

The dialyte refractor revisited

Peter Wise

By embracing 21st century design technology, the dialyte telescope concept now offers apochromatic performance using inexpensive glass types, with the benefits of low cost, very light weight, rapid cool-down times, and atmospheric dispersion control. Much larger apertures than with traditional technologies are now feasible.

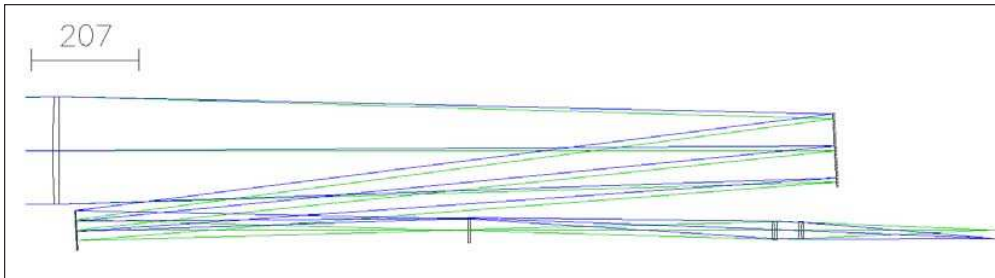


Figure 1. Simplified Zerchromat optical layout.

Following a visit to Hanwell Observatory to see John Wall's 760mm (30-inch) dialyte refractor, I vowed to create an instrument to embody the basic principles in an affordable instrument for amateurs.

The Hanwell 760mm dialyte is reported to be the world's equal-5th largest refractor¹ and is the largest in the United Kingdom. It was made entirely by John Wall, even the objective lens.

A letter in the *BAA Journal* in 2007 October² outlined the work done by both John Wall and myself on retrofocally corrected dialyte refractors. Another paper of interest appeared in the *Journal* in 2002.³

The dialyte configuration consists of a singlet objective lens followed by other lenses to correct for chromatic aberration introduced by the objective lens. In John Wall's design, the field lens is placed beyond the objective's uncorrected focus, followed by a series of corrective lenses to remove or reduce chromatic aberration, spherical aberration, and other optical defects.

Traditional refractors employ at least two objective elements to correct for chromatic aberration. There are instruments with up to four elements for the objective lens, often using low-dispersion glass types, such as fluorite or calcium fluoride to improve optical performance. These latter can cost 30 to 50 times more than standard crown glass, such as BK7, with added problems of difficulty in manufacture, high weight at the front end and slow cool-down times. The largest achromatic refractor is the 40-inch (1.016m) Yerkes, and the largest apochromat refractor to date is 21 inches (0.53m) at the Vatican Observatory.

The greatest problem with apochromatic refractors larger than 200mm is that standard pieces of suitable low-dispersion glass as one or more of the essential elements of the objective lens are only available up to 200mm in diameter. Larger pieces have to be specially cast, which is a very expensive exercise.

performance was exactly up to expectations. No chromatic aberration could be seen visually, at up to $\times 600$ magnification, even on bright stars. However, the triplet corrector element failed after some

After many months of careful design work with an optical design program, Sinclair Optics' OSLO (www.sinopt.com), developed at Rochester University in the 1970s, and in consultation with other optical designers, the first 203mm retrofocally corrected dialyte refractor came into being. Two of these were made, and the



Figure 2. 203mm Zerchromat spot size data.

