Thoughts on optical aberrations and simple telescope testing…

Tom Trusock - 10/14/2005

Today there seem to be more amateurs than ever getting into the hobby, and like many of us, they are not just interested in the targets in the night sky but the optical systems themselves. Although seemingly simple an optical system is quite a complex thing, with various and confusing elements.

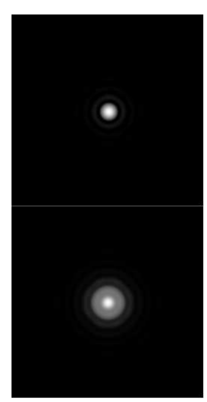
This short paper attempts to answer / educate on some of the more common points of optical aberrations and telescope testing. It flowed out of a discussion about field flatness and pincushion on the forums. As I was typing up a list of the common aberrations, their effects, and some strategies for testing a telescope I soon realized that 1) I needed to show some images, and 2) I was already at 5 pages!

Most commonly today, amateurs tend to want to discuss what is wrong with the optical system of their telescope. While this list is by no means complete, I do hope that one finds it of some assistance. If you are interested in optics and optical design, I highly recommend checking out the sources listed at the bottom of this article.

<disclaimer>
First off, by no means am I am expert in this field. I do not have the experience of Roland Christen, Thomas Back, Vic Menard or Roger Ceragioli. I would not be a bit surprised if I have unintentionally misrepresented something or that I had simply been wrong. This is where the beauty of the Internet comes in. This is intended to be a live document. If you believe you find a misrepresentation or a mistake, please either e-mail me so I may correct the document, or discuss it in the forums in the proper thread.
<disclaimer>

It's my hope that beginning astronomers find something of use here.

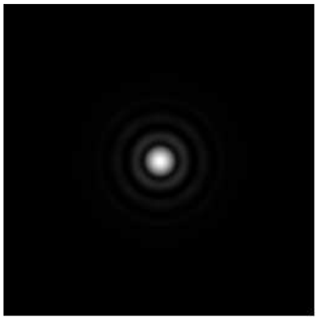
Some common optical Aberrations and their effects



For reference let's present the perfect in focus stellar image. Look closely and note the airy disk surrounded by one ring. For a system without a central obstruction, most of the energy is concentrated in the airy disk with only a small amount in the first and later diffraction rings.

Now, as we defocus VERY slightly, not that it brings more rings into view, and the energy gets shifted from the airy disk to the successive rings. If you look at both sides of focus, in an ideal (ne perfect) system, the rings will be identical. This RARELY happens, and for a number of reasons.

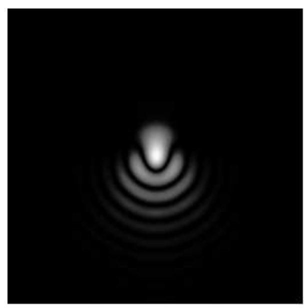
The Aberrations



Spherical Aberration - this occurs when the rays parallel to the optical axis do not come to focus at the same point. Typically in the case of a lens or a spherical mirror the outer rays intersect closer to the lens or mirror than the inner rays. There is no one common focus, but rather a region where it's all equally bad. This is called the zone of confusion as there is no one true exact focus point. Do not confuse the zone of confusion with the depth of field found on longer telescopes. A large depth of field means that critical focus is approached more gradually, but there is still only one best focus point. A mirror or lens suffering from spherical aberration will (among other things) not come to a sharp focus - rather there is a range where best focus is achieved - the aforementioned zone of confusion.

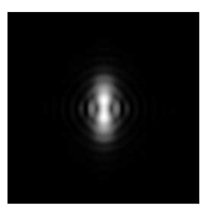
Spherical Aberration results in energy that is supposed to go into the airy disk being thrown out into the diffraction rings. This, an infocus stellar image of a telescope with SA will show more and brighter diffraction rings than it would otherwise.

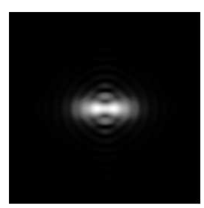
This is probably the most common error today and in most mass produced mirrors results from either NOT grinding the curve deep enough (under correction) or grinding it TOO deep.



