to describe how the eyepiece works is to think of it as acting like a magnifying glass, enlarging the tiny image that the objective lens makes at the focal point. Different eyepieces give you different magnifications. The shorter the eyepiece focal length, the higher the magnifying power – but with a fainter image, and a smaller field of view. You'll find yourself using high power less often than you might think.

Get to know your tripod

Small telescopes often come on a tripod similar to a camera tripod, which lets you tilt the scope up and down or turn it left and right. The up–down direction is the *altitude*; swiveling left and right moves you through the *azimuth*. Such a mount is called an *alt-azimuth mount*. For a small telescope, this is a perfectly reasonable sort of mount. This type of mount is lightweight, requires no special alignment, and it's easy to use since all you have to do is point the telescope wherever you want to look.

A popular, inexpensive variant of the alt-azimuth mount is the *Dobsonian*. Instead of a tripod supporting the center of the telescope tube, a Dobsonian is mounted near the bottom, where the mirror sits. Two design features keep the telescope from tipping over: the base is made especially heavy (and the heaviest part of the telescope itself is the mirror, which is already down at that end in a Newtonian design) and the tube is made of some lightweight material. Also adding to the low cost and simplicity of use, the two axes that the telescope moves about to point at stars have Teflon friction pads, which (when they're tightened just right) let you move the telescope from position to position, but hold it in place when you let go. (For more about Dobs, see page 245.)





There are two basic types of mount, the alt-azimuth (top) and the equatorial (bottom). The equatorial mount is effectively an alt-azimuth mount which has been tilted so that one axis turns with the Earth.

Once you're focused in on an object in the sky, you'll discover that the stars move slowly out of your field of view. Using an alt-azimuth mount, you have to constantly correct in both directions; as the object you're looking at goes from east to west, it also moves higher or lower in the sky. With a little thought it's not hard to understand why. The stars are rising in the east and setting in the west, and so they're slowly moving across the sky. What's really happening, of course, is that the Earth is spinning, carrying us from one set of stars to another.

To correct for this motion, a fancier type of mount can be found (usually on bigger telescopes), called an *equatorial mount*. This can be thought of as an alt-azimuth mount, only tipped over. The axis that used to be pointing straight up now points towards the celestial north pole. (It is tilted from the vertical at an angle of 90° minus the latitude where you're observing.) It's called the *equatorial axis*. With this sort of mount, you can just turn the telescope about this tipped axis in the direction opposite to the Earth's spin, and so keep the object you're observing centered in the telescope.

You can even attach a motor to turn the telescope for you. The motor is called a *clock drive;* it turns the telescope about the tipped axis at half the speed of the hour hand on a clock. Thus, it makes one rotation every day (actually, every 23 hours 56 minutes, since the stars rise four minutes earlier every night).

The extra tip of the equatorial axis can make it awkward at first to find what you're looking for, however. And, depending on the design of the mount, it may shove the telescope off to one side of the tripod. The telescope's weight then has to be balanced out by heavy counterweights. That makes this sort of mount quite burdensome to lug around.

If your telescope does have an equatorial mount, the first thing you must do when you go observing is to make sure you set up the tripod in the right direction; the equatorial axis must be lined up with the spin axis of the Earth. Conveniently for folks in the northern hemisphere, the Earth's axis has pointed (for the past thousand years or so) at a spot very close to a bright star called Polaris. So all you have to do is make sure that the equatorial axis of your tripod is pointing straight at Polaris. But remember, every time you set up the telescope you've got to line it up again!

(Southern-hemisphere observers are out of luck; there is no south polar star.)

If you are planning to use your telescope with a motorized drive to take time-exposure astrophotographs, you'll need more careful alignment. But for casual observing, lining up on Polaris is quite good enough.

Basic telescope math

Learning to calculate the magnification, resolution, or other properties of your telescope is a great way to get to know in detail what it is capable of doing. But be sure you use consistent measurement units: divide millimeters by millimeters, or inches by inches; don't mix them up!

A = **aperture** of telescope (mm): the diameter of the primary mirror of a reflector or the objective lens of a refractor

L_T = **focal length** of telescope (mm): the distance from the main mirror or lens of a telescope to where light from a star is focused to a point

L_E = **focal length** of eyepiece (mm): the distance from the eyepiece lens to where distant light is focused to a point

f = **focal ratio** of telescope = L_T/A

M = **magnification** = L_T/L_E

R = **resolution,** the smallest angle (in arc seconds) the telescope can see

V_A = **apparent field of view**: the angular size (in degrees) of the circle of light you can see when you hold an eyepiece to your eye

We measure the sizes of astronomical objects in arc seconds, arc minutes, and degrees. One degree is sixty arc minutes, written 60'; and each arc minute is 60 arc seconds, or 60". The full Moon is half a degree (30', 30 arc minutes) in size. The planetary nebulae in this book are typically about one arc minute across. An easy double star like Albireo has a separation of about half an arc minute, or 30" (30 arc seconds).

Resolution

$$R \approx 120/A \quad (A \text{ in mm})$$
$$\approx 4.5/A \quad (A \text{ in inches})$$

Resolution is the measure of how much detail your telescope can make out. It determines how far apart two members of a double star must be before you can see them as individual stars, and limits how much detail you can see on the surface of a planet.

Resolution is measured in terms of the smallest angular distance (in arc seconds) between two points that can just barely be seen as individual spots in the telescope image – for example, the separation of a close "cat's-eyes" pair of double stars.

There is a theoretical limit (resulting from the wave nature of light) to how much detail any telescope can resolve, which is approximated by the formula given above. Assuming good conditions, a telescope with a 60 mm wide objective mirror should be able to resolve a double star with a separation of 2 arc seconds. In practice, of course, you'd need very steady skies to do so well.

By this formula, an 8" Dobsonian should have a resolution limit of just over half an arc second. But in reality, that never happens. The general unsteadiness of the sky, even on the best of nights, means an amateur observer generally can't expect to do better than a 1 arc second resolution.

In some cases, the human eye is clever enough to get around this resolution limit. The eye can pick out an object that is narrower than the resolution limit in one direction, but longer than that limit in another direction, especially if there's a strong brightness contrast. The Cassini Division in the rings of Saturn is an example.

You can identify double stars that are a bit closer than the resolution limit if the two stars are of similar brightness; the double will look like an elongated blob of light. On the other hand, if one star is very much brighter than the other, you may need considerably more than the theoretical separation before your eye notices the fainter star. Experience helps.

The easiest way to determine a focal length is simply to find the numbers written on the side of your telescope or eyepiece. The eyepiece to the left has a focal length of 25 mm; the lens/mirror combination of the Maksutov telescope on the right has a combined effective focal length of 1000 mm. It's important in any calculations to use the same unit of length – usually millimeters – for all lengths.

Note that this telescope also tells you its aperture – 90 millimeters, hence the name "C 90" – and the f *ratio,* f/11*, which is (roughly) 1000 divided by 90. Using the 25 mm eyepiece in this telescope would give you a magnification of 40× (i.e. 1000 ÷ 25).*

Magnification

$$M = L_{telescope}/L_{eyepiece}$$

To find the magnification you get with any of your eyepieces, take the focal length of your objective lens, and divide it by the focal length of the eyepiece (usually written on its side).

Be sure both numbers are in the same units. Nowadays, most eyepieces list their focal length in millimeters, so you must also find the focal length of your objective lens in millimeters.