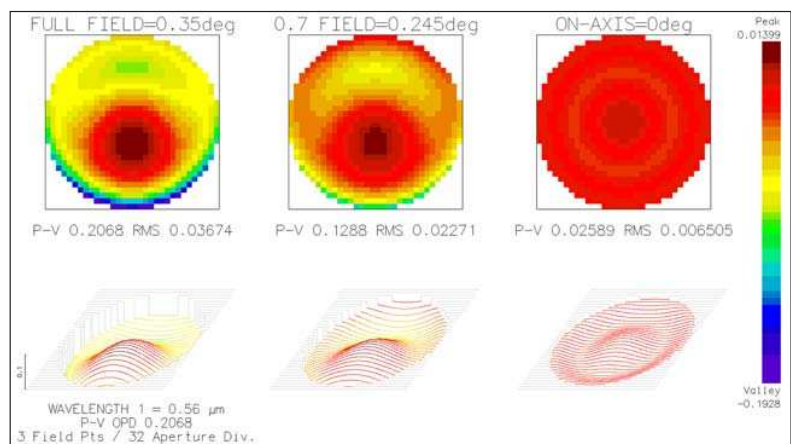


Figure 3. 203mm Zerchromat wavefront analysis over a 0.7° field

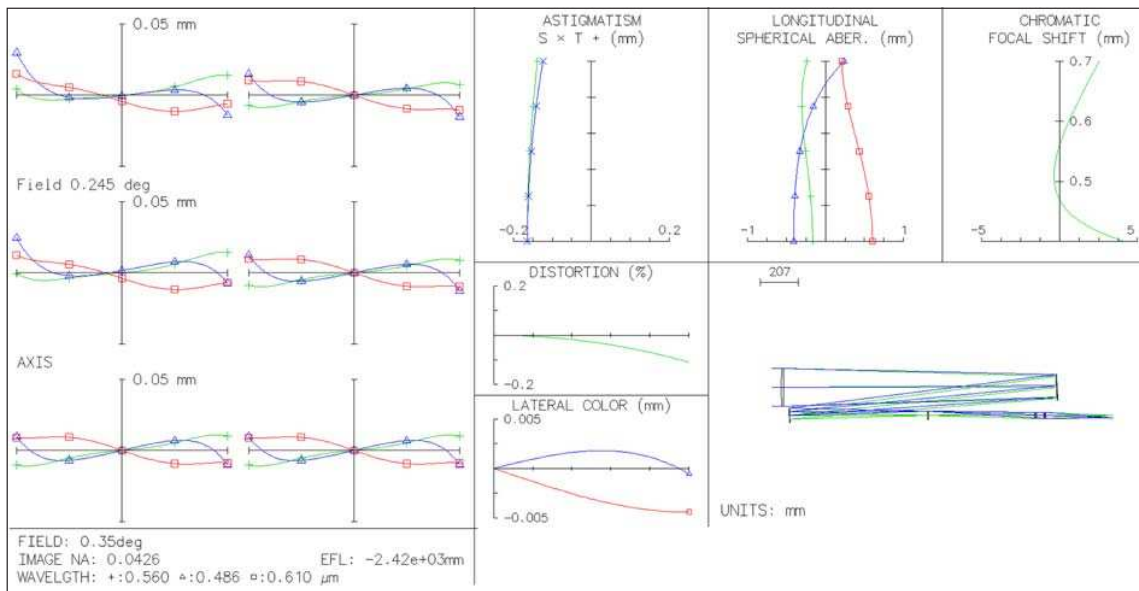


Figure 4. 203mm Zerachromat ray intercept curves

time, due to coefficient of expansion differences in the materials.

The above instruments employed an f19 203mm BK7 glass type plano-convex objective lens, a field lens close to the focus of the converging rays, a negative lens, a doublet lens, a triplet lens and a final singlet lens to correct aberrations of the objective lens. Although there are several optical elements, the overall light loss

is small (approximately 0.3% per surface) when the air-to-glass surfaces are broadband coated. The fold-flat mirrors also require low-loss coatings, as these are the major cause of light loss. A bare aluminium mirror has a reflectivity of approximately 88%, whereas a low-loss surface has a reflectivity of approximately 98%.

The overall focal ratio is f12 (2400mm focal length), and the physical length of the telescope is 1500mm, which is achieved by folding the light path with two flat mirrors. By employing a carbon fibre tube, the expansion problems of a triple light path in an aluminium tube are avoided.

In practice, the design proved much too expensive to manufacture because of the complexity of the corrector system. There were also problems in setting up and maintaining the alignment of all the various corrector lenses.

For some time, the design languished because of the very high costs. However, design work continued in an attempt to simplify it. One of the results is a simplification taken to the limit for a 203mm aperture instrument, and employing readily available glass types. The two corrective doublets are easily mounted and maintained in collimation, and the field lens is very tolerant of tilt and decentration. The plano-convex objective lens is BK7 glass, is only 12mm thick at the centre, and has a focal length of f19 (3800mm).

The optical layout is shown in Figure 1, which shows a plano-convex objective lens to the left-hand side, followed by two fold mirrors, then a plano-convex field lens, and two doublet correctors on the right-hand side. The image plane is on the right-hand side.

The wavelengths employed are 486nm, 560nm and 610nm, to correspond to the mesopic region of the eye's response, which is where light levels are low, but not quite dark.

Performance data are given in Figures 2, 3 and 4.

Figure 2 shows the size of an object viewed at extremely high magnification, so that the black circle (the Airy disc) is dozens of times larger than you would see at the maximum magnification normally used. The spot size is much smaller than the diffraction limit, so no false colour would be seen, even at very high magni-



Figure 5. Webcam image of the Moon.



Figure 6. Jupiter.

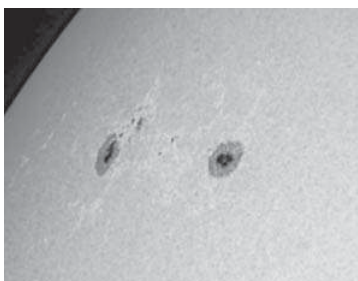


Figure 7. Solar image.



Figure 8. Gibbous Moon in colour.



