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On optics of FD without corrector ring

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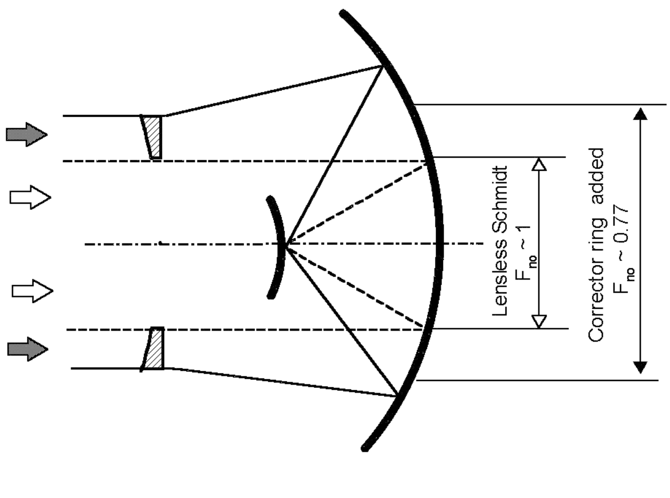
Abstract

This article deals with the change of optical parameters of FD telescopes in the case that the corrector ring is removed from the aperture. The diameter of the aperture remains on the value of 2200 mm. At the end we state recommended values for FD camera shift to minimize the spot size in the range of apertures 1700-2200 mm.

Introduction

Final design of FD telescope is a bifocal system depicted in Fig. 1. Inner part of the telescope is a Schmidt camera without correction plate (lensless design). Outer part is a modified



version of Schmidt camera with correction plate (ordinary design) of annular shape.

Figure1: Drawing of FD telescope optical system.

Minimal spot size in the image plane of the camera is given by spherical aberration of the inner lensless variant. Corrector ring is designed so that it keeps this value even for aperture diameter that doubles its original surface and so considerably increases the signal detected. Should the corrector be removed from the system but the greater aperture kept, we go back to the lensless design. The system has to be recalculated to determine the change in the spot size as well as position of minimum.

The disc of least confusion – overview

Uncorrected spherical aberration determines the spot size of lensless Schmidt camera.

Spherical aberration occurs when light rays parallel to the optical axis enter the system at different heights and come to the focus at different points along the axis of the lensless Schmidt camera. Schmidt camera is liable only to spherical aberration.

Fig. 2 shows an optical beam in a spherical mirror with a focal ratio about *f/1*. We can see that the best image is shifted from the paraxial focal plane.

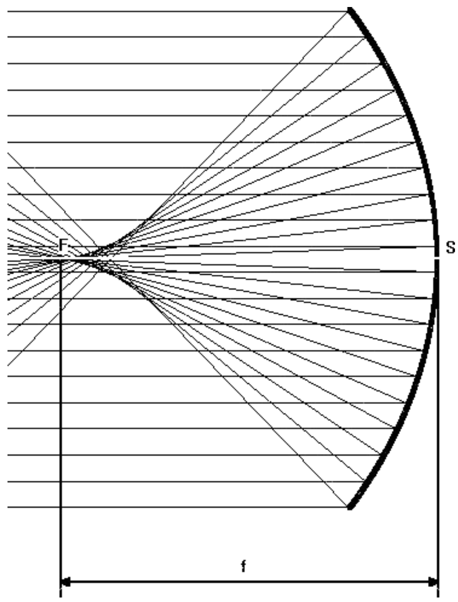


Figure 2: Spherical aberration of a mirror with a **f**no = 1.

Rays near the paraxial focus point touch a surface of revolution called the caustic. The smallest image can be found where the marginal ray meets the caustic. The smallest image patch is called a disc of least confusion. A schematic drawing is shown in Fig. 3.

Is is possible to find intersection of a marginal ray with the caustic [1]. We have found the disc of least confusion numerically. The exact location of the smallest image patch is shifted by Δz from the paraxial focal plane. The radius of curvature of PMT camera is then f - Δz (f is focal length f = -1700 mm). The camera curvature is concentric with the mirror.

