## The Schiefspiegler ( Oblique Telescope )

by Anton Kutter

"The Schiefspiegler (Oblique Telescope)" by Anton Kutter was reproduced and offered for sale in 1958 by Sky Publishing Corp. as "Bulletin A: Gleanings for ATMs."

It has been annotated and transformed into HTML by Mark D. Holm and published on ATMSite.org with the permission of Sky Publishing Corp. Because the ATMSite has been down for some years now, the document has been corrected, reformatted, transformed into a PDF document and published on atm.udjat.nl, in order to keep it accessible to those who are interested.

Original rights are with Sky Publishing Corp, additional rights regarding HTML version are with Mark D. Holm (see the Internet Archive).

This version of the document is for personal reference only, any other use requires approval from Sky \& Telescope / F+W Media, Inc. , Mark D. Holm and myself respectively.

March 2016, Arjan te Marvelde

# SKY AND TELESCOPE Bulletin A 

Gleanings for ATM's

## THE SCHIEFSPIEGLER (OBLIQUE TELESCOPE)

by
ANTON KUTTER

Waldseer Strasse 3
Biberach an der Riss
West Germany

NOTE: Mr. Kutter's figure 3 appears on page 66 of the December, 1958,issue of SKY AND TELESCOPE; his figure 7 is the front-cover picture of the same issue; and some of his moon photographs are reproduced with the article in that issue, 'Moon Photographs with an Off-Axis Reflector, " beginning on page 65.

SKY PUBLISHING CORPORATION
Harvard Observatory
Cambridge 38, Mass.

## Introduction

The Schiefspiegler is a reflecting telescope of high definition for visual and photographic work on the moon, the planets and double stars. By avoiding the additional diffraction effects on the spiders and secondaries or flats of all centric reflectors the original high definition of a long focus mirror is preserved in it.

The fundamental system of the Schiefspiegler is the Cassegrainian, but not in the classical form with a short focus (1:3-1:6) paraboloidal main mirror and the usual 3 or 4 times amplifying ratio by a convex-hyperboloidal secondary, but a device which gets its final ratio of aperture 1:20 by the low primary's focal ratio $1: 12$ and the unusual low amplification ratio A=1.667. This little "optical round about way" preserves the favourable features of the long focus primary and allows the application of spherical curves for primary and secondary until a telescope's aperture of 9 " ( 230 mm ). For telescopes with more than 9" the spherical aberration is eliminated by elliptical correction of the primary ( $56 \%$ of a full parabola; $0.56 \cdot \mathbf{y}_{1}{ }^{2} / \mathbf{r}_{1}$ ) while the secondary keeps its spherical curve in any case.

Besides the ratio of aperture for the primary and the amplifying ratio A there is another parameter, which determines the dimensions of the fundamental system: the distance between the center of the primary and the second focus b (Fig.1). Expressed in fractions of the primary's focal length $\mathbf{f}_{1}$ we find a convenient value for $\mathbf{b}=0.165 \cdot \mathbf{f}_{1}$. All other dimensions will result from the well known cassegrainian formulae in Fig.1.

The numerical values of the radii of curvature of primary and secondary of above mentioned fundamental system are approximately equal, i.e., the condition Petzval is practically accomplished and a flat field of view guaranteed. Of course it is possible to make the r.o.c. of primary and secondary absolutely equal, but the overall length of the telescope will then become a little longer. The ratio of aperture of the primary should not exceed in any case the value 1:12, but a lower value (f.i. 1:13-1:14) simplifies the later correction of the off-axis faults yet results in a considerable lengthening of the system. Above mentioned design has proven optimal. For special 'effects', where a very long focal length is desired (photographic lunar and planetary work) the amplifying ratio A can be enlarged till 2 or 2.5 , but the really flat field of view is then limited to 25-28 minutes of arc.

Above mentioned design is impossible for the classical axial type of the Cassegrain, because the diameter of the secondary and with it the damages of definition become too large.

## The fundamental Cassegrainian system



| Primary: |
| :--- |
| $\mathbf{Y}_{1}$ radius |
| $\mathbf{f}_{1}$ focal length |
| $\mathbf{r}_{1}$ radius of curvature |
|  |
| Secondary: |
| $\mathbf{Y}_{2}$ radius of the light-cone |
| $\mathbf{f}_{2}$ focal length |
| $\mathbf{r}_{2}$ radius of curvature |
| $\mathbf{e} \quad$ separation of mirrors |
| $\mathbf{p} \quad$ residual cone of light |
| $\mathbf{p}$ cutting length |
| $\mathbf{b} \quad$ distance pri vertex to sec-focus |
| $\mathbf{F} \quad$ equivalent system focal length |

Fundamental formulae:

| Amplifying Ratio | $A=\frac{F}{f_{1}}=\frac{p^{\prime}}{p}$ |
| :--- | :--- |
| Residual cone | $p=\frac{f_{1}+b}{A+1}$ |
| Separation of mirrors |  |
| Cutting length | $e^{\prime}=f_{1}-p+b$ |
| R.o.c of the secondary | $r_{2}=\frac{2 \cdot p^{\prime} \cdot p}{p^{\prime}-p}$ |
| Radius of the incoming |  |
| cone on the secondary |  |