Figure 9. 203mm Zerochromat on mount.

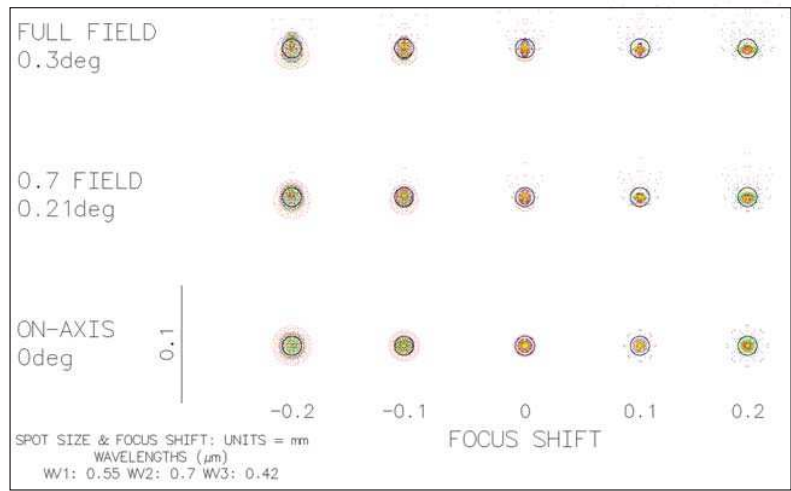


Figure 10. 305mm polychromatic spot plots over a 0°.6 degree field.

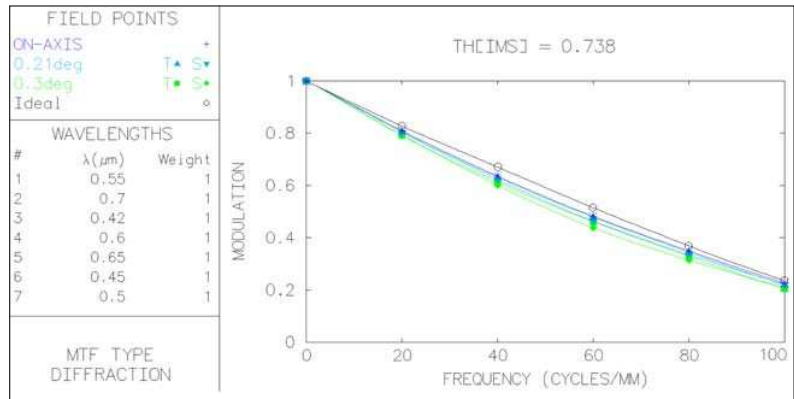


Figure 11. 305mm modulation transfer functions 400nm to 700nm.

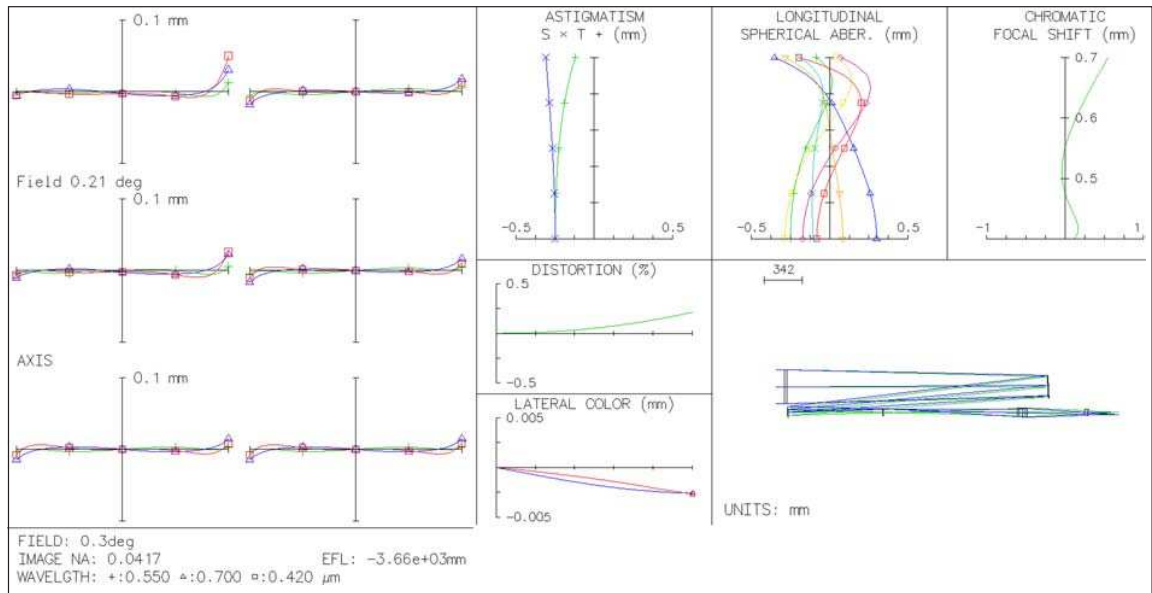


Figure 12. 305mm polychromatic ray intercept curves.

fications. Figure 3 shows the polychromatic wavefront error, which is a way of showing the departure from a perfect system. An optical system having an RMS error of less than 0.04 would be classed as apochromatic.