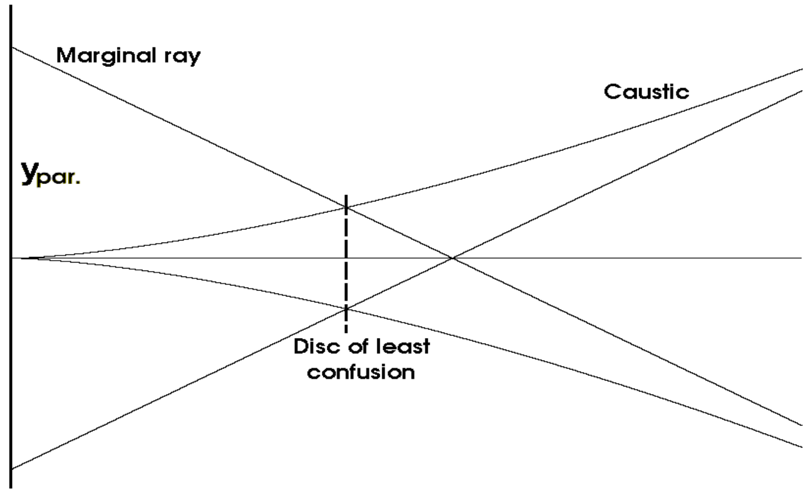


Figure 3: Scheme of the analysis of the smallest image.

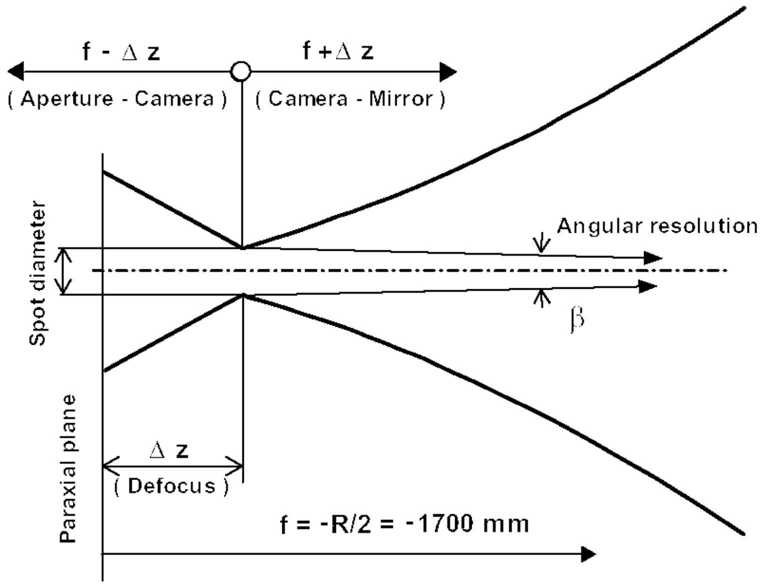


Figure 4. The disc of least confusion parameters.

Fig. 4 specifies basic parameters for the description of position and size of the disc of least confusion for the original lensless variant of the camera.

Comparison of two extreme cases of lensless camera – original with 1700 mm diameter and new 2200 mm in diameter (FD without corrector ring).

Generally it holds that with increasing aperture diameter but constant radius of curvature of a mirror longitudinal and transversal aberration increases. In the first approximation it holds that the position Δz of the disc of least confusion is equal to cca ¾ of the longitudinal spherical aberration. For a greater aperture one should therefore expect not only greater diameter of the spot but also a greater shift Δz from the paraxial plane. It is schematicaly shown in Fig. 5.

