Some Reflective Systems

Introduction to aberrations

OPTI 518

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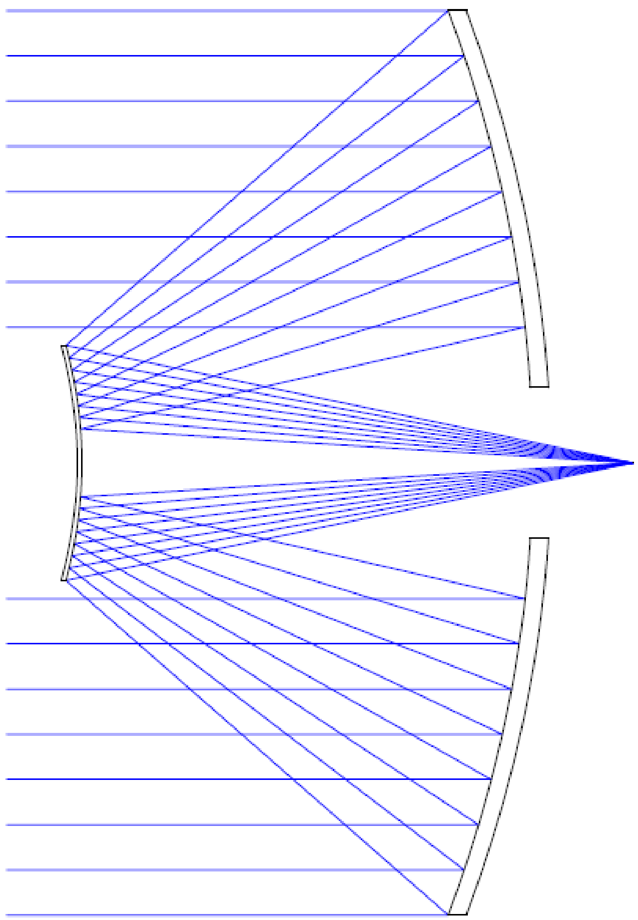
Cassegrain type



- True Cassegrain
- Ritchey-Chretien: aplanatic
- Dall-Kirkham: spherical secondary
- Pressman-Camichel; spherical primary
- Olivier Guyon (no diffraction rings)

Structural coefficients

Seidel sums in terms of structural aberration coefficients
Pupils located at principal planes
$S_I = \frac{1}{4} y_P^4 \Phi^3 \sigma_I$
$S_{II} = \frac{1}{2} Ж y_P^2 \Phi^2 \sigma_{II}$
$S_{III} = Ж^2 \Phi \sigma_{III}$
$S_{IV} = Ж^2 \Phi \sigma_{IV}$
$S_V = \frac{2Ж^3 \sigma_V}{y_P^2}$
$C_L = y_P^2 \Phi \sigma_L$
$C_T = 2Ж \sigma_T$

Stop-shift from principal planes
$\sigma_I^* = \sigma_I$
$\sigma_{II}^* = \sigma_{II} + \bar{S}_\sigma \sigma_I$
$\sigma_{III}^* = \sigma_{III} + 2\bar{S}_\sigma \sigma_{II} + \bar{S}_\sigma^2 \sigma_I$
$\sigma_{IV}^* = \sigma_{IV}$
$\sigma_V^* = \sigma_V + \bar{S}_\sigma (\sigma_{IV} + 3\sigma_{III}) + 3\bar{S}_\sigma^2 \sigma_{II} + \bar{S}_\sigma^3 \sigma_I$
$\sigma_L^* = \sigma_L$
$\sigma_T^* = \sigma_T + \bar{S}_\sigma \sigma_L$
$\bar{S}_\sigma = \frac{y_P \bar{y}_P \Phi}{2Ж}$
$\Delta\bar{S}_\sigma = \frac{y_P \Delta\bar{y}_P \Phi}{2Ж} = \frac{y_P^2 \Phi}{2Ж} \bar{S}$

