Norman Butler

Building and Using Binoscopes

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Preface

As an amateur astronomer living in Topeka, Kansas, in the 1970s, on clear nights, away from the city, one could easily see our spectacular Milky Way galaxy arching across the beautiful Kansas night sky. Seeing this wonderful sight night after night through my trusty telescope really got me thinking about how spectacular these wonderful celestial objects would look through a large binocular telescope. To realize my dream, in the late 1970s I started on my quest to build my first large binocular telescope. By November of 1980, I had completed a dual 6 in. f/15 Cassegrain Dall Kirkham binocular telescope (10 mirrors) on a clock-driven equatorial mount complete with a 360° steel ring OTA rotation system.

In terms of this book, a binoscope and a binocular telescope are one and the same. They both do basically the same thing, which is allowing the observer to view celestial objects with two telescopes, using both eyes. In this book I wanted to show as many photos as possible of different kinds of homemade (some commercial) refractor and reflector binoscopes, binocular telescopes and standard Dobsonian and Cassegrain telescopes to demonstrate how resourceful and creative today's amateur telescope makers really are. The homemade binoscopes pictured in this book should provide the reader with some good ideas on building their own binoscope someday.

It does not take a lot of imagination to understand the simple optics and mechanics behind building a binoscope or a large binocular telescope. What it does take is a little more expense for the cost of optics (times 2) and twice as much materials and time to build, for example, a Dobsonian style binocular telescope or binoscope compared to constructing a single telescope. Beyond that, once you have made the commitment to start your binoscope project and you have created a robust design and have done all of your advance planning and homework, then going forward with your project should be something to really look forward to. And after your binoscope project is finally completed, and you get your first views through it, then that's when the fun begins. Welcome to the binoscope club!

Saipan, CNMI
June 2014

Norman Butler

Acknowledgements

I wanted to take this opportunity to acknowledge some individuals that encouraged me along the way to make this literary endeavor about binoscopes into a successful reality. I wish to extend my sincere thanks and deep appreciation to John Bauer, my late great dear friend, mentor and astronomy professor during my early college years at San Diego City College. Without his inspiration, support and guidance, I would have probably never made it this far in astronomy, especially as a career, and worked at the observatory level in Hawaii. Likewise, I wish to thank astronomers Fred Pilcher, Richard Wilds and Rick Schmidt. All three of them, who in my distant past, encouraged me at some point to pursue some of my lofty goals in astronomy. Likewise, I wish to thank those individuals who contributed images and illustrations for inclusion in my new book. And finally my dear mother Gladys, who was always my main source of encouragement for all of my astronomy endeavors; no matter how outrageous they were, she was always there for me, no matter what.

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About the Author

Norman Butler is a noted award winning telescope maker who has made some very unique one-of-a-kind binocular telescopes. He has also worked in the field of astronomy and electro-optical engineering for AVCO Everett Research Laboratory at Haleakala Observatory on Maui starting in the early 1980s, building electro-optical equipment for use on both 1.6 M and dual 1.2 M telescopes. A graduate of San Diego City College, Norman holds advanced university degrees in Physics and Astronomy including a Ph.D. He also served in the US Navy as an Opticalman on submarine tenders repairing submarine periscopes and optical navigational equipment throughout the 1960s. Starting in 1994, Norman relocated to Hong Kong and started working in nearby Shenzhen, China, as a joint-venture manager in the electronics industry. Starting in 2004, he became a resident of Hong Kong and started teaching at Shenzhen Polytechnic College and Harbin Institute of Technology Shenzhen Graduate School. Norman retired in 2012 and now lives in the Northern Marianas Islands and enjoys searching for comets and other mysterious cosmic interlopers under the beautiful dark tropical skies of Saipan and Guam.

Chapter 1

Why Binoscopes?

Just about all of us enjoy learning about the universe and looking at all of its celestial wonders through a telescope. It can be a lot of fun and educational at the same time. But when it comes wanting to see more in the night sky than just observing with a single telescope, then that's when you start to think about getting a bigger telescope or even a big pair of binoculars. Using two eyes to view the universe with is perhaps one of the most satisfying ways to enjoy doing visual astronomy. Using a pair of binoculars can certainly make your observing experience a lot more satisfying. But what about using a binoscope or binocular telescope to observe the heavens with?