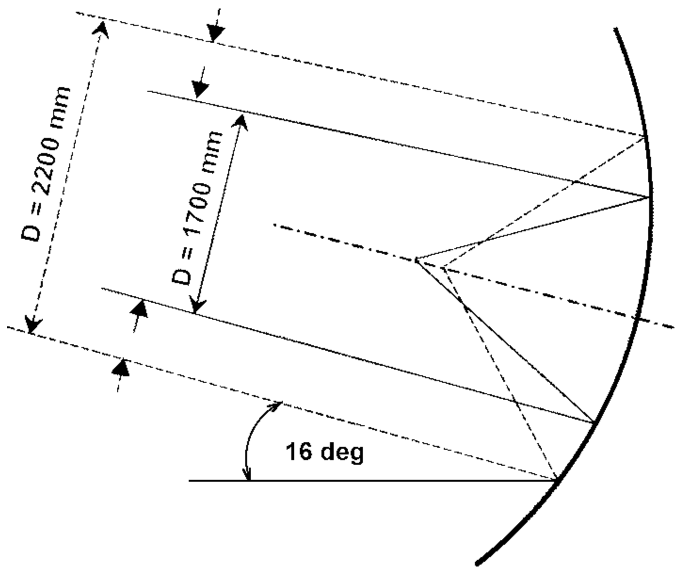


Figure 5: Position of minimum spot size dependence on aperture diameter.

Position as well as size of the minimun spot is given by the position of intersection of the ray from the edge of the aperture with caustic (envelope of reflected rays). See Fig. 3.
Fig.6. is a detail of the situation close to the paraxial plane for extremal apertures 1700 mm and 2200 mm (i.e. semi-apertures 850 mm and 1100 mm).

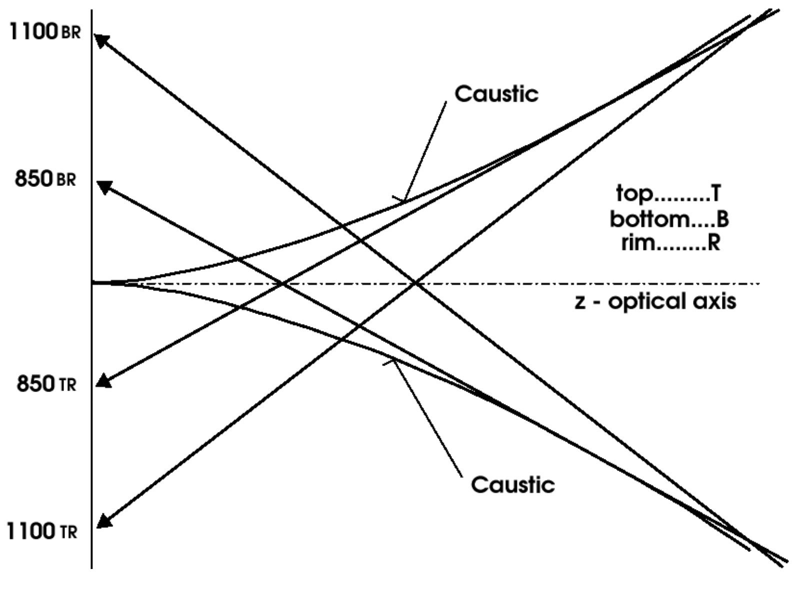


Figure 6: Determination of the discs of least confusion for semi apertures 850 mm and 1100 mm.

