What is an Apochromat?

Please see my essay on this subject at:
http://voltaire.csun.edu/tmb/definition.html

What glass types are used in TMB APOs?

Over four years ago when I started out to design the complete line of TMB apochromats, I looked at every available glass in the Russian Mashpriborintorg glass catalog and ran the best possible three glass combinations through the computer. Being that the design is air spaced, it gave addition degrees of freedom in the design to correct for coma, spherical, zonal spherical and spherochromatism.

The best SD glass (super low dispersion glass) was OK-4, which has an Abbe dispersion of 92+. But this alone does not assure that a lens will be color free. To achieve this goal, the partial dispersions of the SD element must closely be reversed by the partial dispersions of the two mating elements (Pa = Pb). Also, the two mating elements must not generate high internal powers (steep curves), as this increases the mono and polychromatic aberrations. This is where glass choice becomes important.

After many, many long nights, I found, using the glasses that are available from Russia and LZOS (LZOS is the source for high quality glass in Russia), the two other glass types that match with OK-4, for the best corrected apochromat, using LZOS' glass. I then went to the computer, and using what I feel as a designer, the optimum design goals, and optimizing a line of triplet apochromats from 80mm up to 14". The results even surprised me, as the one glass (the last element) was a glass that is not available in the Ohara or Schott catalogs, unless you specify a very expensive custom melt. This glass matches up in the triplet so the violet dispersion is under superb control, as I'm sure anyone that owns a TMB apochromat can testify to.

I cannot give out the glass types, as they are proprietary, but I tell you this: The front element is crown glass, the center element OK-4 SD glass and the last element is a special crown element. The Zeiss APQ uses K-11 crown as the last element, and the Takahashi FCT uses K-3 crown as the last element. In all cases, these glasses are not used like normal crown glass, but as crown glass that acts more like flint glass.

What is the Abbe definition to be an apochromatic? Do the TMB APOs, meet Abbe's definition.

Here is Abbe's definition of an apochromat:

"An objective corrected parfocally for three widely separated wavelengths and corrected for spherical aberration and coma for two widely separated wavelengths."

He was talking about microscope objectives at the time, but it certainly can be applied to astronomical objectives. Let me simply state that no objective on the market today meets this definition in its strictest form. All the ED and fluorite doublets have only two color crossings (the only exceptions are the now canceled TMB fluorite doublet, the rare Astro-Physics 130mm and 152mm ZKN-7/FPL-53 ED doublets, and the Aries CAF-2 doublet), but with two or even three crossings, the correction for spherical is not met in these objectives.

Again, using the Abbe definition in its strictest form, an objective must not only have 3 widely spaced color crossings, coma correction, but be free from spherochromatism. Now, even exotic objectives that are designed for full correction of spherochromatism, will still, at some level, have some residual spherochromatism. What Abbe did not make clear is at what level is spherochromatism sensibly perfect?

Optical designers and experienced planetary observers have different opinions on what "sensibly perfect" spherochromatism is and what the peak visual wavefront should be. The 20th century's greatest optical scientist, James G. Baker, in his revolutionary article "Planetary Telescopes," stated that "sensibly perfect" is 1/4.5 wave OPD P-V spherical at 486nm, 1/40 wave OPD P-V spherical at 546nm, and 1/8 wave OPD P-V spherical at 656nm. Notice the extremely high value at the null wavelength. One must remember that Baker was talking about the ultimate planetary scopes, so a figure this high will not be found in commercially made telescopes – by anyone.

To answer the question about how the TMB apochromats meet the Abbe definition, they do as well as any on the market. The 100mm f/8 model has from 486nm to 706nm better than 1/10 wave OPD P-V spherical, which exceeds the Baker requirement. On the computer, the null is also in excess of 1/40 wave, but glass and figuring limitations do not allow such astronomical wavefront figures. Finally, all TMB triplet SD and fluorite objectives are free from coma.

Thanks for the answer! About the TMB 100/800, if it does not meet Abbe's definition, I think there's no refractor that is so close to it. Am I wrong?

