NEWLY DEVELOPED DIFFRACTION LIMITED OPTICS UP TO 180 DEGREES OBJECT FIELD

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In the last three years the author has developed a number of diffraction limited optics. Some of these are the contents of this paper.

The author has already shown some optics at the IAU-Symposium in Potsdam as poster B 06. In particular, the mirror optics shown there wasn't optimised. The optics were only derived from formulae of third order theory to cancel the third order abberations.

Now, the author will mention some examples which derived from a somewhat different design to achieve maximum performance. It must be mentioned that all surfaces are only true conics. No higher order aspheric terms at the surfaces of the mirrors were used. This is useful to ease the production of the systems. With the use of higher order aspherics the performance of the systems may be better again. Because of limited space, it is not possible to give here spot diagrams, PSFs or other pictures like wavefront aberrations, MTFs and so on simultaneously. The three mirror system developed by the author has image aberrations of below 0.14 arcseconds for an f-number of 4 and a diameter of object field of 2 degrees with a conveniently accessible focal plane somewhat behind the secondary mirror. With higher order aspherics the author has already reached 0.05 arcseconds at the edge of the field of 2 degrees and significantly smaller within this field. The theory of these systems, which was worked out by the author, encloses the so-called Paul-Baker-system. But now it is possible to lay the focus of the system at every position that is wished or needed. Figure 1 shows spot diagrams for 0, 0.5, 1, 1.5 and 2 degrees field diameter. The circle shown is the airy-disk with about 0.1 arcseconds diameter. The diameter of the primary mirror was 2500 millimetres, and hence the focal length of the whole system is about 10,000 millimetres.

The performance of this type of mirror system — as opposed to other mirror systems with the same f-number — is superior because here the sum of the optical powers of the mirrors and the sum of the aspheric deformations of the mirrors is minimum. There is no way to escape from this rule. For instance, a so-called Rumsey-telescope with three hyperbolic mirrors delivers for the same f-number and diameter of object field spot diameters of about 0.4 arcseconds. Additionally, the production of the mirrors of such a system would be much more complicated because of the high amounts of aspheric deviation from the basis sphere. In particular, the secondary and the tertiary mirrors in a Rumsey-telescope are strongly hyperbolical. Moreover a system with large amounts of aspheric deformations is more sensitive to alignment and tilt errors than a system with lower deformations.

The author has developed a very sophisticated design especially suitable for large telescopes.