Fig. 1 - Scheme of the fundamental Cassegrainian system

## The Schiefspiegler system



Fig. 2 - Scheme of the Schiefspiegler

Additional symbols:
$\varphi_{1} \quad$ inclination of the primary
$\varphi_{2} \quad$ inclination of the secondary
$\varphi_{3} \quad$ inclination of the corrector lens
$\Delta \quad$ the first axis-distance
$\Delta^{\prime} \quad$ the second axis-distance
$\mathbf{Y}_{3}$ radius of the cone of light on the corrector-lens
$Y_{3}{ }^{\prime}$ radius of the corrector-lens
$\mathbf{a}_{1 \mathrm{~m}}$ distance of the corrector lens from the meridional focus
$\mathbf{s}$ distance of the corrector lens from the secondary
$\gamma$ variation-angle
$\boldsymbol{\Gamma}$ angle of the extended field of view toward the eyepiece's focal-plane.

All other symbols are cf. Fig.1

There are three devices to change the above mentioned fundamental
Cassegrainian system into a Schiefspiegler:
l) the anastigmatic,
2) the coma-free,
3) the catadioptrical device.

## Three Schiefspiegler devices

## 1) The anastigmatic device

Formerly called 'The Neo-Brachyt'. (All symbols cf. Fig.2)
The inclination $\varphi_{1}$ of the incoming parallel beam of rays is determined by the condition for freedom of silhouetting.
It must be the 'first ax-distance':

$$
\begin{equation*}
\Delta=y_{1}+y_{2} \tag{1}
\end{equation*}
$$

and:

$$
\begin{equation*}
\sin \left(2 \varphi_{1}\right)=\frac{\Delta}{e} \tag{2}
\end{equation*}
$$

If this excentrical system is to be free from astigmatism the inclination $\boldsymbol{\varphi}_{\mathbf{2}}$ of the secondary must become:

$$
\begin{equation*}
\sin \left(\varphi_{2}\right)=\sin \left(\varphi_{1}\right) \cdot \frac{y_{1}}{y_{2}} \sqrt{\frac{f_{2}}{f_{1}}} \tag{3}
\end{equation*}
$$

When $\mathbf{r}_{\mathbf{1}}$ equals $\mathbf{r}_{\mathbf{2}}$ the formula (3) is simplified to:

$$
\begin{equation*}
\sin \left(\varphi_{2}\right)=\sin \left(\varphi_{1}\right) \cdot \frac{y_{1}}{y_{2}} \tag{3a}
\end{equation*}
$$

With $\boldsymbol{\varphi}_{\mathbf{2}}$ the 'second ax-distance' $\boldsymbol{\Delta}^{\prime}$ (important for the construction of the Schiefspiegler) is determined:

$$
\begin{equation*}
\Delta^{\prime}=e \cdot \sin \left(2 \varphi_{2}\right) \tag{4}
\end{equation*}
$$

The inclination $\boldsymbol{\varphi}_{\mathbf{2}}$ of the secondary eliminates the astigmatism of the oblique beam of rays coming from the primary, but isn't sufficient to abolish thoroughly its coma too. It remains therefore a residual coma:

$$
\begin{equation*}
\beta=3 \cdot y_{1}^{2}\left[\sin \left(\varphi_{1}\right) \cdot\left(\frac{1}{r_{1}}\right)^{2}+\left(\frac{y_{2}}{y_{1}}\right)^{3} \cdot \sin \left(\varphi_{2}\right) \cdot\left(\frac{1}{p}+\frac{1}{r_{2}}\right) \cdot \frac{1}{r_{2}}\right] \tag{5}
\end{equation*}
$$

Note: Calculation with the slide rule will do. $r_{2}$ is to be introduced with negative sign. The value of $\boldsymbol{\beta}$ results in the arcus of the angle. To get the angle $\boldsymbol{\beta}$ in seconds of arc multiply the result with the factor 206265. The accuracy of the result is very high and reaches that of a logarithmictrigonometrical computation ( 7 places) within $\pm 1$ to $2 \%$. For the above mentioned fundamental system (probably refers to a $4.25^{\prime \prime}$ F/27 anastigmat, like the Oscar Knab design) the residual coma results of about + 4.8" (undercorrected). This value changes only slowly in moderate changing the dimensions A, b of our fundamental system, but diminishes and enlarges rapidly by diminishing or enlarging the aperture ratio of the primary.

Since the effective injurious coma is only about $32 \%$ of the calculated theoretical value, i.e. 4.8".0.32 = $\mathbf{1 . 5 4 \prime \prime}$, the anastigmatic device of the Schiefspiegler is capable for instruments up to $2.5 "$ aperture. By slightly diminishing of $\boldsymbol{\varphi}_{\mathbf{2}}$, relatively $\boldsymbol{\Delta}^{\prime}$ (about $15 \%$ ), the anastigmatic device with spherical secondary becomes likewise capable for an aperture of 4". By this step the inclination of the primary $\varphi_{1}$ will be likewise diminished and a
slight silhouetting on the edge of the primary will occur (about $2-3 \%$ of its surface).


Fig. 3 - A 4" anastigmatic system
That edge-silhouetting will, contrary to a central silhouetting, do no harm. Fig. 3 shows a 4" (110 mm) Schiefspiegler of anastigmatic device with spherical primary and secondary. Its definition being magnificent, this reflector is specific for the juniors under the ATM's.