Structural aberration coefficients of a reflecting surface in air			
Stop at surface		With stop shift	
$\sigma_I = Y^2 + \alpha$		$\sigma_I = Y^2 + \alpha$	
$\sigma_{II} = -Y$		$\sigma_{II} = -Y\left(1-\bar{S}_\sigma Y\right) + \bar{S}_\sigma \cdot \alpha$	
$\sigma_{III} = 1$		$\sigma_{III} = \left(1-\bar{S}_\sigma Y\right)^2 + \bar{S}_\sigma^2 \cdot \alpha$	
$\sigma_{IV} = -1$		$\sigma_{IV} = -1$	
$\sigma_V = 0$		$\sigma_V = \bar{S}_\sigma \cdot \left(1-\bar{S}_\sigma Y\right) \cdot \left(2-\bar{S}_\sigma Y\right) + \bar{S}_\sigma^3 \cdot \alpha$	

$$\alpha = K = -\varepsilon^2$$

Aspheric mirrors

CONIC

$$\frac{1}{4} y_P^4 \phi^3 \alpha = K y^4 c^3 \Delta(n) = \frac{K y^4 \phi_s^3}{[\Delta(n)]^2}$$

$$\alpha = \frac{4K (y/y_P)^4 (\phi_s/\phi)^3}{[\Delta(n)]^2} \qquad K = \frac{[\Delta(n)]^2 \alpha}{4 (y/y_P)^4 (\phi_s/\phi)^3}$$

GENERAL

$$\frac{1}{4} y_P^4 \phi^3 \alpha = 8 a_4 y^4 \Delta(n)$$

$$\alpha = \frac{32 a_4 (y/y_P)^4 \Delta(n)}{\phi^3} \qquad a_4 = \frac{\phi^3 \alpha}{32 (y/y_P)^4 \Delta(n)}$$

Cassegrain type objective

$$\phi = 1 \qquad y_P = 1 \qquad \mathcal{K} = 1$$

$$\phi_1/\phi = M \qquad \phi_2/\phi = (1-M)(1+ML)$$

$$y_1/y_P = 1 \qquad y_2/y_P = \frac{1}{1+ML}$$

$$S_1 = 0 \qquad S_2 = \frac{1}{2}\,\frac{(1-M)L}{1+ML}$$

$$Y_1 = 1 \qquad Y_2 = \frac{1+M}{1-M}$$

$$L = \frac{\bar{y}_B}{y_B} \qquad M = \frac{1-y_B}{\bar{y}_B}$$

COMPONENT ABERRATIONS

$$\sigma_{I} = Y^2 + \alpha$$

$$\sigma_{II} = -Y$$

$$\sigma_{III} = 1$$

$$\sigma_{IV} = -1$$

$$\sigma_{V} = 0$$

$$Y_1 = 1 \qquad Y_2 = \frac{1+M}{1-M}$$

$$K = \frac{(1-M)^3}{1+ML}$$

Cassegrain type objective

SYSTEM ABERRATIONS

$$\sigma_I = M^3(1+\alpha_1) \quad + K\left[\left(\frac{1+M}{1-M}\right)^2 + \alpha_2\right]$$

$$\sigma_{II} = -1 \quad + \left(\frac{L}{2}\right) K\left[\left(\frac{1+M}{1-M}\right)^2 + \alpha_2\right]$$

$$\sigma_{III} = 1-(1-M)L \quad + \left(\frac{L}{2}\right)^2 K\left[\left(\frac{1+M}{1-M}\right)^2 + \alpha_2\right]$$

$$\sigma_{IV} = -1 - M(1-M)L$$

$$\sigma_V = 2\left(\frac{L}{2}\right)(1-M) - \left(\frac{L}{2}\right)^2(1-M)(3-M) \quad + \left(\frac{L}{2}\right)^3 K\left[\left(\frac{1+M}{1-M}\right)^2 + \alpha_2\right]$$

Cassegrain type objective

SPHERICAL CORRECTION (CASSEGRAIN, GREGORIAN)

$\sigma_{I} = 0$

$\sigma_{II} = -1$

$\sigma_{III} = 1 - (1-M)L$

$\sigma_{IV} = -1 - M(1-M)L$

$\sigma_{V} = (1-M)L - (3-M)(1-M)\left(\frac{L}{2}\right)^2$

$\alpha_1 = -1 \qquad \alpha_2 = -\left(\frac{1+M}{1-M}\right)^2$

$K\left[\left(\frac{1+M}{1-M}\right)^2 + \alpha_2\right] = 0$

Cassegrain type objective

APLANATIC CORRECTION (RITCHEY - CHRÉTIEN)