For instance, with a telescope whose objective has a focal length of 1 meter (that's 100 cm, or 1000 mm), an eyepiece with a focal length of 20 mm gives a power of 1000 ÷ 20, or 50× (50 power). A 10 mm eyepiece would give this telescope a magnification of 100×. When you're making this calculation, don't confuse focal length with aperture!

$$M_{max} \approx 2.5 \times A \quad (A \text{ in mm})$$
$$\approx 60 \times A \quad (A \text{ in inches})$$

Maximum useful magnification is a consequence of your telescope's *resolution*. The image formed by a telescope's primary lens or mirror is never perfect, so there is a limit to how big you can magnify that image and see anything new. Looking through a telescope at extremely high magnification won't help any more than looking at a photograph in a newspaper with a magnifying glass lets you see any more detail. (A newspaper photo is made of little dots; a magnifying glass just shows the same dots looking bigger.) Once you've reached the limit of resolution in the original image, further magnification won't give you any more detail. Of course, even for a bigger telescope, the sky's unsteadiness limits your useful magnification to about 400×.

$$L_{eyepiece} < 7 \times f$$

Longest useful eyepiece: Low power eyepieces (the longer ones) gather light from a wider area of the sky. The lower the power, the wider the circle of light that comes out of the eyepiece: the "exit pupil." But the width of your own eye's pupil is about 7 mm (it gets smaller as you get older). An exit pupil wider than your eye's pupil is a waste, if your goal is to take advantage of your telescope's full aperture. Thus the longest useful eyepiece is just your eye's pupil diameter (i.e. 7mm) times the focal ratio (f) of the telescope.

Of course, there can be reasons to go to an even lower power, for instance to bring more of a large nebula into your field of view. However, in a Dob (or any reflector) if the power is too low, the shadow of the secondary mirror becomes visible as a dim spot in the middle of your view.

Focal ratio *f*

$$f = L_{telescope}/A$$

Focal ratios for refractors are typically large, *f*/12 to *f*/16. Catadioptric reflectors typically have *f*-ratios of *f*/8 to *f*/12. Newtonians, including Dobsonians, commonly have low *f*-ratios of *f*/4 to *f*/7.

The low *f*-ratio of Dobsonians is generally a good thing; it allows for large aperture in a relatively compact package, and it makes it easier to get beautiful views of diffuse deep-sky objects. But telescopes with low *f*-ratios have much greater problems with a field distortion called *coma*, which turns stars near the edge of the field from sharp points into blurry "v"shapes. Also, when f is small you need a more expensive eyepiece with a shorter focal length to get high magnifications to observe planets or double stars. And there is a limit to the longest useful eyepiece (minimum useful magnification) for small-*f* telescopes.

Field of view

$$V = V_A / M$$

The *field of view V* tells you how wide an area of the sky you can see in your eyepiece. When you hold a typical inexpensive eyepiece up to your eye, the field of view appears to be about 50° (the *apparent field*). Since the view through a telescope is magnified, the part of sky you can actually see using this eyepiece is equal to the eyepiece apparent field, divided by the magnification. Thus, a typical low-power eyepiece, about 35× or 40×, shows you roughly 80' of the sky; a similar medium power eyepiece (75×) gives you a 40' view, while a high power eyepiece (150×) should show you 20'. These are the values we assumed for our circles of low-power, medium-power, and high-power telescope views in this book.

Nowadays, most eyepieces that come with telescopes have apparent fields of view of about 50°. But even some modestly-priced eyepieces can range up to 70° apparent field, and special (expensive) designs give apparent views of up to 100°.

Thirty years ago, apparent fields of about 40° were more common. Thus, if you have an older eyepiece, you will see less of the sky than what we indicate here.

To estimate the field of view of an eyepiece, take it out of the telescope, hold it to your eye, and look through it at a bright lamp in a dim room. Move your head so that the lamp (looking like a blurry bright spot) appears at the edge of your field of view, then turn until it sweeps across to the opposite side of the eyepiece view. The angle you turn through is the eyepiece's apparent field of view.

The Moon

You don't need a book to tell you to look at the Moon with your telescope. It is certainly the easiest thing in the nighttime sky to find, and it is probably the richest to explore. But it can be even more rewarding if you have a few ideas of what to look for.

Getting oriented

Setting the stage

The Moon in a small telescope is rich and complex; under high power in a Dob, you can get lost in a jumble of craters and all the mare regions seem to meld together. So the first thing to do is to get oriented.

The round edge of the Moon is called the ***limb***. Since the Moon always keeps the same side facing towards the Earth, craters near the limb always stay near the limb.

The Moon goes through ***phases***, as different sides take turns being illuminated by the Sun. The whole sequence takes about 29 and a half days, the origin of our concept of "month" (think: "moonth"). This means that, except at full Moon, the round disk we see will always have one part in sunlight, one part in shadow. The boundary between the sunlit part and the shadow part is called the ***terminator***.

The terminator marks the edge between day and night on the Moon. An astronaut standing on the terminator would see the Sun rising over the lunar horizon (if the Moon is waxing; or setting, if it's waning). Because the Sun is so low on the horizon at this time, even the lowest hills will cast long, dramatic shadows. We say that such hills are being illuminated at "low Sun angle." Thus, the terminator is usually a rough, ragged line – unlike the limb, which is quite circular and smooth. These long shadows tend to exaggerate the roughness of the surface.

This means that the terminator is the place to look with your telescope to see dramatic features. A small telescope has a hard time making out features on the Moon smaller than about 5 km (or roughly 3 miles) across; but along the terminator, hills only a few hundred meters high can cast shadows many kilometers long, making them quite easily visible in our telescopes.

Basic geography (lunagraphy?)

We see two major types of terrain on the surface of the Moon:

Around the limb of the Moon, and in much of the south, is a rough, mountainous terrain. The rocks in this region appear very light, almost white, in color. This terrain is called ***highlands***.

In contrast are the dark, very flat, low-lying areas; they are called the ***mare***. The term mare, Latin for "sea," describes how the first telescope observers interpreted these flat regions. One large region of the Moon filled with such dark mare material is called an ocean, Oceanus Procellarum.

Throughout the Moon, especially in the highlands but occasionally in mare regions as well, are numerous round bowl-shaped features called ***craters***. Indeed, several of the mare regions themselves appear to be very round, as if they were originally very large craters; these large round depressions are referred to as ***basins***.

Lunar phases

As the Moon proceeds in its phases, the area lit by the Sun first grows in size, or ***waxes***, from the thinnest of crescents until it reaches *full Moon*; then it shrinks back down, or ***wanes***, to a thin crescent again. The point where the Moon is positioned between the Earth and the Sun, so that only the dark, unlit side is facing us, is called *new Moon*.

