

Norman Butler

Building and Using Binoscopes

Second Edition

The Patrick Moore
Practical
Astronomy
Series



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 Springer

Norman Butler
Tamuning, Guam

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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 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, this is not a “How To” book. It’s a book that is designed to give the interested readers, amateur astronomers and amateur telescope builders (experienced or otherwise) ideas, suggestions and important information about “building” and “using” a refractor binoscope or binocular telescope. If you can already build and use a telescope and/or interested in doing so, then after you read this book, you should be able to take some of the more interesting and clever ideas that are presented in the following 10 chapters and incorporate them into building and using your own telescope, binoscope or binocular telescope someday. 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 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 interested reader with some good ideas on building their own binoscope someday.

It does not take a whole 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, time, and ambition 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 by creating a robust design and doing all the advance planning and homework, then you should really look forward to your project. 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!

Please note: All of the author's own proceeds from the sale of this new Springer second edition book *Building and Using Binoscopes* and the first edition of the same book goes to help fund a junior college astronomy scholarship fund.

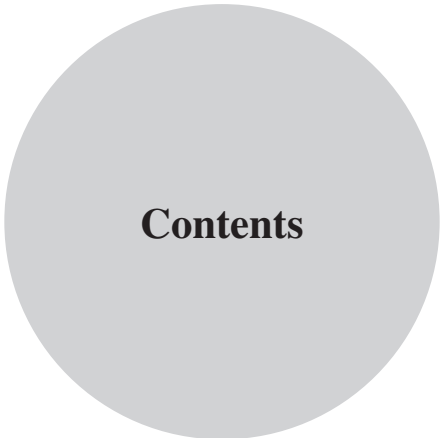
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June 2016

Norman Butler



Acknowledgments

I wanted to take this opportunity to acknowledge some individuals who 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, Rick Schmidt, and Ray Lewis. All four 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 important images, information, website stories and illustrations for inclusion in my new book. And finally, I thank my dear mother Gladys and my brother Mike who were both always my main source of encouragement for all of my astronomy endeavors, no matter how outrageous they were.



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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 the Haleakala Observatory on the island of 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 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 entire 1960s. After a 20-year career in electro-optical engineering, starting in 1994, Norman relocated to Hong Kong and started working in nearby Shenzhen, China as a joint-venture manager in the electronics industry. In 2004, he became a permanent resident of Hong Kong and started teaching at Shenzhen Polytechnic College and Harbin Institute of Technology Shenzhen Graduate School in nearby Shenzhen, China. Norman retired in 2012 and now lives in the Northern Marianas Islands and enjoys searching for comets as well as other strange and 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 to 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 and examples from other experienced binoscope makers on how to design and build a binoscope or a 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 author to let the interested reader see a variety of interesting homemade and commercial binoscopes. There is also 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, 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 the 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 a big refractor binoscope, you won't forget the fantastic view, the detail, the vivid colors or the hues of the nebula and star clusters. You will always remember the wonderful stereo view of the planets and the large craters on the moon surrounded by a rugged lunar landscape. When you are observing with a big binocular telescope or binoscope, you are in for a truly memorable visual experience. Observing the heavens with a pair of big binoculars is a lot of fun too. However, we're talking about big binoculars that are in the 100–150 mm range. Not everyone can afford to go out and pay five or six thousand dollars for a pricey pair of 25×150 mm Fujinon binoculars. It's probably going to be a lot cheaper to just build a binocular telescope or a refractor binoscope and save a lot of time and money in doing it. One of the important things that most astronomers want to get out of their observing sessions is viewing these wonderful astronomical objects and seeing as much detail as their telescopes can provide. And that's why using two eyes to observe with will no doubt make their observing sessions a more memorable experience, especially if they're using a big binocular telescope or refractor binoscope to observe with. As a builder of binocular telescopes and refractor binoscopes, the author has always encouraged people at local star parties and national telescope makers conferences to look through his equipment so that they can enjoy the wondrous views that only a big binoscope or big binocular telescope can provide. Once they see the fantastic views these remarkable big binoculars offer, they too will become smitten with the big binoscope bug and want to observe the heavens with one of their own.

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 greater depth, combined with a very noticeable

stereo effect, especially with lunar and planetary objects. 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 astronomy group has a big binocular telescope or refracting binoscope. If they do, try to attend one of their star parties and then you'll have an excellent opportunity to look through a big binoscope and see why so many amateur astronomers enjoy using one during their observing sessions.

There have been many amateur astronomers who have taken either a homemade or commercial telescope and its Altazimuth or equatorial mounting 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 Figs. 5.28 and 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 for most amateur telescope builders, a labor of love. Obviously, a binoscope is not for everyone that's interested in doing serious astronomical observing. And not everyone wants to build their own telescope or binoscope. But the author is 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 or telescope project, but taking your time and building the binoscope or telescope 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 binoscope or 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 and the best part is...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 late 1920s when Mr. Hilmer Hanson of Nebraska built his first 6-in. Newtonian binocular telescope, a historic 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 a “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 less costly 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 too will become a historic telescope!

