Telescope Resolution Measurement at the 2013 Texas Star Party

Summary

Qualitative field measurements taken with 26 telescopes of varying type and aperture have confirmed that structure below the theoretical resolving power of the telescope (the Dawes limit) can indeed be resolved under some circumstances. Some high quality refractors achieved a resolution around half the Dawes limit.

In the seeing conditions prevailing during the tests, it was found that the maximum useable magnification varied according to telescope aperture as might be expected. However the widely accepted rule of x50 per inch of aperture, was instead found to be x20 for apertures 80-200mm, and x120 for apertures 200-650mm.

Measurements taken on one telescope (10” reflector) over 4 nights showed that the effect of seeing on measured resolution could be severe and variable over a period of an hour or so. Over one particular night the resolution of the telescope varied from 40% to nearly 90% of the Dawes limit, yet on another it remained very close to 100%.

The tests proved very effective in identifying where telescopes could be better collimated or other corrective action taken. The relative performance between telescopes and eyepieces was readily apparent to observers and was widely used. It also allowed observers to closely evaluate their own visual acuity and the impact of any spectacles worn.

Introduction

Each year the dark skies of the Texas Star Party (TSP) attracts hundreds of amateur astronomers and their telescopes from across the US, and a few from even further afield. It attracts a wide variety of astronomers, from the beginner to the seasoned expert, and telescopes ranging through department store budget models, home made projects, large reflectors, to top of the line refractors.

Following the chance find by the author of an optical test target in a scrap box, the idea was developed to set up the target on a nearby hill and see if some useful measurements of telescope resolution could be made.

With a wide variety of telescopes and observers it was hoped that some interesting comparisons might be made.

Target & Measurements

The basis of the optical target was a 3” square 1951USAF “metal on glass” bar target slide. The telescopes at TSP are spread across three fields and the preferred location of the target so that all could see it, meant that this 3” slide would be too small for some telescopes and would need to be supplemented with some larger bar targets. Average distance from observer to target was around 700m.

A photograph of the target is shown below left. The 3” target slide can be seen at lower right within the larger target, which was made by ink jet printing on A4 size OHP acetate. The complete target comprised of 6 groups, each of 6 vertical and horizontal pairs of bar patterns. This covered a resolution range from 4 to 0.1 arc seconds. The target was back illuminated with 40 high power white LEDs, powered from a 12Vdc battery, topped up by a solar panel during the day. A simple radio control system was used to turn the illumination from off, to half power, to full power. The complete target arrangement is shown in the photograph below right.

Due to the spread of telescopes over the three fields, it was necessary to provide look-up adjustment tables so that observers could correct for their range to the target, plus corrections if they were significantly off-axis and hence seeing vertical bars appearing at a closer spacing than if head-on.

All TSP observers were invited to participate by taking measurements after initial set-up

and collimation (for reflectors), and then to repeat them if further collimation, or other action improved the results. They were also asked to get fellow observers to make collaborative measurements.

Findings

Effect of Aperture

The resolution of a telescope is fundamentally determined by its aperture, with telescope type, optics quality, seeing conditions and observer variability also being major factors.

The first finding presented in figure 1 is therefore a plot of measured resolution versus telescope aperture. The basic types of telescopes are differentiated according to the plot legend.

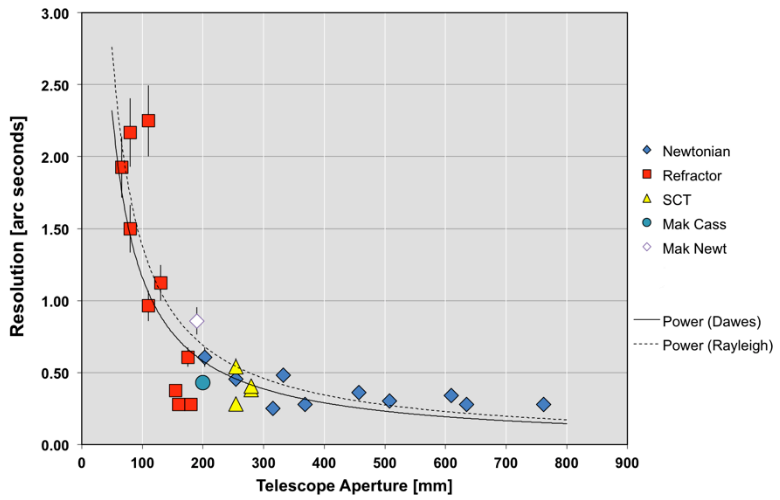
The solid line is the Dawes limit for a telescope of aperture D in mm, given by 116/D in arc seconds, and the dashed line is the Rayleigh Criterion, 138/D arc seconds for 550nm light. At first some may be surprised that the results appear to show that some observers were seeing beyond the Rayleigh or Dawes limit for their telescopes. This is indeed so and will be discussed a little later.

