

Test of Istar 150mm f15 achromatic refractor

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Abstract

Achromatic refractors have been used extensively in the past. In particular long focus refractors are interesting for reduced chromatic aberration. In this brief report¹ a test of a Istar 150mm f15 long focus refractor is performed with simple instruments for Airy's disk quality in terms of aberrations.

1 Introduction and test specifications

It is possible to find different star tests for many different telescopes [7] but it is usually difficult to see in focus images of the Airy's disk. In this brief review the Istar 150mm f15 doublet [8] is tested in order to see in focus images.

The test has been performed in a closed corridor, with an artificial star of $35\mu m$ and with a distance from the focal plane of the camera (Point Grey Flea2 FL2-08S2C-C) to the artificial star of $51.08m \pm 5cm$. This diameter of the artificial source and the distance should be sufficient as suggested in [9, p.83-88].

The doublet is mounted as in Figure 5.

In order to align focuser (an old Contax focusing rail), doublet and artificial star I have used a Hotech laser collimator. The red dot has been used to place the artificial star and the multiple reflections of the red laser on the surfaces of the doublet have been used to align the doublet with the focuser (looking at the lens from just near the focuser itself); the result seems good, and could be used for folded refractors, since it is possible to see the surface of the lens from outside the focuser (because there is no tube). The artificial star is not exactly in the center of the camera, but the offset is little and there are no visible side effects.

Two Manfrotto super clamps have been used to fix the camera to the focusing rail (Figure 1) and the doublet to the tripod (Figure 2). The doublet is visible in Figure 3 and the interferogram in the lens box is reported in Figure 4. The doublet was well packed. The images have been grabbed with a MacBookPro by means of the AstroIICD program². Parameters of the images are reported later.

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Figure 1: Contax focusing rail and the Flea2 camera fixed with a Manfrotto super clamp; the Barlow lens is not present here.



Figure 2: Manfrotto super clamp fixing the doublet.



Figure 3: Doublet number 110033.



Figure 4: Interferometric test as reported from Istar.

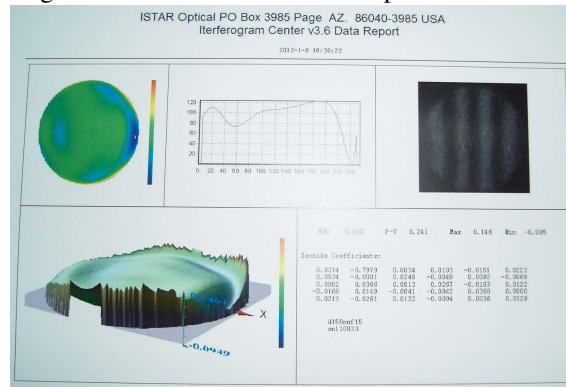
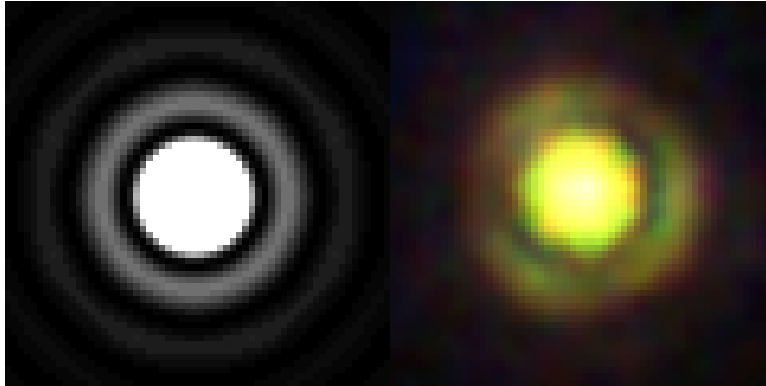


Figure 5: Test environment. Artificial star is not shown.



Figure 6: Image from Aberrator for a perfect 150mm f15 refractor and from the yellow filtered image of the Istar 150mm f15. Please note the actual image is damaged by the local seeing in the laboratory and by the long shutter time. Asymmetric thickenings of the ring are moving with the air currents.



Since the target is a color image of the Airy disk, a color camera has been used. Since images are not raw, in order to minimize demosaicing effects a Barlow lens has been used (a TeleVue Powermate 2,5x). In this way a total focal length of about $2250 \times 2.5 = 5625$ mm has been used.