Figure 4 shows the Ray Intercept Curves, which are a way of demonstrating various optical defects in a system, and is included purely for those versed in optical design.

Surprisingly, the performance is even better than the original 203mm dialyte refractor. With a theoretical polychromatic Strehl

ratio of better than 0.99, from the polychromatic RMS wavefront error figure of 0.005, it can be described as apochromatic.

This is from an approximation of the Strehl ratio $\sim 1 - (39.5 \times x^2)$ where $x =$ the RMS wavefront error in units of the wavelength.

Images taken through an instrument made to this standard are given in Figures 5, 6, 7 and 8. All images are by Dr Josef Ladra. The camera employed for the lunar and solar images in Figures 5 and 7 was a DMK 21AU618 B/W at prime focus. The Jupiter image in Figure 6 was obtained with a colour ZWO ASI 120 MC camera.

One singular advantage of having fold flats is that atmospheric dispersion at low elevations can be eliminated by a small adjustment of the large flat via knobs provided for this purpose. Further advantages of the dialyte system are a much lower weight than a traditional refractor, a much faster cool-down time because of the very thin objective lens, and a balance point for the tube assembly nearer to the eyepiece end, which results in a lower moment of inertia. Contrast is very high, because with only one large baffle, and with the corrector system, virtually no stray light can reach the image plane.

The light loss with such an instrument, with broadband coatings on all air-to-glass surfaces, is estimated to be 6.4%. This is from $8 \times 0.3\%$ loss from refractive elements + $2 \times 2\%$ loss from reflective elements. Such a loss will not be noticeable by eye alone.

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Larger instruments

A 300mm instrument, based on improvements to the 203mm telescope, was designed, though it is naturally more complex. It was designed to have a perfectly flat image plane, and diffraction-limited over a range of 7 wavelengths from 400nm to 700nm. From this design it would appear that instruments up to an aperture of 740mm can be made diffraction-limited, with a perfectly flat field, over the above range of wavelengths, at a cost of a mere fraction of traditional instruments, even if it were possible for them to be made at such large apertures.

The 305mm aperture design employs a singlet BK7 objective lens, a singlet field lens, a quadruplet corrector lens and a singlet field flattener. Theoretical design results are at 100% of 7 wavelengths over the range 420nm to 700nm, and are given in Figures 10, 11, 12 and 13. These have been included for those versed in optical design.

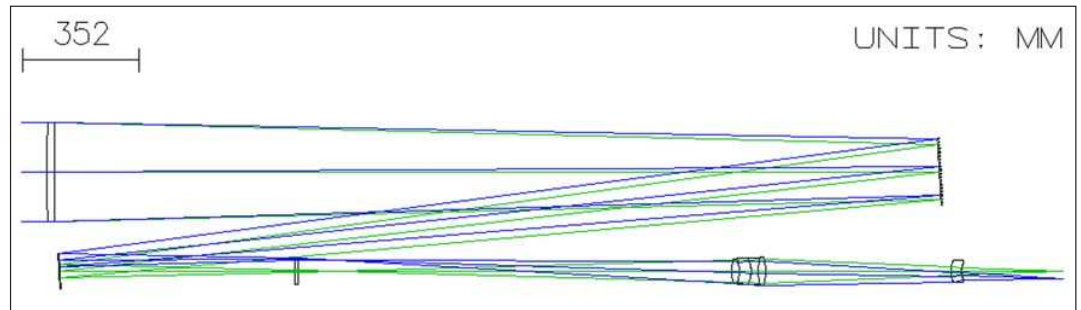


Figure 13. Schematic of 305mm highly corrected dialyte system.

The diffraction-limited available field of the 305mm design is over 0.6° , with an image plane size of 53mm. The overall length of the instrument is approximately 2.9m, with an estimated weight of 40kg. A schematic of the system is given in Figure 13.

The maximum aperture theoretically possible in this design appears to be around 1200mm, with flexure of the objective lens being the main limiting factor. It would be necessary to re-visit the design to see if it can be further improved, and smaller instruments made first to prove the design scale-up. At this aperture, the theoretical on-axis spot size of an f12 design is 13 microns, with a diffraction limit of 8 microns; therefore this instrument could not be classed as apochromatic. However, a traditional BK7/F2 achromat design of this aperture and focal length would have an on-axis spot size of 450 microns. The cost of such large instruments is extremely low when compared with traditional optical designs.

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