Binoscopes are a wonderful way to explore the night sky. This new book on binoscopes gives the reader a good opportunity to find out why a binoscope or binocular telescope is fun and exciting to use for astronomical observing. The book is filled with a wide variety of photos of homemade, commercial binoscopes and binocular telescopes and a few telescope cartoons thrown in for fun and levity. It also describes how binoscopes perform optically and what you can expect to see when you observe with a binoscope or a pair of big binoculars.

The book offers some practical advice, some suggestions from other binoscope makers on how to design and build a binoscope or big binocular telescope, as well as presenting some of my own homemade one-of-a-kind binoscope examples in Chap. 5 for doing so. In writing this book, it was important for the reader to see a variety of interesting homemade and commercial binoscopes as well as some discussion and personal comments from actual binoscope makers and users about the advantages that a binoscope or a binocular telescope has compared to a single telescope. The book will help you decide to either try one, buy one, or make one of your own someday. If you want to build your own binoscope or binocular telescope,

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then you'll find out that making a binoscope or binocular telescope can be a lot of fun, especially if you intend to share the observing experience with others. A binoscope is also great for comet hunting. If you are an active comet hunter, then there is no better way to search the night skies looking for a new comet than using a binoscope. If anything is going to help you find a comet visually, then using a binoscope or binocular telescope is going to be your best bet. And don't forget to add a little bit of luck with that too.

This book is filled with lots of photos of homemade refractor binoscopes and binocular telescopes (some commercial) that were made by some very creative and resourceful amateur telescope makers from all over the world. Some of these new and clever ideas that amateur telescope makers are building into their homemade telescopes today may very well show up in commercial telescopes and binoscopes in the future. When you are trying to decide what you want and really need for your astronomical observing, a binoscope will provide you with some great visual observing using both eyes along with twice as much light gathering power compared to a single telescope of the same aperture. If you have the opportunity to view through a large binocular telescope or big refractor binoscope, you won't forget the fantastic view, the detail, vivid colors and hues of the nebula, star clusters, and a wonderful stereo view of the planets and the great craters on the moon surrounded by a rugged lunar landscape. When you are observing with a binoscope, you are in for a truly memorable visual experience.

What Can One Expect to See in a Binoscope?

The first thing that will become apparent when you look into the eyepieces of a binoscope or binocular telescope, you'll begin to see fainter stars and brighter nebula with a wider field of view, and more depth of field, combined with a very noticeable stereo effect, especially with the moon and planets. You'll see hints of more extended detail and greater resolution in most celestial objects. All of this combines to give the observer a very memorable viewing experience. Each observing session with your binoscope becomes special, where you will find new and interesting objects that you haven't seen before. Probably the best way to decide if you want a binoscope or binocular telescope is to try and find a local astronomy club in your area that has a monthly star party. Ask if someone in their club membership has a big binocular telescope or refracting binoscope. If they do, try to attend one of their star parties and you'll have a good opportunity to look through one and you'll be able to see why so many amateur astronomers enjoy using a binoscope or binocular telescope.

There have been many amateur astronomers who have taken their own telescope and mount and simply made a binoscope out of it. On the Internet are many telescope companies and Internet stores that sell a wide variety of accessories and that also carry a line of parts that can easily adapt a commercial (see Fig. 5.14) or even a homemade Altazimuth or commercial equatorial (see Fig. 5.29) telescope mount to handle a refractor binoscope. Sometimes it's just a little easier and perhaps cheaper to just modify your existing mount to carry two single telescopes and make a binoscope out of it. The actual cost of a refractor binoscope with a set of good ED optics (extra-low dispersion glass) is quite expensive and usually out of the price range of the average individual. A good achromatic binoscope on the other hand is far cheaper compared to a pair of expensive ED refractor optics and can still yield some very pleasing views when used in a refractor binoscope.