H. T. MacGillivray et al. (eds.), Astronomy from Wide-Field Imaging, 109–113.

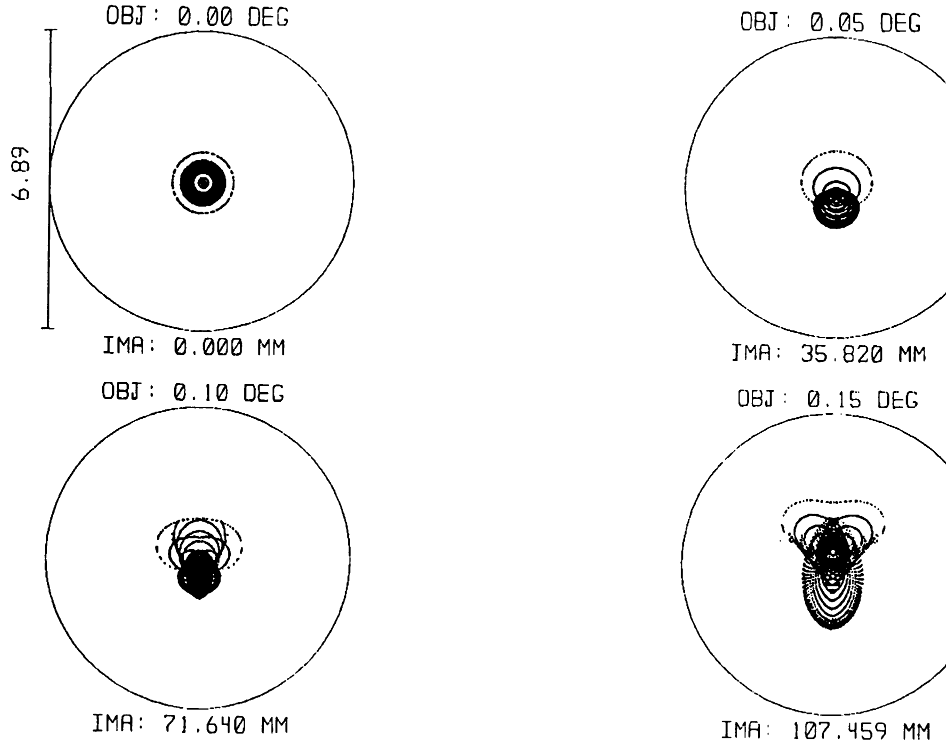

Figure 1.
SPOT DIAGRAM

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FIELD	:	1	2	3	4	5
RMS RADIUS	:	1.25	1.19	1.09	1.30	2.14
GEO RADIUS	:	3.04	2.81	2.10	2.36	4.07
AIRY DISK	:	2.684	REFERENCE: CHIEF RAY			

For the first time in history it is possible to correct simultaneously spherical abberation, coma, astigmatism and distortion in a true two mirror design, whereby the primary mirror reflects the light two times. There is only one solution with defined radius of curvature of the secondary in relation to the curvature of the primary mirror and the distance between them and two defined conic constants of the mirrors that yield such an error free solution. Both mirrors are only slightly hyperbolical, without the need for higher order asphericis. Design examples are given for diameters of the primary of 8000 millimetres. For an f-number of the primary of 1 and a field

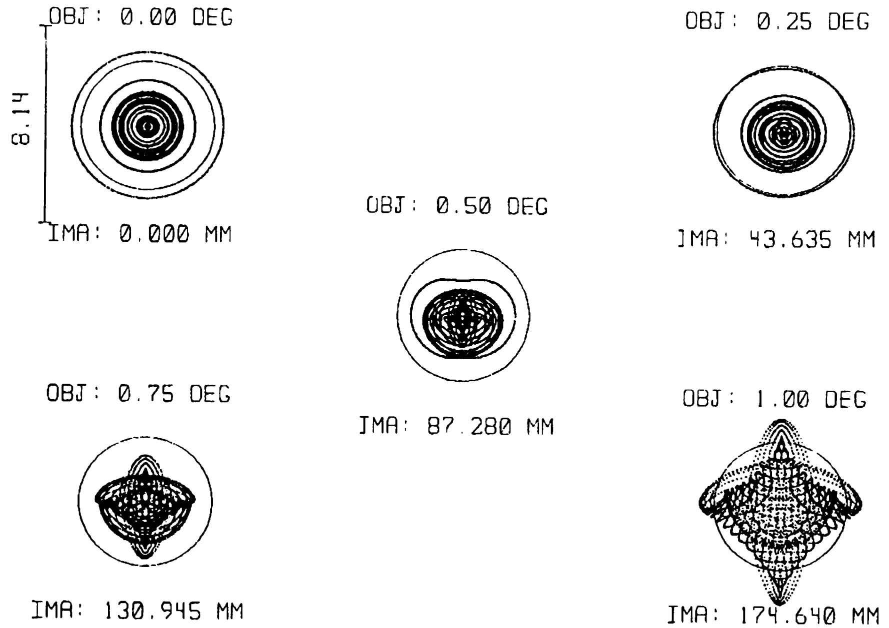

Figure 2.
SPOT DIAGRAM

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FIELD	:	1	2	3	4
RMS RADIUS	:	0.40	0.41	0.51	0.73
GEO RADIUS	:	0.70	0.88	1.05	1.65
AIRY DISK	:	3.443	REFERENCE: MIDDLE		

of 0.3 degree, image aberrations are below 0.015 arcseconds at the edge and significantly smaller within this field. Peak to valley wavefront aberration is below 1/4 wavelength of yellow light. In a wavefront optimised design, 1/10 of a wavelength is possible. Besides every telescope with a parabolic primary could be converted into such a telescope with only a little amount of refiguring of the primary.

Moreover, most Ritchey-Chrétien-telescopes could be converted into such a system without any deviation at the primary. The only thing that is needed is a new secondary!

