Choosing a first telescope
- POPULAR ASTRONOMY
- article -
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There is such a bewildering array of different types & makes of telescope on sale, compared to quarter of a century ago that choosing which type is the one for you can prove very difficult.

Telescopes fall basically into three categories and then various sub-classes:

- **i) refractor**
  - **a) achromatic long focus [ƒ/15 to ƒ/20]**
  - **b) achromatic short focus [ƒ/6 to ƒ/12]**
  - **c) apochromatic long focus [ƒ/18 to ƒ/20]**
  - **d) apochromatic short focus [ƒ/4 to ƒ/9]**

- **ii) reflector**
  - **a) Newtonian long focus [ƒ/7 to ƒ/12]**
  - **b) Newtonian RFT or Dobsonian [ƒ/4 to ƒ/6]**
  - **c) Classical Cassegrain [ƒ/16 to ƒ/20]**
  - **d) Dall-Kirkham Cassegrain [ƒ/12 to ƒ/16]**
  - **e) Newtonian-Cassegrain [ƒ/4-ƒ/16 to ƒ/5-ƒ/20]**
  - **f) Nasmyth-Cassegrain [ƒ/20 to ƒ/50]**
  - **g) Bracht or Schiefspiegler [ƒ/20 to ƒ/40]**

- **iii) catadioptric**
  - **a) Compact Schmidt-Cassegrain or SCT [ƒ/6.3 to ƒ/15]**
  - **b) Maksutov-Cassegrain [ƒ/10 to ƒ/20]**
  - **c) Maksutov-Newtonian [ƒ/3 to ƒ/6]**
  - **d) Wright-Newtonian [ƒ/3 to ƒ/5]**

The different style of mountings include:
Alt-azimuth on tripod or pedestal
Dobsonian
Equatorial
  - **a) Single arm fork**
  - **b) Dual arm fork**
  - **c) German**
  - **d) Porter split-ring**
  - **e) English**
  - **f) Cross-axis**
  - **h) Horseshoe**

If you’re not mechanically minded and good at maths & physics its probably wiser to choose a basic mounting and ‘scope. An achromatic refractor on a tripod, provided it is well made and substantial is ideal. A refractor's object glass rarely requires attention, it stays in collimation [optical alignment] and unlike a reflector’s mirrors, does not need recoating periodically. Achromatic refractors should have a focal ratio roughly 3 times their aperture measured in inches, hence 3-inch ƒ/9; 4-inch ƒ/12; 5-inch ƒ/15 & so on. A 6-inch ƒ/18 would of course be a very unwieldy instrument. Clearly classical long focus achromatics do not scale well. If the focal ratio is significantly faster than the times three rule, then it will exhibit secondary spectrum which is characterised by a purple halo around bright objects. Fast object glasses also suffer markedly from an aberration called sphero-chromatism. Normally a two element O.G. is corrected for colour at two wavelengths and spherical aberration is corrected at the same wavelengths. There is little departure from the ideal correction at different wavelengths in slow O.G.’s, but in fast O.G.’s spherical correction is poor away from the corrected wavelengths. Coma, astigmatism and field curvature also increase, although some O.G.’s correct for coma better than others. Coma manifests itself by v shaped star images off axis, the apex pointing either in or out. A good long focus achromatic will easily support a magnification beyond x50 per inch of aperture, a short focus will not support anything much beyond x25 per inch.

Unless that is you opt for a three or even four element O.G. called an apochromat or dialyt. A three element O.G. has its chromatic and spherical aberrations corrected at three wavelengths, and a four element either three or four depending on the lens groupings. These O.G.’s are very expensive. However if you can afford a good one they are well worth it because they give very high contrast images and are capable of supporting magnifications well in excess of x50 per inch. And because apochromats can have a faster focal ratio they are more portable than their achromatic equivalent. Inch for inch of aperture though a refractor offers considerably less value than a reflector, although up to 6-inches aperture refractors tend to have the edge in performance over a reflector. This is simply due to the cost of optical glass [a mirror can be made from plate glass or borosilicate glass such as pyrex, or low expansion opaque ceramics such as Cervit] and the number of surfaces that need polishing and figuring. A mirror has only one surface, whereas an achromatic objective has four.

