Optical Systems of Schwartschild Telescope for CTA

Memo
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1 Introduction

This memo provides the initial definition of two optical systems (OSs) of Schwartschild-Couder-type (SC) telescopes proposed by the CTA-US collaboration for detailed simulation studies of the performance of the CTA observatory. Both OSs are derived from the exact Schwartschild aplanatic solution [1] characterized by $q = \frac{2}{3}$ and $\alpha = \frac{2}{3}$, for which primary and secondary mirrors are separated by the distance equal to the 3/2 of the OS focal length and the distance between the secondary and the focal plane is equal to 1/3 of the OS focal length. It has been previously shown through extensive simulations of SC telescope optical system performance that this aplanatic solution is close to the optimal for applications in ground-based γ-ray astronomy [2, 3]. The overall layout of the OSs is shown in Fig 1.

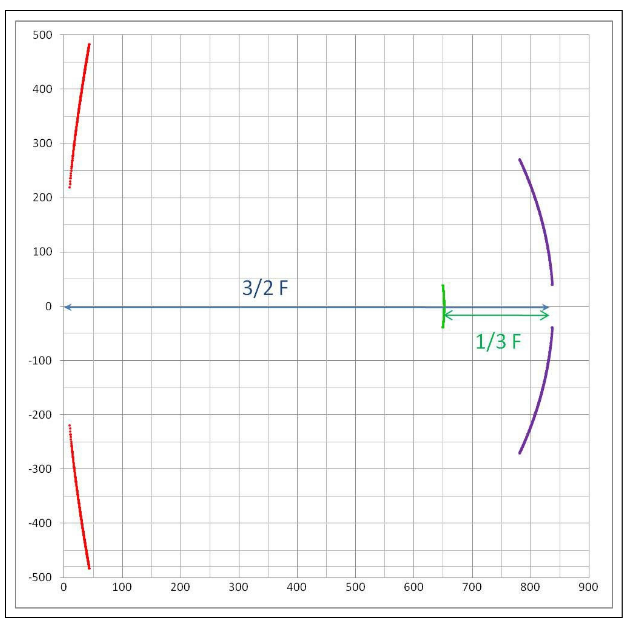

Figure 1: Optical system of the Schwartschild aplanatic (2/3, 2/3) solution.

Parameter \ OS Name	OS8	OS10
Focal Length [m]	5.5863	4.4691
Aperture [m]	9.66	7.73
f/# [1]	$f/0.5781$	$f/0.5781$
Primary Radius max [m]	4.8319	3.8655
Primary Radius min [m]	2.1933	1.7574
Secondary Radius max [m]	2.7083	2.2614
Secondary Radius min [m]	0.3945	0.2076
Effective light collecting area /unvignetted [m^2]	50.33	30.85
Unvignetted Size [deg]	3.50	5.00
Effective light collecting area at FoV edge [m^2]	47.73	29.24
Vignetting at the FoV edge [%]	-5.17	-5.19
Primary projected area [m^2]	58.23	37.24
Secondary projected area [m^2]	22.55	15.93
Design FoV [deg]	8.00	10.00
Design FoV solid angle [deg^2]	50.35	78.67
PSF at the FoV edge (2MAX{RMS}) [arcmin]	3.81	5.65

Table 1: Definition of OSs.

Table 1 summarizes the main parameters of the two OSs denoted as OS8 and OS10. The first, OS8, is tailored to provide 8 degrees field of view (FoV) and an effective light collecting area of 50 m^2. The second, OS10, was optimized to achieve 10 degrees FoV and light collecting area of 30 m^2.

2 Primary Mirror Definition

The primary mirror figure is defined parametrically

$$\frac{1}{F} x_p(\theta,\phi) = \sin\theta\cos\phi$$

$$\frac{1}{F} y_p(\theta,\phi) = \sin\theta\sin\phi$$

$$\frac{1}{F} z_p(\theta) = Z(\theta)$$

as a function of two arguments (θ,ϕ) and the OS focal length F. The sag function $Z(\theta)$ is given by

$$Z(\theta) = \frac{\sin^2\theta}{1944}\frac{(530 + 783\cos\theta + 342\cos 2\theta + 73\cos 3\theta)}{(1+\cos\theta)^3}$$

The azimuthal angle ϕ changes from 0 to 2π, while θ is limited in the range $\theta p_{\min} < \theta < \theta p_{\max}$ with boundary values shown in Table 2 for both OSs.