If you have made the decision to build your own binoscope, be it a binocular telescope or refractor binoscope, then that's when the real fun begins. Building your own binoscope becomes a labor of love. It's not for everyone that's interested in doing serious astronomical observing who wants to build their own telescope or binoscope. But I'm sure there are many serious amateur astronomy minded individuals who would probably love to build their own telescope or binoscope, but finding the time and having the skills and necessary tools do it can be just another item on their wish list. However, for those who do build their own binoscope or binocular telescope, then for them, it becomes more than a project, it becomes a passion. It may take several months to build your binoscope project. But taking your time and building it the way you dreamed you could build it will make it turn out to even better than you ever expected. The key in building a good reliable telescope, is taking your time without being in a hurry to complete it and building it with a good robust design and using quality materials that are long lasting and that can take some wear and tear without having to replace or repair things that normally shouldn't have failed in the first place. But things happen, and, over time, you may want to give your binoscope or binocular telescope a new coat of paint or replace a focuser or even remake something that can make it more efficient optically or mechanically. That's the fun of being an amateur telescope maker and building your own telescope or binoscope. You did it yourself.

Going to Build a Monster Binocular Telescope?

From a historical perspective, the modern binocular telescope age really got started in the 1920s when Mr. Hilmer Hanson of Nebraska built his first 6-in. Newtonian binocular telescope (see Fig. 7.1). Since then, the evolution of binoscopes had been slow, until Lee Cain (see Fig. 5.2) in the early 1980s made a remarkably big 17½-in. Dobsonian binocular telescope (commonly called "Dob" for short). Thirty-four years later, Dobsonian style binocular telescopes are a lot more common now than they were in the past. In the last 20 years, they have been getting bigger and bigger (see Figs. 1.36 and 1.4), and with the availability of larger and thinner mirrors, it won't be too long before we'll see a real big "Monster" binocular telescope in the works. For example, building a big "Monster" 36-in. Dobsonian binocular telescope will be quite a job and will take a lot more time to construct and twice as much materials and expense compared to making a single 36-in. Dobsonian telescope. But after it is finished, it will undoubtedly provide the observer with celestial views that will be nothing short of spectacular. It will become a historic telescope!

Fig. 1.1 A 1980s Dobsonian style Newtonian “rocker box” housed in an Altazimuth mount (Image credit: Halfblue-Wikipedia)

Before you start building a “Monster” Dobsonian binocular telescope, let’s take a look back in telescope making history and see how the big Dobsonian revolution got started. To begin with, let’s give some “kudos” to John Dobson (who the Dobsonian telescope is named after). In the 1960s and 1970s, John Dobson helped popularize the Dobsonian telescope (via The San Francisco Sidewalk Astronomers) with his use of cheap materials, cardboard sonotubes, and thinner primary mirrors that he fashioned himself and placed in a simple Altazimuth mount. Dobson also let the public have an opportunity to view the heavens through his simple but nevertheless humble Dobsonian sidewalk telescopes. The Dobsonian became the standard design for just about all Altazimuth-mounted Newtonian telescopes during that period of time. The Dobsonian telescope became so popular that Coulter Optical Co. in 1980 decided to introduce a “Blue” cardboard sonotube 13.1-in. f/4.5 Dobsonian. It later was changed to a “Red” sonotube and eventually offered in an f/7 version with a simple rectangular wooden “rocker box” at the rear to house the primary mirror and pinion bearings.

Coulter’s Dobsonian telescopes eventually increased in size to 17.5 in. and in the late 1980s were considered the “Monster” Dobs of their time. Even though these big “rocker box” Dobsonians were extremely heavy and very bulky to transport, once set up, the views that these big “Dobs” provided were totally awesome and set the standard for the Dobsonian telescopes we see today. (See Fig. 1.1.)

Fig. 1.2 Greg Boles of Topeka, Kansas, is using a 1980s Coulter Optical "Blue" tube "rocker box" style 13.1-in. f/4.5 Dobsonian to observe the heavens with (Image credit: Rick Schmidt)

Even today, a 1980s Coulter style "Red" or "Blue" sonotube Dobsonian is still a crowd pleaser at local star parties. At national telescope maker's conferences, they are considered as a classic Dobsonian telescope to be admired as a standard even for modern Dobsonian telescopes that amateur telescope makers and commercial telescope companies are building today (Fig. 1.2).

Even though the lighter weight "open truss" (see Fig. 5.8) or "tube truss" (see Fig. 5.56) Dobsonian telescopes are probably the most common types in use today, sonotube style Dobsonians are still around and probably will be for a long time. And don't we wish we could buy a big 13.1-in. Dobsonian today for the same price we bought one for in the 1980s ($395.50USD)?