Very few of us can afford a refractor bigger than 5-inches aperture, and it is a sad fact of observing that anything less than 6-inches aperture lacks the necessary resolution and light grasp for serious work on either the Sun, Moon and planets, or deep-sky objects. If you’re serious about wanting to obtain good views of astronomical objects you should not be considering anything less than 6-inches aperture.

Astronomical telescopes nearly always shock laymen by their size and weight. Your typical man in the street expects to see a puny little 2-inch refractor on a silly little photographic tripod. When he sees some great unwieldy lump, resembling a sewer pipe cocked over at a peculiar angle, he knows he's in dedicated anorak territory. Yet that is precisely what serious viewing of astronomical objects demands. There is no substitute for aperture [up to a point]. Where that point is I'll deal with a little further on.

Astronomical telescopes below 6-inches aperture are classed as "small", no matter what the focal length or physical size. Medium aperture ranges from 6-inches to 10-inches; large by amateur standards means anything bigger than 12-inches aperture. However the medium/large boundaries are blurred because a 7-inch f/20 photo-visual triplet refractor is a big beast by any amateur standard whereas a 12-inch f/4 Dobsonian is a squat wee thing better suited to use as a waste paper basket.

The reason aperture is important for viewing astronomical objects effectively is twofold. Foremost is light gathering power. The whole idea of a telescope is not as most folk imagine simply to make things look bigger & closer, but to gather significantly more light than the naked eye with its puny pathetic 1/4-inch aperture. Light grasp is proportional to the area of the objective, be it a lens [O.G.] or mirror [spec.]. The limiting naked eye magnitude in a rural sky near dark of the Moon is +6.5mv. A 3-inch aperture will take you down to +11.5mv; a 4-inch 12.0mv; a 6-inch 13.0mv; an 8-inch 13.5mv; a 10-inch 14.0mv & a 12-inch 14.5mv. For each doubling in diameter of the objective the light grasp increases fourfold, corresponding to an additional 1.5 magnitudes. Note that this calls for a doubling of the aperture. Doubling up from 3-inches to 6-inches increases the volume of the telescope by two cubed or eightfold. Double up again to 12-inches and you have a four cubed or 64-fold increase in volume. Evidently seeking fainter magnitude stars comes at a considerable material and engineering escalation.

Second to light grasp comes resolution. The naked eye can just about resolve two stars 3 arc minutes separation. It can split lines 1 arc minute apart. A 5.5-inch aperture objective can split a pair of 6th. magnitude stars only 1 arc second separation. Resolution is inversely proportional to the linear aperture. Double the aperture and you halve the resolution limit, i.e. an 11-inch aperture could split 0.5arcsecs and so on.

There is, in both light grasp and resolution a law of diminishing returns. Once the telescope gets bigger than 12-inches aperture the gain in magnitude limit and resolution threshold hardly seems worth all the additional effort. Not as far as visual work is concerned that is.

There is also another factor amateurs tend to overlook. Stars are in essence point sources, so as the aperture increases fainter stars come into the limit of the objective. But deep-sky objects such as galaxies, and the Moon and planets are extended objects. That is they have a sensible area or angular extent. Now it comes as a bit of a surprise to most newcomers to observational astronomy that no telescope used visually can make any extended object appear brighter than it does to the naked eye. This statement flies in the face of common sense. But common sense is not always a reliable guide. The reason for this counterintuitive law of optics is simple. Take for example a 7x50 binocular. The object glasses are 50mm or roughly 2-inches aperture. The eye beam or exit pupil leaving the eyepiece and entering the eye's pupil is 7 times smaller than 50mm because that is the magnification. In other words the exit pupil is slightly over 7mm diameter. The light grasp of the objective is proportional to the area, but the image decreases in surface brightness by the square of the magnification. So although the objective gathers almost 50 times more light then the eye, the image is made 7 times the diameter and consequently 50 times fainter. So all the additional light goes into making the image bigger, and the surface brightness stays unaltered. Except that is for one minor detail I've omitted so far. Light loss in the optical system. Every air-glass surface looses 4% due to reflection unless its bloomed in which case it falls to 0.4%; every light pass through a lens element about 0.5%; every reflection off an aluminium coating 12%, and so on. When you take the light transmission losses into consideration the maximum image brightness of an extended object, at the lowest usable magnification that produces an eye beam equal to the eye's pupil, is actually less than that to the naked eye alone.

