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BACK TO THE BASICS

A Telescopic Primer by

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Telescopes

Here's a basic but deceptively difficult question that has never before been addressed in the *Observer:* **What is a telescope, and how does it work?**

A telescope is an instrument that forms a magnified image of a distant object. (The word telescope is from the Greek word teleskopos, which means "far-seeing.") There are three basic types of telescopes: refractors, reflectors and catadioptrics.

Refractors. **Galileo's** 1-inch "spyglass" telescope in 1609 was the forerunner of the modern refracting telescope, with light rays passing through (and being bent by) a curved objective lens at one end of the tube and an eyepiece at the other end. Today's refractors feature two lenses and an **L**-shaped insert containing a star diagonal mirror to allow the observer to look down through the eyepiece rather than having to position himself under the eyepiece end of the tube when it's tilted up.

Although refractors of more than 5" aperture (lenses) are frightfully expensive, this type of telescope offers excellent image definition in all sizes as well as the virtue of seldom requiring recollimation.

My first 'scope was a 3.5-inch refractor. I got it more than a decade ago, and I use it now for solar observing. It has never needed collimation.

While refractors are excellent for observing objects requiring fine detail or definition such as the Sun, Moon, planets and double stars, they cannot compete with reflectors in terms of deep-sky viewing due to their limited light-gathering potential.

The larger a refractor's objective lens – which serves as the aperture -- the longer the tube must be. Large refractors aren't feasible for amateur astronomy because, in addition to their hefty expense, the extraordinary tube length of a large refractor requires a massive, sturdy (i.e, permanent, as opposed to portable) and *tall* mount because the eyepiece is at the lower end of the tube. **Tom Clark's** new 42-inch reflector would be more than 60 ft. long if it were a refractor.

In fact, the largest refracting telescope in the world is the 40-inch, 62-ft. long Yerkes Observatory refractor at Williams Bay, Wisconsin. It was completed in 1897 and has been in use ever since. A larger (59-inch) French refractor was built and displayed at the Paris Exhibition in 1900, but it never worked.

Reflectors. Reflecting telescopes reflect incoming light rays from a large, concave primary mirror located at the base of the tube back to a smaller secondary mirror positioned diagonally near the aperture (open end) to direct the light through the drawtube, or focuser, to the eyepiece.

Reflectors are much less costly to manufacture per inch of aperture than refractors, and they are more compact than refractors of comparable tube diameter. Because **Sir Isaac Newton** devised the diagonal placement of a secondary mirror for reflectors, this style is popularly known as the "Newtonian reflector."

Since reflectors literally have no size limits, they offer excellent deep-sky observing possibilities. (On the other hand, reflectors tend to require frequent recollimation to keep the two mirrors properly aligned.)

For more about Newtonian reflectors and the way they work, see "Focal Length" on p. 5.

Catadioptrics. Catadioptrics comprise the third basic telescope type. While different catadioptric designs deliver light rays to the eyepiece in varyous ways, the basic *Cassegrain* style (named for the French doctor, **Jacques Cassegrain,** who designed it in 1672) features incoming light rays passing through a corrector plate and bouncing off, first, a concave primary mirror at the eyepiece end, and then off a convex secondary mirror mounted on the corrector plate, before passing through a hole in the primary mirror to reach the eyepiece.

The two most popular forms of Cassegrain telescopes, *Schmidt-Cassegrain* and *Maksutov-Cassegrain,* differ in the way they deliver light between the primary mirror and the eyepiece.

Although Catadioptric telescopes tend to be far more expensive than reflectors of equivalent aperture, their relatively short tubes render them extremely portable and, unlike Dobsonian reflectors, they can easily be adapted for astrophotography. And unlike refractors, reflectors and finderscopes that invert the images they receive, catadioptric 'scopes present an upright image.

If I were in the market for, say, a Schmidt-Cassegrain telescope, I wouldn't buy one at all unless it came with (or I could afford to add to the purchase price) a dual-axis motor drive and computerized finder system. My thinking here is, if I have to do all the work of finding objects and keeping them in view myself, I'd rather buy a Dob and spend those add-on dollars on a few more inches of aperture.

Mountings

There are two basic telescope mounting systems, *altazimuth* and *equatorial.* One – altazimuth – offers quick and easy movement of the tube in any direction; the other one – the equatorial mount – is more complex and expensive but is ideally suited for astrophotography, or – when combined with a motor drive – for tracking objects across the sky without manually readjusting the telescope.

Altazimuth Mounts. The term *altazimuth* is a combination of two words, altitude and azimuth; those words, in turn, refer to the two axes of motion (lying at right angles to each other) along which telescope tubes may be moved. The **azimuth** axis permits the tube to be moved horizontally, or parallel to the horizon; the **altitude** axis permits the aperture end of the tube to be elevated or lowered.