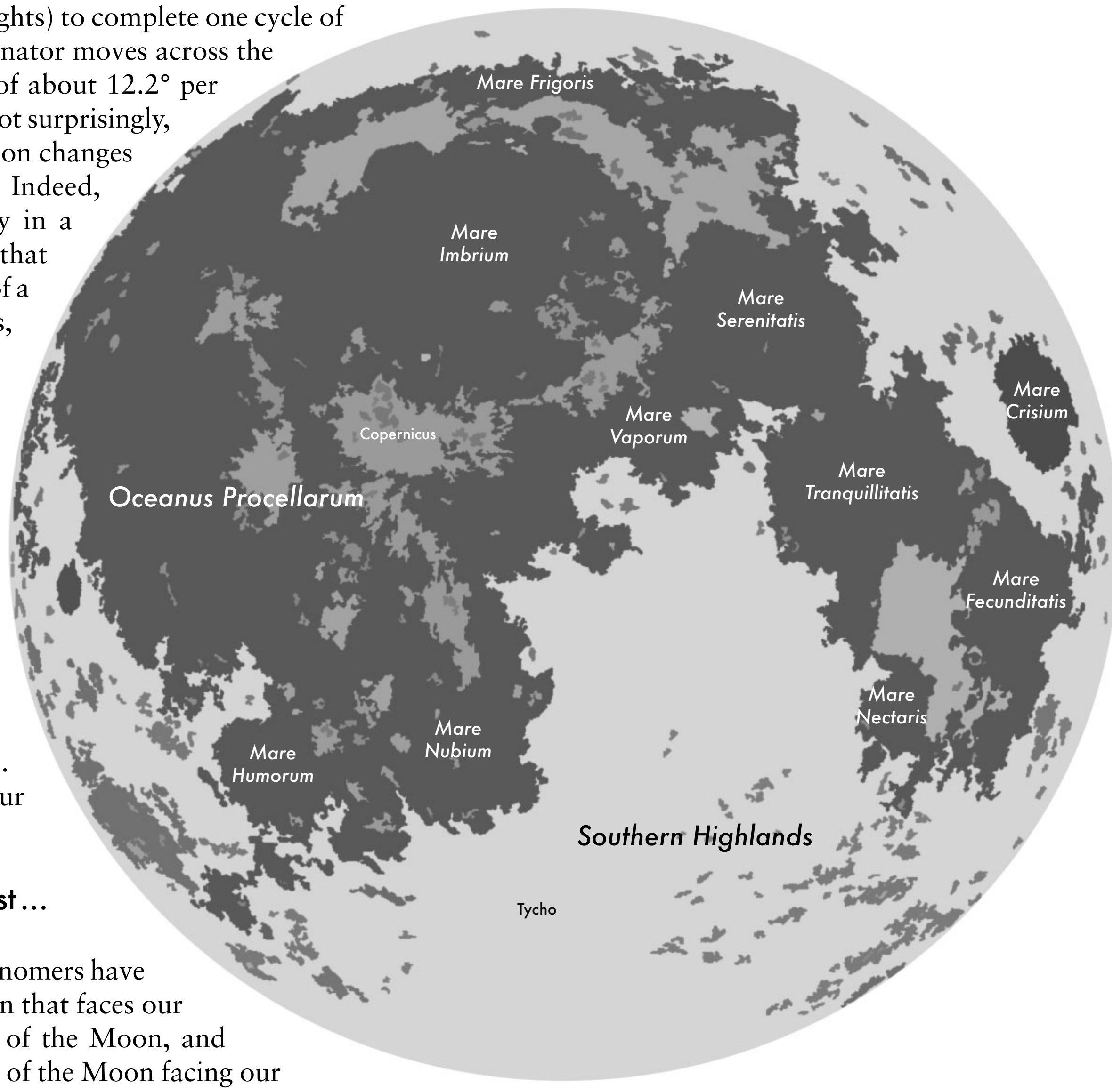
As it proceeds in its orbit past new Moon, the Moon will be visible in the evening sky, setting in the west soon after the Sun sets. By the half Moon phase (also called *first quarter*) it will be at its highest, and due south, at sunset, and it will set at about midnight. The waxing Moon is shaped like the letter D; think of it as "Daring." The full Moon, its earthward face fully illuminated by the Sun, must rise as the Sun sets, and set at sunrise. The waning Moon will not rise until late in the evening, but stays in the sky after sunrise, well into the morning. It's shaped like the letter C; think "Cautious." (In the southern hemisphere, the D and C shapes are reversed, of course. You could say that a Moon visible in the evening is a Corker; one that won't rise until after midnight is Dill.)

We emphasize the waxing Moon, visible in the evening when most of us observe, in the following pages.

Nights of the day

It takes 29.5 Earth days (and nights) to complete one cycle of phases, so that means the terminator moves across the surface of the Moon at a rate of about 12.2° per day, or half a degree per hour. Not surprisingly, then, the appearance of the Moon changes radically from night to night. Indeed, once you start looking closely in a telescope you can easily notice that change occurring over a matter of a few hours, right before your eyes, if you watch a particular spot on the Moon's surface.

Thus, to plan what to look for, it is useful to know what night of the "day" you're looking at. That's how we will describe where to look, and what to look for, in the following pages. But we'll concentrate on things to see at the terminator, where the shadows are most dramatic and subtle features stand out the most… and where the changes from hour to hour are the most obvious.



East is east, and west is west… except on the Moon

Traditionally, Earthbound astronomers have referred to the limb of the Moon that faces our north to be the northern limb of the Moon, and likewise for south; and the limb of the Moon facing our west they call the west side of the Moon, and likewise for east.

This is perfectly logical if you're observing the Moon from Earth. It gets very confusing if you're an astronaut on the Moon itself, though, because (as we saw in the section "How to use this book") these directions are just backwards from what we're used to on terrestrial maps. Thus, with the dawn of the Space Age, NASA created a new terminology for their astronauts who would be exploring the Moon. Now we've got two conflicting ways to refer to directions on the Moon. What's referred to as "west" in one book will be "east" in another.

This book is designed for casual Earthbound observers, not astronauts. But looking at the Moon's surface does feel like looking at a map. So which convention should we use?

The two authors of this book took a vote. It was a tie.

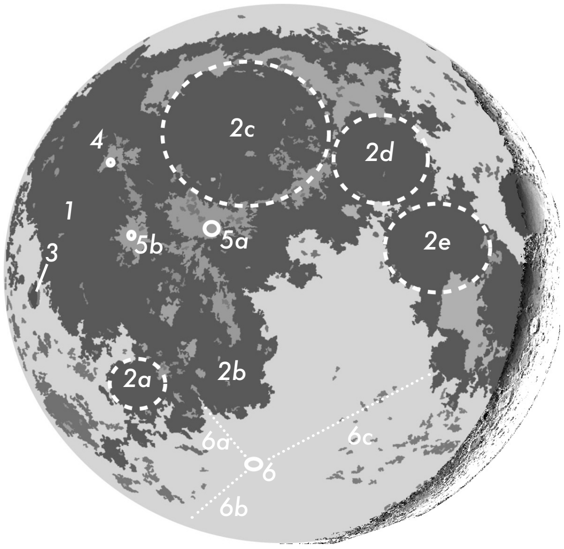
And so, while north and south are unambiguous, for the other directions we'll merely direct you to look "towards the limb" or "towards the terminator." And remember, telescopes with star diagonals give you a mirror image of our photos!

Special events on the Moon

Eclipses

Roughly twice a year the full Moon passes into the shadow of the Earth, and we have a ***lunar eclipse***. The eclipses last for a few hours, not the whole night; and of course they can only be seen when the Moon is up, which is always at night during a full Moon. Whether or not you can see a particular eclipse depends on whether or not it's nighttime in your part of the world when the eclipse occurs. To find these times, check the links on our website **www.cambridge.org/features/turnleft/the_moon.htm.**

The Moon is the one object in the sky where photos give an accurate idea of what you can see in a small telescope. The full lunar disks (pp. 26–36) are by permission of Robert Reeves (www.robertreeves.com), who assembled these from digital images he took with Celestron 8" and Meade 10" catadioptric telescopes. Most of the close-up images on pages 25–37 are by Rik Hill, who used telescopes from a 3.5" Questar to a 14" C-14 in his Tucson backyard. The rest are from Eric Douglass' digital version of the Consolidated Lunar Atlas *compiled in 1967 by Gerard P. Kuiper, Ewen A. Whitaker, Robert G. Strom, John W. Fountain, and Stephen M. Larson at the Lunar and Planetary Laboratory, University of Arizona.*



Observe in the Earthshine during the first days after new Moon!

Look for:
1. Oceanus Procellarum (dark, irregular)
2. Mare basins (dark, round)
a. Mare Humorum
b. Mare Nubium
c. Mare Imbrium
d. Mare Serenitatis
e. Mare Tranquillitatis
3. Grimaldi (dark basin at dark limb)
4. Crater Aristarchus (bright spot)
5. Large craters (pale circles)
a. Copernicus
b. Kepler
6. Crater Tycho (pale circle in south surrounded by a white ring, then a darker ring; then, radiating out from these rings, white rays.)
Look for Tycho's rays:
a. between Humorum and Nubium
b. south toward the dark limb
c. toward Nectaris.