This begs a question. How come a big telescope can render discernible faint galaxies that cannot be seen with the naked eye, if it doesn't make them any brighter? The answer is contrast and resolution. The small field of a telescope removes competing clutter from neighbouring brighter objects; it decreases the sky brightness in proportion to the square of the magnification, and it enables smaller galaxies and other faint objects to be resolved. Galaxies that are too small for the naked eye to resolve, and barely brighter than the sky, cannot be discerned, but they can be in a telescope.

However a galaxy such as the Great Andromeda spiral M32 that is easily seen with the naked eye, does not appear any brighter in a 20-inch telescope that it does in a 2-inch telescope. All the bigger telescope does is make it look bigger [so given the fixed roughly one degree maximum field diameter most telescopes provide you actually see less of it], and enables you to resolve finer details [provided there are finer details to be resolved]. Now anyone who has seen M32 with the naked eye or a binocular knows it looks like a long cigar shaped whispy nebulous patch of light. Bear in mind that no matter how big a telescope you looked through, it would look precisely the same! It would stubbornly remain a whispy evanescent vapour. With extreme difficulty, using a 1-metre class telescope from a professional mountain top site, you could visually begin to make out M32's globular clusters and H2 regions. The question you have to ask yourself is, "Do I want to go to such lengths for so little gain?"

There is also another limiting factor that puts a lid on resolution, and that is our atmosphere. The air is rarely stable enough to give an undisturbed view of extended objects. “Seeing” causes the image to wobble and undulate and shimmer. Occasionally the seeing improves sufficient to permit glimpses of an undistorted view, and on rare occasions to allow lengthy undistorted views. The reason lies in mixing of warm and cold air. Cold air has a higher refractive index. Light that has travelled for squillions of light years without the slightest distortion, in its final millisecond before entering the telescope is completely screwed up by that seething mass of oxygen, nitrogen and water vapour crucial to our existence. Anyone who has flown in a jumbo jet will be familiar with what is called clear air turbulence. There you are cruising the tropopause at 38000 feet, a clear azure sky and all of a sudden the plane plummets like a lead brick and it feels as though the wings are going to fall off. For minutes after its leveled off it feels like you’re cycling down a cobbled street. Those “cobbles” are pockets of warm air cells roughly 4-inches across. Provided your wavefront is less than 4-inches across, most of the deliterious effects of seeing remain invisible. So a 3-inch refractor can be used at fairly high powers on most nights. Go to a 10-inch telescope and you’re not so privileged. If I can use x250 on my 10-inch $f/10$ Calver [a make of Newtonian reflector] on most nights I count myself lucky. That’s only x25 per inch. I have a 3.5-inch $f/11$ guide ‘scope that will allow x200 and provide almost as detailed an image! That’s almost x60 per inch. The occasions I can use x60 per inch on my 10-inch Calver amount to less than once a year!

The largest aperture that can enjoy perfect seeing in the UK is about 10 to 12-inches, and then only 3 to 4 times a year. Clearly there is little to be gained in going beyond 12-inches. A 16-inch reflector may look impressive, but from the UK it scarcely repays all the additional expense and engineering difficulties.