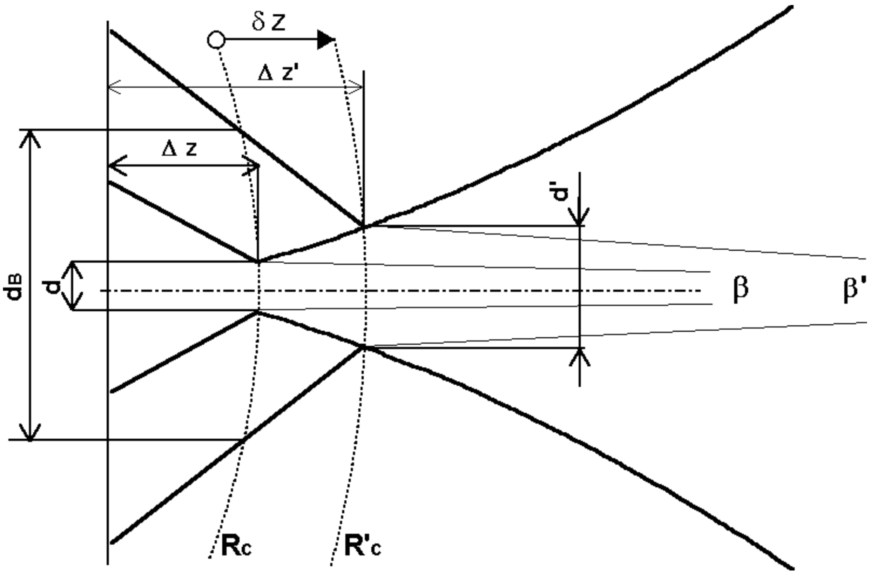


Figure 7: Intersection of beam envelopes for semi-apertures 850 mm and 1100 mm.

Fig.7 is again to scale and shows intersection of beam envelopes for lensless Schmidt camera with apertures 1700 mm and 2200 mm (primed parameters correspond to 2200 mm) . Diameter dB is only illustrative and shows the diameter of the spot in the camera plane with the corrector ring removed. The spot enlarges more than five times.

It is evident from the picture that the minimum spot in case of bigger aperture (2200 mm) is replaced by δZ with respect to the original position (1700 mm). Camera should be therefore shifted by δZ towards the mirror as is indicated in fig. 8.

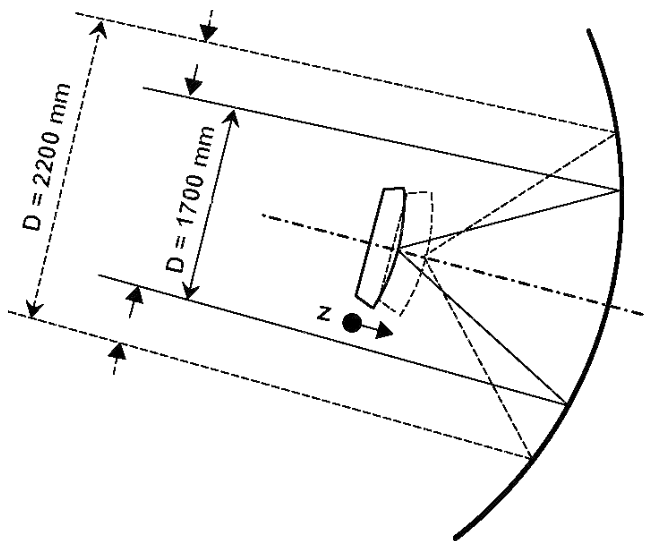


Figure 8: Drawing of camera shift to the new position of the disc of least confusion in case of aperture D = 2200 mm.

Comparison of original and new version of lensless Schmidt camera – spot diagrams.

Optical qualities of lensless Schmidt cameras can be evaluated by means of so called spot diagrams, which clearly show the shape and size of a spot in the camera plane. Figures 9 and 10 show the situation for the 1700 mm and 2200 mm cases respectively. The second case assumes the shift of the camera by δ**Z** towards the mirror as mentioned above. Middle column represents an ideal position.