$$\sigma_{I} = 0$$

$$\sigma_{II} = 0$$

$$\sigma_{III} = 1 - \left(\frac{1}{2} - M \right) L$$

$$\sigma_{IV} = -1 - M(1-M)L$$

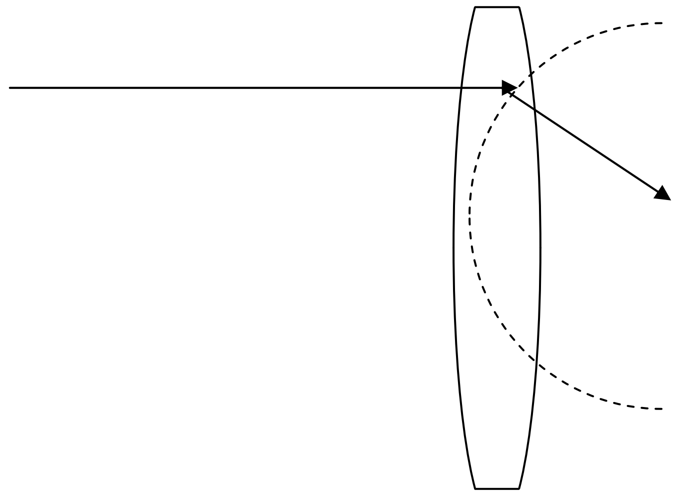
$$\sigma_{V} = (1-M)L - \left[(3-M)(1-M) - 1 \right] \left(\frac{L}{2} \right)^2$$

$$K \left[\left(\frac{1+M}{1-M} \right)^2 + \kappa_2 \right] = \frac{2}{L}$$

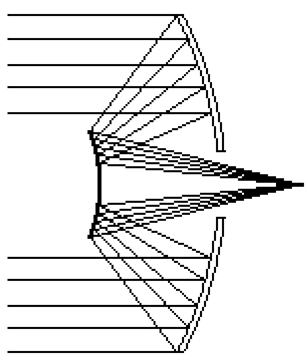
$$\kappa_1 = -1 - \frac{2}{LM^3}$$

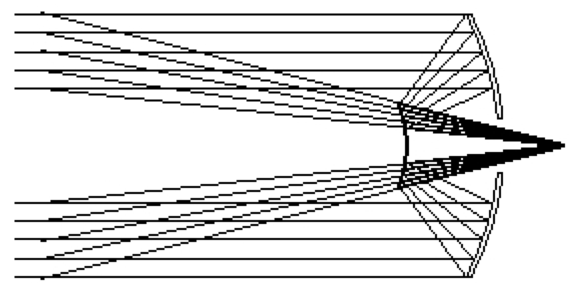
$$\kappa_2 = -\left(\frac{1+M}{1-M} \right)^2 + \frac{2(1+ML)}{L(1-M)^3}$$

Principal surface

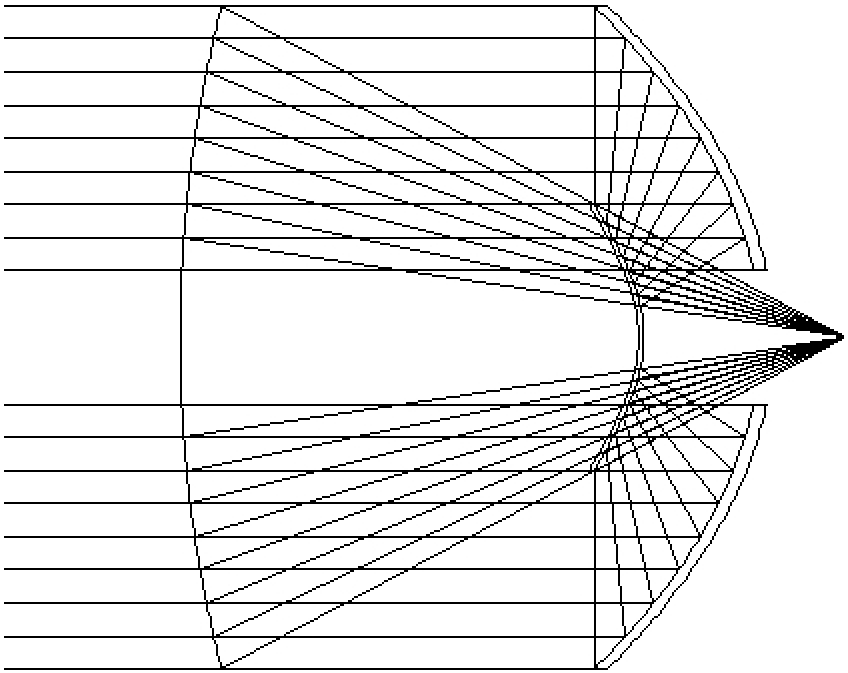


In an aplanat working at m=0
the equivalent
refracting surface
is a hemisphere





Cassegrain's principal surface



Since the equivalent refracting surface in a Cassegrain telescope is a paraboloid then the coma of that Cassegrain is the same of a paraboloid mirror with the same focal length.