So what makes a telescope “Historical”? There are perhaps a few criteria that would possibly make a telescope have some historical interest. One good example would be if it was the “first” of its kind and the actual telescope maker who made it. A good example would be; Sir Issac Newton and his original Newtonian reflecting telescope. So how does the word “historical” relate to Hilmer Hanson and his unique homemade 1920s 6-in f/8 Newtonian binocular telescope? Answer is; Find another Newtonian binocular telescope that was built before the 1920. If in your search you happen to find one that was built before the 1920s and confirm who the actual builder was and the date it was built, then it most likely would be considered as “historical” binocular telescope. The source of this information would likely be found and documented in an old scientific magazine, astronomy book or periodical. Most likely, one would have to find and sort through quit a few different sources in order to find a binocular telescope that actually predates Hilmer Hanson’s 1920s original Newtonian binocular telescope.

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 was started. To begin with, let’s give some “kudos” to the late 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).

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 (US\$395.50)?

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



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



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)

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



Fig. 1.3 A Dobsonian Bino (Image credit: Public Domain—Wikimedia Commons)

lock in both big Dobsonian binocular telescopes on the same object (two people and possibly 1 h 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 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



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

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.

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.

Now, consider standing on a ladder nearly 20 ft off the ground to do some observing through a big 48.9-in. Dobsonian nicknamed “Barbarella”? This is probably one of the biggest amateur Dobsonian made to date. (On a sidenote, 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 below 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.



Fig. 1.5 (Cartoon credit: Jack Kramer)



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

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 that no matter how good your primary mirror is, the quality, or surface flatness, of your secondary mirror and star diagonal is equally important. The secondary mirror and star diagonal are critical optical components of your binocular telescope or refractor binoscope and your telescope's optical performance can depend on their true optical quality.

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. The table below is a very brief description adapted from Optical-technologies.info of Peak-to-Valley vs. RMS of what one should expect to see in the advertised optical quality of optics. The same information can also apply to secondary mirrors, optical flats and mirror star diagonal too.

Surface flatness (peak-to-valley)	Optical Quality	Type of Application
Less than $\lambda/2$ (1/2 wave)	Very low (poor)	Recommended for noncritical diverging applications only.
$\lambda/4$ (1/4 wave)	Low	One of the highest test standards for cube beam splitters. Not considered to be acceptable for high power applications if wave-front error control is the primary element.
$\lambda/10$ (1/10 wave)	Good	Considered the accepted standard for a quality manufacturer. Suitable for most laser and scientific applications.
$\lambda/20$ (1/20 wave)	Very good	Preferred surface flatness for critical wave-front error control application, such as interferometry and/or the use of intense femtosecond laser applications and optical laboratory experiments.

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 or get close to it (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 image falls exactly on the first minimum of the diffraction pattern of the other image. Basically, if you have a telescope, it’s normal that you



Fig. 1.7 (Cartoon credit: Jack Kramer)

would want to 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.

In a typical 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 that are 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 (example: nebulae), 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.

The formal Rayleigh criterion is close to the resolution limit discovered earlier by the noted English astronomer W. R. Dawes who recorded skilled celestial observers with tested experience observing close binary star systems (or double stars) that were the 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 modest 5% dip between the two maximum peaks, whereas at Rayleigh’s Criterion, there is an extremely large and quite noticeable 26.4% dip. Using the point spread function will typically allow resolution of close binary systems with an even smaller separation.

Calculations used to determine Dawes’ limit using basic common units of measurement can present different elementary forms (see below) (Fig. 1.8):

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

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

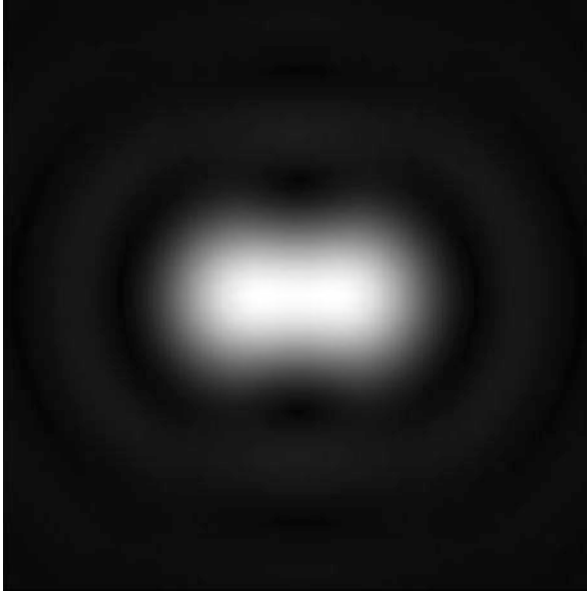


Fig. 1.8 Diffraction pattern matching Dawes' limit (Image credit: Geek3- Creative Commons)

where

D is the diameter of the main lens (aperture) and

R is the resolution power of the telescope—(Adapted from: Angular Resolution– Wikipedia).

