FORUM

A closer look at High magnification - Rodger W. Gordon

Open almost any guide book on amateur astronomy today and invariably one finds words of warning about using ***high*** magnifications on a telescope. No doubt some of this caution is justified, particularly in the case of small 2.4-inch or 3-inch "department store" refractors, often imported from Japan or other Asian sources which are advertised to beginners with power claims of 400x - 600x. Such an instrument usually has a mediocre lens at best and the instrument's barrel is coupled to a mechanically unsound mount or tripod. The tyro soon finds his dreams of high power shattered by poor optical quality and unstable mount and the lesson can be expensive.

The "taboo" against high magnification, however, has crept into the more advanced amateur community to an extent where many amateurs use only low to medium magnifications and thus deny to themselves a major portion of the performance capabilities of their instrument. For argument's sake, we will assume our intermediate or advanced amateur is using a telescope of very good or excellent optical quality, regardless of what its aperture or type may be. In other words, optics whose wave front errors, as measured on the P-V (peak to valley) system, do not exceed l/8 at the image plane.

Before discussing high magnification, we must first ascertain the limits of human vision as this plays a very important role in how much magnification we require to fully exploit the resolving power of the telescope.

The unaided human eye can resolve detail which is 1' (minute) of arc. (1) A person with so called 20/20 vision can resolve this separation on the common eye charts found in doctor's offices. This figure is somewhat misleading if applied to telescopic vision. The charts are of high contrast: black markings on a white background with contrast ratios of 0.90 to 0.95 (1.00 being maximum). The only features we encounter with astronomical subjects which approach these contrast levels are the umbras of sunspots, lunar terminator shadows, Cassini's division in Saturn's ring, and the shadows of satellites in transit across Jupiter when the background is a bright zone. If low contrast charts of 0.20 are substituted, the eye's resolution drops to 2' or 3' arc or worse.

Lunar and Martian features have an average contrast of 0.20 while Jupiter will range from 0.20 to 0.10 or less and Saturn from 0.15 to 0.05. The contrast on Venus seldom exceeds 0.05 and is usually less, which taxes the contrast detection abilities of both telescope and eye.

In a series of tests with students, Allyn J. Thompson found average daytime resolution to be 2-1/2' to 4' arc. With a change in illumination providing increased contrast, a few were able to resolve 2' separation, but only one reached 1-1/2'. Thompson further points out it requires a keen eye to separate the naked eye double e_1 and e_2 Lyrae, which are magnitudes +4 and +5 and separated by 3-1/2'. (2)

If we adopt a slightly more stringent limit of 3' arc as the average, this figure poses definition limits if we wish to obtain visually all that our telescopes are capable of revealing. We must magnify the smallest resolveable details sufficiently large so the eye can detect them.

Assume we now use a telescope of 4 1/2-inch aperture. The well-known Dawes formula R = 4.5/D states that a 4 1/2-inch telescope will resolve 1 arc/second. Recalling that 60 arc/seconds equals 1' (minute) of arc, we discover that to enlarge the smallest details to where the eye can see them at 3' angle, will require a magnification of 180x. (3) Even a more liberal limit of 2' requires 120x. So, if you are average and using less than 180x on your 4 1/2-inch scope, you are not seeing all the detail _ period! The power-per-inch requirements are thus 40x or 27x based on 3' and 2' eye resolution.

A number of authorities (Dollfus (4), Giffen (5), et al) have shown that for minimum resolvability the magnification of the telescope must be at least equal to the aperutre of the instrument in millimeters. This works out to 25x per inch. Texereau gives a slightly higher figure of 1.25 times the aperture (6) or slightly over 31x per inch. Powers of 25x - 40x per inch are commonly employed by skilled lunar and planetary observers, usually discovered by trial and error earlier in their careers.

As the telescope aperture increases, the situation grows progressively worse. If we use the 3' figure, a 9-inch telescope requires 360x and an 18-inch instrument, 720x, if we are to exploit their full resolving power. The difficulty here is the atmosphere seldom allows us to use magnifications much in excess of 300x and once the aperture exceeds 12 inches, we are almost always seeing limited rather than aperture limited except in favored locations like the south-west or in southern Florida or Hawaii or where the trade winds dominate the weather pattern.

Smaller telescopes of 2.4 inches to 7 inches in aperture are more immune to bad seeing and it is well-known that smaller telescopes are more efficient in reaching their theoretical limits on a greater number of nights. The experiences of S.W. Burnham, conceded to be the greatest double star observer of all time, clearly bear this out. (7) We then should not be surprised to find smaller telescopes capable of bearing higher powers-per-inch than their larger counterparts and frequently the smaller instrument is optically superior to the larger one.