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Cassegrain type objective

Dall-Kirkham: Spherical secondary, elliptical primary

Pressman-Camichel: Spherical primary, spheroid secondary

Consider Gregorian possible choices.

Two mirror afocal system

Application to a two mirror Mersenne system

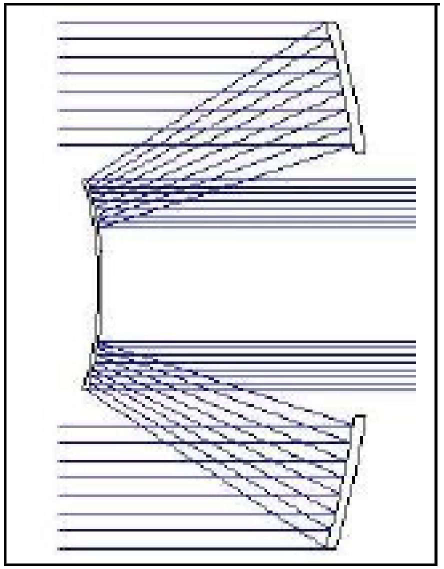
In this section we determine the aberration coefficients of a two mirror afocal system as shown in the figure We normalize the system parameters and set $Ж = 1$, $\Phi_1 = 1$, $y_1 = 1$, $\bar{y}_1 = 0$ and set the magnification to be m and therefore $y_2 = m$. We have that $\bar{y}_2 = 1 - m$, $\Phi_2 = -1/m$ and therefore we can write for the conjugate factors and stop shifting parameters,

$$Y_1 = 1$$

$$Y_2 = -1$$

$$\bar{S}_1 = 0$$

$$\bar{S}_2 = \frac{y_2 \bar{y}_2 \Phi_2}{2Ж} = \frac{m-1}{2}.$$



Two mirror afocal system

Using the formulas in the table the structural coefficients of each mirror are calculated as:

Structural aberration coefficients		
	Mirror 1	Mirror 2
σ_I	$1+\alpha_1$	$1+\alpha_2$
σ_{II}	-1	$\frac{m+1}{2}+\frac{m-1}{2}\alpha_2$
σ_{III}	1	$\left(\frac{m+1}{2}\right)^2+\left(\frac{m-1}{2}\right)^2\alpha_2$
σ_{IV}	-1	-1
σ_V	0	$\frac{m-1}{2}\frac{m+1}{2}\frac{m+3}{2}+\left(\frac{m-1}{2}\right)^3\alpha_2$

Finally the Seidel sums for the two mirror afocal system are given by:

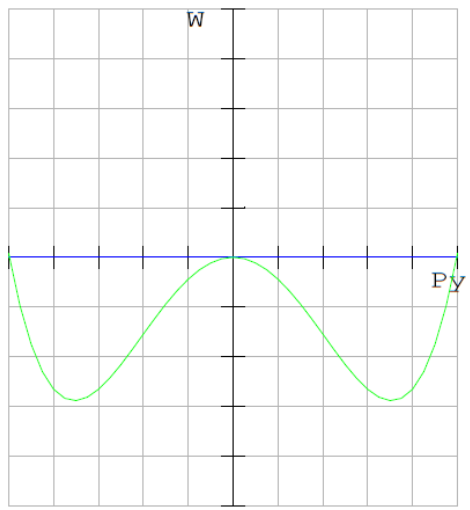
Seidel sums for two mirror afocal system
$S_I = \frac{1}{4}\sigma_{I1} + \frac{1}{4}m^4\left(-\frac{1}{m}\right)^3 \sigma_{I2} = \frac{1}{4}\left((1+\alpha_1) - m(1+\alpha_2)\right)$
$S_{II} = \frac{1}{2}\sigma_{II1} + \frac{1}{2}m^2\left(-\frac{1}{m}\right)^2 \sigma_{II2} = \frac{1}{4}(m-1)(1+\alpha_2)$
$S_{III} = \sigma_{III1} + \left(-\frac{1}{m}\right)\sigma_{III2} = -\frac{1}{4}\frac{(m-1)^2}{m}(1+\alpha_2)$
$S_{IV} = \sigma_{IV1} + \left(-\frac{1}{m}\right)\sigma_{IV2} = -\frac{m-1}{m}$
$S_V = 2\sigma_{V1} + 2\left(\frac{1}{m}\right)^2 \sigma_{V2} = \frac{1}{4}\frac{m-1}{m^2}\left(8 + 6(m-1) + (m-1)^2(1+\alpha_2)\right)$