Recall how the Sun arcs high overhead during the summer, but seems to scoot along the horizon during the winter. Now realize that the daytime sky of the summer is the nighttime sky of the winter. (When a total eclipse in July blocks out the Sun's light, the brighter stars of Orion and other December constellations can become visible!) So at night during the summer, the Moon (and the planets) seem to scoot low along the horizon; while during the winter, the Moon and planets travel a path high overhead, following the same path the Sun will be on six months later.

New Moon

There is something pleasant, beautiful, and reassuring about the return of the new Moon in the evening sky. The best months for spotting a very new Moon are around your hemisphere's spring equinox, when the ecliptic makes a steep angle to the horizon, so the Moon is relatively far above the just-set Sun. Check the time of new Moon for good opportunities – a hair-thin crescent less than about 36 hours after new Moon can be a challenging but thrilling sight. It will be hard to see, so make sure to be prepared to know where to look and to have a horizon clear of obstacles, cloud, or haze. Look just after sunset, preferably with binoculars. The Moon may look beady near the ends of the crescent, due to roughness in its topography.

During the first nights of the new Moon, look into the dark side illuminated by *Earthshine,* sunlight reflected off Earth onto the Moon, for a sneak peek at things you won't get to see again for another couple of weeks.

Occultations

The Moon drifts slowly eastward through the stars of the zodiac, at a rate of about its own diameter per hour. The side that's dark during the waxing phases of the Moon is the leading edge.

If you find a star just beyond this dark limb, watch it in the telescope for about ten or fifteen minutes. As the unlit leading edge of the Moon passes in front of it, the star will suddenly appear to blink out. It is an eerie, surprising, and exciting sight even when you're expecting it. Somehow, one's subconscious is shocked at such a sudden and violent change occurring with no sound at all.

Occultations are easier to observe when the Moon is in its crescent phase, because then in the telescope you can see the dark limb slightly illuminated by Earthshine. This makes it easier to judge how long you need to wait for the occultation.

Some occultations seem to go in double steps, with the star's light blinking from bright, to dim, to off. This happens when close double stars become occulted. Then, when the star reappears on the other side of the Moon, it will likewise seem to "turn on" in stages. Both brightness and color can change in steps like this. For example, when the Moon occults Antares, its greenish seventh-magnitude companion reappears several seconds before the brighter red star.

If the edge of the Moon just grazes the star, then the star can blink several times as it passes behind lunar mountains and valleys. This is called a *grazing occultation.*

Planets get occulted, too! In fact, since both the Moon and the planets follow roughly the same path across the sky (the path of the ecliptic through the zodiac constellations), such occultations are rather common. It is astounding and delightful to see the edge of one of Saturn's rings, or one of the horns of the crescent Venus, peeking out from behind a lunar valley.

Librations

As everyone knows, the Moon always keeps the same face to the Earth. The time it takes for the Moon to spin once on its axis is the same as the time it takes to go once around the Earth; as seen from Earth, the two motions cancel. That's why we only get to see half of the surface of the Moon from Earth.

But as everyone also knows, what "everyone knows" isn't always exactly right.

For one thing, direction of the Moon's pole is slightly tilted (by 6.7°) from the plane of its orbit, so at times we can sneak a peek "under" or "over" the poles of the Moon. But in addition, the Moon's orbit around Earth isn't exactly a circle and so it doesn't move at exactly the same rate as it spins; sometimes it's slower, sometimes it's faster, and so at different times in its orbit we see first the east, then the west sides turn slightly towards us. As a result, we can actually see nearly 60% of the Moon's surface. It's fun to keep an eye out for the extremes of these *librations* when otherwise hidden bits of the Moon creep into our field of view.

This also means that the arrival of features that we identify with a certain "night" of the lunar day can vary significantly from month to month. Objects near the poles, which get tilted into (or out of) the shadows, can appear days before or after their average appearance date. If what you are seeing isn't what we're describing, check our descriptions of the night before (or after) your particular night.

Advanced lunagraphy

The Moon is much like a small planet orbiting the Earth. Indeed, one could argue that the Earth and Moon make up a double planet system, which do a dance around each other as they both orbit the Sun.

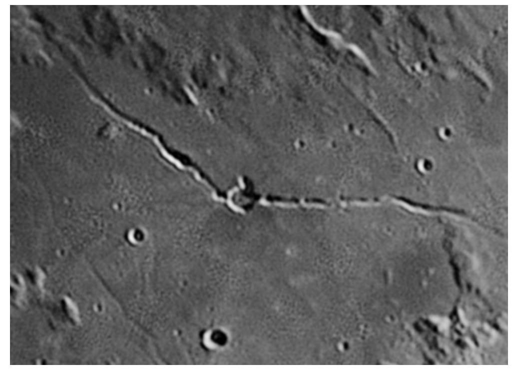
The current preferred theory supposes that the material forming our Moon came from a protoplanet, perhaps as big as Mars, impacting the Earth while it was forming four and a half billion years ago. Its debris formed a swarm of meteoroids that fell together into a ring around the Earth and eventually snowballed into the Moon.

The **craters** we see all over the surface of the Moon are the scars of meteorite impacts from the final stages of the Solar System's formation, the blast holes formed as meteoroids exploded upon impacting the Moon. The material blasted out from these explosions eventually had to fall back to the surface of the Moon. Most of the material is turned up out of the crater, forming a hummocky rim; other pieces, blasted farther out of the crater, made their own craters. Thus, around the bigger craters you'll often see lots of smaller craters in a jumbled strip of land around the crater at least as wide as the crater itself. The region including both the hummocky rim and the jumbled ring of secondary craters is called the **ejecta blanket**.

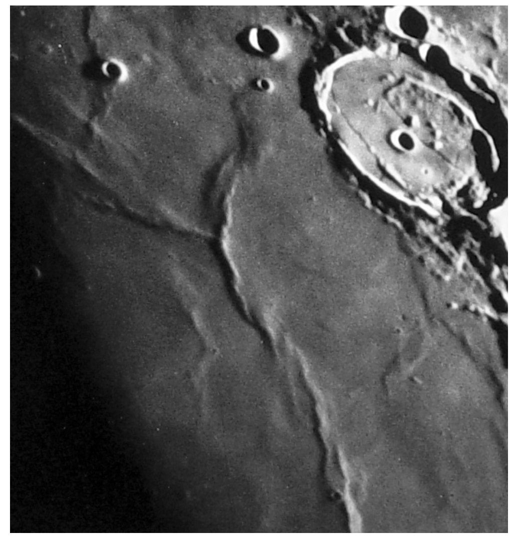
Some of this flying debris travelled hundreds of kilometers away from its crater. The churned-up surface where it landed is lighter in color than the surrounding, untouched rock, and so we see these areas as bright **rays**, radiating away from the crater. These rays are most easily seen during full Moon.

The highlands, with the largest number of craters visible, are clearly the oldest regions. After this crust was well formed, a few final large meteoroids crashed into the surface, making the round **basins**. The mare regions were formed over the next billion years as molten lava from deep inside the Moon erupted and filled the lowest and deepest of the basins.

Relatively few craters are seen in these regions, indicating that most of the accretion of impactors had already finished before these basaltic lavas arrived. The lava flowed in tubes beneath the mare surfaces; once the flow stopped, some of these tubes collapsed to form long cracks, called **rilles**. As the pools of lava cooled, they shrank in volume, causing the surface to buckle and form **dorsa**, or wrinkle ridges.