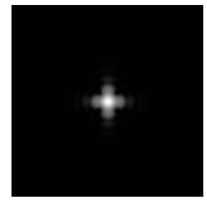
Coma - Coma occurs in a bundle of light rays when the intersection of those rays is shifted with respect to their axis, the resulting image looks comet shaped, with the tail of the comet pointing away from the center of the axis. Can also be induced by miscollimation – thus a comatic star image (on axis in a reflector) may well indicates the telescope is NOT collimated. It's for this reason that we must ensure that are optics are properly collimated (among other things) before evaluating them. While coma is inherent in newtonians, it can be corrected for by the use of particular lenses (ie paracor and paracorr like devices). Coma, however, unlike what most seem to think, is not an aberration unique to reflectors.

Astigmatism occurs when there is a difference in the optical power of the tangential (can be thought of as inner) and sagittal (can be thought of as outer) optical curves.

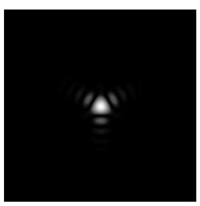




This can be present for several reasons. 1) It can be ground into the lens or the mirror. 2) In some systems like fast air spaced triplets whose curves have deep radii, cool down will cause the curves to shift even more. Until the lens equilibrates, astigmatism will be seen. 3) astigmatism can also be caused by the optics not lying freely / properly in their cell - ie being pinched. Again, this may also show up during the cool down process as the lens cell contracts, it may put pressure on the optics.



Astigmatism is easy to spot, stars do not come to points but rather are seen as line the flip orientation 90 deg as rolled through focus. In best focus stars may appear as crosses or squares. Most observers have a small amount of astigmatism in their own vision. When testing for astigmatism in an optic be sure to test all elements of the chain. Astigmatism may be present in one or more of the following - The objective, the diagonal or secondary, the eyepiece and your eye. AS you rotate the individual components, the lines would rotate with them. Astigmatism is a very common aberration when using inexpensive long focal length, wide field eyepieces in fast telescopes. Naglers and Panopics are well corrected, but at a price.

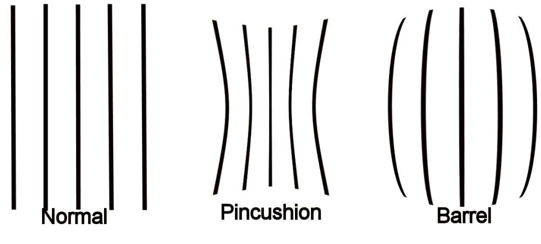


Pinched optics can also cause an aberration in a similar class as astigmatism. If a lens or mirror is too tight in its cell, the optic may get pinched enough to effect the optical figure. If that's the case, the pinched optics can be spotted as triangular or trapezoidal stars. Alleviation of this may involve loosening the optic in it's cell, designing a new support system or simply letting the optic come to ambient temperatures.

Curvature of Field (and conversely Flat Field) - Curved field means that the sharpest image is formed on a curved surface rather than a flat plane. IE either stars in the center of the field can be brought to focus or stars at the edge, but not both. Every eye will automatically refocus a bit to adjust for this effect - this is called visual accommodation. As you get older, you tend to loose this ability.

Distortion, rectilinear distortion and angular- Distortion is not exactly an aberration in the normal sense as it influences image scale rather than sharpness.

To best envisage **rectilinear** aberration, think of a white picket fence. There are two forms:



Negative or Barrel distortion - the slats on the will bend inward

Positive or Pincushion distortion - the slats on the fence will bend outward

Angular distortion occurs when an object looks stretched out - typically near the edges of the fields of view.

False color - there are many things that can cause "false color/chromatic aberration" to appear in a telescope, the two most common are **Longitudinal Chromatic Aberration (Axial chromatic aberration)** and **Lateral Color.**

Longitudinal Chromatic Aberration is seen as color fringes when the object is on the optical axis. **Lateral Color** appears as off axis color fringes.