No, you are not wrong. The only other refractor that is as close to the Abbe's definition as the TMB 100mm f/8, is the Zeiss 100mm f/10 APQ, which hasn't been made in many years.

Now that I have used my TMB 100/800 can you give me some pointers for star testing it?

Please see my essay “A Star Test Primer” at:
http://voltaire.csun.edu/tmb/tmb4.html

Does a lens show undercorrection when reaching thermal equilibrium?

Lenses 6" (152mm) and over do take time to come to thermal equilibrium, especially with a large delta. And, the best figured apochromatic lenses can show a touch of what looks like undercorrection, due to many factors. Roland has two excellent articles about this at:

http://voltaire.csun.edu/roland/startest1.html

http://voltaire.csun.edu/roland/startest2.html

If the seeing is bad, when you focus extra-focal, you are focusing on the upper layers of the atmosphere, which can make the star test pattern look a bit soft. Spherochromatism (which is in all refractive systems to some degree) is always worse in the blue/violet, which again focuses long, so it softens the out of focus extra-focal image. Also, as you already know, until the telescope is fully cooled down, the objective will show undercorrection, which shows nice hard rings intra-focal and soft rings extra-focal. The best way to star test a refractor, is to use a dark green filter, at high power, on a night of excellent seeing. Under these test conditions, you can really tell how well the lens has been figured.

But the star test is only one test, and what really counts is what you see on the Moon, planets, double stars, etc.

Does a triplet design allow for a flat-field?

All close spaced doublet and triplet objectives have field curvature. There are three solutions: A Petzval design, a Cooke Triplet, and using a field flattener.

Does LZOS uses aspherization of the internal radii for final figuring of the SD triplets? In the 80mm, are the outer radii used in similar fashion?

Actually, LZOS doesn't aspherize the internal radii in my designs that would be too difficult. But what I have them do, is allow the internal radii to vary, spherically, to correct for spherical, zonal, coma, and spherochromatic aberration. Then the LZOS master opticians hand figure either R1, R6 (first and last surface) or both, to get an optical null at the peak visual wavelengths, for the highest contrast.

In the TMB 80mm, the outer radii are hand figured just like the LZOS lenses.

How does the TMB-80mm compare in performance to a TV 85 or TV 76?

I'm not one to over promote my telescopes; I believe that their quality speaks for itself, and my customers are my best advertisers. But the TV-85 and TV-76, while very fine scopes are not in the same class as the TMB 80mm f/6 true apochromatic triplet. They are not simple machined polished lenses, with the limited violet color correction of an ED doublet. Even Al would agree, that's why he sells his top-of-the-line TeleVue NP-101.

The TMB lenses are hand figured Super ED triplets that have superior color and spherochromatic aberration control. This all adds up to a higher contrast lens, which is better suited for visual and imaging work.

Thank you for letting me speak about my lens designs. Thomas Back

What’s up with the field flatteners? Some new designs were announced.

The field flattener story is an interesting one. It’s been said, you can spend more money designing and making them, but at some point, you have to make the decision where to stop, so you have just the right balance of performance and cost. All the TMB designed field flatteners are two elements, in a crown/flint front to back order.

The very first field flatteners were made for the TMB 100mm f/8, and the TMB 105mm f/6.2. I found a very good design that was photographically diffraction limited to the corners of a 6x7 frame. It was a cemented design, which saves money. But there are no free lunches, as the radii of R-2/R-3 and R-4 were very steep and a sensitivity analysis showed that there was little room for error.

The first units worked extremely well. I remember a full 6x7 frame that a customer sent me on Tech Pan 6415, that was pin point to the very edge, with a TMB 105mm f/6.2, and with the expected amount of vignetting in the corners (with just a 3.0" focuser I.D., camera and attachments, the resulting vignetting was normal, and a simple cropping took care of that).

But then later on, some customers had problems with a mixture of field curvature (the main problem) and some astigmatism. I was, for a short time, really confused what was happening, because some of the shots would show good images to one edge, and problems at another edge, leading Markus and I to think it was alignment problems at the telescope/camera interface. Well, it turned out that in some cases it was alignment problems, but also the field flattener was out of specification.