It's interesting to note (at least from the author's perspective) that after 1984, it took another 10 years or so to start seeing homemade binocular telescopes and refractor binoscopes beginning to "pop-up" at local star parties, amateur telescope maker events, and astronomy conferences. The idea of combining two big Dobsonian Newtonian telescopes together in a single Altazimuth mount for using two eyes for viewing (in this author's mind) should have happened earlier, but for some reason was slow to catch on. Even more interesting is the fact that there was about a 60-year gap since Hilmer Hanson (see Fig. 7.1) built his first Newtonian binocular telescope back in the 1920s before we started to see any binocular telescopes appear in any real frequency.

It's possible perhaps it was just a matter of convenience for the 60-year gap, and amateur astronomers were perfectly happy just using a big Newtonian telescope for their astronomy observing and obviously, there were other reasons too. Since that time, hardly anything new appeared until 1984, when Lee Cain (see Fig. 5.2) built his remarkable 17.5-in. binocular telescope and Altazimuth mount. After that, the rest is history. Binocular telescopes and refractor binoscopes started to "pop-up" on occasion in the 1990s, and then amateur astronomers and amateur telescope makers began to realize that two eyes are better than one to view the heavens with, especially with a binocular telescope or refractor binoscope.

Since 2004, at least two 22-in. binocular telescopes have already been built (see Fig. 5.8). Even now, a new homemade 28-in. f/4.8 binocular telescope (mirrors and all) has been built by Mr. Joerg Peters of Germany. There is no doubt that it is the current "king" of the amateur-made binocular telescopes. With today's ATMs wanting to build bigger and bigger binoscopes, it's just a matter of time someday before we see a really big "Monster" 36-in. binocular telescope being unloaded off of a truck at a local astronomy club's star party or at a national telescope maker's conference. When that happens, then the sky's the limit when it comes to building a big binocular telescope. One can only imagine how large they will become in the next 25 years or so. So what will be some of the tasks you will need to do after you build a "Monster" binocular telescope? Below is a preview of what you can expect to do and the "estimated" amount of time it will take to do it if you plan to transport it to different observing sites on occasion.

1. Transporting it to and from your favorite observing sites will take a big concerted effort. Probably at least two people will be needed to help load everything into a small truck, and that may take more than 1 or 2 h to load. Don't forget to bring the coffee!
2. The estimated amount of setup time needed for assembly of the big 36-in. Dobsonian binocular telescope and its Altazimuth mount will probably require a minimum of two people at least 2 h of setup time after reaching your observing spot early in the day.
3. Once it has been setup, then comes the collimation and alignment. After the two big Dobsonian Newtonian optical systems have been collimated, someone in the early evening will get up on a big ladder (see Fig. 1.3), point the big binocular telescope at some bright star, center it in the field of view (FOV) in one of the telescope's two eyepieces, and do the final alignment "tweaking" by yelling out commands to someone on the ground to twist and tighten some knobs and bolts to lock in both big Dobsonian binocular telescopes on the same object (two people and possibly 1 h>A total est. time for collimation and alignment 2 h minimum).

After the collimation and alignment has been completed, the "First Light" celestial object we want to check out with the big 36-in. binocular telescope would be M-42, the Great Nebula in Orion. M-42 is made up of wonderful vivid colors of flowing clouds of hydrogen gas, dust, and young bright stars that are in their infancy (see Fig. 1.6). Of course, there is a big list of objects that everyone wants

Fig. 1.3 A 1980s 13.1-in. Coulter Optical Odyssey I Dobsonian (Image credit: Dennis Steele)

to see, and we already have a line of anxious people waiting to get a look through our "Monster" Dobsonian. The line will get longer as the night wears on. The big "Monster" binocular telescope once it's setup and ready for observing would not only draw a long line of anxious individuals waiting for their turn to take a look but would be a big crowd pleaser too. As fun as it may be, there are some concerns taking a big "Monster" binocular telescope to local star parties or even popular telescope makers conference.

1. Requires the use of a big ladder (see Fig. 1.4) that people have to climb up and down on.
2. If a big "Monster" binocular telescope has "no" GOTO or motorized drive capabilities, it would take time and some effort to locate each object and position (push and pull) it until the object is brought into the field of view (FOV). It would be a lot more difficult to maneuver a big Dobsonian by hand at the zenith. (A motorized dual-axis drive system is a must.)
3. Because of the overall height and maneuverability of a big "Monster" binocular telescope, there probably would be very little observing at the zenith. It would be a little "shaky" for an individual standing near the top of a tall ladder trying to maneuver the big dual "Dob" into position and observe objects at the zenith and keeping them in the field of view at the same time. It can be done, but be careful when you do.