Given ϑ angular distance from the optical axis and h ray height from the optical axis [2, p.5], $h = F \tan \vartheta$, where F is the focal length, here 2250mm (without Barlow). For the Point Grey Flea2 0.8 MP Color FireWire 1394b, equipped with a Sony ICX204 1/3" Global Shutter CCD with a maximum resolution of 1032×776 and a pixel size of $4.65 \times 4.65 \mu\text{m}$ for a h of $4.65 \mu\text{m}$ $\vartheta = 0.4262''$, that is 2.346 pixel for each arcsecond. Using also the Barlow lens for each arcsecond there are 5.865 pixels.

For doing the test Aberrator [1] will be used in order to compare actual images with computed images. In order to have the same characteristics, images generated by means of Aberrator have 11,73 pixels for each arcsecond (Aberrator has a maximum of 20 pix/arcsec), while images taken from the camera and used to compare spherical aberration are cropped and enlarged of 2 times (they should be enlarged by 5, but the Barlow is 2,5x, so $5/2.5 = 2$).

In order to verify that such computations are correct, in Figure 6 it is reported a collage of an image from Aberrator for a perfect 150mm f15 refractor and from the yellow filtered image of the Istar 150mm f15 (enlarged of two times). Please note that the diameter of the Airy disk is [2, p.8] $d_{\text{Airy}} = 2.44 \cdot \lambda \cdot f\text{number}$; for a f15 scope with a 2.5x Barlow the fnumber is 37.5. Since for 550nm light (green) $d_{\text{Airy}} = 2.44 \cdot 550 \cdot 10^{-9} \cdot 37.5 = 50.32 \mu\text{m}$ and since each pixel is $4.65 \mu\text{m}$, the diameter of the Airy disk should be $50.32/4.65 = 10.82$ pixels; finally since the original image is cropped and enlarged by 2, the diameter of the disk should be $10.82 \cdot 2 = 21.64$ pixel,

visit <http://creativecommons.org/licenses/by-sa/3.0/>.

²Unfortunately AstroI IDC will be no more supported after September 2012, and it is a pity, since it is an excellent program.

and it is the same value as in Figure 6.

With similar calculation (again in [2, p.8]) it is possible to compute the angular diameter of the Airy disk for the 150mm telescope as of 1.845 arcseconds; $1.845 \cdot 5.865$ (pixels for each arcsecond)= 10.82 pixels (enlarged to 21.64) as before for the diameter of the Airy disk.

As explained in [6, Fig.68] there exist different possibilities for the designer of the doublet. In this case the optimization for the C-e has been chosen; this type of design was also confirmed to me by e-mail from Ales Patrick Krivanek, Istar³ (similar design was also chosen for the Schiaparelli's Merz 220mm f15 telescope used from the 1877 mainly for observing Mars planet and double stars⁴). This means that green and red have a similar focus, while blue is very far from the common focus.

2 Airy's disk results

Third order approximation of Snell's law is associated with seven aberrations:

- Five monochromatic aberrations (von Seidel aberrations) [4, p.82]
 - spherical aberration (SA);
 - coma;
 - astigmatism;
 - curvature of field;
 - distortion.
- Two chromatic aberrations [4, p.112] due to variations of refractive index with wavelength
 - longitudinal chromatic aberration (LCA);
 - transverse chromatic aberration (TCA).

SA will be seen in 2.0.2. Coma was not present, at least in the reduced field of view. Astigmatism was not present, neither in intrafocal nor in extrafocal or in focus. Curvature of field and distortion were not analyzed, also because less interesting, at least in my opinion, in a f15 refractor, which is probably more useful for planets and double stars.

Chromatic aberration has been studied as LCA in the center of the field of view in 2.0.1.

Please note that rough surfaces, zonal aberrations and turned edges were not explicitly addressed, even if visualizing the image by means of eyepieces it appears that:

- rings are more detailed in intrafocal, less clear in extrafocal; maybe it could be a turned edge problem (see [9, p. 215]) as visible in Figure 4?;

³Please note that I am not linked in any way to Istar Optical.