Rilles: *Hyginus Rille looks like a pair of cracks radiating from Hyginus Crater*



Dorsa: *This dorsum, or wrinkle ridge, is found at the limbward edge of Mare Serenitatis*

The Moon today … and tomorrow

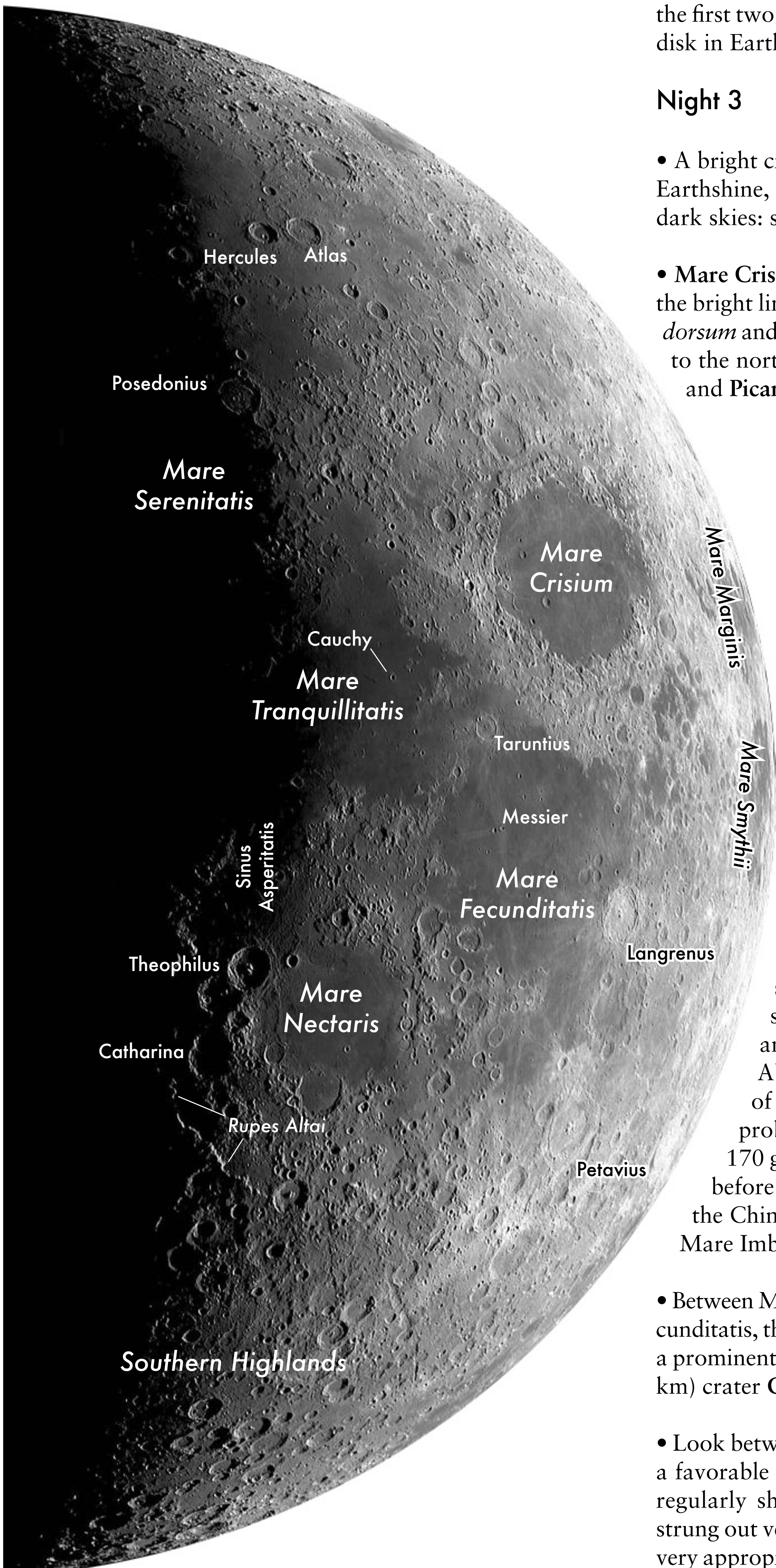
Since the time of mare volcanism, which ended about three billion years ago, the Moon's surface has been essentially unchanged. An occasional meteoroid still strikes, forming fresh-looking craters such as Tycho. But more commonly, the surface gets peppered with innumerable micrometeorites, the tiny bits of dust that make shooting stars when they hit the Earth. On the Moon, with no air to stop them, they have pulverized and eroded the rocks, the hills, and the mountains into the soft, powdery surface seen by the Apollo astronauts.

By seeing how fresh a crater looks, you can get an idea of its relative age. Likewise, by counting how densely packed the craters are in a given region, you can tell (relatively) how old it is. The Apollo samples, taken from a variety of regions and including pieces of the ejecta from fresh craters such as Tycho, allow us to peg some real numbers (determined by decay of radioactive elements in the minerals) to these relative ages. From them we learn that the oldest highlands are around four and a half billion years old. Giant basins were formed by impacts about four billion years ago, then flooded with mare basalts over the next billion years. Since then, nothing much except the occasional impact has occurred. Tycho, for instance, was formed by a meteorite strike about 100 million years ago.

More recent impacts of comets and water-rich meteorites onto the Moon have added one final ingredient to the lunar surface. In 1998, the Lunar Prospector satellite orbiting the Moon found evidence that ice is mixed into the soil in the cold regions around the lunar poles. In 2009, a probe smashing into one of these always-shadowed polar craters confirmed this result, splashing water vapor out of the crater to where it could be detected. This ice could provide the water needed to make human settlements possible on the Moon within the not-too-distant future.

The Apollo astronauts themselves have already left their mark on the Moon. There are new craters now where spent rocket stages crashed into its surface. And at the landing sites themselves are the footprints of the astronauts, undisturbed by air or weather, which could outlast any trace of humankind on Earth.

Crescent Moon: Nights 3–5



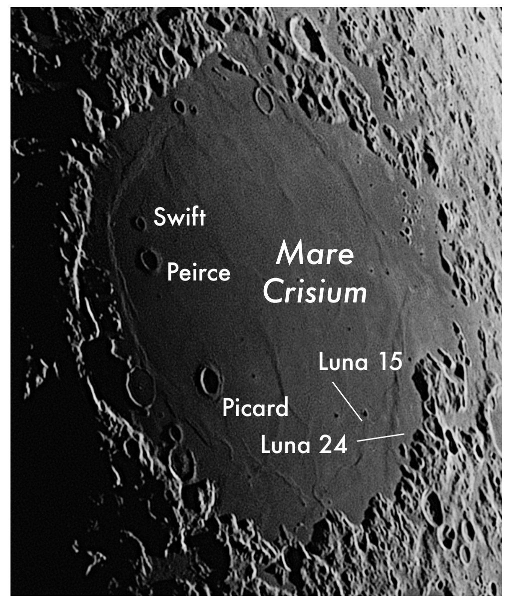
Nights 0–2

The Moon is too close to the Sun for easy observing during the first two nights after new Moon. But try observing the full disk in Earthshine, as described on page 24.

Night 3

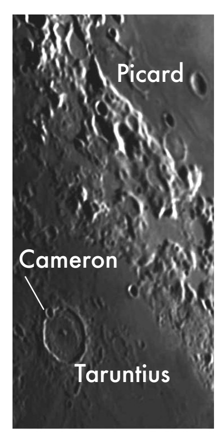
• A bright crescent! This may be the best night for observing Earthshine, as tonight the Moon is up longer in reasonably dark skies: see page 24 for details.

• **Mare Crisium** is a flattened oval north of the equator, near the bright limb. Its surface is broken only by one north–south *dorsum* and three small prominent craters: **Peirce,** 20 km wide, to the north, with small (10 km) **Swift** just north of Peirce; and **Picard**, also 20 km, to the south.