From now on we will refer only to comparisons with the Dawes limit, as this was based on practical measurements, although as we can see it is close to the Rayleigh limit.

In general, it is good to see that most measurements are close to the Dawes limit. There is one refractor measurement at the very top of the graph that is poor, but that is really only the one significant exception.

The error bars represent the difference between one bar pattern and those on either side of it. The difference between patterns on the USAF1951 target is a fixed ratio and hence this becomes quite significant for the larger bars. If we assume the possibility of an observer being optimistic or pessimistic and selecting a bar pattern one away from the "right" one, then these error bars indicate that in most cases this error is insignificant.

Figure 1 Resolution vs Aperture



At larger apertures (>400mm), the telescopes all failed to reach the Dawes limit and we may possibly attribute this to poor seeing (see later section), and their inherent general design of being fast f/no light collectors with less than diffraction limited performance other than exactly on-axis.

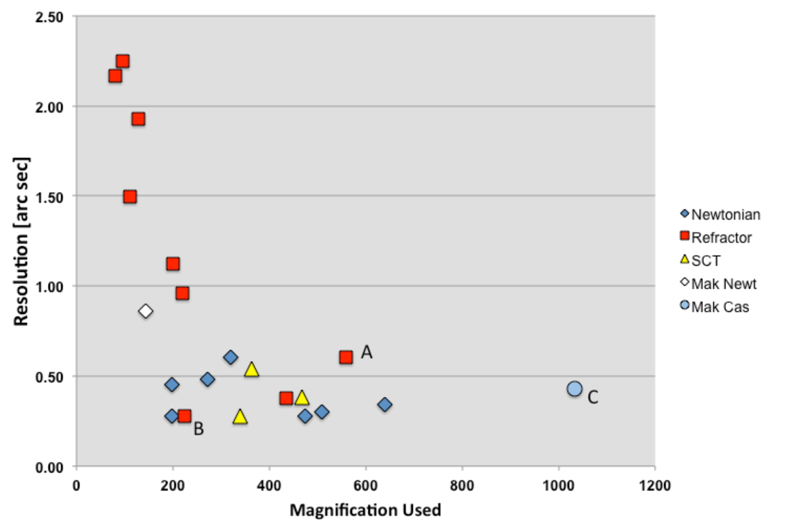
With a few exceptions, telescopes in the 80-400mm aperture range, came close to or exceeded the Dawes limit.

Overall, results in this aperture range fall on or either side of the Dawes limit, irrespective of the telescope type. If we assume that the effect of seeing was roughly the same for all observations in this range, then we can perhaps look for other factors to explain the relative performance of telescopes.

Notable in the aperture range 150-270mm, is the cluster of four refractors below the Dawes limit, along with a Maksutov-Cassegrain and an SCT. All except the SCT were Astrophysics or TEC telescopes. They are of no doubt superior quality, but also we may expect telescopes of that standard to be owned by very experienced observers. However all but one of the top measurements were collaborated by multiple observers, and this points towards telescope quality making a difference, rather than observer.

Significantly, we can see that in the 150-180mm aperture range, high quality telescopes were able to exceed the Dawes limit by up to a factor of two. This is in fact to be expected as the Dawes limit is for point sources, and our target was comprised of bars. This is why small telescopes can often resolve the Cassini division in Saturn's

Figure 2 Resolution vs Magnification



rings, when application of the Dawes suggests they shouldn't.

Effect of magnification

A plot of resolution versus magnification used, figure 2, reveals a distribution that is similar to the shape of the Dawes limit, ie a power curve. Compare figure 2 with figure 1, above it. However, this is to be expected as the maximum magnification useable for a telescope is proportional to its aperture, and hence the horizontal axis in figures 1 and 2 are roughly equivalent.

The graph does have some value in easily identifying those measurements made where the magnification may not have been optimized. The plots for refractor A in figure 2 is a case where too much power was probably used and the measured resolution consequently suffered. Refractor B on the other hand appears to have used too little power, yet has achieved excellent resolution. An example of superb optics and visual acuity.

The Maksutov-Cassegrain measurement, labeled C, with a power of x1033 may be attributed to the relatively high f/no of the telescope at 15.5.

To explore the issue of magnification further, a plot of Magnification versus Aperture was made, figure 3.

A working assumption is that observers will have increased the power they were using to try and resolve smaller and smaller bar patterns, until they reached that point at which seeing and their aperture prevented higher powers from improving matters. A couple of results where it was clear that this was not the case have been excluded from the plot.