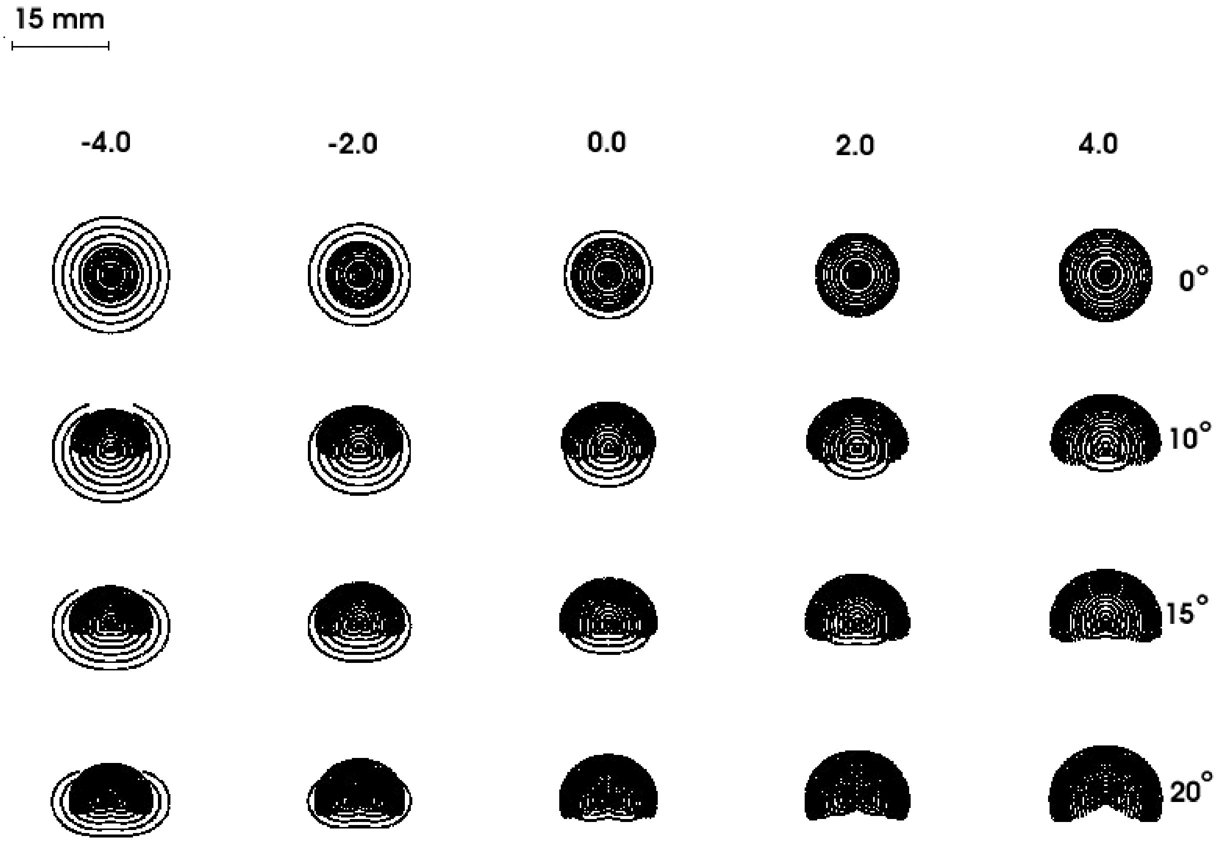


Figure 9: Spot diagram for lensless Schmidt D = 1700 mm.

Spot diagrams are presented for viewing angles of 0°,10°,15° a 20°.
Comparing the spot diagrams with numerical calculations presented in the next section one can conclude that:

- They look almost the same just the size in the first case is 15 mm while in the second case it is 35 mm.
- In the second case are the spots more homogeneous because the camera is shadowing a smaller portion of the aperture.
- Compared to the original position the camera has to be shifted along the optical axis by δ**Z** = 31.8 mm towards the mirror.
- Ideally the radius of curvature of the camera should also change by δ**Z** but this is a small discrepancy that does not have a significant effect on the spot shape and size.