For all reflectors of greater aperture the residual coma must be eliminated by deforming the curve of the spherical secondary, along its meridional diameter (in Fig. 2 the meridional diameter coincides with the paper plane). While the center of the secondary keeps its r.o.c., calculated for the fundamental system (formulae v. Fig.1), shortens the r.o.c. in direction to the upper edge of the secondary continuously until the minimum value:
$r_{2}^{\prime}=r_{1}-0.003921 \cdot r_{2}$
and lengthens the r.o.c. in direction to the lower edge of the secondary until the maximum value:
$r_{2}^{\prime \prime}=r_{2}-0.002597 \cdot r_{2}$

This strong deformation requires special tools and grinding methods, but is a wonderful hobby for old hands. The Schiefspiegler shown in Fig. 4 of 6.5"
( 168 mm ) aperture and 132" ( 3360 mm ) equivalent focal length is of that anastigmatic device. Its definition equals that of a first class apochromatic refractor.


Fig. 4 - $168 / 3360 \mathrm{~mm}$ Schiefspiegler of anastigmatic device Primary is spherical. The spherical secondary is deformed in meridional direction according as described.

## Collimation

The adjustment of the anastigmatic device is very simple, supposed that one of the three adjustment-screws of primary and secondary lies in the meridional plane (i.e. the paper plane of Fig.2) of the system. This screw will be called 'meridional adjustment-screw'. By looking in full daylight through the eyepiece-mounting, closed by a diaphragm with a hole of about l/8", one turns the secondary's adjustment-screws till the full surface of the primary is seen exactly concentrically with the edge of the secondary. Generally the observer sees then the reflected image of the secondary's tubeend somewhere in the reflected image of the primary. Funny to describe these there-and-back-reflections, but easy to discern in practice.

By operating the two adjustment-screws of the primary lying to right and to left of the meridional plane the operator directs the center line of the secondary's tube end image till it is exactly coincidental with the meridional diameter of the secondary. After that the operator turns the meridional adjustment screw of the primary till the image of the secondary's tube end exactly disappears behind the edge of the secondary. Herewith the reflector is pre-adjusted and must give considerable definition on terrestrial objects.

The minute adjustment is done on an artificial star (suns image on a high polished bearing ball or Christmas-tree ball in a distance of minimum 200
focal-lengths) or better on a real star of second or third magnitude, when the seeing is excellent. We operate exclusively with the adjustment-screws of the primary till the extra- and intrafocal star-disks are absolutely circular. The nearer the focus we observe, the better the result will be. The 'how' of turning the adjustment-screws is quickly learned by experience. The difficultties in adjusting doesn't lie in the adjustment itself, but in recognising the actual residuals, that is to say, in the actual seeing.

## 2) The coma-free device

(All symbols cf. Fig.2)
The inclination $\boldsymbol{\varphi}_{\mathbf{1}}$ of the incoming beam of rays is the very same as in the anastigmatic device, defined by the condition for freedom of silhouetting. Therefore we get $\boldsymbol{\varphi}_{1}$ and the first axis-distance $\boldsymbol{\Delta}$, ceteris paribus, equal to those of the anastigmatic device. For elimination of the coma the inclination $\boldsymbol{\varphi}_{\mathbf{2}}$ of the secondary must then be:

$$
\begin{equation*}
\sin \left(\varphi_{2}\right)=\frac{\sin \left(\varphi_{1}\right) \cdot\left(\frac{1}{r_{1}}\right)^{2}}{\left(\frac{y_{2}}{y_{1}}\right)^{3} \cdot\left(\frac{1}{p}+\frac{1}{r_{2}}\right) \cdot\left(\frac{1}{r_{2}}\right)} \tag{6}
\end{equation*}
$$

The second axis-distance $\boldsymbol{\Delta}^{\prime}$, which depends on the inclination $\boldsymbol{\varphi}_{\mathbf{2}}$ of the secondary, becomes again:

$$
\begin{equation*}
\Delta^{\prime}=e \cdot \sin \left(2 \varphi_{2}\right) \tag{4}
\end{equation*}
$$

The exterior of the coma-free device differs from that of the anastigmatic device solely by the longer second axis-distance $\Delta^{\prime}$, respectively by the stronger inclination $\boldsymbol{\varphi}_{\mathbf{2}}$ of the secondary.

This stronger inclination $\boldsymbol{\varphi}_{\mathbf{2}}$ overcorrects the astigmatism of the incoming beam of light end we get therefore a residual astigmatism:

$$
\begin{equation*}
\xi=\sin ^{2}\left(\varphi_{1}\right) \cdot \frac{y_{1}}{f_{1}}+\frac{y_{2}}{y_{1}} \cdot \sin ^{2}\left(\varphi_{2}\right) \cdot \frac{y_{2}}{f_{2}} \tag{7}
\end{equation*}
$$

We get another parameter for this residual astigmatism: a difference between the cutting-lengths of meridional and sagittal rays $\mathbf{p}_{\mathbf{m}}^{\prime}$ and $\mathbf{p}_{\mathrm{s}}^{\prime}$, called 'astigmatical cutting-lengths difference', which will be:

$$
\begin{equation*}
k=\frac{\xi \cdot F_{m}^{2}}{y_{1}} \tag{8}
\end{equation*}
$$

wherein $\mathbf{F}_{\mathbf{m}}$ is the meridional equivalent focal-length of the system, calculated after the well known formula in Fig.1.