Although there are fewer data points than desirable, the graph does appear to show two distinct trends highlighted by the dashed lines.

The blue line represents a magnification scale of about "x20 per inch" of aperture, while the red represents about "x120 per inch".

A scale of "x50 per inch" is often quoted as a maximum useable magnification, and we can see that our results do bracket this number,

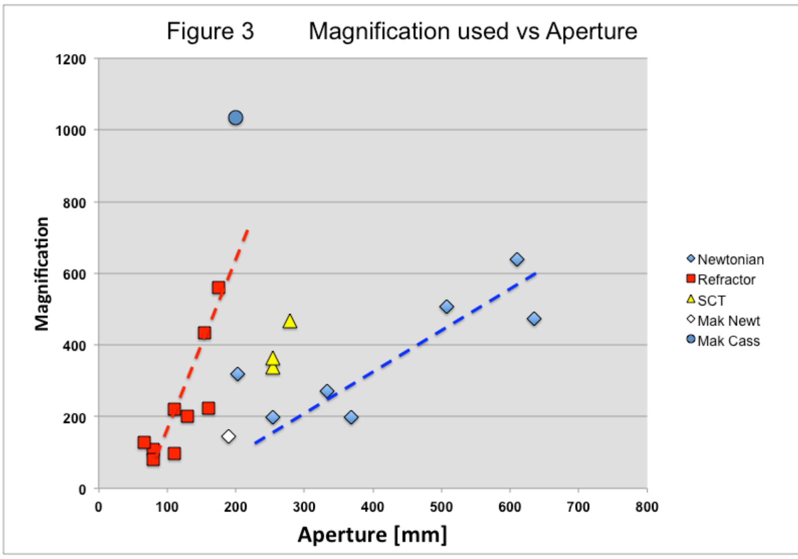


Figure 3 Magnification used vs Aperture

but also show a very wide difference between the two trends.

The blue line represents Newtonian reflectors, with f/numbers 5 or less, and apertures greater than 200mm.

The red line represents refractors, with f/numbers between 5.5 and 9, and apertures less than 180mm.

The question arises whether we can attribute these two trends to the type of telescope, range of f/numbers, or aperture range? This is not easy with the limited data points available.

There are some clues however that might provide some insight as to the drivers behind these two quite disparate trends.

The first is the single Newtonian reflector result sitting between the two trends.

This had an f/no of 7, much higher than the other Newtonians. Similarly the single Mak-Cass results appears to be on an extension of the red trend line, right at the top of the graph. This telescope had an f/no of 15.5.

The cluster of SCT results also sit in the middle between the two trends. They were all working at f10.

The single Makustov-Newtonian working at F5.3 sits down on the blue line. It can be postulated that for all these "hybrid" telescopes employing reflecting and refracting elements in their design, it is f/no that is the major determinant of maximum magnification useable. This is supported by the high f/no Newtonian discussed earlier that also broke "the trend".

There are also two pairs of Newtonian results that add further weight to this theory. At the far right of the blue line are two broadly similar aperture telescopes, but the higher f/no scope (f5) performed significantly better than the other one (f4.2). Similarly the two Newtonians at around 350mm seem to perform according to their respective f/numbers of 4.3 & 4.9.

If aperture alone was the determinant of maximum useable magnification, we would expect to see a much simpler trend line through all the data points and not the complicated plot structure measured.

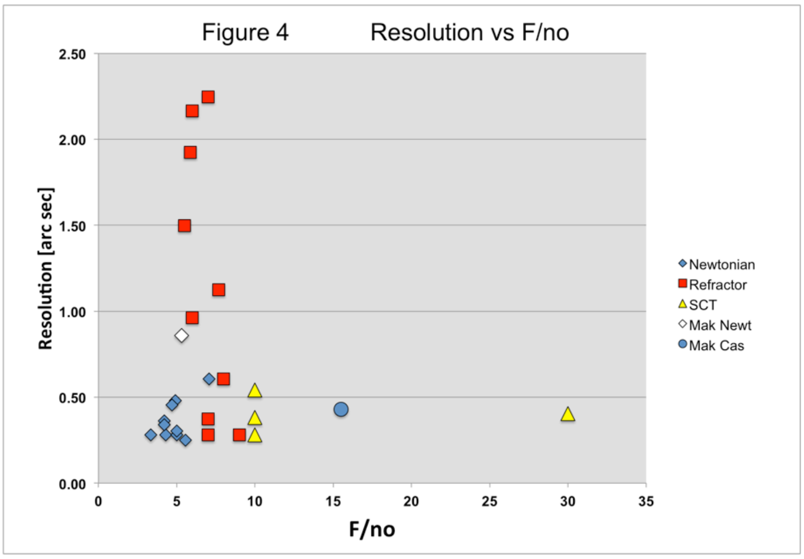
Once again we must consider the quality of the optics being tested. The two refractors at the top of the red trend line, and the Mak-Cass at the very top, are all of the very highest quality available to amateurs.