There was only one solution, to design air spaced field flatteners, with relaxed sensitivity to the radii, and the results of the first field flatteners, made this way, was all that one could ask for. It was the TMB/Povlick 152mm field flattener, which also allowed larger elements, in a custom housing, that was made for minimum vignetting. The cost was very high to make, because of the glass cost, and the very limited custom housings that Tim had made. Tim's test shots showed super sharp images everywhere, and the vignetting, even at the very long edge of the field was essentially free from any vignetting.

Markus has now incorporated my new design in all our TMB 152mm field flatteners with our own housing, and now all the field flatteners for our telescopes either already have the new design, or will very soon, as Markus has them made. My next design is a field flattener/focal reducer.

The price had to go up somewhat on the flatteners, but it is still a very fair price for such a fine piece of glass and metal. With CCD's now at a 35mm chip size, I think there will be a growing interest in field flatteners.

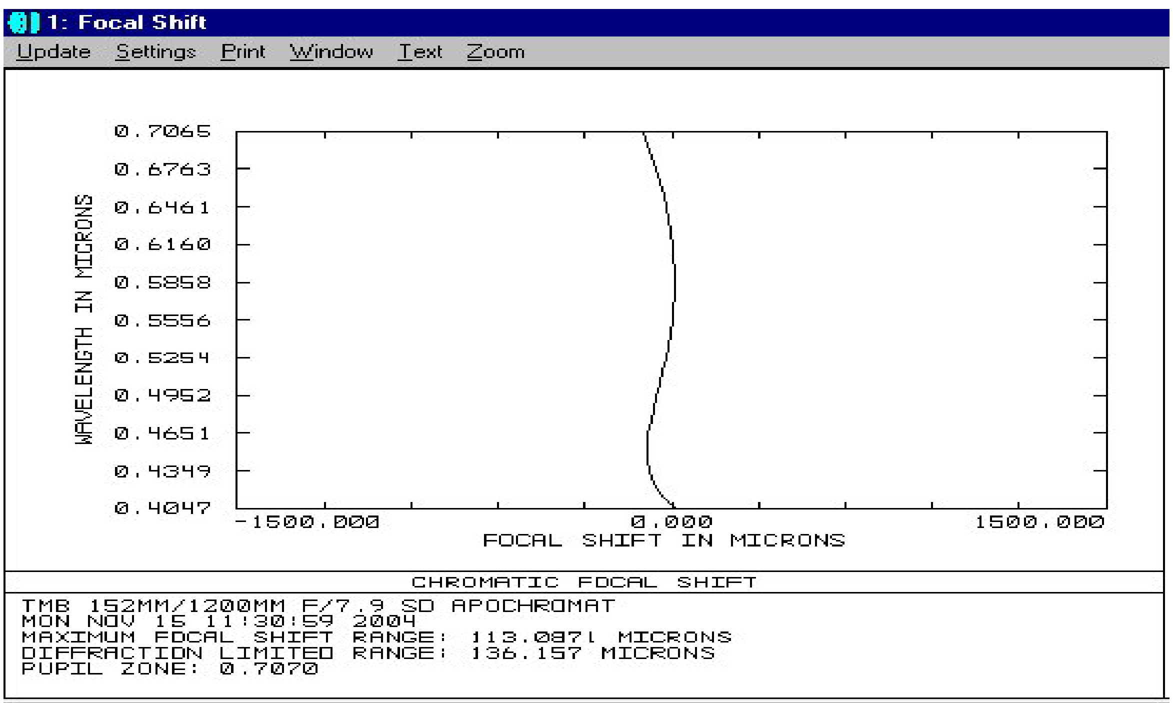
One other point. I am designing a Petzval system, but it is very difficult to make such a system that has a very large, flat field, and doesn't have collimation problems down the road. The TeleVue NP-101 is a good example of what I am talking about. Its unvignetted field for full illumination is not that large, and as the system is not user collimatable, a number of people have to send their telescopes back, to have them re-collimated. I will not release a Petzval telescope unless these problems are solved. And I want to make the point that this has nothing to do with the quality of the TeleVue NP-101. It is one of the finest 4" telescopes on the market, and has excellent color and spherochromatic correction, all at a fast focal ratio. Petzval systems are one good solution, and fully optimized Super ED triplets with matched field flatteners and/or focal reducers are as good or a better solution, in my opinion. Thomas Back