To get, the numerical value of astigmatism in seconds of arc, we have to multiply $\xi$ by the factor 206265. Counting with the slide rule is of sufficient accuracy. $\mathbf{f}_{2}$ has to be introduced with negative sign. At above mentioned fundamental system the numerical value of the overcorrected astigmatism results with -30 seconds of arc.

The astigmatical cutting-length-difference k goes together with an astigmatical focus-length-difference $l$, that is a difference between the meridional and sagittal equivalent focal lengths of the system. While the equivalent meridional focal- and cutting-lengths can be computed with aid of the formulae:

$$
\begin{align*}
F_{m} & =\frac{f_{1} \cdot f_{2}}{f_{1}+f_{2}-e}  \tag{9}\\
p_{m}^{\prime} & =\frac{f_{2} \cdot\left(f_{1}-e\right)}{f_{1}+f_{2}-e} \tag{10}
\end{align*}
$$

(note: $\mathbf{f}_{\mathbf{2}}$ is negative) the sagittal values of these dimensions must be computed by aid of the following analytical formulae (accuracy wanted 5 to 6 places).

Sagittal focal length of primary:

$$
\begin{equation*}
f_{1 s}=f_{1}+f_{1} \cdot \sin ^{2}\left(\varphi_{1}\right) \tag{11}
\end{equation*}
$$

Sagittal residual cone:

$$
\begin{equation*}
p_{s}=f_{1 s}-e \tag{12}
\end{equation*}
$$

Sagittal cutting length:

$$
\begin{equation*}
p_{s}^{\prime}=p_{m}^{\prime}-k \tag{13}
\end{equation*}
$$

Sagittal radius of the beam of rays on the secondary:

$$
\begin{equation*}
y_{2 s}=\frac{y_{1} \cdot p_{s}}{f_{1 s}} \tag{14}
\end{equation*}
$$

Convergence of sagittal rays in the second focus:

$$
\begin{equation*}
U_{s}=\frac{y_{2 s}}{p_{s}^{\prime}} \tag{15}
\end{equation*}
$$

Equivalent saggital focal-length of the system:

$$
\begin{equation*}
F_{s}=\frac{y_{1}}{U_{s}} \tag{16}
\end{equation*}
$$

Astigmatical difference of equivalent focal lengths

$$
\begin{equation*}
\ell=F_{m}-F_{s} \tag{17}
\end{equation*}
$$

The astigmatical difference of focal-lengths will especially engage us in designing the catadioptrical designs of the Schiefspiegler, described later. Concerning the coma-free catoptric design, the overcorrected astigmatism, i.e. the difference k between the cutting lengths of meridional and sagittal rays, will be eliminated by a cylindrical deformation of the spherical secondary along its sagittal diameter (in Fig. 2 perpendicularly to the center of the secondary). By this step the path of meridional rays will be shortened to the sagittal focus and the astigmatical cutting-lengths-difference is eliminated herewith. An astigmatical difference between the meridional and sagittal diameters of the cone of light, coming from the primary, existing on the secondary:
$\delta 2 y_{2}=2 y_{2 s}-2 y_{2 m}$

There will theoretically remain in the corrected second focus a very little residual of astigmatic difference of focal-lengths (about $0.2 \%$ ), which cannot be eliminated by this device, but which is really negligible.

The cylindrical deformation of the spherical secondary is a marvellous hobby for experienced hands and is done empirically till the extra- and intrafocal star disks proves to be exactly circular. A minute residual of under- or overcorrected astigmatism, visible as an elliptical shape of the off-focus star disks, can be eliminated by adjusting the inclination $\boldsymbol{\varphi}_{\boldsymbol{1}}$ of the primary.

Promising attempts the author made in cylindrical warping the secondary with help of a specially designed cell. By turning two fine threaded screws, attached to the sagittal borders of the cell, pressure was transmitted by a system of pressure points to the sagittal edges of the secondary. Difficulties only turned up through uncontrollable elastical and thermical reactions of the cell's material.


Fig. 5 - 200/4000 mm Schiefspiegler in coma-free device
Primary is spherical. The spherical secondary is cylindrically deformed. With this instrument all other devices of the Schiefspiegler were tried out; warped secondary and the different dioptrical correctors.
To left in the background (on the clock) a $60 / 1200 \mathrm{~mm}$ Schiefspiegler in anastigmatical device with spherical mirrors.

## Collimation

The adjustment of this type is very simple. After pre-adjusting in full daylight according to the anastigmatic device,the minute adjustment is limited to eliminate the last deviations of the exactly circular look of an off-focus star disk with aid of the primary's three adjustment screws.

## 3) The catadioptrical devices

(All symbols cf. Fig.2)
To avoid the difficulties in cylindrical deforming of the secondary and to gain full corrected focal lengths, a third optical member in form of a lens is introduced. There are two possibilities, the coma-free mirror system being the first of it.

## 3a) Cylinder lens

To eliminate the overcorrected astigmatism (according to the formulae 7 and 8), we introduce between secondary and uncorrected second focus a plano-convex-cylindrical lens (axis of the cylinder in the sagittal diameter of the beam of rays, cylindrical surface towards the secondary) of such power that the path of the meridional rays will be shortened by the astigmatical difference k, while the convergence of the sagittal rays will suffer no change.
To eliminate at the same step the astigmatical difference of focal lengths too (according to the formulae 11 to 17), it is necessary to install the lens in the plane $X$, where the diameters of meridional and sagittal rays of the cone between secondary and focus are equal.