So what should you be looking out for, besides an aperture greater than 6-inches if neither the additional light grasp or resolution of a monster ‘scope are going to make all that much difference? The best indication of a telescope’s performance besides raw light gathering power and the theoretical limiting resolution that goes with the bigger aperture are the residual aberrations. All telescope optical systems suffer potentially from five aberrations called Seidel errors.

These are:

i) Spherical aberration
ii) Astigmatism
iii) Coma
iv) Distortion
v) Field curvature

and a non Seidel error called chromatic aberration peculiar only to refractors, or catadioptrics.

The ideal telescope would correct all of these potential optical aberrations. In the real world what you get is something quite different. In the last century a theoretical physicist called John William Strutt, a baronet with the title Lord Rayleigh, asked himself the question, “How much residual uncorrected aberration can a telescopic optical system exhibit, be it any of the above in any combination, and still give acceptable images in terms of resolving power and contrast?” Rayleigh concluded that a total peak to valley distortion to the wavefront at the focal plane of the objective amounting to only 1/4 wavelength of green light was acceptable. Since the peak to valley departures to a perfect wavefront are contributed to by every optical surface, clearly this demands a goodly degree of accuracy, otherwise the error budget would soon exceed this fine tolerance. Sad to say almost all commercial telescope optics exceed the Rayleigh limit, and the cheaper end of the market by a wide margin. So much so that not only do many commercial telescopes exhibit residual aberrations over 1/4 wave, most do so by more than a whole wavelength, which is completely unacceptable. Nor can the prospective purchaser of said telescope rely on the claims made by the manufacturer who to put it bluntly lie threw their teeth. In fact if you find a commercial set of optics in the popular SCT’s or Dobsonians that are better than 1 wave you’ll have made a miraculous discovery!

Ask any experienced Lunar & planetary observer what wavefront error he demands of his telescope and he’ll tell you that the Rayleigh limit is too sloppy. He would demand optics better than 1/8th wave, and ideally 1/20th wave. What this means for a two mirror reflector such as a Newtonian or a Cassegrain, are optical surfaces accurate to 1/40th wave a piece!

Why do serious observers demand such accurate mirrors? The reason is image contrast. The smaller the overall aberration to the wavefront the higher the image contrast. A well made objective will focus all the light from a single star into a minute disc called the “spurious” disc, or Airy disc after Sir George Biddell Airy who first successfully investigated the form of the spurious disc theoretically. The Airy disc consists of as central spot surrounded by a series of dark and bright rings, caused by an optical phenomena known as diffraction. A perfect unobstructed objective would put 83% of all the incoming light from a single star into the central spot, and the remaining 17% into the ring system. An optical system with a 1/4 wave P-V error reduces the amount of central illumination of the Airy disc to 68%. A Newtonian or Cassegrain optical system has a secondary mirror that obstructs the incoming wavefront and effects the Airy disc in a similar fashion to distortions in the wavefront caused by residual aberrations. A 20 % c-o reduces the illumination of the central spot to 76%, a 1/3 c-o to 68%. In other words a perfect Newtonian with a 1/3c-o behaves in the same way as an unobstructed system with 1/4 wave residual aberration. If you combine the effects of a Newtonian system at the Rayleigh limit and a 1/3c-o the result is a system with only about 58% of the total energy going into the central spot of the Airy disc. This has a seriously detrimental influence on image contrast.

The best measure of image contrast is termed the Strehl ratio, which is the proportion of light going into the central part of the Airy disc compared with the theoretical maximum. A perfect unobstructed system would have a Strehl ratio of 1.0. In practice no telescope achieves that figure. However a first rate apochromat or a Schiefspiegler will reach 0.98, and certainly better than 0.92. My long focus Newtonian with a 20%c-o achieves 0.88, and my 6-inch Mak-Cass with its 1/4c-o 0.82. A Strehl ratio of 0.8 equates to the Rayleigh limit. You should not entertain buying a telescope with a Strehl ratio lower than 0.8. The trouble is most manufacturers either won’t or can’t tell you what the Strehl ratio of their telescopes is. Predictably the ones that can and do are the most expensive.