	OS8	OS10
$\theta p_{\min}$ [deg]	23.12	23.16
$\theta p_{\max}$ [deg]	59.88	59.88
$\theta s_{\min}$ [deg]	12.05	7.98
$\theta s_{\max}$ [deg]	64.51	66.34

Table 2: Definition of the Primary and Secondary mirrors.

3 Secondary Mirror Definition

The secondary mirror figure is defined parametrically

$$\frac{1}{F}x_s(\theta,\phi) = R(\theta)\sin\theta\cos\phi$$
$$\frac{1}{F}y_s(\theta,\phi) = R(\theta)\sin\theta\sin\phi$$
$$\frac{1}{F}z_s(\theta) = \left(R(\theta)\cos\theta - \frac{1}{3}\right)$$

as a function of two arguments (θ,ϕ). The $R(\theta)$ function, which is the local curvature of the secondary, is given by

$$R(\theta) = 96\frac{(2+\cos\theta)^2}{(890+1191\cos\theta+438\cos 2\theta+73\cos 3\theta)}.$$

The azimuthal angle ϕ changes from 0 to 2π, while θ is limited in the range $\theta s_{\min} < \theta < \theta s_{\max}$ with boundary values shown in Table 2 for both OSs.

4 Camera and Focal Plane Definition

The camera for both OSs is identical and is shown in Fig 2. It consists of 177 MAPMTs with 8×8 pixels, such as Hamamatsu H8500-103 MOD8, or an equivalent assembly of SiPMs with a pixel size of 6.5 mm. Each MAPMT is identified by the pair of indexes $(i=-7,7; j=-7,7)$ as shown in Fig 2 and the coordinates of the MAPMT center are given by

$$x_{ij} = 52\text{ mm } \times i,$$
$$y_{ij} = 52\text{ mm } \times j,$$

$$z_{ij} = \kappa_1\left[\left(\frac{i}{7}\right)^2+\left(\frac{j}{7}\right)^2\right]+\kappa_2\left[\left(\frac{i}{7}\right)^2+\left(\frac{j}{7}\right)^2\right]^2.$$

A small sag, z_{ij}, of MAPMT towards the primary mirror is introduced to minimize astigmatism and improve optical performance. The sag is defined by two constants κ_1 and κ_2.

Basic parameters of the camera in each OS are summarized in Table 3.

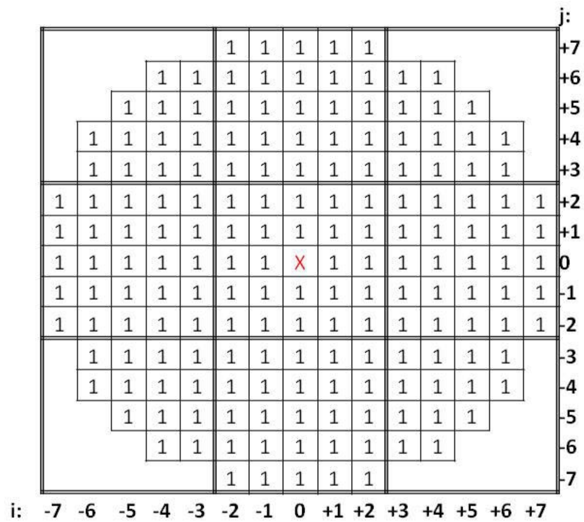

Figure 2: Layout of the camera for Schwartschild telescopes.

5 Performance

The effective collecting area as a function of field angle is shown in Figure 3. The point spread function characteristic $PSF = 2 \times MAX \{\sigma_x, \sigma_y\}$ as a function of field angle is shown in Figure 4.