Color error (secondary spectrum) is inherent in the design of a lensed system. When talking about color error, it is important to talk about telescope design. There are two major types of refractors on the market: achromatic and apochromatic. Achromatic means without color, and by that we can take Apochromatic to mean “even more without color, no really we mean it this time”. Semi-apochromatic is often dismissed as a marketing term, however, there something of a formal definition. There are certain telescopes that are being marketed as SUPERApochromats, I suppose we could say those mean “ok, we weren’t done yet, even though you thought we were, but this time we really mean it”.

Seriously, the description of a telescopes performance can best be made in terms of a telescopes description of how many wavelengths of light (colors) it brings to focus at one point. If it brings two, then the system is said to be achromatic. Three yields an apochromat, and four a superapochromat. Color error can also expressed in terms of the difference in focus position needed to bring particular wavelengths to focus. IE in an apochromat, the difference between the green and red/blue focal points is typically 1/10000 of the focal length. A typical achromat will have a color error of around 1/2000 of the focal length. From Telescope Optics, we learn that the best color correction for a doublet involves the use of fluorite or a fluorite like glass (such as FPL53) and it’s appropriate mating element and will yield 1/160000 of the focal length under the best conditions. As you may begin to see, all apos are not created equal.

It should be noted that a system designed for visual use may not be the best choice as an astrograph. The CCD, CMOS, film or other imaging sensor used most likely has different sensitivities than the human eye. Simply because one looks through a telescope and pronounces it "color free" does not mean it will be a good imager. False color is one of the most subjective aberrations for a number of reasons including but not limited to: experience with different types of optical systems, distribution of rods and cones / individual biology / and color vision. What one sees as objectionable, another may not even notice. I should also note that atmospheric effects can act like a prism and cause false color in an optic (typically Jupiter may appear red on one side and blue on the other). For this reason, avoid testing for color on objects less than 40-45 degrees above the horizon.

There are many other factors that effect optical quality that I have not really covered here – glare, contrast, spherical aberration of the exit pupil (kidney bean / blackout), and miscollimation, to name a few.

One should be aware that rarely is a single aberration present in a system. Usually, there is a mélange of optical defects / aberrations / issues, and the experienced observer must learn to sort them out one optical aberration a time. The good news is that rarely do these completely kill the optics.

Tips/techniques for testing telescopes for beginners / intermediate obsevers:

- Ensure that the scope has reached equilibrium – IE the OTA, and optics are at the same temperature as the outside air.

- Ensure that you have good enough seeing to perform the tests. Poor seeing can easily make you think your optics are terrible. If the moon is shimmering and the stars flickering, pack your testing plans up for the night.

- The best way to test a telescope itself is to test it straight through with the diagonal removed (when possible). This minimizes the number of elements in the chain where something can go wrong. I would suggest testing both this way, and then with the diagonal so to get an idea of how the entire optical system performs.

- Pick simple moderate and high power eyepieces. Plossls are typically good. Steer away from more complex designs as eyepieces have their own aberrations they can induce into the system.

- If you intend to study diffraction rings, use enough power to clearly see them. – *John Crilly reminds me that magnification required varies with aperture, and it might be more useful to readers to state a power range ~30X/inch rather than saying "moderate power".*

- Pick a target over 45 deg high

- Use a moderate power eyepiece and focus on a bright star. You should see at least one unbroken diffraction rings running around the star – perhaps more. You may need to increase magnification. If you see a broken diffraction ring, it may mean that your telescope is slightly miscollimated. If you see a comet shaped blob, it could be one of several things, but most likely indicates that you're telescope is severely miscollimated. For scopes with secondary obstructions, proceed to defocus a bit and study the donut image. The hole should be directly in the center. If it's not, you need to adjust your collimation.

- Once we are assured the telescope is cooled, we have decent seeing, and that our optics are collimated, we can proceed to evaluate the optics:

- Using any target (but I recommend the moon and planets) - Do the "snap" test. (Do images snap to focus in one place? Or is there a zone of confusion with no clear best focus.) This can be due to seeing, or due to a number of other factors including spherical aberration.

- Test for astigmatism by rolling through focus and while observing the shape and position of the defocused star as it passes through the focus points. If you detect astigmatism, rotate your head and observe if the orientation changes. If it does, the astigmatism is in your eyes. You may then try a higher power eyepiece. If it does not change go away, rotate the eyepiece to see if that is contributing to it. Then the diagonal. If it never changes orientation, the astigmatism may be in the optics or in the cell. Ensure that the optic is completely cooled (wait several hours) and test again.