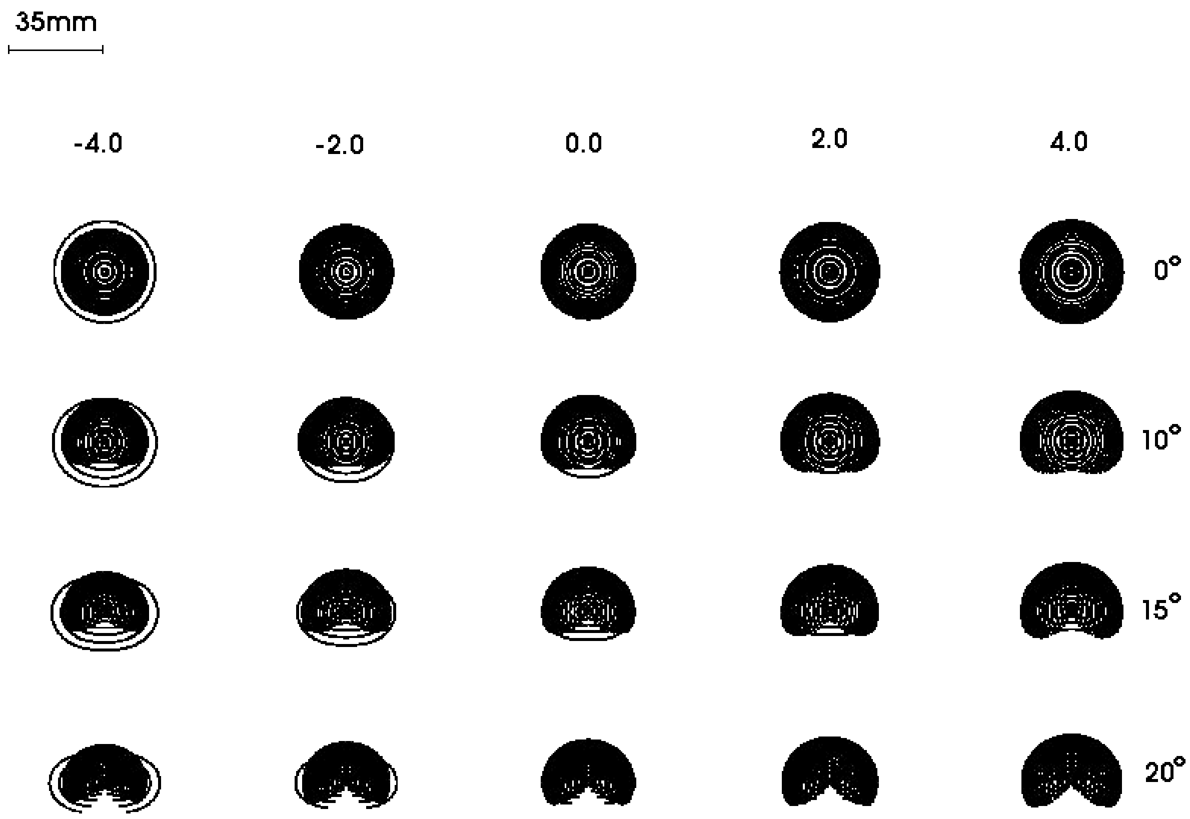


Figure 10: Spot diagram for lensless Schmidt D = 2200 mm.

Conclusion

If the corrector ring is omitted and the aperture diameter is kept at D = 2200 mm the spot increases from cca 15 mm to cca 35 mm. It is necessary to move the camera along the optical axis by 31.8 mm towards the mirror. As the optical axis of FD is inclined by 16° the camera should be replaced by 30.6 mm horizontally and 8.8 mm vertically.

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Effect of shielding on the position and size of the disk of least confusion

Basic consequence of corrector ring removal is the augmentation of minimum spot size from 15 mm to 35 mm. We will learn from the next measurement what are the consequences in terms of signal to noise ratio and consecutive loss of acceptance. Should the spot size be found unacceptable the next possibility would be to reduce the aperture. Therefore we extended the previous analysis to values in between 1700 mm and 2200 mm with the step of 10 mm. Results are presented in a Table and plotted in Fig.11.