Altazimuth mounts resemble a camera tripod. Many small telescopes feature cable-controlled knobs that provide fine-tuned movements for manually tracking objects in azimuth or altitude. Because celestial objects do not move across the sky in straight lines, however, both knobs must be used to keep objects centered in the field of view.

Unquestionably the greatest advance in altazimuth technology arose in the 1970s with the advent of the **Dobsonian mount,** named for its inventor, **John Dobson.** The Dobsonian mount consists of a lazy Susan-like swivel base (for horizontal movement) beneath the "rocker box" in which the telescope tube rests in twin semicircular grooves, thus permitting vertical movement of the tube.

The beauty of the Dobsonian concept is that *both movements can be performed simultaneously.* And because the "Dob" is inexpensive to manufacture, highly transportable and easy to set up and operate even if you wouldn't know your azimuth from a hole in the ground, its appearance revolutionized amateur astronomy and resurrected the altazimuth concept from obscurity.

A clever offshoot of the basic Dobsonian design that has grown in popularity in recent years is the **truss tube Dobsonian.** In this weight-saving design, the tube through which light passes is replaced by 2-8 smaller struts that fit into the corners of the rocker box at one end and support the spider vanes and secondary mirror assembly at the aperture end. To keep ambient light, dust, etc., out of the open area between base and aperture, a black cloth cover can be fitted over the struts. **Joe Auriemma** has a lovely 10-inch Starmaster truss tube Dob.

With a Dob, you're buying more aperture with the money you otherwise would be spending in your purchase price for a more expensive mounting.

The drawback of the Dob is, of course, that if you don't have the hands-on technical skills of a **Doug Maxwell,** who created a motor-driven equatorial platform for his 13" homemade Dob – or if you don't have the financial resources to buy such a ready-made system – you'll have to constantly manually guide your telescope to keep a given field of view centered in the eyepiece. You won't be able to take long-exposure astrophotographs with a Dob, either.

Still, you'll have a hard time convincing most Dob owners that they weren't getting a bargain in purchasing a Dob: studies have shown that, after purchasing another telescope, most Dobsonian owners prefer to keep their Dob rather than selling it.

Like diamonds, Dobs are forever.

Equatorial Mounts. The two axes of motion in an equatorially mounted telescope are referred to as the **polar axis** and the **declination axis.** Moving the telescope around the polar (right ascension) axis permits it to go E-W (or vice versa) across the sky; moving the 'scope around the declination axis permits it to go N-S, etc.

On larger or more expensive telescopes, at least, the right ascension and declination dials (known as setting circles) on an equatorial mount generally will do a good job of helping you to locate celestial objects, or at least to get you close to them, if you know their r.a. and dec. numbers.

Having found a celestial object, you can lock the declination axis and follow the object's path E-W across the sky manually. Adding motor drive will do the job for you – and adding a computerized GoTo system will even find the objects for you, slewing the 'scope around until it reaches the r.a. and dec. coordinates for an object. All you have to do is polar align the 'scope and, in the latter case, locate, center and punch in a couple of guide stars, and the motor drive and GoTo computer will do the rest.

As long as your batteries don't fail, that is.

(Note: Some Dob owners use a modified computerized system that ***Smitty*** *calls "PushTo" -- it's like GoTo without the motors -- to locate objects manually.)*

The two main types of equatorial mounts are the **German**, which requires a counterweight because the polar and declination axes form an off-balance **T**-shape with the tube extending beyond the mount on one side; and the **fork mount**, which needs no counterweight because the tube lies between two large forks at the upper end of the polar axis. Fork mounts are most commonly associated with short-tube catadioptric telescopes, since a long tube could not be swung between the forks to view objects near the celestial poles.

Finderscopes. Basically, a finderscope is a small Galilean "spyglass" telescope mounted on a larger telescope as an aid in locating celestial objects. In order to work effectively, the finderscope must be aligned precisely with the larger telescope's optics, i.e., an object captured in the telescopic field should also be centered in the finderscope's crosshairs.

Finderscopes magnify and invert images. The numbers associated with finders (e.g., 5x25, 6x30, 8x50) refer to the power of magnification – the first number – and to the diameter of the aperture in millimeters (the second number).

What size finderscope you need depends at least partly on the size of your telescope. 6x30 is the bare minimum for a useful finder – but if you use a larger finder with a small 'scope you'll probably need to add a counterweight at the other end of the tube to offset the finder's weight if you also use a Telrad. (But hey, the same thing is true if you use a heavy wide-angle eyepiece such as a Nagler or Pentax.)