- Spend some time on the moon. Assuming the seeing is good (the moon is not seething) is luna sharp? Determine the highest magnification that you can reach before the image begins to degrade. Divide this by the aperture to yield the power per inch. A good telescope will show new details up to and around 40x per inch. An excellent telescope will continue to be sharp, but reveal little detail beyond that. If you have a telescope capable of working at 60x per inch, be satisfied you have an excellent optic. If not, don't despair. You can repeat this on the planets and average the results.

- Locate a double star - in summer and fall, the Double Double is a favorite of mine. Determine the lowest power at which you can make the split. The lower the better. Reference this against comparable sized optics on the internet. This will help to give you an idea of your site, your seeing, your eyes and your optics.

- Repeat the entire process (all evaluations) several times over different nights. NEVER judge an optic by its performance on one night.

- If you run into problems, be ready with spares (to determine that the problem is NOT in the eyepiece, diagonal, filter, etc.)

A further option in optical evaluation involves the use of a Ronchi eyepiece to determine optical quality. The Schmidling Easy Tester (with simple instructions) is available for a reasonable price over the internet.

If you are an experienced user, I'd recommend the star test. The star test is extremely powerful and among other things very sensitive to a number of both interior and exterior variables. The best resource for those wishing to learn to star test is probably HR Suiter's book called *Star Testing an Astronomical Telescope*. Suiter's book is excellent, but unfortunately it has one major flaw. Each defect is discussed and illustrated in isolation. A real system is likely to have some degree of multiple defects. This can make the star test much harder to interpret than some people think. Additionally, different designs of telescopes have different things to be aware of during the test. Still, for the experienced observer, the star test is a quick and fairly easy way to give an individual some idea about the quality of the optical system.

No matter the method you choose, afterwards do NOT be distressed by what your results tell you. I've never seen a perfect telescope nor have I had a perfect night. All systems will have imperfections. Remember to judge the performance of a scope ultimately by 1) it's INFOCUS images and 2) the YOU criteria. Are you satisfied with the performance? As it's your scope, you are the only one that matters.

One last caution about evaluating telescopes. After you've had some practice, it can become second nature and quite fun. However, one shouldn't get carried away. For illustration, I offer the following: I was at a star party one year where a "gentleman" would walk up to a telescope, plopped in his own eyepiece and then proceed to tell the owner everything that was wrong with the telescope. Smiling, he removed his eyepiece, and continued down the line leaving a row of bewildered, angry and generally irked astronomers behind him. While I'm sure he thought he was doing the owners a "favor" he wasn't. Do NOT be like this guy. I'm not sure he survived the night.

Don't ever force an optical evaluation on someone at a star party. I'm frequently asked to evaluate optics. My first question is always – "Are you happy with your scope?" If the answer is "Yes" I reply, "Then does it matter what I tell you? What if I tell you you have severe astigmatism ground into the mirror?" At this point, four out of five think about it for a minute and then politely decline. While it's fun to know your optics are good, it's not so fun to be told you have problems – especially if there's no funds to address the issue.

The motto here is – "Enjoy what you have." If you are happy with your telescope performance, that is all that really matters.

One final thought. For many years, I had probably the worst telescope on the market. The mirror never cooled (as it was totally enclosed, insulated by twin layers of glue board, and enclosed in duct tape), the secondary was on a single stalk that was impossible to align correctly, and the motions and focuser were absolutely terrible. And yet, I loved that scope. It showed me more things in the night sky than anything I'd ever had before, and I spent many many happy hours under the stars with it.

If you have suggestions for improvement or corrections, please e-mail or PM me through the CN Forums.

Images were generated using the freeware program Aberrator – by Cor Berrevoets
http://aberrator.astronomy.net/

Recommended resources for further reading / research

Telescope Optics – Rutten and van Venrooij
Star Testing an Astronomical Telescope – H.R. Suiter
Notes on Eyepiece Evaluation - Michael Hosea
A Survey of Refractive Systems for Astronomical Telescopes - Roger Ceragioli
The Schmidling Easy Tester – Jack Schmidling Productions