This actual plane lies in a distance $\mathbf{a}_{\mathbf{1 m}}$ from the meridional focus, which is given by (Fig.6):

$$
\begin{equation*}
a_{1 m}=\frac{k \cdot F_{m}}{\ell} \tag{18}
\end{equation*}
$$

In this formula all values are known by the former calculations. With aid of $\mathbf{a}_{\mathbf{1 m}}$ and $\mathbf{k}$ we compute the necessary power and the cylindrical r.o.c. of the lens:

$$
\begin{align*}
& \frac{1}{f_{3}}=\frac{1}{a_{1 m}-k}-\frac{1}{a_{1 m}}  \tag{19}\\
& r_{3}=f_{3} \cdot(n-1) \tag{20}
\end{align*}
$$

The focal length $\mathbf{f}_{3}$ results in each case so long (about $\mathbf{3 5} \cdot \mathbf{f}_{1}$ ) that we don't have to fear any injurious chromatical or spherical aberration. But exactly in this fact the main difficulty of this catadioptrical device consists. The location of the lens resulting near by the secondary, the accuracy of its cylindrical surface must be optimal and just this is the 'black sheep'. Cylindrical surfaces are scarcely to be finished to the same exactness as spherical surfaces and the longer the r.o.c. the more difficult the task.

Deviations from the exact value of the r.o.c. are of less importance; they will solely cause a change in the power of the lens, which will be balanced by comparatively small changes of the distance $\mathbf{a}_{\mathbf{1 m}}$. The condition of focal lengths (18) then being violated, the resulting faults are negligible, even in comparatively large instruments.


Fig. $6-\frac{\text { Scheme of the light cone between secondary and focus, }}{\text { in the coma-free device }(\underline{y} \underline{2 s}>\underline{y} \underline{2 m})}$

It is

$$
y_{3 m}=\frac{y_{2 m}}{p_{m}^{\prime}} \cdot a_{1 m}
$$

and

$$
y_{3 s}=\frac{y_{2 s}}{p_{s}^{\prime}} \cdot\left(a_{1 m}-k\right)
$$

It must be a)

$$
y_{3 m}=y_{3 s}
$$

therefore b)

$$
\frac{y_{2 m}}{p_{m}^{\prime}} \cdot a_{1 m}=\frac{y_{2 s}}{p_{s}^{\prime}} \cdot\left(a_{1 m}-k\right)
$$

Where the convergence Um of the meridional rays in $\mathrm{F}^{\prime} \mathrm{m}$ :

$$
U_{m}=\frac{y_{2 m}}{p_{m}^{\prime}}
$$

and the convergence Us of the saggital rays in $F^{\prime} s:$

$$
U_{s}=\frac{y_{2 s}}{p_{s}^{\prime}}
$$

we get $\mathbf{c}$ )

$$
U_{m} \cdot a_{1 m}=U_{s} \cdot\left(a_{1 m}-k\right)
$$

Since

$$
U_{m}=\frac{y_{1}}{F_{m}}
$$

and

$$
U_{s}=\frac{y_{1}}{F_{s}}
$$

we can write formula d

$$
\frac{y_{1}}{F_{m}} \cdot a_{1 m}=\frac{y_{1}}{F_{s}} \cdot\left(a_{1 m}-k\right)
$$

Formula d) solved for $\mathbf{a}_{1 m}$ will then give our formula (18)

$$
a_{1 m}=\frac{k \cdot F_{m}}{F_{m}-F_{s}}=\frac{k \cdot F_{m}}{\ell}
$$

q.e.d.

In Fig. 6 is shown that, if the corrector is placed in the plane $X,\left(\mathbf{y}_{3 \mathrm{~m}}=\mathbf{y}_{3 \mathrm{~s}}\right)$, the final convergence of the meridional rays $\mathbf{U}_{\mathbf{1 m}}$ equals the final convergance $\mathbf{U}_{\mathrm{s}}$ of the saggital rays, i.e., $\mathbf{F}_{\mathbf{m}}$ and $\mathbf{F}_{\mathrm{s}}$ are equalized and the astigmatical difference of focal lengths is eliminated.

To avoid the unduly long r.o.c. of the plano-convex-cylinder, we can construct the corrector-lens as a meniscus-cylinder of a coma-free shape. Its power $\mathbf{f}_{3}$ and its focal distance $\mathbf{a}_{1 m}$ will be the same. Its two radii of cylindrical curvature will become:

$$
\begin{equation*}
\frac{1}{r_{3 / 4}}=\frac{1}{2 f_{3} \cdot(n-1)} \mp\left[\frac{1}{a_{1 m}}-\frac{1}{2 f_{3}}\right] \cdot \frac{1+2 n}{1+n} \tag{21}
\end{equation*}
$$

The minus sign concerns the r.o.c. $\mathbf{r}_{3}$, the plus-sign the r.o.c. $\mathbf{r}_{4} ; \mathbf{n}$ is the medium refractive index of the lens material. The difference between the two r.o.c. resulting only about $1.8 \%$, the accuracy must be within close limits. The diameter of the corrector (although of the plano-convex-cylinder) will be:

$$
\begin{equation*}
d_{3}=2 y_{3}=\frac{2 y_{2} \cdot a_{1 m}}{p_{m}^{\prime}} \tag{22}
\end{equation*}
$$

that is, supposing our above mentioned fundamental system, about $3 / 4$ of the secondary's diameter (ref. "Two-lens catadioptrical device").