Fig. 1.4 A Texas-size 48.9-in. Dobsonian called "Barbarella" (Image credit: Astronomy Technology Today)

Besides having to climb a "tall" ladder and trying to maneuver the big dual Dobsonians into position by hand will be challenging enough, but viewing with a big "Monster" binocular telescope will be the ultimate visual observing experience an observer can have.

How about standing on a ladder nearly 20 ft off the ground doing some observing through a big 48.9-in. Dobsonian nicknamed "Barbarella"? This is probably one of the biggest amateur Dobsonian made to date. (*Note*: A Utah amateur Mike Clements has since made a 70-in. Dob!) Even its Altazimuth mounting is huge, dwarfing a small car. The mirror alone weighs approximately 715 lb and is 4.8-in. thick. The big "Monster" open truss Dobsonian is approximately 20 ft. long. From looking at the photo above, another 5 ft. or 6 ft. of ladder might be needed in order to reach the zenith. Try and picture a big "Monster" Dobsonian binocular telescope this size at a local star party, in Texas maybe (Figs. 1.5 and 1.6).

To coin a phrase, "one picture is worth a thousand words," and the photo of the Great Nebula in Orion taken by the Hubble Space Telescope pictured above proves it. The imagined view of M-42 in a big 36-in. binocular telescope will no doubt be absolutely "stunning" and one that will be remembered for a long time or at least until the next observing session with the big binocular telescope.

How Does Surface Flatness Relate to Optical Quality?

One of the important things to remember when you have a binocular telescope or you're planning to build one is no matter how good your primary mirror is, your secondary mirror's quality or surface flatness is equally important too. The secondary mirror is one of the critical optical components of your telescope or binocular telescope.

Fig. 1.5 Cartoon credit: Jack Kramer

For example, if you have a primary mirror that is certified to be 1/10 wave and your secondary mirror is rated at a 1/4 wave, then what does it really mean in terms of its optical quality? The majority of optical manufacturers specify the optical surface flatness of their optics in a "peak-to-valley" wavelength configuration. Keep in mind that a manufacturer's "peak-to-valley" surface flatness specification can sometimes be a bit imperfect and even slightly misleading. Below is a brief descriptive comparison of what you should expect when you see the advertised optical quality of optics. Likewise, the same for secondary mirrors.

Surface flatness (peak-to-valley)	Quality	Application
Less than λ/2 (1/2 wave)	Very low	Noncritical divergent applications only
λ/4 (1/4 wave)	Low	Often best test standard for a cube beam splitter. Not considered suitable for high power application when wave-front error control is important
λ/10 (1/10 wave)	Good	Considered the general standard for a quality manufacturer. Suitable majority of most laser and scientific applications
λ/20 (1/20 wave)	Very good	This flatness is advised for critical wave-front error control applications such as interferometry or intense femtosecond lasers

Fig. 1.6 The Great Nebula in Orion (Image Credit: Hubble-Wikimedia Commons)

Note

According to Jean Texereau, the famous French optician, the minimal acceptable surface accuracy for a secondary mirror is 1/8 wavelength. It is generally believed that the cheaper commercial telescopes do not meet this requirement (let alone get close) (Fig. 1.7).

Some manufacturers of telescope optics often refer to the optical standard called "Rayleigh's criterion." This is the criterion for the resolving power or angular resolution of an optical instrument. The formal Rayleigh criterion states that the images of two-point objects are resolved when the principal maximum of the diffraction pattern of one falls exactly on the first minimum of the diffraction pattern of the other image. In rather simple terms, if you have a telescope, you would want to

Fig. 1.7 Cartoon credit: Jack Kramer

know if its optical system is "diffraction limited" or not. If it isn't, and you want to do some serious astronomy with it, then obviously you will never be happy with its overall performance.

Note

In a telescope optical system in which the resolution is no longer limited by imperfections in the lenses, but only by diffraction itself, it is said to be diffraction limited.

For example, point-like stellar sources separated by an angle smaller than the angular resolution of a telescope's optical system therefore cannot be resolved. A telescope that has a near-perfect optical system may have an angular resolution less than 1 arcsecond, but astronomical seeing and other atmospheric effects make reaching this angular resolution limit extremely difficult to achieve.