It would appear therefore on the basis of these results that the maximum useable magnification for a telescope can vary between x20 to more than x100 per inch of aperture, depending on f/number and quality of the optics.

As stated above, more data is required to clarify these findings and we may be able to follow this up at a future TSP.

Effect of f/no

The previous section may indicate at first reading that high f/numbers will resolve better. A plot of f/number versus resolution



achieved is shown in figure 4. This plot clearly highlights the limited range of f/numbers for each telescope type, but does not show any other clear correlation.

This is satisfying as it supports the classical theory of optics where the resolving power of a telescope is purely a function of its aperture.

Large f/numbers may have helped observers use a higher magnification, which may have assisted those with poorer eyesight, but in general it is the telescope and not the eye that determines resolving power.

This statement is supported by the generally very good coherence in measurements between different observers on the same telescope.

Effect of Seeing

It quickly became apparent that atmospheric turbulence would be a major factor in making measurements. On the first night wind was also a problem, effectively preventing good readings.

The atmospheric turbulence, or "seeing" had been expected but the severity was unknown and might have negated all measurements. As we have seen this was not the case as some very useful results have come through. This is witness to the skill and determination of the observers to take their time waiting for the seeing to improve, and to repeat measurements on better nights.

The author chose to spend much of his TSP making comparative resolution measurements on his 10" Newtonian. In general these were repeated every 30 minutes, and so did allow some "real" observing in between times. The results are shown in figure 5.

As mentioned above, the wind on the first night prevented good measurements and so none are included for that night. At least this enabled the author to complete his John Wagoner observing list! Also of note is the short curve for the night of the $9^{th}/10^{th}$ where the author fell asleep actually while looking through the eyepiece and decided he should go to bed!

It is apparent from the figure that seeing can vary tremendously, both during a night and from one night to the next.

The line of sight from telescope to target was approximately 700m at an altitude of about 10 degrees or less, depending on observing location. The terrain under this path was a mixture of dirt and rock, with a little scrub.

The author had expected seeing to improve gradually after dusk, as the terrain cooled down to approach the air temperature, and then stay good until sunrise.

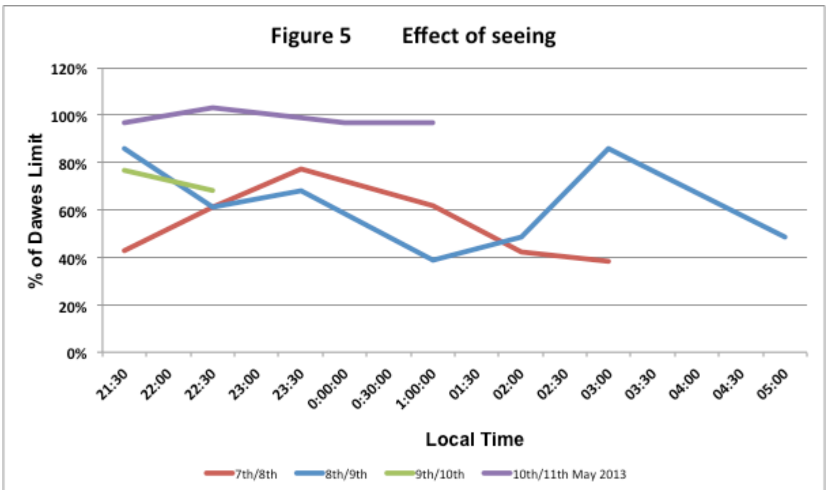
In practice this did not happen. The red and blue lines demonstrate almost reverse behavior over two consecutive nights.

The purple line shows steady performance and this was a night that followed some thunder and very heavy rain during the late afternoon.

These plots taken every 30 minutes do not show a more rapid change in seeing that was observed and noted by nearly all observers. They reported staring at the test target for long periods, waiting for short glimpses of high resolution as the seeing momentarily improved. This technique will be well known to any planetary or double star observers reading this.

Also reported were significant changes in seeing that accompanied the frequent breezes that are well known on TSP nights. These breezes are usually noticed by a sudden chilling effect on the observers, but with the test target we were able to see marked changes in seeing too. Improvements and deteriorations were both noted.