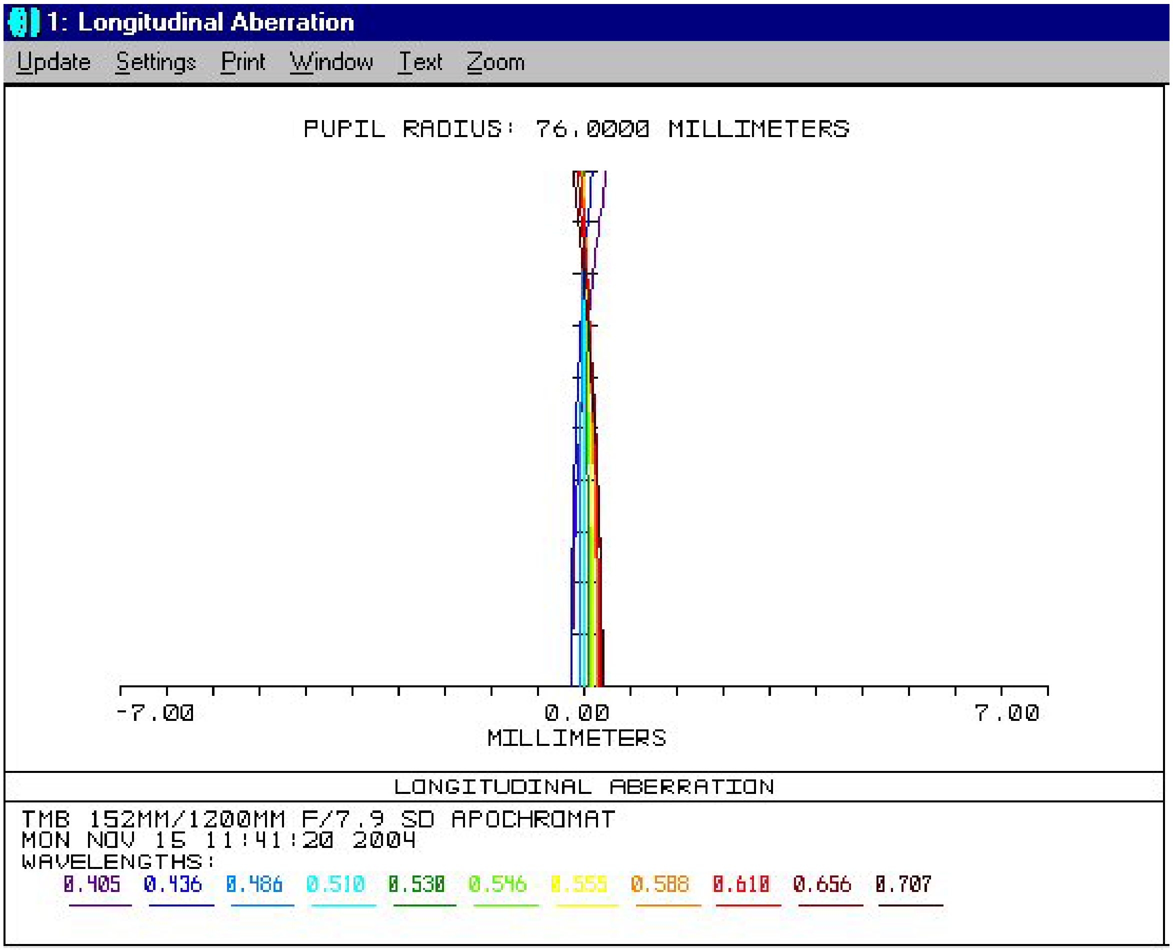
Can you recommend a good reference book on Jupiter?