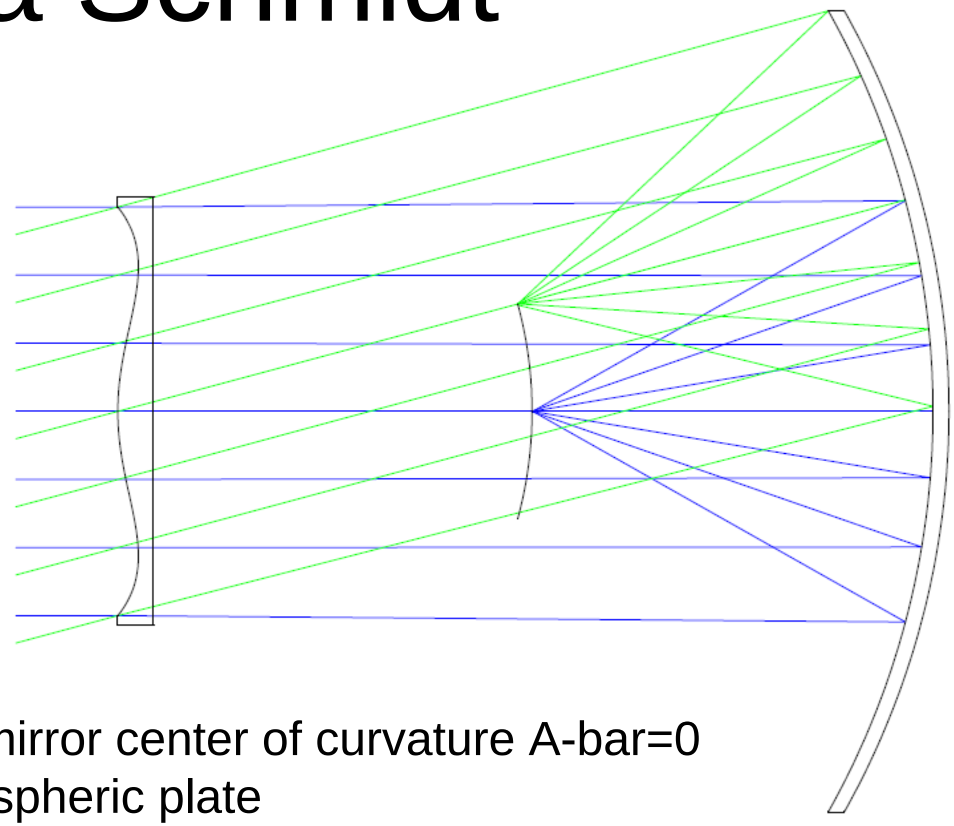
For the particular case of having the mirror as parabolic in optical shape we have that the Seidel sums simplify as:

Seidel sums for afocal system using parabolas
$S_I = 0$
$S_{II} = 0$
$S_{III} = 0$
$S_{IV} = -\frac{m-1}{m}$
$S_V = \frac{1}{2}\frac{m-1}{m^2}(3m+1)$

When a system is free from spherical aberration, coma, and astigmatism it is called an anastigmatic system.