Two popular alternatives to magnifying finderscopes are the little BB gun-style **reflex sight** that uses a red dot to pinpoint targets, and the larger Telrad that uses three concentric red circles measuring ½', 2' and 4' in dia. to accomplish the same thing. The tradeoff between magnifying finderscopes and reflex sights is that, while reflex sights do not invert images, they also do not magnify the field of view, so your star-hopping with a reflex sight is limited to using naked-eye stars and objects.

Eyepieces. An *eyepiece* is a powerful magnifying glass that consists of two or more small lenses that are arranged closely inside a metal or plastic mounting. While eyepieces may contain as many as eight or more lenses, their function is the same as the telescope tube, i.e., to transmit a *focused* enlargement of whatever images appear.

Eyepieces come in three different diameters: .965", 1.25" and 2", with 1.25" being the most commonly encountered. .965" eyepieces are, virtually without exception, of inferior quality and are usually sold with cheap, department store telescopes. 2" eyepieces are generally excellent, offering great eye relief and wide-angle fields of view, especially at low magnifications – but unless your Visa card has high limits you probably don't need a whole set of them.

Various telescopic equipment manufacturers such as Orion offer adapters to fit .965" or 2" eyepieces into 1.25" focusers, or vice versa.

Since switching back and forth between 2" and 1.25" eyepieces also requires inserting or removing the adapter, many (if not most) owners of eyepieces in both sizes tend to prefer 1.25" eyepieces for general observing, saving their 2" eyepiece(s) for occasions involving low-power, wide-field observing.

Eye relief – how far you must place your eye from the eyepiece to see the entire field of view – is generally greatest at low magnifications with most types of eyepieces. While 2" eyepieces are generally best in this regard, expensive brands such as Nagler, Pentax and Radian offer superior eye relief and wide-field views at 1.25". Orion offers a broad array of long eye relief, wide-field, 1.25" and 2" eyepieces, but be advised: *You get what you pay for.* There's just no way that a $49.95 eyepiece – or even one three times that expensive, for that matter – can compete with the view afforded by a Pentax or Nagler eyepiece costing seven to sixteen times as much.

At any rate, eyepieces of short focal length provide greater magnification and narrower fields of view than eyepieces of longer focal length, which provide less magnification and wider fields of view.

For deep-sky observing, I use low power (21mm, 75x), medium power (10mm, 159x) and high power (7mm, 227x) eyepieces. I've never felt a need for anything more than that. (Of course, I could use a **Barlow lens** to double, or even triple, those magnifications, but I find that I lose too much image definition and clarity that way.)

The basic eyepiece styles include Huygenian, Ramsden, Kellner, Orthoscopic, Plossl, Erfle and wide-field. (These are *not* brand names.) Differences among the various styles relate primarily to the number of lenses present and how those lenses are shaped (concave or convex) and located within the eyepiece tube to produce curved, flat, narrow or wide fields of view.

Focal Length. Light rays don't enter a telescope tube as a tiny, laser-like beam; they enter it everywhere and thus must be focused before they reach the eyepiece. In a Newtonian reflector, this focus is achieved via a concave primary mirror surface that reflects the light back to a strategically positioned secondary mirror. It doesn't matter much that a portion of the incoming light is blocked by the secondary mirror, since the curvature of the primary mirror reflects whatever light it receives and secondary mirrors occupy a small portion of the open end, or aperture.

The term **focal length** refers to the distance between a lens or mirror and the point at which it brings parallel light rays into sharp focus. Binoculars, telescopes, magnifying finderscopes and eyepieces all have focal lengths, measured in millimeters.

That's not the end of the process, however. When light rays reach the secondary mirror, they are directed diagonally through a focuser tube to the eyepiece; that focuser can be adjusted closer to, or farther away from, the secondary mirror as necessary to focus the image that appears in the eyepiece. And since visual acuity is highly individualistic, what *you* see as a focused image will be out-of-focus for someone whose eyesight is sharper or weaker than your own.

Before that can happen, though, one more thing must occur, i.e., the eyepiece lenses, however many of them there might be in a given eyepiece, must be coordinated to produce a focused image to pass on to the pupil of your eye. Fortunately, the manufacturers do this and you don't have to worry about it unless, as happened to me once, the lenses fall out of your eyepiece.

Exit Pupil, Eye Relief and Apparent Field of View. As was mentioned earlier, the Earth is a sphere, not a flat plane surface. Stars do not "move" across the night sky in straight lines, but in arcs. Their apparent motions are measured in degrees, minutes and seconds of arc. The terms *arc-minute* and *arc-second* are used to distinguish those measurements of distance from the other, familiar measurements of time.