"***The Giant Planet Jupiter***", by John H. Rogers (ISBN 0-521-41008-8) Cambridge University Press is the greatest book ever printed on the subject of Jupiter. Second would be B.M. Peek's "Jupiter," in the first printing, not the reprint.

Why not the 2'nd edition of Peek's book?

The only reason I recommend the first printing over the reprint, is because Mr. Moore took out some very fine visual drawings, including a folded strip map of the changes in Jupiter's surface, and the much higher print quality. It had nothing to do with it being rare or special because it was the first printing. I always prefer the printing that has the best information, and print quality.





What is the significance of the .707 zone?

The best point to measure color correction is at the .707 zone. Measuring at any other zone will bias the color curve for either the inner zones, or outer zones.

How important is color correction in other zones?

The color curve is not the best method to determine color error. It is only telling you the error at one zone, so it does not take into account the total spherochromatism.

What is the best method to evaluate total color error across the entire objective?

The best method to evaluate total color error across the entire aperture is the LA graph, however, it doesn't easily tell the whole story. A reading of the RMS wavefront/Strehl ratio at each wavelength, the MTF at all spatial frequencies and the encircled energy at each wavelength will tell you the complete story. It also includes the 3rd, 5th, and higher orders of spherical aberration, in addition to the chromatic orders of aberration.

Once a lens hits a Strehl of 0.95 will an even higher value be difficult if not impossible for the visual user to detect any difference?

At focus, you are right. I have tested nearly 1000 lenses, and if the lens is a true Strehl .95, with very low spherochromatism, it is pretty much seeing limited. Remember, a diffraction limited optic has a Strehl of only .80.

Would stopping down a TMB-152 to 100mm improve the 152? What would it do to the Strehl ratio? Tom, have you ever done any experimentation and testing in this regard?

Yes, I have. But it is a lot more complex than it appears on the surface. Lens design is optimized at the aperture the lens is designed at. When you stop down a refractor, now the optimum zonal and spherochromatic correction is shifted, so while you gain from the geometric confusion disk being larger, and in most cases the Strehl ratio will go higher, the lens would be even better if the radii could be changed slightly, to optimize the zonal and spherochromatic correction for the new, smaller aperture. This is a subject that is rarely talked about.

This would imply a telescope starting with (by way of example) on average, a .975 Strehl, and then stopped down from f/7.9 to f/12. A 100mm f/12 TMB! I would think it would HAVE TO improve the wavefront to *some* degree!

No question in most cases this is what would happen. But let's look at a worst case scenario. What if the center 4 inches of the aperture had the greatest OPD wavefront error? And the outer 2" was dead-on. Stopping down a lens like this would not give the gain in wavefront quality that one would normally expect. Fortunately, lenses of the quality of TMB, AP, Tak and TeleVue don't have gross errors anywhere on the aperture, so stopping down a TMB-152 f/7.9 to f/12, would result in a more perfect lens, at least from the standpoint of the ultimate numbers, but the loss in aperture would be fatal in comparison to the lens at full aperture, in average or better seeing.

Regarding the new TMB 203-f/7

How will the color correction be on the 203 F7?

The color correction on the TMB 203mm f/7 will be the best possible of any existing apochromat design on the market, if at the same focal length, or if the other designs were scaled to the very fast f/7, for a 8" APO.

Why f/7?

Because that is what people want, the shortest, fastest large aperture apochromat.

Is this a flourite triplet?

No, it is not a fluorite triplet, it is uses the same glass as our 8" f/9 TMB APO. Just using fluorite in a triplet does not mean great or the best color correction. The two other mating glasses are the determining factor on how well any triplet, be it ED glass or fluorite, will be. In fact, the current TMB SD triplets, if the center SD OK-4 element was changed to fluorite, the color correction would be worse, just as the Astro-Physics EDF FPL-53 design would. Remember, it is the partial matching of all the glasses that give the final color correction.

Does the TMB 203-F/7 meet the abbe criteria?