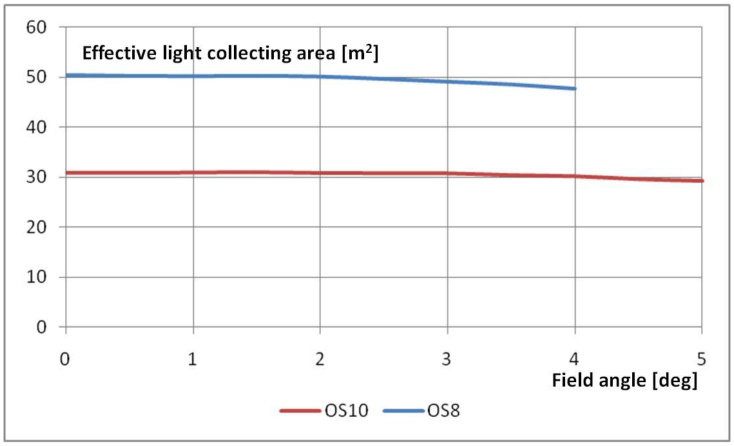

Figure 3: Effective light collecting area for OS8 (blue) and OS10 (brown) as a function of field angle.

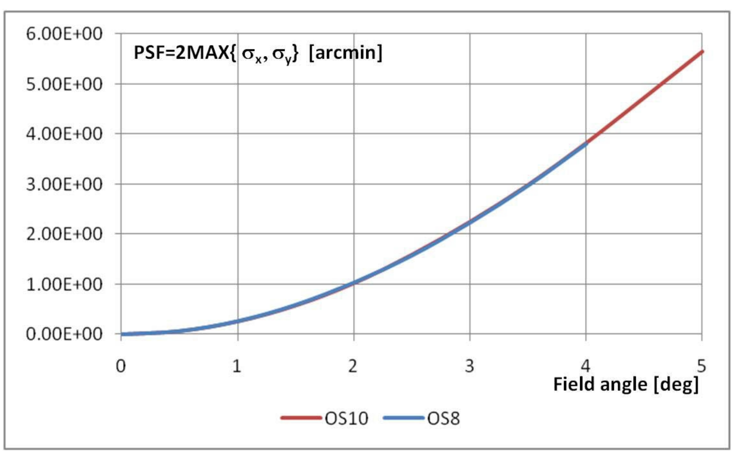

Figure 4: PSF for OS8 (blue) and OS10 (brown) as a function of field angle.

Camera Parameter \ OS Name	**OS8**	**OS10**
Number of H8500 MAPMTs [1]	177	177
Total number of pixels [1]	11328	11328
FoV diameter [deg]	8.00	10.00
MAPMT size [mm]	52.00	52.00
MAPMT angular size [deg]	0.53	0.67
Pixel angular size [deg]	0.06667	0.08333
Pixel angular size [arcmin]	4.00	5.00
FoV solid angle [deg^2]	50.35	78.67
Camera diameter [m]	0.78	0.78
Camera mechanical dimension [m]	1.00	1.00
Focal Plane sag at the FoV edge [mm]	-22.00	-27.01
Characteristic incident angle [deg]	51.25	51.25
MAPMT sag constant, κ_1 [mm]	-19.75	-25.26
MAPMT sag constant, κ_2 [mm]	0.503	1.507
PSF at the FoV edge (2MAX{RMS}) [arcmin]	3.81	5.65

Table 3: Definition of the camera.

References

[1] K. Schwartschild Undersuchungen zur geometrischen Optik II. *Astronomische Mitteilungen der Universitaets-Sternwarte zu Goettingen*, 10:1–+, 1905.

[2] V. Vassiliev, S. Fegan, and P. Brousseau Wide field aplanatic two-mirror telescope for ground-based γ-ray astronomy *Astroparticle Physics*, 28:10-27, September 2007, arXiv:astro-ph/0612718.

[3] V. V. Vassiliev and S. J. Fegan Schwartschild-Couder two-mirror telescope for ground-based γ-ray astronomy In Proc. 30th International Cosmic Ray Conference, Merida, Mexico Volume 708, July 2007, arXiv:0708.2741v1.