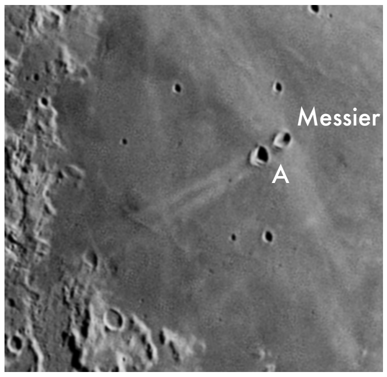
• 50 km from the southern shore of Crisium is where Luna 15 (an unmanned attempt to upstage Apollo 11 by landing softly and returning samples to the Earth) crashed while Armstrong and Aldrin were on the surface 1200 km away. About 60 km from there, near the limbward shore of Crisium is the site of the 1976 unmanned Soviet probe Luna 24 which succeeded in returning about 170 g of Moon rock to the Earth. It would be 37 years before another craft would made a soft lunar landing: the Chinese Chang'e 3 probe, which landed a rover onto Mare Imbrium in 2013.

• Between Mare Tranquillitatis and Mare Fecunditatis, the 55 km crater **Taruntius** shows a prominent central peak and fresh little (10 km) crater **Cameron** on its northern rim.



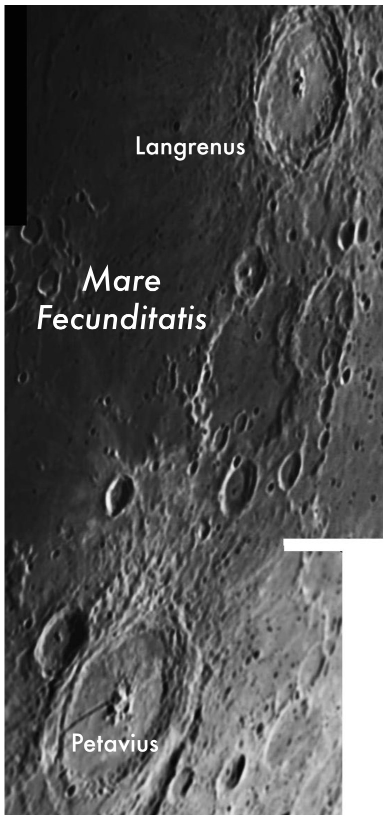
• Look between Crisium and the limb. With a favorable libration, you should see an irregularly shaped patch of mare material, strung out very close to the limb. It is called, very appropriately, **Mare Marginis**. South of it on the limb is **Mare Smythii.**

• **Mare Fecunditatis**, south of Crisium, is just appearing along the equator. The low Sun angle nicely shows a complex system of rilles and wrinkle ridges (dorsa). In the north and terminator side of the mare, note an interesting pair of craters, **Messier** and **Messier A**. Note that unlike most craters, Messier is not circular but quite elongated; and it shows two rays radiating only towards the terminator direction. We'll visit these again, to better effect, on Night 12.



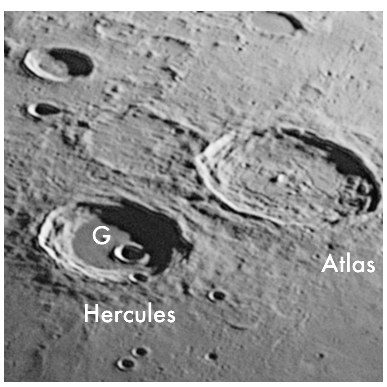
• The very large (130 km) crater **Langrenus**, with its easily visible central peak poking out of the shadow of the crater's sunward rim, is on the south, limbward shore of Fecunditatis.

• Nearby, a little bay of mare lava forms a southern extension of Fecunditatis. Just south and limbward of that bay, the huge, 175 km crater **Petavius** also shows a prominent central peak.

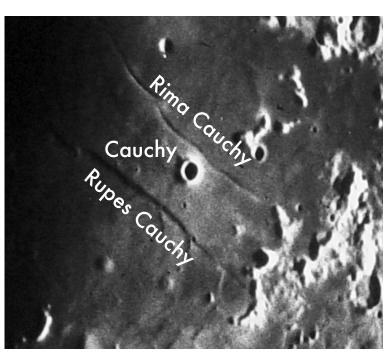


Night 4

• In the north, the attractive crater pair of **Atlas** (87 km) and **Hercules** (70 km) are just appearing tonight. Hercules, which is closer to the terminator, has a floor with dark patches and a prominent 20 km crater, Hercules G.



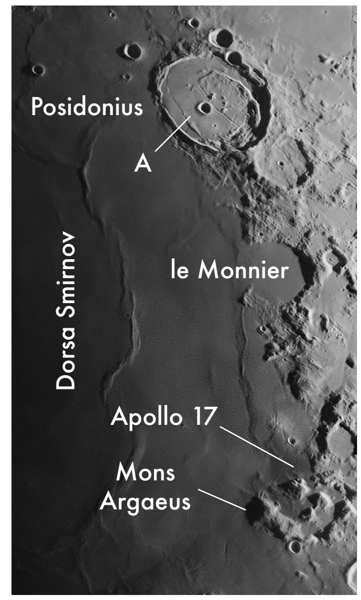
• The first part of **Mare Tranquillitatis** is now visible along the terminator. Halfway up the limbward shore of that mare, look for look for the sharp little (12 km) crater **Cauchy**. This crater will become quite bright closer to full Moon. Flanking Cauchy on either side is a pair of prominent scars across the face of the mare – **Rima Cauchy** close to the shoreline of Tranquillitatis, and **Rupes Cauchy** on the side toward the terminator. Rima Cauchy is a 200 km-long rille – a collapse feature associated with ancient volcanism. Rupes Cauchy is more complicated – part of it is a rille, but part appears as a fault with the limbward side having moved upwards. As a result, shortly after sunrise in this part of the Moon, the fault casts a long shadow, clearly visible across the nearby mare.



• Look again at Mare Fecunditatis; craters Taruntius and Cameron; Langrenus; and Petavius (see Night 3).

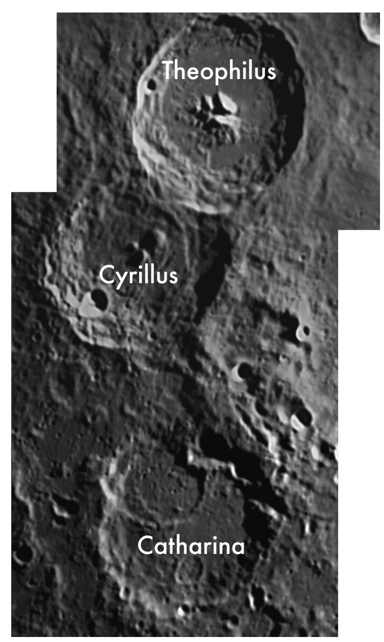
Night 5

• Note the fractured floor of 95 km crater **Posidonius**, with 12 km crater Posidonius A and rilles. South of Posidonius, the 60 km crater **le Monnier** appears as a distinct, rounded extension of dark mare material into the bordering highland material. In 1973, the Soviet Moon rover Lunokhod 2 landed in the southern part of le Monnier and drove more than 36 km across the lunar surface. In the mare, **Dorsa Smirnov** stand out under low Sun angle.



• South of le Monnier find a mountainous promontory between Serenitatis and Tranquillitatis: **Mons Argaeus**. Limbward of it in a small valley surrounded by mountains is the Taurus-Littrow valley, the landing site of Apollo 17 – the last humans to set foot on the Moon.