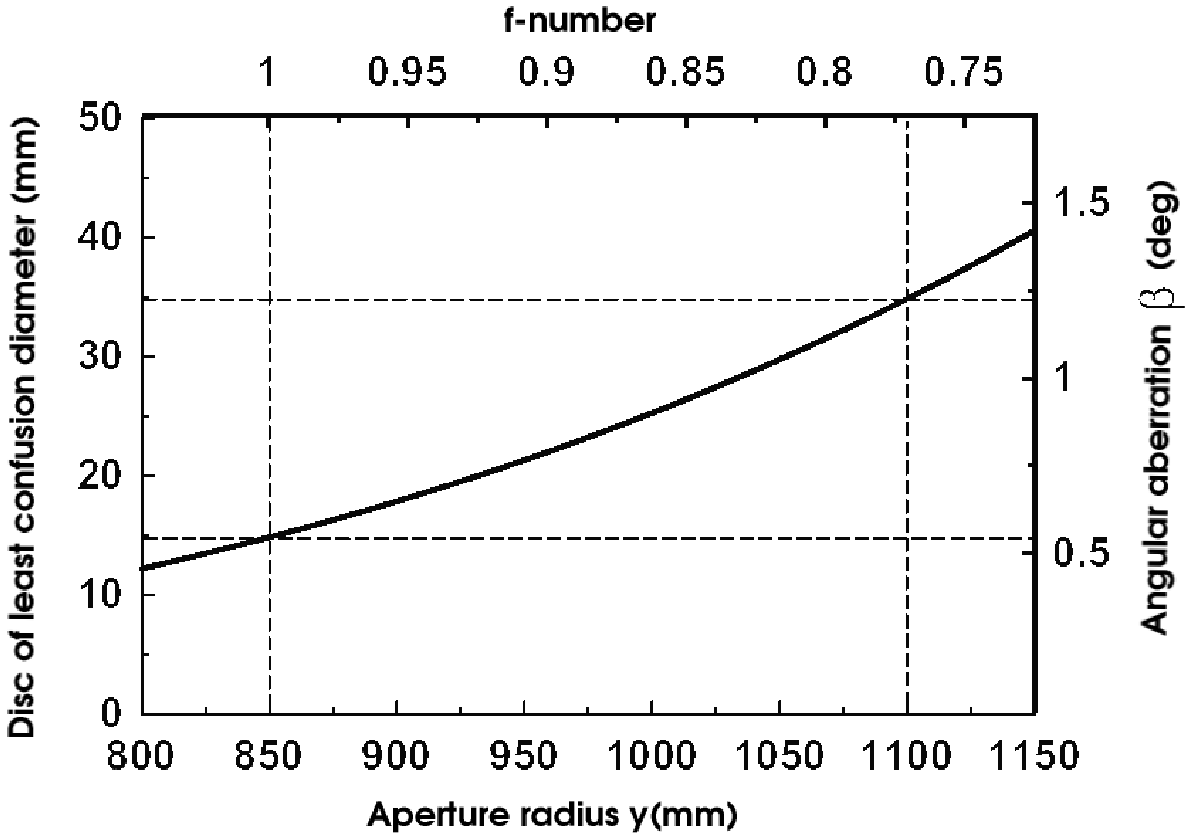

Figure 11: Minimum spot size (linear and angular) versus aperture radius of lensless FD. Relative aperture scale is added. The graph is to scale and can be used as a simple nomogram.

Semiaperture **y** (mm)	f-number **f**no	Minimum spot Diameter **d** (mm)	Angular spot size β (deg)	Camera body radius **Rc** (mm)	Camera-Mirror distance **s** (mm)	Camera axial shift δ**z** (mm)
850	1	14.83	0.51	1742.3	-1657.7	0
860	0.99	15.41	0.53	1743.4	-1656.6	1.07
870	0.98	15.99	0.55	1744.5	-1655.5	2.15
880	0.97	16.60	0.57	1745.6	-1654.4	3.25
890	0.96	17.22	0.60	1746.7	-1653.3	4.37
900	0.94	17.86	0.62	1747.8	-1652.2	5.5
910	0.93	18.52	0.64	1749.0	-1651.0	6.64
920	0.92	19.19	0.67	1750.2	-1649.8	7.81
930	0.91	19.88	0.69	1751.3	-1648.7	8.99
940	0.9	20.59	0.72	1752.5	-1647.5	10.19
950	0.9	21.32	0.74	1753.7	-1646.3	11.4
960	0.89	22.07	0.77	1755.0	-1645.0	12.63
970	0.88	22.84	0.80	1756.2	-1643.8	13.88
980	0.87	23.63	0.82	1757.5	-1642.5	15.15
990	0.86	24.45	0.85	1758.8	-1641.2	16.43
1000	0.85	25.28	0.88	1760.1	-1639.9	17.74
1010	0.84	26.13	0.91	1761.4	-1638.6	19.05
1020	0.83	27.01	0.95	1762.7	-1637.3	20.39
1030	0.83	27.90	0.98	1764.1	-1635.9	21.75
1040	0.82	28.83	1.01	1765.5	-1634.5	23.12
1050	0.81	29.77	1.04	1766.9	-1633.1	24.52
1060	0.8	30.74	1.08	1768.3	-1631.7	25.93
1070	0.79	31.73	1.12	1769.7	-1630.3	27.36
1080	0.79	32.75	1.15	1771.2	-1628.8	28.81
1090	0.78	33.79	1.19	1772.6	-1627.4	30.28
1100	0.77	34.86	1.23	1774.1	-1625.9	31.77