## Collimation

The pre-adjustment of this type of Schiefspiegler is the same as explained for the coma-free device. It is convenient to do this step without the corrector-lens. The minute adjustment will again be done on a real star. The corrector lens is turnable and removable mounted in a sliding tube to adjust the exact position of the cylinder's axis and distance $\mathbf{a}_{1 \mathrm{~m}}$.
Since the exact location, of the meridional focus in the uncorrected second focus of the system is difficult to determine, it is recommended to compute the distance $s$ of the corrector from the center of the secondary:

$$
\begin{equation*}
s=p_{m}^{\prime}-a_{1 m} \tag{23}
\end{equation*}
$$

By looking through the eyepiece the observer removes axially and turns radially the correctors sliding tube till the extra- and intrafocal star disks are equally circular. The very exact adjustment is a matter of little experience but of very good seeing.

## 3b) Spherical lens

The second catadioptrical device, which was designed to avoid the problems concerning the cylindrical surfaces, uses a spherical corrector lens. This device, which theoretically seems to be the most complicated, but proves most simple in realizing, starts from a mirrorsystem, which lies between the comafree and the anastigmatic type.

If we shorten the second axis-distance $\boldsymbol{\Delta}^{\prime}$ computed for the coma-free device multiplying with the factor $\mathbf{t}=0.8$ we get an undercorrected coma $\boldsymbol{\beta}$ about one half of that of the anastigmatic device and an overcorrected astigmatism $\xi$ and $\mathbf{k}$ approximately one half of that of the coma-free device. Both residuals are so brought to values, which can be eliminated at the same step by a simple plano-convex spherical lens, inclined for a certain angle $\varphi_{3}$ along its sagittal diameter. The power of the lens can be chosen freely but a very convenient value will be $\mathbf{f}_{3}=\mathbf{1 8} \cdot \mathbf{f}_{1}$.

Its distance from the meridional focus, $\mathbf{a}_{\mathbf{1 m}}$, must be computed under supposing the new values after the formulae 7 to 17 . For the material of the lens we choose a light Boro Silicate Crown with a medium refraction index of about $\mathbf{n}_{\mathrm{d}}=\mathbf{1 . 5 1 6}$ and a medium dispersion of about $\mathbf{~}_{\mathbf{d}}=\mathbf{6 4}$.

The exact mathematical condition formulae for the inclination $\boldsymbol{\varphi}_{3}$ of the spherical lens are very inconvenient for non mathematicians because they lead to a solution of square equations. But such a computation is really unnecessary, because the exact value of $\varphi_{3}$ can be get by adjusting likewise the exact inclinations $\boldsymbol{\varphi}_{\mathbf{1}}$ and $\boldsymbol{\varphi}_{\mathbf{2}}$ of the mirrors. At the end of this account the formulae will be given. Supposing our above mentioned fundamental system, we will get the inclination $\boldsymbol{\varphi}_{\mathbf{3}}$ of a plano-convex lens with $\mathbf{f}_{3}=\mathbf{1 8} \cdot \mathbf{f}_{1}$, which eliminates the residual coma and the overcorrected astigmatism of our mirror system, about $\mathbf{2 8}^{\circ}$.

This respectively strong inclination is admissible if the two surfaces of the lens are coated to avoid the loss of light owing to reflection (the spherical corrector in the authors 'big one' is not coated and causes little trouble). The theoretical chromatical aberration of the very weak lens has proven negligible and injures neither visual nor photographic work. To avoid comatical spectrum, caused by the inclination of the lens, the lens will not be exactly centered but gets a little wedge of about $1.5-2$ minutes of arc. To eliminate the last residual spectrum colors (over- or undercorrected) the lens will be removed perpendicularly to the secondary's beam of rays up or down. This displacement, got by adjusting, will be in any case very small. An adjusting way of $\pm 2 / 8$ " will be sufficient.

The aperture of the spherical corrector-lens becomes

$$
\begin{equation*}
2 y_{3}^{\prime}=\frac{2 \cdot y_{3}}{\cos \left(\varphi_{3}\right)} \tag{24}
\end{equation*}
$$

wherein $\mathbf{2} \cdot \mathbf{y}_{3}$ is given by the formula (22).

## Collimation

The pre-adjustment is again the same as explained for the coma-free device. The corrector-lens has to be mounted turnable around its sagittal diameter and removable along its meridional diameter. Its center has to be installed in the computed distance $\mathbf{a}_{1 m}$, respectively $\mathbf{s}$. Its flat surface is turned against the incoming beam of rays. The bigger border of the wedge-shaped lens has to be installed in meridional direction against the primary (v. Fig.2).

By observing off-focus-disks of a star the lens will be continously inclined till the strongly elliptical shaped disks gets exactly circular and homogeneously illuminated. If in the beginning of the operation the axis of the elliptical shaped disks doesn't lie exactly parallel to the meridional or sagittal diameters of the mirror's, the pre-adjustment isn't exactly done and cannot be reached by inclination of the lens. First we must eliminate this fault by inclining the primary with aid of its three adjustment-screws.