But high powers must be tailored to the subject at hand. The moon and Mars present fairly contrasty images, but Jupiter and Saturn are not. Fifty to sixty power per inch may "wash out" certain salient features on the latter objects while retaining acceptable contrast levels with the former.

We can get a better idea of this comparison if we compare Mars and Jupiter at perihelic oppositions. Both will attain about -2.7 stellar magnitude, but Mars will be 25 arc/seconds diameter and Jupter 50 arc/seconds. On an area basis (A =pR^2), Jupiter will be only 1/4 as bright as Mars as seen in the telescope if magnifications are identical. This allows us to use higher power-per-inch on Mars without an unacceptable loss of brightness or contrast. Similarly, the moon at or near first or third quarter, when it presents maximum shadow contrast, allows us to use considerably higher powers as compared to its thin crescent or full moon presentations. Sidgwick (8) points out that magnifications of 20x per inch or lower tends to suppress fine detail. With Mars, however, even twice this amount may not be enough. Color filters can be employed to reduce glare as most lunar and planetary observers are aware and we can thus use somewhat less magnification. However, filters have advantages and disadvantages the discussion of which are not within the scope of this paper.

There are other steps we can take to improve image brightness and contrast allowing somewhat higher powers-per-inch. When I use my 3 1/2-inch Questar. I bypass the built-in prism, built-in Barlow and the included four element ocular. These conveniences are nice, but incurr additional light transmission and scattering losses. Instead I employ a 9mm Zeiss monocentric eyepiece (145x) with only 2 air/glass surfaces giving me a total of only 6 air/glass surfaces in the system. The eyepiece is attached axially for this purpose. The number of air/glass surfaces in total is less than found in many 7 or 8 element wide-angle eyepieces with 8 or 10 air/glass surfaces. The increased image brightness and contrast are quite pronounced over the view using the built-in accessories. For maximum high power resolution or for splitting tough doubles I use either a 6mm solid Tolles eyepiece or a modern 6mm Zeiss Abbe type orthoscopic (217x) or perhaps a 5mm Zeiss orthoscopic (260x). With these oculars the power-per-inch is 41x, 62x, and 74x, respectively. On a 2.4-inch Zeiss refractor (uncoated O.G.), I often use 170x and 210x and obtain excellent lunar mages (71x and 88.5x per inch). Similar powers-per-inch are used on a 1950's 3-inch, f/15 Brandon refractor or a 4 1/4-inch, f/10 Bausch and Lomb refractor (lens made in 1944).

At this point we list a table of well-known observers of the past showing the maximum powers they employed on Mars together with my own observations. (I have also added those of my own ~ Chris Lord). Except for my own observations, all the rest lacked modern coatings on objectives or eyepieces. It is indeed unfortunate that many of today's amateurs are not familiar with older references since all too often erroneous opinions are currently held that have been thoroughly discredited for decades.

Observer	Year	Instrument	Magnification	Per Inch
T.R. Cave (9)	1958	3-1/4" Brashear Refractor	250x	77x
G.V. Schiaparelli (10)	1877	8-1/2" Merz Refractor	468x	55x
Attkins (10)	*	8-1/2" Reflector	480x	56x
Backhouse (10)	*	4-1/2" Refractor	370x	82x
Wood (10)	*	3-3/4" Refractor	200x	53x
Sill (10)	1941	7-1/2" Refractor	400x	53x
T. Hake (10)	1941	8" Refractor	400x	50x
T. Hake (10)	1941	3-1/4" Refractor	184x	60x
T. Hake (10)	1941	4-1/2" Refractor	300x	67x
T. Hake (10)	1941	5" Refractor (stopped to 4")	213x	53x
P. Lowell (11)	1894	18" Brashear Refractor**	862x, 135x	48x, 73x
R.S. Richardson (12)	1941	6" Brashear Refractor	500x	83x
R.W. Gordon	1961	4" Unitron Refractor	300x	75x
R.W. Gordon	1971	3-1/2" Questar	250x	71x
C.J.R. Lord	1971	3" Refractor	286x	95x
C.J.R. Lord	1973	6-1/2" Cooke Refractor	400x	62x
C.J.R. Lord	1981	6" Quantum	400x	67x
C.J.R. Lord	1989	10-1/4" Calver Reflector	457x	45x

Also, W.H. Pickering (1926) recommended 55x per inch for Mars. (10)
* Before 1896
** 18" Brashear on loan from Amherst College. Later sold to University of Pennsylvania, where Walter Leight frequently used it at 962x and 1,218x on Saturn.