The angular resolution R of a telescope can usually be determined by

$$R = \frac{\lambda}{D}$$

where

λ is the wavelength of the observed radiation and
D is the diameter of the telescope's objective or aperture.

Resulting R is in radians. Sources larger than the angular resolution are more commonly called extended sources or diffuse sources, and smaller sources are commonly called point sources. For example, in yellow light with a wavelength of 580 nm, for a resolution of 0.1 arcsecond, we need $D = 1.2$ m. This formula, for light with a wavelength of about 562 nm, is also called and known as Dawes' limit.

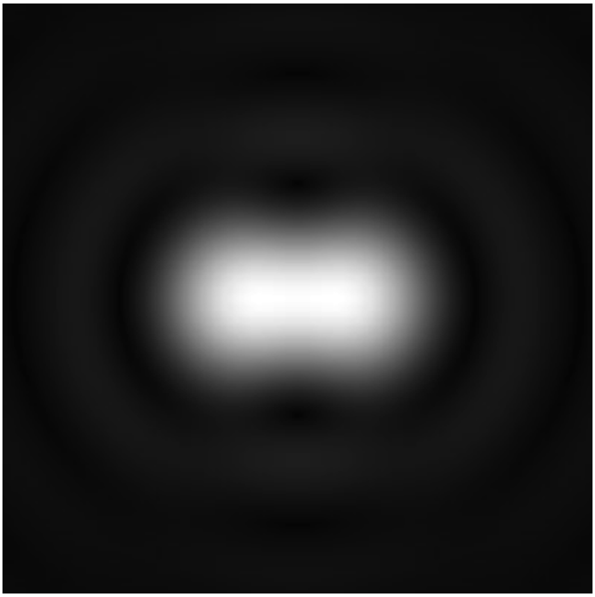

Fig. 1.8 Diffraction pattern matching Dawes' limit (Image credit: Geek3- Creative Commons)

The formal Rayleigh criterion is close to the resolution limit discovered earlier by the noted English astronomer W. R. Dawes who recorded skilled observers with tested experience observing close binary star systems (double stars) that were same or nearly equal in brightness. The result, with *D* inches θ in sub-arcseconds, was found to be slightly narrower than the original calculation compared to the Rayleigh criterion. Using airy disks as a point spread function, the math shows that at Dawes limit, there is a 5 % dip between the two maximum peaks, whereas at Rayleigh's Criterion, there is a considerably larger 26.4 % dip. Using the point spread function will allow resolution of close binary systems with an even smaller separation.

Calculations used to determine Dawes' limit using common units of measurement can take on different elementary forms (see below) (Fig. 1.8):

$$R = \frac{4.56}{D} \quad D \text{ in inches}, R \text{ in arc seconds}$$

$$R = \frac{11.58}{D} \quad D \text{ in centimeters}, R \text{ in arc seconds}$$

where

D is the diameter of the main lens (aperture) and
R is the resolution power of the telescope – (Adapted from: Angular Resolution – Wikipedia).

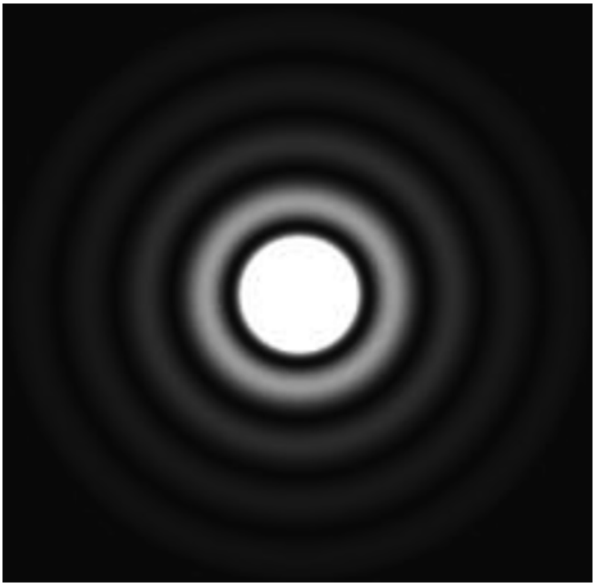

Fig. 1.9 Airy disk diffraction pattern (Image credit: GoldAstro.com)

It's important at this point to include some discussion about atmospheric effects on seeing and star images in general. Without an atmosphere, a small star would have an apparent size more commonly called an "Airy disk."