⁴<http://www.cloudynights.com/ubbthreads/showflat.php/Cat/0/Number/3642270/page/0/view/collapsed/sb/5/o/all/fpart/1/vc/1>

- white focus is quite near to red focus (as already said);
- with a 12.5 mm Baader Genuine Ortosopic eyepiece the image is excellent, and Airy disk can be clearly seen (with one ring) at 180x; it is excellent also with a red filter (an Edmund Optics NT30-634 red filter) in front of the artificial star (in particular with left eye, since I have 0.5 diopter of astigmatism in my right eye, and at 180x the exit pupil is a little less than 1 mm, probably sufficient to enhance the astigmatism);
- with a 5 mm (12.5 Baader plus TeleVue 2.5 Barlow Powermate) at 450x image is good, even very good; in particular putting a red filter in front of the artificial star image is really good;
- with a TeleVue 3.5 mm Nagler at 642x image is sufficient, no more;
- putting an Edmund Optics NT30-635 blu filter if front of the artificial star the image is bad; it is possible to see the disk, but not the ring at all;
- even if the test has been performed in a corridor, the image is always slightly moving (probably because air conditioning is partially working - the test was performed on 21st of April 2012 and partially on 25th of February 2012) and sometimes it appears that the ring is weakened in three points (maybe due to the spacers of the doublet?); please note that visually image is more detailed than in images here reported due to long exposure time required (probably stacking more images would have been better).

2.0.1 Chromatic aberration

An achromatic 150mm f15 doublet can be considered as a good compromise in terms of lack of LCA, but it is far from perfection.

For example in [10, p.25] a refractor should have a chromatic aberration index $CA = fnumber/diameter_{inches}$ greater than 3 (Sidgwick standard) or even 5 (Conrady standard) and the doublet here analyzed has a value of only $CA = 15/6 = 2.5$.

In [11, p.263-303] four examples of design (by means of Zemax) of two classical achromats (f/5 and f/15) and two apochromats (both f/15 with different glasses) are detailed with several interesting diagrams.

In [5] interesting diagrams on how residual color is represented around Airy's disk are shown; it could be useful to compare such diagrams with results here reported, in particular considering that this scope is a C-e corrected type.

In Figure 7 it is possible to see what is the actual LCA of the doublet. Please note that the image has received a further $\gamma = 2$ improvement in order to make easier to see differences on paper, but at the eyepiece Figure 8 appears more correct. Please also note that the camera has filters in front of the pixels, and the response of these filters can be seen on the Point Grey website and can influence the result, in particular taking only one channel.

All cited images are available in 16 bit for channel, RGB .psd format⁵.

⁵<http://staff.polito.it/bartolomeo.montrucchio/Istar150f15/Istar150f15images.zip>

Figure 7: Comparison among Airy's disks in different lights or with a filter on the eyepiece.