As for the Abbe criteria, there are no commercial lenses that meet these strict criteria in the absolute definition. Abbe stated that two wavelengths had to be nulled to meet the definition. That was because in his day, they found a glass combination that resulted in such a lens. Today's lenses are not nulled at two wavelengths, only one. But, if you take the two best corrected apochromats ever sold on the market, the TMB 100mm f/8, and the Zeiss 100mm f/10 APQ, you will find that they are color corrected so well, that in effect, that are nulled at a wide range of wavelengths, because the spherochromatism is so low, that from violet to
the deep red, there is less than 1/10 wave or better P-V OPD correction.

Regarding the new TMB 130-f/9

Is the improved color correction in the TMB 130-f/9 due to going from f/6 to f/9, or is a new glass and optical design combination being used?

It's an LZOS built SD triplet like the 130-f6, 100-f8, 152-f7.9, 175-f8 etc.

Moving to f/9 from f/6 improves things several ways.

1. The size of the color error around the airy disc shrinks, making it less noticeable.
2. The linear size of the airy disc at the focal plane increases, making any surrounding color error less noticeable.
3. Spherical aberration is better corrected across a wider range of wavelengths (spherochromatism).
4. Eyepieces have an easier time with an f/9 light cone than f/6.
5. Lower fifth order spherical aberration.
6. Flatter field.
7. Greater depth of focus.
8. Higher average Strehl Ratio.
9. Smoother micro-ripple from less figuring.

In going from 479 nm to 656 nm are all colors smaller in size than the airy disc?

Actually, the TMB 130mm f/9 is even better than that. The spots at the blue end are less than the Airy disc to past 435.8nm. I'll send you a spot diagram with more wavelengths, so you can see, and later, maybe we can post it.

< Place 130/9 Spot DIAGRAM Here >

Thanks for the spot diagram. I see there are 4 perfect color crossings and color #5 is extremely close to this crossing, therefore is this lens design a 'super apochromat'?

Well, the official designation for a four color crossing, highly corrected lens, is a Super-Achromat. Five crossings is called a Hyper-Achromat. Now it might not sound so great to have achromat in the definition, instead of apochromat, but what matters is the performance, not the words that define it. The only other lens that I know that reached Super-Achromatic performance was the APOMAX, but the fourth crossing was well into the near infrared (passed 1000nm), so it didn't really have any visual impact on the performance.

A true Baker Super-Apochromat is a lens that has four color crossings over the full aperture, not just at one zone. Or in other words, a Super-Apochromat is a lens that has four widely spaced color crossings, coma corrected, and has zero spherochromatism (1/10 - 1/20 P-V wavefront or better from 400nm to 700nm). I have designed such lenses, but they cannot be put into production for a variety of reasons.

I want to add that the TMB 130mm f/9 nearly meets the Baker Super-Apochromat criteria. It is better that 1/10 P-V wavefront from 450nm to 706nm, very close to achieving what is considered the *Gold* standard or ultimate lens design. I believe this will be the highest corrected lens of it aperture ever put into production.

Can you comment on selecting an f/6 versus f/9 of the same aperture?

An interesting subject indeed. If most people had the choice, they will always pick the f/6 or fast lens over an f/9 or slow lens. Imaging wide field objects, lowest power viewing, weight, length, and mount considerations favor the f/6 versions.

But there is no way to match the wavefront quality of the f/9 lens, with all things being equal, vs. the f/6 lens. Adding a Barlow will not lower the mono or polychromatic aberrations. It does improve eyepiece performance however, especially off-axis, as the eyepiece *sees* a f/10.8 light cone, even though the damage has been done in terms of spherochromatism, average Strehl ratio, and depth of focus.

The $64,000.00 question is how much difference is there? For the casual and many serious observers, there is none. The TMB triplet even at f/6 has spherical aberration, and higher order aberrations under excellent control, but what about the dedicated planetary observer?

If you do a major part of your observing viewing the planets, the Moon, and double stars, the choice should be the f/9 lens, as long as the considerations of the mount and portability do not interfere with your choice. The actual difference visually between the f/6 and f/9 is not a huge difference, but in good seeing, with the best diagonals and eyepieces, there is a noticeable difference that allows image contrast at the lowest levels to be seen more clearly, and in the case of a feature that is at the limit of visibility in the f/6 lens, will now show itself without the observer feeling that it is at the limit anymore.