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 optical telescope normally has 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. The term "gamma stretch," which is called a "stretch function," has been applied to enhance the overall contrast and brightness of the extremely faint outer rings of the point source image. Spider vanes that

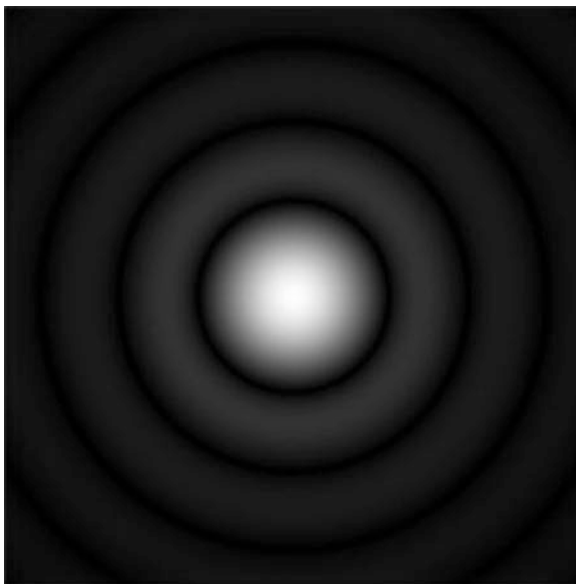


Fig. 1.9 A computer generated image of an Airy Disk pattern (Image credit: Public Domain–Wikimedia Commons)

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 caused by the bending of light around obstacles or structures 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 a jetty's edge. All telescope optical systems show faint light and dark diffraction rings around a star's Airy disk at high magnification, 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 wouldn't normally be considered to be a real or immediate concern. For example, in a perfect refractor telescope, approximately 84% of the light would typically be imaged in the Airy disk itself, with half of the remaining light falling in the first diffraction ring and the left over balance would be distributed 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 greater 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. It is easy to



Fig. 1.10 Diffraction spikes from various stars seen in an image taken by the Hubble Space Telescope (Image credit: Public Domain—Wikimedia Commons)

see how a less experienced beginning or novice observer can struggle separating the intrinsically faint diffraction rings from the bright Airy disk. Catadioptric and reflecting telescope diffraction rings appear to be almost twice the overall brightness of those produced by a refracting telescope. The major reason is due to the additional diffraction caused by their secondary mirror, secondary holder and spider vane obstructions. But their overall brightness is still low compared to their Airy disk (only 4% as bright in comparison to the first ring). Optically speaking, a catadioptric telescope's diffraction with its increased ring brightness will appear as having lower contrast and with a noticeable (though slight) loss of sharpness on planets, binary stars, and star clusters when compared with that of a refractor telescope. The spider vanes holding a Newtonian reflector's secondary 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 diffraction spikes of various stars in a globular cluster radiating outward from the bright images of the stars taken by the Hubble telescope.

A catadioptric telescope also has a round secondary mirror shadow, as shown in Fig. 1.14, but does not have any visible bright 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 first enters the Earth's atmosphere, the different stratified layers of temperature combined with different extreme wind speeds and air currents have a tendency to warp and bend the light waves, leading to bloated star images that are often distorted and scintillated 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 often noted on scales that are greater than 10–20 cm and at visible wavelengths that are below the best seeing conditions, and this will frequently lower the resolution limit of some of the world’s finest optical telescopes to be about the same as achieved by a space-based 10–20 cm telescope. The “seeing disk” diameter is most often defined as the “full width at half maximum” (FWHM), which is the common and accepted measure of the astronomical seeing conditions. Based on the definition, “seeing” is considered a constantly changing variable and will often 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 often talk about “good” nights with moments of clear conditions and low average seeing disk diameter, and “bad” nights where the atmospheric environment produces seeing disk diameters so large and bloated that not all of the observational data is considered useable. In some cases, the observational data is ignored. A medium to high power eyepiece can demonstrate a typical night of “bad seeing” when it is used to look at the moon. The FWHM of the “seeing disk” diameter is measured in arcseconds and it is 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 typically a lot worse. 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 conditions 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



Fig. 1.11 (Cartoon credit: Jack Kramer)

with the ground and sometimes provides seeing conditions as good as 0.4" arcseconds (Fig. 1.11)—(Adapted from: *Astronomical Seeing*—Wikipedia).

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

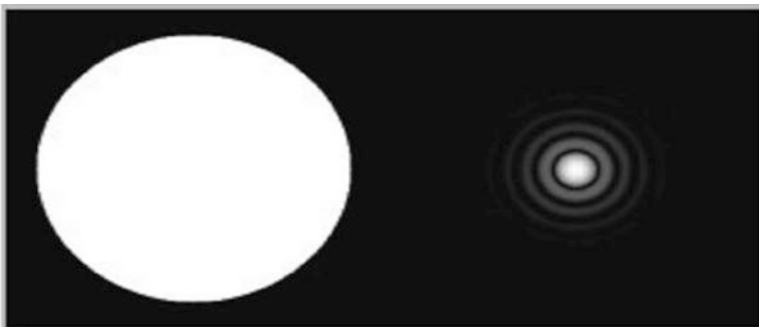


Fig. 1.12 Diffraction pattern Airy disk (*right*) of an unobstructed circular entrance pupil (Image credit: Rene Pascal)