In general, the power-per-inch figures are often well in excess of the usual dictum not to exceed 50x per inch. We should emphasize that these magnifications will not often be suitable for Jupiter and Saturn.

It is interesting to note the magnifications employed by double star observers. R.G. Aitken in his classic "The Binary Stars" used up to 3000x on the Lick 36-inch (about 83x per inch). Aitken also refers to S.W. Burnham's discoveries of double stars only 0.2 arc /second separation with a 6-inch Alvan Clark refractor. (13) No magnification is given, but it would have to be quite high to detect the residual elongation of two stars this close together in an instrument of this size. Aitken states these doubles were difficult to measure in the 36-inch Lick refractor.

Although I have cautioned against using too high a power on Jupiter and Saturn, it is interesting to note that W.R. Dawes used 323x, 425x and 460x on his excellent 6 1/3-inch Merz refractor between 1850 and 1854 for observations of sub-divisions in Saturn's rings. Dawes states that 460x gave him a better view of the division in A (Encke's) than did 323x. (14) W.S. Jacobs at Madras Observatory in 1852 used 365x on a 6.2-inch refractor for ring division observations. We might point out that Encke's division is of very low contrast (about 0.05) as are other sub-divisions that are sometimes noticed in small apertures. Unless the rings are tilted at or near maximum to Earth, many sub-divisions remain undetected and are none too easy in small apertures even when favorably presented. I have seen Encke's only a few times in 6-inch to 8-inch reflectors -- though I glimpsed it in 1973, on two occasions, with a 3 1/2-inch catadioptric.

The resolving power of the human eye is fairly constant from about 5mm to 1mm exit pupil. At 1mm this would correspond to 25x per inch. Below 1mm it falls slightly down to 0.5mm (corresponding to 50x per inch) and deteriorates somewhat below this. It might thus be argued there is no need to press magnification beyond 50x per inch. While it is true that powers in excess of 50x per inch will not reveal new details, they do enlarge the scale of what is visible, making it easier to see as long as the light levels/contrast levels are sufficient. In such circumstances, the higher magnification might aid in determining if that tiny object we are seeing is a crater mound or a crater pit. It is also fun to push optics to 100x per inch or more to examine the perfection of the stellar diffraction pattern. The aesthetic satisfaction of owning an instrument capable of rendering such high powers without image breakdown is a source of pride to the lucky owner and they feel justly proud of their equipment.

There are other reasons for using high powers. Astigmatism is less bothersome with smaller exit pupils. A person suffering from severe astigmatism, who needs to wear glasses when observing at low power, can frequently remove them for high magnifications. There is ample evidence that myopia and presbyopia do not seriously interfere with telescopic vision. It is said that W.R. Dawes of "Dawes' Limit" fame had myopia of such a severe nature, he once passed his wife on the street without recognizing her! (The reaction of Mrs. Dawes is not recorded.)

Telescopes work best for contrast and definition when we use as few air/glass surfaces as possible. This means eliminating prism diagonals, mirror diagonals, Barlow lenses (except if additional eye relief is necessary) and eyepieces with many elements and air/glass surfaces. Each additional element in the optical train slightly degrades the image and these losses will mount up noticeably regardless of whether the optics have no coatings, standard coatings, or multi-coatings. My best oculars have only two or four air/glass surfaces. Even today the now discontinued (and much lamented) Zeiss monocentric is still the "sine' qua non" of lunar and planetary oculars, but top quality four element-four air/glass surface oculars such as the Plossl or Abbe' orthoscopics are excellent substitutes when maximum contrast and definition are required. A really good eyepice can increase contrast by 20%, 30%, or more over an indifferent one. A 20% loss of contrast is endured when we go from a perfect telescope with zero obstruction to a perfect telescope with 30% obstruction (15) (based on the redistribution of light in the disc/ring system) so it behooves us not to increase losses futher by using the wrong eyepieces, i.e. those of lesser quality.

I am not averse to low power viewing. In fact, my repertoire of low power/wide angle eyepices is probably greater than the total number of eyepieces most have in their collections. Few persons have ever seen, for example, the entire moon at 166x with room to spare as I have on my 4 1/4-inch f/10 refractor using a Jena 12.5mm super wide angle 90° eyepiece (plus 2x Barlow lens), and the aesthetic views of the Milky Way star clusters and star fields with a 40mm 65° Erfle or a 28mm military Zeiss 80° eyepiece are most gratifying in one's less serious moments. But the low end of the power spectrum is not an end unto itself and the observer who uses a 16-inch or 18-inch reflector at perhaps 80x or 90x on Jupiter and Saturn and extols these "high" power views is obviously missing much of what his instrument is capable of showing.