Table: Relative aperture, minimum spot size (linear and angular), ideal radius of curvature, distance between camera and mirror depending on the radius of entrance aperture with 10 mm steps. Also a shift of the camera to the position of minimal spot is added.

Appendix

Schmidt camera, modification of which is used in FD optical system has been known for a long time and it is widely used in diferent areas of astronomical observations. Its construction has qualitative limits given by relative aperture size and field of view. To keep a certain optical quality one of these parameters has to be constrained. Schmidt cameras with relative aperture around $f_{no} = 1$ have a field of view of up to 5°. On the contrary cameras with large fields of view above 10° have their relative aperture limited to $f_{no} = 2$ or more. The second case is more frequent. Due to favourable **f/D** ratio designing of Schmidt optical systems can be based on results of a third-order theory (Seidl space). Relations based on this approximation are used for example in literature [2] that was used as a reference for the first calculations of FD telescope. Their precision is relevant in cases where relative aperture **f/D** is around 3 or more. However, FD telescopes have relative aperture around 1 for which the relations mentioned above loose precision as one can see in Fig. 12. The difference for entrance window of 1700 mm is 10% while at 2200 mm it amounts to 20%. In this case exact trigonometric ray tracing is essential.

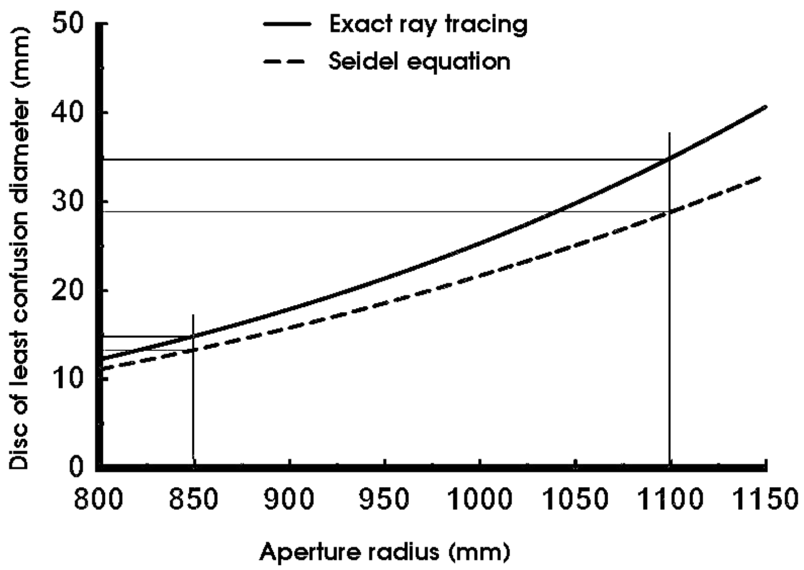

Figure 12: Dependence of minimum spot size on aperture. Comparison of exact numerical calculation and approximation.

[1] M.Hrabovsky, M.Palatka, et al., The optical analysis of the proposed Schmidt camera design, GAP-99-025

[2] M.Born and E.Wolf, Principles of Optics, Pergamon Press, 1980

[3] M. Palatka et al., Bifocal Optical system of the Schmidt Camera (Design of the Corrector Ring), GAP-2000 –002

[4] SIGMA 2100, Optical Design Software, KIDGER OPTIC