You might ask, well if f/9 is better for low contrast work, why not go to f/12, f/15? In the days of the achromat, this would be absolutely true. But with the use of fully optimized triplets using Super ED glass or fluorite, with two other matching glasses, the degree of optical correction reaches a level at f/9 that is close to perfect, and any gains at longer focal ratios with a 5.1" aperture, would not have any visible gain.

So the choice is not that hard to make. You just need to see where your greatest interests are, and how important, or practical a long focal ratio telescope will work with your mount, and any other portability issues.

I have one further question. Is the advantage of the longer focal ratio you described, a function of aperture? In other words, as the aperture gets larger and larger, the lenses get more and more difficult to figure to perfection.

Unfortunately, that is true. Ask any mirror maker how easy it is to make and figure a 6" f/6 Newtonian primary vs. a 16" f/6 Newtonian primary.

With doublet and triplet objectives, the larger the glass, the less likely that the glass elements will all be homogeneous (index of refraction variations, etc.) which are nearly impossible to figure out. Only the Clarks would do spot figuring to try and compensate for these errors. He actually used his thumb as the pitch lap!

Finally, the larger the aperture, the more difficult it is to control the radii, figure, and to control zonal aberration.

As aperture gets smaller and smaller, the easier it is to make the lenses closer to perfection, correct?

Yes, as long as the focal ratio is reasonable (i.e., ~f/6 and longer). The TeleVue Petzvals don't count, because the front objective is telecompressed by the rear elements.

If this is so, is there a cut-off point when the longer focal ratio no longer matters because the aperture is too small to resolve the small low contrast features anyway, not to mention enough light gather to see them well enough? I'm talking about finest APOs such as the TMBs. And if this is so, what aperture would that be?

There is no clear cut answer to your question. For any given aperture and design, there is a focal length that is necessary to control aberrations so the lens is usable. Even a 80mm triplet APO with the best glasses and design has to be around f/5 or longer, if it is going to deliver high contrast and sharp images (again, this does not apply to a Petzval lens). If your question is what aperture is too small to do any useful work, and thus the focal ratio becomes meaningless, that aperture would be quite small indeed. I would estimate, assuming a high quality apochromat, around 15-20mm. Remember what Galileo used, and he was able to see craters on the Moon, the moons of Jupiter, not to mention many more stars than the naked eye. But today's amateur would not be very happy with less than a 1-inch telescope.

You promised to write a review of your TMB 1.8x Barlow, is it ready?

As promised, here is a short review of the TMB 1.8x ED Barlow vs. the reference standard Barlow, the Zeiss 2x ED Barlow. Both Barlows are 1.25". A TeleVue 2.5x Powermate was also used in the tests.

The Zeiss Barlow is quite short, has a compression ring eyepiece clamping system, is a cemented doublet design, and has most excellent multicoatings. It is almost impossible to find on the used market.

The TMB Barlow is more standard looking, but shorter than the TeleVue Barlows. It also has a compression ring eyepiece clamping system, is a cemented doublet TMB design, and the multicoatings are as dark, or darker than the Zeiss. Both are baffled very well, with no significant reflections internally.

Bench testing was done by a double pass autocollimator, with my personal reference TMB 100mm f/8 objective (Strehl .997). Because of my health, sky testing was done with a TMB 80mm/600mm (Strehl .982) on a very lightweight Alt-Az mount. TMB Super Monos and a TeleVue 3mm - 6mm Zoom were the test eyepieces.

First test was on terrestrial objects. It was apparent at first glance that with the TMB 100mm, and the TMB Barlow, the images were brighter, as Markus had said. However, I believe this was due to the lower magnification (1.8x vs. 2x) with the TMB Barlow. I tried to match the magnifications with the Zoom eyepiece as closely as possible to compensate, but the TMB Barlow was still brighter. I believe that it was due to the TeleVue Zoom eyepiece, not the Barlows. Ultra multicoated doublet Barlows are going to have light transmission in the 97% to 99% range, so any difference in brightness is most likely in some other part of the test setup, assuming good glass, which both the Zeiss and TMB have. Call it even, but very hard to quantify. On stars, no difference was seen in limiting magnitude.