Interference patterns are created when light waves that pass through an aperture or opening of a telescope become disrupted and disturbed. A typical telescopes normally have a round, circular, or even an annular aperture. An annular aperture is defined as a circular outer border that has a circular central obstruction that is basically considered round and or circular. A good example is a secondary mirror of a Newtonian reflector or a Cassegrain catadioptric telescope. The circular aperture produces a diffraction pattern that distributes the light from a point source of light, such as a stellar image or star, into a bull's-eye target-shaped image which is commonly referred to as an Airy disk (see Fig. 1.9). The Airy disk in the figure above is a simulated image of a point source that is monochromatic (single-wavelength) light and is an example where astronomical seeing is considered excellent, thus producing a stellar image that appears nearly perfect without the blurring and other initial effects. A term called a gamma stretch which is called a "stretch function" has been applied to bring out the overall contrast and brightness of the extremely faint outer rings of the point source image. Spider vanes that secure the telescope's secondary holder in a ridged fashion within the telescope's optical tube have various configurations and shapes and are sometimes jokingly referred to by some telescope makers as a "necessary evil" in a telescope. Spider vanes produce another effect commonly referred to as Newtonian Spikes that will be discussed in more detail later in the chapter.

Diffraction in simple terms is an optical interference effect due to the bending of light around obstacles in its path (e.g., the edges of a telescope tube or its secondary holder spider vanes) similar to the way ocean or lake waves are bent or deflected around dock pilings or the edge of a jetty. All telescope optical systems show faint light and dark diffraction rings around a star's Airy disk at high power, as the diffracted light waves alternately cancel out and reinforce or strengthen each other. Diffraction rings are intrinsically faint and an inexperienced or novice observer's inability to see them shouldn't be an immediate concern. For example, in a perfect refractor, approximately 84 % of the light would be imaged in the Airy disk, with half of the remainder falling in the first diffraction ring and the balance dispersed among the second, third, fourth diffraction rings, etc. Since the first diffraction ring is approximately six times the area of the Airy disk itself, its fainter light is spread out and dispersed over a much larger area.

So as a result, the brightness of the first diffraction ring is actually less than 2 % than that of the Airy disk. The other diffraction rings are even fainter yet. It is easy to see how a less experienced beginning observer can have difficulty separating the intrinsically faint diffraction rings from the bright Airy disk. Catadioptric and reflecting telescope diffraction rings appear to be almost twice the brightness as those of a refracting telescope. The reason is due to the additional diffraction caused by their secondary mirror and spider vane obstructions. But their overall brightness is still low in comparison to their Airy disk (only 4 % as bright in the case of the first ring). Optically speaking, a catadioptric telescope's diffraction with its increased ring brightness will exhibit itself as having lower contrast and with a slightly noticeable loss of sharpness on planets, binary stars, and star clusters when compared with that of a refracting telescope. The spider vanes holding a Newtonian reflector's diagonal mirror create additional diffraction spikes that also lower contrast and radiate out from each star's image, an effect particularly visible on long-exposure photos. The image in Fig. 1.10 shows the Airy disk image of a slightly out-of-focus star in a properly collimated Newtonian telescope. The diffraction spikes of the spider vanes supporting the secondary mirror are shown radiating outward from the Airy disk.

A catadioptric telescope also has a round secondary mirror shadow, as shown in Fig. 1.14, but does not have any visible diffraction spikes and spider vane shadows. A typical telescope star image that's a result of diffraction would normally be inversely proportional to the telescope's diameter. However, when light enters the Earth's atmosphere, the different stratified layers of temperature combined with different wind speeds and air currents have a tendency to warp and bend the light waves, leading to star images that are somewhat distorted in appearance. The effects of the atmosphere can be shown as moving and turbulent cells of rotating air. At many of the well-known observatories around the world, the initial effects of air turbulence is only noted on scales that are somewhat larger than 10–20 cm and at visible wavelengths that are below the best seeing conditions, and this will lower the resolution limit of some of the world's finest optical telescopes to be about the same as perceived by a space-based 10–20 cm telescope. The "seeing disk" diameter is most often defined as the "full width at half maximum" (FWHM),