The usual rule of thumb (often found by trial and error) is 30x to 40x per inch for planetary observing and a somewhat higher 50x per inch for double stars. This writer will not dispute these figures and they are an excellent general guide. But, at the same time, there are instruments and objects that will bear more magnification, when seeing permits, and it would be foolish not to exploit these opportunities when they occur. So, don't be afraid to push the power. You may be surprised at the results.

References

(1) B.K. Johnson, *Optics and Optical Instruments*, pp. 43-45, Dover, 1960.
(2) Allyn J. Thompson, *Making Your Own Telescope*, pp. 173-175 Sky Publishing Co., 1947.
(3) W.T. Olcott, *Field Book of The Skies*, Appendix XVII, pp. 469 G.P. Putmans Sons, 1954.
(4) A. Dollfus, *Visual and Photographic Studies of Planets at Pic du Midi, Planets and Satellites* ed. by G.P. Kuiper, pp. 545-546 Univ. of Chicago Press, 1961.

(5) C.H. Giffen, *Foundations of Visual Planetary Astronomy, Part I*, Journal of the Assoc. of Lunar and Planetary Observers, Vol. 17 Nos. 3-4, pp. 69-71, 1963.
(6) H. Rutten and M. Venrooij, *Telescope Optics, Evaluation and Design* pp. 217-218 Willmann-Bell, 1988.
(7) L. Bell, *The Telescope*, pp. 263-264 Dover, 1981.
(8) J.B. Sidgwick, *Observational Astronomy for Amateurs*, p. 107 Faber and Faber Ltd., 1957.
(9) T.R. Cave, *Observations of Mars p. 133. Telescopes, How to Make and Use Them*.T. and L. Page, editors, Macmillan, 1965.
(10) H.B. Webb, *Observations of Mars and Its Canals*, pp. 39 and various drawings. Privately published, 1941.
(11) P. Lowell, *Mars*, p.217 Houghton, Mifflin and Co., 1985.
(12) R.S. Richardson, *Exploring Mars*, p.158 McGraw-Hill, 1954.
(13) R.G. Aitken, T*he Binary Stars*, pp. 29, 59. Dover, 1964.
(14) T.H. Dunham, Jr., *The Influence of Central Stops on Performance of a Telescope*, Univ. of Rochester. (Unfortunately I only have a copy of this article and the publication date and publisher are not included, but a similar article may be found by the author in J. Opt. Soc. America, pp. 41, 290. 1951).
(15) A.F. Alexander, *The Planet Saturn*, pp. 166-168. Faber and Faber Ltd., 1962.

Rodger W. Gordon
637 Jacobsburg Rd
Nazareth, PA 18064

About the Author:

Rodger W. Gordon has been an amateur astronomer for over 50 years. Since 1962 he has written over 300 articles that have been variously published in *Review of Popular Astronomy, Star and Sky, Sky and Telescope,*The Astronomical League *Reflector, Zeiss Historica,* the *Practical Observer*, the *Amateur Telescope Maker's Journal*, & *ATM Journal*, the LVAAS *Observer,* and the *1983 Yearbook of Astronomy*. During his astronomical career Rodger *"The Eyepiece King"* Gordon, has owned over 70 telescopes, 350 - 400 eyepieces, 60 binocular, 50+ colour filters, 15 Barlows and numerous other optics. He has written over 80% of the catalogue descriptions for the Vernonscope auctions. Vernonscope being the world's largest scientific instrument auction house. He has worked for Edmund Scientific, Vernoscope, Optical Techniques, and as an occasional consultant to the Questar Corps. In 1962 Rodger W. Gordon was an independent co-discoverer of the 4 - 5 day rotation of Venus' upper atmosphere (see Sky & Telescope June 1999, p59). He is the author of a major article on resolution and contrast, referenced in Price's *"The Planet Observer's Handbook"* and Dobbins, Capen and Parker's *"Introduction to Observing and Photographing the Solar System."* When observing he uses mostly refractors and Maksutovs, and constantly experiments with various optical accessories. He is quite rightly regarded as an expert on astronomical eyepieces, their design and useage. He is working on a -- soon to be published -- book about telescope eyepieces. He divides his time between astronomy, birding, long walks and writing exceedingly long letters. (*Rodger and I have been writing one another for almost a decade and the file of correspondence this end exceeds a thousand pages!*)