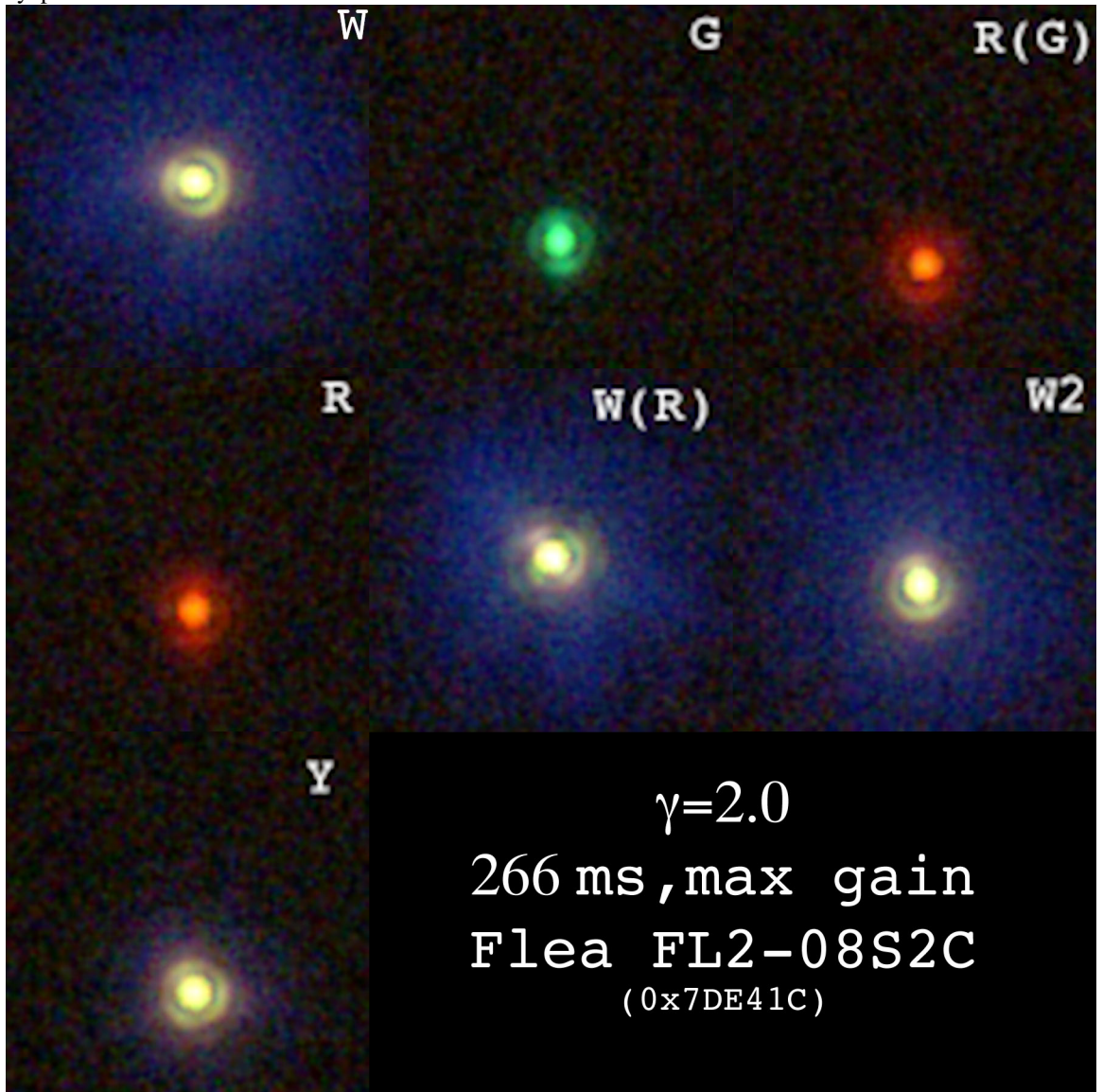
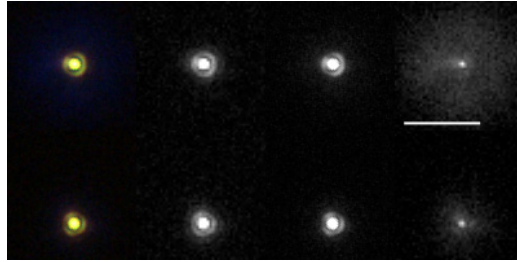


Figure 8: False color with a white artificial star. Top row from the left: original image no filters, its red channel, its green channel, its blue channel. The segment is 10" and printed on the paper is 10mm (1 mm for each arcsecond). Bottom row: yellow filter on the eyepiece, its red channel, its green channel, its blue channel.

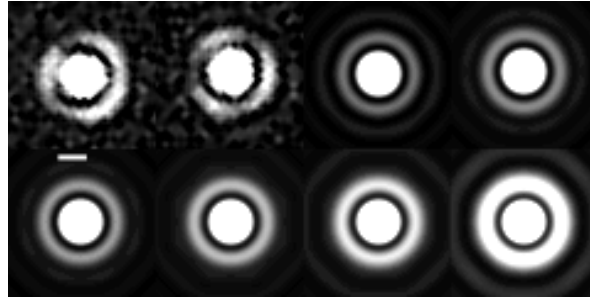


In Figure 7:

- W image is with a white artificial star and with no filters in front of the camera; this is the 20120421_195409.83_U_100x100.psd image in the archive;
- G image is with a Edmund Optics NT46-139 green filter in front of the artificial star and with no filters in front of the camera (**refocusing**); this is the 20120421_-202315.45_U_100x100.psd image in the archive;
- R(G) image is with a Edmund Optics NT30-634 red filter in front of the artificial star, with no filters in front of the camera and **without refocusing** with respect to the G image (it is for testing how different are the focus of green and red); this is the 20120421_202821.59_U_100x100.psd image in the archive;
- R image is with a Edmund Optics NT30-634 red filter in front of the artificial star, with no filters in front of the camera and **refocusing** with respect to the R(G) image (true red focus); this is the 20120421_203000.81_U_100x100.psd image in the archive;
- W(R) is like W, but **without refocusing** with respect to the R image (it is again for testing how different are the focus of red and white); this is the 20120421_-203326.85_U_100x100.psd image in the archive;
- W2 image is like W; it is simply to have a second source of W (it has been refocused); this is the 20120421_203501.70_U_100x100.psd image in the archive;
- Y image is with a white artificial star and with a Baader yellow 495nm long-pass filter in front of the camera (refocused); since red and green are very near, this kind of filtering is really very effective, even if it is very good for example for the Mars planet but not for blue stars (please remember that image has been enhanced with a $\gamma = 2$); this is the 20120421_203716.82_U_100x100.psd image in the archive.