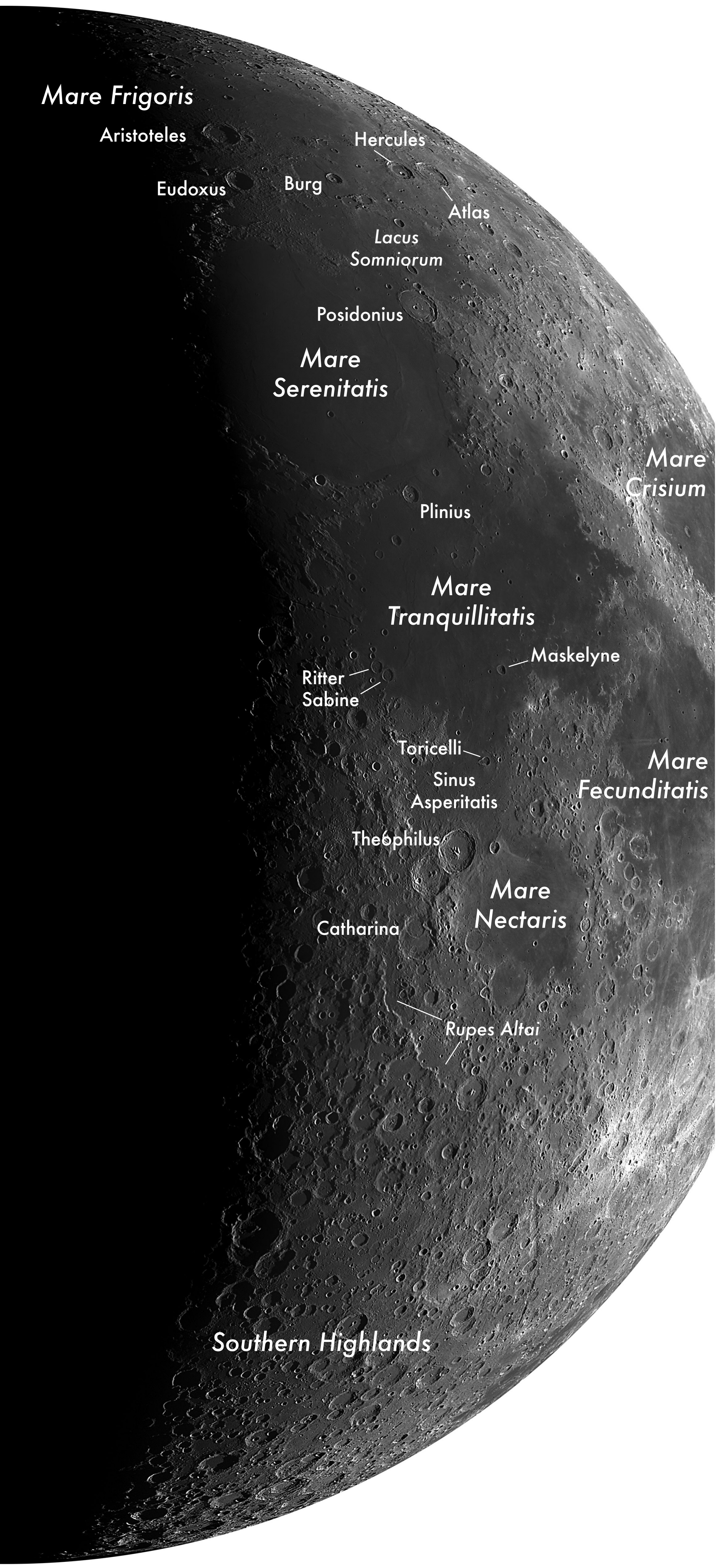
• At the southern end of Tranquillitatis, away from Serenitatis, the mare protrudes southward into a small bay (about 180 km across), **Sinus Asperitatis**. South of Asperitatis is **Mare Nectaris** (about twice its size, 350 km). Toward the terminator and just south of Asperitatis, three great (100 km) craters **Theophilus**, **Cyrillus**, and **Catharina** emerge tonight into daylight. Once the shadows of the rims leave the crater floors, these craters become complex and fascinatingly different areas to explore at high power. South of Catharina, the long escarpment of **Rupes Altai**, which runs hundreds of kilometers north–south, may be catching the light of the morning Sun.



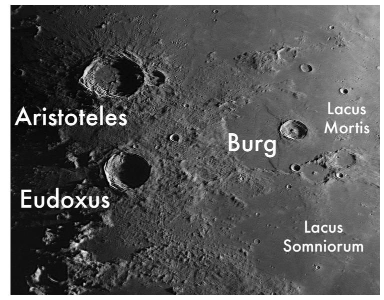
• South of Nectaris, the **Southern Highlands** are starting to get interesting, with a chaotic jumble of craters just starting to emerge. The best, though, is yet to come…

Also see www.cambridge.org/features/turnleft/the_moon.htm

Approaching half: Night 6



• The patch of mare appearing near the terminator far to the north is the start of **Mare Frigoris**. Cutting off its southern half, near the terminator, the 85 km crater **Aristoteles** should just be making its appearance. The complex, terraced look of its rim is the result of the several fault scarps that are part of the rim structure. The 65 km crater **Eudoxus** to its south shows similar morphology.

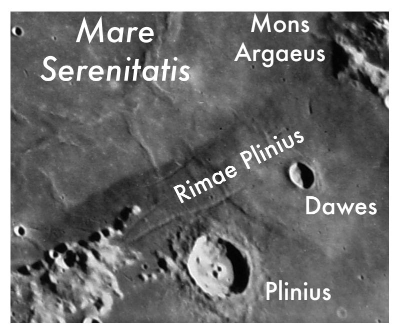


• Away from the terminator, the mare material of Mare Frigoris connects southward (around crater **Burg**) to **Lacus Mortis** and, farther south, **Lacus Somniorum**: the eerily named lakes of death and dreams, respectively. Just limbward of Lacus Mortis is **Hercules** (70 km) and **Atlas** (87 km). If you saw them when they were nearer the terminator a night or two ago, you will see the difference Sun angle makes now to the sharpness of their features and the length of their shadows.

• Southward of Lacus Somniorum and angling toward the limb are three large mare in succession: **Serenitatis**, **Tranquillitatis**, and **Fecunditatis**, each between 600 and 750 km across. The smaller oval-looking mare, limbward of Tranquillitatis, is **Mare Crisium**. Making a triangle southward from Tranquillitatis and Fecunditatis is **Mare Nectaris**.

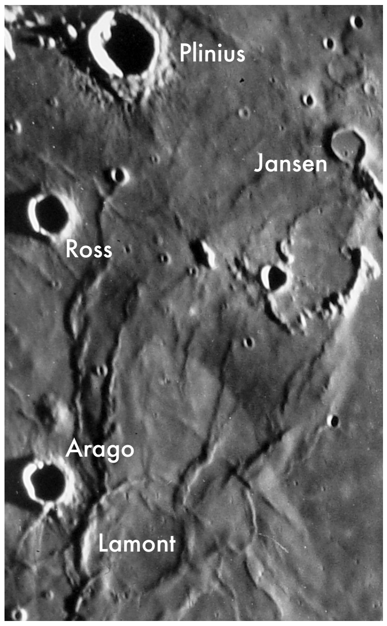
• As described in Night 5, see the spectacular 95 km crater **Posidonius,** on the northern part of the limbward shore of Serenitatis, and **Dorsa Smirnov**, on the plains of Serenitatis.

• A promontory of highland material cuts off part of the connection between Mare Serenitatis and Mare Tranquillitatis. The 45 km crater **Plinius** is at the limbward end of the promontory; 18 km **Dawes** sits farther limbward and to its north, in the middle of the gap between the two mare. A prominent dark band, 20 to 25 km wide, arcs along the southern shore of Serenitatis and then just north of Plinius and Dawes.