Although not everyone was diligent about recording the time of their resolution measurements, inspection of the detailed results



do show that most of the best were indeed taken during the night of 10/11th May.

An unknown is the relevance of these measurements across a very low 700m path to a target, to more conventional astronomical observing at say 45 degrees elevation through a much longer atmospheric path. Clearly our measurements were only sensitive to local ground level effects, but how significant are these in practice compared to the seeing over the middle to upper atmosphere?

Two qualitative inputs can be added to the results in figure 5 however. The first is an observer situated near the author who was doing video measurements of close double stars. We found broad correlation between my measurements of good or bad seeing, versus his success in capturing useable frames. The second is the authors observations of the "double – double", ε Lyrae. Although always able to split both doubles with the 10", it was quite challenging most of the time, except notably on the stable night, 10/11th May.

Other Findings

Improving Performance

One of the expected uses of the target was for observers to check their telescope performance and potentially improve it through better collimation or other actions.

20% of the test program participants reported a significant improvement (>20%) in resolution performance through use of the test target and corrective action.

Astigmatism

Very few measurements reported showed astigmatism. There were two notable exceptions, both with SCTs. One was corrected by some expert help on collimation, the other was corrected by replacing the diagonal with a higher quality item. These results alone justify future deployment of the test target at TSP!

Visual Acuity

In one or two instances, there appeared an observer who could not achieve the same resolution as his colleagues on the same telescope. In at least one of these this was put down to a previously known eye problem, but these tests allowed the impact to be quantified.

Many observers verbally reported how they tried either eye, and with or without spectacles. The author, committed to making his repeated measurements every 30 minutes took some time to explore this. With astigmatism in both eyes, corrected on one side by his spectacles, but needing a new prescription on the other, these effects were pronounced.
Even with the much reduced exit pupil present at the high magnifications used for these tests, it was clear that good correction for the astigmatism was essential in achieving the best telescope test results.

Equipment Evaluation

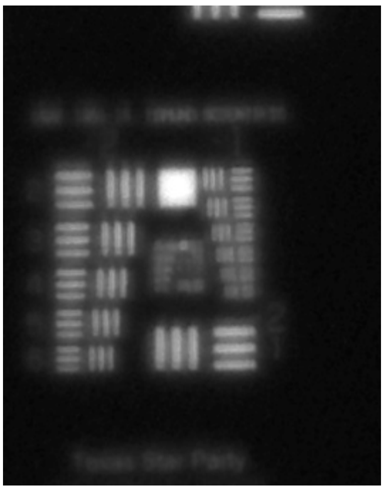
The bar target allowed observers to evaluate relative performance of different telescopes and eyepieces.

The author was witness to many instances where telescope owners were actively seeking out equivalent telescopes to their own and then making their own comparisons of resolution.

It was also clear that a lot of eyepiece swapping was going on. In some instances this was to try a higher power or fill in a gap that the observer couldn't achieve with his own eyepieces, in other cases it was to try an alternative eyepiece type or manufacturer. In two known cases this resulted in a trip to the vendors the next day!

CCD Imaging

A few observers attempted to capture the target image with a ccd. As it turned out only one had the right configuration to capture a useable image. This was using an



SCT with a x3 barlow operating at f30 and a video camera for image capture. Using the "lucky imaging" technique he captured many two thousand frames, selected the best 100, and then aligned, stacked and sharpened the result using Registax 6. An example resulting image is shown here.

Overall Conclusions

The overall results show very strong correlation with the Dawes limit for resolution as a function of telescope aperture.

Some higher quality refractors achieved a resolution twice as good as indicated by the Dawes limit. This strongly supports other experimental findings that structure finer than this limit can in practice be seen.

The large aperture reflectors tested could not achieve the Dawes limit, due probably to the disproportionate impact of atmospheric seeing on the larger aperture, but may also arise from inherent general poorer performance for fast f/no systems.

The widely adopted rule of x50 magnification per inch of aperture was found to be a gross simplification for the conditions at TSP. Better figures would be x20 for large apertures (>200mm), x100 for smaller apertures. x50 remained appropriate for SCTs and high f/no Newtonians.

The effect of atmospheric turbulence on the tests was variable and at times strong. Nevertheless good readings were made, thanks to the perseverance and skill of the participants. There was some qualitative indications that the turbulence apparent in the test target correlated with the seeing apparent in the night sky.

The test target proved valuable in identifying collimation or performance problems with telescopes and facilitating their correction. The horizontal & vertical bar patterns were very useful allowing observers to explore differences between their eyes and the impact of using spectacles or not. This was particularly effective at quantifying the effect of ocular astigmatism.

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