In Figure 8 are analyzed false colors in the different channels. Please remember that channels also depend on the filters inside the color camera used and that in this

Figure 9: Different values of SA. Upper row from left to right: greenW, greenY, no SA, 1/8 SA. Lower row from left to right: 1/6.66 SA, 1/5 SA, 1/4 SA, 1/3 SA. The little segment under the first image is 1 arcsecond. When printed on paper the diameter of the Airy's disk is the same as in [9, p.180] in order to make comparisons easier.



case no image enhancement has been used. Again images are available in the archive. In the top row the image W can be seen in all channels; green channel (focus has been done for white) is the best, blue channel presents a large dispersion, with a diameter of about 20 arcseconds (the segment in the figure is 10 arcseconds long).

Putting a yellow filter in front of the camera blue dispersion is strongly reduced, and image is very good; please note that the two images appears both slightly yellow, even without the yellow filter.

2.0.2 Spherical aberration

The standard method suggested from Suiter in [9, p. 191] for computing the SA requires that the refractor is artificially obstructed to 33%. Than moving from the focus to intrafocal and then from the focus to extrafocal it is required to find when the shadow of the obstruction appears clearly. If the ratio of the defocusing distances at which the obstruction shadow clearly appears is lower than 2:1 the SA is lower than 1/4 wavelength. In other terms the shadow of the obstruction should be the same size at equal distances inside and outside focus; if it is larger inside focus, the mirror is under-corrected, if it is larger outside, the mirror is over-corrected [9, p. 179].

Unfortunately this method requires good experience, and "is not suggested as a measurement technique" [9, p. 192].

For all these reasons in this review a different method has been used. It uses focused patterns as reported in [9, p. 180]; in fact the rings moves and changes when SA increases. Also this method is probably not so good for measurement purposes, but it uses in focus images, that here are available.

In Figure 9 in the upper left corner of the image it is reported the same image as in Figure 7 (image W), but limited to the green channel only (it is basically the 20120421_195409.83_U_100x100.psd file in the archive, but enlarged twice and with only the green channel) and strongly unsharpmasked (373%, 3.0 pixels, 0 levels in Photoshop). The image reported in Figure 7 as Y (yellow) is the second from left in the upper row of Figure 9 (file 20120421_203716.82_U_100x100.psd in the archive), again

only the green channel and with the same unsharp mask. The unsharp mask has been done in order to enhance the structure of the image; for every comparison it is always possible to see the original images in the archive.

Going from left to right and again in the lower row from left to right then we have (prepared with Aberrator) no SA, 1/8 SA, 1/6.66 SA, 1/5 SA, 1/4 SA and finally 1/3 SA. The little segment under the top left image represents one arcsecond. When printed on paper the diameter of the Airy's disk is the same as in [9, p.180] in order to make comparisons easier.

Given the thickness of the rings and in particular the position of the second ring (please note that with 1/4 of SA the first ring is much larger than before, and the third ring is now the second), it appears (at least in my opinion) that the doublet has an amount of SA between 1/6.66 and 1/5, (maybe $1/6\lambda$) that is good for this kind of refractor. It should be possible to get the original 16 bit images in order to compute the image profile to search for the rings (here the images are 8 bit for printing limitations, but archive images are 16-bit).

It is important to note that the yellow filtered image is the best. This means that using the yellow filter it should be possible to get very good results at the telescope.

3 Conclusion

This preliminary test has been performed both to verify the quality of the lens and to have some data to compare performance of the final telescope with the lens alone, in order to compute also the MTF of the final telescope by means of Imatest [3]. The idea is to design and build a folded refractor and use a simple Vixen GP class mount instead of an expensive mount⁶. The Istar 150mm f15 lens seems to be very good from this preliminary test, for reduced chromatic and spherical aberrations.

References

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⁶An interesting example is in <http://www.astro-vr.de/fh150.htm>.

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