If the off-focus star-disks look circular but not homogeneously illuminated, there will be a residual coma existent. If a concentration of light is visible in the border of the star disks, which lies (in meridional direction) on the side of the primary, the coma is yet under-corrected and the inclination $\varphi_{3}$ of the corrector must be enlarged. If a concentration of light is conspicuous in the border opposite to the primary, the coma is
overcorrected and $\boldsymbol{\varphi}_{3}$ must be diminished. Since each change of $\boldsymbol{\varphi}_{3}$ changes the astigmatism of the lens too, the shape of the out of focus disk will become slightly elliptical. By operating the meridional adjustment screw of the primary the elliptical shape will be brought back to its circular look. The focal image of the star must then show its ideal look. If in meridional direction a very faint spectrum is visible (at a power of 30 times per inch aperture) the center of the corrector must be removed perpendicularly to the axis of the eyepiece in direction blueish to yellowish. This operation is to be controlled at a star with little zenith-distance, to avoid atmospherical spectrum. It is although recommended, to use for this trial exclusively achromatical eyepieces. Worthless to say again, that a little experience and a very good seeing is all.

## 3c) Two-lens catadioptrical device

There must be mentioned a third possibility for a cylindrical corrector near the equivalent focus (as a variant of 3a).


Fig. 8 - Two lens corrector
To correct the astigmatical cutting-length-difference k and the astigmatical focal length difference $l_{\text {, }}$ this type of corrector must be a system of two airspaced cylindrical lenses of short and nearly equal r.o.c. The first, a plano-concave cylinder equals the radii $\mathbf{y}_{3 \mathrm{~m}}$ and $\mathbf{y}_{3 \mathrm{~s}}$ of the distorted cone of light in the plane X (Fig.8) and the second, a plano-convex-cylinder, located in the plane $X$, will bring the sagittal rays into the meridional focus. Each of the two lenses must be adjustable.

If the two lenses are made of the same material (a light Boro-SilicateCrown) a negligible amount of chromatical aberration will result. To avoid all chromatical residuals, the two components of the corrector can be constructed as an achromatical system. Both lenses are to be coated. This device of a corrector being more complicated the author doesn't recommend it for ATM's. If wanted, the computation formulae are disposable.


Fig.8a - Near-focus corrector
Corrector lens of a 200 mm Coma-free system, which can be adjusted axially and rotationally throu a hatch in the tube.
(ref. Fig. 26 "Der Schiefspiegler", A.Kutter)

## Conclusion

Not to discourage ATM's, which are not fond of mathematics but only as a control for computists the three conditions for this simplest device of medium and big sized Schiefspiegler are given in the following.

## 1) condition of focal lengths

$$
a_{1 m}=\frac{k \cdot F_{m}}{\ell}
$$

Gives the location where meridional and sagittal beam diameters are equal, measured frm the meridional focus. This is also the location of the corrector lens.

## 2) condition of coma

$$
\beta=3 \cdot y_{1}^{2}\left[\begin{array}{l}
\left\{\left(\frac{y_{2}}{y_{1}}\right)^{3} \cdot \sin \left(\varphi_{2}\right) \cdot\left(\frac{1}{p}+\frac{1}{r_{2}}\right) \cdot \frac{1}{r_{2}}\right\}+ \\
\left\{\left(\frac{y_{3}}{y_{1} \cdot \cos \left(\varphi_{3}\right)}\right)^{2} \cdot \sin \left(\varphi_{3}\right) \cdot \frac{1}{2 f_{3}}\left[\left(\frac{1}{a_{1 m}}-\frac{1}{2 f_{3}}\right) \cdot\left(\frac{1}{n}+2\right)+\frac{1}{2 r_{3}} \cdot\left(\frac{1}{n}+1\right)\right]\right\}
\end{array}\right]
$$

Where the three terms represent coma contributions of primary mirror, secondary mirror and corrector lens.

## 3) condition of astigmatism

$$
\xi=\sin ^{2}\left(\varphi_{1}\right) \cdot \frac{y_{1}}{f_{1}}+\frac{y_{2}}{y_{1}} \cdot \sin ^{2}\left(\varphi_{2}\right) \cdot \frac{y_{2}}{f_{2}}+\frac{y_{3}}{y_{1} \cdot \cos \left(\varphi_{3}\right)} \cdot \sin ^{2}\left(\varphi_{3}\right) \cdot \frac{y_{3}}{f_{3} \cdot \cos \left(\varphi_{3}\right)}
$$

Again, the three terms represent the contributions of the optimal elements.