The length of the example system is 6400 mm and the f-number of the whole system is about

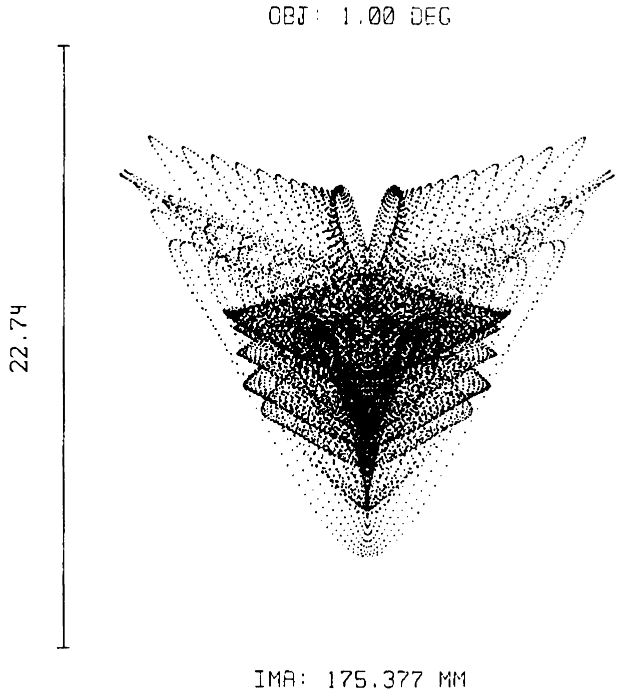

Figure 3.
SPOT DIAGRAM
LENS HAS NO TITLE
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FIELD	:	5	
RMS RADIUS	:	3.59	
GEO RADIUS	:	11.37	
AIRY DISK	:	2.686	REFERENCE: MIDDLE

5. The production of the mirrors is practicable because they only slightly deviate from a parabola. Figure 2 shows spot diagrams for 0, 0.1, 0.2 and 0.3 degrees field diameter. The circle shown there is the airy-disk with a diameter of about 0.03 arcseconds. All rays are well within the tiny airy-disk. If for example the f-number of the primary is 2, image aberration drops down below 0.002 arcseconds. In both cases, distortion is far below 0.001 arcseconds at the edge of the field. It must be mentioned that all of the above described mirror systems are claims of German patent registrations and are now underway as world-wide patent registrations.

In addition to the systems described here, the author has made extensive studies of two mirror systems and associated correctors. One result is a system with an f-number of 4 designed for a field of 2 degrees diameter. The diameter of the primary is 2500 millimetres.

In the wavelength range from 400 nanometres to 700 nanometres, image aberrations at the edge of the field are below 0.25 arcseconds and significantly below that within this field.

But in terms of wavefront aberrations such a system doesn't reach the same quality as the three mirror system described first. On the other hand a two mirror solution has lower problems of vignetting and hence lower problems of secondary diffraction. The corrector consists of three conveniently located lenses whereby the focal plane is nicely accessible located behind the primary mirror. The lenses are spherically shaped. The mirrors may be only simple conics.

Figure 3 shows the spot diagram for 2 degrees field diameter. Rays are traced for 400, 450, 500, 550, 600, 650 and 700 nanometres. The circle shown there is the airy-disk with a diameter of about 0.1 arcseconds. On axis, all rays fall within a circle of 0.1 arcseconds. For a field of 1 degree, all rays fall within a circle of 0.010 millimetres and for a field of 1.5 degrees all rays fall within a circle of 0.014 millimetres.

Besides this system, the author has developed two mirror correctors for classical Cassegrains and for Ritchey-Chrétiens that yield a diffraction limited performance. The field is mainly restricted for geometrical reasons. The corrector systems can additionally serve as focal reducers. Systems with a flat field which are at least in third order free from spherical aberration, coma and astigmatism are possible. Distortion is of very acceptable order.

Last, but not least, the author has developed a lens system which is capable of imaging the whole sky visible in one place on earth nearly diffraction limited and without any distortion on a curved field. A design example was already given at the conference in Potsdam in August 1993. Unfortunately the free diameter of the aperture stop of the system is limited to the order of 100 millimetres. On the other hand the system is capable of giving more different image points than any other optical system in the world. With an f-number of 5 and 500 millimetres focal length it delivers about $7.4E^{+9}$ different image points whereby only three lens elements were used. With more design effort the number may be 4 times higher. In comparison, a Schmidt-telescope with an f-number of 3 shows about $4E^{+8}$ different image points.