WIDE-FIELD-IMAGING 3-MIRROR-SYSTEMS WITH HIGH LIGHT GATHERING POWER AND A WIDE-FIELD OPTICAL SYSTEM FOR THE 'LARGE IMAGING TELESCOPE' (LITE)

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1. Introduction

The desire of astronomers for wide field telescope systems which surpass the RCC (1:8 max. 1.5 degree) in light gathering power and field of view are relative concrete today. For this type of telescope, detectors planned ARE CCDs in multichip arrangement.

3-mirror-telescopes permit fast focal ratios and large field of views. Different optical systems are presented here with focal ratios up to 1:2.5 and fields up to 3.2 degree with sectional drawing, aberration- and spot diagram.

The size of the field requires a multichip arrangement of 2048 x 2048 pixel CCDs. The focal length of these systems is determined by the pixel size of 15 µm.

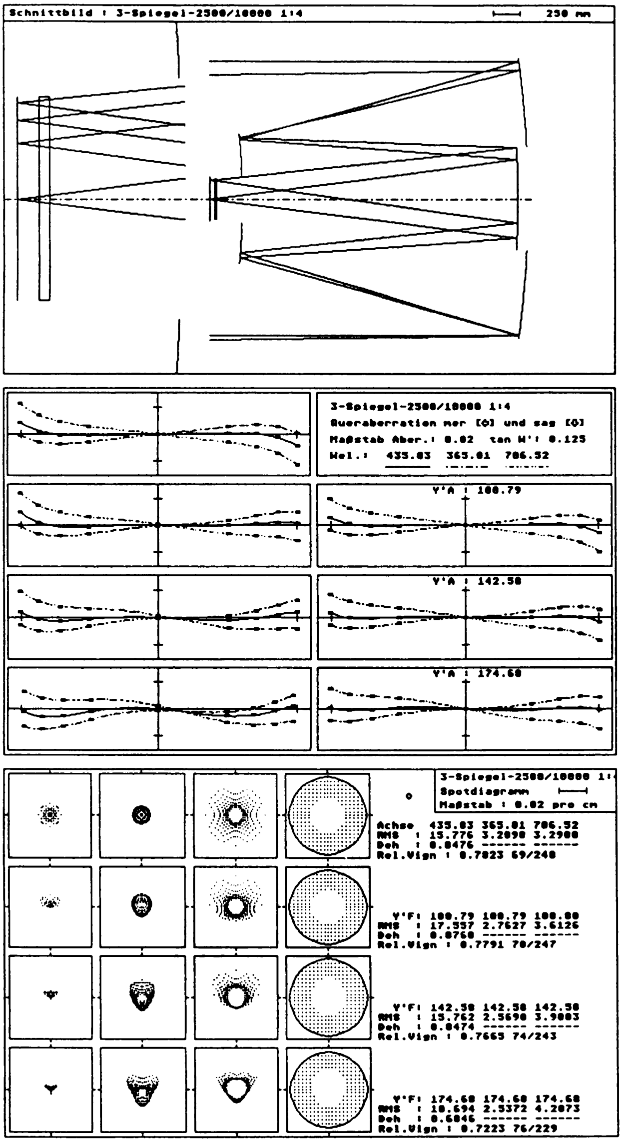
The linear field up to 400 mm, the spatial resolution and the aperture angle require some compromises. The optical range for the focal length is from 6.25 to 10 m. Maximal resolution (1/3" per pixel) is attainable for a focal length of 9-10 m. Unfortunately, in this case the field is only 2 degrees. For fields of 3.2 degrees shorter focal lengths are necessary.

The aperture should be 2-3 m. It is determined by the attainable image quality and the focal ratio.

				2°	2.5°	3°	3.2°
f'	Pixel″	″pro mm	µm pro″	linear field of view in mm			
6250	0.495	33.00	30.3	218	273	327	349
7000	0.442	29.47	33.9	244	305	366	391
7500	0.413	27.50	33.4	262	327	393	(420)
10000	0.310	20.63	48.5	349	(436)	(524)	(560)