On the test bench, the on-axis sharpness, contrast, correction, and scatter in both Barlows are in a class by themselves. The Powermate 2.5x, one of the best Barlows on the market, had the same degree of correction, but it just didn't have the same low level of scatter, and contrast. I would guess that having 2 additional air to glass surfaces, 4 elements vs. 2, and the level of polish and coating simply doesn't match the Zeiss and TMB. Now, these are not great differences, but are visible. Off-axis, the correction of a Barlow depends on a lot of variables, such as the eyepieces' off-axis performance, and the primary or objectives off-axis aberrations. All I can say is that with the TMB and TeleVue eyepieces, it was very hard to detect any difference between the Barlows, because at these focal ratios (f/14.4, f/16, f/20) eyepiece off-axis correction is going to be excellent. On a f/4 system, the test would have been much more demanding, and I then would most likely be able to see and rank the off-axis performance of the three Barlows.

On to Jupiter and the star test: The Zeiss and TMB gave the most textbook Airy disks, with what appeared to me as adding no color whatsoever to the image, either in the form of a color shading (this was the case with Jupiter too) or adding higher order color to the image. The TeleVue seemed to add a touch of red when defocused out to one ring defocus. This was ultra subtle, and I believe is of no consequence in normal viewing.

By far, viewing Jupiter was the test that I felt was the most meaningful. Seeing was excellent, and with only 80mm of aperture, I could hold detail steady through the tests. Both the TMB and Zeiss showed as pure an image as could be imagined. No aberration, no color shadings (pure white), a dead sharp "snap" focus, and jet black backgrounds. Superb! I felt that all the detail that could be seen on Jupiter in a small 80mm aperture was visible. To tell the truth, I felt that if I did a double blind test between these Barlows, I would not be comfortable doing so. Why you ask? Because I would not be able to consistently tell the difference, without knowing which Barlow was in the system at the time. Knowing which Barlow under test could add a bias, and that would not make for an accurate review. I was able to tell that the TeleVue was in the system. It just didn't have the color purity, and the lowest level contrast details that the other two Barlows had. And I made sure to match magnification levels as closely as possible on all tests. The great range of TMB Super Monos and the TeleVue Zoom eyepiece (an excellent eyepiece) made this possible.

In conclusion, my goal in designing the TMB ED Barlow was to match or better the best Barlow I know, the Zeiss 2x ED Barlow. It is my opinion that I at least matched, and possibly exceeded its performance.

I look forward to other reviews of the TMB Barlow. Thomas Back

How is it that the higher powered Zeiss unit ends up having the shorter body?

Good question. "Shorty" Barlows have to either be triplets (which splits the internal powers into the three elements), or a doublet, with shorter radii, and/or the use of very high index glass, so the curves don't become bowling balls. Steep radii are generally not desirable, because they can have higher levels of aberration. Zeiss must have done their homework well, with the 2x Barlow.

Generally, especially in "simple" designs (i.e., non-Powermate), I always thought that the stronger the negative power, the longer the body tends to be. What other variable are you controlling to affect this, having a longer body than the Zeiss yet still only 1.8X power? And what is the advantage gained? I'm sure it wasn't by accident.

You're correct. But as above, you can make variations in the glass types, with steeper curves to achieve a high power Barlow, and still have superb performance. In designing the TMB Barlow, I did not want to make it too short, as it would have compromised the performance. We used expensive glass, but why make it short, when you can get better overall correction with a moderate Barlow length. I feel the TMB Barlow is still compact enough, which is nice, and I didn't compromise the aberration control. So, to answer your question, the variables in a two element cemented Barlow are the following: The glass types, their radius' (R-1, R-2/R-3, and R-4), glass thickness, aperture and the optical path length.