So what is the Strehl ratio going to be for a typical Dobsonian with its low quality thin mirrors that sag under their own weight, and are roughly figured, and has a huge secondary to evenly illuminate the fast focal plane? Typically its around 0.5, which is why Dobsonians are derisively referred to as “light buckets”. And what about the ubiquitous Schmidt-Cassegrain telescope? Well an 8-inch SCT has a whopping 40%c-o, and badly figured optics. The typical Strehl ratio is in the region of 0.6 to 0.7.

So what can you conclude from this monologue? Aperture alone is not an arbiter of light grasp, resolution or image contrast. Optical accuracy and a design without any, or as small as practicable a central obstruction should be your yardstick. It affords the observer little if he invests his money in a monster Dobsonian when most of the extra light grasp is squandered by spewing the light into the outer parts of the spurious disc instead of concentrating it into a “diffraction limited” central spot.

Ironically, despite all the so called improvements in telescopes and the greater variety that are on offer compared to quarter of a century ago, it is the traditional long focus achromatic refractor or the *ƒ*/8 Newtonian with its modest sized central obstruction that continue to afford best value, and best performance. A large Mak-Cass is the best alternative if you want portability; smaller Mak-Cass ‘scopes not so, due to the relatively large c-o.

What would I choose if I were faced with the problem today? All things considered I’d go for an 8-inch *ƒ*/7 Newtonian with a 2-inch flat, a 2-inch focuser, and a heavy duty German equatorial fitted with drives to both RA & DEC and setting circles and hand slow motions. I’d keep the mounting under a weatherproof run off shedette, and carry the ‘scope out when I wanted to observe and bring it back indoors once I’d finished. At some later stage I’d probably build a bigger runoff shed or runoff roof type observatory to save me the bother.

But I wouldn’t simply buy the entire ‘scope and mount off one manufacturer. I’d get 1/16th wave optics made by a reputable firm such as Hytel, I’d buy an Astrola barrel assembly through Venturescope, and either a Vixen Atlux or Losmandy G3 German equatorial head through Broadhurst Clarkson & Fuller. And I’d get a local engineering firm to make the minor alterations to ensure it all fitted together OK.

What I wouldn’t do is waste my money on an SCT or a Dobsonian, which despite their immense popularity are without a doubt the nadir in ‘scope design.

If I lived in a flat with either a balcony or roof access, I’d buy either an Intes or a Meade 7-inch or even 8-inch Mak-Cass. For 20 years I’ve owned an Optical Techniques, Quantum 6-inch *ƒ*/15 Mak-Cass on a single arm fork equatorial, supported on a Sanders & Davis cine camera tripod. Its a fag to setup and dismantle admittedly, but it does give superb views of the Moon, planets and deep-sky objects. And that, if you’ll forgive the pun, is the object of the exercise. Try to buck the rules and you’ll only end up disappointed, or worse still disillusioned. Which is presumably why there are so many Dobos & SCT’s and tacky little cheapo department store ‘scopes on sale in Astronomy Now’s classified ads.

Notice that nowhere do I mention computer controlled “GOTO” drive control systems. There is a good reason for this. Call me old fashioned if you will, but I happen to think it is desireable that an astronomer actually know the constellations, and learn how to star hop using an observer’s guide, and to use setting circles, and how to polar align his ‘scope, before progressing to a GOTO system. Computer control of a telescope is a luxury, not a necessity. Better to spend your money on the essentials at first. And amongst all the luxury items a GOTO controller comes a long way down the list. Having said that, the two equatorial heads I specifically refer to do have various drive system options. That however is not why I mentioned them. Both are solidly designed and built, and will adequately support either an 8-inch Newtonian or a Maksutov-Cassegrain. A good solid mounting is equally important to excellent optics. The two combined go to make observing a pleasure not a trial.