Dark material like this, sampled by Apollo 11 and Apollo 17 astronauts, is rich in both titanium and small glass beads. It's the result of the last bits of mare lava freezing into glass instead of forming mineral crystals. A series of rilles, **Rimae Plinius**, run within the dark band along the southern shore of Serenitatis. They are presumably the collapsed lava tubes that brought this last bit of dark material to the surface of the Moon. Then, when the fresh impact of crater Dawes occurred, lighter colored rock from beneath this dark layer was splashed up on top of it, making the lighter apron around the crater.

• Across the northern part of Tranquillitatis runs a string of craters nearly buried under a series of volcanic flows, which produced a startling array of dorsa visible with the low Sun angle at this time. Look limbward and south from Plinius for **Jansen** and its companions, and follow the dorsa south to the partially buried crater **Lamont**. These impacts must have occurred after formation of the mare basin, but before the lava filled it. By contrast, craters **Ross** and **Arago** were made after the lava filled the basin.



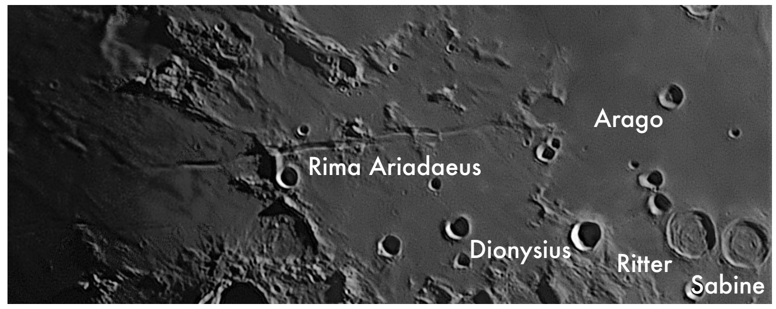
Note how this image, at low Sun angle, shows the complex dorsa near Arago; they disappear as the Sun gets higher (as in the image below.)

• Fresh-looking 25 km crater **Maskelyne** is easily the most prominent crater in southern Tranquillitatis. It is located north and limbward of the mare passageway leading from Tranquillitatis into **Sinus Asperitatis**.

• Draw a line from Maseklyne, past the little (6 km) crater **Maskelyne G** (small craters are named for the nearest large crater, with letters assigned in a haphazard order), to the slightly worn-looking 30 km craters **Ritter** and its twin **Sabine**, just south and limbward of Ritter. North of Ritter, on the south-terminator corner of Tranquillitatis, you'll find a smaller pair of identical twins – sharp little (12 km) **Ritter B** and **C** (running north–south).

Step southward from Ritter, to Sabine, to a series of rilles; starting near Sabine, they run away from the terminator for 180 km, all the way to the start of the mare passageway into Sinus Asperitatis. Crater **Moltke** sits just north of their far end (away from Sabine and Ritter).

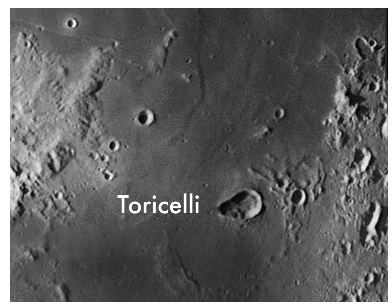
Now move back to the north. Between Moltke and Maskelyne G, look in high power for a string of tiny (4 km) craters. The first and easiest to find is **Armstrong**; the other two in the line are **Collins** in the middle (Surveyor 5 landed near here), and **Aldrin,** towards Sabine. Step from Maskelyne G to Armstrong. One step farther brings you to *Statio Tranquillitatis,* as it is named on the official IAU Moon map: **Tranquility Base**, the landing site of Apollo 11. (Another way to find the site is to step from the crater **Manners** to **Arago B**; three steps farther is the Apollo 11 site.)



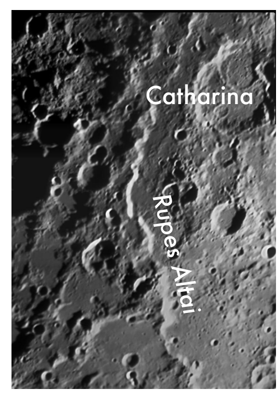
• Step northwards from Sabine to Ritter; four more steps brings you to a large rille, **Rima Ariadaeus**. It runs for 220 km in a nearly straight line from the shoreline of Tranquillitatis towards the terminator.

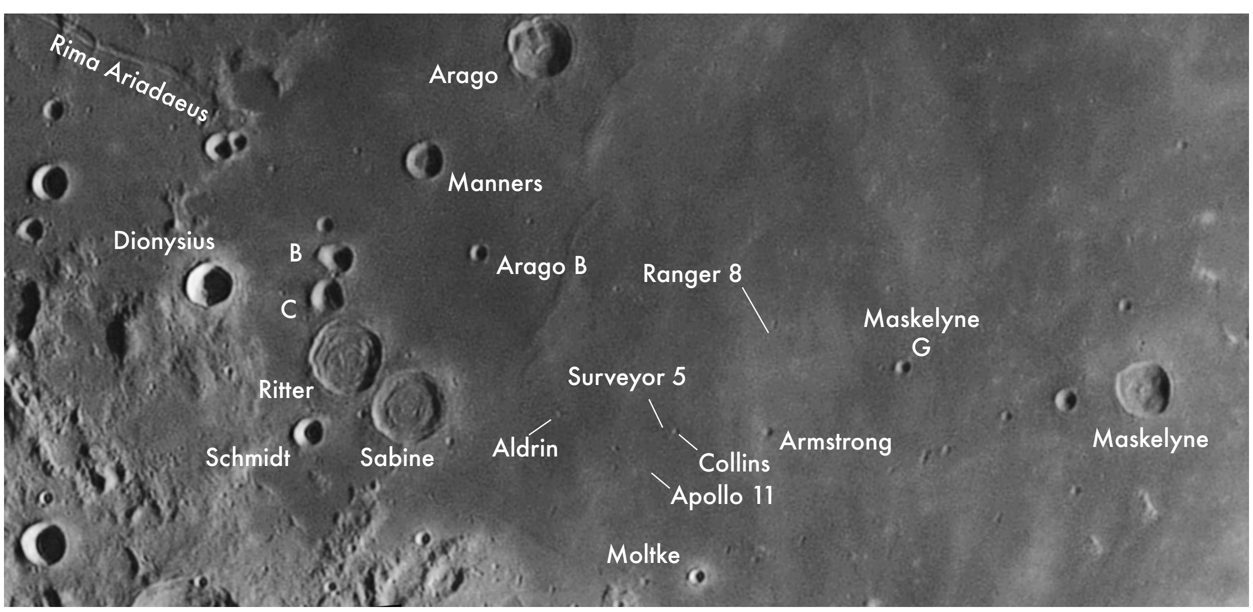
• The region just north of Rima Ariadaeus looks like it was scraped by a giant rake. These grooves in the craters and mountains all point back towards the center of Mare Serenitatis, and were probably formed by material thrown out of the Moon when the impact that formed Serenitatis occurred.

• Sinus Asperitatis, mentioned above, is a 200 km bay between Tranquillitatis and Mare Nectaris. In the north of Sinus Asperitatis, look for the 20 km crater **Toricelli**. It looks misshapen because of a 10 km crater that overlaps it on its nightward flank.



• South of Toricelli is the Theophilus/Cyrillus/Catharina trio (see Night 5). South of Catharina, see the **Rupes Altai** curve almost 500 km south and then limbward, with its marked mountain front catching the morning Sun.





• Now's the time to start exploring in the **Southern Highlands**. Take some time to pick out features there at the start of your observing session, and return sometime later, but before the Moon gets too low in the sky. You'll likely see some significant changes as more of the rough topography is exposed to the rising Sun.

Also see www.cambridge.org/features/turnleft/the_moon.htm