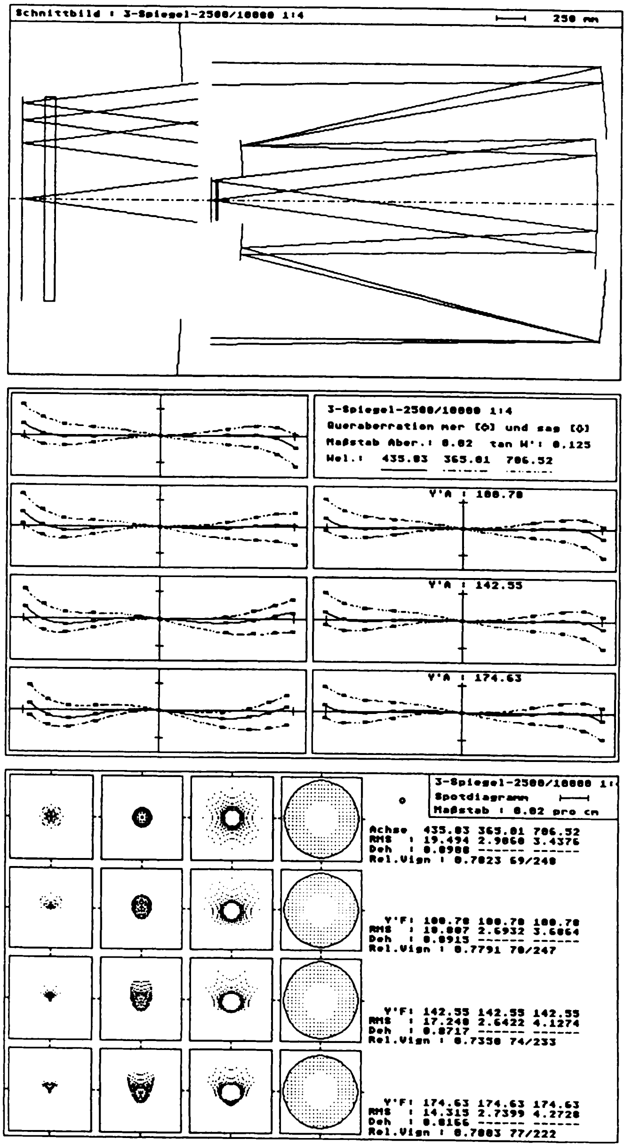
Statement: The calculations of the optical systems were carried out with optical design and analysis software developed by the author.

H. T. MacGillivray et al. (eds.), Astronomy from Wide-Field Imaging, 101–107.



3-mirror-system 2500/10000 (field: 350 mm, 2 degree)
system 4 LITE version 1

Figure 1. 3-mirror system 2500/10000 (field: 350 mm, 2 degree) system 4 LITE version 1.



3-mirror-system 2500/10000 (field: 350 mm, 2 degree)
system 3 LITE version 2

Figure 2. 3-mirror-system 2500/10000 (field: 350mm, 2 degree) system 3 LITE version 2.

2. Telescope Parameters Investigated

focal length	6.25 - 10 m
aperture	2 - 3 m
focal ratio	up to 1:2.5
image field	up to 3.2 Grad (for 400 mm linear field)
spectral range	365.01 nm 706.52 nm (f dispersive effect for visible window of the CCD)

3. Systems Investigated

— RRC-system with quartz-Gascoigne-plate and flattening lens
— RCC-system with Gascoigne-plate in reflection, 3-mirror variant
— 3-mirror systems with conic section- and overdeformed mirrors

4. General

Ritchey-Chretien-systems, which are known and are wide-spread in astronomical technology, have a very high image quality for aperture ratios from 1:6 to 1:15. The technologies, necessary for making the systems, are already routine.

They are unsuitable for higher light-gathering powers and so are used on Schmidt- and also Slevogt-systems. These two system-types attain not only a high light-gathering power, but also a wide-field. This wide field must be leveled additionally at the Schmidt-system.

The Schmidt-plate as a refracting element limits the maximum free aperture. Alongside technological expenditures for such a large optical element, the length of construction for a Schmidt-telescope has special limitations. The chromatic influences of the Schmidt-plate and the flat field lens are another matter. They limit the attainable image quality. Achromatism of flat field lens and Schmidt-plate is possible, especially the achromatism of the Schmidt-plate is difficult to realise (2 plates!). Alongside the large mass, the availability of the optical media has special limits. These are big, rare, voltage-free quartz- or grown glass plates and of achromatism also light flint plates. Then the transmission is especially reduced in UV.

The Tautenburg Schmidt-telescope with a Schmidt-plate diameter of 1340 mm is unsurpassable until today. It represents a technical limit and this limit can only be exceeded with a very large expenditure.

By the use of CCD-cameras, especially CCD-Array-cameras, old limits (spectral range) and the demands on accessibility to the focal plane are canceled or have lost their importance, but the plane field is absolutely necessary.

The structure of extreme light-gathering wild-field-telescopes for CCD-cameras requires other types of systems. In the first place these are the complex constructed 3-mirror-telescopes. They are light-gathering, wide-field-telescopes without refracting elements! Up to a focal ratio of 1:4 and a large image quality, these systems can be executed with conic section planes. The expenditure is comparable with a RCC-telescope. With increasing light-gathering power the optimal plane deviates more and more from the conic section.

Of course a 1:2.5 3.2 degree telescope can also be realized with conic section planes, but then the image quality is up to only moderate demands. The planes must not exceed the 4-th order and that's why they can still be tested very well (modified Offner-systems).

With all represented variants the vignette lies below 50% of the primary mirror diameter, therefore it is maximum 25% of the plane. Because of the relative positions of the mirror, the diameter of the mirror and the position of the focus the maximum linear image field is limited. The effective field of view in degrees is therefore limited in many cases and not by the image quality. In particular this makes itself felt in longer focal distance systems. So for example the optical effiency of the 1:4 systems is sufficient for a 2-4 degree image field, but the linear extension and the diameter of the secondary mirror are in contradiction to each other (central vignette). Here is the main compromise zone of the 3-mirror-systems.