Finally two peculiarities of the Schiefspiegler have to be mentioned. -1- The axis of the incoming beam of light being not parallel to the axis of the beam, reflected from the secondary, a finder is necessary, which must be inclined against the incoming beam of rays under the variation angle:

$$
\begin{equation*}
\gamma=2 \varphi_{2}-2 \varphi_{1} \tag{25}
\end{equation*}
$$

-2- The extended field of view doesn't lie perpendicularly to the axis of the eyepiece, but is inclined under a certain angle $\boldsymbol{\Gamma}$ against it. This effect is common to all off-axis telescopes. For visual observation this peculiarity will do less harm, because the accommodation of the human eye equals the caused differences in focusing. For photographic work the plateholder will be
inclined under the angle $\boldsymbol{\Gamma}$, which can be determined empirically or by a simple computation:

$$
\begin{align*}
& \delta=\varphi_{1}-\varphi_{2}  \tag{25}\\
& \sin (\vartheta)=\frac{\sin \left(\varphi_{1}\right) \cdot e}{r_{2}}  \tag{26}\\
& \imath=\delta-\vartheta  \tag{27}\\
& \Gamma=\gamma-\imath \tag{28}
\end{align*}
$$

Since the inclination $\boldsymbol{\Gamma}$ of the extended field of view depends on the inclination $\varphi_{2}$ of the secondary, it will result lowest in the anastigmatic device and largest in all coma-free devices. In the last explained device with a spherical corrector lens it reaches nearly its minimum value.

Generally can be stated: by the adjustable inclinations of the mirrors an the corrector even considerable amounts of deviation from the theoretical parameters of the Schiefspiegler can be fairly eliminated and the system been brought to full definition.

The author tried out in a twentyfive years labour, to give the astronomical mirror its theoretical definition with means accessible for an ATM. It has proved in hundreds of nights of visual and photographic observation with Schiefspiegler of the different devices and sizes from two to twelve inches aperture that this is possible.
The lunar photographs, taken with the authors optical not yet finished 'big one', a 12 -inch constructed after the device described last, may show it. These results were gained under unfavourable climatic circumstances (the authors observatory being on the house roof inmidst a 20,000 -population town under $48^{\circ}$ northern latitude) and with an unfinished primary, which suffers from a turned down edge and zonal defects, so that its aperture must be stopped down to 10". With an equally sized Schiefspiegler, the mirrors of which are accurate to $1 / 8$ wave-length, the results can be considerably surpassed.

## Recommended reading

These references are taken from the online version on ATM Site

## Books

```
Der Schiefspiegler. Ein Spiegelteleskop fuer hohe Bilddefinition
    Kutter, Anton
    Biberach a.d. Riss
    Buchhandlung Fritz Wichhardt, 1953
Bauanleitung für den Kosmos-schiefspiegler : system Kutter DBPa DBGMa
    Kutter, Anton
    Stuttgart
    Franckh'sche Verlagshandlung Kosmos-Lehrmittel, c1964, 1967
```


## Sky and Telescope Articles

## Letter,

Anton Kutter; Sky \& Telescope; Oct 1958; 654
Anton Kutter's catadioptric telescope,
Sky \& Telescope; Dec 1958; 61
Testing Long-Focus Convex Spherical Secondary Mirrors, Anton Kutter; Sky \& Telescope; Apr 1959; 348
An Improved 4 1/4-inch Unobstructed Oblique Reflector, Oscar R Knab; Sky \& Telescope; Oct 1961; 232
A Wall-Mounted Schiefspiegler for Lunar and Planetary Work, Oscar R Knab; Sky \& Telescope; May 1963; 292
A New Three-Mirror Off-Axis Amateur Telescope, Richard A Buchroeder; Sky \& Telescope; Dec 1969; 418
A New Three-Mirror Unobstructed Reflector, Anton Kutter; Sky \& Telescope; Jan 1975; 46
Making the Kutter Tertiary, Oscar R Knab; Sky \& Telescope; Jan 1975; 48;

## More About the Tri-Schiefspiegler,

 Anton Kutter; Sky \& Telescope; Feb 1975; 115Mounting a 6-inch Tri-Schiefspiegler,
Harold M Benson; Sky \& Telescope; Sep 1979; 270
Optical Innovator Dies - Kutter, Anton, R.W. Sinnott; Sky \& Telescope, May 1985; 461

A New Concept for Tilted-Component Telescopes, Erwin Herrig; Sky \& Telescope; Nov 1997; 113
Box: A Breakthrough in the Design of Unobstructed Telescopes, Jose M Sasian; Sky \& Telescope; Nov 1997; 114
New Twist on Tilted-Mirror Telescopes, John Francis; Sky \& Telescope; Jul 1999; 128

## Other Magazines

## Der Schiefspiegler,

Kutter, A., Sterne und Weltraum, 1/1965, 12

## Links

```
Sky and Telescope website: http://www.skyandtelescope.com
Brief Kutter biography,
    http://www.seds.org/~ spider/scopes/kutter.html
Brief Scheifspiegler history
    http://www.seds.org/~spider/scopes/schiefh.html
Der Vater des Schiefspieglers
    http://www.astronomie.de/bibliothek/artikel/geschichte/kutter/index.htm
A very nice 200mm scheifspiegler by Philip Doutreligne
    http://users.telenet.be/philipdo/kutter.htm
A 250mm improved schiefspiegler using a double meniscus lens corrector, by
Georg Dittié
    http://www.videoastronomy.org/schiefspiegler/kutter_en.htm
Oscar Knab's 3 inch and 4.25 inch schiefspieglers
    http://telescopemaking.org/schief.html
Two 4.25 inch schiefspiegler designs, one by Knab and one by Dave Groski.
A picture of Dave's schief at Stellafane 2005.
A Schiefspiegler toolkit by Arjan te Marvelde.
Walks through the design process for a Kutter schiefspiegler.
Download the Excel spreadsheet for the toolkit.
Two pictures of Bill Cheng's 4.25 inch schief at Stellefane 2004. \underline{1 2}
```