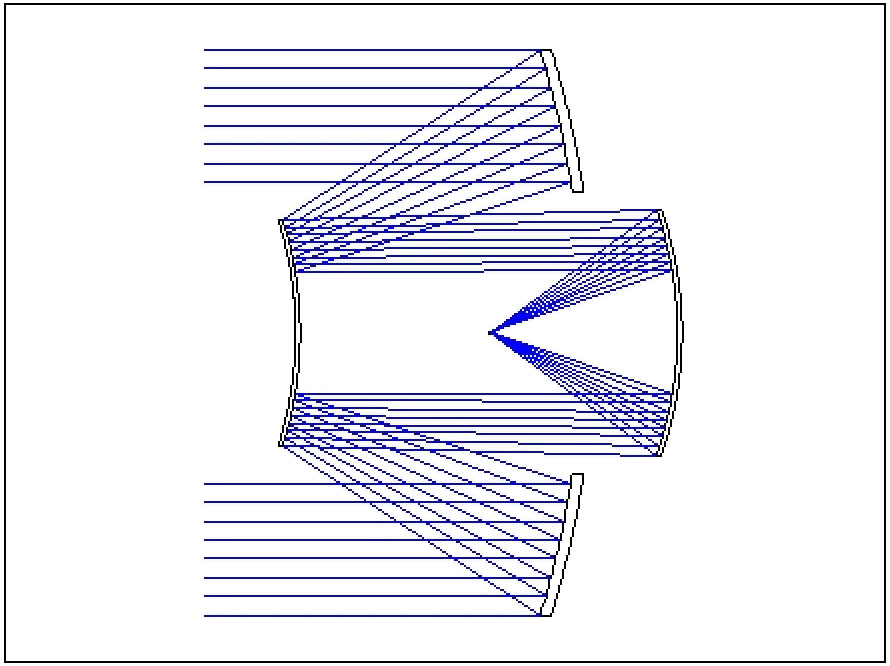
Camera Schmidt

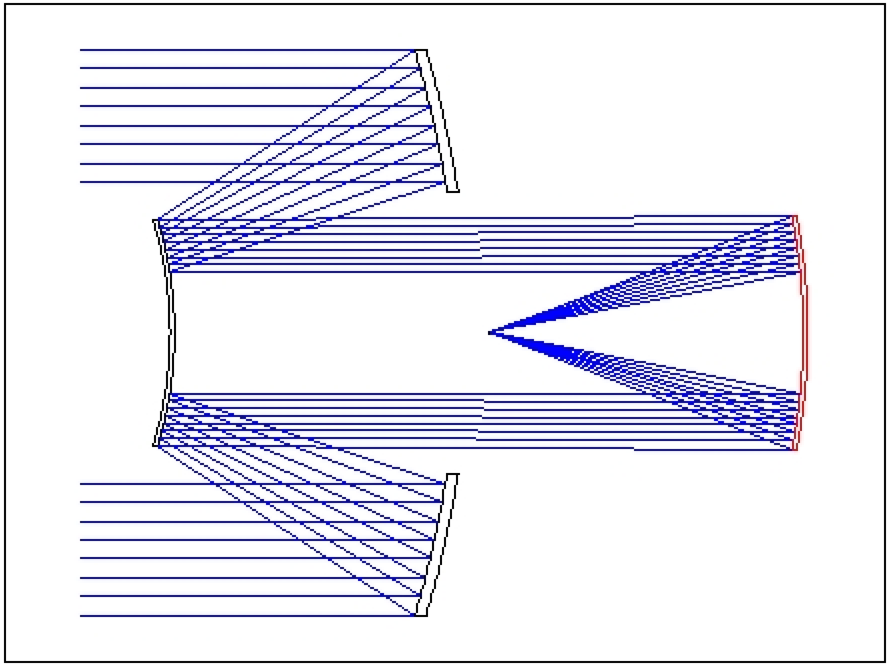




Aspheric plate at mirror center of curvature A-bar=0
Stop aperture at aspheric plate
Note symmetry about mirror CC
No spherical aberration
No coma
No astigmatism.
Anastigmatic over a wide field of view!
Satisfies Conrady's D-d sum
Note long radius on plate