It is shown that in the focal ratios of 1:6-1:15 the 3-mirror-systems represent no real alternative to the classical systems, but in the light gathering field on the other side of 1:6 they are a real alternative. The maximum focal ratio and the image field depend on the demand of the image quality. Both parameters run in the correction against each other. With longer focal lengths the linear field is often restricted by the central vignette.

The 3-mirror-systems can be realized without breaking elements. Nevertheless the not excluded window of the CCD-camera and also filter glasses, as not to mirror systems belonging breaking elements, show a distinct influence on the chromatic image quality. In particular with extreme light gathering power (focal ratios of 1:2.5 to 1:4) window-stoutnesses of more than 10 mm quartz-glass make itself felt. This longitudinal chromatic aberration depends on the dispersion and can be reduced only by appropriate media selection. Here quartz-glass is nearly irreparable.

The chromatic variation of the image quality is unimportant for a mere control system. If required, the focus must be changed by detailed observations about a large spectral field. This results from the task, the effective pixel size of the CCD, the pixelbinning and naturally the seeing conditions.

If the use of rare quartz-glass-plates as vacuum windows (mechanical pressure strain) and, because of cool technical reasons fails (further more are filter thicknesses) increasing chromatic influences must be considered with the 3-mirror-systems by focal ratios of 1:2.5 to 1:5 or it must be renounced of the extreme apertures. By a linear wide field of 350 mm one can expect with a window thickness of 20-30 mm. Focal ratios of 1:4 to 1:5 are a good compromise here.

System 1: RCC-system with field system 5; system examples were inspected with a focal length of 10 m and focal ratios of 1:4; (1:4.35); 1:5; 1:6 and 1:8.

The RCC-system with 'Gascoigne-Schmidt-plate' and flattening lens is unsuitable for focal ratios of 1:4 to 1:6. Beside of an insufficient monochromatic image quality a relative large chromatic image error arises. As a colour longitudinal error it depends on the thickness of the both correcting lenses and the focal ratio in the first place.

The flattening lens can serve as CCD-window. For a field of view larger 1.5 degree the image quality decrease is too much. This is without signification by the usual RCC-systems with focal ratios of 1:8 to 1:15 respectively it is superimposed by seeing conditions. Focal ratios of more than 1:6 and large fields can not attained with these optical systems if a high image quality is aimed. The length of construction of the systems is relatively high.

System 2: RCC-system as a 3-mirror-system Modified RCC-type with reflecting correcting plate.

Several versions with focal ratios of 1:5 and 1:4.35 were investigated using fields of 1.5-2 degrees. In all cases the primary mirror is a hyperbolic (as can be proved by an Offnersystem). In the basic form the secondary mirror is a hyperbolic with additional deformation. The correcting plate is a reflecting 'Gascoigne-Schmidt-plate' with higher deformation. The image quality of a 2.5 degree field is also very moderate with extreme deformation, but the central field is good. By a focal ratio of 1:4.35 a 2.5 degree field is possible at the most, but appears concerning the image quality to big. By a focal ratio of 1:4.35 to 1:5 a image field of 1.5 - maximum 2 degree is still possible concerning the image quality.

System 3: 3-mirror-system with 3-hyperbolic mirrors and overdeformed mirrors.
Modified 3-mirror-system with 3 hyperbolic mirrors. By a focal ratio of 1:4 image fields are attainable to 2 degrees with mere hyperbel planes. With overdeformed primary and secondary mirrors focal ratios to about 1:2.5 and image fields to about 3.2 degrees are possible. This type of system attains a very high image quality.

The system is uncritical concerning the relative position of the mirrors to each other and also concerning the position of the focus. Here the constructor has a relative large freeroom by arranging the setting for mirror 1 and 3 and also for the position of the focus (CCD-camera-top) and mirror 2.

The vignette is influenced unfavourable by the diameter ratio of mirror 2 and 3. Besides the large image field and the high light gathering power the system also has a very high image quality.

System 4: 3-mirror-system with 3-overdeformed mirrors.
Modified 3-mirror-system with 3 overdeformed mirrors. By focal ratios to 1:4 image fields to about 2 degrees are possible. This system attains a high image quality. The primary- and secondary mirror are overdeformed (spherical aberration). The system is uncritical concerning the relative position of the mirrors to each other and also concerning the position of the focus. The high light gathering power is not attained as in system 3, but the construction is more favourable, especially the diameter ratio of mirror 2 and 3.

Large Imaging Telescope (LITE).
For the Large Imaging Telescope (LITE) the construction according to system 4 or system 3 is especially suitable. The construction according to system 3 can be realized with 3 hyperbolic mirrors. The construction according to system 4 requires overdeformed mirrors, but is more compact. A system according to system 4 is the basis for planning at present.

The image field of the 2500/10000 (1:4) telescope amounts only 270 mm (1.55 degree) here. The position of the focus, relative to the 2nd secondary mirror, is adapted of the focus, relative of the cryostate. These modifications are slightly related to the variation width of the system type.

Compared to the RCC-systems 1 and 2 these both 3-mirror-versions are distinguished by a comparatively high image quality and a compact way of building.

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