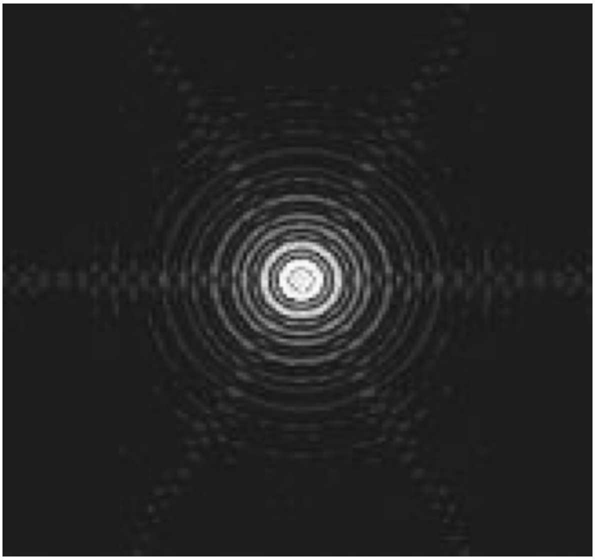

Fig. 1.10 An Airy disk diffraction pattern in a Newtonian telescope (Image credit: www.astronomyhints.com)

which is the common and accepted measure of the astronomical seeing conditions. Based on the definition, "seeing" is considered a constant variable ever-changing quantity and often will differ from location to location, from night to night, hour to hour, and frequently changes on a scale of minutes or even seconds. Professional and amateur astronomers alike often talk about "good" nights with moments of good seeing with a low average seeing disk diameter and "bad" nights where the atmospheric seeing conditions that produced seeing disk diameters that were so high and bloated that all of the observational data recorded during the observing period was not considered useable and/or ignored. One only has to look through a medium to high power eyepiece at the moon to see the visual effects of a typical night of "bad seeing." The FWHM of the "seeing disk" diameter is measured in arcseconds and normally abbreviated with the symbol of (″). For example, 1.0″ seeing is considered a good one for average astronomical sites. When compared to the cities, especially the larger ones, the seeing conditions are a lot worst. Good seeing nights are normally clear, especially those with cold nights without gusts of wind or turbulent air currents. For example, when warmer air moves upward via the convection currents, it will often degrade the seeing much the same as wind and clouds do. At some of the best high-altitude observatories located on such mountaintop sites such as Mauna Kea and Haleakala in Hawaii, the wind brings in stable dry air which has not previously been in contact with the ground and sometimes provides seeing conditions as good as 0.4″ arcseconds (Fig. 1.11) – (Adapted from: Astronomical Seeing – Wikipedia).

Fig. 1.11 Cartoon credit: Jack Kramer

Diffraction Pattern of Obstructed Optical Systems

By Rene Pascal

With the only exception of the "Schiefspiegler" (Oblique Telescope, like the design by Anton Kutter), every telescope with the main objective being a mirror is obstructed, and the quality of the image suffers more or less from the resulting disturbance of the diffraction pattern. As a rule of thumb, we have learned that a central obstruction of less than 20 % (linear diameter) is negligible for the quality of the resulting image. But what is the effect of more complicated obstructions, like thick vanes carrying the secondary mirror or other constructive elements that protrude into the optical path? Since this may be an important question when planning and constructing telescopes and other optical instruments, I ran some simulations to get an idea of the influences on image quality.

Figure 1.12 (right) shows the simulated diffraction pattern that would result from a circular unobstructed opening (left) in monochromatic light. The diffraction pattern is displayed in a logarithmic gray scale as it would be seen by the human eye with a scaling from black to white of eight astronomical magnitudes (8 mag.) The field of the simulated views is 6″ (arcseconds) wide. This will be true for all of the following simulated diffraction patterns unless otherwise stated.

If we know the energy distribution in the diffraction pattern, we are able to simulate the image that would result from imaging an object with an instrument with exactly this entrance pupil but an otherwise perfect optical system. This gives us the opportunity to compare the influence of obstructions on the image quality bare from different optical conditions of the instruments used normally for such side-by-side tests. I used Mars (an image from the Hubble Space Telescope) as test object, since its surface with the many low contrast features of different size is very sensitive to a decrease in image contrast of the optical instrument (Fig. 1.13).