There are 60 arc-seconds in one arc-minute of sky; 60 arc-minutes in one degree; and 360 degrees comprise the entire celestial sphere.

The term **exit pupil** refers to the image that forms on a telescope's primary mirror or lens when you aim the 'scope at something. The higher an eyepiece's magnification, the smaller the diameter of the exit pupil becomes. In order to see the entire field of view in your eyepiece, the pupil of your eye must be brought close to the plane of the exit pupil in the eyepiece; otherwise, you won't see the image at all.

The term **eye relief** refers to the distance between the eyepiece and the image, or exit pupil. To get your eye close enough to the eyepiece to see the image while wearing glasses, you need large eye relief, especially at high magnifications.

And what does all this have to do with anything? Well, for starters you may have wondered exactly what the term **apparent field of view** refers to. So here's the answer:

If you aim your telescope at the daytime sky with your eye at the exit pupil where you can see the entire field of view, you'll see a circular disk of light inside the borders of your tube. The apparent angular diameter of that disk is the apparent field of view for that eyepiece and, according to what eyepiece design you're using, can range anywhere from about 25 degrees to more than 80 degrees.

Determining Eyepiece Magnifications, True Fields of View and Dawes Limits. (Note: the portions of this section within quotation marks are from *Observe Galaxy Groups and Clusters* [A.L., 2001] by **Robert McGown** and **Miles Paul,** p. 146.)

***"(To determine the) magnification of a given eyepiece: divide the focal length of the telescope by the focal length of the eyepiece."**

The focal length of my 12.5-inch Dob is 1587mm; my 10mm Pentax eyepiece thus has a magnification of **158.7x**, or **159x**.

***"(To determine the) true field of view in degrees, given an eyepiece's apparent field...divide the apparent**

field of view (in degrees) by the magnification. Multiply by 60 to get the true field in arc-minutes."

(A reminder: 60 arc-minutes = 1 degree.)

The apparent field of view of my 10mm Pentax eyepiece is 70 degrees; dividing that by 159x gives a total of .440, or 44% of one degree. Multiplying that by 60 yields a true field of view for my 10mm eyepiece of **26.4** arc-minutes, or nearly half a degree -- not bad for a medium power eyepiece. (The true field of view for my Meade 9.7mm Super Plossl eyepiece is 19.5 arc-minutes. The difference between the two – a 26% larger field of view when using the 10mm Pentax -- is critical when you're trying to keep an object in the field while dictating observing notes, consulting atlases, star charts or photos to verify star fields, etc.)

***"(To determine the) true field of view of a given eyepiece in arc-minutes using the *star drift method*,"** select a bright star near the celestial equator (e.g., *Betelgeuse).* Place the star at the E edge of your field of view and time in seconds how long it takes for the star to drift through the center of your field of view to the W edge. Dividing that time by 4 will give you a workable approximation of the field of view in arc-minutes for that eyepiece. (The *Observer,* Feb., 2002, p. 4)

*The **Dawes Limit** refers to the smallest separation of double stars that your telescope can show as two distinct objects with blackness between them, as measured in arc-seconds. That limiting resolution principle operates independently of magnification, and is determined solely by aperture width.

To determine the Dawes Limit for your telescope, divide 4.56 by your telescope's aperture in inches.

In my case, dividing 4.56 by 12.5 inches yields a figure of **0.3648**, or slightly more than 1/3 arc-second. No matter how sharp my vision might be (and it isn't), or how much I pump up the magnification, I won't visually split a double star of 1/3 arc-second or less in separation in my 12.5-inch Dob.

Still... The Dawes Limit is theoretical, and doesn't take into account such factors as air clarity or a *faint* companion being lost in the *BRIGHT* primary star's glow. The dwarf mag. 7 companion star *Sirius B* lies a healthy 10" from mag. –1.46 *Sirius* – but I'll bet you haven't seen *Sirius B* lately. *Sirius* is simply too bright, unless you use some kind of blocking technique to cloak some of the Dog Star's overwhelming glare.

The closest double stars in the A. L.'s Double Star Club are *Zeta Aquarii* (mags. 4.3 & 4.5, separation 1.8") and *Alpha Piscium* (mags. 4.2 & 5.1, separation 1.7"). I separated them about eight years ago with my 10-inch Dob, describing the *Zeta Aqr* pair as "very close, almost touching" at 147x; and more recently, **John Wallace** split them with his 8-inch Dob.

More to the point, Double Star Club list creator **John Wagoner** stated that "All objects on this list were observed with a 3-inch refractor using between 75x and 150x." He recommends using a 60mm telescope or larger for the project. So don't let the Dawes Limit be the reason why you don't give the Double Star Club a try.

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