Paul-Baker system
Anastigmatic-Flat field

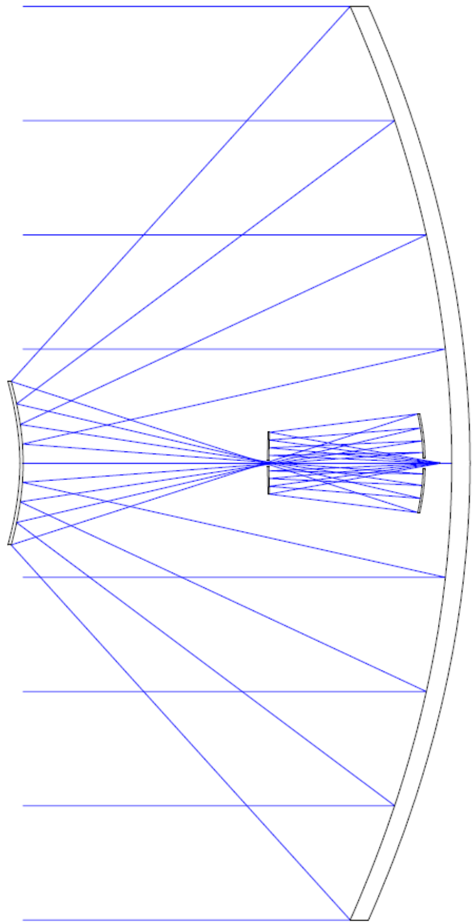




Anastigmatic
Parabolic primary
Spherical secondary and tertiary
Curved field
Tertiary CC at secondary

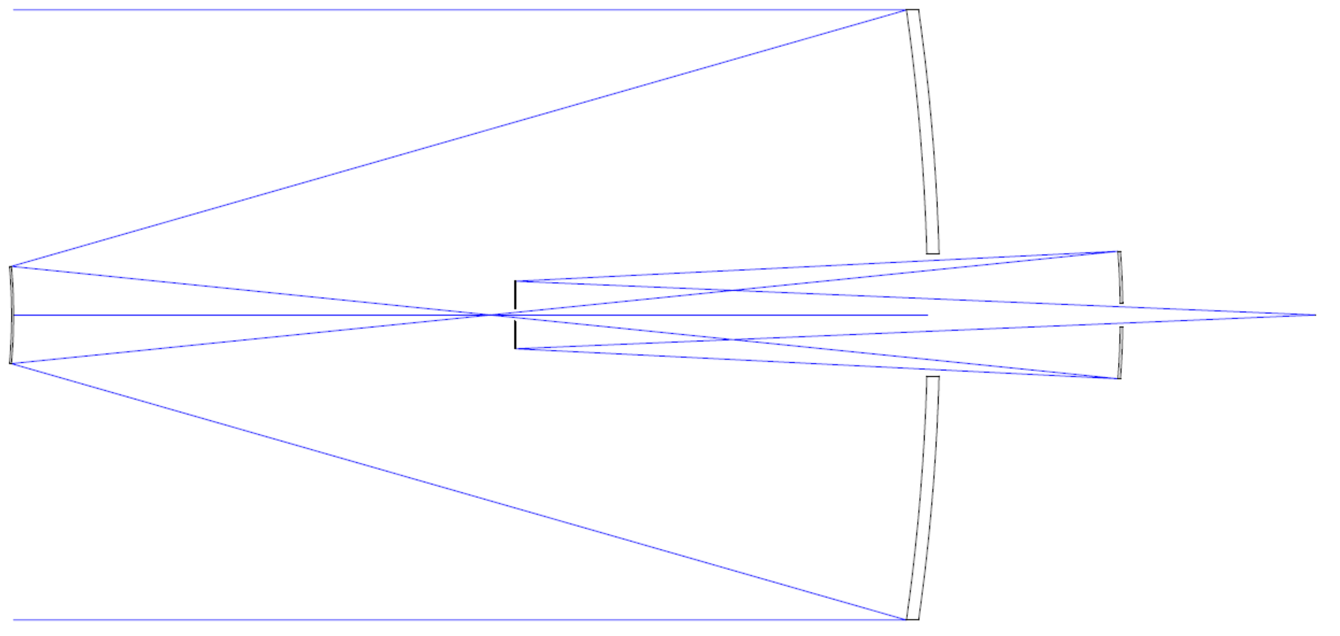
Anastigmatic, Flat field
Parabolic primary
Elliptical secondary
Spherical tertiary
Tertiary CC at secondary

Meinel's two stage optics concept (1985)



Large Deployable Reflector
Second stage corrects for errors of first stage; fourth mirror is at the exit pupil.

Aplanatic, Anastigmatic, Flat-field, Orthoscopic (free from distortion, rectilinear, JS 1987)



Spherical primary telescope.
The quaternary mirror is near the exit pupil. Spherical aberration and Coma are then corrected with a single aspheric surface. The Petzval sum is zero. If more aspheric surfaces are allowed then more aberrations can be corrected.

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